

THESIS

WATER CHEMISTRY VARIATION BETWEEN LITHOLOGIES
IN DINOSAUR NATIONAL MONUMENT, COLORADO

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR
SUPERVISION BY WILLIAM JOSEPH RICE ENTITLED WATER CHEMISTRY
VARIATION BETWEEN LITHOLOGIES IN DINOSAUR NATIONAL
MONUMENT, COLORADO BE ACCEPTED AS FULFILLING IN PART
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ABSTRACT OF THESIS

WATER CHEMISTRY VARIATION BETWEEN LITHOLOGIES IN DINOSAUR NATIONAL MONUMENT, COLORADO

In 1997, 61 water samples were taken in Dinosaur National Monument. These samples represented five lithologies; alluvial and colluvial (AC), conglomerate-sandstone (SS), siltstone-shale-sandstone (SSh), limestone and limestone-sandstone (LS), and evaporite (WSP). Trilinear diagrams, Wilcoxon Rank Sum test, ionic ratios and mass-balance modeling were used to show differences between them. Trilinear diagrams showed qualitative differences between lithologies. SSh indicated increasing Na^+ levels with increasing SO_4^{2-} levels compared to SS. Concentrations for Na^+ and Cl^- in the SSh were higher than the SS. Na^+ ranged from 3 to 27 mg/L in the SSh and from 2 to 10 mg/L in the SS. Cl^- ranged from 2.3 to 8.3 mg/L in the SS and 0.6 to 30 mg/L in the SSh. WSP had higher values of Na^+ , SO_4^{2-} and Cl^- than all other lithologies; Na^+ ranged from 104 - 314 mg/L; SO_4^{2-} from 45 - 195 mg/L, and Cl^- from 148 - 455 mg/L. Wilcoxon Rank Sum tests showed quantitative differences between lithologies. Significant Na^+ differences between the SS and SSh (p -value 0.021) indicate the possibility of marine shales in the SSh. Significant differences between the WSP and other lithologies reflect the dissolution of halite in evaporite deposits. Ionic ratios showed contrasts between lithologic weathering processes. Si/TDS ratios

showed contrasts between lithologic weathering processes. Si/TDS ratios suggested that silicate weathering was highest in LS (0.042), and higher in the SS (0.026) and SSh (0.036) than in the WSP (0.006). Na⁺/Si ratios indicated feldspar weathering in the SS, SSh and LS with values of 0.6, 0.4 and 0.9, respectively, and halite dissolution in the WSP (0.0). Mass balance modeling indicated contributions of ions to solution by minerals through distinct weathering processes. Dissolved constituents in the SS were mainly from anorthite, calcite and gypsum, at 30, 32 and 15 weight percent, respectively. The SSh constituents were mainly from anorthite, gypsum and dolomite at 12, 21 and 43%, respectively. The LS constituents were mainly from calcite, gypsum, albite and dolomite, at 29, 19, 14 and 13%, respectively. The WSP constituents were mainly from halite and gypsum, at 57 and 19%, respectively. In summary, each method used in this study could detect some difference between lithologies, however, ionic ratios and mass-balance modeling, which differentiate lithologies by weathering processes and source minerals, were the most effective.

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INTRODUCTION

The ionic composition of natural water depends upon a region's climate, geology and biota. Although each of these components contribute to natural water composition, the ultimate source of most dissolved ions in natural water is the mineral assemblage of rock near the land surface (Hem, 1989). The influence of rock-water interactions can be determined by analyzing river or stream chemistries, however, these interactions are influenced by diverse lithologies, precipitation patterns, aspect and soil depth within a watershed (Bluth and Kump, 1994). By analyzing water at a point of discharge from a geologic formation, a more specific indication can be obtained of how natural water composition evolves from precipitation with that particular formation (Kimball, 1981). Techniques such as trilinear diagrams, regression analysis and other comparison statistical methods, ionic ratios and mass-balance modeling have been used to analyze the composition and evolution of natural waters.

Trilinear diagrams can demonstrate certain relationships among individual samples and indicate similarities or differences in the composition of water from certain geologic and hydrologic units (Hem, 1992). The diagrams can also be used to illustrate the relative abundance of major dissolved constituents, and

determine if a spring water is a mixture of other waters (Phillips and Denburgh, 1971). A study of similarities and differences between geologic and hydrologic units was described by trilinear diagrams in the granitic environment of the Sierra Nevada Mountains (Feth et al., 1964). Another study used trilinear diagrams to note similarities and differences between geologic lithologies and activities due to waste-disposal in the Snake River Plain Aquifer (Knobel et al., 1997). A third study used the diagrams to explain the chemical character of spring water in sedimentary rocks, and changes in the chemical character of groundwater along water flow paths in the Uinta Basin (Kimball, 1981; Wanty et al., 1991).

Regression analysis and other comparison statistics of water chemistry are widely used in water-analysis interpretations to establish correlations and inferences as to the processes occurring within a study area (Hem, 1992). For example, mean chemical compositions of precipitation and snowmelt were used to perform mass-balance analysis for weathering reactions on springs in the Uinta Basin (Kimball, 1981). Regression analysis of total dissolved solids (TDS) and specific conductance were used to define relationships at Benton Lake, Montana (Nimick, 1997). Regression analysis also was used to denote relationships between specific conductance and various cation concentrations on streams in the Yampa River Basin (Parker, 1991).

Ionic ratios also can express the relationships among ions and portray similarities or differences among spring waters (Hem, 1992). There are no fixed rules for the ions selected to form ratios, but to portray comparisons between springs, ions can be selected that help determine the types of minerals being weathered (Garrels and MacKenzie, 1967; Hounslow, 1995). For instance, the ratio of Si/TDS may help identify water influenced by the solution of silicate minerals (Hem, 1992). The ratio of HCO_3^-/Si also can indicate silicate weathering if the ratio value is less than five; a value greater than ten indicates the possibility of carbonate weathering (Hounslow, 1995). The ratio of $\text{Si}/(\text{Na}^+ + \text{K}^+ - \text{Cl}^-)$ can indicate cation exchange if the ratio is less than one; a value between one and two can indicate albite weathering, and a value greater than two can indicate the weathering of ferromagnesian minerals (Hounslow, 1995). The ratio of $\text{Mg}^{2+}/\text{Ca}^{2+} + \text{Mg}^{2+}$ can be useful in studying limestone or dolomite formations (Meisler and Becker, 1967; Holland, 1978). Calcium approximately equals magnesium in a dolomite aquifer, while other sedimentary rocks would have more calcium than magnesium, unless the calcium is precipitating or significant ion exchange is occurring. Silicate weathering can sometimes be distinguished by a larger concentration of magnesium than calcium, especially in ultramafic aquifers (Hounslow, 1995). The ratio $\text{Ca}^{2+}/(\text{Ca}^{2+} + \text{SO}_4^{2-})$ can indicate gypsum dissolution at ratio values equal to 0.5; pyrite oxidation with ratios less than 0.5 and pH less than 5.5; calcium removal with ratios less than 0.5 and neutral pH; or other calcium sources than gypsum with values greater than 0.5

(Hounslow, 1995). The 1:1 ratio of Na^+/Cl^- can indicate the presence of salts, and larger ratios can indicate the presence of silicate weathering (Drever, 1988). A value of near one in the ratio $(\text{Ca}^{2+}+\text{Mg}^{2+})/\text{SO}_4^{2-}$ is used to indicate dedolomitization reactions (Hounslow, 1995).

Mass-balance modeling is used to relate the observed water chemistry to source minerals through weathering reactions. Equilibrium reactions are used to predict altered and primary minerals based upon ionic concentrations in the water. Mass-balance modeling of spring waters in the relatively homogenous lithology of the Sierra Nevada Mountains indicated that silicates are a major control of continental aqueous chemistry (Garrels and Mackenzie, 1967; Smith and Drever, 1976). Mass-balance modeling of spring waters in the mixed lithology of the Uinta Basin indicated differences in weathering reactions between shallow, intermediate and deep circulation springs in the Green River formation (Kimball, 1981). Further groundwater studies noted different weathering reactions as one moved downgradient in the Green River formation of the Piceance Basin (Stanley and Sulnier, 1981). Other spring studies have determined the effect evaporative processes have on weathering reactions in playa environments (Smith and Drever, 1976). Studies in the Snake River Plain Aquifer System have linked ground water chemistry to various minerals composing the aquifer by geochemical equilibrium diagrams (Knobel et al., 1997).

Trilinear diagrams, comparison statistical methods, ionic ratios and mass-balance modeling were used to analyze the composition and evolution of natural waters in Dinosaur National Monument. The purpose of this study was to inventory and chemically evaluate water samples from the springs, seeps and two wells at one point in time with respect to the surrounding lithologies. This evaluation involved characterizing the water chemistry of samples in relation to the local lithologies, and using this knowledge, describing the similarities and differences between them.

HYPOTHESIS

Rock-water interactions are the ultimate source of spring water chemistry. The type of geologic formation that spring water has contact with, therefore, should be the primary influence on spring water chemistry. This study hypothesized that different lithologies in Dinosaur National Monument produce waters of different chemistry. To test the hypothesis, the following objectives were established:

- 1) To determine if trilinear diagrams show differences in water chemistry between different lithologies.
- 2) To determine by the Wilcoxon Rank Sum Test if cations B, Ba^{2+} , Ca^{2+} , Cd^{2+} , Fe^{2+} , K^+ , Li^+ , Mg^{2+} , Mn^{2+} , Si , Sr^{2+} , V^{2+} , Zn^{2+} and Na^+ show significant differences between lithologies.
- 3) To determine by ionic ratio analysis of water chemistry that Si/TDS , HCO_3^-/Si , $\text{Si}/(\text{Na}^+ + \text{K}^+ - \text{Cl}^-)$, Na^+/Si , Na^+/Cl , $\text{Mg}^{2+}/(\text{Ca} + \text{Mg}^{2+})$, $\text{Ca}^{2+}/(\text{Ca}^{2+} + \text{SO}_4^{2-})$, and $(\text{Ca}^{2+} + \text{Mg}^{2+})/\text{SO}_4^{2-}$ values show different minerals undergoing weathering in different lithologies.
- 4) To determine if geochemical modeling by MINTEQA2 and mass balance calculations from spring water data predict different minerals undergoing weathering in different lithologies.

METHODOLOGY

Site Description

This study evaluated springs, seeps and wells in Dinosaur National Monument, which covers an area of 834 km² (322 sq. mi.), in northwestern Colorado and eastern Utah (Figure 1). The area is semi-arid and is characterized by high plateaus, cliffs, benches and valleys surrounding the confluence of the Green and Yampa rivers. The altitude ranges from 2,745 meters (9,005 feet) on Zenobia Peak in the northeastern portion of the Monument to 1,441 meters (4,730 feet) where the Green River flows out of the Monument (USGS, 1971). The average annual precipitation at Dinosaur Headquarters was approximately 290 mm (11.4 in.) during the time period 1963-1996 (Petersburg, S., 1998).

The geology exposed in the Monument ranges in age from Precambrian to Holocene, although not all time periods are represented (Appendix A) (Sumsion, 1976). In the northern part of the Monument, Pre-Cambrian red quartzite of the Uinta Mountain Group is predominant, and younger strata consisting of mixed sandstone, siltstone, shale and carbonate formations comprise the rest of the surficial geology (Hansen et al., 1983). The major faults in the Monument are the Yampa, Red Rock, Mitten, and Island Park faults (Hansen et al., 1983).

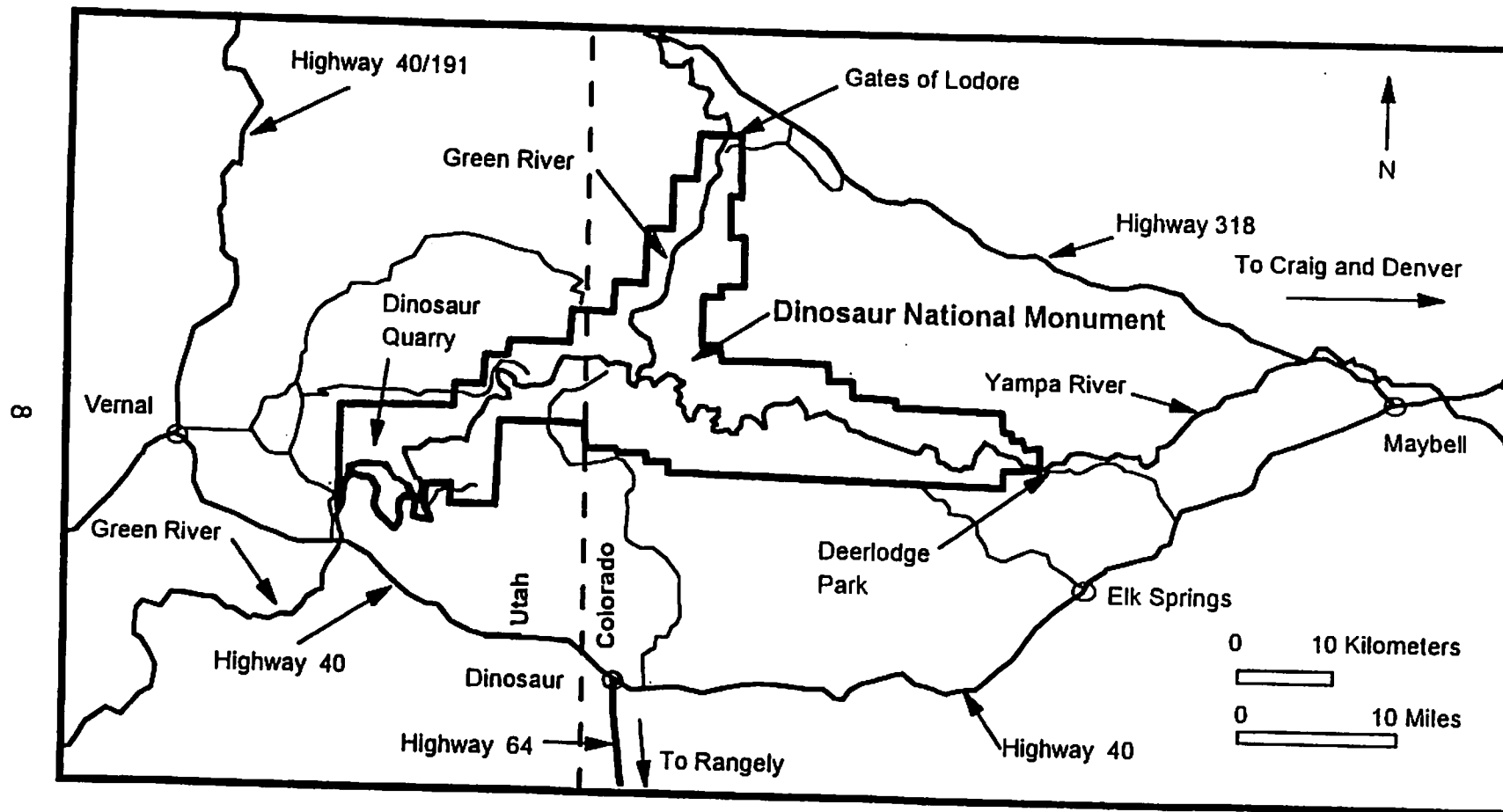


Figure 1. Overview of Dinosaur National Monument, Colorado. A more detailed map is on file at the Department of Earth Resources, Colorado State University, Fort Collins, Colorado.

Prior to this study, the locations of springs, seeps and wells within the Monument had never been comprehensively mapped or studied, consequently, their chemical characteristics and relationship to the local geology were largely unknown. Historical analysis of spring and well water chemistry in the Monument consists of 25 different springs and 22 different wells sampled between the years 1948 and 1971 (Sumsion, 1976). The analysis indicated that water chemistry and discharge varied significantly between sites, and that there were generally high bicarbonate concentrations and slightly elevated pH (Sumsion, 1976). No spring was consecutively sampled; therefore, no relationships between discharge and water chemistry variation could be made. These springs typically emanated from faults, jointing patterns, colluvial or alluvial material and were shallow, predominately recharged by precipitation events (Sumsion, 1976).

Sampling Methodology

Springs, seeps, and artesian well sites were sampled during late July and August of 1997. Vegetation change and water on the ground surface helped indicate the location of all sites. Springs were defined as surface water emanating with a discernable flow. Seeps were defined as surface water without measurable flow. In some cases, creeks were sampled when their point of issuance could not be accessed due to cliffs or landslides.

Springs, seeps and creeks generally emanated from faults or jointing patterns within the geologic formations, therefore the assumed water flow paths were along these patterns (USGS, 1971; Hansen, et al., 1983). Field parameters and three sub-samples for total cations, dissolved cations and dissolved anions were taken from each sampling point, as close as possible to the source. In general, samples taken from a lithology were assumed to be representative of the same lithology, regardless of whether the sample site was a spring, seep, creek, or one of the two wells sampled.

Sample Analysis

Field parameters of spring water were taken at each site. Discharge was measured based on the continuity equation (Stednick, 1991). Temperature, pH, electrical conductivity, hardness, alkalinity, total dissolved solids, oxidation reduction potential and dissolved oxygen were determined on unfiltered samples. Temperature was measured with a meter or a non-mercury filled thermometer (Stednick, 1991). The pH, conductivity and oxidation reduction potential were measured using meters. Alkalinity, hardness and dissolved oxygen were determined using Hach field kits (Hach, 1997).

Three sub-samples were taken at each site and collected in 60 mL HDPE bottles. Two of these sub-samples were acidified for cation analysis of total and dissolved constituents; these bottles contained 1 mL of ultra-pure nitric acid to

acidify the sample to a pH less than 2 (EPA, 1997). The third sub-sample was taken to test for anions and was not acidified. The dissolved cation sample was filtered through a 0.45 μm filter (Stednick, 1991). All three sub-samples were kept as cold as field conditions would allow. After they were taken from the field, the two cation sub-samples were refrigerated and the anion sub-samples were frozen until laboratory analysis. Anions and cations were analyzed by ion chromatography (IC) and inductively coupled plasma (ICP) methods, respectively (Table 1).

Quality Control and Assurance Program

Quality control and assurance procedures used for laboratory analysis included duplicate water samples taken in the field for ten separate sites. Additionally, four de-ionized water samples and ten split samples from the Poudre River (taken in Fort Collins, Colorado) were included in the anion analysis. The cation analysis included ten test samples of cations mixed in various concentrations from chemical salts. The concentrations were determined by taking the mean concentration of major cations from existing spring data (Sumsion, 1976). These concentrations were then varied by 1 to 5 mg/L and prepared according to standard methods and procedures.

Ionic balances on individual samples were performed by MINTEQA2, a geochemical speciation program (Allison et. al, 1991). This program calculated

Table 1. List of tested water quality parameters used with detection limits for cations by ICP and anions by IC methods. These methods analyzed in ppm, however, this study assumes that 1 ppm = 1 mg/L. Bicarbonate was measured as alkalinity in the field; it is included here to complete the list of anions used. Bicarbonate was calculated from alkalinity based on MINTEQA2 modeling methods. A complete list of analyzed constituents is located in Appendix B.

CATIONS (mg/L)		CATIONS (mg/L)		ANIONS (mg/L)	
Ion	Detection Limit	Ion	Detection Limit	Ion	Detection Limit
B ³⁺	0.01	Mn ²⁺	0.0005	HCO ₃ ⁻	0.1
Ba ²⁺	0.0001	Si ⁴⁺	0.02	Cl ⁻	0.1
Ca ²⁺	0.005	Sr ²⁺	0.1	SO ₄ ²⁻	0.1
Cd ⁺	0.001	V ²⁺	0.0015		
Fe ²⁺	0.005	Zn ²⁺	0.001		
K ⁺	0.035	Na ⁺	0.008		
Li ⁺	0.0015				
Mg ²⁺	0.0005				

a bicarbonate species concentration from field alkalinity measurements and also speciated ionic components, assuming that the ions in the water and source minerals were in equilibrium. Ionic balance was used to indicate whether the analytical results were valid, and although some variance is expected with the analytical results of natural waters, water should have no charge imbalance (Hem, 1992). Ionic balance was analyzed after MINTEQA2 speciated the data, assuming all ionic components stayed in solution. A less than 10% difference between the sum of cations and sum of anions was considered an acceptable result and those samples that passed were used in further calculations. Samples that did not have an ionic balance within 10% were assumed to have error involved with the field alkalinity measurement. This measurement was recalculated in MINTEQA2 to a near-zero charge balance. The samples were then used in further calculations with the other samples.

Geologic Grouping

Based on the observed geologic formations of the sample sites, five different lithologies were identified for analysis (Table 2). Springs and seeps that were sampled within stream beds, with no distinct geologic formation present on the surface, or were considered to have a significant amount of influence from surficial deposits, were listed in the alluvium and colluvium AC lithology. Alluvial deposits are defined as material deposited by running water and colluvial deposits are defined as loose and incoherent deposits, usually at the foot of a

Table 2. Summarized stratigraphic descriptions of the geologic formations and lithologies sampled in Dinosaur National Monument. ID denotes the lithology associated with the geologic formation. The formation descriptions are summaries from the overall stratigraphic descriptions in Appendix A (Information taken from Hansen, et al., 1983). Appendix B shows the relation of individual samples to geologic formation. The geologic formations are in order of descending age. AC represents the alluvial and colluvial lithology, SS represents the sandstone lithology, SSh represents the sandstone-shale lithology, LS represents the limestone lithology and WSP represents the evaporite lithology.

ID	Age	Formation	Description
AC	Quaternary	Alluvium/Colluvium	Unconsolidated clay, silt, sand, gravel
SS	Tertiary	Bishops Conglomerate	Conglomerate
SS	Jurassic/Triassic	Glen Canyon	Sandstone
SSh	Triassic	Moenkopi Formation	Shale, siltstone and sandstone
SS	Pennsylvanian	Weber Formation	Cross-bedded sandstone
LS	Pennsylvanian	Morgan Formation	Limestone, sandstone and shale
LS	Mississippian	Madison Formation	Limestone and dolomite
SSh/WSP	Cambrium	Lodore Formation	Sandstone, shale and siltstone
SSh/WSP	Proterozoic	Uinta Formation	Quartzitic sandstone, shale and siltstone

cliff or slope, that were brought there chiefly by gravity (Bates and Jackson, 1983). Springs and wells that could be identified in the field as emanating from the Bishops Conglomerate, Glen Canyon Sandstone, and Weber Sandstone Formations were considered the sandstone SS lithology. Springs that could be identified in the field as emanating from the Moenkopi, Lodore and Uinta Formations were considered part of the siltstone-shale-sandstone SSh lithology. Springs that could be identified in the field as emanating from the Morgan and Madison Formation were considered in the limestone LS lithology. A fifth group was formed for springs emanating from the Morgan and Lodore Formations that exhibited distinctly different water chemistry and temperatures greater than 18° Celsius. This group was called the evaporite lithology (WSP).

Trilinear Diagram Analysis

Trilinear diagrams of lithologic sample groups indicated their water type based on the dominant cations and anions. Possible mixtures of waters or more dilute composition of other spring waters were also readily discerned. The graphing position of the groups of samples demonstrated the degree of similarity or difference between lithologies.

Wilcoxon Rank Sum Test

The Wilcoxon Rank Sum test was used to determine significant differences between lithologies of cations B, Ba²⁺, Ca²⁺, Cd²⁺, Fe²⁺, K⁺, Li⁺, Mg²⁺, Mn²⁺, Si,

Sr^{2+} , V^{2+} , Zn^{2+} and Na^+ . Skewness and non-normality were observed in most lithologic data sets, therefore the non-parametric method was used to determine significant differences in cations between lithologies (Ott, 1993). The Wilcoxon Rank Sum test assumes that samples are independent and taken from two populations that are identical but not necessarily normally distributed. Independent random samples from them should be similar (Ott, 1993).

Ionic Ratios

Median values of each lithology were compared, based on ionic ratios that indicated whether silicate, carbonate or dissolution minerals were contributing the ions (Hem, 1992; Hounslow, 1995). The ionic ratios used the median values of the ions present. Median values are less susceptible to extreme outliers in the data and, after an evaluation of parametric methods, were determined to convey a better representation of the central tendency within a given lithology than average values (Ott, 1993). Observed similarities and trends in the ratios also were compared and contrasted.

Mass-Balance Modeling

To determine how geology influences spring water chemistry, probable precipitation water chemistry and likely minerals undergoing weathering were used in a mass-balance model. The geochemical speciation model MINTEQA2 was used to select possible source minerals of the ions in each lithology. X-ray

diffraction data from selected sites and general stratigraphic descriptions were also used for mineral selection. The information was then used to determine likely reactions and various mineral contributions based on the chemical composition of each water.

Mass Balance

MINTEQA2 and the mass-balance model were both used assuming that equilibrium had been established between the lithology minerals and the analyzed water chemistry. Possible minerals identified by MINTEQA2, X-ray diffraction and stratigraphic description were then incorporated into mass-balance calculations. If biota are ignored, the general equation for mass-balance calculations is (rock + atmospheric input = altered rock plus solution). Values for rock-water interaction are generally found by simply subtracting atmospheric deposition values from the spring water composition. For most natural waters, the amount of material derived from precipitation is small compared to the amount derived from interactions with rocks (Drever, 1997). Atmospheric input consists of water, carbon dioxide, oxygen and other species dissolved in the water, along with dry deposition of soluble material. To simplify the analysis, this study ignored the complexities of soil and the effects that biota may have. This means that the analysis treated precipitation and spring water data as representative of long periods of time, so that cation exchange in the soil can be assumed as a steady state and exchange sites do not represent a source

or a sink for ions. The effects of biota are usually difficult to evaluate and are generally estimated to be small compared to the effects of rock-water interaction (Drever, 1997). After subtraction of the precipitation values, an ionic balance was performed to verify that the cations and anions charge balance. If they did not balance, the bicarbonate value was assumed to be in error and was adjusted to balance the cations and anions. Dissolved species from mineral equilibrium reactions were then subtracted from the spring water chemistry until as near a balance as possible was achieved with the minerals chosen. The dissolved mineral contributions based on chemical composition of the water sample were calculated and compared between lithologies.

Precipitation Calculations

To meet mass balance requirements, (rock + atmospheric input = altered rock + solution), precipitation chemistry was evaluated. Data from the Uinta Basin, located approximately 48 kilometers (30 miles) southeast of the Monument, were the closest precipitation chemistry (Kimball, 1981). Precipitation samples were not collected within the Monument boundaries.

Spring Rock Sampling and Analysis

Rock samples were collected from selected sites and analyzed for clay and other minerals. Mineral identification helped in differentiating various reactions and suggested minerals to use in mass-balance calculations. The springs

selected for rock sampling could be sampled directly at the point of issuance from a competent, well-defined geologic formation. An assumption was made that an individual rock sample could adequately characterize each of the lithologies.

Non-oriented bulk powder samples were prepared by either ball milling for five to ten minutes or by hand grinding. Any clay constituents in the bulk sample were noted and a suspension made to better examine the clays. Calcite was present in some of the samples containing clay and was removed by an acid wash of 0.5 M HCl to highlight the clay peaks. X-ray diffraction methods (XRD) were used to determine the minerals present. XRD method settings included an accelerating voltage of 45 kilovolts with a current of 40 milliamps; a 2θ range of 3 to 40 degrees, continuous scanning at a rate of $2^\circ\theta$ per minute using X-rays, on a Scintac XDS 2000 machine (Chen, 1977; Moore and Reynolds, 1997).

RESULTS

In general, approximately 40% of the Monument area was explored for springs. Mainly the northeast, west central and southern portions of the Monument were covered, encompassing a wide range of geologic formations and lithologies. Sixty-one samples consisting of springs, seeps, creeks and two wells were taken during the 1997 field season (Appendix B). The QA/QC program indicated satisfactory field and laboratory results for the samples analyzed (Appendix B). Sample results were grouped in relation to lithology at the point of issuance, and concentration range and median values depicted for pH, EC, TDS, major cations and anions (Table 3). Median values of constituents were used due to the heavy skewness and low sample sizes observed in the data. The AC lithology had a median pH of 7.8, with TDS ranging from 37 to 950 mg/L. Median concentrations for Ca^{2+} , Na^+ , HCO_3^- , and SO_4^{2-} were 93, 10, 154 and 30 mg/L, respectively. The SS lithology had a median pH of 7.7, with TDS ranging from 152 to 308 mg/L. Median concentrations for Ca^{2+} , Na^+ , HCO_3^- , and SO_4^{2-} were 61.5, 5, 144 and 29 mg/L, respectively. The SSh lithology had a median pH of 7.9, with TDS ranging from 72 to 270 mg/L. Median concentrations for Ca^{2+} , Na^+ , HCO_3^- , and SO_4^{2-} were 42, 7, 86 and 35 mg/L, respectively. The LS lithology had a median pH of 7.8, with TDS ranging from 176 to 221 mg/L.

Table 3. Range and median values of pH, EC, TDS, major cations and anions by lithology in Dinosaur National Monument. Values in parentheses indicate median values for constituents and all values are in mg/L, except for pH and EC, which are in pH units and $\mu\text{hos/cm}$, respectfully. AC represents alluvial and colluvial lithology, SS represents conglomerate-sandstone lithology, SSh represents sandstone-shale lithology, LS represents limestone and limestone-shale-sandstone lithology and WSP represents evaporite lithology.

Ion	AC	SS	SSh	LS	WSP
Sample Size	14	20	15	5	5
pH	7.1-8.5 (7.8)	7.4-8.6 (7.7)	6.9-8.7 (7.9)	7.5-8.3 (7.8)	7.6-9 (8.3)
EC	90-1900 (560)	152-740 (410)	116-558 (365)	390-510 (470)	1040-2390 (1580)
TDS	37-950 (257)	152-308 (215)	72-270 (172)	176-221 (206)	407-1460 (950)
Ca^{2+}	26-486 (93)	44-105 (61.5)	16-73 (42)	52-58 (54)	66-93 (70)
K^{+}	0.7-12 (2.6)	0.1-1.7 (1.2)	0.5-6.7 (1.6)	0.41-1.9 (1.0)	6.6-15 (9.9)
Mg^{2+}	6.1-230 (31)	14-37 (28)	4-36 (15)	15-35 (26)	24-30 (24)
Na^{+}	3-116 (10)	2-10 (5)	3-27 (7)	4-8 (7)	104-314 (180)
Si	5.1-9.5 (6.5)	3.2-11 (5.5)	2.6-11 (6.2)	7.1-10 (8.6)	4.7-8.2 (5.7)
HCO_3^{-}	33-273 (154)	94-239 (144)	12-159 (86)	133-185 (144)	23-125 (111)
SO_4^{2-}	6.4-789 (30)	7.6-80 (29)	9.3-46 (35)	8.4-33 (10)	45-195 (121)
Cl^{-}	1.8-77 (9.2)	2.3-8.3 (4.1)	0.6-30 (8.4)	2.9-9.8 (4.9)	148-455 (111)

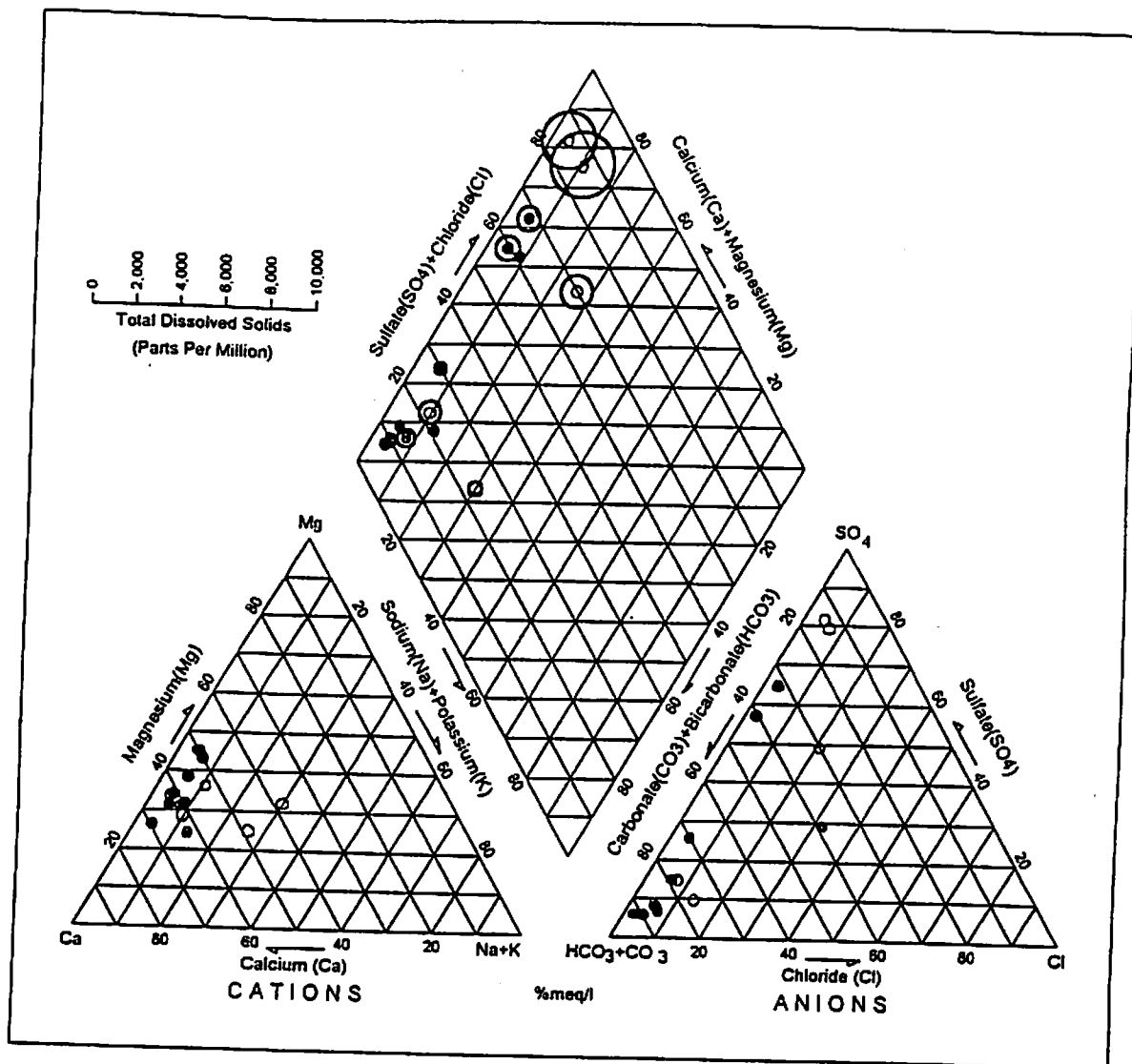
Median concentrations for Ca^{2+} , Na^+ , HCO_3^- , and SO_4^{2-} were 54, 7, 144 and 10 mg/L, respectively. The WSP lithology had a median pH of 8.3, with TDS ranging from 407 to 1460 mg/L. Median concentrations for Ca^{2+} , Na^+ , HCO_3^- , and SO_4^{2-} were 70, 180, 111 and 121 mg/L, respectively. Trilinear diagrams, ionic ratios, statistical analysis and mass-balance modeling procedures performed on the samples determined differences between lithologies.

Trilinear Diagram Analysis

Based on the five lithologies sampled, five diagrams were plotted. Individual sample analysis for each lithologic group were plotted, and observations made based upon the major cations and anions.

For the AC lithology, only the springs and seeps within it were compared, since the AC lithology can represent many types of geologic formations and other lithologies. The AC lithology indicated two types of water, one a calcium-sulfate water and the other a calcium-bicarbonate water. Trilinear diagram observations indicated two groups of springs and seeps, one of higher SO_4^{2-} concentration (210 to 789 mg/L) and the other of lower SO_4^{2-} concentration (6.4 to 40 mg/L) (Figure 2).

When only seeps are considered in the AC lithology, seeps were observed to have either higher SO_4^{2-} or higher Na^+ concentrations than springs;



Legend:

- Open Circles: Seeps (n=5)
 Dark Circles: Springs (n=9)

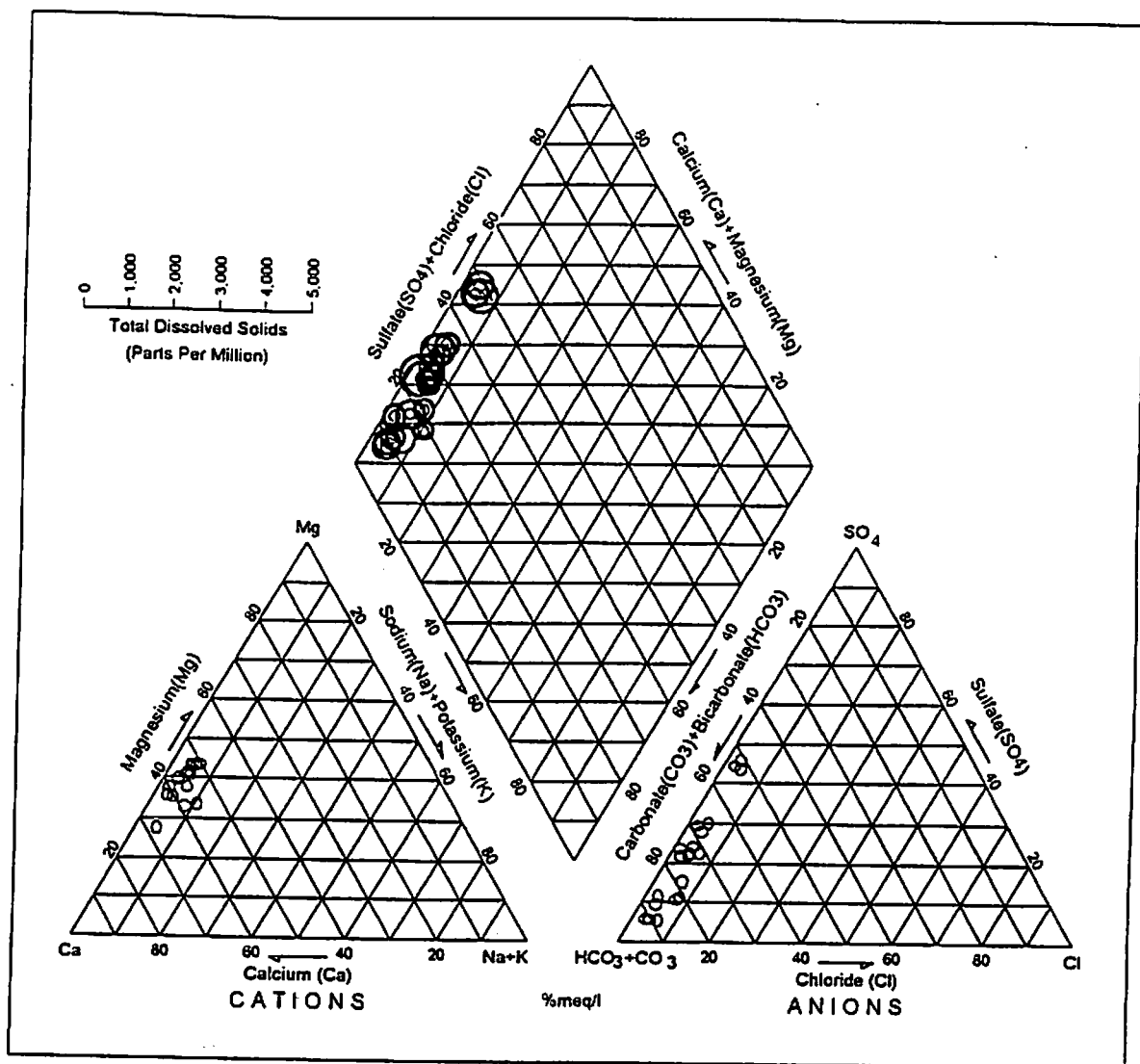
Figure 2. Trilinear diagram relationship between seeps and springs in AC lithology.

concentrations of SO_4^{2-} in the seeps ranged from 40 to 789 mg/L and from 6.4 to 230 mg/L in the springs; concentrations of Na^+ ranged from 37 to 72 mg/L in the seeps and 2.9 to 10 mg/L in the springs (Figure 2).

The SS lithology samples were plotted (Figure 3). Overall, this group of samples were classified as a calcium-bicarbonate water (Table 3). The SS lithology SO_4^{2-} ranged from 7.6 to 80 mg/L, Cl^- concentrations ranged from 2.3 to 8.3 mg/L and HCO_3^- concentrations ranged from 94 to 239 mg/L. Ca^{2+} concentration ranges ranged from 44 to 105 mg/L, and Mg^{2+} concentrations ranged from 14 to 37 mg/L. Na^+ ranged from 2 to 10 mg/L.

The SSh lithology samples were plotted (Figure 4). Overall, this group of samples was a calcium-bicarbonate water (Table 3). The SSh lithology SO_4^{2-} ranged from 9.3 to 46 mg/L, and Cl^- concentrations ranged from 0.6 to 30 mg/L. HCO_3^- concentrations ranged from 12 to 159 mg/L. Ca^{2+} and Mg^{2+} concentrations ranged from 16 to 73 mg/L and from 4 to 36 mg/L, respectfully. Na^+ ranged from 3 to 27 mg/L.

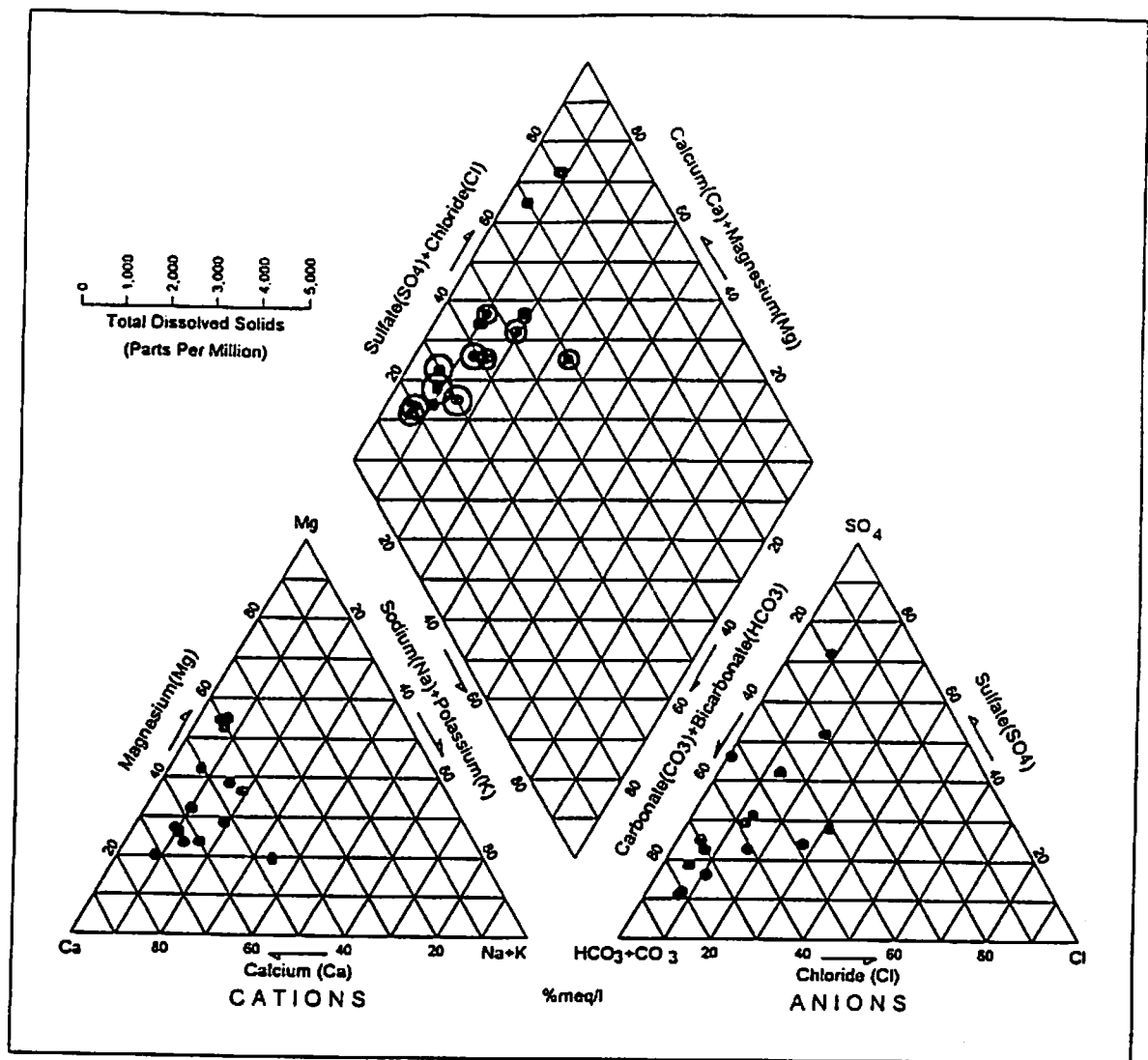
The LS lithology were plotted (Figure 5). The water from this lithology was classified as a calcium-bicarbonate water (Table 3). The LS lithology SO_4^{2-} ranged from 8.4 to 33 mg/L, and Cl^- levels ranged from 2.9 to 9.8 mg/L. HCO_3^-



Legend:

Open Circles: Conglomerate-Sandstone (SS) Lithology (n=20)

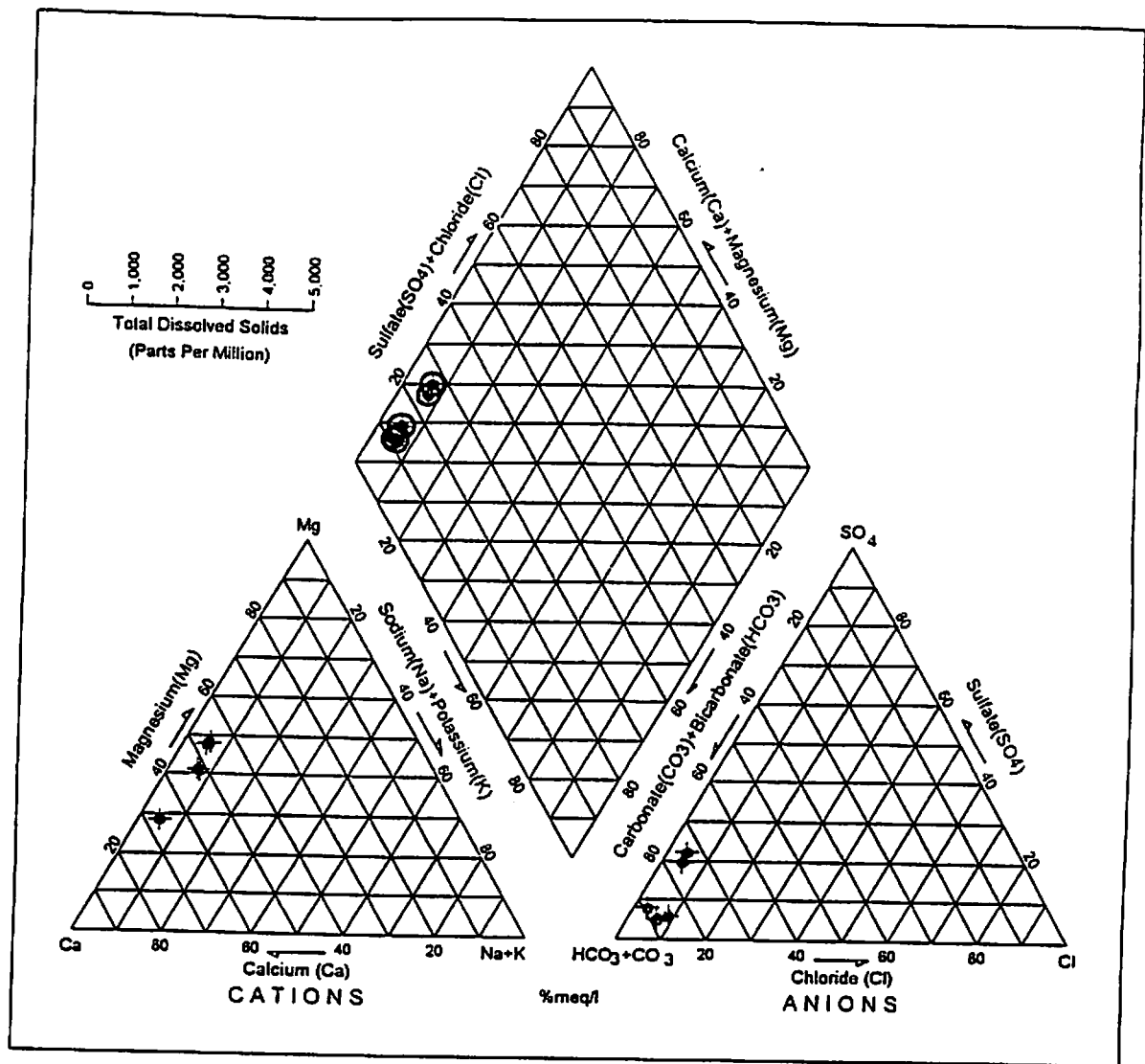
Figure 3. Trilinear diagram of SS lithology samples.



Legend:

Dark Circles: Siltstone-Sandstone-Shale (SSh) Lithology (n=15)

Figure 4. Trilinear diagram of SSh lithology samples.



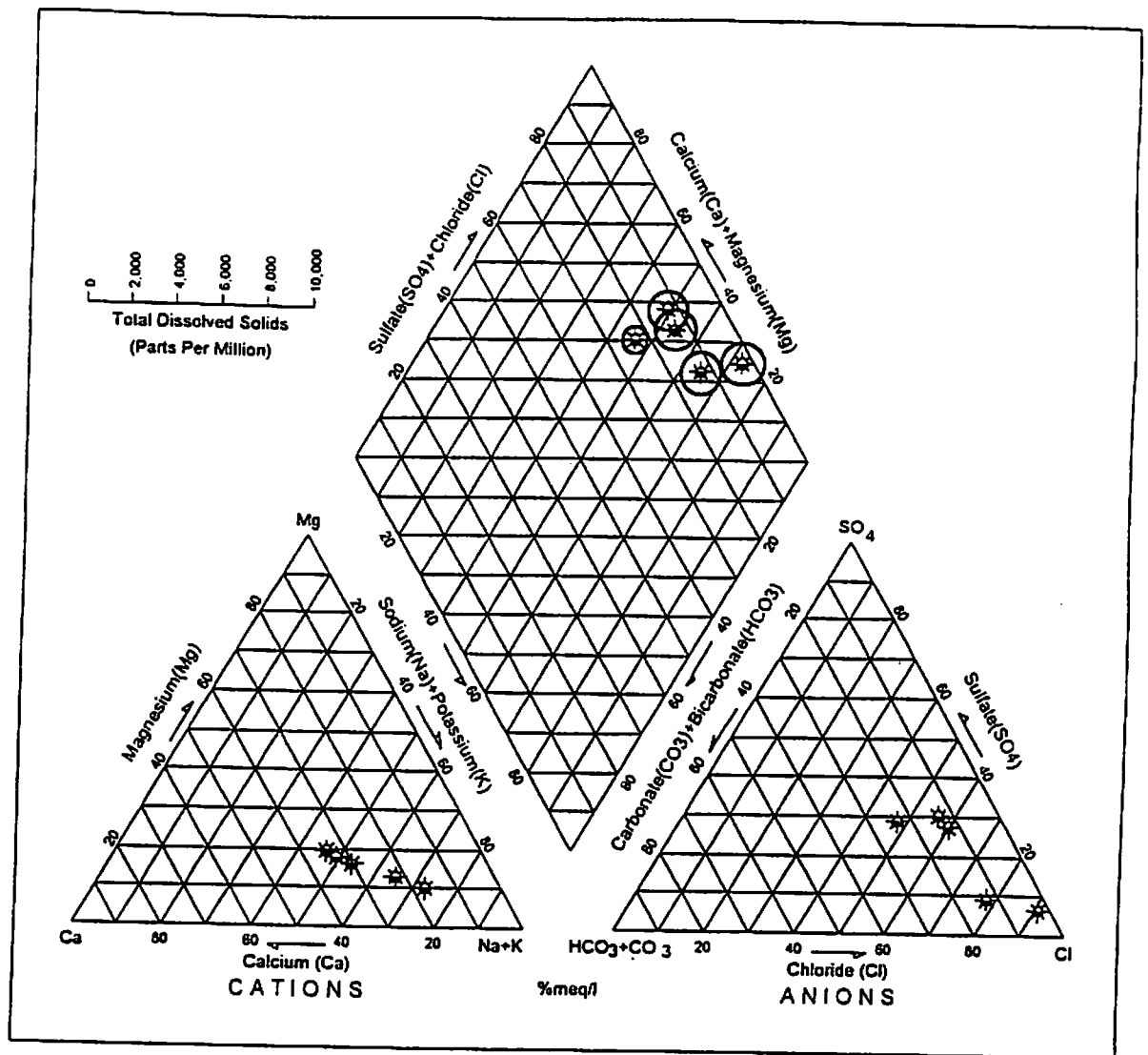
concentrations ranged from 133 to 185 mg/L Ca^{2+} and Mg^{2+} concentrations ranged from 52 to 58 mg/L and from 15 to 35 mg/L, respectively. Na^+ ranged from 2.1 to 10 mg/L.

The WSP lithology were then plotted (Figure 6). The water from this lithology was classified as a sodium-chloride water. The WSP lithology SO_4^{2-} ranged from 45 to 195 mg/L, and Cl^- levels ranged from 148 to 455. Ca^{2+} and Mg^{2+} concentrations ranged from 66 to 93 mg/L, and from 24 to 30 mg/L, respectively. Na^+ ranged from 104 to 314 mg/L.

Wilcoxon Rank Sum Test

The Wilcoxon Rank Sum test analyzed for significant differences between lithologies with a ($p \leq 0.05$). These tests were made between the lithologic sample groups for 14 cations (Table 4). Only cations were tested because the cation analysis had a higher degree of accuracy in ICP analysis than the anion analysis by IC methods (Appendix B).

The AC and SS lithologies had significant differences in the major cations K^+ and Na^+ with p-values of 0.005 and 0.022. Significant differences were indicated for B, Cd^{2+} , Fe^{2+} and Mn^{2+} with p-values of 0.008, 0.027, 0.035, and 0.026, respectively. The cation Si was also significantly different with a p-value of 0.03.



Legend:

Circles: Warm Springs (WSP) Lithology (n=5)

Figure 6. Trilinear diagram of WSP lithology samples.

Table 4. Statistical p-values of lithologic comparisons by the Wilcoxon Rank Sum test. Significant differences are indicated by the letter (a) on comparisons with ($p \leq 0.05$). The AC lithology represents alluvial and colluvial deposits, the SS lithology represents sandstone lithology samples, the SSh lithology represents sandstone-shale samples, the LS lithology represents limestone and limestone-shale-sandstone samples and the WSP lithology represents evaporite lithology samples.

Cation	AC - SS	AC - SSh	AC - LS	AC - WSP	SS - SSh	SS - LS	SSh - LS	WSP - SS	WSP - SSh	WSP - LS
B	0.008 ^a	0.526	0.031 ^a	0.005 ^a	0.002 ^a	0.397	0.018 ^a	4E-05 ^a	0.0001 ^a	0.008 ^a
Ba ²⁺	0.344	0.63	0.103	0.02 ^a	0.376	0.398	0.075	0.015 ^a	0.062	0.008 ^a
Ca ²⁺	0.256	0.002 ^a	0.256	0.838	0.001 ^a	0.236	0.104	0.037 ^a	0.002 ^a	0.0079 ^a
Cd ²⁺	0.027 ^a	0.458	0.317	0.754	0.239	0.005 ^a	0.129	0.290	1.000	0.238
Fe ²⁺	0.035 ^a	0.173	0.051	0.113	0.335	0.469	0.158	1.000	0.416	0.722
K ⁺	0.005 ^a	0.212	0.031 ^a	0.001 ^a	0.066	0.882	0.159	4E-05 ^a	0.0003 ^a	0.008 ^a
Li ⁺	0.064	0.265	0.401	0.0003 ^a	0.418	0.765	0.983	6E-05 ^a	0.0001 ^a	0.008 ^a
Mg ²⁺	0.431	0.025 ^a	0.670	0.403	0.036 ^a	0.907	0.191	0.342	0.255	0.548
Mn ²⁺	0.026 ^a	0.058	0.194	0.027 ^a	0.350	0.521	0.852	0.561	0.316	0.452
Si	0.03 ^a	0.957	0.058	0.405	0.074	0.002 ^a	0.137	0.327	0.541	0.04 ^a
Sr ²⁺	0.059	0.02 ^a	0.391	0.073	0.182	0.518	0.124	2E-05 ^a	0.0001 ^a	0.008 ^a
V ²⁺	0.462	0.772	0.070	0.622	0.309	0.016 ^a	0.069	0.344	0.916	0.016 ^a
Zn ²⁺	0.065	0.018 ^a	0.033 ^a	0.446	0.214	0.119	0.809	0.702	0.332	0.357
Na ⁺	0.022 ^a	0.370	0.150	0.0002 ^a	0.021 ^a	0.250	0.539	2E-05 ^a	6E-05 ^a	0.008 ^a

The AC and SSh lithologies had significant differences in the major cations Ca^{2+} and Mg^{2+} , with p-values of 0.002 and 0.025. Significant differences were also indicated for Sr^{2+} and Zn^{2+} with p-values of 0.02 and 0.018.

The AC and LS lithologies had a significant difference in the major cation K^+ with a p-value of 0.031. Significant differences were also indicated for Zn^{2+} with a p-value of 0.033.

The AC and WSP lithologies had significant differences in the major cations K^+ and Na^+ with p-values of 0.001 and 0.0002. Significant differences were indicated for B and Ba^{2+} with p-values of 0.005 and 0.02. The cations Li^+ , Mn^{2+} , and Sr^{2+} also indicated significant differences with p-values of 0.0003, 0.027, and 0.073, respectively.

The SS and SSh lithologies had significant differences in the major cations Ca^{2+} , Mg^{2+} and Na^+ with p-values of 0.001, 0.036 and 0.021, respectively. Significant differences were also indicated for the cation B with a p-value of 0.002.

The SS and LS lithologies had no significant differences in the major cations Ca^{2+} , K^+ , Mg^{2+} or Na^+ . Significant differences were indicated for the cations Cd^{2+} and V^{2+} with p-values of 0.005 and 0.016. Si was also significantly different with a p-value of 0.002.

The SSh and LS lithologies had no significant differences in the major cations Ca^{2+} , K^+ , Mg^{2+} or Na^+ . The only significant difference was indicated by the cation B with a p-value of 0.018.

The WSP and SS lithologies had significant differences in the major cations Ca^{2+} , K^+ and Na^+ with p-values of 0.002, 0.00004 and 0.00002, respectively.

Significant differences were indicated for B and Ba^{2+} with p-values of 0.00004 and 0.015. The cations Li^+ and Sr^{2+} also indicated significant differences with p-values of 0.00006, and 0.00002.

The WSP and SSh lithologies had significant differences in the major cations Ca^{2+} , K^+ and Na^+ with p-values of 0.002, 0.0003 and 0.00006, respectively.

Significant differences were indicated for B with a p-value of 0.0001. The cations Li^+ and Sr^{2+} also indicated significant differences with a p-value of 0.0001 for both cations.

The WSP and LS lithologies had significant differences in the major cations Ca^{2+} , K^+ and Na^+ with p-values of 0.0079, 0.008 and 0.008, respectively. Significant differences were indicated for B and Ba^{2+} with a p-value of 0.008 for both cations. The cations Li^+ , Sr^{2+} , and V^{2+} also indicated significant differences with p-values of 0.008, 0.008, and 0.016, respectively. The cation Si was also significantly different with a p-value of 0.04.

Ionic Ratio Analysis

Ionic ratio values of Si/TDS , HCO_3^-/Si , $\text{Si}/(\text{Na}^+ + \text{K}^+ - \text{Cl}^-)$, Na^+/Si , Na^+/Cl^- , $\text{Na}^+/(\text{Na}^+ + \text{Cl}^-)$, $\text{Mg}^{2+}/(\text{Ca}^{2+} + \text{Mg}^{2+})$, $\text{Ca}^{2+}/(\text{Ca}^{2+} + \text{SO}_4^{2-})$, and $(\text{Ca}^{2+} + \text{Mg}^{2+})/\text{SO}_4^{2-}$ were calculated to identify source rocks and weathering processes (Table 5). These ratios were made based on the median value of each ion (Appendix C). The AC lithology was not considered in the ratio analysis due to the variety of geologic formations this lithology represented.

For the Si/TDS ratio, the LS lithology had the highest ratio (0.042) (Table 5). The SSh lithology had the second highest ratio (0.036), the SS lithology had a ratio of (0.025), and the WSP lithology had the lowest Si/TDS ratio (0.006).

HCO_3^-/Si ratios indicated that the SS lithology had the only ratio with a value greater than ten (12). The WSP lithology had the second highest ratio value (9), the LS lithology had a ratio value of (8), and the SSh lithology had the lowest ratio value (6).

The $\text{Si}/(\text{Na}^+ + \text{K}^+ - \text{Cl}^-)$ ratios indicated that the SSh, LS and SS lithologies had ratio values above one (1.8, 1.5, and 1.4, respectively). The WSP lithology was the only lithology to have a ratio value less than one (-0.9).

Table 5. Ionic ratio results by lithology. All ionic ratios were calculated by meq/L except Si/TDS, which is in mg/L, and $(Ca^{2+}+Mg^{2+})/SO_4^{2-}$, which is a molar ratio. Na⁺ indicates that the amount of Na after using Na to balance Cl. Ratios are based on median values of the samples. The SS lithology represents sandstone formation samples, the SSh lithology represents sandstone-shale samples, the LS lithology represents limestone and limestone-shale-sandstone samples and the WSP lithology represents samples from evaporite deposits.

Lithology	Sample Size	$\frac{Si}{TDS}$	$\frac{HCO_3^-}{Si}$	$\frac{Si}{(Na^++K^+-Cl^-)}$	$\frac{Na^+}{Si}$
SS	20	0.026	12	1.4	0.6
SSh	15	0.036	6	1.8	0.4
LS	5	0.042	8	1.5	0.9
WSP	5	0.006	9	-0.9	0.0

Lithology	$\frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})}$	$\frac{Ca^{2+}}{(Ca^{2+}+SO_4^{2-})}$	$\frac{(Ca^{2+}+Mg^{2+})}{SO_4^{2-}}$
SS	0.3	0.8	8.7
SSh	0.2	0.7	4.6
LS	0.3	0.9	23.2
WSP	0.2	0.6	2.2

The Na^+/Si ratio after using Na^+ to balance Cl^- ratios indicated that the LS lithology was the closest to a 1:1 ratio (0.9). The SS lithology had a value of (0.59) and the SSh lithology had a value of (0.4). The WSP lithology was the only lithology to have no Na^+ after balancing Cl^- , for a ratio of (0.0).

The total Na^+/Cl^- ratio was highest for the LS lithology (2.3). The SS lithology was second highest (2.0) and the SSh lithology had a value of (1.4). The WSP lithology had the only ratio value less than one (0.9).

The $\text{Na}^+/(\text{Na}^++\text{Cl}^-)$ ratio indicated that the SS and LS lithologies both had values above 0.5 (0.7, 0.7). The SSh lithology had a similar ratio value (0.6), and the WSP lithology had a value of (0.5).

The $\text{Mg}^{2+}/(\text{Ca}^{2+}+\text{Mg}^{2+})$ ratio indicated that all the lithologies had values less than five. The SS and LS lithologies both had ratio values of (0.3). The SSh and WSP lithologies had both had a similar value (0.2).

The $\text{Ca}^{2+}/(\text{Ca}^{2+}+\text{SO}_4^{2-})$ ratio was above 0.5 for all lithologies. The LS lithology had the highest value (0.9). The SS lithology had the next highest value (0.8) and the SSh lithology had a value of (0.7). The WSP lithology had the lowest value (0.6).

The $(\text{Ca}^{2+} + \text{Mg}^{2+})/\text{SO}_4^{2-}$ ratio was above one for all the lithologies. The LS lithology had the highest value (23.2). The SS lithology had the next highest value (8.7) and the SSh lithology had a value of (4.6). The WSP lithology had the lowest value (2.2).

Mass Balance Modeling

For the mass balance, median concentrations of Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Si, Cl^- , HCO_3^- and SO_4^{2-} in mmol/L were used for each lithology in question (Appendix B). Precipitation chemistry concentrations (mmol/L) were subtracted from these initial median values, to characterize the amount of ions that came from potential dissolved minerals. An ionic balance (cation-anion) was performed and the bicarbonate ion adjusted to obtain a near 0% difference between cations and anions. The bicarbonate ion was adjusted based on the assumption that field alkalinity measurements could be the source of error. Potential dissolved minerals were then chosen and used to account for the ions in the samples. These minerals were used in a five part sequence (Faure, 1998). In general, the sequence consists of assuming the chloride concentrations originated from halite. Then possible silicate minerals are used to account for the silica. Sulfate minerals are then used to account for the sulfate. Bicarbonate minerals are then used and, lastly, other minerals are considered to account for any cations and anions still in the water. Mass-balance modeling then suggested differences in potential dissolved minerals between the various lithologies (Table 6).

Table 6. Summarized mass balance results for lithologies in weight percent. NA means that the mineral was not used in the analysis. The SS lithology represents sandstone samples, the SSh lithology represents sandstone-shale samples, the LS lithology represents limestone and limestone-shale-sandstone samples and the WSP lithology represents warm spring samples.

Mineral	Lithology			
	SS	SSh	LS	WSP
Halite (NaCl)	2	6	3	57
Albite (NaAlSi ₃ O ₈)	6	8	14	NA
Anorthite (Ca ₂ Al ₂ Si ₂ O ₈)	30	12	14	NA
Orthoclase (KAlSi ₃ O ₈)	3	6	3	NA
Gypsum (CaSO ₄)	15	21	19	19
Calcite (CaCO ₃)	32	3	29	1
Dolomite CaMg(CO ₃) ₂	2	43	13	11
Mg-Smectite Mg _{0.167} (Al _{1.67} Mg _{0.33})Si ₄ O ₁₀ (OH) ₂	10	1	9	NA
Magnesite (MgCO ₃)	NA	NA	NA	3
PotassiumMagnesium Chloride (KCl) (MgCl ₂)	NA	NA	NA	5
Langbeinite K ₂ Mg ₂ (SO ₄) ₃	NA	NA	NA	4
Amorphous Silica (SiO ₂)	NA	NA	NA	1

Potential dissolved minerals were chosen by saturation indices, calculated by MINTEQA2 for each individual spring, X-ray diffraction data, and stratigraphic literature. Saturation indices that were within 1 to -1 over or under-saturated were considered as potential dissolved minerals. These minerals were barite, magnesite, calcite and dolomite (Table 7). Barite was not considered in the lithologic analysis, due to barite's low ionic contribution to the water chemistry (Appendix B). Magnesite was also not considered in the lithologic analysis, except for the WSP lithology, due to the lack of the mineral magnesite in most sedimentary environments except for marine evaporite deposits (Holland, 1978). Both calcite and dolomite are common sedimentary minerals, and were considered in the lithologic analysis. Secondly, X-ray diffraction data from rock samples of the various lithologies were evaluated (Table 8). Within the SS lithology, the major minerals identified by the rock samples were quartz, feldspars, and serpentine group minerals. Minor amounts of montmorillinite were also indicated. Within the SSh lithology, the major minerals identified were quartz, feldspars, and calcite with minor amounts of illite or micas. Within the LS lithology, the major minerals identified were quartz, feldspars, and calcite with minor amounts of illite and albite. Albite, anorthite, and orthoclase were assumed to be the feldspars present in the rock samples. A Mg-smectite (montmorillinite) ion exchange between Mg^{2+} and Ca^{2+} was used to explain the concentrations of Mg^{2+} present within the water. In the WSP lithology, no rock samples were obtained due to overlaying colluvial material. MINTEQA2

Table 7. Summarized saturation index results from MINTEQA2 modeling of individual springs. Minerals selected were within a saturation index of -1 to +1, except for values of magnesite in the SSh lithology. A negative value indicates that the sample is undersaturated with respect to that mineral, a positive value indicates that the sample is oversaturated with respect to that mineral. Overall average saturation or under-saturation is also indicated. The SS lithology represents sandstone samples, the SSh lithology represents sandstone-shale samples, the LS lithology represents limestone and limestone-shale-sandstone samples and the WSP lithology represents warm spring samples.

Mineral	Lithology			
	SS	SSh	LS	WSP
Barite	SI -1.0 to 0.5 Saturated	SI -0.5 to 0.2 Saturated	SI -0.5 to 0.5 Saturated	SI -0.5 to 0.5 Saturated
Magnesite	SI -0.5 to 1.0 Undersaturated	SI -2.0 to 0.5 Undersaturated	SI -0.7 to 0.5 Saturated	SI -0.5 to 0.5 Saturated
Calcite	SI -1.0 to 0.5 Saturated	SI -1.2 to 1.0 Saturated	SI -0.1 to 1.0 Saturated	SI 0.0 to 1.0 Saturated
Dolomite	SI 0.0 to 1.0 Saturated	SI -1.1 to 1.0 Undersaturated	SI -0.2 to 1.5 Saturated	SI 0.0 to 1.0 Saturated

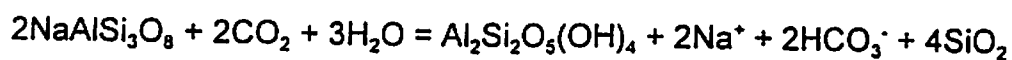
Table 8. Summarized X-ray diffraction pattern results. Minerals selected were distinguished by bulk and suspended samples of each lithology. The WSP lithology, which represents warm spring samples, did not have rock samples associated with it. The SS lithology represents sandstone samples, the SSh lithology represents sandstone-shale samples, the LS lithology represents limestone and limestone-shale-sandstone samples.

Lithology	SS	SSh	LS
Observed Minerals	quartz, feldspars, illite or montmorillinite, serpentine minerals, gypsum	quartz, feldspars, illite or micas, calcite	quartz, feldspars, illite or micas, calcite, albite
Sample Size	2	3	2

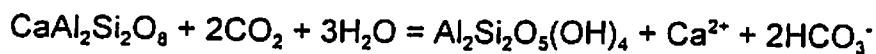
calculations and weathering literature identified the major potential minerals as halite, gypsum, calcite, and dolomite. The minerals magnesite, potassium chloride, magnesium chloride, and langbeinite also were included due to their common presence in evaporite deposits (Holland, 1978). Lastly, amorphous silica was chosen to be the source of the silica content in the WSP lithology (Drever, 1988).

After determining the dissolved minerals that may contribute to water chemistry within each lithology, weathering reactions and cation exchange were used to link these minerals to the water chemistry. Cation exchange was used to account for the observed Mg^{2+} ions observed in the water chemistry of the SS, SSh and LS lithologies. The products of these reactions and exchanges were then subtracted from the adjusted water chemistry data until as many ions within the water were allotted to a mineral as possible. Assuming that weathering to kaolinite is the stable phase for feldspars, weathering reactions for albite, anorthite and orthoclase are as follows (adapted from Faure, 1998)

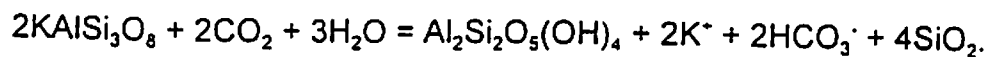
(albite)



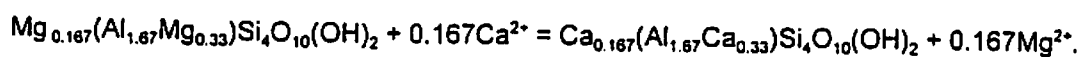
(anorthite)



(orthoclase)



To account for the Mg^{2+} present in the SS and LS lithologies, studies have shown that a Ca^{2+} ion can readily exchange a Mg^{2+} ion from Mg-smectites (Drever, 1988). The cation exchange for Mg-smectite assumes that Mg^{2+} is replaced by Ca^{2+} in the reaction (adapted from Drever, 1988)



Other weathering reactions used for calcite, dolomite, gypsum, halite, magnesite, langbeinite, and potassium and magnesium chlorides used simple dissociation in the presence of water (Faure, 1998).

SS Lithology

Based by weight percent ions in solution, ions came mainly from either anorthite (30%) or calcite (32%) (Table 9). The feldspars, including anorthite, contributed 39%. Gypsum contributed 15%, dolomite 2%, Mg-smectite ion exchange contributed 10% and halite 2%. In the ionic balance before minerals were included, about 10 mg/L HCO_3^- was needed to balance the 0.6% difference in cations and anions. The mass-balance closed with an excess of 0.9 mg/L Na^+ and a deficit of 7.2 mg/L HCO_3^- .

Table 9. Mass-balance calculations for Conglomerate-Sandstone (SS) Lithology. All values are in mmol/L unless otherwise indicated. Milligrams per liter is abbreviated (mg/L), and weight percent is (Wt%).

	Na	K	Mg	Ca	Si	Cl	HCO ₃	SO ₄		
SS Formation Values	0.2284	0.0415	1.1520	1.5470	0.1941	0.1145	2.3590	0.3205		
Precipitation Values	0.035	0.008	0.008	0.057	0.003	0.022	0.108	0.024		
Subtracted Total	0.1934	0.0335	1.1440	1.4900	0.1911	0.0925	2.2510	0.2965		
Ionic Balance (meq/L)	7.83	0.04	1.98	3.49		8.30	2.36	2.52		
Ionic Balance (meq/L)	Total: 13.34					Total: 13.18				
	Difference: 0.6%		Adjusted Bicarbonate:				2.5246			
Minerals									mg/L	Wt%
Halite	0.0925					0.0925			5.4	2%
Albite	0.0619				0.1237		0.0619		16.2	6%
Anorthite				0.2980			0.5960		82.9	30%
Orthoclase		0.0335			0.0671		0.0335		9.3	3%
Gypsum				0.2965				0.2965	40.4	15%
Calcite				0.8694			1.7387		87.0	32%
Dolomite			0.0261	0.0261			0.1043		4.8	2%
Mg-Smectite			1.1179						27.2	10%
TOTAL REMAINING	0.039	0	0	0	0	0	-0.118	0	273.2	100%

Table 10. Mass-balance calculations for Siltstone-Shale-Sandstone (SSh) Lithology. All values are in mmol/L unless otherwise indicated. Milligrams per liter is abbreviated (mg/L), and weight percent is (Wt%).

	Na	K	Mg	Ca	Si	Cl	HCO ₃	SO ₄		
Formation Values	0.3219	0.0532	0.6172	1.048	0.2208	0.2375	1.4152	0.3596		
Precipitation	0.035	0.008	0.008	0.057	0.003	0.022	0.108	0.024		
Subtracted Total	0.2869	0.0452	0.6092	0.9910	0.2178	0.2155	1.3072	0.3356		
Ionic Balance (meq/L)	7.83	0.05	1.98	3.49		8.30	1.42	2.52		
Ionic Balance (meq/L)	Total:	13.35			Total:	12.24				
	Difference:		4.4%	Adjusted Bicarbonate:			2.5410			
Minerals									mg/L	Wt%
Halite	0.2155					0.2155			12.6	6%
Albite	0.0637				0.1275		0.0637		16.7	8%
Anorthite				0.0926			0.1852		25.8	12%
Orthoclase		0.0452			0.0903		0.0452		12.6	6%
Gypsum				0.3356				0.3356	45.7	21%
Calcite				0.0563			0.1126		5.6	3%
Dolomite			0.5065	0.5065			2.0260		93.4	43%
Mg-Smectite			0.1026						2.5	1%
TOTAL REMAINING	0.008	0	0	0	0	0	0	0	214.8	100%

SSh Lithology

Based by weight percent ions in solution, ions came mainly from either dolomite (43%) or gypsum (21%) (Table 10). The feldspars as a whole contributed 26%, while halite 6%, and calcite 3%. Mg-smectite ion exchange contributed 1%. In the ionic balance before minerals were included, 68.7 mg/L HCO_3^- was needed to balance the 4.4% difference in cations and anions. The mass-balance closed with an excess of 0.2 mg/L Na^+ .

LS Lithology

Based by weight percent ions in solution, ions came mainly from either calcite (29%) or gypsum (19%) (Table 11). The feldspars as a whole contributed 28%, dolomite 13%, halite 3%, and Mg-smectite ion exchange contributed 9%. Before minerals were included, 9.1 mg/L HCO_3^- was needed to balance a 0.6% cation-anion difference. The mass-balance closed with an excess of 0.8 mg/L Na^+ .

WSP Lithology

Based by weight percent ions in solution, ions came mainly from halite (57%) (Table 12). Gypsum contributed 19%, calcite 1% and dolomite 11%. Magnesite contributed 3%, langbeinite 4%, potassium and magnesium chlorides 5% and amorphous silica 1%. In the ionic balance before minerals were included, about 61 mg/L HCO_3^- was needed to balance the 3.8% difference in cations and anions. The mass-balance closed with a deficit of 0.5 mg/L of HCO_3^- .

Table 11. Mass-balance calculations for Limestone and Limestone-Sandstone (LS) Lithology. All values are in mmol/L unless otherwise indicated. Milligrams per liter is abbreviated (mg/L), and weight percent is (Wt%).

	Na	K	Mg	Ca	Si	Cl	HCO ₃	SO ₄		
Formation Values	0.3132	0.0332	1.0697	1.3474	0.3062	0.1374	2.3590	0.3596		
Precipitation	0.035	0.008	0.008	0.057	0.003	0.022	0.108	0.024		
Subtracted Total	0.2782	0.0252	1.0617	1.2904	0.3032	0.1154	2.2510	0.3356		
Ionic Balance (meq/L)	7.83	0.03	1.98	3.49		8.30	2.36	2.52		
Ionic Balance (meq/L)	Total:	13.33			Total:	13.18				
	Difference:		0.6%	Adjusted Bicarbonate:			2.5082			
Minerals									mg/L	Wt%
Halite	0.1154					0.1154			6.7	3%
Albite	0.1264				0.2527		0.1264		33.1	14%
Plagioclase				0.0926			0.1852		25.8	11%
Orthoclase		0.0252			0.0504		0.0252		7.0	3%
Gypsum				0.3356				0.3356	45.7	19%
Calcite				0.6925			1.3851		69.3	29%
Dolomite			0.1697	0.1697			0.6787		31.3	13%
Mg-Smectite			0.8921						21.7	9%
TOTAL REMAINING	0.036	0	0	0	0	0	0	0	240.6	100%

Table 12. Mass-balance calculations for the evaporite (WSP) Lithology. All values are in mmol/L unless otherwise indicated. Milligrams per liter is abbreviated (mg/L), and weight percent is (Wt%).

	Na	K	Mg	Ca	Si	Cl	HCO ₃	SO ₄		
Formation Values	7.8295	0.3289	0.9875	1.7466	0.2030	8.3012	1.8033	1.2596		
Precipitation	0.035	0.008	0.008	0.057	0.003	0.022	0.108	0.024		
Subtracted Total	7.7945	0.3209	0.9795	1.6896	0.2000	8.2792	1.6953	1.2356		
Ionic Balance (meq/L)	7.83	0.33	1.98	3.49		8.30	1.80	2.52		
Ionic Balance (meq/L)	Total:	13.63			Total:	12.63				
	Difference:		3.8%	Adjusted Bicarbonate:			2.8033			
Minerals									mg/L	Wt%
Halite	7.7945					7.7945			455.5	57%
Anhydrite (Gypsum)				1.1233				1.1233	152.9	19%
Calcite				0.0944			0.1888		9.4	1%
Dolomite			0.4719	0.4719			1.8876		87.0	11%
Magnesite			0.3133				0.6266		26.4	3%
Potassium Chloride		0.2460				0.2460			18.3	3%
Magnesium Chloride			0.1193			0.2387			11.4	2%
Langbeinite		0.0749	0.0749					0.1123	31.1	4%
Amorphous Silica					0.2000				12.0	1%
TOTAL REMAINING	0	0	0	0	0	0	-0.008	0	804.1	100%

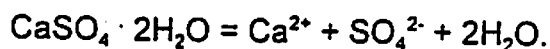
DISCUSSION

Trilinear Diagram Analysis

Trilinear diagrams of individual samples portrayed similarities and differences between lithologies. Water types and sample plotting patterns were compared and contrasted between lithologies.

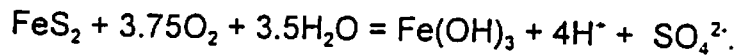
AC Lithology

The AC lithology was not compared to other lithologies, due to the diversity of lithologies it represents. Springs and seeps within the AC lithology, however, were compared to each other (Figure 2). Two groups of springs and seeps were indicated, one of higher SO_4^{2-} concentration (206 to 789 mg/L) and the other of lower SO_4^{2-} concentration (6.4 to 41 mg/L). The higher SO_4^{2-} level in the first group may be the result of either gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) or anhydrite (CaSO_4) dissolution, or contact with shale deposits (Drever, 1988). Gypsum and anhydrite dissolution are involved in the reaction:



Shales in the Monument may be of marine origin, and could have pyrite associated within them. Pyrite produces sulfate ions when exposed to aerated

water in the reaction:



To determine which of these reactions is the actual cause of the high SO_4^{2-} levels, further investigation of the rocks involved would be needed such as petrographic analysis (Drever, 1988).

Within the AC lithology, seeps had either higher SO_4^{2-} or higher Na^+ concentrations than springs. Concentrations of SO_4^{2-} in the seeps ranged from 41 to 789 mg/L and ranged from 6.4 to 230 mg/L in the springs; concentrations of Na^+ ranged from 37 to 72 mg/L in the seeps and from 2.9 to 10 mg/L in the springs. One explanation may be that seeps are influenced by evaporation processes, which increases ions in solution (Drever, 1988). This effect on ion concentration by evaporation has been observed in playa regions of the western United States (Smith and Drever, 1976).

SS Lithology

Water from the SS lithology was classified as a calcium-bicarbonate water and was typical of waters coming from a resistate lithology (Drever, 1988). A resistate is composed of highly resistant minerals, such as quartz grains, cemented with material normally deposited from water that has moved through the rock (Hem, 1992). Sandstone, a resistate, typically weathers analogous to granites, with bicarbonate as the major anion and sodium and calcium as the

major cations (Drever, 1988). In this SS lithology, however, calcium and magnesium were the major cations. The presence of Mg^{2+} suggests that dolomite is present, since dolomite is one of the main contributors of Mg^{2+} in natural waters (Holland, 1978; Drever, 1988). The possible presence of dolomite is not unusual in the SS lithology, as studies of sandstones in the Uinta Basin found that feldspar grains were commonly replaced by authigenic calcite and dolomite (Wanty, et al., 1991).

The SS lithology samples tended to have a wide range of SO_4^{2-} , Cl^- , and HCO_3^- concentrations, but a narrow range of Na^+ , Ca^{2+} , and Mg^{2+} concentrations (Figure 14). SO_4^{2-} concentrations ranged from 7.6 to 80 mg/L, Cl^- concentrations ranged from 2.3 to 8.3 mg/L and HCO_3^- concentrations ranged from 94 to 239 mg/L. Na^+ concentrations ranged from 2 to 10 mg/L, Ca^{2+} concentrations ranged from 44 to 105 mg/L, and Mg^{2+} concentrations ranged from 14 to 37 mg/L. The narrow range of Na^+ , Ca^{2+} and Mg^{2+} observed between samples in the SS lithology may indicate a concentration or dilution of the same water chemistry. This suggests that in general, the water chemistry of the SS lithology is produced only by interactions with the sandstone components themselves, and is not the result of transmitted water from other lithologies (Hem, 1992). It is interesting to note that the highest SO_4^{2-} levels observed were from two wells within the Weber formation, with concentrations of 76 and 99 mg/L, representing the deepest samples taken in the SS lithology. This is consistent with observations that in the

weathering zone, SO_4^{2-} is generally flushed out or can be precipitated as gypsum, an occurrence that depends on gypsum solubility conditions and can also sometimes happen in the alteration zone of sulfide ore bodies in semi-arid to arid areas where limestone is abundant (Holland, 1978).

SSh Lithology

Water from the SSh lithology samples was classified as a calcium-bicarbonate water. The SSh lithology was classified as a hydrolyzate (shales), which are largely composed of clay minerals and other fine-grained particulate matter that has been formed by chemical reactions between water and silicates. Many of the same minerals are found in hydrolyzates as in sandstones (resistates), however, the particles are much finer-grained (Hem, 1992).

The SS and SSh lithology were classified as a calcium-bicarbonate water, however, the trilinear diagram of SSh lithology samples indicated increasing Na^+ levels with increasing SO_4^{2-} levels compared to the SS lithology. Also, the concentration ranges for Na^+ and Cl^- in the SSh lithology were higher than in the SS lithology. Na^+ ranged from 3 to 27 mg/L in the SSh lithology and from 2 to 10 mg/L in the SS lithology. Cl^- ranged from 2.3 to 8.3 mg/L in the SS lithology and 0.6 to 30 mg/L in the SSh lithology. The SSh lithology water chemistry may be influenced by trapped seawater in marine shales, causing an increase in Na^+ and Cl^- with higher SO_4^{2-} levels relative to the SS lithology, however, studies have

indicated that the form in which seawater ions are present in shale is unknown (USGS, 1971; Drever, 1988). Higher values of sulfate in some of the SSh lithology samples may be from the presence of pyrite, which also is commonly associated with marine shales and contributes sulfate to solution after oxidation (Drever, 1988). Another explanation for higher ionic concentrations is that the smaller grain sizes in shales offer more surface area to react with passing water, which increases the mechanisms and rates of transfer of solutes in rock-water interactions (Salbu and Steinnes, 1995). The SS lithology also has a higher HCO_3^- range than the SSh lithology. Concentrations of HCO_3^- ranged from 94 to 239 mg/L for the SS lithology, and 12 to 159 mg/L for the SSh lithology, indicating that the SS lithology may be more influenced by bicarbonate minerals than the SSh lithology.

LS Lithology

Water from the LS lithology was classified as a calcium-bicarbonate water, typical for a precipitate formation. A precipitate is a group composed of the common alkaline earth carbonates, calcite and dolomite (Hem, 1992). Water chemistry in precipitates often has calcium, magnesium and bicarbonate as the only significant solutes, with sulfate commonly present from pyrite oxidation or gypsum dissolution (Drever, 1988). In general, there is little discernable difference between the SS and LS lithologies. The LS lithologic concentrations of SO_4^{2-} ranged from 8.4 to 33 mg/L, concentrations of Cl^- ranged from 2.9 to 9.8

mg/L, and concentrations of HCO_3^- ranged from 133 to 185 mg/L. The similarity of the SS and LS lithologies may indicate that the SS lithology has significant amounts of carbonates or that the LS lithology has significant amounts of silicates. The SSh lithology includes a wider range of Na^+ , Cl^- , and SO_4^{2-} concentrations than the LS lithology, potentially due to a higher influence of pore waters, and pyrite oxidation or gypsum dissolution (Drever, 1988).

WSP Lithology

Water from the WSP lithology was classified as a sodium-chloride water, typical for an evaporite (Hem, 1992). Evaporites generally contain large amounts of Ca^+ , Na^+ , Cl^- , and SO_4^{2-} , depending on the type of evaporite, and weather by simple solution, producing saline waters (Hem, 1992; Drever, 1988; Hounslow, 1995). Differences between the WSP lithology and all other lithologies were mainly due to higher concentrations of Na^+ , Cl^- , and SO_4^{2-} in the WSP lithology. The WSP lithologic concentrations of Na^+ ranged from 104 to 314 mg/L, concentrations of SO_4^{2-} ranged from 45 to 195 mg/L, and concentrations of Cl^- ranged from 148 to 455 mg/L. Other occurrences of elevated Na^+ , and Cl^- in ground water were documented in the Uinta Basin. The Uinta Basin study found sodium-chloride dominated ground waters, and speculated that some type of brine existed that was originally from connate waters of an ancient lake, but did not specifically indicate that these water came from evaporite deposits (Wanty, et al., 1991).

Wilcoxon Rank Sum Test

The Wilcoxon Rank Sum test analyzed for significant differences between lithologies with a ($p \leq 0.05$). Overall, these tests indicated that the cations B, Ca^{2+} , K^+ , Sr^{2+} and Na^+ had the most significant differences, which were five or more out of the ten lithologic comparisons made (Table 4). In general, the tests agreed with the results made by trilinear diagram analysis.

The AC lithology was first compared to other lithologies. The AC and SS lithologies had significant differences in major cations K^+ and Na^+ , with p-values of 0.005 and 0.022. The AC and SSh lithologies had significant differences in major cations Ca^{2+} and Mg^{2+} , with p-values of 0.002 and 0.025. The AC and LS lithologies had a significant difference in the major cation K^+ with a p-value of 0.031. The AC and WSP lithologies had significant differences in major cations K^+ and Na^+ with p-values of 0.001 and 0.0002. For these significant differences between major cations, the AC lithology had higher median concentration values in each significant difference comparison, except for the WSP lithology. The AC and SS lithologies had median concentrations for K^+ of 2.6 and 1.2 mg/L, with Na^+ concentrations 10 and 5 mg/L, respectfully. The AC and SSh lithologies had median concentrations for Ca^{2+} of 93 and 42 mg/L, with Mg^{2+} concentrations of 31 and 15 mg/L. The AC and LS lithologies had median concentrations for K^+ of 2.6 and 1.0 mg/L. The AC and WSP lithologies had median concentrations for K^+ of 2.6 and 9.9 mg/L, with Na^+ concentrations of 10 and 180 mg/L. Elevated

concentrations indicated between the AC and SS, SSh and LS lithologies could be due to the seeps of the AC lithology, which may be subject to evaporation and subsequent ionic concentration (Smith and Drever, 1978; Drever, 1988).

SS and SSh lithologic comparisons indicated significant differences in the cations B, Ca^{2+} , Mg^{2+} , and Na^{+} , with p-values of 0.002, 0.001, 0.036 and 0.021, respectfully. Of these differences, B and Na^{+} were the only two cations to have higher median concentration values in the SSh lithology than the SS lithology, at 0.045 and 0.027 mg/L for cation B, with 7.4 and 5.5 mg/L for cation Na^{+} , respectfully. These two cations may have had higher concentrations in the SSh lithology due to trapped seawater in the shales when it was deposited (Drever, 1988). Silica also had a greater median value concentration in the SSh lithology than the SS lithology, at 6.2 and 5.5 mg/L, respectfully, but the difference was not significant, with a p-value of 0.07.

SS and LS lithologic comparisons indicated significant differences in the cations Cd^{2+} , Si, and V^{2+} , with p-values of 0.005, 0.002 and 0.016, respectfully. Of these differences, each median cation concentration was higher in the LS lithology than the SS lithology. The median concentration for the cation Cd^{2+} was 0.0002 mg/L in the SS lithology and 0.002 in the LS lithology. Cation Si was 5.5 in the SS lithology and 8.6 mg/L in the LS lithology. Cation V^{2+} was 0.003 in the S lithology and 0.006 mg/L in the LS lithology. These differences could indicate

higher dissolution rates in the LS lithology compared to the SS lithology, due to the higher Si concentrations, however, the lithologies are more similar than different (Hem, 1992). This similarity between the lithologies could indicate high carbonate concentrations in the SS lithology or a significant portion of silicate minerals present in the LS lithology. Further investigation of the rocks using petrographic analysis would be needed to make the correct deduction (Drever, 1988; Faure, 1998).

In addition to the comparisons already stated, the SSh lithology was significantly different from the LS lithology for the cation B, with a p-value of 0.018. The lack of significant differences, again, could indicate high carbonate concentrations in the SS lithology or a significant portion of silicate minerals present in the LS lithology. Further investigation of the rocks using petrographic analysis would be needed to make the correct deduction (Drever, 1988; Faure, 1998).

In comparison to all lithologies, the cations, Ca^{2+} , K^+ , Li^+ , Sr^{2+} and Na^+ , were elevated in the WSP lithology. For the WSP and SS lithology, the median concentration for Ca^{2+} was 70 and 61.5 mg/L, 9.9 and 1.15 mg/L for the cation K^+ , 0.11 and 0.008 mg/L for Li^+ , 1 and 0.23 mg/L for Sr^{2+} , and 180 and 5.25 mg/L for Na^+ . For the WSP and SSh lithology, the median concentration for Ca^{2+} was 70 and 42 mg/L, 9.9 and 1.6 mg/L for K^+ , 0.11 and 0.009 mg/L for Li^+ , 1 and 0.19 mg/L for Sr^{2+} , and 180 and 7.4 mg/L for Na^+ . For the WSP and LS lithology, the

median concentration for Ca^{2+} was 70 and 54 mg/L, 9.9 and 1 mg/L for K^+ , 0.11 and 0.007 mg/L for Li^+ , 1 and 0.26 mg/L for Sr^{2+} , and 180 and 7.2 mg/L for Na^+ . Elevated concentrations of ions in evaporite deposits, relative to the other lithologies is expected, as they are mainly composed of carbonates, sulfates and salts, which weather by simple dissolution (Holland, 1978). The trace metal Li^+ is associated with alkali feldspars and the trace metal Sr^{2+} can replace Ca^{2+} in carbonates and gypsum (Salbu and Steinnes, 1995). The feldspars, carbonates and gypsum are all present in evaporite deposits, therefore, elevated trace metals in association with these minerals can exist (Holland, 1978).

Ionic Ratio Analysis

Ionic ratio analysis was used to determine weathering processes and minerals in each of the lithologies (Table 5). All calculations were performed in meq/L except the ratio Si/TDS (mg/L) and the ratio $(\text{Ca}^{2+} + \text{Mg}^{2+})/\text{SO}_4^{2-}$ (mmol/L). The AC lithology was not analyzed due to the variety of lithologies it represents.

The ratio Si/TDS showed evidence of higher Si concentrations in the SS and SSh lithologies, with ratio values of 0.026 and 0.036, respectfully, compared to the WSP lithology, with a ratio value of 0.006. The WSP lithology ratio is consistent with other observations made of evaporite deposits, which typically have low Si/TDS ratios because their TDS values consist mainly of the ions Na^+ , SO_4^{2-} , and Ca^{2+} (Drever, 1988). The higher ratio in the SSh lithology compared to

the SS lithology may relate to the fact that shales (SSh lithology) tend to have finer particles and, hence, larger surface areas than sandstones (SS lithology), which may allow more Si to weather into solution (Salbu and Steinnes, 1995). The LS lithology had the highest Si/TDS ratio at 0.042. Studies have indicated that this may be due to higher dissolution rates experienced by a precipitate (LS lithology), in general, as opposed to a resistate (SS lithology) or a hydrolyzate (SSh lithology) (Drever, 1988).

The SS lithology is the only lithology that has a HCO_3^-/Si ratio value greater than ten, with a ratio value of 12. No lithologies other than the SS lithology have ratio values less than five; the SSh, LS and WSP lithologies values were 6, 8 and 9, respectively (Table 5). The numbers ten and five are an arbitrary division of the HCO_3^-/Si ratios. Ratio values less than five indicate silicate weathering and ratio values greater than ten indicate carbonate weathering (Hounslow, 1995). Other ratio values are ambiguous. These arbitrary distinctions were made by assuming that carbonates dissolve without releasing silica, whereas albite and other silicates release silica (Hounslow, 1995). Based on the HCO_3^-/Si ratio for the SS lithology, there may be evidence of carbonate minerals occupying the spaces between quartz grains (Drever, 1988).

The ratio $\text{Si}/(\text{Na}^+ + \text{K}^+ - \text{Cl}^-)$ is a comparison of silica with nonhalite sodium. The assumption is that after subtracting Cl^- from Na^+ , the remaining Na^+ is due to

albite or ion exchange, and the K^+ is from the weathering of biotite and feldspars (Hounslow, 1995). This ratio also assumes that the main weathering product is kaolinite or montmorillonite. Therefore, a ratio value less than one indicates cation exchange; a ratio value greater than one and less than two indicates the possibility of albite weathering; and a ratio value greater than two indicates ferromagnesian weathering (Hounslow, 1995). The ratio $Si/(Na^+ + K^+ - Cl^-)$ for the SS, SSh and LS lithologies suggests albite weathering, for the ratio values were 1.4, 1.8 and 1.5, respectfully. The ratio for the WSP lithology indicates cation exchange, for the ratio value was -0.9. The SS and SSh lithologies are both composed, in part, of silicate minerals; therefore, it is not unreasonable to suggest albite weathering within them. However, it is unusual for albite weathering to be occurring to a significant extent in the LS lithology. The presence of albite in the LS lithology could be from the sandstones and shales mixed in with the lithology, or from the fact that few limestones formations are purely limestone or dolomite and can contain many impurities (Holland, 1978).

The ratio Na/Cl was analyzed as Na^+/Si after subtracting the Na^+ used to equal Cl^- concentrations. The subtraction of equal amounts of Na^+ and Cl^- assumes that all the Cl^- present is a result of the dissociation of halite in the equation



After subtracting an equal amount of Na^+ to equal Cl^- , there were still Na^+ ions left in the SS, SSh and LS lithologies. Studies have indicated that more Na^+ than

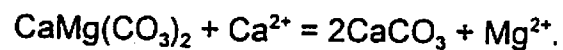
Cl^- indicates the possibility of feldspar weathering (Drever, 1988, Hounslow, 1995). The WSP lithology had used all of its Na^+ to equal Cl^- for a Na^+/Si ratio value of 0.0, which indicates that all of the sodium may be in the form of halite, a common mineral in evaporites (Holland, 1978). The SS, SSh and LS lithologies had Na^+/Si ratio values of 0.6, 0.4 and 0.9. For the SS and SSh lithologies, the almost 0.5 ratio formed between the remaining Na^+ and Si may indicate the presence of albite (Faure, 1998).

$\text{Mg}^{2+}/(\text{Ca}^{2+}+\text{Mg}^{2+})$ ratios can provide an indication of the type of carbonate weathering present in a lithology (Hounslow, 1995). The SS lithology had a $\text{Mg}^{2+}/(\text{Ca}^{2+}+\text{Mg}^{2+})$ ratio of 0.3 and a HCO_3^-/Si value of 12, suggesting the likelihood of limestone-dolomite weathering. This result may be another sign that the SS lithology has a high degree of carbonates associated with it. The other lithologies were ambiguous with respect to this ratio, as it is used in conjunction with definite results made with the HCO_3^-/Si ratio values.

The ratio of $\text{Ca}^{2+}/(\text{Ca}^{2+}+\text{SO}_4^{2-})$ was calculated to determine some of the potential sources of Ca^{2+} and SO_4^{2-} . The ratio's primary assumption is that SO_4^{2-} comes mainly from the oxidation of pyrite, and if SO_4^{2-} is greater than Ca^{2+} , the inference is that Ca^{2+} has been removed from the system by precipitation or ion exchange reactions (Hounslow, 1995). The $\text{Ca}^{2+}/(\text{Ca}^{2+}+\text{SO}_4^{2-})$ ratio values for the SS, SSh, LS and WSP lithologies are 0.8, 0.7, 0.9, and 0.6, respectfully. All ratio values

are greater than 0.5, indicating that the main Ca^{2+} sources should be carbonate or silicates, and not necessarily gypsum. This result, however, is contrary to the literature, as gypsum is a common secondary weathering mineral in arid environments (Drever, 1988).

The ratio $(\text{Ca}^{2+} + \text{Mg}^{2+})/\text{SO}_4^{2-}$ can be used to determine the likelihood of dedolomitization, which is indicated by a molar ratio approaching one (Hounslow, 1995). Dedolomitization is the replacement of dolomite by calcite according to the reaction (Hounslow, 1995)



The ratio values for the SS, SSh, LS and WSP lithologies were 8.7, 4.6, 23.2 and 2.2, respectfully. All of the ratios were greater than one; therefore dedolomitization is unlikely.

Mass-Balance Modeling

Mass-balance results by lithology were calculated as weight percent (Table 6).

The percentage indicates the ionic concentration in the water that may be attributable to a specific dissolved mineral.

Weathering Mineral Selection

Dissolved mineral selections were dependent on several assumptions that may or may not introduce error into the mass-balance results. These assumptions

consisted of the amount of silica and the source of the sulfate found in the water chemistry of the various lithologies, the type of weathering process feldspars undergo, and the source of the magnesium concentrations in the lithologic water chemistry.

In analyzing for the presence and amount of silicate minerals that contribute to the overall water chemistry of a lithology, the assumption was made that the amount of silica analyzed in the samples is indicative of the amount of silicate weathering (Garrels and Mackenzie, 1967; Kimball, 1981). The problem with this assumption is that under many natural conditions, a significant amount of silica can be present as amorphous silica, precipitating out of the water, and hence not analyzed. Conversely, amorphous silica could contribute higher silica amounts into the water by silica dissolution (Hounslow, 1995). The possibility that amorphous silica can precipitate can be seen in activity diagrams involving silicate weathering (Faure, 1998; Drever, 1988).

Gypsum was the only sulfate mineral considered in the mass balance. Barite was predicted to be present by MINTEQA2 analysis, however, it was not considered because it contributed only a very small portion of ions into solution. Using only the mineral gypsum may or may not be correct, as sulfate in these lithologies could have also come from pyrite oxidation processes, although only gypsum was observed in X-ray diffraction of the rock samples analyzed (Drever,

1988). There is no easy way to distinguish between these two alternatives without further investigation of the rock mineralogy involved by methods such as petrographic analysis (Drever, 1988).

The feldspar minerals selected for the SS, SSh, and LS lithologies; albite, anorthite and orthoclase, are common feldspars found in many environments.

The presence of albite and other feldspars in the LS lithology is attributed to the fact that this lithology contains, besides limestones, geologic formations that are a mixture of limestones, sandstones and shale beds (Hansen, et al., 1983).

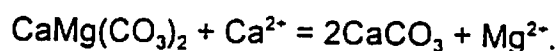
These sandstone and shale beds could contain feldspars. The WSP lithology used other minerals besides feldspars to account for the water chemistry constituents. Feldspars may be present in evaporite deposits, but salts, sulfates and carbonates are usually the most prevalent (Holland, 1978).

Weathering reactions selected for the feldspars (albite, anorthite, orthoclase) assumes that they weather into kaolinite. Feldspars, in general, are assumed to weather into either kaolinite or smectite. This assumption is based on research by various authors (Helgeson, et al., 1969; Drever, 1988). Basically, these authors indicated that natural waters in contact with igneous rock for a short time produces either gibbsite or kaolinite; after longer periods of contact, only kaolinite is formed, and further alteration forms smectite (Drever, 1988). For example, research conducted on Sierra Nevada springs found that ephemeral springs

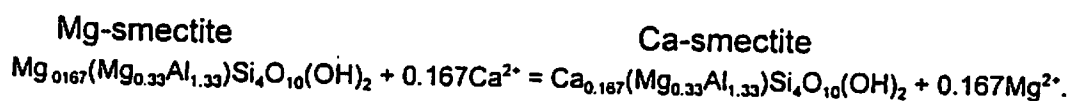
produced kaolinite, and perennial springs produced either kaolinite or smectite (Feth, 1964; Garrels and Mackenzie, 1967). In determining whether to use kaolinite or smectite, the simplest reaction, feldspar to kaolinite, was used. The alteration of feldspar to smectite depends on the composition and free energy assumed for the smectite in question. Smectites are naturally highly variable in composition, therefore only an approximate assumption as to whether a water is over or undersaturated with respect to kaolinite or smectite can be made (Drever, 1988). Due to the complications inherent in smectite approximations, the assumption made for the Monument springs was that feldspars weather to kaolinite and not to smectite.

The source of the magnesium in each of the lithologies is dependent on many sources, however, the assumption made was that it came from Mg-smectite. Calcite was first considered as the source of the magnesium. Magnesium can substitute for calcium in the calcite structure; calcite that is formed in modern, shallow-marine environments can contain up to 11 to 19 mole percent MgCO_3 (Drever, 1988). This amount could not encompass all of the Mg^{2+} observed in the water samples, however. Dolomite was then considered as the source of the magnesium. Dolomite weathers to produce one mole of Ca^{2+} and one mole of Mg^{2+} for every four moles of HCO_3^- (Faure, 1998). Mass-balance indicated, though, that dolomite could not account for all the magnesium in the lithologic water chemistries. Another reaction, dedolomitization, the replacement of

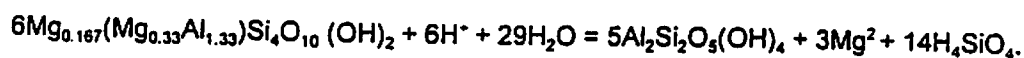
dolomite by calcite according to the reaction:



and another possible source of magnesium, was determined by ionic ratios to not be likely in any of the lithologies (Hounslow, 1995). Since carbonates could not account for the presence of magnesium, Mg-smectite was used to explain the presence of Mg^{2+} ions in the water samples of the SS, SSh, and LS lithologies. Although smectites were indicated in only one X-ray diffraction pattern, for the SS lithology, the assumption was that it is also present in the LS lithology. The presence of Mg-smectite can be either the result of the lithologies producing a smectite or of smectite deposition during the lithologic formation. One theory behind this assumption is that the lithologies were subjected to events that incorporated volcanic glass or pyroxenes into the lithology, which in turn provided a vehicle for Mg-smectite formation. To account for the Mg^{2+} ions, ion exchange between Mg-smectites and Ca^{2+} ions in water replace each other in the reaction (adapted from Drever, 1988)



The reaction of smectite to kaolinite was additionally considered as a possible way magnesium could be released, but rejected after mass-balance manipulation indicated there was not enough silica in the lithologic mass-balance to account for the reaction (adapted from Drever, 1988)



Comparisons Among Lithologies

Summarized mass balance results for gypsum in the SS, SSh, LS and WSP lithologies indicated that gypsum remained about equal, contributing 15%, 21%, 19% and 19% by weight percent. This observation suggests that the gypsum contribution of a given lithology is approximately the same, relative to the other ions in solution for that lithology. This result appears unusual, and further rock analysis to determine the presence of pyrite formation and oxidation should be performed to verify these results (Drever, 1988; Holland, 1978).

The SS lithology mass-balance indicated that feldspars contributed 39%, calcite at 32% and dolomite at 2% by weight percent. The SS lithology had the most contribution by feldspars of all the lithologies, and this was expected given the assumption that it is made up of mainly quartz and feldspar minerals. The higher calcite levels compared to dolomite are due to the fact that calcite can be more easily dissolved and precipitated in natural waters, whereas dolomite is not likely to precipitate or be found in large amounts in sandstone formations (Drever, 1988). Halite and Mg-smectite composed 2% and 10% each by weight percent. For weathering reactions in the SS lithology, carbonate weathering of calcite and dolomite composed 34% by weight percent of the ions in solution, sulfate weathering of gypsum 15%, halite dissolution 2% and Mg-smectite ion-exchange 10% by weight percent. These results indicate that the material between sandstone grains, which is assumed to be carbonates, can contribute

significantly to weathering, since these minerals can more easily dissolve and dissolve again as water moves through the lithology (Hem, 1992). A second possibility is that there is an influence of other lithologies affecting the water chemistry. This study assumed that the water chemistry from each lithology was exposed only to that lithology, or had enough contact time with that lithology to consider other lithologies an insignificant influence.

The SSh lithology mass-balance indicated that feldspar weathering composed 26%, carbonate weathering of calcite and dolomite composed 46% by weight percent of the ions in solution, sulfate weathering of gypsum 21%, and halite dissolution 6%. The lower contribution by feldspars in the SSh lithology compared to the SS and LS lithology may be due because the SSh shales generally have less porosity than sandstones, making them more susceptible to preferential paths of flow that isolate many feldspars from water and weathering reactions (Hem, 1992). Another explanation is that, in shales, the quantity of calcium present as a constituent of silicate minerals is small, causing lower percentages for anorthite which drastically decrease the overall feldspar contribution (Holland, 1978). For the carbonate contributions, the opposite of the SS lithology occurs; dolomite has the higher weight percentage of ions in solution as compared to calcite. These results indicate that the shales may be shallow marine in origin, where carbonates, especially dolomite, can form as an integral part of the shale lithology (Drever, 1988; Holland, 1978).

The mass-balance of the LS lithology indicated that feldspar weathering composed 28%, carbonate weathering of calcite and dolomite composed 42% by weight percent of the ions in solution, sulfate weathering of gypsum 19%, halite dissolution 3% and Mg-smectite ion-exchange 9% by weight percent. The results of feldspar weathering indicate that there may be significant sandstone and shale beds between limestone layers in the LS lithology. These results also indicate, however, that the LS lithology is primarily subject to carbonate weathering, with feldspar weathering secondary in importance.

The mass-balance of the WSP lithology indicated that dissolution of halite and other chlorides was the dominant weathering mechanism at 62% by weight percent. Carbonate weathering of calcite, magnesite and dolomite composed 15% by weight percent of the ions in solution. Sulfate weathering of gypsum and langbeinite composed 23% by weight percent. Amorphous silica composed 1% by weight percent. The water chemistry supports the theory that this lithology is an evaporite of marine origin (Holland, 1978). Halite and gypsum had the highest percentage contributions; these two components are common in evaporite deposits, and tend to precipitate first in evaporite formation (Holland, 1978). In the WSP lithology, silicate minerals that could be present are quartz, opal, talc, illite and kaolinite (Holland, 1978). To simplify the WSP lithology analysis, the silica content was assumed to come from amorphous silica ($\text{SiO}_{2(\text{amorph})}$).

Discriminatory Analysis

The methods used to in this study to differentiate lithologies; trilinear diagrams, ionic ratios, Wilcoxon Rank sum test, and mass-balance modeling; can be used with varying degrees of effectiveness. Methods that noted weathering processes taking place, such as ionic ratios and mass-balance modeling, were found to be the most effective in discerning differences between lithologies.

Trilinear diagrams provided qualitative indications of lithologic differences, and worked best when there were large lithologic variations. The Wilcoxon Rank Sum test was a quantitative method, but could only analyze individual ions between lithologies. These two methods made stronger conclusions together, such as noting differences in ions between the WSP lithology and all other lithologies, or the increases of Na^+ in conjunction with increases of SO_4^{2-} in the SSh lithology.

The ionic ratios Si/TDS and Na^+/Si were the most useful of the ionic ratios used. While these two ionic ratios could note differences in weathering processes, the mass-balance could additionally note the degree of influence on water chemistry these processes have in a particular lithology. Overall, the ionic ratios provided a good screening method of weathering processes, and the mass-balance provided the best indicator of differences between lithologies.

CONCLUSIONS

Trilinear Diagram Analysis

Trilinear diagrams showed differences between the SS, SSh, LS and WSP lithologies. Differences in the AC lithology were only analyzed between springs and seeps within the AC lithology, due to the assortment of geologic formations this lithology represents. Within the AC lithology, seeps had either higher SO_4^{2-} or higher Na^+ concentrations than springs. Concentrations of SO_4^{2-} in the seeps ranged from 41 to 789 mg/L and ranged from 7.3 to 232 mg/L in the springs; concentrations of Na^+ ranged from 37 to 72 mg/L in the seeps and from 2.9 to 10 mg/L in the springs. The seeps may be influenced by evaporation processes, which concentrate ions in solution.

The SS and SSh lithology were classified as a calcium-bicarbonate water, however, the trilinear diagram of SSh lithology samples indicated increasing Na^+ levels with increasing SO_4^{2-} levels compared to the SS lithology. Also, the concentration ranges for Na^+ and Cl^- in the SSh lithology were higher than in the SS lithology. Na^+ ranged from 3 to 27 mg/L in the SSh lithology and from 2 to 10 mg/L in the SS lithology. Cl^- ranged from 2.3 to 8.3 mg/L in the SS lithology and 0.6 to 30 mg/L in the SSh lithology. The SSh lithology water chemistry may be

influenced by trapped seawater in marine shales, causing an increase in Na^+ and Cl^- with higher SO_4^{2-} levels relative to the SS lithology. The SS lithology also has a higher HCO_3^- range than the SSh lithology. Concentrations of HCO_3^- ranged from 94 to 239 mg/L for the SS lithology, and 12 to 159 mg/L for the SSh lithology, indicating that the SS lithology may be more influenced by bicarbonate minerals than the SSh lithology.

Water from the WSP lithology was classified as a sodium-chloride water, typical for an evaporite and significantly different from the other, bicarbonate dominated lithologic waters. Concentrations of SO_4^{2-} ranged from 45 to 195 mg/L, Cl^- ranged from 148 to 455 mg/L, and HCO_3^- ranged from 23 to 125 mg/L.

Wilcoxon Rank Sum Test

Statistical analysis indicated differences in cation concentrations between lithologies. The AC and SS lithologies had significant differences in the major cations K^+ and Na^+ with p-values of 0.005 and 0.022. The AC and SSh lithologies had significant differences in the major cations Ca^{2+} and Mg^{2+} , with p-values of 0.002 and 0.025. The AC and LS lithologies had a significant difference in the major cation K^+ with a p-value of 0.031. For each of these significant, the AC lithology had higher median concentration values, which may indicate the influence seeps have in the AC lithology.

The SS and SSh lithologic comparisons indicated significant differences in the cations B and Na⁺, with p-values of 0.002 and 0.021. These were the only two cations to have significant differences and higher median concentrations in the SSh lithology, indicating the possible influence of trapped seawater in shales of the SSh lithology.

The cations, Ca²⁺, K⁺, Li⁺, Sr²⁺ and Na⁺ were significantly different and had higher median concentrations in the WSP lithology compared to the other lithologies.

The occurrence of elevated concentrations of ions is typical of evaporite deposits, which allows increased concentrations of these ions by simple dissolution.

Ionic Ratio Analysis

The ratio Si/TDS showed evidence of differences between the SS, SSh, LS and WSP lithologies. The SS and SSh lithologies had ratio values of 0.026 and 0.036, respectively, and the WSP lithology had a ratio value of 0.006. The WSP lithology ratio was consistent with an evaporite deposit, which typically has low Si/TDS ratios. The higher ratio in the SSh lithology compared to the SS lithology may relate to the fact that shales (SSh lithology) tend to have finer particles and, larger surface areas than sandstones (SS lithology), allowing more Si to weather into solution. The LS lithology had the highest Si/TDS ratio at 0.042, which may be due to higher dissolution rates than the other lithologies.

The Na^+/Si ratio values after subtracting the Na^+ used to equal Cl^- concentrations in the SS, SSh, and LS lithologies were 0.6, 0.4 and 0.9. More Na^+ than Cl^- in these lithologies indicates feldspar weathering. The WSP lithology had a ratio value of 0.0, indicating that all of the Na^+ was in the form of halite. An almost 0.5 ratio between the remaining Na^+ and Si in the SS and SSh lithology also indicates the presence of albite.

The ratio $\text{Mg}^{2+}/(\text{Ca}^{2+}+\text{Mg}^{2+})$ was used in conjunction with the HCO_3^-/Si ratio, indicating only one difference in weathering minerals between lithologies. The SS lithology had a $\text{Mg}^{2+}/(\text{Ca}^{2+}+\text{Mg}^{2+})$ ratio value of 0.3 and a HCO_3^-/Si value of 12, indicating the likelihood of limestone-dolomite weathering. The other lithologies were ambiguous with respect to this ratio.

Mass-Balance Modeling

Mass-balance modeling indicated distinct differences in the evolution of spring water from the lithologies. Dissolved constituents in the SS lithology water chemistry were composed mainly from the minerals anorthite, calcite and gypsum. Feldspar weathering contributed 39%, carbonate weathering 34%, sulfate weathering 15%, halite dissolution 2% and Mg-smectite ion exchange 10%. These results indicated that carbonates, which are assumed to be present in-between the feldspar and quartz grains, contribute significantly to the water chemistry. Calcite was the dominant carbonate at 35% and dolomite was at 2%

by weight percent. The higher calcite levels compared to dolomite may indicate that calcite can more easily dissolve and precipitate in natural waters, whereas dolomite is not likely to precipitate or be found in large amounts in sandstones.

Dissolved constituents in the SSh lithology water chemistry were composed mainly from the minerals anorthite, gypsum and dolomite. Feldspar weathering contributed 26%, carbonate weathering 46%, sulfate weathering 21%, and halite dissolution 6%. The lower contribution by feldspars in the SSh lithology compared to the SS lithology may be due to shales in the SSh lithology having less porosity than sandstones, making them more susceptible to preferential paths of flow that isolate many feldspars from water and weathering reactions. Dolomite was the dominant carbonate at 43% , while calcite was at 3% by weight percent. These results, which are the opposite of the SS lithology, indicated that the SSh lithology may be shallow marine in origin.

Dissolved constituents in the LS lithology water chemistry were composed mainly from the minerals calcite, dolomite, gypsum, albite and anorthite. Feldspar weathering contributed 28%, carbonate weathering 42%, sulfate weathering 19%, halite dissolution 3% and Mg-smectite ion exchange 9%. Calcite was the dominant carbonate at 31%, while dolomite was at 14% by weight percent. Feldspar weathering results indicated the possibility of sandstone and shale beds between limestone layers in the LS lithology.

Dissolved constituents in the WSP lithology water chemistry were composed mainly from the minerals halite and gypsum. Feldspar weathering contributed 0%, carbonate weathering 15%, sulfate weathering 23%, halite and other chloride dissolution 62% and amorphous silica 2% by weight percent ions in solution. Halite was the dominant source mineral at 57%, dolomite was the dominant carbonate at 11% , while calcite was at 1% by weight percent. The water chemistry supports the theory that this lithology is an evaporite.

Discriminatory Analysis

The methods used to in this study to differentiate lithologies; trilinear diagrams, ionic ratios, Wilcoxon Rank sum test, and mass-balance modeling; can be used with varying degrees of effectiveness. Methods that noted weathering processes taking place, such as ionic ratios and mass-balance modeling, were found to be the most effective in discerning differences between lithologies.

The ionic ratios Si/TDS and Na^+/Si were the most useful of the ionic ratios used. While these two ionic ratios could note differences in weathering processes, the mass-balance could additionally note the degree of influence on water chemistry these processes have in a particular lithology. Overall, the ionic ratios provided a good screening method of weathering processes, and the mass-balance provided the best indicator of differences between lithologies.

RECOMMENDATIONS

The recommendations posed for further study are meant to compliment and further refine the existing conclusions and database of this thesis. Three recommendations can be made to accomplish this purpose:

- The first recommendation would be to continue the spring inventory of the Monument until all springs have been sampled and to re-sample selected springs over time. This will increase the sample sizes of the geologic formations and predict any variability in water chemistry. Further sampling would also provide a statistically better database to determine average and median concentrations of constituents.
- Secondly, to perform a complete petrographic rock analysis on each lithology. This could help verify the assumptions made concerning silica, gypsum and pyrite, as well as other minerals, providing a check on the mass-balance results.
- Thirdly, to continue with a discriminatory analysis of the methods used, incorporating alternate methods so that the ability to quantitatively differentiate lithologies by water chemistry is further refined.

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APPENDIX A
STRATIGRAPHIC DESCRIPTIONS OF GEOLOGIC FORMATIONS

Table 1

Summarized Stratigraphy of Dinosaur National Monument

Time Series	Formation	Lithology
Quaternary	Alluvium, Colluvium, Landslides	Poorly sorted gravel, sand and silt, landslides and colluvium are heterogeneous mixes of soil and rock
Tertiary	Brown's Park	Fine to coarse-grained sandstone, calcareous to tuffaceous
Tertiary	Bishop Conglomerate	Conglomerate and coarse, stony sandstone; red chert common
Cretaceous	Mancos Shale	Main body is shale, silty to clayey, generally calcareous, with a calcareous sandstone member and a hard, siliceous shale member
Lower Cretaceous	Dakota Sandstone	Medium to coarse-grained sandstone, with subordinate chert-pebble conglomerate
Jurassic	Cedar Mountain	Claystone, siltstone, shale and fine to coarse-grained sandstone
Jurassic	Stump	Glaucconitic siltstone and shale above medium-coarse grained sandstone
Jurassic	Entrada Sandstone	Fine to medium-grained eolian sandstone
Jurassic	Carmel	Shale, siltstone, mudstone and some sandstone
Jurassic/Triassic	Glen Canyon Sandstone	Mostly fine-grained eolian sandstone
Triassic	Chinle	Siltstone, shale, sandstone and conglomerates
Triassic	Moenkopi	Gypsiferous siltstone and shale
Permian	Park City	Limestone, siltstone, sandstone and dolomite, locally phosphatic
Pennsylvanian	Weber Sandstone	Fine to very fine-grained eolian sandstone
Pennsylvanian	Morgan	Cherty limestone and massive, fine-grained sandstone, over interbedded shale and siltstone
Pennsylvanian	Round Valley Limestone	Cherty limestone
Mississippian	Doughnut Shale and Humbug	Clayey shale over fine to very fine-grained sandstone interbedded with limestone and shale
Mississippian	Madison Limestone	Cherty, locally dolomitic limestone
Cambrian	Lodore	Sandstone over glauconitic shale over coarse to medium grained sandstone
Proterozoic	Uinta Mountain Group	Quartzitic sandstone cemented by quartz overgrowths or hematite, occasional beds of silty shale and micaceous siltstones

Note: Information taken from Hansen, Wallace R., Rowley, Peter D. and Carrara, Paul E., 1983, Geologic Map of Dinosaur National Monument and Vicinity, Utah and Colorado, US Geological Survey Map I-1407, 1:50,000.

APPENDIX B

**COMPLETE DATA SET FROM SAMPLE ANALYSIS
AND
QA/QC RESULTS**

TABLE 1
FIELD DATA - SAMPLE LOCATIONS

SAMPLE	GEO - UNIT	LATITUDE	LONGITUDE	USGS QUADRANGLE	ELEV. (ft.)	IMPACT DESCRIPTION
Red Rock Seep	Alluvium	N40 28' 53"	W108 56' 26"	Hells Canyon	5400	Some impacts from cows
East Serviceberry Draw Spring	Colluvial	N40 26' 54"	W108 49' 56"	Tanks Peak	6180	Cow impact all the way up draw
West Serviceberry Seep	Colluvial	N40 26' 54"	W108 50' 29"	Tanks Peak	6520	Elk/Cow highly impacted
Jones Hole above Hatchery	Colluvial	N40 35' 30"	W109 03' 43"	Jones Hole	5640	No impacts observed
Jones Hole SE of Hatchery	Colluvial	N40 35' 03"	W109 03' 22"	Jones Hole	5480	No impacts observed
Mantle Spring	Alluvium	N40 28' 20"	W108 53' 30"	Hells Canyon	5170	Some impacts from cows
West Serviceberry Spring	Colluvial	N40 26' 46"	W108 50' 31"	Tanks Peak	6380	Highly impacted
Red Rock Collontail Seep	Alluvium	N40 29' 04"	W108 55' 19"	Hells Canyon	5240	No impacts
Zenobia Creek Spring	Alluvium	N40 36' 59"	W108 54' 03"	Canyon of Lodore South	6980	Lots of impact
Lower Disaster Seep	Alluvium	N40 38' 37"	W108 55' 31"	Canyon of Lodore North	5300	No impact
Serviceberry Spring	Colluvial	N40 26' 11"	W108 50' 27"	Tanks Peak	7640	Medium impacted by elk
The Seeps	Colluvial	N40 27' 02"	W108 49' 52"	Tanks Peak	6120	Very cow impacted
Tamarisk Seep	Colluvial	N40 28' 08"	W108 54' 41"	Hells Canyon	5400	Very cow impacted
Johnson Draw Spring	Alluvium	N40 26' 40"	W108 47' 33"	Tanks Peak	6320	Cow impact 20x20 foot area, streambed
Elk Spring	Colluvial	N40 26' 27"	W108 44' 55"	Haystack Rock	7283	Very impacted, Elk wallow
Snow Ranch Spring	Alluvium	N40 30' 57"	W109 03' 55"	Jones Hole	7560	Cow impact 15x40 foot area, intense
Valley View Spring	Bishops	N40 30' 17"	W109 04' 40"	Stuntz Reservoir	7480	Area impacted, intense
Harper's Corner Spring	Bishops	N40 31' 25"	W109 02' 41"	Jones Hole	7440	Small area around tanks stomped up
Tom's Spring 1	Glen Canyon	N40 27' 53"	W108 57' 01"	Hells Canyon	5860	No impacts observed
SOB Spring	Glen Canyon	N40 27' 11"	W108 54' 48"	Hells Canyon	6440	Some impact from cows
Tom's Spring 2	Glen Canyon	N40 27' 53"	W108 57' 02"	Hells Canyon	5820	No impacts observed
Green Patch Spring	Moenkopi	N40 26' 54"	W108 53' 14"	Hells Canyon	5700	Evidence of winter range disturbance
Smelly Spring	Moenkopi	N40 26' 36"	W108 47' 40"	Tanks Peak	6440	Intense cow/elk impacted - mainly trails

Note: 1) All locations are approximate - no GPS data available.

TABLE 1
FIELD DATA - SAMPLE LOCATIONS

SAMPLE	GEO - UNIT	LATITUDE	LONGITUDE	USGS QUADRANGLE	ELEV. (ft.)	IMPACT DESCRIPTION
Pool Spring	Weber	N40 29' 38"	W109 01' 05"	Stuntz Reservoir	5480	No impacts
Pool Creek Spring	Weber	N40 29' 37"	W109 01' 17"	Stuntz Reservoir	5480	No impacts
Juniper Spring	Weber	N40 26' 53"	W109 14' 16"	Split Mountain	5040	No impacts
Hidden Forest Spring	Weber	N40 26' 54"	W109 14' 45"	Split Mountain	5400	No impacts
Joint Spring	Weber	N40 26' 52"	W109 13' 52"	Split Mountain	5040	No Impacts
Hanging Spring	Weber	N40 26' 40"	W109 13' 19"	Split Mountain	5320	No impacts
Morris Well	Weber	N40 25' 33"	W109 10' 05"	Split Mountain	5360	No impacts, irrigation system
Hogan Spring	Weber	N40 30' 50"	W109 01' 48"	Jones Hole	7240	No impact
Echo Park Well	Weber	N40 31' 05"	W108 59' 28"	Canyon of Lodore South	6085	No impacts
Elder Spring	Weber	N40 25' 52"	W109 11' 17"	Split Mountain	5380	No impacts
Box Elder Spring	Weber	N40 25' 38"	W109 10' 40"	Split Mountain	5440	No impacts
Ely Creek Falls	Weber	N40 33' 53"	W109 03' 34"	Jones Hole	5940	No impacts observed
Big Draw	Weber	N40 33' 53"	W109 03' 51"	Jones Hole	5280	No impacts observed
Ely Spring	Weber	N40 34' 06"	W109 03' 53"	Jones Hole	5440	No impacts observed
Ely Falls Seep	Weber	N40 33' 53"	W109 03' 34"	Jones Hole	5940	No impacts observed
Marthas Spring	Morgan	N40 26' 12"	W108 51' 55"	Tanks Peak	7780	Very cow impacted
Upper Thanksgiving Spring	Morgan	N40 26' 22"	W108 37' 45"	Haystack Rock	6400	No impacts observed
Rat Spring 1	Morgan	N40 26' 57"	W108 53' 00"	Hells Canyon	6020	Evidence of winter range disturbance
Rat Spring 2	Morgan	N40 26' 54"	W108 53' 02"	Hells Canyon	5880	Evidence of winter range disturbance
Limestone Spring West	Madison	N40 35' 38"	W108 55' 36"	Canyon of Lodore South	7350	Lots of impact around spring development
Limestone Spring	Madison	N40 33' 54"	W108 57' 26"	Canyon of Lodore South	5680	No impacts observed
Mitten Canyon Warm Springs	Madison - warm spring	N40 28' 38"	W109 13' 06"	Split Mountain	4880	No impacts observed

Note: 1) All locations are approximate - no GPS data available.

TABLE 1
FIELD DATA - SAMPLE LOCATIONS

SAMPLE	GEO - UNIT	LATITUDE	LONGITUDE	USGS QUADRANGLE	ELEV. (ft.)	IMPACT DESCRIPTION
Limestone Spring East	Madison	N40 35' 31"	W108 55' 34"	Canyon of Lodore South	7350	Lots of impact around spring development
Warm Pool Spring	Madison - warm spring	N40 29' 08"	W109 14' 53"	Split Mountain	4840	No impacts observed
Warm Spring River Left	Madison - warm spring	N40 28' 56"	W109 13' 50"	Split Mountain	4840	No impacts observed
DSL	Lodore	N40 33' 33"	W108 57' 37"	Canyon of Lodore South	5400	No impacts observed
Limestone Creek	Lodore	N40 33' 45"	W108 57' 46"	Canyon of Lodore South	5200	No impacts observed
Mile 221 River Left Spring	Lodore - warm spring	N40 32' 14"	W109 01' 29"	Jones Hole	5040	Some impact, but tank on rock
Mile 221 River Right Spring	Lodore	N40 32' 05"	W109 01' 29"	Jones Hole	5040	No impacts observed
Bassett 1 Spring	Uinta Mtn. Group	N40 37' 40"	W108 53' 35"	Canyon of Lodore North	7180	Lots of cow/elk impact
Rippling Creek	Uinta Mtn. Group	N40 35' 09"	W108 59' 05"	Canyon of Lodore South	5280	No impacts observed
Bassett 2 Spring	Uinta Mtn. Group	N40 38' 04"	W108 53' 15"	Canyon of Lodore North	7280	Elk impact
Massey Spring	Uinta Mtn. Group	N40 35' 24"	W108 59' 05"	Canyon of Lodore South	5200	No impacts observed
Upper Lil' Joe Spring	Uinta Mtn. Group	N40 36' 11"	W108 51' 46"	Zenobia Peak	8240	No impacts observed
Winnies Grotto	Uinta Mtn. Group	N40 41' 07"	W108 54' 19"	Canyon of Lodore North	5600	Elk impact around tank
Pol Creek Seep	Uinta Mtn. Group	N40 37' 56"	W108 56' 24"	Canyon of Lodore North	5350	No impact
Buffam Spring	Uinta Mtn. Group	N40 36' 07"	W108 53' 32"	Canyon of Lodore South	7320	Small "bath" made with rocks
Chokecherry Spring	Uinta Mtn. Group	N40 36' 21"	W108 54' 28"	Canyon of Lodore South	7320	No impacts
Wild Canyon Spring	Lodore - warm spring	N40 32' 31"	W108 59' 16"	Canyon of Lodore South	5250	No impacts observed
Zenobia Creek Outlat	Flooding Creek	N40 34' 47"	W109 56' 17"	Canyon of Lodore North	5240	No impacts

Note: 1) All locations are approximate - no GPS data available.

TABLE 1 (CONT.)
FIELD DATA - ANALYSIS

SAMPLE	DATE	DIS_GPM	TEMP_C	PH	EC	TDS	ORP	ALK	HARD	DO	DUP.	COMMENTS
Red Rock Seep	08/07/97	NM	30.0	8.00	1900	(749)	295	280	1190	5.1	N	Lots of tamarisk
East Serviceberry Draw Spring	08/08/97	0.2	12.0	7.80	920	(377)	310	245	422	4.8	N	
West Serviceberry Seep	08/09/97	NM	14.0	8.00	710	(297)	290	456	442	4.5	N	Standing water near a seep
Jones Hole above Hatchery	08/05/97		13.9	7.80	90	37	315	160	200	7.6	N	Sampled at gabion/pool intake to hatchery
Jones Hole SE of Hatchery	08/05/97	793	12.5	8.00	365	150	325	162	188	9.1	N	no surface expression 50 ft. upstream
Mantle Spring	08/07/97		17.5	7.10	(830)	(343)	250	310	505	3.6	N	Sampled from pipe
West Serviceberry Spring	08/09/97	0.3	11.0	7.80	420	(187)	310	250	302		N	
Red Rock Coltonail Seep	08/18/97	1.5	18.0	7.20	1590	(631)	110	230	976	1.2	N	Old impacts along canyon in other areas
Zenobia Creek Spring	08/20/97	16	25.0	8.00	560	(240)	320	207	271	3.7	N	Along bedrock contact - 7000 ft. elevation
Lower Disaster Seep	09/20/97	NM	16	7.6	(1229)	950	195	322	462	4.4	N	Clear water by river
Serviceberry Spring	08/13/97	2.3	9.0	8.00	320	(149)	305	207	185	6.5	N	
The Seeps	08/14/97	NM	26.0	8.50	560	(240)	260	275	210	5.1	N	Sample taken from standing water near seep
Tamarisk Seep	08/18/97	NM	17.0	7.80	1660	(658)	250	255	2405	4.9	N	
Johnson Draw Spring	07/29/97	16	9.0	7.44	462	216	231	257	264	8.7	N	Disappears about 40 yards downstream
Elk Spring	07/30/97	0.04	16.8	7.31	201	92	208	116	99	3.5	N	
Snow Ranch Spring	07/24/97	0.81	14.8	7.38	460	274		352	325	1.4	N	
Valley View Spring	07/28/97	0.25	16.4	7.61	604	280	154	280	320	5.5	N	Just above filler reservoir
Harper's Corner Spring	07/24/97	0.27	13.3	7.79	419	220		269	280	9.2	N	
Tom's Spring 1	08/07/97	3	10.4	8.00	407	167	310	210	234	7.5	N	Right out of rock
SOB Spring	08/15/97	3.4	9.8	7.60	370	(168)	360	256	199	6.7	Y	
Tom's Spring 2	08/07/97	12	10.4	8.00	(327)	(152)	342	220	280	7.8	N	Concrete spring box
Green Patch Spring	08/14/97	0.3	20.0	8.30	560	(240)	240	235	308	5.2	N	White deposits on soil below vegetation
Smelly Spring	07/29/97	1.1	12.6	7.63	580	270	253	245	308	5.5	N	

Note: 1) All locations are approximate - no GPS data available.

2) DIS_GPM means discharge (gpm), TEMP_C means temperature, EC means electroconductivity (uhos/cm), ORP means redox potential (mV), ALK means alkalinity as CaCO3 (mg/L), HARD means hardness as CaCO3 (mg/L), DO means dissolved oxygen (mg/L), DUP., means duplicate sample taken.

3) "NM" means Not Measureable and relates to seeps that have no discernable discharge.

4) Numbers in parenthesis represent calculated values of based on Standard Methods EC calculations and regression equation $y=0.3799(x) + 27.85$ obtained by field values of TDS vs. EC. Standard deviation of TDS is 44 mg/L.

TABLE 1 (CONT.)
FIELD DATA - ANALYSIS

SAMPLE	DATE	DIS_GPM	TEMP_C	PH	EC	TDS	ORP	ALK	HARD	DO	DUP.	COMMENTS
Pool Spring	07/24/97	673	11.4	7.51	313	178		250	269	8.3	N	Bubbling sand & water cress type vegetation
Pool Creek Spring	07/24/97	90	11.6	7.80	330	186		191	278	9.6	N	
Juniper Spring	08/19/97	1.6	17.6	7.50	560	(240)	355	303	329	3.5	N	Tested highest point of discernable flow
Hidden Forest Spring	08/19/97	0.9	17.0	7.40	570	(244)	360	213	203	3.0	N	Still water
Joint Spring	08/19/97	0.5	19.0	7.80	460	(202)	330	156	253	5.4	N	Comes out of colluvial material in joint line
Hanging Spring	08/19/97	0.6	21.5	8.60	590	(251)	300	300	358	5.3	Y	hanging cliff, can only sample at low point
Morris Well	08/18/97	20	17.0	7.60	510	(221)	335	115	301	4.3	Y	Comes out of steel pipe
Hogan Spring	07/24/97	0.6	15.3	7.48	430	214		282	295	4.0	N	Sheep watering hole
Echo Park Well	07/24/97	16	14.8	7.43	481	249		251	346	2.9	N	Flows into welland
Elder Spring	08/18/97	NM	22.0	7.70	740	(308)	335	393	470	5.1	N	Standing water sample
Box Elder Spring	08/18/97	0.5	15.8	7.60	390	(176)	340	188	291	3.6	N	Bubbling, white sand
Ely Creek Falls	08/05/97	673	16.0	8.50	489	201	295	209	277	8.0	N	Stream sample
Big Draw	08/05/97	421	14.1	8.40	(379)	(172)	290	230	272	6.8	N	Stream sample
Ely Spring	08/05/97	16	23.5	8.20	564	232	295	400	319	6.0	N	Iron staining in stream
Ely Falls Seep	08/05/97	NM	13.2	7.80	527	216	330	209	254	6.0	N	Stream sample
Marthas Spring	08/13/97	0.3	14.0	7.80	390	(176)	330	240	210	4.3	N	
Upper Thanksgiving Spring	07/30/97	0.1	24.7	8.10	995	450	156	386	451	3.6	N	
Rat Spring 1	08/14/97	1.7	14.0	7.80	470	(205)	300	236	277	5.5	Y	2-4 ft. wide riparian area in draw
Rat Spring 2	08/14/97	2.5	15.0	8.30	460	(202)	300	222	220	6.5	Y	Seeps out of cul-bank south -side of fault
Limestone Spring West	08/20/97	0.2	18.0	7.50	510	(221)	330	281	236	4.2	Y	DO solution fizzes on soil
Limestone Spring	08/04/97	6.7	18.3		528	217	400				N	Sampled spring
Mitten Canyon Warm Springs	08/05/97	4.0	23.7		1480	407	230	178	342	4.5	N	Lots of tamarisk, seeps out of fan

Note: 1) All locations are approximate - no GPS data available.

2) DIS_GPM means discharge (gpm), TEMP_C means temperature, EC means electroconductivity (uhos/cm), ORP means redox potential (mV), ALK means alkalinity as CaCO₃ (mg/L), HARD means hardness as CaCO₃ (mg/L), DO means dissolved oxygen (mg/L), DUP., means duplicate sample taken.

3) "NM" means Not Measureable and relates to seeps that have no discernable discharge.

4) Numbers in parenthesis represent calculated values of based on Standard Methods EC calculations and regression equation $y = 0.3799(x) + 27.85$ obtained by field values of TDS vs. EC. Standard deviation of TDS is 44 mg/L.

TABLE 1 (CONT.)
FIELD DATA - ANALYSIS

SAMPLE	DATE	DIS_GPM	TEMP_C	PH	EC	TDS	ORP	ALK	HARD	DO	DUP.	COMMENTS
Limestone Spring East	08/20/97	1	17.0	7.80	480	(210)	320	308	286	6.2	N	DO solution fizzes on soil
Warm Pool Spring	09/22/97	224	32.0	8.60	(1576)	1460	340	185	355	2.6	Y	White deposits around spring
Warm Spring River Left	09/22/97	7.8	21.0	9.00	(1038)	950	340	208	298	4.4	N	Definite vegetation change
DSL	08/04/97	0.03	19.8	8.60	276	113	280	94			N	Comes out of shale member
Limestone Creek	08/04/97		15.7	8.40	558	230	305	260	278	5.1	N	Sampled creek
Mile 221 River Left Spring	08/04/97	1.4	19.8	7.60	2390	984	320	38	280		N	Measured at river's edge
Mile 221 River Right Spring	08/04/97	4.0	19.5	7.80	416	171	320	111	140		N	Measured at river's edge
Bassett 1 Spring	08/20/97	4.8	18.0	7.10	510	(221)	235	265	286	2.5	N	Developed with fenced spring
Rippling Creek	08/04/97	211	15.9		460	189	285	199	242	6.5	N	Water milky-cloudy from rain
Bassett 2 Spring	08/20/97	0.6	13.5	7.30	460	(202)	340	205	243	5.4	Y	Developed with fenced spring
Massey Spring	08/04/97	1.2	14.7	7.20	373	172	300	144	170	7.2	N	Some sulfide - black mud, horsetails
Upper Lit' Joe Spring	08/21/97	0.3	11.5	8.00	(116)	(72)	345	80	95	5.9	N	Aspens, comes out of bed of draw
Winnies Grotto	08/03/97	0.1	17.8	8.70	279	128	280	89	102	6.7	N	Seep from headwall
Pot Creek Seep	08/03/97	NM	17.2	8.70	365	168	270	149	176	5.9	N	
Buffam Spring	08/20/97	0.3	16.0	6.90	230	(115)	375	73	131	4.4	Y	Bentonite used in spring house
Chokecherry Spring	08/20/97	0.8	22.0	8.00	(198)	(103)	320	26	94	5.6	N	Yellow tinge to water, quakies
Wild Canyon Spring	08/04/97	1347	17.7	8.00	1839	756	315	190	290	5.8	Y	Comes out of bottom of alluvium
Zenobia Creek Outlet	09/20/97	898	15.0	8.20	(97)	110	295	55	95	6.6	N	Creek at flood stage

- Note: 1) All locations are approximate - no GPS data available.
2) DIS_GPM means discharge (gpm), TEMP_C means temperature, EC means electroconductivity (uhos/cm), ORP means redox potential (mV), ALK means alkalinity as CaCO₃ (mg/L), HARD means hardness as CaCO₃ (mg/L), DO means dissolved oxygen (mg/L), DUP., means duplicate sample taken.
3) "NM" means Not Measurable and relates to seeps that have no discernable discharge.
4) Numbers in parenthesis represent calculated values of based on Standard Methods EC calculations and regression equation $y=0.3799(x) + 27.85$ obtained by field values of TDS vs. EC. Standard deviation of TDS is 44 mg/L.

TABLE OF CATION ANALYSIS

Analysis Performed by Colorado School of Mines, December 15, 1997

SAMPLE	Ag	Al	B	Ba	Ca	Cd	Fe	K	Li	Mg	Mn	S	Si	Sr	V	Zn	Na
Snow Ranch Spring	0.000	0.01	0.08	0.18	93	0.002	0.14	1	0.009	29	0.37	5.5	9.5	0.28	0.0031	0.012	13
Test Standard A					85/80			2.7/3		22/31							43/69
Harper's Corner Spring	0.000	0.00	0.036	0.12	76	0.001	0.055	0.23	0.008	27	0.085	3.4	7.1	0.23	0.0029	0.009	6.2
Hogan Spring	0.000	0.00	0.034	0.082	65	0.002	0.000	0.96	0.008	30	0.0021	3.5	11	0.28	0.0099	0.008	6
Echo Park Well	0.000	0.00	0.037	0.028	67	0.000	0.000	1.9	0.009	35	0.0000	37	4.4	0.46	0.0047	0.011	6
Pool Creek Spring	0.000	0.013	0.024	0.093	53	0.000	0.000	1.1	0.006	25	0.0000	12	4.7	0.28	0.0031	0.002	4.3
Pool Spring	0.000	0.012	0.031	0.091	49	0.000	0.000	1.3	0.008	25	0.0014	12	4.9	0.28	0.006	0.002	4.3
Valley View Spring	0.000	0.016	0.054	0.15	78	0.002	0.000	0.11	0.014	32	0.022	5.7	9.9	0.27	0.009	0.01	10
Johnson Draw Spring	0.000	0.017	0.025	0.084	53	0.000	0.000	1.1	0.005	29	0.0000	3.6	5.1	0.12	0.0076	0.007	4.7
Smelly Spring	0.000	0.013	0.045	0.091	67	0.002	0.000	1.7	0.016	34	0.0000	22	8.5	0.35	0.0074	0.004	9.9
Test Standard B					80/75			1.8/1		24/36							26/74
Elk Spring	0.000	0.00	0.031	0.069	28	0.002	0.023	4.9	0.002	6.1	0.39	3.3	5.7	0.1	0.0019	0.008	3.3
Upper Thanksgiving Spring	0.003	0.017	0.22	0.12	67	0.003	0.000	2.2	0.049	70	0.0038	27	18	0.84	0.018	0.002	44
Winnies Grotto	0.000	0.00	0.044	0.18	38	0.001	0.01	1.5	0.008	8.7	0.0022	4.7	7.2	0.21	0.0082	0.001	6.2
Pot Creek Seep	0.000	0.00	0.069	0.11	45	0.002	0.000	1.6	0.012	15	0.0034	12	11	0.27	0.013	0.009	18
Massey Spring	0.000	0.018	0.044	0.093	50	0.000	0.000	1.1	0.012	12	0.033	10	6.1	0.25	0.0048	0.006	15
Rippling Creek	0.000	0.024	0.033	0.085	38	0.000	0.007	1.6	0.005	31	0.0019	5.5	4.8	0.12	0.0069	0.000	4.4
Limestone Creek	0.000	0.00	0.047	0.11	46	0.000	0.000	2	0.009	36	0.0024	6.1	8	0.19	0.0063	0.000	7.4
Test Standard C					83/85			8.4/10		17/26							23/84
Limestone Spring	0.000	0.00	0.039	0.095	42	0.001	0.008	2.8	0.007	38	0.0028	6.6	5.3	0.18	0.0049	0.000	6.2
DSL/C	0.000	0.017	0.084	0.043	22	0.000	0.012	6.7	0.006	11	0.0082	13	2.6	0.11	0.0035	0.007	6.8
Wild Canyon Spring	0.000	0.00	0.24	0.069	68	0.001	0.000	8.9	0.11	24	0.0008	29	5.5	1.2	0.0043	0.002	222
Mile 221 River Right Spring	0.000	0.015	0.073	0.091	34	0.000	0.000	3	0.021	8.7	0.0021	9.6	4.9	0.17	0.0048	0.008	27
Mile 221 River Left Spring	0.000	0.021	0.29	0.058	66	0.000	0.011	15	0.166	24	0.0063	31	4.7	1.1	0.0059	0.01	314
Jones Hole above Hatchery	0.000	0.00	0.019	0.11	44	0.001	0.000	1	0.005	15	0.0009	2.8	5.3	0.17	0.0029	0.013	3.3
Test Standard D					78/75			8.5/10		17/28							23/64
Detection Limits	<0.001	<0.001	<0.01	<0.0001	<0.005	<0.001	<0.005	<0.035	<0.0015	<0.0005	<0.0005	<0.02	<0.1	<0.1	<0.0015	<0.001	<0.008

TABLE OF CATION ANALYSIS

Analysis Performed by Colorado School of Mines, December 16, 1997

SAMPLE	Ag	Al	B	Ba	Ca	Cd	Fe	K	Li	Mg	Mn	S	Si	Sr	V	Zn	Na
Jones Hole SE of Hatchery	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ely Spring	0.000	0.00	0.029	0.23	63	0.000	0.057	1.3	0.008	29	0.017	6.1	5.5	0.19	0.0000	0.01	6.5
Big Draw	0.000	0.014	0.026	0.085	51	0.000	0.007	1.6	0.008	26	0.0013	14	5.5	0.21	0.0052	0.003	5.3
Ely Creek Falls	0.000	0.00	0.027	0.085	51	0.000	0.028	1.7	0.008	26	0.0033	14	5.2	0.22	0.0024	0.003	5.3
Ely Falls Seep	0.000	0.00	0.026	0.084	54	0.000	0.000	1.6	0.007	26	0.0000	15	5.4	0.22	0.0018	0.003	5.5
Mitten Canyon Warm Springs	0.000	0.00	0.16	0.049	85	0.002	0.009	9.9	0.093	28	0.01	55	7.1	0.86	0.004	0.004	140
Tom's Spring 1	0.000	0.00	0.039	0.085	44	0.001	0.000	1.1	0.008	16	0.0000	4.9	8.1	0.23	0.0072	0.005	8.9
Test Standard E					79/75			3.1/3		21/31							41/69
Tom's Spring 2	0.000	0.00	0.034	0.09	50	0.000	0.000	1	0.008	17	0.0000	7.2	6.4	0.27	0.0063	0.002	7.3
Mantle Spring	0.000	0.00	0.049	0.068	126	0.002	0.12	2.6	0.017	38	0.017	64	7.4	1	0.0021	0.006	10
Red Rock Seep	0.002	0.019	0.26	0.095	291	0.002	0.17	12	0.073	121	0.2	361	9	4.9	0.0071	0.046	61
East Serviceberry Draw Spring	0.000	0.00	0.084	0.088	97	0.001	0.000	2.1	0.017	41	0.01	81	8.8	0.84	0.0092	0.003	10
West Serviceberry Seep	0.000	0.011	0.089	0.12	117	0.002	0.033	1.8	0.015	33	0.12	14	9.3	0.48	0.0055	0.004	20
West Serviceberry Spring	0.000	0.00	0.04	0.039	59	0.001	0.000	2.1	0.017	31	0.0017	23	6.5	0.37	0.0067	0.004	7.6
Test Standard F					75/75			10/10		17/26							49/74
Serviceberry Spring	0.000	0.00	0.014	0.088	52	0.000	0.000	0.71	0.003	12	0.002	2.2	5.1	0.14	0.0041	0.003	2.9
Marthas Spring	0.000	0.00	0.017	0.09	58	0.001	0.000	1	0.006	15	0.035	3.4	7.1	0.21	0.0064	0.002	4.2
The Seeps	0.000	0.00	0.18	0.18	45	0.000	0.011	5.9	0.033	23	0.016	6.2	8.2	0.49	0.0068	0.003	37
Rat Spring 1	0.000	0.00	0.042	0.11	54	0.002	0.000	1.9	0.016	26	0.0009	8.8	10	0.36	0.011	0.002	7.5
Rat Spring 2	0.000	0.00	0.037	0.096	52	0.002	0.000	1.7	0.015	25	0.0028	10	10	0.42	0.0097	0.000	6.6
Green Patch Spring	0.000	0.00	0.073	0.08	57	0.002	0.013	2.2	0.037	29	0.0021	20	11	0.8	0.0093	0.000	20
SOB Spring	0.000	0.00	0.028	0.33	57	0.002	0.000	0.54	0.008	14	0.0014	3.16	8.2	0.21	0.0078	0.007	4.4
Tamarisk Seep	0.004	0.019	0.31	0.021	489	0.002	0.045	8	0.18	230	0.071	768	8.2	9.7	0.0094	0.013	116
Red Rock Cottontail Seep	0.000	0.015	0.056	0.047	252	0.001	1.6	2.6	0.022	83	0.5	229	5.9	2.1	0.0038	0.009	18
Box Elder Spring	0.000	0.00	0.026	0.031	64	0.000	0.000	1.5	0.007	29	0.0008	29	4.8	0.47	0.0032	0.004	4.7
Elder Spring	0.000	0.01	0.059	0.093	105	0.000	0.23	0.88	0.008	37	0.33	21	5.8	0.43	0.0022	0.005	5.1
Detection Limits	<0.001	<0.001	<0.01	<0.0001	<0.005	<0.001	<0.005	<0.035	<0.0015	<0.0005	<0.0005	<0.02	<0.1	<0.1	<0.0015	<0.001	<0.008

TABLE OF CATION ANALYSIS

Analysis Performed by Colorado School of Mines, December 15, 1997

SAMPLE	Ag	Al	B	Ba	Ca	Cd	Fe	K	Li	Mg	Mn	S	Si	Sr	V	Zn	Na
Morris Well	0.000	0.00	0.023	0.034	81	0.000	0.000	1.5	0.007	28	0.002	25	4.8	0.42	0.0033	0.002	4.6
Test Standard G					84/80			1.1/1		25/36							46/74
Hidden Forest Spring	0.000	0.00	0.025	0.23	68	0.000	0.000	1.6	0.09	34	0.28	14	4.7	0.13	0.0024	0.005	5.2
Juniper Spring	0.000	0.00	0.023	0.2	75	0.000	0.014	1.2	0.003	32	0.0025	13	4.4	0.14	0.0000	0.003	3.9
Hanging Spring	0.000	0.01	0.023	0.13	78	0.001	0.000	1.3	0.006	33	0.07	20	5.5	0.23	0.0018	0.002	4.4
Test Standard H					97/85			.93/1		25/36							46/74
Joint Spring	0.000	0.00	0.016	0.23	60	0.000	0.008	1.1	0.003	23	0.0076	4.7	3.2	0.0	0.0019	0.002	2.1
Limestone Spring West	0.000	0.01	0.017	0.2	57	0.002	0.000	0.41	0.007	35	0.0045	3.3	8.6	0.28	0.0083	0.005	7.3
Limestone Spring East	0.000	0.00	0.018	0.19	52	0.001	0.01	0.47	0.007	33	0.0043	3.4	8	0.24	0.0059	0.008	7.2
Chokecherry Spring	0.000	0.068	0.038	0.05	28	0.001	0.037	0.88	0.0000	4.8	0.0055	12	6.2	0.12	0.0000	0.001	3.3
Buffam Spring	0.000	0.011	0.023	0.041	29	0.000	0.000	0.51	0.004	8.8	0.0094	5.6	6.3	0.0	0.0022	0.005	5.5
Zenobia Creek Spring	0.000	0.014	0.064	0.11	74	0.001	0.075	4.1	0.012	24	0.12	6.7	8.3	0.31	0.003	0.004	10
Test Standard I					81/80			8/10		17/28							23/64
Bassett 1 Spring	0.000	0.00	0.064	0.1	73	0.002	0.22	3.2	0.019	19	0.062	10	10	0.33	0.0039	0.003	9.9
Bassett 2 Spring	0.000	0.00	0.061	0.11	67	0.001	0.006	1	0.014	15	0.0068	11	9.8	0.28	0.0028	0.003	15
Upper Lil' Joe Spring	0.000	0.028	0.00	0.039	18	0.000	0.018	0.5	0.002	4	0.0041	3.2	5.4	0.0	0.0000	0.007	2.7
Lower Disaster Seep	0.000	0.00	0.11	0.1	120	0.000	0.2	3	0.031	37	1.2	89	5.3	0.89	0.0018	0.009	72
Test Standard J					91/85			4.7/3		20/31							46/69
Zenobia Creek Outlet	0.000	0.088	0.029	0.027	17	0.000	0.071	2.5	0.009	2.5	0.02	1.5	2.8	0.0	0.0029	0.009	1.4
Warm Pool Spring	0.000	0.00	0.22	0.041	93	0.001	0.000	13	0.12	30	0.0000	88	8.2	1	0.0056	0.006	180
Warm Spring River Left	0.000	0.00	0.12	0.043	70	0.000	0.000	6.6	0.065	24	0.0009	42	5.7	0.68	0.0047	0.004	104
Detection Limits	<0.001	<0.001	<0.01	<0.0001	<0.005	<0.001	<0.005	<0.035	<0.0015	<0.0005	<0.0005	<0.02	<0.1	<0.1	<0.0015	<0.001	<0.008

Note: 1) Analyst: Mard Walt: ICP Analysis

2) No cation analysis performed on Jones Hole SE of Hatchery.

3) If value was below detection limits, the value was set to zero; all other values are expressed in ppm.

4) As, Be, Co, Cr, Cu, Mo, Ni, Pb, Sb, Se, Sn and Ti were analyzed but all values fell below detection limits.

5) Duplicate samples are not indicated on this table.

6) Test standard results are given as analysis value/standard solution value.

TABLE OF ANION ANALYSIS

Analysis Performed by the Colorado State University Soil Laboratory, 11-27-98 through 03-03-98

SAMPLE	Nitrate	Sulfate	Phosphate	Chloride	Fluoride	Bromide
Snow Ranch Spring	0.4	13.4	<0.1	9.9	0.4	0.1
Poudre Sample A	0.4	8.9	<0.1	1.4	0.5	<0.1
Harper's Corner Spring	0.4	8.0	<0.1	4.1	0.4	<0.1
Deionized Water A1	0.1	<0.1	<0.1	0.9	0.6	<0.1
Hogan Spring	2.3	8.6	<0.1	3.2	0.4	<0.1
Echo Park Well	1.3	99.3 + 0.25	<0.1	6.6	0.3	<0.1
Pool Creek Spring	3.6	41.3 + 0.1	<0.1	4.2	0.4	<0.1
Pool Spring	3.9	36.59 + 0.1	<0.1	3.7	0.3	<0.1
Valley View Spring	0.1	14.5	<0.1	3.8	0.3	<0.1
Poudre Sample B	0.3	8.8	<0.1	1.5	0.4	<0.1
Johnson Draw Spring	4.4	7.9	<0.1	4.2	0.2	<0.1
Smelly Spring	4.6	37.3 + 0.1	<0.1	8.5	0.4	<0.1
Elk Spring	11.8	10.4	<0.1	3.0	0.4	<0.1
Upper Thanksgiving Spring	0.1	91 + 0.1	<0.1	94.6	0.5	0.3
Poudre Sample C	0.3	9.5	<0.1	0.6	0.6	<0.1
Winnies Grotto	5.1	14.5	<0.1	0.6	0.4	<0.1
Pot Creek Seep	0.2	34.94 + 0.1	<0.1	29.1	0.4	<0.1
Massey Spring	2.0	34.54 + 0.1	<0.1	10.6	0.4	<0.1
Rippling Creek	4.5	16.1 + 0.02	<0.1	4.1	0.3	<0.1
Limestone Creek	4.8	16.87 + 0.02	<0.1	8.0	0.3	<0.1
Limestone Spring	2.7	18.25 + 0.02	<0.1	8.4	0.3	<0.1
Poudre Sample D	0.4	8.5	<0.1	1.4	0.5	<0.1
DSLCL	3.0	42.12 + 0.1	<0.1	9.8	0.6	<0.1
Wild Canyon Spring	1.9	63.6 + 0.1	<0.1	399 + 0.5	0.3	<0.1
Mile 221 River Right Spring	1.9	36.1 + 0.1	<0.1	29.5 + 0.1	0.4	0.1
Mile 221 River Left Spring	0.6	44.5 + 0.1	<0.1	454.7 + 0.5	0.3	<0.1
Deionized Water B1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Jones Hole above Hatchery	0.6	7.3	<0.1	3.5	0.4	<0.1
Jones Hole SE of Hatchery	1.7	7.0	<0.1	2.1	0.4	<0.1
Ely Spring	0.0	16.52 + 0.02	<0.1	8.3	0.3	<0.1
Big Draw	2.6	36.2 + 0.1	<0.1	4.3	0.5	<0.1
Poudre Sample E	0.3	9.0	<0.1	1.4	0.3	<0.1
Ely Creek Falls	8.8	30 + 0.02	<0.1	4.1	0.3	<0.1
Ely Falls Seep	1.6	28.8 + 0.02	<0.1	4.1	0.3	<0.1
Mitten Canyon Warm Spgs.	0.5	183.2 + 0.5	<0.1	294.3 + 0.5	0.3	0.3
Poudre Sample F	0.3	7.9	<0.1	1.1	0.5	<0.1
Tom's Spring 1	3.2	14.0	<0.1	6.8	0.5	<0.1
Tom's Spring 2	3.0	20.3 + 0.02	<0.1	6.0	0.5	<0.1
Mantle Spring	0.0	206.4 + 0.5	<0.1	6.3	0.4	<0.1
Red Rock Seep	2.7	789 + 1	<0.1	32.5 + 0.1	0.6	<0.1
East Serviceberry Spring	0.3	232.1 + 0.02	<0.1	8.6	0.3	<0.1
Poudre Sample G	0.3	7.4	<0.1	1.0	0.6	<0.1
West Serviceberry Seep	0.0	41.0	<0.1	14.8	0.5	<0.1
West Serviceberry Spring	1.3	43.4 + 0.02	<0.1	5.2	0.4	<0.1
Serviceberry Spring	3.5	6.4	<0.1	1.8	0.4	<0.1
Marthas Spring	1.6	10.0	<0.1	2.9	0.4	<0.1
The Seeps	1.8	16.45 + 0.02	<0.1	17 + 0.02	0.7	0.1
Deionized Water C1	<0.1	0.2	<0.1	0.4	0.5	<0.1
Rat Spring 1	3.7	27.12 + 0.1	<0.1	4.7	0.6	<0.1
Rat Spring 2	4.6	33.19 + 0.1	<0.1	4.9	0.6	<0.1
Green Patch Spring	1.4	39.6 + 0.1	<0.1	6.0	0.9	<0.1
Poudre Sample H	0.2	9.6	<0.1	1.4	0.5	<0.1

TABLE OF ANION ANALYSIS

Analysis Performed by the Colorado State University Soil Laboratory, 11-27-98 through 03-03-98

SAMPLE	Nitrate	Sulfate	Phosphate	Chloride	Fluoride	Bromide
SOB Spring	1.7	7.6	<0.1	5.8	0.3	<0.1
Tamarisk Seep	0.0	2457 + 1	<0.1	23.41 + 0.1	1.1	<0.1
Red Rock Cottontail Seep	0.0	687 + 0.5	<0.1	43.5 + 0.1	0.4	<0.1
Box Elder Spring	19 + 0.1	79.6 + 0.1	<0.1	3.8	0.4	<0.1
Elder Spring	0.2	58.6 + 0.1	<0.1	2.3	0.4	<0.1
Poudre Sample I	0.3	8.0	<0.1	1.5	0.5	<0.1
Morris Well	3.5	76 + 0.1	<0.1	3.2	0.3	<0.1
Hidden Forest Spring	1.1	31.6 + 0.1	<0.1	6.3	0.4	<0.1
Juniper Spring	0.2	40.9 + 0.1	<0.1	3.8	0.4	<0.1
Hanging Spring	<0.1	61 + 0.1	<0.1	3.2	0.3	<0.1
Joint Spring	0.3	14.5 + 0.02	<0.1	2.7	0.4	<0.1
Limestone Spring West	5.5	9.0	<0.1	9.8	0.3	<0.1
Poudre Sample J	<0.1	8.3	<0.1	1.4	0.6	<0.1
Limestone Spring East	3.4	8.4	<0.1	8.0	0.3	<0.1
Chokecherry Spring	0.1	45.7 + 0.1	<0.1	4.1	0.3	<0.1
Buffam Spring	2.6	19.3 + 0.02	<0.1	5.9	0.4	<0.1
Zenobia Creek Spring	0.0	19.4 + 0.02	<0.1	15.6 + 0.02	0.3	<0.1
Bassett 1 Spring	0.5	28.0 + 0.02	<0.1	13.3 + 0.02	0.5	0.1
Deionized Water D1	<0.1	<0.1	<0.01	<0.1	<0.1	<0.1
Bassett 2 Spring	5.4	36.1	<0.1	18.9	1.1	0.1
Upper Lil' Joe Spring	7.4	8.3	<0.1	2.1	0.5	<0.1
Lower Disaster Seep	0.0	248.4 + 0.5	ND	77 + 0.1	0.0	<0.1
Zenobia Creek Outlet	0.1	3.8	ND	0.9	0.3	<0.1
Warm Pool Spring	0.5	194.9 + 0.5	ND	266.5 + 0.5	0.3	0.5
Warm Spring River Left	0.1	121 + 0.5	ND	148.2 + 0.5	0.1	1.3
Detection Limits	<0.1	<0.1	<0.01	<0.1	<0.1	<0.1

- Note: 1) Values include a plus or minus dilution error rate, if diluted for analysis.
2) If a value was below detection limits, the value was set to zero; all other values are expressed in ppm.
3) Phosphate was not analyzed for the last four sample sites.
4) Values in bold were obtained in successive analytical re-runs.
5) Values do not include an estimated 5% IC analysis error rate.

TABLE OF ANIONS BY GEOLOGIC FORMATION

FORMATION	SAMPLE	Nitrate	Sulfate	Chloride	Bicarbonate
Colluvial	East Serviceberry Draw Spring	0.3	232.1	8.6	146.9
Colluvial	West Serviceberry Seep	0.0	41.0	14.8	273.4
Alluvium	Red Rock Seep	2.7	789.0	32.5	167.9
Colluvial	Jones Hole above Hatchery	0.6	7.3	3.5	95.92
Colluvial	Jones Hole SE of Hatchery	1.7	7.0	2.1	No Data
Alluvium	Mante Spring	0.0	206.4	6.3	185.8
Colluvial	West Serviceberry Spring	1.3	43.4	5.2	149.9
Alluvium	Zenobia Creek Spring	0.0	19.4	15.6	32.97
Alluvium	Lower Disaster Seep	0.0	248.4	77.0	193
Alluvium	Red Rock Cottontail Seep	0.0	687.0	43.5	152.9
Colluvial	Serviceberry Spring	3.5	6.4	1.8	124.1
Colluvial	The Seeps	1.8	16.5	17.0	164.9
Colluvial	Tamarisk Seep	0.0	2457.0	23.4	152.9
Colluvial	Elk Spring	11.8	10.4	3.0	69.54
Alluvium	Johnson Draw Spring	4.4	7.9	4.2	154.1
Alluvium	Snow Ranch Spring	0.4	13.4	9.9	211
Bishops	Harper's Corner Spring	0.4	8.0	4.1	161.3
Bishops	Valley View Spring	0.1	14.5	3.8	167.9
Glen Canyon	Tom's Spring 1	3.2	14.0	6.8	125.9
Glen Canyon	SOB Spring	1.7	7.6	5.8	153.5
Glen Canyon	Tom's Spring 2	3.0	20.3	6.0	131.9
Moenkopi	Smelly Spring	4.6	37.3	8.5	146.9
Moenkopi	Green Patch Spring	1.4	39.6	6.0	140.9
Weber	Pool Creek Spring	3.6	41.3	4.2	114.5
Weber	Morris Well	3.5	76.0	3.2	68.94
Weber	Pool Spring	3.9	36.6	3.7	149.9
Weber	Box Elder Spring	19.0	79.6	3.8	112.7
Weber	Elder Spring	0.2	58.6	2.3	235.6
Weber	Big Draw	2.6	36.2	4.3	137.9
Weber	Ely Creek Falls	8.9	30.0	4.1	125.3
Weber	Ely Spring	0.0	16.5	8.3	239.8
Weber	Hogan Spring	2.3	8.6	3.2	169.1
Weber	Echo Park Well	1.3	99.3	6.6	150.5
Weber	Juniper Spring	0.2	40.9	3.8	181.6
Weber	Hidden Forest Spring	1.1	31.6	6.3	127.7
Weber	Hanging Spring	0.0	61.0	3.2	179.9
Weber	Ely Falls Seep	1.6	28.8	4.1	125.3
Weber	Joint Spring	0.3	14.6	2.7	93.52
Morgan	Marthas Spring	1.6	10.0	2.9	143.9
Morgan	Upper Thanksgiving Spring	0.1	91.0	94.6	231.2
Morgan	Rat Spring 2	4.6	33.2	4.9	141.5
Morgan	Rat Spring 1	3.7	27.1	4.7	133.1
Madison	Limestone Spring West	5.5	9.0	9.8	168.2
Madison	Limestone Spring East	3.4	8.4	8.0	184.6

TABLE OF ANIONS BY GEOLOGIC FORMATION

FORMATION	SAMPLE	Nitrate	Sulfate	Chloride	Bicarbonate
Lodore	Limestone Creek	4.8	16.9	8.0	155.9
Lodore	Mile 221 River Right Spring	1.9	36.1	29.5	66.55
Lodore	DSLCL	3.0	42.1	9.8	56.35
Lodore	Limestone Spring	2.7	18.3	8.4	155.9
Uinta	Pot Creek Spring	0.2	34.9	29.1	89.33
Uinta	Massey Spring	2.0	34.5	10.6	86.33
Uinta	Rippling Creek	4.5	16.1	4.1	11.93
Uinta	Upper Lil' Joe Spring	7.4	9.3	2.1	47.96
Uinta	Winnies Grotto	5.1	14.5	0.6	53.36
Uinta	Bassett 1 Spring	0.5	28.0	13.3	158.9
Uinta	Bassett 2 Spring	5.4	36.1	18.9	122.9
Uinta	Buffam Spring	2.6	19.3	5.9	43.76
Uinta	Chokecherry Spring	0.1	45.7	4.1	15.59
Madison - ws	Warm Springs - Mitten Canyon	0.5	183.2	294.3	106.7
Madison - ws	Warm Pool Spring	0.5	194.9	266.5	110.9
Madison - ws	Warm Spring River Left	0.1	121.0	148.2	124.7
Lodore - ws	Wild Canyon Spring	1.9	63.6	399.0	113.9
Lodore - ws	Mile 221 River Left Spring	0.6	44.5	454.7	22.78

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Note:

- 1) Zenobia Creek Outlet was deleted because sample was taken during flood stage.
- 2) Carbonate was calculated from alkalinity measurements through MINTEQA2. This value was calculated as total CO₃ and speciated through the program. This speciation indicated that more than 92% of the total CO₃ was as carbonate, so total CO₃ was assumed to represent total carbonate. The other values were given as H₂CO₃ - no values of CO₃ were speciated.
- 3) "ws" designations are for warm springs.

Quality Control and Assurance Program (QA/QC)

Analysis

Quality control and assurance procedures followed standard protocol for gathering field samples. Cation QA/QC consisted of duplicate samples and submission of quality control standards. These QA/QC samples were distributed between the samples as indicated in Appendix A. Cation duplicate sampling was very good overall, with total average differences <3% for most of the cations analyzed. The exceptions to this analysis were vanadium(V), zinc(Zn) and phosphorous(P), which were 22%, 19% and 37%, respectively. Among individual springs, variance among cation species excluding V, Zn and P was <10%, except for one Lithium value at 11% (Table 1).

Cation analysis versus prepared standard samples were also performed (Table 2). However, errors in standard preparation allowed large differences in the results. In general, though, samples of the same standard for a constituent had the same percentage difference, which indicates that the laboratory analysis yielded consistent results and were considered acceptable. No re-runs were performed on cation analysis.

Anion analysis consisted of duplicate samples, de-ionized water samples and split samples from a Poudre River sample. These QA/QC samples were distributed between samples as seen in the cation and anion tables. If a QA/QC sample indicated questionable results, the samples for that constituent, as well

as samples above and below it were re-analyzed. The duplicate sample analysis indicated acceptable results, with constituent differences <8% except for flouride measurements. Overall flouride measurements had a difference of <12% except for one sample that was about 42% (Table 3). The results of the de-ionized water and Poudre River split samples were considered acceptable in the anion analysis. The values obtained and used from re-analyzed samples are indicated in bold in Table 4. Re-runs were also performed on results that showed trends between samples and from knowledge of the source areas. A total of three re-runs of selected analysis were performed. After the re-runs, acceptable values were obtained and no further re-runs were performed.

Ionic balances and electroconductivity measurements were also performed on laboratory results for each sample. In general, the meq/L sum of cations versus anions in each sample should balance for most natural waters (Hem, 1989). Ionic balances were calculated by MINTEQA2, which speciated the components. The water chemistry was balanced assuming no solids precipitated. Variability due to organic matter or other constituents were considered to possibly influence the ionic balance, and a less than 10% variability was determined to represent acceptable values for further analysis. Fifteen samples did not meet this criteria, as shown on Table 5.

Field alkalinity measurements were suspected to be in error, after QA/QC results had been used to verify the other ions for samples in Table 5. The alkalinity

measurements of these fifteen samples were manipulated with MINTEQA2 until as near a zero ionic balance as possible with whole alkalinity numbers was obtained. One sample did not meet this criteria; Tamarisk Seep was still about 4% out of balance when alkalinity was zero. Some other measurement was wrong that was not indicated by QA/QC procedures so Tamarisk Seep was dropped from further consideration.

Field versus calculated electroconductivity (EC) measurements were evaluated as well. In general, differences for springs with a less than 10% ionic balance difference were within 200 uhos/cm of each other. The exceptions to this were Wild Canyon spring and Big Draw spring. These springs were still considered for further analysis, however, because of their <6% difference in ionic balance. The only other spring dropped from further consideration was Zenobia Creek outlet. This sample was taken during flood stage and was not thought to represent the normal concentrations for it's constituents.

Table 1
QUALITY CONTROL AND ASSURANCE TESTING
CATION ANALYSIS

SPRING	B	Ba	Ca	K	Li	Mg	S	Si	Sr	V	Zn	Na	P
Echo Well	0.037	0.029	67	1.9	0.009	35	37	4.4	0.46	0.0046	0.015	8	<.005
Echo Well Duplicate	0.037	0.028	67	1.9	0.009	35	37	4.4	0.46	0.0047	0.011	8	0.067
DIFFERENCE (ppm)	0	0.001	0	0	0	0	0	0	0	0.0001	0.004	0	0.067
Percent Difference	0%	2%	0%	0%	0%	0%	0%	0%	0%	1%	15%	0%	100%
Wild Canyon	0.24	0.069	68	8.9	0.11	24	29	5.5	1.2	0.0043	0.002	222	0.079
Wild Canyon Duplicate	0.25	0.07	70	9.2	0.12	25	30	5.7	1.2	0.0062	0.01	229	0.12
DIFFERENCE (ppm)	0.01	0.001	2	0.3	0.01	1	1	0.2	0	0.0019	0.008	7	0.041
Percent Difference	2%	1%	1%	2%	4%	2%	2%	2%	0%	18%	67%	2%	21%
Rat Spring 1	0.042	0.11	54	1.9	0.016	26	8.6	10	0.36	0.011	0.002	7.5	0.005
Rat Spring 1 Dup.	0.04	0.11	54	1.8	0.016	26	8.5	10	0.35	0.01	0.001	7.4	0.034
DIFFERENCE (ppm)	0.002	0	0	0.1	0	0	0.1	0	0.01	0.001	0.001	0.1	0.029
Percent Difference	2%	0%	0%	3%	0%	0%	1%	0%	1%	5%	33%	1%	74%
Rat Spring 2	0.037	0.096	52	1.7	0.015	25	10	10	0.42	0.0097	0	6.6	0
Rat Spring 2 Duplicate	0.035	0.096	51	1.7	0.015	25	10	10	0.42	0.0098	0	6.5	0.016
DIFFERENCE (ppm)	0.002	0	1	0	0	0	0	0	0	0.0001	0	0.1	0.018
Percent Difference	3%	0%	1%	0%	0%	0%	0%	0%	0%	1%	0%	1%	100%
SOB Spring	0.026	0.33	57	0.54	0.008	14	3.16	6.2	0.21	0.0078	0.007	4.4	0.28
SOB Duplicate	0.022	0.33	58	0.53	0.008	14	3.12	6.3	0.21	0.0075	0.002	4.4	0.26
DIFFERENCE (ppm)	0.004	0	1	0.01	0	0	0.04	0.1	0	0.0003	0.005	0	0.02
Percent Difference	8%	0%	1%	1%	0%	0%	1%	1%	0%	2%	58%	0%	4%
Morris Well	0.023	0.034	61	1.5	0.007	28	25	4.8	0.42	0.0033	0.002	4.6	0.18
Morris Well Duplicate	0.022	0.035	62	1.6	0.008	29	26	4.8	0.43	0.0031	0.002	4.6	0.16
DIFFERENCE (ppm)	0.001	0.001	1	0.1	0.001	1	1	0	0.01	0.0002	0	0	0.02
Percent Difference	2%	1%	1%	3%	7%	2%	2%	0%	1%	3%	0%	0%	6%

Table 1
QUALITY CONTROL AND ASSURANCE TESTING
CATION ANALYSIS

SPRING	B	Ba	Ca	K	Li	Mg	S	Si	Sr	V	Zn	Na	P
Hanging Spring	0.023	0.13	78	1.3	0.006	33	20	5.5	0.23	0.0018	0.002	4.4	0.094
Hanging Spring Duplicate	0.022	0.13	78	1.3	0.006	33	20	5.5	0.24	0	0.002	4.4	0.29
DIFFERENCE (ppm)	0.001	0	0	0	0	0	0	0	0.01	0.0018	0	0	0.198
Percent Difference	2%	0%	0%	0%	0%	0%	0%	0%	2%	100%	0%	0%	51%
Limestone West	0.017	0.2	57	0.41	0.007	35	3.3	8.6	0.26	0.0063	0.005	7.3	0.28
Limestone West Dup.	0.017	0.2	56	0.4	0.006	35	3.3	8.5	0.25	0.0067	0.003	7.2	0.26
DIFFERENCE (ppm)	0	0	1	0.01	0.001	0	0	0.1	0.01	0.0004	0.002	0.1	0.02
Percent Difference	0%	0%	1%	1%	8%	0%	0%	1%	2%	3%	25%	1%	4%
Buffam Spring	0.023	0.041	29	0.51	0.004	9.8	5.6	6.3	0	0.0022	0.005	5.5	0.22
Buffam Spring Duplicate	0.023	0.041	29	0.51	0.005	9.7	5.6	6.4	0	0	0.005	5.5	0.2
DIFFERENCE (ppm)	0	0	0	0	0.001	0.1	0	0.1	0	0.0022	0	0	0.02
Percent Difference	0%	0%	0%	0%	11%	1%	0%	1%	0%	100%	0%	0%	5%
Bassett 2	0.061	0.11	67	1	0.014	15	11	9.8	0.28	0.0028	0.003	15	0.27
Bassett 2 Duplicate	0.059	0.11	67	1.1	0.014	15	11	9.8	0.28	0.0031	0.004	15	0.13
DIFFERENCE (ppm)	0.002	0	0	0.1	0	0	0	0	0	0.0003	0.001	0	0.14
Percent Difference	2%	0%	0%	5%	0%	0%	0%	0%	0%	5%	14%	0%	35%
Warm Pool Spring	0.22	0.041	93	13	0.12	30	68	8.2	1	0.0056	0.006	180	0.31
Warm Pool Duplicate	0.22	0.04	91	13	0.12	29	67	8	0.98	0.0054	0.006	176	0.25
DIFFERENCE (ppm)	0	0.001	2	0	0	1	1	0.2	0.02	0.0002	0	4	0.06
Percent Difference	0%	1%	1%	0%	0%	2%	1%	1%	1%	2%	0%	1%	11%
AVERAGE DIFFERENCE	2%	0%	1%	1%	3%	1%	1%	0%	1%	22%	18%	0%	37%

Note: 1) Duplicate samples are listed in ppm.
2) Analysis performed at the Colorado School of Mines.

Table 2
QUALITY CONTROL AND ASSURANCE TESTING
CATION STANDARD ANALYSIS

SPRING	Ca	K	Mg	Na
Analyzed Standard A	85	2.7	22	43
Calculated Standard	80	3	31	69
DIFFERENCE (ppm)	5	-0.3	-9	-26
Percent Difference	3%	5%	17%	23%
Analyzed Standard B	80	1.6	24	26
Calculated Standard	75	1	36	74
DIFFERENCE (ppm)	5	0.6	-12	-48
Percent Difference	3%	23%	20%	48%
Analyzed Standard C	93	8.4	17	23
Calculated Standard	85	10	26	64
DIFFERENCE (ppm)	8	-1.6	-9	-41
Percent Difference	4%	9%	21%	47%
Analyzed Standard D	78	8.5	17	23
Calculated Standard	75	10	26	64
DIFFERENCE (ppm)	3	-1.5	-9	-41
Percent Difference	2%	8%	21%	47%
Analyzed Standard E	79	3.1	21	41
Calculated Standard	75	3	31	69
DIFFERENCE (ppm)	4	0.1	-10	-28
Percent Difference	3%	2%	19%	25%
Analyzed Standard F	75	10	17	49
Calculated Standard	75	10	26	74
DIFFERENCE (ppm)	0	0	-9	-25
Percent Difference	0%	0%	21%	20%
Analyzed Standard G	84	1.1	25	46
Calculated Standard	80	1	36	74
DIFFERENCE (ppm)	4	0.1	-11	-28
Percent Difference	2%	5%	18%	23%
Analyzed Standard H	97	0.93	25	46
Calculated Standard	85	1	36	74
DIFFERENCE (ppm)	12	-0.07	-11	-28
Percent Difference	7%	4%	18%	23%
Analyzed Standard I	81	8	17	23
Calculated Standard	80	10	26	64
DIFFERENCE (ppm)	1	-2	-9	-41
Percent Difference	1%	11%	21%	47%
Analyzed Standard J	91	4.7	20	46
Calculated Standard	85	3	31	69
DIFFERENCE (ppm)	6	1.7	-11	-23
Percent Difference	3%	22%	22%	20%

Table 3

QUALITY CONTROL AND ASSURANCE TESTING

ANIONS

Sample ID	NO3	SO4	HPO4	CL	F	Br
Wild Canyon Spring	1.9	63.6	<0.1	399.0	0.3	<0.1
Wild Canyon Spring Dup.	2.14	62.9	<0.1	444	0.38	<0.1
DIFFERENCE (ppm)	0.25	0.7	0	45	0.06	0
Percent Difference	6%	1%	0%	5%	9%	0%
Rat Spring 1	3.7	27.1	<0.1	4.7	0.6	<0.1
Rat Spring 1 Dup.	3.67	27.6	<0.1	5.5	0.52	0.1
DIFFERENCE (ppm)	0.06	0.48	0	0.76	0.12	0
Percent Difference	1%	1%	0%	7%	10%	0%
Rat Spring 2	4.6	33.2	<0.1	4.9	0.6	<0.1
Rat Spring 2 Duplicate	4.14	32.72	<0.1	4.92	0.55	0.1
DIFFERENCE (ppm)	0.49	0.47	0	0.05	0.01	0
Percent Difference	6%	1%	0%	1%	1%	0%
SOB Spring	1.7	7.6	<0.1	5.8	0.3	<0.1
SOB Duplicate	1.7	8.12	<0.1	6.73	0.32	<0.1
DIFFERENCE (ppm)	0.03	0.55	0	0.96	0.02	0
Percent Difference	1%	4%	0%	8%	3%	0%
Morris Well	3.5	76.0	<0.1	3.2	0.3	<0.1
Morris Well Duplicate	4.85	83	<0.1	3.38	0.37	<0.1
DIFFERENCE (ppm)	1.39	7	0	0.16	0.05	0
Percent Difference	17%	4%	0%	2%	7%	0%
Hanging Spring	<0.1	61.0	<0.1	3.2	0.3	<0.1
Hanging Spring Duplicate	<0.1	63.3	<0.1	3.19	0.25	<0.1
DIFFERENCE (ppm)	0	2.3	0	0	0.05	0
Percent Difference	0%	2%	0%	0%	9%	0%
Limestone West	5.5	9.0	<0.1	9.8	0.3	<0.1
Limestone West Dup.	5.23	7.63	<0.1	7.45	0.43	<0.1
DIFFERENCE (ppm)	0.26	1.39	0	2.34	0.09	0
Percent Difference	2%	8%	0%	14%	12%	0%
Buffam Spring	2.6	19.3	<0.1	5.9	0.4	<0.1
Buffam Spring Duplicate	2.63	18.9	<0.1	6.38	0.32	<0.1
DIFFERENCE (ppm)	0.08	0.37	0	0.47	0.04	0
Percent Difference	2%	1%	0%	4%	6%	0%
Bassett 2	5.4	36.1	<0.1	18.9	1.1	0.1
Bassett 2 Duplicate	5.57	35.53	<0.1	17.59	0.46	0.14
DIFFERENCE (ppm)	0.22	0.54	0	1.31	0.67	0.01
Percent Difference	2%	1%	0%	4%	42%	4%
Warm Pool Spring	0.5	194.9	ND	266.5	0.3	0.5
Warm Pool Duplicate	0.56	198	ND	310.3	0.37	0.59
DIFFERENCE (ppm)	0.09	3.1	0	43.8	0.05	0.07
Percent Difference	9%	1%	0%	8%	7%	6%
AVERAGE DIFFERENCE	4%	2%	0%	5%	11%	1%

Note: 1) Duplicate samples are listed in ppm.

2) Without Bassett2 value for Fluoride, average difference is 6%.

Table 4

QA/QC TESTING - ANIONS

POUDRE RIVER SAMPLES - ppm

Sample ID	NO3	SO4	HPO4	CL	F	Br
A	0.37	8.85	<0.1	1.4	0.46	<0.1
B	0.29	8.76	<0.1	1.47	0.43	<0.1
C	0.32	9.49	<0.1	0.59	0.58	<0.1
D	0.42	8.52	<0.1	1.4	0.52	<0.1
E	0.34	9.04	<0.1	1.41	0.31	<0.1
F	0.29	7.9	<0.1	1.1	0.5	<0.1
G	0.25	7.4	<0.1	0.99	0.55	<0.1
H	0.24	9.57	<0.1	1.36	0.53	<0.1
I	0.26	8.03	<0.1	1.54	0.54	<0.1
J	0	8.33	<0.1	1.4	0.55	<0.1

DE-IONIZED WATER SAMPLES - ppm

Sample ID	NO3	SO4	HPO4	CL	F	Br
A1	0.09	<0.1	<0.1	0.86	0.57	<0.1
B1	<0.1	<0.1	<0.1	<0.1	0.55	<0.1
C1	<0.1	0.22	<0.1	0.38	0.51	<0.1
D1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Note: 1) Numbers in bold represent re-run samples.
 2) All analysis performed by the CSU Soil Laboratory.

TABLE 5

SPRINGS WITH >10% IONIC BALANCE

Spring	Cations	Anions	%Diff.
Pool Spring	4.5400E-03	5.7330E-03	11.8
Elk	2.0580E-03	2.7960E-03	15.2
Winnies	2.8940E-03	2.0830E-03	16.3
DSLCL	2.3410E-03	2.9780E-03	12.0
Mile 221 River Left	1.9220E-02	1.4390E-02	14.4
Ely Spring	5.4800E-03	8.1060E-03	19.3
Red Rock Seep	2.1990E-02	1.7420E-02	11.6
SOB	4.1210E-03	5.3900E-03	13.3
Tamarisk Seep	3.3480E-02	4.1880E-02	11.1
Morris Well	5.2720E-03	3.7180E-03	17.3
Hidden Forest	6.2710E-03	4.9000E-03	12.2
Joint	4.8780E-03	3.9200E-03	18.0
Chokecherry	1.8630E-03	1.5100E-03	10.5
Zenobia Creek	5.9930E-03	4.5380E-03	13.8
Upper Lil Joe Spring	1.2370E-03	1.9740E-03	23.0

Note: 1) HCO₃ was calculated from alkalinity measurements through MINTEQA2/PRODEFA2.

2) Cation and anions are expressed as millieq/L.

TABLES OF EC CALCULATIONS

Snow Ranch Spring

	mg/L	mM	k	???
Ca	93	2.3	276.4	9.3
Mg	29	1.2	126.6	4.8
Na	13	0.6	28.3	0.6
K	1	0.0	1.9	0.0
SO4	13.36	0.1	22.3	0.6
Cl	9.93	0.3	21.4	0.3
HCO3	211	3.5	153.9	3.5
		TOTAL	630.9	18.9
		IS		0.00947

$$y = 0.905901 - 0.04292x$$

Calc EC = 518

Valley View Spring

	mg/L	mM	k	???
Ca	78	1.9	231.6	7.8
Mg	32	1.3	139.7	5.3
Na	10	0.4	21.8	0.4
K	0.11	0.0	0.2	0.0
SO4	14.45	0.2	24.1	0.6
Cl	3.75	0.1	8.1	0.1
HCO3	167.9	2.8	122.5	2.8
		TOTAL	548.0	16.9
		IS		0.00847

$$y = 0.910178 - 0.04087x$$

Calc EC = 454

Harper's Corner Spring

	mg/L	mM	k	???
Ca	76	1.9	225.6	7.6
Mg	27	1.1	117.9	4.4
Na	6.2	0.3	13.5	0.3
K	0.23	0.0	0.4	0.0
SO4	7.97	0.1	13.3	0.3
Cl	4.1	0.1	8.8	0.1
HCO3	161.3	2.6	117.7	2.6
		TOTAL	497.3	15.4
		IS		0.00770

$$y = 0.91375 - 0.03917x$$

Calc EC = 415

Johnson Draw Spring

	mg/L	mM	k	???
Ca	53	1.3	157.4	5.3
Mg	29	1.2	126.6	4.8
Na	4.7	0.2	10.2	0.2
K	1.1	0.0	2.1	0.0
SO4	7.93	0.1	13.2	0.3
Cl	4.21	0.1	9.1	0.1
HCO3	154.1	2.5	112.4	2.5
		TOTAL	431.0	13.3
		IS		0.00663

$$y = 0.919049 - 0.03666x$$

Calc EC = 364

Hogan Spring

	mg/L	mM	k	???
Ca	65	1.6	193.0	6.5
Mg	30	1.2	131.0	4.9
Na	6	0.3	13.1	0.3
K	0.98	0.0	1.8	0.0
SO4	8.6	0.1	14.3	0.4
Cl	3.15	0.1	6.8	0.1
HCO3	169.1	2.8	123.4	2.8
		TOTAL	483.4	14.9
		IS		0.00746

$$y = 0.914871 - 0.03864x$$

Calc EC = 405

Smelly Spring

	mg/L	mM	k	???
Ca	67	1.7	198.9	6.7
Mg	34	1.4	148.5	5.6
Na	9.9	0.4	21.6	0.4
K	1.7	0.0	3.2	0.0
SO4	37.3	0.4	62.2	1.6
Cl	8.46	0.2	18.2	0.2
HCO3	146.9	2.4	107.2	2.4
		TOTAL	559.7	17.0
		IS		0.00848

$$y = 0.91016 - 0.04088x$$

Calc EC = 464

Echo Park Well

	mg/L	mM	k	???
Ca	67	1.7	198.9	6.7
Mg	35	1.4	152.8	5.8
Na	8	0.3	17.4	0.3
K	1.9	0.0	3.6	0.0
SO4	99.3	1.0	165.5	4.1
Cl	6.64	0.2	14.3	0.2
HCO3	150.5	2.5	109.8	2.5
		TOTAL	682.4	19.6
		IS		0.00982

$$y = 0.904483 - 0.0436x$$

Calc EC = 542

Elk Spring

	mg/L	mM	k	???
Ca	26	0.6	77.2	2.6
Mg	6.1	0.3	26.6	1.0
Na	3.3	0.1	7.2	0.1
K	4.9	0.1	9.2	0.1
SO4	10.35	0.1	17.3	0.4
Cl	3.02	0.1	6.5	0.1
HCO3	69.54	1.1	50.7	1.1
		TOTAL	194.7	5.5
		IS		0.00276

$$y = 0.94504 - 0.02455x$$

Calc EC = 174

Note: 1) All values taken from ion analysis and used according to Standard Methods.

TABLES OF EC CALCULATIONS

Pool Creek Spring

	mg/L	mM	k	???
Ca	53	1.3	157.4	5.3
Mg	25	1.0	109.2	4.1
Na	4.3	0.2	9.4	0.2
K	1.1	0.0	2.1	0.0
SO4	41.28	0.4	68.8	1.7
Cl	4.15	0.1	8.9	0.1
HCO3	114.5	1.9	83.5	1.9
		TOTAL	439.2	13.3
		IS		0.00667

$$y = 0.918883 - 0.03674$$

Calc EC = 371

Pool Spring

	mg/L	mM	k	???
Ca	49	1.2	145.5	4.9
Mg	25	1.0	109.2	4.1
Na	4.3	0.2	9.4	0.2
K	1.3	0.0	2.4	0.0
SO4	36.59	0.4	61.0	1.5
Cl	3.72	0.1	8.0	0.1
HCO3	149.9	2.5	109.4	2.5
		TOTAL	444.8	13.3
		IS		0.00665

$$y = 0.918939 - 0.03671$$

Calc EC = 376

Pot Creek Spring

	mg/L	mM	k	???
Ca	45	1.1	133.6	4.5
Mg	15	0.6	65.5	2.5
Na	18	0.8	39.2	0.8
K	1.6	0.0	3.0	0.0
SO4	34.94	0.4	58.2	1.5
Cl	29.1	0.8	62.7	0.8
HCO3	89.33	1.5	65.2	1.5
		TOTAL	427.5	11.5
		IS		0.00576

$$y = 0.923824 - 0.03441$$

Calc EC = 365

Massey Spring

	mg/L	mM	k	???
Ca	50	1.2	148.5	5.0
Mg	12	0.5	52.4	2.0
Na	15	0.7	32.7	0.7
K	1.1	0.0	2.1	0.0
SO4	34.54	0.4	57.6	1.4
Cl	10.56	0.3	22.8	0.3
HCO3	86.33	1.4	63.0	1.4
		TOTAL	378.9	10.8
		IS		0.00540

$$y = 0.92595 - 0.03341$$

Calc EC = 325

Upper Thanksgiving Spring

	mg/L	mM	k	???
Ca	67	1.7	198.9	6.7
Mg	70	2.9	305.7	11.5
Na	44	1.9	95.9	1.9
K	2.2	0.1	4.1	0.1
SO4	91	0.9	151.7	3.8
Cl	94.6	2.7	203.9	2.7
HCO3	231.4	3.8	168.8	3.8
		TOTAL	1129.0	30.4
		IS		0.01521

$$y = 0.8859 - 0.05262$$

Calc EC = 886

Winnies Grotto

	mg/L	mM	k	???
Ca	38	0.9	112.8	3.8
Mg	9.7	0.4	42.4	1.6
Na	6.2	0.3	13.5	0.3
K	1.5	0.0	2.8	0.0
SO4	14.5	0.2	24.2	0.6
Cl	0.59	0.0	1.3	0.0
HCO3	53.36	0.9	38.9	0.9
		TOTAL	235.9	7.2
		IS		0.00360

$$y = 0.938109 - 0.02775$$

Calc EC = 208

DSLCL

	mg/L	mM	k	???
Ca	22	0.5	65.3	2.2
Mg	11	0.5	48.0	1.8
Na	6.8	0.3	14.8	0.3
K	6.7	0.2	12.6	0.2
SO4	42.12	0.4	70.2	1.8
Cl	9.79	0.3	21.1	0.3
HCO3	56.35	0.9	41.1	0.9
		TOTAL	273.2	7.4
		IS		0.00371

$$y = 0.937213 - 0.02816$$

Calc EC = 240

Wild Canyon Spring

	mg/L	mM	k	???
Ca	68	1.7	201.9	6.8
Mg	24	1.0	104.8	3.9
Na	22.2	1.0	48.4	1.0
K	8.9	0.2	18.7	0.2
SO4	63.6	0.7	106.0	2.7
Cl	444	12.5	956.8	12.5
HCO3	113.9	1.9	83.1	1.9
		TOTAL	1517.7	28.0
		IS		0.01448

$$y = 0.8881 - 0.05154$$

Calc EC = 1197

Note: 1) All values taken from ion analysis and used according to Standard Methods.

TABLES OF EC CALCULATIONS

Rippling Creek

	mg/L	mM	k	???
Ca	38	0.9	112.8	3.8
Mg	31	1.3	135.4	5.1
Na	4.4	0.2	9.6	0.2
K	1.6	0.0	3.0	0.0
SO4	16.1	0.2	26.8	0.7
Cl	4.1	0.1	8.8	0.1
HCO3	119.2	2.0	87.0	2.0
		TOTAL	383.4	11.9
		IS		0.00593

$$y = 0.922856 - 0.03487$$

Calc EC = 327

Limestone Creek

	mg/L	mM	k	???
Ca	46	1.1	136.6	4.6
Mg	36	1.5	157.2	5.9
Na	7.4	0.3	16.1	0.3
K	2	0.1	3.8	0.1
SO4	16.87	0.2	28.1	0.7
Cl	8.03	0.2	17.3	0.2
HCO3	155.9	2.6	113.7	2.6
		TOTAL	472.8	14.4
		IS		0.00719

$$y = 0.916236 - 0.03799$$

Calc EC = 397

Mile 221 River Right Spring

	mg/L	mM	k	???
Ca	34	0.8	101.1	3.4
Mg	8.7	0.4	38.0	1.4
Na	27	1.2	58.8	1.2
K	3	0.1	5.6	0.1
SO4	36.1	0.4	60.2	1.5
Cl	29.5	0.8	63.6	0.8
HCO3	66.55	1.1	48.5	1.1
		TOTAL	375.8	9.5
		IS		0.004751

$$y = 0.929973 - 0.03153$$

Calc EC = 325

Mile 221 River Left Spring

	mg/L	mM	k	???
Ca	86	1.6	196.2	6.6
Mg	24	1.0	104.8	3.9
Na	314	13.7	684.3	13.7
K	15	0.4	28.2	0.4
SO4	44.5	0.5	74.2	1.9
Cl	454.7	12.8	979.9	12.8
HCO3	22.78	0.4	16.8	0.4
		TOTAL	2084.1	39.8
		IS		0.0

$$y = 0.873524 - 0.05873$$

Calc EC = 1590

Red Rock Seep

	mg/L	mM	k	???
Ca	291	7.3	864.0	29.0
Mg	121	5.0	528.4	19.9
Na	61	2.7	132.9	2.7
K	12	0.3	22.6	0.3
SO4	789	8.2	1315.0	32.9
Cl	32.5	0.9	70.0	0.9
HCO3	167.9	2.8	122.5	2.8
		TOTAL	3055.4	88.4
		IS		0.04422

$$y = 0.831297 - 0.08024$$

Calc EC = 2111

Limestone Spring

	mg/L	mM	k	???
Ca	42	1.0	124.7	4.2
Mg	36	1.5	157.2	5.9
Na	6.2	0.3	13.5	0.3
K	2.6	0.1	4.9	0.1
SO4	18.25	0.2	30.4	0.8
Cl	8.38	0.2	18.1	0.2
HCO3	155.9	2.6	113.7	2.6
		TOTAL	462.5	14.0
		IS		0.00760

$$y = 0.91716 - 0.03755$$

Calc EC = 389

East Service Berry

	mg/L	mM	k	???
Ca	97	2.4	288.3	9.7
Mg	41	1.7	179.0	6.7
Na	10	0.4	21.8	0.4
K	2.1	0.1	3.9	0.1
SO4	232.1	2.4	386.8	9.7
Cl	8.55	0.2	18.4	0.2
HCO3	146.9	2.4	107.2	2.4
		TOTAL	1005.5	29.2
		IS		0.0

$$y = 0.887694 - 0.05174$$

Calc EC = 792

West Serviceberry Seep

	mg/L	mM	k	???
Ca	117	2.9	347.8	11.7
Mg	33	1.4	144.1	5.4
Na	20	0.9	43.6	0.9
K	1.6	0.0	3.0	0.0
SO4	40.98	0.4	68.3	1.7
Cl	14.78	0.4	31.9	0.4
HCO3	273.4	4.5	199.4	4.5
		TOTAL	838.1	24.8
		IS		0.0

$$y = 0.89518 - 0.04809$$

Calc EC = 672

Note: 1) All values taken from ion analysis and used according to Standard Methods.

TABLES OF EC CALCULATIONS

Jones Hole above Hatchery

	mg/L	mM	k	???
Ca	44	1.1	130.8	4.4
Mg	15	0.6	65.5	2.5
Na	3.3	0.1	7.2	0.1
K	1	0.0	1.9	0.0
SO4	7.25	0.1	12.1	0.3
Cl	3.48	0.1	7.5	0.1
HCO3	95.92	1.6	70.0	1.6
		TOTAL	294.9	9.0
		IS		0.0

$$y = 0.931628 - 0.03076$$

Calc EC = 256

Ely Spring

	mg/L	mM	k	???
Ca	63	1.6	187.3	6.3
Mg	29	1.2	126.6	4.8
Na	6.5	0.3	14.2	0.3
K	1.3	0.0	2.4	0.0
SO4	16.52	0.2	27.5	0.7
Cl	8.27	0.2	17.8	0.2
HCO3	239.8	3.9	174.9	3.9
		TOTAL	550.8	16.2
		IS		0.0

$$y = 0.911806 - 0.0401$$

Calc EC = 458

Big Draw

	mg/L	mM	k	???
Ca	51	1.3	151.6	5.1
Mg	26	1.1	113.5	4.3
Na	5.3	0.2	11.5	0.2
K	1.6	0.0	3.0	0.0
SO4	36.2	0.4	80.3	1.5
Cl	4.25	0.1	9.2	0.1
HCO3	137.9	2.3	100.6	2.3
		TOTAL	449.8	13.5
		IS		0.0

$$y = 0.918374 - 0.03698$$

Calc EC = 379

Ely Crk Fall

	mg/L	mM	k	???
Ca	51	1.3	151.6	5.1
Mg	26	1.1	113.5	4.3
Na	5.3	0.2	11.5	0.2
K	1.7	0.0	3.2	0.0
SO4	30	0.3	50.0	1.3
Cl	4.06	0.1	8.7	0.1
HCO3	125.3	2.1	91.4	2.1
		TOTAL	430.0	13.1
		IS		0.0

$$y = 0.919597 - 0.0364$$

Calc EC = 364

West Service Spring

	mg/L	mM	k	???
Ca	59	1.5	175.4	5.9
Mg	31	1.3	135.4	5.1
Na	7.6	0.3	16.6	0.3
K	2.1	0.1	3.9	0.1
SO4	43.4	0.5	72.3	1.8
Cl	5.2	0.1	11.2	0.1
HCO3	149.9	2.5	109.4	2.5
		TOTAL	524.2	15.8
		IS		0.0

$$y = 0.91283 - 0.03961$$

Calc EC = 437

Serviceberry Spring

	mg/L	mM	k	???
Ca	52	1.3	154.6	5.2
Mg	12	0.5	52.4	2.0
Na	2.9	0.1	6.3	0.1
K	0.71	0.0	1.3	0.0
SO4	6.37	0.1	10.6	0.3
Cl	8.55	0.2	18.4	0.2
HCO3	124.1	2.0	90.5	2.0
		TOTAL	334.2	9.8
		IS		0.0

$$y = 0.928865 - 0.03205$$

Calc EC = 288

Marthas Spring

	mg/L	mM	k	???
Ca	58	1.4	172.4	5.8
Mg	15	0.6	65.5	2.5
Na	4.2	0.2	9.2	0.2
K	1	0.0	1.9	0.0
SO4	9.95	0.1	16.6	0.4
Cl	2.86	0.1	6.2	0.1
HCO3	143.9	2.4	105.0	2.4
		TOTAL	376.7	11.3
		IS		0.0

$$y = 0.924415 - 0.03413$$

Calc EC = 322

The Seeps

	mg/L	mM	k	???
Ca	45	1.1	133.8	4.5
Mg	23	0.9	100.4	3.8
Na	37	1.6	80.8	1.6
K	5.9	0.2	11.1	0.2
SO4	16.45	0.2	27.4	0.7
Cl	17	0.5	36.8	0.5
HCO3	164.9	2.7	120.3	2.7
		TOTAL	510.3	13.9
		IS		0.0

$$y = 0.917411 - 0.03744$$

Calc EC = 429

Note: 1) All values taken from ion analysis and used according to Standard Methods.

TABLES OF EC CALCULATIONS

Ely Seep

	mg/L	mM	k	???
Ca	54	1.3	160.5	5.4
Mg	28	1.2	122.3	4.6
Na	5.5	0.2	12.0	0.2
K	1.8	0.0	3.0	0.0
SO4	28.8	0.3	48.0	1.2
Cl	4.06	0.1	8.7	0.1
HCO3	125.3	2.1	91.4	2.1
		TOTAL	445.9	13.6
		IS		0.0

$$y = 0.918073 - 0.03712$$

$$\text{Calc EC} = 376$$

Warm Mitten Canyon

	mg/L	mM	k	???
Ca	85	2.1	252.7	8.5
Mg	28	1.2	122.3	4.6
Na	140	6.1	305.1	6.1
K	9.9	0.3	18.6	0.3
SO4	183.2	1.9	305.3	7.6
Cl	294.3	8.3	634.2	8.3
HCO3	106.7	1.7	77.8	1.7
		TOTAL	1716.0	37.1
		IS		0.0

$$y = 0.876672 - 0.05716$$

$$\text{Calc EC} = 1319$$

Tom Spring 1

	mg/L	mM	k	???
Ca	44	1.1	130.8	4.4
Mg	16	0.7	69.9	2.6
Na	8.9	0.4	19.4	0.4
K	1.1	0.0	2.1	0.0
SO4	14	0.1	23.3	0.6
Cl	6.84	0.2	14.7	0.2
HCO3	125.9	2.1	91.8	2.1
		TOTAL	352.0	10.3
		IS		0.0

$$y = 0.927523 - 0.03268$$

$$\text{Calc EC} = 303$$

Tom Spring 2

	mg/L	mM	k	???
Ca	50	1.2	148.6	5.0
Mg	17	0.7	74.2	2.8
Na	7.3	0.3	15.9	0.3
K	1	0.0	1.9	0.0
SO4	20.3	0.2	33.8	0.8
Cl	6.02	0.2	13.0	0.2
HCO3	131.9	2.2	96.2	2.2
		TOTAL	383.7	11.3
		IS		0.0

$$y = 0.924447 - 0.03412$$

$$\text{Calc EC} = 328$$

Rat Spring 1

	mg/L	mM	k	???
Ca	54	1.3	160.5	5.4
Mg	26	1.1	113.5	4.3
Na	7.5	0.3	16.3	0.3
K	1.9	0.0	3.6	0.0
SO4	27.12	0.3	45.2	1.1
Cl	4.74	0.1	10.2	0.1
HCO3	141.5	2.3	103.2	2.3
		TOTAL	452.6	13.6
		IS		0.0

$$y = 0.918123 - 0.0371$$

$$\text{Calc EC} = 382$$

Rat Spring 2

	mg/L	mM	k	???
Ca	52	1.3	154.6	5.2
Mg	25	1.0	109.2	4.1
Na	6.6	0.3	14.4	0.3
K	1.7	0.0	3.2	0.0
SO4	33.19	0.3	55.3	1.4
Cl	4.87	0.1	10.5	0.1
HCO3	133.1	2.2	97.1	2.2
		TOTAL	444.2	13.3
		IS		0.0

$$y = 0.918873 - 0.03674$$

$$\text{Calc EC} = 375$$

Green Patch

	mg/L	mM	k	???
Ca	57	1.4	169.4	5.7
Mg	29	1.2	128.6	4.8
Na	20	0.9	43.8	0.9
K	2.2	0.1	4.1	0.1
SO4	39.8	0.4	66.0	1.7
Cl	6	0.2	12.9	0.2
HCO3	140.9	2.3	102.8	2.3
		TOTAL	525.5	15.5
		IS		0.0

$$y = 0.913464 - 0.03931$$

$$\text{Calc EC} = 438$$

SOB spring

	mg/L	mM	k	???
Ca	57	1.4	169.4	5.7
Mg	14	0.6	61.1	2.3
Na	4.4	0.2	9.8	0.2
K	0.54	0.0	1.0	0.0
SO4	7.56	0.1	12.8	0.3
Cl	5.77	0.2	12.4	0.2
HCO3	153.5	2.5	112.0	2.5
		TOTAL	378.2	11.2
		IS		0.0

$$y = 0.924788 - 0.03396$$

$$\text{Calc EC} = 323$$

Note: 1) All values taken from ion analysis and used according to Standard Methods.

TABLES OF EC CALCULATIONS

Mantle Spring

	mg/L	mM	k	???
Ca	126	3.1	374.5	12.6
Mg	38	1.8	165.9	6.3
Na	10	0.4	21.8	0.4
K	2.6	0.1	4.9	0.1
SO4	206.4	2.2	344.0	8.6
Cl	6.25	0.2	13.5	0.2
HCO3	185.8	3.0	135.5	3.0
		TOTAL	1060.2	31.1
		IS		0.0

$$y = 0.884832 - 0.05314$$

Calc EC = 830

Red Rock Cottontail

	mg/L	mM	k	???
Ca	252	6.3	749.1	25.1
Mg	83	3.4	362.4	13.7
Na	18	0.8	39.2	0.8
K	2.6	0.1	4.9	0.1
SO4	687	7.2	1145.0	28.6
Cl	43.5	1.2	93.7	1.2
HCO3	137.9	2.3	100.6	2.3
		TOTAL	2495.0	71.8
		IS		0.0

$$y = 0.842857 - 0.07425$$

Calc EC = 1772

Box Elder Spring

	mg/L	mM	k	???
Ca	64	1.6	190.2	6.4
Mg	29	1.2	126.8	4.8
Na	4.7	0.2	10.2	0.2
K	1.5	0.0	2.8	0.0
SO4	79.6	0.8	132.7	3.3
Cl	3.8	0.1	8.2	0.1
HCO3	112.7	1.8	82.2	1.8
		TOTAL	553.0	16.7
		IS		0.0

$$y = 0.910793 - 0.04058$$

Calc EC = 459

Elder Spring

	mg/L	mM	k	???
Ca	105	2.6	312.1	10.5
Mg	37	1.5	161.6	6.1
Na	5.1	0.2	11.1	0.2
K	0.98	0.0	1.8	0.0
SO4	58.6	0.6	97.7	2.4
Cl	2.3	0.1	5.0	0.1
HCO3	235.8	3.9	171.9	3.9
		TOTAL	761.1	23.2
		IS		0.0

$$y = 0.897721 - 0.04688$$

Calc EC = 613

Tamarisk Seep

	mg/L	mM	k	???
Ca	489	12.2	1453.6	48.8
Mg	230	9.5	1004.4	37.8
Na	116	5.0	252.8	5.0
K	8	0.2	15.0	0.2
SO4	2457	25.6	4095.0	102.4
Cl	23.41	0.7	50.4	0.7
HCO3	152.9	2.5	111.5	2.5
		TOTAL	6982.8	197.4
		IS		0.1

$$y = 0.785726 - 0.10473$$

Calc EC = 4311

Buffam Spring

	mg/L	mM	k	???
Ca	29	0.7	86.2	2.9
Mg	9.8	0.4	42.8	1.6
Na	5.5	0.2	12.0	0.2
K	0.004	0.0	0.0	0.0
SO4	19.27	0.2	32.1	0.8
Cl	5.91	0.2	12.7	0.2
HCO3	43.76	0.7	31.9	0.7
		TOTAL	217.8	6.4
		IS		0.0

$$y = 0.941128 - 0.02635$$

Calc EC = 193

Zenobia Creek

	mg/L	mM	k	???
Ca	74	1.8	220.0	7.4
Mg	24	1.0	104.8	3.9
Na	10	0.4	21.8	0.4
K	4.1	0.1	7.7	0.1
SO4	19.39	0.2	32.3	0.8
Cl	15.58	0.4	33.6	0.4
HCO3	124.1	2.0	90.5	2.0
		TOTAL	510.7	15.2
		IS		0.0

$$y = 0.91432 - 0.0389$$

Calc EC = 427

Bassett 1

	mg/L	mM	k	???
Ca	73	1.8	217.0	7.3
Mg	19	0.8	83.0	3.1
Na	9.9	0.4	21.6	0.4
K	3.2	0.1	6.0	0.1
SO4	27.95	0.3	46.6	1.2
Cl	13.31	0.4	28.7	0.4
HCO3	158.9	2.6	115.9	2.6
		TOTAL	518.7	15.1
		IS		0.0

$$y = 0.914528 - 0.0388$$

Calc EC = 434

Note: 1) All values taken from ion analysis and used according to Standard Methods.

TABLES OF EC CALCULATIONS

Morris Well

	mg/L	mM	k	???
Ca	61	1.5	181.3	6.1
Mg	28	1.2	122.3	4.6
Na	4.6	0.2	10.0	0.2
K	1.5	0.0	2.8	0.0
SO4	76	0.8	126.7	3.2
Cl	3.22	0.1	6.9	0.1
HCO3	68.94	1.1	50.3	1.1
		TOTAL	500.3	15.3
		IS		0.0

$$y = 0.913926 - 0.03909$$

Calc EC = 418

Hidden Forest

	mg/L	mM	k	???
Ca	68	1.7	202.1	6.8
Mg	34	1.4	148.5	5.6
Na	5.2	0.2	11.3	0.2
K	1.6	0.0	3.0	0.0
SO4	31.57	0.3	52.6	1.3
Cl	6.29	0.2	13.6	0.2
HCO3	127.7	2.1	93.2	2.1
		TOTAL	524.3	16.2
		IS		0.0

$$y = 0.911792 - 0.0401$$

Calc EC = 436

Juniper Spring

	mg/L	mM	k	???
Ca	75	1.9	222.9	7.5
Mg	32	1.3	139.7	5.3
Na	3.9	0.2	8.5	0.2
K	1.2	0.0	2.3	0.0
SO4	40.89	0.4	66.2	1.7
Cl	3.81	0.1	8.2	0.1
HCO3	181.7	3.0	132.6	3.0
		TOTAL	582.3	17.7
		IS		0.0

$$y = 0.908438 - 0.0417$$

Calc EC = 481

Hanging

	mg/L	mM	k	???
Ca	78	1.9	231.9	7.8
Mg	33	1.4	144.1	5.4
Na	4.4	0.2	9.6	0.2
K	1.3	0.0	2.4	0.0
SO4	61	0.6	101.7	2.5
Cl	3.19	0.1	6.9	0.1
HCO3	179.9	2.9	131.2	2.9
		TOTAL	627.8	19.0
		IS		0.0

$$y = 0.905738 - 0.043$$

Calc EC = 569

Bassett 2

	mg/L	mM	k	???
Ca	67	1.7	199.2	6.7
Mg	15	0.6	65.5	2.5
Na	15	0.7	32.7	0.7
K	1	0.0	1.9	0.0
SO4	36.07	0.4	60.1	1.5
Cl	18.9	0.5	40.7	0.5
HCO3	122.9	2.0	89.7	2.0
		TOTAL	489.7	13.9
		IS		0.0

$$y = 0.917481 - 0.03741$$

Calc EC = 412

Lil Joe Spring

	mg/L	mM	k	???
Ca	16	0.4	47.6	1.6
Mg	4	0.2	17.5	0.7
Na	2.7	0.1	5.9	0.1
K	0.5	0.0	0.9	0.0
SO4	9.29	0.1	15.5	0.4
Cl	2.13	0.1	4.6	0.1
HCO3	47.96	0.8	35.0	0.8
		TOTAL	126.9	3.6
		IS		0.0

$$y = 0.954711 - 0.02013$$

Calc EC = 116

Limestone West

	mg/L	mM	k	???
Ca	57	1.4	169.4	5.7
Mg	35	1.4	152.8	5.8
Na	7.3	0.3	15.9	0.3
K	0.41	0.0	0.8	0.0
SO4	9.02	0.1	15.0	0.4
Cl	9.79	0.3	21.1	0.3
HCO3	168.5	2.8	122.9	2.8
		TOTAL	498.0	15.2
		IS		0.0

$$y = 0.914241 - 0.03894$$

Calc EC = 455

Limestone East

	mg/L	mM	k	???
Ca	52	1.3	154.6	5.2
Mg	33	1.4	144.1	5.4
Na	7.2	0.3	15.7	0.3
K	0.47	0.0	0.9	0.0
SO4	8.38	0.1	14.0	0.3
Cl	8.03	0.2	17.3	0.2
HCO3	184.6	3.0	134.7	3.0
		TOTAL	481.2	14.5
		IS		0.0

$$y = 0.915804 - 0.0382$$

Calc EC = 441

Note: 1) All values taken from ion analysis and used according to Standard Methods.

TABLES OF EC CALCULATIONS

Joint spring

	mg/L	mM	k	???
Ca	60	1.5	178.4	6.0
Mg	23	0.9	100.4	3.8
Na	2.1	0.1	4.6	0.1
K	1.1	0.0	2.1	0.0
SO4	14.58	0.2	24.3	0.6
Cl	2.67	0.1	5.8	0.1
HCO3	93.52	1.5	68.2	1.5
		TOTAL	383.7	12.1
		IS		0.0

$$y = 0.922179 - 0.03518$$

Calc EC = 354

Chokecherry Spring

	mg/L	mM	k	???
Ca	28	0.7	83.2	2.8
Mg	4.8	0.2	21.0	0.8
Na	3.3	0.1	7.2	0.1
K	0.68	0.0	1.3	0.0
SO4	45.7	0.5	76.2	1.9
Cl	4.08	0.1	8.8	0.1
HCO3	15.59	0.3	11.4	0.3
		TOTAL	209.0	6.0
		IS		0.0

$$y = 0.94286 - 0.02555$$

Calc EC = 197

Warm Pool Spring

	mg/L	mM	k	???
Ca	93	2.3	276.4	9.3
Mg	30	1.2	131.0	4.9
Na	180	7.8	392.3	7.8
K	13	0.3	24.4	0.3
SO4	194.9	2.0	324.8	8.1
Cl	266.5	7.5	574.3	7.5
HCO3	110.9	1.8	80.9	1.8
		TOTAL	1804.2	39.8
		IS		0.0

$$y = 0.873275 - 0.05885$$

Calc EC = 1576

Warm Spring River Left

	mg/L	mM	k	???
Ca	70	1.7	208.1	7.0
Mg	24	1.0	104.8	3.9
Na	104	4.5	226.6	4.5
K	6.6	0.2	12.4	0.2
SO4	121	1.3	201.7	5.0
Cl	148.2	4.2	319.4	4.2
HCO3	124.7	2.0	91.0	2.0
		TOTAL	1183.9	26.9
		IS		0.0

$$y = 0.89138 - 0.04994$$

Calc EC = 1038

Lower Disaster Seep

	mg/L	mM	k	???
Ca	120	3.0	356.7	12.0
Mg	37	1.5	161.6	6.1
Na	72	3.1	156.9	3.1
K	3	0.1	5.6	0.1
SO4	248.4	2.6	414.0	10.4
Cl	77	2.2	165.9	2.2
HCO3	193	3.2	140.8	3.2
		TOTAL	1401.5	37.0
		IS		0.0

$$y = 0.876876 - 0.05708$$

Calc EC = 1229

Zenobia Creek Outlet

	mg/L	mM	k	???
Ca	17	0.4	50.5	1.7
Mg	2.5	0.1	10.9	0.4
Na	1.4	0.1	3.1	0.1
K	2.5	0.1	4.7	0.1
SO4	3.8	0.0	6.3	0.2
Cl	0.9	0.0	1.9	0.0
HCO3	32.97	0.5	24.1	0.5
		TOTAL	101.5	3.0
		IS		0.0

$$y = 0.958757 - 0.01829$$

Calc EC = 97

Note: 1) All values taken from ion analysis and used according to Standard Methods.

APPENDIX C

STATISTICAL SUMMARIES FOR LITHOLOGIES

Table 1
Statistical Data for Alluvial and Colluvial (AC) Lithology

15 Samples	Al	B	Ba	Ca	Cd	Fe	K	Li	Mg	Mn	S	Si	Sr	V	Zn	Na
Mean	0.007	0.091	0.089	129.2	0.00113	0.161	3.5	0.028	50.1	0.201	109.3	7	1.5	0.005	0.001	25.9
Standard Error	0.002	0.023	0.011	32.2	0.00022	0.104	0.8	0.01	14.9	0.083	53.8997	0.4	0.7	0.0007	0.003	8.4
Median	0	0.06	0.084	93	0.001	0.033	2.6	0.017	31	0.071	14	6.5	0.48	0.0041	0.007	10
Mode	0	0.064	0.068	NA	0.002	0	1	0.017	29	0.12	NA	5.1	NA	NA	0.003	10
Standard Deviation	0.008	0.089	0.043	124.8	0.00083	0.403	3.1	0.04	57.6	0.321	208.8	1.7	2.6	0.003	0.011	32.7
Range	0.019	0.296	0.159	463	0.002	1.6	11.3	0.158	223.9	1.2	765.8	4.4	9.6	0.0076	0.043	113.1
Minimum	0	0.014	0.021	26	0	0	0.71	0.002	6.1	0	2.2	5.1	0.1	0.0018	0.003	2.9
Maximum	0.019	0.31	0.18	489	0.002	1.6	12	0.16	230	1.2	768	9.5	9.7	0.0094	0.046	116

Table 2
Statistical Data for Conglomerate-Sandstone (SS) Lithology

18 Samples	Al	B	Ba	Ca	Cd	Fe	K	Li	Mg	Mn	S	Si	Sr	V	Zn	Na
Mean	0.0038	0.031	0.125	63.4	0.00045	0.02	1.12	0.012	26.8	0.04	13.2	5.9	0.23	0.004	0.005	5.5
Standard Error	0.0013	0.0024	0.018	3.3	0.00017	0.012	0.1	0.004	1.4	0.02	2.1	0.4	0.02	0.0006	0.0007	0.4
Median	0	0.027	0.092	61.5	0	0	1.15	0.008	27.5	0.002	12.5	5.5	0.23	0.003	0.0035	5.25
Mode	0	0.026	0.085	51	0	0	1.1	0.008	25	0	14	5.5	0.23	0	0.002	4.3
Standard Deviation	0.006	0.011	0.08	14.9	0.0008	0.052	0.453	0.019	6.3	0.091	9.3	1.9	0.1	0.003	0.003	1.8
Range	0.016	0.043	0.302	61	0.002	0.23	1.59	0.087	23	0.33	33.8	7.8	0.47	0.01	0.009	7.9
Minimum	0	0.016	0.028	44	0	0	0.11	0.003	14	0	3.2	3.2	0	0	0.002	2.1
Maximum	0.016	0.059	0.33	105	0.002	0.23	1.7	0.09	37	0.33	37	11	0.47	0.01	0.011	10

Table 3
Statistical Data for Siltstone-Sandstone-Shale (SSh) Lithology

15 Samples	Al	B	Ba	Ca	Cd	Fe	K	Li	Mg	Mn	S	Si	Sr	V	Zn	Na
Mean	0.013	0.05	0.087	43.5	0.0008	0.022	2	0.01	18.3	0.01	10.1	7	0.2	0.005	0.005	10.5
Standard Error	0.005	0.005	0.01	4.2	0.00022	0.014	0.4	0.002	2.9	0.004	1.4	0.6	0.04	0.0008	0.0007	1.8
Median	0.011	0.045	0.091	42	0.001	0.007	1.6	0.009	15	0.003	10	6.2	0.19	0.005	0.0035	7.4
Mode	0	0.044	0.11	38	0	0	1.6	0.012	15	0.002	10	11	0	0	0.002	6.2
Standard Deviation	0.018	0.02	0.039	17	0.00086	0.056	1.5	0.009	11.6	0.017	5.4	2.5	0.15	0.003	0.003	7
Range	0.068	0.073	0.151	57	0.002	0.22	6.2	0.037	32	0.062	18.8	8.4	0.6	0.013	0.009	24.3
Minimum	0	0	0.039	16	0	0	0.5	0	4	0	3.2	2.6	0	0	0.002	2.7
Maximum	0.068	0.073	0.19	73	0.002	0.22	6.7	0.037	36	0.062	22	11	0.6	0.013	0.011	27

Table 4
Statistical Data for Limestone and Limestone-Sandstone (LS) Lithology

5 Samples	Al	B	Ba	Ca	Cd	Fe	K	Li	Mg	Mn	S	Si	Sr	V	Zn	Na
Mean	0.002	0.026	0.14	54.6	0.0016	0.002	1.1	0.01	26.8	0.0095	5.7	8.7	0.3	0.008	0.003	6.6
Standard Error	0.002	0.006	0.023	1.2	0.00024	0.002	0.3	0.002	3.5	0.0064	1.5	0.6	0.04	0.001	0.001	0.6
Median	0	0.017	0.11	54	0.002	0	1	0.007	26	0.0043	3.4	8.6	0.26	0.006	0.002	7.2
Mode	0	0.017	NA	52	0.002	0	NA	0.007	NA	NA	3.4	10	NA	NA	0.002	NA
Standard Deviation	0.004	0.013	0.053	2.8	0.00055	0.004	0.7	0.005	7.9	0.0143	3.3	1.3	0.09	0.002	0.002	1.4
Range	0.01	0.026	0.11	6	0.001	0.01	1.49	0.01	20	0.0341	6.7	2.9	0.21	0.005	0.006	3.3
Minimum	0	0.016	0.09	52	0.001	0	0.41	0.006	15	0.0009	3.3	7.1	0.21	0.006	0	4.2
Maximum	0.01	0.042	0.2	58	0.002	0.01	1.9	0.016	35	0.035	10	10	0.42	0.011	0.006	7.5

Table 5
Statistical Data for Evaporite (WSP) Lithology

5 Samples	Al	B	Ba	Ca	Cd	Fe	K	Li	Mg	Mn	S	Si	Sr	V	Zn	Na
Mean	0.0042	0.026	0.052	76.4	0.0008	0.004	10.7	0.111	26	0.0036	45	6.2	1	0.005	0.005	192
Standard Error	0.0042	0.006	0.005	5.3	0.00037	0.002	1.5	0.017	1.3	0.002	7.4	0.6	0.09	0.0004	0.001	36.3
Median	0	0.017	0.049	70	0.001	0	9.9	0.11	24	0.0009	42	5.7	1	0.005	0.004	180
Mode	0	0.017	NA	NA	0	0	NA	NA	24	NA	NA	NA	NA	NA	0.004	NA
Standard Deviation	0.009	0.013	0.012	11.9	0.00084	0.0055	3.3	0.037	2.8	0.0044	16.5	1.4	0.2	0.0008	0.003	81.2
Range	0.021	0.026	0.028	27	0.002	0.011	8.4	0.101	6	0.01	39	3.5	0.52	0.002	0.008	210
Minimum	0	0.016	0.041	66	0	0	6.6	0.065	24	0	29	4.7	0.68	0.004	0.002	104
Maximum	0.021	0.042	0.069	93	0.002	0.011	15	0.166	30	0.01	68	8.2	1.2	0.006	0.01	314

Table 6

**Statistical Data for
Alluvial and Colluvial (AC) Lithology**

15 Samples	pH	EC	TDS
Mean	7.7	732.7	341.6
Standard Error	0.1	139.8	69.5
Median	7.8	560	257
Mode	8	560	240
Standard Deviation	0.39	522.9	260.2
Range	1.4	1810	913
Minimum	7.1	90	37
Maximum	8.5	1900	950

**Statistical Data for
Conglomerate-Sandstone (SS) Lithology**

15 Samples	pH	EC	TDS
Mean	7.8	406	214
Standard Error	0.08	35.7	9.1
Median	7.7	410	215
Mode	7.6	NA	NA
Standard Deviation	0.36	159.8	40.7
Range	1.2	588	156
Minimum	7.4	152	152
Maximum	8.6	740	308

**Statistical Data for
Siltstone-Shale-Sandstone (SSh) Lithology**

15 Samples	pH	EC	TDS
Mean	7.9	352	174
Standard Error	0.16	34.6	14.9
Median	7.9	365	172
Mode	7.8	460	NA
Standard Deviation	0.6	133.8	57.7
Range	1.8	442	198
Minimum	6.9	116	72
Maximum	8.7	558	270

**Statistical Data for
Limestone & Limestone-Sandstone (LS) Lithology**

15 Samples	pH	EC	TDS
Mean	7.9	462	203
Standard Error	0.17	19.8	7.5
Median	7.8	470	206
Mode	7.8	NA	NA
Standard Deviation	0.33	44.4	16.7
Range	0.8	120	45
Minimum	7.5	390	176
Maximum	8.3	510	221

**Statistical Data for
Evapoite (WSP) Lithology**

15 Samples	pH	EC	TDS
Mean	8.3	1665	911
Standard Error	0.3	222.6	171.2
Median	8.3	1576	950
Mode	NA	NA	NA
Standard Deviation	0.62	497.8	382.8
Range	1.4	1352	1053
Minimum	7.6	1038	407
Maximum	9	2390	1460