CONTRIBUTIONS OF KARST GROUNDWATER TO WATER QUALITY AND QUANTITY IN A MOUNTAIN RIVER BASIN: THE KAWEAH RIVER, SEQUOIA AND KINGS CANYON NATIONAL PARKS, CALIFORNIA

DISSERTATION

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by

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San Marcos, Texas
August 2013

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

ABSTRACT

CONTRIBUTIONS OF KARST GROUNDWATER TO WATER QUALITY AND QUANTITY IN A MOUNTAIN RIVER BASIN: THE KAWEAH RIVER, SEQUOIA AND KINGS CANYON NATIONAL PARKS, CALIFORNIA

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Under current climate conditions, hydrology of Sierra Nevadan rivers is primarily controlled by three mechanisms: rainfall-runoff, snow accumulation and seasonal melting, and groundwater recharge, storage, and subsequent discharge. Snowmelt and groundwater storage provide temporal distribution of the seasonal precipitation and

support stream flows during the annual dry season. The role of snowmelt hydrology in biogeochemical processes and maintaining river discharge has been the focus of numerous studies. However, the extent to which groundwater contributes to discharge and the temporal distribution of water in these systems has not previously been quantified. To address this need, field documentation of karst springs in the Kaweah River basin was conducted from 2010 – 2012. These data show that karst springs fall into two distinct categories: one with high seasonality and another with minimal seasonal variation in flow and chemistry. A more in depth look at Big Spring (low seasonal variability) and Tufa Spring (high seasonal variability) show that most low flow discharge from these aquifers is water that was stored within the aquifer, rather than quick flow through the system via large conduits. This pattern of water storage also plays a role in controlling nutrient movement through these karst groundwater systems. Finally, when karst of the Kaweah basin is taken as a whole, it represents a large component of baseflow river discharge, likely controlling the baseflow characteristics of the river.

CHAPTER I

INTRODUCTION

Water resources in the western United States are a high-priority issue for managers concerned about meeting both ecological and human requirements, and predicting availability at annual timescales. The Sierra Nevada mountain range in California, USA, provides a substantial amount of the water required to meet agricultural, industrial, and domestic demands throughout the state. Additional stresses on water resources result from competition between these human needs and ecosystem needs, both in the mountain range and downstream in the San Joaquin Valley, where all of the water from the basin is allocated for human use. As climatic patterns change and human water requirements increase, additional and new stresses will be placed on these limited water resources.

Precipitation in the Sierra Nevada primarily falls during the winter months along both north-south and elevational gradients, with higher precipitation amounts at more northerly and/or higher elevation locations. Due to the region's Mediterranean climate and related seasonality of precipitation, with a winter wet season and summer dry season, storage and subsequent distribution of precipitation to river systems over annual timescales is essential for meeting ecosystem and human needs during the dry season. Temporal distribution of water supplied to river systems is currently controlled by three interconnected subsystems that influence the larger, basin-scale, hydrologic systems in different ways. First, overland flow and quick, subsurface flow paths allow rapid transport of water to the river systems. Water following these pathways is not considered important in terms of water stored over seasonal time scales. These flow paths can however, deliver water to other longer-term storage components of the system, and quickly deliver water to downstream artificial storage systems such as reservoirs. Secondly, seasonal snowfall and subsequent melt is the dominant process controlling seasonal distribution of water under current climatic conditions. Melt waters follow multiple flow paths to reach the stream network, including surface and subsurface pathways, and can feed other storage components of the system. Due to its importance in supplying waters for human needs in California, snowfall and snowmelt processes have been the focus of many studies in the Sierra Nevada (Dozier and Melack 1989; Elder et al. 1991; Marks et al. 1992), and snowpack is monitored throughout winter months to predict water availability during the following summer. The third process controlling the temporal distribution of water to river systems is the infiltration and recharge of water into, storage in, and delayed discharge from, aquifer systems into surface streams. The amount and temporal distribution of groundwater delivered to streams varies and depends on both precipitation dynamics and aquifer properties. Relatively few studies have investigated mountain groundwater resources that may contribute substantially to maintaining year-round baseflow and supporting biogeochemical cycles in these river systems.

Future climate change scenarios predict warming trends with little change in annual precipitation for the southern Sierra Nevada, but under the most conservative of these predictions, there will be a rise in the snowpack elevation with an earlier onset of melting. Under the most extreme scenarios a complete loss of seasonal snowpack within this portion of the mountain range is predicted (Gleick 1987; Maurer 2007; Wilby and Dettinger 2000). Thus, for the entire range of predictions, the role of snowmelt in the hydrological system will be substantially decreased, increasing the importance of rainfall and recharge to groundwater systems in sustaining baseflow to the rivers.

Future climate scenarios highlight the importance of characterizing mountain aquifers properties and developing a more detailed understanding of their potential responses to predicted climatic variation. Previous researchers have documented the presence of a variety of aquifer types in mountain systems (Clow et al., 2003), the potential hydrologic implications of groundwater storage in and discharge from mountain aquifers (Peterson, 2008; Tague and Grant, 2005), and the presence of individual karst aquifers in mountain river basins (Despain, 2006; Faulkner, 2009; Ford, 1971; Kahn, 2008; Sara, 1977; Tobin and Doctor, 2009). However, there has been no prior work focusing on the basin-wide hydrologic role of karst groundwater in a mountain river basin. This dissertation focuses on quantifying the current role of karst (and unconsolidated) aquifers in the Kaweah River basin (Figure 1.1) by addressing the question: What roles do karst aquifers play in basin-scale hydrology of a mountain river, with emphasis on discharge, geochemistry, and nutrient dynamics?

To answer this larger question, four specific research questions and hypotheses were addressed as part of this dissertation. Each research question is presented in a chapter format, with each of the chapters representing a manuscript that has been published, or prepared for publication, in a peer-reviewed scientific journal.

(1) Can karst aquifers be categorized based on seasonality of water chemistry and discharge? *Karst aquifers of the Kaweah River basin were categorized based on differences and variations in measured hydrogeochemical and hydrologic parameters. Differences in Saturation Indices of Calcite, Calcium: Magnesium ratios, liquid water stable isotope values, and overall seasonality of geochemistries between springs are likely a result of differing geologic histories and represent differences in storage capacities between groups. When grouped, representative, continuously monitored springs provided data on hydrologic behavior of each group.*

(2) How does the geochemistry and discharge of karst springs vary temporally and spatially within karst groundwater systems in the Kaweah River basin? *My hypothesis is that snowmelt seasonally increases discharge from karst springs as a result of direct recharge in sinking streams and sinkholes, and decreases the concentration of dissolved solids in the system. Low flow periods are dominated by water stored for longer periods in the epikarst and fractures, with higher dissolved solid concentrations. Aquifers that have higher connectivity to surface streams will also experience greater variation in chemistry seasonally.*

(3) How do karst aquifers respond to fire and potential fire retardant chemical contamination? *My hypothesis is that nitrate levels in these systems will increase after a fire and remain high for multiple years before returning to base level conditions. However, phosphate will decrease in concentration in a downstream direction due to biotic and abiotic uptake in a phosphate-limited system. Basins that received the highest amount of fire retardant will have the highest dissolved loads of both nutrients.*

(4) What are the current and historic contributions of karst groundwater to river discharge, and can a model be developed to fit observed hydrologic data? *My hypothesis is that baseflow discharge is positively correlated with the amount of karst and unconsolidated aquifer units: the higher the proportion of karst present within a basin, the higher the baseflow will be in the dry season, and the more water that is stored within these aquifers. Additionally, these karst aquifers act as drains for the surrounding fractured non-karst bedrock aquifers that have lower storage capacity than the karst and unconsolidated aquifers.*

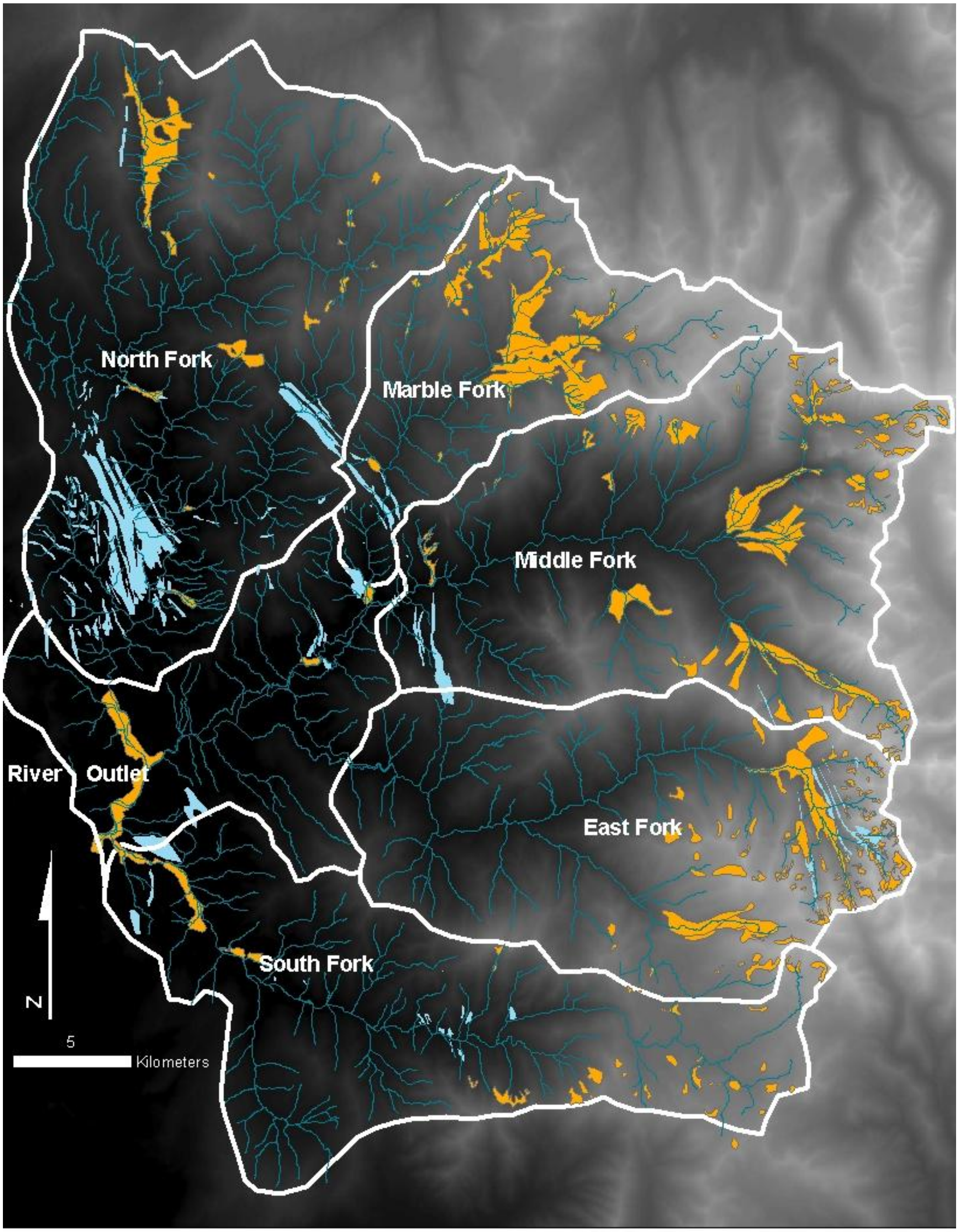

Figure 1.1: Basin map of the Kaweah Watershed. Light blue indicates karst bedrock, orange indicates unconsolidated materials. The remainder of the basin is crystalline bedrock (granodiorites, schist, quartzite, or other metamorphic rocks). Elevation changes from approximately 300 masl at the river outlet to 3700 masl in the East (central right).

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CHAPTER II

HYROLOGIC AND GEOCHEMICAL CHARACTERIZATION OF MARBLE KARST AQUIFERS IN A MOUNTAIN RIVER SYSTEM

Abstract

Historically, research on mountain river hydrology has focused on the dynamics of snowmelt-derived discharge. However, more recent research has documented the importance of groundwater in mountain hydrologic systems. Despite this recognition, there have been few attempts to quantify the extent of karst aquifers and the hydrologic role of karstic groundwater sources in mountain systems. In this study, we document the hydrology and geochemistry of 47 perennial karst springs in the Kaweah River, a mountain river basin in the Sierra Nevada, California and completed dye traces on all known large sinking streams that had not previously been traced to springs. These springs have a wide range of inter- and intra-spring variability in discharge and geochemistry. Statistical analyses of variability, discharge, and geochemical parameters were used to categorize karst springs in the basin and determine that they fall into one of two groups: high elevation springs of the Mineral King Valley, and lower elevation springs throughout the rest of the basin. Six springs (three from each group) were continuously monitored for stage, temperature, and specific conductivity. These data were used for hydrograph recession analysis, the results of which were then used to characterize the hydrograph recession behavior of each group. Both groups showed statistically similar baseflow recession slopes, indicating that there is minimal difference in the nature or type of storage component of the aquifers. The biggest difference between each group is the variability in amount of water remaining in the aquifer during baseflow conditions. High elevation springs have baseflow that is much lower than lower elevation springs, in spite of the fact that more precipitation falls at higher elevation. This difference is likely due to differences in recent geomorphology: high elevation aquifers were glaciated as recent as 41 kya, while there is no evidence that low elevation springs have been under glacial ice.

Keywords: *Mountain hydrology, glaciokarst, karst groundwater*

Introduction

Prescribed Mountain river systems are frequently referred to as the water towers of the world (Clow et al., 2003, Viviroli et al., 2003). Storage in these systems is often dominated by snowpack that accumulates over the course of a winter and melts over the subsequent summer (Bales et al., 2006; Kattelman and Elder, 1991). However, increasing evidence is showing that groundwater storage is critical to maintaining baseflow in rivers draining mountain systems. For example, Clow et al. (2003) documented the presence and hydrologic importance of different aquifers to maintaining flow in these hydrologic systems. In a study of alpine hydrologic systems in the Colorado Rocky Mountains of the United States, they showed that unconsolidated deposits, particularly talus slopes, provide the largest amount of storage of all measured groundwater types in a mountain environment, though other unconsolidated materials, such as glacial and landslide deposits, also provide significant groundwater storage. Although bedrock aquifer storage has been assumed or measured to be negligible in many snowmelt dominated systems, some types of bedrock aquifers, such as volcanic (Tague and Grant, 2004) and karst systems (Perrin et al., 2003), have significant amounts of storage.

In many types of hydrologic systems around the world, karst plays a significant role in storing water and maintaining flow of surface river systems (Han and Liu, 2004; Jemcov, 2006, Karimi et al., 2005). Flow in karst aquifers is often dominated by turbulent flow through conduits, with additional inputs from primary and secondary porosity. The spatial scale and storage capacity of these aquifers can be very large, with spatial extents of 1000 km^2 or larger in systems such as the Upper Floridian Aquifer in Florida, U.S.A. (Moore et al., 2009), the Pennyroyal Plateau of Kentucky (Palmer, 1981), and the Edwards Aquifer in Texas, U.S.A. (Quick and Ogden, 1985; Hunt et al., 2010). However, karst aquifers are not well documented in all settings and, to date, very little research has focused on the role that karst aquifers with limited spatial extent play in contributing to the hydrology and geochemistry of mountain systems. Previous work in mountain karst systems has primarily focused on documentation (Kahn, 2008; Karimi et al., 2005), speleogenesis (Despain and Stock, 2005; Ford, 1971; Lauritzen, 2001), and characterization of individual aquifers typically related to either large cave systems (Abu-Jaber, 2001; Despain, 2006; Sara, 1977; Smart, 1983) or important water supplies (Oraseanu and Mather, 2000; Perrin et al., 2003).

Based on the results of many studies of karst systems around the world, it is possible to generalize and state that, for epigenic karst systems, the geochemistry of karst groundwater is primarily controlled by the type of recharge area (Florea and Vacher, 2006; Lauritzen, 2001) and the maturity and relative contributions of fissure, conduit, and diffuse flow (Atkinson, 1985, Karimi et al., 2005). The relative importance of autogenic *vs.* allogenic recharge to a spring has been shown to play an important role in controlling the chemistry of a given spring (Padilla et al., 1994), with allogenic recharge generally resulting in lower specific conductance than autogenic recharge. Also, karst systems with a well-developed conduit network and poorly-developed or absent epikarst, fewer fractures, and low matrix porosity will discharge water with lower specific conductance than a similar conduit system with more epikarstic, fracture, and matrix porosity. This is primarily due to shorter residence times and less dissolution in the conduits (Worthington, 2009).

Perrin et al. (2003) found that alpine karst systems can have substantial autogenic diffuse recharge, where water is stored in the epikarst and slowly recharges underlying aquifers and spring systems. Faulkner (2009), in analogous high latitude systems, found that rapid conduit development can occur, increasing the ability of allogenic sinking streams to enter the aquifer and rapidly move through and discharge at the springs.

An understanding of the role of conduit, fracture and matrix dominated flowpaths within a karst system is needed to document the storage capacity and residence time of water within an aquifer. Analysis of continuous discharge data provides a means of quantifying which flow paths are dominant during baseflow recession in karst aquifers

(Kovacs et al., 2005). However, a mountain setting with a large number of remote springs creates logistical problems for instrumentation and data collection, making continuous monitoring of all springs both cost- and labor-prohibitive. Alternatively, springs can be characterized by collecting seasonal physiochemical parameters to assess both the values and variability of these parameters at a given site under hydrological extremes. Statistical analyses of water quality and quantity data can then be used to separate springs into groups, and representative springs can then be selected from each group for instrumentation and continuous data collection. Analysis of the continuous data can then be used to generally understand and predict the aquifer storage properties for other springs in a given group that are only sampled periodically.

Recognizing that little research has been conducted to address basic questions about the importance of karst aquifers in mountain hydrologic systems, the goals of this research were to: 1) document, characterize, and group springs based on measured hydrogeochemical parameters, and 2) use continuous data from representative springs to assess baseflow characteristics of springs in each group. We hypothesized that 1) springs could be classified based on seasonal variability of discharge and chemistry, which would indicate a difference in storage between each group, and 2) that these groups would be predominantly correlated with spring elevation, which acts as a proxy for the effects of recent glaciation in the basin on the amount and maturity of epikarst, soil, and associated unconsolidated deposits present in each springshed.

Study Site

The Kaweah River Basin is on the western slope of the Southern Sierra Nevadas of California and drains west out of the mountain range, from elevations up to 3700 masl, into the San Joaquin Valley, and terminates at Tulare Lake, a closed basin at the southern end of the valley. Currently, the majority of the water from this river is used for agricultural purposes and does not reach the lake. This study focuses on the river system above Lake Kaweah, a manmade reservoir at the boundary between the valley floor and mountain range, at an elevation of 200 m asl (Figure 1).

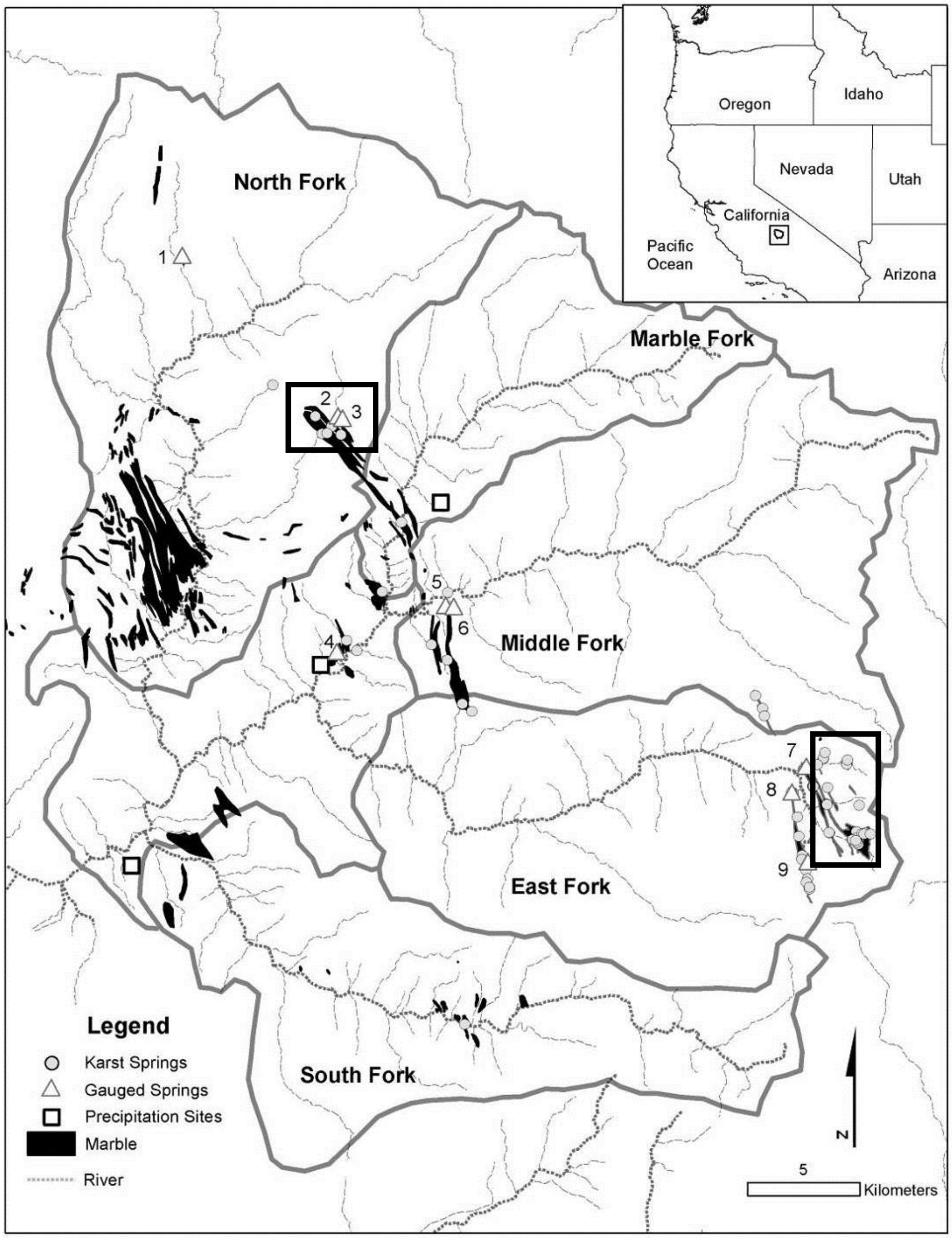

Figure 2.1. Study location with all documented spring sites, continuously monitored springs (1-Big Spring; 2- Crystal Cave 3- Mossy Spring; 4-Alder Spring; 5- Warm River Spring; 6- Upper Smoking Spring; 7- Monarch Spring; 8- Tufa Spring; 9- White Chief Spring), precipitation sites, and dye trace locations highlighted (A-Yucca Creek; B- Eastern Mineral King). Note: Big Spring is located in a band of marble completely covered by landslide deposits to the north of the spring and has no surface expression visible at the scale of this map.

Most of the Southern Sierra Nevada region experiences a Mediterranean Climate, with hot, dry summers, and cool wet winters. Precipitation varies with elevation: locations at 500 masl elevation receive 500 mm of precipitation per year (primarily as rainfall), and elevations around 2000 masl receive 1000 mm of precipitation per year (primarily as snowfall). The snowline in the Kaweah River basin depends on slope and aspect, but is typically around 2000 masl. During late spring through summer, a large annual snowmelt event accounts for most of the total annual discharge in the river (SEKI 2005).

Surface geology in the Kaweah River basin is dominated by granite to grano-diorites of the larger Sierran Batholith (Sisson and Moore, 1994). Throughout the basin is a series of northwest-southeast trending bands of metamorphosed marine sediments that are part of the Kings terrain (Bateman and Clark, 1974; Nokleburg, 1983). Contained within these are bands of highly karstified marble typical of a kind of karst termed ‘stripe karst’; with highly karstified regions along contacts with adjacent insoluble bedrock, and little to no surface water (Lauritzen, 2001). More than 275 caves have been documented in marble bands across most of the elevational range in the basin; the highest known marble is found at 3300 masl and the lowest at 200 masl. The basin also experienced significant glaciation, with large portions of the basin above 2000 masl covered by glaciers during the Tahoe glacial maximum, between 41,000 and 50,000 years b.p. (Moore and Mack 2008).

Methods

Field and Lab Documentation

Field reconnaissance and documentation of spring locations occurred between 2007 and 2012. Between 2007 and 2009, and prior to more detailed aquifer characterization, sites were located (GPS locations) and photographed as part of a preliminary spring inventory. Beginning in 2010, additional sites were photographed, located (GPS documentation), and all springs were sampled and measured for discharge. All sites were, at a minimum, sampled, and field parameters and discharge measured during both seasonal high flow and baseflow conditions from 2010 to 2012. In an earlier study, Despain (2006) showed that there is a direct relationship between specific conductivity at Tufa Spring and the water chemistry, documenting that when specific conductivity is stable during baseflow conditions, major ion concentrations also experience little variability. To verify this in another system, analysis of bi-weekly samples collected at Big Spring from 2006 – 2007 showed that there was minimal variation in water chemistry during baseflow recession. Thus a single sample collected at or near the end of baseflow conditions can be assumed to be representative of the geochemical composition of water in the aquifer under baseflow conditions (Appendix 1).

Using preliminary data from 2009 and existing data from previous studies, nine spring sites were also chosen for continuous monitoring of stage, temperature, and specific conductivity over the study period. Sites were chosen to represent a range of discharges, geochemistries, and spring elevations in the basin. Due to the narrow spatial extent of metamorphic rock bands, springs often occur in geographically close groups or clusters controlled by geology and/or topography. In these cases, the largest easiest to access springs were generally chosen from each cluster.

Sample collection and preservation in the field followed published USGS protocols (Shelton, 1994) for major cation, major anion, and nutrient analyses. Field parameters were measured on a Hanna water quality probe and included specific conductance, dissolved oxygen, pH, and temperature. Samples were refrigerated and analyzed as soon as possible on Dionex ICS-1600 ion chromatographs at Texas State University to measure Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, NO_3^{-}, PO_4^{-3}, $SO_4^{-2,}$,Cl^{-}, Br^{-}, and F^{-}. Alkalinity was measured by titration in the same lab using the inflection point method (Rounds, 2006). Liquid water stable isotopes (δD and $\delta^{18}O$) were also analyzed in the same lab on a Los Gatos Research DTL – 100 Liquid Water Stable Isotope Analyzer. All ion concentration data was converted to molarity and then to total proportion of cations present and total proportion of anions present.

Precipitation samples were collected for liquid water stable isotope analysis at three sites in the basin, at elevations of 200 masl, 500 masl, and 2000 masl. The 200 masl site was set up for this study in the town of Three Rivers and samples were collected weekly from November 2010 through May 2011. The 500 masl and 2000 masl sites were located within Sequoia National Park and are maintained by the National Park Service as part of the National Atmospheric Deposition Program. Samples at all three sites were homogenized over weekly intervals and protected from evaporation prior to analysis.

Discharge measurements were collected using either a pygmy meter, a turbine flow meter (Global Water hand held flow meter), Marsh-McBirney flow meter, or, in the case of some very low flow springs, by directly timing volumetric measurements. Discharge in spring runs was measured at sites having as uniform a cross-section and flow as possible, and with minimal riffles. In a few cases, where spring discharge proved too difficult to gauge directly, spring discharge was determined by subtracting measured surface stream flow above and below the spring; the difference is assumed to be spring discharge. Due to the steep and rocky terrain the accuracy of these measurements decreased and is estimated to be +/- 10%.

Dye Trace

In addition to understanding and characterizing spring hydrology and geochemistry, it is important to understand the relationships between surface hydrology and subsurface flow. This allows for more accurate quantification of allogenic and autogenic components of discharge from karst springs and improves the necessary framework to interpret flow path length and storage properties of a karst aquifer (Benischke et al., 2007). The two karst aquifers with the largest springs, Tufa Spring (Despain, 2006) and Big Spring (Tinsley, 1981), have previously been successfully and completely traced. Little data is available on groundwater flowpaths in other karst aquifers in the basin. To improve our understanding of these flowpaths, and to begin delineating springsheds, additional dye traces were conducted in the karst of Yucca Creek and the eastern Mineral King Valley. Hydrologic connections between sinking streams and springs were determined using established dye-tracing methods (Benischke et al., 2007) during high flow conditions in June 2012. In the eastern Mineral King Valley, 125 mL of concentrated Rhodamine WT was injected into Rainbow Creek (Figure 2.2). Three dyes were used to quantify connections in the Yucca Creek system: Fluorescein in Upper Yucca Creek; Eosin in Windy Canyon; and Rhodamine WT in Cave Creek (Figure 2.3). Activated charcoal dye receptors were placed at all spring and surface stream sites one week prior to dye injection. Receptors were replaced prior to dye injection to document background fluorescence and again at one and three weeks after the injections in the Yucca Creek trace and at one and six weeks after the injection in Mineral King.

Assessing variability among karst springs

Determining if either autogenically-derived diffuse recharge or basin-wide allogenic recharge is the dominant source of waters for mountain karst springs would provide evidence indicating where the majority of water is being stored within these aquifer-surface stream systems and thus give insight into the storage properties of these systems. A number of methods were used to assess patterns in variability and, by association, the role of autogenic and allogenic recharge among karst springs in the Kaweah basin: variability in modeled source water elevation, hydrogeochemical variability (specifically calcite saturation indices and Ca:Mg ratios), comparison of rock and water sample chemistry, and a principal components analysis. These methods were all chosen to look at how springs throughout the park varied both seasonal and between springs.

Source water elevation modeling using liquid water stable isotopes

Liquid water stable isotopes from precipitation in mountain environments have a distinct lapse rate characterized by a predictable rate of fractionation, or lapse rate, as a function of elevation change. As elevation increases, heavier isotopes rain out first, leaving progressively depleted (or isotopically lighter) waters at higher elevations. When assessing water leaving a mountain drainage basin, multiple samples from the same site over time provide an opportunity to assess seasonality in recharge source elevation. Using weekly homogenized precipitation data from three different elevations (200 masl, 500 masl, and 2000 masl (Figure 2.1)) from the week of December 20, 2010, an isotopic lapse rate was determined for the Kaweah basin. This can then be used to model an average recharge elevation for a given water body. Modeled elevations were then compared with the spring elevation to estimate the average source elevation for water discharging from a spring at any given time. This can also be used to infer an elevation at which the majority of water stored in the aquifer was derived from.

Hydrochemical Comparisons

Calcium – magnesium ratios and calcite saturation indices (SI_C) were calculated for all spring samples collected. Ca:Mg ratios were molarity-based calculations. SI_C was calculated with all available geochemical data for each site using WEB-PHREEQ (Saini-Eidukat, 2001). Average values and standard deviations were calculated for both Ca:Mg ratios and SI_C for individual springs. Little difference was seen between proximal springs in the same marble band; therefore, they were grouped for comparisons. This created fourteen groups, one for each major band of marble with known springs.

Rock –Water Chemistry Comparison

Rock samples were randomly collected from an outcrop of each marble band in the proximity of springs, when possible. Five grams of each rock sample were finely crushed and placed in 30 ml of 15% HCl by volume for 3 weeks. The remaining undissolved portion of the rock was then dried and weighed to determine the percent of the sample that was dissolved. The dissolved portions of the samples were diluted to 1:200 concentrations and analyzed for major cations following the same procedure used for water samples. This allowed direct quantification of ion chemistry of the soluble fraction of the host rock. Cation data from dissolved rock samples were then compared with the geochemical data obtained from spring samples, with Ca:Mg ratios being of primary interest. When Ca:Mg ratio of rock ions and water ions are similar, the water sample is closer to equilibrium with the dissolvable portion of the rock, this provides a means of comparing relative residence times in each aquifer: springs with water chemistries that more closely match rock chemistries are assumed to have longer residence times. However, this method assumes that each sample is representative of a homogeneous host marble.

Principal Components analysis

Principal components analysis (PCA) is a multivariate statistical technique that was used to reduce the dataset while retaining variance within a dataset. This allows for visualization of separations in the dataset due to variability in the data. This method has been used in a number of studies to interpret hydrologic and hydrogeochemical datasets (Doctor et al. 2006; Karimi et al., 2005). To determine whether or not springs could be grouped in a PCA framework, all field parameters, ion chemistry, $SI_{C,}$ and isotope data were used. All data were initially assessed for correlation prior to running the PCA. When parameters were highly correlated (r^2> 0.60), one of the two variables was removed (Table 2.1). All remaining variables were then included in the PCA for analysis (Appendix B). The PCA was conducted on all individual water samples. Chemistry data was converted from mg/L to a molar percent in order to remove an elevational signal (decreasing concentrations with increasing elevation) from the data and specifically compare the proportional amounts of each ion relative to the total dissolved solute load, as was done by Karimi et al. (2005). The PCA and correlation analyses were conducted in R (R Development Core Team, 2012).

Table 2.1. Correlation Matrix of all variables considered for PCA. Grey highlights indicate variable was removed from analysis.

	Elevation	SI	Discharge	pH	temp	S.C.	δD	$\delta^{18}O$	Cl	NO_3	SO_4	Alkalinity	Na	K	Mg	Ca	Ca:Mg
Elevation	1.00																
SI	-0.81	1.00															
Discharge	0.25	-0.06	1.00														
pH	-0.05	0.45	0.23	1.00													
temp	-0.86	0.74	-0.25	0.19	1.00												
S.C.	-0.67	0.72	-0.23	-0.07	0.59	1.00											
δD	-0.94	0.75	-0.30	0.02	0.78	0.69	1.00										
$\delta^{18}O$	-0.91	0.73	-0.27	0.03	0.78	0.67	0.99	1.00									
Cl	0.00	-0.11	0.00	-0.35	-0.10	0.25	0.00	-0.01	1.00								
NO_3	0.61	-0.51	0.01	-0.05	-0.48	-0.47	-0.53	-0.51	-0.04	1.00							
SO_4	0.20	-0.26	-0.03	0.23	0.07	-0.34	-0.31	-0.26	-0.07	0.34	1.00						
Alkalinity	-0.32	0.42	0.02	-0.01	0.11	0.27	0.38	0.34	-0.40	-0.51	-0.85	1.00					
Na	-0.16	-0.13	-0.03	-0.15	0.15	-0.15	0.08	0.07	0.51	-0.17	0.19	-0.34	1.00				
K	-0.01	-0.29	-0.03	0.03	0.15	-0.44	-0.10	-0.08	0.07	0.00	0.61	-0.52	0.51	1.00			
Mg	-0.47	0.49	-0.17	-0.10	0.31	0.71	0.54	0.49	-0.09	-0.32	-0.39	0.44	-0.34	-0.50	1.00		
Ca	0.58	-0.46	0.20	0.18	-0.41	-0.67	-0.61	-0.55	-0.13	0.42	0.30	-0.28	-0.12	0.20	-0.89	1.00	
Ca:Mg	0.33	-0.46	0.01	-0.25	-0.14	-0.26	-0.35	-0.31	0.01	0.26	0.56	-0.52	0.18	0.28	-0.23	0.15	1.00

Aquifer Storage Analysis

Following spring classification, continuous discharge, conductivity, and temperature data from selected springs were used to quantify representative aquifer storage and response properties for each grouping of springs. Hydrographs from the continuously monitored springs were analyzed to determine baseflow recession characteristics. Recession coefficients for each component of the spring hydrographs were calculated using a form of Maillet's equation (Maillet 1905):

(1) $\alpha = (\log Q_1 - \log Q_2)/(0.4343(t_1 - t_2)$

in which Q_1 and Q_2 (m^3/s) are discharges at the beginning and end of straight line segments from $t_1$to t_2 (days), and α is the slope coefficient of the straight line segments of the recession curve in semi-log space. These coefficients provide a means of quantifying and comparing aquifer properties and retention times between the different springs (Dewandel et al. 2003; Jeanin and Sauter 1998). The steepness of the slope (α) of individual components in a hydrograph recession curve is related to retention time: steeper slopes are related to shorter residence times.

Results

Initial Documentation

Initial field work documented a total of 47 perennial karst springs within the Kaweah Basin, with numerous ephemeral springs, especially in the Mineral King area, that are highly dependant on precipitation. The 47 karst springs are spread relatively evenly throughout the karst bands in the basin (Figure 2.1) and have measured discharges ranging from 3.91 to 0.001 m^3/s. When looked at collectively, proportion of ions varied over the spatial extent of the basin, but not between peak and base flow periods (Table 2.2). At high elevations, cations are overwhelmingly dominated by calcium, which accounts for 81% of the total cations in solution. At lower elevations, calcium is still the dominant cation at most karst springs, but it only accounts for 63% of the cations on average, with some sites dominated by magnesium. Lower elevation springs had an increase in magnesium and sodium, when compared with high elevation springs. Anions for all sites were overwhelmingly dominated by alkalinity, accounting for more than 90% of all anions in solution at all springs.

Table 2.2. Relative Ion proportions of dissolved anion and cations, averaged among all springs for peak discharge, baseflow, by elevation (above and below 2000 m), and then separate base and peak flow values for high (H-base and H-peak, respectively) and low (L-base and L-peak, respectively) elevation springs.

Sampling Period	Anions				Cations			
	Cl	NO3	SO4	Alk	Na	K	Mg	Ca
Peak Flow	1.86%	0.94%	3.70%	93.50%	14.56%	2.35%	15.71%	67.38%
Base Flow	2.33%	0.83%	3.42%	93.42%	13.27%	2.18%	13.69%	70.85%
High Elev.	1.79%	1.75%	5.30%	91.17%	11.86%	2.33%	4.70%	81.11%
Low Elev	2.21%	0.44%	2.68%	94.66%	15.08%	2.25%	20.05%	62.62%
H-peak	1.32%	1.89%	5.66%	91.13%	12.58%	2.49%	5.18%	79.75%
H-base	2.21%	1.62%	4.96%	91.20%	11.21%	2.18%	4.27%	82.34%
L-peak	2.08%	0.55%	2.89%	94.48%	15.37%	2.29%	20.05%	62.28%
L-base	2.41%	0.29%	2.39%	94.92%	14.66%	2.19%	20.04%	63.12%

Dye Traces

Dye trace results revealed a highly connected karstic system on the east side of Mineral King Valley and in Yucca Creek. For the East Mineral King trace, Rhodamine WT injected in Rainbow Basin was not detected in the adjacent Onion Meadow Spring along Franklin Creek. Prior to this trace, it was hypothesized that water sinking in the Rainbow

Basin discharged from the nearby Onion Meadow Spring, but this was based entirely on their proximity. Instead, all of the waters sinking in Rainbow Basin flowed north, apparently through one or more narrow bands of marble, where a portion discharges at Crystal Creek Spring. The remaining water in the aquifer continued through this or a parallel band of marble to Aspen and Monarch Springs, which discharge from what were previously assumed to be separate bands of marble (Figure 2.2). All positive traces were recovered one week after injection. These results show that the two bands of marble represent a single highly connected aquifers in the subsurface, even though the surface expression of marble bedrock indicates no connection. Rather than representing a separate aquifer system, the Monarch Spring band of marble must therefore be a portion of a larger complexly folded marble band that is connected in the subsurface to the Aspen Spring band of marble and is actually an extension of the karst system that begins in the Rainbow Basin.

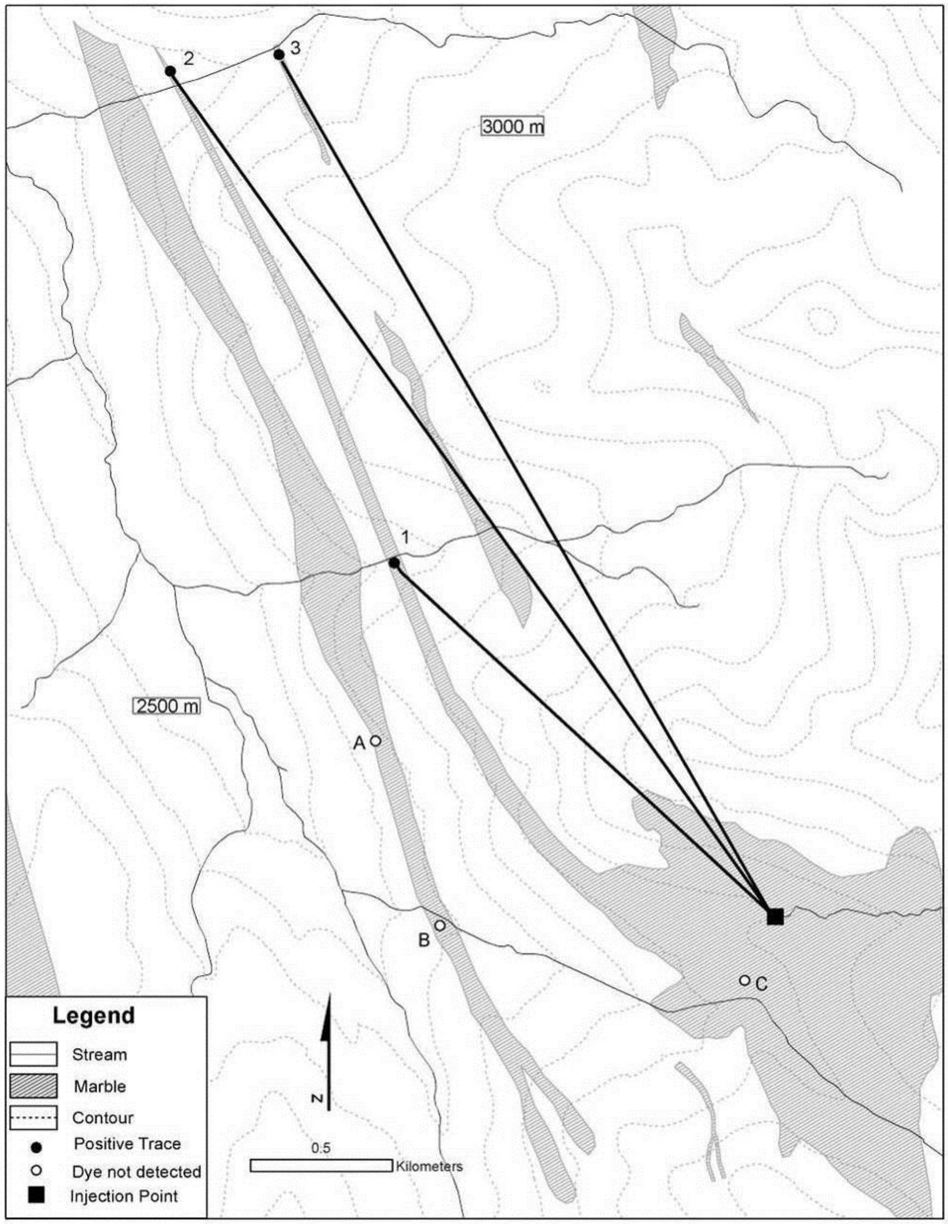

Figure 2.2. Eastern Mineral King Valley dye trace. Positive traces were obtained at (1) Crystal Spring, (2) Aspen Spring (on north side of Monarch Creek), and (3) Monarch Spring, and a no dye was detected at Not Soda Spring (A), Beulah Spring (B), and Onion Meadow Spring (C).

In Yucca Creek, dyes were injected in Upper Yucca Creek (Fluorescein), Windy Creek (Eosin), and Cave Creek (Rhodamine WT) and were recovered within one week of the injection date at Crystal Cave, Windy Spring, Contact Spring, Kuala Spring, Lange

Spring, Cave Creek Spring, and at Lower Yucca Creek as waters followed three converging flow paths. Water and Fluorescein dye from Upper Yucca Creek sinks into alluvium in its bed before entering the marble and flowing through Crystal Cave and into Cascade Creek. Downstream of this point, and below the confluence of Cascade, Windy, and Upper Yucca Creeks, a portion of the water and dye sank into marble again and reemerged at Contact Spring. Further downstream a portion sank into a third band of marble and reemerged at both Kuala and Lange Springs. Water and Eosin dye in Windy Creek sank at the injection point, emerged at Windy Spring and then was detected at Kuala and Lange springs following the same flow paths that Fluorescein followed from Yucca Creek to these springs. The Cave Creek injection of Rhodamine WT dye sank immediately and emerged at Cave Creek Spring before flowing down the surface Cave Creek and intersecting Lower Yucca Creek (Figure 3). This dye was not detected at the Lower Yucca Creek site, likely due to dilution and photodegradation.

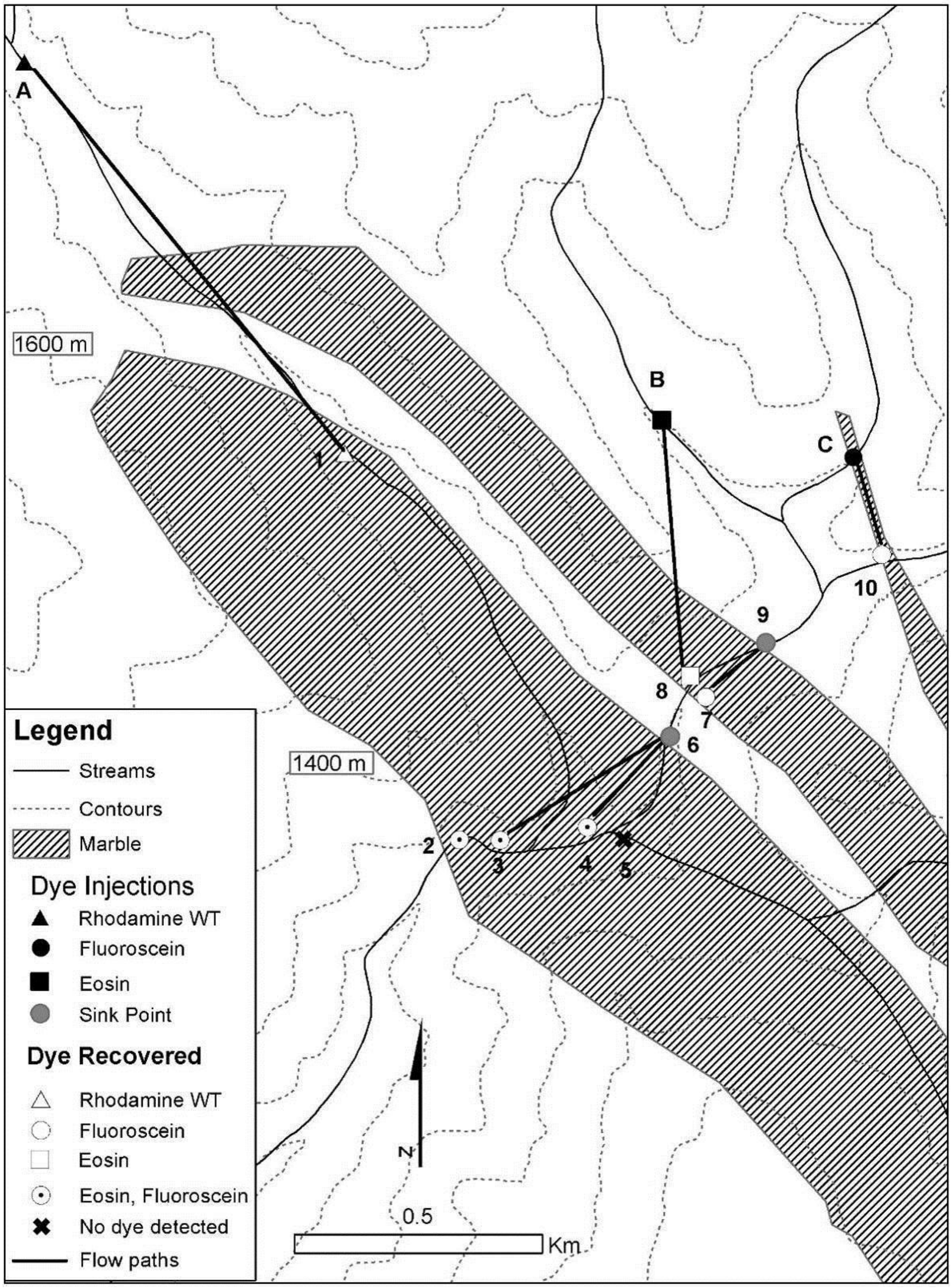

Figure 2.3. Yucca Creek dye traces. Sites monitored include: Cave Creek Spring (1), Lower Yucca Creek (2), Lange Spring (3), Kuala Spring (4), Rimstone Creek (5), Contact Spring (7), Windy Spring (8), and Crystal Cave (10). Points (6) and (9) represent sink points in the Yucca Creek where dye sank and reemerged at downstream springs. Injection sites are Cave Creek Sink (A), Windy Creek Sink (B) and Upper Yucca Creek (C). Cave Creek Sink (A) and Windy Creek Sink (B) are located in marble, even though available geologic data do not accurately represent the boundaries of marble for these two areas.

With the completion of these two traces, sinking streams have now been traced to most of the larger karst springs in the Kaweah Basin. However, at least 20 other smaller springs have not yet been dye traced. The high total dissolved solids load, elevated temperatures, low discharge variability, and low discharge (< 1.0 l/s) of some of these springs suggest minimal connectivity with sinking streams and that discharge is likely dominated by diffuse recharge or flow through deep regional flowpaths.

Source Water Elevation Models

Liquid water stable isotope data can be separated into two groups based on site elevation and seasonal variability. Due to the isotopic lapse rate of precipitation, lower elevation sites are more enriched in heavier isotopes relative to higher elevation sites. Samples from lower elevation springs also have low seasonal variability while high elevation sites have higher seasonal variability. Low variability suggests that low elevation aquifers have residence times in excess of the sampling period, likely greater than one year. High elevation springs showed a distinct seasonality in isotopic values, indicating an average residence time of less than one year.

An isotopic lapse rate for the basin was established using precipitation samples. Initially δD and $\delta^{18}O$ were each plotted separately against elevation. The regression line between elevation and each isotope was calculated. Both relationships showed a strong correlation between elevation and isotopic values (δD r^2= 0.987; $\delta^{18}O$ r^2= 0.993). These two regression lines were then solved for elevation and the resulting elevation values were averaged together, creating a recharge water elevation model:

(2) $$\text{Elevation} = \left(\frac{\delta D + 52.521}{-0.0151} + \frac{\delta^{18}O + 7.6903}{-0.002}\right)/2$$

When modeled elevation is plotted against average basin elevation, a distinct difference is seen between high elevation and lower elevation aquifers (Figure 2.4). As with the raw isotopic data, at low elevation sites, there is no significant difference between high flow and low flow samples ($F_{1,122}$= 2.332, p= 0.129), which again suggests that the discharge is derived from a well-mixed storage compartment with multi-year residence times. However, high elevation sites show a significant decrease in modeled elevation during low flow periods ($F_{1,69}$=27.84, p=0.000001). Therefore, for higher elevation sites during high flow conditions, water from higher elevations in the basin is the dominant water source, while during low flow conditions, water stored at lower elevations (closer to the spring) dominates. This implies that there is a seasonal change in the dominant water source, with snow at higher elevations dominating high flow conditions and water stored in aquifers closer to the spring mouth dominating during low flow conditions.

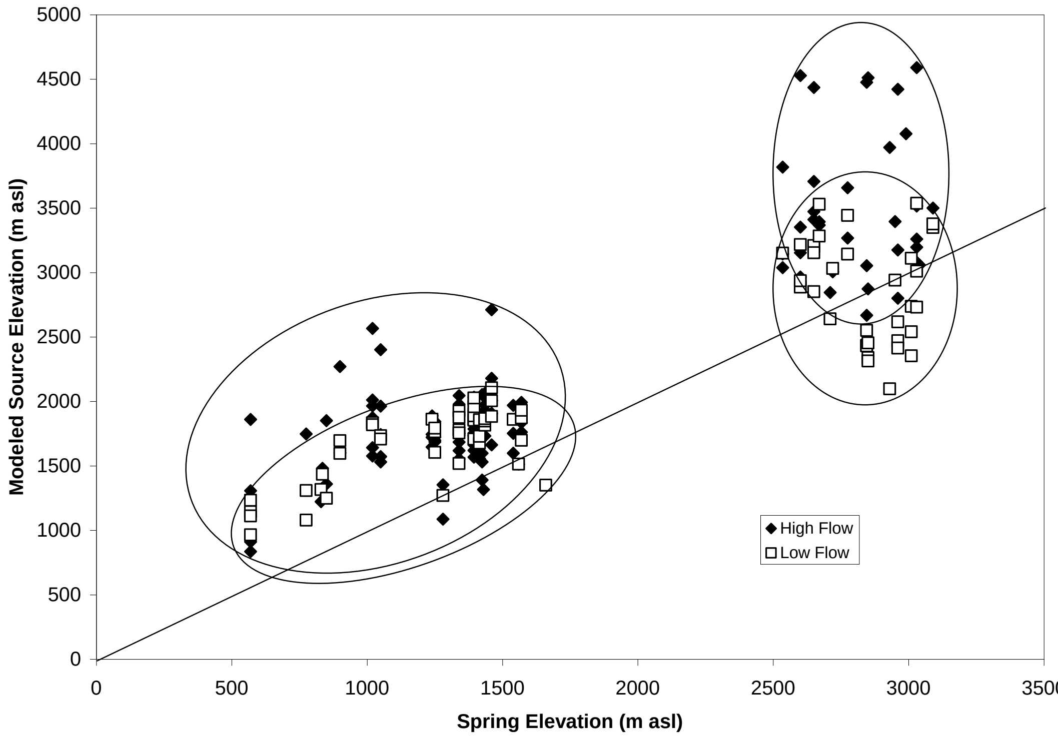

Figure 2.4. A comparison of modeled source water elevation from all spring sites compared to spring elevation. Ovals bound high flow and low flow samples. The line represents a1:1 relationship between spring elevation and modeled elevation.

Water Chemistry Comparisons

Calcium-Magnesium ratios provide insight into the length of time water is in contact with the host marble (Hunkeler and Mudry, 2007), when rock chemistry is accounted for. Dolomitic and magnesium-rich marble typically require longer periods of time to dissolve but typically have lower ratios due to higher amounts of Mg in the host rock. However, seasonal variability of Ca:Mg ratios also provides insight into dominant flow paths that the water is taking en route to the spring. Springs in the Kaweah basin showed a high range of Ca:Mg ratios, but values generally follow an elevational trend, with lower elevation springs exhibiting relatively higher concentrations of magnesium to calcium when compared to higher elevation springs. High elevation springs not only have the lowest concentrations of dissolved magnesium, but also a higher variability in Ca:Mg ratios, supporting the idea that higher springs are characterized by generally lower residence time of the waters within the aquifer. This high variability in Ca:Mg ratios is mirrored by variability in discharge as well. When springs are separated based on the band of marble in which they are located, two groupings become apparent: low Ca:Mg values and variability, and high Ca:Mg values and high variability (Figure 2.5a). Although the actual values of the ratio may be a result of variations in rock chemistry, the distinct difference in variability is likely due to differences in aquifer storage capacity.

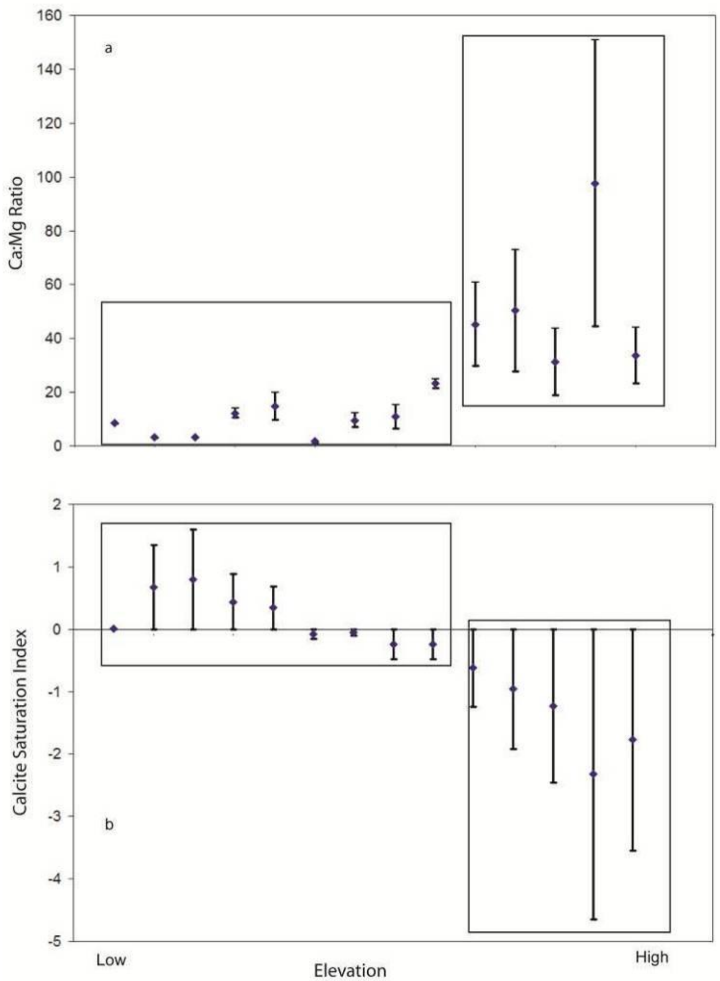

Figure 2.5. Mean Ca:Mg ratio values with 1 standard deviation error bars. Calcite Saturation Index with 1 standard deviation error bars. Rectangles indicate grouping.

SI_C showed decreasing saturation and an increase in variability with an increase in elevation (Figure 2.5b). Dolomite saturation indices (SI_D) showed a similar pattern to calcite and are not shown. Low elevation springs, on average, were supersaturated with respect to calcite. Middle elevation springs were approximately at equilibrium with respect to calcite and showed little variation between high and low flow conditions. High elevation springs showed the most variability, with most springs reaching equilibrium during low flow conditions, but average concentrations well below equilibrium. This suggests that there are differences in how or where water is stored within these systems. At low elevation, it is likely that the majority of water moves relatively slowly through a system that contains thicker soils and a well-developed epikarst, and that super-saturated waters are the result of relatively greater amounts of water-rock interaction. High elevations show a dominance of quick flow pathways during high flow condition and a switch to dominance of relatively longer residence pathways during low flow conditions. With SI_C typically reaching equilibrium, these residence times still appear to approximate those seen in low-elevation systems.

Rock Chemistry

Rock cation data showed that most samples were dominated by Ca^+, representing 91 – 99% of all dissolvable cations in all but two samples. Those two samples were dolomitic, with calcium and magnesium representing 50% and 49% respectively, of the cations in one White Chief sample, and 58% and 41% in a Cave Creek sample (Table 2.3). Multiple samples were taken from one Eastern Mineral King band of marble and the White Chief band of marble and show that the primary assumption of comparing water and rock chemistry is violated: rock chemistry is highly variable in a given rock band and thus the hand samples collected likely do not reflect aquifer-scale rock chemistry. Additionally, the lack of a relationship between rock and water Ca:Mg ratios indicate that the rock samples are not representative of the marble bands as a whole.

Table 2.3. Cation proportion data for soluble fraction of each marble sample and the proportion of insoluble rock in each sample (as a percent by weight of original sample).

Rock Band	Li	Na	K	Mg	Ca	Sr	Ba	Ca:Mg ratio	Percent undissolved
Alder	0.0%	0.0%	0.2%	8.2%	91.4%	0.0%	0.2%	11.1	36.0%
Rainbow Basin/ Crystal Creek	0.0%	0.0%	0.3%	4.4%	95.3%	0.0%	0.0%	21.7	9.0%
Rainbow Basin/ Crystal Creek	0.0%	0.0%	0.3%	1.4%	98.3%	0.0%	0.0%	71.0	30.2%
Beulah Spring	0.0%	0.0%	0.2%	0.0%	99.3%	0.0%	0.4%	na	24.2%
Bluebell Spring	0.0%	0.0%	0.2%	0.1%	99.6%	0.0%	0.1%	1357.5	29.4%
Onion Meadow Spring	0.3%	0.0%	0.3%	3.1%	96.2%	0.0%	0.0%	31.0	28.2%
Marble Fork	0.0%	0.0%	0.3%	0.3%	99.1%	0.0%	0.2%	311.7	29.8%
Big Spring	0.0%	0.0%	0.8%	0.2%	98.9%	0.0%	0.2%	453.8	3.4%
White Chief a	0.0%	0.0%	0.2%	0.0%	99.6%	0.0%	0.2%	na	26.2%
White Chief b	0.0%	0.0%	0.2%	49.6%	50.1%	0.0%	0.0%	1.0	32.8%
Crystal Cave	0.0%	0.0%	0.3%	0.5%	99.2%	0.0%	0.0%	213.5	50.2%
Windy Creek	0.0%	0.0%	0.3%	0.0%	99.4%	0.0%	0.2%	3652.4	23.6%
Cave Creek	0.0%	0.0%	0.2%	41.2%	58.6%	0.0%	0.0%	1.4	31.6%

Principal Components Analysis

Results of the PCA using physical and chemical data from individual spring samples (Table 2.1) shows that samples can be divided into 2 distinct groups, primarily along principal component axis 1 (PC1), with principal component axis 2 (PC 2) providing additional separation (Figure 2.6, table 2.4). These distinct groups separate based on elevation/ location within the Kaweah River Basin, with one group comprised of high elevation springs in the Mineral King area of the East Fork and the other group comprised of lower elevation springs further west and north, spread between the lower East Fork, Middle Fork, Marble Fork, and North Fork. This separation occurred in spite of attempts to remove elevation data and other variables closely correlated to elevation. These two axes explain a combined 41.7% of the variability in the data (Table 2.4), with PC 1 accounting for 24% of the variability. Loadings describe the relative importance of each variable to a given component. The dominant loadings in PC1 represent a gradient between positively loaded SI_C and specific conductivity and negatively loaded nitrate proportions. The dominant loadings in PC 2 represent a gradient between positively loaded alkalinity and negatively loaded sodium and chloride proportions (Table 2.4).

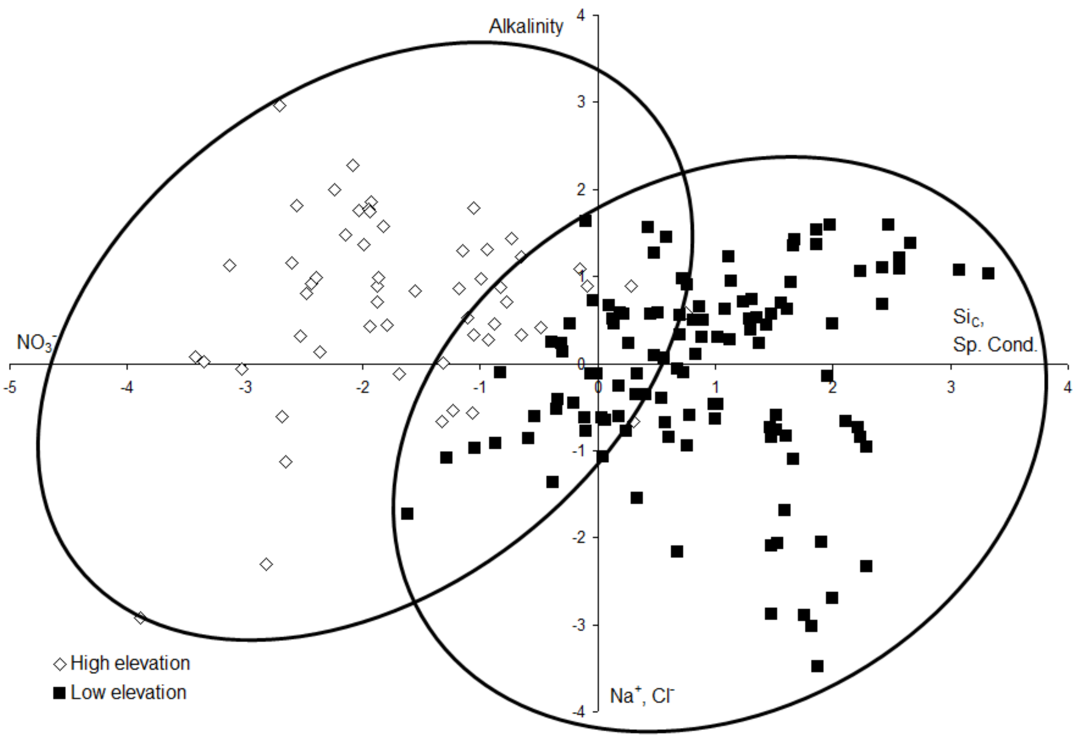

Figure 2.6. Principal Components Analysis of data for all spring samples. PC 1 (X-axis) shows a gradient between SI_C and specific conductance (positively loaded) and nitrate (negatively loaded). PC 2 (Y-axis) shows a gradient between alkalinity (positively loaded) and sodium and chloride (negatively loaded).

Table 2.4. Results of PCA showing standard deviation, proportion of variance explained by principal components 1 – 3, total variance explained, and the associated loadings of each PC axis.

	Comp.1	Comp.2	Comp.3
Standard Dev.	1.6978	1.4491	1.2327
Prop of Var.	0.2415	0.1759	0.1273
Var. Total	0.2415	0.4174	0.5447
Loadings			
SI	0.475		-0.412
Discharge	-0.101	0.134	0.104
pH			-0.685
temp	0.361	-0.133	0.255
Sp. Cond	0.463	-0.167	-0.36
Cl^-		-0.535	-0.197
$NO3^-$	-0.383		-0.221
Alkalinity	0.269	0.453	0.353
Na^+		-0.51	0.169
K^+	-0.241	-0.336	0.175
Ca^{2+}	-0.361	0.236	-0.267
Ca:Mg			

Representative Aquifer Properties

On average, lower elevation springs show a slightly flatter recession slope (α) than higher elevation springs (0.0105 compared to 0.01340) indicating longer residence times within these aquifers. Although this is the average behavior, results from individual springs reveals additional complexity (Table 2.5). At lower elevation springs, α ranges from a minimum of 0.0021 at Crystal Cave to a maximum of 0.0233 at Alder Spring. High elevation springs range from 0.0055 at White Chief Spring to 0.0297 at Tufa Spring. Due to either lack of power in the analysis or the variability in the data, the recession slopes are not significantly different between high and low elevation springs ($F_{1,27}$=3.391, p=0.077). However, when comparing recession slopes of individual springs, ANOVA showed significant differences between springs ($F_{5,23}$= p=0.023). When a

Tukey's HSD was run on this ANOVA, it revealed that all springs were similar to each other with the exception of White Chief Spring, which was significantly different than Big Spring (p=0.022), Crystal Cave (p=0.023) and Tufa Spring (p=0.048) and potentially different than Alder Spring (p=0.086) and Monarch Spring (p=0.101). These differences may be due to a larger number of large conduits and fractures with reduced amounts of epikarst leading directly from the surface to the aquifer. Additionally, these high elevation aquifers express various types of glaciokarst similar to variations of Canadian styles of alpine karst (Ford and Williams, 2007, Smart, 1983), where glacial effects have a direct impact on subsurface conduit development. Other reasons for differences may include shorter time periods of data collection, compared to the other springs, which may have resulted in not documenting true baseflow conditions, especially in White Chief Spring where instrument tampering resulted in the loss of a season of low-flow data. Regardless, recession slope values for all springs are with the range of values reported as being typical for fracture and conduit dominated aquifer systems such as those found in the marble karst of the Kaweah Basin (Kovacs et al., 2004).

Table 2.5. Raw data used to calculate recession slopes for each of the selected springs and average coefficient value (α).

Site	α	Group	Start Date	alpha	Q1	Q2	t1	t2
Alder Spring		Low	08/25/10	0.0233	0.0046	0.0036	26.0	36.5
Alder Spring		Low	01/22/11	0.0183	0.0127	0.0101	22.0	34.5
Alder Spring		Low	05/23/11	0.0148	0.0117	0.0074	23.0	54.0
Alder Spring		Low	07/16/11	0.0141	0.0069	0.0046	16.0	44.8
Alder Spring		Low	09/20/11	0.0243	0.0064	0.0044	20.0	35.4
α average	**0.0157**							
Big Spring		Low	09/04/10	0.0072	6.0713	4.9029	4.0	33.6
Big Spring		Low	10/10/10	0.0192	5.4326	4.9450	10.0	14.9
Big Spring		Low	09/25/11	0.0102	3.0635	2.7648	25.0	35.1
Big Spring		Low	12/08/11	0.0036	3.5732	3.0116	8.0	55.0
Big Spring		Low	06/25/12	0.0102	3.2248	1.9640	25.0	73.4
Big Spring		Low	08/12/12	0.0015	1.9640	1.7424	12.0	91.8
α average	**0.0087**							
Crystal Cave		Low	06/14/10	0.0021	0.9400	0.8900	14.0	40.5
Crystal Cave		Low	09/04/11	0.0043	1.0000	0.8700	4.0	36.7
Crystal Cave		Low	01/07/12	0.0030	0.7900	0.7300	7.0	33.5
Crystal Cave		Low	08/21/12	0.0021	1.2500	1.1300	21.0	68.9
α average	**0.0028**							
Monarch Spring		High	10/28/11	0.0121	0.4518	0.3885	28.0	40.5
Monarch Spring		High	12/02/11	0.0214	0.3070	0.2122	2.0	19.3
Monarch Spring		High	07/21/12	0.0086	0.3071	0.2619	21.0	39.5
Monarch Spring		High	10/21/12	0.0069	0.3291	0.2710	23.0	51.0
Monarch Spring		High	01/12/12	0.0544	0.3388	0.2032	12.3	21.7
α average	**0.0123**							
Tufa Spring		High	08/25/10	0.0297	3.0933	1.9900	23.8	38.6
Tufa Spring		High	11/27/10	0.0122	1.9503	1.5612	27.1	45.3
Tufa Spring		High	10/11/10	0.0160	1.3423	1.0991	11.3	23.8
Tufa Spring		High	11/02/01	0.0058	4.4552	3.4824	2.8	45.3
Tufa Spring		High	12/27/11	0.0032	3.1175	2.6799	0.1	47.2
α average	**0.0159**							
White Chief Sp		High	06/25/12	0.0056	0.7842	0.7663	25.5	29.7
White Chief Sp		High	08/05/12	0.0125	0.3801	0.3532	5.7	11.6
White Chief Sp		High	10/16/12	0.1293	0.0478	0.0209	16.9	23.3
α average	**0.0491**							

Discussion

Aquifer Classification

All methods used to assess and classify variability between karst springs in the Kaweah River basin split the data into 2 distinct groups: high elevation aquifers (above 2000 masl) and low elevation aquifers (below 2000 masl). This separation shows that karst aquifers in the Mineral King sub-basin of the East Fork are distinctly different from aquifers in the rest of the basin. There are three potential explanations for these differences: 1) bedrock chemical composition (related to the depositional environment of original sedimentary rocks), 2) metamorphic history, and 3) recent geomorphic history.

The first two of these are difficult to differentiate because original sedimentary fabrics and composition have been extensively altered by metamorphism resulting from accretionary events and proximity to the underlying Sierra Nevada Batholith. Busby-Spera (1983) determined that the high elevation marbles of the Mineral King Valley were near-shore carbonate deposits along a volcanic island arc off the then- west coast of North America. This environment may have been different than the depositional environment of the lower elevation marbles. All marbles have been assigned to the Mesozoic Era (Sisson and Moore, 1994), however finer scale dating has not been conducted, so the exact timing of the deposition of each limestone is unknown. Similarly, the dates of accretion events are not known, nor is it known how closely related these bands of marble are. There is a large east/west offset between the lower and higher marble bands (Figure 1), which could indicate separate provenances and depositional histories, or may indicate differences in metamorphic histories of these two blocks of marble. Despite these uncertainties, both the original carbonate's physical and chemical properties, and subsequent metamorphism have influenced the physical and chemical properties of the marbles that are currently exposed to karstification.

The third explanation for differences arising between these two groups of aquifers is related to the effects of Pleistocene glaciation. Moore and Mack (2008) mapped the maximum glacial extent during the Tahoe period (41 – 50 kya), which showed that all Mineral King aquifers were under glacial ice during this period and all other documented karst aquifers were below the maximum glacial extent. Because the lower elevation sites were not affected by glaciation, they typically have larger deposits of thicker, older, and more weathered unconsolidated deposits associated with them (compared to higher elevation aquifers) and thus are likely to have a greater storage capacity and residence time associated with these unconsolidated aquifer materials.

This latter explanation is supported by the isotopic elevation models. A larger seasonal variation in source water elevation is seen in the higher elevation springs, indicating a shorter residence time in these higher elevation aquifers when compared to lower elevation aquifers, which exhibit more constant isotopic values. This is in line with previous research by Perrin et al. (2003) who noted substantial epikarstic reservoirs in karst in the Swiss Alps. Increased epikarstic and associated unconsolidated deposits provide additional storage capacity in lower elevation springs and increase residence time within the aquifers. This is also supported by the relative concentration data that show an increase in dissolved magnesium and sodium relative to the total dissolved cations at lower elevation springs; again suggesting that there is increased residence time in the lower elevation aquifers relative to the high elevation aquifers.

PCA results show that, although middle and lower elevation springs have generally higher ion concentrations, the higher elevations springs have a greater proportion of their dissolved load as calcium and bicarbonate. This is likely due to lower elevation springs having greater interaction with the surrounding, more developed, unconsolidated materials, which contribute higher amounts of non-carbonate-derived solutes, as is seen in lower elevation sites, with an increased contribution of sodium to the dissolved load. Dye trace data also supports these findings, as flow paths from sinking streams at lower elevations encounter more unconsolidated deposits from sink to spring, indicating that these waters may be adding to water stored in the epikarst and surrounding aquifers. It is likely that these lower elevation springs are associated with more mature unconsolidated aquifers that are feeding into the karst systems, increasing residence time within these aquifers when compared to higher elevation aquifers. This is consistent with an existing conceptual model for karst aquifer storage in the basin as discussed in chapter III.

Aquifer Storage

On average, all baseflow hydrographs showed similar recession slopes. This suggests that water storage is occurring in portions of the aquifers with similar storage properties. The biggest difference between these two groups of aquifers, therefore, is not the type of storage, but the amount of storage available. High elevation springs typically show a flashy response during the spring snowmelt and a much lower baseflow level. Lower elevation springs are typically less flashy during peak discharge and start their baseflow recession at relatively higher discharge levels.

This observation is, again, a result of where this primary storage is occurring. As proposed in the conceptual model in chapter III there is likely significant storage associated with epikarst and/or unconsolidated deposits that overlie and drain directly into underlying or adjacent karst aquifers. At higher elevations, Tahoe glaciation in the upper reaches of the basin reduced the thickness and amount of epikarst and unconsolidated deposits directly associated the karst (Moore and Mack, 2008). Additionally, the younger deposits that are now associated with these high elevation karst aquifers are less weathered with thinner and less well-developed soils profiles and epikarst. At these high elevation sites, baseflow is still maintained by water stored within these components of the aquifer; however, due to the reduction in their extent and maturity, baseflow is maintained at a lower level than at lower elevations in spite of the larger amount of precipitation at the higher elevation sites. This is similar to patterns observed by Liu et al. (2012) who found that subsurface flow is the dominant component of stream discharge. However, the sites in the Kaweah River have more significant deep storage than those documented by Liu et al. (2012) in the Merced River.

Conclusion

Field documentation and characterization of 47 karst springs within the Kaweah River basin, has shown that that these springs fall into two distinct categories, defined largely by the amount and duration of storage associated with each group. The similarities in recession slopes of the two groups indicates that water storage is occurring in similar locations within the aquifer, likely within epikarst and associated unconsolidated deposits and soils. However the largest difference between the two groups is the amount of water stored, with generally larger amounts of water stored at lower elevations, which results in an increase in residence time within aquifers, less flashy discharge behavior, and more stable geochemistry. This difference is most likely due to differences in Pleistocene glaciation of the two areas. Low elevation sites have thicker soils, and more weathered unconsolidated deposits and epikarst, which have not been affected by recent glaciation. High elevation aquifers in Mineral King have as recently as 50 kya been glaciated, resulting in a decrease in aquifer storage capacity related to glacial scouring of epikarst and older unconsolidated deposits associated with karst aquifers and leaving behind younger, less weathered unconsolidated deposits.

This suggests that springs at lower elevations may be more important to overall storage of water within the river basin. However, to verify this, more springs need to be monitored to further assess the variability seen among aquifer recession slopes to determine if the similarities between storage types of both high and low elevation aquifers is truly similar. Additionally, a larger sample size could help determine if there are significant differences in the baseflow recessions between the two groups of aquifers.

Acknowledgments

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CHAPTER III

QUANTIFYING CONCENTRATED AND DIFFUSE RECHARGE IN TWO MARBLE KARST AQUIFERS: BIG SPRING AND TUFA SPRING, SEQUOIA AND KINGS CANYON NATIONAL PARKS, CALIFORNIA, USA

Abstract

To improve water management in mountain systems, it is essential that we understand how water moves through them. Researchers have documented the importance of porous-media aquifers in mountain river systems, but no previous research has explicitly included mountain karst as part of the conceptual models. To do so, we used discharge and geochemical parameters measured along upstream-to-downstream transects under high- and low-flow conditions in 2010 to assess storage characteristics and geochemical properties of two mountain marble-karst systems, the Big Spring and Tufa Spring systems in Sequoia and Kings Canyon National Parks, California. During both high- and low-flow conditions, we also quantified the relative contributions of concentrated and diffuse recharge in both karst systems, and we used a simple linear mixing model to calculate specific conductivity in unsampled diffuse sources which ranged from 34 µS cm^{-1} to 257 µS cm^{-1}. Data show that the Big Spring system has a much higher seasonal storage capacity than the Tufa Spring system, and that diffuse sources dominate discharge and geochemistry under baseflow conditions in both aquifer systems. Baseflow in Big Spring was 0.114 m^3 s^{-1}: in Tufa Spring it was 0.022 m^3 s^{-1}. Snowmelt-derived allogenic recharge dominates both systems during high-discharge periods, measured at Big Spring as 0.182 m^3 s^{-1} and Tufa Spring as 0.220 m^3 s^{-1}. A conceptual model is proposed that explicitly includes the effects of karst aquifers on mountain hydrology when karst is present in the basin.

Keywords — Marble karst, Source water management, Mountain aquifer, Aqueous Geochemistry

Introduction

Understanding how water enters and is stored in karst aquifers is essential to characterizing storage properties, as well as assessing the vulnerability of an aquifer to contamination (Scanlon et al., 2003). In mountain aquifer systems, little is known about storage and vulnerability relative to our understanding of larger aquifers that are more intensively used and studied. For example, the Edwards Aquifer in central Texas is intensively utilized for municipal and agricultural water, and many studies have been performed to assess its storage properties and vulnerability (Musgrove and Banner, 2004; Scanlon et al., 2003; Slade et al., 1986). In mountain aquifers, however, an individual aquifer is rarely utilized directly, and it is often relatively small and difficult to access for study. Despite this, the combined effects of many small mountain-aquifer systems can be important because they contribute significant amounts of water to mountain river systems (Clow et al., 2003) that may be heavily or entirely exploited for municipal, agricultural, and industrial uses as they leave the mountain range. In most cases, although small mountain aquifers can be vitally important to the surface water system, especially during dry seasons after snowmelt, they are not well characterized or studied because snowmelt dominates annual discharge. As a result, little is known about how storage varies spatially along an elevational gradient, as a function of rock type or other geologic materials, or how vulnerable these smaller aquifers are to contamination and climate change.

Clow et al. (2003) built a conceptual model of groundwater systems in mountain ranges that describes their importance in storing water and influencing biogeochemical processes. They found that aquifers in unconsolidated porous media in the Colorado Rockies, USA, play a significant role in storing water over seasonal timescales. Although they were able to quantify the roles these aquifers play in contributing to the stream systems, the systems they focused on did not include karst aquifers. Karst aquifers are often conceptualized as a network of conduits that are surrounded by and connected to a matrix, each having its own continuum of properties (Bakalowicz, 2005). To better understand storage properties and potential flow paths in a karst aquifer, it is important to quantify how the conduit and matrix components, as well as any associated porous media such as soils and glacial sediments, contribute to controlling discharge and geochemistry at a spring. The relative importance of each of these components depends on a variety of geological variables, such as matrix porosity, fracture frequency and aperture, epikarst thickness, soil thickness, and phreatic storage, that ultimately affect both water storage and contaminant movement in an aquifer (Ford and Williams, 2007).

In some regions of the Sierra Nevada in Sequoia and Kings Canyon National Parks (SEKI), California (Figure 3.1), karst aquifers, formed in numerous long and narrow bands of marble in the Kaweah River basin, contribute substantially to maintaining river flows during the dry season (Despain, 2006; Tobin and Doctor, 2009). However, with only a few exceptions, even the most basic quantitative data describing how, how much, where, and when water enters and moves through these groundwater systems and what their geochemical properties are is nonexistent.

Six of the karst aquifers in the Kaweah River basin provide the only known habitat for two endemic aquatic species, an isopod (*Bomanecellus sequoia*) and an undescribed flatworm. Recent applications of fire-retardants in one of these watersheds highlighted the need for at least a basic understanding of how the systems function before management strategies can be implemented. However, in order to develop realistic and effective management strategies for both the surface and subsurface systems associated with these and other aquifers in SEKI, resource managers first require the development of conceptual models that describe how water and mobilized contaminants move through the aquifer systems.

Flow dynamics and pollutant type have been shown to play major roles in determining the overall impact a contaminant has on a karst ecosystem. For example, Loop and White (2001) documented that if contaminants enter the karst system via concentrated recharge, they remain primarily in the conduit systems. Conversely, if contaminants enter a system via diffuse infiltration, they are likely to behave more similarly to contaminants in typical porous media and fractured aquifers. While SEKI karst systems contain both rapid and slow flowpaths, the systems are additionally complicated by the fact that they may include flow derived from multiple karstic sources, as well as from adjacent non-karstic groundwater sources and varying amounts and types of overlying porous media such as glacial deposit. In Indiana, Iqbal and Krothe (1995) documented multiple flow paths in a flat-lying mantled karst, where movement through overlying unconsolidated materials is typically dominated by laminar flow and transport in the karst bedrock is usually through conduits with turbulent flow. Although their study occurred in a different geologic setting, it showed that karst systems that are overlain by porous media may have substantial amounts of water stored in an overlying perched aquifer, whether this is part of the epikarst or not.

SEKI receives airborne contaminants of local, national, and international origins. Significant amounts of lead, cadmium, mercury, and other heavy metals, as well as currently and previously used pesticides have been documented in snow, lake sediment, and both wet and dry atmosphere samples collected in SEKI (Landers et al., 2010). The negative effects of these contaminants on aquatic ecosystems have been repeatedly documented (Hafner et al., 2007; Schwint et al., 2008), and research in the Kaweah River basin in SEKI has shown that pollutants deposited on the land surface are easily mobilized and transported into aquatic systems via seasonal precipitation runoff and snowmelt (Engle et al., 2008). In certain areas, contaminants are transported into and through karst aquifers before being discharged into the larger river system (Despain and Tobin, 2010).

One of the major issues hindering our understanding of how potential contaminants enter and move through small mountain-karst systems is the lack of a generalized conceptual model describing storage and flow in these systems. For this reason, there is a need for a conceptual hydrogeologic model that can be used as a foundation for additional work in SEKI and elsewhere. Clow et al. (2003) provide a starting point for this work by describing storage and recharge in non-karstic mountain aquifer systems. Besides the lack of karst in their study system, a difference between their system and those found in the Kaweah River basin is the significantly lower quantities and thicknesses of unconsolidated glacial and landslide deposits in the Kaweah. Without extensive unconsolidated deposits, dry-season baseflow should be extremely low in the Kaweah. However, the opposite has been documented. Peterson et al. (2008) found that, relative to basin size, baseflow was higher in the Kaweah than in surrounding river basins with more substantial glacial deposits. This finding strongly suggests that different storage components must be supporting baseflow. In the Kaweah Basin, the most likely candidate is karst.

Because of their diversity and distribution across a large elevation gradient, the karstified marble aquifers in SEKI provide ideal study systems for adapting the conceptual model of mountain aquifer systems to include the effects of karst on storage, baseflow, and stream chemistry. To achieve this, we measured upstream-to-downstream variations in water quantity and chemistry in two aquifer systems, the Tufa Spring system (Fig. 3.2) and the Big Spring system (Fig. 3.3). These systems are typical of karstic systems in the Kaweah Basin in that they include narrow bands of marble bedrock that are at least partially mantled by overlying unconsolidated glacial and landslide materials. These unconsolidated deposits add another layer of complexity to storage, flow, and recharge processes already known to occur in the karstic portion of the aquifer systems.

By measuring all concentrated recharge sources in both stream-aquifer systems and measuring changes in chemistry as water moves from upstream sink-points, through multiple sections of a karst aquifer, and eventually rises at a spring, it is possible to calculate the contributions of concentrated and diffuse recharge components to spring discharge, as well as to constrain both the potential source areas and the basic geochemistry of diffuse recharge.

The primary goals of this research were to determine the source locations for and quantify amounts of water in two marble karst systems, to determine the proportions derived from diffuse karst and unconsolidated sources versus concentrated sources of recharge such as sinking streams during both high- and low-flow conditions, and to adapt and modify the mountain-aquifer conceptual model to include the effects of karst.

Although it is a concern to resource managers in SEKI and elsewhere, this study does not specifically address the fate and transport of contaminants in mountain marble karst aquifers. Instead, this study focuses on seasonal changes in groundwater contributions from the two largest karst aquifers in the Kaweah River basin in order to provide insight into aquifer properties such as storage, concentrated versus diffuse sources, relative residence times, and generalized flow paths in the aquifer. In doing this, the study provides a hydrogeological and geochemical framework upon which future studies about fate and transport of contaminants, monitoring protocols, and management strategies can be built.

Study Site

Sequoia and Kings Canyon National Parks, in the southern Sierra Nevada of California, contains approximately fifty documented karst aquifers, primarily in the Kaweah River basin (Fig. 3.1). The river basin has a catchment of 1080 km^2 and ranges in elevation from approximately 300 masl at the base of the Sierra Nevada, to over 4,000 masl in the upper reaches of the drainage. Spring discharge from karst aquifers is a significant source of baseflow into all forks of the Kaweah River during the dry season. Despain (2006) documented that Tufa Spring contributed approximately 30 percent of the discharge of the entire East Fork, as measured at the USGS gauging station near the confluence with the Middle Fork during low-flow conditions in 2003. The region experiences a Mediterranean climate, with most precipitation falling during winter months. Precipitation varies along an elevational gradient, with an annual average of 35 cm at 500 masl and 100 cm at 2000 masl. At elevations above 2000 masl, precipitation is primarily in the form of snow that begins melting in late spring and supplies large amounts of melt water to the river system during early summer. The wet season is followed by a long dry period through the summer months and into the fall. As snowmelt decreases throughout the summer, discharge from karst aquifers in the park supplies an increasingly larger proportion of water in the rivers (Despain, 2006).

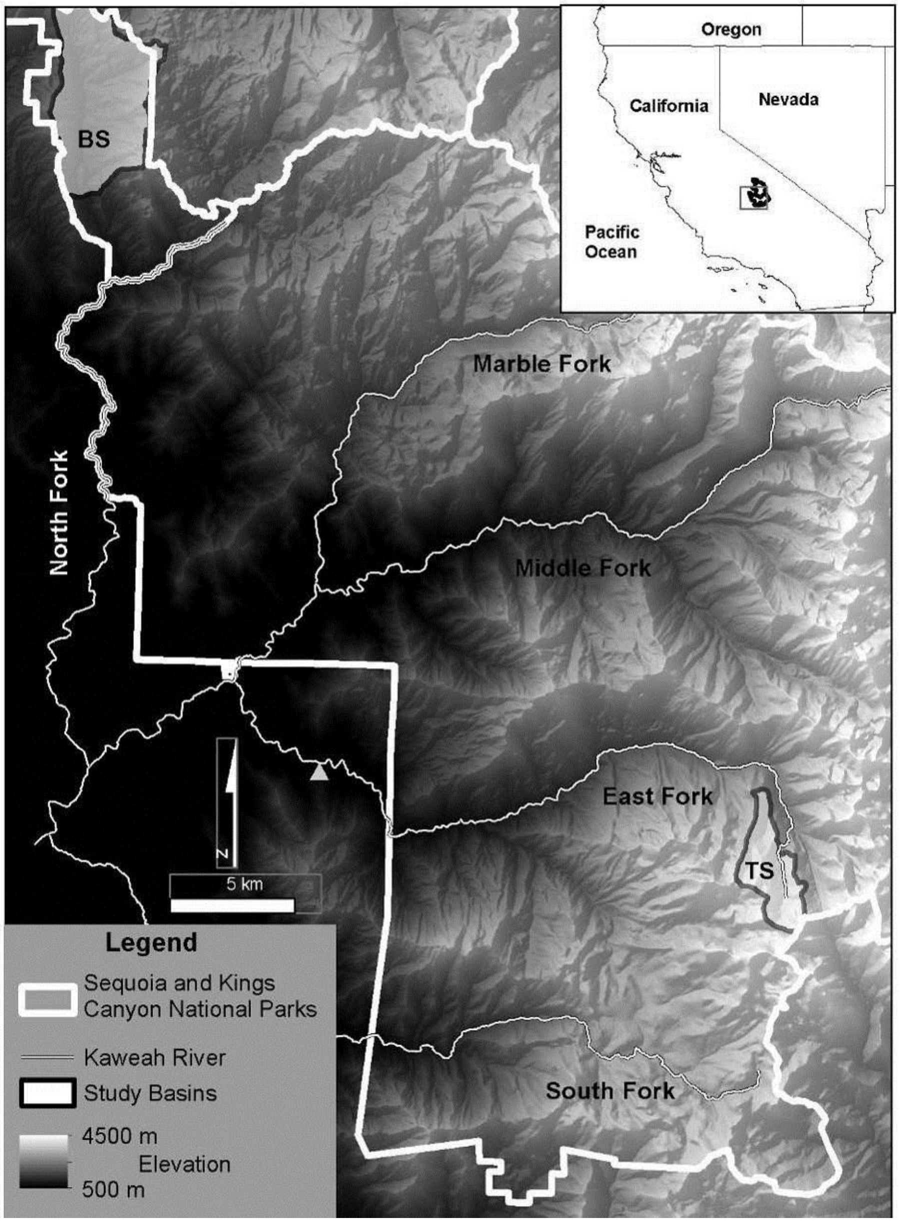

Figure 3.1. Drainage basin locations. Inset map shows Sequoia and Kings Canyon National Parks and the study location (rectangle) in the state of California, USA. Study Groundwater systems studied are noted by letters BS for Big Spring and TS for Tufa Spring. USGS gauging site 11208731, on the East Fork, is noted by a gray triangle.

Surface geology in the Kaweah River basin is dominated by the granite to grano-diorites of the larger Sierran Batholith (Sisson and Moore, 1994). A series of northwest-southeast trending bands of schists, quartzites, and marbles along the western edge of the mountain range are derived from Mesozoic-aged marine sediments. The highly karstified marbles are bounded by relatively insoluble non-karstic rocks and are excellent examples of marble-stripe karst as described by Lauritzen (2001). Unlike karst drainage basins developed in regions with extensive horizontally bedded carbonates and substantially less topographic relief, the contributing areas associated with stripe-karst aquifers have distinct boundaries. Typically, each band of marble is exposed in only one or two surface drainage basins, which constrains the areas of potential karstic and contributing drainage.

Water emerging at Tufa Spring is derived from two high-elevation basins (Despain, 2006). More than forty caves have been documented in these basins, the longest of which are White Chief Cave, with approximately 1.6 km of mapped passage, and Cirque Cave, with approximately 1 km. The Big Spring system drains a larger basin in a mid-elevation coniferous forest and contains the longest known cave in California: Lilburn Cave, with over 32 km of mapped passage.

Many karst aquifers in SEKI are mantled by significant deposits of unconsolidated material such as alluvium, talus, and glacial or landslide deposits. The Big Spring and Tufa Spring aquifers are both mantled to varying degrees by these deposits. More than half of the marble that contains the Tufa Spring system is exposed in outcrops, with the remainder mantled by talus, alluvium, or glacial moraines (Fig. 3.2). The Big Spring system is almost entirely mantled by a series of mature landslide deposits, with only a few small surface outcrops of marble exposed in the basin (Fig. 3.3).

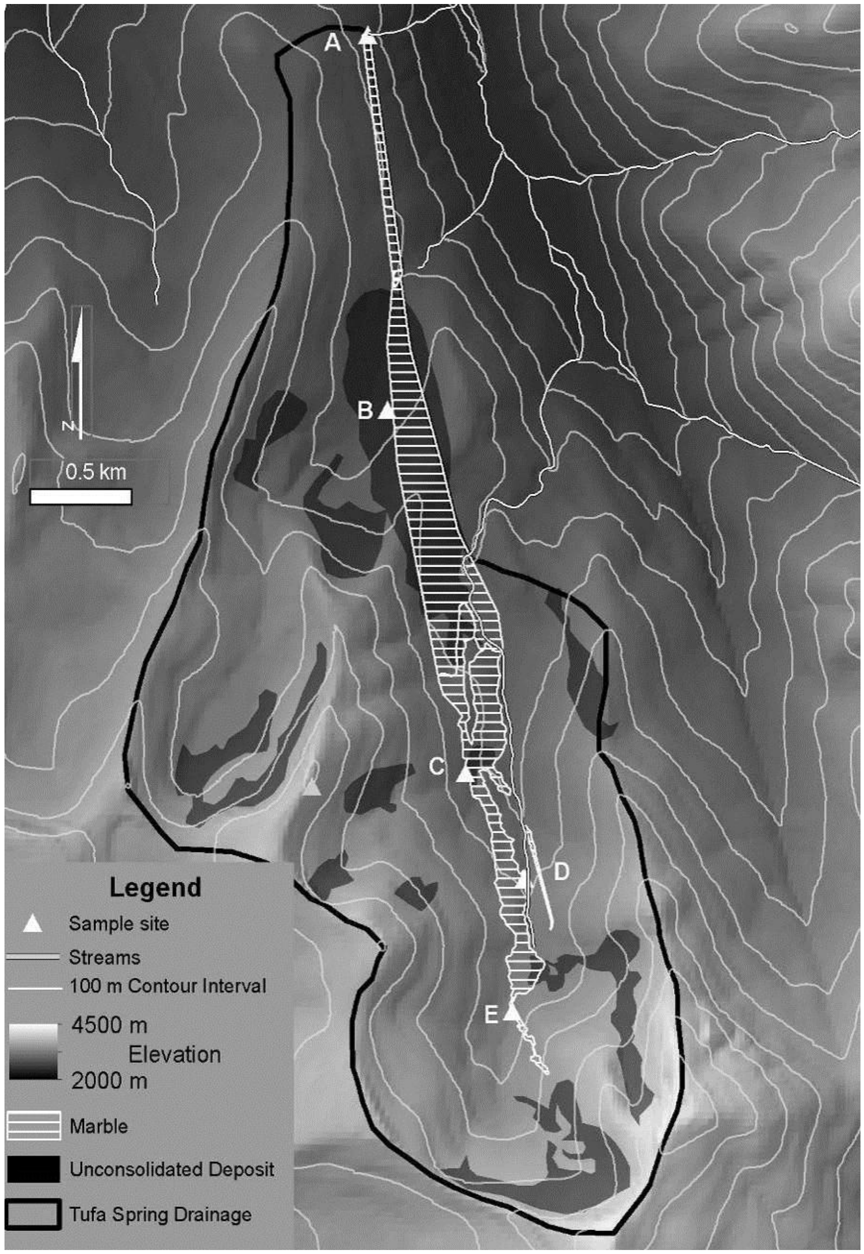

Figure 3.2. Tufa Spring geology showing the spatial relationship between the marble bedrock and unconsolidated deposits. Sampling locations are marked: A, Tufa Spring; B, Eagle Sink; C, White Chief Lake; D, White Chief Spring; and E, Cirque Stream, the outlet of the system.

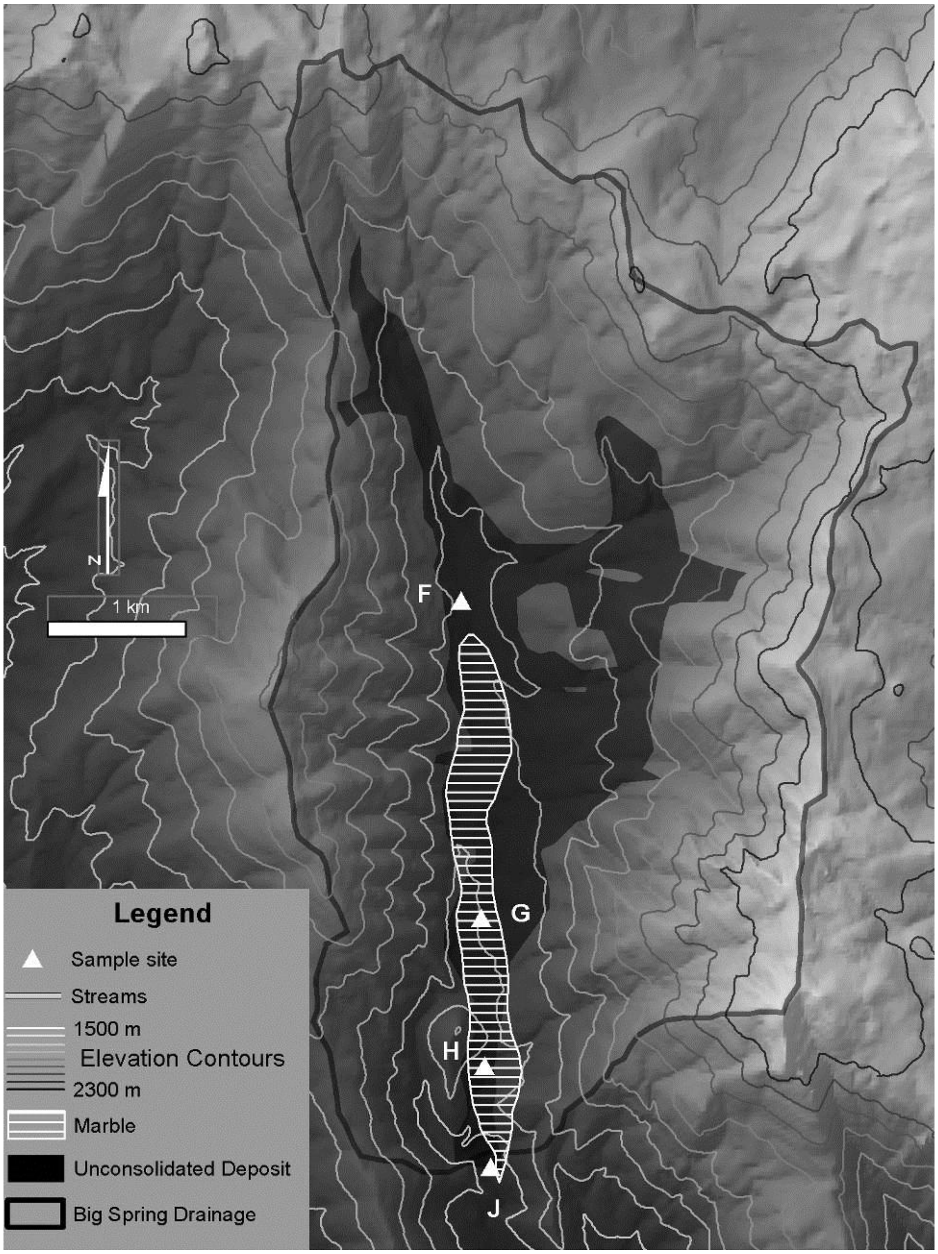

Figure 3.3. Big Spring geology showing the spatial relationship between the bedrock marble and unconsolidated deposits. Sampling locations are marked: F, Redwood Creek; G, White Rapids (Lilburn Cave main conduit; H, Z-Room (Lilburn Cave main conduit); and J, Big Spring, the outlet of the system.

Methods

In 2010, water samples and discharge measurements were collected during high-flow (July–August) and low-flow (September–October) conditions at a series of points along the Big Spring and Tufa Spring stream-aquifer systems. Although dye tracing was not conducted as part of this study, previous dye-trace studies at Tufa Spring (Despain, 2006) and Big Spring (Tinsley et al., 1981) documented the flow routes used in the analyses and discussion of this paper.

Water samples (125 mL) were collected from all surface streams and springs, as well as at a number of sites in caves. Sample collection and preservation in the field followed published USGS protocols (Shelton, 1994) for major cation, major anion, and nutrient analyses. Field protocol included on-site measurement of specific conductance, dissolved oxygen, pH, and temperature and filtering of each sample through a 0.45 µm syringe filter. After field work, the samples were refrigerated and analyzed as soon as possible on Dionex ICS-1600 ion chromatographs at Texas State University to measure Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, NO_3^{-}, PO_4^{3-}, SO_4^{2-},Cl^{-}, Br^{-}, and F^{-}. Alkalinity was measured by titration in the same lab using the inflection-point method (Rounds, 2006).

Discharge measurements were collected using either a pygmy meter or a turbine flow-meter (a Global Water hand-held flow meter). Springs and streams were gauged at sites having as uniform a cross-section and flow as possible, and with minimal riffles. In rocky streams, whenever possible, the most consolidated section of a stream channel having the fewest flow routes around boulders was used in order to minimize errors in the totals. However, due to the steep and rocky nature of nearly all stream channels and spring runs, the accuracy of discharge measurements is estimated to be ± 10%.

In the Big Spring system, surface-water samples were collected upstream of the karst system, at each known surface tributary upstream of where it recharges the karst system, and at Big Spring. Samples were also collected at two locations along the main stream in Lilburn Cave (sites G and H on Fig. 3.3) and at each known subsurface tributary to the main stream in the cave. Due to low flows in each surface tributary during the August sampling and no flowing water at these sampling sites in September, data from these sites could not be included in our analyses.

The Tufa Spring system is a more complex system in which water flows sequentially through a series of karst aquifers and short surface streams before finally emerging at Tufa Spring. Additionally, there are two non-karstic surface streams, White Chief Creek and Eagle Creek, flowing directly into the aquifer via sink points. Samples were collected at sinkpoints upstream of each karst segment, at each known infeeder into the system, and at each spring (Fig. 3.2).

To quantify the relative importance of diffuse flow to discharge at any given point along the aquifer transect, a mixing model, modified from Lackey and Krothe (1996), was used that incorporates discharge (Q), and geochemical parameters,: either specific conductance or ion concentration. With this method, geochemical properties can be determined for water that is added between two measured points in a system. In more detail, a measured geochemical parameter (specific conductance or any major ion can be used in these chemically undersaturated systems) at an upstream site (C_U) is multiplied by the flow measured at the upstream site (Q_U) and then subtracted from the geochemical parameter measured downstream (C_D) multiplied by the flow at the downstream site (Q_D). This value is then divided by the difference in measured discharge between upstream and downstream sites $(Q_D - Q_U = Q_{dif})$ to calculate the geochemical parameter of interest that is added to the flow system between two measured locations. The entire expression can be written as:

$$C_{\text{dif}} = \left[\left(C_{\text{D}} Q_{\text{D}} \right) - \left(C_{\text{U}} Q_{\text{U}} \right) \right] / Q_{\text{dif}} \quad (3.1)$$

Because we have measured all concentrated recharge sources, the additional water is assumed to be from diffuse sources. To calculate values for each diffuse input (1 and 2 on Fig. 3.4 and 3, 4, and 5 in Fig. 3.5) the measured values for the site(s) immediately upstream were used for the upstream values, and the site immediately downstream was used for the downstream values.

The model assumes that measured sink-point discharge values represent all concentrated recharge locations and that any additional water measured at a downstream site is from diffuse inputs. Due to the limited extent of the marble karst in the basins, we believe that we identified and quantified most, if not all, surface tributaries. Additional assumptions of the model are that minimal chemical evolution is occurring along the main flow path of the system and that additional solutes entering the system are derived from the diffuse recharge and flow components. In support of these assumptions, flow times through the aquifers are fast, with water traveling the length of the system in approximately one day (Despain, 2006; Tobin and Doctor, 2009). Additional evidences that minimal dissolution is occurring along the main conduit in both systems is that there is almost no change in the saturation index along the main stream conduit in Lilburn Cave and there are negligible changes in measured conductivity and calcium, bicarbonate, and other ions along the main stream conduit during both sampling periods, indicating minimal dissolution along the main conduit.

Results and Discussion

Tufa and Big Springs exhibit different responses during the dry season. Tufa Spring discharge decreased by an order of magnitude, while Big Spring discharge decreased by less than 50%. Tufa Spring also showed much larger differences in the proportions of discharge derived from concentrated and diffuse flow under different flow regimes. Mixing-model results show that the proportion of diffuse water in the Tufa Spring system was 41% during high flow and 68% during baseflow (Table 3.1). The magnitude of the change in discharge values in the system, however, suggests that, although a large portion of the discharge was derived from diffuse recharge under both conditions, the average residence time in the Tufa Spring system is relatively low. Discharge decreased from 0.22 $m^3 s^{-1}$ to 0.02 $m^3 s^{-1}$ between high flow and baseflow periods. Calculated values in the Tufa Spring system show high conductivity and ionic concentrations for diffuse input source 2 in Figure 3.4, between points D and E in Figure 3.2, which is consistent with values from other karst springs in SEKI that are dominated by diffuse contributions; small karst springs without any known concentrated recharge have conductivity values ranging from 350 $\mu S\ cm^{-1}$ to 650 $\mu S\ cm^{-1}$). Low conductivity values calculated for diffuse source 1, located between points A and B, indicate that these waters are likely flowing quickly through high-permeability, younger deposits and have less time for water-rock interaction. These results are supported by geologic observations in these two areas. Diffuse source 2 water is derived from thick and poorly sorted glacial deposits lying directly on marble, while source 1 water flows through more recent, primarily granitic talus deposits. During the high-flow period, source 2 had generally higher calculated values than during low flow. Although we have minimal evidence in support of this, one explanation is that this water may be recharging via piston flow through the glacial deposits. Under this scenario, there may be a perched longer-term (annual) storage component in the system that is displaced as recent snowmelt water infiltrates and flushes it out. Then, during low-flow conditions, all the older water has been displaced and only more recent low-conductivity snowmelt waters remain and are recharging the system.

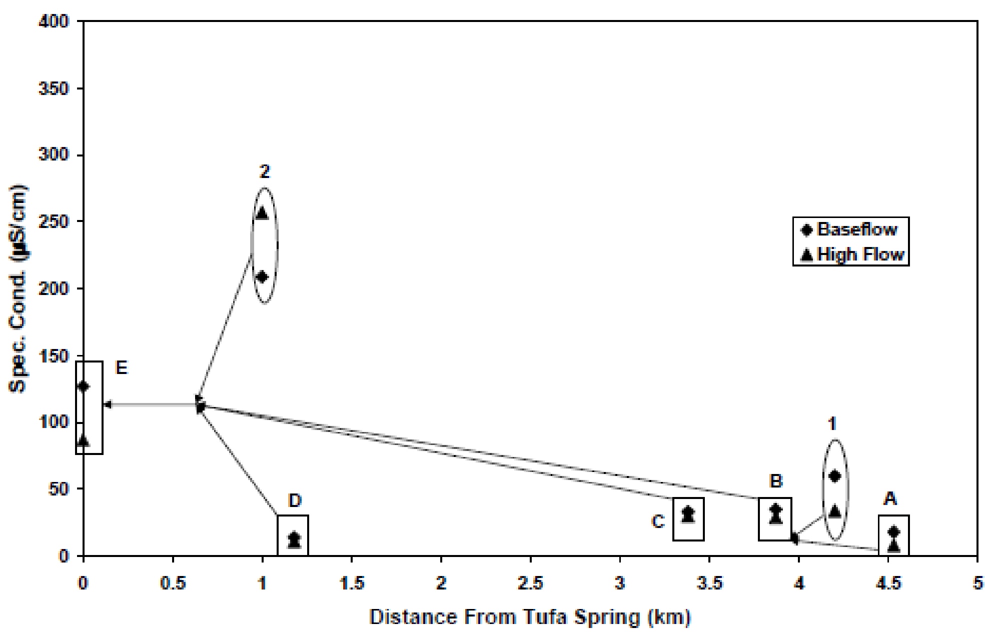

Figure 3.4. Downstream change in specific conductance values in the Tufa Springs system measured at surface infeeders (A, C, D) and springs (B, E) and calculated for diffuse inputs (1, 2), showing assumed mixing scenarios. Data are derived from values in Table 3.1.

Table 3.1. Mixing model results along the Tufa Spring Transect. Letters and Numbers in Parentheses correspond to locations shown on figure 5. Grayed rows indicate calculated values.

	July						October					
Sample Site	Discharge (m^3/s)	Proportion of total flow	Sp Cond (mS/cm)	Ca^{2+}	Mg^{2+}	HCO_3^-	Discharge (m^3/s)	Proportion of total flow	Sp Cond (mS/cm)	Ca^{2+}	Mg^{2+}	HCO_3^-
Cirque Cave	0.0389	0.18	8.00	1.70	0.11	4.92	0.0023	0.13	18.00	4.74	0.30	12.32
Diffuse flow	0.0291	0.13	34.00	11.46	0.28	30.85	0.0028	0.10	60.00	22.23	0.42	59.31
White Chief Sprin (Cirque +Diffuse)	0.0681	0.31	29.00	5.89	0.18	16.01	0.0051	0.23	35.00	11.91	0.35	32.75
White Chief Lake	0.0451	0.20	30.00	5.95	0.17	14.17	0.0004	0.03	33.00	9.96	0.16	9.86
Eagle Sink	0.0468	0.21	11.00	2.53	0.14	8.00	0.0042	0.19	14.00	3.48	0.27	11.09
Diffuse Flow	0.0605	0.27	257.04	71.42	5.90	174.30	0.0079	0.55	209.00	58.91	5.69	217.21
Tufa Spring (White Chief Sp. +White Chief Lake+ Eagle Sink+Diffuse)	0.2204	1.00	87.00	22.89	1.74	56.68	0.0221	1.00	127.00	36.10	3.26	129.40

Big Spring responds differently to seasonal changes in the proportions of discharge derived from diffuse and concentrated recharge. Using only the difference between concentrated recharge and spring discharge to quantify diffuse recharge, the high-flow period in August appears to be dominated by diffuse flow, accounting for 72% of the discharge at Big Spring (Table 3.2). However, during September the percentage actually decreased to 52%, which is surprising because the diffuse contribution would be expected to increase as rapid recharge, dominated by snowmelt, decreases throughout the dry season. Calculated values for specific conductance and chemical concentrations in diffuse source 5 in Figure 3.5 during August high-flow conditions are lower, in some cases substantially, than might be expected for diffuse flow in this system, which are approximately the values found during September. For example, the specific conductivity was 144 µS cm^{-1} during high flow versus 217 µS cm^{-1} during low flow. This likely reflects the contributions of undetected and unmeasured sources of concentrated recharge into the system. In reality, the apparent decrease in the proportion of diffuse contribution to Big Spring between high flow and low flow is likely related to hidden sources of concentrated recharge, which violates the first assumption of the mixing model, that all unaccounted-for discharge is derived from diffuse sources. The lower specific conductivity and ion concentrations (Table 2) for August supports this, and subsequent field observations found that a series of small but unmeasured surface infeeders were likely still flowing during the August sampling, but were sinking upstream from our previously established sampling sites. If this was the case, then water was following unseen rapid flowpaths through and under landslide deposits before directly recharging the karst aquifer. During low-flow conditions in the Big Spring system, calculated specific conductance values for all three diffuse sources (3, 4, and 5) are relatively high, which is consistent with what is expected for water flowing slowly through overlying weathered, unconsolidated materials and small fractures in the karst. Calculated values are also consistent with the specific conductivity of drip waters in Lilburn Cave (measured between 160 and 200 $\mu S\ cm^{-1}$) which are slightly higher than the calculated high-flow, diffuse sources at points 4 and 5 in Figure 5 and Table 2.

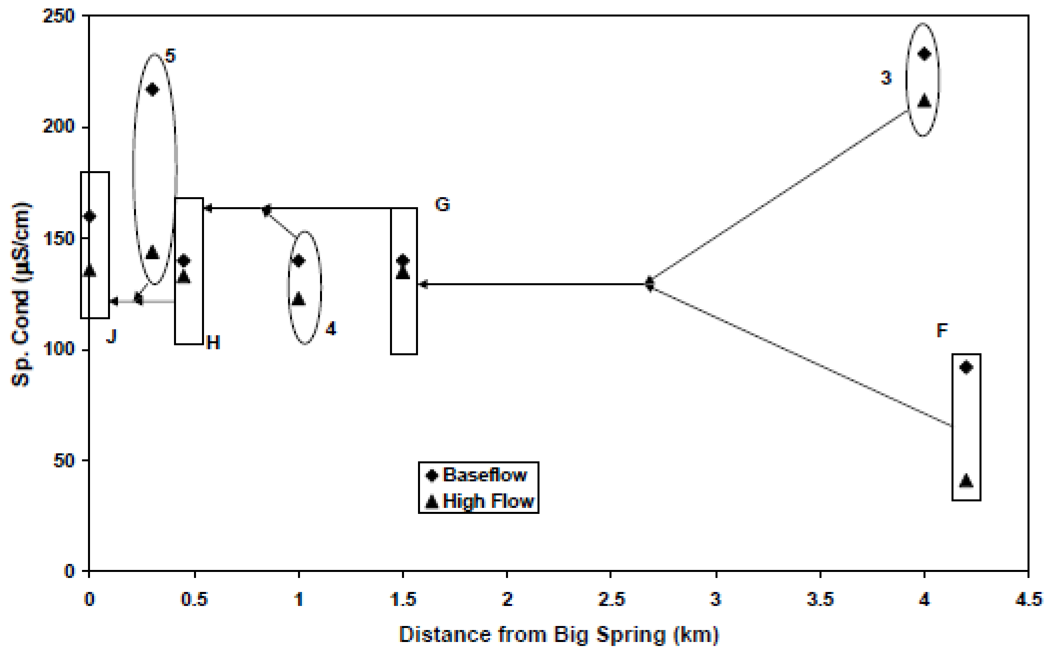

Figure 3.5. Downstream change in specific conductance values in the Big Spring system measured at the main surface infeeder (F), two cave stream sites (G, H), and Big Spring (J) and calculated for diffuse inputs (3, 4 ,5), showing assumed mixing scenario. Data are those in Table 3.2.

Table 3.2. Mixing model results along the Big Spring Transect. Letters and Numbers in Parentheses correspond to locations shown on figure 5. Grayed rows indicate calculated values.

Sampling Site	August Discharge (m^3/s)	Proportion of flow	Sp Cond (µS/cm)	Ca^{2+}	Mg^{2+}	HCO_3^-	September Discharge (m^3/s)	Proportion of flow	Sp Cond (µS/cm)	Ca^{2+}	Mg^{2+}	HCO_3^-
Redwood Cr (F)	0.0520	0.28	41.00	5.51	0.64	27.70	0.0541	0.48	92	5.92	0.7	30.81
Diffuse (3)	0.0624	0.34	212.00	58.32	2.21	201.48	0.0282	0.24	233	102.4	3.88	344.88
White Rapids (G) (Redwood Cr. + Diffuse)	0.1145	0.62	135.00	34.56	1.50	123.00	0.0823	0.72	140	38.72	1.78	h 135.50
Diffuse (4)	0.0210	0.12	123.00	29.72	1.15	123.00	0.0023	0.02	140	27.06	0	135.50
Z-Room (H) (White Rapids + Diffuse)	0.1355	0.74	133.00	33.78	1.45	123.00	0.0846	0.74	140	38.37	1.7	135.50
Diffuse (5)	0.0466	0.26	144.00	35.13	1.45	73.00	0.0297	0.26	217	38.53	1.69	135.50
Big Sp (J) (Z-Room + Diffuse)	0.1821	1.00	136.00	34.14	1.45	110.00	0.1143	1	160	38.41	1.7	135.50

In both the Tufa Spring and Big Spring systems, ion concentrations and total solute load increase as water moves from the headwater regions toward the springs. This is expected in groundwater systems due to water-rock interactions as water moves through the system. However, this research has shown that the reasons for increased solute loads may have little to do with the length of the primary conduit system, and much more to do with inputs from diffuse sources,: either small fractures and epikarst sources or overlying unconsolidated materials. In both systems, similar trends occur in ionic concentrations and specific conductance. Upstream tributaries that flow over or through non-carbonates have relatively low concentrations, while calculated diffuse inputs and locations sampled farther downstream have higher concentrations (Tables 3.1 and 3.2). While this is consistent with a model of downstream chemical evolution in which solute load increases as a function of residence time, system length, and rates of interactions with geologic materials, measured changes in water chemistry in the Big Spring system indicate that increased solute load is dominated by diffuse inputs along the main flow path rather than by dissolution of marble in the main stream conduit. In accessible portions of the main stream conduit where there is little observed diffuse or other input, specific conductance and ion concentrations stay relatively constant between sampling sites (Figure 3.5), and the water is consistently undersaturated with respect to calcite. Only when additional water enters the system between the accessible cave and Big Spring does the chemistry change significantly.

Samples taken at Tufa Spring were also undersaturated with respect to calcite during both sampling periods. Because of the quick flow times in the aquifer, less than one day for storm pulses to move through the system, it is likely that measured changes in the ionic concentrations and specific conductance are due to seasonally variable contributions of diffuse flow into the system, rather than chemical evolution of waters along the main conduit, which is inaccessible.

Conclusion

Using simple methods and relatively easy to obtain field data, this study quantified the amounts of water derived from concentrated and diffuse recharge sources in the Big Spring and Tufa Spring karst systems. The proportion of flow derived from each type of recharge varies temporally, with concentrated recharge dominating during high flow and diffuse recharge dominating during baseflow conditions. Our data indicate that, although karst aquifers in Sequoia and Kings Canyon National Parks are complex systems with multiple flow paths, storage compartments, and residence times, many of them may be relatively easy to delineate and characterize because of their limited spatial extent and narrow geologic constraints.

This research highlights the importance of quantifying karstic aquifers in mountain hydrologic systems. Currently, karstic groundwater storage in the Kaweah River basin is not included in the conceptual model as described by Clow et al. (2003), nor is it included in any current water-management plans or basin models. In addition, high baseflow discharge in the Kaweah River, relative to basin size and the number and size of porous media aquifers in the basin, does not follow the expected trend in which lesser amounts of these aquifer materials correlate with lower dry-season baseflow (Peterson et al. 2008). These findings highlight the importance of and need for modifying the existing conceptual model to include karst, even in settings where the aerial extent of karst may seem insignificant.

In most mountain basins, a substantial amount of water is stored in unconsolidated, porous deposits, as described by Clow et al. (2003). However, karst aquifers also have potentially substantial storage and can contribute significant amounts of groundwater to surface systems during seasonal dry periods, especially in systems such as the Kaweah that contain relatively few unconsolidated aquifer materials and numerous small karst aquifers. Based on our findings in two systems in SEKI, karst aquifers contribute significant amounts of water to the river system and should be included in conceptual models of mountain hydrology whenever karst is present. Karst aquifers are found elsewhere in the Sierra Nevada range and in many other mountain settings, yet because of the importance of snowmelt to annual river discharge, they are often ignored or underappreciated with respect to their contribution during the dry season. In addition, with future changes in climate predicted to result in increasing snowline elevations and less snowmelt discharge, the importance of seasonal or longer karstic storage in maintaining dry season flows will increase.

The susceptibility of any aquifer to contamination is a function of geologic materials, contaminant type, and the transport and flow regime. For a contaminant entering a system via diffuse flowpaths, it is likely that it will be temporally and spatially distributed, which means that it may be detected at the spring in low concentrations for long periods of time. However, if a contaminant enters an aquifer at a concentrated recharge site, it is more likely to be flushed quickly through the conduit system, bypassing most of the smaller fractures and pores, and behaving according to the model proposed by Loop and White (2001). Due to the variability in the retention time and amount of water stored in the two aquifers we studied, the residence time of a contaminant in each aquifer will be different. Higher storage in the diffuse component of the Big Spring system relative to the Tufa Spring system suggests that contaminants are likely to remain in storage for longer periods of time in the Big Spring system. Although this means that a potential contaminant will be spatially and temporally dispersed as it moves through a porous media, sensitive organisms may be exposed to low concentrations for extended periods of time. In the Tufa Spring system, where rapid conduit flow and concentrated recharge dominate, potential contaminants will be flushed quickly through the system. However, if contaminants are deposited aerially and are stored in snowpack, they may also be released over the same time period as the snowmelt occurs.

The major differences in seasonal storage capacity between these two aquifers indicate that overlying unconsolidated materials must contribute substantially more to diffuse flow and storage on annual or shorter time scales than fracture storage does. However, in order to quantify these contributions, additional data are needed. Data presented here are not sufficient to separate matrix and fracture storage in the karst from storage in overlying unconsolidated deposits. Future study is needed to determine if there is a relationship between the proportion of diffuse flow and the amount, type, and maturity of available unconsolidated material. Although a relationship appears to exist in these two aquifers, where more mature unconsolidated materials correlate with larger and longer storage capacity, hydrogeochemical properties of some other karst springs in SEKI indicate much longer average residence times and larger karstic storage capacity. Characterizing recharge, hydrogeologic, and geochemical properties of these springs is the subject of current and future studies.

As SEKI begins planning for mitigation of potential anthropogenic impacts to the aquatic systems in the parks, including spills of toxins, use of fire-retardant or similar chemicals, and deposition of airborne contaminants in the basin, a better understanding of residence times and storage properties is required. Karst aquifers that are supplied by large amounts of water slowly flowing through unconsolidated material prior to entering a conduit system have greater potential for contaminant removal through natural attenuation, bioremediation, or biological uptake of nutrients such as nitrate and phosphate. This is because water moving through the unconsolidated material typically has a longer residence time and thus more time to interact and react with the surrounding materials. Water that enters the karst quickly, via larger conduits and fractures, typically has less potential for removal of contaminants from the water, thus increasing the likelihood that contaminants could leave the system in dangerous concentrations.

However, the quick-flow systems also have the potential to flush the contamination through the system rapidly, minimizing potential long-term impacts. In either case, the results of this study contribute to improving our incomplete understanding of how marble aquifer systems in mountains function and will assist managers at SEKI and elsewhere in making scientifically informed and justifiable decisions.

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CHAPTER IV

POST-FIRE NUTRIENT MOBILITY IN A MOUNTAIN SURFACE WATER – KARST GROUNDWATER SYSTEM: THE HIDDEN FIRE, SEQUOIA NATIONAL PARK

Abstract

Post-fire nutrient mobility in strongly coupled surface water – groundwater systems is not well studied in fire dominated ecosystems. In 2008, the Hidden Fire in the Kaweah River basin in the Sierra Nevada, CA, U.S.A. provided an opportunity to document how nutrient concentrations change post-fire in a karstic groundwater – surface water system. Results from four years of sampling and water quality data (2009 – 2012) suggest that nutrient byproducts from 94 Phos-Check D75 R fire retardant that was dropped to combat the fire were mobilized into the aquatic system. Dissolved nitrate concentrations sharply increased at most monitoring sites with the onset of winter precipitation and seasonal snowmelt in the Spring of 2009, remained elevated during seasonal sampling at some sites in 2010, and returned to normal concentrations in 2011 and 2012. Nitrate increased in concentration in a downstream direction in Yucca Creek as tributaries with high rates of retardant application joined the main stem of Yucca Creek. Average nitrate concentrations in sub-basins during the 2009 high-discharge period are strongly correlated with the amount of retardant applied in each sub-basin. Dissolved phosphate

concentrations were highest upstream of sinkpoints where streams directly recharge the marble karst aquifers, and decreased between recharge sites and springs; indicating organic or inorganic uptake of P in the subterranean conduit system. Although measured nutrient concentrations were within the range documented post-fire in other aquatic systems that did not receive fire-retardant, the fact that fire-retardant derived nutrients appear to have entered and flushed through the Yucca Creek system suggests that managers should consider the potential impacts of retardant application on aquatic ecosystems.

Keywords: Fire effects, Mountain Hydrogeology, Nutrient mobility, Karst

Introduction

In September 2008, the lightning-initiated Hidden Fire burned 1500 hectares in the headwaters of the Upper Yucca Creek watershed, a tributary of the Kaweah River in Sequoia National Park in the southern Sierra Nevada of California, USA (Figure 4.1). The fire provided a unique opportunity to document the post-fire movement of naturally-released and artificially-applied nutrients through a karst groundwater-surface water system. During initial fire suppression efforts, approximately 20 drops of the fire-retardant chemical 94 Phos-Check D75 R were dropped from bomber aircraft in the headwaters of Cave Creek, Windy Creek, and to a lesser extent, Upper Yucca Creek. Phos-Check consists primarily of phosphorous, ammonium, and sulfate compounds that quickly degrade into nitrate, phosphate, and sulfate. Although the fire-retardant was not dropped directly into the aquatic systems, the onset of winter rain and snow in December

2008 provided a mechanism for quickly mobilizing 94 Phos-Check D75 R byproducts into nearby streams that subsequently drain into and through karst aquifers.

The dynamics of post-fire nutrient release and transport are complex, but fires often result in large increases in nitrate concentrations and loads after precipitation events mobilize natural and fire retardant-related nutrients into aquatic ecosystems (Engle et al., 2008; Hauer and Spencer, 1998; Turner et al., 2007; Wan et al., 2001). These and other studies have focused on understanding nitrate transport and cycling in surface water systems in which nitrate is assumed to be transferred from a terrestrial environment into a surface aquatic system via overland flow and/or shallow subsurface flow, and did not directly assess nutrient movement through strongly coupled surface water-groundwater systems such as those found in karst. In karst environments, surface water and groundwater systems are intimately connected via direct and diffuse recharge of surface water into the groundwater environment, and discrete points such as springs discharging groundwater into the surface water environment.

In a karst aquifer, transport is often dominated by rapid turbulent flow through conduits in which relatively little attenuation of contaminants or nutrients occurs. The movement of nitrate through agriculturally or anthropogenically impacted karst systems, in particular, has been the focus of many studies showing that nitrate can rapidly enter an aquifer where it may then behave as a conservative or semi-conservative tracer (Perrin et al., 2007). While this and other previous work has focused on agriculture-related fluxes of nitrate through aquifers, and the potential impacts that high nutrient loads can have on the aquatic environment (Iqbal and Krothe, 1995; Mahler et al., 2006; Perrin et al., 2007), it does provide a good foundation upon which additional research can be built to assess fate and transport of nitrate in karst systems that periodically or frequently experience wildfire.

In contrast with nitrate, dissolved phosphorus (P) has been shown to have relatively low mobility in aquatic systems and is rapidly removed from solution in surface and subsurface environments because many aquatic systems are P-limited and organic uptake and inorganic sorption of P result in low concentrations (Smil, 2000). In the case of both nitrate and phosphorus, little attention has been given to documenting the role that karst groundwater systems play in transporting, storing, and cycling these nutrients post-fire as they move from the terrestrial environment, through karstic surface water-groundwater systems, and discharge into surface water. This is particularly true of mountain hydrologic systems in which rapid conduit flow through karst aquifers is often an important part of the hydrologic system.

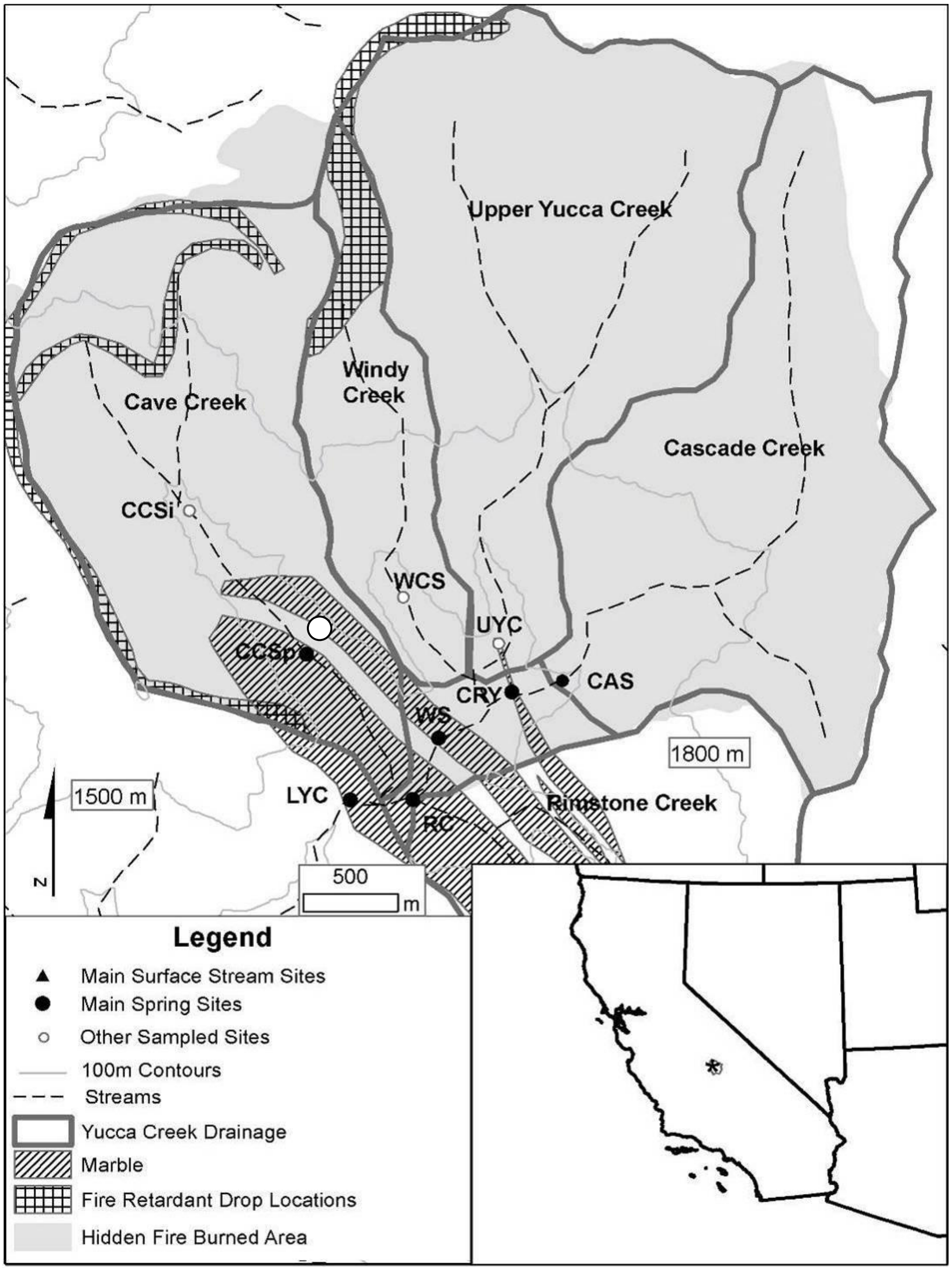

Figure 4.1. Study location with sub-drainages (labeled) and sampling sites:LYC- Lower Yucca Creek, CCSp- Cave Creek Spring, UYC-Upper Yucca Creek, CAS- Cascade Creek, CRY- Crystal Cave, WS-Windy Spring, RC- Rimstone Creek, CCSi- Cave Creek Sink. CAS was gauged from 2010 – 2012.

In order to better manage negative impacts to aquatic ecosystems, it is essential to assess how fire-related nutrients move through aquatic systems. Several recent studies have focused on measuring the environmental impacts of fire retardants (e.g., McDonnell et al., 1996) and have shown that the nutrient byproducts of fire retardant (phosphate and nitrate) frequently exceed the acute toxicity of aquatic invertebrates when used in concentrations necessary for fire suppression. Even after accounting for dilution expected in a typical mountain stream system, it is still possible that nutrient concentrations could exceed the acute toxicity levels of aquatic invertebrates. A U.S. Geological Survey study on the effects of high nutrient concentrations and other fire-retardant chemicals found that these chemicals are toxic to many aquatic organisms including fish, amphibians, and invertebrates, and concluded that "fire control managers need to consider protection of aquatic resources, especially if endangered species are present" (Hamilton et al., 1998). In the case of the Hidden Fire, Yucca Creek is contains the majority of the known habitat for the stygobiotic isopod, *Bomanasellus sequoiae,* the Big Spring Isopod (Bowman, 1975; Lewis, 2008). *B. sequoiae* has been identified from 3 springs and 2 caves in Yucca Creek and one other cave in the Kaweah basin. Although this species was not affected by fire suppression activities, understanding how nutrients move through these systems is critical to enhance management of the species (Krejca, 2009).

The goals of this research were to use existing and new data to develop a better understanding of how nutrients moved through the surface water and karst groundwater systems of the Yucca Creek drainage in the years following the Hidden fire. Of special interest was assessing whether or not fire retardant-related byproducts were mobilized into the aquatic system, and if concentrations reached levels that might pose a danger to aquatic organisms. We hypothesized that 1) post-fire nitrate levels would increase as nitrate washed off the landscape and into the hydrologic system, 2) that post-fire phosphate levels would not increase, as phosphate is rapidly sequestered via biotic and abiotic processes in the system, and 3) that higher nutrient concentrations would be observed in sub-basins in which larger amounts of fire retardant were applied.

Study Site

The Upper Yucca Creek Hydrologic System

The Kaweah River basin is part of a fire-dominated ecosystem in the southern Sierra Nevada of California, USA (Kilgore, 1973). The role of fire in the Sierras has been extensively studied for more than three decades (Caprio, 2004; Kilgore and Taylor, 1979; Pitcher, 1987; Swetnam, 1993). These studies show that fire activity in the mountain range drastically decreased after Euro-American settlement of the area and subsequent fire-suppression. Prior to Euro-American settlement, fire was relatively frequent, with return intervals between 9 and 35 years, depending on site aspect and elevation (Caprio, 2004). Recent management activity in the National Parks has focused on returning these ecosystems to their pre-Euro-American fire regimes (Caprio and Graber, 2000) through the use of both prescribed and managed natural fires.

Bedrock geology of the basin is typical of most of the Sierra Nevada, dominated by plutonic rocks of the Sierra Nevada batholith, but the Yucca Creek basin also contains hundreds of hectares of northwest-southeast trending bands of metamorphic rocks comprised primarily of schist, quartzite, and marble (Sisson and Moore, 1994). The marble bands are highly karstified and host significant cave and karst resources;

currently, 12 springs and more than 40 caves have been documented in the Yucca Creek drainage, including two of the ten longest caves in California. Of the 5 major sub-basins (Upper Yucca Creek/Crystal Cave Spring, Cascade Creek, Rimstone Creek, Cave Creek/Spring, and Windy Canyon/Spring) in the Yucca Creek basin, four contain significant amounts of karst (Figure 4.1). During baseflow conditions, all the surface waters in Yucca Creek flow through at least one of these karst aquifers and emerge at a spring. This is exemplified by waters in the upper section of Yucca Creek, which completely sink as they flow onto the band of marble hosting Crystal Cave, flows through Crystal Cave, and emerge at the Crystal Cave Spring in the adjacent Cascade Creek drainage.

Without detailed data for the number and size of retardant drops (these data are not available), we assumed that the amount of retardant dropped in each basin was directly proportional to the surface area covered by the drops (this information was available). Using these assumptions, and based on documented locations of retardant drops, it was assumed that each of the five sub-basins received differing amounts of nutrient contamination. The Cave Creek drainage had the greatest likelihood of impact from these chemicals because it had the largest volume/area of retardant dropped in it. Drainages contributing water to Crystal Cave Spring and Windy Spring received substantially fewer retardant drops and were assumed to have less impact. Cascade Creek, which has no karst, was burned but not affected by fire-retardant. Rimstone Creek did not receive any retardant drops and only a small portion of the basin burned. The

Lower Yucca Creek site is at the downstream end of the burned area (Figure 1) and integrates drainage from all burned and retardant drop areas in the Yucca Creek basin.

Methods

Water Sampling

Periodic water samples were collected from springs, caves, and streams within and immediately downstream of the burn area, beginning in late November 2008 and continuing periodically through July 2009 (Table 4.1). Additional samples were collected during high and low flow conditions in 2010 – 2012, including Cascade Creek, where sampling started in 2010. Water samples were collected using existing USGS protocols (Shelton, 1994) for major cation, major anion, and nutrient analyses. Due to initial concerns regarding fire retardant contamination of the aquatic system, samples from November 2008 to April 2009 were analyzed for NO_3^- and PO_4^{3-} on a flow injection analyzer with a detection limit of 0.01 mg/L. Major cations (Ca^{2+}, K^+, Mg^{2+}, Na^+) were analyzed on an atomic absorption spectrophotometer with a detection limit of 0.1 mg/L. Major anions were not analyzed in 2008-2009 and no sample remains for additional analyses. For samples collected between April 2009 and July 2009, major anions (F^-, Cl^-, Br^-, NO_2^-, NO_3^-, and SO_4^{2-}) were analyzed on a Dionex ICS-1600, with detection limits of 0.1 mg/L. Major cations (Ca^{2+}, K^+, Mg^{2+}, Na^+) were analyzed on an atomic absorption spectrophotometer with a detection limit of 0.1 mg/L. For samples collected from 2010 through 2012, all major anions (F^-, Cl^-, Br^-, NO_2^-, NO_3^-, and SO_4^{2-}) and cations (Ca^{2+}, K^+, Mg^{2+}, Na^+, Li^+, and NH_4^+) were analyzed on a Dionex ICS-1600 with detection limits of

0.1 mg/L. Samples collected prior to 2010 were analyzed for only nitrate, rather than both nitrate and ammonia, because ammonia has been shown to rapidly convert to nitrate in similar systems (Turner et al., 2007).

Table 4.1. Sampling sites, number of samples collected per year, and sampling interval.

Site	2009		2010		2011		2012	
	Number of Samples	Sampling interval	Number of Samples	Sampling interval	Number of Samples	Sampling interval	Number of Samples	Sampling interval
Lower Yucca Creek	8	periodic (12/08 to 7/09)	1	low flow	2	Seasonal	2	Seasonal
Cave Creek Spring	7	periodic (12/08 to 7/09)	3	Seasonal	2	Seasonal	2	Seasonal
Cave Creek Sink	1	May	0		0		1	June
Upper Yucca Creek	3	May-June	1	low flow	2	Seasonal	2	Seasonal
Cascade Creek	0		1	high flow	2	Seasonal	2	Seasonal
Crystal Cave	8	periodic (12/08 to 7/09)	6	Seasonal	2	Seasonal	2	Seasonal
Windy Spring	2	high flow	2	Seasonal	1	October	2	Seasonal
Rimstone Creek	1	high flow	1	high flow	2	Seasonal	2	Seasonal

Discharge Estimation

Due to equipment failure, continuous discharge was not measured directly in Yucca Creek during 2008-2009. Combined with nutrient concentrations, these data would have allowed calculation of nutrient loads exported from the system, and would have provided specific dates and times for when peak discharge and runoff occurred. Peak discharge data provides insight into how runoff is impacting concentrations of nutrients in the aquatic system. However, discharge data for the Kaweah River, downstream of Yucca Creek, are available for this time period. Using discharge data from the Kaweah River in 2010 – 2012, and data from a gauging station that was installed on Cascade Creek in 2010 (Figure 4.1), a relationship was established between the timing of peak snowmelt discharge at the two sites. This relationship was then used to estimate the timing of peak discharge in Yucca Creek in 2009. Using river and creek hydrographs, a correlation between the two sites, as well as a scaling relationship between Cascade Creek and

Lower Yucca Creek, were determined in order to model Yucca Creek discharge during 2009.

Nutrient variability comparisons

Four different comparisons were conducted to assess temporal variability in nutrient concentrations throughout the aquatic system: 1) temporal comparisons of nitrate, phosphate, sulfate and sodium concentration variability across the peak snowmelt discharge period and into baseflow conditions in 2009, 2) spatial comparisons of highest detected nitrate, phosphate, and sulfate concentration for 2009 – 2010, 3) site-by-site comparison of highest detected nutrient values from 2009 – 2012, and 4) regression analysis of highest detected nutrient concentrations against the amount of fire retardant applied.

To assess spatial and temporal variation in post-fire ion concentrations the first analysis investigated temporal variability in nutrient concentrations in multiple samples collected at three sites prior to seasonal peak in discharge, through peak discharge, and into baseflow conditions in 2009, the year immediately following the fire. Specifically, nitrate, phosphate, and sodium concentrations were compared between three sites: Crystal Cave (representing the Upper Yucca Creek sub-basin), Cave Creek, and Lower Yucca Creek. Sodium was chosen for the comparison because it has been documented to act as a conservative cation tracer in similar systems (Bencala, 1985) and because data for other conservative tracers such as chloride and bromide were not available from this time period. Unfortunately, no sulfate concentration data are available from samples prior to

May 2009, so it was not included in this analysis; no additional sample volume remains for chemical analysis.

The second analysis investigated spatial variability in nutrient concentrations in samples collected along flow paths at a given time. This analysis provides insight into processes and sources that may affect nutrient concentrations as they move through the system. Sample locations included sinking points in surface streams, springs, and sites downstream of each karst area. This analysis focused on the periods in which the highest nitrate, phosphate, and sulfate concentrations were detected in samples collected in 2009 (after May) and 2010, and allowed us to determine how concentrations changed along stream-groundwater transects in the Yucca Creek system.

The third analysis assessed the duration of elevated nitrate, phosphate, and sulfate concentrations at different sites in the basin, using nutrient concentration data from samples collected during high flow from the outlets of all five sub-basins and Lower Yucca Creek from 2009 – 2012; one sample per site, per year. One-way Analyses of variance (ANOVA) were conducted to determine if nitrate concentrations were constant across the years and sub-basins sampled. If the ANOVA showed that concentrations were not constant across years and sub-basins, a Tukey's HSD post-hoc analysis, was then used to determine which sub-basins and years had different concentrations.

The fourth analysis used regression modeling to determine if there were relationships between the 2009 concentration data for the three main constituents of fire retardant chemicals (nitrate, phosphate, and sulfate). The amount of retardant dropped in each sub-basin was treated as the response variable, and the proportion of the basin covered by fire-retardant (as a proxy for volume of retardant dropped) and year were used as predictor variables. For the temporal comparison of 2009 data, the 2009 – 2012 site comparison, and the regression analysis, Crystal Cave water chemistry data was used to represent the Upper Yucca Creek basin because, during sampling periods in 2009, all the water in Upper Yucca Creek sank into the aquifer and flowed through Crystal Cave. Crystal Cave was chosen for a comparison because it is more comparable to Cave Creek Spring, since both sites represent surface streams that sink, flow through a karst aquifer, and emerge at a spring.

Results and Discussion

Discharge estimation

Discharge was not measured in Yucca Creek during the 2009 snowmelt pulse following the fire due to instrument failure, but we did continuously measured discharge in Cascade creek from 2010 – 2012. Using these data and US Army Corps of Engineer data recorded on the Kaweah River downstream of the study site, a relationship was established between peak discharges at the Kaweah River and Cascade Creek sites (Figure 4.2b). Although only three years of peak discharge were used, the timing of the peaks is strongly correlated (r^2=0.994), even though small precipitation or melting events caused different small-scale responses in Cascade Creek and the Kaweah River. Using this relationship, we used 2009 hydrograph data from the Kaweah River to predict the timing of the peak snowmelt discharge in the Cascade Creek basin in 2009, with a calculated peak discharge date of April 14, 2009. To estimate discharge in Yucca Creek during 2009, we first used continuous discharge data from the Cascade Creek and the Kaweah River sites during 2010-2012 to develop a relationship that allowed us to estimate discharge in Cascade Creek in 2009 (Figure 4.2a,c). Next, using measured discharge values from Cascade Creek and Lower Yucca Creek in 2010 – 2012, a scaling relationship was determined between these two sites (Figure 4.2d), which finally allowed us to estimate discharge in Lower Yucca Creek during 2009, which allowed us to make more reasonable interpretations of the hydrochemical data.

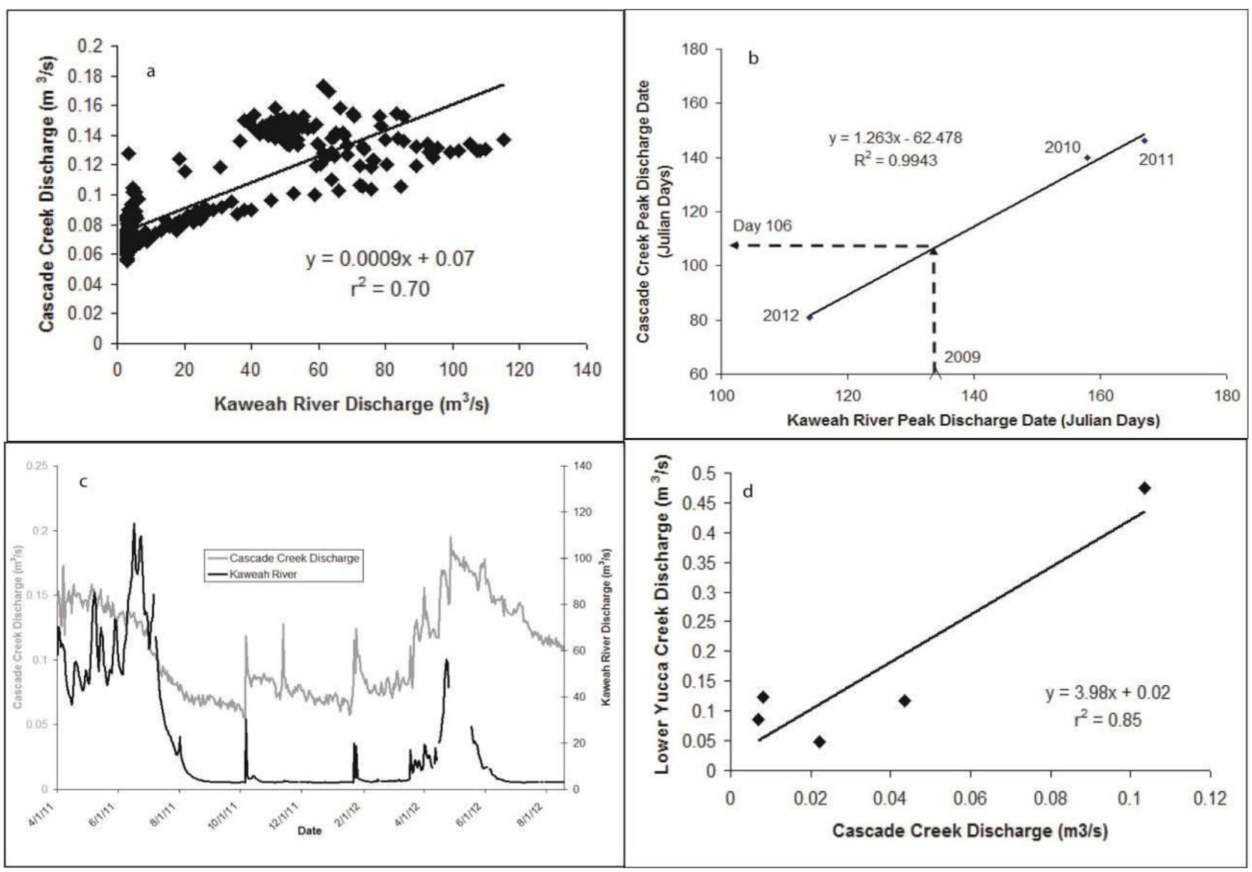

Figure 4.2. a) regression model between Kaweah River and Cascade Creek 2011 – 2012 b) relationship between peak discharge in the Kaweah River and Cascade Creek for 2010 – 2012, c) comparison of Cascade Creek and Kaweah River hydrograph 2011 – 2012, d) scaling relationship between Cascade Creek and Lower Yucca Creek.

2009 Temporal Ion Patterns

Distinctly different temporal patterns were observed between nitrate (Figure 4.3a), and phosphate and sodium (Figure 4.3 b-c). Due to the seasonality of precipitation and discharge in the basin, we expected that most ions would also show seasonal changes in concentration that are inversely related to discharge; i.e., as discharge increases, ion concentrations decrease due to dilution by recent runoff or snowmelt. In 2009, sodium and phosphate concentrations behaved as predicted at all sites and concentrations decreased during the Spring season peak discharge, followed by an increase in concentration as discharge decreased during the seasonal dry period (Figure 4.3b and c).

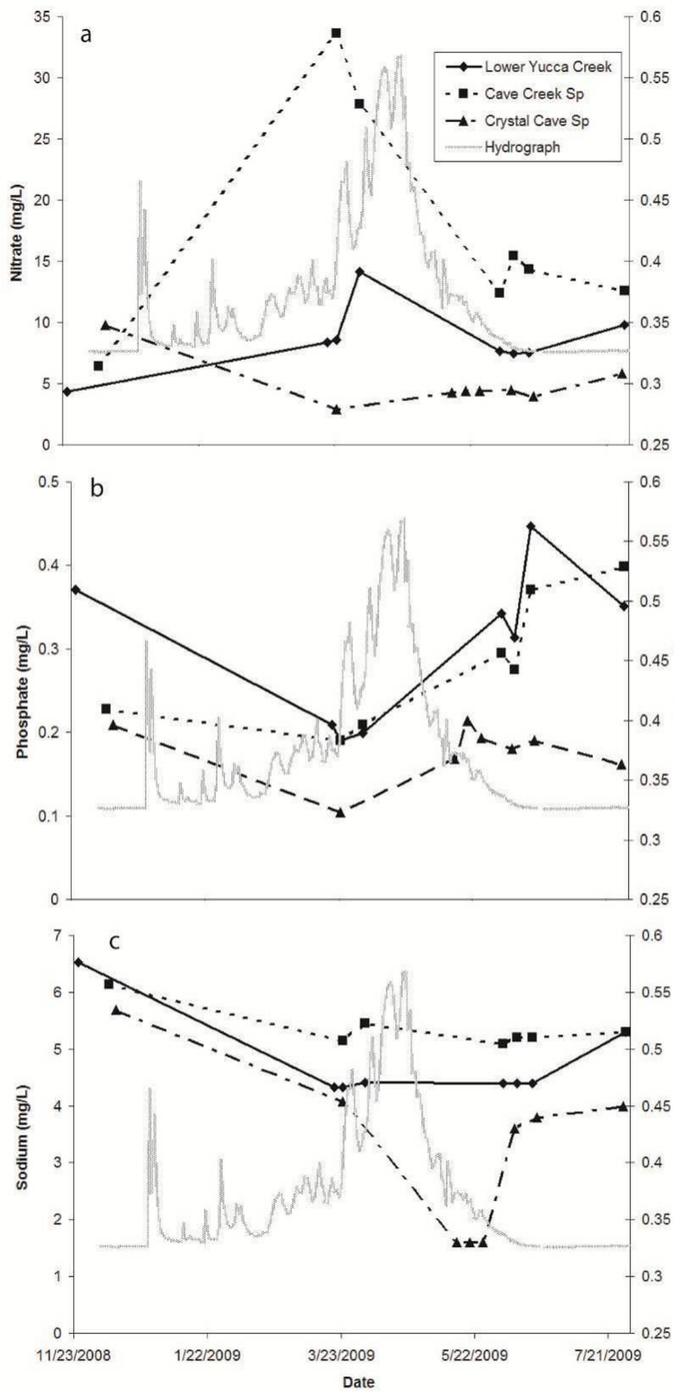

Figure 4.3. Seasonal trends in ion concentrations (a-Nitrate, b- Phosphate, c- Sodium) at 2009 sampling sites, with estimated discharge at Yucca Creek in grey (calculated using method described above).

However, nitrate concentrations at Cave Creek and Lower Yucca Creek did not follow the expected trend and were negatively correlated with the concentrations of phosphate and sodium (r^2 = -0.81 and -0.55, respectively). Just prior to the modeled maximum discharge, and during the period of increasing discharge related to rainfall and snowmelt, nitrate concentrations sharply increased at Cave Creek and Lower Yucca Creek, indicating that a pulse of nitrate was flushed out of the drainage basin and moved through both the surface and subsurface components of the hydrologic system (Figure 4.3a). The large increase in nitrate concentration coincided with an increase in discharge, indicating not just an increase in concentration, but also a substantial increase in the nitrate load transported through the system. This pulse was not observed at Crystal Cave, where nitrate concentrations did not significantly increase during peak discharge. These data suggest that the majority of the increase in nitrate concentrations measured in Lower Yucca Creek was due to the increased load entering the system from Cave Creek, which received the largest amounts of fire-retardant.

2009 – 2010 Spatial Comparison

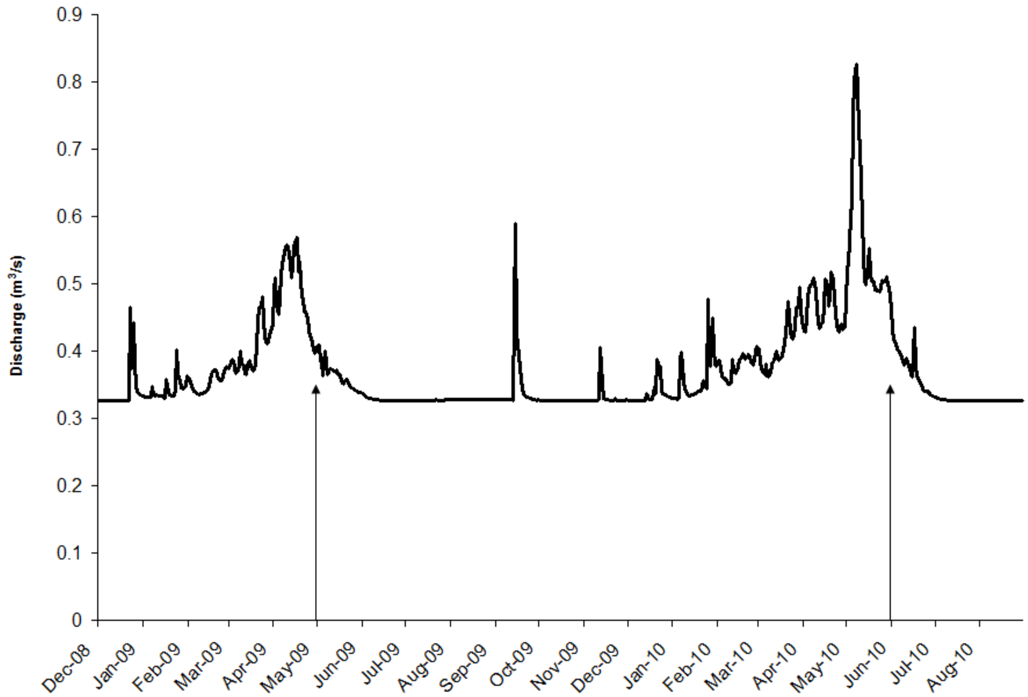

Figure 4.4. Arrows indicate the timing of May 2009 and June 2010 sampling events relative to discharge on the estimated Lower Yucca Creek hydrograph.

For comparison of concentrations between consecutive years, average concentrations from May 2009 were compared to samples from June 2010, since both sampling periods occurred during similar points on the creeks hydrograph recession (Figure 4.4). In Yucca Creek, nitrate concentrations in 2009 generally increased in a downstream direction, with the highest concentrations in the Cave Creek sub-basin. Nitrate appears to act as a relatively conservative ion once it enters Yucca Creek, and concentrations increase as additional sources enter the stream system (e.g., when Cave Creek Spring and Windy Creek Spring enter Lower Yucca Creek) (Figure 4.5).

Phosphate on the other hand, had highest concentrations at the upstream-most sites, above the karst. After water sank into the karst and discharged from springs, phosphate concentrations were dramatically reduced. This is likely due to the phosphate-limited nature of the system, causing phosphate to be quickly utilized by the biologic system. Sulfate concentrations decreased slightly from 2009 to 2010 but no other discernable change occurred between years; the majority of the variability existed between sites rather than between years, likely due to the natural relative abundance of sulfate within the groundwater system.

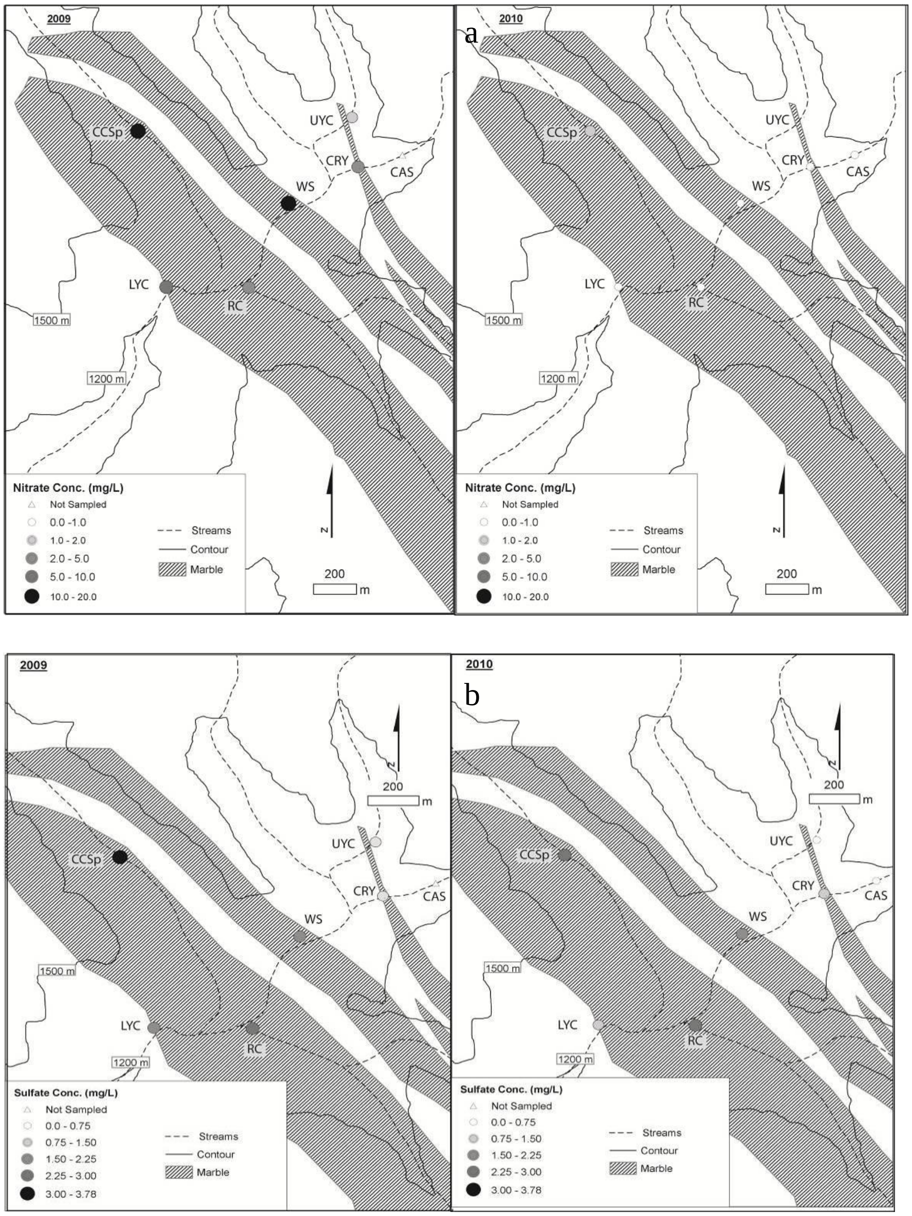

Figure 4.5. Spatial patterns of nitrate (a), sulfate (b), and phosphate (c) concentrations from May 2009 and June 2010 at sites: LYC- Lower Yucca Creek, CCSp- Cave Creek Spring, UYC-Upper Yucca Creek, CAS-Cascade Creek, CRY- Crystal Cave, WS- Windy Spring, RC- Rimstone Creek, CCSi- Cave Creek SinkNote: Phosphate was not detected at any site in 2010.

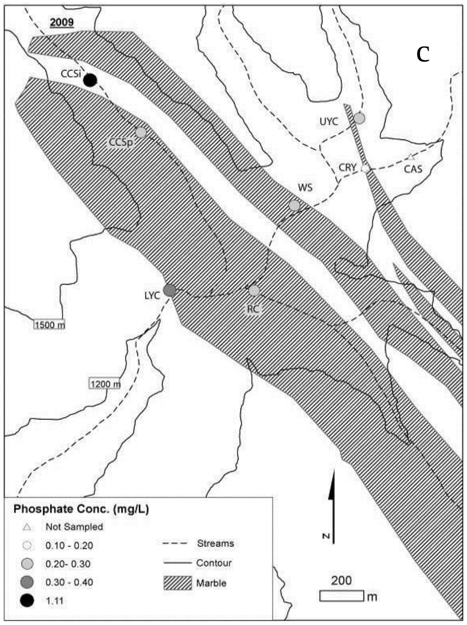

Figure 4.5 Continued

2009 – 2012 Site by Site Comparison

ANOVA results showed that nitrate concentrations were different between both year ($F_{3, 32}$ = 24.41, $p < 0.0001$) and sub-basin ($F_{4, 29}$ = 10.70, $p < 0.001$). Tukey's HSD showed that 2009 nitrate levels were significantly higher ($\alpha = 0.05$) than all other years. The difference in nitrate levels among the other three years (2010 – 2012) was insignificant. When comparing sub-basins at the same significance level, Cave Creek had significantly higher nitrate levels than all other basins in both 2009 and 2010. Although natural nitrate release is known to occur after fire burns a forest (Engle et al. 2008), all sub-basins experienced similar fire intensity, contain similar vegetation, and thus would have been expected to release similar levels of natural post-fire nitrate. The fact that this is not the case strongly suggests that the factor contributing to the difference between Cave Creek and other sub-basins was the larger amount of fire retardant applied rather than natural release. In 2011 and 2012, there were no significant differences between the sub-basins; all had similarly low nitrate concentrations (Figure 4.5). Phosphate showed a similar pattern with significant differences between years ($F_{3,32}$ = 59.24, $p < 0.0001$) and in 2009 there was a difference between sites measured ($F_{3,12}$=17.32, $p < 0.0001$). Tukey's HSD showed that Crystal Cave was significantly different from Cave Creek and Lower Yucca Creek, while Windy Spring was significantly different from Lower Yucca Creek. Phosphate was measured in the aquatic system in 2009 but was below detectable levels from 2010 – 2012, likely due to the surrounding ecosystem being P-limited, or due to inorganic uptake of P. This lack of phosphate after 2009 is similar to the marked decrease in nitrate levels by 2010. Sulfate concentrations were different between sites ($F_{3,32}$=27.24, $p < 0.0001$) but not different between years ($F_{3,32}$=0.881, p=0.461). This indicates that either sulfate from the fire and fire retardant chemicals is stored within the system or, more likely, that natural sulfate variability is higher between springs than it is due to fire and/or fire retardant chemicals.

Regression Analysis

The Cave Creek sub-basin not only had the highest concentration of nitrate in the aquatic system, it also contained the largest surface area affected by fire-retardant. We predicted that nitrate, phosphate, and sulfate concentrations would be highly correlated with the area covered by fire-retardant drops. The results of a simple linear regression between the proportion of a sub-basin covered by fire retardant (predictor) and average concentration from May through July 2009 (response), revealed that a strong relationship existed between nitrate and area covered by fire-retardant (r^2 = 0.81, $F_{1, 3}$ = 18.73, p =

0.02) (Figure 4.6), but not between phosphate ($F_{1, 3}$ = 0.30, p = 0.62) or sulfate ($F_{1, 3}$ = 1.63, p = 0.29) and area covered by fire-retardant. Due to the often rapid uptake of P in the aquatic environment (Smil, 2000), high natural variability of sulfate concentrations between burned and unburned sites (Table 4.2), and the relatively conservative nature of nitrate in karst systems (Perrin et al., 2007), we concluded that nitrate is the best tracer of retardant-related chemicals in these environments and systems.. Cave Creek had 38.4 hectares (9.5% of basin) of associated drainage basin covered by fire-retardant while Windy Spring (9.5 ha, 7.4%), Crystal Cave Spring (5.4 ha, 1.2%), and Lower Yucca Creek (53.3 ha, 2.9%) each had less (Figure 4.6).

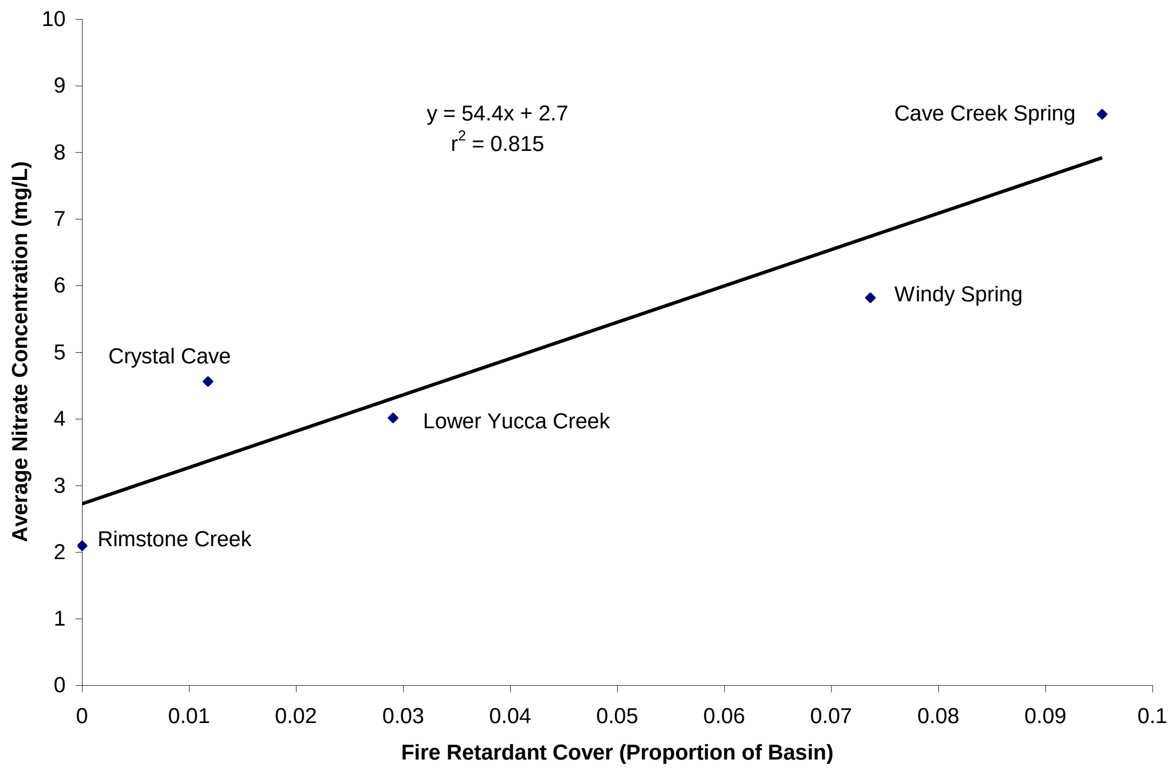

Figure 4.6. Relationship between May – July average 2009 nitrate concentrations and the proportion of each basin affected by fire-retardant.

Table 4.2. Data used for regression analysis.

Basin	Area (Ha)	Retardant Area (Ha)	Prop. of Basin	NO_3 (mg/L)	SO_4 (mg/L)	PO_4 (mg/L)
Lower Yucca Creek	1835	53.3	0.029	7.440	2.000	0.310
Crystal Cave	459	5.4	0.012	4.560	1.520	0.214
Cave Creek	403	38.4	0.095	15.440	3.780	0.280
Rimstone Creek	327	0	0.000	4.730	2.880	0.280
Windy Creek	129	9.5	0.074	12.900	1.920	0.250

Conclusion

As predicted, nitrate was a relatively conservative ion once it entered the surface and groundwater systems. Concentrations were highest in 2009, the year immediately after the fire, and decreased substantially in the following two years. Phosphate concentrations were relatively low throughout the entire study period and were only above the detection limit of the analytical equipment in 2009. These data show that phosphate is not being exported from these systems post-fire, while nitrate is. Elevated nitrate concentrations only occurred for 2 years in the Yucca Creek system, which contrasts with findings from studies in other systems in the Kaweah basin. Those studies found that, even in cases in which no fire retardant was used, increased nitrate loads persisted for 3 years post-fire (Engle et al., 2008). Nitrate concentrations measured by Engle et al. (2008) are similar to those measured in this study but, in our case, the strong correlation between the amount of fire retardant applied and nitrate concentrations in each sub-basin suggests that the fire retardant chemicals did influence nitrate concentrations in the aquatic systems.

High levels of nitrate measured both above and below karst aquifers indicate that the marble karst systems had little to no effect on the mobility or concentration of nitrate within this mountain hydrologic system, and that the system has a low assimilative capacity for nitrate. Phosphate responded differently as it moved through the system, with the highest concentrations observed in surface streams above the karst and decreasing dramatically between sink points and karst springs, indicating that there is high organic and/or inorganic demand for P along the flow path, and a relatively high assimilative capacity. These post-fire nutrient dynamics show that fire and fire-retardant related chemicals mobilized quickly into the surface water – groundwater systems in Yucca Creek, but that the fate of these nutrients varies depending on numerous factors including organic uptake, inorganic sorption, and flow paths. To improve management of these aquatic systems, it is critical that managers consider the potential impacts of fire-retardant application; especially in systems that are home to sensitive aquatic organisms, including cave-adapted species.

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CHAPTER V

THE ROLE OF KARST GROUNDWATER IN A SNOWMELT-DOMINATED HYDROLOGIC SYSTEM IN THE SIERRA NEVADA: THE KAWEAH RIVER, CALIFORNIA, USA

Abstract

By volume, most water leaving mountain rivers in the western United States is sourced directly from snowmelt, but baseflow is often maintained by delayed release from other storage components; primarily groundwater in several types of aquifer systems. Little work has been done to assess the role of karstic groundwater in these mountain systems. We address this knowledge gap by taking two approaches: directly measuring the amount of water discharging from karst springs, and conducting 3-component end member mixing models to determine the relative contribution of karst and non-karst groundwater to river discharge of the Kaweah River and its five forks (North, Marble, Middle, East, and South), in the Sierra Nevada, California, USA. Additionally, hydrograph recessions and modeled source water elevations were compared between rivers and karst springs in order to better understand the physical and spatial properties of these groundwater resources.

The river and springs have statistically similar baseflow recession coefficients ($F_{1, 63}$= 2.799, p= 0.099) and basins with significant karst have modeled baseflow source water

elevations that are similar to source water elevations of karst springs. The percentage of total discharge that is derived from karst groundwater in each fork depends on season and the amount of karst present. Measured contributions by karst springs to the North Fork, East Fork, and Kaweah River ranged from 3.5% to 16% during high flow and 20% to 65% during baseflow conditions. The large range is most likely due to variations in the amount of karst present in each basin, with the North Fork having the largest proportion of karst (4.4%) and largest contribution of karst (65% of baseflow in 2012).

End member mixing models produced results comparable to direct-measurements. During low flow conditions, karstic waters comprised a maximum of 79% of discharge in the North Fork, and a minimum of 0.1% in the Middle Fork. During high flow conditions, the proportion of discharge accounted for by karst is lower and ranges from 26% in the North Fork to 0% in the Middle and Marble Forks.

Karst aquifers may be the single most important non-snow storage component in the Kaweah River basin: mapped karst represents just 1.4% of the surface area, but water from karst aquifers represents 8% of discharge during high flow and 48 % during low flow, based on mixing model results. Similar situations likely exist in other Sierran systems containing karst.

Keywords: Karst, Mountain Hydrology, Surface water – Groundwater Interactions

Introduction

Mountain Groundwater Systems

Researchers and resource managers are becoming increasingly aware of the importance of groundwater in many different ecosystems, and mountain hydrologic systems are no exception. Until recently, most hydrologic research in montane systems focused on snowmelt hydrology (Dozier et al, 1995; Elder et al., 1991; Huth et al., 2004) and chemical transport through these systems (Sickman et al., 2003; Stoddard, 1995). It was previously assumed that hydrologic behavior in snow-fed mountain systems are dominated by snowmelt (Peterson et al., 2008) and have negligible storage other than in snow pack (Kattelmann and Elder, 1991; Singh et al., 2000). However, many recent studies have documented the fallacies of a snowmelt-only conceptual model of storage in mountain river systems, and have repeatedly shown that groundwater systems are a critical component of mountain hydrology. Water budget imbalances (Heard, 2005), hydrograph characteristics (Peterson, 2008; Tague and Grant, 2004), and physical documentation of aquifers (Clow et al., 2003) all lend support to the idea that significant groundwater resources exist in most mountain environments.

Clow et al. (2003) documented a variety of aquifers types in the alpine headwaters of a Rocky Mountain river in the U.S.A. and suggested that these findings could be generalized to describe other mountain systems. These aquifers provide significant amounts of water to river systems, maintain baseflow during dry periods, and influence their geochemistry. Building on this work, Peterson (2008) measured distinct differences between peak and baseflow-discharge properties in a series of Sierran Rivers and attributed inter-basin differences to variability in the size and storage capacity of aquifers within individual basins.

Despite this recent recognition that groundwater is an important part of the hydrologic cycle in snowmelt-dominated mountain systems, previous studies have neglected to specifically consider the contributions made by karstic aquifers. In many cases, this is likely due to little or no carbonate bedrock within the studied drainages. Alternatively, this may be because many mountain karst systems are often small (when compared with other potential groundwater storage: e.g., alluvial, glacial sediments, etc.), remote, and difficult to access, or because they are often undocumented. However, numerous mountain basins in western North America, and others around the world, have varying amounts of carbonate bedrock (Veni et al., 2001) and related karst aquifers that provide substantial amounts of groundwater to larger hydrologic systems (Karimi et al., 2005). In many cases, a lack of information about their importance may prevent recognition of their overall value and result in karstic groundwater contributions being neglected in resource management efforts.

Because the importance of karst aquifers was not well understood in snowmelt – influenced mountain hydrologic systems where they represent a minority of the geologic units, the primary objectives of our research were to quantify the relationship between the baseflow behavior of rivers and karst springs, and through modeling and direct measurement, to assess the relative importance of karst in controlling basin-scale hydrology. By doing this, we aimed to gain a better understanding of the role(s) that karstic groundwater have in influencing hydrology and geochemistry at different spatial and temporal scales in a mountain river basin.

Study Site

The Kaweah River drains 1080 km^2 of the southern Sierra Nevada, CA, U.S.A. The region experiences a Mediterranean climate with hot, dry summers, and cool, wet winters. Precipitation varies along an elevational gradient, with locations around 500 masl receiving an average of 500 mm of precipitation per year, primarily as rainfall, and elevations around 2000 masl receiving an average of 1000 mm of precipitation per year, primarily as snowfall (Boiano et al., 2005). The snowline in the Kaweah basin depends on slope and aspect, but is typically around 2000 masl elevation. River discharge follows a distinct seasonal pattern, with a large snowmelt-driven peak in discharge in late spring and early summer followed by a long seasonal baseflow recession during summer and fall.

Bedrock geology in the basin is dominated by a series of intrusive grano-diorites which are part of the larger Sierra Nevada batholith (Sisson and Moore, 1994). However, there are also a series of northwest to southeast trending bands of metamorphosed marine sediments that include thin marble bands (Sisson and Moore, 1994; Figure 5.1). Although these marble bands account for only 3% of the surface area in the basin, more than 275 caves and 47 springs have been documented in the marble.

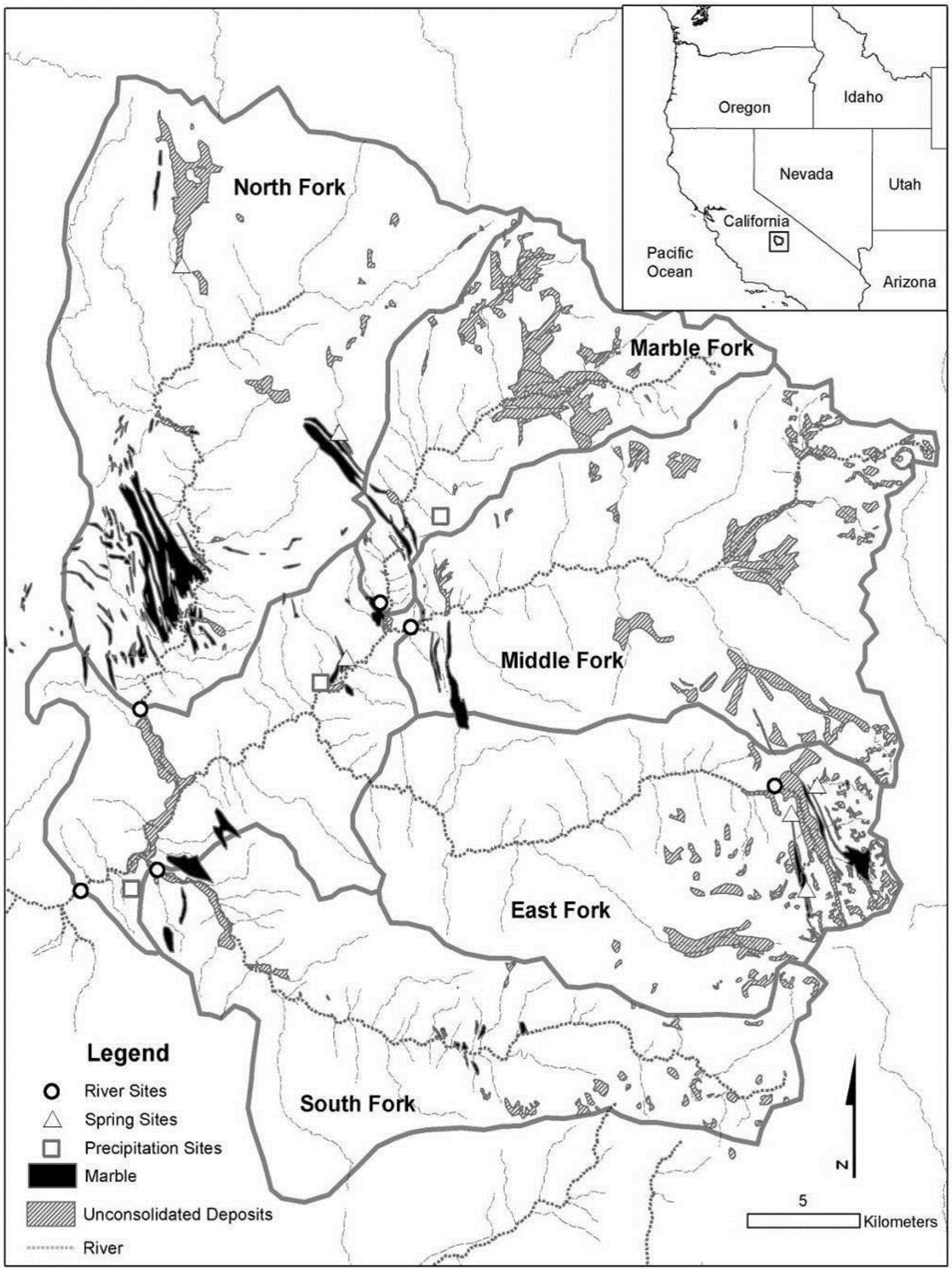

Figure 5.1. Basin hydrogeologic map of the Kaweah Watershed, including all five major forks of the river. All unmarked geologic units are fractured grano – diorite or metamorphic rocks, assumed to have negligible groundwater storage. Elevation ranges from approximately 300 masl at the river outlet (central left) to 3700 masl in the East. Marked spring and river sites are gauge locations where continuous data were recorded. Sites where periodic measurements were made are not shown here, for clarity.

Karst of the Kaweah Basin

Previous research has shown that the hydrogeologic properties of marble karst aquifers in the Kaweah River are distinctly different from those in the surrounding fractured rocks (igneous and other metamorphic). However, these studies focused on characterizing individual aquifers rather than the basin scale importance of multiple karst aquifers (Abu-Jaber et al. 2001; Despain 2006; Sara 1977; Tobin and Doctor 2009; Urzendowski 1993). While characterizing Tufa Spring, the second largest karst spring in the basin, Despain (2006) determined that it contributes to a very small percentage of river discharge during seasonal snowmelt and peak flows. However, during baseflow conditions, the spring accounts for approximately 30% of the total discharge in the East Fork of the Kaweah River. Chapter III of this dissertation showed variability in the source water or hydrogeologic properties of the two largest springs in the basin: Tufa and Big Spring Karst in the Kaweah basin is not limited to these two aquifers. Kahn (2008) documented 16 karst aquifers within the East Fork drainage basin and, in Chapter II of this dissertation, a total of a total of 47 perennial karst springs were documented in the Kaweah River Basin. This suggests that the role of karst in storing water and maintaining baseflow in the river may be much larger than previously assumed.

Methods

Field and Laboratory Methods

Water samples and discharge data were collected at least twice per year (at or near peak flow and at baseflow conditions during 2010, 2011, and 2012) from karst springs, non-karst springs, and river sites throughout the Kaweah River Basin. Samples were collected using existing protocols for major ion and stable isotope analyses (Shelton, 1994) and discharge was measured using either a pygmy flow meter, turbine flow meter, or a Marsh-McBirney flow meter.

In addition to seasonal water sampling, 9 karst springs were gauged and continuously monitored for temperature, specific conductivity, and stage using CTD-Diver dataloggers (Schlumberger Water Services) in each spring (Figure 5.1). CTD dataloggers were not vented to the atmosphere, so Baro-Diver barologgers (Schlumberger Water Services) were installed nearby to compensate for atmospheric pressure differences that occurred over the course of the study. Using discharge measurements from seasonal sampling events, rating curves were established for each of the 9 springs to convert stage to discharge.

Major cations and anions were analyzed on Dionex ICS-1600 ion chromatographs, with a detection limit of 0.1 mg/L. Alkalinity was measured using the inflection point method (Rounds, 2006). Liquid water stable isotopes (δD and $\delta^{18}O$) were analyzed on a Los Gatos Research DTL-100 Liquid Water Stable Isotope Analyzer. Precipitation samples were collected along an elevational gradient at stations at 200 masl, 800 masl, and 2000 masl in 2010 – 2012, homogenized over weekly intervals and protected from evaporation prior to analysis, and analyzed for liquid water stable isotopes.

Source Water Elevation Modeling

Stable isotope data from precipitation samples collected at three sites (Figure 5.1) were used to determine a linear rate of change in precipitation isotopic composition along an elevational gradient. This isotopic lapse rate was then used to model the average elevation at which the source precipitation fell for any given groundwater or surface-water sample. It is useful for determining the average source elevation for spring waters, as well as investigating seasonal changes in source elevation of both surface- and groundwater that may be related to variability in the proportion of water derived from different sources; e.g., high elevation snowmelt *vs.* lower elevation groundwater storage. This provides insight into the source elevation for the dominant storage component supplying water to each monitoring site and assumes that water moving through the system is minimally affected by evaporation, which can alter the isotopic composition of the water.

Measured Karst Groundwater Contributions

Measured discharge from all documented karst springs and each fork of the Kaweah River was used to quantify the contribution of karst aquifers to river discharge. However, direct spring measurements do not accurately represent the total amount of water derived from karst because these measurements sometimes include water that sinks into and flow through a karst aquifer but is not stored within it; e.g., sinking streams contributing allogenic direct recharge. Additionally, direct measurements do not include water that discharges from karst aquifers via diffuse groundwater – surface water interaction in stream channels.

Modeled Karst Groundwater Contributions

In an attempt to eliminate some uncertainty associated with direct measurement methods, a 3-component mixing model used sulfate concentrations and specific conductivity values to calculate the relative contribution of each component (Lee and Krothe, 2001).

(1) $$Q_k = Q_{meas} * \frac{SC_{meas} - SC_{s+nk}}{SC_k - SC_{s+nk}}$$

(2) $$\frac{Q_k}{Q_{meas}} = \mathrm{Q'_k}$$

(3) $$Q'_{nk} = \frac{SO_{4_s}(Q'_k - 1) + SO_{4_{meas}} - Q'_k * SO_{4_k}}{SO_{4_{nk}} - SO_{4_s}}$$

(4) $$Q'_s = 1 - (Q'_k + Q'_{nk})$$

Where Q_{meas} is the total discharge at a given point, *Q'* is the proportion of total discharge for a given end-member, *SC* is specific conductivity, SO_4 is sulfate concentration, and subscripts $_k$ (karst), $_{nk}$ (non-karst), and $_s$ (snowmelt) represent the three end-members and $_{meas}$ represents measured values. Samples representing each end member were collected from alpine lakes (representing snowmelt), non-karst springs, and karstic drip water.

In addition to using the mixing model to calculate the source-water fractions in each fork, upstream to downstream transects were analyzed to assess longitudinal changes in water composition in the upstream portion of the East Fork above Cold Springs (Figure 5.2a) and in the Marble Fork (Figure 5.2b). The Marble Fork transect consists of four sampling points along the fork; two above known karst, one at the karst, and the fourth below the karst and just upstream of the confluence with the Middle Fork (Figure 5.2b). The East Fork transect focused on water flowing through the Mineral King Valley and includes a sampling site on the East Fork as it exits the valley, and sites at six tributary streams (Figure 5.2a).

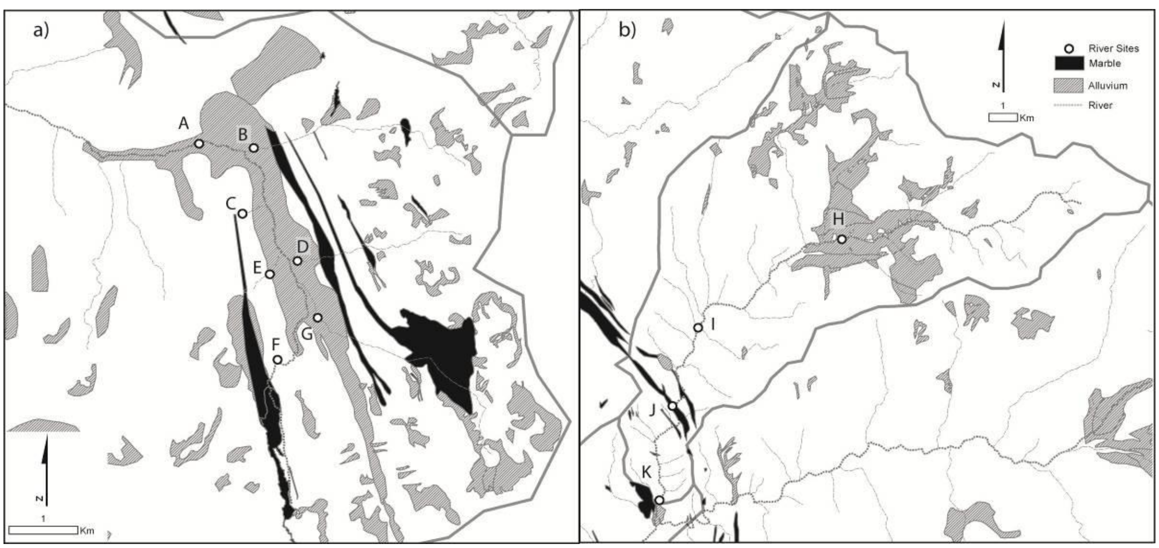

Figure 5.2. East Fork (a) and Marble Fork (b) transects. East Fork Sites: A- East Fork above Cold Springs; B- Monarch Cr; C- Tufa Spring; D- Crystal Cr; F- Eagle Meadow Sp; F- White Chief Cr; G- Franklin Cr. Marble Fork sites: H- Lodgepole; I- Crystal Cave Rd.; J- Marble Falls; K- Potwisha.

Hydrograph Recession behavior

A detailed statistical and geochemical analysis in Chapter II has shown that karst springs in the Kaweah basin can be divided into two groups with distinctly different hydrologic and geochemical characteristics. Three springs were selected from each group, plus three additional springs that appeared to exhibit unusual hydrologic behavior, (9 total) for continuous hydrogeochemical monitoring (discharge, T, and SC), and hydrographs from 2010 – 2012 were used to quantify baseflow recession coefficients of each group. A similar analysis was performed for each fork and the main stem of the Kaweah River using publicly available data (Table 5.1). Average baseflow recession coefficients were calculated using all baseflow periods in the period of record for each site.

Table 5.1. Hydrograph data source and length of record for all sites used in recession analysis (USGS-United States Geological Survey; USACE- U.S. Army Corps of Engineers).

Site	Data Record	Data Source
Kaweah River	1958-1990, 2009-2012	USGS, USACE
North Fork	1910-1960, 1980-1981	USGS
East Fork	1958-2008	USGS
South Fork	1958-1990	USGS
Marble Fork	1950-2002	USGS
Middle Fork	1949-2002	USGS
Big Spring	2010-2012	This project
Crystal Cave	2010-2012	This project
Alder Spring	2010-2012	This project
Tufa Spring	2010-2012	This project
Monarch Sp	2011-2012	This project
White Ch. Sp	2011-2012	This project

Recession coefficients for baseflow of each spring and river hydrograph were calculated using a form of Maillet's equation (Maillet, 1905):

$$\alpha = \frac{(\log_{10} Q_1 - \log_{10} Q_2)}{0.4343 * (t_2 - t_1)} \quad (5)$$

Where Q_1 and Q_2 (m^3/s) are discharge measured at the beginning and end of straight line segments in the hydrograph from $t_1$to t_2 (days) and α is the slope coefficient of a straight line segment on the hydrograph recession curve in semi-log space. Calculating α for recession curves from various sites over different years allows quantitative comparison of aquifer properties and retention times between the different springs and rivers (Dewandel et al. 2003; Jeanin and Sauter 1998). The steepness of the slope (α) of individual components (Figure 5.3) in a hydrograph recession curve is related to retention time: steeper slopes are related to shorter residence times. A minimum of three baseflow coefficients were calculated for each spring and ten for each of the three river forks. These values were then compared statistically using an ANOVA to test for differences between spring and river baseflow slopes.

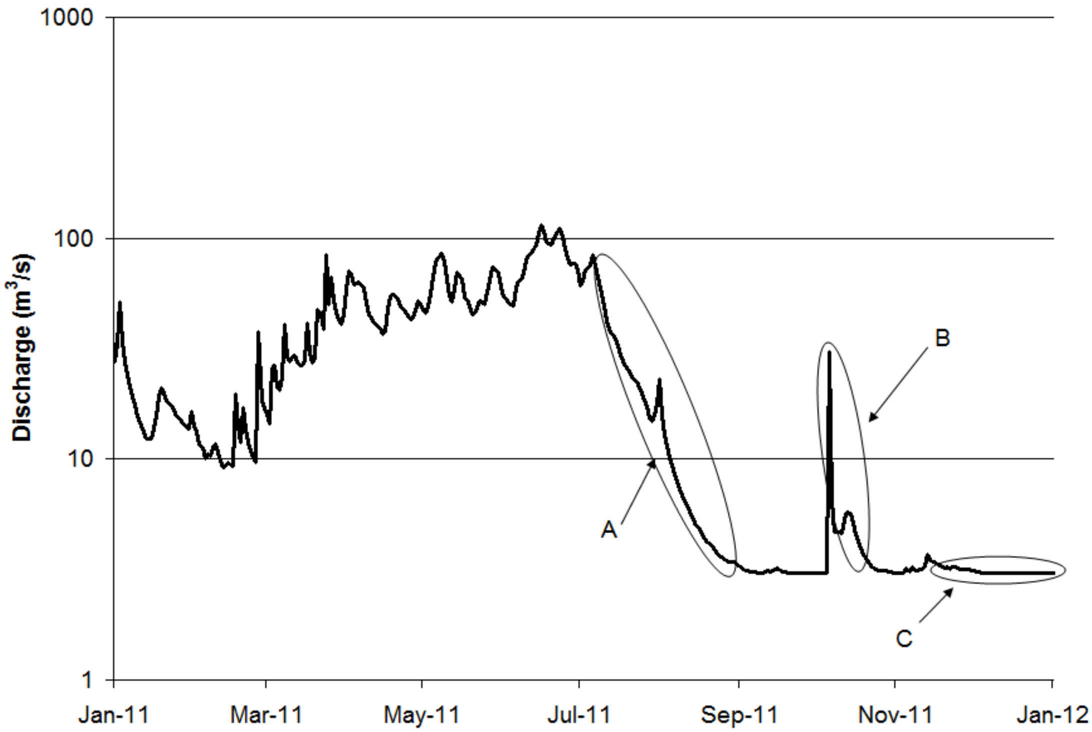

Figure 5.3. Example of a Kaweah River hydrograph over a one-year period with characteristic features labeled: A- snowmelt recession, B- stormflow pulse and recession, and C- baseflow recession.

Regression Analyses

To determine if a quantifiable relationship exists between the hydrogeologic characteristics of karstic and unconsolidated aquifers, and river baseflow behavior, simple linear regression models were created. Recession coefficients for each fork and the main river, averaged over the entire length of record for each site, were used as the response variable. This response variable was regressed against all possible combination of three predictor variables: 1) the percent of surface area covered by karst, 2) percent surface area covered by unconsolidated deposits, and 3) percent of each basin above 2000 m. These variables were assumed to account for the importance of karst, unconsolidated deposits, and snowmelt in influencing baseflow behavior of each fork. The best fit models for each response variable were then determined using Akaike information criterion (AIC) analysis for finite sample sizes.

Results

Source Water Elevation Modeling

To assess the validity of the model assumption that spring sample isotopic values are not being significantly altered through evaporation, all isotope values for river and spring samples were plotted along with values for rain and snow during the study period (Figure 5.4). All stable isotope samples fall within the range of isotopic values obtained from precipitation samples, indicating that there is minimal modification of water isotopes from precipitation through the hydrologic system.

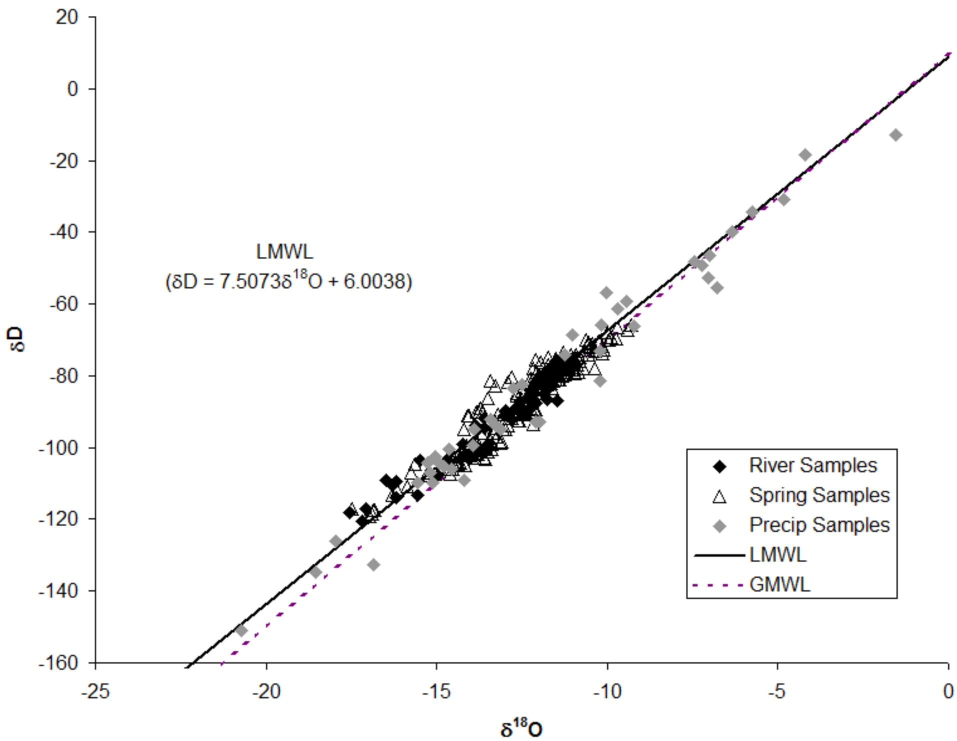

Figure 5.4. Isotope biplot of spring, river, and precipitation (snow, rain, and mixed) samples collected during 2010, 2011, and 2012. Line and equation represent the local meteoric water line (LMWL). The global meteoric water line (GMWL) is plotted using $\delta D = 8\delta^{18}O + 10$.

When isotopic data (both δD and $\delta^{18}O$) from precipitation samples taken during the same sampling interval were plotted against elevation, the resulting linear regressions (δD $r^2 = 0.987$; $\delta^{18}O$ $r^2 = 0.993$) created a source water elevation model:

(6) $$Elevation = \frac{\left(\frac{\partial D + 52.521}{-0.0151} + \frac{\partial^{18}O + 7.690}{-0.002}\right)}{2}$$

Equation 6 uses both δD and $\delta^{18}O$ values from each water sample to model an average source water elevation for each sample. When equation (6) is applied to isotope data from samples collected at high and low discharge levels in different forks of the Kaweah River, the model shows a distinct seasonality in source water elevation (Table 5.2). Samples collected at or near peak discharge indicate that the majority of water is derived from relatively high elevations within the basin (relatively depleted isotope values), while samples from baseflow periods indicate that water is derived from much lower elevations. The modeled source water elevations during baseflow conditions mirror karst spring source water elevations in basins where measured karst spring discharge accounts for more than 20 % of the total river discharge. In the remaining basins, modeled source water elevations decrease in elevation, but remain above the modeled source water elevations for the karst springs. This suggest that karstic storage is dominating discharge in basins with more than 20% of the baseflow discharge being derived directly from karst springs, and also suggests that diffuse baseflow contributions from karst aquifers may be just as important as discrete springs.

Table 5.2. Averaged source water elevation for each fork of the Kaweah River during peak and baseflow flow, average karst spring source elevation during baseflow, and average percent of baseflow discharge accounted for by karst springs 2010 – 2012. No spring samples were taken from the South Fork, so it was excluded from this analysis.

Site	High Flow Elev. (m)	Low Flow Elev. (m)	Low Flow Sp Elev. (m)	Percent Karst Discharge
Marble Fork	3225	2000	1385	2.5%
Middle Fork	3510	2515	1690	4.2%
North Fork	2400	1800	1800	88.5%
East Fork (at Mineral King)	3550	3005	2805	43.0%
Kaweah River	3250	2200	2150	20.0%

End-Member Mixing Models

Three end-members were created using averaged geochemical data from 10 samples from 7 non-karst springs in the basin, 7 drip water samples from three caves (to represent water chemistry of waters stored within the karst), and 15 samples during high flow periods from 5 alpine lakes (representing the snowmelt end member) (Table 5.3). Lake samples are from the headwaters of the river, and in areas with no known carbonate outcrops. These waters are essentially recent snowmelt that has had little to no interaction with geologic materials, and thus approximate direct snowmelt runoff.

Table 5.3. Data used in end member mixing models to represent snowmelt (alpine lakes), karst storage (karst drips), and non-karst storage (non-karst springs).

End Member	Samples	SO4 (mg/L)	SO4 (St. Dev)	Spec. Cond. (µS/cm)	Spec. Cond. (St.Dev.)
Non-karst Springs	10	8.8	10.2	89.6	51
Karst Drip	7	1.7	1	242	103.8
Alpine Lakes	15	1.43	1.1	11.9	5.9

From these data, non-karst springs were found to have distinctly higher sulfate values when compared to the other two end-members, and karst drip samples had distinctly higher specific conductivity, when compared to the other two end-members. When plotted on a cross-plot, river samples plotted in a space bounded by the three end-members (Figure 5.5). Using these data (Table 5.4) and the end member mixing model (equations 2-5), the percent contribution of each of the three end members to total discharge was calculated during periods of both high and low flow (Table 5.5). In the North and South Forks, the forks with the lowest average basin elevations, karstic sources constituted a substantial portion of flow throughout the year, with high flow contribution in the North Fork reaching 26 % of the total discharge, and 79 % during low flow. The East Fork and Kaweah River downstream of confluence of the five forks also have relatively large contributions of karst during high flow periods. During low flow periods, karst becomes increasingly important in all forks.

Table 5.4. Raw data from each river sampling site to calculate end member proportions of discharge.

Year	Flow	Site	Discharge (m3/s)	SO4 (mg/L)	Spec. Cond. (µS/cm)
2011	High Flow	Kaweah River	115.0	0.8	50
		Marble Fork	2.9	0.3	25
		Middle Fork	28.3	0.9	18
		North Fork	14.2	1.3	52
		South Fork	14.2	0.8	71
		East Fork	5.9	2.7	39
	Low Flow	Kaweah River	3.1	2.0	102
		Marble Fork	0.3	0.5	60
		Middle Fork	3.1	1.5	24
		North Fork	0.2	2.8	198
		South Fork	0.2	2.7	181
		East Fork	0.7	5.8	90
2012	High Flow	Kaweah River	48.1	1.7	72
		Marble Fork	2.5	0.4	32
		Middle Fork	8.5	1.2	30
		North Fork	2.1	1.6	101
		South Fork	2.1	1.3	75
		East Fork	1.2	2.0	73
	Low Flow	Kaweah River	0.7	3.3	119
		Marble Fork	0.1	1.5	73
		Middle Fork	2.1	2.4	40
		North Fork	0.1	3.0	217
		South Fork	0.1	4.8	147
		East Fork	0.2	8.0	280

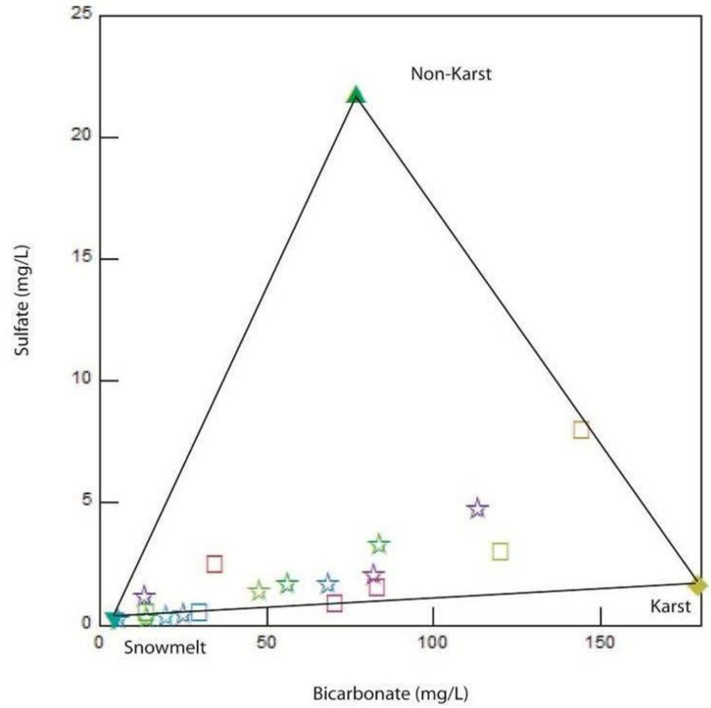

Figure 5.5. Sulfate – Bicarbonate cross plot of river samples bounded by three end-members (snowmelt, karst, and non-karst). Stars represent peak flow samples, squares represent baseflow samples.

Table 5.5. Modeled contributions of three components to river discharge during peak and baseflow, averaged between 2011 and 2012. GW total indicates total groundwater contribution from all sources to river discharge.

	Site	Snow	Non-Karst	Karst	GW total
High Flow	North Fork	73.8%	0.0%	26.2%	26.2%
	East Fork	80.8%	12.3%	6.9%	19.2%
	Marble fork	100.0%	0.0%	0.0%	0.0%
	South Fork	82.9%	0.0%	17.1%	17.1%
	Middle Fork	100.0%	0.0%	0.0%	0.0%
	Kaweah River	90.4%	1.6%	8.0%	9.6%
Low Flow	North Fork	20.7%	0.0%	79.3%	79.3%
	East Fork	25.9%	51.3%	22.9%	74.1%
	Marble fork	89.0%	0.3%	10.7%	11.0%
	South Fork	1.1%	41.9%	57.0%	98.9%
	Middle Fork	92.1%	7.7%	0.1%	7.9%
	Kaweah River	40.3%	11.8%	47.9%	59.7%

Transects of East Fork and Marble Fork

The East and Marble Forks of the Kaweah River provide a great opportunity to assess the role of karst in the basin supporting baseflow discharge at different locations. Both basins have large portions of their drainage above 2000 masl, with 1.9% and 3.8 % of the surface area of the basin accounted for by karst, respectively. Karst in the East Fork is almost exclusively above 2000 masl in elevation, while karst in the Marble fork is all below 1500 masl.

The Marble Fork transect consists of two sites above the karst (Lodgepole and Crystal Cave Rd.), one site at the karst (Marble Falls), and one site downstream of the karst (Potwisha) (Figure 5.2). Using the same 3-component mixing model described above, the relative roles of each of the three components can be determined at each of the sites, and changes can be used to illustrate the important effects that karstic sources have on modifying discharge and geochemistry in this type of a hydrologic system. At the two sites above the karst, discharge is almost exclusively controlled by snowmelt from high elevations (Table 5.6). During high flow periods, this is true for the entire transect: contributions of other sources to discharge are not significant. However, during low flow conditions, once the river passes Marble Falls, the second in a series of three bands of marble that the river crosses, the contribution of karst is quickly noticeable, accounting for 2.6 % of the total discharge at the falls. This relative contribution continues to increase in a downstream direction as karstic springs continue to add water until the confluence with the Middle Fork. Just upstream of the confluence, at the Potwisha site, water derived from karst accounts for 10.7% of the total discharge of the river. Seasonal variations in source water above Marble Falls varies minimally between high and low flow, however, below Marble Falls, there is a distinct seasonal difference. High flow is dominated by snowmelt runoff, as is expected during seasonal peak discharge. However, karst becomes increasingly important during baseflow conditions.

Table 5.6. Modeled contributions of three components of discharge to the Marble Fork from Upstream (Lodgepole) to downstream (Potwisha) during peak and baseflow periods, averaged from 2011-2012.

	Site	Snow	Non-Karst	Karst	GW Total
High Flow	Lodgepole	100.0%	0.0%	0.0%	0.0%
	Crystal Cave Rd.	100.0%	0.0%	0.0%	0.0%
	Marble Falls	100.0%	0.0%	0.0%	0.0%
	Potwisha	100.0%	0.0%	0.0%	0.0%
Low Flow	Lodgepole	98.3%	1.7%	0.0%	1.7%
	Crystal Cave Rd.	99.4%	0.6%	0.0%	0.6%
	Marble Falls	97.4%	0.0%	2.6%	2.6%
	Potwisha	89.0%	0.3%	10.7%	11.0%

Data from tributaries to the East Fork in Mineral King Valley reveal a somewhat different picture. Most of the karst in this basin is located at or near the headwaters of the basin where precipitation is much higher than at the Marble Fork karst. In the Mineral King karst systems, larger proportions of total water in the headwaters region are stored in karst aquifers and released during baseflow periods (Table 5.7). All tributaries show karst representing >10.5 % of the total flow during low flow periods and a maximum of 66 %. Additionally, there is a distinct seasonality in the contribution of direct snowmelt to discharge of the tributaries and East fork, with a substantial decrease in relative contribution of snowmelt during low flow periods. During low flow conditions, non-karst groundwater also appears to provide a significant amount of water to the river.

Table 5.7. End-member mixing models results: relative contribution of 3 components to each major tributary and the East Fork during peak and baseflow, averaged from 2010 – 2012.

	Site	**Snow**	**Non-Karst**	**Karst**	**GW Total**
High Flow	Monarch	89.6%	6.7%	3.6%	10.4%
	Crystal	83.3%	12.0%	4.7%	16.7%
	Franklin	85.7%	14.3%	0.0%	14.3%
	Tufa Sp	71.6%	7.2%	21.2%	28.4%
	East Fork	80.8%	12.3%	6.9%	19.2%
Low Flow	Monarch	56.3%	33.2%	10.5%	43.7%
	Crystal	32.5%	43.7%	23.8%	67.5%
	Franklin	39.9%	47.2%	12.9%	60.1%
	Tufa Sp	25.0%	8.8%	66.2%	75.0%
	East Fork	49.5%	18.0%	32.5%	50.5%

Measured discharges

Summing the continuous discharge data from 9 gauged springs produces a hydrograph with similar features as the Kaweah River discharge in 2011 (Figure 6). Baseflow conditions showed similarly flat recession slopes, throughout the dry period in the fall of 2011, but springs had an initial response to snowmelt that was delayed by 13 days relative to the snowmelt-related increase in river discharge in March of 2012. This phenomenon has previously been documented in mountain groundwater systems and is the result of delayed infiltration and recharge to groundwater systems, relative to surface water runoff (Bengtsson, 1982).

The contribution of discrete karst springs to river discharge is clearly illustrated by differences in measured discharges. Measured discharge of springs in the North Fork contributed 16 % of total fork discharge during high flow, on average during high flow but this contribution increased to 65% during low flow conditions. Similar proportions are seen in the East Fork; with average high and low flow contributions of 14 % and 65%, respectively. For the entire Kaweah River, karst springs on average account for 3.5% of the rivers discharge during high flow periods, but 20 % during low flow conditions. When compared to the values determined via the mixing models, there is no clear relationship between measured and modeled percentages. This is likely due to differences between where water is stored in these three river basins. Although water is emerging from karst aquifers, it may not have been stored within that aquifer. Adjacent aquifers, as discussed in chapter III, and conduit flow through the system, complicate the interpretation of water discharged from springs. Additionally, surface water – groundwater interactions within stream channels may increase or decrease the contribution of karst groundwater, based on the general direction of flow along these stretches of stream. End-member mixing models calculate a fraction of discharge based on the geochemical properties of each end-member, rather than relying solely on measured discharge values.

Table 5.8. Measured relative contributions of all springs to the North Fork, East Fork, and Kaweah River during high and low flow sampling, averaged over 2011 – 2012. Discharge measurements are in m^3/s.

	Site	Total Discharge	Spring Discharge	Karst Contribution
High Flow	North Fork	3.0	0.5	16.7%
	East Fork	12.0	1.7	14.5%
	Kaweah River	82.0	2.9	3.5%
Low Flow	North Fork	0.2	0.2	65.2%
	East Fork	0.4	0.3	64.5%
	Kaweah River	2.2	0.4	19.7%

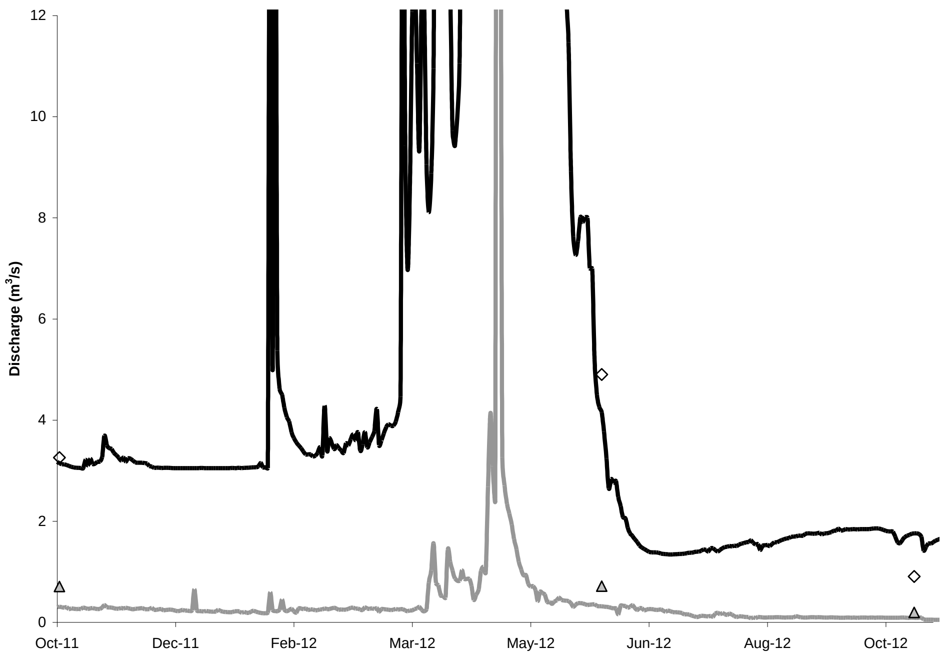

Figure 5.6. A comparison of Kaweah River discharge (black line) with the summed total of discharge from nine continuously monitored springs (grey line). Grey triangles indicate total measured discharge from all known karst springs, as measured during sampling periods. River baseflow (derived from USACE data) in late 2012 appears to be inaccurate, when compared to our measured values (white diamonds). This is likely due to changes in channel morphology affecting the rating curve for the site.

Recession coefficients

When comparing recession behavior of springs and the Kaweah River, hydrograph properties appear to be similar on a basin scale between the two. A minimum of ten baseflow recession slopes from ten separate years were calculated for the North Fork, East Fork, and Kaweah River during the seasonal low flow period. Ten North Fork recession slopes ranged from 0.0075 to 0.0161, with an average of 0.01245. Ten East Fork slopes had a range of 0.0048 to 0.0152, with an average of 0.0135. Twenty recession slopes of the Kaweah River at the Three Rivers gauging site ranged from 0.0035 to 0.0213, with an average of 0.0124. Three baseflow recession slopes per site (one per year from 2010 – 2012) from three springs in the North Fork and three springs in the East Fork showed statistically similar values to both each other and the river recession slopes ($F_{1, 63}$= 2.799, p= 0.099), with North Fork springs' recession slopes ranging from 0.0029 to 0.0233 and an average of 0.0106 and East Fork springs ranging from 0.0032 to 0.1290 and an average of 0.0157. Together, these springs had an average recession slope of 0.0128 (Table 5.9).

Table 5.9. Baseflow recession coefficients for rivers and springs.

Site	α	SD	n
North Fork	0.0125	0.004	10
NF Springs	0.0106	0.006	10
East Fork	0.0135	0.004	6
EF Springs	0.0157	0.014	12
Kaweah R	0.0124	0.006	20
Kaweah Sp	0.0128	0.011	27

Regression Modeling

Average baseflow recession slopes (α) for the period of record for each fork and the Kaweah River at Three Rivers were calculated to determine typical baseflow behavior of each river. These values were then regressed against all possible combinations of percent karst, percent non-karst, and percent of basin above 2000 masl (Table 5.10). The percent karst plus percent non-karst (unconsolidated) deposits was by far the best fit model; 4.2 times more likely to be the best fit than the next best model. This model explained 88.4% of the variation within the data (Table 5.11). The coefficients for unconsolidated deposits in this model were not significantly different than zero (t-value: 2.71, p-value: 0.073), suggesting that karst plays a dominant role in controlling the baseflow behavior of each fork while non-karst aquifers have a relatively lower storage capacity and do not significantly impact baseflow characteristics of the river.

Table 5.10. Data used for regression analysis: values represent percent of each basin covered by a given water storage compartment.

Basin	α	% Karst	% non-karst	% above 2000m
North	0.0048	4.4	4.5	27
South	0.0118	0.2	0.2	31
East	0.0089	1.9	5.2	64
Middle	0.0167	0.1	7.1	63
Marble	0.0089	3.8	13.1	77
Kaweah	0.0124	1.4	10.3	49

Table 5.11. Regression model comparison using Akaike Information Criterion (AIC) and showing model parameters (k-percent karst; u- percent unconsolidated (non-karst) deposits, 2k- percent basin above 2000 m), AIC and AICc (adjusted for small sample size); Akaike weights, adjusted r2 values and p-values for each model.

Parameter	df	AIC	AIC_c	Akaike wt	adj. r^2	p-value
k+u+2k	5	-56.222	-53.722	0.165	0.826	0.103
k+u	4	-58.193	-56.593	0.691	0.884	0.018
k+2k	4	-53.808	-52.208	0.077	0.758	0.055
u+2k	4	-43.122	-41.522	0.000	-0.436	0.800
k	3	-52.778	-51.855	0.065	0.700	0.024
u	3	-44.249	-43.326	0.001	-0.245	0.909
2k	3	-44.780	-43.857	0.001	-0.140	0.568

Discussion

Baseflow river behavior, when assessed using the methods described above, reveals some interesting temporal and spatial trends that can be used to infer dominant water storage type, as well as its elevation. Isotope source water elevation models showed a distinct difference in the dominant source water elevation for all forks of the Kaweah River. However, in basins with significant karst (North and East), the baseflow source water elevation decreases to an elevation similar to the source water elevations for karst springs. The same is true of the Kaweah River as a whole; source water elevation decreases, indicating a larger percentage of discharge derived from lower elevation groundwater systems. Although evaporative effects on liquid water isotopes may result in a decrease in source water elevation in these models, no evaporative trend was detected in the δD – $\delta^{18}O$ plot (Figure 5.4), which suggests that the changes in modeled source elevation are most likely due to changes in the dominant storage component of the system that is supplying water to the river. Conversely, if snowmelt was the dominant storage location supplying rivers during low flow, source water elevation would show an increase in elevation as snow at lower elevations melted, leaving the remaining snow at progressively higher elevations throughout the dry season.

Similarly, baseflow recession data show that, during baseflow conditions, there is no significant difference between river recession slopes and karst spring recession slopes. Therefore, as river source water elevation decreases, storage in karst systems is likely dominating baseflow discharge in the rivers. When end-member mixing and regression models are used, the seasonal importance of karst groundwater contributions becomes even more apparent. End-member mixing models show that, during low-flow periods, karst groundwater accounted for up to 79% of the discharge of the North Fork and 49% of discharge in the whole river. This is a significant increase from the directly measured spring discharge, which accounts for 65 % of the total discharge of the North Fork and 20% of baseflow discharge of the whole river. This difference is reasonable however, since it is likely that water is discharging from karst aquifers directly into stream channels via either seepage flow or springs discharging in the streambed in areas where surface waters flow across marble bands. Additionally, due to the rugged and remote nature of many of the marble bands, it is very likely that undocumented springs and aquifers exist in some portions of the basin.

Regression models showed that the variables that best explained baseflow recession were a combination of the amount of karst present and the amount of unconsolidated material present. Although hydrograph data for non-karst springs are not available (these springs are typically small), the best fit regression model shows that non-karst aquifers had a coefficient that was not significantly different than zero, indicating that they did not significantly affect the response of river baseflow. Therefore, the regression models suggest that the presence of karst was the dominant factor controlling baseflow behavior.

Previous work has shown the importance of groundwater in influencing river chemistry and flow in mountain settings (Clow et al., 2003; Liu et al., 2012), this research has shown that karst groundwater, specifically, plays a major role in maintaining baseflow in the Kaweah River. Although snowmelt dominates peak discharge, and thus the majority of water leaving this mountain basin can be directly tied to the seasonal melt of snow pack, our data clearly show that baseflow in these rivers is controlled by groundwater storage and subsequent discharge. In some forks of the Kaweah River, karst groundwater dominates baseflow; even in basins with very small areas of exposed karst. In the Kaweah River Basin as a whole, karst supplies significant amounts of water from aquifers that have high storage capacity and long residence times, relative to the non-karst aquifers elsewhere in the basin. The karst aquifers release a significant amount of flow in the basin during the seasonal dry season when water from snowmelt is no longer available.

Conclusion

This research has shown that even when karst accounts for only a small component of surface geology it may still be significant hydrologically. In the Kaweah River basin, karst accounts for 1.4 % of the surface area, however it provides an average of 49 % of the baseflow of the basin, according to mixing models. Although it has been extensively documented that snowmelt accounts for the most volume of water leaving mountain river basins (Clow et al., 2003; Kattelmann and Elder, 1991, and citations therein), our work has shown that even seemingly insignificant amounts of karst can play a major role in controlling river baseflow characteristics of a mountain river and should be recognized as an important part of the water budget in this and similar hydrologic systems.

One uncertainty in this research is whether the non-karst groundwater chemistry data are truly representative of all non-karst groundwater sources. Our sample size is small in comparison to the number of non-karst aquifers present in the basin, and therefore the geochemical data may not be representative of all non-karst groundwater in the basin. However, non-karst springs tend to be small and difficult to detect, and non-karst groundwater is likely dominated by diffuse contributions to streams as streams flow through unconsolidated alluvial or glacial deposits. To further verify the importance of non-karst groundwater in the Kaweah River, a more comprehensive investigation into these groundwater sources is necessary to better constrain the chemistry of these aquifers and thus their relative contributions as determined by end-member mixing models.

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CHAPTER VI

SUMMARY AND CONCLUSIONS

This dissertation provides added information on the importance of groundwater, in mountain hydrology and provides information that is useful to and needed by managers who are seeking to improve natural resource and ecosystem management in mountain hydrologic systems. The studies presented in this dissertation collectively and individually contribute to a greatly increased understanding of the characteristics of mountain hydrogeology (karst hydrogeology, in particular). Previous studies had primarily focused on individual aquifers (Abu-Jaber, 2001; Despain, 2006; Perrin et al., 2006; Smart, 1983), instead of seeking to understand how karst aquifers influence hydrology at a river-basin scale. My work expanded on our previous knowledge by describing, modeling, and documenting how spatially limited karst aquifers are disproportionally important to the larger hydrologic function of a mountain river basin. These studies also provided insight into seasonality of karst spring behavior and spatial and temporal patterns of ion chemistry in the aquatic system. Finally, these studies looked at the role of karst groundwater at a river-basin scale. Below I provide a brief summary of findings, implications of those findings, and potential future research directions where we still need to improve our knowledge of groundwater, with a focus on karst, in mountain settings.

Chapter II documented 47 individual karst springs in the Kaweah basin and documented flow paths using dye traces for all remaining large, previously untraced sinking streams in the basin. Using hydrologic and geochemical data, we described similarities and differences between karst aquifers of the Kaweah River Basin. Springs were categorized using a series of methods and tools including liquid water isotope variability, calcium: magnesium ratios, calcite saturation indices, and principal components analysis of data from seasonal water samples from all of the 47 documented karst springs in the basin. All methods of analysis showed a similar pattern, with low elevation springs being distinctly different from high elevation springs of the Mineral King Valley. Lower elevation springs showed less variability in water chemistry and discharge, while high elevation springs showed large seasonal shifts in both chemistry and discharge. These differences represent differences in storage capacity of each group of aquifers. Separation into these two groups is likely due to relative differences in glacial history: all high elevation sites were glaciated during the peak of the Tahoe Glaciation (Moore and Mack, 2008). This resulted in the removal of epikarst and adjacent unconsolidated deposits. Lower elevation sites that were not directly affected by glaciation are associated with a relatively well-developed epikarst and more weathered soils and unconsolidated deposits, all of which increase the storage capacity of lower elevation karst aquifers. In addition, low elevation systems receive much less infiltration and recharge due to an elevational precipitation gradient, and are thus less hydrologically dynamic systems.

The results of Chapter III were published in the Journal of Cave and Karst Studies in 2012 (Tobin and Schwartz, 2012) and focus on a comparison between the two largest springs in the Kaweah River Basin: Big Spring and Tufa Spring. These two springs also are representative of each group of springs as determined in Chapter II. Measured discharge and chemistry showed a distinct difference between the two aquifers. Big Spring maintained a much higher discharge through baseflow conditions, had a smaller peak snowmelt discharge, and maintained more constant hydrogeochemistry when compared to Tufa Spring. Using end – member mixing models, the chemistry of unmeasured water added to discharge along flow paths in each aquifer was modeled. These models showed unmeasured water added to spring discharge had higher conductivity values than water from sinking streams, suggesting that this water was stored either in the karst or at the boundary between karst and adjacent unconsolidated deposits. We hypothesize that the difference between these two spring is not the storage location, but instead the amount of storage available in the location; Big Spring has a much larger associated unconsolidated deposit, providing a larger reservoir for storage than is available at Tufa Spring.

The results of Chapter IV indicated that different nutrients have different mobilities when moving through the surface water – karst groundwater system post-fire. Phosphate is rapidly taken up, either through biotic or abiotic means, and removed from the aquatic system. Sulfate does not show any significant patterns related to fire or fire-retardant chemistry and is likely controlled more by variations in bedrock geology than fire effects. Nitrate appears to act conservatively in the aquatic system, compared to phosphate and sulfate, and concentrations spiked during peak discharge the season after a fire and remained elevated for two years. Although observed concentrations are similar to those measured in aquatic systems affected by fires not controlled with fire retardant (Engle et al., 2008), the correlation between area affected by retardant drops and nitrate concentration suggests that, in this system at least, fire retardant byproducts entered and moved through the aquatic system and likely dominated the increase in nitrate concentrations that were measured.

Chapter V assessed the overall importance of karst groundwater storage to river baseflow conditions. Although other researchers have documented the importance of non-karst groundwater resources on a smaller scale (Clow et al., 2003; Liu et al., 2012), the role that karst plays in affecting basin-scale hydrology has generally been overlooked in systems in which it is of relatively minor spatial significance. Through directly measuring the amount of water contributed to river discharge, the baseflow characteristics of karst aquifers were compared to river baseflow, and by modeling the role of karst aquifers throughout the year using hydrogeochemistry, we were able to show that, although karst only represents a small portion of the whole basin in terms of area (<2%), end – member mixing models show that 48% of discharge in the Kaweah River during baseflow conditions can be attributed to water stored in karst.

Combined, these studies provide resource managers with an enhanced understanding of the controls of river baseflow of the Kaweah River. The findings of this work also have implications for guiding the development of improved management plans for this and other mountain hydrologic systems. Whenever karst is present within a hydrologic system, it is likely to provide substantial groundwater storage, even if it only accounts for a small portion of the surface area of the drainage basin. Karst has been documented in mountainous regions around the world (Karimi et al., 2004; Veni, 2001) and thus likely provides substantial amounts of water to river baseflow in many mountain hydrologic systems.

Although these studies do show that karst is important within mountain hydrologic systems, more data is necessary to further understand the broader implications of karst groundwater to river hydrology. First, further insight into the dynamics of nutrient movement within karst systems, such as those in the Kaweah River, requires a combination of nutrient concentration and discharge data focused on sampling at high frequency from the end of baseflow conditions through peak snowmelt discharge into baseflow conditions. These data would help answer questions regarding nutrient export from surface water – karst groundwater systems. It is hypothesized that there is no difference in the ability to export nitrate from a surface water – karst groundwater system, post-fire, when compared to a typical non-karst mountain stream, However, it is also hypothesized that, due to increased surface water – groundwater interactions, phosphate export would be greatly reduced in a karstic system.

Second, within the Kaweah River basin specifically, there remain a number of karst bands that have not been well studied; in the North Fork, for example. Through documenting these bands, further constraint on the role of karst in basin scale hydrology can be obtained and the hypotheses regarding grouping of karst springs and relationships between karst spring hydrograph recessions and river baseflow conditions can be further verified.

Finally, no thorough documentation of non-karst springs and aquifers exists within the basin. Based on mixing model results, it is hypothesized that these non-karst groundwater systems may play a substantial role in modifying baseflow characteristics of the Kaweah River. Through quantifying the extent, geochemistry, and recession behavior of non-karst springs, the role they play in river baseflow conditions would be documented and further constrain the role of karst groundwater in basin scale hydrology. One factor that may hinder this work is if the majority of non-karst water enters the surface stream system via diffuse discharge and hyporheic zone interactions.

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APPENDIX 1

REDWOOD CREEK 2007 BASEFLOW DATA

Date	Sample ID	Site	Alk	Li	Na	NH4	K	Mg	Mn	Ca	Sr	Ba	% Error
05/25/07	RC297	Big Spring	98.58	0	4.1589	0	1.5357	0.1066	0	6.7976	0	0	-0.47983
06/02/07	RC 299	Big Spring	82.15	0.1197	3.6848	0	1.4077	0.9242	0	18.8032	0	0	-0.04625
06/10/07	RC 301	Big Spring	123.22	0.1184	3.7319	0	1.442	0.8691	0	14.4683	0	0	-0.33352
06/18/07	RC303	Big Spring	98.58	0	3.9996	0	1.4207	1.1094	0	20.5844	0	0.2251	-0.09643
06/26/07	RC 305	Big Spring	82.15	0.1183	3.9481	0	1.4616	1.0521	0	13.4875	0	0	-0.15484
07/04/07	RC 321	Big Spring	98.58	0	4.1391	0	1.5456	1.1247	0	11.2584	0	0	-0.29814
07/08/07	RC 322	Big Spring	98.58	0.1183	4.2944	0	1.4294	1.3963	0	21.0702	0	0	-0.06935
07/16/07	RC 324	Big Spring	82.15	0.1182	4.4465	0	1.7445	1.3914	0	13.8949	0	0	-0.31046
07/24/07	RC 326	Big Spring	98.58	0.119	3.5513	0	1.2953	1.1362	0	13.0244	0	0	-0.26056
08/01/07	RC 328	Big Spring	82.15	0.1024	4.1558	0	1.4978	1.4557	0	15.6322	0	0	-0.08599
08/09/07	RC 330	Big Spring	98.58	0.1021	4.5281	0	1.504	1.5208	0	13.5068	0	0	-0.21274
08/17/07	RC 332	Big Spring	98.58	0.1194	4.5287	0	1.4496	1.8054	0	17.5713	0	0	-0.11743
10/14/07	RC 335	Big Spring	98.58	0.1185	4.4909	0	1.0926	1.96	0	28.6707	0	0	0.06262

APPENDIX 2

PRINCIPAL COMPONENT ANALYSIS DATA

Season	Date (YYMMDD)	Site	Elevation Group	Elevation (m)	SIcal	Discharge (m3/s)	pH	Temp (°C)	Spec. Cond. (µS/cm)	δD (°/oo)	$\delta^{18}O$ (°/oo)	Cl^- (% of anions)	NO_3^- (% of anions)	SO_4^{2-} (% of anions)	alkalinity (% of anions)	Na^+ (%of cations)	K^+ (% of cations)	Mg^{2+} (% of cations)	Ca^{2+} (% of cations	Ca/Mg
High Flow	110709	Aspen Spring	High	2535	-0.63	2.27	7.87	8.09	64.0	-107.04	-15.74	0.8%	0.0%	2.8%	96.4%	17.5%	2.6%	5.7%	74.2%	12.96
High Flow	120608	Aspen Spring	High	2535	-0.73	0.32	7.76	6.25	45.0	-100.28	-13.94	0.9%	0.3%	4.4%	94.4%	18.0%	2.5%	4.9%	74.6%	15.36
High Flow	100728	Tufa Sp	High	2600	0.10	9.00	8.57	8.41	70.0	-99.10	-13.38	1.3%	0.0%	2.9%	95.8%	12.3%	1.9%	9.3%	76.4%	8.21
High Flow	100805	Tufa Sp	High	2600	0.84	7.79	9.14	8.52	87.0	-99.31	-14.11	0.9%	0.4%	2.0%	96.7%	13.1%	2.0%	9.5%	75.4%	7.90
High Flow	110708	Tufa Sp	High	2600	-1.22	138.06	7.74	6.79	50.0	-119.13	-16.98	1.1%	0.0%	3.1%	95.9%	13.0%	2.3%	9.3%	75.5%	8.15
High Flow	120616	Tufa Sp	High	2600	-1.22	5.85	7.16	8.30	109.2	-104.93	-14.16	0.9%	0.4%	2.3%	96.4%	10.6%	1.4%	8.9%	79.1%	8.91
High Flow	100713	Monarch Sp	High	2650	-0.18	0.50	8.55	8.44	54.0	-100.16	-14.04	3.1%	2.4%	4.9%	89.7%	20.5%	1.8%	6.1%	71.7%	11.79
High Flow	110709	Monarch Sp	High	2650	-0.87	2.97	7.64	5.00	73.0	-104.62	-15.62	3.9%	1.2%	4.8%	90.0%	21.6%	1.9%	6.7%	69.8%	10.39
High Flow	120611	Monarch Sp	High	2650	-0.50	0.82	8.05	6.95	55.0	-103.87	-14.53	2.8%	0.5%	4.5%	92.1%	12.0%	0.8%	4.9%	82.2%	16.71
High Flow	110706	Not Soda Sp	High	2650	-3.17	0.30	7.13	6.23	34.0	-117.31	-16.85	1.3%	0.0%	7.2%	91.5%	20.0%	5.6%	8.0%	66.4%	8.32
High Flow	120608	Not Soda Sp	High	2650	-1.25	1.03	7.70	19.70	61.7	-105.92	-14.51	0.9%	1.9%	11.4%	85.8%	9.5%	3.5%	2.7%	84.3%	31.51
High Flow	120607	Beulah Sp	High	2670	-0.98	0.41	7.60	5.58	61.0	-104.57	-14.37	0.4%	3.7%	7.0%	89.0%	4.8%	1.8%	2.5%	90.9%	37.09
High Flow	120612	TG Rise	High	2700	0.19	0.62	9.15	5.96	39.0	-95.95	-13.32	1.6%	0.8%	2.0%	95.5%	7.0%	1.6%	4.1%	87.3%	21.16
High Flow	120611	Crystal Creek Spring	High	2775	-2.43	1.10	6.30	5.96	52.0	-107.49	-15.04	0.6%	0.9%	2.8%	95.8%	6.2%	1.4%	2.2%	90.2%	40.99
High Flow	110707	Bogaz	High	2845	-3.44	10.48	7.02	4.21	8.0	-118.40	-16.87	0.0%	0.0%	6.7%	93.3%	11.2%	6.1%	6.9%	75.8%	10.97
High Flow	120616	Bogaz	High	2845	-2.46	1.63	6.53	10.20	33.6	-101.01	-13.48	0.4%	1.5%	5.0%	93.1%	2.9%	0.7%	5.1%	91.4%	18.07
High Flow	110707	Corrigans Sink	High	2850	-3.65	2.46	7.01	5.17	7.0	-118.40	-17.01	0.0%	10.2%	5.1%	84.8%	12.1%	7.1%	6.9%	73.9%	10.66
High Flow	120616	Corrigans Sink	High	2850	-2.95	0.30	6.80	5.40	23.6	-98.43	-13.10	1.7%	0.0%	3.4%	94.9%	7.8%	1.2%	2.2%	88.8%	40.18
High Flow	110707	White Chief Mine	High	2930	-1.84	0.08	7.87	6.22	13.0	-110.76	-15.86	0.0%	2.2%	2.8%	95.0%	4.1%	1.2%	3.3%	91.4%	27.48
High Flow	100729	White Chief Sp	High	2960	-1.30	2.41	8.26	4.68	19.0	-94.66	-13.31	1.0%	3.5%	7.8%	87.8%	12.8%	0.0%	4.3%	82.9%	19.16
High Flow	110707	White Chief Sp	High	2960	-1.60	79.63	7.81	3.12	8.0	-117.31	-16.80	0.0%	0.9%	2.6%	96.5%	3.6%	1.8%	5.1%	89.4%	17.52
High Flow	120616	White Chief Sp	High	2960	-1.98	1.52	7.44	5.40	34.2	-101.85	-13.86	1.5%	1.3%	7.3%	89.9%	6.1%	1.9%	4.1%	88.0%	21.65
High Flow	120616	White Chief- Bat Slab	High	3010	-1.97	1.63	7.37	4.30	24.3	-100.65	-13.76	0.7%	2.2%	6.1%	91.0%	4.0%	0.5%	3.2%	92.2%	28.45
High Flow	100713	Bluebell Sp	High	3030	-1.08	0.94	8.89	7.24	15.0	-99.10	-13.84	1.4%	5.5%	10.4%	82.7%	24.3%	0.0%	3.9%	71.8%	18.56
High Flow	110709	Bluebell Sp	High	3030	-2.39	2.88	7.45	4.78	15.0	-117.15	-17.49	0.8%	4.0%	7.3%	87.9%	14.8%	2.4%	6.6%	76.2%	11.54
High Flow	120608	Bluebell sp	High	3030	-2.18	0.05	7.80	6.36	17.0	-101.42	-14.00	5.1%	4.2%	6.8%	84.0%	25.2%	6.2%	4.2%	64.3%	15.25
High Flow	120607	Onion Mdw Sp	High	3030	-3.41	3.38	6.51	11.11	19.0	-105.92	-14.68	2.6%	5.1%	21.6%	70.7%	18.7%	6.1%	2.6%	72.6%	27.98
High Flow	120611	Shower Cave	High	3090	-2.72	0.20	7.02	10.30	23.7	-106.07	-14.60	1.4%	0.0%	3.6%	95.0%	18.6%	3.4%	1.8%	76.2%	41.91
High Flow	100511	Alder Sp	Low	570	-0.21	1.21	7.75	13.14	166.0	-65.69	-9.29	1.9%	0.0%	3.0%	95.1%	25.6%	2.7%	12.4%	59.4%	4.80
High Flow	101227	Alder Sp	Low	570	-0.29	1.88	7.37	14.01	192.0	-69.83	-9.97	1.2%	0.0%	2.2%	96.6%	23.5%	2.2%	12.6%	61.6%	4.87
High Flow	110710	Alder Sp	Low	570	0.56	1.00	8.25	13.63	215.0	-75.39	-12.10	1.4%	0.0%	2.3%	96.4%	25.8%	2.3%	12.5%	59.4%	4.75
High Flow	120609	Alder Sp	Low	570	-0.19	0.93	7.44	13.40	218.0	-69.97	-10.61	1.6%	0.0%	2.4%	96.0%	23.6%	2.4%	12.3%	61.7%	5.02
High Flow	110710	Stream 3	Low	775	0.79	1.00	8.36	19.68	305.0	-74.95	-11.71	1.7%	0.0%	5.7%	92.6%	29.8%	3.8%	22.7%	43.6%	1.92
High Flow	120609	Stream 3	Low	775	0.02	0.03	7.48	19.19	317.0	-71.83	-10.57	1.3%	0.0%	7.4%	91.3%	13.7%	3.5%	28.8%	54.0%	1.87
High Flow	120618	Hospital Rock Sp	Low	830	-0.17	0.17	7.81	16.00	170.0	-74.30	-10.73	1.4%	0.0%	11.6%	87.0%	20.6%	3.6%	11.0%	64.8%	5.87
High Flow	100526	Keyhole Spring	Low	830	-0.23	0.95	7.78	10.68	220.0	-70.34	-10.22	1.6%	0.8%	9.2%	88.4%	12.1%	3.0%	9.3%	75.7%	8.11
High Flow	110710	Stream 2	Low	850	1.14	0.50	8.58	19.89	348.0	-76.27	-11.95	1.2%	0.5%	6.4%	92.0%	13.0%	3.3%	28.7%	55.0%	1.91
High Flow	110710	Stream 1	Low	900	0.55	1.50	8.09	14.37	252.0	-81.76	-12.90	0.6%	0.0%	4.2%	95.3%	10.5%	3.0%	9.1%	77.3%	8.49
High Flow	120609	Stream 1	Low	900	-0.14	0.16	7.37	12.68	232.0	-75.61	-11.04	0.5%	0.0%	4.2%	95.3%	9.1%	2.7%	9.8%	78.4%	7.99
High Flow	100514	Warm River	Low	1020	0.02	2.20	7.71	17.04	289.0	-76.90	-11.03	0.8%	1.9%	3.9%	93.4%	9.4%	1.4%	8.6%	80.6%	9.34
High Flow	100602	Warm River	Low	1020	0.02	0.98	7.55	19.12	328.0	-79.05	-12.04	0.6%	1.9%	3.6%	93.9%	7.7%	1.9%	8.0%	82.5%	10.28
High Flow	100702	Warm River	Low	1020	0.25	0.61	7.77	18.94	296.0	-75.62	-10.94	0.6%	2.1%	3.7%	93.6%	7.0%	1.6%	7.3%	84.1%	11.53
High Flow	101228	Warm River	Low	1020	-0.05	6.67	7.30	16.41	256.0	-79.24	-11.65	0.3%	1.7%	1.9%	96.2%	5.0%	1.0%	6.1%	87.8%	14.37
High Flow	110710	Warm River	Low	1020	0.33	5.00	8.01	18.00	163.0	-86.16	-13.50	0.6%	0.9%	3.8%	94.6%	10.3%	2.2%	9.6%	78.0%	8.16
High Flow	100514	Upper Smoking Sp	Low	1050	0.57	0.00	8.28	12.41	127.0	-74.75	-10.87	1.2%	0.4%	7.1%	91.2%	13.4%	2.6%	11.3%	72.7%	6.42
High Flow	100702	Upper Smoking Sp	Low	1050	0.46	0.13	8.31	13.73	223.0	-75.47	-10.94	1.6%	0.7%	14.2%	83.5%	11.5%	3.3%	11.9%	73.4%	6.19
High Flow	110710	Upper Smoking Sp	Low	1050	0.49	1.00	8.25	14.00	150.0	-82.86	-13.28	1.3%	0.0%	12.5%	86.2%	12.4%	3.3%	11.6%	72.7%	6.27
High Flow	120617	Upper Smoking Sp	Low	1050	-1.25	0.04	6.34	13.00	264.0	-81.98	-11.64	1.0%	0.0%	10.2%	88.7%	11.4%	3.0%	12.1%	73.5%	6.05
High Flow	100512	Lange Sp	Low	1240	-0.40	0.64	7.44	8.56	207.0	-75.82	-11.49	0.9%	2.0%	1.6%	95.5%	8.9%	1.7%	39.4%	50.1%	1.27
High Flow	100605	Lange Sp	Low	1240	0.15	0.65	7.91	15.16	234.0	-75.82	-11.19	0.9%	1.4%	1.4%	96.2%	10.3%	1.8%	37.9%	50.0%	1.32
High Flow	110630	Lange Sp	Low	1240	-0.04	0.22	7.72	9.69	201.0	-81.22	-11.44	0.7%	0.4%	0.9%	98.0%	10.3%	1.8%	38.8%	49.0%	1.26
High Flow	120606	Lange Sp	Low	1240	0.00	0.15	7.75	9.30	312.0	-77.98	-11.30	1.0%	0.6%	0.9%	97.5%	10.7%	1.4%	37.3%	50.5%	1.35
High Flow	100512	Kuala Sp	Low	1250	-0.65	0.20	7.05	8.93	291.0	-77.98	-11.69	1.5%	1.1%	1.1%	96.3%	10.5%	1.6%	38.7%	49.2%	1.27
High Flow	100605	Kuala Sp	Low	1250	-0.39	0.06	7.16	11.56	313.0	-77.11	-11.23	1.9%	1.0%	1.4%	95.7%	9.5%	1.4%	36.9%	52.2%	1.41
High Flow	110630	Kuala Sp	Low	1250	-0.28	0.05	7.70	10.66	349.0	-76.95	-11.20	0.9%	0.6%	0.8%	97.8%	8.4%	1.1%	42.1%	48.4%	1.15
High Flow	120606	Kuala Sp	Low	1250	-0.36	0.01	7.05	9.40	329.0	-77.60	-11.26	1.0%	0.4%	0.8%	97.8%	9.2%	1.2%	37.1%	52.5%	1.42
High Flow	100526	MC Sp3	Low	1270	0.21	0.03	7.78	8.44	116.0	-68.06	-9.98	0.5%	0.2%	4.6%	94.7%	3.6%	1.4%	7.8%	87.2%	11.12
High Flow	100526	MC Sp4	Low	1275	0.36	0.02	8.05	11.64	264.0	-72.09	-10.51	0.8%	1.1%	3.7%	94.4%	4.3%	1.2%	8.1%	86.4%	10.63
High Flow	100512	Contact Sp	Low	1340	-0.39	0.19	7.61	8.06	145.0	-76.68	-11.50	1.7%	1.1%	1.8%	95.4%	15.0%	2.4%	11.4%	71.2%	6.24

Season	Date (YYMMDD)	Site	Elevation Group	Elevation (m)	SIcal	Discharge (m3/s)	pH	Temp (°C)	Spec. Cond. (μS/cm)	δD (‰)	$\delta^{18}O$ (‰)	Cl^- (% of anions)	NO_3^- (% of anions)	SO_4^{2-} (% of anions)	alkalinity (% of anions)	Na^+ (%of cations)	K^+ (% of cations)	Mg^{2+} (% of cations)	Ca^{2+} (% of cations	Ca/Mg
High Flow	100605	Contact Sp	Low	1340	-0.33	0.11	7.69	15.01	155.0	-75.82	-10.82	2.3%	0.8%	1.7%	95.2%	17.3%	2.6%	11.0%	69.1%	6.27
High Flow	110630	Contact Sp	Low	1340	-0.28	0.23	7.81	9.50	120.0	-82.28	-11.66	1.6%	0.0%	1.1%	97.3%	21.6%	2.9%	9.8%	65.6%	6.67
High Flow	120610	Contact Sp	Low	1340	-0.84	0.08	7.21	8.60	167.4	-82.98	-11.84	1.9%	0.0%	0.9%	97.2%	19.7%	2.7%	9.7%	67.9%	6.99
High Flow	100512	Hurricane Crawl	Low	1340	-0.76	1.52	7.84	7.93	70.0	-74.75	-11.22	1.9%	1.1%	2.6%	94.5%	25.6%	3.6%	9.1%	61.8%	6.78
High Flow	120606	Hurricane Crawl	Low	1340	0.09	0.24	8.16	10.30	171.5	-78.43	-11.00	1.0%	1.2%	1.3%	96.5%	17.9%	2.1%	10.4%	69.7%	6.72
High Flow	100522	Crystal Cave	Low	1395	-1.00	1.07	7.28	9.00	101.0	-76.90	-11.39	1.8%	1.6%	1.9%	94.7%	24.6%	3.9%	7.4%	64.0%	8.64
High Flow	100605	Crystal Cave	Low	1395	-1.35	1.06	7.42	10.17	75.0	-76.90	-11.48	3.3%	2.5%	3.3%	90.9%	26.6%	4.0%	7.2%	62.2%	8.59
High Flow	100609	Crystal Cave	Low	1395	-1.42	1.02	7.22	8.51	73.0	-76.90	-11.74	2.4%	1.1%	2.5%	94.0%	24.7%	4.0%	7.4%	63.9%	8.61
High Flow	110224	Crystal Cave	Low	1395	-1.14	1.20	7.24	8.04	71.0	-79.35	-11.80	1.3%	0.0%	1.2%	97.5%	28.5%	3.9%	7.3%	60.3%	8.23
High Flow	110701	Crystal Cave	Low	1395	-0.55	1.23	7.88	9.26	79.0	-83.35	-11.62	0.0%	0.0%	0.2%	99.8%	28.4%	4.3%	7.1%	60.2%	8.53
High Flow	120606	Crystal Cave	Low	1395	-2.09	1.37	6.17	9.04	77.0	-79.76	-11.23	1.1%	0.0%	0.8%	98.1%	23.7%	2.7%	7.5%	66.0%	8.77
High Flow	100522	Mossy Sp	Low	1395	-0.68	0.33	6.78	9.00	736.0	-77.98	-11.26	8.7%	0.2%	1.2%	89.9%	32.7%	2.3%	20.0%	45.0%	2.25
High Flow	100605	Mossy Sp	Low	1395	-0.38	0.14	7.09	10.21	575.0	-80.34	-11.93	9.5%	0.2%	1.3%	89.0%	26.7%	1.8%	16.0%	55.5%	3.46
High Flow	100609	Mossy Sp	Low	1395	-0.62	0.14	7.21	9.87	504.0	-79.91	-11.83	17.0%	0.3%	2.2%	80.5%	29.8%	2.0%	17.8%	50.4%	2.83
High Flow	110224	Mossy Sp	Low	1395	-0.11	0.23	7.26	9.87	478.0	-81.00	-11.82	6.6%	0.0%	0.9%	92.5%	27.0%	1.9%	15.8%	55.3%	3.50
High Flow	110701	Mossy Sp	Low	1395	0.23	0.20	7.74	9.74	546.0	-81.22	-12.02	7.0%	0.0%	0.9%	92.1%	31.9%	2.1%	17.9%	48.2%	2.69
High Flow	120606	Mossy Sp	Low	1395	-0.61	0.29	6.52	10.12	579.0	-79.33	-11.42	6.2%	0.0%	1.3%	92.5%	24.1%	1.3%	14.2%	60.3%	4.23
High Flow	100512	Cave Cr Sp	Low	1415	-0.25	3.18	7.62	8.37	181.0	-74.75	-11.37	0.7%	2.3%	1.5%	95.5%	10.2%	1.9%	41.6%	46.4%	1.12
High Flow	100605	Cave Cr Sp	Low	1415	-0.42	0.39	7.86	11.91	164.0	-75.02	-10.94	1.7%	2.7%	2.8%	92.8%	16.0%	2.4%	37.6%	44.1%	1.17
High Flow	110630	Cave Cr Sp	Low	1415	-0.32	3.50	7.69	9.56	142.0	-78.02	-10.68	0.8%	0.0%	1.3%	97.9%	16.5%	2.3%	36.0%	45.2%	1.26
High Flow	120606	Cave Cr Sp	Low	1415	-0.33	2.39	7.70	8.80	243.0	-78.21	-11.09	1.1%	1.0%	1.3%	96.6%	16.0%	2.3%	36.7%	45.1%	1.23
High Flow	100512	WTF Sp	Low	1425	0.68	0.01	8.37	11.40	436.0	-73.56	-11.30	0.3%	1.9%	2.3%	95.4%	1.7%	0.7%	69.8%	27.8%	0.40
High Flow	100605	WTF Sp	Low	1425	0.96	0.01	8.54	13.93	466.0	-72.83	-10.56	0.7%	3.0%	4.2%	92.1%	2.2%	0.6%	52.3%	44.9%	0.86
High Flow	110630	WTF Sp	Low	1425	0.93	0.00	8.20	13.17	422.0	-82.28	-11.96	0.3%	0.0%	1.3%	98.4%	2.9%	0.6%	54.7%	41.8%	0.77
High Flow	120606	WTF Sp	Low	1425	1.04	0.00	8.32	10.90	591.0	-74.82	-10.86	0.4%	0.2%	1.0%	98.5%	2.7%	0.5%	52.5%	44.3%	0.84
High Flow	100512	Rimstone Sp	Low	1435	0.05	0.11	8.00	10.53	433.0	-80.13	-11.76	7.1%	0.0%	2.2%	90.7%	21.6%	2.3%	25.2%	50.9%	2.02
High Flow	100609	Rimstone Sp	Low	1435	0.06	0.12	7.69	14.57	485.0	-77.76	-11.28	10.1%	0.0%	3.0%	87.0%	20.2%	2.1%	23.2%	54.4%	2.35
High Flow	110701	Rimstone Sp	Low	1435	0.45	0.06	7.88	13.39	395.0	-81.22	-11.78	1.8%	0.0%	1.1%	97.1%	16.2%	1.9%	18.9%	62.9%	3.33
High Flow	120606	Rimstone Sp	Low	1435	-0.27	0.00	7.03	8.50	459.0	-82.19	-12.01	0.5%	0.0%	2.0%	97.4%	6.0%	1.3%	14.9%	77.8%	5.23
High Flow	100626	Big Spring	Low	1460	-0.12	9.00	8.43	8.21	89.0	-77.76	-11.00	2.1%	0.0%	2.3%	95.7%	17.6%	2.8%	4.8%	74.7%	15.51
High Flow	100704	Big Spring	Low	1460	-0.37	8.00	7.97	8.59	98.0	-80.08	-11.67	1.4%	0.0%	1.6%	97.0%	18.1%	3.0%	4.9%	74.0%	15.02
High Flow	100815	Big Spring	Low	1460	-0.11	6.43	7.85	9.24	136.0	-81.35	-11.90	1.0%	0.0%	1.2%	97.8%	15.3%	2.4%	5.4%	76.8%	14.15
High Flow	110703	Big Spring	Low	1460	-0.23	19.57	7.99	8.92	98.0	-88.94	-13.71	0.8%	0.0%	0.9%	98.2%	18.6%	3.1%	5.2%	73.1%	14.14
High Flow	100522	Equinous Sp	Low	1540	-0.30	0.16	7.08	9.00	467.0	-76.04	-10.97	0.6%	0.0%	0.7%	98.7%	1.8%	1.0%	59.1%	38.1%	0.65
High Flow	100609	Equinous Sp	Low	1540	-0.32	0.09	7.11	8.65	368.0	-76.68	-11.50	0.6%	0.0%	0.9%	98.5%	2.0%	0.8%	47.8%	49.4%	1.03
High Flow	120606	Equinous Sp	Low	1540	-0.07	0.00	7.13	10.00	586.0	-78.10	-12.18	0.3%	0.0%	0.4%	99.3%	1.7%	0.9%	47.6%	49.8%	1.05
High Flow	100609	Dogwood Sp	Low	1570	-0.42	0.18	7.01	8.18	394.0	-77.98	-11.66	0.7%	0.0%	0.6%	98.7%	1.8%	0.6%	47.7%	49.9%	1.05
High Flow	110701	Dogwood Sp	Low	1570	1.02	0.08	8.28	8.42	344.0	-80.15	-12.00	0.2%	0.0%	0.2%	99.5%	1.3%	0.5%	54.1%	44.1%	0.82
High Flow	120606	Dogwood Sp	Low	1570	-0.14	0.02	7.06	10.00	595.0	-79.15	-11.21	0.3%	0.0%	0.2%	99.5%	1.3%	0.4%	48.3%	50.0%	1.04
High Flow	100526	MC Sp2	Low	1600	-0.33	0.01	7.78	11.63	267.0	-70.83	-10.53	1.8%	0.3%	6.2%	91.6%	13.8%	4.4%	7.0%	74.8%	10.64
High Flow	100526	MC Sp 1	Low	1650	0.31	0.02	7.91	9.02	310.0	-74.75	-10.80	0.4%	1.0%	1.7%	96.9%	2.7%	1.7%	10.1%	85.5%	8.44
Low Flow	121024	Aspen Spring	High	2535	-0.27	0.18	8.02	6.57	76.0	-100.35	-13.96	1.1%	0.2%	4.9%	93.8%	15.9%	2.5%	4.3%	77.3%	17.89
Low Flow	101017	Tufa Sp	High	2600	1.10	0.78	9.10	6.81	127.0	-98.57	-13.14	7.1%	0.0%	2.9%	90.0%	13.7%	1.6%	11.1%	73.6%	6.64
Low Flow	111022	Tufa Sp	High	2600	0.12	5.11	8.32	6.30	143.9	-98.00	-13.41	0.9%	0.6%	2.1%	96.4%	11.3%	1.7%	9.6%	77.3%	8.04
Low Flow	121030	Tufa Sp	High	2600	0.54	0.78	8.41	6.06	279.0	-102.03	-14.00	1.4%	0.0%	1.9%	96.7%	14.4%	1.8%	11.4%	72.4%	6.35
Low Flow	111022	Monarch Sp	High	2650	-0.44	0.26	8.29	6.84	107.0	-96.04	-13.33	2.2%	2.5%	5.5%	89.8%	15.6%	1.6%	6.5%	76.3%	11.79
Low Flow	121024	Monarch Sp	High	2650	0.01	0.16	8.69	6.83	41.0	-100.85	-14.10	1.7%	1.3%	5.4%	91.6%	13.9%	1.6%	6.0%	78.5%	12.97
Low Flow	111022	Not Soda Sp	High	2650	0.09	0.24	8.83	6.68	37.0	-102.91	-13.85	0.6%	0.9%	7.5%	91.0%	9.0%	1.8%	2.5%	86.7%	34.50
Low Flow	121025	Not Soda Sp	High	2650	-0.78	0.20	7.86	4.80	217.0	-101.77	-13.78	0.6%	0.6%	7.7%	91.1%	10.3%	2.6%	2.6%	84.5%	32.93
Low Flow	111022	Beulah Sp	High	2670	-0.09	1.97	8.24	5.66	69.0	-101.93	-14.28	0.5%	3.5%	5.8%	90.2%	4.5%	1.5%	2.3%	91.6%	40.02
Low Flow	121025	Beulah Sp	High	2670	-0.62	0.21	7.69	5.30	357.0	-105.91	-14.74	0.6%	2.6%	5.8%	91.0%	5.6%	2.1%	2.8%	89.4%	31.45
Low Flow	111023	TG Rise	High	2700	-1.22	0.13	7.62	3.94	110.0	-90.74	-13.19	0.5%	0.0%	2.1%	97.4%	6.9%	1.5%	4.9%	86.7%	17.73
Low Flow	111023	Crystal Creek Spring	High	2775	-0.46	0.56	8.06	5.90	87.0	-103.12	-13.56	1.0%	1.1%	3.0%	95.0%	7.3%	2.1%	2.6%	88.0%	33.62
Low Flow	121025	Crystal Creek Spring	High	2775	0.06	0.66	8.41	6.56		-105.11	-14.50	0.5%	0.7%	3.9%	94.8%	9.0%	2.0%	2.8%	86.2%	30.55
Low Flow	101017	Bogaz	High	2845	-0.42	0.11	8.75	5.66	43.0	-92.33	-12.62	27.4%	2.7%	5.9%	64.0%	28.4%	4.3%	3.2%	64.2%	20.11
Low Flow	111022	Bogaz	High	2845	-1.94	1.04	7.35	3.10	49.9	-89.97	-12.47	0.4%	3.1%	6.1%	90.3%	5.8%	2.3%	4.6%	87.3%	19.16
Low Flow	121030	Bogaz	High	2845	-0.91	0.18	7.82	4.41	168.0	-90.53	-12.38	1.5%	2.4%	4.0%	92.2%	8.7%	3.3%	4.6%	83.3%	18.12
Low Flow	101017	Corrigans Sink	High	2850	-0.91	0.02	8.40	7.36	33.0	-90.04	-12.08	6.0%	2.1%	5.2%	86.7%	6.5%	0.0%	2.4%	91.1%	38.28
Low Flow	111022	Corrigans Sink	High	2850	-1.39	0.35	7.90	5.30	33.5	-89.26	-12.08	0.6%	1.8%	2.5%	95.0%	5.2%	1.4%	3.2%	90.1%	27.95

Season	Date (YYMMDD)	Site	Elevation Group	Elevation (m)	SIcal	Discharge (m3/s)	pH	Temp (°C)	Spec. Cond. (µS/cm)	δD (°/oo)	$\delta^{18}O$ (°/oo)	Cl^- (% of anions)	NO_3^- (% of anions)	SO_4^{2-} (% of anions)	alkalinity (% of anions)	Na^+ (%of cations)	K^+ (% of cations)	Mg^{2+} (% of cations)	Ca^{2+} (% of cations	Ca/Mg
Low Flow	121030	Corrigans Sink	High	2850	-1.39	0.06	7.56	6.17	161.0	-90.68	-12.45	0.8%	2.5%	4.3%	92.5%	8.2%	2.2%	3.3%	86.2%	26.17
Low Flow	111022	White Chief Mine	High	2930	-1.23	0.00	7.66	4.50	65.3	-83.88	-11.93	0.5%	1.7%	3.4%	94.4%	3.9%	1.7%	3.1%	91.3%	29.79
Low Flow	101017	White Chief Sp	High	2960	-0.31	0.18	8.68	4.07	35.0	-93.37	-12.16	0.9%	2.4%	4.2%	92.5%	4.6%	1.4%	4.3%	89.6%	20.61
Low Flow	111022	White Chief Sp	High	2960	-1.25	1.43	8.02	3.20	46.3	-91.72	-12.97	1.7%	3.0%	5.4%	89.9%	10.1%	4.4%	5.0%	80.5%	15.94
Low Flow	121030	White Chief Sp	High	2960	-1.11	0.26	7.72	4.59	162.0	-89.57	-12.44	0.7%	2.3%	4.4%	92.5%	6.9%	2.4%	4.8%	85.9%	18.01
Low Flow	101017	White Chief- Bat Slab	High	3010	-0.09	0.14	9.24	4.71	27.0	-92.33	-12.58	2.6%	2.6%	6.5%	88.3%	10.9%	0.0%	4.4%	84.7%	19.41
Low Flow	111022	White Chief- Bat Slab	High	3010	-1.47	1.48	7.97	4.80	37.4	-92.99	-13.28	1.1%	2.0%	7.4%	89.4%	9.9%	3.2%	5.4%	81.6%	15.23
Low Flow	121030	White Chief- Bat Slab	High	3010	-1.54	0.19	7.66	5.79	151.0	-89.18	-12.25	1.2%	2.9%	6.6%	89.4%	9.8%	3.2%	6.0%	81.1%	13.61
Low Flow	111022	Bluebell sp	High	3030	-1.68	0.21	7.62	4.98	74.0	-95.06	-12.98	0.5%	2.7%	5.7%	91.1%	10.0%	2.2%	3.1%	84.7%	27.01
Low Flow	111022	Onion Mdw Sp	High	3030	-1.66	2.37	8.00	9.92	20.0	-107.24	-14.59	0.5%	0.0%	6.4%	93.1%	18.2%	0.2%	0.1%	81.6%	1446.00
Low Flow	121025	Onion Mdw Sp	High	3030	-2.08	0.55	7.40	5.00	108.7	-100.41	-13.39	2.9%	1.4%	14.5%	81.1%	24.7%	4.5%	1.9%	68.9%	36.11
Low Flow	111022	Shower Cave	High	3090	-1.25	0.40	8.43	5.36	17.0	-102.20	-14.51	0.0%	0.0%	0.0%	100.0%	23.4%	3.4%	2.2%	71.0%	32.20
Low Flow	121025	Shower Cave	High	3090	-1.47	0.10	7.54	3.50	15.0	-103.94	-14.39	0.8%	0.6%	2.7%	95.9%	14.9%	3.0%	1.5%	80.7%	52.73
Low Flow	101018	Alder Sp	Low	570	0.37	0.13	7.89	15.16	256.0	-66.65	-9.68	3.1%	0.1%	1.1%	95.7%	23.2%	1.9%	12.4%	62.5%	5.02
Low Flow	111024	Alder Sp	Low	570	0.95	0.28	8.41	14.91	273.0	-69.47	-9.89	1.4%	1.0%	3.0%	94.5%	4.8%	1.4%	9.4%	84.4%	8.99
Low Flow	121022	Alder Sp	Low	570	-0.37	0.13	7.09	14.64	230.0	-70.38	-10.26	1.3%	0.1%	2.8%	95.8%	21.9%	2.1%	12.2%	63.8%	5.22
Low Flow	111024	Stream 3	Low	775	0.24	0.05	7.69	14.40	424.0	-69.57	-9.75	1.9%	0.0%	5.9%	92.2%	27.0%	3.4%	24.6%	44.9%	1.82
Low Flow	121027	stream 3 (deer Cr	Low	775	0.92	0.01	8.39	14.17	257.0	-71.19	-10.45	1.0%	0.0%	6.6%	92.4%	13.5%	3.6%	29.7%	53.2%	1.79
Low Flow	111024	Hospital Rock Sp	Low	830	0.74	0.06	8.37	13.02	180.0	-74.25	-10.55	1.2%	0.4%	9.0%	89.4%	14.3%	2.6%	9.6%	73.5%	7.68
Low Flow	111024	Keyhole Spring	Low	830	0.66	0.80	8.30	17.03	287.0	-73.69	-10.15	1.0%	0.0%	5.3%	93.7%	18.2%	3.6%	10.9%	67.4%	6.21
Low Flow	111024	Stream 2	Low	850	1.06	0.02	8.51	16.20	396.0	-71.79	-10.13	1.0%	0.0%	6.3%	92.7%	12.3%	3.2%	29.0%	55.4%	1.91
Low Flow	111024	Stream 1	Low	900	0.72	0.20	8.13	13.20	362.0	-76.76	-10.87	0.6%	0.1%	4.5%	94.8%	8.8%	2.7%	9.9%	78.7%	7.94
Low Flow	121027	stream 1 (slide Sp)	Low	900	0.61	0.07	8.17	13.23	154.0	-76.71	-11.27	0.7%	0.0%	5.0%	94.2%	12.2%	3.6%	14.3%	70.0%	4.89
Low Flow	111024	Warm River	Low	1020	0.33	0.13	7.68	18.88	302.0	-79.83	-11.41	0.5%	0.1%	2.9%	96.5%	6.8%	1.6%	7.5%	84.1%	11.20
Low Flow	121027	Warm River	Low	1020	0.02	0.06	7.36	18.63	192.0	-80.05	-11.32	0.4%	1.3%	2.9%	95.4%	6.6%	1.6%	7.0%	84.8%	12.07
Low Flow	101228	Upper Smoking Sp	Low	1050	1.06	0.30	8.79	10.19	173.0	-78.42	-11.23	0.8%	0.0%	6.8%	92.4%	10.0%	3.5%	11.7%	74.8%	6.37
Low Flow	111024	Upper Smoking Sp	Low	1050	1.45	0.04	9.12	13.19	250.0	-78.23	-11.22	0.9%	1.4%	9.8%	87.8%	11.7%	3.5%	12.6%	72.2%	5.75
Low Flow	121027	Upper Smoking Sp	Low	1050	0.73	0.02	8.27	10.53	189.0	-79.50	-10.95	0.8%	0.0%	9.0%	90.2%	12.1%	3.6%	12.7%	71.6%	5.64
Low Flow	111020	Lange Sp	Low	1240	0.30	0.01	7.96	10.37	187.0	-78.62	-11.68	0.9%	0.2%	0.9%	97.9%	12.0%	1.8%	35.3%	50.9%	1.44
Low Flow	101013	Kuala Sp	Low	1250	-0.49	0.14	7.08	10.42	308.0	-75.62	-11.05	6.0%	0.9%	0.7%	92.3%	9.8%	1.3%	35.8%	53.0%	1.48
Low Flow	111020	Kuala Sp	Low	1250	-0.62	0.11	6.89	10.36	304.0	-77.49	-11.44	0.4%	0.3%	0.4%	98.9%	11.0%	1.5%	45.7%	41.8%	0.91
Low Flow	121023	Kuala Sp	Low	1250	-0.30	0.06	6.98	10.51	288.0	-78.44	-11.43	1.1%	0.5%	0.7%	97.7%	9.3%	1.3%	36.0%	53.4%	1.48
Low Flow	111024	MC Sp4	Low	1275	0.61	0.01	8.01	16.66	351.0	-72.69	-10.10	0.6%	0.3%	1.8%	97.3%	24.6%	2.2%	12.2%	61.0%	5.00
Low Flow	111020	Contact Sp	Low	1340	-0.46	0.01	7.54	11.26	115.0	-79.41	-11.83	2.7%	0.4%	1.1%	95.9%	22.0%	3.0%	10.1%	64.9%	6.42
Low Flow	121023	Contact Sp	Low	1340	-0.31	0.00	7.52	10.28	130.0	-79.18	-11.66	3.1%	0.2%	0.8%	95.9%	21.8%	2.7%	9.8%	65.6%	6.67
Low Flow	101015	Hurricane Crawl	Low	1340	0.42	0.07	8.41	10.53	171.0	-74.16	-10.90	3.7%	2.1%	1.5%	92.8%	14.2%	1.7%	10.7%	73.4%	6.83
Low Flow	111020	Hurricane Crawl	Low	1340	0.26	0.14	8.04	10.73	143.0	-77.33	-11.52	0.7%	0.7%	1.1%	97.4%	15.6%	2.0%	10.2%	72.2%	7.07
Low Flow	121023	Hurricane Crawl	Low	1340	0.59	0.10	8.24	10.21	163.0	-77.61	-11.39	0.5%	0.4%	1.0%	98.1%	13.4%	1.7%	11.1%	73.8%	6.65
Low Flow	101013	Crystal Cave	Low	1395	-0.79	0.83	7.55	10.85	83.0	-75.26	-11.51	4.9%	0.0%	0.7%	94.4%	23.3%	3.8%	7.2%	65.8%	9.16
Low Flow	121023	Crystal Cave	Low	1395	-0.91	0.37	7.35	11.01	86.0	-79.31	-11.59	1.5%	0.3%	0.9%	97.4%	22.6%	3.8%	7.0%	66.6%	9.48
Low Flow	111020	Crystal Cave	Low	1395	-1.44	0.75	6.90	10.80	73.0	-79.46	-11.54	1.5%	0.0%	1.1%	97.4%	24.2%	3.7%	7.3%	64.8%	8.82
Low Flow	101014	Mossy Sp	Low	1395	0.34	0.05	7.38	10.12	603.0	-78.80	-11.76	28.0%	0.1%	0.7%	71.3%	17.5%	1.0%	10.4%	71.2%	6.88
Low Flow	111020	Mossy Sp	Low	1395	-0.30	0.08	7.14	9.96	546.0	-81.32	-11.71	7.5%	0.0%	0.9%	91.6%	33.8%	2.1%	19.9%	44.2%	2.22
Low Flow	121023	Mossy Sp	Low	1395	0.82	0.06	7.59	10.02	564.0	-81.65	-11.94	4.8%	0.0%	0.5%	94.7%	19.9%	1.2%	11.8%	67.1%	5.66
Low Flow	101013	Cave Cr Sp	Low	1415	-0.33	0.78	7.76	9.66	163.0	-75.39	-11.37	4.5%	0.4%	1.5%	93.6%	16.6%	2.1%	35.7%	45.6%	1.28
Low Flow	111020	Cave Cr Sp	Low	1415	-0.51	0.90	7.42	9.75	157.0	-78.36	-11.70	0.9%	0.8%	1.5%	96.8%	15.9%	2.1%	36.1%	45.9%	1.27
Low Flow	121023	Cave Cr Sp	Low	1415	-0.17	0.23	7.58	9.70	168.0	-78.09	-11.22	0.7%	0.5%	1.2%	97.6%	14.6%	1.9%	36.3%	47.2%	1.30
Low Flow	101013	Rimstone Sp	Low	1435	0.81	0.27	7.90	10.96	395.0	-78.80	-11.47	7.5%	0.0%	0.7%	91.8%	11.0%	0.9%	12.3%	75.8%	6.15
Low Flow	111020	Rimstone Sp	Low	1435	0.20	0.03	7.64	10.06	339.0	-78.42	-11.65	1.7%	0.2%	1.3%	96.8%	15.4%	0.0%	19.3%	65.3%	3.38
Low Flow	121028	Rimstone Sp	Low	1435	0.61	0.04	7.89	9.78	337.0	-80.98	-11.39	1.7%	0.0%	1.1%	97.2%	13.0%	1.6%	16.1%	69.3%	4.31
Low Flow	100919	Big Spring	Low	1460	-0.62	4.04	7.20	9.24	160.0	-79.64	-11.63	1.0%	0.0%	1.1%	97.9%	14.7%	2.2%	5.7%	77.4%	13.57
Low Flow	111020	Big Spring	Low	1460	-0.24	5.00	7.66	9.00	191.0	-81.73	-11.84	1.2%	0.0%	1.1%	97.7%	15.1%	2.7%	5.5%	76.8%	13.89
Low Flow	121031	Big Spring	Low	1460	-0.10	2.21	7.67	9.22	132.0	-83.49	-12.01	1.1%	0.0%	1.1%	97.8%	15.7%	2.3%	6.9%	75.1%	10.95
Low Flow	111021	Equinous Sp	Low	1540	0.41	0.02	8.12	8.73	387.0	-79.70	-11.53	0.3%	0.0%	0.5%	99.2%	2.1%	0.9%	67.5%	29.4%	0.44
Low Flow	101013	Dogwood Sp	Low	1570	-0.11	0.04	7.28	9.02	373.0	-76.93	-11.25	1.3%	0.0%	0.3%	98.4%	1.5%	0.5%	48.0%	50.0%	1.04
Low Flow	111021	Dogwood Sp	Low	1570	-0.10	0.04	7.59	8.93	399.0	-78.56	-11.73	0.4%	0.0%	0.4%	99.3%	2.4%	0.7%	67.8%	29.0%	0.43
Low Flow	121028	Dogwood Sp	Low	1570	-0.12	0.02	7.11	9.18	356.0	-80.14	-11.76	0.3%	0.0%	0.3%	99.4%	2.0%	0.6%	47.7%	49.7%	1.04
Low Flow	111024	Paradise Sp	Low	1600	0.21	0.01	8.15	10.67	153.0	-73.06	-10.37	3.1%	0.1%	1.0%	95.8%	34.4%	4.3%	13.4%	47.9%	3.59
Low Flow	111024	MC Sp 1	Low	1650	0.77	0.20	7.97	17.16	385.0	-78.13	-10.35	0.3%	0.3%	1.3%	98.1%	1.9%	1.1%	9.2%	87.8%	9.55

APPENDIX 3

DYE TRACE RESULTS

CRAWFORD HYDROLOGY LAB * HOFFMAN ENVIRONMENTAL RESEARCH INSTITUTE

** Hydrogeologists, Geologists, Environmental Scientists **
** Karst Groundwater Investigations * Fluorescent Dye Analysis*

LABORATORY REPORT SHEET

FLUORIMETRIC ANALYSIS RESULTS

YUCCA

Analysis requested by:

BEN TOBIN

	FLUORESCEIN	EOSINE	RHODAMINE WT
Color Index:	Acid Yellow 73	Acid Red 87	
Dye Receptor:	Activated Charcoal	Activated Charcoal	Activated Charcoal
Analysis by:	Spectrofluorophotometer	Spectrofluorophotometer	Spectrofluorophotometer

Lab ID	Event	Date Collected	Feature Name	TIME COLLECTED	Peakfit	FLUORESCEIN PQL in Eluent: 0.005 ppb PQL in Water: 0.010 ppb λ in Eluent: 516.0 nm λ in Water: 510.0 nm			EOSINE PQL in Eluent: 0.005 ppb PQL in Water: 0.010 ppb λ in Eluent: 540.1 nm λ in Water: 534.4 nm			RHODAMINE WT PQL in Eluent: 0.005 ppb PQL in Water: 0.010 ppb λ in Eluent: 567.7 nm λ in Water: 574.5 nm			Comments
						Results	Conc in ppb	Peak Center (nm)	Results	Conc in ppb	Peak Center (nm)	Results	Conc in ppb	Peak Center (nm)	
EL-001-0	BG1	06/10/12	Rimstone Creek	945		ND			ND			ND	0.052	NPI	
EL-001-0	02	06/18/12	Rimstone Creek	1215		B	0.008	507.2,POR	ND	0.026	NPI	ND	0.058	NPI	
EL-001-0	03	07/22/12	Rimstone Creek	1804		ND	0.015	NPI	ND	0.018	NPI	ND	0.062	NPI	
EL-002-0	BG1	06/10/12	Kuala Spring	1000		B	0.011	506.4,POR	ND			IB	0.076	563.6	
EH-002-0	02	06/18/12	Kuala Spring	1223		+++	13.821	515.6	ND			ND			
EL-002-0	03	07/22/12	Kuala Spring	1807		++	1.002	516.0	+?	0.993	538.2	ND			Receptor found out of water at retrieval
EL-003-0	BG1	06/10/12	Lower Yucca Creek	1045		ND	0.008	NPI	ND			ND	0.092	NPI	
EH-003-D	02	06/18/12	Lower Yucca Creek	1245		+++	227.500	515.6	ND			ND			DILUTED 1:100
EH-003-0	03	07/22/12	Lower Yucca Creek	1844		++	1.460	516.6	+?	7.411	539.2	ND			
EL-004-0	BG1	06/10/12	Lange Spring	1115		B	0.014	507.0,POR	ND			ND	0.080	NPI	
EH-004-0	02	06/18/12	Lange Spring	1240		+++	84.473	515.8	ND			ND			
EH-004-0	03	07/22/12	Lange Spring	1837		++	1.536	516.2	+?	5.053	539.4	ND			
EL-005-0	BG1	06/10/12	Cave Creek Spring	1200		ND			B	0.094	531.4,POR	ND	0.024	NPI	
EH-005-0	02	06/18/12	Cave Creek Spring	1330		ND			ND			++	2.377	566.2	
EH-005-0	03	07/22/12	Cave Creek Spring	1903		ND			ND			+++	9.102	566.2	
EL-006-0	BG1	06/10/12	Schist Falls	1100		ND			ND	0.013	NPI	ND	0.079	NPI	
EH-006-D	02	06/18/12	Schist Falls	1400		+++	271.400	515.6	ND			ND			DILUTED 1:100
EH-006-0	03	07/22/12	Schist Falls	2104		++	1.742	516.8	+?	9.810	539.0	ND			
EL-007-0	BG1	06/10/12	Contact Spring	1115		ND	0.015	NPI	ND			B	0.086	561.2,POR	
EH-007-0	02	06/18/12	Contact Spring	1620		+++	7.833	515.6	ND			B	0.027	565.6	
EH-007-0	03	07/22/12	Contact Spring	2145		++	2.194	515.6	ND			ND			
EL-008-0	BG1	06/10/12	Crystal Cave	1030		B	0.020	507.2,POR	ND			ND	0.114	NPI	
EH-009-D	02	06/18/12	Hurricane Crawl	2345		+++	120.7	515.8	ND			ND			No Background/DILUTED 1:100
EH-008-0	03	07/22/12	Crystal Cave	2231		+++	49.189	515.6				ND			
EL-008-0	04	10/23/12	Crystal Cave	1745		++	0.617	516.4	ND			ND	0.013	NPI	
EH-008-D	02	06/18/12	Crystal Cave	1700		ND			+++	1965.300	540.2	ND			DILUTED 1:100
EH-009-D	04	10/23/12	Hurricane Crawl	1500		ND			+++	505.800	539.8	ND			DILUTED 1:100

Approved by: L. Bledsoe **on** 11/26/12 — Peakfit needed for acurate results

Comments: These samples were most likely mislabled in the lab or field.

DUP = Field Duplicate
B = Background
ND = No Detection
IB = Initial Background
Q = Lab Duplicate
\+ = Positive
?+ = Questionable Positive
Peakfit Utilized

LABORATORY REPORT SHEET

FLUORIMETRIC ANALYSIS RESULTS

MIKI

Analysis requested by:

BEN TOBIN

RHODAMINE WT

Color Index:

Dye Receptor:
Activated Charcoal
Analysis by:
Spectrofluorophotometer

Lab ID	Event	Date Collected	Feature Name	TIME COLLECTED	Peakfit	RHODAMINE WT PQL in Eluent: 0.005 ppb PQL in Water: 0.010 ppb λ in Eluent: 567.7 nm λ in Water: 574.5 nm Results	Conc in ppb	Peak Center (nm)	Comments
EL-001-0	BG1	06/11/12	Monarch Spring	-		ND	0.022	NPI	
EL-001-0	02	06/15/12	Monarch Spring	-		+?	0.089	565.0	
EL-002-0	BG1	06/11/12	Crystal Creek	-		B	0.095	559.2,POR	
EH-002-0	02	06/15/12	Crystal Creek	-		+?	91.498	567.8	
EL-003-0	BG1	06/11/12	Crystal Spring	-		ND	0.043	NPI	
EH-003-D	02	06/15/12	Crystal Spring	-		+?	359.200	567.2	DILUTED 1:100
EL-004-0	BG1	06/11/12	East Fork	-		IB	0.089	563.2	
EL-004-0	02	06/15/12	East Fork	-		ND	0.037	NPI	
EL-005-0	BG1	06/11/12	Beulah	-		B	0.040	561.45,POR	
EL-005-0	02	06/15/12	Beulah	-		B	0.033	558.8.POR	
EL-006-0	BG1	06/11/12	Onion Meadow Spring	-		B	0.062	558.2,POR	
EL-006-0	02	06/15/12	Onion Meadow Spring	-		ND	0.051	NPI	
EL-007-0	BG1	06/11/12	Shower Cave	-		ND	0.090	NPI	
EH-007-D	02	06/15/12	Shower Cave	-		+?	2716.100	567.8	DILUTED 1:100
EL-008-0	02	06/15/12	Aspen Spring	-		+?	0.060	562.6	No Background
EL-009-0	02	06/15/12	Monarch Creek	-		ND	0.052	NPI	No Background
EL-010-0	02	06/15/12	Not Soda Spring	-		ND	0.088	NPI	No Background

Approved by: **L. Bledsoe** **on** **07/31/12**

Comments:

DUP = Field Duplicate **Q = Lab Duplicate**
B = Background **+ = Positive**
ND = No Detection **?+ = Questionable Positive**
IB = Initial Background **Peakfit Utilized** **Peakfit needed for acurate results**

APPENDIX 4

RAW DATA FROM FIELD MEASUREMENTS AND LAB ANALYSES

Date	Sample ID	Site	Field Water Quality						Isotopes		
			Discharge	DO	pH	Temp	Spec.Con	ORP	δD	δO	δ-excess
100511	KH-1	Alder Sp	1.205	6.9	7.75	13.14	166	20.3	-65.69	-9.29	8.63
100512	KH-2	Rimstone Sp	0.107	4.1	8.00	10.53	433	-2.8	-80.13	-11.76	13.95
100512	KH-3	Kuala Sp	0.199	4.52	7.05	8.93	291	32.6	-77.98	-11.69	15.54
100512	KH-4	WTF Sp	0.007	7.91	8.37	11.4	436	11.1	-73.56	-11.3	16.84
100512	KH-5	Cave Cr Sp	3.179	7.59	7.62	8.37	181	27.4	-74.75	-11.37	16.21
100512	KH-6	Lange Sp	0.636	6.88	7.44	8.56	207	52	-75.82	-11.49	16.1
100512	KH-7	Contact Sp	0.194	5.56	7.61	8.06	145	14.9	-76.68	-11.5	15.32
100512	KH-8	Hurricane Crawl	1.516	5.53	7.84	7.93	70	21.6	-74.75	-11.22	15.01
100514	KH-9	Upper Smoking Sp	0.004	8.94	8.28	12.41	127	12	-74.75	-10.87	12.21
100514	KH-10	Warm River	2.201	8.79	7.71	17.04	289	4	-76.9	-11.03	11.34
100522	KH-11	Mossy Sp	0.327	6.59	6.78	np	736	9.3	-77.98	-11.26	12.1
100522	KH-12	Crystal Cave	1.07	5.31	7.28	np	101	6.6	-76.9	-11.39	14.22
100522	KH-13	Equinous Sp	0.163	5.38	7.08	np	467	18	-76.04	-10.97	11.72
100526	KH-14	MC Sp 1	0.024	5.23	7.91	9.02	310	15.1	-74.75	-10.8	11.65
100526	KH-15	MC Sp3	0.029	7.45	7.78	8.44	116	28	-68.06	-9.98	11.78
100526	KH-16	MC Sp2	0.005	3.87	7.78	11.63	267	3.8	-70.83	-10.53	13.41
100526	KH-17	MC Sp4	0.021	6.2	8.05	11.64	264	40.3	-72.09	-10.51	11.99
100526	KH-18	Keyhole Spring	0.948	8.15	7.78	10.68	220	34.2	-70.34	-10.22	11.42
100602	KH-19	Warm River	0.982	4.27	7.55	19.12	328	1.6	-79.05	-12.04	17.27
100605	KH-20	Rimstone Cr @ Yucc	0.477	5.58	8.46	13.84	425	13	-76.04	-11.65	17.16
100605	KH-21	Kuala Sp	0.057	3.07	7.16	11.56	313	19.1	-77.11	-11.23	12.73
100605	KH-22	Lange Sp	0.654	4.76	7.91	15.16	234	0	-75.82	-11.19	13.7
100605	KH-23	WTF Sp	0.006	5.56	8.54	13.93	466	21.9	-72.83	-10.56	11.65
100605	KH-24	Cave Cr Sp	0.39	5.42	7.86	11.91	164	22.2	-75.02	-10.94	12.5
100605	KH-25	Contact Sp	0.107	4.16	7.69	15.01	155	-7.6	-75.82	-10.82	10.74
100605	KH-26	Mossy Sp	0.14	4.9	7.09	10.21	575	32.2	-80.34	-11.93	15.1
100605	KH-27	Crystal Cave	1.062	5.34	7.42	10.17	75	7.2	-76.9	-11.48	14.94
100609	KH-28	Mossy Sp	0.14	7.13	7.21	9.87	504	53.8	-79.91	-11.83	14.73
100609	KH-29	Crystal Cave	1.02	7.52	7.22	8.51	73	73.8	-76.9	-11.74	17.02
100609	KH-30	Rimstone Sp	0.122	4.91	7.69	14.57	485	39	-77.76	-11.28	12.48
100609	KH-31	Dogwood Sp	0.175	3.68	7.01	8.18	394	27.5	-77.98	-11.66	15.3
100609	KH-32	Equinous Sp	0.091	3.9	7.11	8.65	368	25.8	-76.68	-11.5	15.32
100626	KH-33	Big Spring		7.7	8.43	8.21	89	3.8	-77.76	-11	10.24
100626	KH-34	Baldy Sp	0.196	3.59	6.39	9.11	26	41.2	-71.96	-10.11	8.92
100702	KH-35	Warm River	0.614	7.18	7.77	18.94	296	32.8	-75.62	-10.94	11.9
100702	KH-36	Upper Smoking Sp	0.129	8.34	8.31	13.73	223	18.3	-75.47	-10.94	12.05
100704	KH-37	Big Spring		7.52	7.97	8.59	98	19.2	-80.08	-11.67	13.28
100713	KH-38	Monarch Sp	0.496	3.75	8.55	8.44	54	-45.2	-100.16	-14.04	12.16
100713	KH-39	Bluebell Sp	0.936	3.58	8.89	7.24	15	-92.1	-99.1	-13.84	11.62
100714	KH-40	Aspen Spring	0.594	3.9	8.11	6.28	64	-18	-98.04	-13.81	12.44
100715	KH-41	Crystal Cave		6.49	7.36	9.86	85	7.1	-74.27	-11.08	14.37
100720	KH-42	Alder Sp	0.335	5.17	7.60	13.94	224	164.8	-67.14	-9.4	8.06
100721	KH-43	Mossy Sp	0.092	7.08	7.45	9.99	622	35.6	-79.03	-10.83	7.61
100721	KH-44	Crystal Cave	0.874	6.78	7.81	10.25	84	26.9	-76.55	-10.99	11.37
100722	KH-45	Panorama Overflow S	0.7	4.77	8.17	8.03	26	12.1	-100.16	-13.61	8.72
100722	KH-46	Meadow Sp	1.35	4.83	7.71	12.74	17	15.5	-102.27	-14.14	10.85
100722	KH-47	Franklin blw karst	9.133	5.05	7.52	13.55	18	28.9	-103.32	-14.09	9.4
100722	KH-48	Beulah Sp	0.284	5.66	8.33	5.51	57	39.3	-104.38	-14.29	9.94
100722	KH-49	Not Soda Sp	0.108	4.82	8.88	8.83	32	-10.5	-101.42	-13.86	9.46
100723	KH-50	Bogaz	0.447	5.59	7.86	6.02	19	22.7	-95.08	-13.06	9.4
100723	KH-51	White Chief Lake	1.593	5.46	7.60	5.97	20	42.6	-94.87	-13.06	9.61
100723	KH-52	Bogaz	2.128	5.57	7.63	7.24	20	73.9	-93.82	-12.89	9.3
100723	KH-53	White Chief Creek ab	3.614	5.56	7.98	8.31	21	11.4	-94.87	-13.01	9.21
100728	KH-54	East Fork @ Miki Rd		9.82	8.08	10.8	66	-11.7	-100.16	-13.47	7.6
100728	KH-55	Tufa Sp		7.83	8.57	8.41	70	-33.9	-99.1	-13.38	7.94
100729	KH-56	Cirque Entrance	1.376	5.96	7.07	10.91	8	-4.1	-90.44	-12.45	9.16
100729	KH-57	White Chief Sp	2.405	5.95	8.26	4.68	19	-12.3	-94.66	-13.31	11.82
100729	KH-58	Eagle Sink	1.653	5.97	7.20	14.03	11	-24.7	-94.66	-13.16	10.62
100804	KH-59	Crystal Creek Spring	21.945	1.5	9.17	13.24	100	-46.5	-102.27	-14.17	11.09
100805	KH-60	East Fork @ Miki Rd		4.55	9.79	12.66	81	-41.2	-99.1	-14.23	14.74
100805	KH-61	Tufa Sp	7.789	4.35	10.14	8.52	87	-28.1	-99.31	-14.11	13.57
100814	KH-62	Lilburn-East St	0.006	6.3	7.94	7.44	233	-21.8	-76.47	-11.4	14.73
100814	KH-63	Lilburn-White Rapids	4.045	7.66	7.74	9.19	135	-4.9	-81.14	-11.51	10.94
100814	KH-64	Lilburn-Mays Infeeder	0.043	7	7.87	7.86	99	-17.7	-76.91	-10.95	10.69
100814	KH-65	Lilburn-Alto St.	0.001	5.59	8.03	8.27	213	-19.9	-76.72	-11.17	12.64
100814	KH-66	Lilburn-West St	0.108	7.79	8.35	6.5	147	-7.9	-77.97	-11.35	12.83
100814	KH-67	Lilburn-Enchanted R	4.037	7.26	8.30	9.16	134	-12.4	-81.14	-11.74	12.78
100814	KH-68	Lilburn-Z room	4.788	8.31	8.22	9.26	133	-0.9	-81.35	-11.84	13.37
100815	KH-69	Mays Creek	0.005	5.15	8.57	12.07	24	np	-78.18	-11.4	13.02
100815	KH-70	Big Spring	6.433	7.45	8.05	9.24	136	-7.7	-81.35	-11.9	13.85
100815	KH-71	Volvo Creek	0.05	6.99	8.80	12.02	37	-24.1	-82.2	-12	13.8
100815	KH-72	Redwood Cr	1.839	6.24	8.24	14.1	41	-23.2	-80.93	-11.81	13.55

Date	Sample ID	Site	Anions								Cations								Charge Balance (% error)
			F	Cl	NO_2	Br	NO_3	PO_4	SO_4	Alk	Li	Na	NH_4	K	Mg	Ca	Sr	Ba	
100511	KH-1	Alder Sp	0.22	1.97	0.00	0.00	0.00	0.00	4.41	106.57	0.00	7.57	0.00	1.37	4.00	31.98	np	np	8.6%
100512	KH-2	Rimstone Sp	0.09	7.83	0.00	0.00	0.00	0.00	3.43	99.37	0.00	8.26	0.00	1.51	10.54	35.46	np	np	22.0%
100512	KH-3	Kuala Sp	0.13	2.58	0.00	0.00	1.75	0.00	2.55	178.87	0.00	5.02	0.00	1.35	20.20	42.79	np	np	13.2%
100512	KH-4	WTF Sp	0.10	0.80	0.00	0.00	4.41	0.00	8.34	261.38	0.00	1.10	0.00	0.74	48.00	31.89	np	np	9.9%
100512	KH-5	Cave Cr Sp	0.10	1.15	0.00	0.00	3.41	0.00	3.36	168.03	0.00	3.60	0.00	1.14	16.08	29.92	np	np	1.2%
100512	KH-6	Lange Sp	0.10	1.27	0.00	0.00	2.62	0.00	3.18	149.36	0.00	3.51	0.00	1.13	16.93	35.86	np	np	12.6%
100512	KH-7	Contact Sp	0.09	1.58	0.00	0.00	0.96	0.00	2.42	97.85	0.00	4.18	0.00	1.15	3.47	36.08	np	np	14.1%
100512	KH-8	Hurricane Crawl	0.07	0.92	0.00	0.00	0.50	0.00	1.83	51.34	0.00	3.60	0.00	0.87	1.40	15.83	np	np	7.9%
100514	KH-9	Upper Smoking Sp	0.11	1.78	0.00	0.00	0.61	0.00	15.01	147.90	0.00	4.57	0.00	1.54	4.21	45.09	np	np	-0.5%
100514	KH-10	Warm River	0.10	0.91	0.00	0.00	2.11	0.00	6.76	123.20	0.00	2.87	0.00	0.71	2.85	44.45	np	np	7.0%
100522	KH-11	Mossy Sp	0.19	16.44	0.00	0.00	0.42	0.00	3.19	185.00	0.00	16.34	0.00	1.96	10.90	40.92	np	np	1.5%
100522	KH-12	Crystal Cave	0.07	0.96	0.00	0.00	0.76	0.00	1.40	54.21	0.00	3.68	0.00	1.02	1.21	17.38	np	np	8.8%
100522	KH-13	Equinous Sp	0.17	0.77	0.00	0.00	0.00	0.00	1.44	147.86	0.00	1.10	0.00	0.99	38.30	41.21	np	np	35.9%
100526	KH-14	MC Sp 1	0.00	0.67	0.00	0.00	1.52	0.00	3.89	71.47	0.00	0.95	0.00	1.07	3.95	55.55	np	np	41.4%
100526	KH-15	MC Sp3	0.00	0.75	0.00	0.00	0.33	0.00	10.05	59.15	0.00	1.50	0.00	1.01	3.57	66.22	np	np	49.5%
100526	KH-16	MC Sp2	0.06	1.46	0.00	0.00	0.23	0.00	6.93	78.86	0.00	3.09	0.00	1.69	1.72	30.48	np	np	9.7%
100526	KH-17	MC Sp4	0.10	0.91	0.00	0.00	1.11	0.00	5.92	115.75	0.00	1.62	0.00	0.81	3.35	59.28	np	np	22.7%
100526	KH-18	Keyhole Spring	0.09	1.36	0.00	0.00	0.62	0.00	11.05	82.15	0.00	4.36	0.00	1.85	3.68	49.70	np	np	28.6%
100602	KH-19	Warm River	0.09	0.86	0.00	0.00	2.57	0.00	7.49	49.28	0.00	2.60	0.00	1.09	2.97	50.87	np	np	46.6%
100605	KH-20	Rimstone Cr @ Yucc	0.18	1.67	0.00	0.00	0.26	0.00	2.26	147.86	0.00	2.14	0.00	1.11	35.82	41.80	np	np	34.0%
100605	KH-21	Kuala Sp	0.13	2.94	0.00	0.00	1.41	0.00	2.99	160.19	0.00	5.65	0.00	1.44	23.99	56.45	np	np	28.6%
100605	KH-22	Lange Sp	0.10	1.33	0.00	0.00	1.85	0.00	2.83	49.29	0.00	3.97	0.00	1.19	15.88	34.90	np	np	54.7%
100605	KH-23	WTF Sp	0.08	1.05	0.00	0.00	4.27	0.00	9.03	154.03	0.00	1.81	0.00	0.89	46.88	67.02	np	np	43.8%
100605	KH-24	Cave Cr Sp	0.13	1.17	0.00	0.00	1.72	0.00	2.71	69.54	0.00	4.65	0.00	1.20	11.92	23.30	np	np	30.2%
100605	KH-25	Contact Sp	0.10	1.77	0.00	0.00	0.57	0.00	1.86	79.54	0.00	4.56	0.00	1.18	3.17	33.07	np	np	20.4%
100605	KH-26	Mossy Sp	0.24	18.39	0.00	0.00	0.36	0.00	3.46	87.60	0.00	17.85	0.00	2.10	11.68	67.46	np	np	42.9%
100605	KH-27	Crystal Cave	0.05	0.96	0.00	0.00	0.66	0.00	1.36	28.79	0.00	4.04	0.00	1.06	1.20	17.20	np	np	35.9%
100609	KH-28	Mossy Sp	0.20	18.89	0.00	0.00	0.30	0.00	3.47	97.36	0.00	18.09	0.00	2.10	11.78	55.52	np	np	34.5%
100609	KH-29	Crystal Cave	0.06	0.97	0.00	0.00	0.42	0.00	1.47	42.21	0.00	3.68	0.00	1.02	1.21	17.33	np	np	20.1%
100609	KH-30	Rimstone Sp	0.10	7.76	0.00	0.00	0.00	0.00	3.24	72.96	0.00	8.47	0.00	1.54	10.60	41.42	np	np	38.1%
100609	KH-31	Dogwood Sp	0.14	0.86	0.00	0.00	0.00	0.00	1.08	129.56	0.00	1.36	0.00	0.83	40.28	70.18	np	np	51.9%
100609	KH-32	Equinous Sp	0.13	0.80	0.00	0.00	0.00	0.00	1.69	141.28	0.00	1.45	0.00	1.04	37.87	65.20	np	np	46.0%
100626	KH-33	Big Spring	0.07	0.76	0.00	0.00	0.00	0.00	1.18	38.55	0.00	3.17	0.00	0.87	0.94	24.41	np	np	35.9%
100626	KH-34	Baldy Sp	0.07	1.30	0.00	0.00	0.00	0.00	0.88	17.18	0.00	3.85	0.00	0.69	0.56	3.71	np	np	9.6%
100702	KH-35	Warm River	0.10	0.85	0.00	2.58	0.00	0.00	7.22	140.30	0.00	2.58	0.00	1.00	2.91	55.89	np	np	10.9%
100702	KH-36	Upper Smoking Sp	0.10	1.57	0.00	0.64	0.00	0.00	19.56	88.57	0.00	4.36	0.00	2.16	4.92	50.76	np	np	22.9%
100704	KH-37	Big Spring	0.07	0.76	0.00	0.00	0.00	0.00	1.24	57.58	0.00	3.53	0.00	1.01	1.05	26.32	np	np	22.5%
100713	KH-38	Monarch Sp	0.04	1.42	0.00	1.00	0.00	0.00	3.22	45.38	0.00	2.12	0.00	0.32	0.69	13.50	np	np	-2.9%
100713	KH-39	Bluebell Sp	0.10	0.14	0.00	0.50	0.00	0.00	1.48	9.03	0.00	0.70	0.00	0.00	0.12	3.77	np	np	6.7%
100714	KH-40	Aspen Spring	0.00	0.41	0.00	0.28	0.00	0.00	2.85		0.00	2.75	0.00	0.60	0.74	17.87	np	np	85.3%
100715	KH-41	Crystal Cave	0.07	1.06	0.00	0.61	0.00	0.00	1.15		0.00	3.95	0.00	1.14	1.25	18.63	np	np	89.3%
100720	KH-42	Alder Sp	0.29	2.54	0.00	0.28	0.00	0.00	6.23		0.00	9.73	0.00	1.34	5.09	43.44	np	np	85.0%
100721	KH-43	Mossy Sp	0.22	21.40	0.00	0.28	0.00	0.00	3.73		0.00	19.68	0.00	2.17	13.01	114.63	np	np	83.1%
100721	KH-44	Crystal Cave	0.07	0.95	0.00	0.63	0.00	0.00	1.11		0.00	4.13	0.00	1.15	1.26	18.53	np	np	89.8%
100722	KH-45	Panorama Overflow S	0.20	0.19	0.00	0.23	0.00	0.00	0.75		0.00	0.95	0.00	0.28	0.12	7.06	np	np	83.3%
100722	KH-46	Meadow Sp	0.21	0.14	0.00	0.55	0.00	0.00	3.16		0.00	0.80	0.00	0.30	0.08	3.53	np	np	38.1%
100722	KH-47	Franklin blw karst	0.22	0.15	0.00	0.57	0.00	0.00	3.36		0.00	1.00	0.00	0.27	0.09	3.43	np	np	36.4%
100722	KH-48	Beulah Sp	0.00	0.30	0.00	1.76	0.00	0.00	4.43		0.00	1.16	0.00	0.32	0.29	17.48	np	np	74.2%
100722	KH-49	Not Soda Sp	0.20	0.15	0.00	0.62	0.00	0.00	3.64		0.00	0.82	0.00	0.32	0.14	8.24	np	np	60.9%
100723	KH-50	Bogaz	0.00	0.27	0.00	0.43	0.00	0.00	1.73		0.00	0.46	0.00	0.26	0.18	5.66	np	np	70.4%
100723	KH-51	White Chief Lake	0.00	0.11	0.00	0.46	0.00	0.00	1.75	14.17	0.00	0.43	0.00	0.23	0.17	5.95	np	np	8.1%
100723	KH-52	Bogaz	0.00	0.11	0.00	0.39	0.00	0.00	1.33		0.00	0.38	0.00	0.21	0.15	5.95	np	np	77.8%
100723	KH-53	White Chief Creek ab	0.00	0.14	0.00	0.37	0.00	0.00	1.75		0.00	0.50	0.00	0.26	0.18	5.87	np	np	73.1%
100728	KH-54	East Fork @ Miki Rd	0.12	0.29	0.00	0.00	0.00	0.00	4.80		0.00	1.20	0.00	0.48	0.77	16.70	np	np	75.4%
100728	KH-55	Tufa Sp	0.00	0.70	0.00	0.00	0.00	0.00	2.22	56.68	0.00	1.79	0.00	0.48	1.48	20.20	np	np	9.7%
100729	KH-56	Cirque Entrance	0.04	0.49	0.00	0.34	0.00	0.00	1.75	4.92	0.00	1.48	0.00	0.00	0.11	1.70	np	np	4.5%
100729	KH-57	White Chief Sp	0.00	0.17	0.00	0.53	0.00	0.00	1.83	16.01	0.00	0.50	0.00	0.00	0.18	5.89	np	np	1.8%
100729	KH-58	Eagle Sink	0.00	0.15	0.00	0.00	0.00	0.00	0.78	8.00	0.00	0.63	0.00	0.27	0.14	2.53	np	np	5.2%
100804	KH-59	Crystal Creek Spring	0.17	0.23	0.00	0.26	0.00	0.00	1.85		0.00	1.46	0.00	0.53	0.23	14.47	np	np	85.3%
100805	KH-60	East Fork @ Miki Rd	0.12	0.32	0.00	0.00	0.00	0.00	5.39		0.00	1.35	0.00	0.51	0.90	19.62	np	np	76.5%
100805	KH-61	Tufa Sp	0.00	0.80	0.00	0.30	0.00	0.00	2.43	89.60	0.00	2.18	0.00	0.59	1.74	22.89	np	np	-5.4%
100814	KH-62	Lilburn-East St	0.05	0.65	0.00	0.31	0.00	0.00	0.72	145.00	0.00	1.97	0.00	1.17	2.00	67.76	np	np	20.4%
100814	KH-63	Lilburn-White Rapids	0.10	1.13	0.00	0.00	0.00	0.00	1.69	123.00	0.00	4.14	0.00	1.19	1.50	34.56	np	np	-0.9%
100814	KH-64	Lilburn-Mays Infeeder	0.00	0.68	0.00	0.00	0.00	7.94	0.37	123.00	0.00	3.20	0.00	0.79	0.65	26.11	np	np	-21.5%
100814	KH-65	Lilburn-Alto St.	0.00	0.69	0.00	0.37	0.00	3.49	0.56	135.50	0.00	2.03	0.00	0.85	2.49	61.41	np	np	17.1%
100814	KH-66	Lilburn-West St	0.07	0.50	0.00		0.00	3.06	3.26	135.50	0.00	2.39	0.00	0.96	1.29	42.37	np	np	-1.8%
100814	KH-67	Lilburn-Enchanted R	0.09	1.08	0.00		0.00	0.00	1.66	111.00	0.00	3.53	0.00	1.01	1.46	33.90	np	np	2.4%
100814	KH-68	Lilburn-Z room	0.09	1.05	0.00	0.00	0.00	0.56	1.75	123.00	0.00	3.65	0.00	1.02	1.45	33.78	np	np	-3.1%
100815	KH-69	Mays Creek	0.00	0.80	0.00		0.00	0.00	0.23	13.61	0.00	4.07	0.00	0.89	0.16	1.39	np	np	5.8%
100815	KH-70	Big Spring	0.08	1.00	0.00		0.00	0.00	1.76	110.00	0.00	3.74	0.00	1.03	1.45	34.14	np	np	3.4%
100815	KH-71	Volvo Creek	0.10	0.62	0.00		0.00	0.00	0.72	13.91	0.00	5.69	0.00	1.11	0.52	3.79	np	np	30.8%
100815	KH-72	Redwood Cr	0.04	0.56	0.00		0.00	0.00	0.74	27.70	0.00	3.89	0.00	1.14	0.64	5.51	np	np	3.5%

	Sample		Field Water Quality						Isotopes		
Date	ID	Site	Discharge	DO	pH	Temp	Spec.Con	ORP	δD	δO	δ-excess
100918	KH-73	Redwood Cr	1.911	10.8	7.33	14.99	92	-38.4	-78.8	-11.24	11.12
100918	KH-74	Lilburn-White Rapids	2.906	6.46	7.64	9.2	140	-36.8	-79.84	-11.65	13.36
100918	KH-75	Lilburn-Enchanted R	2.278	5.13	7.73	9.05	139	-27.6	-80.88	-12.04	15.44
100918	KH-76	Lilburn-Z room	2.989	5.7	7.93	9.31	140	-28.6	-80.88	-12.23	16.96
100919	KH-77	Big Spring	4.038	5.37	7.20	9.24	160	-30.8	-79.64	-11.63	13.4
101013	KH-78	Dogwood Sp	0.042	6.13	7.28	9.02	373	38	-76.93	-11.25	13.07
101013	KH-79	Rimstone Sp	0.273	11.47	7.90	10.96	395	-90	-78.8	-11.47	12.96
101013	KH-80	Kuala Sp	0.137	4.35	7.08	10.42	308	-75	-75.62	-11.05	12.78
101013	KH-81	Yucca Cr- Lower	3.015	11.58	8.09	11.66	175	-65	-75.35	-11.51	16.73
101013	KH-82	Cave Cr Sp	0.781	11.44	7.76	9.66	163	-80	-75.39	-11.37	15.57
101013	KH-83	Yucca Creek at Schis	2.685	11.65	8.28	12.5	131	-89	-75.47	-11.38	15.57
101013	KH-84	Yucca Creek at Guide	2.766	11.85	8.05	12.9	108	-96	-75.68	-11.47	16.08
101013	KH-85	Crystal Cave	0.832	11.7	7.55	10.85	83	-28	-75.26	-11.51	16.82
101014	KH-86	Marble Fork @ Crysta	8.331	3.75	7.69	10.51	24	-100	-81.92	-12.1	14.88
101014	KH-87	Cascade Cr	0.24	5.21	8.23	12.03	91	-99.6	-76.72	-11.52	15.44
101014	KH-88	Mossy Sp	0.045	5.68	7.38	10.12	603	-80	-78.8	-11.76	15.28
101014	KH-89	Yucca Cr-Upper	0.236	5.4	7.78	12.62	34	-95	-75.06	-11.02	13.1
101015	KH-90	Hurricane Crawl	0.069	11.36	8.41	10.53	171	-75	-74.16	-10.9	13.04
101015	KH-91	Yucca Creek at Casc	0.012	3.85	6.94	13.04	62	-127	-74.62	-11.01	13.46
101016	KH-92	Slide Sp	0.002	5.9	8.85	23.34	136	4	-53.64	-6.12	-4.68
101016	KH-93	Big Fern Sp.	0.001	1.51	6.49	16.14	103	4	-66.27	-9.63	10.77
101016	KH-94	Marble Fork @ Potwis	11.73	10.16	8.02	16.17	76	-35.4	-79.84	-11.49	12.08
101017	KH-95	Cirque Entrance	0.08	4.7	7.77	7.34	18	-49.4	-89.21	-12.13	7.83
101017	KH-96	White Chief-Bat Slab	0.135	4.58	9.24	4.71	27	-68.3	-92.33	-12.58	8.31
101017	KH-97	White Chief Sp	0.18	4.6	8.68	4.07	35	-58.1	-93.37	-12.16	3.91
101017	KH-98	White Chief Lake	0.015	4.6	8.71	8.09	15	-65.5	-88.17	-11.86	6.71
101017	KH-99	Corrigans Sink	0.016	4.51	8.40	7.36	33	-72	-90.04	-12.08	6.6
101017	KH-100	Bogaz	0.107	4.7	8.75	5.66	43	-71.9	-92.33	-12.62	8.63
101017	KH-101	Eagle Sink	0.149	4.84	8.10	5.94	14	-64	-93.37	-12.48	6.47
101017	KH-102	Eagle Meadow Sp	0.083	4.96	9.20	5.69	201	-64.5	-96.7	-13.01	7.38
101017	KH-103	Tufa Sp	0.78	5.05	9.10	6.81	127	-80	-98.57	-13.14	6.55
101018	KH-104	Alder Sp	0.134	8.92	7.89	15.16	256	-98	-66.65	-9.68	10.79
101227	KH-105	Alder Sp	1.88	6.25	7.37	14.01	192	-83.3	-69.83	-9.97	9.93
101228	KH-106	Warm River	6.668	7.9	7.30	16.41	256	-77.3	-79.24	-11.65	13.96
101228	KH-107	Upper Smoking Sp	0.3	8.5	8.79	10.19	173	-99.2	-78.42	-11.23	11.42
110224	KH-108	Cascade Cr	7.02	11.72	7.26	2.49	31	-19.5	-81.22	-12.59	19.5
110224	KH-109	Mossy Sp	0.225	8.77	7.26	9.87	478	-96.7	-81	-11.82	13.56
110224	KH-110	Crystal Cave	1.196	9.68	7.24	8.04	71	-79.9	-79.35	-11.8	15.05
110224	KH-111	Marble Fork @ Crysta	86.7	11.75	9.08	1.29	11	-59	-91.87	-13.62	17.09
110225	KH-112	Marble Fork @ Potwis	103.68	12.4	8.26	3.17	28	-61.2	-89.74	-12.97	14.02
110225	KH-113	Middle Fork at Potwis	np	10.85	8.56	3.74	29	-51.5	-90.81	-12.87	12.15
110225	KH-114	Salt Cr	13.875	10.45	7.98	6.18	43	-44.4	-73.76	-10.86	13.12
110225	KH-115	North Fork at Kaweah	np	10.75	8.41	6.28	52	-63.6	-82.28	-11.82	12.28
110225	KH-116	South Fork at SF Rd.	np	10.62	8.64	7.2	81	-89.1	-80.15	-11.59	12.57
110225	KH-117	Main Kaweah River at	np	10.8	8.56	6.34	55	-75	-84.41	-12.2	13.19
110224	KH-118	Snow sample at CC r	np	np	np	np	np	np	-83.35	-12.75	18.65

Date	Sample ID	Site	Anions F	Cl	NO_2	Br	NO_3	PO_4	SO_4	Alk	Cations Li	Na	NH_4	K	Mg	Ca	Sr	Ba	Charge Balance
100918	KH-73	Redwood Cr	0.08	1.28	0.00		0.00	0.00	0.87	30.81	0.00	5.29	0.00	0.81	0.70	5.92	np	np	3.1%
100918	KH-74	Lilburn-White Rapids	0.11	1.37	0.00	0.41	0.00	0.00	2.37	135.50	0.00	3.89	0.00	1.05	1.78	38.72	np	np	-1.2%
100918	KH-75	Lilburn-Enchanted R	0.10	1.36	0.00		0.00	0.00	2.32	135.50	0.00	3.90	0.00	1.03	1.71	38.35	np	np	-1.6%
100918	KH-76	Lilburn-Z room	0.12	1.28	0.00		0.00	0.00	2.20	135.50	0.00	4.06	0.00	1.05	1.70	38.37	np	np	-1.3%
100919	KH-77	Big Spring	0.10	1.26	0.00		0.00	0.00	2.00	135.50	0.00	4.00	0.00	1.04	1.70	38.41	np	np	-1.2%
101013	KH-78	Dogwood Sp	0.12	3.14	0.00	0.00	0.00	0.00	1.01	156.08	0.00	1.09	0.00	0.59	38.65	67.08	np	np	42.2%
101013	KH-79	Rimstone Sp	0.12	23.96	0.00	0.00	0.00	0.00	3.24	119.25	0.00	8.35	0.00	1.21	10.25	105.05	np	np	40.9%
101013	KH-80	Kuala Sp	0.11	10.88	0.00	1.55	0.00	0.00	1.88	182.76	0.00	5.53	0.00	1.30	22.10	54.48	np	np	17.5%
101013	KH-81	Yucca Cr- Lower	0.12	8.76	0.00	0.86	0.00	0.00	1.40	85.16	0.00	5.19	0.13	1.21	9.69	33.55	np	np	23.5%
101013	KH-82	Cave Cr Sp	0.18	4.44	0.00	0.38	0.00	0.00	2.09	100.77	0.00	5.56	0.00	1.23	13.01	27.70	np	np	19.3%
101013	KH-83	Yucca Creek at Schis	0.09	10.59	0.00	0.34	0.00	0.00	1.09	72.76	0.00	5.74	0.00	1.27	2.81	28.47	np	np	11.8%
101013	KH-84	Yucca Creek at Guide	0.00	12.01	0.00	0.24	0.00	0.00	0.85	42.94	0.00	6.09	0.00	1.32	2.13	21.65	np	np	18.6%
101013	KH-85	Crystal Cave	0.04	3.39	0.00	0.00	0.00	0.00	0.68	70.52	0.00	3.77	0.00	1.06	1.27	19.38	np	np	-0.3%
101014	KH-86	Marble Fork @ Crysta	0.00	2.55	0.00	0.00	0.00	0.00	0.24	16.59	0.00	3.18	0.00	0.90	0.43	3.73	np	np	4.5%
101014	KH-87	Cascade Cr	0.09	14.02	0.00	0.00	0.00	0.00	0.75	37.82	0.00	7.05	0.00	1.44	2.18	16.32	np	np	12.5%
101014	KH-88	Mossy Sp	0.23	89.37	0.00	0.20	0.00	0.00	2.97	147.86	0.04	22.07	0.00	2.19	14.27	163.54	np	np	34.6%
101014	KH-89	Yucca Cr-Upper	0.00	2.74	0.00	0.00	0.00	0.00	0.49	23.42	0.00	3.27	0.93	1.01	0.64	5.46	np	np	7.3%
101015	KH-90	Hurricane Crawl	0.19	2.92	0.00	1.51	0.00	0.00	1.68	80.52	0.00	4.60	0.00	0.93	3.80	43.30	np	np	29.3%
101015	KH-91	Yucca Creek at Casc	0.04	3.44	0.00	0.00	0.00	0.00	1.21	37.58	0.00	3.73	0.00	1.22	1.06	10.26	np	np	3.0%
101016	KH-92	Slide Sp	0.12	4.79	0.00	0.00	0.00	0.00	1.75	61.98	0.00	5.41	0.00	1.70	2.22	22.05	np	np	13.1%
101016	KH-93	Big Fern Sp.	0.12	11.34	0.00	0.00	0.00	0.00	0.24	67.83	0.00	11.09	0.00	1.63	2.36	12.16	np	np	-4.3%
101016	KH-94	Marble Fork @ Potwis	0.00	3.08	0.00	0.00	0.00	0.00	0.60	28.79	0.00	3.40	0.00	1.04	2.42	12.80	np	np	27.7%
101017	KH-95	Cirque Entrance	0.00	1.26	0.00	0.38	0.00	0.00	1.80	12.32	0.00	0.83	0.00	0.00	0.30	4.74	np	np	1.6%
101017	KH-96	White Chief-Bat Slab	0.00	0.58	0.00	0.52	0.00	0.00	2.06	21.41	0.00	0.61	0.00	0.00	0.27	8.68	np	np	6.2%
101017	KH-97	White Chief Sp	0.00	0.29	0.00	0.71	0.00	0.00	1.93	32.75	0.00	0.34	0.13	0.18	0.35	11.91	np	np	3.8%
101017	KH-98	White Chief Lake	0.00	0.39	0.00	0.00	0.00	0.00	1.59	9.86	0.00	0.66	0.00	0.00	0.13	4.21	np	np	8.0%
101017	KH-99	Corrigans Sink	0.00	0.98	0.00	0.31	0.00	0.00	1.19	15.37	0.00	0.39	0.00	0.00	0.16	9.96	np	np	25.4%
101017	KH-100	Bogaz	0.00	6.91	0.00	0.63	0.00	0.00	2.11	17.57	0.00	3.41	0.00	0.88	0.42	14.02	np	np	25.0%
101017	KH-101	Eagle Sink	0.00	0.48	0.00	0.00	0.00	0.00	1.27	11.09	0.00	0.79	0.00	0.31	0.27	3.48	np	np	2.5%
101017	KH-102	Eagle Meadow Sp	0.20	0.93	0.00	0.00	0.00	0.00	45.96	128.10	0.00	3.39	0.00	1.70	3.48	60.06	np	np	2.8%
101017	KH-103	Tufa Sp	0.31	9.39	0.00	0.00	0.00	0.00	5.37	129.40	0.00	3.69	0.00	0.75	3.26	36.10	np	np	-6.0%
101018	KH-104	Alder Sp	0.05	5.29	0.00	0.13	0.00	0.00	2.66	178.90	0.00	10.54	0.00	1.48	6.17	51.68	np	np	6.4%
101227	KH-105	Alder Sp	0.23	1.90	0.00	0.00	0.00	0.00	4.92	166.30	0.00	8.47	0.00	1.39	4.97	40.34	np	np	-1.6%
101228	KH-106	Warm River	0.08	0.62	0.00	0.00	2.85	0.00	4.93	197.20	0.00	2.10	0.00	0.75	2.77	66.34	np	np	3.2%
101228	KH-107	Upper Smoking Sp	0.10	1.33	0.00	0.00	0.00	0.00	15.22	160.20	0.00	3.41	0.00	2.05	4.38	46.50	np	np	-2.8%
110224	KH-108	Cascade Cr	0.13	1.68	0.00	0.00	0.00	0.00	1.54	38.20	0.00	5.10	0.00	1.16	1.06	7.17	0.00	0.00	-1.6%
110224	KH-109	Mossy Sp	0.25	16.96	0.00	0.00	0.00	0.00	3.27	258.76	0.00	17.02	0.00	2.07	10.87	63.44	0.00	0.00	0.4%
110224	KH-110	Crystal Cave	0.11	1.05	0.00	0.00	0.00	0.00	1.39	87.45	0.00	4.14	0.00	0.99	1.16	15.97	0.00	0.00	-15.6%
110224	KH-111	Marble Fork @ Crysta	0.00	0.36	0.00	0.00	0.00	0.00	0.35	12.82	0.00	2.15	0.00	0.66	0.34	2.01	0.00	0.00	1.9%
110225	KH-112	Marble Fork @ Potwis	0.05	0.47	0.00	0.00	0.00	0.00	0.85	20.95	0.00	2.37	0.00	0.78	0.99	4.80	0.00	0.00	7.6%
110225	KH-113	Middle Fork at Potwis	0.11	0.67	0.00	0.00	0.00	0.00	1.76	26.70	0.00	3.20	0.00	0.93	0.80	4.99	0.00	0.00	-2.9%
110225	KH-114	Salt Cr	0.26	2.43	0.00	0.00	0.00	0.00	2.05	45.70	0.00	8.79	0.00	1.23	1.23	4.12	0.00	0.00	-10.2%
110225	KH-115	North Fork at Kaweah	0.11	1.46	0.00	0.00	0.00	0.00	3.22	69.82	0.00	5.13	0.00	1.11	2.00	12.44	0.00	0.00	-10.2%
110225	KH-116	South Fork at SF Rd.	0.18	2.72	0.00	0.00	0.00	0.00	3.35	110.90	0.00	7.36	0.00	1.45	2.14	13.36	0.00	0.00	-24.7%
110225	KH-117	Main Kaweah River at	0.12	2.07	0.00	0.00	0.00	0.00	2.73	34.68	0.00	5.38	0.00	1.05	1.54	9.52	0.00	0.00	10.3%
110224	KH-118	Snow sample at CC r	0.06	1.40	0.00	0.00	0.36	0.00	0.27	NA	0.00	0.81	0.76	1.48	0.12	0.45	0.00	0.00	

Date	Sample ID	Site	Field Water Quality						Isotopes		
			Discharge	DO	pH	Temp	Spec.Con	ORP	δD	δO	δ-excess
110630	KH-119	Rimstone Cr @ Yucc	0.675	6.77		10.29	379	np	-79.09	-11.47	12.67
110630	KH-120	Kuala Sp	0.21	3.34		10.66	349	np	-76.95	-11.2	12.65
110630	KH-121	Yucca Cr- Lower	16.756	6.5		11.39	112	np	-82.28	-11.9	12.92
110630	KH-122	Lange Sp	0.216	5.26	7.72	9.69	201	np	-81.22	-11.44	10.3
110630	KH-123	Cave Cr Sp	3.496	6.41	7.69	9.56	142	np	-78.02	-10.68	7.42
110630	KH-124	WTF Sp	0.004	3.84	8.20	13.17	422	np	-82.28	-11.96	13.4
110630	KH-125	Cave Cr	2.52	6.25	8.83	10.8	157	np	-80.15	-11.47	11.61
110630	KH-126	Yucca Creek at Schis	11.76	5.55	8.30	13.29	79	np	-83.35	-11.92	12.01
110630	KH-127	Contact Sp	0.231	4.23	7.81	9.5	120	np	-82.28	-11.66	11
110630	KH-128	Yucca Creek at Guide	9.9	5.33	8.16	13.5	52	np	-84.2	-12.11	12.68
110630	KH-129	Yucca Creek at Casc	2.64	5.42	8.07	14.25	30	np	-83.35	-12.01	12.73
110701	KH-130	Marble Fork @ Lodge	np	5.05	7.23	6.54	4	-226.8	-113.19	-15.56	11.29
110701	KH-131	Crystal Cave	1.232	8.17	7.88	9.26	79	np	-83.35	-11.62	9.61
110701	KH-132	Mossy Sp	0.198	7.99	7.74	9.74	546	np	-81.22	-12.02	14.94
110701	KH-133	Cascade Cr	3.657	7.42	7.96	15.36	57	np	-84.41	-12.6	16.39
110701	KH-134	Rimstone Sp	0.06	5.56	7.88	13.39	395	np	-81.22	-11.78	13.02
110701	KH-135	Dogwood Sp	0.08	7.3	8.28	8.42	344	np	-80.15	-12	15.85
110701	KH-136	Marble Fork @ Crysta	np	0.45	7.84	13.39	6	np	-107.64	-14.96	12.04
110703	KH-137	Big Spring	47.025	8.28	7.96	8.7	99	np	-86.54	-12.49	13.38
110703	KH-138	Big Spring		7.92	8.04	8.75	99	np	-84.41	-12.24	13.51
110703	KH-139	Big Spring		7.73	8.00	8.72	98	np	-84.41	-12.42	14.95
110703	KH-140	Big Spring		7.48	7.93	8.73	98	np	-85.48	-12.63	15.56
110703	KH-141	Big Spring	19.569	6.9	7.99	8.92	98	np	-88.94	-13.71	20.74
110703	KH-142	Redwood Cr blw Big S	23.639	5.81	8.00	13.35	89	np	-90.03	-13.83	20.61
110703	KH-143	Redwood Cr abv Big S	4.07	5.64	7.82	15.61	46	np	-87.85	-13.76	22.23
110703	KH-144	Pebble Pile Cr	0.467	4.14	6.99	16.76	10	np	-88.94	-13.77	21.22
110703	KH-145	Lilburn Drip	np	np	7.29	np	161	np	-83.26	-13.23	22.58
110703	KH-146	Lilburn-East St	np	np	7.86	np	89	np	-81.3	-13.42	26.06
110703	KH-147	Lilburn-Alto St.	np	np	7.92	np	89	np	-80.43	-12.8	21.97
110703	KH-148	Lilburn-West St	np	np	8.05	np	81	np	-91.12	-14.1	21.68
110703	KH-149	Lilburn-White Rapids	11.016	6.22	8.01	8.97	97	np	-90.03	-13.84	20.69
110703	KH-150	Lilburn-Enchanted R	np	np	7.96	np	97	np	-90.03	-13.65	19.17
110703	KH-151	Lilburn-Yellow Floored	np	np	8.03	np	93	np	-91.12	-14.04	21.2
110703	KH-152	Lilburn-Z room	np	np	7.75	np	98	np	-90.03	-13.75	19.97
110703	KH-153	Lilburn-Davis Exit	np	np	7.82	np	152	np	-82.39	-13.34	24.33
110705	KH-154	Mays Creek	0.216	7.95	7.52	12.18	18	np	-84.57	-13.27	21.59
110705	KH-155	Redwood Cr-Contact	13.344	8.23	7.57	13.32	38	np	-90.03	-14.15	23.17
110705	KH-156	Volvo Creek	0.315	7	7.66	11.04	34	np	-88.94	-13.94	22.58
110705	KH-157	Redwood Cr	np	7.24	7.53	13.56	33	np	-90.9	-14.11	21.98
110706	KH-158	Franklin Blw Beulah	73.2	8.45		5.96	21	-324.9	-119.49	-17.65	21.71
110706	KH-159	Not Soda Sp	0.304	4.95	7.13	6.23	34	-309.1	-117.31	-16.85	17.49
110706	KH-160	Soda Sp	0.001	0	6.86	11.05	1635	-174	-113.16	-16.31	17.32
110706	KH-161	East Fork below Soda	97.02	7.29	8.05	5.71	28	-220.7	-120.58	-17.17	16.78
110707	KH-162	White Chief Cr blw Cr	18.048	8.14	7.24	6.09	12	-328	-120.58	-17.08	16.06
110707	KH-163	Snow @ Crabtree	np	np	np	np	np	np	-109.67	-15.56	14.81
110707	KH-164	White Chief Mine	0.075	7.72	7.87	6.22	13	-381.7	-110.76	-15.86	16.12
110707	KH-165	Cirque Entrance	32.33	8.02	7.10	3.04	3	343.7	-118.4	-16.97	17.36
110707	KH-166	Snow @ Cirque	np	np	np	np	np	np	-105.3	-14.78	12.94
110707	KH-167	Spring abv White Chie	1.428	8.23	7.13	2.39	7	-405	-111.85	-16.14	17.27
110707	KH-168	Snow @ Sp abv WC	np	np	np	np	np	np	-104.21	-15.27	17.95
110707	KH-169	White Chief Sp	79.625	8.09	7.81	3.12	8	-369	-117.31	-16.8	17.09
110707	KH-170	Snow @ White Chief	np	np	np	np	np	np	-104.21	-14.94	15.31
110707	KH-171	White Chief Lake	2.5	8	7.23	4.73	3	-268.9	-118.18	-16.82	16.38
110707	KH-172	Snow at WC Lake,blw	np	np	np	np	np	np	-109.89	-15.13	11.15
110707	KH-173	Bogaz	10.476	8.09	7.02	4.21	8	-414	-118.4	-16.87	16.56
110707	KH-174	Corrigans Sink	2.464	7.47	7.01	5.17	7	-387.7	-118.4	-17.01	17.68
110707	KH-175	White Chief Creek abv	92.4375	8.26	7.11	4.16	9	-383.3	-119.49	-17.45	20.11
110707	KH-176	Eagle Sink	34.58	7.96	6.92	6.79	5	-397.5	-118.18	-17.16	19.1
110707	KH-177	Snow Sample @ Eag	np	np	np	np	np	np	-92.21	-13.41	15.07
110707	KH-178	Snow Sample @ Eag	np	np	np	np	np	np	-99.57	-13.94	11.95
110707	KH-179	Eagle Meadow Sp	1.028	8.19	8.01	8.63	159	-397.1	-105.72	-15.3	16.68
110708	KH-180	Tufa Sp	138.06	8.21	7.74	6.79	50	-364.2	-119.13	-16.98	16.71
110708	KH-181	Crystal Creek @ Trail	49.5	7.57	7.56	11.06	26	-376	-122.2	-17.59	18.52
110708	KH-182	Chihuahua Cr @ Trail	2.88	6.95	7.14	15.7	28	-399.5	-113.63	-16.77	20.53
110708	KH-183	East Fork @ Miki Rd	205.344	8.13	7.55	8.57	41	-366.6	-118.03	-17.57	22.53
110708	KH-184	Monarch Cr @ MIKI R	75.782	7.73	7.27	9.21	19	-372.9	-115.83	-17.19	21.69
110709	KH-185	Monarch Lake	18.13	7.91	6.83	3.13	4	-380.4	-123.52	-18.19	22
110709	KH-186	Snow Sample @ Mon	np	np	np	np	np	np	-102.64	-15.04	17.68
110709	KH-187	Monarch Cr abv karst	25.92	7.64	6.67	4.99	4	-357.7	-121.54	-17.95	22.06
110709	KH-188	City Lights Sink	0.117	7.13	7.74	10.49	9	-384.5	-116.05	-16.11	12.83
110709	KH-189	Bluebell Sp	2.883	7.7	7.45	4.78	15	-393	-117.15	-17.49	22.77
110709	KH-190	Monarch Cr blw Karst	30.38	7.89	7.89	5.27	8	-267.6	-121.32	-17.15	15.88
110709	KH-191	Snow Sample on Mon	np	np	np	np	np	np	-150.99	-20.71	14.69
110709	KH-192	Snowmelt Sample on	np	np	np	np	np	np	-100.44	-14.65	16.76
110709	KH-193	Monarch Cr abv Ghog	46.62	8.3	7.78	8.28	7	-381.3	-118.03	-17.12	18.93
110709	KH-194	Snow Sample abv Gh	np	np	np	np	np	np	-107.04	-15.2	14.56
110709	KH-195	Snow Sample @ Gho	np	np	np	np	np	np	-134.73	-18.54	13.59
110709	KH-196	Monarch Cr. blw Ghog	67.59	4.77	7.29	np	17	-410.3	-116.93	-17.15	20.27
110709	KH-197	Monarch Sp	2.97	6.66	7.64	np	73	-398.7	-104.62	-15.62	20.34
110709	KH-198	Aspen Spring	2.268	6.96	7.87	8.09	64	-424.5	-107.04	-15.74	18.88
110709	KH-199	East Fork @ Cold Sp	206.796	8.98	7.68	9.45	39	-413.6	-116.93	-17.08	19.71
110709	KH-200	Cold Springs	0.096	3.04	7.44	7.01	21	-400.7	-105.94	-15.8	20.46
110709	KH-201	Snowmelt Sample @	np	np	np	np	np	np	-125.94	-17.97	17.82
110710	KH-202	Marble Fork @ Marble	np	10.5	7.70	10.9	9	-374.1	-110.34	-16.28	19.9
110710	KH-203	Stream 1	np	10.63	8.09	14.37	252	-368.5	-81.76	-12.9	21.44
110710	KH-204	Stream 2	np	10.44	8.58	19.89	348	-396.8	-76.27	-11.95	19.33
110710	KH-205	Stream 3	np	8.5	8.36	19.68	305	-430	-74.95	-11.71	18.73
110710	KH-206	Alder Sp	np	9.14	8.25	13.63	215	-351	-75.39	-12.1	21.41
110710	KH-207	Warm River	np	np	8.01	np	163	np	-86.16	-13.5	21.84
110710	KH-208	Upper Smoking Sp	np	np	8.25	np	150	np	-82.86	-13.28	23.38
110710	KH-209	Marble Fork @ Potwis	np						-109.46	-16.18	19.98
110710	KH-210	Middle Fork at Potwis	np						-113.85	-16.19	15.67
110710	KH-211	North Fork at Kaweah	np						-93.85	-13.86	17.03
110710	KH-212	South Fork at SF Rd.	np						-103.74	-15.48	20.1
110710	KH-213	Main Kaweah River at	np						-109.24	-16.47	22.52

	Sample		Anions								Cations								Charge Balance
Date	ID	Site	F	Cl	NO_2	Br	NO_3	PO_4	SO_4	Alk	Li	Na	NH_4	K	Mg	Ca	Sr	Ba	(% error)
110630	KH-119	Rimstone Cr @ Yucc	0.33	1.47	0.00	0.00	0.00	0.00	2.40	340.91	0.00	2.43	0.00	0.94	42.58	65.42	np	0.00	9.4%
110630	KH-120	Kuala Sp	0.22	2.56	0.00	0.00	1.68	0.00	3.20	316.26	0.00	5.74	0.00	1.29	31.27	59.92	np	0.00	4.2%
110630	KH-121	Yucca Cr- Lower	0.09	1.32	0.00	0.00	0.00	0.00	1.49	90.09	0.00	4.06	0.00	1.11	5.17	18.09	np	0.00	-0.7%
110630	KH-122	Lange Sp	0.20	1.21	0.00	0.00	0.63	0.00	2.24	184.83	0.00	3.98	0.00	1.21	16.40	34.51	np	0.00	2.1%
110630	KH-123	Cave Cr Sp	0.20	1.06	0.00	0.00	0.00	0.00	2.35	139.65	0.00	4.88	0.00	1.20	11.64	24.41	np	0.00	0.6%
110630	KH-124	WTF Sp	0.31	1.09	0.00	0.00	0.00	0.00	6.02	357.34	0.00	2.28	0.00	0.80	47.27	60.30	np	0.00	7.4%
110630	KH-125	Cave Cr	0.23	1.09	0.00	0.00	0.00	0.00	2.36	139.65	0.00	4.85	0.00	1.21	11.91	24.69	np	0.00	1.3%
110630	KH-126	Yucca Creek at Schis	0.13	1.34	0.00	0.00	0.00	0.00	1.15	42.72	0.02	4.15	0.00	1.07	1.27	12.34	np	0.00	9.2%
110630	KH-127	Contact Sp	0.10	1.58	0.00	0.00	0.00	0.00	1.63	106.79	0.02	4.56	0.00	1.08	2.27	25.26	np	0.00	-4.7%
110630	KH-128	Yucca Creek at Guide	0.10	1.37	0.00	0.00	0.00	0.00	1.02	45.18	0.02	4.18	0.00	1.16	1.07	12.42	np	0.00	6.4%
110630	KH-129	Yucca Creek at Casc	0.05	0.65	0.00	0.00	0.00	0.00	0.89	20.54	0.00	2.98	0.00	0.90	0.50	3.44	np	0.00	-1.9%
110701	KH-130	Marble Fork @ Lodge	0.12	0.89	0.00	0.00	0.00	0.00	1.15	9.86	0.00	0.39	0.00	0.12	0.15	4.28	np	0.00	5.2%
110701	KH-131	Crystal Cave	0.00	0.00	0.00	0.00	0.00	0.00	0.20	78.04	0.01	3.94	0.00	1.03	1.07	15.17	np	0.00	-10.3%
110701	KH-132	Mossy Sp	0.42	17.21	0.00	0.00	0.00	0.00	3.25	246.44	0.04	17.58	0.00	1.96	10.79	48.32	np	0.00	-5.8%
110701	KH-133	Cascade Cr	0.20	1.55	0.00	0.00	0.00	0.00	1.01	35.32	0.02	4.64	0.00	1.09	1.03	7.37	np	0.00	1.9%
110701	KH-134	Rimstone Sp	0.19	4.37	0.00	0.00	0.00	0.00	3.84	254.65	0.02	7.00	0.00	1.42	8.92	49.44	np	0.00	-10.8%
110701	KH-135	Dogwood Sp	0.39	0.89	0.00	0.00	0.00	0.00	1.21	398.41	0.00	1.10	0.00	0.69	48.64	66.17	np	0.00	5.4%
110701	KH-136	Marble Fork @ Crysta	0.00	0.23	0.00	0.00	0.00	0.00	0.21	5.34	0.00	0.80	0.00	0.26	0.13	0.66	np	0.00	-8.2%
110703	KH-137	Big Spring	0.14	1.52	0.00	0.00	0.00	0.00	1.16	94.47	0.02	3.47	0.00	1.13	0.92	21.92	np	0.00	-9.3%
110703	KH-138	Big Spring	0.12	0.62	0.00	0.00	0.00	0.00	1.10	90.36	0.00	2.93	0.00	0.90	0.92	21.92	np	0.00	-7.5%
110703	KH-139	Big Spring	0.13	0.66	0.00	0.00	0.00	0.00	1.14	90.36	0.00	3.02	0.00	0.97	0.94	22.30	np	0.00	-6.6%
110703	KH-140	Big Spring	0.13	0.72	0.00	0.00	0.00	0.00	1.13	90.36	0.00	2.99	0.00	0.96	0.92	23.06	np	0.00	-5.4%
110703	KH-141	Big Spring	0.18	0.70	0.00	0.00	0.00	0.00	1.13	90.36	0.00	3.07	0.00	0.89	0.93	21.90	np	0.00	-7.4%
110703	KH-142	Redwood Cr blw Big S	0.07	0.89	0.00	0.00	0.00	0.00	1.13	53.40	0.00	3.27	0.00	1.09	0.90	18.16	np	0.00	10.5%
110703	KH-143	Redwood Cr abv Big S	0.06	0.57	0.00	0.00	0.00	0.00	1.17	26.70	0.00	3.40	0.00	1.09	0.80	5.74	np	0.00	4.2%
110703	KH-144	Pebble Pile Cr	0.00	0.33	0.00	0.00	0.00	0.00	0.32	5.34	0.00	1.79	0.00	0.35	0.16	0.48	np	0.00	8.2%
110703	KH-145	Lilburn Drip	0.00	1.02	0.00	0.00	1.20	0.00	0.36	100.00	0.00	1.35	0.00	1.93	0.37	33.54	np	0.00	3.3%
110703	KH-146	Lilburn-East St	0.06	0.63	0.00	0.00	0.00	0.00	0.37	164.29	0.01	2.02	0.00	0.88	1.31	33.28	np	0.00	-18.3%
110703	KH-147	Lilburn-Alto St.	0.06	0.63	0.00	0.00	0.00	0.00	0.44	180.72	0.01	1.89	0.00	0.74	2.03	36.48	np	0.00	-17.8%
110703	KH-148	Lilburn-West St	0.13	0.43	0.00	0.00	0.00	0.00	1.25	98.58	0.00	2.71	0.00	0.96	0.91	24.47	np	0.00	-7.4%
110703	KH-149	Lilburn-White Rapids	0.16	0.67	0.00	0.00	0.00	0.00	1.20	98.58	0.00	3.00	0.00	0.93	0.97	21.16	np	0.00	-12.9%
110703	KH-150	Lilburn-Enchanted R	0.23	1.70	0.00	0.00	0.00	0.00	1.20	139.65	0.00	3.00	0.00	0.94	0.97	21.28	np	0.00	-29.5%
110703	KH-151	Lilburn-Yellow Floorec	0.13	0.44	0.00	0.00	0.00	0.00	0.48	90.36	0.00	2.22	0.00	0.32	0.40	23.01	np	0.00	-8.1%
110703	KH-152	Lilburn-Z room	0.19	0.63	0.00	0.00	0.00	0.00	1.12	90.36	0.00	2.95	0.00	0.89	0.96	21.49	np	0.00	-8.3%
110703	KH-153	Lilburn-Davis Exit	0.06	0.60	0.00	0.00	0.00	0.00	3.61	98.53	0.00	2.03	0.00	0.94	1.17	24.99	np	0.00	-8.5%
110705	KH-154	Mays Creek	0.05	0.59	0.00	0.00	0.00	0.00	0.26	16.43	0.00	3.55	0.00	0.83	0.25	1.14	np	0.00	-7.6%
110705	KH-155	Redwood Cr-Contact I	0.19	0.50	0.00	0.00	0.00	0.00	0.76	28.75	0.00	3.31	0.00	1.08	0.63	5.05	np	0.00	-4.0%
110705	KH-156	Volvo Creek	0.08	0.68	0.00	0.00	0.00	0.00	0.70		0.00	5.89	0.00	1.18	0.53	3.96	np	0.00	85.7%
110705	KH-157	Redwood Cr	0.19	0.53	0.00	0.00	0.00	0.00	0.64	26.70	0.00	3.42	0.00	1.08	0.58	3.98	np	0.00	-6.2%
110706	KH-158	Franklin Blw Beulah	0.12	0.13	0.00	0.00	0.50	0.00	2.48	16.43	0.00	0.58	0.00	0.14	0.13	4.94	np	0.00	-10.0%
110706	KH-159	Not Soda Sp	0.07	0.11	0.00	0.00	0.00	0.00	0.90	28.75	0.00	0.29	0.00	0.14	0.12	1.73	np	0.00	-63.3%
110706	KH-160	Soda Sp	0.20	0.35	0.00	0.00	3.53	0.00	1.34	944.69	0.01	15.72	0.00	3.14	8.52	198.31	np	0.00	-15.7%
110706	KH-161	East Fork below Soda	0.10	0.17	0.00	0.00	0.51	0.00	3.59	25.00	0.00	0.76	0.00	0.08	0.43	10.24	np	0.00	5.8%
110707	KH-162	White Chief Cr blw Cr	0.00	0.68	0.00	0.00	0.45	0.00	1.02	11.01	0.00	0.67	0.11	0.59	0.15	2.62	np	0.00	-9.2%
110707	KH-163	Snow @ Crabtree	0.00	5.81	0.00	0.00	0.00	0.00	0.35	NA	0.00	3.21	3.05	7.20	0.18	1.27	np	0.00	
110707	KH-164	White Chief Mine	0.00	0.00	0.00	0.00	0.24	0.00	0.48	12.32	0.00	0.12	0.00	0.06	0.11	4.96	np	0.00	9.5%
110707	KH-165	Cirque Entrance	0.00	0.11	0.00	0.00	0.26	0.00	0.56	2.05	0.00	0.15	0.00	0.14	0.10	0.71	np	0.00	-0.6%
110707	KH-166	Snow @ Cirque	0.00	0.27	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.14	0.00	0.20	0.08	2.21	np	0.00	
110707	KH-167	Spring abv White Chie	0.00	0.00	0.00	0.00	0.22	0.00	0.26	9.08	0.00	0.06	0.00	0.09	0.13	2.23	np	0.00	-11.0%
110707	KH-168	Snow @ Sp abv WC	0.00	0.61	0.00	0.00	0.00	0.00	0.23	NA	0.00	0.46	0.00	0.33	0.43	6.69	np	0.00	
110707	KH-169	White Chief Sp	0.00	0.00	0.00	0.00	0.18	0.00	0.83	23.24	0.00	0.14	0.00	0.12	0.21	6.05	np	0.00	-10.5%
110707	KH-170	Snow @ White Chief	0.00	0.65	0.00	0.00	0.00	0.00	0.44	NA	0.00	0.37	0.38	0.31	0.14	3.65	np	2.11	
110707	KH-171	White Chief Lake	0.00	0.00	0.00	0.00	0.29	0.00	0.28	1.85	0.00	0.14	0.00	0.12	0.07	0.62	np	0.00	4.6%
110707	KH-172	Snow at WC Lake,blw	0.00	0.59	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.35	0.20	0.39	0.08	0.35	np	0.00	
110707	KH-173	Bogaz	0.00	0.00	0.00	0.00	0.00	0.00	0.51	5.54	0.00	0.16	0.00	0.15	0.11	2.00	np	0.00	7.2%
110707	KH-174	Corrigans Sink	0.00	0.00	0.00	0.00	0.41	0.00	0.32	4.10	0.00	0.15	0.01	0.15	0.09	1.63	np	0.00	9.7%
110707	KH-175	White Chief Creek ab	0.00	0.00	0.00	0.00	0.32	0.00	0.81	8.63	0.00	0.15	0.00	0.13	0.13	2.58	np	0.00	-5.4%
110707	KH-176	Eagle Sink	0.00	0.00	0.00	0.00	0.00	0.00	0.45	18.48	0.00	0.33	0.00	0.17	0.13	1.24	np	0.00	-54.8%
110707	KH-177	Snow Sample @ Eag	0.00	1.41	0.00	0.00	0.00	0.00	0.26	NA	0.00	0.71	2.01	1.86	0.10	0.37	np	0.00	
110707	KH-178	Snow Sample @ Eag	0.00	0.69	0.00	0.00	0.00	0.00	0.36	NA	0.00	0.54	0.25	0.48	0.92	23.56	np	0.00	
110707	KH-179	Eagle Meadow Sp	0.14	0.16	0.00	0.00	0.00	0.00	38.35	123.22	0.01	2.99	0.00	1.58	2.15	34.91	np	0.00	-17.7%
110708	KH-180	Tufa Sp	0.00	0.33	0.00	0.00	0.00	0.00	1.34	32.45	0.01	1.03	0.00	0.32	0.81	10.95	np	0.00	7.5%
110708	KH-181	Crystal Creek @ Trail	0.10	0.00	0.00	0.00	0.00	0.00	1.80	28.75	0.00	0.43	0.00	0.25	0.17	5.30	np	0.00	-26.4%
110708	KH-182	Chihuahua Cr @ Trail	0.00	0.12	0.00	0.00	0.00	0.00	4.89	11.91	0.00	0.93	0.00	0.39	0.26	3.86	np	0.00	-9.7%
110708	KH-183	East Fork @ Miki Rd	0.07	0.14	0.00	0.00	0.20	0.00	3.04	30.81	0.00	0.61	0.00	0.30	0.45	8.26	np	0.00	-10.1%
110708	KH-184	Monarch Cr @ MIKI R	0.06	0.29	0.00	0.00	0.00	0.00	1.17	14.28	0.00	0.56	0.00	0.19	0.22	3.50	np	0.00	-10.7%
110709	KH-185	Monarch Lake	0.16	0.24	0.00	0.00	0.36	0.00	0.45	2.88	0.00	0.44	0.00	0.23	0.06	0.77	np	0.00	-7.1%
110709	KH-186	Snow Sample @ Mon	0.00	5.72	0.00	0.00	0.00	0.00	0.55	NA	0.00	3.95	1.82	4.52	0.30	24.00	np	0.00	
110709	KH-187	Monarch Cr abv karst	0.13	0.19	0.00	0.00	0.00	0.00	0.62	3.39	0.00	0.37	0.00	0.17	0.08	0.93	np	0.00	-6.3%
110709	KH-188	City Lights Sink	0.00	0.18	0.00	0.00	0.29	0.00	0.78	16.02	0.00	0.32	0.00	0.13	0.20	4.72	np	0.00	-4.0%
110709	KH-189	Bluebell Sp	0.12	0.11	0.00	0.00	0.47	0.00	1.33	12.32	0.00	0.41	0.00	0.11	0.20	3.80	np	0.00	-5.4%
110709	KH-190	Monarch Cr blw Karst	0.11	0.22	0.00	0.00	0.33	0.00	0.87	12.32	0.00	0.32	0.00	0.13	0.12	4.86	np	0.00	5.6%
110709	KH-191	Snow Sample on Mon	0.00	0.93	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.52	0.17	0.80	0.08	0.80	np	0.00	
110709	KH-192	Snowmelt Sample on	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.01	0.00	0.00	0.04	0.36	np	0.00	
110709	KH-193	Monarch Cr abv Ghog	0.07	0.09	0.00	0.00	0.00	0.00	0.76	10.22	0.00	0.29	0.00	0.12	0.19	3.12	np	0.00	-1.7%
110709	KH-194	Snow Sample abv Gh	0.00	5.10	0.00	0.00	0.00	0.00	0.00	NA	0.00	3.64	0.66	2.26	0.04	0.26	np	0.00	
110709	KH-195	Snow Sample @ Gho	0.00	0.81	0.90	0.00	0.00	0.00	0.26	NA	0.00	0.52	0.17	0.74	0.44	8.25	np	0.00	
110709	KH-196	Monarch Cr. blw Ghog	0.07	0.14	0.00	0.00	0.00	0.00	0.89	13.86	0.00	0.43	0.00	0.15	0.23	5.01	np	0.00	6.2%
110709	KH-197	Monarch Sp	0.05	1.79	0.00	0.00	0.52	0.00	3.15	45.18	0.01	2.06	0.00	0.31	0.70	12.07	np	0.00	-7.5%
110709	KH-198	Aspen Spring	0.00	0.45	0.00	0.00	0.00	0.00	2.14	57.50	0.00	2.33	0.00	0.59	0.83	17.95	np	0.00	3.4%
110709	KH-199	East Fork @ Cold Sp	0.07	0.18	0.00	0.00	0.26	0.00	2.68	38.20	0.00	0.87	0.00	0.66	0.69	9.58	np	0.00	-9.0%
110709	KH-200	Cold Springs	0.07	0.27	0.00	0.00	0.00	0.00	0.53	20.54	0.00	1.94	0.00	0.79	0.42	4.81	np	0.00	2.4%
110709	KH-201	Snowmelt Sample @	0.00	0.10	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.01	0.06	5.33	np	0.00	
110710	KH-202	Marble Fork @ Marble	0.00	0.20	0.00	0.00	0.00	0.00	0.22	13.96	0.00	0.87	0.00	0.26	0.32	4.53	np	0.00	10.6%
110710	KH-203	Stream 1	0.22	1.02	0.00	0.00	0.00	0.00	10.49	184.83	0.01	3.71	0.00	1.83	3.50	49.49	np	0.00	-5.8%
110710	KH-204	Stream 2	0.27	2.60	0.00	0.00	0.94	0.00	20.03	221.80	0.01	6.63	0.00	2.86	15.97	50.92	np	0.00	-0.3%
110710	KH-205	Stream 3	0.53	3.40	0.00	0.00	0.00	0.00	15.94	201.26	0.02	14.42	0.00	3.21	12.00	38.41	np	0.00	-2.8%
110710	KH-206	Alder Sp	0.49	2.22	0.00	0.00	0.00	0.00	5.33	172.51	0.01	9.11	0.00	1.41	4.81	38.12	np	0.00	-5.5%
110710	KH-207	Warm River	0.19	0.89	0.00	0.00	1.20	0.00	7.74	147.83	0.00	2.64	0.00	0.96	2.67	36.28	np	0.00	-10.4%
110710	KH-208	Upper Smoking Sp	0.24	1.66	0.00	0.00	0.00	0.00	22.39	119.11	0.01	4.40	0.00	2.01	4.47	46.72	np	0.00	6.7%
110710	KH-209	Marble Fork @ Potwis	0.00	1.08	0.00	0.00	0.00	0.00	0.30	20.54	0.00	1.47	0.00	0.66	0.73	6.19	np	0.00	9.2%
110710	KH-210	Middle Fork at Potwis	0.10	1.10	0.00	0.00	0.00	0.00	0.89	16.43	0.00	2.42	0.00	0.08	0.34	5.26	np	0.01	9.6%
110710	KH-211	North Fork at Kaweah	0.17	2.05	0.00	0.00	0.00	0.00	1.34	41.07	0.00	4.06	0.00	1.41	1.28	8.75	np	0.00	-1.2%
110710	KH-212	South Fork at SF Rd.	0.06	0.67	0.00	0.00	0.00	0.00	0.81	16.93	0.00	2.82	0.00	0.40	0.54	3.74	np	2.14	10.5%
110710	KH-213	Main Kaweah River at	0.10	1.04	0.00	0.00	0.00	0.00	0.82	16.43	0.00	2.26	0.00	0.63	0.45	3.57	np	0.00	0.8%

Date	Sample ID	Site	Field Water Quality						Isotopes		
			Discharge	DO	pH	Temp	Spec.Con	ORP	δD	δO	δ-excess
111020	KH-214	Quartzite seep @ Rin	0.006	0.77	6.64	9.69	258	-34	-79.04	-11.52	13.12
111020	KH-215	Rimstone Sp	0.034	6.17	7.64	10.06	339	-66.5	-78.42	-11.65	14.78
111020	KH-216	Rimstone Cr @ Yucc	0.266	6.21	8.40	10.09	324	-80	-76.58	-11.51	15.5
111020	KH-217	Kuala Sp	0.11	3.2	6.89	10.36	304	-87.5	-77.49	-11.44	14.03
111020	KH-218	Lange Sp	0.006	7.24	7.96	10.37	187	-76.3	-78.62	-11.68	14.82
111020	KH-219	Yucca Cr- Lower	4.346	8.51	7.69	10.48	151	-62.1	-77.95	-11.61	14.93
111020	KH-220	Cave Cr	1.311	8.7	8.1	11.21	163	-73	-78.62	-11.68	14.82
111020	KH-221	Cave Cr Sp	0.896	7.84	7.42	9.75	157	-95	-78.36	-11.7	15.24
111020	KH-222	Yucca Cr-Schist Falls	3.651	8.25	8.08	11.75	113	-111.5	-79.57	-11.7	14.03
111020	KH-223	Hurricane Crawl Drip	np	5.7	8.51	10.39	116	-116.4	-80.39	-11.82	14.17
111020	KH-224	Hurricane Crawl	0.139	8.51	8.04	10.73	143	-88	-77.33	-11.52	14.83
111020	KH-225	Contact Sp	0.005	3.9	7.54	11.26	115	-99.1	-79.41	-11.83	15.23
111020	KH-226	Yucca Creek at Guide	3.165	8.25	7.83	12.38	86	-59.2	-79.88	-11.61	13
111020	KH-227	Yucca Creek at Casc	0.124	9.89	6.94	13.04	26	-41.6	-79.06	-11.44	12.46
111020	KH-228	Crystal Cave	0.746	10.66	6.90	10.8	73	-53.5	-79.46	-11.54	12.86
111020	KH-229	Crystal Drip1	np	9.66	7.63	11.33	342	-56.3	-84.08	-11.97	11.68
111020	KH-230	Crystal- fairy Pools	np	7.77	7.90	11.29	130	-65	-79.14	-11.51	12.94
111020	KH-231	Crystal- Ephemiral	np	8.86	7.37	10.92	297	-65.5	-83.41	-11.95	12.19
111020	KH-232	Mossy Sp	0.075	13.72	7.14	9.96	546	-94	-81.32	-11.71	12.36
111020	KH-233	Cascade Cr	0.291	10.52	8.02	10.92	80	-122	-80.24	-11.62	12.72
111021	KH-234	Yucca Creek at Schis	0.475	11.57	7.62	10.1	31	-96.9	-80.22	-11.69	13.3
111021	KH-235	Yucca Cr-Upper	0.501	10.35	7.75	10.18	31	-102.2	-79.33	-11.52	12.83
111021	KH-236	Dogwood Sp	0.037	5.95	7.59	8.93	399	-126.4	-78.56	-11.73	15.28
111021	KH-237	Equinous Sp	0.015	9.17	8.12	8.73	387	-124.7	-79.7	-11.53	12.54
111021	KH-238	Marble Fork @ Crysta	27.943	11.6	7.51	8.79	12	-100.4	-89.09	-12.23	8.75
111021	KH-239	Marble Fork @ Lodge	17.517	9.7	7.46	8.61	7	-120.8	-90.52	-12.43	8.92
111021	KH-240	Slide Sp	0.003	10.05	8.48	22.1	115	-143.1	-69.56	-9.93	9.88
111021	KH-241	Big Fern Sp	0.028	12.15	8.18	15.44	62	-164	-70.1	-10.48	13.74
111020	KH-242	Lilburn-East St	0.002	np	8.04	10.1	338	np	-77.54	-11.42	13.82
111020	KH-243	Lilburn-West St	0.074	np	7.77	6.2	248	np	-81.57	-11.64	11.55
111020	KH-244	Lilburn-Alto St.	0.001	np	7.95	7.4	359	np	-75.88	-10.98	11.96
111020	KH-245	Lilburn-Mays Infeeder	0.051	np	7.84	8.4	114	np	-77.76	-11.43	13.68
111020	KH-246	Lilburn-White Rapids	4.559	np	7.64	8.8	198.6	np	-81.5	-11.59	11.22
111020	KH-247	Lilburn-Enchanted R	5.375	np	7.66	9	199.3	np	-82.12	-12.1	14.68
111020	KH-248	Lilburn-Z room	5.482	np	7.63	9	198.9	np	-81.16	-11.85	13.64
111020	KH-249	Lilburn-Yellow Floored	0.001	np	7.81	7.3	238	np	-80.64	-11.76	13.44
111020	KH-250	Pebble Pile		np			58	np	-77.64	-11.46	14.04
111020	KH-251	Big Spring		np			191	np	-81.73	-11.84	12.99
111020	KH-252	Redwood Cr-Contact Falls		np			85	np	-81.75	-11.74	12.17
111020	KH-253	Redwood Cr blw Big Spring		np			195	np	-81.75	-11.71	11.93
111020	KH-254	Redwood Cr abv Big Spring		np			122	np	-76.21	-11.02	11.95
111021	KH-255	Mays Creek		np			70	np	-78.02	-11.23	11.82
111021	KH-256	Volvo Creek		np			52.2	np	-82.7	-11.67	10.66
111021	KH-257	Redwood Cr	0.327	np			54.9	np	-82.57	-11.25	7.43
111022	KH-258	Franklin Lake	1.597	7.23	8.45	9.04	16	-137.3	-108.08	-13.75	1.92
111022	KH-259	Snow @ Franklin	np	np	np	np	np	np	-75.16	-10.46	8.52
111022	KH-260	Alto Cave	0.829	8.28	7.86	9.35	12	-133	-101.2	-13.97	10.56
111022	KH-261	Shower Cave	0.402	7.1	8.43	5.36	17	-130.6	-102.2	-14.51	13.88
111022	KH-262	Onion Mdw Sp	2.372	7.45	8.00	9.92	20	-141.7	-107.24	-14.59	9.48
111022	KH-263	Franklin blw Karst	0.897	7.88	7.90	8.02	23	-121	-107.24	-14.54	9.08
111022	KH-264	Franklin blw Onion Mc	2.951	7.75	7.62	8.58	23	-111.2	-108.19	-14.57	8.37
111022	KH-265	Franklin Abv Beulah	3.197	8.72	8.03	7.39	31	-118.5	-101.93	-13.52	6.23
111022	KH-266	Franklin Blw Beulah	4.566	10.53	8.05	6.6	47	-82.1	-102.91	-13.98	8.93
111022	KH-267	Beulah Sp	1.369	8.88	8.24	5.66	69	-73.8	-101.93	-14.28	12.31
111022	KH-268	Not Soda Sp	0.239	8.58	8.83	6.68	37	-110.2	-102.91	-13.85	7.89
111022	KH-269	Soda Sp	0.001	0.34	7.19	10.41	1805	-148	-102.91	-13.6	5.89

Date	Sample ID	Site	Anions								Cations								Charge Balance (% error)
			F	Cl	NO_2	Br	NO_3	PO_4	SO_4	Alk	Li	Na	NH_4	K	Mg	Ca	Sr	Ba	
111020	KH-214	Quartzite seep @ Rin	0.16	3.25	0.00	0.00	0.00	0.00	7.27	207.01	0.01	3.85	2.09	0.00	8.57	40.01	0.95	0.37	-9.8%
111020	KH-215	Rimstone Sp	0.17	4.34	0.00	0.00	0.37	0.00	4.54	262.87	0.02	6.74	1.05	0.00	9.23	52.06	1.06	0.33	-9.8%
111020	KH-216	Rimstone Cr @ Yucc	0.18	1.85	0.00	0.00	0.00	0.00	2.88	291.62	0.01	2.76	2.75	1.06	33.84	39.14	0.00	0.33	1.4%
111020	KH-217	Kuala Sp	0.06	1.22	0.00	0.00	0.77	0.00	1.42	299.84	0.02	5.63	5.62	1.29	25.62	39.05	1.02	0.35	-3.2%
111020	KH-218	Lange Sp	0.17	1.90	0.00	0.00	0.36	0.00	2.56	213.58	0.01	4.80	4.80	1.24	15.46	37.15	0.00	0.22	0.2%
111020	KH-219	Yucca Cr- Lower	0.15	2.27	0.00	0.00	0.00	0.00	2.12	142.95	0.01	5.17	5.17	1.20	8.96	31.34	0.60	0.16	7.7%
111020	KH-220	Cave Cr	0.19	1.24	0.00	0.00	0.64	0.00	2.98	151.97	0.01	5.14	5.24	1.19	13.31	27.86	0.60	0.18	7.8%
111020	KH-221	Cave Cr Sp	0.19	1.26	0.00	0.00	1.02	0.00	3.00	147.86	0.01	5.16	5.26	1.19	13.04	27.58	0.60	0.17	8.4%
111020	KH-222	Yucca Cr-Schist Falls	0.15	2.74	0.00	0.00	0.23	0.00	1.64	131.43	0.01	5.60	5.60	1.22	2.67	26.57	0.52	0.11	-2.7%
111020	KH-223	Hurricane Crawl Drip	0.00	0.57	0.00	0.00	4.17	0.00	1.51	110.90	0.00	0.77	0.76	0.11	0.65	36.10	1.29	0.00	0.6%
111020	KH-224	Hurricane Crawl	0.21	0.94	0.00	0.00	0.90	0.00	2.20	143.76	0.01	4.65	4.65	1.03	3.32	39.13	0.90	0.17	5.5%
111020	KH-225	Contact Sp	0.12	2.73	0.00	0.00	0.34	0.00	1.55	106.79	0.01	5.37	5.37	1.26	2.70	28.86	0.68	0.18	9.3%
111020	KH-226	Yucca Creek at Guide	0.13	2.88	0.00	0.00	0.00	0.00	1.40	78.04	0.01	5.69	5.69	1.29	1.99	19.71	0.44	0.10	11.7%
111020	KH-227	Yucca Creek at Casc	0.10	0.84	0.00	0.00	0.00	0.00	1.47	35.32	0.00	3.60	3.60	1.05	0.83	7.68	0.16	0.00	13.7%
111020	KH-228	Crystal Cave	0.11	0.98	0.00	0.00	0.00	0.00	1.01	69.82	0.01	3.95	3.95	1.04	1.31	19.25	0.43	0.06	11.3%
111020	KH-229	Crystal Drip1	0.00	0.42	0.00	0.00	0.40	0.00	1.19	207.01	0.00	0.90	0.06	0.24	10.43	38.78	1.12	0.27	-9.0%
111020	KH-230	Crystal- fairy Pools	0.00	0.40	0.00	0.00	4.20	0.00	1.49	164.29	0.00	0.72	0.07	0.24	4.89	29.05	0.63	0.17	-19.1%
111020	KH-231	Crystal- Ephemiral	0.06	0.46	0.00	0.00	1.16	0.00	2.33	246.44	0.00	0.97	0.97	0.30	7.90	64.22	1.26	0.32	-1.7%
111020	KH-232	Mossy Sp	0.25	21.89	0.00	0.00	0.00	0.00	3.67	289.57	0.05	19.55	19.55	2.07	12.58	46.55	1.00	0.21	-0.3%
111020	KH-233	Cascade Cr	0.14	3.60	0.00	0.00	0.00	0.00	1.33	82.15	0.02	6.66	6.66	1.41	2.12	16.02	0.38	0.06	6.7%
111021	KH-234	Yucca Creek at Schis	0.06	0.84	0.00	0.00	0.00	0.00	0.70	41.07	0.00	3.25	0.98	0.00	0.88	5.77	0.79	0.00	-10.9%
111021	KH-235	Yucca Cr-Upper	0.10	0.82	0.00	0.00	0.00	0.00	0.74	24.64	0.00	3.24	3.24	0.94	0.66	5.48	0.13	0.00	20.7%
111021	KH-236	Dogwood Sp	0.17	1.05	0.00	0.00	0.00	0.00	1.50	308.05	0.00	1.24	1.23	0.66	37.79	26.96	0.00	0.43	-5.4%
111021	KH-237	Equinous Sp	0.17	0.93	0.00	0.00	0.00	0.00	1.91	301.89	0.00	1.10	1.09	0.84	37.71	27.37	0.00	0.33	-4.4%
111021	KH-238	Marble Fork @ Crysta	0.05	0.38	0.00	0.00	0.00	0.00	0.28	19.72	0.00	1.68	1.68	0.52	0.37	5.61	0.08	0.00	18.2%
111021	KH-239	Marble Fork @ Lodge	0.00	0.30	0.00	0.00	0.00	0.00	0.31	12.32	0.00	0.84	0.83	0.26	0.17	3.51	0.00	0.00	12.6%
111021	KH-240	Slide Sp	0.12	1.39	0.00	0.00	0.00	0.00	2.08	78.04	0.00	4.37	4.37	1.27	2.07	17.89	0.45	0.10	6.0%
111021	KH-241	Big Fern Sp	0.15	2.48	0.00	0.00	0.00	0.00	0.69	73.93	0.01	7.54	7.54	1.58	1.66	13.98	0.38	0.12	11.8%
111020	KH-242	Lilburn-East St	0.04	0.81	0.00	0.00	0.14	0.00	0.42	234.12	0.00	2.09	2.09	1.00	1.69	36.36	0.00	0.25	-27.7%
111020	KH-243	Lilburn-West St	0.11	0.62	0.00	0.00	0.18	0.00	2.75	180.72	0.00	2.75	2.75	1.09	1.47	45.91	1.01	0.31	-5.3%
111020	KH-244	Lilburn-Alto St.	0.08	1.14	0.00	0.00	0.29	0.00	1.04	197.00	0.00	3.77	3.77	0.62	2.55	36.00	0.62	0.49	-15.2%
111020	KH-245	Lilburn-Mays Infeeder	0.12	0.82	0.00	0.00	0.00	0.00	0.42	82.15	0.00	4.59	0.00	0.82	1.01	26.04	0.00	0.27	7.3%
111020	KH-246	Lilburn-White Rapids	0.17	1.25	0.00	0.00	0.00	0.00	1.65	115.00	0.00	3.92	0.00	1.12	1.63	37.79	0.79	0.23	6.4%
111020	KH-247	Lilburn-Enchanted R	0.13	1.22	0.00	0.00	0.00	0.00	1.72	151.98	0.00	4.28	0.00	1.05	1.61	36.17	0.74	0.29	-8.5%
111020	KH-248	Lilburn-Z room	0.10	1.06	0.00	0.00	0.00	0.00	1.67	106.79	0.01	3.81	0.00	1.14	1.58	37.09	0.83	0.28	9.3%
111020	KH-249	Lilburn-Yellow Floored	0.00	0.36	0.00	0.00	0.80	0.00	0.51	151.97	0.00	3.22	0.00	0.49	0.74	46.12	0.00	0.53	-0.1%
111020	KH-250	Pebble Pile	0.08	0.69	0.00	0.00	0.00	0.00	0.24	12.32	0.00	3.14	0.00	0.70	0.21	1.31	0.00	0.00	1.1%
111020	KH-251	Big Spring	0.13	1.35	0.00	0.00	0.00	0.00	1.67	119.11	0.01	3.92	0.00	1.20	1.57	36.36	0.76	0.21	3.0%
111020	KH-252	Redwood Cr-Contact I	0.10	0.83	0.00	0.00	0.00	0.00	1.22	49.29	0.00	3.46	0.00	1.26	1.07	13.66	0.25	0.03	5.0%
111020	KH-253	Redwood Cr blw Big S	0.13	1.03	0.00	0.00	0.00	0.00	1.67	119.11	0.01	3.68	0.00	1.05	1.56	35.81	0.69	0.16	2.2%
111020	KH-254	Redwood Cr abv Big S	0.11	1.16	0.00	0.00	0.00	0.00	2.97	61.61	0.00	4.30	0.00	1.38	1.72	13.15	0.32	0.05	-4.4%
111021	KH-255	Mays Creek	0.10	1.04	0.00	0.00	0.00	0.00	0.28	20.53	0.01	4.39	0.00	1.12	0.28	2.37	0.05	0.01	-1.9%
111021	KH-256	Volvo Creek	0.14	0.92	0.00	0.00	0.00	0.00	0.57	49.29	0.00	6.34	0.00	1.34	0.73	12.53	0.27	0.03	7.9%
111021	KH-257	Redwood Cr	0.12	0.92	0.00	0.00	0.00	0.00	0.85	41.07	0.00	5.47	0.00	1.16	0.82	6.68	0.23	0.27	-3.5%
111022	KH-258	Franklin Lake	0.24	0.11	0.00	0.00	0.33	0.00	3.26	8.21	0.00	0.55	0.00	0.24	0.09	4.13	0.00	0.00	1.2%
111022	KH-259	Snow @ Franklin								NA									
111022	KH-260	Alto Cave	0.28	0.13	0.00	0.00	0.00	0.00	0.66	10.27	0.00	0.77	0.00	0.26	0.07	3.23	0.00	0.00	0.9%
111022	KH-261	Shower Cave	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.38	0.00	0.86	-0.04	0.22	0.09	4.76	0.00	0.02	9.6%
111022	KH-262	Onion Mdw Sp	0.10	0.06	0.00	0.00	0.00	0.00	1.10	12.32	0.00	0.59	0.00	0.01	0.00	4.82	0.00	0.00	6.0%
111022	KH-263	Franklin blw Karst	0.05	0.05	0.00	0.00	0.00	0.00	0.74	17.25	0.00	0.75	0.00	0.29	0.05	6.57	0.00	0.00	9.9%
111022	KH-264	Franklin blw Onion Mc	0.27	0.15	0.00	0.00	0.22	0.00	3.63	14.38	0.00	0.69	-0.02	0.27	0.14	7.00	0.00	0.01	6.4%
111022	KH-265	Franklin Abv Beulah	0.08	0.08	0.00	0.00	0.16	0.00	1.40	16.43	0.00	0.67	0.00	0.28	0.34	5.07	0.00	0.00	0.6%
111022	KH-266	Franklin Blw Beulah	0.13	0.20	0.00	0.00	1.24	0.00	4.84	38.13	0.00	0.67	0.05	0.34	0.24	14.72	0.27	0.00	1.4%
111022	KH-267	Beulah Sp	0.00	0.33	0.00	0.00	2.14	0.00	5.43	65.72	0.00	0.74	0.10	0.43	0.41	27.11	0.64	0.00	7.1%
111022	KH-268	Not Soda Sp	0.23	0.25	0.00	0.00	0.32	0.00	4.40	41.07	0.00	0.91	0.00	0.31	0.28	15.97	0.00	0.11	3.6%
111022	KH-269	Soda Sp	0.47	0.46	0.00	0.00	2.20	0.00	0.69	677.71	0.01	16.85	0.17	3.45	10.11	96.69	3.05	0.02	-26.1%

Date	Sample ID	Site	Field Water Quality						Isotopes		
			Discharge	DO	pH	Temp	Spec.Con	ORP	δD	δO	δ-excess
111022	KH-270	Snow @ WC 1	np		np	np	np	np	-71.93	-10.27	10.23
111022	KH-271	White Chief Cr blw Cr	0	np	6.60	1.6	42.2	np	-99.96	-13.37	7
111022	KH-272	White Chief Creek ab	2.099	np	8.01	3.5	51	np	-91.15	-12.09	5.57
111022	KH-273	Corrigans Sink	0.35	np	7.90	5.3	33.5	np	-89.26	-12.08	7.38
111022	KH-274	Bogaz	1.041	np	7.35	3.1	49.9	np	-89.97	-12.47	9.79
111022	KH-275	Bogaz	1.25	np	7.89	4.3	49.2	np	-91.98	-12.8	10.42
111022	KH-276	White Chief Mine	0.003	np	7.66	4.5	65.3	np	-83.88	-11.93	11.56
111022	KH-277	Snow @ WC 2	np		np	np	np	np	-76.04	-10.92	11.32
111022	KH-278	Snow @ WC 3	np		np	np	np	np	-86.74	-12.18	10.7
111022	KH-279	White Chief Sp	1.426	np	8.02	3.2	46.3	np	-91.72	-12.97	12.04
111022	KH-280	White Chief- Bat Slab	1.48	np	7.97	4.8	37.4	np	-92.99	-13.28	13.25
111022	KH-281	Cirque Entrance	0.316	np	7.73	7.2	21.1	np	-89.2	-12.65	12
111022	KH-282	White Chief Lake	0.165	np	7.69	5.7	13.83	np	-92.58	-12.57	7.98
111022	KH-283	Eagle Sink	0.712	np	7.89	6.1	20.2	np	-96.04	-12.88	7
111022	KH-284	Eagle Meadow Sp	0.203	np	8.36	4	347	np	-95.06	-13.22	10.7
111022	KH-285	Tufa Sp	5.112	np	8.32	6.3	143.9	np	-98	-13.41	9.28
111022	KH-286	Monarch Lake	0.158	5.51	7.23	8.88	59	np	-97.02	-13.04	7.3
111022	KH-287	Snow @ Monarch La	np	np	np	np	np	np	-71.34	-10.58	13.3
111022	KH-288	Snow @ Upper Mona	np	np	np	np	np	np	-62.23	-9.78	16.01
111022	KH-289	Monarch Cr abv karst	1.157	5.72	7.66	9.41	61	np	-94.07	-12.55	6.33
111022	KH-290	bb sp?1	np	5.38	6.80	9.57	65	np	-97.22	-13.11	7.66
111022	KH-291	bb sp?2	np	2.11	6.31	12.97	67	np	-90.12	-12.23	7.72
111022	KH-292	cl sink?1	np	2.51	6.25	12.57	74	np	-90.98	-12.53	9.26
111022	KH-293	City Lights Sink	np	3.84	7.68	13.7	77	np	-91.05	-12.33	7.59
111022	KH-294	Bluebell sp	0.205	5.89	7.62	4.98	74	np	-95.06	-12.98	8.78
111022	KH-295	Monarch Cr blw Karst	1.395	6.02	8.16	9.07	92	np	-94.07	-12.8	8.33
111022	KH-296	Monarch Cr abv Ghog	1.576	5.83	7.40	8.85	94	np	-94.07	-12.7	7.53
111022	KH-297	Monarch Cr. blw Gho	1.741	6.3	7.18	7.98	91	np	-95.25	-13.12	9.71
111022	KH-298	Monarch Sp	0.263	6.74	8.29	6.84	107	np	-96.04	-13.33	10.6
111022	KH-299	city Lights snow	np		np	np	np	np	-83.89	-11.62	9.07
111023	KH-300	TG Tarn	np	79	7.13	9.48	91	np	-78.03	-9.92	1.33
111023	KH-301	Languid Lady Snow	np		np	np	np	np	-71.68	-10.62	13.28
111023	KH-302	TG Rise	0.13	7.42	7.62	3.94	110	np	-90.74	-13.19	14.78
111023	KH-303	TG Sink	0.108	7.2	7.42	4.83	83	np	-86.43	-12.9	16.77
111023	KH-304	Marmota Follis	0.039	9	7.86	3.57	127	np	-95.06	-14.18	18.38
111023	KH-305	Empire Sp	0.035	5.56	7.75	9.44	84	np	-96.04	-13.69	13.48
111023	KH-306	Empire Mine	0.001	5.87	9.75	14.09	72	-166.9	-97.02	-13.24	8.9
111023	KH-307	Monarch Cr @ MIKI R	3.51				49		-95.06	-13.26	11.02
111023	KH-308	East Fork @ Miki Rd	24.155	14.08	8.93	6.76	86	-121.8	-100.95	-13.72	8.81
111023	KH-309	East Fork @ Cold Sp	25.166	8.66	8.49	7.32	90	-113.6	-98.98	-13.49	8.94
111023	KH-310	Chihuahua Sp	0.05	np	5.69	7	39.3	np	-100.95	-13.86	9.93
111023	KH-311	Crystal Lake	0.845208	np	7.37	7	10.62	np	-96.78	-12.88	6.26
111023	KH-312	Crystal Cr Abv Karst	0.4824688	np	7.43	9.1	28.8	np	-99.34	-13.47	8.42
111023	KH-313	Cobalt Cr Abv karst	0.0446813	np	8.22	8.2	60.4	np	-94.96	-12.48	4.88
111023	KH-314	Cobalt Cr-Mdw Trib	0.0118	np	7.82	11.8	83.1	np	-98.02	-13.48	9.82
111023	KH-315	Crystal Cr blw karst	0.9222525	np	7.49	8.2	27	np	-97.66	-12.95	5.94
111023	KH-316	Crystal Creek Spring	0.555	np	8.06	5.9	87	np	-103.12	-13.56	5.36
111023	KH-317	Crystal Cr lower falls	0.1723785	np	8.33	8.2	144.7	np	-105.11	-13.96	6.57
111023	KH-318	Crystal Creek @ Trail	1.9909238	np	8.05	8.5	78.4	np	-100.34	-13.21	5.34
111024	KH-319	Paradise Sp	0.01	9.6	8.55	10.67	153	-110.3	-73.06	-10.37	9.9
111024	KH-320	Upper Smoking Sp	0.041	11.55	9.12	13.19	250	-140.3	-78.23	-11.22	11.53
111024	KH-321	Warm River	0.132	9.6	7.68	18.88	302	-135.1	-79.83	-11.41	11.45
111024	KH-322	Hospital Rock Sp	0.06	10.98	8.37	13.02	180	-146.9	-74.25	-10.55	10.15
111024	KH-323	Alder Sp	0.284	11.1	8.41	14.91	273	-150	-69.47	-9.89	9.65
111024	KH-324	MC Sp 1		9.98	7.97	17.16	385	-146.6	-78.13	-10.35	4.67
111024	KH-325	MC Sp4	0.013	10.15	8.01	16.66	351	-148.1	-72.69	-10.1	8.11
111024	KH-326	Keyhole Spring		9.24	8.30	17.03	287	-157.9	-73.69	-10.15	7.51
111024	KH-327	Middle Fork at Potwis	110.222	np	7.89	11.3	52.1	np	-89.83	-12.62	11.13
111024	KH-328	Marble Fork @ Marble Falls		np	7.69	10.1	45.6	np	-87.52	-12.09	9.2
111024	KH-329	Stream 1		np	8.13	13.2	362	np	-76.76	-10.87	10.2
111024	KH-330	Stream 2		np	8.51	16.2	396	np	-71.79	-10.13	9.25
111024	KH-331	Stream 3		np	7.69	14.4	424	np	-69.57	-9.75	8.43
111024	KH-332	Marble Fork @ Potwisha		np	7.77	12.7	59.7	np	-86.6	-11.78	7.64
111024	KH-333	Salt Cr		np			307	np	-61.86	-8.63	7.18
111024	KH-334	South Fork at SF Rd.		np			181	np	-86.8	-11.45	4.8
111024	KH-335	North Fork at Kaweah River Dr		np			198	np	-78.43	-11.1	10.37
111024	KH-336	Main Kaweah River at Slick Rock		np			142	np	-87.79	-12.2	9.81

Date	Sample ID	Site	Anions								Cations								Charge Balance (% error)
			F	Cl	NO_2	Br	NO_3	PO_4	SO_4	Alk	Li	Na	NH_4	K	Mg	Ca	Sr	Ba	
111022	KH-270	Snow @ WC 1								NA									
111022	KH-271	White Chief Cr blw Cr	0.00	0.77	0.00	0.00	0.00	0.00	3.57	18.34	0.00	1.05	0.07	0.79	0.50	6.73	0.00	0.14	4.3%
111022	KH-272	White Chief Creek ab	0.00	0.26	0.00	0.00	0.19	0.00	1.67	32.86	0.00	0.36	0.00	0.32	0.26	9.42	0.00	0.08	-6.7%
111022	KH-273	Corrigans Sink	0.00	0.12	0.00	0.00	0.33	0.00	0.71	20.54	0.00	0.27	0.00	0.13	0.18	8.34	0.00	0.09	10.3%
111022	KH-274	Bogaz	0.00	0.08	0.00	0.00	0.61	0.00	1.86	21.10	0.00	0.32	0.00	0.23	0.28	8.89	0.00	0.06	9.3%
111022	KH-275	Bogaz	0.00	0.24	0.00	0.00	0.54	0.00	1.92	28.75	0.00	0.35	0.03	0.25	0.28	7.94	0.00	0.05	-9.4%
111022	KH-276	White Chief Mine	0.00	0.18	0.00	0.00	0.56	0.00	1.74	36.97	0.00	0.29	0.00	0.23	0.25	12.58	0.00	0.18	0.4%
111022	KH-277	Snow @ WC 2								NA									
111022	KH-278	Snow @ WC 3								NA									
111022	KH-279	White Chief Sp	0.00	0.43	0.00	0.00	0.69	0.00	1.93	24.64	0.00	0.55	0.08	0.42	0.30	7.99	0.00	0.04	-1.3%
111022	KH-280	White Chief- Bat Slab	0.00	0.20	0.00	0.00	0.35	0.00	2.00	18.48	0.00	0.44	0.00	0.25	0.26	6.58	0.00	0.00	1.5%
111022	KH-281	Cirque Entrance	0.00	0.11	0.00	0.00	0.61	0.00	1.61	10.27	0.00	0.34	0.00	0.14	0.27	3.41	0.00	0.00	-2.6%
111022	KH-282	White Chief Lake	0.00	0.12	0.00	0.00	0.24	0.00	0.85	14.79	0.00	0.43	0.00	0.15	0.57	4.98	0.00	0.00	8.0%
111022	KH-283	Eagle Sink	0.06	0.17	0.00	0.00	0.18	0.00	1.27	21.04	0.00	0.69	0.00	0.31	0.36	7.56	0.00	0.02	6.9%
111022	KH-284	Eagle Meadow Sp	0.23	0.28	0.00	0.00	0.00	0.00	66.40	135.54	0.01	3.37	0.02	1.73	3.59	57.37	0.00	0.00	-7.6%
111022	KH-285	Tufa Sp	0.05	0.78	0.00	0.00	0.48	0.00	2.73	94.47	0.01	2.01	0.00	0.53	1.87	24.99	0.00	0.27	-4.5%
111022	KH-286	Monarch Lake	0.23	0.13	0.00	0.00	0.12	0.00	0.62	4.93	0.00	0.49	0.00	0.28	0.26	1.72	0.00	0.00	8.7%
111022	KH-287	Snow @ Monarch Lake								NA									
111022	KH-288	Snow @ Upper Monarch Karst								NA									
111022	KH-289	Monarch Cr abv karst	0.16	0.10	0.00	0.00	0.00	0.00	1.08	14.79	0.00	0.37	0.00	0.18	0.09	6.31	0.00	0.00	10.0%
111022	KH-290	bb sp?1	0.21	0.09	0.00	0.00	0.00	0.00	0.34	8.22	0.00	0.67	0.00	0.19	0.13	7.37	0.00	0.00	44.8%
111022	KH-291	bb sp?2	0.05	0.41	0.00	0.00	0.00	0.00	0.70	8.22	0.00	0.58	0.03	0.26	0.33	3.68	0.00	0.00	18.9%
111022	KH-292	cl sink?1	0.06	0.81	0.00	0.00	0.00	0.00	0.75	16.43	0.00	0.92	0.05	0.38	0.38	13.79	0.00	0.00	42.2%
111022	KH-293	City Lights Sink	0.00	0.24	0.00	0.00	0.00	0.00	1.34	12.32	0.00	0.48	0.03	0.36	0.49	4.01	0.00	0.00	5.9%
111022	KH-294	Bluebell sp	0.14	0.11	0.00	0.00	0.50	0.00	1.67	20.54	0.00	0.53	0.00	0.20	0.18	8.24	0.00	0.00	6.7%
111022	KH-295	Monarch Cr blw Karst	0.13	0.61	0.00	0.00	0.35	0.00	2.23	24.64	0.00	0.80	0.01	0.18	0.33	9.35	0.00	0.00	4.5%
111022	KH-296	Monarch Cr abv Ghog	0.14	0.58	0.00	0.00	0.24	0.00	2.11	23.64	0.00	0.84	0.00	0.24	0.41	6.07	0.00	0.01	-10.4%
111022	KH-297	Monarch Cr. blw Gho	0.11	0.53	0.00	0.00	0.00	0.00	2.11	24.64	0.00	0.82	0.00	0.27	0.35	8.26	0.00	0.01	0.7%
111022	KH-298	Monarch Sp	0.06	1.00	0.00	0.00	1.06	0.00	3.59	45.18	0.01	1.58	0.00	0.28	0.72	14.06	0.00	0.07	-2.3%
111022	KH-299	city Lights snow								NA									
111023	KH-300	TG Tarn	0.00	0.42	0.00	0.00	0.00	0.00	2.22	20.94	0.00	0.45	0.00	0.35	0.56	8.51	0.00	0.01	9.7%
111023	KH-301	Languid Lady Snow							0.21	NA									
111023	KH-302	TG Rise	0.00	0.18	0.00	0.00	0.00	0.00	1.14	41.07	0.00	0.56	0.00	0.21	0.43	12.78	0.00	0.00	-0.3%
111023	KH-303	TG Sink	0.00	0.19	0.00	0.00	0.00	0.00	0.99	24.64	0.00	0.69	0.00	0.23	0.23	7.60	0.00	0.00	0.0%
111023	KH-304	Marmota Follis	0.00	0.26	0.00	0.00	0.44	0.00	1.03	53.40	0.00	0.55	0.00	0.24	0.62	20.47	0.00	0.00	9.3%
111023	KH-305	Empire Sp	0.04	0.36	0.00	0.00	0.00	0.00	1.03	12.32	0.00	1.65	0.00	0.34	0.26	2.71	0.00	0.00	-0.6%
111023	KH-306	Empire Mine	0.05	0.26	0.00	0.00	1.14	0.00	0.79	69.00	0.00	0.66	0.00	0.14	0.70	17.58	0.00	0.15	-9.8%
111023	KH-307	Monarch Cr @ MIKI R	0.11	1.23	0.00	0.00	0.43	0.00	3.22	31.63	0.01	1.72	0.00	0.46	0.59	13.19	0.00	0.08	10.4%
111023	KH-308	East Fork @ Miki Rd	0.14	0.44	0.00	0.00	0.00	0.00	6.70	58.40	0.01	1.46	0.00	0.60	1.10	24.75	0.00	0.19	10.3%
111023	KH-309	East Fork @ Cold Sp	0.13	0.93	0.00	0.00	0.17	0.00	5.78	75.00	0.01	1.96	0.01	0.70	1.22	27.24	0.00	0.01	5.2%
111023	KH-310	Chihuahua Sp	0.05	0.40	0.00	0.00	0.31	0.00	12.42	10.27	0.00	1.46	0.00	0.69	0.51	6.31	0.04	0.00	-6.2%
111023	KH-311	Crystal Lake	0.27	0.75	0.00	0.00	0.32	0.00	0.83	7.39	0.00	0.57	0.00	0.62	0.10	3.18	0.00	0.00	6.6%
111023	KH-312	Crystal Cr Abv Karst	0.22	0.15	0.00	0.00	0.14	0.00	3.33	6.55	0.00	0.72	0.00	0.30	0.15	3.08	0.00	0.00	-0.9%
111023	KH-313	Cobalt Cr Abv karst	0.00	0.99	0.00	0.00	0.17	0.00	1.45	5.75	0.00	0.35	0.00	1.23	0.08	1.71	0.00	0.00	-7.7%
111023	KH-314	Cobalt Cr-Mdw Trib	0.10	0.18	0.00	0.00	0.18	0.00	5.03	28.75	0.00	1.42	0.00	0.42	0.33	9.77	0.00	0.00	-1.9%
111023	KH-315	Crystal Cr blw karst	0.20	0.25	0.00	0.00	0.45	0.00	3.67	10.27	0.00	0.85	0.00	0.42	0.17	4.05	0.00	0.00	-3.7%
111023	KH-316	Crystal Creek Spring	0.21	0.50	0.00	0.00	0.51	0.00	2.16	53.40	0.00	0.92	0.00	0.46	0.36	20.21	0.00	0.00	6.2%
111023	KH-317	Crystal Cr lower falls t	0.15	0.33	0.00	0.00	0.19	0.00	7.85	73.93	0.00	0.87	0.00	0.74	0.47	28.98	0.00	0.00	3.8%
111023	KH-318	Crystal Creek @ Trail	0.21	0.18	0.00	0.00	0.00	0.00	4.12	49.29	0.00	0.82	0.00	0.41	0.30	14.41	0.00	0.00	-8.0%
111024	KH-319	Paradise Sp	0.19	4.26	0.00	0.00	0.12	0.00	2.00	143.76	0.02	10.58	0.00	2.27	4.48	26.79	0.93	0.13	-6.0%
111024	KH-320	Upper Smoking Sp	0.15	1.73	0.00	0.00	2.46	0.00	26.18	180.72	0.02	4.75	0.03	2.47	5.55	53.20	1.86	0.34	-3.9%
111024	KH-321	Warm River	0.10	0.98	0.00	0.00	0.22	0.00	8.40	213.58	0.01	2.55	0.00	1.02	3.06	57.14	0.00	0.50	-7.1%
111024	KH-322	Hospital Rock Sp	0.17	1.77	0.00	0.00	0.49	0.00	18.77	143.76	0.02	6.05	0.00	1.92	4.44	56.75	0.00	0.00	9.7%
111024	KH-323	Alder Sp	0.31	2.54	0.00	0.00	1.66	0.68	7.53	180.72	0.00	1.97	0.03	1.03	4.23	63.28	0.00	0.00	4.7%
111024	KH-324	MC Sp 1	0.00	0.67	0.00	0.00	0.68	0.00	4.56	266.98	0.00	0.86	0.02	0.84	4.52	71.84	2.45	0.00	-5.2%
111024	KH-325	MC Sp4	0.15	1.28	0.00	0.00	0.69	0.00	5.86	244.65	0.02	10.78	0.00	1.71	5.84	48.68	1.57	0.49	-9.7%
111024	KH-326	Keyhole Spring	0.15	1.74	0.00	0.00	0.00	0.00	12.47	171.00	0.01	5.79	0.00	1.96	3.77	38.96	1.29	0.00	-10.2%
111024	KH-327	Middle Fork at Potwis	0.06	0.93	0.00	0.00	0.00	0.00	1.53	20.53	0.02	2.74	0.03	0.85	0.70	5.17	0.11	0.00	6.8%
111024	KH-328	Marble Fork @ Marble	0.00	0.58	0.00	0.00	0.00	0.00	0.70	36.97	0.00	2.20	0.02	0.78	1.55	7.95	0.00	0.03	0.1%
111024	KH-329	Stream 1	0.14	1.28	0.00	0.00	0.20	0.00	13.09	213.58	0.01	3.89	0.04	2.07	4.80	63.60	0.00	0.42	-1.0%
111024	KH-330	Stream 2	0.19	2.34	0.00	0.00	0.00	0.00	20.92	238.22	0.02	6.27	0.04	2.84	16.12	51.32	0.00	0.00	-3.0%
111024	KH-331	Stream 3	0.31	4.60	0.00	0.00	0.00	0.00	20.44	246.44	0.03	15.79	0.00	3.49	15.72	47.79	1.56	0.37	-2.2%
111024	KH-332	Marble Fork @ Potwis	0.08	0.45	0.00	0.00	0.00	0.00	0.45	22.86	0.00	2.04	0.00	0.65	1.06	5.90	0.14	0.00	9.8%
111024	KH-333	Salt Cr	0.36	10.63	0.00	0.00	0.00	0.00	2.02	156.08	0.02	21.54	0.00	2.49	7.91	27.62	1.15	0.34	2.3%
111024	KH-334	South Fork at SF Rd.	0.17	3.34	0.00	0.00	0.00	0.00	2.74	86.25	0.02	6.45	0.00	1.36	2.49	19.74	0.00	0.17	-2.4%
111024	KH-335	North Fork at Kaweah	0.15	2.02	0.00	0.00	0.00	0.00	2.84	82.15	0.01	5.51	0.00	1.47	3.14	21.68	0.77	0.21	5.1%
111024	KH-336	Main Kaweah River at	0.13	2.49	0.00	0.00	0.00	0.00	2.05	38.63	0.02	4.34	0.00	1.07	1.52	11.46	0.36	0.09	9.7%

	Sample		Field Water Quality						Isotopes		
Date	ID	Site	Discharge	DO	pH	Temp	Spec.Con	ORP	δD	δO	δ-excess
120606	KH-337	Rimstone Cr @ Yucc	0.067	np	8.29	8.8	518	np	-77.29	-11.16	11.99
120606	KH-338	Kuala Sp	0.01	np	7.05	9.4	329	np	-77.6	-11.26	12.48
120606	KH-339	Yucca Cr- Lower	4.136	np	8.11	9.7	126	np	-79.05	-11.49	12.87
120606	KH-340	Lange Sp	0.15	np	7.75	9.3	312	np	-77.98	-11.3	12.42
120606	KH-341	WTF Sp	0.001	np	8.32	10.9	591	np	-74.82	-10.86	12.06
120606	KH-342	Cave Cr Sp	2.394	np	7.70	8.8	243	np	-78.21	-11.09	10.51
120606	KH-343	Yucca Cr-Schist Falls	3.817	np	8.28	10.7	123.6	np	-79.95	-11.34	10.77
120606	KH-344	Hurricane Crawl	0.241	np	8.16	10.3	171.5	np	-78.43	-11	9.57
120606	KH-345	Cascade Cr	1.54	10.06	6.78	8.15	59	-38.5	-79.63	-11.32	10.93
120606	KH-346	Mossy Sp	0.294	10.69	6.52	10.12	579	-37.2	-79.33	-11.42	12.03
120606	KH-347	Crystal Cave	1.365	9.61	6.17	9.04	77	27.7	-79.76	-11.23	10.08
120606	KH-348	Crystal Drip1	np	np	np	np	np	np	-79.23	-11.4	11.97
120606	KH-349	Yucca Cr-Upper	2.944	10.77	6.18	11.56	26	39	-80.18	-11.79	14.14
120606	KH-350	Yucca Creek at Casc	1.8	7.86	6.30	16.04	28	30.6	-80.87	-11.5	11.13
120606	KH-351	Yucca Creek at Guide	2.5	9.43	7.23	11.93	69	-53.1	-78.98	-11.33	11.66
120606	KH-352	Dogwood Sp	0.015	np	7.06	10	595	np	-79.15	-11.21	10.53
120606	KH-353	Equinous Sp	0.001	np	7.13	10	586	np	-78.1	-12.18	19.34
120606	KH-354	Marble Fork @ Crystal Rd.		np	7.64	np	19.07	np	-90.35	-12.84	12.37
120606	KH-355	Marble Fork @ Lodgepole		np	7.83	np	24.7	np	-92.28	-12.8	10.12
120606	KH-356	Rimstone Sp	0.004	np	7.03	8.5	459	np	-82.19	-12.01	13.89
120607	KH-357	Franklin Lake	2.995	6.88	6.37	11.4	17	-0.9	-105.59	-15	14.41
120607	KH-358	Onion Mdw Sp	3.376	6.89	6.51	11.11	19	12.7	-105.92	-14.68	11.52
120607	KH-359	Franklin blw karst	3.376	7.2	6.66	10.48	21	15	-105.92	-14.8	12.48
120607	KH-360	Franklin blw Onion Mo	5.373	6.99	8.91	10.88	21	31.4	-104.74	-14.66	12.54
120607	KH-361	Beulah Sp	0.414	8.46	7.60	5.58	61	-31.3	-104.57	-14.37	10.39
120608	KH-362	Aspen Spring	0.321	7.23	7.76	6.25	45	-40.3	-100.28	-13.94	11.24
120608	KH-363	Monarch Cr abv Ghog	3.017	8.1	7.49	8.41	13	-41.5	-100.33	-13.91	10.95
120608	KH-364	Monarch Cr blw Karst	4.475	7.03	6.78	8.49	8	25	-100.59	-14.11	12.29
120608	KH-365	Bluebell sp	0.047	7.28	7.80	6.36	17	-27.2	-101.42	-14	10.58
120608	KH-366	Monarch Cr abv karst	4.592	7.04	6.37	10.25	6	30	-101.58	-14.09	11.14
120608	KH-367	Monarch Lake	1.996	6.37	7.17	9.73	8	-31.8	-102.58	-14.36	12.3
120608	KH-368	Cystal Lake	1.741	7.49	6.70	5.94	6	20.5	-100.49	-13.64	8.63
120608	KH-369	Crystal Cr Abv Karst	2.474	6.57	6.32	13.86	12	10.3	-101.8	-14.22	11.96
120608	KH-370	Cobalt Cr Abv karst	0.26	7.41	6.53	8.96	12	12.3	-101.04	-13.98	10.8
120608	KH-371	Crystal Cr blw karst	2.746	7.18	6.40	12.43	39.7	24.6	-101.87	-13.98	9.97
120608	KH-372	Cold Springs	0.019	np	6.30	12.4	36.6	np	-96.62	-13.82	13.94
120608	KH-373	East Fork @ Cold Sp	38.2	np	6.48	10.7	73	np	-99.19	-13.94	12.33
120608	KH-374	Monarch Cr @ MIKI R	6.02	np	7.72	10.2	56.7	np	-100.23	-14.03	12.01
120608	KH-375	East Fork @ Miki Rd	40.398	np	8.10	11.4	9.22	np	-103.2	-14.29	11.12
120608	KH-376	Crystal Creek @ Trail	3.352	np	7.85	15.3	60.3	np	-102.1	-14.12	10.86
120608	KH-377	Not Soda Sp	1.025	np	7.70	19.7	61.7	np	-105.92	-14.51	10.16
120608	KH-378	Soda Sp	0.001	np	6.42	21	1784	np	-106.93	-15.25	15.07
120608	KH-379	East Fork below Soda	17.127	np	7.23	17.1	8.71	np	-103.68	-14.71	14
120609	KH-380	Salt Cr	0.51	np	7.33	18.7	128.1	np	-66.31	-9.28	7.93
120609	KH-381	North Fork at Kaweah	73.85	np	7.34	21.8	101.8	np	-80.18	-11.72	13.58
120609	KH-382	South Fork at SF Rd.	75	np	7.95	19.3	74.6	np	-87.46	-12.58	13.18
120609	KH-383	Main Kaweah River at	np	np	7.33	22.7	72.4	np	-85.31	-11.85	9.49
120609	KH-384	Alder Sp	0.927	np	7.44	13.4	218	np	-69.97	-10.61	14.91
120609	KH-385	Middle Fork at Potwis	np	np	6.95	16.7	29.3	np	-94.64	-13.59	14.08
120609	KH-386	Marble Fork @ Potwis	90	np	7.27	14.8	32.4	np	-89.21	-12.61	11.67
120609	KH-387	Marble Fork @ Marble	47.083	11.43	6.55	12.73	22	32.7	-89.06	-12.62	11.9
120609	KH-388	Stream 1	0.161	11.43	7.37	12.68	232	-32.3	-75.61	-11.04	12.71
120609	KH-389	Stream 2	0.026	10.04	7.48	19.19	317	-20.5	-71.83	-10.57	12.73
120610	KH-390	Cave Cr Sink	0.271	9.17	6.91	15.32	51	-45.5	-80.25	-11.41	11.03
120610	KH-391	Cave Cr Trib	0.169	9.9	7.08	13.98	58	-17.8	-78.97	-11.39	12.15
120610	KH-392	Contact Sp	0.078	np	7.21	8.6	167.4	np	-82.98	-11.84	11.74
120610	KH-393	Yucca-upper	0.158	np	7.03	14.9	62.8	np	-80.04	-11.5	11.96
120611	KH-394	Monarch Sp	0.816	8.73	8.05	6.95	55	-62	-103.87	-14.53	12.37
120611	KH-395	Chihuahua Sp	1.505	7.8	4.90	3.81	18	90	-107.36	-15.12	13.6
120611	KH-396	Crystal Creek Spring	1.101	8.59	6.30	5.96	52	-29.4	-107.49	-15.04	12.83
120611	KH-397	Shower Cave	0.196	np	7.02	10.3	23.7	np	-106.07	-14.6	10.73
120611	KH-398	Lilburn-Alto St.	0.503	np		10.6	20.8	np	-106.04	-14.56	10.44
120612	KH-399	Empire Sp	0.03	7.28	7.81	12.98	14	-106	-104.03	-14.45	11.57
120612	KH-400	TG Tarn	0	7.1	5.65	21.26	7	-2.5	-97.54	-13.17	7.82
120612	KH-401	TG Rise	0.622	8.32	9.15	5.96	39	-148	-95.95	-13.32	10.61
120612	KH-402	TG Sink	0.478	8.15	8.30	11.87	15	-87	-93.73	-12.82	8.83
120612	KH-403	Marmota Follis	0.323	13.64	6.92	3.33	43	-28.3	-99.14	-13.54	9.18

Date	Sample ID	Site	Anions F	Cl	NO_2	Br	NO_3	PO_4	SO_4	Alk	Cations Li	Na	NH_4	K	Mg	Ca	Sr	Ba	Charge Balance
120606	KH-337	Rimstone Cr @ Yucca	0.06	1.90	0.00	0.00	0.28	0.00	2.48	305.00	0.00	2.35	0.00	0.86	36.13	46.82	0.00	0.05	2.9%
120606	KH-338	Kuala Sp	0.09	2.66	0.00	0.00	0.90	0.00	2.79	275.48	0.00	5.46	0.00	1.20	24.07	56.79	0.00	0.04	4.1%
120606	KH-339	Yucca Cr- Lower	0.07	1.92	0.00	0.00	0.38	0.00	1.51	104.43	0.00	4.43	0.00	0.88	6.94	24.31	0.00	0.00	4.9%
120606	KH-340	Lange Sp	0.10	1.78	0.00	0.00	0.89	0.00	2.10	180.56	0.00	4.26	0.00	0.99	16.19	36.56	0.00	0.00	4.4%
120606	KH-341	WTF Sp	0.06	1.42	0.00	0.00	0.54	0.00	4.81	380.64	0.00	2.04	0.00	0.66	43.15	60.67	0.00	0.07	2.1%
120606	KH-342	Cave Cr Sp	0.08	1.46	0.00	0.00	1.12	0.00	2.37	134.20	0.00	5.04	0.00	1.22	12.58	25.77	0.00	0.00	5.1%
120606	KH-343	Yucca Cr-Schist Falls	0.06	1.94	0.00	0.00	0.27	0.00	1.13	66.12	0.00	4.61	0.00	0.93	1.96	18.84	0.00	0.00	6.0%
120606	KH-344	Hurricane Crawl	0.08	0.87	0.00	0.00	1.01	0.00	1.59	94.43	0.00	4.14	0.00	0.82	2.62	29.32	0.39	0.00	7.2%
120606	KH-345	Cascade Cr	0.06	2.57	0.00	0.00	0.16	0.00	0.96	49.29	0.00	5.55	0.00	1.08	1.50	11.27	0.00	0.00	2.4%
120606	KH-346	Mossy Sp	0.13	20.72	0.00	0.00	0.00	0.00	6.08	336.80	0.00	19.75	0.00	1.87	12.75	89.96	0.00	0.05	1.4%
120606	KH-347	Crystal Cave	0.03	0.92	0.00	0.00	0.00	0.00	1.01	90.36	0.00	3.85	0.00	0.77	1.34	19.53	0.00	0.00	-9.4%
120606	KH-348	Crystal Drip1	0.00	0.38	0.00	0.00	0.13	0.00	1.22	328.91	0.00	0.79	0.00	0.00	11.42	91.74	0.00	0.05	1.1%
120606	KH-349	Yucca Cr-Upper	0.02	0.60	0.00	0.00	0.00	0.00	0.82	20.74	0.00	2.83	0.00	0.56	0.55	4.49	0.00	0.00	3.6%
120606	KH-350	Yucca Creek at Casc	0.06	0.72	0.11	0.00	0.00	0.00	0.72	20.50	0.00	2.90	0.00	0.66	0.57	4.67	0.00	0.00	5.3%
120606	KH-351	Yucca Creek at Guide	0.04	1.89	0.00	0.00	0.00	0.00	0.98	50.51	0.00	4.73	0.00	1.00	1.43	13.82	0.00	0.00	6.7%
120606	KH-352	Dogwood Sp	0.11	0.92	0.00	0.00	0.00	0.00	1.25	385.03	0.00	1.03	0.00	0.51	40.37	69.75	0.00	0.02	3.7%
120606	KH-353	Equinous Sp	0.09	1.01	0.00	0.00	0.00	0.00	2.13	379.42	0.00	1.35	0.00	1.18	40.16	70.11	0.00	0.12	4.4%
120606	KH-354	Marble Fork @ Crysta	0.00	0.28	0.00	0.00	0.00	0.00	0.44	25.47	0.00	1.31	0.00	0.45	0.23	7.68	0.00	0.00	3.7%
120606	KH-355	Marble Fork @ Lodge	0.00	0.13	0.00	0.00	0.00	0.00	0.20	5.86	0.00	0.57	0.00	0.29	0.09	1.26	0.00	0.00	-1.0%
120606	KH-356	Rimstone Sp	0.08	1.35	0.00	0.00	0.00	0.00	7.01	261.08	0.00	3.32	0.00	1.28	8.98	78.19	0.00	0.16	3.5%
120607	KH-357	Franklin Lake	0.27	0.74	0.00	0.00	0.40	0.00	2.91	9.04	0.00	1.13	0.00	0.81	0.10	4.03	0.00	0.00	3.0%
120607	KH-358	Onion Mdw Sp	0.26	0.24	0.00	0.00	0.42	0.00	2.80	7.08	0.00	0.62	0.00	0.35	0.09	4.34	0.00	0.00	9.9%
120607	KH-359	Franklin blw karst	0.21	0.18	0.00	0.00	0.47	0.00	3.08	11.96	0.00	0.59	0.00	0.33	0.10	5.26	0.00	0.00	1.4%
120607	KH-360	Franklin blw Onion Mc	0.23	0.16	0.00	0.00	0.46	0.00	3.05	9.76	0.00	0.56	0.00	0.28	0.10	5.19	0.00	0.00	6.9%
120607	KH-361	Beulah Sp	0.01	0.20	0.00	0.00	1.65	0.00	4.86	47.82	0.00	0.57	0.00	0.37	0.31	19.45	0.00	0.00	4.7%
120608	KH-362	Aspen Spring	0.00	0.51	0.00	0.00	0.14	0.00	3.55	58.56	0.00	2.56	0.00	0.62	0.75	19.31	0.00	0.00	3.9%
120608	KH-363	Monarch Cr abv Ghog	0.14	0.37	0.00	0.00	0.46	0.00	1.19	8.54	0.00	0.56	0.00	0.31	0.14	3.30	0.00	0.00	3.3%
120608	KH-364	Monarch Cr blw Karst	0.13	0.23	0.00	0.00	0.63	0.00	1.71	11.96	0.00	0.48	0.00	0.24	0.16	5.02	0.00	0.00	5.3%
120608	KH-365	Bluebell sp	0.13	0.56	0.00	0.00	0.42	0.00	1.04	10.00	0.00	0.69	0.00	0.30	0.13	3.22	0.00	0.00	-2.4%
120608	KH-366	Monarch Cr abv karst	0.16	0.20	0.00	0.00	0.38	0.00	0.83	12.32	0.00	0.33	0.00	0.25	0.21	4.54	0.00	0.00	4.2%
120608	KH-367	Monarch Lake	0.17	0.27	0.00	0.00	0.38	0.00	0.46	4.93	0.00	0.49	0.00	0.28	0.05	1.31	0.00	0.00	-8.1%
120608	KH-368	Cystal Lake	0.22	0.58	0.00	0.00	0.34	0.00	0.58	3.69	0.00	0.49	0.00	0.33	0.07	1.40	0.00	0.00	-1.7%
120608	KH-369	Crystal Cr Abv Karst	0.17	0.34	0.00	0.00	0.28	0.00	2.10	5.75	0.00	0.65	0.00	0.31	0.10	2.41	0.00	0.00	-1.5%
120608	KH-370	Cobalt Cr Abv karst	0.01	0.39	0.00	0.00	0.27	0.00	1.46	9.03	0.00	0.90	0.00	1.04	0.13	3.35	0.00	0.00	9.7%
120608	KH-371	Crystal Cr blw karst	0.14	0.21	0.00	0.00	0.30	0.00	2.17	11.96	0.00	0.61	0.00	0.34	0.12	4.07	0.00	0.00	-3.9%
120608	KH-372	Cold Springs	0.00	0.46	0.00	0.00	0.00	0.00	0.74	20.54	0.00	2.42	0.00	0.98	0.67	5.23	0.00	0.00	9.7%
120608	KH-373	East Fork @ Cold Sp	0.08	0.59	0.00	0.00	0.00	0.00	2.03	82.14	0.00	2.20	0.00	1.00	1.13	28.16	0.00	0.02	6.6%
120608	KH-374	Monarch Cr @ MIKI R	0.09	0.47	0.00	0.00	0.22	0.00	2.45	22.80	0.00	0.86	0.00	0.28	0.37	8.88	0.00	0.00	6.3%
120608	KH-375	East Fork @ Miki Rd	0.10	0.38	0.00	0.00	0.13	0.00	4.85	65.71	0.00	1.03	0.00	0.61	0.77	19.89	0.00	0.00	-4.3%
120608	KH-376	Crystal Creek @ Trail	0.13	0.16	0.00	0.00	0.21	0.00	2.86	24.64	0.00	0.62	0.00	0.41	0.22	10.77	0.00	0.00	9.5%
120608	KH-377	Not Soda Sp	0.20	0.21	0.00	0.00	0.41	0.00	3.83	22.17	0.00	0.64	0.00	0.40	0.20	10.36	0.00	0.00	8.5%
120608	KH-378	Soda Sp	0.25	0.66	0.00	0.00	6.11	0.00	0.74	903.61	0.00	16.99	0.00	3.67	10.73	258.00	0.00	0.27	-1.3%
120608	KH-379	East Fork below Soda	0.17	0.17	0.00	0.00	0.26	0.00	6.03	59.15	0.00	0.74	0.00	0.41	0.54	16.93	0.00	0.00	-10.0%
120609	KH-380	Salt Cr	0.17	3.36	0.00	0.00	0.00	0.00	0.90	71.25	0.00	12.58	0.00	1.67	3.55	13.29	0.00	0.02	8.8%
120609	KH-381	North Fork at Kaweah	0.07	1.24	0.00	0.00	0.00	0.00	1.64	68.56	0.00	4.39	0.00	1.09	2.27	19.78	0.00	0.00	7.3%
120609	KH-382	South Fork at SF Rd.	0.07	1.46	0.00	0.00	0.00	0.00	1.34	48.31	0.00	3.98	0.00	0.86	1.33	14.04	0.00	0.00	7.2%
120609	KH-383	Main Kaweah River at	0.06	1.76	0.00	0.00	0.00	0.00	1.69	56.36	0.00	3.38	0.00	1.14	1.20	17.85	0.00	0.02	6.7%
120609	KH-384	Alder Sp	0.17	2.49	0.00	0.00	0.00	0.00	5.37	163.48	0.00	9.44	0.00	1.65	5.38	44.97	0.66	0.05	4.3%
120609	KH-385	Middle Fork at Potwis	0.06	0.65	0.00	0.00	0.00	0.00	1.17	13.66	0.00	1.96	0.00	0.86	0.42	3.82	0.00	0.00	9.5%
120609	KH-386	Marble Fork @ Potwis	0.00	0.29	0.00	0.00	0.00	0.00	0.38	20.01	0.00	1.47	0.00	0.55	0.70	4.43	0.00	0.00	1.6%
120609	KH-387	Marble Fork @ Marble	0.00	0.26	0.00	0.00	0.00	0.00	0.27	14.15	0.00	1.51	0.00	0.56	0.50	3.62	0.00	0.00	10.2%
120609	KH-388	Stream 1	0.06	0.88	0.00	0.00	0.00	0.00	10.44	181.78	0.00	3.56	0.00	1.82	4.20	55.94	0.00	0.00	1.1%
120609	KH-389	Stream 2	0.08	2.57	0.00	0.00	0.00	0.00	21.15	200.32	0.00	6.69	0.00	2.93	15.33	47.82	0.00	0.00	1.6%
120610	KH-390	Cave Cr Sink	0.07	0.98	0.00	0.00	0.00	0.00	0.95	41.72	0.00	5.18	0.00	1.14	1.61	7.87	0.08	0.00	2.8%
120610	KH-391	Cave Cr Trib	0.18	1.03	0.00	0.00	0.00	0.00	1.68	32.94	0.00	6.84	0.00	1.03	0.57	5.99	0.00	0.00	3.8%
120610	KH-392	Contact Sp	0.06	1.90	0.00	0.00	0.00	0.00	1.27	104.19	0.00	4.66	0.00	1.11	2.51	29.25	0.00	0.00	2.7%
120610	KH-393	Yucca-upper	0.06	0.83	0.00	0.00	0.00	0.00	1.02	50.75	0.00	4.29	0.00	1.14	0.55	13.35	0.00	0.00	2.4%
120611	KH-394	Monarch Sp	0.07	1.40	0.00	0.00	0.24	0.00	3.11	49.29	0.00	1.59	0.00	0.19	0.71	19.83	0.00	0.00	9.2%
120611	KH-395	Chihuahua Sp	0.00	0.25	0.00	0.00	0.31	0.00	9.31	2.05	0.00	1.18	0.00	0.32	0.38	2.73	0.00	0.00	-10.3%
120611	KH-396	Crystal Creek Spring	0.26	0.22	0.00	0.00	0.31	0.00	1.55	41.07	0.00	0.58	0.00	0.23	0.23	15.56	0.00	0.00	5.7%
120611	KH-397	Shower Cave	0.34	0.16	0.00	0.00	0.00	0.00	0.58	11.91	0.00	0.54	0.00	0.17	0.06	4.04	0.00	0.00	0.5%
120611	KH-398	Lilburn-Alto St.	0.29	0.00	0.00	0.00	0.00	0.00	0.60	17.25	0.00	0.54	0.00	0.15	0.07	7.07	0.00	0.00	10.5%
120612	KH-399	Empire Sp	0.00	0.19	0.00	0.00	0.00	0.00	0.84	9.85	0.00	1.36	0.00	0.06	0.21	2.49	0.00	0.00	3.7%
120612	KH-400	TG Tarn	0.00	0.32	0.00	0.00	0.00	0.00	2.00	16.43	0.00	0.30	0.00	0.13	0.38	6.22	0.00	0.00	4.3%
120612	KH-401	TG Rise	0.00	0.51	0.00	0.00	0.23	0.00	0.90	32.85	0.00	0.56	0.00	0.22	0.36	12.80	0.00	0.00	9.3%
120612	KH-402	TG Sink	0.06	0.43	0.00	0.00	0.00	0.00	0.74	12.23	0.00	0.69	0.00	0.11	0.17	3.86	0.00	0.00	1.0%
120612	KH-403	Marmota Follis	0.00	0.35	0.00	0.00	0.32	0.00	0.86	49.29	0.00	0.29	0.00	0.10	0.45	18.31	0.00	0.00	6.7%

Date	Sample ID	Site	Field Water Quality Discharge	DO	pH	Temp	Spec.Con	ORP	Isotopes δD	δO	δ-excess
120608	KH-404	Lilburn-East St	np	np	np	np	np	np	-80.56	-12.17	16.8
120608	KH-405	Lilburn-West St	np	np	np	np	np	np	-85.03	-12.63	16.01
120608	KH-406	Lilburn-Alto St.	np	np	np	np	np	np	-79.73	-11.81	14.75
120608	KH-407	Lilburn-Mays Infeeder	np	np	np	np	np	np	-83.41	-12.17	13.95
120608	KH-408	Lilburn-White Rapids	np	np	np	np	np	np	-86.09	-12.23	11.75
120608	KH-409	Lilburn-Enchanted R	np	np	np	np	np	np	-85.05	-12.1	11.75
120608	KH-410	Lilburn-Yellow Floored	np	np	np	np	np	np	-86.28	-12.13	10.76
120608	KH-411	Lilburn-Z room	np	np	np	np	np	np	-85.86	-12.14	11.26
120608	KH-412	Big Spring	np	np	np	np	np	np	-84.98	-12.11	11.9
120608	KH-413	Redwood Cr	np	np	np	np	np	np	-85.36	-12.13	11.68
120616	KH-414	Cirque Entrance	1.536	np	5.81	13.5	12.78	np	-99.66	-13.45	7.94
120616	KH-415	White Chief- Bat Slab	1.626	np	7.37	4.3	24.3	np	-100.65	-13.76	9.43
120616	KH-416	White Chief Sp	1.522	np	7.44	5.4	34.2	np	-101.85	-13.86	9.03
120616	KH-417	White Chief Lake	0.545	np	6.73	13.6	11.11	np	-98.26	-13.16	7.02
120616	KH-418	Corrigans Sink	0.301	np	6.80	5.4	23.6	np	-98.43	-13.1	6.37
120616	KH-419	Bogaz	1.625	np	6.53	10.2	33.6	np	-101.01	-13.48	6.83
120616	KH-420	White Chief Creek ab	3.261	np	6.45	7.2	35.6	np	-99.83	-13.45	7.77
120616	KH-421	Eagle Sink	1.165	np	6.18	14.4	15.03	np	-101.05	-13.28	5.19
120616	KH-422	Eagle Meadow Sp	0.176	np	7.16	10.7	332	np	-101.84	-13.97	9.92
120616	KH-423	Tufa Sp	5.846	np	7.16	8.3	109.2	np	-104.93	-14.16	8.35
120617	KH-425	Upper Smoking Sp	0.044	np	6.34	13	264	np	-81.98	-11.64	11.14
120617	KH-424	Creek below warm riv	0.23	np	np	np	np	np	-81.39	-11.64	11.73
120618	KH-426	Warm River	0.352	np				np	-82.39	-11.78	11.85
120618	KH-427	Hospital Rock Sp	0.173	np	7.81	16	170	np	-74.3	-10.73	11.54
121020	KH-428	Lilburn-East St	np	np	np	np	np	np	-76.9	-11.23	12.94
121020	KH-429	Lilburn- West St	np	np	np	np	np	np	-80.3	-11.64	12.82
121020	KH-430	Lilburn- Alto St	np	np	np	np	np	np	-77.32	-11.66	15.96
121020	KH-431	Lilburn- Mays infeede	np	np	np	np	np	np	-81.75	-11.69	11.77
121020	KH-432	Lilburn- Upstream Ris	np	np	np	np	np	np	-84.1	-12.51	15.98
121020	KH-433	Lilburn- White Rapids	np	np	np	np	np	np	-83.48	-12.25	14.52
121020	KH-434	Lilburn- Enchanted R	np	np	np	np	np	np	-83.62	-12.2	13.98
121020	KH-435	Lilburn- Z- Room	np	np	np	np	np	np	-83.72	-12.22	14.04
121022	KH-436	Main Kaweah River at	23.808	8.43	7.96	17.57	119	-71.3	-82.84	-11.48	9
121022	KH-437	South Fork at SF Rd.	4.9797	8.05	7.75	15.78	147	-53.9	-78.95	-10.85	7.85
121022	KH-438	Alder Sp	0.1283	2.77	7.09	14.64	230	-36.5	-70.38	-10.26	11.7
121023	KH-439	Rimstone Cr @ Yucc	0.1752	4.93	8.03	8.11	292	1.8	-77.25	-11.3	13.15
121023	KH-440	Kuala Sp	0.0615	2.23	6.98	10.51	288	-5.7	-78.44	-11.43	13
121023	KH-441	Lower Yucca Cr	1.7103	7.18	7.93	9.28	170	0.1	-78.73	-11.83	15.91
121023	KH-442	Cave Creek Spring	0.2273	6.43	7.58	9.7	168	-2.5	-78.09	-11.22	11.67
121023	KH-443	Schist Falls	2.1786	6.5	8.16	9	128	17	-79.33	-11.44	12.19
121023	KH-444	Contact Sp	0	3.46	7.52	10.28	130	-5.5	-79.18	-11.66	14.1
121023	KH-445	Hurricane Crawl	0.102	4.68	8.24	10.21	163	-5.1	-77.61	-11.39	13.51
121023	KH-446	Guide Pool	1.305	7	8.14	8.84	107	-2.9	-79.47	-11.54	12.85
121023	KH-447	Upper Yucca Cr	0.0754	3.53	7.90	9.27	34	-10.6	-77.49	-11.5	14.51
121023	KH-448	Crystal Cave	0.3705	6.63	7.35	11.01	86	-4.4	-79.31	-11.59	13.41
121023	KH-449	Mossy Sp	0.0611	5.87	7.59	10.02	564	-10.8	-81.65	-11.94	13.87
121023	KH-450	Cascade Cr	0.783	6.94	8.27	7.51	89	-9.1	-79.65	-11.56	12.83
121024	KH-451	Black Wolf Falls	1.4134	5.83	8.25	3.72	51	0.2	-98.68	-13.72	11.08
121024	KH-452	Aspen Spring	0.1806	5.62	8.02	6.57	76	-13.2	-100.35	-13.96	11.33
121024	KH-453	Monarch Sp	0.1634	5.49	8.69	6.83	41	-5.1	-100.85	-14.1	11.95
121024	KH-454	Monarch blw ghog	0.3119	4.91	7.82	3.45	36	-6.2	-96.12	-13.3	10.28
121024	KH-455	Monarch blw karst	0.2285	4.87	7.69	5.86	34	1.4	-91.61	-12.65	9.59
121024	KH-456	Monarch abv karst	0.1251	5.08	7.33	4.62	10	-6.3	-93.9	-12.74	8.02
121024	KH-457	Monarch Lake	0.102	3.63	7.53	8.38	7	-23.4	-92.31	-11.94	3.21
121025	KH-458	Alto Cave	0.1215		7.44	1.9	10		-102.72	-14.11	10.16
121025	KH-459	Shower Cave	0.095		7.54	3.5	15		-103.94	-14.39	11.18
121025	KH-460	Franklin Lake	0.483		7.96	8.9	21		-103.01	-13.49	4.91
121025	KH-461	Onion Mdw Sp	0.5525		7.40	5	108.7		-100.41	-13.39	6.71
121025	KH-462	Franklin Cr abv Beulal	0.6528		7.61	4.4	201		-101.07	-13.83	9.57
121025	KH-463	Beulah Sp	0.21		7.69	5.3	357		-105.91	-14.74	12.01
121025	KH-464	Franklin at Trail	0.212		7.63	3.9	347		-103.44	-14.32	11.12
121025	KH-465	Not Soda Sp	0.195		7.86	4.8	217		-101.77	-13.78	8.47
121025	KH-466	Crystal Creek abv kar	0.4681	6.02	7.03	6.82		-12.7	-99.81	-13.69	9.71
121025	KH-467	Crystal Creek blw kar	0.4088	6.61	7.28	4.81		0.6	-98.95	-13.48	8.89
121025	KH-468	Crystal Creek Spring	0.6585	5.6	8.41	6.56		-6	-105.11	-14.5	10.89
121025	KH-469	Soda Sp		9.45	6.22	10.06	1087	14.89	-107.9	-15.2	13.7
121025	KH-470	East Fork below Soda	1.8864	6.69	6.88	4.8	7	10.7	-102.76	-14.02	9.4
121025	KH-471	ystal Creek at trail	1.0605	5.7	7.91	5.09		2.8	-101.21	-13.73	8.63
121025	KH-472	Monarch Creek at Rd	1.4741	6.14	7.80	5.6		-0.2	-98.41	-13.52	9.75
121027	KH-473	Warm River	0.0647	6.43	7.36	18.63	192	-1.4	-80.05	-11.32	10.51
121027	KH-474	Upper Smoking Sp	0.0246	9.51	8.27	10.53	189	1.1	-79.5	-10.95	8.1
121027	KH-475	Marble Falls	4.8262	7.39	8.14	9.77	51	-29.4	-82.5	-11.63	10.54
121027	KH-476	Slide Sp	0.0729	7.04	8.17	13.23	154	-45.7	-76.71	-11.27	13.45
121027	KH-477	stream 3 (deer Cr	0.0091	9.28	8.39	14.17	257	-49.8	-71.19	-10.45	12.41
121028	KH-478	Rimstone Sp	0.0423	5.72	7.89	9.78	337	-28.6	-80.98	-11.39	10.14
121028	KH-479	Dogwood Sp	0.0248	5.67	7.11	9.18	356	-41.4	-80.14	-11.76	13.94
121028	KH-480	Marble Fork at CC Bri	2.8173	7.59	7.82	7.51	22	-61.9	-85.95	-12.33	12.69
121030	KH-481	East Fork at Cold Spr	6.5056	9.62	8.04	4.2	80	-27.7	-102.05	-14.19	11.47
121030	KH-482	Cirque Entrance	0.03	7.96	7.52	4.59	118	-55.4	-85.8	-11.96	9.88
121030	KH-483	Bat Slab	0.1891	6.3	7.66	5.79	151	-20.1	-89.18	-12.25	8.82
121030	KH-484	White Chief Sp	0.2632	7.01	7.72	4.59	162	-25.7	-89.57	-12.44	9.95
121030	KH-485	White Chief Lake	0.0234	5.66	7.65	5.83	181	-35.7	-91.4	-12.46	8.28
121030	KH-486	Corrigans Sink	0.0648	7.19	7.56	6.17	161	-32.4	-90.68	-12.45	8.92
121030	KH-487	Bogaz	0.176	8.54	7.82	4.41	168	-27.1	-90.53	-12.38	8.51
121030	KH-488	Whtie Chief Cr abv Cr	0.6371	6.6	7.70	4.65	168	-49	-91.62	-12.42	7.74
121030	KH-489	Eagle Sink	0.085	6.2	8.02	3.78	139	-55	-100.07	-13.66	9.21
121030	KH-490	Eagle Meadow Sp	0.0972	6.78	8.27	2.77	143	-41.8	-99.68	-13.64	9.44
121030	KH-491	Tufa Sp	0.7828	6.6	8.41	6.06	279	-46.2	-102.03	-14	9.97
121030	KH-492	East Fork at Mineral I	2.3334	6.91	8.11	6.24	283	-43.5	-103.17	-14.04	9.15
121031	KH-493	Volvo Creek	0.0385	6.7	7.94	8.44	13	-93	-83.31	-11.98	12.53
121031	KH-494	Big Spring	2.2143	5.51	7.67	9.22	132	-53.1	-83.49	-12.01	12.59
121031	KH-495	Mays Creek	0.0153	5.9	7.56	9.08		-64.3	-80.75	-11.72	13.01
121031	KH-496	Redwood Cr	0.327	6.69	7.38	8.63	19	-54.9	-83.19	-11.93	12.25
121101	KH-497	Marble Fork at Lodge	1.0166	6.19	6.67	7.98		-35.2	-91.28	-13.02	12.88
121101	KH-498	Marble Fork at Potwis	4.4352	8.11	8.03	12.52	53	-55.6	-82.71	-11.71	10.97
121101	KH-499	Middle Fork at Potwis	8.809	8.3	7.98	12.04	24	-70.8	-88.62	-12.61	12.26
121101	KH-500	North Fork at Kaweah	4.3726	7.95	8.02	15.4	117	-65.7	-76.47	-11.23	13.37

	Sample		Anions								Cations								Charge
Date	ID	Site	F	Cl	NO_2	Br	NO_3	PO_4	SO_4	Alk	Li	Na	NH_4	K	Mg	Ca	Sr	Ba	Balance
120608	KH-404	Lilburn-East St	0.02	0.91	0.00	0.00	0.00	0.00	0.26	227.41	0.00	1.57	0.00	0.83	1.94	73.00	0.00	0.00	1.7%
120608	KH-405	Lilburn-West St	0.02	0.68	0.00	0.00	0.27	0.00	0.85	150.55	0.00	3.26	0.00	1.29	2.08	44.62	0.00	0.02	1.2%
120608	KH-406	Lilburn-Alto St.	0.02	0.92	0.00	0.00	0.28	0.00	0.34	222.53	0.00	1.94	0.00	0.66	2.65	72.77	0.00	0.05	3.4%
120608	KH-407	Lilburn-Mays Infeeder	0.03	0.70	0.00	0.00	0.00	0.00	0.25	56.61	0.00	3.20	0.00	0.68	0.46	17.03	0.00	0.00	4.5%
120608	KH-408	Lilburn-White Rapids	0.06	1.29	0.00	0.00	0.00	0.00	1.34	99.80	0.00	3.46	0.00	0.95	1.29	29.84	0.00	0.00	1.7%
120608	KH-409	Lilburn-Enchanted R	0.08	1.18	0.00	0.00	0.00	0.00	1.30	96.14	0.00	3.37	0.00	0.89	1.28	29.50	0.00	0.00	3.0%
120608	KH-410	Lilburn-Yellow Floored	0.00	0.94	0.00	0.00	0.90	0.00	0.51	123.71	0.00	1.81	0.22	0.74	0.73	41.33	0.00	0.00	3.5%
120608	KH-411	Lilburn-Z room	0.07	1.18	0.00	0.00	0.00	0.00	1.29	100.04	0.00	3.37	0.00	0.86	1.26	29.61	0.00	0.00	1.1%
120608	KH-412	Big Spring	0.07	1.11	0.00	0.00	0.00	0.00	1.31	100.28	0.00	3.35	0.00	0.86	1.26	29.64	0.00	0.00	1.1%
120608	KH-413	Redwood Cr	0.03	0.65	0.00	0.00	0.00	0.00	0.60	26.35	0.00	3.44	0.00	0.95	0.65	5.59	0.07	0.00	4.2%
120616	KH-414	Cirque Entrance	0.00	0.13	0.00	0.00	0.00	0.00	1.41	13.55	0.00	0.16	0.00	0.03	0.09	6.01	0.00	0.00	9.4%
120616	KH-415	White Chief- Bat Slab	0.00	0.16	0.00	0.00	0.46	0.00	1.96	22.59	0.00	0.17	0.00	0.04	0.15	7.06	0.00	0.00	-7.3%
120616	KH-416	White Chief Sp	0.00	0.31	0.00	0.00	0.25	0.00	2.16	20.53	0.00	0.23	0.00	0.12	0.17	6.04	0.00	0.00	-10.3%
120616	KH-417	White Chief Lake	0.00	0.36	0.00	0.00	0.25	0.00	0.57	3.70	0.00	0.29	0.00	0.14	0.04	1.74	0.00	0.00	9.1%
120616	KH-418	Corrigans Sink	0.00	0.20	0.00	0.00	0.00	0.00	0.57	12.32	0.00	0.22	0.00	0.06	0.07	4.64	0.00	0.02	5.7%
120616	KH-419	Bogaz	0.00	0.11	0.00	0.00	0.39	0.00	2.01	28.75	0.00	0.18	0.00	0.07	0.34	10.11	0.00	0.01	1.0%
120616	KH-420	White Chief Creek abv	0.00	0.17	0.00	0.00	0.26	0.00	1.69	20.54	0.00	0.19	0.00	0.12	0.17	6.79	0.00	0.01	-3.2%
120616	KH-421	Eagle Sink	0.00	0.24	0.00	0.00	0.00	0.00	1.02	26.70	0.00	0.54	0.00	0.24	0.15	7.02	0.00	0.00	-9.0%
120616	KH-422	Eagle Meadow Sp	0.28	1.50	0.00	0.00	0.00	0.00	59.95	90.36	0.00	4.08	0.00	1.99	3.47	58.55	0.00	0.00	6.2%
120616	KH-423	Tufa Sp	0.00	0.58	0.00	0.00	0.24	0.00	2.19	69.82	0.00	1.46	0.00	0.33	1.33	19.75	0.00	0.04	-2.2%
120617	KH-425	Upper Smoking Sp	0.22	1.64	0.00	0.00	0.00	0.00	23.18	154.70	0.00	4.59	0.00	2.11	5.35	53.93	0.68	0.00	3.5%
120617	KH-424	Creek below warm rive	0.19	2.35	0.00	0.00	1.68	0.00	8.35	147.38	0.00	3.36	0.00	1.52	3.28	51.00	0.00	0.04	4.7%
120618	KH-426	Warm River	0.12	0.75	0.00	0.00	2.03	0.00	6.96	201.79	0.00	2.17	0.00	0.85	3.00	66.25	0.00	0.10	1.8%
120618	KH-427	Hospital Rock Sp	0.23	1.37	0.00	0.00	0.00	0.00	16.11	92.72	0.00	5.33	0.00	1.61	3.12	30.51	0.00	0.00	2.0%
121020	KH-428	Lilburn-East St	0.00	0.59	0.00	0.00	0.00	0.00	0.63	211.94	0.00	1.40	0.00	1.11	2.01	56.00	0.00	0.08	-7.0%
121020	KH-429	Lilburn- West St	0.12	0.48	0.00	0.00	0.20	0.00	3.67	172.51	0.00	2.08	0.00	1.07	1.78	50.45	0.89	0.04	-2.4%
121020	KH-430	Lilburn- Alto St	0.05	0.72	0.00	0.00	0.16	0.00	0.45	246.44	0.01	2.02	0.00	0.80	2.62	71.83	0.00	0.09	-2.1%
121020	KH-431	Lilburn- Mays infeeder	0.09	0.60	0.00	0.00	0.22	0.00	0.29	133.08	0.00	3.86	0.00	0.90	0.86	34.12	0.00	0.00	-6.0%
121020	KH-432	Lilburn- Upstream Ris	0.20	1.57	0.00	0.00	0.00	0.00	2.13	157.72	0.01	4.40	0.00	1.06	2.22	48.66	0.00	0.03	2.5%
121020	KH-433	Lilburn- White Rapids	0.20	1.56	0.00	0.00	0.00	0.00	2.11	157.72	0.01	4.42	0.00	1.06	2.23	48.85	0.00	0.07	2.7%
121020	KH-434	Lilburn- Enchanted R	0.20	1.56	0.00	0.00	0.00	0.00	2.11	164.29	0.01	4.39	0.00	1.05	2.22	48.79	0.00	0.02	0.6%
121020	KH-435	Lilburn- Z- Room	0.21	1.48	0.00	0.00	0.00	0.00	2.03	164.29	0.01	4.47	0.00	1.06	2.17	48.69	0.00	0.09	0.6%
121022	KH-436	Main Kaweah River at	0.17	8.15	0.00	0.00	0.00	0.00	3.31	83.79	0.01	9.28	0.00	1.77	2.64	19.25	0.00	0.02	-2.0%
121022	KH-437	South Fork at SF Rd.	0.21	5.69	0.00	0.00	0.00	0.00	4.76	113.36	0.01	9.33	0.00	1.90	3.37	30.53	0.00	0.07	2.5%
121022	KH-438	Alder Sp	0.60	2.47	0.00	0.00	0.21	0.00	7.30	193.04	0.01	10.62	0.00	1.79	6.49	56.38	0.00	0.14	5.6%
121023	KH-439	Rimstone Cr @ Yucca	0.25	2.31	0.00	0.00	0.00	0.00	2.95	336.80	0.01	3.29	0.00	1.29	33.09	59.11	0.00	0.14	1.5%
121023	KH-440	Kuala Sp	0.24	3.18	0.00	0.00	1.46	0.00	2.84	320.37	0.02	6.15	0.00	1.44	25.94	64.15	0.00	0.12	1.7%
121023	KH-441	Lower Yucca Cr	0.18	2.95	0.00	0.00	0.00	0.00	2.14	182.37	0.01	5.78	0.00	1.32	11.54	40.52	0.00	0.00	1.9%
121023	KH-442	Cave Creek Spring	0.10	1.23	0.00	0.00	0.89	0.00	3.10	197.15	0.01	5.53	0.00	1.26	15.01	32.57	0.00	0.00	-3.5%
121023	KH-443	Schist Falls	0.17	3.79	0.00	0.00	0.00	0.00	1.59	133.08	0.01	6.53	0.00	1.35	3.40	35.26	0.00	0.00	0.5%
121023	KH-444	Contact Sp	0.18	4.27	0.00	0.00	0.25	0.00	1.48	143.76	0.01	6.40	0.00	1.39	3.15	35.00	0.00	0.04	-4.3%
121023	KH-445	Hurricane Crawl	0.21	0.84	0.00	0.00	0.65	0.00	2.22	172.51	0.01	4.66	0.00	1.00	4.20	46.59	0.81	0.00	-0.2%
121023	KH-446	Guide Pool	0.18	4.32	0.00	0.00	0.00	0.00	1.37	103.50	0.01	7.15	0.00	1.47	2.70	27.73	0.00	0.00	2.5%
121023	KH-447	Upper Yucca Cr	0.14	1.17	0.00	0.00	0.00	0.00	0.91	54.22	0.00	3.54	0.00	1.21	0.69	11.63	0.00	0.00	-7.3%
121023	KH-448	Crystal Cave	0.14	1.06	0.00	0.00	0.17	0.00	0.84	73.93	0.01	4.19	0.00	1.20	1.42	22.41	0.00	0.00	6.4%
121023	KH-449	Mossy Sp	0.60	26.59	0.00	0.00	0.00	0.00	3.96	575.03	0.05	22.72	0.00	2.33	14.75	139.19	0.00	0.00	-5.6%
121023	KH-450	Cascade Cr	0.19	5.48	0.00	0.00	0.00	0.00	1.38	98.58	0.02	8.24	0.00	1.62	2.83	21.83	0.00	0.00	-2.6%
121024	KH-451	Black Wolf Falls	0.12	1.56	0.00	0.00	0.40	0.00	4.34	61.61	0.01	1.90	0.00	0.35	0.68	17.06	0.00	0.00	-8.0%
121024	KH-452	Aspen Spring	0.10	0.78	0.00	0.00	0.14	0.00	5.05	73.93	0.00	2.82	0.00	0.75	0.84	24.93	0.00	0.00	3.1%
121024	KH-453	Monarch Sp	0.09	0.83	0.00	0.00	0.59	0.00	3.78	49.29	0.01	1.47	0.00	0.29	0.70	15.07	0.00	0.00	-3.2%
121024	KH-454	Monarch blw ghog	0.09	1.74	0.00	0.00	0.83	0.00	4.44	29.26	0.00	1.41	0.00	0.27	0.57	11.86	0.00	0.00	3.6%
121024	KH-455	Monarch blw karst	0.12	0.88	0.00	0.00	0.60	0.00	2.28	24.34	0.00	0.65	0.00	0.51	0.33	9.94	0.00	0.00	6.4%
121024	KH-456	Monarch abv karst	0.18	0.49	0.00	0.00	0.00	0.00	0.80	9.55	0.00	0.67	0.00	0.45	0.13	2.67	0.00	0.00	-4.0%
121024	KH-457	Monarch Lake	0.23	0.30	0.00	0.00	0.00	0.00	0.44	3.08	0.00	0.61	-0.47	0.38	0.05	1.58	0.00	0.00	5.1%
121025	KH-458	Alto Cave	0.42	0.46	0.00	0.00	0.00	0.00	0.92	11.40	0.00	1.16	-0.49	0.67	0.10	4.31	0.00	0.00	3.5%
121025	KH-459	Shower Cave	0.39	0.25	0.00	0.00	0.16	0.00	1.18	32.04	0.00	1.13	0.00	0.39	0.13	11.16	0.00	0.00	3.4%
121025	KH-460	Franklin Lake	0.30	0.18	0.00	0.00	0.17	0.00	3.52	8.38	0.00	0.75	0.00	0.37	0.09	4.39	0.00	0.00	3.9%
121025	KH-461	Onion Mdw Sp	0.52	0.55	0.00	0.00	0.24	0.00	3.82	16.43	0.01	1.33	0.00	0.42	0.11	6.75	0.00	0.00	0.5%
121025	KH-462	Franklin Cr abv Beulal	0.28	0.35	0.00	0.00	0.41	0.00	5.88	45.18	0.02	1.10	0.00	0.51	0.24	14.18	0.00	0.00	-7.5%
121025	KH-463	Beulah Sp	0.04	0.44	0.00	0.00	1.77	0.00	6.10	73.93	0.00	0.88	0.00	0.57	0.48	25.22	0.00	0.00	-2.1%
121025	KH-464	Franklin at Trail	0.13	0.30	0.00	0.00	0.94	0.00	7.21	64.07	0.00	0.92	0.00	0.54	0.47	23.68	0.00	0.00	0.5%
121025	KH-465	Not Soda Sp	0.28	0.30	0.00	0.00	0.30	0.00	5.86	53.40	0.00	1.05	0.00	0.46	0.29	15.68	0.00	0.00	-9.7%
121025	KH-466	Crystal Creek abv kar	0.21	0.70	0.00	0.00	0.00	0.00	9.13	17.74	0.00	1.39	0.00	0.73	0.33	7.59	0.00	0.00	-6.3%
121025	KH-467	Crystal Creek blw kar	0.16	0.61	0.00	0.00	0.00	0.00	7.94	15.20	0.00	1.42	0.00	0.62	0.33	7.04	0.00	0.00	-1.9%
121025	KH-468	Crystal Creek Spring	0.22	0.36	0.00	0.00	0.49	0.00	3.95	73.93	0.02	1.27	0.00	0.50	0.44	22.28	0.00	0.00	-4.8%
121025	KH-469	Soda Sp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2033.13	0.02	17.03	-0.25	3.62	10.68	217.83	5.25	0.09	-44.9%
121025	KH-470	East Fork below Soda	0.13	0.24	0.00	0.00	0.00	0.00	18.11	120.14	0.00	1.96	0.00	0.61	1.68	45.44	0.00	0.00	1.4%
121025	KH-471	ystal Creek at trail	0.17	0.39	0.00	0.00	0.22	0.00	7.47	58.53	0.00	1.21	0.00	0.68	0.44	20.34	0.00	0.00	-2.1%
121025	KH-472	Monarch Creek at Rd	0.07	1.49	0.00	0.00	0.34	0.00	4.70	58.53	0.00	1.94	0.00	0.55	0.75	17.66	0.00	0.00	-4.0%
121027	KH-473	Warm River	0.12	0.89	0.00	0.00	2.32	0.00	8.16	206.39	0.02	2.62	0.00	1.10	3.04	61.15	0.00	0.04	-3.0%
121027	KH-474	Upper Smoking Sp	0.17	1.72	0.00	0.00	0.00	0.00	26.62	206.39	0.02	5.01	0.00	2.59	5.75	54.08	0.00	0.00	-8.6%
121027	KH-475	Marble Falls	0.11	1.50	0.00	0.00	0.22	0.00	0.84	70.85	0.00	3.99	0.00	1.18	2.29	13.06	0.00	0.00	-8.3%
121027	KH-476	Slide Sp	0.16	1.35	0.00	0.00	0.00	0.00	13.23	191.00	0.02	4.64	0.00	2.34	5.95	48.44	0.00	0.00	-5.1%
121027	KH-477	stream 3 (deer Cr	0.58	2.51	0.00	0.00	0.00	0.00	22.76	246.00	0.03	7.00	0.00	3.20	16.82	50.20	0.00	0.00	-4.7%
121028	KH-478	Rimstone Sp	0.20	5.10	0.00	0.00	0.00	0.00	4.55	314.21	0.02	7.14	0.00	1.55	9.64	69.33	0.00	0.06	-8.1%
121028	KH-479	Dogwood Sp	0.37	1.19	0.00	0.00	0.00	0.00	1.33	391.22	0.02	1.43	0.00	0.77	37.72	65.51	0.00	0.00	-0.3%
121028	KH-480	Marble Fork at CC Bri	0.15	1.13	0.00	0.00	0.00	0.00	0.47	29.88	0.02	3.71	0.00	1.12	0.60	4.43	0.00	0.00	-7.8%
121030	KH-481	East Fork at Cold Spr	0.09	1.15	0.00	0.00	0.00	0.00	7.95	144.78	0.02	3.00	0.00	0.92	2.04	37.97	0.00	0.02	-8.1%
121030	KH-482	Cirque Entrance	0.00	0.75	0.00	0.00	0.65	0.00	1.90	14.48	0.00	0.99	-0.42	0.50	0.40	4.96	0.00	0.00	-0.8%
121030	KH-483	Bat Slab	0.00	0.29	0.00	0.00	0.64	0.00	2.25	23.72	0.00	0.58	0.00	0.33	0.38	8.72	0.00	0.00	3.8%
121030	KH-484	White Chief Sp	0.00	0.29	0.00	0.00	0.84	0.00	2.47	40.05	0.00	0.59	0.00	0.35	0.44	13.31	0.00	0.00	-0.3%
121030	KH-485	White Chief Lake	0.00	0.30	0.00	0.00	0.80	0.00	1.99	12.94	0.00	0.84	0.00	0.35	0.24	4.78	0.00	0.00	3.6%
121030	KH-486	Corrigans Sink	0.00	0.25	0.00	0.00	0.72	0.00	1.95	32.35	0.00	0.61	0.00	0.28	0.27	11.58	0.00	0.08	3.0%
121030	KH-487	Bogaz	0.00	0.72	0.00	0.00	1.07	0.00	2.74	49.29	0.00	0.81	-0.27	0.53	0.46	13.94	0.00	0.04	-8.8%
121030	KH-488	Whtie Chief Cr abv Cr	0.00	0.29	0.00	0.00	0.80	0.00	2.74	52.37	0.00	0.56	0.00	0.35	0.44	17.51	0.00	0.00	-0.2%
121030	KH-489	Eagle Sink	0.00	0.54	0.00	0.00	0.13	0.00	2.20	13.86	0.00	1.13	0.00	0.53	0.48	4.22	0.00	0.00	2.1%
121030	KH-490	Eagle Meadow Sp	0.25	0.49	0.00	0.00	0.00	0.00	76.95	123.22	0.02	3.52	-0.36	1.68	3.78	62.28	0.00	0.00	-4.9%
121030	KH-491	Tufa Sp	0.09	1.86	0.00	0.00	0.00	0.00	3.70	144.78	0.02	4.25	0.00	0.91	3.68	38.98	0.00	0.17	-1.2%
121030	KH-492	East Fork at Mineral I	0.12	0.62	0.00	0.00	0.00	0.00	9.64	123.22	0.02	2.28	0.00	0.96	1.81	37.07	0.00	0.00	-3.6%
121031	KH-493	Volvo Creek	0.40	0.78	0.00	0.00	0.00	0.00	0.61	40.05	0.00	6.24	0.00	1.29	0.79	7.96	0.00	0.00	3.4%
121031	KH-494	Big Spring	0.20	1.56	0.00	0.00	0.00	0.00	2.19	154.03	0.02	4.43	0.00	1.12	2.11	38.48	0.00	0.00	-6.4%
121031	KH-495	Mays Creek	0.13	1.31	0.00	0.00	0.00	0.00	0.30	17.56	0.00	4.54	-0.41	1.43	0.34	2.56	0.00	0.00	3.8%
121031	KH-496	Redwood Cr	0.20	0.72	0.00	0.00	0.00	0.00	0.71	33.89	0.00	4.84	0.00	1.35	0.97	7.06	0.00	0.00	5.7%
121101	KH-497	Marble Fork at Lodge	0.09	0.39	0.00	0.00	0.00	0.00	0.49	14.48	0.00	2.44	0.00	0.76	0.40	2.99	0.00	0.00	7.4%
121101	KH-498	Marble Fork at Potwis	0.12	1.32	0.00	0.00	0.00	0.00	1.49	83.17	0.02	3.88	0.00	1.35	3.39	17.12	0.00	0.00	-3.8%
121101	KH-499	Middle Fork at Potwis	0.14	2.05	0.00	0.00	0.00	0.00	2.45	35.12	0.02	5.28	0.00	1.31	1.34	8.54	0.00	0.00	6.7%
121101	KH-500	North Fork at Kaweah	0.20	2.98	0.00	0.00	0.00	0.00	2.97	120.14	0.02	6.53	0.00	1.69	3.90	25.68	0.00	0.00	-5.0%

APPENDIX 5

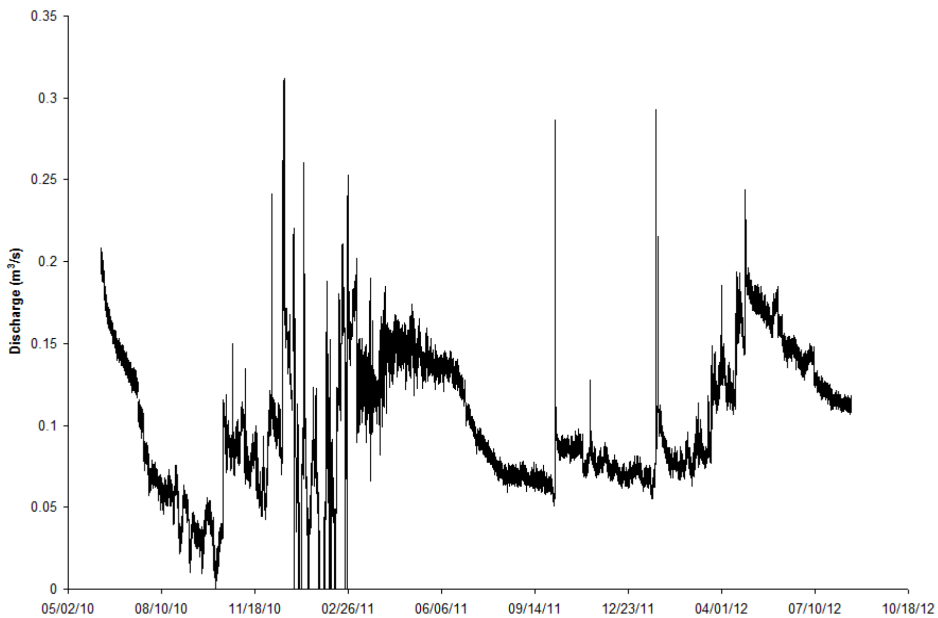
PRECIPITATION ISOTOPE DATA

Sample ID	Site	Elevation (m)	Date	Form	δD	δO
KR1	Ash Mtn	514	4/6/2010	Rain	-48.14	-7.45
KR2	Lower Kaweah	1945	4/6/2010	mix	-65.68	-10.16
KR3	Ash Mtn	514	4/13/2010	Rain	-59.32	-9.44
KR4	Lower Kaweah	1945	4/13/2010	mix	-82.32	-12.5
KR5	Ash Mtn	514	4/20/2010	Rain	-73.09	-10.2
KR6	Ash Mtn	514	4/27/2010	mix	-93.81	-13.26
KR7	Lower Kaweah	1945	4/27/2010	mix	-81.5	-10.2
KR8	Ash Mtn	514	5/4/2010	Rain	-30.8	-4.82
KR9	Lower Kaweah	1945	5/4/2010	mix	-49.2	-7.22
KR10	Ash Mtn	514	5/11/2010	Rain	-52.84	-7.06
KR11	Lower Kaweah	1945	5/18/2010	Rain	-94.83	-13.12
KR12	Ash Mtn	514	5/19/2010	Rain	-55.37	-6.8
KR13	Ash Mtn	514	6/1/2010	Rain	-34.2	-5.77
KR14	Lower Kaweah	1945	10/5/2010	Rain	-66.28	-9.22
KR15	Ash Mtn	514	10/19/2010	Rain	-12.93	-1.56
KR27	Three Rivers	313	10/26/2010	rain	-18.57	-4.19
KR16	Ash Mtn	514	11/1/2010	Rain	-46.57	-7.02
KR17	Ash Mtn	514	11/9/2010	Rain	-39.76	-6.34
KR18	Ash Mtn	514	11/22/2010	Rain	-56.89	-10.02
KR19	Lower Kaweah	1945	11/23/2010	mix	-68.72	-11.02
KR28	Ash Mtn	313	12/1/2010	Rain	-61.22	-9.7
KR20	Ash Mtn	514	12/6/2010	Rain	-74.12	-11.25
KR21	Lower Kaweah	1945	12/7/2010	Rain	-94.83	-13.9
KR22	Ash Mtn	514	12/21/2010	BIG	-92.78	-12.08
KR23	Three Rivers	313	12/21/2010	Rain	-92.78	-11.99
KR24	Lower Kaweah	1945	12/21/2010	mix	-106.11	-14.55
KR25	Ash Mtn	514	12/28/2010	Rain	-132.57	-16.84
KR26	Three Rivers	313	12/28/2010	Rain	-109.19	-14.19
KR28	Lower Kaweah	1945	3/6/2012	np	-57.63	-9.58
KR29	Lower Kaweah	1945	3/20/2012	np	-98.64	-13.29
KR30	Lower Kaweah	1945	3/27/2012	np	-111.48	-15.7
KR31	Lower Kaweah	1945	4/3/2012	np	-52.31	-8.72
KR32	Lower Kaweah	1945	4/17/2012	np	-99.5	-13.85
KR33	Lower Kaweah	1945	5/1/2012	np	-100.39	-13.19
KR34	Lower Kaweah	1945	10/23/2012	np	-59.03	-9.55
KR35	Lower Kaweah	1945	11/13/2012	np	-50.78	-8.91
KR36	Lower Kaweah	1945	11/20/2012	np	-85.41	-12.2
KR37	Lower Kaweah	1945	12/4/2012	np	-68.64	-10.84
KR38	Lower Kaweah	1945	12/18/2012	np	-70.96	-10.43
KR39	Lower Kaweah	1945	12/27/2012	np	-71.54	-10.34
KR40	Lower Kaweah	1945	1/15/2013	np	-63.87	-9.85
KR41	Lower Kaweah	1945	3/12/2013	np	-78.26	-10.57
KR42	Ash Mtn	514	2/14/2012	np	-63.42	-9.11
KR43	Ash Mtn	514	2/21/2012	np	-100.97	-13.91
KR44	Ash Mtn	514	2/28/2012	np	-55.8	-8.84
KR45	Ash Mtn	514	3/6/2012	np	-25.58	-5.52
KR46	Ash Mtn	514	3/13/2012	np	-49.47	-6.95
KR47	Ash Mtn	514	3/20/2012	np	-92.13	-12.6
KR48	Ash Mtn	514	3/27/2012	np	-94.88	-12.96
KR49	Ash Mtn	514	4/3/2012	np	-35.64	-6.4
KR50	Ash Mtn	514	4/17/2012	np	-91.72	-12.28
KR51	Ash Mtn	514	5/1/2012	np	-77.12	-10.28
KR52	Ash Mtn	514	5/29/2012	np	-74.74	-8.86
KR53	Ash Mtn	514	9/26/2012	np	-51.18	-8.14
KR54	Ash Mtn	514	10/16/2012	np	-44.67	-7.49
KR55	Ash Mtn	514	10/23/2012	np	-25.51	-4.12
KR56	Ash Mtn	514	11/13/2012	np	-53.29	-9.41
KR57	Ash Mtn	514	11/20/2012	np	-55.69	-7.06
KR58	Ash Mtn	514	12/4/2012	np	-52.2	-6.67
KR59	Ash Mtn	514	12/18/2012	np	-53.86	-7.62
KR60	Ash Mtn	514	1/2/2013	np	-65.19	-9.52
KR61	Ash Mtn	514	1/8/2013	np	-62.7	-9.74
KR62	Ash Mtn	514	1/15/2013	np	-48.58	-8.61
KR63	Ash Mtn	514	1/29/2013	np	-95.73	-12.63
KR64	Ash Mtn	514	2/12/2013	np	-63.41	-9.8
KR65	Ash Mtn	514	2/19/2013	np	-3.63	-2.87

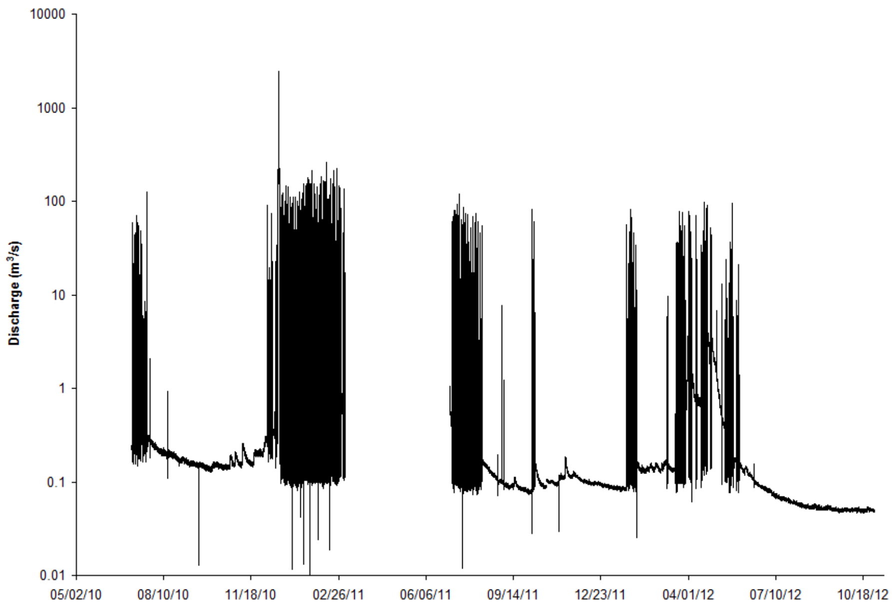
APPENDIX 6

SPRING AND CREEK HYDROGRAPHS

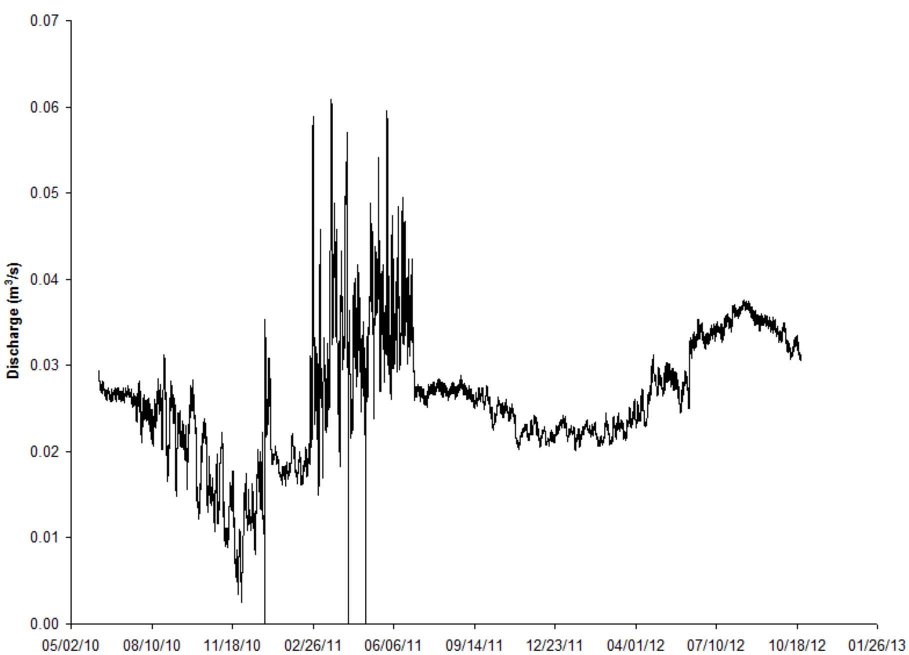
Cascade Creek:



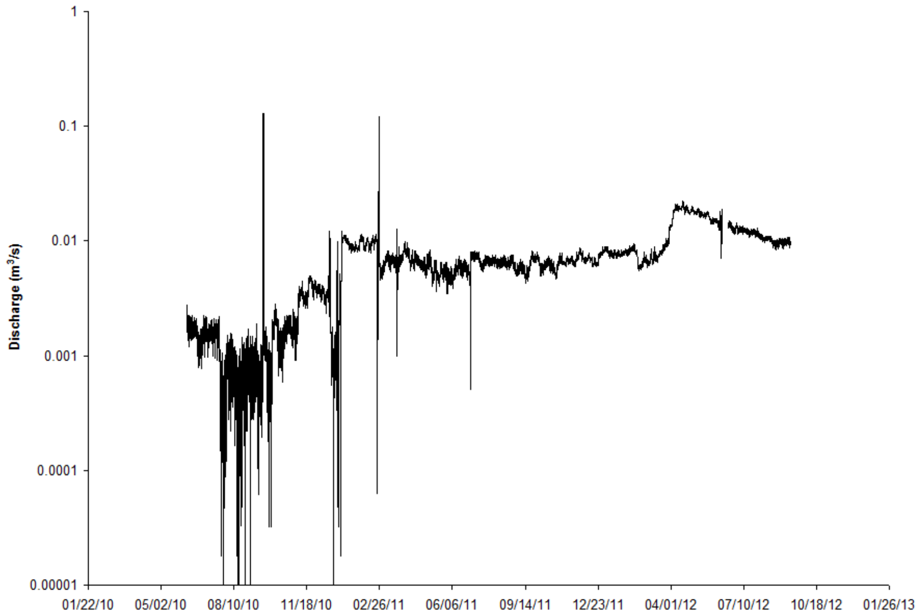
Big Spring:



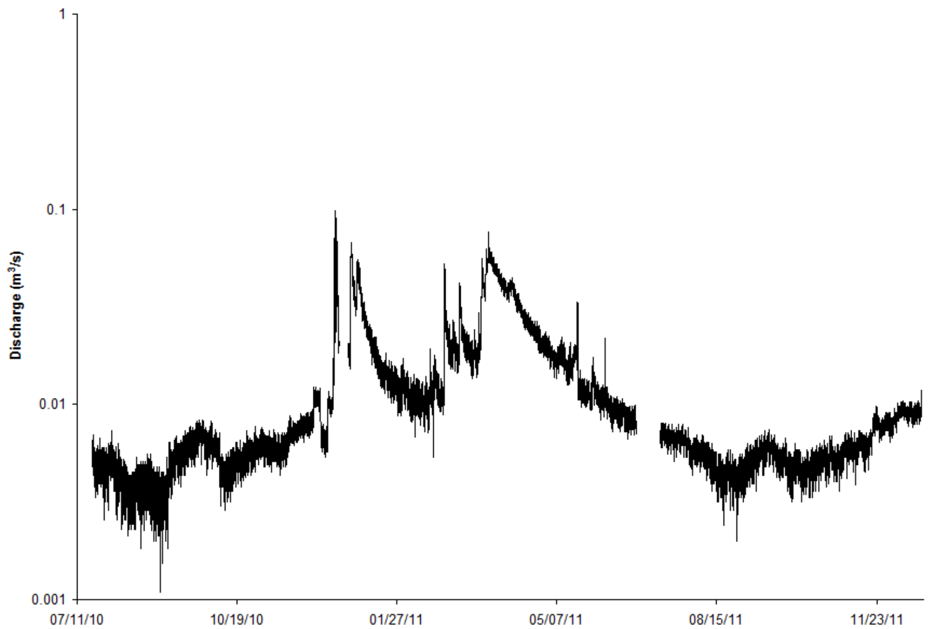
Crystal Cave:



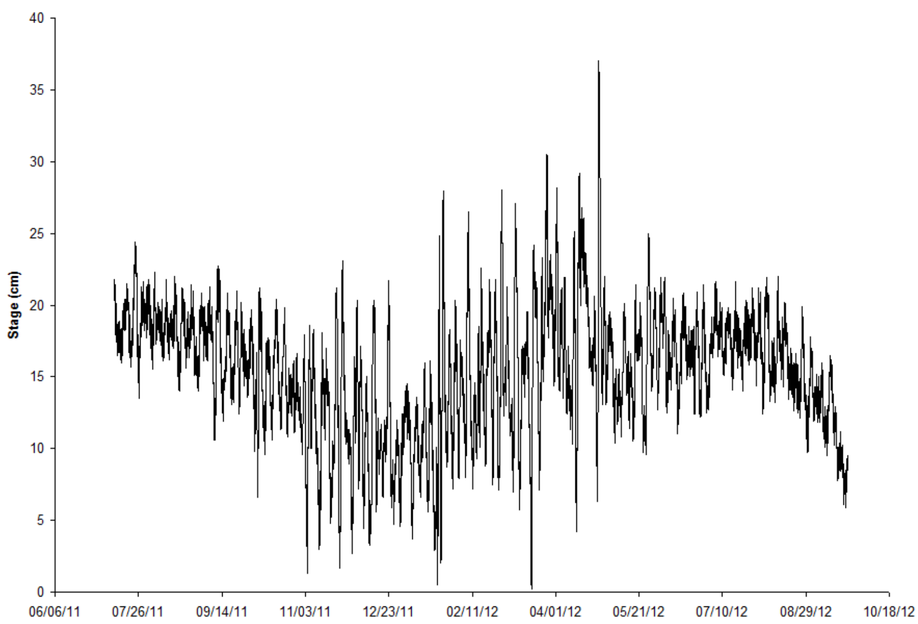
Mossy Spring:


Discharge (m3/s)
1
0.1
0.01
0.001
0.0001
0.00001
01/22/10
05/02/10
08/10/10
11/18/10
02/26/11
06/06/11
09/14/11
12/23/11
04/01/12
07/10/12
10/18/12
01/26/13

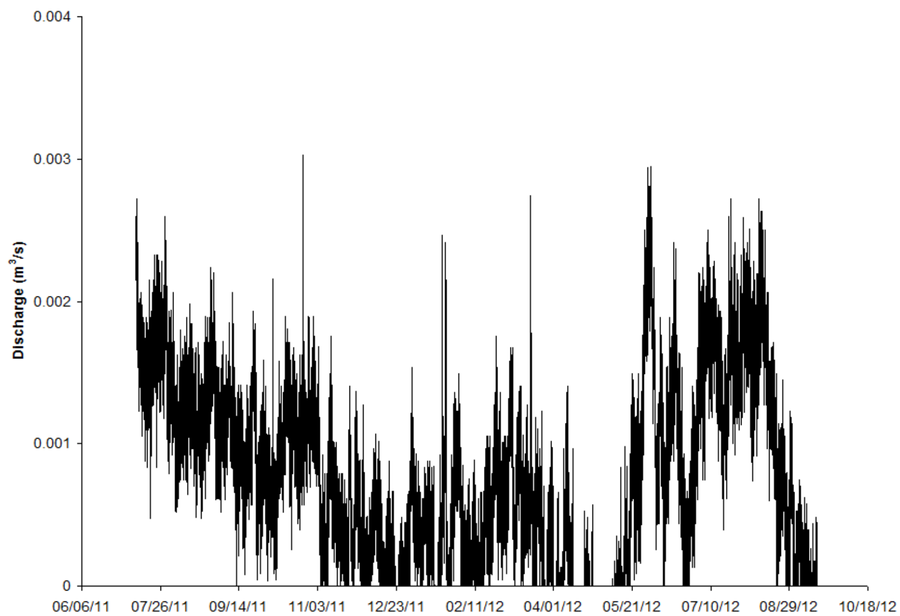
Alder Spring:



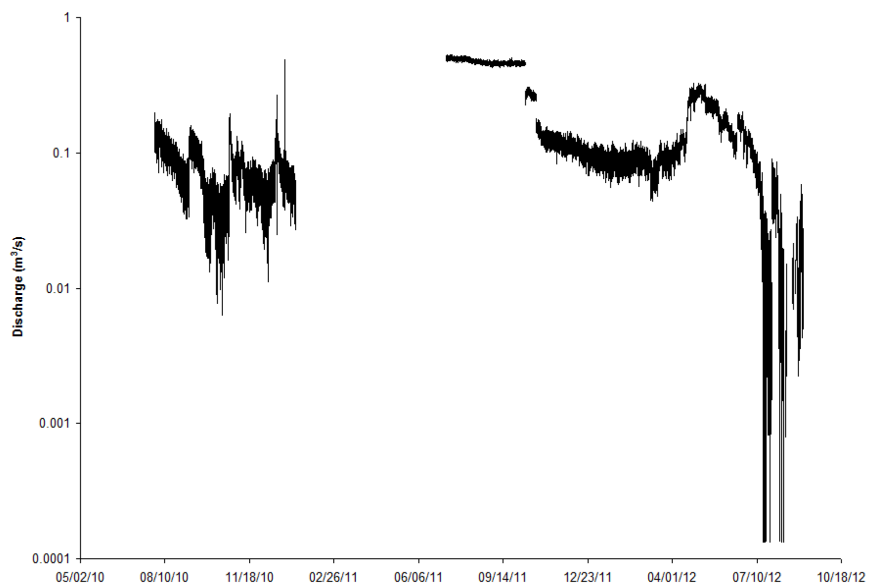
Warm River Cave:



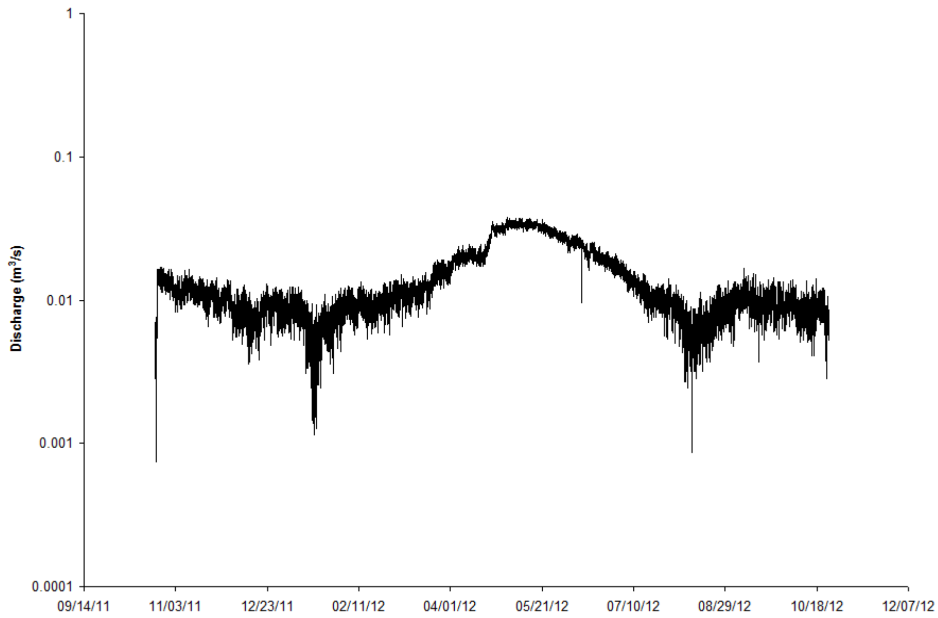
Upper Smoking Spring:



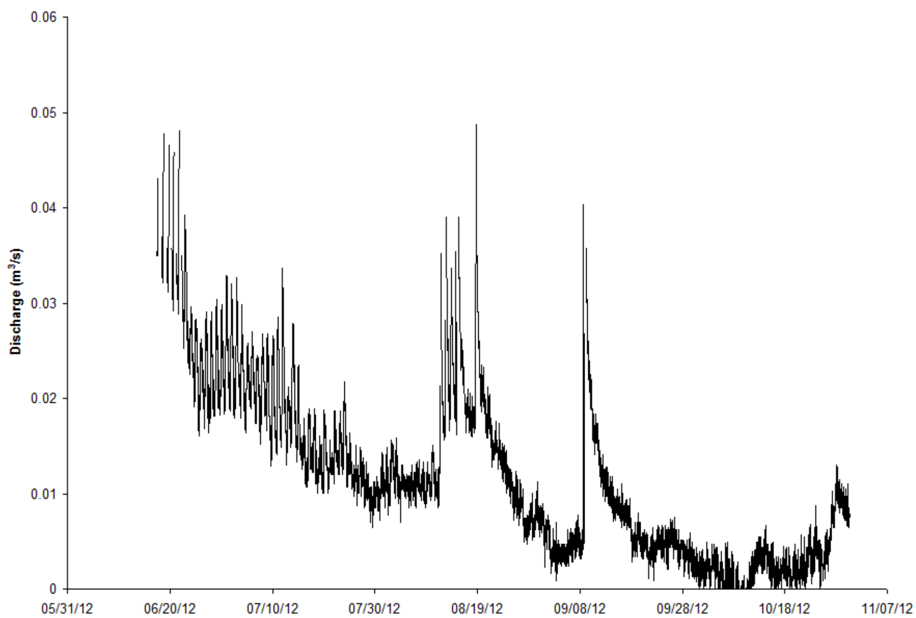
Tufa Spring:



Monarch Spring:



White Chief Spring:



VITA

Benjamin W. Tobin was born on 1 August 1980 in Alexandria, Virginia to Robert and Elizabeth Tobin. Benjamin received a B.A. in Earth Sciences from the University of New Hampshire in May 2002, and a M.Sc. in Geoscience from Western Kentucky University in August 2007. He entered the Aquatic Resources Ph.D. program at Texas State University-San Marcos in August 2009. While at Texas State, Benjamin worked as a National Science Foundation- Project Flowing Waters fellow, a lab instructor for Earth Science and General Science, and as a research assistant for Dr. Benjamin Schwartz. Benjamin has currently written 3 peer-reviewed publications and has presented his research at 15 regional, national, and international conferences, including International Congress of Speleology and Geological Society of America.

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