INVESTIGATION OF SPATIAL AND TEMPORAL VARIATIONS IN WATER QUALITY AROUND NORA, IL

Benjamin J. Maas

128 Pages August 2010

This study examined the water quality in a karstic system around Nora, IL for spatial and temporal variations in water quality that were statistically different from one another.

APPROVED:

Date Eric W. Peterson, Chair

Date John Kostelnick

Date Stephen J. Van der Hoven

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The geologic landscape around Nora, Illinois is composed of Galena Limestone, overlaid by thin Quaternary deposits. The weathering of the Galena Limestone has created a terrain with karst and mantled epikarst. A high degree of connectivity between the surface water and the groundwater as a result of the karst causes the groundwater to be very susceptible to contamination. Construction of a large dairy operation, 6,850 head of cattle, was initiated southwest of Nora late in 2008. Owing to the potential for contamination of surface water, groundwater, and private wells, surface water and groundwater were monitored for a year to assess the spatial and temporal variability of the waters. These data will establish baseline chemistry data for comparison to future data in monitoring for potential changes in water quality. Six streams and six springs, in close proximity to the dairy operation, were sampled monthly for this study. Baseline water chemistry was established through monitoring the concentrations of major anions and cations, pH, temperature, specific conductance, carbon dioxide, alkalinity, hardness, and dissolved oxygen. Nitrate as nitrogen values ranged from 2.9 to 14.6 mg/L for stream locations and from 0.3 to 30.1 mg/L for spring locations. Except for temperature and sulfate, the water quality of streams and springs were statistically different from each other. As a whole, the streams experienced less spatial variation than the springs. Statistically different concentrations of chloride, nitrate as nitrogen, and sulfate were observed among both the streams and the springs. Almost all of the alkalinity and calcite levels for the streams were statistically similar spatially. Conversely, alkalinity and calcite values at the spring locations were statistically different spatially. Temporal analyses were only conducted on the stream data and one spring location; with the exception of temperature, none of the locations exhibited statistically different temporal variation among the chemical parameters. The data indicate that the water quality characteristics exhibited spatial variations, but temporal variations in water quality characteristics were not observed, which indicates that the surface water and groundwater are susceptible to local influences.

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BENJAMIN J. MAAS

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CHAPTER I

INTRODUCTION

Introduction

About 17 % of the Earth's surface is covered by carbonate rocks (Gillieson, 1996). Furthermore, about 7-10% of the Earth's surface is considered karst (Gillieson, 1996, Green et al., 2006). Karst is formed by the dissolution of the bedrock, usually limestone (Gillieson, 1996, Palmer, 2007). As a result of the carbonate bedrock being easily dissolved by acidified groundwater, the permeability of karst is high, which means that a karst unit has the potential to be a good aquifer. About 25 % of the world's population is dependent on karst aquifers for potable water (Gillieson, 1996, Green et al., 2006). The United States is even more dependent on karst since karst covers about 20% of the surface and karst aquifers supply about 40% of the drinking water (Green et al., 2006).

One area in particular of the United States that depends on karst aquifers is the Driftless Area of northwestern Illinois, northeastern Iowa, southwestern Wisconsin, and southeastern Minnesota (Leigh and Knox 1994, Figure I-1). This region was not glaciated during glacial activity throughout the Pleistocene (Stiles and Stensvold, 2008). As a result of the lack of glaciation, there is limited soil development on top of the carbonate bedrock (Stiles and Stensvold, 2008). Soil development in the Driftless Area from carbonates is limited due to the fact carbonates have low amounts of impurities (Stiles and Stensvold, 2008) and as a result very large amounts of carbonate bedrock are required to form soil (Olson et al., 1980). Most of the soil within the Driftless Area formed from the dissolution of loess, colluvium, or alluvium, which have the needed quartz, feldspars, and micas (Frolking et al., 1983), for soil formation (Stiles and Stensvold, 2008). Northwestern Illinois, more specifically, the area around Nora, Jo Daviess County, Illinois (Figure I-1) has features that are common of karstic terrains, such as a shallow groundwater table (Panno, 2008), limited soil coverage, epikarst, sinkholes, and fractured bedrock.

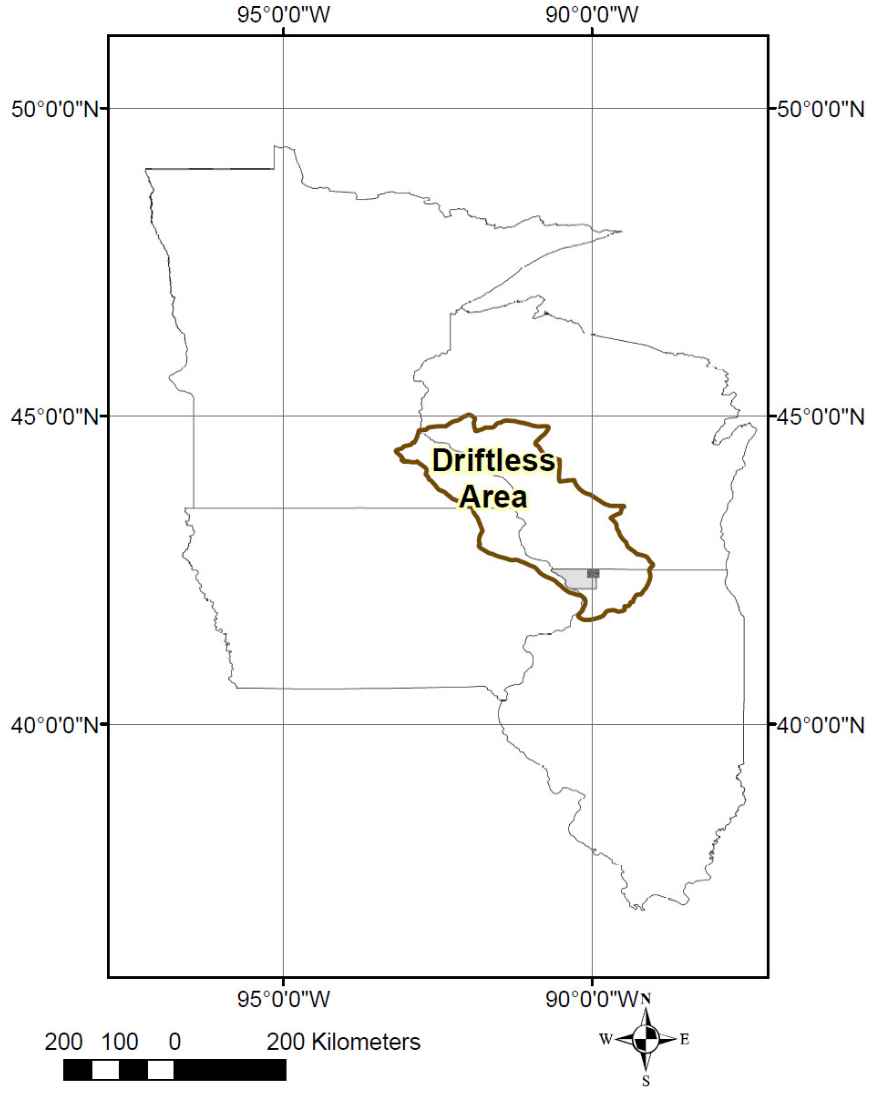

Figure I-1: Location of the Driftless Area of northeast Iowa, northwest Illinois, southeast Minnesota, and southwest Wisconsin. The light gray area indicates the location of Jo Daviess County, and the darker gray area is the study area.

A feature common in areas with karst, is karren. Karren develops from the dissolution of carbonate bedrock, which leads to the widening of fractures into fissures (Palmer, 2007). These fissures are widest at the top of the bedrock and generally decrease in width as distance from the surface increases. The bedrock surrounding the fissures does not dissolve as quickly and has a higher topography. Common features observed in karren are channels, horizontal and vertical fractures, and fissures. If there is soil covering the bedrock, the fissures of the karren will not be as pronounced. Below the karren is epikarst, which can be thought of as a transitional area from the overlying karren and Quaternary deposits to the underlying karst. The epikarst usually extends a few meters to several meters into the bedrock (Palmer, 2007). For the most part, epikarst does not have a direct vertical connection from the surface to the underlying karst aquifer, which would allow for the direct movement of water and contaminants from the surface to the groundwater system. Instead the vertical connections, fissures, gradually pinch downward since the magnitude of dissolution decreases as distance from the surface increases (Palmer, 2007). The degree of dissolution decreases because the water becomes more similar to the surrounding bedrock and the water becomes less aggressive. This gradual decrease in fissure size causes the water to flow into horizontal bedding planes because they become a more favorable flow path. The horizontal bedding planes transport the water to larger openings, which then allow the water to travel to the deeper bedrock and into the karstic area of the bedrock (Palmer, 2007). The horizontal bedding planes are places that experience an increased amount of dissolution, as a result of more water flowing there, and these horizontal bedding planes have a higher secondary porosity than the primary porosity of the surrounding matrix. The increased porosity at the horizontal bedding planes is secondary porosity, meaning a change in the porosity was experienced after the bedrock had been formed. As a result of the dissolution the horizontal bedding planes become areas of preferred water movement since the water encounters less resistance along the horizontal bedding places. These paths of preferred water movement cause shorter travel times, relative to more homogeneous bedrock, for water to be transported from the surface to the saturated zone through drainage networks. The preferred paths of water migration can cause an increase of allogenic water to enter the system, which can increase the dissolution rate of the bedrock (Palmer, 2001). Allogenic water is water that comes from a source that is dissimilar to the water in the bedrock. This increase to the dissolution rate of the bedrock can cause an increase in the ion concentration of the groundwater that is in contact with the bedrock. Therefore these drainage networks can potentially be a significant controlling factor of the water chemistry of the saturated zone and as a result an understanding of the drainage networks is needed. Some of the surface features that help to control the water quality and quantity that enters into the saturated zone are vegetation, soil, regolith, closed depressions, and sinkholes (Gillieson, 1996). This flux in dissolution can play a role in the overall water chemistry of the system through the contribution of ions into the groundwater.

In addition to bedrock dissolution, another source of ions in ground water is from rainwater. In northwestern Illinois, rain water contains 0.11 milligram per Liter (mg/L) chloride, 0.35 mg/L calcite, 0.051 mg/L magnesium, 0.027 mg/L potassium, 0.074 mg/L sodium, 0.52 mg/L ammonium, 1.14 mg/L nitrate, 1.42 mg/L sulfate with an average pH of 5.55 (NADP, 2009). The ions in the rainwater that enters into the unsaturated zone become concentrated as the result of evapotranspiration. Another reason why the concentration of ions in water increases is that the materials that the water flows through dissolve and the ions are added to the groundwater. Since the bedrock of the Driftless Area is dominated by dolomites and limestones, the natural water chemistry of the area is classified as a bicarbonate water chemistry. The major ions that are present in bicarbonate waters, and which will be further concentrated, are calcium, magnesium, bicarbonate, sodium, and chloride (Palmer, 2007), with bicarbonate, calcium, and magnesium being the dominant ions. There are various natural sources from which calcium, magnesium, bicarbonate, sodium, and chloride originate. The dominant source of calcium is from the limestone and dolomite bedrock (Palmer, 2007). Almost all of the magnesium in the groundwater comes from dolomite (Palmer, 2007). However, since most limestone is not pure limestone some magnesium is found in limestone as well. Sulfate that originates from nature in carbonate terrains usually comes from gypsum, anhydrite, or the oxidation of sulfide, such as pyrite (Palmer, 2007). The range of the sulfate concentration in the groundwater can vary and sometimes can reach high concentrations due to the fact that the cation that bonds with the sulfate does not form insoluble compounds (Hem, 1959). Bottrell et al. (2008) reported that rainwater contained about 5 mg/L SO_4 and after evapotranspiration the rainwater had a SO_4 concentration around 10 mg/L. The rainwater SO_4 concentration reported by Bottrell et al. (2008) is higher than the NADP reported rainwater concentration in northwest Illinois, but is to be expected since their study site is closer to the ocean, which is a major source of SO_4. In carbonate terrains, sodium and chloride are most commonly from salts; with the most abundant source of salt being road salt (Palmer, 2007). Hem (1959) reported that sodium concentrations in water from a pure limestone source were 1 or 2 mg/L. The natural concentration of these ions will be low and elevated levels usually indicate a nearby source of contamination. Other ions that are present in small concentrations in groundwater that flows through carbonate are bromide, fluoride, iron, manganese, and potassium.

Along with the geochemical signature of the geologic material, people have a significant role in influencing the quality of the surface water and groundwater in an area. People can affect the surface water and groundwater quality through the input of pollutants into the surface water and groundwater systems. Possible sources of pollutants in agricultural areas include various agricultural practices (Crain, 2002 and Taraba et al. 1996), leaky septic systems, the fertilization of lawns and fields, application of pesticides to fields (Panno and Kelly, 2004), road salt, and wastewater (Katz, and Griffin, 2008; Mahler, 2000; Mooers and Alexander, 1994). Additionally, several studies have examined the impact that agriculture has had on karstified areas (e.g. Gupta et al., 2004; Kresic and Papic, 1992; Long et al., 2008; Mooers and Alexander, 1994; Nguyet and Goldscheider, 2006; Panno and Kelly, 2004; Peterson et al., 2002). One of the largest sources of agricultural contamination is fertilizer, which includes both animal waste, i.e. manure, and commercially made fertilizer. Nitrate as nitrogen is commonly found in fertilizers (Maticic, 1999). Typically, the nitrate as nitrogen concentration in non contaminated groundwater is below 0.1 mg/L, but can be as high as 3.0 mg/L (Liu et al. 2005). Nitrate as nitrogen concentrations are important to monitor because the drinking water standard for nitrate as nitrogen is 10 mg/L (U.S. EPA, 2009) at which point health problems for infants can occur, mainly methemoglobinemia or blue baby syndrome (Crain, 2002). The use of animal waste on fields can lead to negative effects on the environment, such as surface water runoff entering into streams and surface water infiltrating through the soil and into the groundwater systems (Gupta et al., 2004).

Wastewater is another source of nitrate that can infiltrate into groundwater systems. The application of wastewater to karst terrains affects the amount of nitrate in the groundwater (Katz, and Griffin, 2008; Mahler, 2000; Mooers and Alexander, 1994). In the Driftless Area of southeastern Minnesota, Mooers and Alexander (1994) observed that the application of wastewater from a meat-canning operation to fields resulted in contaminated waters in the epikarst and the shallow groundwater system.

Chloride is an important element for animal and plants (Hem, 1959) and it is another ion that is a common byproduct of agricultural activity (Hem, 1959; Link and Inman, 2003; Mooers and Alexander, 1994). While chloride does have a drinking water standard of 250 mg/L, this standard is not regulated and there is not a health risk associated with this concentration (U.S. EPA, 2009). Above a chloride concentration of 250 mg/L, a salty taste in the water may be present (Quade, et al., 1996). From the personal experience of collecting water samples at karst springs in west central Wisconsin, located in the Drifltess Area, it was found that chloride concentrations had a range between 5.8 and 29.1 mg/L (unpublished data). Chloride is useful as an inexpensive tracer, because the presence of chloride usually indicates a nearby source of contamination. Another reason why chloride is an effective tracer is that it is a conservative ion, meaning it will not react with other ions in the water. Animal waste is a common source of chloride (Mooers and Alexander, 1994) as well as wastewater (Hem, 1959) and fertilizer. However, chloride is also common in salts, such as road salt, so the presence of chloride does not definitely indicate an agricultural source.

Other ions that are associated with agricultural activity are sodium, potassium (Geiffioen, 2001), and sulfate (Bottrell et al., 2008; Einsiedl and Mayer, 2005). Usually water that is from carbonate rocks has low concentrations of sodium, around 1 or 2 mg/L (Hem, 1959), and elevated sodium concentrations indicates contamination. Common anthropogenic sources of sodium are sewage sources (Hem, 1959), such as from people and animals. A common source of potassium in agricultural areas is potash (Bray, 1944). Potassium is added to fields to replace the potassium used by plants during growth, which is removed when the plant is harvested (Hem, 1959). Concentrations of potassium are ordinarily less than 10 mg/L and if sodium concentrations are over 5 mg/L then in most cases concentrations of potassium will be less than 5 mg/L (Hem, 1959). Sulfate can originate from several sources such as sewage, household and industrial cleaning products, demolition waste, and industrial sulphuric acid (Bottrell et al., 2008).

The addition of bacteria is another way in which people can influence the quality of the surface water and groundwater in an area. There are several general common sources of bacteria that can be contributed to surface water and groundwater systems including agricultural run-off, urban run-off, leaky septic systems, waste-water discharge, sewage, and irrigation that uses primary-treated waste-water (Mahler et al., 2000). In areas with high agricultural activity the dominant source of bacteria, fecal coliform and *Escherichia coli* (*E. coli*), is from livestock (Howell et al., 1995; Davis et al., 2005). Elevated fecal coliform concentration in water is a source of concern because of the health risks. The USEPA standard for primary contact water is 200 colony forming units per 100 mL (CFU/100 mL) (Howell et al., 1995). Bacteria is an area of concern in karst terrains since the thin soils can contribute to poor water quality because there is less soil coverage to trap or filter, the fecal coliform as it travels from the surface to the saturated zone (Howell et al., 1995). Some of the sediment grains, and the bacteria that is adsorbed to the sediment, can get trapped in the epikarst during lower periods of flow and become mobile during higher periods of flow (Massei et al., 2002). This storage can result in bacteria being present in the water even after the source has been removed. The persistence of bacteria in a groundwater system is due to its long life span. For example Stoddard et al. (1998) found, through the study of soil in agriculturally active areas, that the survival time of fecal coliform was about six months after spring application of manure and two months after fall applications.

Temporal and spatial variations of major ion concentrations (Nguyet and Goldscheider, 2006; Pionke and Urban, 1985) and of field measured parameters (Ozyurt, and Bayari 2008; Pionke and Urban, 1985) are common in a watershed. The faster response time of the karst system is a result of the high secondary porosity of the karst system. Studies on the water quality variability of various karst terrains have shown that spatial and temporal variations are common and that temporal variations can occur over short periods of time, (Debrewer et al., 2008; Iqbal, and Krothe, 1994; Liu, et al., 2005; Nguyet and Goldscheider, 2006; Pasquarell and Boyer, 1995; Tryon, 1976). In a karst terrain in Missouri, Tyron (1976) found that nitrate as nitrogen levels in the groundwater were highest during the winter months when there was no uptake of nitrogen by the plants, and the nitrate as nitrogen levels were observed to decrease through the summer. Tyron (1976) also found that groundwater quality was best in forested areas and the poorest in agricultural areas. In northwest Vietnam, Nguyet and Goldscheider (2006) identified spatial and temporal variations in conductivity, calcium, magnesium, sulfate, and temperature at two “swallow holes” and temporal variations at two springs.

The current study encompasses watersheds in the area near an under construction dairy operation, referred to as the mega-dairy from this point, outside of Nora, IL (Figure I-2). The main watersheds of interest are Canyon Rd Watershed, Quarry Hill Rd

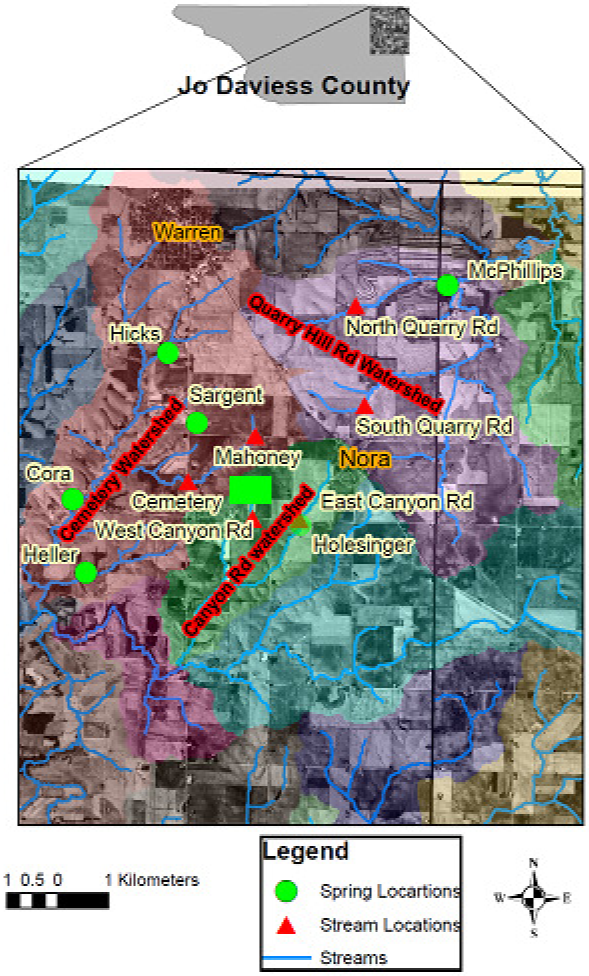

Figure I-2. Locations of the watersheds which had streams that were sampled during this study. The watersheds were named for the purpose of this study only. The green box indicates the approximate location of the mega-dairy.

Watershed, and Cemetery Watershed because these are the only watersheds that had streams that were sampled for this study. Since surface runoff from the mega-dairy has the potential to affect the surface water quality of local streams, the streams around the mega-dairy were the main focus of this study. The infiltration of water into the subsurface from mega-dairy also has the potential to affect the groundwater quality and therefore local springs were also sampled. A concern associated with the mega-dairy is its manure storage lagoon. Storage lagoons are prone to leaking as the structure ages (Glanville et al., 1999; Link and Inman, 2003; Quade et al., 1996). Another concern associated with the future operation of the mega dairy is the application of the manure generated on site to area fields. Manure that is applied to area fields can be flushed into streams during precipitation events and can infiltrate through the soil into the groundwater systems (Gupta et al., 2004). Link and Inman (2003) stated that groundwater monitoring around storage lagoons should be completed if: depth to water is shallow, less than about 15 meters (m); unsaturated soils are present that allow for rapid movement of contaminants; or if the groundwater is used for drinking. The area near the mega-dairy fits all of the requirements stated by Link and Inman (2003). First, the water-table is shallow, about 6 m (Panno, 2008). Second, the local karst topography allows for the rapid movement of surface borne particles into the groundwater as a result of the epikarst, and third the water from the carbonate aquifer is used for drinking (Panno, 2008). Therefore, this area was monitored to gain a better understanding of how the water quality of an area with karst topography changes spatially and temporally over the course of a year. This area was also monitored to obtain background water chemistry data for the surface water and groundwater before a dramatic change in land use is initiated. Development of background water chemistry data will ensure that any future changes in the water chemistry are true changes and not an expected spatial or temporal difference.

The research reported here examines whether the high degree of heterogeneity of karst bedrock and the short residence times associated with karst produced spatial and temporal changes in the water quality around the Nora, IL area. Specifically, the following research questions were asked:

1. Are spatial variations in temperature, specific conductance, pH, D.O., CO_2, alkalinity, and hardness, laboratory measurements, major ion chemistry, and B.O.D., present among the stream and spring sample locations?
2. Are temporal variations between warm and cold months in temperature, specific conductance, pH, D.O., CO_2, alkalinity, and hardness, laboratory measurements, major ion chemistry, and B.O.D., present among the stream sample locations and Hicks spring?

CHAPTER II

GEOLOGIC SETTING

The study site is located in the Driftless Area of northwestern Illinois (Figure I-1). The area is called the Driftless Area because during the past periods of glacial activity, the region was not covered by the glacial ice that covered most of the Midwest. There have been four glacial episodes in roughly the last 1,000,000 years (Frankie and Nelson, 2002). The name and age of these glacial episodes are; pre-Illinois Glacial episode (1,000,000 years ago), late pre-Illinois Glacial episode (600,000 years ago), Illinois Glacial episode (250,000 years ago), and late Wisconsin Glacial Episode (22,000 years ago) (Frankie and Nelson, 2002). The soils that cover the Paleozoic bedrock are developed predominately from loess derived from the surrounding glacial sediment with the lower soil horizons having some residuum dolomitic limestone (Tegeler, 1996). Soils are predominated silt loams and silty clay loams with a moderate hydraulic conductivity (4×10^{-7} m/s to 1×10^{-5} m/s) (Tegeler, 1996).

The dominant soil types of the area are the Tama-Muscatine (T-M), Fayette-Palsgorve-Rozetta (F-P-R), and Dubuque-Lacrescent-Dunbarton (D-L-D) associations (Tegeler, 1996). Underlying the T-M soil association is loess, primarily the Peoria Silt Formation (Tegeler, 1996). Underlying the F-P-R and D-L-D soil associations is the Galena Group followed by the Platteville Group which are from the Ordovician Period.

The Galena Group is about 20 m thick in the area around the study site, but can be as thick as 75 m when overlain by the Maquoketa Shale Group. The Platteville Group is about 15 m thick in the Jo Daviess area (Willman and Folata, 1978). Both of the groups are dominantly composed of dolomite, with some limestone, and the groups have few impurities in them, mostly argillaceous material and chert (Willman and Folata, 1978). The grain size of the Galena Group and Platteville Group is fine or medium grained with the Platteville group having a more uniform grain size (Willman and Folata, 1978). The porosity of the both groups ranges from dense, low porosity, to vuggy, high porosity (Willman and Folata, 1978). Unaltered bedding planes range from very tight with no visible break to very thick with a layer of argillaceous material (Willman and Folata, 1978). The Galena and Platteville Groups are highly weathered and have typical karstic surface features, including sinkholes, karren, epikarst, and fractures. Located in the Wisconsin Arch, the Galena Group and Platteville Group have a regional dip of five to six meters per kilometer (Frankie and Nelson, 2002).

No conclusive evidence of glaciation from the Wisconsin Glacial Episode was found in the study site. Due to the absence of glaciation, the majority of the study area is covered by the Peoria Silt Formation (Figure II-1), which is composed from silt and clay from wind-deposited glacial material. The Peoria Silt Formation is of Quaternary age. Thickness of the Peoria silt ranges from zero to ten meters thick, and is thicker in the southern portion of the study area than in the northern portion. The other dominant formation is the Cahokia Formation, which is present in modern streams and creeks valleys. The Cahokia Formation is associated with the flood plain deposits and is

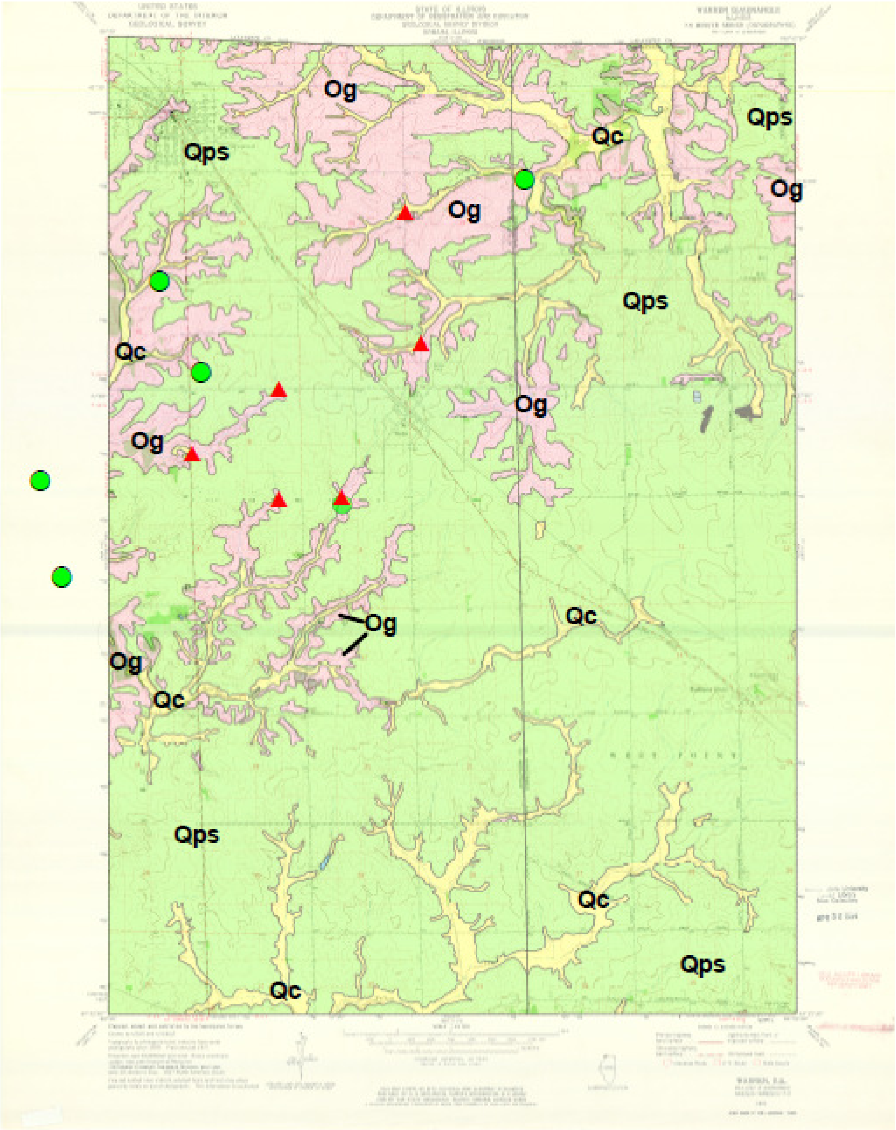

Figure II-1. Surface geology map of the Warren Quadrangle, Jo Daviess, and Stephenson Counties IL. The circles indicate the locations of spring locations, and the triangles indicate the locations of stream locations. Qps indicates the Peoria Silt Formation, the Qc indicates the Cahokia Formation and the Og indicates the Galena Group.

composed of dark gray to black stratified silt with some gravel. The Cahokia Formation is of Quaternary age. The Galena Group was exposed in the northern portion of the study area at some road cuts along highway 78 and Mesong Road. The Galena Group was also exposed in a small section upstream of the West Canyon sample location. In most cases, the Galena Group bedrock was not exposed in streams, but rather pieces of the bedrock and chert were present in the streams or in low lying areas. Pieces of Galena Group dolomite were also present in low lying areas, in the northern portion of the study site.

The sample locations of East Canyon Rd, West Canyon Rd, and Cemetery are located in the Galena Group, with pieces of the carbonate bedrock in the streambed. A thin covering of Cahokia Formation overlying the Galena Group was present at East Canyon Rd, West Canyon Rd, and Cemetery. The sample location of Mahoney is located on the edge of the Peoria Silt Formation before discharging across the Galena Group. Both the North Quarry Rd and South Quarry Rd sample locations are located in the Cahokia Formation with exposure of the Galena Group near the sample locations. The streams in the area are dominantly gaining streams. This is especially evident between the locations of Mahoney and Cemetery. At the Cemetery sampling location, which is located downstream from Mahoney, there is a noticeable gain in the volume of water in the stream during base flow conditions. All of the streams are influenced by tile drains, and this influence is greatest during and after precipitation events. East Canyon Rd, West Canyon Rd and Cemetery were all about the same width, 2 m, and depth 0.3 m. Mahoney, North Quarry Rd, and South Quarry Rd did not have pieces of Galena Group in the stream bed. Mahoney had the smallest stream dimensions of the six stream sample locations with a width of 0.5 m and a depth of 0.1 m. North Quarry Rd was the widest stream, about 4 m wide, and it had a depth of about 0.3 m. South Quarry had a slightly greater width than Mahoney, 0.6 m, and South Quarry had a depth of about 0.2 m.

Five of the six springs sampled, Cora, Heller, Hicks, Holesinger, and Sargent, flowed directly out of the Galena Group, the Galena Group was visible as loose pieces of rock at these five springs. McPhillips spring flowed out of the Cahokia Formation, but also probably originated from the Galena Group. The flow rates of five of the springs, Cora, Heller, Holesinger, McPhillips, and Sargent, were low, less than 0.05 liters/second (L/s). Hicks spring had a flow rate of about 0.1 L/s.

Through the use of data obtained from the National Map Seamless Server (USGS, 2010) the watershed of the study area were determined (Figure I-2). The Canyon Rd watershed had an area of roughly 9 square kilometers (km). The Cemetery watershed had an area of roughly 28 square km and the Quarry Hill Rd watershed had an area of roughly 24 square km.

Within the region are two small urban areas, Warren with a population of about 1,000 people and Nora with a population less than 200 people. However, the land use is dominated by agricultural activity. From the examination of land cover data in GIS, it was determined that row crop, such as corn and soybeans, is the dominant land cover type in the study area (USGS, 2010). The Canyon Rd. watershed was about 66% row crops, the Quarry Hill watershed was about 70% row crops and the Cemetery watershed was about 55% row crops. The next most abundant land cover in the study area was pasture (USGS, 2010). The Canyon Rd. watershed was about 11 % pasture, the Quarry Hill watershed was about 10 % pasture and the Cemetery watershed was about 15 % pasture. Tile drains are used by farmers as a way to drain the water from the soil in areas with a shallow water table (Kladivko et al., 1991). Once the water enters the tile drains, it is usually transported rapidly to an outlet which is commonly a ditch or a stream

(Kladivko et al., 1991). The water that enters into the ditches or streams from the tile drains contributes to the total flow volume of the streams.

CHAPTER III

METHODOLOGY

The hypotheses were tested by sampling the surface water and groundwater of Driftless Area from September 2008 to January 2010, excluding November 2008 to January 2009. Figure I-2 shows the locations of the six stream locations that where the initial places where sampling started in September of 2008 (East Canyon Rd., West Canyon Rd., Cemetery, Mahoney, North Quarry Rd., and South Quarry Rd.). Starting in May of 2010, six spring locations were added (Cora, Heller, Hicks, Holesinger, McPhillips, and Sargent springs) (Figure I-2). The locations of the streams were selected because of their proximity to high-density animal and agricultural operations and their accessibility. The spring locations were sampled as they became known to us. The spring locations were added because an understanding of how the groundwater quality changes spatially was desired.

Analyses for spatial and temporal changes to the water quality were monitored through the examination of water characteristics and water quality indicators, which included: field measurements of pH, temperature, specific conductance, dissolved oxygen (D.O.), turbidity, carbon dioxide, hardness, alkalinity, and total coliform; and laboratory measurements of major ion chemistry and biologic oxygen demand (B.O.D.). A HACH digital titrator (Model AL-36DT) was used in association with the HACH Ecology Combination Test Kit (cat. 20638-00) to measure alkalinity (Hach Number14389-01), carbon dioxide (Hach Number14380-01), and hardness (Hach Number14399-01). Bicarbonate (HCO_3^-) was determined from the alkalinity through the use of equation (1):

$$1.22 \text{ x alkalinity concentration (mg/L)} \qquad (1)$$

An Oakton PC10 meter was used to measure pH and conductivity (specific conductance). A YSI Model 85 meter was used to measure D.O. and temperature. Turbidity was measured with a HANNA instruments Microprocessor Turbidity Meter (Model Number HI 93703). The turbidity for each sample location was measured at least three times per visit and the average of these readings was recorded. Total coliform was measured following Hach method 8074 which is designed for potable water. Total coliform samples were collected in Nasco WHIRL – PAK (Hach number 2075333). Field samples were filtered in sterilized filter funnels (Hach number 2831500). Total coliform filtered water samples were then incubated for 24 hours at 35.5 degrees Celsius in the fore mentioned filters using a Hach MEL/MF Portable Incubator Laboratory (Hach number 25699-00). The broth used for the total coliform analyses was m-ColiBlue24® (Hach number 2608442), which was used on the filtered total coliform water samples so that the colony forming units (CFU) could be seen. Biological Oxygen Demand was determined by collecting water in opaque Nalgene bottle at each sampling location. The opaque Nalgene bottles were transported back to Illinois State University and left undisturbed for five days at which time the D.O. was measured using a YSI Model 85 meter. The difference between the initial and final D.O. reading at each location was interpreted as the B.O.D. Water samples for anion analysis were collected in a Nalgene bottle after the bottle had been tripled rinsed. Water for the cations were filtered in the field with a portable filtering unit using a 0.45 μm filter and acidified with nitric acid; the filtered water was used to pre-rinse a Nalgene bottle prior to the final sample collection. Both the cation and anion samples were stored in a cooler for transportation to Illinois State University. All samples were placed in a refrigerator until they are analyzed for major anion and cation concentrations.

The following anions were analyzed with a Dionex ion chromatograph: chloride (Cl^-), fluoride (F^-), sulfate (SO_4^-), nitrate as nitrogen (NO_3-N), and bromide (Br^-). The following cations were analyzed with an ICP spectrometer: calcium (Ca^{2+}), iron (Fe^{2+}), magnesium (Mg^{2+}), manganese (Mn^{2+}), sodium (Na^+), silicon (Si^{4+}). The cation potassium (K^+) was measured on an atomic adsorption spectrometer. In order to provide a quality check, duplicate anion and cation samples were collected on each sampling trip. Replicate samples were also used as a means of providing a quality check that the Dionex ion chromatograph was working properly. Standards were measured on the ICP spectrometer as a way to check for instrument drift. If drift greater than 10 % was encountered, the ICP spectrometer was then re-calibrated. The duplicate ($n = 13$) and replicate ($n = 14$) anion samples were used to ensure QA/QC. The average analytical error for the anions was 1.7 % and the cation error was 7 %.

Statistical analyses on the resulting data from the field and lab measurements were completed in SPSS to assess potential spatial and temporal differences in the water quality. All water quality variables were statistically analyzed with the exception of total coliform. An independent samples *t*-test was used for all of the analyses because it allowed for the comparison of one group's mean to that of another group's mean. For example Cora spring data compared with Heller spring data. An independent samples *t*-test was also used because each sample location behaves independently of the other sample locations. If the difference in means and standard deviations of the two groups were large enough then the two groups would be deemed statistically different. An alpha (α) of 0.05 was used for all of the analyses as the threshold that needed to be crossed before the samples were deemed statistically different.

In order to do the statistical analyses the data had to be broken into separate datasets. The first step was to divide the stream water-quality data into one dataset and the spring water-quality data into another dataset. This was done because it was thought that the stream data and the spring data were statistically different from one another. The assumption of the stream data being statistically different from the spring data was tested by using an independent sample t-test between the "Stream data" dataset and the "Spring data" dataset. The sample size (N) of the stream dataset was 49 and the spring dataset had an N of 49. There were 96 degrees of freedom for this analysis. With the exception of five parameters, this assumption was found to be a valid assumption (see Table lV-1).

Since the assumption of the "Stream data" dataset and "Spring data" dataset being statistically different was true, the "stream data" dataset and "spring data" dataset were further separated into datasets based on the time interval that a group of sample locations was sampled. This was done in order to complete accurate spatial analyses of the stream and spring water quality data. If the data were not separated into groups then different sized datasets would have been compared to each other, which could have adversely affected the results. Four stream datasets were created for this thesis. One of the stream datasets, "Stream data", included all of the stream sampling dates from September 2008 until January 2010 except for Mahoney and West Canyon Rd because they were not sampled over the entire period. The "Stream data" stream dataset had an N of 16 and 30 degrees of freedom for all of the water quality variables. A second stream dataset, "Stream data no feb." was used for the analysis of data between Mahoney and East Canyon Rd., Cemetery, North Quarry Rd., and South Quarry Rd. The "Stream data no feb." dataset included data from September 2008 until January 2010 with the month

February 2009 and West Canyon Rd being excluded. This dataset excluded data from February 2009 because no water was flowing at Mahoney. The "Stream data no feb." stream dataset had an N of 15 and 28 degrees of freedom for all of the water quality variables. West Canyon Rd was excluded from the "Stream data no feb." because it was not sampled over the entire sampling period. A third dataset, "Stream data WC M" was used to analyze spatial differences between Mahoney and West Canyon Rd, included only data from Mahoney and West Canyon Rd. The "Stream data WC M" dataset included data from September and October 2008 and data from March to July 2009. This dataset excluded data from February 2009 because no water was flowing at Mahoney. The "Stream data WC M" stream dataset had an N of 8 and 14 degrees of freedom for all of the water quality variables. The fourth data set, "Stream data not past july", was used to analyze data between West Canyon Rd and: East Canyon Rd, Cemetery, North Quarry Rd, and South Quarry Rd, and had data from September 2008 through July 2009, but excluded data from Mahoney. The "Stream data not past july" stream dataset had an N of 9 and 16 degrees of freedom for all of the water quality variables. These datasets were then used in SPSS with the independent samples t-test to see if there was a statistical difference between each of the sample locations.

There were three spring datasets created for this project. The first dataset, "Spring data May" only had data from Hicks and Heller spring from May 2009 to November 2009. The "Spring data May" spring dataset had an N of 9 and 16 degrees of freedom for all of the water quality variables. A second dataset, "Spring data june end" had data from June 15th 2009 through November 2009. This dataset included data from all of the springs except for Holesinger spring, since it was not first sampled until June 30th 2009.

The “Spring data june end” spring dataset had an N of 8 and 14 degrees of freedom for all of the water quality variables. The third spring dataset, “Springs Holesinger” had data from all of the springs and had data from June 30th 2009 until November 2009. The “Springs Holesinger” spring dataset had an N of 7 and 12 degrees of freedom for all of the water quality variables. These datasets were then used in SPSS with the independent samples t-test to see if there was a statistical difference between each of the sample locations.

Once the separate stream and spring datasets were formed, independent sample t-tests were completed between a sample location and the other sample locations from that dataset to check for any spatial variations in the data that were statistically significant. For example the spatial analyses of Mahoney and the other sample locations were completed by using the “Stream data not past july” and “Stream data WC M” datasets for the reasons previously given.

In order to complete a temporal analysis of the data, each of the stream sample locations and Hicks spring were separated into a dataset, with the sample location being used as the dataset name. This was done to allow the characteristics of that location to be compared for statistical differences. The data for each location was divided into warm vs. cold months. Warm months were April through September. The cold months were October through March. The “East canyon”, “Cemetery”, “North Quarry Road”, and “South Quarry Road” datasets had an N of 9 for warm month and an N of 7 for cold months and there were 14 degrees of freedom. The “West canyon” dataset had an N of 6 for warm month and an N of 3 for cold months and there were 7 degrees of freedom. The “Mahoney” dataset had an N of 9 for warm month and an N of 6 for cold months and there were 13 degrees of freedom. The “Hicks Spring” dataset had an N of 7 for warm month and an N of 4 for cold months and there were 9 degrees of freedom. The reason why the other springs were not analyzed for temporal variability was that the other springs only had a sample size of N = 1 for cold months, which was not enough data to complete statistical analyses on the data. The temporal analysis was done by completing independent samples *t*-tests between the warm and cold months for each of the water quality characteristics.

CHAPTER IV

RESULTS

SPSS Analysis

SPSS was used to determine if the stream and spring datasets were statistically different from one another. Table IV-1 indicates that the fluoride, sulfate, sodium, and potassium data for the streams were not statistically different from those for the springs; the remaining water quality parameters were statistically differences from each other.

Table IV-1. *p*-values from the independent samples t-test between the stream and spring datasets.

pH	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)
<0.001	<0.001	<0.001	<0.001	0.030	<0.001	<0.001	<0.001	<0.001

Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)
0.001	0.135	0.221	0.013

Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Manganese (mg/L)	Sodium (mg/L)	Silicon (mg/L)	Potassium (mg/L)
<0.001	0.028	<0.001	0.001	0.110	<0.001	0.270

Note: *p*-values less than 0.05 are indicated by gray squares.

Given the differences among the parameters, the individual stream and spring datasets were then analyzed to see if statistically significant spatial and temporal differences were present in each of the datasets. A complete listing of the results from the statistical analyses can be found in Appendix B; a synopsis of major variables is provided below.

Stream Dataset

Water samples were collected at East Canyon Rd., West Canyon Rd., Mahoney, Cemetery, North Quarry Rd., and South Quarry Rd. Sample collection at the streams, minus West Canyon Rd., was conducted between September, 2008 and January, 2010. Sample collection at West Canyon Rd. started September, 2008, and stopped in July, 2009. A complete water sample dataset can be found in Appendix A.

Chloride

Chloride concentrations were between 2.7 and 20.6mg/L (Figure IV-1). With the exception of Mahoney and West Canyon Rd, the chloride

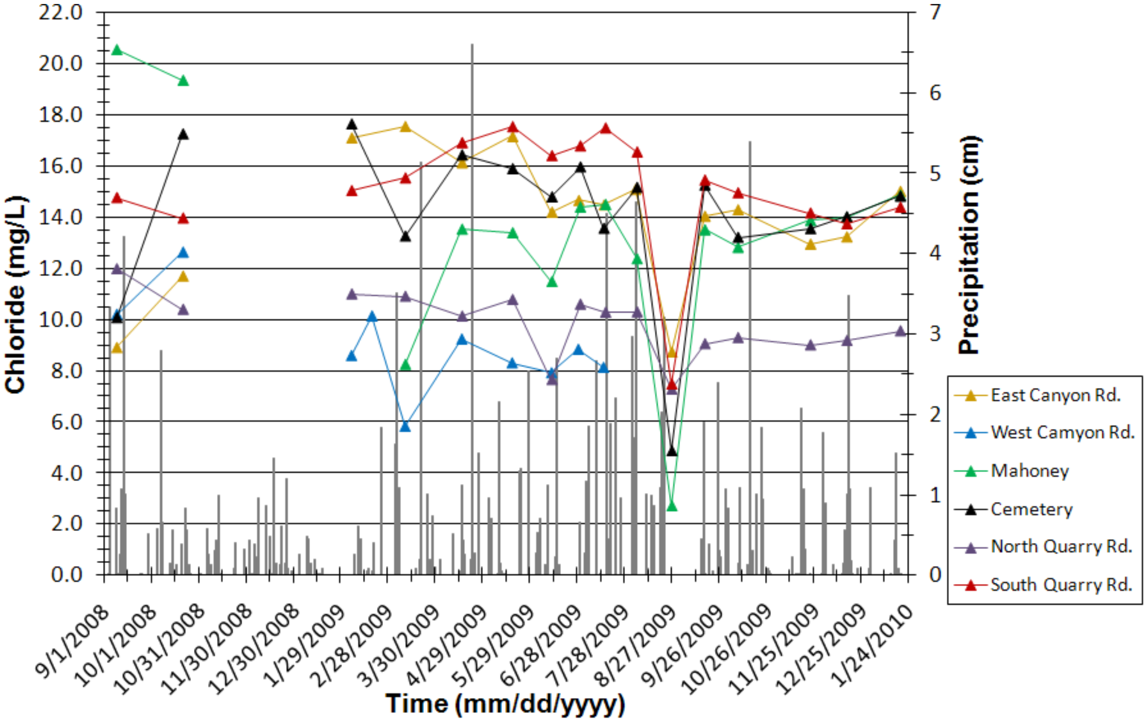

Figure IV-1. Temporal fluctuations in chloride concentrations for the stream locations. Precipitation is the amount of rain and/or snow melt for that particular day as recorded at Stockton, IL (National Climate Data Center).

concentrations were similar to each other (Appendix A-1 through A-6). No clear pattern was present among the chloride concentrations. The statistical analyses indicated that North Quarry Rd. and West Canyon Rd. had chloride concentrations that were statistically different from the other stream location because they had *p*-values that were less than the α value.

Nitrate as Nitrogen

Nitrate as nitrogen concentrations were between 2.9 and 14.6 mg/L (Figure IV-2).

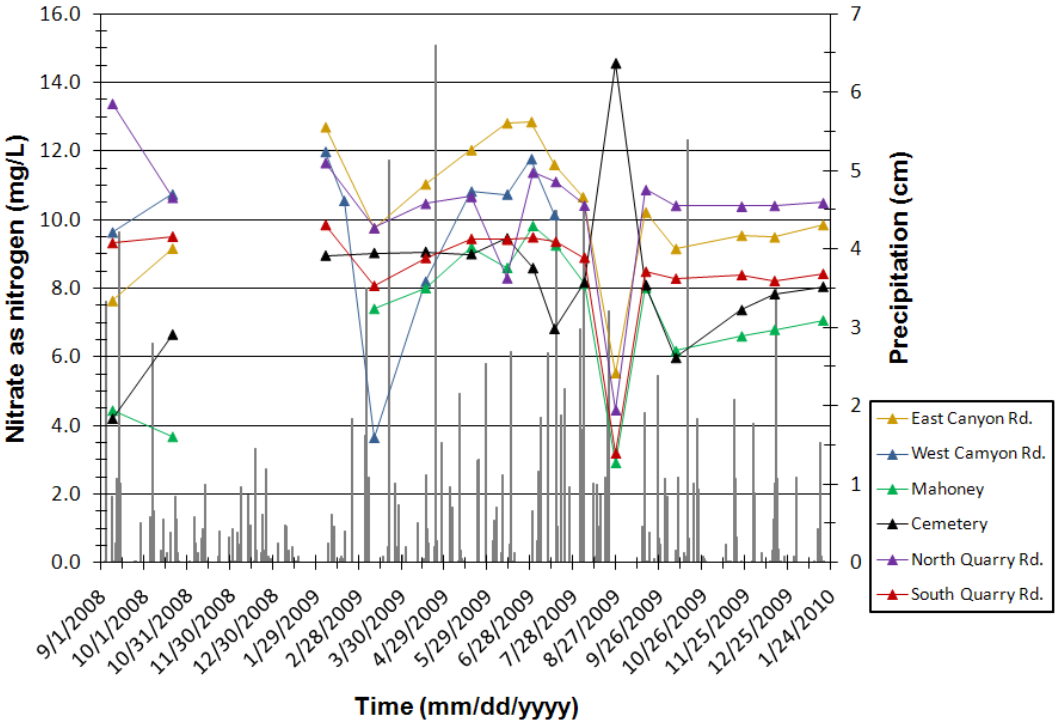

Figure IV-2. Temporal fluctuations for nitrate as nitrogen concentrations for the stream locations.

For the most part, the streams had nitrate as nitrogen concentrations that increased from March 11, 2009 to June 30, 2009. From September 17, 2009 to the end of the sampling period the nitrate as nitrogen concentrations either increased slightly, or remained steady (Figure IV-2). The decline in nitrate as nitrogen concentrations on August 27, 2009 were the result of a precipitation event. Even though fluctuations in nitrate as nitrogen concentrations were observed, temporal variations were found to be not significant according to an independent samples t-test (Appendix B-21). Mahoney had nitrate as nitrogen concentrations that were statistically different from: East Canyon Rd., North Quarry Rd., and South Quarry Rd. Cemetery had nitrate as nitrogen concentrations that were statistically different from: East Canyon Rd., North Quarry Rd (Appendix B-13).

Alkalinity (as $CaCO_3$)

Alkalinity concentrations were between 80 and 270 mg/L (Figure IV-3).

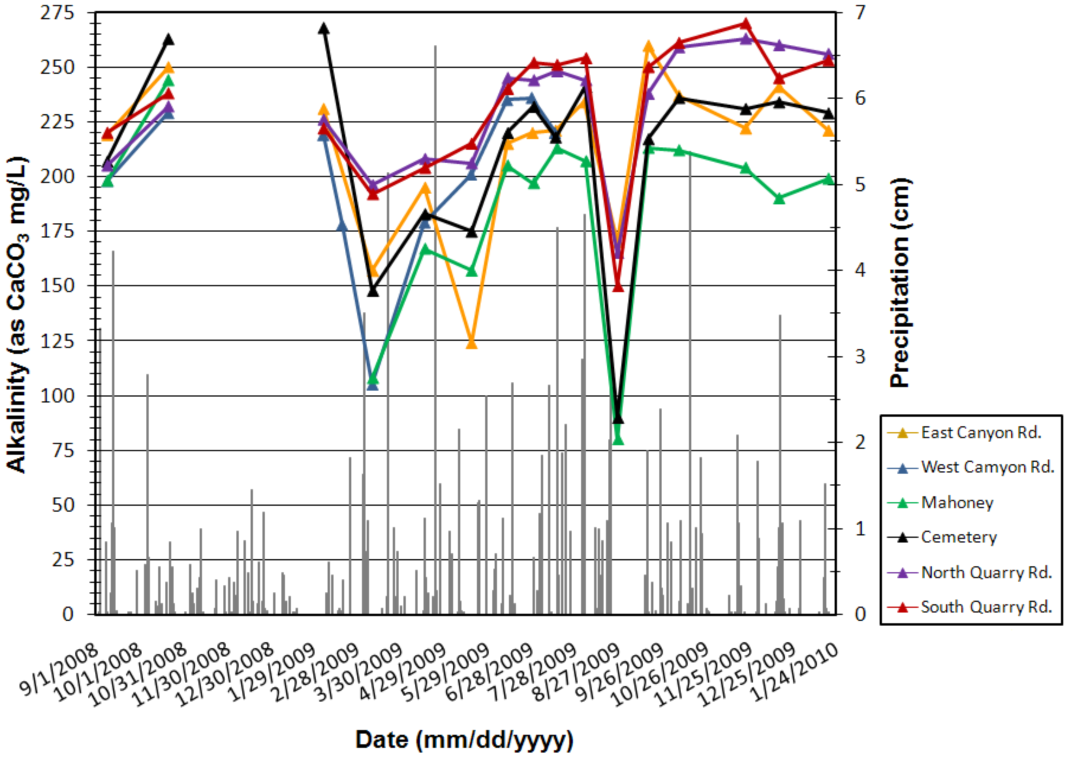

Figure IV-3. Temporal fluctuations of alkalinity concentrations the stream locations.

The alkalinity concentrations for the stream locations increased from March to October, 2009, at which time the alkalinity concentrations remained stable to the end of the monitoring period (Figure IV-3). Though temporal fluctuations were present, these temporal variations were found to be not significant according to an independent samples t-test (Appendix B-21). Mahoney had alkalinity concentrations that were spatially different from North Quarry Rd. and South Quarry Rd (Appendix B-9).

Calcium

Calcium concentrations were between 20.9 and 77.7 mg/L (Figure IV-4).

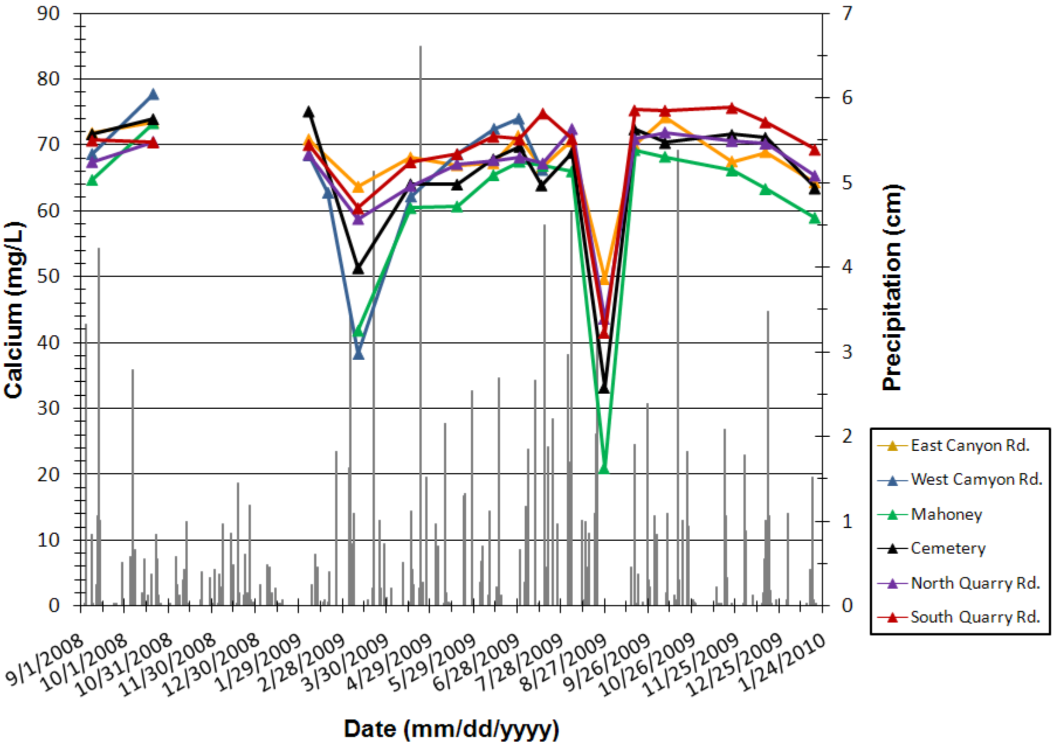

Figure IV-4. Temporal fluctuations of calcium concentrations for the stream locations.

Calcium concentrations were stable except for when samples were collected during or immediately after precipitation events (Figure IV-4). Temporal fluctuations and spatial variability of calcite concentrations were not statistically significant (Appendix B-21).

Magnesium

Magnesium concentrations were between 11.2 and 40.9 mg/L (Figure IV-5).

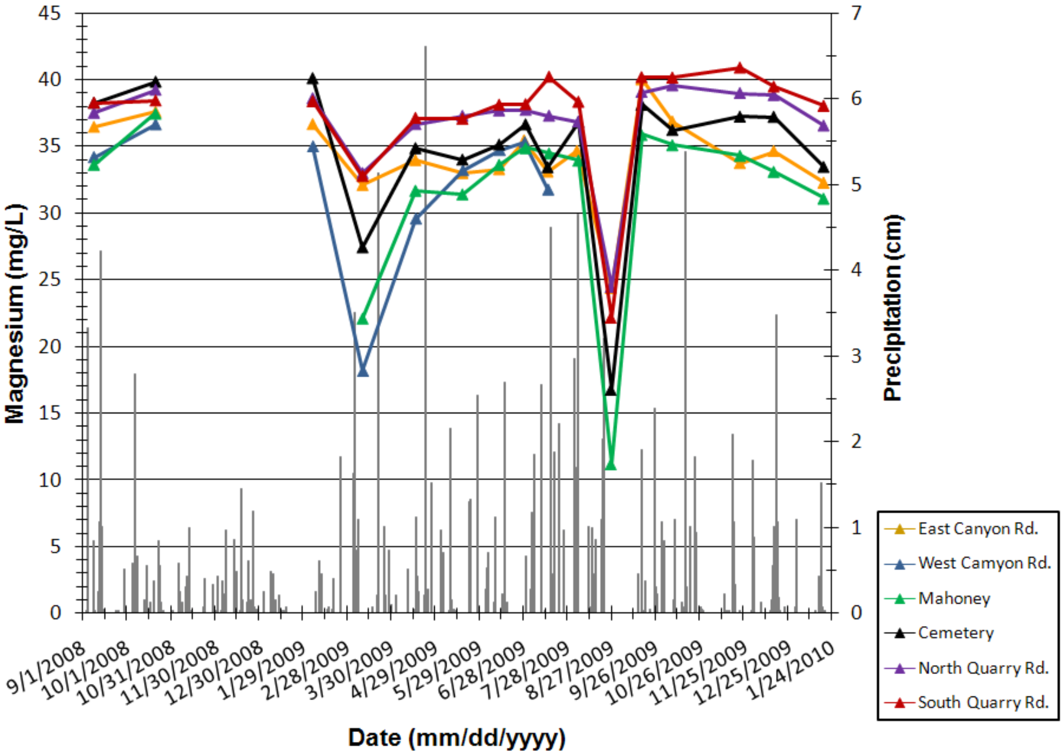

Figure IV-5. Temporal fluctuations of magnesium concentrations for the stream locations.

Magnesium concentrations were stable except for when samples were collected during or immediately after precipitation events (Figure IV-5). Temporal variations were not statistically significant (Appendix B-21). North Quarry Rd. and South Quarry Rd. had magnesium concentrations that were statistically different from magnesium concentrations at East Canyon Rd. West Canyon Rd. and Mahoney (Appendix B-16), which indicated spatial variability.

Specific Conductance

Specific conductance concentrations were between 221 mS/cm and 1062 mS/cm (Figure IV-6). Specific conductance concentrations were at their highest in February 2009 (Figure IV-6). Specific conductance concentrations increased from March to the end of June, remained stable until early August and then started to decrease until January,

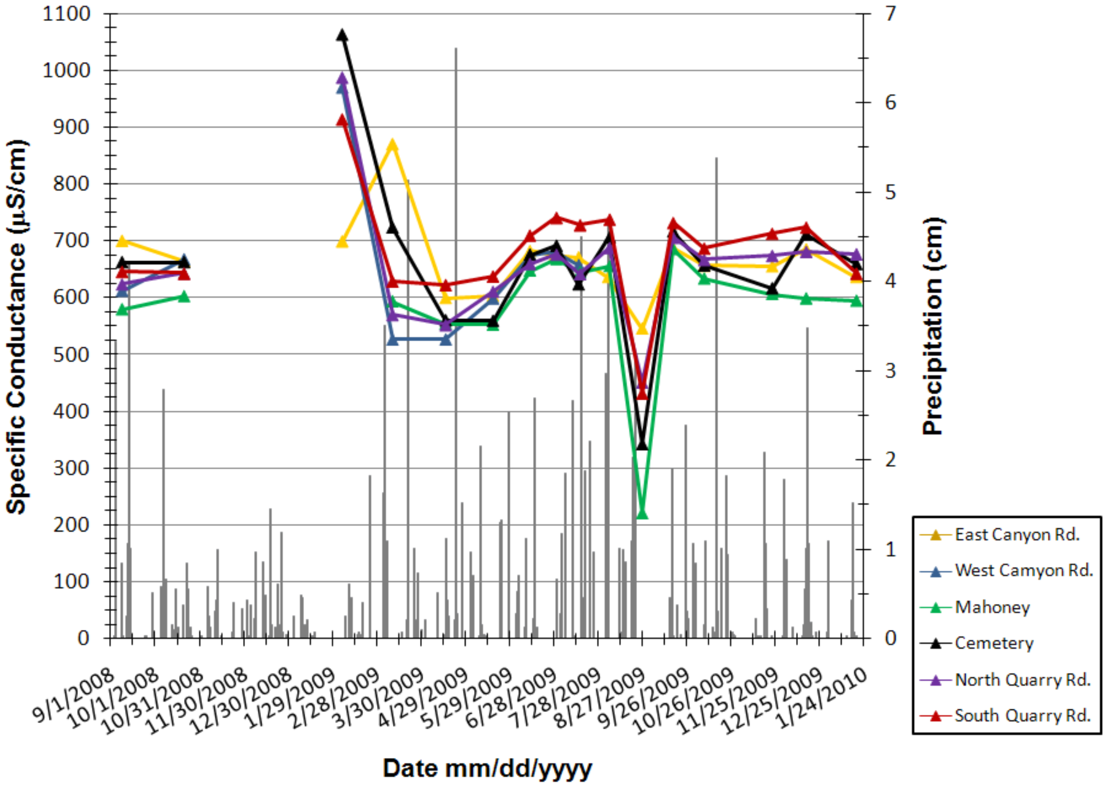

Figure IV-6. Temporal fluctuations of specific conductance concentrations for the stream locations.

2010. The lower specific conductance concentrations on August 27, 2009 were the result of a precipitation event that occurred during the collection of samples. Despite the fluctuations in specific conductance, temporal variations were not statistically significant (Appendix B-21). Spatial variations in specific conductance concentrations were only observed between Mahoney and South Quarry Rd. (Appendix B-3).

Dissolved Oxygen

Dissolved oxygen (D.O.) concentrations were between 0.4 and 18.5 mg/L (Figure IV-7). The low D.O. concentrations observed at South Quarry Rd. might have been the

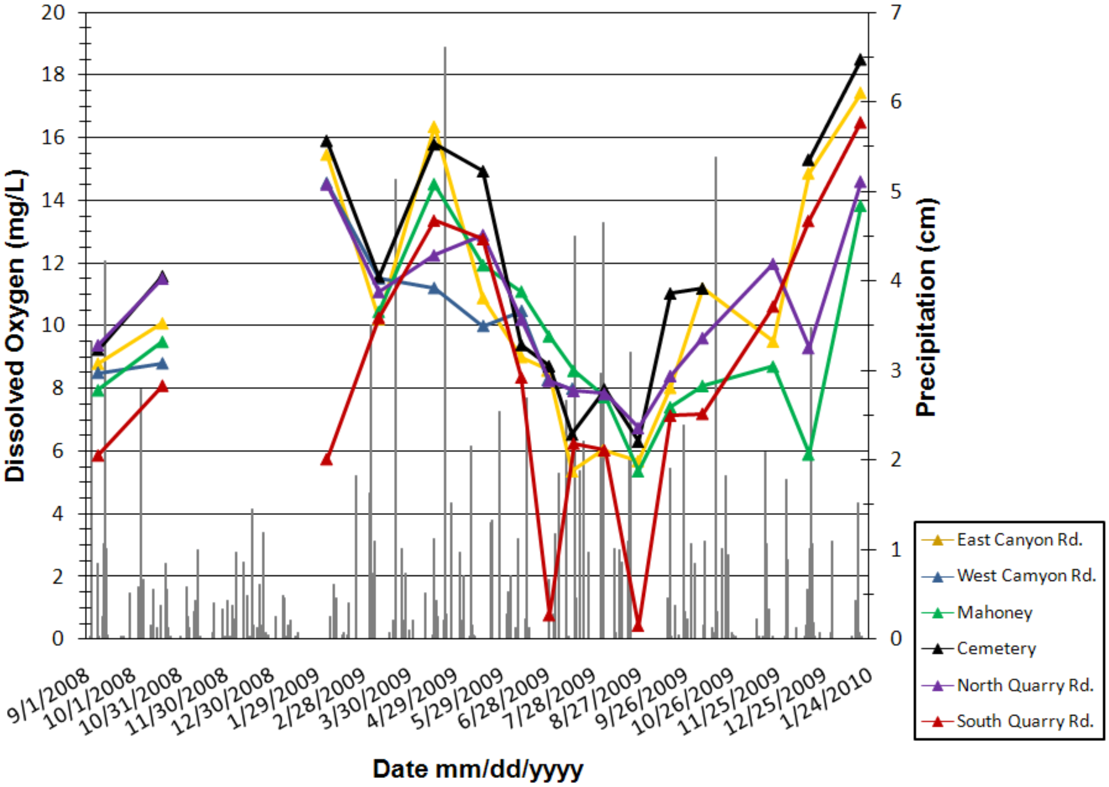

Figure IV-7. Temporal fluctuations of dissolved oxygen concentrations for the stream locations.

result of the YSI-85 probe being submerged in sediment, and hence these readings might not be true values. Dissolved oxygen concentrations were the highest in cold months and lower in warm months (Figure IV-7), which resulted in temporal variations in D.O. concentrations being observed at Cemetery, East Canyon Rd. and North Quarry Rd (Appendix B-21). Spatial variations were present between Cemetery and South Quarry Rd (Appendix B-4).

Sulfate

Sulfate concentrations were between 7.7 and 43.4 mg/L (Figure IV-8).

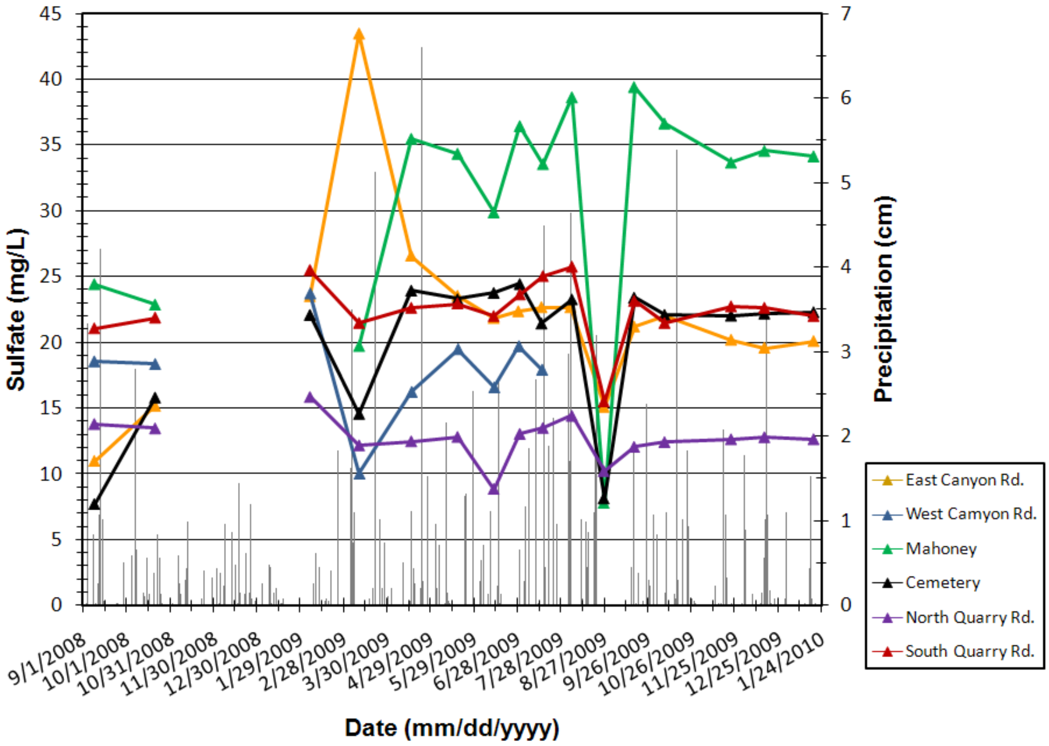

Figure IV-8. Temporal fluctuations of sulfate concentrations for the stream locations.

Sulfate concentrations were stable except when samples were collected during precipitation events during the sampling period (Figure IV-8). Despite there being fluctuations in the sulfate concentrations, temporal variations were not observed, as indicated by the statistical analysis (Appendix B-21). Mahoney and North Quarry Rd. had sulfate concentrations that were statistically different from the sulfate concentrations at each of the other stream locations (Appendix B-12). South Quarry Rd. had sulfate concentrations that were statistically different from the sulfate concentrations at West Canyon Rd., Mahoney, and North Quarry Rd (Appendix B-12).

pH

The pH of the water in the streams had values between 6.2 and 8.1 (Figure IV-9).

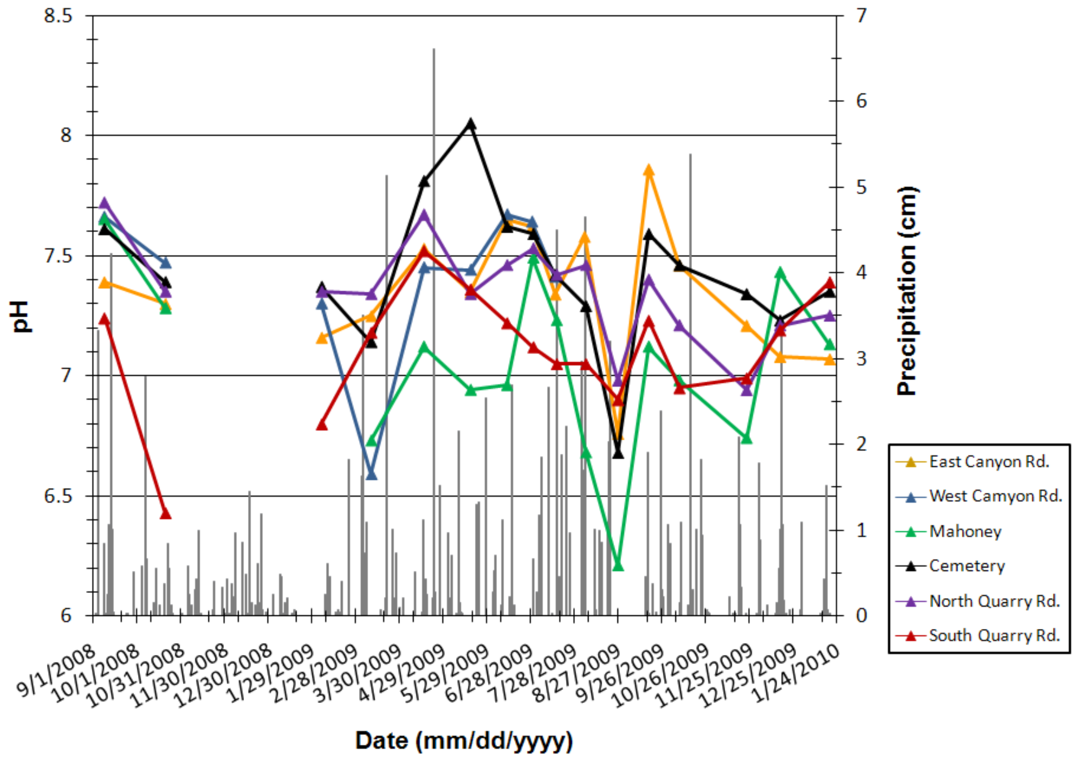

Figure IV-9. Temporal fluctuations of pH for the stream locations.

Temporal variability in pH between warm months and cold months was only present at North Quarry Rd (Appendix B-21). The pH of the streams was observed to decreased during or immediately after precipitation events, as indicated by Figure IV-9. Spatial variability between the stream locations was present at some of the streams (Appendix B-1). Mahoney and South Quarry Rd. had pH values that were statistically different from the pH values at East Canyon Rd., Cemetery and North Quarry Rd. (Appendix B-1).

Temperature

Temperatures of the stream water were between 0.2 and 20.3 degrees Celsius (°C) (Figure IV-10). There was a seasonal component to the temperature at the streams and each stream had similar water temperatures and trends (Figure IV-10). Temporal variability was present between the cold months and the warm months at each of the

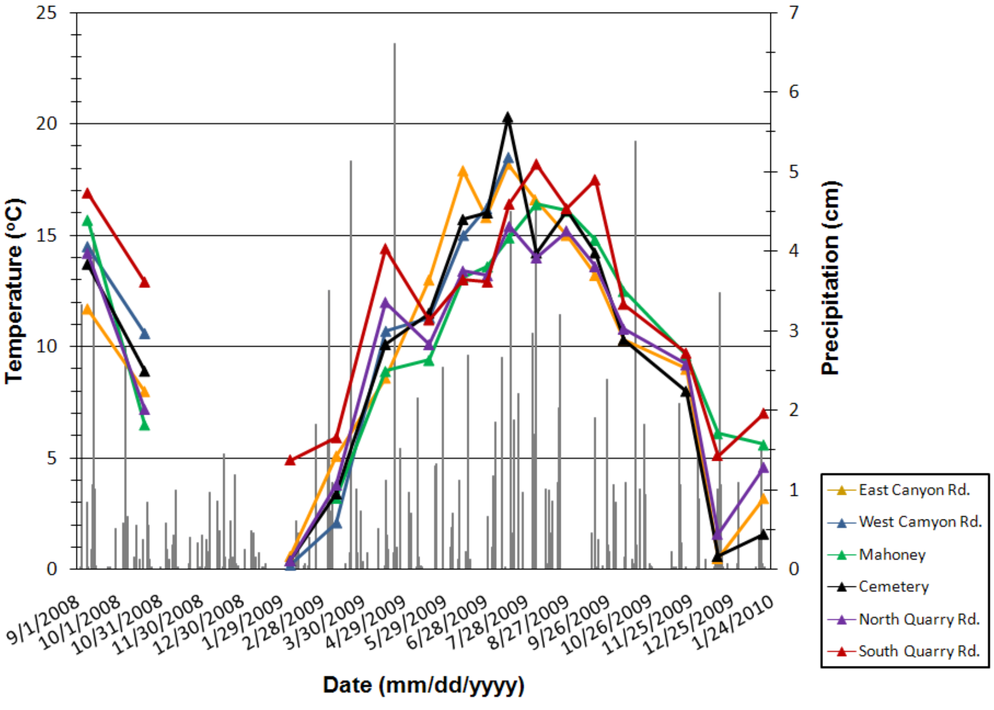

Figure IV-10. Temporal fluctuations of temperature for the stream locations.

sampled streams (Appendix B-21). However, spatial variability of the water temperature among the streams was not observed (Appendix B-2).

Potassium

Potassium concentrations observed at the streams were between 0.1 and 8.4 mg/L (Figure IV-11). Temporal variations in potassium concentrations were not present between cold months and warm months as indicated by the independent samples t-tests (Appendix B-21). South Quarry Rd. had potassium concentrations that were statistically

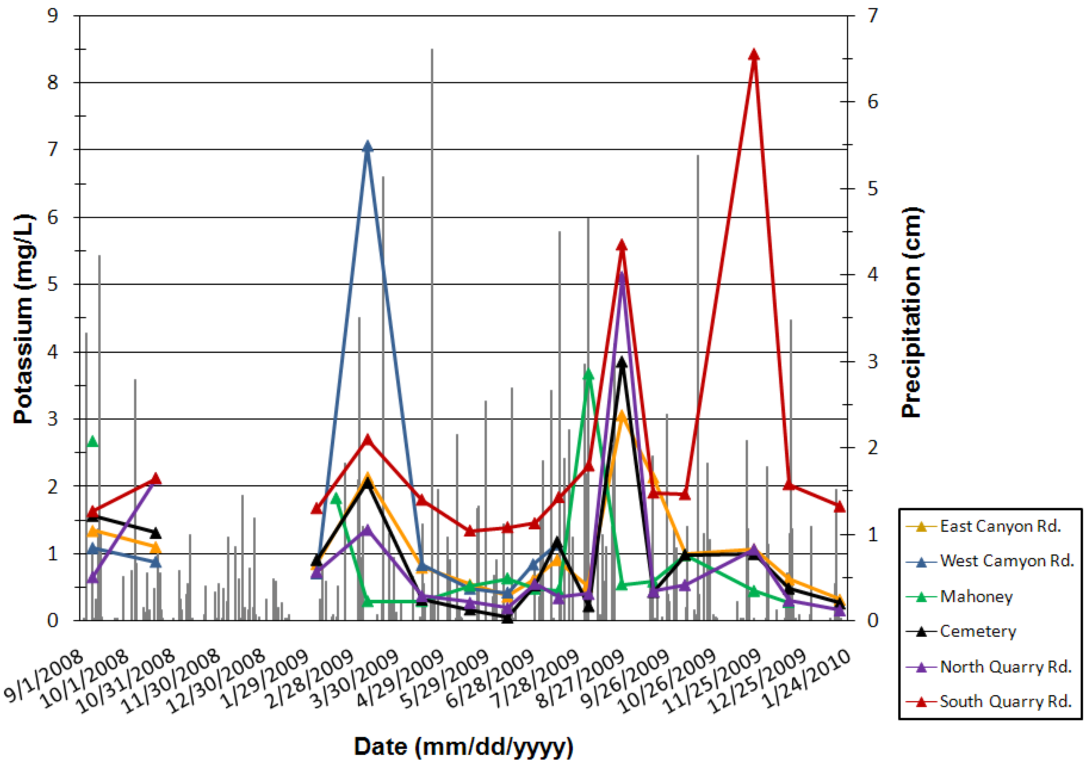

Figure IV-11. Temporal fluctuations of potassium concentrations for the stream locations.

different from the potassium concentrations at the streams except West Canyon Rd. (Appendix B-20).

Sodium

Sodium concentrations observed at the streams were between 2.8 and 17.4 mg/L (Figure IV-12). Temporal variations in sodium concentrations were not present between cold months and warm months as indicated by the independent samples t-test (Appendix B-21). South Quarry Rd. had sodium concentrations that were statistically different from the sodium concentrations at Mahoney, Cemetery, and North Quarry Rd. (Appendix B-18). East Canyon Rd. had sodium concentrations that were statistically

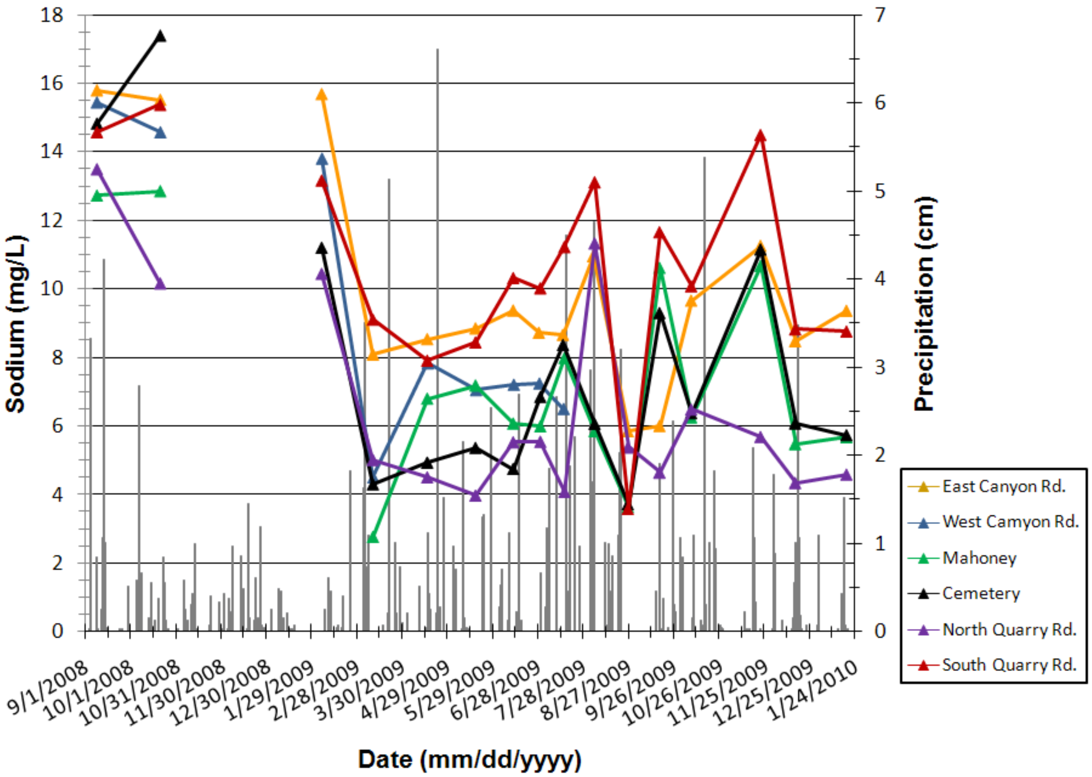

Figure IV-12. Temporal fluctuations of sodium concentrations for the stream locations.

different from the sodium concentrations at Mahoney and North Quarry rd (Appendix B-18).

Spring Data

Water samples at the springs had different sampling intervals due to the fact that their locations became known to us at different times. Heller spring was sampled from May 18 to November 23, 2009. Hicks spring was sampled between May 18, 2009 and January 19, 2010. Cora, McPhillips, and Sargent springs were sampled between June 12 and November 23, 2009. Holesinger spring was sampled between June 30 and November 23, 2009. A complete listing of the water sample data can be found in Appendix A.

Chloride

Temporal variations in the chloride concentrations were not observed to be significant at Hicks spring according to an independent samples t-test (Appendix B-41). Spatial variability among the chloride concentrations were observed between all of the spring locations except between: Cora and Sargent springs; Heller and McPhillips springs; Holesinger and Cora springs; and Holesinger and Sargent springs (Appendix B-30). Chloride concentrations at the springs were between 5.4 and 26.7 mg/L (Figure IV-13).

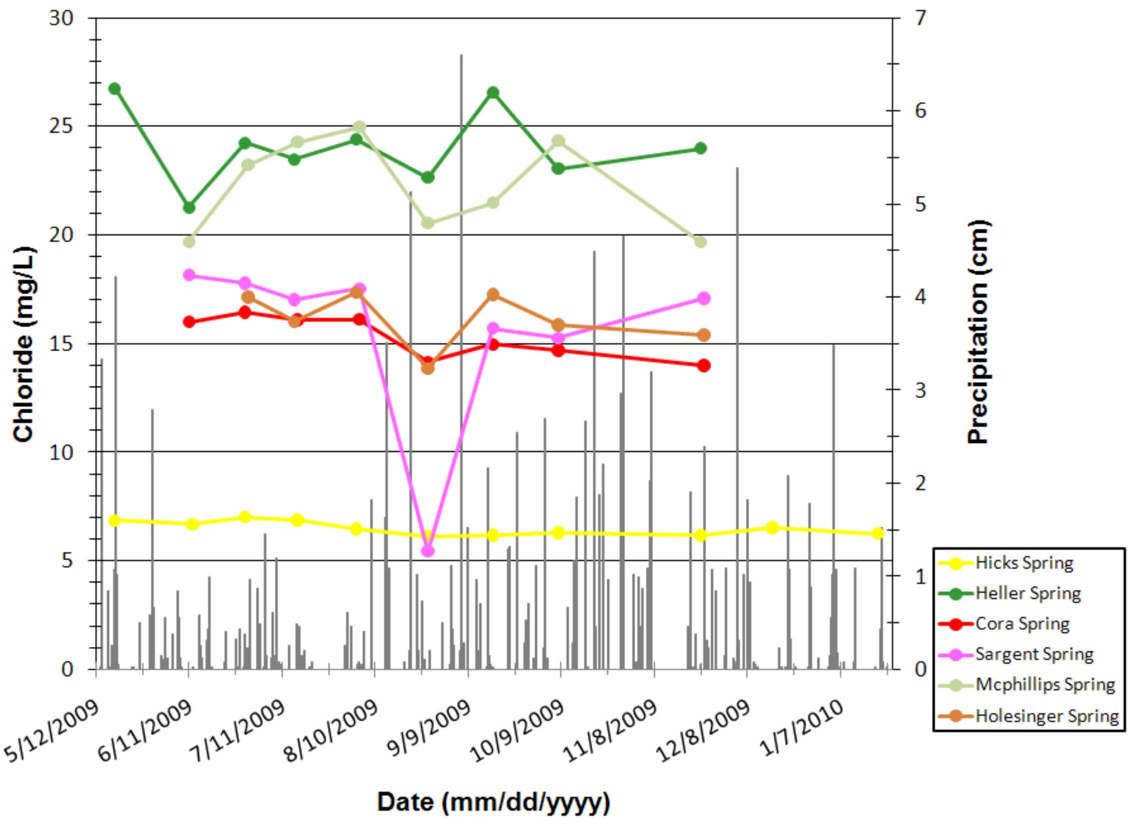

Figure IV-13. Temporal fluctuation of chloride concentrations for the spring locations.

Nitrate as Nitrogen

Temporal variations in nitrate as nitrogen concentrations were not observed to be significant at Hicks spring according to an independent samples t-test (Appendix B-41). Spatial variations in nitrate as nitrogen concentrations were present at each of the spring location combinations except between: Sargent and Cora springs; Sargent and Heller springs; and Cora and Heller springs (Appendix B-33). Nitrate as nitrogen concentrations at the springs were between 0.3 and 30.1 mg/L (Figure IV-14).

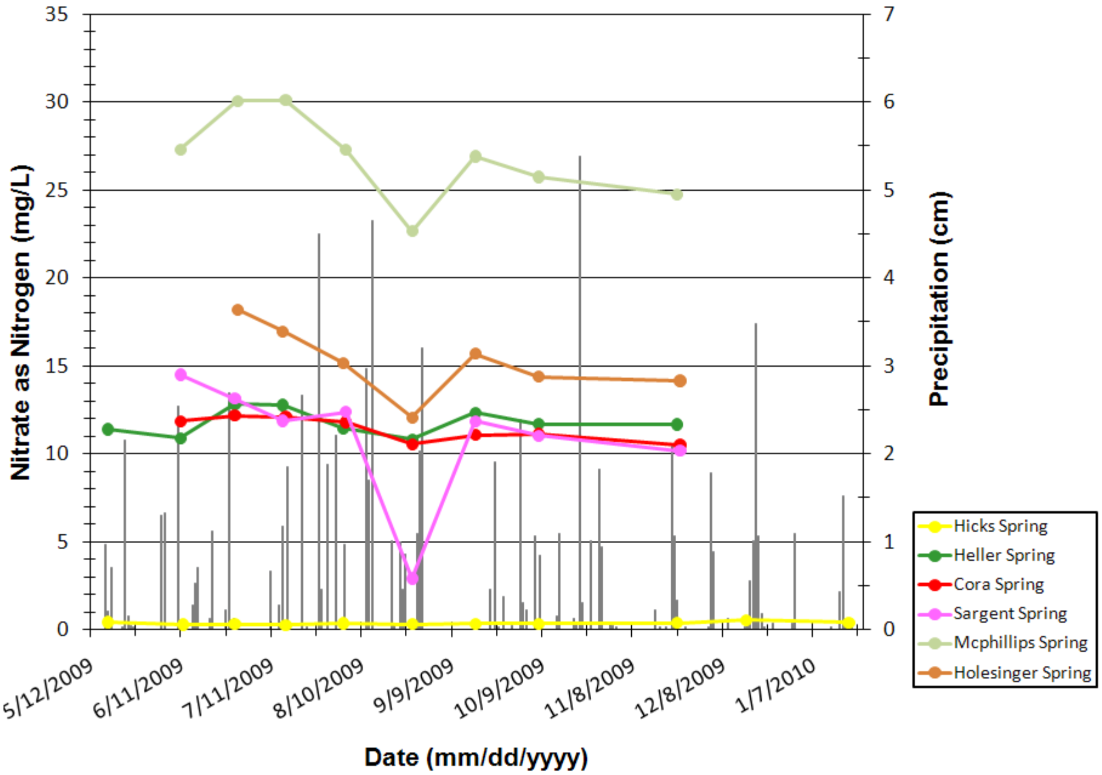

Figure IV-14. Temporal fluctuations of nitrate as nitrogen concentrations for the spring locations.

Water samples at the spring locations had lower nitrate as nitrogen concentrations when collected during a precipitation even on August 27, 2009 (Figure IV-14). Nitrate as nitrogen concentrations decreased over the monitoring period (Figure IV-12).

Alkalinity (as $CaCO_3$)

Temporal variability in alkalinity concentrations was not present between cold months and warm months at Hicks spring as indicated by an independent samples t-test (Appendix B-41). Spatial variations in alkalinity were observed at all of the spring locations except between Cora and Heller springs (Appendix B-29). Alkalinity concentrations for the springs were stable over the monitoring period (Figure IV-15). Alkalinity concentrations were between 134 and 331 mg/L (Figure IV-15) Heller,

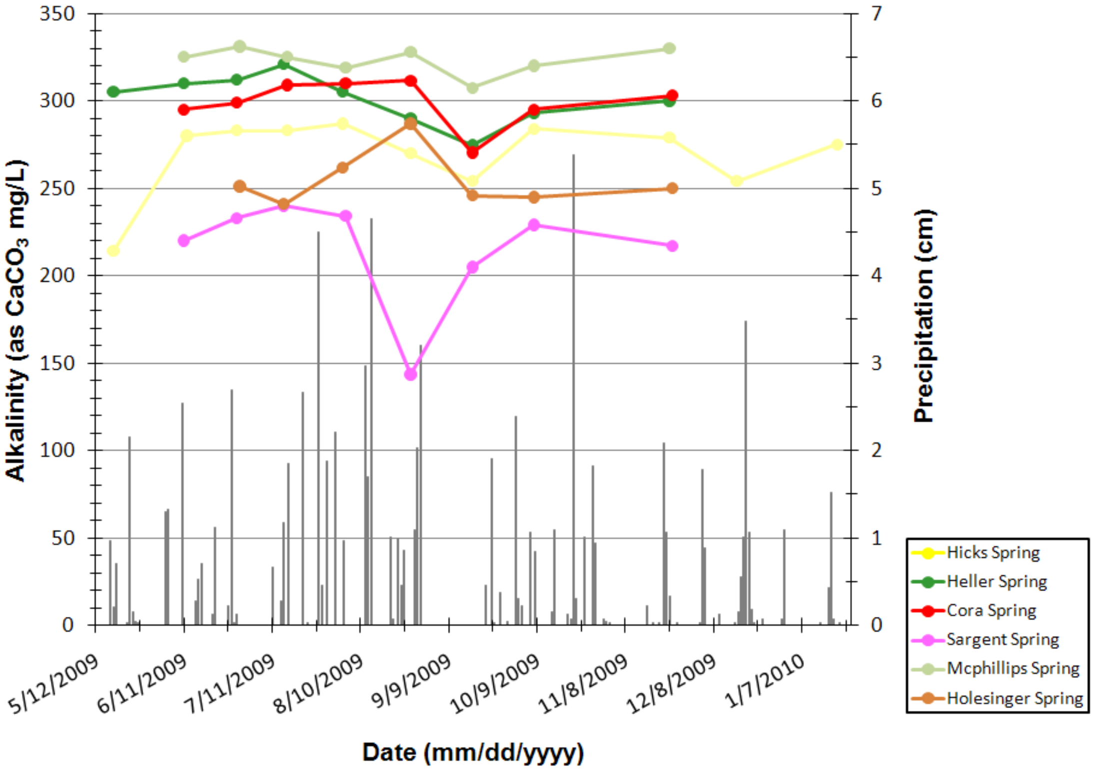

Figure IV-15. Temporal fluctuation in alkalinity (as $CaCO_3$) concentrations for the spring locations.

Hicks, and Sargent springs were observed to have lower alkalinity concentrations during the precipitation event on August 27, 2009 (Figure IV-15).

Calcium

Temporal variations in calcium concentrations were not observed at Hicks spring between the cold months and the warm months as indicated by an independent samples t-test (Appendix B-41). Spatial variations in calcium concentrations were observed between all of the spring locations except for: Hicks and Sargent springs; Cora and Heller springs; and Heller and Holesinger springs (Appendix B-34). Calcium concentrations were between 36.5 and 104.9 mg/L (Appendixes A-7 through A-12). Sargent spring was the only spring that had a lower calcium concentration during the precipitation event on August 27, 2009 (Figure IV-16).

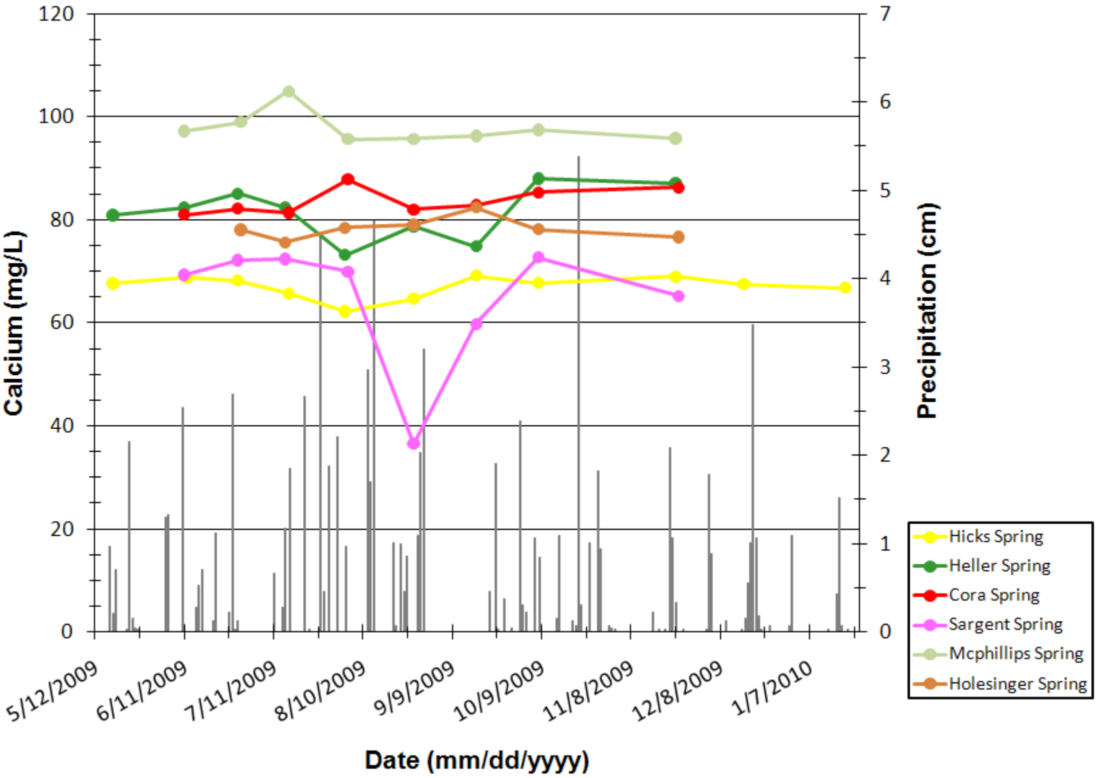

Figure IV-16. Temporal fluctuations in calcium concentrations at the spring locations.

Magnesium

Temporal variations in magnesium concentrations were not observed at Hicks spring between cold months and warm months as indicated by an independent samples t-test (Appendix B-41). Spatial variations in magnesium concentrations were observed between each of the springs except between: Cora and Heller springs; and between Hicks and Holesinger springs (Appendix B-36). Magnesium concentrations were between 18.7 and 59.7 mg/L (Appendixes A-7 through A-12). The only spring that was observed to have lower magnesium concentrations during the precipitation event on August 27, 2009 was Sargent spring (Figure IV-17).

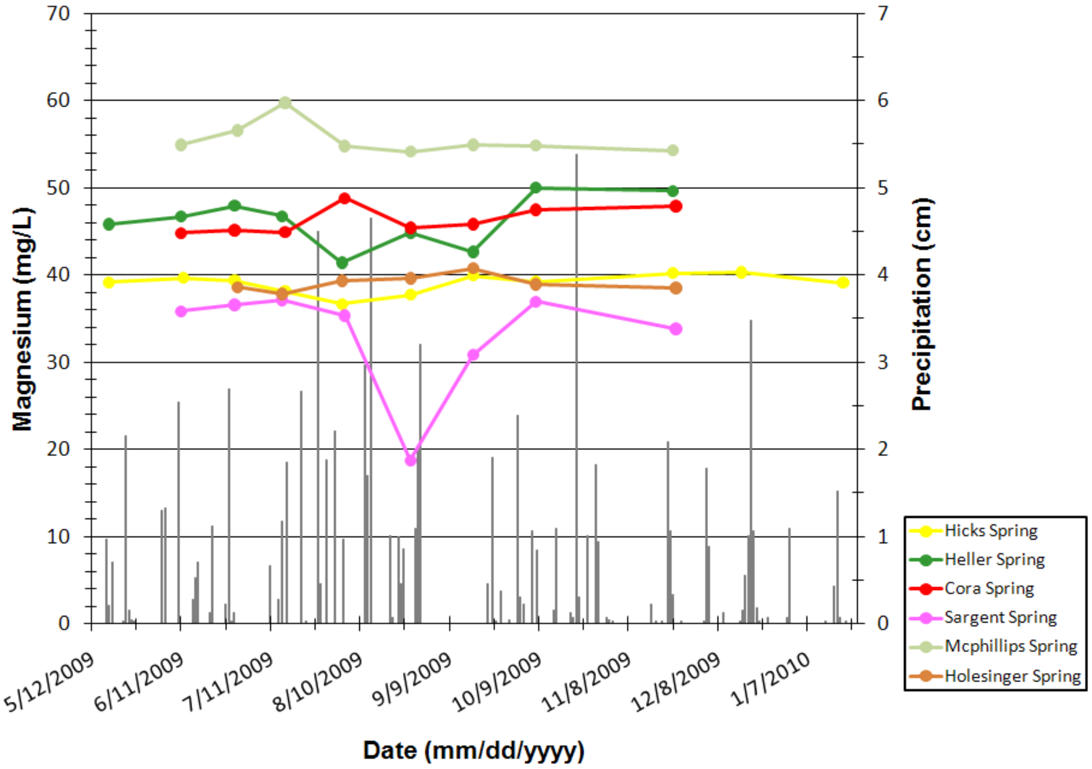

Figure IV-17. Temporal fluctuations in magnesium concentrations at the spring.

Specific Conductance

Specific conductance values were between 452 µS/cm and 1069 µS/cm (Figure IV18). Sargent spring was the only spring that was observed to have a lower specific conductance value as a result of the precipitation event on August 27, 2009 (Figure IV-18). Hicks spring displayed temporal variability in its specific conductance values over

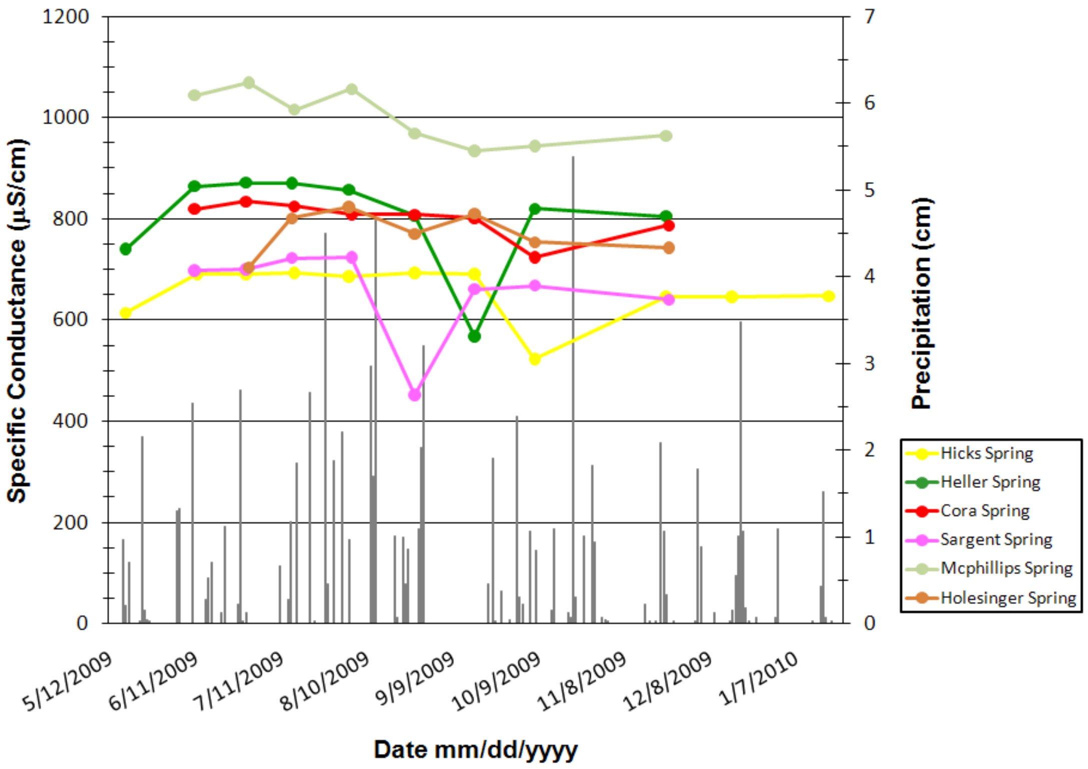

Figure IV-18. Temporal fluctuations in specific conductance at the springs.

the monitoring period (Appendix B-41). Spatial variations were observed between almost all of the springs during the monitoring period except; between Cora and Heller springs; between Hicks and Sargent springs; between Heller and Holesinger springs; and between Cora and Holesinger springs (Appendix B-23).

Dissolved Oxygen

Dissolved Oxygen, D.O., concentrations were between 0 mg/L and 9.3 mg/L (Figure IV-19). All of the springs, except for Hicks spring, appear to have had lower D.O.

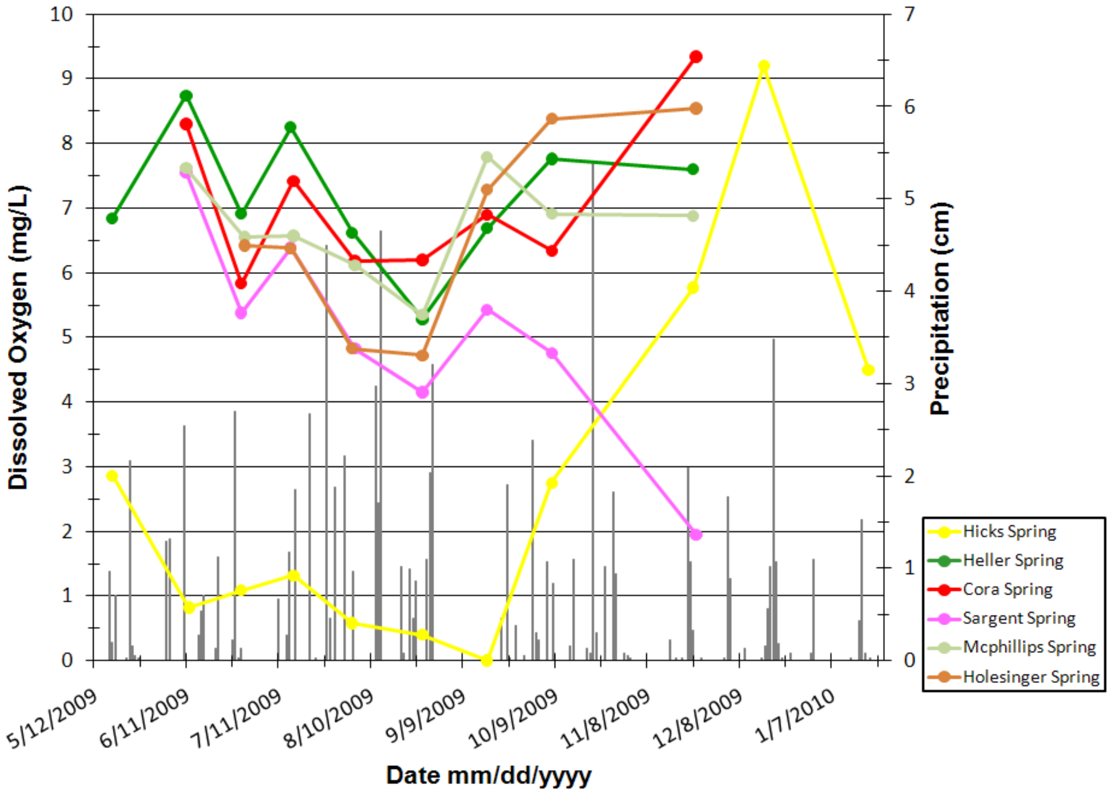

Figure IV-19. Temporal fluctuations in dissolved oxygen at the springs.

concentrations during the precipitation event on August 27, 2009. Hicks spring displayed temporal variability in its D.O. concentrations (Appendix B-41). Hicks and Sargent springs had D.O. concentrations that were spatially different from the D.O. concentrations at the other springs (Appendix B-24).

Sulfate

Temporal variations in sulfate concentrations were not observed at Hicks spring between cold months and warm months as indicated by an independent samples t-test (Appendix B-41). Sulfate concentrations displayed spatial variability between all of the springs (Appendix B-32). The sulfate concentrations were between 7.6 and 31.1 mg/L

(Figure IV-20). Holesinger and Sargent springs were observed to have lower sulfate concentrations during the precipitation event on August 27, 2009 (Figure IV-20).

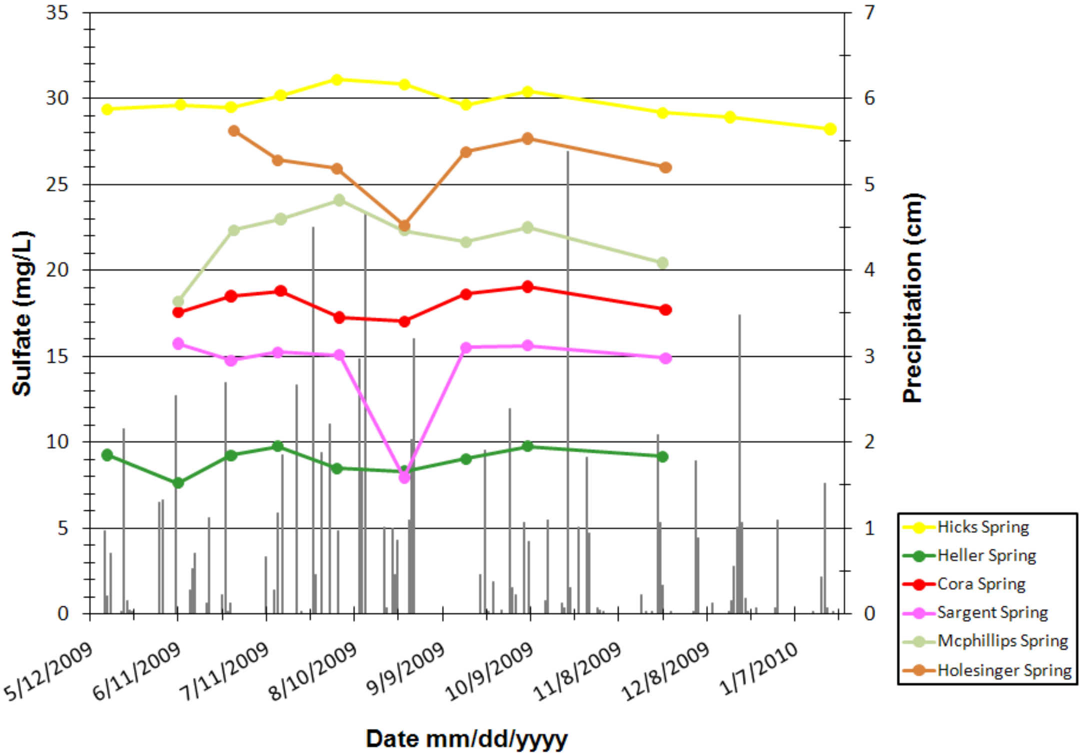

Figure IV-20. Temporal fluctuations in sulfate concentrations at the springs.

pH

Temporal variations of pH were not observed at any of the springs between warm and cold months as indicated by an independent samples t-test (Appendix B-41). Spatial variations in pH were observed between Hicks spring and all of the other springs (Appendix B-21). The pH of the springs were between 6.4 and 6.9 (Appendix A-7 through A-12). No clear pattern in pH during precipitation events was observed at the springs (Figure IV-21).

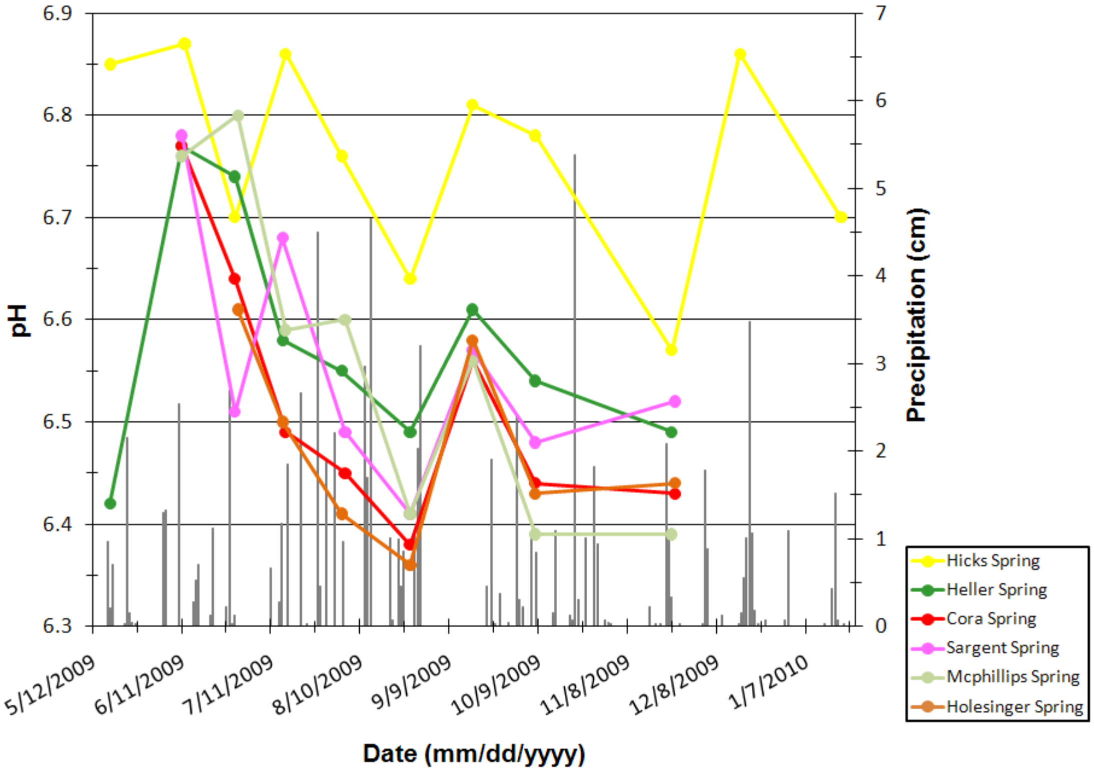

Figure IV-21. Temporal fluctuations in pH at the springs.

Temperature

Temporal variations in the water temperature between warm and cold months were observed at Hicks spring as indicated by an independent samples t-test (Appendix B-41). Spatial variability in the water temperature at the springs were present between Holesinger spring and all of the other springs except Sargent spring (Appendix B-22). Additionally, Sargent spring had water temperatures that exhibited spatial variability from Hicks and McPhillips springs (Appendix B-22). The temperature of the spring water was between 9.0 and 14.0 °C (Appendixes A-7 through A-12). The temperatures of the spring water did not appear to be affected by the precipitation event on August 27, 2009 as indicated by field measurements (Figure IV-22). There was a seasonal warming affect on the water at all of the springs except Hicks spring (Figure IV-22).

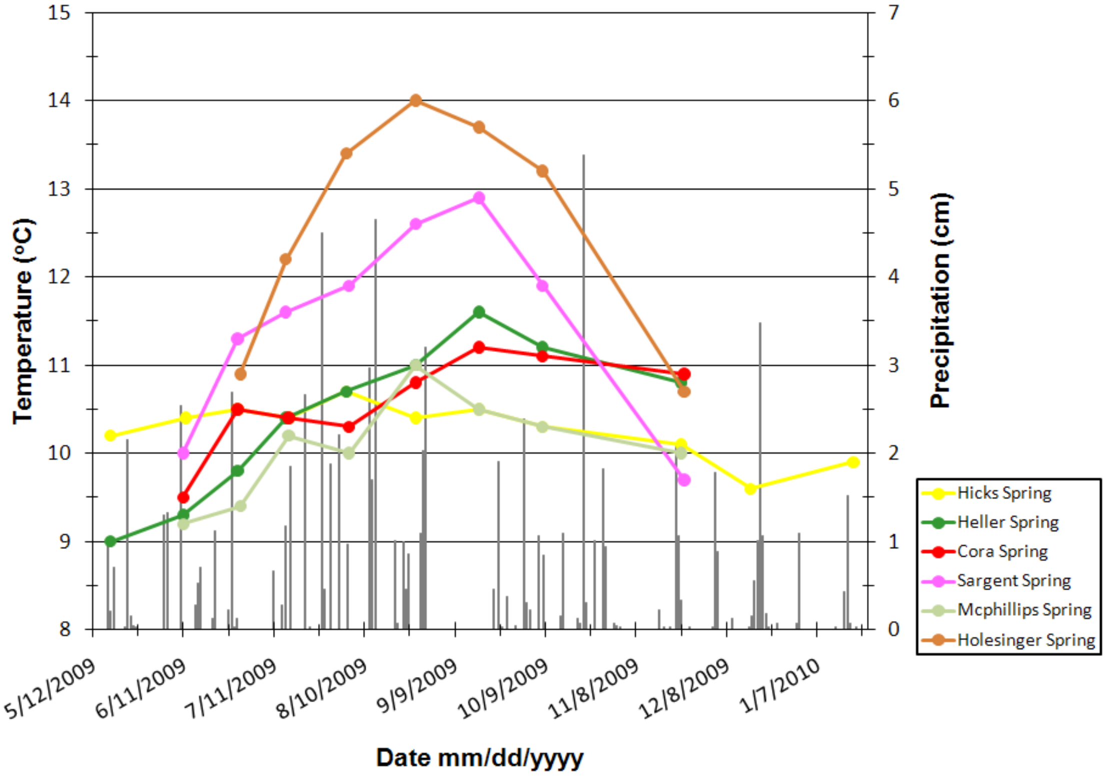

Figure IV-22. Temporal fluctuation in temperature at the springs.

Potassium

Temporal variations of potassium concentrations at Hicks spring for cold and warm months were not observed as indicated by an independent samples t-test (Appendix B-41). Spatial variations of potassium concentrations were observed between: McPhillips spring and all of the other springs except Sargent spring; and Holesinger spring and all of the other springs (Appendix B-40). Potassium concentrations were between 0 and 3.8 mg/L (Appendix A-7 through A-12). Holesinger spring usually had the highest potassium concentrations (Figure IV-23). Holesinger and McPhillips springs were observed to have had lower potassium concentrations during the precipitation event on August 27, 2009 (Figure IV-19). Sargent spring was observed to have potassium concentrations that were higher than the other springs during the precipitation event on August 27, 2009 than at any other time over the sampling period (Figure IV-23).

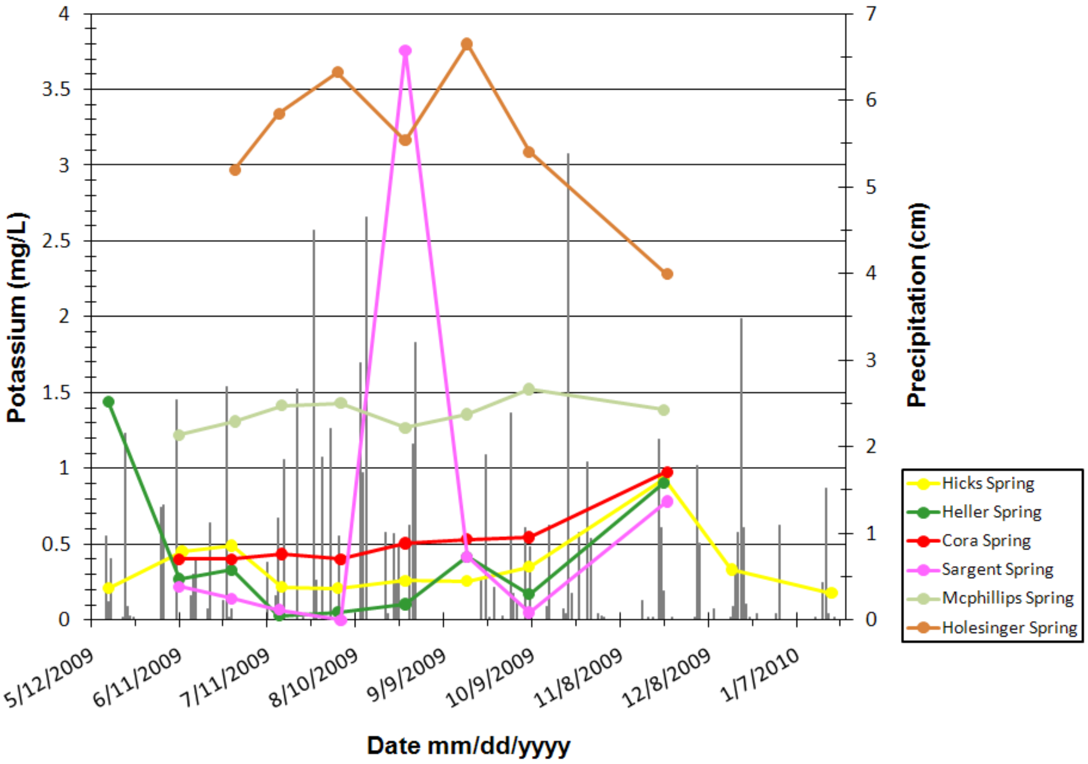

Figure IV-23. Temporal fluctuations in potassium concentrations at the springs.

Sodium

Temporal variations at Hicks spring for the sodium concentrations were not observed between warm and cold months as indicated by an independent samples t-test (Appendix B-41). Sodium concentrations at Cora spring were statistically different from the sodium concentrations at; Heller, Hicks and Sargent springs; which indicated spatial variability (Appendix B-38). Both Heller and Sargent springs had sodium concentrations that were statistically different from the sodium concentrations at McPhillips and Holesinger springs (Appendix B-38). Sodium Concentrations were between 2.9 and 14.7 mg/L (Appendix A-7 through A-12). Hicks, Holesinger and Sargent springs were observed to have lower sodium concentrations during the precipitation event on August 27, 2009 (Figure IV-24).

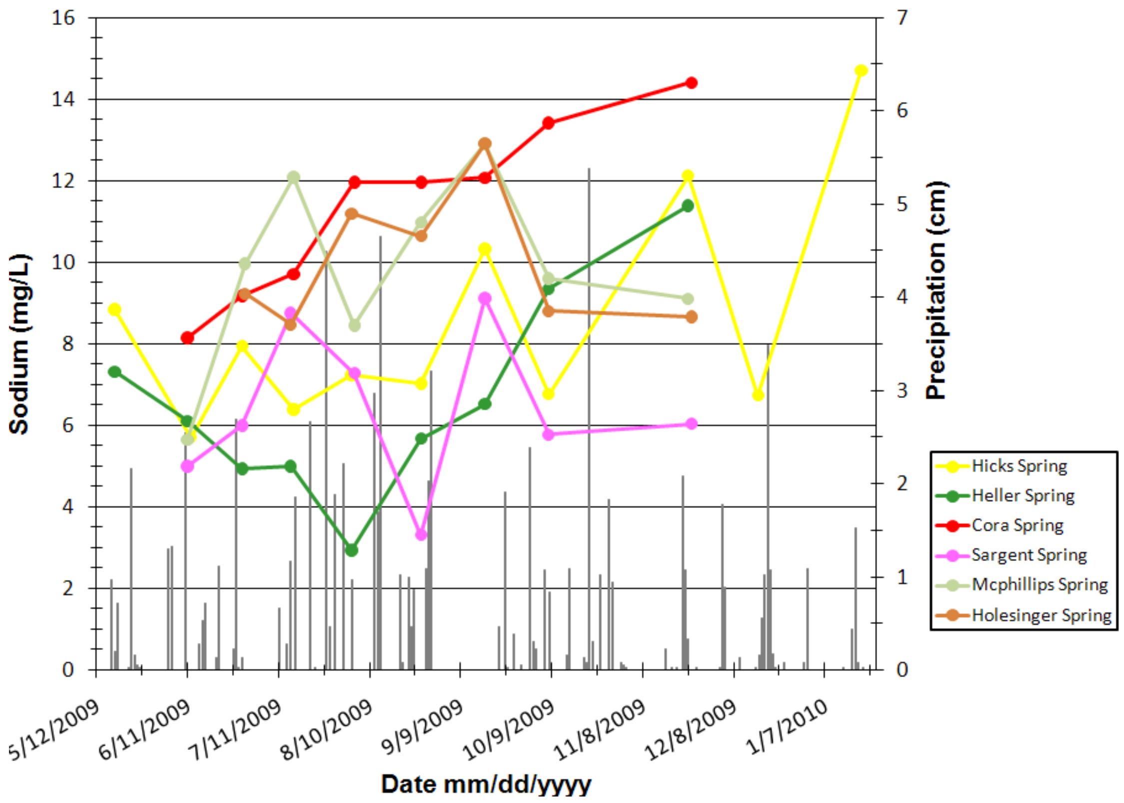

Figure IV-24. Temporal fluctuations in sodium concentrations at the springs.

CHAPTER V

DISCUSSION

Discussion

Comparison Between Stream and Spring Datasets

Through the analysis of Table IV-1 it was determined that the spring and stream water quality data are statistically different from each other. Fluoride, sodium, sulfate, and potassium are the only parameters that are similar between the stream and spring (Table IV-1). Since the spring and stream water quality data are for the most part statistically different from each other this is thought to indicate that different processes are controlling the water quality. However, even though the spring and stream water quality are statistically different, the piper plot (Figure V-I) shows that the water type is the same for both the springs and streams. The water type of the springs and streams is calcium-magnesium bicarbonate.

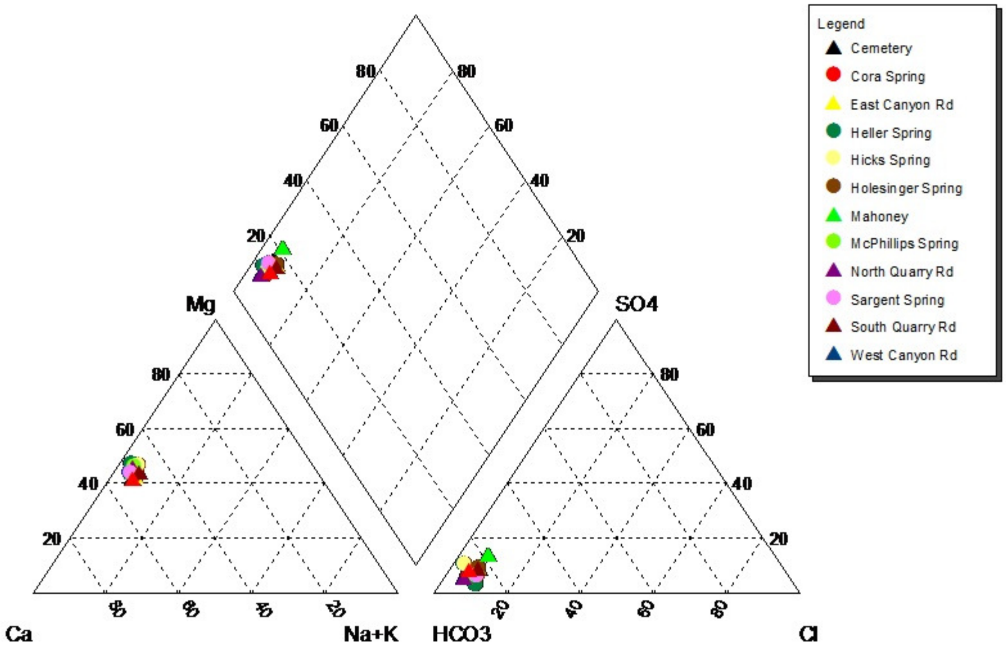

Figure V-I. Piper plot showing the average water type for the stream and spring locations over the monitoring period.

The springs and streams have a similar water type as the result of the springs and streams flowing through the carbonate bedrock. Possible sources of the water contributing to the total spring and stream water volume are: precipitation, infiltrating soil water, epikarst water, and phreatic water (Lee and Krothe, 2001). While the streams around the study site are above ground and not below, the samples were collected during base flow conditions and appeared to be influenced by groundwater due to the stability of the flow throughout the monitoring period. The springs seem to be more heavily influenced by epikarstic and phreatic water, with some precipitation and soil water influence as indicated by elevated nitrate as nitrogen concentrations, in the spring water. The reason why epikarstic and phreatic water are believed to be the major contributors to the total spring water volume is the springs have calcium (Figure IV-16) and magnesium (Figure IV-17) concentrations higher than those of the streams' calcium (Figure IV-4) and magnesium (Figure IV-5) concentrations, which can indicate a longer residence time.

The spring and stream water quality data displayed a low amount of temporal variability over the monitoring period, as indicated by the statistical analyses (Appendix B-21 and B-41). The only parameters that displayed some amount temporal variability in the streams were: temperature, dissolved oxygen and pH (Appendix B-21). The parameters that displayed temporal variability in Hicks spring were: temperature, specific conductance, dissolved oxygen, fluoride, and silicon (Appendix B-41). The apparent temporal variability observed in fluoride and silicon at Hicks spring might be the result of the low concentrations of these two ions and the analytical error of the ICP. The temporal variability in temperature in the six stream locations and in Hicks spring is the result of the seasonal variation in temperatures. The temporal variability in dissolved oxygen at East Canyon Rd., North Quarry Rd., South Quarry Rd., and Hicks spring is more likely the result of oxygen having a greater amount of solubility in cold water, than in warm water than actual temporal variations. North Quarry road was the only stream location that had pH values that displayed a temporal variation over the sampling period. Since other parameters that could indicate a seasonal difference in residence times did not display temporal variations, a change in residence times is not thought to be the reason behind the pH variation at North Quarry Rd. North Quarry Rd. also displayed temporal variability between warm and cold months for its pH. The pH values at North Quarry Rd. were on average higher during warm months than in cold months. Higher average pH values in the warm months could be due to longer residence times.

The near absence in temporal variability in the streams seems to indicate that the water flowing into and through the streams has had sufficient to equilibrate with the carbonate bedrock in the area. Even though the streams and springs displayed limited amounts of temporal variability, a precipitation event on August 27, 2009 produced noticeably lower alkalinity (Figure IV-3), calcium (Figure IV-4), chloride (Figure IV-1), magnesium (Figure IV-5), nitrate as nitrogen (Figure IV-2), pH (Figure IV-9), and specific conductance (Figure IV-6) values in most cases for the streams and lower chloride (Figure IV-13), nitrate as nitrogen (Figure IV-14), and pH (Figure IV-21) values for the springs were observed. Since more of the stream parameters were observed to be affected by the precipitation event, this is thought to indicate that the streams reacted more strongly to the precipitation events than the springs do. The apparent lack of reaction by the springs suggests that the spring react in a more "delayed-flow" manner as the result of the springs being influenced by soil and phreatic zone water (William, 1983).

Before the way that the system reacts to precipitation events can be fully assessed by monitoring of a precipitation event would need to be completed.

Spatial variations in the water quality data were more common in the spring water data than the stream water data (Appendix B). The greater amount of spatial variability in the spring water data is thought to be the result of how the bedding planes, conduits, and fractures connect from the surface to each of the springs and control the residence time of the springs. The stream data do show some spatial variability, but this spatial variability was mostly present in parameters that can be affected by human activities, such as chloride, nitrate as nitrogen, and sulfate (discussed later). There was an absence in spatial variability among the stream water parameters that are controlled by the carbonate and karstic system, such as alkalinity, calcium, and specific conductance; which is probably the result of the similarity of the bedrock over the study area. Spatial variability was not observed in the temperature of the stream water over the monitoring period which, along with the temporal analyses and Figure IV-8, indicates that the stream water is being influenced by the daily average temperature. The spring data exhibited varying amounts of spatial variability among the parameters that can be influenced by human activities and parameters controlled by the carbonate bedrock, but as with the streams the most variability was among the parameters that can be influenced by human activities (Appendix B). The lack of spatial variability in the stream parameters was not what was predicted in the hypothesis, as it was thought that there would be spatial variability in all of the water parameters. As a result of the limited amount of spatial variability, the water flowing through the study area is thought to be similar, since there is less spatial variability among the spring and stream water quality parameters that are controlled by the carbonate system.

The statistical similarity of the pH values for four of the six stream locations is thought to indicate that most of the same processes are controlling the streams. The pH values for the majority of the sampling period at Mahoney and South Quarry Rd. were lower than the pH values at the other stream locations. Due to the fact that there are several factor that could be controlling the pH values at the stream, the exact reason why the pH values at Mahoney and South Quarry Rd. were different from the other streams is not known. A possible explanation of the lower pH values at Mahoney and South Quarry Rd. could be that the stream water at Mahoney and South Quarry Rd. either had a shorter residence time than the other four streams. A shorter residence time would cause pH values to be lower because there would have been less time for the acid in the system to be consumed in the dissolution of the dolomite and limestone. Equation (2) represents the process that occurs when an acid ,H^+ ion, comes into contact with the mineral calcite, $CaCO_3$, :

$$CaCO_3 + H^+ \leftrightarrow Ca^{2+} + HCO_3^- \tag{2}$$

The resulting process causes the calcite, or limestone and/or dolomite, to dissolve into calcium and bicarbonate which increases the pH of the water as a result of the acid being consumed.

Spatial variations in water temperature values were observed at some of the springs. Sargent and Holesinger springs were the springs that had temperatures that were statistically different from most of the other spring locations. In almost every case, the water temperatures at Sargent and Holesinger springs were warmer than the other spring (see appendix A). The warmer spring water temperatures indicates that Sargent and Holesinger springs have not had a chance to fully equilibrate to the ground temperature; which suggests that the residence times at Sargent and Holesinger springs is less than the residence time at the other springs. Hicks spring had stable water temperatures, which indicates either a long flow path or the water is from a deep source and has had sufficient time to equilibrate with the karst bedrock Due to the fact that Cora, Heller, McPhillips, and Sargent springs had temperatures that were statistically similar to the temperatures at Hicks spring it is thought that they have sufficient time to equilibrate with the karst bedrock and acquire a temperature that is close to the average annual temperature.

The residence times of each of the springs is thought to be different from one another. Evidence for this are drawn from the specific conductance (Figure IV-18), alkalinity (Figure IV-15), calcium concentration (Figure IV-16), and magnesium (Figure IV-17) concentration data. Each of these parameters displayed spatial variation among most of the springs (Appendix B). Ozyurt and Bayari (2008) stated that specific electroconductivity is a reliable descriptor of residence times of the water and that “slow” water, or water with longer residence times, would be indicated by higher specific conductance values. The use of specific conductance was also used by Shuster and White (1971) to differentiate the flow paths of groundwater. Specific conductance can be used as a means to differentiate flow paths of water, and the residence time, because the specific conductance in carbonate systems depends on the amount of calcium and magnesium ions in solution (White, 1988). McPhillips spring had the highest average specific conductance value, at 999 µs/cm, and Hicks and Sargent springs had the lowest average specific conductance values at about 660 µs/cm. The fact that McPhillips spring had the highest average specific conductance is not thought to indicate that McPhillips spring has the longest residence time, but rather that the water flowing though the fractures from the surface to McPhillips spring are tighter than the fractures that connect Hicks spring to the surface (Williams, 1983). McPhillips spring also had some of the highest anthropogenic influences being its high nitrate as nitrogen (Figure IV-14), sulfate (Figure IV-20) and sodium (Figure IV-24) concentrations (discussed later) which gives support to the idea that the water flowing through McPhillips spring has a shorter residence time than the water flowing through Hicks spring.

The springs and streams in the study site had elevated, nitrate as nitrogen, sodium, and sulfate concentrations (Figures IV-2, IV-8, IV-12, IV-14, IV-20, and IV-24), indicating human influences on the overall water quality. Kang et al. (2008) found that low order streams had more elevated nitrate concentrations than higher order streams due to the fact that lower order streams received greater amounts of shallow groundwater that contained higher nitrate concentrations from agricultural land use. Since the streams in the Nora area are low order streams and most of the land use is for agricultural practices the high anthropogenic ions present at the streams, especially nitrate as nitrogen, seem to be the result of infiltrating soil water that has had contact with land used for agricultural uses. The springs in the Nora area also appear to be getting infiltrating soil water, as a result of the elevated ion concentrations. Possible source of contamination, based on the ions that are elevated, include: road salt, fertilizer, sewage, and manure. The elevated nitrate as nitrogen (NO_3^--N) concentrations were the most significant of the ions because this is the only ion that has a drinking water standard, which is 10 mg/L (EPA, 2009). Average NO_3^--N concentrations greater than 10 mg/L were observed at East Canyon Rd.

and North Quarry Rd and all of the spring locations except Hicks spring. All of the springs and streams, except Hicks spring, had nitrate as nitrogen concentrations above 3.0 mg/L which Liu et al. (2005) stated as the expected upper background nitrate as nitrogen concentration. With the exception of Hicks, Mahoney, and South Quarry Rd. all of the springs and streams had nitrate as nitrogen concentrations above the drinking water standard of 10 mg/L (EPA, 2009) at some point during the monitoring period. McPhillips spring had nitrate as nitrogen concentrations that were about 2.5 times the drinking water standard (Figure IV-X). The reason as to why McPhillips spring had such high nitrate as nitrogen concentrations is not known. However, one possible explanation could be that there is a high amount of agricultural activity around McPhillips spring.

Spatial variability in the nitrate as nitrogen concentrations between the streams were observed when two streams had sufficiently different average nitrate as nitrogen concentrations . This was true for Cemetery, second lowest average nitrate as nitrogen concentration, and East Canyon Rd. and North Quarry Rd., two highest average nitrate as nitrogen concentrations. Similarly, Mahoney, lowest average nitrate as nitrogen concentration, had nitrate as nitrogen concentrations that were statistically different from the nitrate as nitrogen concentrations at East Canyon Rd., North Quarry Rd., and South Quarry Rd ,higher average nitrate as nitrogen concentrations; 10.2 mg/L, 10.3 mg/L and 8.6 mg/L respectively. The lower average NO_3^-N concentrations at Cemetery and Mahoney as compared to the average NO_3^-N at the other stream locations suggests Cemetery and Mahoney are the least affected by human activities. The sample location of Mahoney had the least amount of agricultural activity around it and the highest amount of trees and grasses, which serve as a buffer and nitrate sink.

All of the springs combinations except those of Cora, Heller, and Sargent springs; displayed spatial variability in regards to their nitrate as nitrogen concentrations over the sampling period (Appendix B-33).. The reason as to why Cora, Heller, and Sargent springs were the most different from the other springs is not known, as Cora and Heller springs flowed out of pastures used for grazing cattle and Sargent spring was located in grassland between two fields used for row crops. In general there was not a common land connection that could be drawn for each of the springs.

With average sodium concentrations greater than 6.4 mg/L for all of the springs and streams, human influences are apparent. Waters in systems dominated by limestone tend to have average sodium concentrations below 2 mg/L (Hem, 1959). Even though the Galena Group is mostly comprised of dolomite and not limestone, the concentration of 2 mg/L should still apply to this area because as with limestone, dolomite does not have very much sodium. Since carbonate rocks do not have significant amounts of sodium (Palmer, 2007), the sodium probably has an anthropogenic source. While road salt would seem to be a logical source of the sodium, neither sodium nor chloride concentrations (discussed below) increase during the winter, which argues against the application of road salt as the reason behind the spatial variability in sodium concentrations. Rather, it is thought that variations in manure applications may be behind the varying sodium concentrations in the springs and streams. Upstream of South Quarry Rd., which has the highest average sodium concentrations, is pasture used for the grazing of cattle, which could be contributing to the sodium levels of the stream there. Cora spring had the highest sodium concentrations among the springs, which might be a result of the land around Cora spring being used for pasture land. The land around Heller spring was also used as pasture for grazing cattle, but does not appear to be as affected as Cora spring or South Quarry Rd.

Average sulfate concentrations for each stream and all of the springs except Heller are above the concentration of 10 mg/L which represents rainwater that has experienced evapotranspiration (Bottrell et al., 2008). Sulfate concentrations of the streams and springs displayed the greatest amount of spatial variability among the water quality parameters. Mahoney had the highest average sulfate concentration at 30.8 mg/L and North Quarry Rd. had the lowest average sulfate concentration at 12.7 mg/L of the stream locations . Hicks spring had the highest average sulfate concentration, 29.7 mg/L and Heller spring had the lowest average sulfate concentration, 9.0 mg/L among the six springs. The fact that Mahoney had the highest average sulfate concentrations and North Quarry had the lowest average sulfate concentrations is puzzling, since this is the opposite result of the average nitrate as nitrogen concentrations. This could be suggesting that a source not related to nitrate as nitrogen could be affecting the streams. The variations in the sulfate concentrations could be due to variations of sulfate in the various soils. Bloem et al. (2001) stated that variations of sulfate concentrations are caused by losses of sulfur by leaching or deep drainage and sulfur inputs by via plants roots or capillary action of deeper soil water. However, given the fact that there most of the soil around the Nora, IL area is derived from loess, Figure II-1, the variations to the sulfate concentrations does not seem to be attributed to differences in soil types. Rather, the observed variability appears to be due to differences in human activities, which can contribute sulfate to water (Brottrell et al. 2008). The exact source of the sulfate is not know, but could be determined through isotopic studies (Brottrell et al, 2008).

The average chloride concentrations, of the springs and streams are between 6.5 mg/L and 24.0 mg/L, which has a similar to chloride concentrations measured in karst waters of the Driftless Area of Wisconsin (unpublished data). Hicks spring had the lowest chloride concentration of the springs and streams, indicating that it is the least affected by anthropogenic sources of chloride. North Quarry Rd. and West Canyon Rd. had chloride concentrations that were statistically different from the other stream locations and most of the spring displayed spatial variability in the chloride concentrations. Both North Quarry Rd. and West Canyon Rd. had average chloride concentrations that were lower than the other stream locations, which might be the result in land use difference upstream of the sample collection location. Even though the range of average chloride concentrations was similar to what was found during past research in Wisconsin, the fact that there was such a large amount of spatial variability in the chloride data for the springs and streams suggests an anthropogenic source; especially since there was a low amount of spatial variability in the parameters controlled by the carbonate system

The average potassium concentrations were between 1.0 mg/L and 2.5 mg/L, for the streams and 0.4 mg/L and 3.4 mg/L for the springs. Holesinger and McPhillips springs and South Quarry Rd. had potassium concentrations that were different spatially from almost all of the other spring or stream locations. However, due to the fact that the average potassium concentrations are within the expected range as given by Hem (1959) the springs and streams do not appear to have an anthropogenic source that is affecting the overall water quality.

As a result of Hicks spring having the lowest concentrations of chloride, nitrate as nitrogen, D.O., having the highest average pH values, and the most stable temperature measurements of the springs over the monitoring period the source of water flowing into and through Hicks spring is thought to be from a deeper source than the other spring locations. As equation (2) indicates, the pH of water will increase when H^+ ions are in contact with $CaCO_3$ to form HCO_3^-. This process occurs for a longer period of time in water that has longer residence times, which means that older, deeper water should have a higher pH than shallow, younger water. The lower D.O. values are thought to be the result of the oxygen being consumed by the decay of organic matter through biological activity. The low chloride and nitrate as nitrogen concentrations seem to indicate that the deeper groundwater has not been affected by human activities. The reason why the stable temperature at Hicks spring is thought to indicate a deep water source, or at the very least a long flow path, is that water that resides for a sufficient period of time in the karst bedrock will equilibrate to the ambient temperature, which is similar to the average annual temperature. The average annual temperature for Stockton, IL was about 8 degrees Celsius for the year 2009, which was slightly lower than the average temperature at Hicks spring.

Through the comparison of Figures IV 1-IV 24 and Tables IV-1 some general comments can be made about the spring and stream data. The first of these comments is that most of the streams, except Mahoney, had decreasing chloride concentrations from spring until late fall, and then increasing chloride concentrations from fall to January, 2010, and the springs generally had stable chloride concentrations. Second nitrate as nitrogen concentrations at each of the streams increased from March to the end of June and then decreased to October, and then increased until January, 2010. The degree of nitrate as nitrogen increase at East Canyon Rd., West Canyon Rd., and Mahoney was greater than that observed at Cemetery, North Quarry Rd., and South Quarry Rd.. Cora, Heller, Hicks, and Sargent springs had constant nitrate as nitrogen concentrations whereas Holesinger and McPhillips springs had decreasing nitrate as nitrogen concentrations. Third alkalinity and specific conductance concentrations at the streams increased from March, 2009 until September, 2009 and then generally decreased until January, 2010. The patterns in the alkalinity and specific conductance concentrations are thought to indicate longer residence times of the contributing surface and groundwater components increases during warmer months. Longer residence times in warmer months are to be expected due to the increase in evapotranspiration, which causes less water to make it to the streams. The fourth observation is that the springs and streams seem as if they react to precipitation events, as indicated on August 27, 2009 when lower chemistry and field measurements were observed. The fifth observation is that while Figures IV-1 through IV-24 show that fluctuations in the spring and stream water parameters were observed at the six stream locations these fluctuations were for the most part not statistically different. This observation was contrary to part of the hypotheses because it was thought that spatial variations would be present in the stream water parameters.

CHAPTER VI

CONCLUSIONS

Conclusions

While there were statistical differences in the spring and stream water quality parameters, the overall water type was the same, as indicated by Figure V-1. The similarity in the water type indicates that the water flowing through the springs is mostly the same, and that different processes are altering the individual parameters of the system. This alteration in the stream and spring water parameters was especially true among those parameters that can be influence by human activities.

The streams parameters displayed less spatial variability than the spring parameters did over the monitoring period. The greater amount of spatial variability observed for the springs is thought to be a result of the springs being more affected by the bedding planes, conduits, and fractures than the streams. This result was contrary to the hypothesis because spatial and temporal variations were thought to be present among the both the springs and streams. In both the springs and streams, the most spatial variability among water quality parameters was observed among parameters related to an anthropogenic source, namely chloride, nitrate as nitrogen, and sulfate.

With the exception of temperature, dissolved oxygen, and pH, temporal variations were not present over the monitoring period at the stream locations. Hicks spring only had temporal variability present in temperature, specific conductance, dissolved oxygen, fluoride, and silicon. This lack in temporal variability was not predicted by the hypothesis as it was thought that the system would display temporal variability among all the parameters over the monitoring period. The apparent lack of temporal variability might be the result of the karstic system being dominated by “delayed throughflow” from the soil and phreatic zone. This hypothesis would need to be checked by sampling before, during and after a precipitation event at the springs and streams to see exactly how the system reacted to precipitation events. Before this explanation can be confirmed or denied the springs (Figure l-2) would need to be delineated.

The elevated nitrate as nitrogen, sodium, and sulfate concentrations are thought to indicate that people have had influence on the overall water quality of both the streams and the springs. While Hicks spring did not have elevated nitrate as nitrogen concentrations, the sodium concentrations were above 2 mg/L which Hem (1959) stated as being the upper limit for limestone systems. However, these sodium concentrations could be the result of deeper water, which would have higher sodium concentrations. Based on the elevated nitrate as nitrogen and sodium concentrations it is thought that possible sources of contamination include: fertilizers, manure, sewage, road salt, and pesticides. The chloride concentrations do display some spatial variability, which indicates that while even though the chloride concentrations of the springs and streams are not elevated, the springs and streams have been influenced by human activities.

All of the springs, except Hicks spring, seem to have shallow water sources since they display a seasonal temperature pattern, have similar pH values, and have higher chloride and nitrate as nitrogen and concentrations. Since Hicks spring had the lowest chloride and nitrate as nitrogen concentrations, the most stable temperatures, and significantly higher pH values than the other springs, it is thought that the source water of Hicks spring is from deep water. Higher pH values indicate that the water has had more contact with the carbonate bedrock because more of the H^+ ions have been consumed in the formation of bicarbonate. The more stable temperatures at Hicks spring indicates that the water has had sufficient time to equilibrate to the bedrock; which indicates a sufficiently long flow path and a deeper water source.

Even though there is an apparent lack of temporal variability in the karstic system, this does not mean that the system does not react in a karstic manner. As observed during a precipitation event on August 27, 2009 both the streams and springs can display signatures that are different from those signatures displayed non-precipitation events. The apparent lack of temporal variability could be the result of the karstic system reacting in a delayed flow manner (Williams, 1983). The karstic system already shows signs of being influenced by anthropgenic sources, and the addition of a large single source, in the mega-dairy has the potential to further accent this signal. Additionally if the mega-dairy saturates the soil zone, and hence the soil water zone with by products from its operations, then the affects of this could possibly be felt the most during precipitation events. The effects of the mega-dairy could be most strongly felt during precipitation events because the karstic system has demonstrated that it can significantly react to precipitation events, as seen on August 27, 2009, and if the soil water is quickly transported to the streams and springs during precipitation events then the anthropogenic signature already present would be modified.

Future work in this area would need to include the installation of data loggers for an extended period of time so that the true nature of this karst system can be understood. Automatic samplers should also be installed immediately before a precipitation event so an understanding of how the water quality characteristics in this karst system change during a precipitation event can be understood. A dye or salt trace should also be completed for springs in an attempt to delineate the individual springs so that the source of the water contributing to the flow of the spring can be determined.

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APPENDIX A

WATER CHEMISTRY DATA

Table A-1 a: Field and laboratory measurements for East Canyon Rd.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	7.39	11.7	700	8.8	39.50	44	4.5	329.03	219	---	8.90	---
10/21/2008	7.3	8.0	664	10.08	31.50	120	5.98	337.77	250	---	11.70	0.20
2/5/2009	7.16	0.6	699	15.45	7.15	---	11.1	327.43	231	---	17.11	0.14
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	7.25	5.1	871	10.22	20.47	164	7.57	290.80	157	---	17.56	0.18
4/16/2009	7.53	8.6	599	16.34	10.51	53	12.76	309.58	195	---	16.14	0.18
5/18/2009	7.35	13.0	603	10.89	17.29	8	8.01	302.59	124	---	17.17	0.27
6/12/2009	7.65	17.9	682	9.01	35.41	32	5.4	304.52	215	---	14.21	0.14
6/29/2009	7.62	15.8	675	8.58	36.85	50	5.05	323.80	220	TNTC	14.66	0.20
7/16/2009	7.34	18.2	671	5.37	38.67	72	2.81	302.02	221	240	14.49	0.19
8/4/2009	7.58	16.6	636	6.03	19.82	46	3.17	318.53	234	582	15.10	0.24
8/27/2009	6.76	15.0	545	5.7	767.67	50	5.7	224.05	170	---	8.73	0.30
9/17/2009	7.86	13.2	687	8.03	31.13	106	6.01	339.23	260	193	14.04	0.33
10/8/2009	7.46	10.3	656	11.19	4.99	32	7.1	336.59	237	10	14.30	0.31
11/23/2009	7.21	9.0	655	9.5	0.64	92	3.93	307.08	222	90	12.95	0.29
12/16/2009	7.08	0.5	685	14.86	5.31	17	10.32	314.37	241	19	13.24	0.33
1/19/2010	7.07	3.2	636	17.42	4.73	56	9.72	293.13	221	148	15.02	0.28

Note: TNTC indicates Too Numerous To Count, in regards to the total coliform samples

Table A-2 b: Field and laboratory measurements for East Canyon Rd.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	10.94	7.63	267.18	---	71.78	0.028	36.44	0.081	15.80	5.46	1.35	6.90
10/21/2008	15.13	9.16	305.00	---	73.42	0.141	37.57	0.96	15.52	5.33	1.11	0.63
2/5/2009	23.47	12.69	281.82	---	70.81	0.177	36.64	0.13	15.69	4.77	0.85	-1.71
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	43.44	9.75	191.54	---	63.65	0.026	32.08	0.044	8.09	4.26	2.14	2.40
4/16/2009	26.56	11.03	237.90	---	68.09	0.022	33.95	0.034	8.53	3.77	0.80	0.20
5/18/2009	23.50	12.03	151.28	---	66.89	0.034	32.98	0.036	8.85	4.19	0.55	13.99
6/12/2009	21.81	12.81	262.30	---	67.2	0.034	33.26	0.047	9.37	4.73	0.37	-3.76
6/29/2009	22.33	12.85	268.40	---	71.35	0.231	35.43	0.053	8.72	5.19	0.61	-2.06
7/16/2009	22.63	11.60	269.62	---	66.48	0.125	33.09	0.060	8.66	4.74	0.92	-4.86
8/4/2009	22.63	10.66	285.48	---	70.54	0.035	34.64	0.031	10.96	5.37	0.53	-3.60
8/27/2009	15.06	5.53	207.40	---	49.66	0.144	24.34	0.040	5.84	5.04	3.06	-2.97
9/17/2009	21.17	10.21	317.00	---	70	0.056	40.00	0.064	6.00	6.00	2.14	-5.42
10/8/2009	21.97	9.15	289.14	---	74.15	0.039	36.84	0.062	9.66	6.05	0.99	-0.88
11/23/2009	20.16	9.54	270.84	---	67.47	0.068	33.72	0.042	11.26	5.11	1.07	-1.70
12/16/2009	19.55	9.49	294.02	---	68.89	0.081	34.63	0.016	8.48	5.52	0.62	-4.81
1/19/2010	20.05	9.85	269.62	---	64.3	0.050	32.25	0.017	9.36	4.69	0.33	-5.04

Table A-2 a: Field and laboratory measurements for West Canyon Rd.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	7.66	14.5	612	8.49	861.00	86	4.46	311.78	198	---	10.19	---
10/21/2008	7.47	10.6	667	8.79	28.00	134	5.29	344.63	229	---	12.61	0.23
2/5/2009	7.3	0.2	969	14.54	14.56	---	8.67	314.66	219	---	8.57	0.15
2/18/2009	7.19	3.4	594	12.08	---	136	8.05	284.13	178	---	10.12	0.06
3/11/2009	6.59	2.1	526	11.5	139.67	82	10.76	170.31	105	---	5.81	7.92
4/16/2009	7.45	10.7	526	11.19	38.40	26	6.58	276.78	179	---	9.22	0.20
5/18/2009	7.44	11.3	598	9.98	9.68	20	6.1	307.62	201	---	8.29	0.32
6/12/2009	7.67	15.0	675	10.46	20.91	76	6.72	323.49	235	---	7.90	0.14
6/29/2009	7.64	16.2	681	8.26	43.71	78	5.28	329.79	236	TNTC	8.82	0.22
7/16/2009	7.41	18.5	657	7.98	848.00	60	5.26	295.77	220	TNTC	8.11	0.24
8/4/2009	---	---	---	---	---	---	---	---	---	---	---	---
8/27/2009	---	---	---	---	---	---	---	---	---	---	---	---
9/17/2009	---	---	---	---	---	---	---	---	---	---	---	---
10/8/2009	---	---	---	---	---	---	---	---	---	---	---	---
11/23/2009	---	---	---	---	---	---	---	---	---	---	---	---
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Note: TNTC indicates Too Numerous To Count, in regards to the total coliform samples

Table A-2 b: Field and laboratory measurements for West Canyon Rd.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	18.53	9.63	241.56	---	68.61	0.016	34.17	0.041	15.44	4.97	1.08	5.71
10/21/2008	18.33	10.73	279.38	---	77.72	0.029	36.63	0.028	14.57	4.41	0.88	3.08
2/5/2009	23.69	11.97	267.18	---	68.43	0.026	34.98	0.107	13.80	4.68	0.70	-0.15
2/18/2009	19.07	10.55	217.16	---	62.74	0.015	31.01	0.095	9.42	3.92	1.20	2.93
3/11/2009	10.01	3.64	128.10	---	38.31	0.053	18.16	0.122	4.50	2.23	7.06	2.43
4/16/2009	16.22	8.19	218.38	---	62.17	0.010	29.57	0.031	7.83	3.45	0.83	2.98
5/18/2009	19.47	10.82	245.22	---	68.56	0.014	33.19	0.034	7.05	4.13	0.48	1.13
6/12/2009	16.57	10.73	286.70	---	72.43	0.026	34.7	0.050	7.21	4.54	0.42	-1.98
6/29/2009	19.69	11.76	287.92	---	73.98	0.015	35.29	0.006	7.24	5.02	0.84	-2.33
7/16/2009	17.91	10.13	268.40	---	66.2	0.022	31.74	0.096	6.50	4.74	1.14	-3.63
8/4/2009	---	---	---	---	---	---	---	---	---	---	---	---
8/27/2009	---	---	---	---	---	---	---	---	---	---	---	---
9/17/2009	---	---	---	---	---	---	---	---	---	---	---	---
10/8/2009	---	---	---	---	---	---	---	---	---	---	---	---
11/23/2009	---	---	---	---	---	---	---	---	---	---	---	---
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Table A-3 a: Field and laboratory measurements for Mahoney.

Date	pH	Temperature (°C)	Specific conductance (mS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO$_2$ (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as CaCO3	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	7.65	15.7	579	7.95	10.32	86	3.21	299.88	198	---	20.56	0.23
10/21/2008	7.28	6.5	602	9.49	708.00	105	6.19	337.1914	244	---	19.36	0.30
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	6.73	3.2	593	10.45	36.99	150	7.4	195.22	108	---	8.24	0.23
4/16/2009	7.12	8.9	554	14.51	0.69	80	10.48	281.16	167	---	13.54	0.33
5/18/2009	6.94	9.4	552	11.93	3.73		8.39	280.69	157	---	13.39	0.33
6/12/2009	6.96	13.1	647	11.09	2.49	12	7.02	301.71	205	---	11.48	0.17
6/29/2009	7.49	13.6	667	9.67	9.60	50	6.5	311.94	197	385	14.40	0.23
7/16/2009	7.23	14.9	644	8.57	8.25	70	5.84	308.70	213	124	14.50	0.22
8/4/2009	6.68	16.4	655	7.73	2.96	94	4.22	304.45	207	205	12.37	0.26
8/27/2009	6.21	16.1	221	5.37	845.25	60	2.92	98.11	80	---	2.70	0.36
9/17/2009	7.12	14.8	685	7.41	4.07	78	4.83	320.40	213	342	13.51	0.35
10/8/2009	6.98	12.5	633	8.09	6.02	98	3.87	314.67	212	85	12.82	0.35
11/23/2009	6.74	9.6	606	8.7	0.53	84	4.6	306.26	204	20	13.88	0.32
12/16/2009	7.43	6.1	598	5.91	0.67	110	2.13	294.26	190	23	14.00	0.34
1/19/2010	7.13	5.6	594	13.82	0	50	7.55	275.02	199	8	14.87	0.36

Table A-3 b: Field and laboratory measurements for Mahoney.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	24.43	4.43	241.56	---	64.7	0.020	33.65	0.014	12.72	4.39	---	2.41
10/21/2008	22.88	3.66	297.68	---	73.32	0.035	37.49	0.058	12.85	3.91	2.68	0.86
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	19.74	7.40	131.76	---	41.8	0.383	22.1	0.013	2.755	4.72	1.83	3.40
4/16/2009	35.49	8.00	203.74	---	60.41	0.032	31.7	0.0033	6.791	3.66	0.29	1.25
5/18/2009	34.35	9.20	191.54	---	60.67	0.15	31.43	0.0025	7.177	4.00	0.29	2.98
6/12/2009	29.89	8.60	250.10	---	65.43	0.034	33.65	0.0035	6.066	4.33	0.52	-1.98
6/29/2009	36.45	9.82	240.34	---	67.47	0.012	34.9	0.0039	5.983	4.53	0.63	-1.26
7/16/2009	33.56	9.26	259.86	---	66.83	0.054	34.5	0.0063	7.978	4.82	0.48	-3.24
8/4/2009	38.64	8.14	252.54	---	66.02	0.021	33.96	0.0069	5.848	4.79	0.45	-3.34
8/27/2009	7.81	2.89	97.60	---	20.92	0.78	11.16	0.006	3.631	---	3.69	-3.70
9/17/2009	39.42	8.01	260.00	---	69.23	0.025	35.89	0.0066	10.610	5.13	0.54	-0.75
10/8/2009	36.65	6.17	258.64	---	68.2	0.023	35.12	0.011	6.246	5.00	0.58	-1.28
11/23/2009	33.67	6.60	248.88	---	66.15	0.037	34.32	0.010	10.67	4.95	0.98	0.47
12/16/2009	34.56	6.79	231.80	---	63.32	0.018	33.12	0	5.466	4.43	0.44	-0.92
1/19/2010	34.15	7.06	242.78	---	58.94	0.037	31.1	0	5.663	4.08	0.27	-6.12

Table A-4 a: Field and laboratory measurements for Cemetery.

Date	pH	Temperature (°C)	Specific conductance (mS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as CaCO3	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	7.61	13.7	662	9.24	25.62	148	4.34	336.24	207	---	10.06	---
10/21/2008	7.39	8.9	662	11.58	11.46	90	7.34	348.42	263	---	17.26	0.21
2/5/2009	7.37	0.4	1062	15.9	2.10	116	9.66	352.44	268	---	17.64	0.16
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	7.14	3.4	723	11.56	24.37	126	8.01	240.96	148	---	13.26	0.21
4/16/2009	7.81	10.1	560	15.79	2.59	90	10.11	303.32	183	---	16.43	0.20
5/18/2009	8.05	11.5	559	14.93	2.96	18	11.27	299.64	175	---	15.90	0.29
6/12/2009	7.62	15.7	675	9.39	7.15	30	5.55	313.87	220	---	14.79	0.13
6/29/2009	7.59	16	691	8.71	10.18	114	5.27	324.85	232	TNTC	15.96	0.40
7/16/2009	7.42	20.3	623	6.53	23.72	60	4.23	296.99	218	73	13.56	0.22
8/4/2009	7.29	14.2	706	7.98	6.84	60	4.86	323.32	241	85	15.16	0.25
8/27/2009	6.68	16.1	342	6.3	862.33	54	3.59	151.74	90	---	4.85	0.32
9/17/2009	7.59	14.2	716	11.03	6.65	74	8.39	337.51	217	---	15.26	0.34
10/8/2009	7.46	10.3	656	11.19	4.99	32	7.01	324.54	236	53	13.21	0.33
11/23/2009	7.34	8	616		6.37	52	-5.57	331.75	231	167	13.54	0.31
12/16/2009	7.23	0.6	711	15.3	5.80	118	10.65	330.57	234	14	14.01	0.33
1/19/2010	7.35	1.6	659	18.5	4.83	82	12.21	295.93	229	16	14.82	0.31

Note: TNTC indicates Too Numerous To Count, in regards to the total coliform samples

Table A-4 b: Field and laboratory measurements for Cemetery.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Manganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potassium (mg/L)	Charge Balance
9/9/2008	7.68	4.19	252.54	---	71.7	0.018	38.24	0.21	14.83	4.22	1.56	12.33
10/21/2008	15.79	6.65	320.86	---	73.98	0.090	39.82	0.0507	17.40	3.46	1.31	0.33
2/5/2009	22.10	8.95	326.96	---	75.16	0.013	40.08	0.007	11.20	4.33	0.91	-3.69
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	14.56	9.02	180.56	---	51.34	0.112	27.43	0.013	4.29	4.14	2.06	1.22
4/16/2009	23.95	9.05	223.26	---	64.1	0.030	34.85	0.005	4.92	2.79	0.32	1.69
5/18/2009	23.29	8.99	213.50	---	64.04	0.017	33.99	0.006	5.35	1.91	0.17	3.09
6/12/2009	23.78	9.45	268.40	---	67.88	0.018	35.12	0.025	4.74	3.87	0.05	-3.51
6/29/2009	24.45	8.59	283.04	---	69.79	0.024	36.63	0.014	6.84	4.13	0.53	-3.13
7/16/2009	21.44	6.81	265.96	---	63.92	0.067	33.42	0.012	8.36	4.59	1.18	-2.35
8/4/2009	23.28	8.16	294.02	---	68.9	0.030	36.8	0.014	6.06	4.44	0.22	-4.58
8/27/2009	8.11	14.55	109.80	---	33.16	0.099	16.77	0.027	3.71	5.39	3.86	-3.74
9/17/2009	23.41	8.09	265.00	---	72.44	0.015	38.10	0.014	9.29	4.85	0.43	2.56
10/8/2009	22.10	5.97	287.92	---	70.36	0.022	36.21	0.016	6.37	4.81	0.99	-1.70
11/23/2009	22.04	7.36	281.82	---	71.6	0.019	37.21	0.015	11.15	4.88	1.00	0.93
12/16/2009	22.21	7.82	285.48	---	71.16	0.004	37.19	0	6.07	4.77	0.48	-1.79
1/19/2010	22.31	8.04	279.38	---	63.46	0.030	33.44	0	5.72	4.15	0.26	-6.66

Table A-5 a: Field and laboratory measurements for North Quarry Rd.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	7.72	14.2	624	9.39	4.29	82	4.59	322.42	205	---	11.97	---
10/21/2008	7.35	7.2	643	11.51	4.01	118	7.11	337.20	232	---	10.38	---
2/5/2009	7.35	0.4	988	14.51	2.89	162	9.92	329.70	226	---	10.99	0.13
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	7.34	3.8	570	11.09	7.30	124	5.09	282.23	196	---	10.89	0.15
4/16/2009	7.67	12	552	12.25	1.79	200	8.58	309.82	208	---	10.12	0.20
5/18/2009	7.34	10.1	611	12.9	3.73	64	9.48	320.63	206	---	10.76	0.22
6/12/2009	7.46	13.4	660	10.21	5.34	70	6.7	323.81	245	---	7.64	0.10
6/29/2009	7.53	13.2	676	8.26	11.17	62	5.56	325.05	244	310	10.59	0.17
7/16/2009	7.42	15.4	642	7.93	14.65	66	5.16	320.99	248	5	10.27	0.15
8/4/2009	7.46	14	688	7.84	11.84	78	4.89	332.27	244	TNTC	10.29	0.20
8/27/2009	6.98	15.2	451	6.75	880.00	72	3.87	209.18	165	---	7.26	0.27
9/17/2009	7.4	13.6	706	8.41	6.64	110	6.71	337.50	238	242	9.04	0.26
10/8/2009	7.21	10.8	667	9.62	2.85	108	5.45	342.10	259	216	9.28	0.29
11/23/2009	6.94	9.2	674	11.98	2.18	104	7.61	336.49	263	212	9.00	0.26
12/16/2009	7.21	1.6	681	9.3	1.19	110	4.27	334.79	260	118	9.16	0.28
1/19/2010	7.25	4.6	677	14.6	2.71	80	6.7	313.25	256	41	9.54	0.27

Note: TNTC indicates Too Numerous To Count, in regards to the total coliform samples

Table A-5 b: Field and laboratory measurements for North Quarry Rd.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	13.80	13.39	250.10	---	67.40	0.014	37.49	0.0068	13.49	4.26	0.66	3.48
10/21/2008	13.46	10.65	283.04	---	70.47	0.099	39.22	0.012	10.16	4.09	2.12	1.79
2/5/2009	15.86	11.67	275.72	---	68.52	0.036	38.58	0.0082	10.44	4.15	0.74	0.56
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	12.16	9.76	239.12	---	58.73	0.025	32.98	0.011	5.02	4.03	1.36	-1.21
4/16/2009	12.46	10.48	253.76	---	63.75	0.024	36.64	0.0071	4.51	3.18	0.38	0.23
5/18/2009	12.80	10.68	251.32	---	67.06	0.019	37.26	0.024	3.98	3.83	0.28	1.75
6/12/2009	8.81	8.30	298.90	---	67.66	0.15	37.67	0.016	5.53	4.39	0.20	-1.77
6/29/2009	13.04	11.39	297.68	---	68.09	0.022	37.71	0.014	5.55	4.4	0.56	-4.13
7/16/2009	13.49	11.12	302.56	---	67.19	0.0095	37.27	0.014	4.09	4.39	0.35	-5.78
8/4/2009	14.43	10.42	297.68	---	72.42	0.022	36.84	0.014	11.33	4.78	0.41	-0.99
8/27/2009	10.18	4.45	201.30	---	43.52	0.26	24.45	0.062	5.38	5.83	5.11	-2.27
9/17/2009	12.03	10.88	290.00	---	70.87	0.016	39.05	0.027	4.65	4.77	0.45	-0.90
10/8/2009	12.41	10.42	315.98	---	71.89	0.025	39.55	0.026	6.49	5.02	0.54	-3.08
11/23/2009	12.62	10.39	320.86	---	70.60	0.020	38.97	0.022	5.69	4.57	1.07	-4.62
12/16/2009	12.78	10.41	317.20	---	70.18	0.0036	38.81	0.0009	4.35	4.63	0.31	-5.02
1/19/2010	12.63	10.49	312.32	---	65.29	0.030	36.54	0.0049	4.59	4.35	0.17	-7.62

Table A-6 a: Field and laboratory measurements for South Quarry Rd.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	7.24	16.9	646	5.86	17.48	160	1.18	333.81	220	---	14.76	0.22
10/21/2008	6.43	12.9	643	8.09	22.1	80	4.06	333.87	238	---	13.96	0.20
2/5/2009	6.8	4.9	914	5.74	9.35	206	0.86	332.66	222	---	15.03	0.10
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	7.18	5.9	629	10.26	12.92	54	7.2	285.62	192	---	15.52	0.18
4/16/2009	7.52	14.4	623	13.36	1.54	58	9.28	320.93	204	---	16.90	0.27
5/18/2009	7.36	11.2	638	12.77	5.26	84	10.2	323.76	215	---	17.53	0.24
6/12/2009	7.22	13	710	8.35	20.26	88	4.6	334.69	240	---	16.39	0.11
6/29/2009	7.12	12.9	741	0.76	19.90	92	5.39	333.74	252	TNTC	16.77	0.16
7/16/2009	7.05	16.4	728	6.24	26.11	72	3.58	352.07	251	10	17.47	0.16
8/4/2009	7.05	18.2	738	6.03	23.15	112	3.85	334.69	254	TNTC	16.54	0.20
8/27/2009	6.9	16.2	432	0.42	784.33	78	-2.43	194.74	150	---	7.47	0.28
9/17/2009	7.23	17.5	732	7.13	13.28	88	5.27	353.14	250	391	15.44	0.28
10/8/2009	6.95	11.9	687	7.19	12.66	98	3.66	352.94	261	450	14.94	0.23
11/23/2009	6.99	9.7	713	10.62	3.54	134	6.39	357.05	270	107	14.15	0.27
12/16/2009	7.19	5.1	724	13.35	1.32	136	9.43	345.70	245	124	13.73	0.29
1/19/2010	7.39	7	643	16.5	11.03	86	9.22	329.40	253	29	14.39	0.27

Note: TNTC indicates Too Numerous To Count, in regards to the total coliform samples

Table A-6 b: Field and laboratory measurements for South Quarry Rd.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	21.03	9.31	268.40	---	70.71	0.19	38.25	0.12	14.58	4.59	1.63	3.29
10/21/2008	21.85	9.50	290.36	---	70.47	0.053	38.41	0.063	15.38	4.91	2.12	0.44
2/5/2009	25.46	9.84	270.84	---	70.07	0.075	38.36	0.045	13.17	4.67	1.68	1.39
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	21.45	8.06	234.24	---	60.45	0.027	32.76	0.027	9.11	4.33	2.70	0.24
4/16/2009	22.60	8.87	248.88	---	67.43	0.021	37.11	0.021	7.91	3.38	1.80	1.81
5/18/2009	22.92	9.43	262.30	---	68.68	0.015	37.04	0.041	8.44	3.85	1.34	-0.15
6/12/2009	21.97	9.41	292.80	---	71.31	0.020	38.1	0.080	10.32	4.49	1.39	-1.82
6/29/2009	23.61	9.48	307.44	---	70.88	0.019	38.13	0.081	10.02	4.64	1.45	-4.30
7/16/2009	25.00	9.35	306.22	---	74.83	0.088	40.19	0.083	11.23	5.27	1.84	-1.47
8/4/2009	25.72	8.88	309.88	---	70.95	0.028	38.32	0.096	13.12	5.06	2.31	-3.37
8/27/2009	15.47	3.19	183.00	---	41.54	0.18	22.14	0.077	3.58	5.76	5.60	-2.66
9/17/2009	23.12	8.48	305.00	---	75.31	0.015	40.16	0.056	11.66	4.96	1.90	-0.07
10/8/2009	21.44	8.27	318.42	---	75.28	0.077	40.13	0.12	10.08	5.66	1.88	-1.83
11/23/2009	22.71	8.38	329.40	---	75.69	0.024	40.88	0.048	14.50	5.14	8.43	-0.48
12/16/2009	22.59	8.21	298.90	---	73.5	0.031	39.45	0.017	8.82	5.02	2.03	-0.55
1/19/2010	21.96	8.41	308.66	---	69.34	0.019	38.01	0.014	8.76	4.5	1.70	-4.31

Table A-7 a: Field and laboratory measurements for Cora spring.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/12/2009	6.77	9.5	819	8.3	0.97	60	4.63	386.28	295	---	16.00	0.08
6/29/2009	6.64	10.5	834	5.83	1.95	96	2.73	390.72	299	96	16.44	0.12
7/16/2009	6.49	10.4	825	7.42	7.70	104	4.94	387.86	309	49	16.09	0.10
8/4/2009	6.45	10.3	808	6.18	0.06	122	2.99	419.98	310	22	16.12	0.17
8/27/2009	6.38	10.8	808	6.2	1.31	128	3.17	391.47	311	---	14.14	0.22
9/17/2009	6.56	11.2	801	6.9	0.95	136	4.73	394.99	270	20	14.96	0.23
10/8/2009	6.44	11.1	724	6.34	0.21	108	2.83	408.08	295	30	14.69	0.23
11/23/2009	6.43	10.9	787	9.34	0.00	126	5.82	412.14	303	17	13.99	0.22
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Table A-7 b: Field and laboratory measurements for Cora spring.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/12/2009	17.55	11.85	359.90	---	80.94	0.012	44.80	0.0025	8.14	6.17	0.40	-4.53
6/29/2009	18.49	12.17	364.78	---	82.16	0.016	45.14	0.0003	9.18	6.24	0.40	-4.58
7/16/2009	18.79	12.10	376.98	---	81.39	0.039	44.91	0.0027	9.71	6.51	0.44	-6.05
8/4/2009	17.24	11.81	378.20	---	87.85	0.025	48.80	0.0019	11.96	6.14	0.40	-1.61
8/27/2009	17.03	10.55	380.00	---	82.03	0.020	45.40	0.0044	11.96	7.18	0.51	-4.28
9/17/2009	18.62	11.06	330.00	---	82.75	0.013	45.82	0.0019	12.07	6.93	0.53	1.40
10/8/2009	19.05	11.11	359.90	---	85.29	0.029	47.46	0.0041	13.41	7.73	0.54	-0.28
11/23/2009	17.71	10.48	369.66	---	86.26	0.019	47.86	0.0007	14.40	7.44	0.98	-0.09
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Table A-8 a: Field and laboratory measurements for Heller spring.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	6.42	9	740	6.84	1.87	90	3.63	390.30	305	---	26.74	0.19
6/12/2009	6.77	9.3	864	8.74	1.11	90	5.15	397.40	310	---	21.27	0.08
6/29/2009	6.74	9.8	871	6.91	0.63	124	3.92	409.44	312	TNTC	24.24	0.14
7/16/2009	6.58	10.4	870	8.25	3.05	124	5.97	397.81	321	47	23.48	0.11
8/4/2009	6.55	10.7	857	6.62	0.06	126	4.29	352.91	305	239	24.39	0.15
8/27/2009	6.49	11	806	5.28	0.64	144	2.19	380.86	290	---	22.65	0.22
9/17/2009	6.61	11.6	568	6.69	0.49	108	4.21	362.08	275	232	26.56	0.24
10/8/2009	6.54	11.2	820	7.76	0.23	148	4.28	425.11	293	205	23.04	0.24
11/23/2009	6.49	10.8	805	7.6	0.90	160	3.89	421.60	300	25	23.98	0.22
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Note: TNTC indicates Too Numerous To Count, in regards to the total coliform samples

Table A-8 b: Field and laboratory measurements for Heller spring.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	9.26	11.39	372.10	---	80.87	0.16	45.82	0.0022	7.32	6.19	1.44	-5.98
6/12/2009	7.62	10.88	378.20	---	82.28	0.029	46.69	0.0059	6.11	6.33	0.27	-5.06
6/29/2009	9.23	12.82	380.64	---	85.06	0.032	47.93	0.0014	4.94	6.5	0.33	-5.57
7/16/2009	9.75	12.77	391.62	---	82.38	0.032	46.73	0.002	5.00	6.57	0.03	-8.06
8/4/2009	8.46	11.44	372.10	---	73.19	3E-04	41.39	0	2.94	5.38	0.05	-11.88
8/27/2009	8.32	10.81	353.80	---	78.72	0.017	44.83	0.0036	5.67	6.61	0.10	-4.83
9/17/2009	9.01	12.32	335.00	---	74.82	0.011	42.63	0.0029	6.52	6.02	0.42	-6.15
10/8/2009	9.76	11.69	357.46	---	87.96	0.022	49.98	0.0027	9.35	7.89	0.17	0.40
11/23/2009	9.17	11.66	366.00	---	87.13	0.054	49.63	0.0039	11.38	7.47	0.91	-0.41
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Table A-9 a: Field and laboratory measurements for Hicks spring.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	6.85	10.2	614	2.86	2.03	200	1.06	329.85	214	---	6.86	0.33
6/12/2009	6.87	10.4	691	0.82	1.49	76	-2.4	334.78	280	---	6.67	0.21
6/29/2009	6.7	10.5	691	1.09	0.96	120	-1.09	332.12	283	40	7.01	0.26
7/16/2009	6.86	10.4	693	1.32	5.68	110	-0.66	320.60	283	1	6.87	0.27
8/4/2009	6.76	10.7	686	0.58	0.57	104	-1.27	305.99	287	26	6.46	0.33
8/27/2009	6.64	10.4	693	0.4	0.72	110	-2.11	316.46	270	---	6.13	0.37
9/17/2009	6.81	10.5	691	0	2.30	116	-1.9	336.80	254	0	6.18	0.38
10/8/2009	6.78	10.3	523	2.75	0.00	152	-0.11	330.51	284	6	6.28	0.38
11/23/2009	6.57	10.1	646	5.77	0.00	174	2.17	337.53	279	0	6.18	0.37
12/16/2009	6.86	9.6	646	9.2	2.38	122	5.66	334.10	254	0	6.53	0.43
1/19/2010	6.7	9.9	647	4.5	4.01	118	-3.3	327.42	275	0	6.25	0.37

Table A-9 b: Field and laboratory measurements for Hicks spring.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	29.36	0.42	261.08	---	67.64	0.027	39.15	0.012	8.84	5.15	0.21	7.03
6/12/2009	29.61	0.30	341.60	---	68.76	0.039	39.67	0.012	5.70	5.06	0.45	-4.83
6/29/2009	29.47	0.31	345.26	---	68.17	0.032	39.38	0.012	7.94	5.1	0.49	-5.05
7/16/2009	30.17	0.28	345.26	---	65.65	0.032	38.11	0.014	6.39	4.96	0.22	-7.32
8/4/2009	31.10	0.37	350.14	---	62.2	0.017	36.65	0.0023	7.24	4.6	0.21	-9.99
8/27/2009	30.80	0.30	329.40	---	64.65	0.019	37.71	0.005	7.03	4.75	0.26	-5.65
9/17/2009	29.63	0.33	310.00	---	69.14	0.032	39.93	0.015	10.33	5.38	0.26	1.15
10/8/2009	30.41	0.35	346.48	---	67.74	0.028	39.25	0.014	6.77	5.19	0.35	-5.88
11/23/2009	29.16	0.39	340.38	---	69.02	0.086	40.18	0.014	12.12	5.64	0.93	-2.18
12/16/2009	28.89	0.54	309.88	---	67.48	0.003	40.28	0	6.73	5.48	0.33	-0.40
1/19/2010	28.21	0.40	335.50	---	66.78	0.048	39.08	0.011	14.71	5.57	0.18	-2.18

Table A-10 a: Field and laboratory measurements for Holesinger spring.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/12/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/29/2009	6.61	10.9	703	6.42	2.73	122	3.53	353.49	251	172	17.14	0.19
7/16/2009	6.5	12.2	801	6.38	5.49	116	3.36	344.21	241	73	16.01	0.17
8/4/2009	6.41	13.4	823	4.83	0.86	98	2.16	357.50	262	160	17.36	0.21
8/27/2009	6.36	14	770	4.72	3.91	140	1.97	360.19	287	---	13.85	0.28
9/17/2009	6.58	13.7	810	7.28	10.04	118	5.27	373.39	246	---	17.25	0.30
10/8/2009	6.43	13.2	754	8.38	2.10	6	5.03	355.15	245	90	15.87	0.30
11/23/2009	6.44	10.7	743	8.54	0.00	108	4.72	349.66	250	10	15.39	0.28
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Table A-10 b: Field and laboratory measurements for Holesinger spring.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/12/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/29/2009	28.13	18.20	306.22	---	78.04	0.022	38.59	0.0003	9.22	5.31	2.97	-5.92
7/16/2009	26.41	16.94	294.02	---	75.64	0.049	37.79	0.0026	8.47	5.56	3.34	-4.90
8/4/2009	25.92	15.16	319.64	---	78.46	0.010	39.31	0.0013	11.19	5.89	3.61	-4.81
8/27/2009	22.61	12.05	350.00	---	79.04	0.029	39.61	0.0018	10.64	5.9	3.17	-5.96
9/17/2009	26.88	15.70	300.00	---	82.42	0.015	40.77	0.0098	12.91	6.03	3.80	-0.31
10/8/2009	27.65	14.39	298.90	---	78.16	0.0098	38.92	0.0042	8.80	5.46	3.09	-3.04
11/23/2009	25.99	14.15	305.00	---	76.67	0.017	38.49	0	8.66	5.19	2.28	-4.30
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Table A-11 a: Field and laboratory measurements for McPhillips spring.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/12/2009	6.76	9.2	1044	7.62	1.42	66	4.01	468.52	325	---	19.69	0.08
6/29/2009	6.8	9.4	1069	6.55	1.33	144	3.13	479.59	331	220	23.22	0.11
7/16/2009	6.59	10.2	1015	6.57	3.40	52	3.99	507.53	325	58	24.28	0.09
8/4/2009	6.6	10	1056	6.12	0.39	---	3	463.77	319	20	24.98	0.15
8/27/2009	6.41	11	969	5.35	1.07	144	2.35	461.47	328	---	20.54	0.21
9/17/2009	6.56	10.5	934	7.79	3.73	148	5.28	466.09	307	147	21.48	0.25
10/8/2009	6.39	10.3	944	6.91	0.35	148	3.44	468.76	320	26	24.34	0.22
11/23/2009	6.39	10	964	6.88	1.89	180	2.39	462.26	330	10	19.67	0.24
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Table A-11 b: Field and laboratory measurements for McPhillips spring.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/12/2009	18.17	27.28	396.50	---	97.23	0.048	54.91	0.0092	5.66	4.96	1.22	-5.67
6/29/2009	22.32	30.06	403.82	---	98.96	0.014	56.55	0.0098	9.96	5.17	1.31	-5.99
7/16/2009	22.98	30.10	396.50	---	104.9	0.035	59.74	0.0035	12.08	5.56	1.41	-2.40
8/4/2009	24.08	27.26	389.18	---	95.59	0.025	54.75	0.0034	8.45	5.05	1.43	-6.10
8/27/2009	22.30	22.66	400.00	---	95.69	0.014	54.13	0.0048	10.98	5.45	1.27	-4.54
9/17/2009	21.64	26.90	375.00	---	96.27	0.022	54.90	0.0042	12.90	5.44	1.36	-2.77
10/8/2009	22.49	25.74	390.40	---	97.44	0.015	54.84	0.0032	9.60	5.3	1.52	-4.72
11/23/2009	20.41	24.75	402.60	---	95.79	0.013	54.26	0	9.10	5.39	1.39	-5.51
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Table A-12 a: Field and laboratory measurements for Sargent spring.

Date	pH	Temperature (°C)	Specific conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$	Total coliform CFU/100 mL	Chloride (mg/L)	Fluoride (mg/L)
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/12/2009	6.78	10	698	7.55	2.97	46	3.93	320.41	220	---	18.16	0.14
6/29/2009	6.51	11.3	700	5.38	2.40	100	2.76	330.55	233	81	17.79	0.18
7/16/2009	6.68	11.6	722	6.39	8.03	82	3.76	333.41	240	56	17.03	0.19
8/4/2009	6.49	11.9	724	4.83	1.40	108	1.85	319.85	234	145	17.52	0.31
8/27/2009	6.41	12.6	452	4.15	843.00	62	1.21	168.09	143	---	5.44	0.35
9/17/2009	6.57	12.9	661	5.43	2.32	110	2.96	276.05	205	---	15.69	0.30
10/8/2009	6.48	11.9	668	4.76	3.73	82	1.41	333.32	229	69	15.25	0.30
11/23/2009	6.52	9.7	640	1.95	0.00	130	-1.84	301.68	217	40	17.08	0.28
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

Table A-12 b: Field and laboratory measurements for Sargent spring.

Date	Sulfate (mg/L)	Nitrate as nitrogen (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (ppm)	Sodium (mg/L)	Silicon (mg/L)	Potasium (mg/L)	Charge Balance
9/9/2008	---	---	---	---	---	---	---	---	---	---	---	---
10/21/2008	---	---	---	---	---	---	---	---	---	---	---	---
2/5/2009	---	---	---	---	---	---	---	---	---	---	---	---
2/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
3/11/2009	---	---	---	---	---	---	---	---	---	---	---	---
4/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
5/18/2009	---	---	---	---	---	---	---	---	---	---	---	---
6/12/2009	15.72	14.49	268.40	---	69.33	0.012	35.83	0.0005	5.00	4.98	0.22	-4.42
6/29/2009	14.74	13.14	284.26	---	72.16	0.035	36.58	0.0024	6.00	4.97	0.14	-3.92
7/16/2009	15.23	11.88	292.80	---	72.4	0.029	37.13	0.0059	8.75	5.08	0.07	-3.13
8/4/2009	15.07	12.37	285.48	---	69.93	0.019	35.33	0.0016	7.28	5.05	0.00	-4.94
8/27/2009	7.95	2.92	175.00	---	36.5	0.047	18.72	0.048	3.31	4.65	3.76	-5.73
9/17/2009	15.49	11.85	250.00	---	59.78	0.011	30.84	0.0029	9.11	4.84	0.42	-5.54
10/8/2009	15.61	11.02	279.38	---	72.71	0.01	36.92	0.0034	5.77	5.36	0.05	-1.58
11/23/2009	14.89	10.17	264.74	---	65.19	0.012	33.79	0	6.03	5.3	0.78	-3.86
12/16/2009	---	---	---	---	---	---	---	---	---	---	---	---
1/19/2010	---	---	---	---	---	---	---	---	---	---	---	---

APPENDIX B

TABLES FROM SPSS ANALYSIS

Stream SPSS Analysis

Table B-1. *p*-values from the independent samples t-test for pH for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.972^{+}	0.012$^{\wedge}$	0.419*	0.988*	0.012*
West Canyon Rd	xxx	0.163$^{\%}$	0.298^{+}	0.619^{+}	0.068^{+}
Mahoney	xxx	xxx	0.004$^{\wedge}$	0.009$^{\wedge}$	0.518$^{\wedge}$
Cemetery	xxx	xxx	xxx	0.381*	0.002*
North Quarry	xxx	xxx	xxx	xxx	0.005*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the "Stream data not past July" stream dataset
$^{\wedge}$ indicates the use of the "Stream data no Feb." stream dataset
* indicates the use of the "Stream data" stream dataset
$^{\%}$ indicates the use of the "Stream data WC_M" stream dataset

Table B-2. *p-values* from the independent samples t-test for temperature for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.994^{+}	0.991$^{\wedge}$	0.960*	0.795*	0.359*
West Canyon Rd	xxx	0.483$^{\%}$	0.973^{+}	0.702^{+}	0.682^{+}
Mahoney	xxx	xxx	0.949$^{\wedge}$	0.738$^{\wedge}$	0.338$^{\wedge}$
Cemetery	xxx	xxx	xxx	0.843*	0.346*
North Quarry Rd	xxx	xxx	xxx	xxx	0.196*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the "Stream data not past July" stream dataset
$^{\wedge}$ indicates the use of the "Stream data no Feb." stream dataset
* indicates the use of the "Stream data" stream dataset
$^{\%}$ indicates the use of the "Stream data WC_M" stream dataset

Table B-3. *p-values* from the independent samples t-test for specific conductance for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.590^{+}	0.320$^{\wedge}$	0.948*	0.747*	0.567*
West Canyon Rd	xxx	0.642$^{\%}$	0.616^{+}	0.922^{+}	0.466^{+}
Mahoney	xxx	xxx	0.205$^{\wedge}$	0.181$^{\wedge}$	0.029$^{\wedge}$
Cemetery	xxx	xxx	xxx	0.860*	0.647*
North Quarry Rd	xxx	xxx	xxx	xxx	0.454*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-4. *p-values* from the independent samples t-test for dissolved oxygen for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.772^{+}	0.519$^{\wedge}$	0.393*	0.959*	0.143*
West Canyon Rd	xxx	0.338$^{\%}$	0.313^{+}	0.460^{+}	0.157^{+}
Mahoney	xxx	xxx	0.101$^{\%}$	0.399^{+}	0.501^{+}
Cemetery	xxx	xxx	xxx	0.281$^{\wedge}$	0.027$^{\wedge}$
North Quarry Rd	xxx	xxx	xxx	xxx	0.101*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-5. *p-values* from the independent samples t-test for turbidity for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.141^{+}	0.660$^{\wedge}$	0.956*	0.925*	0.936*
West Canyon Rd	xxx	0.358$^{\%}$	0.118^{+}	0.109^{+}	0.122^{+}
Mahoney	xxx	xxx	0.644$^{\wedge}$	0.624$^{\wedge}$	0.615$^{\wedge}$
Cemetery	xxx	xxx	xxx	0.971*	0.984*
North Quarry Rd	xxx	xxx	xxx	xxx	0.985*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-6. *p-values* from the independent samples t-test for carbon dioxide for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.848^{+}	0.341$^{\wedge}$	0.252*	0.011*	0.010*
West Canyon Rd	xxx	0.947$^{\%}$	0.376^{+}	0.106^{+}	0.183^{+}
Mahoney	xxx	xxx	0.996$^{\wedge}$	0.132$^{\wedge}$	0.136$^{\wedge}$
Cemetery	xxx	xxx	xxx	0.119*	0.111*
North Quarry Rd	xxx	xxx	xxx	xxx	0.943*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-7. *p-values* from the independent samples t-test for B.O.D. for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.725^{+}	$0.363^{\wedge}$	0.534*	0.483*	0.057*
West Canyon Rd	xxx	$0.581^{\%}$	0.510^{+}	0.722^{+}	0.281^{+}
Mahoney	xxx	xxx	$0.093^{\wedge}$	$0.706^{\wedge}$	$0.439^{\wedge}$
Cemetery	xxx	xxx	xxx	0.144*	0.014*
North Quarry Rd	xxx	xxx	xxx	xxx	0.111*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-8. *p-values* from the independent samples t-test for hardness concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.358^{+}	$0.062^{\wedge}$	0.832*	0.497*	0.187*
West Canyon Rd	xxx	$0.826^{\%}$	0.454^{+}	0.239^{+}	0.110^{+}
Mahoney	xxx	xxx	$0.164^{\wedge}$	$0.029^{\wedge}$	$0.012^{\wedge}$
Cemetery	xxx	xxx	xxx	0.488*	0.232*
North Quarry Rd	xxx	xxx	xxx	xxx	0.490*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-9. *p-values* from the independent samples t-test for alkalinity for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.954+	0.084^	0.915*	0.136*	0.122*
West Canyon Rd	xxx	0.513%	0.599+	0.190+	0.145+
Mahoney	xxx	xxx	0.174^	0.002^	0.002^
Cemetery	xxx	xxx	xxx	0.161*	0.145*
North Quarry Rd	xxx	xxx	xxx	xxx	0.894*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-10. *p-values* from the independent samples t-test for chloride concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	<0.001^{+}	0.652$^{\wedge}$	0.980*	<0.001*	0.256*
West Canyon Rd	xxx	0.003$^{\%}$	<0.001^{+}	0.047^{+}	<0.001^{+}
Mahoney	xxx	xxx	0.674$^{\wedge}$	0.003$^{\wedge}$	0.159$^{\wedge}$
Cemetery	xxx	xxx	xxx	<0.001*	0.316*
North Quarry Rd	xxx	xxx	xxx	xxx	<0.001*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-11. *p-values* from the independent samples t-test for fluoride concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.336^{+}	$0.085^{\wedge}$	0.232*	0.217*	0.318*
West Canyon Rd	xxx	$0.361^{\%}$	0.344^{+}	0.310^{+}	0.330^{+}
Mahoney	xxx	xxx	$0.635^{\wedge}$	$0.004^{\wedge}$	$0.009^{\wedge}$
Cemetery	xxx	xxx	xxx	0.021*	0.036*
North Quarry Rd	xxx	xxx	xxx	xxx	0.816*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the "Stream data not past July" stream dataset
$^{\wedge}$ indicates the use of the "Stream data no Feb." stream dataset
* indicates the use of the "Stream data" stream dataset
$^{\%}$ indicates the use of the "Stream data WC_M" stream dataset

Table B-12. *p-values* from the independent samples t-test for sulfate concetrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.107^{+}	$0.004^{\wedge}$	0.403*	<0.001*	0.724*
West Canyon Rd	xxx	$0.001^{\%}$	0.428^{+}	0.002^{+}	0.001^{+}
Mahoney	xxx	xxx	$<0.001^{\wedge}$	$<0.001^{\wedge}$	$0.001^{\wedge}$
Cemetery	xxx	xxx	xxx	<0.001*	0.100*
North Quarry Rd	xxx	xxx	xxx	xxx	<0.001*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the "Stream data not past July" stream dataset
$^{\wedge}$ indicates the use of the "Stream data no Feb." stream dataset
* indicates the use of the "Stream data" stream dataset
$^{\%}$ indicates the use of the "Stream data WC_M" stream dataset

Table B-13. *p-values* from the independent samples t-test for nitrate as nitrogen for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.224^{+}	<0.001$^{\wedge}$	0.010*	0.933*	0.180*
West Canyon Rd	xxx	0.140$^{\%}$	0.105^{+}	0.277^{+}	0.582^{+}
Mahoney	xxx	xxx	0.167$^{\wedge}$	<0.001$^{\wedge}$	0.031$^{\wedge}$
Cemetery	xxx	xxx	xxx	0.007*	0.305*
North Quarry Rd	xxx	xxx	xxx	xxx	0.153*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-14. *p-values* from the independent samples t-test for calcite concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.522^{+}	0.082$^{\wedge}$	0.517*	0.564*	0.592*
West Canyon Rd	xxx	0.539$^{\%}$	0.894^{+}	0.946^{+}	0.444^{+}
Mahoney	xxx	xxx	0.329$^{\wedge}$	0.171$^{\wedge}$	0.053$^{\wedge}$
Cemetery	xxx	xxx	xxx	0.841*	0.328*
North Quarry Rd	xxx	xxx	xxx	xxx	0.332*

$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-15. *p-values* from the independent samples t-test for iron concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.034^{+}	0.521$^{\wedge}$	0.026*	0.169*	0.219*
West Canyon Rd	xxx	0.178$^{\%}$	0.146^{+}	0.237^{+}	0.154^{+}
Mahoney	xxx	xxx	0.202$^{\wedge}$	0.284$^{\wedge}$	0.312$^{\wedge}$
Cemetery	xxx	xxx	xxx	0.591*	0.342*
North Quarry Rd	xxx	xxx	xxx	xxx	0.794*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-16. *p-values* from the independent samples t-test for magnesium concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.215^{+}	0.211$^{\wedge}$	0.780*	0.049*	0.035*
West Canyon Rd	xxx	0.781$^{\%}$	0.148^{+}	0.018^{+}	0.013^{+}
Mahoney	xxx	xxx	0.234$^{\wedge}$	0.015$^{\wedge}$	0.011$^{\wedge}$
Cemetery	xxx	xxx	xxx	0.222*	0.154*
North Quarry Rd	xxx	xxx	xxx	xxx	0.713*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-17. *p-values* from the independent samples t-test for manganese concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.323^{+}	$0.129^{\wedge}$	0.182*	0.126*	0.432*
West Canyon Rd	xxx	$0.025^{\%}$	0.477^{+}	0.011^{+}	0.797^{+}
Mahoney	xxx	xxx	$0.196^{\wedge}$	$0.151^{\wedge}$	$<0.001^{\wedge}$
Cemetery	xxx	xxx	xxx	0.452*	0.032*
North Quarry Rd	xxx	xxx	xxx	xxx	<0.001*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the "Stream data not past July" stream dataset
$^{\wedge}$ indicates the use of the "Stream data no Feb." stream dataset
* indicates the use of the "Stream data" stream dataset
$^{\%}$ indicates the use of the "Stream data WC_M" stream dataset

Table B-18. *p-values* from the independent samples t-test for sodium concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.363^{+}	$0.040^{\wedge}$	0.096*	0.003*	0.575*
West Canyon Rd	xxx	$0.597^{\%}$	0.746^{+}	0.201^{+}	0.290^{+}
Mahoney	xxx	xxx	$0.813^{\wedge}$	$0.345^{\wedge}$	$0.009^{\wedge}$
Cemetery	xxx	xxx	xxx	0.296*	0.033*
North Quarry Rd	xxx	xxx	xxx	xxx	0.001*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the "Stream data not past July" stream dataset
$^{\wedge}$ indicates the use of the "Stream data no Feb." stream dataset
* indicates the use of the "Stream data" stream dataset
$^{\%}$ indicates the use of the "Stream data WC_M" stream dataset

Table B-19. *p-values* from the independent samples t-test for silicon concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.196^{+}	$0.011^{\wedge}$	0.004*	0.009*	0.262*
West Canyon Rd	xxx	$0.768^{\%}$	0.254^{+}	0.626^{+}	0.554^{+}
Mahoney	xxx	xxx	$0.246^{\wedge}$	$0.806^{\wedge}$	$0.153^{\wedge}$
Cemetery	xxx	xxx	xxx	0.383*	0.037*
North Quarry Rd	xxx	xxx	xxx	xxx	0.106*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

Table B-20. *p-values* from the independent samples t-test for potassium concentrations for each of the stream locations.

Location	West Canyon Rd	Mahoney	Cemetery	North Quarry Rd	South Quarry Rd
East Canyon Rd	0.477^{+}	$0.700^{\wedge}$	0.669*	0.639*	0.010*
West Canyon Rd	xxx	$0.486^{\%}$	0.433^{+}	0.318^{+}	0.700^{+}
Mahoney	xxx	xxx	$0.963^{\wedge}$	$0.911^{\wedge}$	$0.009^{\wedge}$
Cemetery	xxx	xxx	xxx	0.921*	0.007*
North Quarry Rd	xxx	xxx	xxx	xxx	0.009*

Note: *p*-values less than 0.05 are indicated by gray squares.
$^{+}$ indicates the use of the “Stream data not past July” stream dataset
$^{\wedge}$ indicates the use of the “Stream data no Feb.” stream dataset
* indicates the use of the “Stream data” stream dataset
$^{\%}$ indicates the use of the “Stream data WC_M” stream dataset

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Table IV-21. *p-values* from the independent samples t-test for temporal variability for each of the stream locations.

Location	pH	Temperature (℃)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$
East Canyon Rd	0.083	0.000	0.146	0.033	0.305	0.203	0.175	0.520	0.385
West Canyon Rd	0.253	0.008	0.541	0.144	0.277	0.091	0.253	0.624	0.568
Mahoney	0.985	0.001	0.667	0.972	0.860	0.056	0.611	0.548	0.645
Cemetary	0.219	0.000	0.118	0.038	0.386	0.423	0.080	0.459	0.167
North Quarry Rd	0.046	0.001	0.183	0.035	0.377	0.188	0.941	0.414	0.179
South Quarry Rd	0.135	0.000	0.410	0.120	0.368	0.311	0.944	0.504	0.388

Location	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Nitrate as Nitrogen (mg/L)
East Canyon Rd	0.539	0.663	0.464	0.606
West Canyon Rd	0.914	0.428	0.874	0.640
Mahoney	0.687	0.492	0.861	0.239
Cemetary	0.433	0.922	0.938	0.396
North Quarry Rd	0.851	0.343	0.338	0.671
South Quarry Rd	0.491	0.838	0.756	0.291

Location	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Maganese (mg/L)	Sodium (mg/L)	Silicon (mg/L)	Potassium (mg/L)
East Canyon Rd	0.489	0.897	0.568	0.352	0.225	0.627	0.741
West Canyon Rd	0.609	0.151	0.645	0.147	0.439	0.296	0.424
Mahoney	0.809	0.755	0.786	0.323	0.931	0.816	0.764
Cemetary	0.442	0.730	0.472	0.409	0.393	0.400	0.880
North Quarry Rd	0.476	0.481	0.361	0.252	0.913	0.948	0.962
South Quarry Rd	0.532	0.545	0.474	0.144	0.413	0.485	0.419

Note: *p-values* less than 0.05 are indicated by gray squares.

Spring SPSS Analysis

Table B-22. *p-values* from the independent samples t-test for pH for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	0.003[#]	0.002[-]	0.004[-]	0.016[-]	<0.001[@]
Heller Spring	xxx	0.220[-]	0.479[-]	0.628[-]	0.067[@]
Cora Spring	xxx	xxx	0.585[-]	0.570[-]	0.862[@]
Sargent Spring	xxx	xxx	xxx	0.917[-]	0.337[@]
McPhillips Spring	xxx	xxx	xxx	xxx	0.396

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the “Spring data May” spring dataset
[-] indicates the use of the “Spring data june end” spring dataset
[@] indicates the use of the “Springs Holesinger” spring dataset

Table B-23. *p-values* from the independent samples t-test for temperature for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	0.914[#]	0.412[-]	0.019[-]	0.136[-]	0.001[@]
Heller Spring	xxx	0.970[-]	0.086[-]	0.139[-]	0.011[@]
Cora Spring	xxx	xxx	0.063[-]	0.090[-]	0.010[@]
Sargent Spring	xxx	xxx	xxx	0.007[-]	0.193[@]
McPhillips Spring	xxx	xxx	xxx	xxx	0.001[@]

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the “Spring data May” spring dataset
[-] indicates the use of the “Spring data june end” spring dataset
[@] indicates the use of the “Springs Holesinger” spring dataset

Table B-24. *p-values* from the independent samples t-test for specific conductance for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	0.002[#]	<0.001[-]	0.873[-]	<0.001[-]	0.002[@]
Heller Spring	xxx	0.858[-]	0.007[-]	<0.001[-]	0.535[@]
Cora Spring	xxx	xxx	0.001[-]	<0.001[-]	0.238[@]
Sargent Spring	xxx	xxx	xxx[-]	<0.001[-]	0.010[@]
McPhillips Spring	xxx	xxx	xxx	xxx	<0.001[@]

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the “Spring data May” spring dataset
[-] indicates the use of the “Spring data june end” spring dataset
[@] indicates the use of the “Springs Holesinger” spring dataset

Table B-25. *p-values* from the independent samples t-test for dissolved oxygen for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001[#]	<0.001[-]	0.002[-]	<0.001[-]	<0.001[@]
Heller Spring	xxx	0.776[-]	0.007[-]	0.303[-]	0.604[@]
Cora Spring	xxx	xxx	0.015[-]	0.518[-]	0.753[@]
Sargent Spring	xxx	xxx	xxx	0.021[-]	0.029[@]
McPhillips Spring	xxx	xxx	xxx	xxx	0.934[@]

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the “Spring data May” spring dataset
[-] indicates the use of the “Spring data june end” spring dataset
[@] indicates the use of the “Springs Holesinger” spring dataset

Table B-26. *p-values* from the independent samples t-test for turbidity for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	$0.435^{\#}$	0.875^{-}	0.344^{-}	0.777^{-}	$0.390^{@}$
Heller Spring	xxx	0.443^{-}	0.342^{-}	0.169^{-}	$0.178^{@}$
Cora Spring	xxx	xxx	0.345^{-}	0.960^{-}	$0.531^{@}$
Sargent Spring	xxx	xxx	xxx	0.329^{-}	$0.355^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	$0.460^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the “Spring data May” spring dataset
$^{-}$ indicates the use of the “Spring data june end” spring dataset
$^{@}$ indicates the use of the “Springs Holesinger” spring dataset

Table B-27. *p-values* from the independent samples t-test for carbon dioxide for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	$0.732^{\#}$	0.466^{-}	0.054^{-}	0.765^{-}	$0.213^{@}$
Heller Spring	xxx	0.147^{-}	0.009^{-}	0.911^{-}	$0.097^{@}$
Cora Spring	xxx	xxx	0.145^{-}	0.384^{-}	$0.378^{@}$
Sargent Spring	xxx	xxx	xxx	0.070^{-}	$0.799^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	$0.161^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the “Spring data May” spring dataset
$^{-}$ indicates the use of the “Spring data june end” spring dataset
$^{@}$ indicates the use of the “Springs Holesinger” spring dataset

Table B-28. *p-values* from the independent samples t-test for B.O.D. for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001$^{\#}$	<0.001^{-}	0.004^{-}	<0.001^{-}	<0.001$^{@}$
Heller Spring	xxx	0.657^{-}	0.011^{-}	0.148^{-}	0.566$^{@}$
Cora Spring	xxx	xxx	0.024^{-}	0.343^{-}	0.813$^{@}$
Sargent Spring	xxx	xxx	xxx	0.071^{-}	0.038$^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	0.591$^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the "Spring data May" spring dataset
$^{-}$ indicates the use of the "Spring data june end" spring dataset
$^{@}$ indicates the use of the "Springs Holesinger" spring dataset

Table B-29. *p-values* from the independent samples t-test for hardness concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001$^{\#}$	<0.001^{-}	0.192^{-}	<0.001^{-}	<0.001$^{@}$
Heller Spring	xxx	0.601^{-}	0.001^{-}	<0.001^{-}	0.014$^{@}$
Cora Spring	xxx	xxx	<0.001^{-}	<0.001^{-}	<0.001$^{@}$
Sargent Spring	xxx	xxx	xxx	<0.001^{-}	0.033$^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	<0.001$^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the "Spring data May" spring dataset
$^{-}$ indicates the use of the "Spring data june end" spring dataset
$^{@}$ indicates the use of the "Springs Holesinger" spring dataset

Table B-30. *p-values* from the independent samples t-test for alkalinity for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	0.004$^{\#}$	0.003^{-}	<0.001^{-}	0.000^{-}	0.010$^{@}$
Heller Spring	xxx	0.825^{-}	<0.001^{-}	0.002^{-}	<0.001$^{@}$
Cora Spring	xxx	xxx	<0.001^{-}	0.001^{-}	0.001$^{@}$
Sargent Spring	xxx	xxx	xxx	<0.001^{-}	0.014$^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	<0.001$^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the "Spring data May" spring dataset
$^{-}$ indicates the use of the "Spring data june end" spring dataset
$^{@}$ indicates the use of the "Springs Holesinger" spring dataset

Table B-31. *p-values* from the independent samples t-test for chloride concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	0.000$^{\#}$	0.000^{-}	0.000^{-}	0.000^{-}	0.000$^{@}$
Heller Spring	xxx	0.000^{-}	0.000^{-}	0.189^{-}	0.000$^{@}$
Cora Spring	xxx	xxx	0.901^{-}	0.000^{-}	0.157$^{@}$
Sargent Spring	xxx	xxx	xxx	0.001^{-}	0.568$^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	0.000$^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the "Spring data May" spring dataset
$^{-}$ indicates the use of the "Spring data june end" spring dataset
$^{@}$ indicates the use of the "Springs Holesinger" spring dataset

Table B-32. *p-values* from the independent samples t-test for fluoride concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001[#]	<0.001[-]	0.085[-]	<0.001[-]	0.008[@]
Heller Spring	xxx	0.921[-]	0.035[-]	0.858[-]	0.076[@]
Cora Spring	xxx	xxx	0.030[-]	0.933[-]	0.066[@]
Sargent Spring	xxx	xxx	xxx	0.030[-]	0.415[@]
McPhillips Spring	xxx	xxx	xxx	xxx	0.070[@]

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the "Spring data May" spring dataset
[-] indicates the use of the "Spring data june end" spring dataset
[@] indicates the use of the "Springs Holesinger" spring dataset

Table B-33. *p-values* from the independent samples t-test for sulfate concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001[#]	<0.001[-]	<0.001[-]	<0.001[-]	<0.001[@]
Heller Spring	xxx	<0.001[-]	<0.001[-]	<0.001[-]	<0.001[@]
Cora Spring	xxx	xxx	0.002[-]	<0.001[-]	<0.001[@]
Sargent Spring	xxx	xxx	xxx	<0.001[-]	<0.001[@]
McPhillips Spring	xxx	xxx	xxx	xxx	0.001[@]

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the "Spring data May" spring dataset
[-] indicates the use of the "Spring data june end" spring dataset
[@] indicates the use of the "Springs Holesinger" spring dataset

Table B-34. *p-values* from the independent samples t-test for nitrate as nitrogen concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001[#]	<0.001[-]	<0.001[-]	<0.001[-]	<0.001[@]
Heller Spring	xxx	0.281[-]	0.531[-]	<0.001[-]	0.001[@]
Cora Spring	xxx	xxx	0.752[-]	<0.001[-]	0.002[@]
Sargent Spring	xxx	xxx	xxx	<0.001[-]	0.009[@]
McPhillips Spring	xxx	xxx	xxx	xxx	<0.001[@]

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the “Spring data May” spring dataset
[-] indicates the use of the “Spring data june end” spring dataset
[@] indicates the use of the “Springs Holesinger” spring dataset

Table B-35. *p-values* from the independent samples t-test for calcite concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001[#]	<0.001[-]	0.631[-]	<0.001[-]	<0.001[@]
Heller Spring	xxx	0.573[-]	0.003[-]	<0.001[-]	0.246[@]
Cora Spring	xxx	xxx	0.004[-]	<0.001[-]	0.008[@]
Sargent Spring	xxx	xxx	xxx	<0.001[-]	0.015[@]
McPhillips Spring	xxx	xxx	xxx	xxx	<0.001[@]

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the “Spring data May” spring dataset
[-] indicates the use of the “Spring data june end” spring dataset
[@] indicates the use of the “Springs Holesinger” spring dataset

Table B-36. *p-values* from the independent samples t-test for iron concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	0.759[#]	0.110[-]	0.156[-]	0.175[-]	0.216[@]
Heller Spring	xxx	0.623[-]	0.717[-]	0.809[-]	0.767[@]
Cora Spring	xxx	xxx	0.931[-]	0.783[-]	0.846[@]
Sargent Spring	xxx	xxx	xxx	0.880[-]	0.825[@]
McPhillips Spring	xxx	xxx	xxx	xxx	0.732[@]

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the "Spring data May" spring dataset
[-] indicates the use of the "Spring data june end" spring dataset
[@] indicates the use of the "Springs Holesinger" spring dataset

Table B-37. *p-values* from the independent samples t-test for magnesium concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001[#]	<0.001[-]	0.022[-]	<0.001[-]	0.603[@]
Heller Spring	xxx	0.946[-]	<0.001[-]	<0.001[-]	0.001[@]
Cora Spring	xxx	xxx	<0.001[-]	<0.001[-]	<0.001[@]
Sargent Spring	xxx	xxx	xxx	<0.001[-]	0.044[@]
McPhillips Spring	xxx	xxx	xxx	xxx	<0.001[@]

Note: *p-values* less than 0.05 are indicated by gray squares.
[#] indicates the use of the "Spring data May" spring dataset
[-] indicates the use of the "Spring data june end" spring dataset
[@] indicates the use of the "Springs Holesinger" spring dataset

Table B-38. *p-values* from the independent samples t-test for manganese concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001$^{\#}$	0.001^{-}	0.633^{-}	0.008^{-}	0.005$^{@}$
Heller Spring	xxx	0.556^{-}	0.375^{-}	0.156^{-}	0.722$^{@}$
Cora Spring	xxx	xxx	0.333^{-}	0.072^{-}	0.692$^{@}$
Sargent Spring	xxx	xxx	xxx	0.580^{-}	0.360$^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	0.466$^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the "Spring data May" spring dataset
$^{-}$ indicates the use of the "Spring data june end" spring dataset
$^{@}$ indicates the use of the "Springs Holesinger" spring dataset

Table B-39. *p-values* from the independent samples t-test for sodium concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	0.197$^{\#}$	0.007^{-}	0.159^{-}	0.109^{-}	0.118$^{@}$
Heller Spring	xxx	0.001^{-}	0.946^{-}	0.017^{-}	0.018$^{@}$
Cora Spring	xxx	xxx	<0.001^{-}	0.192^{-}	0.076$^{@}$
Sargent Spring	xxx	xxx	xxx	0.006^{-}	0.005$^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	0.613$^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the "Spring data May" spring dataset
$^{-}$ indicates the use of the "Spring data june end" spring dataset
$^{@}$ indicates the use of the "Springs Holesinger" spring dataset

Table B-40. *p-values* from the independent samples t-test for silicon concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	<0.001$^{\#}$	<0.001^{-}	0.700^{-}	0.162^{-}	0.013$^{@}$
Heller Spring	xxx	0.587^{-}	<0.001^{-}	<0.001^{-}	0.012$^{@}$
Cora Spring	xxx	xxx	<0.001^{-}	<0.001^{-}	<0.001$^{@}$
Sargent Spring	xxx	xxx	xxx	0.033^{-}	0.003$^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	0.072$^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the "Spring data May" spring dataset
$^{-}$ indicates the use of the "Spring data june end" spring dataset
$^{@}$ indicates the use of the "Springs Holesinger" spring dataset

Table B-41. *p-values* from the independent samples t-test for potassium concentrations for each of the spring locations.

Location	Heller Spring	Cora Spring	Sargent Spring	McPhillips Spring	Holesinger Spring
Hicks Spring	0.831$^{\#}$	0.256^{-}	0.547^{-}	<0.001^{-}	<0.001$^{@}$
Heller Spring	xxx	0.070^{-}	0.407^{-}	<0.001^{-}	<0.001$^{@}$
Cora Spring	xxx	xxx	0.740^{-}	<0.001^{-}	<0.001$^{@}$
Sargent Spring	xxx	xxx	xxx	0.172^{-}	0.001$^{@}$
McPhillips Spring	xxx	xxx	xxx	xxx	<0.001$^{@}$

Note: *p-values* less than 0.05 are indicated by gray squares.
$^{\#}$ indicates the use of the "Spring data May" spring dataset
$^{-}$ indicates the use of the "Spring data june end" spring dataset
$^{@}$ indicates the use of the "Springs Holesinger" spring dataset

Table IV-42. *p-values* from the independent samples t-test for temporal variability for Hicks spring.

Location	pH	Temperature (℃)	Specific Conductance (μS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	CO_2 (mg/L)	B.O.D. (mg/L)	Hardness (mg/L)	Alkalinity (mg/L) as $CaCO_3$
Hicks Spring	0.395	0.007	0.040	0.002	0.757	0.338	0.313	0.172	0.696

Location	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Nitrate as Nitrogen (mg/L)
Hicks Spring	0.160	0.041	0.113	0.058

Location	Calcite (mg/L)	Iron (mg/L)	Magnesium (mg/L)	Manganese (mg/L)	Sodium (mg/L)	Silicon (mg/L)	Potassium (mg/L)
Hicks Spring	0.413	0.523	0.146	0.921	0.173	0.012	0.300

Note: *p-values* less than 0.05 are indicated by gray squares.