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DISCHARGE MONITORING, CHEMICAL CHARACTERIZATION, AND SOURCE IDENTIFICATION OF SPRINGS ALONG THE EAST SIDE OF SOUTHERN CACHE VALLEY, UTAH

by

Aric Alan Olsen

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

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ABSTRACT

Discharge Monitoring, Chemical Characterization, and Source Identification of Springs Along the East Side of Southern Cache Valley, Utah

by

Aric Alan Olsen, Master of Science

Utah State University, 2007

Major Professor: Thomas E. Lachmar
Department: Geology

Discharge monitoring and water sampling of springs in the southeastern portion of Cache Valley, Utah was performed in order to determine recharge sources and the cause of decreasing flows for some springs. The discharges of 43 springs were measured monthly from May or June of 2005 through March of 2006. Water samples from 36 of these springs plus an additional 10 were analyzed for major ions and trace metals. Twenty-one of the springs were analyzed for deuterium and oxygen-18 and 10 of these were analyzed for tritium.

The springs were divided into groups based on when they had their peak discharge. Peak discharges in the summer months suggest recharge from excess irrigation water and/or canal water, whereas peak discharges in winter months suggest recharge from rivers, and peak discharges in spring months suggest recharge by precipitation and/or river water recharge. Multiple discharge peaks suggest multiple recharge sources.

The chemical data collected in the study were compared with data from previous investigations to determine potential spring sources, including: shallow ground water, deep ground water, irrigation (river/canal) water, and precipitation. Spring water is characterized by calcium, magnesium, and bicarbonate, similar to deep ground water and river water. However, most of the 21 springs analyzed for deuterium and oxygen-18 displayed an evaporative signature; thus, chemically, the shallow, unconfined aquifer that recharges these springs appears to be recharged in part by excess irrigation water and/or canal water. Several of the springs have high chloride levels indicating the shallow, unconfined aquifer recharging those springs has surface runoff infiltrating into it.

Because of the evaporative signature in the stable isotopes, the similarity of major ion and trace metal values, and the discharge trends observed throughout the year, it seems unlikely that the springs are directly connected hydraulically with the deep, confined aquifer, from which most of the wells in the valley withdraw their water. Thus, the recent drought, rather than increased pumping, probably has been responsible for decreases in spring discharges.

(186 pages)

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Dr. Tom Lachmar conceived this project and sought the funding that made this research possible. He also provided me with the knowledge and support necessary to complete my thesis. While collecting data in the field, Tom taught me to think critically about ground-water systems as well as how to gather data in a scientific manner. These skills have made me confident I can work in the ground-water field. Dr. Pete Kolesar also deserves my thanks for his input in the geochemistry field. Dr. Bill Doucette provided his expertise in the analysis and collection of hydrochemical data and in the setup of the project.

I need to thank the Cache County Council, who provided the money for this study, and Lynn Lemon, the county executive, for recommending that the Council fund the project. I am also grateful to the University of Miami's tritium laboratory for processing 10 samples free of charge, which provided useful insight about the ground water in Cache Valley.

Kevin Randall, a fellow graduate student in hydrogeology, was involved in this study from the beginning. He was a field assistant for this project and helped collect the majority of the data for this thesis. He also provided suggestions and ideas that helped this project work so well. This research would not have been possible if it weren't for the generosity of the many landowners in Cache Valley that allowed me to access the springs on their property. These gracious and intelligent individuals were not only welcoming, but were eager to provide me with the knowledge they had about the history of their spring(s), which was extremely useful in this study.

I especially need to thank my wife for her support, and her sacrifices that allowed me to complete this research. She put her schooling and career aside to take care of our two children while I worked through school. I will be forever grateful to her and my children as well as my parents, brothers, and in-laws for always being extremely supportive of me and always being there to help out in any way possible.

Aric Olsen

CONTENTS

CHAPTER

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER I

INTRODUCTION

Statement of the Problem

In the mid-1800s Cache Valley was developed for agriculture because of the abundant surface water, suitable soil properties, and appropriate climate. Since then, the population and landscape have changed dramatically. Much of the agricultural land has been converted to residential use, especially in the southeastern portion of the valley, which is the focus area of this study. Decreases in spring discharges have been reported to the Cache County Council by a small number of residents in the College Ward/Young Ward areas and are being blamed on the increase in ground-water pumping by the neighboring cities, primarily Nibley. The possibility of a decrease in spring discharge has senior surface water rights holders concerned because many farmers rely on water from these springs to water crops and livestock.

A study by Kariya et al. (1994) led the Utah State Engineer to restrict future ground water withdrawals in Cache Valley to 25,500 acre-feet per year. Other studies by Robinson (1999) and Myers (2003) have found that Kariya et al. (1994) may have overestimated the impact ground water withdrawals would have on valley surface water systems that gain water from aquifers, and that the springs may be acting as overflow valves for the aquifers. To understand the impact present ground water withdrawals have on the springs in this area, a long-term spring monitoring study is necessary.

This study investigates the sources of the spring water, whether from the shallow unconfined aquifer, the deep (greater than approximately 60 feet, depending on location) confined aquifer that is known as the principal aquifer, leakage from unlined irrigation canals, unconsumed irrigation water, river water, or precipitation. Depending on the source of the spring water, decreases in discharge could result from various causes. If the source is the principal aquifer, then over pumping of the ground water in that aquifer would decrease the discharge of springs. If the source of a spring is mainly excess irrigation water, changes in land use could be potential causes of a decrease in discharge. If the source is precipitation, then a drought would be expected to reduce the discharge of that spring. This analysis was done on a case-by-case basis in Chapter 4, where such factors are taken into consideration. This study has developed and initiated an approach for the long-term monitoring of these springs, which has provided suggestions for the source of spring water and will eventually determine a source of recharge.

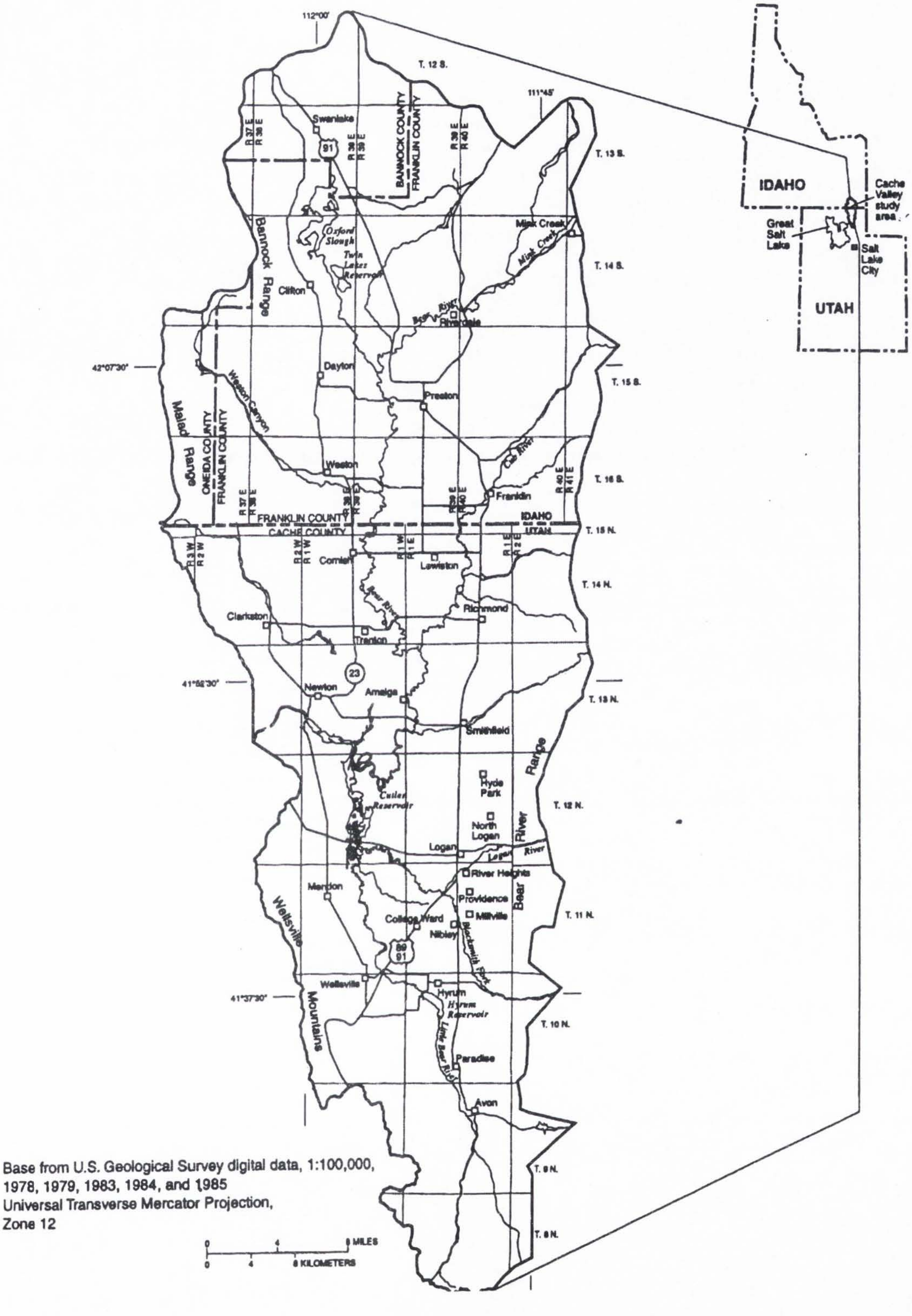
Objectives

The five main objectives of this study were to: 1) record spring discharges to determine if and when there were fluctuations; 2) determine why spring discharges do or do not fluctuate; 3) quantify spring discharges for use in water management and modeling; 4) determine or suggest the sources of spring recharge; 5) initiate long-term monitoring of springs in southeastern Cache Valley, Utah.

Since it was possible that different springs in the valley would have different recharge sources, this study attempted to monitor as many springs as possible to accurately characterize their sources and potential changes in discharge. The discharges of 43 springs in the southeastern portion of Cache Valley were measured monthly. Water samples from 36 of these springs plus an additional ten, which were not monitored for discharge, were analyzed for major ions and trace metals (Al, As, B, Ba, Ca, Cd, Cl, Co, Cu, Fe, K, Mg, Mn, Mo, Na, P, Pb, S, Si, Sr, and Zn) and compared with the chemistry of shallow ground water, deep ground water, precipitation, and surface water data collected in previous studies to aid in determining the sources of the springs. The stable isotopes deuterium and oxygen-18 (^{18}O) were sampled in 21 springs to help determine the sources of the spring water, and the radioactive isotope tritium was analyzed in ten spring samples to get an idea of when the water entered the ground water system.

Location

Cache Valley is a north-south trending valley extending from northern Utah into southern Idaho (Figure 1) and has an area of approximately 660 square miles (Kariya et al., 1994). The Bear River Range trends north-south and borders the valley to the east. The



Base from U.S. Geological Survey digital data, 1:100,000, 1978, 1979, 1983, 1984, and 1985
Universal Transverse Mercator Projection,
Zone 12

Figure 1: Location of the study area (Kariya et al., 1994).

Wellsville Mountains and the Malad and Bannock Ranges bound it to the southwest and northwest, respectively.

The study area is in the portion of Cache Valley that is above the deep, confined aquifer, also known as the principal aquifer, into which nearly all of the most productive wells in Cache Valley are completed. This also happens to be the portion of the valley where the majority of the new residential development is occurring. This area extends from Smithfield in the north to Hyrum in the south, with the Bear River Range as the eastern border and the Little Bear and Bear Rivers as the western border (Figure 2).

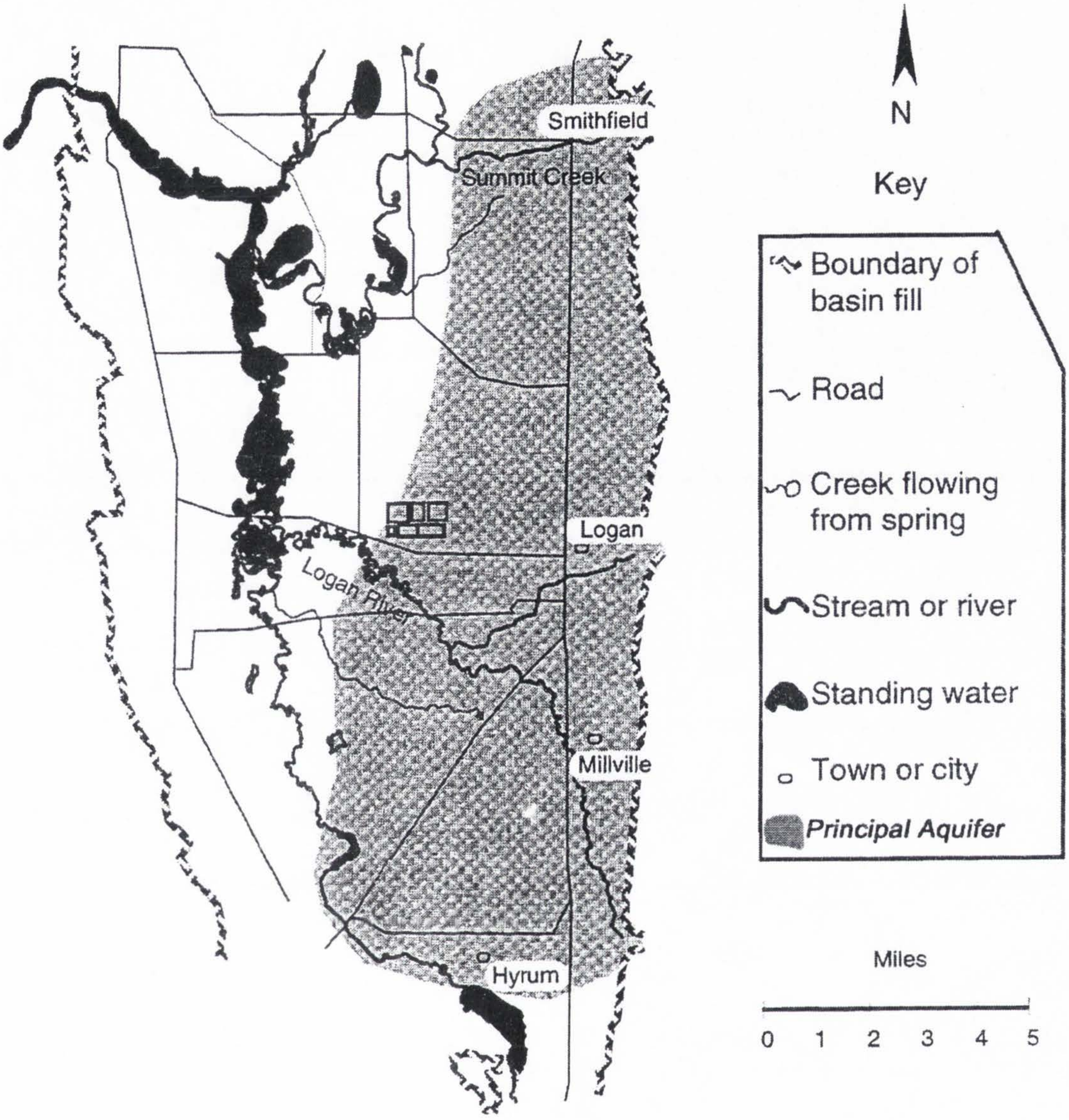


Figure 2: Approximate extent of the principal aquifer (Robinson, 1999).

CHAPTER II

BACKGROUND

Stratigraphy

The useful ground-water supply in Cache Valley is in the Quaternary basin fill deposits that are present from the surface down to a depth of several hundred feet. This section will only briefly discuss stratigraphy older than the Quaternary because the basin fill deposits are the only ones that directly affect the springs in this study.

Pre-Quaternary Stratigraphy

Cenozoic age sediments and sedimentary rocks fill the basin. In the upper 950 feet (less depending on location) of the valley, below the Cenozoic deposits are Proterozoic and Paleozoic rocks. These rocks consist mostly of limestone, dolostone, shale, and sandstone, with an aggregate thickness of more than 30,000 feet in the mountains adjacent to Cache Valley (Williams, 1962).

The Wasatch Formation is Tertiary in age and is made up of poorly cemented to well-cemented conglomerate and sandstone (Bjorklund and McGreevy, 1971). This formation is found throughout Cache Valley and is 328 feet thick in the central portion of the valley.

The Salt Lake Formation overlies the Wasatch Formation and consists of conglomerates, tuffaceous sandstones and siltstones, and limestones. Evans and Oaks (1996) reported that this formation is thickest along the eastern margin of the valley (approximately 9,000 feet) and thins toward the west.

Quaternary Stratigraphy

By interpreting well log data, Robinson (1999) determined that Quaternary deposits overlying the Salt Lake Formation are up to 950 feet thick in places. These deposits are made up of fluvial and lacustrine sediments, and lie between the underlying Tertiary Salt Lake Formation and deposits of the Little Valley lake cycle. They also comprise the principal aquifer in the valley (Bjorklund and McGreevy, 1971). The depth to the upper contact of the principal aquifer varies but is generally between 60 and 150 feet below the surface. The depth to the lower contact is not well known because few boreholes have been drilled all the way through these sediments.

Overlying the principal aquifer are fluvial and lacustrine sediments. Levels of ancient Lake Bonneville fluctuated during its existence between 140,000 and 13,000 years ago. During that time, rivers deposited deltaic sediment at the mouths of their canyons along the valley margins, forming shorelines and deltas that are 120 feet thick in places. These deltas are the only areas where surface water can recharge the principal aquifer (Robinson, 1999) because lake clays, which are up to 150 feet thick in places and act as confining layers, were deposited everywhere else around the valley.

There were two major lake cycles in Cache Valley during the last 200,000 years, including the Little Valley and Bonneville lake cycles (Robinson, 1999). The fluctuations in lake levels created an upper confined aquifer as described by Robinson (1999), which is present in discontinuous lenses between the upper confining layer and the lower confining layer. The older of the two cycles is the

Little Valley lake cycle, which was present between 140,000 and 90,000 years ago. During that time, Lake Bonneville rose and inundated Cache Valley, depositing lake clays that created the lower confining layer of the upper, confined aquifer. These confining layers were deposited in the center of the valley, as well as those areas along the margins of the valley where no rivers flowed out of the Bear River Range.

The younger of the two lake cycles is the Lake Bonneville cycle. Lake levels fluctuated during this cycle, forming deltaic and shoreline deposits at multiple elevations along the margins of the valley, and depositing the upper confining layer of the upper confined aquifer. This confining layer is present at the surface near the center of the valley except where post-Lake Bonneville alluvium has been deposited near present day streams.

After the lake level dropped to its current position at the Great Salt Lake 13,000 years ago, fluvial processes began to shape the landscape by down cutting into the deltas and re-depositing the material as alluvial fans and in stream channels farther out in the valley. This created a shallow, unconfined aquifer. The deltaic deposits are up to 120 feet thick and alluvial deposits are generally less than 30 feet thick (Robinson, 1999). Many of the springs in the study area emerge from the toes of the alluvial fans.

Hydrogeologic Setting

Several previous studies (Fortier, 1897; Israelsen and McLaughlin, 1935; Israelsen et al., 1946; Peterson, 1946; Beer, 1967; McGreevy and Bjorklund, 1970; Bjorklund and McGreevy, 1971; Kariya et al., 1994; Robinson, 1999;

Myers, 2003) have examined the surface and ground water resources in Cache Valley. Many of the studies before 1950 were aimed at increasing agricultural productivity and characterizing soil and hydrologic conditions in Cache Valley. Since then, university and state researchers in Utah have become aware of the large ground and surface water potential, and have completed many studies to better understand it. Many of these studies have recognized the need for additional research and monitoring of the springs in Cache Valley.

Ground water in Cache Valley occurs in unconsolidated basin fill deposits toward the center of the valley, and in deltaic sediments, which were deposited by rivers that flowed into ancient Lake Bonneville from the Bear River Range. These deposits formed terraces along the margins of the valley during the Quaternary. These latter deposits formed the thick (several hundred feet) unconfined aquifer along the eastern margin of Cache Valley. The upper 60 feet or so of this unconfined aquifer can be considered to be the eastern portion of the shallow ground water system, which is made up of alluvial deposits in the western portion of the system. The alluvial deposits in which the shallow ground water occurs in are generally less than 30 feet below the surface and extend 1 to 2 miles west of the towns of Smithfield, Logan, and Hyrum.

Much of the recharge to the basin fill deposits occurs along the margins of the valley, which are a few hundred feet higher than the center of the valley, contributing to the hydraulic head in the system and creating many flowing wells toward the center of the valley. Ground water recharge comes from four sources, including infiltration of precipitation in the unconfined aquifer at the valley margins, surface and subsurface flow from the Bear River Range, and excess irrigation and canal water. Approximately 65% of the surface water that enters Cache Valley comes from the Bear River and the remaining 35% comes from smaller streams that drain the western half of the Bear River Range (Robinson, 1999). Ground water flow in Cache Valley generally follows the surface water flow paths, discharging into Cutler Reservoir in the western portion of the valley.

Bjorklund and McGreevy (1971) described the ground water conditions in Cache Valley at that time. They conducted pumping and recovery tests and then calculated transmissivity, hydraulic conductivity and storativity. Their study indicated that the aquifer beneath the towns of Smithfield, Hyrum and Wellsville is capable of producing twice the amount of water pumped at that time. They also examined at many springs, measuring discharge, temperature, and specific conductance, and analyzing them for major ions. Bjorklund and McGreevy (1971) concluded that the springs in this portion of Cache Valley are fed by the shallow, unconfined aquifer. Many of the springs used by Bjorklund and McGreevy (1971) were also examined in this investigation, and the data they collected provides a useful comparison to data collected in this study.

Bjorklund and McGreevy (1971) found that ground water conditions in the valley varied greatly with geographic location. This is because: (1) the history of Lake Bonneville cycles is complex, (2) multiple rivers flow into the valley from nearby mountains, and (3) the fault system is complex. Bjorklund and McGreevy (1971) divided the valley into areas where ground water conditions are generally similar. They noted that none of these areas is independent of the others, but the boundaries between these areas show approximately where general conditions change. The Smithfield-Hyrum-Wellsville area (Area 1) is the only one of the eleven areas that coincides with the area of interest to this study.

Pre- and post-Bonneville alluvial fan deposits, as well as Bonneville deltaic deposits from Summit Creek, the Logan River, Blacksmith Fork and the Little Bear River, coalesce in Area 1 along the base of the Bear River Range. This forms a single but complex aquifer system from the town of Smithfield south to the town of Hyrum. Near Logan, the water-bearing materials are at least 1,000 feet thick and are very coarse along the mountain front, becoming finer toward the center of the valley (Bjorklund and McGreevy, 1971). Next to the mountains is an unconfined aquifer that is hydraulically connected to the deep, confined (principal) aquifer, which is the largest and most productive aquifer system in Cache Valley.

Previous Hydrogeologic Investigations

Bjorklund and McGreevy (1971) developed a conceptual model for the ground water in Cache Valley that has one confining layer above the principal aquifer (Figure 3A). That conceptual model was not used in the numerical simulation model developed later by Kariya et al. (1994) (Figure 3B).

Herbert and Thomas (1992) conducted a seepage study along 48.53 miles of the Bear River through Cache Valley in both Idaho and Utah. They measured the discharge along the river at specific points and estimated that the net seepage

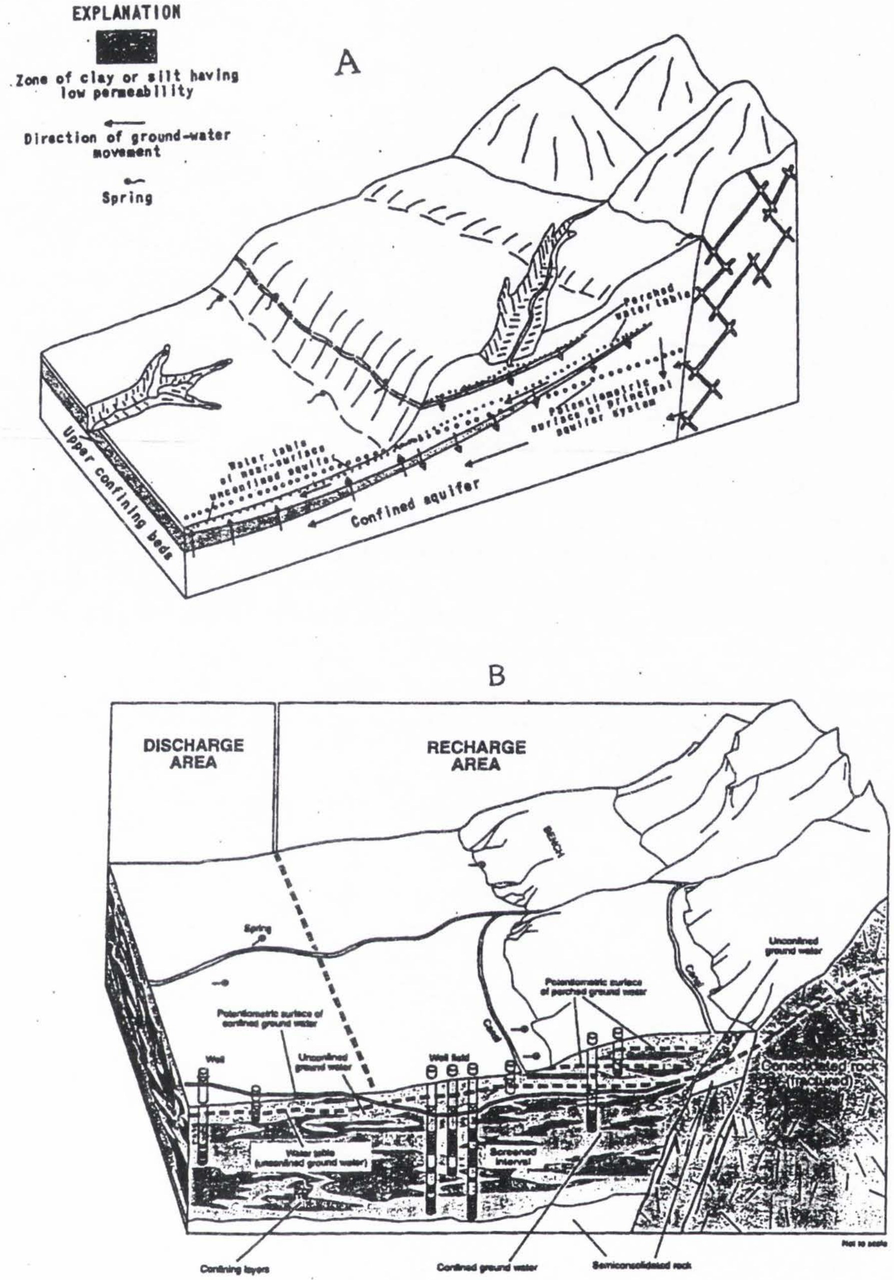


Figure 3: Hydrogeologic conceptual models for Cache Valley. (A) Bjorklund and McGreevy (1971). (B) Kariya et al. (1994).

into this section of the Bear River, including Cutler Reservoir, was 79.0 cubic feet per second (cfs). The water that seeps into the Bear River is from the shallow, unconfined aquifer near the center of the valley.

One of the most influential studies was conducted by Kariya et al. (1994), who developed a numerical ground water simulation model for Cache Valley. This study modeled what would happen to the ground water in Cache Valley if there was an increase in ground water withdrawals of 30 cfs (21,700 acre-feet per year) for 30 years. The model indicated that there could be ground water level declines of as much as 10 to 51 feet. These results caused the Utah State Engineer to limit future ground water withdrawals in Cache Valley to 25,500 acre-feet per year. The concern was that ground water pumping would not only lower the piezometric surface, but will also decrease the amount of, or even eliminate, both the water discharging from springs and the water that the aquifers contribute to the rivers flowing through the valley. This would cause many problems for farmers with senior water rights, who need that surface water for irrigation and livestock.

However, Kariya et al. (1994) made several assumptions in their model that may not have been entirely accurate. The first assumption was not including a continuous confining layer in their conceptual model (Figure 3B). The lack of a continuous confining layer assumes that rivers and springs are hydraulically connected to the principal aquifer, and that they gain their water from it. The second assumption was that there is a no-flow boundary between the adjacent Bear River Range and the valley. Such an assumption would not account for any ground water that may enter the valley from the surrounding mountains. The third assumption was the use of 1976 land-use estimates to compute recharge from precipitation and unconsumed irrigation water because more recent estimates were not available for the valley. Because the percentage of ground water that is recharged from precipitation was not measured, the fourth assumption was to use a percentage based on other studies in Utah, which found that this percentage was between 1 and 20%. The fifth assumption was to divide the total spring discharge in the valley, calculated by Bjorklund and McGreevy (1971), evenly among the springs in the numerical model.

A later study by Robinson (1999) developed a more detailed hydrostratigraphic conceptual model of the valley using over 200 driller's logs, as well as ground water and surface water chemistry. Based on this information, Robinson's (1999) conceptual model included two continuous confining layers above the principal aquifer, which is the one that most of the wells are completed into. These confining layers are illustrated in Figure 4 and can be compared with the schematic diagram in Figure 3B that illustrates the conceptual model used by Kariya et al. (1994). Robinson (1999) stated that the Bear River and other rivers that run through the valley gain their water from the shallow, unconfined aquifer that overlies the principal aquifer and is separated from it by the two continuous confining layers. Robinson also determined that the springs along the east side of Cache Valley may be acting as overflow valves for the principal aquifer, and he recommended that any future studies include spring discharge monitoring to determine what effect withdrawals from the principal aquifer may have on their discharges.

Robinson (1999) also collected deuterium and oxygen-18 data, together with major ion and trace metal data from many wells in the valley and from two springs, that will provide a useful comparison with the results obtained in this study. He found that the total dissolved solids (TDS) contents generally increased with well depth and with distance away from the Bear River Range.

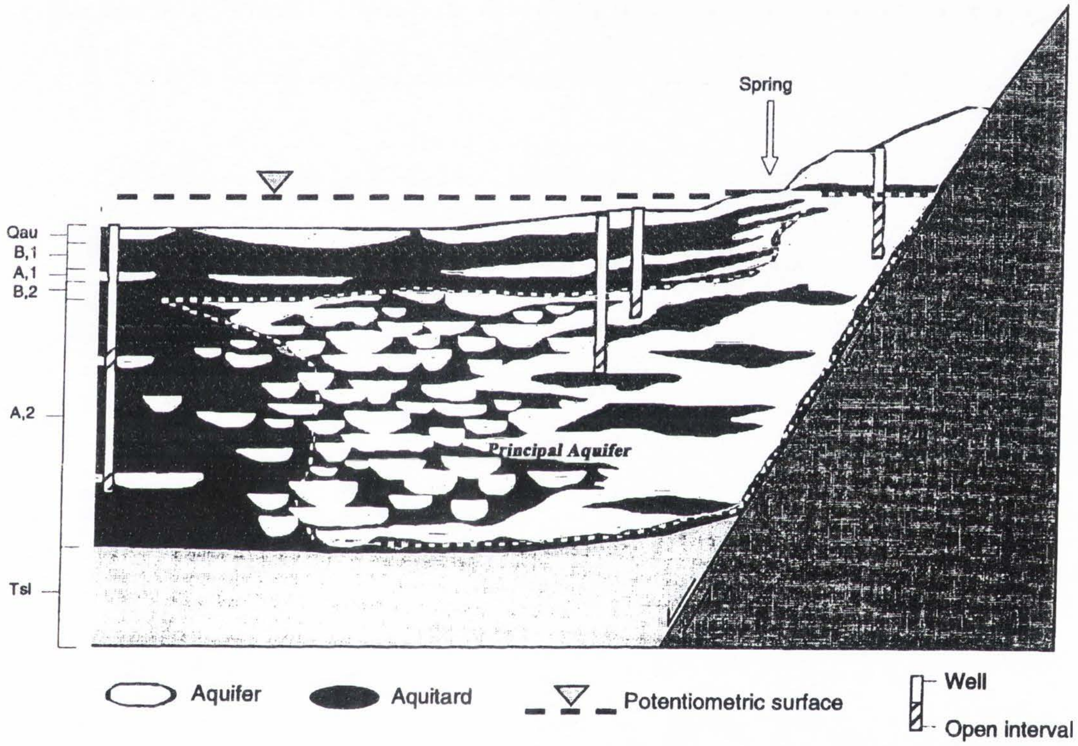


Figure 4: Hydrogeologic conceptual model for Cache Valley (Robinson, 1999).

Since then, Myers (2003) has used the conceptual model developed by Robinson (1999) as the basis for a new numerical model of Cache Valley using MODFLOW (McDonald and Harbaugh, 1988), which is the same computer code used by Kariya et al. (1994). Myers (2003) concluded that Kariya et al. (1994) may have greatly overestimated the decrease in spring and river discharges caused by increased ground water withdrawals. The differences in their results most likely come from Kariya et al. (1994) not using a continuous confining layer, only discontinuous ones throughout the valley, using a no-flow boundary between the Bear River Range and the valley, and from underestimating recharge from precipitation and unconsumed irrigation water (57 cfs, or 1.17 in/year). Myers (2003) had two continuous confining layers, as described by Robinson (1999), employed a general head boundary along the eastern margin of the valley, and used a more reasonable estimate of recharge from precipitation (108 cfs) and unconsumed irrigation water (75 cfs).

The model developed by Myers (2003) required subsurface inflow into the principal aquifer (63 cfs) from the surrounding mountains in order to match the hydraulic heads in the model to the measured heads in this aquifer. He suggested that much of the deep (greater than 150 feet) ground water along the southeastern margin of the valley is recharged by subsurface flow from the Bear River Range, and then moves west and north across the valley, exiting through Cutler Reservoir in the western part of the valley. Also, Myers' model required subsurface flow out of the unconfined aquifer (69 cfs) in order for modeled heads to match heads in that aquifer.

The predictive simulations done by Myers (2003) were similar to those done by Kariya et al. (1994). When a simulation was run using the average annual precipitation rate of 1.2 feet and additional pumping from the principal aquifer of 34 cfs, there was very little decrease in stream or spring discharges. However, when the precipitation rate was decreased to 1 foot per year to simulate drought conditions, the discharge of the aquifer to streams and springs decreased.

History of Cache Valley Land Development

In the mid-1800s, settlers from southern Utah came into Cache Valley searching for summer pasture and found suitable grazing land here. These settlers were not able to cultivate the land because no canals had yet been dug to carry water from the higher elevations to the valley throughout the summer growing season (Shaw, 1996). In 1870, four homesteaders, Peter and Everett Van Orden, Robert Wall, and John M. Bernhisel, applied for four quarter sections of land in Cache Valley. These hardy settlers were faced with land that was too muddy to plant usually until late June and that received little precipitation after that (Shaw, 1996). It became immediately apparent that drainage and irrigation were needed for agriculture to be successful in Cache Valley.

Canals began to be hand dug in the late 1800s to bring irrigation water from higher elevations to the fields later in the growing season. Ditches to drain excess surface and flood irrigation water were also hand dug during that time. However, the high piezometric surface and poor drainage of the soils in the central portions of the valley created salinity and alkalinity problems as irrigation increased. The solution to these problems came in the 1930s when many people were looking for work during the Great Depression. The Works Progress Administration (WPA) was a federal agency that put these people to work all over the country. They did many projects in Cache Valley, including the installation of field drains (Shaw, 1998).

These field drains or drain tiles were hand dug initially, and were installed from below the benches on the margins of Cache Valley across to the Little Bear and Bear Rivers, where many of them discharge. Since ceramic was not used at that time, most of the drain tiles were made of concrete and were eight inches inside diameter. The depths of these drain tiles varied, but today they can be found approximately 15 feet below the surface in some places. Often times, drains were placed in areas of natural drainage, but other times they were laid out in grid patterns to cover a particular area.

The installation of drain tiles in Cache Valley has continued to today. Few records have been kept over the years as to the location of these drain tiles, but many of the springs included in this study have eight-inch concrete pipes contributing some, if not all, of the flow to the spring. Because few records were kept, many of these drain tiles have been covered up by sediment. Where this has occurred, the water flowing out of the ground appears to be a natural spring.

The upward hydraulic gradient in much of the valley also led landowners to drill artesian wells, not only to obtain irrigation water but also in an attempt, at least in a few cases, to lower the piezometric surface and promote better drainage of the soils. In 1930, a 14-inch well was drilled near Highway 91 2.5 miles north of Logan to be used for a pumping test (Israelsen et al., 1935). The test was conducted on September 1, 1932. During this test, the piezometric surface was measured every half hour. Drawdowns ranged from 10.89 feet at 820 feet away from the pumping well to 3.33 feet at a point 3,680 feet away. The piezometric surface was almost back to its original elevation 8.25 hours after pumping stopped (Israelsen et al., 1935).

In 1931, 25 wells ranging from 2 to 5 inches in diameter were completed in the shallow aquifer approximately 40 feet below the surface (Israelsen et al., 1955). Twelve of these wells were drilled on the two-acre Bell tract south of Logan airport, and eleven were drilled along the Logan-Benson Canal. The piezometric surface was lowered considerably just from the water flowing out of these wells under artesian conditions (Israelsen et al., 1955).

Potential Spring Source Characteristics

There are six potential sources of recharge to springs in Cache Valley: 1) water in storage in the shallow, unconfined aquifer, 2) water in storage in the deep, confined (principal) aquifer, 3) excess irrigation water, 4) river water, 5) canal water, and 6) precipitation. The relationships of these potential sources to spring water chemistry are discussed in Chapter 4. It is important to note that even if a spring has the major ion and/or isotopic signature of a particular source (e.g., principal aquifer), that water could have been pumped from the ground and used for irrigation. Therefore, it could be possible for that spring to be fed entirely by irrigation water even though its major ion chemistry matches that of the principal aquifer. The same could be possible for river water, canal water or spring water, since they are all used for irrigation. An evaporative isotopic signature from the preferential evaporation of hydrogen and oxygen-16 relative to the heavier isotopes deuterium and oxygen-18 during irrigation would resolve this potential problem. However, the springs that were not analyzed for isotopes in this study would be extremely difficult, if not impossible, to sample for stable isotopes because the water emerges from beneath a pond.

Shallow, Unconfined Aquifer

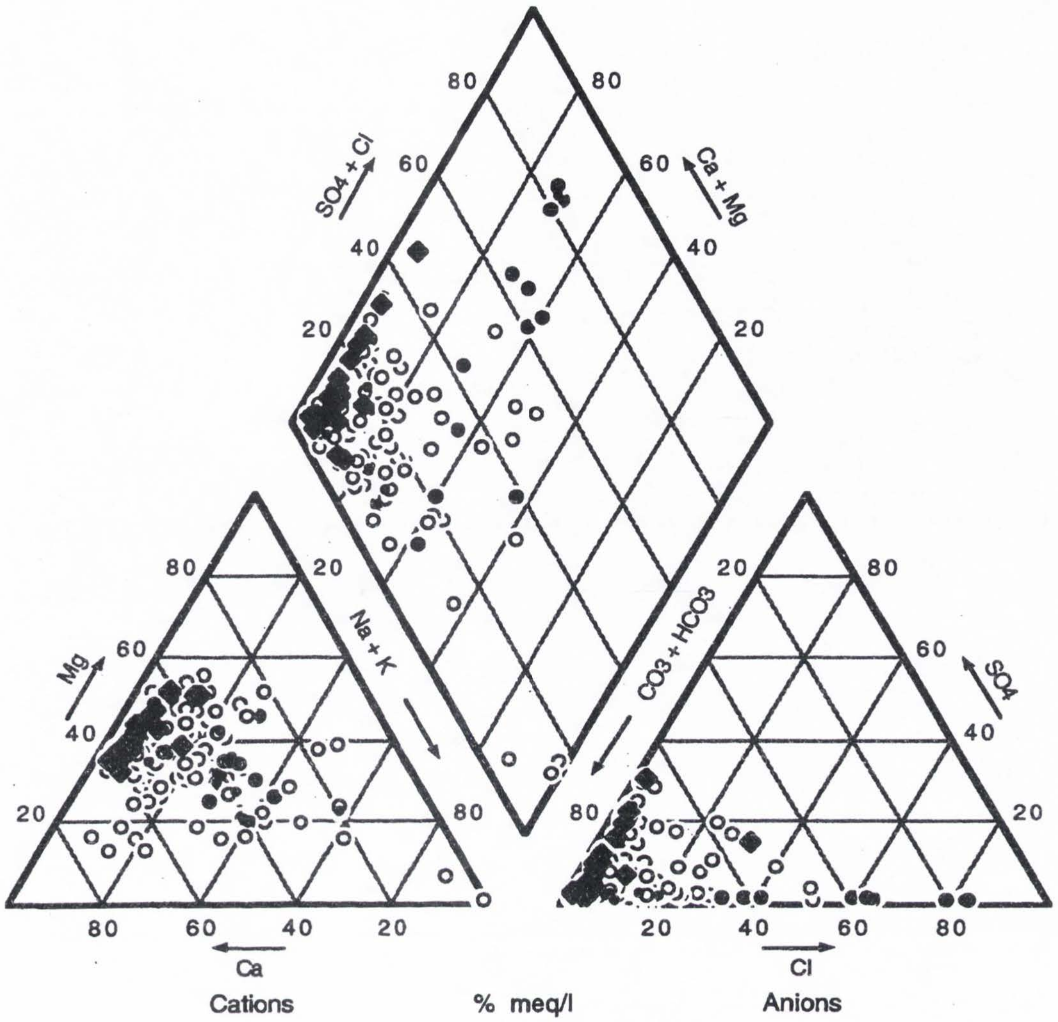
The shallow, unconfined aquifer is considered to be less than approximately 50 feet below the surface. This includes the shallow water in the coarse deltaic and alluvial material at the surface along the eastern margin of the valley (the right side of Figure 4) that are above the two continuous confining layers. This stratigraphy makes this aquifer the most likely source of the water discharging from the springs. There are five potential sources of recharge to the shallow, unconfined aquifer, including precipitation, excess irrigation water, river water, canal water and water in storage in the principal aquifer. Little chemistry data have been collected from the shallow, unconfined aquifer, but it would be likely this aquifer would have characteristics of one or more of the potential sources listed previously, since the soils are relatively well drained (Erickson and Mortensen, 1974) and the surficial deposits that make up this aquifer are relatively coarse (McCalpin, 1989) along the eastern valley margin.

Principal Aquifer

Major ions in wells are plotted on a trilinear diagram (Piper, 1944) in Figure 5. Wells in the eastern portion of the valley plot farther to the left on the diagrams compared to the wells farther west.

Analysis of total dissolved solids (TDS) by Robinson (1999) indicates several distinct changes in ground water chemistry with depth in the valley. Generally, the deeper the water is, the higher the TDS content is. Concentrations in most wells shallower than 300 feet are less than 400 mg/L. For wells less than 300 feet deep, sodium plus potassium dominate over chloride, but the reverse is true for most wells deeper than 400 feet. Calcium plus magnesium dominate over sodium plus potassium in wells in the eastern portion of southern Cache Valley, and the opposite is true for wells farther to the west (Figure 6). These data will be compared to spring chemistries in Chapter 5 in order to determine the source(s) of spring water.

Isotopic data from wells completed in the deep, confined (principal) aquifer sampled by Robinson (1999) are listed in Table 1. Ratios of deuterium to hydrogen (D/H) and oxygen-18 to oxygen-16 ($^{18}O/^{16}O$) found in the principal aquifer near the center of the valley were lower than surface water values. Figure 7 shows these data plotted with other potential sources, all of which have unique isotopic ratios that will prove to be extremely useful when identifying the source of spring water in Chapter 5. The wells located at (B 13 1) 27 bcc and (A 12 1) 6 cbc (Table 1) had lower delta D and delta ^{18}O values than any of the other wells in Robinson's (1999) study. This is because these wells are completed in a local



◆ Wells in the Logan quadrangle. Open intervals range between 98 and 250 feet.

● Wells in the Wellsville and Newton quandrangles. Open intervels range between 200 and 400 feet.

○ Wells completed in the Paradise, Richmond, Clarkston, Smithfield, Mount Pisgah, Cutler Dam, and Trenton quadrangles. Open intervals range between 10 and 700 feet.

Figure 5: Trilinear (Piper, 1944) plot of major ion concentrations from wells in Cache Valley (Robinson, 1999). Dark diamonds are wells in the study area of this spring study, some of the open circles are in this study area and some are not.

minor confined aquifer in the Barrens region of Cache Valley and in a deep (>500 feet) confined aquifer near the Bear River, respectively, that probably are not hydraulically connected with the principal aquifer. The ground water at these locations was likely recharged when the climate was cooler and wetter (Robinson, 1999). These two wells were outside the study area for this investigation. All but two of the other well water samples in that study plotted to the left of the GMWL.

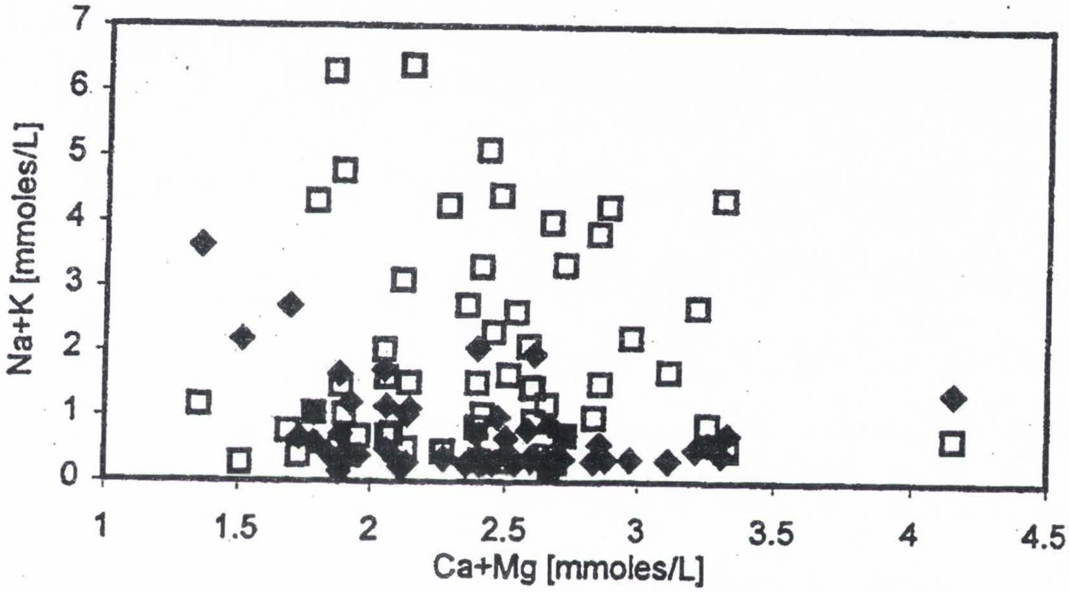


Figure 6: Plot of concentrations of sodium plus potassium versus calcium plus magnesium from wells sampled by Robinson (1999). Open squares are wells toward the center of Cache Valley, dark diamonds are wells closer to the eastern portion of the valley.

Table 1: Stable isotopic data (per mil) from wells in the study area.

Sample location	Source of water sample	Delta D	Delta O-18
(A-13-1) 29 adc	principal aquifer	-126	-17.1
(B 13 1) 27 bcc	local minor confined aquifer	-143	-18.8
(B-11-1) 36 abc	principal aquifer	-124	-16.7
(A-10-1) 21 caa	principal aquifer	-118	-16.5
(A-12-1) 33 bca	principal aquifer	-123	-17.5
(B-11-1) 35 acc	principal aquifer	-128	-16.6
(A-12-1) 34 cca	principal aquifer	-124	-17.4
(A 12 1) 6 cbc	deep (>500 ft.) confined aquifer	-138	-18.1
(A-12-1) 31 bcd	principal aquifer	-125	-17.6
(A-12-1) 17 daa	principal aquifer	-124	-17.4
(A-12-1) 8 aab	principal aquifer	-127	-17.8
(B-12-1) 36 caa -2	principal aquifer	-127	-17.5

Robinson (1999) found moderate levels of tritium (Figure 8) in the principal aquifer in the eastern part of the valley, and low levels in the western portion of the valley, indicating that most, if not all, of the ground water in the western portion probably is pre-bomb water. Carbon-14 dating indicated that the water in wells located at (B 13 1) 27 bcc and (A 12 1) 6 cbc (wells 3 and 10 in Figure 8) is more than 20,000 years old.

Irrigation Water

The defining characteristic of irrigation water is its evaporative isotopic signature, which occurs as the result of the preferential evaporation of hydrogen and oxygen-16 relative to deuterium and oxygen-18 during irrigation. There are multiple sources of irrigation water, which could potentially indicate that spring water was recharged by a source other than irrigation water. For example, often

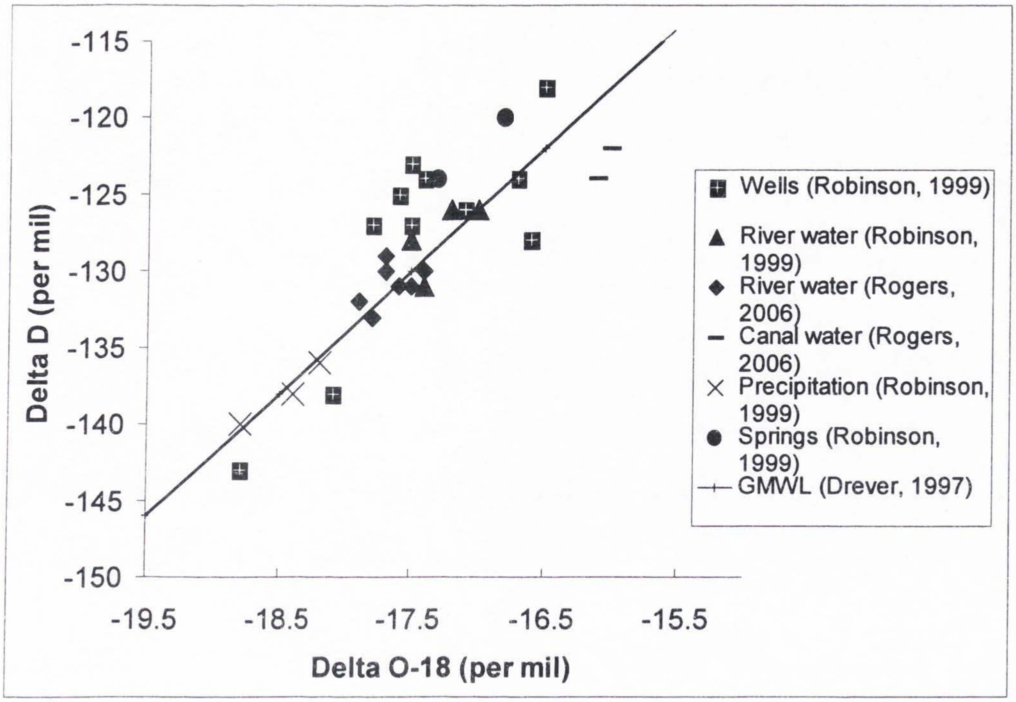


Figure 7: Plot of delta D versus delta O-18 in water sampled from potential spring sources by previous researchers.

times water for sprinkler irrigation is pumped from the principal aquifer or from ponds fed by springs. Other fields are flood irrigated with water either directly from a river or by river water via the canal system. If irrigation water that is pumped from the principal aquifer, or from any other source, infiltrates and is partly or entirely the source of water to a spring, then major ion and trace metal concentrations will be misleading, and only an evaporative isotopic signature will indicate if it is irrigation water or some other potential source that is contributing to the spring's discharge.

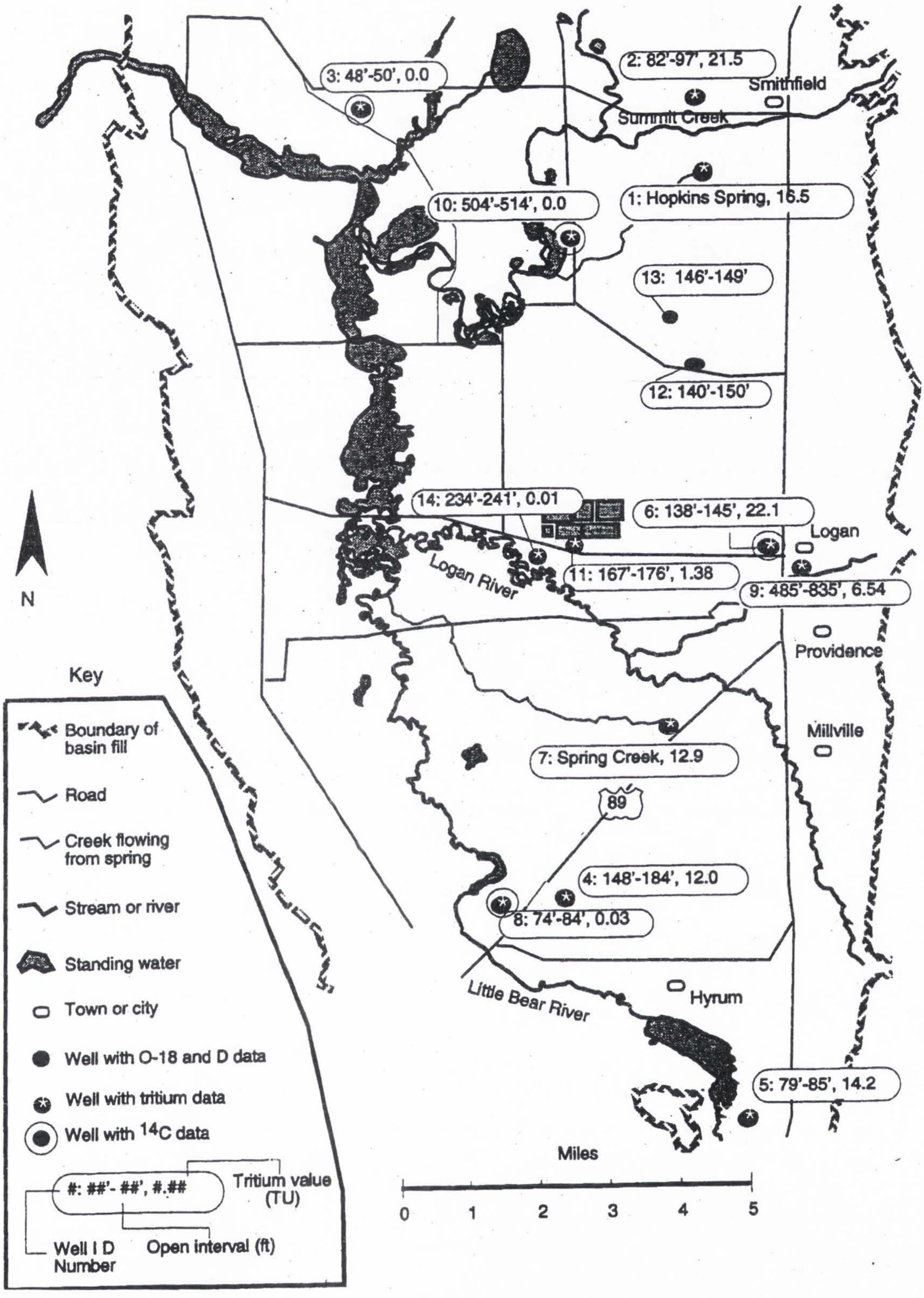


Figure 8: Locations and results of wells sampled for tritium, and locations of wells sampled for deuterium and oxygen-18, and carbon-14 (Robinson, 1999).

River Water

There are four perennial streams that flow into the study area from the adjacent Bear River Range. The Logan River is the largest of the four and flows into the valley through the town of Logan. Summit Creek flows in through the town of Smithfield, and the Blacksmith Fork and Little Bear Rivers flows in through the town of Hyrum in the southern portion of the study area.

These four rivers cross the eastern, unconfined aquifer that is adjacent to the Bear River Range, and they lose some of their water to that aquifer along those reaches. Robinson (1999) sampled the Logan River, Blacksmith Fork River, and Summit Creek in the summer and fall of 1998, and Rogers (2006) sampled the Logan River for stable isotopes (Table 2). Figure 7 shows these data plotted with other potential sources, all of which have unique isotopic ratios that will prove to be extremely useful when identifying the source of spring water discussed in Chapter 5. Isotopic ratios from river water generally plot near the

Table 2: Stable isotopic data (per mil) from rivers in the study area. Robinson's (1999) samples were collected on 6/26/1998 and Rogers (2006) collected samples on 12/20/2005.

Body of Water	Reference	Delta D	Delta O-18
Logan River at 600 S.	Robinson, 1999	-128	-17.5
Summit Creek at 1700 W.	Robinson, 1999	-126	-17.2
Blacksmith Fork River at Hwy. 165	Robinson, 1999	-131	-17.4
Logan River at mouth of canyon	Rogers, 2006	-130	-17.4
Logan River at mouth of canyon	Rogers, 2006	-130	-17.7
Logan River at mouth of canyon	Rogers, 2006	-131	-17.5
Logan River at mouth of canyon	Rogers, 2006	-132	-17.9
Logan River at mouth of canyon	Rogers, 2006	-129	-17.7
Logan River at mouth of canyon	Rogers, 2006	-131	-17.6
Logan River at mouth of canyon	Rogers, 2006	-133	-17.8

Global Meteoric Water Line (Drever, 1997), and are slightly more negative than most well water values and less negative than precipitation values (Robinson, 1999).

Robinson (1999) also sampled the Logan River and Summit Creek for major ions (Figure 9 and Table 3) and basic chemistry (Table 4). Robinson (1999) found river water to be very similar chemically to ground water in the principal aquifer (Figure 5). This is because rivers recharge the principal aquifer where they flow across the unconfined portion of this aquifer along the eastern margin of the valley.

The plot of concentrations of sodium plus potassium versus calcium plus magnesium shown in Figure 10 also indicates rivers have a unique chemistry compared to canal water and precipitation. Rivers have slightly less sodium plus potassium and calcium plus magnesium than canal water and more calcium plus magnesium and sodium plus potassium when compared to precipitation.

Canal Water

Water from rivers flowing out of the mountains is directed through unlined irrigation canals in Cache Valley, and therefore canal water and river water should have similar chemistries. However, the stable isotopes in canal water sampled by Rogers (2006), which are presented in Table 5 and plotted with other potential sources in Figure 7, plot farther to the right side of the graph than any of the other potential sources. Because canals generally flow more slowly than rivers, and are longer than the stream reaches crossing the study area, greater

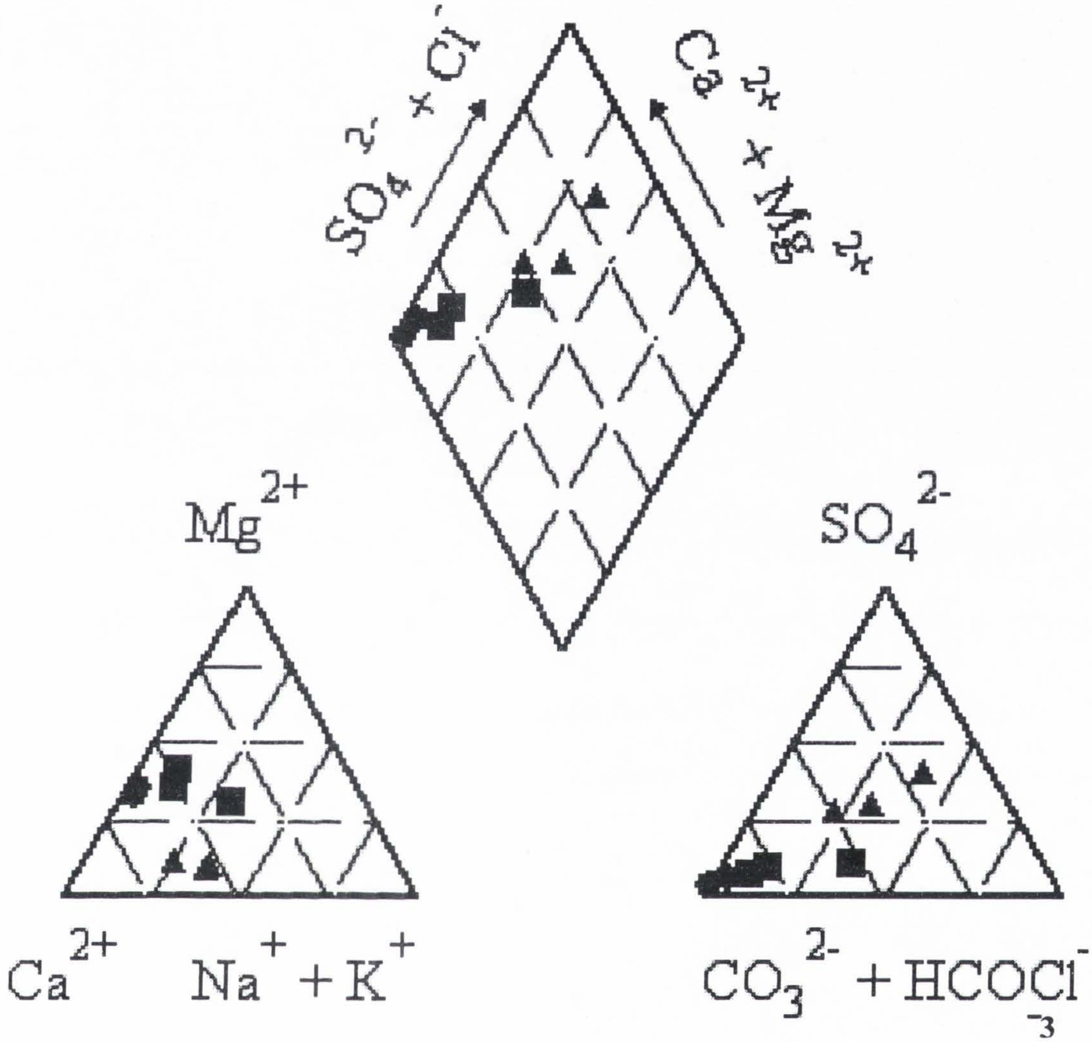


Figure 9: Trilinear plot (Piper, 1944) of major ion concentrations in river water (circles), canal water (squares) (Robinson, 1999), and precipitation (triangles) (NADP, 2006) sampled in the study area.

Table 3: Concentrations (mg/L) of major ions and trace metals detected in river water in the study area (Robinson, 1999).

River	Ca	Cl	Mg	Na	Si	SO4	Sr
Logan River at 600 S.	50.1	3.84	15.6	3.33	2.38	7.53	0.08
Summit Creek at 1700 W.	46.5	<3	15.6	1.98	2.22	4.35	0.06

Table 4: Basic chemistry of river water in the study area (Robinson, 1999).

River	Field pH	Field Alk	Temp (C)	Field EC (µS)
Logan River at 600 S.	8.48	84.2	12.5	252
Summit Creek at 1700 W.	8.49	113	10	219

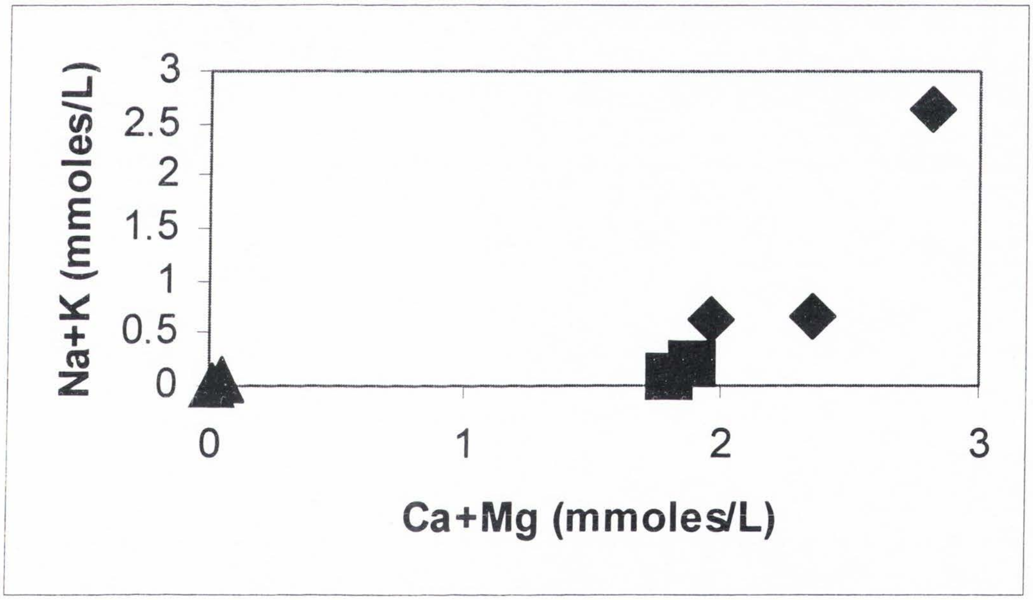


Figure 10: Plot of concentrations of sodium plus potassium versus calcium plus magnesium from river water (squares) (Robinson, 1999), canal water (diamonds) (Robinson, 1999), and precipitation (triangles) (NADP, 2006).

preferential evaporation of the lighter isotopes occurs as a result of canal water being exposed to the atmosphere for a longer period of time.

Robinson (1999) measured basic chemistry in canal water (Table 6). Concentrations of major ions and trace metals from canal water collected in the summer by Robinson (1999) are shown in Table 7 and plotted on a trilinear diagram (Piper, 1944) in Figure 9. These data are different than the river water results from the same study. Canal water has higher concentrations of major ions and trace metals than river water and precipitation, and more than most water samples from wells in the study area, which will be one of the defining characteristics of canal water when determining the source of spring water in Chapter 5. The reason for the unique chemistry of canal water is because springs, precipitation, and road runoff flow into these canals, changing the water chemistry. Canal water was also found to have higher concentrations of major ions and trace metals in the fall than in the summer. The plot of concentrations of sodium plus potassium versus calcium plus magnesium shown in Figure 10 also indicates canal water has higher amounts of sodium plus potassium and calcium plus magnesium compared to precipitation and river water.

Precipitation

Most of the precipitation in this part of Utah comes during the winter months as snow. Spring months are typically wet until June when precipitation becomes less intense and infrequent (WRCC, 2006). There was a drought in Cache Valley from 1988-1994 (except for 1993) and 1999-2003 (NADP, 2006)

Table 5: Deuterium (D) and oxygen-18 (18-O) data (per mil) from canal water in the study area (Rogers, 2006).

Body of Water	Date Sampled	Delta D	Delta 18-O
Northern Canal (near Logan Canyon)	12/20/2005	-122	-16
Northern Canal (near Logan Canyon)	12/20/2005	-124	-16.1

Table 6: Basic chemistry of canal water in the study area (Robinson, 1999).

Field Alkalinity (mg/L)	Field EC (ųS)	Field pH	Temp (C)
102.7	243	8.65	23.2
119.8	*	8.10	*
85.6	*	8.83	*

* The measurement was not taken due to equipment problems.

Table 7: Concentrations (mg/L) of major ions and trace metals from canal water in the study area (Robinson, 1999).

Al	B	Ca	Cl	Fe	K	Mg	Mn	Na	Si	SO4	Sr
<0.00015	<0.2	51.2	16.8	0.00011	<4	26.4	<0.00002	13.9	4.76	14.79	0.20
<0.00015	0.23	62.2	73.7	0.00006	9	30.8	0.00003	55.6	5.89	30.30	0.29
0.00016	1.24	46.6	9.66	0.00013	<4	19.5	0.00002	13.1	4.75	8.73	0.20

(Figure 11) that brought concerns about decreasing spring discharges and made this study desirable.

Chemical data (Table 8) are gathered weekly in the southern part of Cache Valley by the National Atmospheric Deposition Program/National Trends Network (NADP) and are available on their website. Carbonate and bicarbonate concentrations in precipitation samples were not measured by the NADP. Since these values are necessary to plot data on a trilinear diagram, the aquatic chemistry software MINEQL (Schecher and McAvoy, 1998) was used to determine HCO_3 and CO_3 concentrations using the measured chemistry data from NADP, assuming equilibrium with atmospheric CO_2.

Weighted mean concentrations of major ions for the years 2002-2004 presented in Table 8 are plotted on a trilinear diagram (Piper, 1944) in Figure 9, which shows that precipitation has lower concentrations of major ions relative to river water, canal water, and ground water in the principal aquifer (Figure 5) in southeastern Cache Valley. The plot of concentrations of sodium plus potassium versus calcium plus magnesium shown in Figure 10 also indicates precipitation has lower values of sodium plus potassium and calcium plus magnesium relative to river water, canal water, and deep ground water (Figure 6).

Snow samples were collected for stable isotope analysis by Robinson (1999). The results of this analysis are plotted with other potential spring sources in Figure 7 and are presented in Table 9. These values are much different than any other potential spring source, which will aid in the spring water source identification that is discussed in detail in Chapter 5.

Table 8: Concentrations (mg/L) of major and minor ions in precipitation (rain/snow) (NADP, 2006). Values are weighted means from 2002-2004. Bicarbonate (HCO_3) values have been calculated by MINEQL (Schecher and McAvoy, 1998).

Ca	Mg	K	Na	NH4	NO3	Cl	SO4	HCO_3	pH
1.72	0.15	0.092	1.199	0.79	1.13	1.29	1.66	1.07	6.6
0.26	0.029	0.028	0.19	0.7	0.78	0.31	0.38	0.66	6.35
0.45	0.047	0.033	0.193	0.69	0.82	0.31	0.5	1.17	6.56

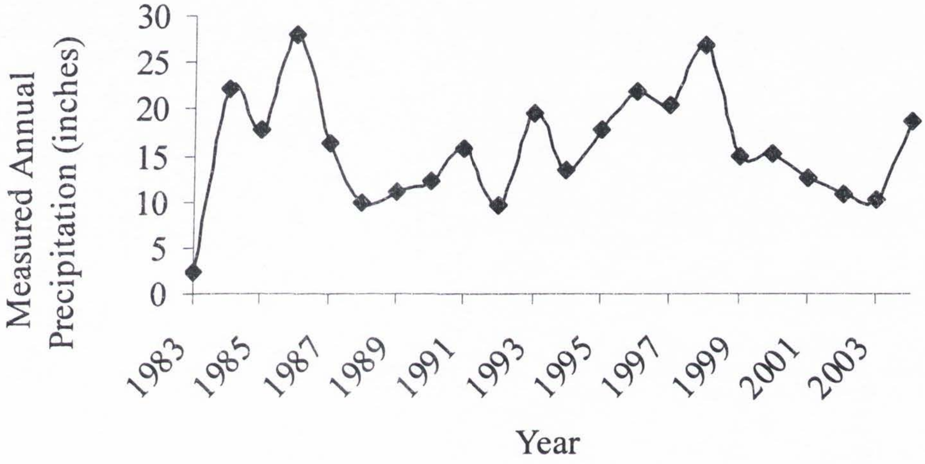


Figure 11: Annual precipitation in Cache Valley from 1983-2004 (NADP, 2006).

Table 9: Deuterium (D) and oxygen-18 (O-18) data (per mil) from snow samples in the study area (Robinson, 1999).

Location	Sample Date	Delta D	Delta O-18
East Hyrum	3/26/1998	-140	-18.8
Avon	3/26/1998	-138	-18.4
Smithfield	3/26/1998	-136	-18.2

Surface Geology and Soil Type at Spring Sites

Most of the springs emerge from the base of the alluvial fan deposits because fine-grained lacustrine sediments underlie these deposits, as shown in Figure 4. There are also a few springs that emerge from the lake clays farther to the west that are recharged mainly from field drains, and also springs that emerge from the deltaic deposits in the eastern portion of the study area (Plate 1).

The surface geology, as described by McCalpin (1989), and soil conditions, as described by Erickson and Mortensen (1974), are defined here and compared to discharge and chemistry data from springs in Chapter 4. Definitions for Quaternary surface geology from McCalpin (1989) are: *lbpm:* Lacustrine silt and clay related to Provo and Bonneville shoreline (upper Pleistocene); *lps:* Lacustrine sand and silt related to Provo and younger shoreline (uppermost Pleistocene); *lpg:* Lacustrine sand and gravel related to Provo and younger shoreline (uppermost Pleistocene); *aly:* Younger stream alluvium, undivided (Holocene to uppermost Pleistocene); *al1:* Stream alluvium (uppermost Holocene); *af1:*Fan alluvium (upper Holocene); *af2:* Fan alluvium (middle Holocene to uppermost Pleistocene); *lpd:* Deltaic deposits related to Provo and younger shoreline (uppermost Pleistocene).

Definitions of soil classifications from Erickson and Mortensen (1974) are: *Ak:* Airport silt clay loam; *Am:* Airport-Salt Lake clay loam; *Cd:* Cardon silty clay; *Ck:* Collett silty clay loam; *GsA:* Greenson loam (0-3% slopes); *GsC:* Greenson loam (6-10% slopes); *GrA:* Green Canyon gravelly loam; *Lr:* Logan silty clay loam; *MeC:* Mendon silt loam; *Pn:* Payson silt loam; *Pu:* Provo loam;

Pv: Provo gravelly loam; *RhA:* Ricks gravelly loam; *Rs:* Roshe Springs silt loam; *Rt:* Rough broken land; *SvB:* Steed gravelly loam; *SwD:* Sterling gravelly loam (10-20% slopes); *SwF2:* Sterling gravelly loam (20-50% slopes, eroded); *TtA:* Trenton silty clay loam; *Wn:* Winn silt loam; *WIE2:* Wheelon-Colliston complex; *Wp:* Winn-Provo complex.

Spring Chemistry Data from Previous Studies

Robinson (1999) analyzed Spring Creek #1 (Spring 57) and Hopkins Spring (Spring 224) for major ions and the stable isotopes deuterium and oxygen-18. He did not measure any discharges. Major ions from these springs are included in Table 10 but are not plotted on the trilinear (Piper, 1944) diagram (Figure 12) because alkalinity was not measured and is important for that plot. The stable isotopic ratios of spring water sampled by Robinson (1999) are presented in Table 11 and plotted along with the results from wells, river water, canal water and precipitation in Figure 7. The results from the two springs sampled in 1999 plotted to the left of the GMWL.

DeVries (1982) looked at two springs in this study area: Springs 1 and 92. The landowner of Spring 1 was not willing to allow access to his spring for this study. Spring 92 could not be located, perhaps because it was diverted with drain tiles or even dried up. Chemistry data from these two springs are also included in Table 10.

Bjorklund and McGreevy (1971) sampled several springs in this study area as well as springs in other parts of Cache Valley. Every spring that was in

Table 10: Concentrations (mg/L) of major and minor ions and trace metals from springs sampled by previous researchers.

					Specific		Hardness					
Spring #	Location	Reference	Temp.	pH	Conductance	TDS	(as CaCO3)	HCO3	CO3	Al	B	Ca
1	(A-10- 1) 3aba	DeVries (1982)	NA	6.7	NA	358	NA	190	NA	NA	NA	87
50	(A-11- 1) 15bbc	McGreevy and Bjorklund (1970)	NA	8.3	596	354	326	348	8	NA	0.02	74
57	(A-11-1) 17bbc	Robinson (1999)	*	8.1	*	NA	*	NA	NA	<0.00015	<0.2	61.3
59	(A-11- 1) 18bdd	McGreevy and Bjorklund (1970)	11	8.2	553	330	290	300	0	NA	0.04	66
68	(A-11- 1) 23cda	McGreevy and Bjorklund (1970)	12	7.9	465	275	251	280	0	NA	0.04	54
91	(A-11- 1) 34dcb	McGreevy and Bjorklund (1970)	NA	7.8	605	345	322	366	1	NA	0	88
92	(B-11- 1) 12aaa	DeVries (1982)	NA	NA	NA	208	188	NA	NA	NA	NA	NA
103	(A-12- 1) 4bab	McGreevy and Bjorklund (1970)	NA	8.3	888	512	428	448	12	NA	0.01	90

Spring #	Cl	F	Fe	K	Mg	Mn	Na	NO3	SiO2	SO4	Sr
1	11	NA	0	1.2	13	NA	10	NA	NA	9	9
50	8.6	0.3	NA	1.2	35	NA	7.2	14	11	24	NA
57	30.5	NA	1E-04	<4	29.1	3E-05	22	NA	8.6	33.9	0.22
59	9.5	0.5	NA	1.9	31	NA	10	2.5	9.2	51	NA
68	6.5	0.2	NA	0.7	28	NA	4.8	2.8	7.3	29	NA
91	11	0.1	0.02	2	25	NA	8.7	5.2	13	11	NA
92	NA	NA	0.03	NA	NA	NA	NA	NA	NA	6.4	6.4
103	60	0.3	NA	4.6	50	NA	31	17	14	13	NA

NA: Not analyzed

* The measurement was not taken due to equipment problems

Table 11: Deuterium (D) and oxygen-18 (^{18}O) data (per mil) from springs in the study area (Robinson, 1999).

Spring #	Spring Name	Delta D	Delta O-18
57	Spring Creek #1	-124	-17.3
224	Hopkins Spring	-120	-16.8

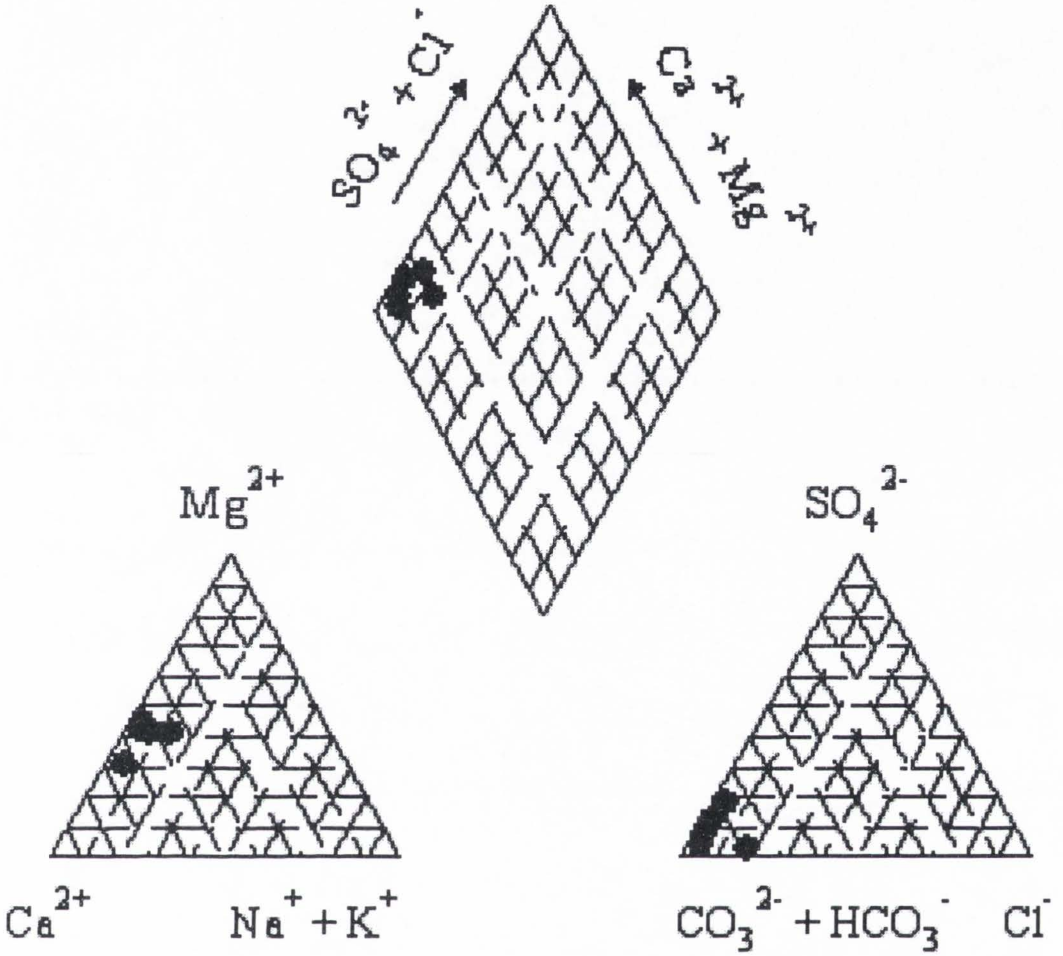


Figure 12: Trilinear (Piper, 1944) plot of major ion concentrations from springs in the study area (McGreevy and Bjorklund, 1970).

the study area was revisited in May or June of 2005. Major ion and trace metal concentrations from McGreevy and Bjorklund (1970) are presented in Table 10 and Figure 12, and discharge data from both studies are presented in Table 12. Springs 2, 68, 103, 127, 199, and 205 were no longer present at the locations given by McGreevy and Bjorklund (1970).

One possible reason for springs no longer being present in some areas is that the landowners have used drain tiles to drain the spring water, allowing for more useable land. Springs 124, 128, 126, 127, and 132 were all within approximately 100 yards of each other at some point. Spring 132, reported to have a large discharge on the water right, was just a trickle in May of 2005. The other four springs could not be found. A nearby landowner said there used to be a large spring there approximately 30 to 40 years ago, but it has since been drained using drain tiles. It is likely that at least some of this water now discharges into the pond where Springs 129, 130, and 131 are located and also to the canal that is a few hundred yards west of where these springs used to be.

Another possible reason for springs no longer being present is man-made environmental changes. The landowner where Spring 19 used to be located said he had recently filled in that spring by bringing in coarse fill material so that he would have more useable land. This spring was not looked at by previous studies, but is just an example of a spring being filled in to suit development.

Figures 13 and 14 are plots of ionic ratios from springs sampled by McGreevy and Bjorklund (1970), DeVries (1982), and Robinson (1999). Concentrations of sodium plus potassium versus calcium plus magnesium are plotted in Figure 13, and chloride versus sodium plus potassium are plotted in Figure 14. These data are compared to ionic ratios in spring water and discussed farther in Chapter 4.

Table 12: Historical discharges (gallons per minute (gpm)) from springs in the study area (McGreevy and Bjorklund, 1970), and the discharge/status of those springs in May/June of 2005 (* indicates that observation was made in the summer of 2004).

#	Location	Discharge from McGreevy and Bjorklund (1970)	Q (gpm)/status in May/June 2005
2	(A-10- 1) 3bbb	300 (measured)	Spring has dried up*
46	(A-11- 1) 10ccd	1,530 (measured)	674.6*
49	(A-11- 1) 14ccd	none given	Cannot get landowner's permission
50	(A-11- 1) 15bbc	1,800 (reported)	230.9*
57	(A-11- 1) 17bdb	2,430 (measured)	2,046
58	(A-11- 1) 18bcd	2,700 (estimated)	3,736
59	(A-11- 1) 18bdd	2,700 (estimated)	Flows into #58 (Spring Creek #3)
68	(A-11- 1) 23cda	1,570 (measured)	Area inaccessible; possibly capped
91	(A-11- 1) 34dcb	250 (reported)	City of Nibley water supply
95	(B-11- 1) 13aab	450 (measured)	160.2
103	(A-12- 1) 4bab	2,600 (reported)	No flow
127	(A-12- 1) 23cdd	none given	Cannot verify; bio-restricted area
129	(A-12- 1) 26bab	none given	28.6
132	(A-12- 1) 26abb	none given	Diffuse flow
147	(A-12- 1) 29cac	3,600 (reported)	Not possible to measure
148	(A-12- 1) 29cda	none given	75
198	(A-13- 1) 29bab	1,000 (estimated)	127.5
199	(A-13- 1) 29acb	1,000 (estimated)	No flow
200	(A-13- 1) 29bac	1,000 (estimated)	31.4
202	(A-13- 1) 29bca	1,000 (estimated)	Found in conjunction with #201
203	(A-13- 1) 29bcd	150 (reported)	337.9
204	(A-13- 1) 29bdc	450 (reported)	6.35
205	(A-13- 1) 29bdc	1,000 (estimated)	Cannot verify

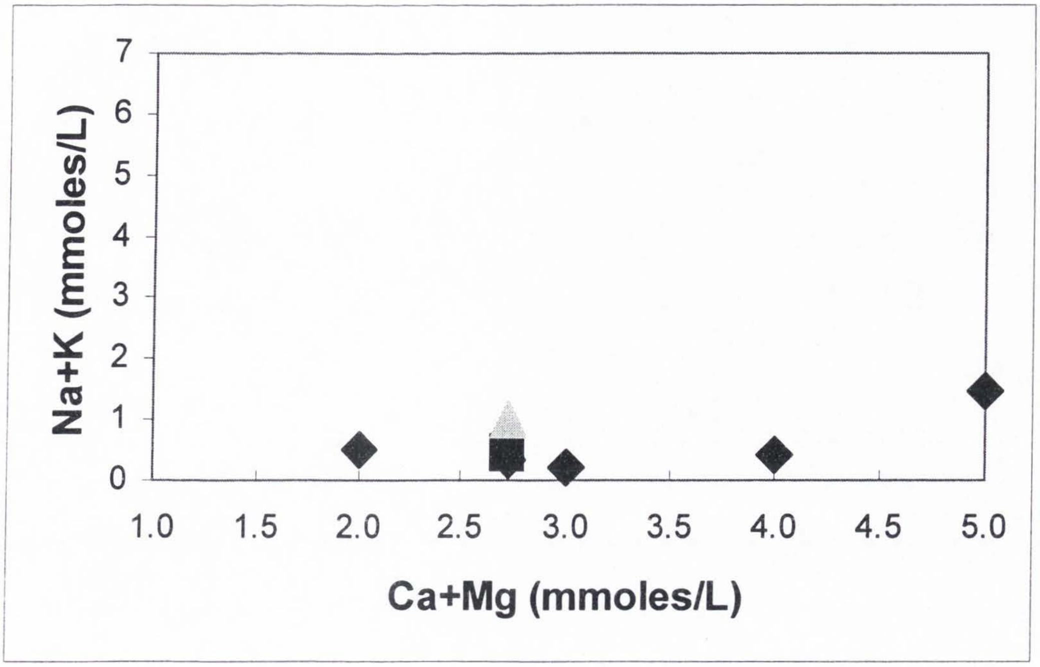


Figure 13: Plot of concentrations of sodium plus potassium versus calcium plus magnesium from springs sampled by previous researchers. Diamonds are spring sampled by McGreevy and Bjorklund (1970), the square is a spring sampled by DeVries (1982), and the triangle is a spring sampled by Robinson (1999).

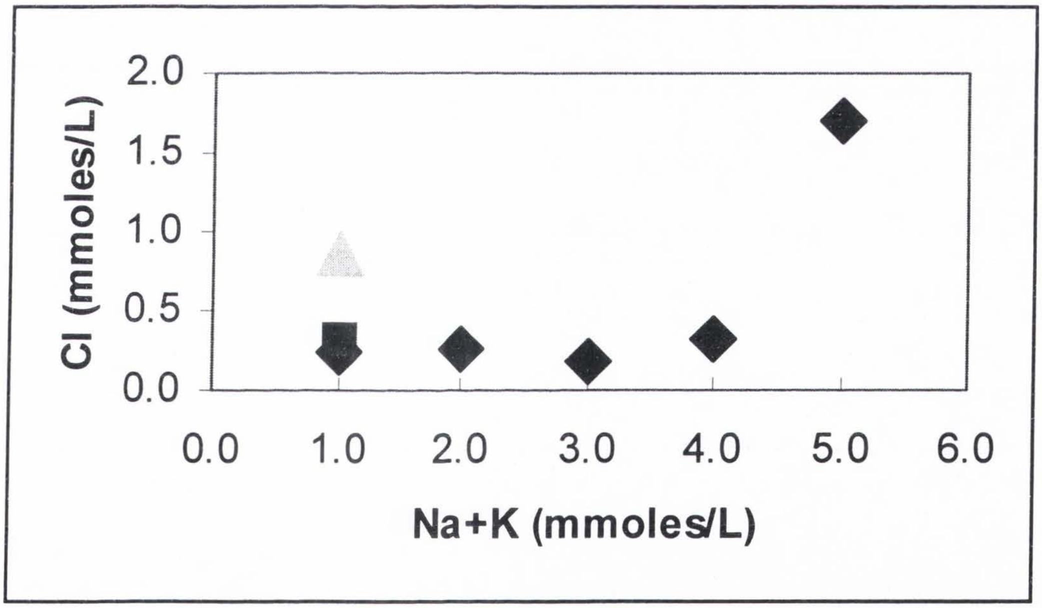


Figure 14: Plot of concentrations of chloride versus sodium plus potassium from springs sampled by previous researchers. Diamonds are spring sampled by McGreevy and Bjorklund (1970), the square is a spring sampled by DeVries (1982), and the triangle is a spring sampled by Robinson (1999).

CHAPTER III

METHODS

Spring Selection Process

Numerous springs have been identified and used in previous studies on the ground water in Cache Valley (McGreevy and Bjorklund, 1970; Bjorklund and McGreevy, 1971; DeVries, 1982; Robinson, 1999). Each of these springs was visited during this study to confirm its existence. Aerial photographs and U.S. Geological Survey 7.5-minute topographic quadrangles were used to locate springs that may not have been described previously. Also, a list of 225 springs that have had water rights filed on them was obtained from the Cache Valley office of the Utah Division of Water Rights, and each was visited in the field after gaining the landowner's permission. The location and status of each of these springs are presented in Appendix A. Some of these springs no longer exist for various reasons. One hundred nine springs were located in the field, and their discharge/status and basic chemistry are presented in Appendix B. These springs had discharges ranging from no flow to over 4,000 gallons per minute (gpm).

Since it was possible that different springs in the valley would have different recharge sources, this study attempted to monitor as many springs as possible to accurately characterize their sources and the potential for reductions in discharge. All springs that did not have canals, rivers, or flowing wells draining into them (46 total) were chosen for analysis of major ions and 36 of those were chosen for monthly discharge monitoring. The names and numbers of the 53 springs for which discharges were monitored and/or samples were collected for chemical analysis are presented in Table 13.

Most spring names listed in this study were taken directly from either the spring name or the owner of the spring as they appear on the water right obtained from the Utah Division of Water Rights. If these were not given, the last name of the landowner was used if it was provided while asking permission to gain access to the spring. In a few cases, it was necessary to use a name based on the spring's location or some other feature. Also, north and south were added to existing spring names when multiple springs were encountered.

Numbers were assigned to springs after organizing their Township and Range abbreviations from south to north in increasing order. If multiple springs were found associated with one water right or in an area with only one number assigned, a letter was used after the number to represent that spring so that a previous spring with the next consecutive number would not be duplicated.

Spring Site Descriptions

All springs that were sampled and analyzed for major ions, isotopes, and/or monitored for discharge are discussed in this section. A description of the site where these measurements were made is given for

Table 13: Location, name and work performed at each spring in this study. Q: discharge monitoring was done; MI and TM: major ions and trace metals were analyzed; D/^{18}O: deuterium and oxygen-18 were analyzed; ^{3}H: tritium was analyzed.

Number	Name	Location	Q	MI and TM	D/^{18}O	^{3}H
13	John Nielsen Spring	(A 10 1) 4 acc	Yes	Yes	No	No
14	West Camp Hollow Spring	(A 10 1) 4 aba	Yes	Yes	Yes	No
23	Libbie Spring	(A 10 1) 6 ada	Yes	Yes	Yes	Yes
35	Hansen Spring	(A 11 1) 4 cdc	Yes	Yes	No	No
36	Parker Spring	(A 11 1) 5 cdc	Yes	Yes	Yes	Yes
37	Davis Spring	(A 11 1) 5 bbc	Yes	Yes	No	No
38	S.W. Field Irr. Co. Spring	(A 11 1) 6 ada	Yes	Yes	No	No
39	Fredrick Spring	(A 11 1) 7 daa	Yes	No	No	No
44	Ditch Spring	(A 11 1) 10 dda	Yes	Yes	Yes	No
46	Little Ballard Spring	(A 11 1) 10 ccd	Yes	Yes	No	No
46a	Little Ballard Inlet	(A 11 1) 10 ccd	No	Yes	No	No
47	Banellis Spring	(A 11 1) 11 cba	Yes	Yes	No	No
50	Big Ballard Spring	(A 11 1) 15 bbc	Yes	Yes	No	No
56	Campbell Spring	(A 11 1) 17 add	Yes	Yes	Yes	No
57	Spring Creek #1	(A 11 1) 17 bbc	Yes	Yes	No	No
58	Spring Creek #3	(A 11 1) 18 bbd	Yes	Yes	No	No
60	Del Hansen Spring	(A 11 1) 18 dbb	Yes	Yes	Yes	Yes
71	John Scheiss Spring	(A 11 1) 28 dbc	No	Yes	Yes	No
87	House Spring	(A 11 1) 34 caa	No	Yes	No	No
89	Barn Yard Spring	(A 11 1) 34 dbc	Yes	Yes	Yes	Yes
93	South Blue Spring	(B 11 1) 13 dbc	Yes	Yes	No	No
95	Spring Creek #4	(B 11 1) 12 ddc	Yes	Yes	No	No
105	Park Spring	(A 12 1) 11 bab	No	Yes	Yes	No
114	North Bodrero Spring	(A 12 1) 20 abd	Yes	No	No	No
130	Sheep Spring	(A 12 1) 26 bab	Yes	No	No	No
134	Snider Spring	(A 12 1) 29 bab	Yes	Yes	No	No
145	Jensen Spring	(A 12 1) 29 ccd	Yes	No	No	No
147	Tree Spring	(A 12 1) 29 cac	No	Yes	Yes	Yes
149	North Blue Spring	(A 12 1) 29 acb	Yes	Yes	No	No
153	Thalman Spring	(A 12 1) 32 bbb	No	Yes	No	No
158	Road Spring	(A 12 1) 32 dab	Yes	Yes	Yes	No
159	Merrill Spring	(A 12 1) 32 dbd	Yes	Yes	No	No
163	Johnson Spring	(A 12 1) 34 acd	Yes	Yes	Yes	No

Table 13: (continued)

Number	Name	Location	Q	MI and TM	D/^{18}O	^{3}H
164	Blair Spring	(A 12 1) 34 add	Yes	Yes	Yes	Yes
172	North Corbett Spring	(A 13 1) 15 dac	Yes	Yes	No	No
173	Nelson Spring	(A 13 1) 15 dbc	No	Yes	No	No
182	Joseph Smith Spring	(A 13 1) 17 dca	Yes	Yes	No	No
187	William Smith Spring	(A 13 1) 20 aba	Yes	No	No	No
188	Mathers Spring	(A 13 1) 20 cca	Yes	Yes	Yes	No
188a	Mathers Spring Outlet	(A 13 1) 20 cca	Yes	No	No	No
189	Corbett Spring	(A 13 1) 20 caa	Yes	Yes	No	No
192	North Hansen Spring	(A 13 1) 20 abc	No	Yes	Yes	Yes
192a	North Hansen Spring Outlet	(A 13 1) 20 abc	No	Yes	No	No
198	North Erickson Spring	(A 13 1) 29 bab	Yes	Yes	Yes	No
200	Anderson Spring	(A 13 1) 29 bac	Yes	Yes	Yes	Yes
201	Outlet Spring	(A 13 1) 30 ada	Yes	No	No	No
203	South Erickson Spring	(A 13 1) 29 bcd	Yes	Yes	Yes	Yes
212	Low Spring	(A 13 1) 29 cda	Yes	Yes	Yes	Yes
215	Soreson Spring	(A 13 1) 29 cdb	Yes	Yes	No	No
219	Hammer Spring	(A 13 1) 29 cac	No	Yes	No	No
221	Gittens Spring	(A 13 1) 29 ccd	Yes	Yes	No	No
222	Small Seep Spring	(A 13 1) 29 bdc	Yes	Yes	Yes	No
224	Hopkins Spring	(A 13 1) 32 adc	Yes	Yes	Yes	No

each spring and is to be used with Plate 1. Reports from landowners have provided useful anecdotal evidence that also is described in this section.

John Nielsen Spring (13). This spring is located in the city of Hyrum and flows out of a pond that sits on deltaic deposits, which suggests this spring would be gaining water from excess irrigation water, precipitation, and/or canal water. The landowner modified this spring in 2004 by digging out the area where the spring emerged and creating the pond from which the water currently flows.

West Camp Hollow Spring (14). This spring also flows from delta deposits in the city of Hyrum, which suggests this spring would be gaining water from excess irrigation water, precipitation, and/or canal water. The landowner of this spring said it has been constant since settlement, which suggests that ground water from the principal aquifer recharges this spring. There is a cistern next to the road where the water emerges. The water then flows into a pond in a residential back yard. Discharge measurements were taken at the 8-inch corrugated galvanized steel culvert that drains the pond to the north. Reports from surrounding landowners indicate this spring was present during the settlement of Cache Valley in the mid- to late-1800s and its discharge has not fluctuated for as long as anyone can remember. Drain tiles were installed, according to the landowner, to make the water flow out at one particular location.

Libbie Spring (23). Libbie Spring emerges in the middle of an alfalfa field, just below the deltaic deposits, which suggests this spring would be gaining water from excess irrigation water, precipitation, and/or canal water. According to McCalpin (1989) it is on lacustrine sand and silt related to Provo and younger shorelines. There is an 8-inch concrete field drain that the water flows out of and into a vertical, approximately 30-inch diameter corrugated galvanized steel culvert. Some of the water was flowing around the steel culvert as well as through it, so discharge measurements should be considered minimum values.

Hansen Spring (35). Hansen Spring emerges from under a pond located immediately west of 500 West on the Logan Golf Course driving range. The pond drains through a 24-inch corrugated plastic culvert that drains west, under the driving range. There are a large number of branches from nearby trees blocking the flow and making measurements difficult. Also, there is the potential hazard of being next to water that is several feet deep and having golf balls being hit in one's direction.

Parker Spring (36). Parker Spring is in the middle of a pasture that has residential development to the east and north. Water flows into a series of man-made ponds from an 8-inch concrete culvert.

Davis Spring (37). Davis Spring emerges from under a pond, and the outlet was accessed from the house to the north. The outlet flows through a vegetation-choked channel, and the area surrounding it is extremely muddy from the spring water year round.

South West Field Irrigation Company Spring (38). This spring emerges from an area that is extremely wet year around. Measurements were made where the outlet flows under 1900 West.

Fredrick Spring (39). Fredrick Spring emerges from under a pond just south of the canal that parallels that section of the Logan River. This area is extremely boggy, and it is not possible to measure in the summer because of the canal water backing up into the pond. Water samples for major ion analysis were not collected for this reason.

Ditch Spring (44). Ditch Spring is located just east of 100 East and 300 South in the city of Providence. A water sample was collected where the water emerges from the ground, and discharge measurements were made at the culvert on the west side of the road.

Little Ballard Spring (46 and 46a). There is an 8-inch concrete culvert contributing to the flow of Little Ballard Spring, as well as water flowing in from under the pond. Isotope and major ion water samples were taken from the 8-inch culvert. This is identified as Spring 46a. The discharge of the pond, which was much greater than that from the concrete culvert, was measured in the dairy pasture before the stream crossed the highway. There is a small pump and a board that goes across the channel where discharge measurements were made and samples for major ion chemistry were collected. This is identified as Spring 46. The landowners directly north of the pond stated the discharge from the pond decreased significantly after the housing development to the east was built and the city sewer was installed, which was during a drought in Cache Valley. These data suggest the shallow, unconfined aquifer recharges these springs.

Banellis Spring (47). Banellis Spring flows out of a concrete box that was perhaps at one time a cistern. It is located approximately 50 feet south of 100 South in Providence. Discharge was measured several feet downstream from the outlet of the small pond and water samples were taken at the concrete box.

Big Ballard Spring (50). There is no visible inlet to the large pond where the spring is located. Discharge measurements and water samples were taken at the head gate at the west outlet. Water flowed over and through the boards on the head gate but only the water flowing over was measurable. The water flowing through probably can be assumed to be constant, making changes in discharge accurate. This spring all but stopped flowing towards the end of the drought that lasted from 1988-1994 (except for 1993) and 1999-2003 (NADP, 2006), but water remained in the pond, which suggests the shallow, unconfined aquifer recharges this spring.

Campbell Spring (56). Campbell Spring is located in the center of a pasture. There is a vertical, wooden barrel, approximately 12 inches in diameter, where the water emerges from the ground. It was put in decades ago by the landowner to keep the water flowing out of the same spot. A small diameter pipe that is a few feet long drains the water out of the wooden barrel. Discharge measurements and chemical samples were taken where the water flows out of this pipe. The landowner said this spring has been around for as long as he can remember and has always had the same, steady discharge. He also said he has never needed to irrigate his hay field where the spring is located.

Spring Creek #1 (57). This spring emerges from beneath a large pond located just west of a trailer park on Highway 89/91. Major ion samples were taken at the outlet of this pond, but since the head gate had more water flowing through it than over it, discharge measurements were made farther downstream where it crosses under a gravel road located at approximately 1800 West.

Spring Creek #3 (58). This area was drastically modified in the past when there was a fish farm there. The only structures left from that time are the head gates and fish runs. The water flows out of the pond and under the earth dam for approximately 50 feet before it flows into the fish runs. Discharge was measured and major ion samples were taken at the heads of the two fish runs and were added together to determine the total discharge.

Del Hansen Spring (60). The first few discharge measurements were made and ion and isotope samples were taken in the middle of the pasture, next to a fence where the water emerged from an 8-inch concrete culvert. Between August and October of 2005 the spring area was trampled by cattle, disrupting the flow, and making discharge measurements impossible. In November, water was found seeping up from the ground approximately 30 feet south of 2200 South, and then flowing through a dilapidated culvert under the road. Discharge monitoring was done at this location for the remainder of the study. Discharges measured at this spring prior to November were not used for this reason.

John Scheiss Spring (71). This spring emerged on the east side of the canal in the ranch pasture. Water flowed over an area a few feet wide, but was only a few inches deep before entering the canal. Discharge measurements were not possible, but ion and isotope samples were collected.

House Spring (87). This spring emerged from the deltaic deposits exposed in the Hollow Road area, which would suggest excess irrigation water, precipitation, and/or canal water would be the source of recharge to this spring. The water flowed into a steel tank that held water for use at the dairy next to the spring. Samples were collected and the discharge was measured in May of 2005, but discharge measurements were not continued and samples were not analyzed for isotopes because this spring is so close to Spring 89, which was more accessible.

Barn Yard Spring (89). This spring is accessed by driving through the farm to the northeast of the spring and heading south on the road that goes up the hill for about 50 yards. Park where the canal goes under this road and walk straight up the hill to the cistern. Water flows out of deltaic deposits and into a cistern where the water was sampled, and the discharge flowing from the cistern was added to the discharge flowing from a 1-inch plastic pipe to determine the total discharge. Since this spring emerges from deltaic deposits, it is likely excess irrigation water, precipitation, and/or canal water would be the source of recharge to this spring. Many of the spring owners in this area said their springs' discharges increased when the fields above the hill were irrigated. The ones we measured were nearly constant year round. There were two other large springs (Springs 1 and 90) that landowners would not give us permission to measure because they were afraid it would somehow adversely affect their water rights.

South Blue Spring (93). This spring emerges from under a pond that is in the middle of a large dairy operation. Discharge was measured and water samples were taken at the outlet, before the discharge crossed under the driveway. There are two other springs in that dairy, but the middle one had very little flow and the spring farthest to the south had an outlet that was choked with branches and had two canals flowing into it.

Spring Creek #4 (95). Spring Creek 4 emerges from under a pond on the north side of 1800 South and the outlet flows under the road. Discharge was measured and water samples were taken at the outlet on the south side of the road. Two 8-inch concrete field drains were found flowing into the pond on the north side after water samples from the outlet had been analyzed. The spring owner said these drained the fields to the north and northeast and that the spring decreased in discharge dramatically after a Providence city sewer line was installed to the east, which suggests the shallow, unconfined aquifer is the source of recharge to this spring.

Park Spring (105). This spring emerged from a hillside in the small park in the town of Hyde Park. Discharge was not monitored because of the low flow, which ceased altogether in August of 2005, which suggests precipitation and/or river water recharge this spring.

North Bodrero Spring (114). This area has many springs, and the discharges of most of them are difficult to measure because of diffuse flow and ditches flowing into the area. North Bodrero Spring emerges from under a pond about a hundred yards east of the location where discharge was measured. The water flows from the first pond into the second, and discharge measurements and water samples were taken at the outlet of the second pond. The head gate was closed for flood irrigation for a few months during monitoring, which is why samples for chemistry were not taken. The landowner said the springs in this area were changed when a Logan city sewer line was put in several years before, which suggests the shallow, unconfined aquifer is the source of recharge to this spring.

Sheep Spring (130). There are three inlets to this pond (Springs 129, 130, and 131), which is located in the middle of Utah State University's sheep pasture. Major ion and isotope samples were not collected from this area because the head gate was closed all summer to allow water to be pumped out for sprinkler irrigation. When monitoring resumed in the fall, discharge was measured at the outlet only, partly because the fence and steep slope around the pond was potentially dangerous with snow on the ground.

Snider Spring (134). This spring is accessed by going through the farm to the north of the pond and walking south behind the large hay barn. There are two ponds that have spring water emerging underneath them. Discharge was measured where the outlet of the second pond flows under a driveway in the pasture.

Jensen Spring (145). Jensen Spring is in the middle of a cow pasture. It emerges under a large pond and discharge measurements were made at the outlet where it flows through a culvert under a driveway. There is a ditch that drains into the east end of the pond. The ditch drains a small flowing well as well as the boggy field to the east and south of the pond. This inlet was not flowing when water samples were taken.

Tree Spring (147). The area around Tree Spring has many ponds, flowing wells and small ditches flowing into larger ditches. Discharge from springs in this area could not be sorted out from the other sources. However, Tree Spring had a green plastic pipe flowing into the east end of the pond. There was a large amount of water flowing out of this pipe but because it hung over the water a few feet past the shore of the pond, discharge measurements were not possible. Basic chemistry was measured at this pipe.

North Blue Spring (149). North Blue Spring emerges from under a pond directly west of Gossner's Cheese factory. The outlet flows into another pond and then under a gravel road located at approximately 1200 West. Measurements were made at the culvert where the large, upper ponds flow into the small, lower pond.

Thalman Spring (153). Thalman Spring emerges from under a pond on the south side of 600 North, just east of the gate to the city sewer ponds. The discharge from a ditch flowing into the east end of the pond from the north was subtracted from the discharge measured at the outlet to the south. Major ion water samples were taken from the east end of the pond in an attempt to minimize the amount of ditch water in the water sample. This spring was not monitored because the outlet to the pond was backed up from flood irrigation between August and November of 2005.

Road Spring (158). This spring is located where the Utah Department of Transportation roadwork vehicles are kept. This area is fenced in and only accessible during state working hours. Road Spring emerges in the southwest corner of this fenced in area. Measurements were made several feet away from the location where water emerges from the ground.

Merrill Spring (159). Merrill Spring emerges from under a pond in the northeast corner of a pasture. Measurements were made at the outlet of a small pond that flows under a field driveway.

Johnson Spring (163). Johnson Spring emerges from the west hillside next to, as well as under, the pond in the back yard of the house south of the Northern Canal. Water samples were collected where the spring seeps out of the hillside, and discharge was measured at the outlet to the north. Since this spring emerges from deltaic deposits, it is likely excess irrigation water, canal water, and/or precipitation are the source of recharge to this spring.

Blair Spring (164). This spring is located a few hundred yards down the foot trail that follows the south edge of the Northern Canal. There are dozens of springs flowing from just north of the Northern Canal, especially in the spring months. Blair Spring is the first one that flows out of a pipe that sticks out of the hillside. Water also flows on the ground around the pipe, so discharge measurements should be considered minimum values. Since this spring emerges from deltaic deposits, it is likely excess irrigation water, canal water, and/or precipitation are the source of recharge to this spring.

North Corbett Spring (172). This spring is up a four-wheel drive vehicle road that goes through a pasture, immediately west of the Bear River Range. The water flows into a bathtub that acts as a water trough. Measurements were made at the plastic pipe that is the overflow from the bathtub. According to the landowner, this spring did not flow for many years after the Richmond earthquake in 1962 (UUSS, 2006). Based on the chemistry and location, and since it only flowed for the first few months of monitoring, it is most likely a bedrock spring.

Nelson Spring (173). Nelson Spring emerges in an underground tank in the middle of a farm. The water from this spring is used as a water source for this family farm. Measurements were made at the overflow from the underground tank. Based on the location and chemistry of this spring, it is likely a bedrock spring.

Joseph Smith Spring (182). Joseph Smith Spring is located farther north than any spring included in this study. It emerges from under a large pond and measurements were made at the outlet to the west.

William Smith Spring (187). There are multiple small inlets on the east side of the large pond that the main spring emerges under, making analysis for major ions not meaningful. There is also a large flowing well discharging directly into the pond. The small spring inlets slowed to nearly nothing after the spring months. Basic chemistry was measured at the pond outlet to the west.

Mathers Spring (188 and 188a). Mathers Spring originates from an 8-inch concrete field drain, as well as under a pond that this field drain flows into. Discharge measurements were made and water samples were collected at the field drain identified as Spring 188. Discharge monitoring at the outlet of the pond was numbered Spring 188a.

Corbett Spring (189). Measurements were made at the outlet of the large pond where the driveway that heads south off 6600 North crosses over the outlet of the pond. The south hillside of the pond was extremely boggy and there were two small springs flowing into the pond from the east.

North Hansen Spring (192 and 192a). Spring 192 emerges from an 8-inch concrete field drain on the east side of the gravel road and flows into the pond on the west side of the road. Chemistry measurements were made at the field drain. Spring 192a was the discharge out of the pond on the west side of the road. Discharge was not monitored because of the small size of this spring and because of its location close to other larger springs.

North Erickson Spring (198). North Erickson Spring is accessed by going south across the lawn of the only house in that area and following the fence line to a large pit in the ground. Measurements were made at the field drain that flows into the pit from the east. The pit is drained to the south and most likely flows into the Mountain Valley Trout Farm ponds.

Anderson Spring (200). This spring flows from an 8-inch field drain that is a few feet away from a large flowing well, both of which flow into a pond and provide part of the water for the Mountain Valley Trout Farm. It is located at the northeastern corner of the trout farm's land and can be found by following the northernmost trout run to the east.

Outlet Spring (201). This "spring" is actually the outlet of the Mountain Valley Trout Farm, which is the sum of several springs and flowing wells that provide water to the trout farm. Measurements were made at the end of the pasture road, directly west and below the hill from the trout farm.

South Erickson Spring (203). This spring is located approximately 30 feet north of the highway. It emerges from under a pool that is approximately 5 feet in diameter and a few feet deep. Measurements were made on the west part of the pool where the water flows out and into a field drain.

Low Spring (212). There are two separate field drains that discharge next to each other about 30 feet off the west side of the road.

Their waters flow into one channel and measurements were made a few feet below the drains.

Sorenson Spring (215). This is the first pond a few hundred yards north of Gittens Spring (221). Measurements were made where the first moderately sized pond flows into another pond, which then flows into a ditch that flows into Summit Creek. During the spring months, this whole area is extremely boggy and it takes a few months before snowmelt and precipitation evaporate and/or infiltrate.

Hammer Spring (219). This spring is located several feet south of the bank of Summit Creek. Discharge and chemistry were measured at the culvert that flows under the riverbank and into the river. This spring was not monitored because the landowner plugged the outlet to allow for flood irrigation throughout the summer.

Gittens Spring (221). This spring emerges beneath a large pond and the outlet is to the west. Measurements where made were the outlet flows through a corrugated steel culvert and down into what looks to be the natural drainage of the pond.

Small Seep Spring (222). This spring can be found by following the middle trout run east at the Mountain Valley Trout farm. The last pond up that run has water flowing out of the entire eastern hillside, but there are two channels for which it is possible to measure discharge. The discharge from this spring was the sum of the discharges from these two seeps, and water samples were taken from the south seep only because it is the larger of the two.

Hopkins Spring (224). This spring flowed out of a steel pipe that is approximately 75 yards north of the house at the corner of 800 West and 5000 North. Measurements were made at the pipe. The spring owner said the discharge has not changed since he can remember, which suggests the principal aquifer is the source of recharge to this spring.

Discharge Measurements

Discharges were measured at every spring in the study area that had measurable flow during the first field visit in May or June of 2005 (Appendix A). Several springs also had discharges measured during the summer of 2004 and those are noted with an asterisk in Appendix A. Table 13 provides a list of the names and locations of the springs monitored for discharge and sampled for chemistry. Every attempt was made to measure the discharge at the exact same location each month. A 2-liter or 5-gallon bucket and a stopwatch were used to measure the discharges of springs that were too shallow for the flow meter to measure. Those springs that had a deep enough channel (depth greater than 3 inches) were measured by placing a FLO-MATE Model 2000 portable flow meter in the center of the channel at 6/10$^{\text{ths}}$ the total depth whenever possible. This technique gives the average velocity of the flow in the channel, which is multiplied by the measured cross sectional area of the channel to get the discharge (Rantz et al., 1982).

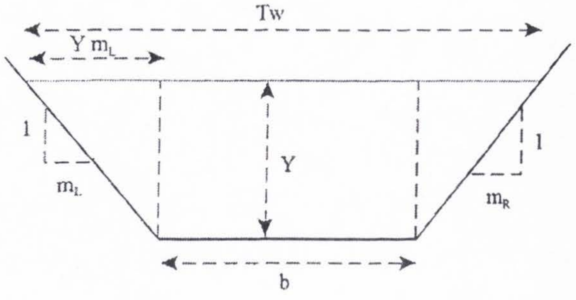
When discharge was measured in a culvert, the depth of water in the center of the culvert, the diameter of the culvert, and the velocity of the water at 6/10^{ths} the total depth were used to calculate discharge using the formulas shown in Figure 15 (Crowe et al., 2001). Three springs (50, 58, and 182) had water flowing through small cracks as well as over their head gates. It was only possible to measure the discharges flowing over the head gates for these particular springs. However, flow through the small cracks can be considered nearly constant, and therefore the changes in discharge would be accurate. However, errors in discharge measurements may have occurred when measuring the cross-sectional area because of irregularly shaped channels due to the poorly sorted sediment on the bed of the channel. There is also a 2% error possible from the flow meter.

Hydrochemistry

Spring water chemistry was analyzed for comparison with shallow ground water, deep ground water, precipitation, river water, and canal water chemistry from previous studies to aid in determining the source of recharge to the springs. The chemistry of each spring was also compared to other springs to look for any indication of unique recharge sources.

Sampling Strategy

Most of the springs selected to have their discharges monitored each month were analyzed for major ions and trace metals. A few of the



$$A = (Y\cdot b) + \left(\frac{Y^2}{2} m_L\right) + \left(\frac{Y^2}{2}\right.$$

$$P = b + \left(Y\cdot\sqrt{1+m_L{}^2}\right) + \left(Y\cdot\sqrt{}\right.$$

$$T_W = b + Y\cdot(m_L + m_R)$$

$$A\cdot h_c = \left(\frac{Y^2\cdot b}{2}\right) + \left(\frac{Y^3}{6} m_L\right) +$$

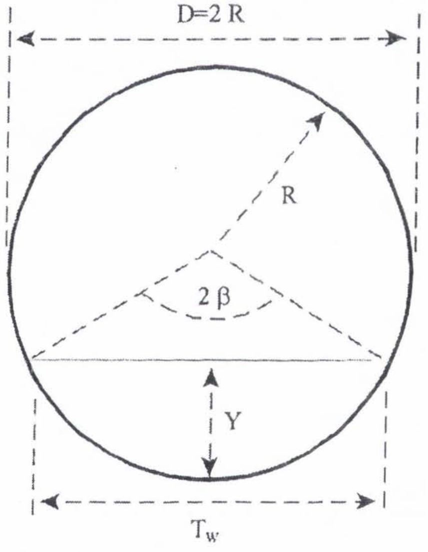
$$A = (Y\cdot b) + (Y^2\cdot m)$$

$$P = b + \left(2\cdot Y\cdot\sqrt{1+m^2}\right)$$

$$T_W = b + (2\cdot Y\cdot m)$$

$$A\cdot h_c = \left(\frac{Y^2\cdot b}{2}\right) + \left(\frac{Y^3\cdot m}{3}\right)$$

$$R_h = \frac{A}{P} \qquad E = Y + \frac{Q^2}{2g\cdot A^2} + \Delta z \qquad M = (A\cdot h$$



$$\beta = a\cos\left(1-\frac{Y}{R}\right) \quad \textit{in radians}$$

$$A = R^2\cdot(\beta - \cos(\beta)\cdot\sin(\beta))$$

$$P = 2\cdot R\cdot\beta$$

$$T_W = 2\cdot R\cdot\sin(\beta)$$

$$A\cdot h_c = R\cdot\left(\frac{2}{3}R^2\cdot\sin(\beta)^3 - A\cdot\cos(\beta)\right.$$

Figure 15: Culvert discharge calculations (Crowe et al., 2001).

springs (39, 114, 130, 145, 187, 188a, and 201) that were monitored for discharge were not analyzed for chemistry for reasons discussed in the spring site description section of Chapter 3. There were also a few springs (46a, 71, 87, 105, 147, 153, 173, 192, 192a, and 219) that were sampled for major ions, stable isotopes and/or tritium that were not monitored for discharge because of various reasons discussed in the spring site description section of Chapter 3.

Only springs where water could be seen emerging from a hillside or a field drain were analyzed for the stable isotope ratios D/H and $^{18}O/^{16}O$ (21 springs total). Water that sits in a pond for a period of time will have isotopic fractionation due to preferential evaporation of the lighter isotope and will not give representative delta D and delta ^{18}O values for the spring water (Drever, 1997).

Ten of the springs analyzed for stable isotopes were also analyzed for the radioactive isotope tritium based on the geographic location, the stable isotope results, and the results from the other chemical analyses.

Sampling Protocol

Field measurements. A YSI model 33 salinity, conductivity, and temperature meter was used to measure those parameters, and pH was measured using an Orion model 230A pH meter. Alkalinity was measured in the field using a Hach Test Kit, Model AL-AP with an accuracy of 20-milligrams per liter (mg/L) of $CaCO_3$. The titration was done using

Bromcresol Green-Red indicator powder and sulfuric acid added to the spring water that had been filtered through a 0.45-micron (ɥm) filter.

Major ions and trace metals. Analysis for major ions and trace metals (Al, As, B, Ba, Ca, Cd, Cl, Co, Cu, Fe, K, Mg, Mn, Mo, Na, P, Pb, S, Si, Sr, and Zn) was performed by the Utah State University Analytical Laboratory using Inductively Coupled Plasma Optical Emission Spectrometry and a Lachat flow injector analyzer for the Cl analysis. Samples were collected in 60-milliliter (mL) polyethylene containers, which were stored in the dark and refrigerated until being analyzed. After filtering the water through a 0.45-μm filter, reagent-grade nitric acid was added to the samples, lowering the pH to less than 2 in order to prevent precipitation of metals and sorption to the container.

Deuterium and oxygen-18. Unfiltered samples were collected using 50-mL clear glass bottles with Teflon lined caps, making sure no headspace was in the container, and taping the cap with electrical tape. The samples were then stored in the dark and refrigerated until being analyzed by the Stable Isotope Ratio Facility for Environmental Research (SIFER) at the University of Utah using a thermo-chemical elemental analyzer (TCEA) coupled to an Isotope Ratio Mass Spectrometer.

Tritium. Each spring sample was collected, unfiltered, in two 500-mL polyethylene bottles with polyseal caps. Sample bottles were rinsed two times with the water that was being collected, and filled with ½ inch of headspace left. Watches and compasses were not near samples at the time of collection because of the tritium given off by some of these devices. Analysis was performed by the University of Miami's Tritium Laboratory using the gas proportional counting technique.

CHAPTER IV

RESULTS

Discharge Monitoring

General Discharge Trends

Discharge data collected during this study are presented in Appendix C. Most of the springs that were chosen for monitoring had discharges that fluctuated, but all of them (except Spring 172) flowed throughout the year. Peak spring discharges at certain times of the year suggest that they receive most of their recharge from precipitation, river water, canal water and/or irrigation water depending on what time of year their discharges were highest.

The surface geology (McCalpin, 1989) and soil classification (Erickson et al., 1974) at each spring site, along with general discharge trends for each monitored spring, are presented in Table 14. The purpose of this table is to show that there is no obvious relationship between the discharge trend and the material from which each spring emerges. There does not appear to be any correlation between discharge amounts or fluctuations and the surficial geology or soil type.

Springs with Highest Discharges in Spring Months

May and June are considered spring months because agricultural irrigation did not begin until the latter part of June in 2005. Springs that have their highest discharges during these months are likely getting that increase in recharge from precipitation and/or river water since they are at their highest during these months. The water from these two sources infiltrates into the shallow,

Table 14: General discharge trends, surface geology (McCalpin, 1989), and soil classifications (Erickson et al., 1974) at spring sites. Definitions of abbreviations can be found on pages 35 and 36.

Spring #	Spring Name	Discharge Trends	Soil Classification	Surficial Geology
39	Fredrick Spring	highest in spring	Cd	lbpm
159	Merrill Spring	highest in spring	Ck	lbpm
172	North Corbett Spring	highest in spring	WIE2	lbg
182	Joseph Smith Spring	highest in spring	Ck	lbpm
201	Outlet Spring	highest in spring	GsA	af1
212	Low Spring	highest in spring	Cd	af2
13	John Nielsen Spring	highest in summer	Pv	lpd
36	Parker Spring	highest in summer	Rs	aly
37	Davis Spring	highest in summer	GsC	aly
38	S.W. Field Irr. Co. Spring	highest is summer	Lr	aly
44	Ditch Spring	highest in summer	SwD	af2
56	Campbell Spring	highest in summer	Pu	lps
57	Spring Creek #1	highest in summer	Rt	lps
134	Snider Spring	highest in summer	Pn	lbpm
163	Johnson Spring	highest in summer	SwF2	lpd
188	Mathers Spring	highest in summer	GsA	af1
203	South Erickson Spring	highest in summer	GrA	af1
35	Hansen Spring	highest in winter	Wp	aly
46	Little Ballard Spring	highest in winter	Rs	aly
47	Banellis Spring	highest in winter	SwD	al1
50	Big Ballard Spring	highest in winter	Wn	aly
60	Del Hansen Spring	highest in winter	Ck	lbpm
95	Spring Creek #4	highest in winter	Cd	lbpm
130	Sheep Spring	highest in winter	GsA	lps
145	Jensen Spring	highest in winter	Am	lbpm
149	North Blue Spring	highest in winter	Ck	lbpm
158	Road Spring	highest in winter	Ck	lbpm
187	William Smith Spring	highest in winter	Rs	lbpm
198	North Erickson Spring	highest in winter	Ak	af1
215	Sorenson Spring	highest in winter	Cd	af2
14	West Camp Hollow Spring	similar Q in mult. seasons	SvB	lpd
23	Libbie Spring	similar Q in mult. seasons	RhA	lps
58	Spring Creek #3	similar Q in mult. seasons	Cd	lbpm
89	Barn Yard Spring	similar Q in mult. seasons	Rt	lpd

Table 14. (continued)

Spring #	Spring Name	Discharge (Q) Trends	Soil Classification	Surficial Geology
93	South Blue Spring	similar Q in mult. seasons	Ck	lbpm
114	North Bodrero Spring	similar Q in mult. seasons	Am	lbpm
164	Blair Spring	similar Q in mult. seasons	SwF2	lpd
188a	Mathers Spring Outlet	similar Q in mult. seasons	GsA	af1
189	Corbett Spring	similar Q in mult. seasons	Rt	lbpm
200	Anderson Spring	similar Q in mult. seasons	GsA	af1
221	Gittens Spring	similar Q in mult. seasons	Cd	af2
222	Small Seep Spring	similar Q in mult. seasons	GrA	af1
224	Hopkins Spring	similar Q in mult. seasons	GsA	af2

unconfined aquifer along the margin of the valley, flows through that aquifer, and emerges at the surface via these springs.

Six springs (39, 159, 172, 182, 201, and 212) had their highest measured discharges in May or June of 2005. Spring 39 is close to the Logan River, Spring 172 emerges below an ephemeral drainage that flows out of the Bear River Range, and Spring 212 is near Summit Creek. However, springs 159, 172, 182, and 201 are not within a few miles of any rivers, suggesting they receive some of their recharge from precipitation. The chemistry of these waters will be used to support these hypotheses or offer new ones in the following section.

Springs with Highest Discharges in Summer Months

Summer months are defined as July through September because those are the months when precipitation is lowest and irrigation is highest. Eleven springs (13, 36, 37, 38, 44, 56, 57, 134, 163, 188, and 203) had their highest discharges during the summer months. It is likely excess irrigation water and/or canal water contributes to the recharge of these springs during the summer months by infiltrating into the shallow, unconfined aquifer that recharges these springs. Spring 57 is close to a small unnamed canal and Spring 163 is a few feet above the Northern Canal. These canals are likely sources of recharge to these springs. However, Utah State University is located on top of the hill these springs emerge from making it possible the lawn irrigation used on that campus provides some of the recharge to these springs in the summer months. Chemistry will be used in the following chapters to confirm this recharge hypothesis or suggest others.

The rest of the springs in this category are not within a few miles of a canal, but there are irrigated fields in the recharge areas to the east of all of these springs. Another possibility for the discharge trend of these springs is that there is a lag between when the increased precipitation (i.e., snowmelt) and/or river water infiltrated into the shallow, unconfined aquifer along the eastern margin of the valley in the spring months and when that recharge caused an increase in discharge at the springs. However, these springs are located throughout the study area. Some of the springs (13, 44, and 163) are along the eastern margin. Other springs (36, 37, 56, 57, 134, and 188) are about as far west as most of the other springs.

Springs with Highest Discharges in Winter Months

Thirteen springs (35, 46, 47, 50, 60, 95, 130, 145, 149, 158, 187, 198, and 215) had their highest discharges during the months of November through March. The surprising increase in discharge during this time of the year may be from precipitation (i.e., snowmelt) in the valley infiltrating into the shallow, unconfined aquifer that recharges these springs. The winter of 2005-2006 had measurable snow falls (Figure 16) followed by periods of time with above freezing temperatures in the valley and on the benches along the margin of the valley. However, an increase in discharge should also have been observed in these springs during spring months if precipitation was the source of the increased discharge.

A more likely possibility is that these springs are still recovering from the drought Cache Valley experienced from 1988-1994 (except for 1993) and 1999-2003 (Figure 11). If this is in fact the case, rivers and/or ground water from the principal aquifer are recharging these springs since the piezometric surface in the shallow, unconfined aquifer has been rising the past two years since the end of the drought. Rivers are the only significant source that recharges the shallow, unconfined aquifer in the winter months. The water that recharges these springs is likely river water, which also recharges the principal aquifer. This would suggest that these springs are acting as an overflow valve for the principal aquifer. These springs are likely going to be especially good indicators of the condition of the shallow, unconfined aquifer in the future.

Little and Big Ballard Springs (46 and 50) had their highest discharges in the winter months (Table 24, Figures 30 and 31, Appendix C). Discharge from these two springs ceased during the last few years of the drought Cache Valley experienced from 1988-1994 (except for 1993) and 1999-2003, and no water was flowing out of the ponds overlying the springs when their discharges were measured on June 19, 2004. According to the landowners, land development

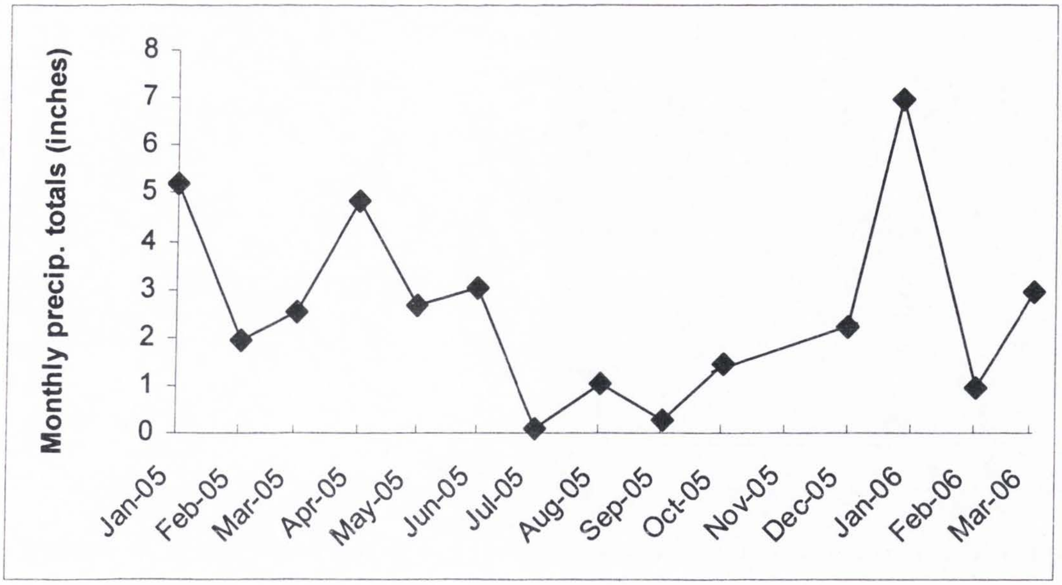


Figure 16: Monthly precipitation totals from January 2005 through March 2006 (WRCC, 2006). No data were collected in November 2005.

directly east of Little Ballard Spring (46) and the installation of a Providence city sewer line also decreased the discharge of that spring significantly.

The springs that had their highest discharges in the winter months are located throughout the study area, giving no geographic relationship that may suggest a reason for this trend. The chemistry of the water from these springs is compared to that of potential sources of recharge to the shallow, unconfined aquifer in Chapter 5.

Springs with Peak Discharges in Multiple Seasons

Springs in this category had discharges in more than one season that were within roughly 10% of one another. Fluctuations seemed to deviate more or less from an average for each spring. The discharges of 13 springs (14, 23, 58, 89, 93, 114, 164, 188a, 189, 200, 221, 222, and 224) had similar peak discharges in more than one season. The reason for this discharge trend is likely because the shallow, unconfined aquifer that recharges these springs is receiving recharge from some combination of the potential sources, including precipitation, excess irrigation water, canal water, and/or river water. The seasons in which these springs had peak discharges will provide some idea of the source of the increased recharge.

Four of the springs (14, 23, 93, and 188a) had peak discharges in two seasons. Springs 23 and 93 had peak discharges in the summer months and in the winter months. Based on the times of the year that the potential sources of recharge to the shallow, unconfined aquifer are at their highest, it is likely that excess irrigation water and/or canal water was the source of the increased flow through the shallow, unconfined aquifer in the summer months. When irrigation stopped later in the fall months, the amount of water in the shallow, unconfined aquifer went back to its state of recovering from the drought. If this is the case, these springs are getting an increased recharge from excess irrigation water in the summer months, but get their main source of recharge from river water that flows through the shallow, unconfined aquifer, similar to springs that had their highest discharges in the winter months.

Spring 14 had peak discharges in the spring and summer months. This discharge trend suggests this spring gains most of its water from river water and precipitation in the spring months and irrigation and canal water in the summer months. Spring 188a had peak discharges in the spring and winter months, suggesting river water and precipitation recharge the shallow, unconfined aquifer that this spring gains its water from in the spring months. The peak discharge in the winter months indicates this spring is also recovering from the drought and that river water and/or ground water from the principal aquifer may be recharging this spring as well. Spring 93 is the furthest west spring monitored in this study, which may indicate a lag in the increased discharge measurements from increased precipitation and/or river water during the spring months.

The other nine springs (58, 89, 114, 164, 189, 200, 221, 222, and 224) had much greater fluctuations in their discharges than the ones mentioned previously. These springs generally increased and then decreased every month or two and had peak discharges that were similar to one another in every season. Many of them had one of their peak discharges in October, which is unusual because no other springs had that trend, and because irrigation and precipitation both are low at that time of the year. There is no obvious explanation for the discharge trend shown in these springs other than the shallow, unconfined aquifer that recharges these springs is getting recharged from precipitation, excess irrigation water, river water, canal water, and perhaps even ground water from the principal aquifer at different times of the year. These springs are located throughout the study area, which does not provide any suggestions of recharge based on geographic similarities.

Geographic Relationships

Generally, springs in the eastern portion of the study area (Springs 13, 14, 23, 44, 46, 47, 50, 89, 130, 158, 159, 163, and 164) have the smallest discharges. Of these, springs 46 and 50 are the only ones that have discharges greater than 500 gpm. Springs 35, 36, 37, 38, 39, 56, 57, 58, 60, 93, 95, 114, 134, 145, 149, 172, 182, 187, 188, 188a, 189, 198, 200, 201, 203, 212, 215, 221, 222, and 224 are located in the western portion of the study area, and generally have the highest discharges. Springs 38, 60, 188a, 203 and 221 have maximum discharges between 500 and 1,000 gpm (Figure 30, Appendix C); Springs 37, 134, and 189 have discharges between 1,000 and 2,000 gpm (Figure 31, Appendix C); and Springs 57, 58, and 201 have discharges greater than 2,000 gpm at some time of the year (Figure 32, Appendix C).

Higher discharges in the western portion of the study area may be the result of irrigation in the cities being confined mainly to lawns in disconnected neighborhoods and infiltration being inhibited by paved surfaces. Also, the shallow ground water system has been affected by sewer, water and utility lines, and therefore no longer follows natural flow paths in populated areas. Springs that emerge farther west in the study area often have field drains contributing to their discharge, so it makes sense that these springs would have larger discharges, since the farther west a spring is the larger area it drains.

Several landowners reported that their springs drastically decreased in discharge after the installation of a sewer system for a nearby city before this study began. These sewer pipes are as deep as 20 feet in some areas according to homeowner reports, and are generally backfilled with coarse unconsolidated material that would act as a preferential flow path for shallow ground water. During monitoring visits, landowners reported that the discharges of springs 46, 95, and 114 decreased in discharge by more than 50% after the Providence, Nibley, and Logan, respectively, sewers were installed to the east of their springs.

When these sewers were installed, it is likely they were backfilled with material that is coarser than the native material, which provides a path of least resistance for shallow ground water to flow through. Breaking up the native material alone will also increase permeability of that material, allowing for water to flow more easily. However, it is also possible that eliminating discharge from septic tanks caused some of the decrease in recharge to springs.

Major Ions and Trace Metals

Major ion and trace metal results from spring water collected in July of 2005 can be found in Table 25, which is included in Appendix D. A trilinear plot (Piper, 1944) was used to summarize these data (Figure 17). The data can be compared to precipitation, river water, and canal water chemistries on the same plot, and to ground water in the principal aquifer in Figure 5. Most of the springs have nearly the same chemistry when compared to each another except for a few irregularities that will be discussed in this section. Total dissolved solids (TDS) are below 400 mg/L in all springs, except for the water sampled from spring 188 on February, 15 2006. All springs are characterized by calcium, magnesium, and bicarbonate, which are the dominant major ions.

Concentrations of major ions and trace metals (Table 10 and Figure 12) and ionic ratios of sodium plus potassium versus calcium plus magnesium (Figure 13) and chloride versus sodium plus potassium (Figure 14) in spring water

Concentrations of major ions and trace metals (Table 10 and Figure 12) and ionic ratios of sodium plus potassium versus calcium plus magnesium (Figure 14) in spring water sampled by McGreevy and Bjorklund (1970) , DeVries

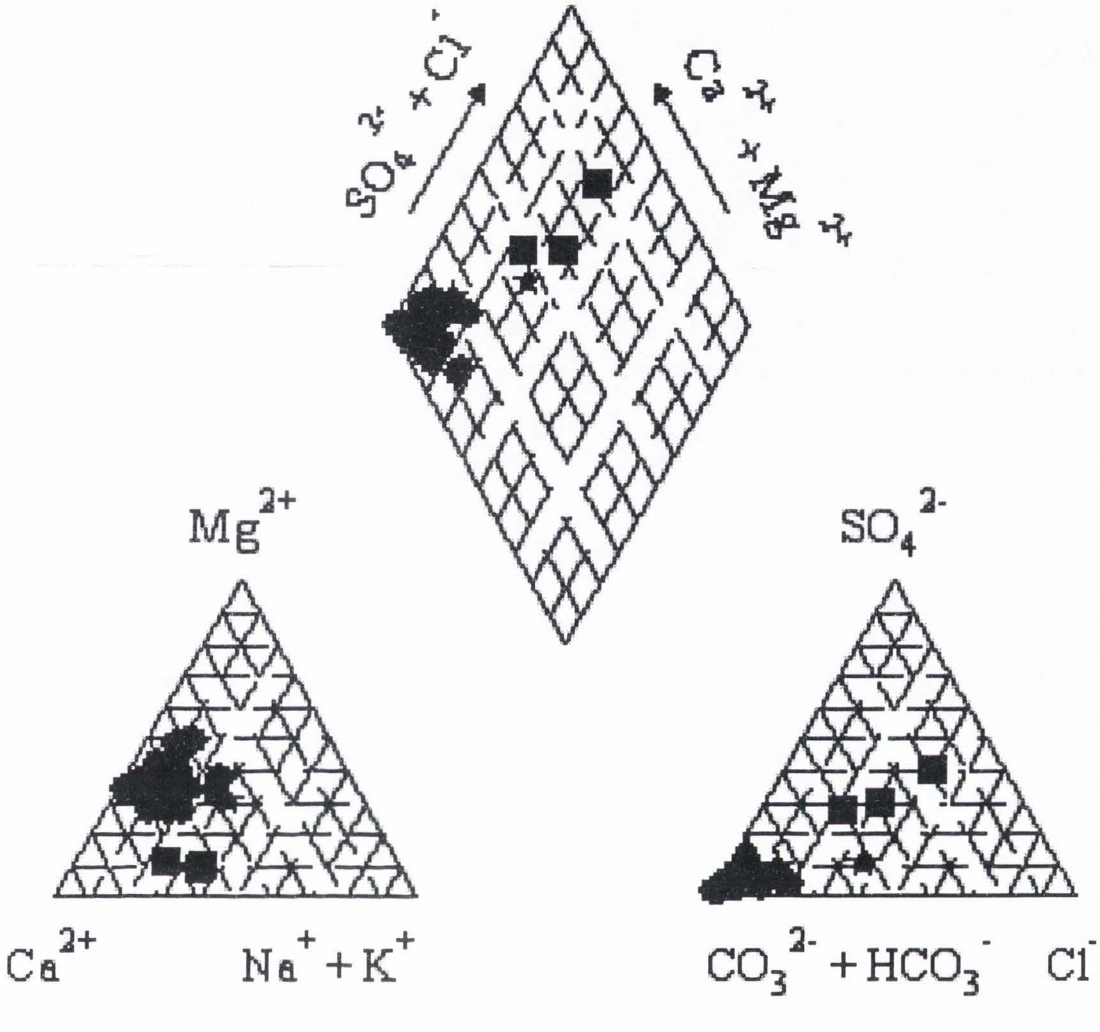


Figure 17: Trilinear plot (Piper, 19944) of major ion concentrations from springs (circles), canal water (stars), river water (triangles) (Robinson, 1999), and precipitation (squares) (NADP, 2006).

(1982), and Robinson (1999) are similar to spring water sampled in this study (Figures 17, 18, and 19). This indicates the source of recharge to these springs has not changed much, if at all, since those studies.

Comparison to Potential Spring Sources

Figure 10 has sodium plus potassium versus calcium plus magnesium from canal water and river water sampled by Robinson (1999), and precipitation sampled by the NADP (2006). River water and canal water have similar ratios to spring water, and precipitation has significantly lower concentrations of those major ions than other potential sources and the spring water itself. The ratios from well water sampled by Robinson (1999) presented in Figure 6 are also similar to spring and river water chemistries. Sodium plus potassium dominate over chloride in wells less than 300 feet deep, which is true for the majority of springs, but some springs have equal ratios. Based on this similarity, Robinson (1999) suggested rivers recharge the principal aquifer where they flow across the unconfined portion of the aquifer along the eastern margin of the valley, which seems to be the case for the shallow, unconfined aquifer as well. Ionic ratios suggest that rivers and canals lose some of their water when they flow across the shallow, unconfined aquifer. This water then flows through that aquifer and recharges springs. Based on ionic ratios, precipitation does not directly contribute much recharge to the water in the shallow, unconfined aquifer that discharges from the springs.

Robinson (1999) sampled three canals in the study area during June of 1999 for major ions and trace metals. Two of those samples have similar concentrations of major ions to spring water, as shown in Figure 17. The third

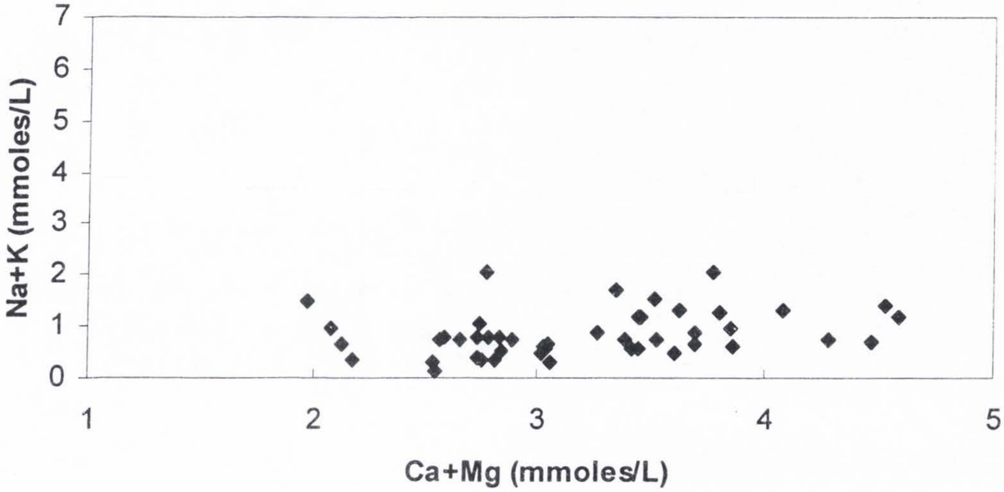


Figure 18: Plot of concentrations of sodium plus potassium versus calcium plus magnesium from spring water.

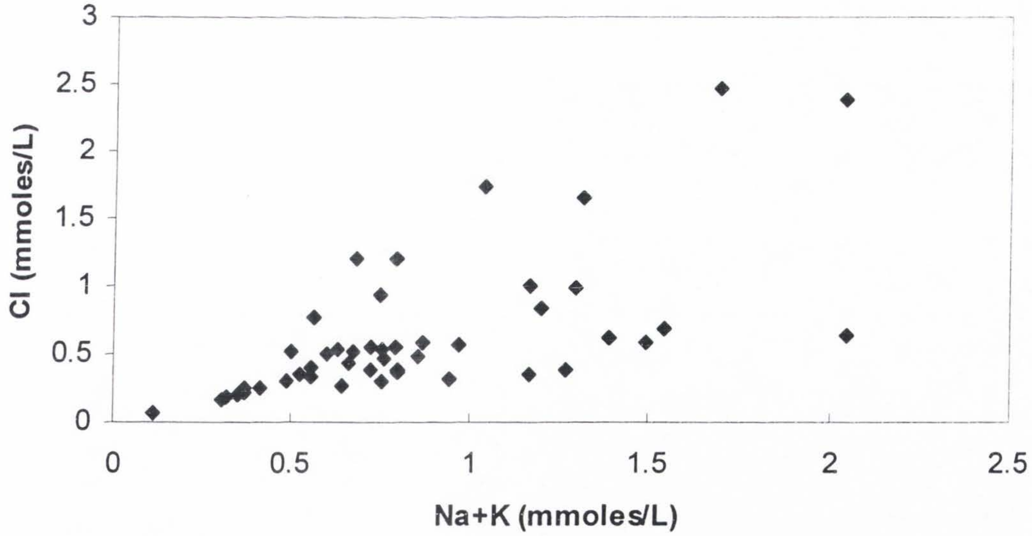


Figure 19: Plot of concentrations of chloride versus sodium plus potassium in spring water.

canal water sample had slightly less calcium and magnesium, and significantly less chloride and sulfate than the other two canal water samples and the spring water samples. Since the chemistries of most canal and spring waters are very similar, and because the canals have no lining and flow across the alluvial and deltaic deposits that would allow infiltration, it is likely water leaks out of the canals, flows through the shallow, unconfined aquifer, and discharges from springs.

Well water chemistries from Robinson (1999) (Figure 5) are similar to river water, most of the canal water samples, and spring water (Figure 17). This similarity again suggests rivers and canals are recharging the shallow, unconfined aquifer that recharges springs. Concentrations of major and minor ions in precipitation (Table 8 and Figure 17) are much lower than in springs and lower than any of the other potential sources, suggesting again that precipitation does not contribute a significant amount of recharge to the shallow, unconfined aquifer. However, this hypothesis is dependent on the rate of infiltration being high relative to the rate of dissolution, which is likely the case in the alluvial and deltaic deposits that most of these springs emerge from.

Spring Water Chemistry

Tables 15 and 16 list the average, maximum, and minimum concentrations for major ions and trace metals, and for basic chemical parameters of all springs analyzed for major ions and trace metals. Aluminum, As, B, Cd, Co, Cr, Mo, Pb, and Se were below the detection limits (Al: 0.12, As: 0.1, B: 0.1, Cd: 0.01, Co: 0.01, Cr: 0.01, Mo: 0.15, Pb: 0.03, and Se: 0.1 mg/L) in every spring sampled, including the five springs sampled in the winter of 2006. Concentrations of Ba, Cu, Fe, Mn, Ni, PO_4, Sr, and Zn vary from <0.01 to 1.15 mg/L. Since the concentrations of these constituents are so low, they will not be discussed in any more detail.

Samples collected from springs 13 and 163 (Table 25, Appendix D) had concentrations of chloride and sodium that were more than double the average (Table 15). Springs 14 and 164 also had high chloride, but not high sodium

Table 15: Average (of constituents with all concentrations above the detection limits), maximum, and minimum values for major ions and trace metals in spring water (not including February 2006 sample.

	Ba	Ca	Cl	Cu	Fe	K	Mg	Mn
Average	0.11	75.29	22.64	NA	NA	5.16	32.05	NA
Maximum	0.61	114.70	87.30	0.06	0.45	32.77	52.62	0.04
Minimum	0.04	43.68	2.42	<0.01	<0.01	0.60	19.35	<0.01
	Na	Ni	PO4	SiO2	SO4	Sr	Zn	TDS
Average	16.58	NA	NA	157.62	19.69	0.22	NA	232.37
Maximum	43.60	0.01	1.15	475.33	63.06	0.49	0.07	395.46
Minimum	2.24	<0.01	P<0.1	67.06	4.24	0.09	<0.01	126.68

Table 16: Average, maximum, and minimum values for basic chemical parameters of springs analyzed for major ions and trace metals (not including temperatures measured in February of 2006).

	Temp (°C)	pH	EC (ųS)	Alkalinity (mg/L as CaCO3)
Average	15.5	7.43	533	340
Max	27.1	7.97	890	460
Min	10.8	6.63	445	240

concentrations. Springs 13, 14, 163, and 164 were the only monitored springs that emerge from deltaic deposits in the Hyrum area (Springs 13 and 14) and in the Logan area (Springs 163 and 164). Since these springs are closer to the population centers within the recharge area along the eastern margin of the valley, it seems likely that much of the water recharging these springs is runoff containing deicing salts from roads and parking lots that flows through the shallow, unconfined aquifer and contributes to the recharge of these springs. Water from springs that emerge farther west would be more diluted since they drain a larger area of the shallow, unconfined aquifer, which would explain why those springs have lower chloride levels.

Springs 36, 46, 46a, 47, and 56 also had chloride levels higher than most springs sampled in the summer of 2005, but not as high as the other four discussed previously. These five springs receive their recharge near populated areas in the southeastern portion of the study area, and it is likely that chloride-rich runoff from roads is contributing to the high levels of chloride in these springs as well.

Three of the springs (23, 172, and 173) sampled had much higher silica concentrations than any other spring. Springs 172 and 173 are near the north-eastern boundary of the study area, and are located closer to the Bear River Range than any of the other springs sampled. This, along with the chemistry, suggests they are most likely recharged from a bedrock source. The bedrock in the Salt Lake Group in the adjacent mountains is a mixture of conglomerates, breccias, tuffs, and limestones, all of which are calcareous (Williams, 1962). It is possible that the tuffs are the source of the silica.

Spring number 172 was reported by the landowner to have decreased in discharge after the magnitude 5.7 Richmond earthquake in 1962 (UUSS, 2006). It did not flow at all for many years, but resumed shortly before the first measurements were made for this study. The landowner attributed the rejuvenation to precipitation amounts during the previous winter being significantly greater than the past several years when Cache Valley had experienced a drought (Figure 11). The discharge from Spring 172 was low to begin with, and it ceased flowing after August of 2005. Spring 173 nearby has been continuously used as a water source for a small family farm, but its discharge was not monitored as part of this study.

Spring 23 emerges at the base of alluvial deposits in the south-central portion of the study area. It is not apparent why this spring has higher silica levels than most of the other springs. One possibility is that there is a deep, bedrock component of recharge to this spring.

Five springs (23, 56, 58, 60, and 93) had over double the average concentration of sulfate from all springs. Robinson (1999) found sulfate concentrations in wells were considerably higher near the Blacksmith Fork River between the cities of Logan and Hyrum (Figure 20) than anywhere else in the southeastern portion of Cache Valley. Robinson (1999) suggested that since the Blacksmith Fork River had nearly double the sulfate concentrations compared to the other rivers in the study area, the few small mines in that river's watershed are

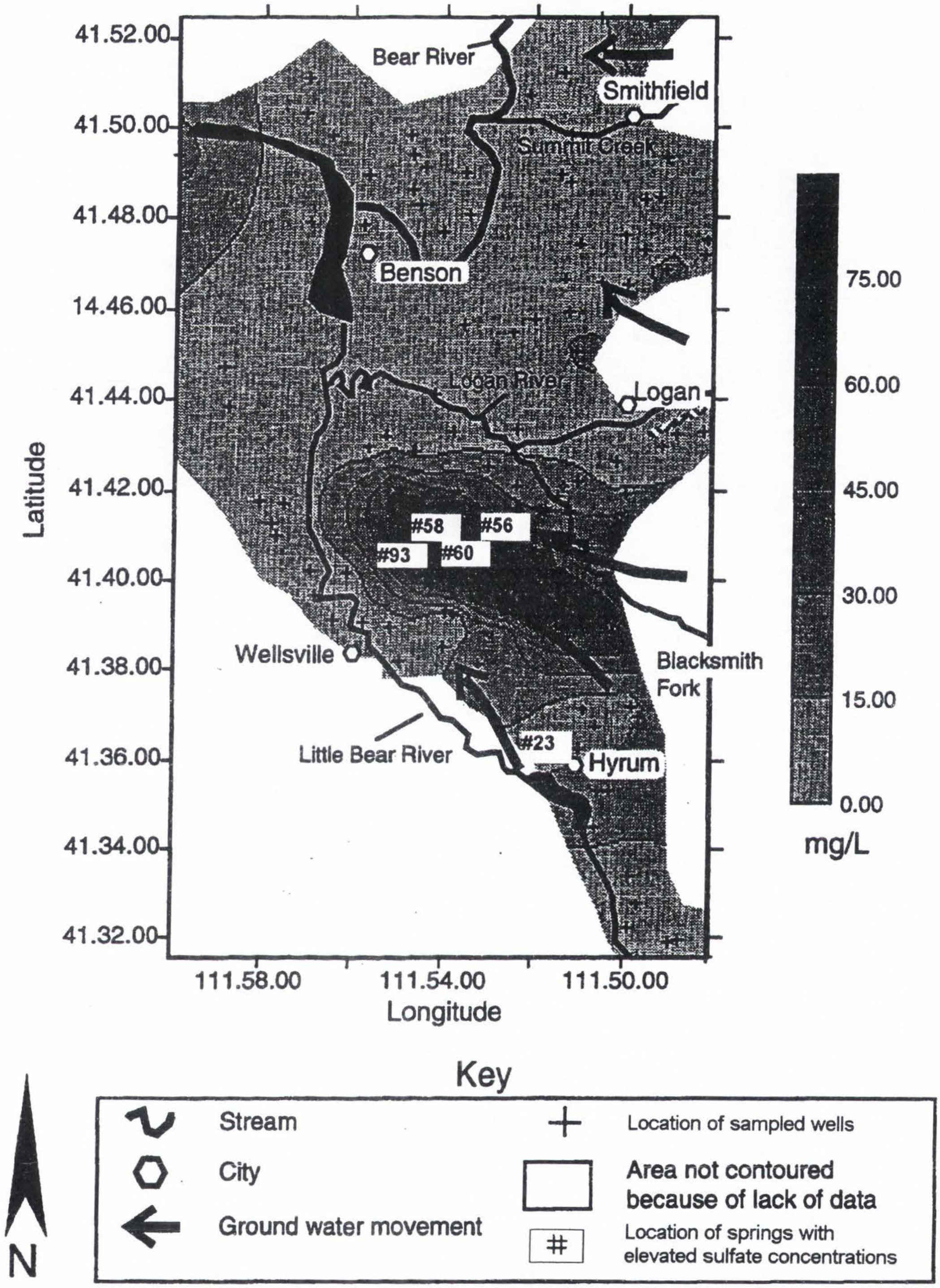


Figure 20: Areal distribution of sulfate (SO_4^{2-}) in Cache Valley (Robinson, 1999) and locations of springs sampled in this study that have elevated sulfate concentrations.

likely contributing acid mine drainage. He also suggested the high sulfate in that area could be from a localized anthropogenic source or perhaps a local bed of gypsum or other sulfur-containing mineral.

Springs 56, 58, 60, and 93 are all within about a mile of the wells that also had elevated sulfate concentrations and are near the Blacksmith Fork River. These springs support Robinson's (1999) hypothesis that the Blacksmith Fork River is supplying the elevated sulfate, since these springs are most likely getting the majority of their recharge from that river.

Spring 23 is a few miles south of the other four. The explanation of the elevated levels is this spring is not certain, but may be from other sources suggested by Robinson (1999), including fertilizers, biogenic gasses in the soil, or buried sulfur in sediments from continental water bodies.

None of the samples had concentration of calcium or magnesium that were more than double the average concentrations. However, spring 172, as well as Springs 13 and 163 discussed previously, had a sodium concentration more than double the average, and Springs 36, 71, and 192 had more than double the average concentration of potassium.

Five springs (14, 36, 158, 188, and 224) had duplicate samples analyzed for major ions in the winter of 2006 (Table 25, Appendix D). Duplicates were collected for three reasons, including: 1) to see if there was any seasonal variation in spring water chemistry, 2) to ensure the sampling process was done properly, and 3) to see if the analytical methods had any possible errors. The last two reasons are assumed to have minimal to no effect on the results of the analyses since the values were still in the same range as samples analyzed in the summer of 2005.

Spring 36 and 188 are located farther west in the study area than the deltaic deposits, but it seems likely that the elevated chloride levels in those springs during the winter are also from road deicing salts. Another possibility is that canal water and/or river water, which have higher concentrations of major ions in the winter months, are causing the increase in chloride in these springs.

Chloride and Na concentrations were higher and SiO_2 concentrations were lower in the winter of 2006 than in the summer of 2005 for Springs 36, 158, 188, and 224, and about the same for Spring 14. Potassium and SO_4 concentrations were lower in the winter of 2006 than in the summer of 2005 for springs 14, 36, and 158. Springs 188 and 224 had higher concentrations of K and SO_4 in the winter of 2006 than in the summer of 2005. Springs 14, 36, and 158 are located in the southern half of the study area, and Springs 188 and 224 are located in the northern half. This may have something to do with the seasonal trends in chemistry. Calcium and magnesium concentrations were about the same in both the summer of 2005 and winter of 2006 for all five springs.

All of the springs had higher total dissolved solids (TDS) in the winter of 2006 than in the summer of 2005. Temperatures of spring water samples collected in the winter of 2006 were significantly lower, confirming that their recharge is from water in the shallow, unconfined aquifer since the temperature of deeper ground water would not be significantly affected by surface temperature changes over the period of a few months.

Robinson (1999) sampled canal water and river water in the summer and fall of 1998. Concentrations of major ions and trace metals were higher for canal and river water in the fall months. The 5 springs sampled for major ions and trace metals in the winter months also had higher concentrations than in the summer months. This supports the idea that rivers and canals lose water to the shallow, unconfined aquifer that discharges from these springs.

Isotopes

Deuterium and Oxygen-18

The ratios of the stable isotopes deuterium (^2H) to hydrogen and oxygen-18 to oxygen-16 in precipitation depends on elevation, latitude, distance away from the oceans or other evaporative sources, the temperature of the water when it was evaporated and precipitated, and the isotopic composition of the evaporation source (Drever, 1997). Delta D and $\delta\ ^{18}O$ are determined from Equation 1 (Drever, 1997) using the measured ratios of D/H and $^{18}O/^{16}O$ in the water sample and the Vienna Standard Mean Ocean Water (V-SMOW) value. R in Equation 1 is the ratio of D/H or $^{18}O/^{16}O$.

$$\delta = \frac{(R)_{sample} - (R)_{standard}}{(R)_{standard}} \text{ X } 1000 \qquad \text{Equation 1}$$

These values represent the relative difference between the ratio of the isotopes in the sample and the V-SMOW ratios (Drever, 1997). Values are given in parts per thousand, or per mil units (i.e., $\delta\ ^0/_{00} = \delta \text{ x } 1000$). The isotopic composition of seawater is, by the definition of SMOW, zero per mil for both δD and $\delta^{18}O$. The water vapor that evaporates from the oceans has a $\delta^{18}O$ value of about -13 $^{0}/_{00}$, and the first rain that forms from that water would have a $\delta\ ^{18}O$ of about -3 $^{0}/_{00}$ (Drever, 1997). As rain continues to fall, the heavier isotopes (D and ^{18}O) fall preferentially from the moisture in the atmosphere, leaving the vapor progressively lighter. This process is called Rayleigh fractionation. The opposite happens when the water is exposed to the atmosphere after deposition. The lighter isotopes evaporate preferentially, leaving the remaining water enriched with the heavy isotopes. Such heavy isotope enrichment is referred to in this thesis as an evaporative signature.

The stable isotope ratios of springs sampled in this study are presented in Table 17, and plotted as δD versus $\delta^{18}O$ in Figure 21. Also on that plot are samples from wells, river water, canal water, and precipitation in the study area from Robinson (1999), Rogers (2006), and the NADP (2006). All of the spring values plot near or below the Global Meteoric Water Line (GMWL), which is described by Equation 2 (Drever, 1997) and is shown as the solid line in Figure 21.

$$\delta D = 8\ \delta^{18}O\ + 10 \qquad\qquad \text{Equation 2}$$

Every spring sampled for D and ^{18}O has heavier (less negative) isotopic ratios than precipitation in the study area, again indicating that precipitation contributes very little directly to spring recharge. Most of the spring samples have heavier (less negative) isotopic ratios than river water as well. Therefore, it

Table 17: Deuterium (D) and oxygen-18 (^{18}O) data (per mil) from spring water.

#	Sample Date	δD	$\delta^{18}O$
14	26-Jul-05	-123	-15.7
23	12-Jul-05	-123	-15.8
36	13-Jul-05	-126	-16.7
44	12-Jul-05	-124	-16.4
56	13-Jul-05	-125	-16.3
60	13-Jul-05	-129	-16.7
71	12-Jul-05	-126	-16.3
89	12-Jul-05	-121	-16.2
105	18-Jul-05	-131	-17.2
147	14-Jul-05	-134	-17.9
158	14-Jul-05	-125	-16.0
163	18-Jul-05	-125	-16.5
164	18-Jul-05	-125	-16.8
188	15-Jul-05	-125	-16.2
192	18-Jul-05	-119	-15.3
198	15-Jul-05	-125	-16.6
200	15-Jul-05	-127	-16.4
203	15-Jul-05	-130	-16.9
212	15-Jul-05	-130	-17.1
222	15-Jul-05	-126	-16.2
224	15-Jul-10	-123	-16.4

seems likely that most of the springs in the study area get some of their recharge from excess irrigation water and canal water that infiltrates into the shallow, unconfined aquifer that discharges from the springs.

Water samples from Springs 14, 23, 44, 56, 71, 89, 158, 188, 222, and 224 plotted near canal water samples (Figure 21). It is likely these springs get a larger percentage of their recharge from leakage of water in unlined irrigation canals.

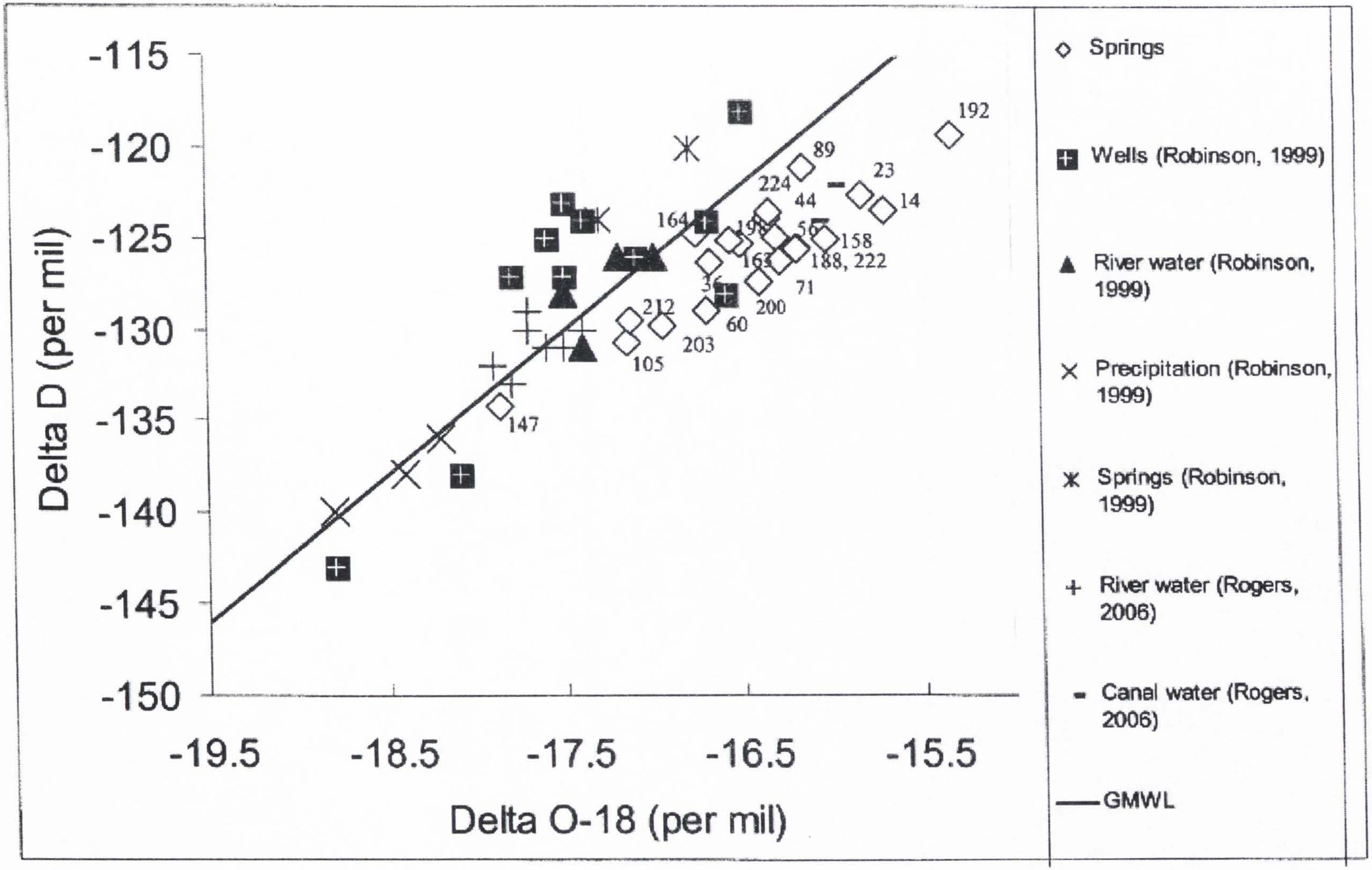


Figure 21: Plot of delta D versus delta O-18 in water from springs, canals, rivers, wells, and precipitation.

Excess irrigation water is also a likely contributor to these springs since that water would also have an evaporative signature.

The water sampled from Spring 192 has isotopic ratios that are less negative than any other spring or potential source. One explanation could be that it receives a larger percentage of its water from unlined irrigation canals or excess irrigation water, since they both would have an evaporative signature.

Six spring water samples (36, 60, 163, 164, 198 and 200) plot near ground water samples from wells (Figure 21). Springs 60 and 164 have nearly identical isotopic ratios as Wells 8 and 4 (Robinson, 1999), respectively. Both of these wells are located at the southwestern edge of the study area, but the springs are located 3 to 4 miles northeast of those wells. Well 4 has an open interval from 148 to 184 feet and Well 8 has an open interval from 74 to 84 feet below the surface. Spring 60 emerges in the western portion of the study area and Spring 164 emerges from the deltaic deposits along the eastern margins of the valley. It would be highly unlikely for the principal aquifer to be contributing recharge to these springs, especially because Spring 164 emerges from deltaic deposits at a relatively high elevation along the margin of the valley and has major ion concentrations that indicate local surface water contributing to the recharge of that spring. Also, the two continuous confining layers between the springs and the principal aquifer would not allow the aquifer to recharge the springs. The more probable explanation is that Springs 60 and 164 probably get a larger portion of their recharge from rivers than the springs that plot near the canal water samples. Such an interpretation is reasonable because they plot between canal water and river water on Figure 21. Another possible reason for these similarities could be that rivers recharge both the shallow, unconfined aquifer and the principal aquifer, as suggested by Robinson (1999).

Isotopic ratios indicate some of the springs get their recharge from river water, which is confirmed by the discharge trends and major ion and trace metal concentrations discussed preciously in this chapter. Specifically, Springs 105, 203, and 212 have δD and δ^{18}O values that are similar to river water (Figure 21), perhaps indicating that these springs get a higher percentage of their recharge from the rivers that flow through the study area. Spring 105 does have an ephemeral drainage from the nearby mountains flowing east and north of it, as well as a canal between it, and the mountains that could be recharging that spring. However, Springs 203 and 212 are not any closer geographically to rivers or canals than any other springs.

Spring 147 had isotopic ratios near those of precipitation samples collected by Robinson (1999). This may indicate that this spring is getting a larger percentage of its recharge directly from precipitation. However, more recent isotope data for precipitation would be necessary to farther support this idea.

Robinson (1999) sampled two springs for D and ^{18}O (Table 11). Hopkins Spring (224) was also sampled in July of 2005 for this study (Table 17). Spring Creek #1 was not sampled for D and ^{18}O in this study. The δD value for Hopkins Spring (224) sampled in 1998 was less negative than all of the springs sampled in 2005 except Spring 192. The δ^{18}O value was more negative than 16 of the spring sampled in 2005 (14, 23, 36, 44, 56, 60, 71, 89, 158, 163, 188, 192, 198, 200, 222, and 224) and less negative than four (105, 147, 203, and 212) (it was the same as Spring 164). While the different isotopic ratios in 1999 and 2005 could be due to differences in the isotopic ratios of the precipitation during the different time periods, a more likely cause for this difference may be analytical inconsistencies due to the analyses being performed by two different labs.

Tritium

Tritium is a radioactive isotope whose concentration in the atmosphere and in rainwater increased during the1950s and 1960s from above ground thermonuclear testing (Drever, 1997). Between 1962 and 1965, the concentration in rainwater increased from approximately 5 tritium units (TU) to over 1,000 TU and has tapered off sharply since the end of the 1960s.

Tritium values measured in spring samples collected on February 15 and 16, 2006 are presented in Table 18. These values indicate that the spring water is either recent (post-1969) water or a mixture of bomb (1952 to 1969) water and pre- and/or post-bomb water. Since the discharge trends, major ions, and stable isotopic ratios in spring water seem to indicate that most, if not all, of the water recharging the springs is from the shallow, unconfined aquifer, it seems most likely the water discharging from these springs is post-bomb water.

Robinson (1999) also sampled Spring Creek #1 (57) and Hopkins Spring (224) for tritium. Tritium levels in these two springs were 12.9 and 16.5 TU Tritium Units (TU), respectively, which are slightly higher than samples collected in 2006. The slightly higher tritium levels in spring water sampled by Robinson are likely explained by the radioactive decay of tritium, which has a half-life of 12.3 years (Drever, 1997).

Well water samples collected by Robinson (1999) vary between 0.0 and 22.1 TU (Figure 8). The water in four of the 10 wells (3, 8, 10, and 14) sampled for tritium in that study were recharged prior to 1952. However, Well 3 is not located in the area of interest for this study, nor is it completed in the principal aquifer. The tritium levels in the other six wells indicated that the water was either post-bomb water or a mixture of bomb water and pre-bomb water.

Table 18: Tritium values (in TU) from spring samples

Spring #	Spring Name	Tritium Count	One Sigma Error
23	Libbie Spring	9.2	0.3
36	Parker Spring	9.3	0.3
60	Del Hansen Spring	8.36	0.28
89	Barn Yard Spring	12.2	0.4
147	Tree Spring	8.96	0.30
164	Blair Spring	8.9	0.29
192	North Hansen Spring	9.2	0.3
200	Anderson Spring	10.1	0.3
203	South Erickson Spring	9.8	0.3
212	Low Spring	8.28	0.27

CHAPTER V

DISCUSSION

Source of Spring Water

Discharge Data

Table 19 summarizes the probable sources of recharge to springs monitored for discharge and sampled for chemical analysis in this study. Springs 39, 159, 172, 182, 201, and 212 had their highest discharges in the spring months (May-June). Based on the discharge data, the water that recharges the shallow, unconfined aquifer and that discharges from the aquifer as springs probably originates primarily as river water. A less likely source, based on major ion concentrations, is precipitation.

Springs 13, 36, 37, 38, 44, 56, 57, 134, 163, 188, and 203 had their highest discharges in the summer months (July-September). These springs likely gain most of their water from excess irrigation water and/or canal water that recharges the shallow, unconfined aquifer to the east of these springs.

Springs 35, 46, 47, 50, 60, 95, 130, 145, 149, 158, 187, 198, and 215 had their highest discharges in the winter months (November-March). It is not apparent exactly why these springs have this discharge trend, but one possibility is that these springs are slowly recovering from the drought Cache Valley experienced between 1988-1994 (except for 1993) and 1999-2003 (NADP, 2006). This would suggest that the shallow ground

Table 19: Most likely sources of recharge for springs based on discharge trends (Q), major ions and trace metals (MI and TM), and stable isotopes (D/18O). NM: not measured; prec: precipitation; d.g.w.: principal aquifer; irr: excess irrigation water.

#	Q	MI and TM	D/18O
13	irr; canals	prec.; rivers; irr; canals	NM
14	prec.; rivers; irr; canals	prec.; rivers; irr; canals	irr; canals
23	rivers; irr; canals; d.g.w	bedrock	irr; canals
35	rivers; d.g.w	rivers; irr; canals	NM
36	irr; canals	prec.; rivers; irr; canals	rivers; irr; canals; d.g.w
37	irr; canals	rivers; irr; canals	NM
38	irr; canals	rivers; irr; canals	NM
39	prec.; rivers	rivers; irr; canals	NM
44	irr; canals	rivers; irr; canals	irr; canals
46	rivers; d.g.w	prec.; rivers; irr; canals	NM
46a	NM	prec.; rivers; irr; canals	NM
47	rivers; d.g.w	prec.; rivers; irr; canals	NM
50	rivers; d.g.w	rivers; irr; canals	NM
56	irr; canals	prec.; rivers; irr; canals	irr; canals
57	irr; canals	rivers; irr; canals	NM
58	prec.; rivers; irr; canals; d.g.w	rivers; irr; canals	NM
60	rivers; d.g.w	rivers; irr; canals	rivers; irr; canals; d.g.w
71	NM	rivers; irr; canals	irr; canals
87	NM	rivers; irr; canals	NM
89	prec.; rivers; irr; canals; d.g.w	rivers; irr; canals	irr; canals
93	rivers; irr; canals; d.g.w	rivers; irr; canals	NM
95	rivers; d.g.w	rivers; irr; canals	NM
105	NM	rivers; irr; canals	rivers
114	prec.; rivers; irr; canals; d.g.w	rivers; irr; canals	NM
130	rivers; d.g.w	rivers; irr; canals	NM
134	irr; canals	rivers; irr; canals	NM
145	rivers; d.g.w	rivers; irr; canals	NM
147	NM	rivers; irr; canals	prec.; rivers
149	rivers; d.g.w	rivers; irr; canals	NM
153	NM	rivers; irr; canals	NM
158	rivers; d.g.w	rivers; irr; canals	irr; canals
159	prec.; rivers	rivers; irr; canals	NM
163	irr; canals	prec.; rivers; irr; canals	rivers; irr; canals; d.g.w
164	prec.; rivers; irr; canals; d.g.w	prec.; rivers; irr; canals	rivers; irr; canals; d.g.w
172	prec.; rivers	bedrock	NM
173	NM	bedrock	NM
182	prec.; rivers	rivers; irr; canals	NM
187	rivers; d.g.w	rivers; irr; canals	NM
188	irr; canals	rivers; irr; canals	irr; canals
188a	prec.; rivers; d.g.w	rivers; irr; canals	NM
189	prec.; rivers; irr; canals; d.g.w	rivers; irr; canals	NM

Table 19. (continued)

#	Q	MI and TM	D/18O
192	NM	rivers; irr; canals	irr; canals
192a	NM	rivers; irr; canals	NM
198	rivers; d.g.w	rivers; irr; canals	rivers; irr; canals; d.g.w
200	prec.; rivers; irr; canals; d.g.w	rivers; irr; canals	rivers; irr; canals; d.g.w
201	prec.; rivers	rivers; irr; canals	NM
203	irr; canals	rivers; irr; canals	rivers
212	prec.; rivers	rivers; irr; canals	rivers
215	rivers; d.g.w	rivers; irr; canals	NM
219	NM	rivers; irr; canals	NM
221	prec.; rivers; irr; canals; d.g.w	rivers; irr; canals	NM
222	prec.; rivers; irr; canals; d.g.w	rivers; irr; canals	irr; canals
224	prec.; rivers; irr; canals; d.g.w	rivers; irr; canals	irr; canals

water discharging from these springs is recharged by rivers and/or ground water from the principal aquifer. These springs may be especially good indicators of a decrease in the amount of ground water in that system.

Springs 23 and 93 had peak discharges in the summer and winter months. It is likely that excess irrigation water and/or canal water was the source of the increased flow through the shallow, unconfined aquifer in the summer months. When irrigation stopped later in the fall, the amount of water in the shallow, unconfined aquifer went back to its state of recovering from the drought Cache Valley experienced from 1988-1994 (except for 1993) and 1999-2003 (NADP, 2006) (Figure 11).

Spring 14 had peak discharges in the spring and summer, and spring 188a had peak discharges in the spring and winter. Peak discharges in the spring are from precipitation and/or river water. Peak discharges in the summer are from irrigation water and/or canal water, and peak discharges in the winter suggest that springs are recharged from rivers and/or deep ground water, and they are likely slowly recovering from the drought.

Springs 58, 89, 114, 164, 189, 200, 221, 222, and 224 had similar peak discharges all three seasons. These springs generally increased and then decreased every month or every two months. The shallow, unconfined aquifer that recharges these springs must be getting recharged from precipitation, river water, excess irrigation water, canal water, and/or ground water from the principal aquifer at different times of the year.

Major Ions and Trace Metals

The major ion compositions of the 46 springs analyzed for major ions are somewhat similar to one another (Figure 17). Figures 33 to 39, which are included in Appendix D, show the range of concentrations for major ions in each spring. The water discharging from springs in the study area is composed of calcium, magnesium, and bicarbonate. However, the range in concentrations varies considerably (Table 15), and some unusually high levels of a few ions were found in some samples, indicating a specific source of recharge to those springs.

Major ions and trace metals from deep wells (deeper than 300 feet) are plotted on Figure 5. River and canal water sampled by Robinson (1999) are plotted on Figure 9, and precipitation chemistry from the NADP (2006) is also plotted with the other potential sources on Figure 9. These plots indicate major ion concentrations in precipitation are much less than in spring water or in any of the other potential sources, virtually eliminating precipitation as a significant source of direct recharge for most of the springs.

Based on the overall chemistries of the spring water samples, it appears that river water, excess irrigation water, and canal water are the sources of water recharging the shallow, unconfined aquifer that discharges from nearly all of the springs. Canal water, river water, and ground water from the principal aquifer all have similar major ion compositions (Figure 9).

Robinson (1999) suggested that the rivers flowing into the valley recharge the principal aquifer where they flow across the unconfined portion of this aquifer along the eastern margin of the valley. Since major ions in spring water matched both river water and ground water from the principal aquifer, it could be an indication that both are recharging the shallow, unconfined aquifer in the vicinity of these springs. However, because of the two continuous confining layers that separate the shallow, unconfined aquifer and the principal aquifer, and because increased ground water pumping from the principal aquifer in the summer had no obvious effect on overall spring discharges, it seems more likely that river water is the only one of the two potential sources contributing to spring recharge.

Springs 13, 14, 36, 46, 46a, 47, 56, 163, and 164 had chloride levels that suggest runoff (i.e., precipitation) from roads and parking lots is infiltrating into the water recharging the shallow, unconfined aquifer that discharges from these springs. Springs 23, 172, and 173 have unusually high silica that, along with their locations, suggest a bedrock source for these springs.

Stable Isotopes

Stable isotopic data (Figure 21) indicate that the water in all of the springs (except Spring 147) has an evaporative signature. This is most likely a result of excess irrigation water and/or canal water infiltrating into the shallow, unconfined aquifer. Both of these potential sources have heavier isotopic ratios because of their long exposure to the atmosphere, which would cause preferential evaporation of the lighter isotopes.

Spring 147 plots near the precipitation values (Figure 21). It was not possible to measure the discharge of this spring, but when tritium samples were collected in February of 2006, the discharge appeared to be roughly the same as it was in July of 2005, when stable isotope and major ion samples were collected. It is difficult to explain why this spring has such light isotopic ratios, but it appears to be receiving a larger percentage of its recharge directly from precipitation than any of the other springs sampled for stable isotopes.

Springs 105, 203, and 212 plot near the river water values (Figure 21), indicating the water recharging the shallow, unconfined aquifer that discharges from those springs may be mostly coming from rivers. Springs 105 and 212 had their highest discharges in the spring months when the rivers in the study area also have their highest discharges. Spring 105 has ephemeral mountain drainages to the east that flows into the Hyde Park and Smithfield Canal, which flow east and north of this spring. Spring 212 also has a river (Summit Creek) that flows east-west a few hundred yards north of where the spring emerges. The discharges of these two springs support the river recharge idea. However, Spring 203 had its highest discharge in August and is not near any rivers.

Springs 36, 60, 163, 164, 198 and 200 plot near some of the water taken from wells completed in the principal aquifer, but have slightly more negative δD values. This is perhaps due to river water recharging both the shallow, unconfined aquifer in the vicinity of these six springs and also the principal aquifer. Springs 36 and 60 are located in farm pastures in the western portion of the study area, which does not support this idea. Spring 163 and 164 emerge in the deltaic deposits on the eastern margin of the valley, and Springs 198 and 200 are located between Summit Creek and an ephemeral stream that are approximately one mile apart from each other. The location of these four springs does support the idea that river water contributes a large portion of their recharge.

All of the remaining springs (14, 23, 44, 56, 71, 89, 158, 188, 192, 222, and 224) are less negative in δD and $\delta^{18}O$ than all of the potential recharge sources except excess irrigation and/or canal water, making these the most likely sources of water recharging the shallow, unconfined aquifer that discharges from these springs. Spring 192 has the heaviest isotopic signature, likely indicating excess irrigation water and/or canal water contributes a larger proportion of its recharge than any of the other springs sampled for stable isotopes. This spring has agricultural land in its recharge area to the east, supporting this idea.

Tritium

Tritium data indicate that the water in the shallow, unconfined aquifer that discharges from springs was recharged after 1969. Three of the nine wells located in this study area that were sampled by Robinson (1999) had tritium levels indicating they were recharged before 1952. The other six had levels indicating recharge after 1969. This supports the idea that river water, excess irrigation water, and canal water, not water from the principal aquifer, are the primary sources of water recharging the shallow, unconfined aquifer that discharges from springs in the southeastern portion of Cache Valley.

Conceptual Model

The hypothesis that river water, excess irrigation water, and canal water infiltrate into and flow through the shallow, unconfined aquifer, and discharges from springs is supported by the stratigraphy in the valley as shown in the new conceptual model that is presented in Figure 22. The top of the upper confining layer is the lower boundary of the alluvial and deltaic deposits along the valley margin, which make up the shallow, unconfined aquifer. The two confining layers that separate the shallow,

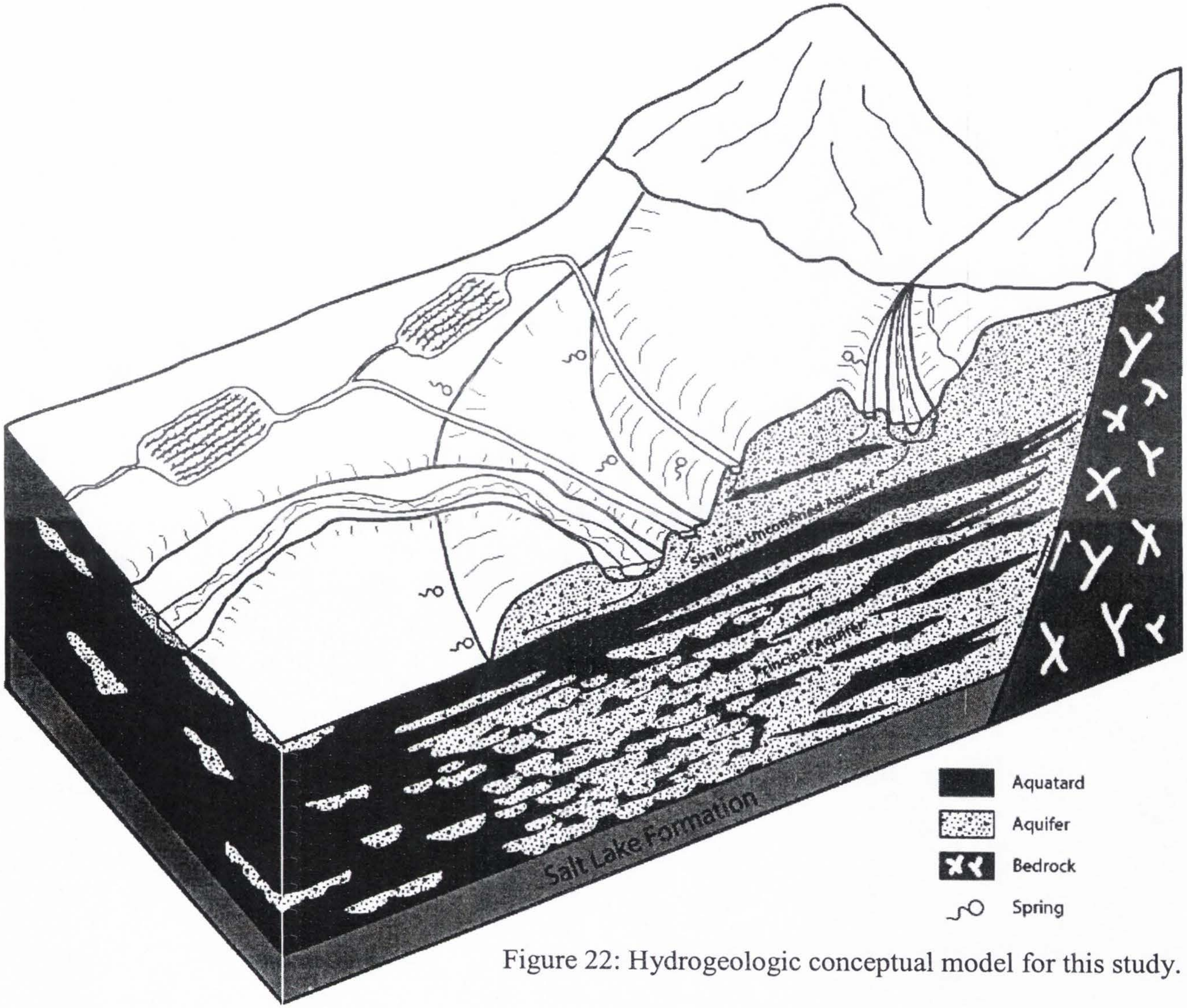


Figure 22: Hydrogeologic conceptual model for this study.

unconfined aquifer from the principal aquifer would not allow much, if any, water from the principal aquifer to recharge the shallow, unconfined aquifer directly. Instead, rivers that enter the valley from the Bear River Range recharge the shallow, unconfined aquifer as they flow across the coarse material along the margin of the valley. Robinson (1999) also found that these rivers recharge the principal aquifer.

Most of the springs that were sampled for stable isotopes had an evaporative signature, indicating that they gain at least part of their recharge from irrigation and/or canal water. There are many agricultural fields located on the deltaic and alluvial deposits along the eastern margin of the valley, which is the recharge area for the shallow, unconfined aquifer. Much of the land in this area that is not residential or commercially developed is irrigated by either flood or sprinkler irrigation, the excess of which is able to infiltrate into the shallow, unconfined aquifer. There are also several unlined irrigation canals that flow across this area. The river water that is directed across the recharge area through these canals also infiltrates into the shallow, unconfined aquifer.

Along the eastern margin of the valley, precipitation would also be able to infiltrate into the shallow, unconfined aquifer, since the alluvial and deltaic deposits are fairly well drained. However, toward the center of the valley the soils are poorly drained lacustrine deposits and infiltration of precipitation would be limited. Nonetheless, the chemistry of the spring, and well (Robinson, 1999), water indicates that the contribution of precipitation to the shallow, unconfined aquifer is relatively small, even along the eastern margin of the valley.

CHAPTER VI

CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

Conclusions

The discharges of 43 springs in the southeastern portion of Cache Valley were measured monthly from May, 2005 through March, 2006. Water samples from 36 of these springs plus an additional ten were analyzed for major ions and trace metals. Those springs that emerged directly from the ground or from a culvert were analyzed for stable isotopic ratios of D/H and $^{18}O/^{16}O$. Ten of the 21 springs analyzed for stable isotopes were also analyzed for tritium. These data were used to identify the source(s) of spring recharge, determine the relationship between springs and the principal aquifer, and to identify discharge trends.

There are six lines of evidence indicating that the water discharging from the shallow, unconfined aquifer at most of the springs in the southeastern portion of Cache Valley is recharged mainly by water lost from rivers, excess irrigation water and canal water, and not by precipitation or the principal aquifer. These indicators include: (1) Two continuous confining layers separate the principal aquifer from the shallow, unconfined aquifer. (2) Spring discharges did not noticeably decrease/increase when ground water pumping increased/decreased in the summer/winter. (3) The discharges of 13 springs (35, 46, 47, 50, 60, 95, 130, 145, 149, 158, 187, 198, and 215) have increased continuously since monitoring began in the summer of 2005, suggesting that the decrease in the discharge of rivers resulting from drought conditions between 1988-1994 (except for 1993) and 1999-2003 (NADP, 2006) decreased the amount of ground water in storage within the shallow, unconfined aquifer that discharges from these springs. (4) The major ions and trace metals in spring water are very similar to river water and canal water. Precipitation contributes very little directly to the shallow, unconfined aquifer based on chemistries of spring water being much different than precipitation. (5) River water and canal water have higher values of major ions and trace metals in the fall and winter months, which were also observed in spring water. (6) Stable isotopes show an evaporative signature characteristic of river, irrigation and/or canal water.

Nine springs (13, 14, 36, 46, 46a, 47, 56, 163, and 164) had high chloride levels, indicating they receive some of their recharge from infiltration of precipitation. Some canal water samples also had similar levels of chloride (Robinson, 1999), indicating again that canal water recharges the shallow, unconfined aquifer. These springs are located along the eastern margin of the valley, which shows that the recharge area for the shallow, unconfined aquifer is in the deltaic deposits. Spring 147 did not have elevated chloride levels but did have isotope ratios that suggest this spring may receive some of its recharge from precipitation. This spring is located in the western portion of the study area, which may explain why it does not have elevated chloride levels since the chloride would be more dilute from the larger volume of ground water in that area.

Table 19 lists the sources of recharge to the shallow, unconfined aquifer that discharges from each spring based on discharge trends, major ions and trace metals, and stable isotopes. Rivers are the major source of recharge to the shallow, unconfined aquifer, but discharge trends and spring water chemistries indicate there is a significant contribution from some of the other potential sources as well. All but one of the springs sampled for stable isotopes had an evaporative signature. This was most likely caused by irrigation and/or canal water infiltrating into the shallow, unconfined aquifer, since those two sources are exposed to the atmosphere longer, allowing for preferential evaporation of the lighter isotopes. This seems to indicate that excess irrigation water and canal water are important recharge sources for most of the springs as well as rivers.

While there are likely multiple sources for each spring, the discharge trends, major ions and trace metals concentrations, and D/H and $^{18}O/^{16}O$ ratios for most of the springs suggest the majority of their recharge comes from a particular source. The major sources of recharge to each spring are summarized in Table 20, and are based mainly on chemistry because discharge trends may be affected by lag times, which are not fully understood and may vary from spring to spring and between seasons.

Springs 14, 23, 36, 44, 56, 71, 89, 158, 188, 192, 222, and 224 appear to gain the majority of their recharge from excess irrigation water and/or canals water based mostly on the fact that the deuterium and oxygen-18 results show an evaporative signature in the water from these springs. Many of these springs also had peak discharges in the summer and/or major ion and trace metals that suggest recharge from irrigation water and/or canal water. Springs 13, 37, 38, 57, 87, 134, 163, 164, and 192a also appear to receive much of their recharge from excess irrigation water and/or canal water based on major ion and trace metal content, discharge trends, and/or locations that suggest this source of recharge.

Springs 35, 39, 46, 46a, 47, 58, 60, 93, 95, 105, 114, 130, 145, 147, 149, 159, 182, 187, 188a, 198, 203, 212, and 215 gain most of their water from rivers that lose some of their water to the shallow, unconfined aquifer based on major ion and trace metal concentrations, discharge trends, location, and/or deuterium and oxygen-18 values. Springs172 and 173 are most likely bedrock springs based on their major ion concentrations and their locations.

Springs 93, 189, 200, 201, and 221 appear to have multiple sources of recharge based on the fact they have peak discharges in multiples season and based on their chemistries. Spring 201 definitely

Table 20: Major source of recharge for each spring and the justifications for this conclusion based on discharge trends, major ions and trace metals (MI and TM), deuterium and oxygen-18 (D/18O), and/or location.

Spring #	Source	Justification (listed in order of importance)
13	irrigation/canals	location; highest Q in summer
14	irrigation/canals	D/18O; location;
23	irrigation/canals	D/18O; location
36	irrigation/canals	D/18O; highest Q in summer
37	irrigation/canals	MI and TM; highest Q in summer
38	irrigation/canals	MI and TM; highest Q in summer
44	irrigation/canals	D/18O; MI and TM; highest Q in summer
56	irrigation/canals	D/18O; highest Q in summer
57	irrigation/canals	MI and TM; highest Q in summer
71	irrigation/canals	D/18O; MI and TM
87	irrigation/canals	location; MI and TM
89	irrigation/canals	D/18O; location; MI and TM
134	irrigation/canals	MI and TM; highest Q in summer
158	irrigation/canals	D/18O; MI and TM
163	irrigation/canals	location; highest Q in summer
164	irrigation/canals	location
188	irrigation/canals	D/18O; MI and TM; highest Q in summer
192	irrigation/canals	D/18O; MI and TM
192a	irrigation/canals	MI and TM; location
222	irrigation/canals	D/18O; MI and TM
224	irrigation/canals	D/18O; MI and TM
35	rivers	MI and TM; highest Q in winter
39	rivers	MI and TM; highest Q in spring
46	rivers	highest Q in winter
46a	rivers	MI and TM; location

Table 20. (continued)

Spring #	Source	Justification (listed in order of importance)
47	rivers	location; highest Q in winter
50	rivers	highest Q in winter; MI and TM
58	rivers	MI and TM; location
60	rivers	highest Q in winter; MI and TM
93	rivers	MI and TM
95	rivers	MI and TM; highest Q in winter
105	rivers	D/18O; MI and TM
147	rivers	MI and TM; D/18O
149	rivers	MI and TM; highest Q in winter
159	rivers	MI and TM; highest Q in spring
182	rivers	MI and TM; highest Q in spring
187	rivers	MI and TM; highest Q in winter
188a	rivers	MI and TM; highest Q in spring
198	rivers	MI and TM; highest Q in winter
203	rivers	D/18O; MI and TM;
212	rivers	D/18O; MI and TM; highest Q in spring
215	rivers	MI and TM; highest Q in winter
172	bedrock	MI and TM; location
173	bedrock	MI and TM; location
93	multiple	MI and TM; highest Q in summer and winter
189	multiple	MI and TM; highest Q in multiple seasons
200	multiple	D/18O; MI and TM; highest Q in multiple seasons
201	multiple	outlet for spring area with many flowing wells in it
221	multiple	MI and TM; highest Q in multiple seasons
153	indeterminate	MI and TM
219	indeterminate	MI and TM

does not have one major source because it is the outlet for a large area with multiple springs and flowing wells. Finally, a single source of the majority of the recharge to Springs 153 and 219 cannot be determined because the only data collected were major ion and trace metal concentrations, which are similar to both river and water and irrigation/canal water.

The shallow, unconfined aquifer is made up of deltaic and alluvial deposits along the eastern portion of the study area, and has two continuous confining layers below it (Figure 22). When the rivers that originate in the Bear River Range enter the valley, they lose some of their water as they flow along these deposits. River water is one of the two main sources of recharge to the shallow, unconfined aquifer.

Excess irrigation water and water seeping from unlined irrigation canals contribute a significant amount of water to the shallow, unconfined aquifer, too. A system of canals brings water from the rivers at higher elevations to fields in the eastern portion of the valley where it is used for irrigation. Excess irrigation water and canal water infiltrate into the shallow, unconfined aquifer through the deltaic and alluvial deposits. The two continuous confining layers that are present at the surface west of the alluvial deposits forces the shallow ground water out at the surface as springs at the base of the alluvial deposits, as illustrated in Figure 22.

Implications

The implications of this study include:

(1) The source of recharge to springs in southeastern Cache Valley is shallow ground water that is recharged mostly by rivers, excess irrigation water and canals. Major ions in spring waters

are very similar to these. Ground water in the principal aquifer also is similar chemically to river water because rivers also recharge the principal aquifer. Irrigation and/or canal water also contribute during the summer months to many of the springs, giving spring water an evaporative isotopic signature.

(2) Increased pumping from the principal aquifer should not have a direct effect on spring discharges because the springs do not appear to be hydraulically connected to the principal aquifer. However, if the piezometric surface of the principal aquifer was lowered below the confining layers adjacent to the Bear River Range, the amount of river water, excess irrigation water, and canal water that recharge the shallow, unconfined aquifer may decrease as more of that water recharges the principal aquifer.

(3) Drought conditions would likely decrease the discharges of those springs listed in Table 20 whose primary source of recharge is river water.

(4) The springs listed in Table 20 that receive much of their recharge from excess irrigation and/or canal water can be expected to be affected by any decreases in the amounts of these sources, resulting from irrigated fields being developed for residential use or canals being lined. In such situations,

much less recharge would be provided to the shallow, unconfined aquifer.

(5) The ten springs that may receive some of their recharge from precipitation (13, 14, 36, 46, 46a, 47, 56, 147, 163, and 164) will also likely see a decrease in their discharges if there is development in their recharge areas to the east. Buildings, driveways, and roads decrease the area through which precipitation can infiltrate, and the water that runs off those surfaces no longer follows natural flow paths, but instead flows out of the area through storm drains.

(6) Development not only takes irrigated fields out of production and increases the area covered by impermeable surfaces, it also disrupts the shallow ground water system. Sewer and other utility lines require the digging of trenches. If these trenches are backfilled with material that is coarser than the native material or even with the native material if it is less compacted than it originally was, shallow ground water will be diverted along these paths of least resistance.

Recommendations

Since the recharge area of the springs in the southeastern portion of Cache Valley is along the eastern margin of the valley, it is important to consider how changes in land use will likely affect the discharges of the springs. It is also necessary to protect that area from ground water contamination. Since high chloride levels, probably from road deicing salts, have been found in some springs, it is possible for contaminants, including agricultural runoff, to infiltrate and flow through the shallow, unconfined aquifer and discharge from a spring farther to the west. This water would be used again for watering crops and livestock, which, depending of the amount and type of contaminant, could have serious adverse impacts. Most of the development along the margins of the valley is residential, which is probably better than industrial, since the waste from some industries could adversely impact the shallow ground water quality. Also, the concentrations of agricultural chemicals used in these areas should be low, since excess irrigation water and canal water contribute to many springs and will dilute the chemicals.

Future Monitoring

A summary of monitoring recommendations is provided in Table 21. Twenty-seven springs should continue to have their discharges monitored in the future because of some combination of being accessible, having significant discharges, and/or being located either where no other springs exist or near residential/industrial development. It may also be useful to sample these springs at different times of the year also to see if the chemistry changes, perhaps indicating and better quantifying a different source at different times of the year. Duplicate, blank, and spike samples should be collected in

Table 21: Continued discharge monitoring recommendations for springs.

#	Name	Recommendation	Reason
13	John Nielsen Spring	Yes	Q trend/MI-TM/location
14	West Camp Hollow Spring	Yes	Q trend/MI-TM/location
23	Libbie Spring	Yes	Q trend/MI-TM/location
35	Hansen Spring	No	near other spings/dangerous
36	Parker Spring	Yes	Q trend/MI-TM/location
37	Davis Spring	No	difficult to measure accurately/near other springs
38	S.W. Field Irr. Co. Spring	Yes	Q trend/location
39	Fredrick Spring	No	cannot measure during irrigation season
44	Ditch Spring	No	small Q/near other springs
46	Little Ballard Spring	Yes	large Q/location
47	Banellis Spring	Yes	Q trend/MI-TM/location
50	Big Ballard Spring	Yes	large Q/location
56	Campbell Spring	Yes	Q trend/MI-TM/location
57	Spring Creek #1	Yes	large Q/location
58	Spring Creek #3	Yes	large Q/location
60	Del Hansen Spring	Yes	Q trend/MI-TM/location
89	Barn Yard Spring	Yes	Q trend/MI-TM/location
93	South Blue Spring	Yes	Q trend/location
95	Spring Creek #4	Yes	Q trend/location
114	North Bodrero Spring	Yes	Q trend/location
130	Sheep Spring	Yes	large Q/location
134	Snider Spring	Yes	large Q/location
145	Jensen Spring	Yes	Q trend/location
149	North Blue Spring	Yes	large Q/location
158	Road Spring	Yes	Q trend/location
159	Merrill Spring	No	near other springs
163	Johnson Spring	Yes	Q trend/MI-TM/location
164	Blair Spring	No	Q trend/MI-TM/location
172	North Corbett Spring	No	little to no Q/likely a bedrock spring
182	Joseph Smith Spring	Yes	large Q/location
187	William Smith Spring	Yes	large Q/location
188	Mathers Spring	Yes	Q trend/location
188a	Mathers Spring Outlet	Yes	large Q/location
189	Corbett Spring	Yes	large Q/location

Table 21. (continued)

#	Name	Recommendation	Reason
198	North Erickson Spring	No	difficult to measure accurately/near other springs
200	Anderson Spring	Yes	Q trend/location
201	Outlet Spring	Yes	location/good measure of large spring area
203	South Erickson Spring	Yes	large Q/location
212	Low Spring	Yes	Q trend/location
215	Sorenson Spring	No	small Q/near other springs
221	Gittens Spring	Yes	large Q/location
222	Small Seep Spring	Yes	Q trend/location
224	Hopkins Spring	Yes	large Q/location

future spring sampling events because of possible variability in analytical results. Those springs whose discharges were highest during the winter months (35, 46, 47, 50, 60, 95, 130, 145, 149, 158, 187, 198, and 215) are especially important to monitor because they seem to be more sensitive to a decrease in recharge to the shallow, unconfined aquifer resulting from drought conditions. However, Springs 35, 37, 39, 44, 159, 164, 172, 198, and 215 do not necessarily need to continue to be monitored in the future because they have low discharges, and/or they are near a larger, more accessible spring.

It is probably only necessary to measure the discharges of the springs in Cache Valley three times per year (spring, summer, and winter), since there do not seem to be large seasonal fluctuations in discharge. It may also be beneficial to measure water levels in non-flowing wells and discharges of flowing wells throughout the study area that are completed into the principal aquifer three times per year.

The condition of the principal aquifer could be monitored, at least partially, by monitoring the water levels in and discharges of wells, which would be a good indicator of the condition of the principal aquifer, which is the ground water supply that many people in Cache Valley depend on. The USGS monitors many wells in Cache Valley already and present their data on their website (USGS, 2006), which would be beneficial to use also. The water levels in and discharges of these wells were higher when the valley was first settled according to measurements made by the USGS between the 1930s and the present.

Future Studies

Future studies on the ground water conditions in Cache Valley are necessary to allow optimum use of the largest source of ground water in the state of Utah (UDWR, 2006). Multiple-well pumping tests in wells completed in the principal aquifer would give transmissivity and storativity values that could be used to create simulation and optimization models to develop and manage the ground and surface water resources most efficiently. Existing wells throughout the study area could be used as monitoring wells in these studies as long as they are located near the test wells. Observation wells could be completed into the confining layers to provide data that would indicate the amount of water that could potentially flow through these aquitards.

It would also be useful to determine how much water the unlined irrigation canals contribute to the ground water. This could be accomplished by measuring discharge in canals at several points along their reaches. During the irrigation season, which usually goes from April to September, the canals are nearly full of water. It would also be valuable to measure non-point source recharge from irrigated fields and precipitation.

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APPENDICES

Appendix A: Location and discharge/status of all springs above the principal aquifer with water rights filed on them

Table 22: Location and discharge/status of all springs above the principal aquifer with water rights filed on them. UTM coordinates are given for those spring that had their discharges monitored and/or were sampled for chemical analysis. * : Report from June-August of 2004; all others are from May-June, 2005.

Spring Number	Water right number(s)	Discharge (gpm) / status	Location	Legal Description	UTM Coordinates	
					X	Y
1		Cannot get permission from landowner		(A 10-1) 3aba		
2*		Spring has dried up		(A 10-1) 3bbb		
3	25-4613	Cannot get permission from landowner	Center located S 440ft W 1800ft from the NE cor.	(A 10-1) 3		
	25-4614		area is 200ft wide 550ft long.			
4*	25-588	Spring dried up after irrigation stopped	S1850ft E870ft from N1/4 cor.	(A 10-1) 3		
5*	25-48	Spring dried up after irrigation stopped	S2187ft E244ft from N1/4 cor.	(A 10-1) 3		
6*	25-1793	Spring dried up after irrigation stopped	S2465ft W520ft from N1/4 cor.	(A 10-1) 3		
	25-116					
7*	25-355	Found in conjunction with #4,5,6	S2480ft W650ft from N1/4 cor.	(A 10-1) 3		
	25-118					
8*	25-74	Diffuse/low flow	N5ft W1230ft from S1/4 cor.	(A 10-1) 4		
9	25-565	Diffuse/low flow	N960ft E350ft from W1/4 cor.	(A 10-1) 3		
10	25-564	Diffuse/low flow	N800ft E460ft from W1/4 cor.	(A 10-1) 3		
11	25-563	Diffuse/low flow	N785ft E425ft from W1/4 cor.	(A 10-1) 3		
12	25-562	Diffuse/low flow	N735ft E430ft from W1/4 cor.	(A 10-1) 3		

13*	25-1453	7.4	S2330ft W310ft from N4 cor.	(A 10-1) 3bdd	429929.07	4609431.53
14*	25-438	77.04	S70ft E970ft from N4 cor.	(A 10-1) 4aba	430194.96	4610118.59
15	25-490	Cannot verify	S1200ft E260ft from NW cor.	(A 10-1) 4bbc		
16	25-35,36	No flow	S2618ft E40ft from N4 cor.	(A 10-1) 5acc		
17	25-109, 25-273,274	Cannot verify	N 230ft E 170ft from the S4 cor.	(A 10-1) 5dcc		
18	25-1145	No flow	N 320ft E 2540ft from W4 cor.	(A 10-1) 5bdd		
19*	25-253	Owner filled in spring	N 1630ft W 195ft from S4 cor.	(A 10-1) 5cad		
20*	25-1270	Cannot verify, area has been developed	N 1450ft W 460ft from S4 cor.	(A 10-1) 5cad		
21	25-124	Cannot verify, area has been developed	N 2200ft W 160ft from S1/4 cor.	(A 10-1) 5caa		
22	25-41	Cannot verify	N70ft E35ft from S1/4 cor.	(A 10-1) 5cdd		
23 N	25-186	Cannot verify	S 630ft W2620ft from E1/4 cor.	(A 10-1) 5dbb		
23	25-1358	17.8	S2045ft W300ft from NE cor.	(A 10-1) 6add	427355.01	4609558.16
24	25-10393	Cannot get permission from land owner	S 2050ft E 970ft from NWcor.	(A 10-1) 6bca		
	25-4314					
31*	25-538	No flow	S 580ft E 1800ft from NW cor.	(B 10-1) 1bac		
	25-631					
32*	25-3066	Cannot verify	West) N 960ft E 2090ft from the W4 cor.	(A 11-1) 3		
			East) N 980ft E 2140ft from the W4 cor.	(A 11-1) 3bdb		
33*	25-5012	Ditch/canal water	S 1075ft E 745ft from the W4 cor.	(A 11-1) 3		

			S 855ft E 1065ft "			
			S 795ft E 1180ft "			
			S 725ft E 1215ft "			
			S 670ft E 1238ft"			
			S 384ft E 1328ft"			
			S 205ft E 1400ft"			
			S 100ft E 1768ft"			
34	25-4990	Cannot verify; area has been developed	N 560ft E 645ft from the W4 cor.	(A 11-1) 4		
35	25-5152	237.1	N 150ft W 1310ft from the S4 cor.	(A 11-1) 4cdc	429514.65	4618285.76
	25-5153		N 210ft W1340ft from the S4 cor.			
36	25-5143	50.4	N 490ft E 1660ft from the SW cor.	(A 11-1) 5cdc	427971.89	4618367.23
37	25-5145	495.3	N 1685ft E 110ft from the W4 cor.	(A 11-1) 5bbc	427486.87	4619595.78
38	25-5144	511.9	N 1220ft W 370ft from the E4 cor.	(A 11-1) 6ada	426863.36	4619305.28
39	25-6281	39	S440ft W590ft from E4 cor.	(A 11-1) 7daa	427300.31	4617312.15
40	25-1771	Found in conjunction with 39	N2150ft W610ft from SE cor.	(A 11-1) 7daa		
41	25-5155	Spring has been filled in	S 1070ft E 950ft from the NW cor.	(A 11-1) 8bbd		
42	25-5157	Found in conjunction with #36	S 420ft E 1350ft from the NW cor.	(A 11-1) 8bba		
43*	25-1768	No flow	N230ft E50ft from SW cor.	(A 11-1) 8ccc		
44	25-3018	2.5	N 1010ft W 460ft from the SE cor.	(A 11-1) 10	432220.75	4616867.53
45	25-3253	Found in conjunction with 44	N 830ft W 400ft from the SE cor.	(A 11-1) 10		
46*	25-5041	No flow		(A 11-1) 10ccd	431034.72	4616678.40

47	25-2985	Not measured	S 600ft E 530ft from the W4 cor.	(A 11-1) 11cba	432561.98	4617218.65
48	25-2984	Cannot verify	S 780ft E 430ft from the W4 cor.	(A 11-1) 11cbc		
49		Will not allow access until end of summer		(A 11-1) 14ccd		
50*		No flow		(A 11-1) 15bbc	430793.21	4616378.69
51	25-2175	No flow	1)N 205ft E 2175ft from the S4 cor.	(A 11-1) 16		
			2) N 350ft E 2200ft from the S4 cor.			
52*	25-4626	No flow	N 240ft W 1290ft from the SE cor.	(A 11-1) 16ddc		
53	25-2243	Found in conjunction with #52	N 350ft W 1320ft from the SE cor.	(A 11-1) 16		
54*	25-4538	Cannot verify; area has been developed	S 500ft W 930ft from the N4 cor.	(A 11-1) 17baa		
55*	25-708	No flow	N1455ft W640ft from SE cor.	(A 11-1) 17dad		
56*	25-1770	3.8	N 525ft W 150ft from E4 cor.	(A 11-1) 17add	429040.94	4615986.74
57		4990.5		(A 11-1) 17bdb	427520.96	4616267.15
58		3736		(A 11-1) 18bcd	426234.89	4616369.83
59		Flows into #58 (Spring Creek #2)		(A 11-1) 18bdd		
60	25-557	Not measured	S280ft W2400ft from E1/4 cor.	(A 11-1) 18dbb	426772.47	4615760.36
61	25-558	No flow	S730ft W2030ft from E1/4 cor.	(A 11-1) 18dbc		
62*	25-1230	Dried up	N870ft E270ft from S1/4 cor.	(A 11-1) 18		
63*	25-1229	No flow	N690ft E275ft from S4 cor.	(A 11-1) 18dcc		

64*	25-3503	Cannot verify	S 1000ft W 150ft from the NE cor.	(A 11-1) 21		
65	25-4615	Cannot verify	S 100ft W 1970ft from the NE cor.	(A 11-1) 21aba		
66	25-4542	Spring originates at #67	N2000ft W 440ft from the SE cor.	(A 11-1) 21dad		
67*	25-4530	No flow	N 1480ft W 400ft from the SE cor.	(A 11-1) 21dad		
	25-4620, 4543					
68	25-4528	Area inaccessible; possibly capped	N690ft W2650ft from SE cor.	(A 11-1) 23cda		
	(multiple water rights)					
69		Cannot verify	NW 1/4	A 11-1 (27)		
70*	25-4852	No flow	S590ft W850ft from NE cor.	A 11-1 (28aab)		
71*	25-726	Diffuse flow	N 1670ft E 210ft from S1/4 cor.	A 11-1 (28dbc)	429965.67	4612185.11
72*	25-732	Found in conjunction with #71	N1530ft E210ft from S1/4 cor.	A 11-1 (28dbc)		
73*	25-733	Found in conjunction with #71	N1340ft E205ft from S1/4 cor.	A 11-1 (28dbc)		
74*	25-1766	Found in conjunction with #71	N1340ft E230ft from S1/4 cor.	A 11-1 (28dbc)		
75*	25-1370	Spring has dried up; only flows during irrigation	N350ft E680ft from S1/4 cor.	A 11-1 (28dcc)		
76	25-1144	Cannot get permission from land owner	N660ft W1220ft from S4 cor.	A 11-1 (31cdc)		
77	25-569	Cannot get permission from land owner	N440ft E115ft from SW cor.	A 11-1 (31)		
78*	25-524	No flow	N1072ft W1855ft from S1/4 cor.	A 11-1 (32)		
79*	25-514	Cannot verify, area has been developed	N1000ft E40ft from SW cor.	A 11-1 (32)		
80*	25-2001	Spring has dried up after irrigation stopped	N460ft E755ft from S1/4 cor.	A 11-1 (32dcc-		

81*	25-11	Spring has dried up after irrigation stopped	N320ft W2180ft from SE cor.	A 11-1 (32dcc)		
82*	25-513	Spring has dried up after irrigation stopped	N300ft W1810ft from SE cor.	A 11-1 (32dcd)		
83*	25-1767	Spring has dried up after irrigation stopped	N240ft W1810ft from SE cor.	A 11-1 (32dcd)		
84*	25-938	Spring has dried up after irrigation stopped	N60ft W1410ft from SE cor	A 11-1 (32dcd)		
85*	4X(25-326)	Found in conjunction with #14	N105ft E1045ft from S1/4 cor.	A 11-1 (32dcd)		
86	25-4691	Cannot verify	S 1330ft E 2150ft from the NW cor.	A 11-1 (34)		
			S 250ft E 1780ft from the NW cor.			
87	25-4621	0.5	N 1480ft W 2590ft from the SE cor.	A 11-1 (34)	431573.03	4610569.31
89	25-4622	4.65	N 1615ft W 2660ft from the SE cor.	A 11-1 (34)	431612.54	4610446.50
90	25-4352	Cannot get permission from landowner	N 40ft W 2130ft from the SE cor.	A 11-1 (34dcc)		
91	25-2167	City of Nibley water supply	N1035ft W2375ft from SE cor.	A 11-1 (34dcb)		
92		Cannot verify		B 11-1 (12aaa)		
93	25-976	Not measured	Stock water from stream from a point at S950ft W2100ft)	B 11-1 (13db)	425274.52	4615554.64
			from the E4 cor. to a point S810ft W1540ft from E4 cor.			
94	25-974	No flow	S615ft W200ft from E1/4 cor.	B 11-1 (13daa)		
95		160.2		B 11-1 (13aab)	425579.46	4616690.62
96	25-426	Diffuse/low flow	N275ft E1420ft from W1/4 cor.	B 11-1 (25)		
97	25-425	Diffuse/low flow	N1940ft W610ft from S1/4 cor.	B 11-1 (25caa)		

98	25-176	Cannot verify	N720ft E1200ft from S1/4 cor.	B 11-1 (35dca)		
99*	25-220	Cannot verify	S750ft W1090ft from NE cor.	B 11-1 (36acc)		
100	25-191	Dry	S570ft E570ft from NW cor.	B 11-1 (36)		
101*	25-1748	No flow	N470ft W760ft from SE cor.	B11-1 (36ddd)		
102	25-5183	No flow	S1350ft E415ft from N4 cor.	A 12-1 (2acb)		
	25-8227					
103	25-10389	No flow	S 540 ft E 1170 ft from NW cor.	A 12-1 (4bab)		
104	25-6201	Diffuse flow	N1245ft E1185ft from the W4 cor.	A 12-1 (10bad)		
105	25-3222	Diffuse flow	S 405ft W 765ft from the N4 cor.	A 12-1 (11)	432956.92	4627806.27
106	25-5491	Swampy; no outlet	S 1230ft E 215ft from the W4 cor.	A 12-1 (16)		
107	25-6296	Diffuse flow	S 122ft W 1795ft from E4 cor.	A 12-1 (16dba)		
108	25-5580	Swampy; no outlet	S 1500ft W 430ft from the E4cor.	A 12-1 (17dda)		
109	25-5581	Swampy; no outlet	N 910ft W 330ft from the SE cor.	A 12-1 (17dda)		
110	25-5583	No flow	N 660ft W 690ft from the SE cor.	A 12-1 (17dda)		
111	25-5669	No flow	S 230ft W 425ft from the NE cor.	A 12-1 (20aaa)		
	25-5672					
112	25-5584	Diffuse flow	S 1145ft E 1980ft from the N4 cor.	A 12-1 (20aac)		
	25-5600					
	25-5599					

113	25-5585	Diffuse flow	S 1255ft E 1645ft from the N4 cor.	A 12-1 (20adb)		
	25-5671					
	25-5674					
114	25-5586	79.4	S 1030ft E 560ft from the N4 cor.	A 12-1 (20)	428118.54	4624458.86
115	25-3007	Diffuse Flow	N 830ft E 2430ft from the W4 cor.	A 12-1 (20)		
116	25-3008	118.31	1)N 330ft E 1400ft from the W4 cor.	A 12-1 (20bdc)		
			2)N 25ft E 1615ft from the W4 cor.			
			3) S 605ft E 1065ft from the W4 cor.	A 12-1 (20cba)		
			S 100ft E 1005ft from the W4 cor.			
117	25-5609	No flow	N 900ft W 180ft from the SE cor.	A 12-1 (20dda)		
118	25-3009	233.59	N 1400ft E 1005ft from the SW cor.	A 12-1 (20cbd)		
119	25-5005	45.2	N 1065ft E 970ft from the SW cor.	A 12-1 (20cca)		
			N 1400ft E 1005ft from the SW cor.			
120	25-5222,5853	23.5	N 470ft E 970ft from the SW cor.	A 12-1 (20)		
	25-5828		N 470ft E 950ft from the SW cor.			
121	25-5610	5.46	N 385ft E 970ft from the SW cor.	A 12-1 (20)		
	25-5830, 5854					
122	25-3225	Cannot verify; area has been developed	S 180ft W 2210ft from the E4 cor.	A 12-1 (23)		
123	25-2965	Cannot verify; area has been developed	S 110ft W 2540ft from the E4 cor.	A 12-1 (23)		
124	25-3006	No flow	N 343ft W 180ft from the S4 cor.	A 12-1 (23)		

125	25-2163	No flow	N 985ft E 450ft from the SW cor.	A 12-1 (23ccb)		
126	25-3017	Cannot verify; biorestricted area	N 15ft W 570ft from the S4 cor.	A 12-1 (23)		
127		Cannot verify; biorestricted area		A 12-1 (23cdd)		
128	25-3005	Cannot verify	S 80ft E 260ft from the N4 cor.	A 12-1 (26)		
129	25-2160	28.6	S 120ft E 1420ft from the NW cor.	A 12-1 (26bab)		
130	25-2161	114.8	S 220ft E 1560ft from the NW cor.	A 12-1 (26)	432933.65	4623019.39
131	25-2162	87.2	S 130ft E 1670ft from the NW cor.	A 12-1 (26)		
132		Diffuse flow		A 12-1 (26abb)		
133		Cannot verify; area developed		A 12-1 (26bab)		
134	25-3010	123.2	S 490ft E 1730ft from the NW cor.	A 12-1 (29bab)	428106.90	4622947.81
	25-5017,5018, 5829,5852					
135	25-5831	55.28	S 840ft W 1240ft from the N4 cor.	A 12-1 (29)		
	25-5833, 5851					
136	25-5652	32.2	S 1395ft W 560ft from the N4 cor.	A 12-1 (29bda)		
137	25-5859	23.78	S 995ft E 1040ft from the NW cor.	A 12-1 (29)		
	25-5860, 5861					
138	25-5673	61.6	N 215ft E 1200ft from the W4 cor.	A 12-1 (29bcd)		
139	25-5648	186.6	N 445ft E 1485ft from the W4 cor.	A 12-1 (29bdc)		
140	25-5651	145.61	N 1245ft E 1160ft from the W4 cor.	A 12-1 (29)		

141	25-5650	Found in conjunction with #140	N 1120ft E 1190ft from the W4 cor.	A 12-1 (29)		
142	25-5649	Found in conjunction with #140	N 785ft E 1250ft from the W4 cor.	A 12-1 (29bca)		
143	25-5862	4.1	S 290ft E 1095ft from the W4 cor.	A 12-1 (29)		
	25-6021		S 310ft E 1020ft from the W4 cor.			
144*	25-6026	No flow	N 420ft W 360ft from the SE cor.	A 12-1 (29ddd)		
	25-6027, 6028					
145	25-6025	292.3	N 840ft E 790ft from the SW cor.	A 12-1 (29cca)	427782.75	4621605.24
146	25-6024	Diffuse flow	N 590ft E 1075ft from SW cor.	A 12-1 (29ccd)		
147	25-5841	Diffuse flow	S 995ft E 840ft from the W4 cor.	A 12-1 (29cac)	428121.22	4621893.55
148		75		A 12-1 (29cda)		
149	25-5832	159.3	N390ft E875ft from W1/4 cor.	A 12-1 (29acc)	428400.79	4622461.88
	through 25-5840, 25-5647					
150	25-5398	No flow	N 155ft W 2185ft from the E4 cor.	A 12-1 (31)		
	25-5399					
	25-5400					
	25-5401					
151	25-5759	No flow	N 1410ft E 5ft from the SW cor.	A 12-1 (31)		
152*	25-5975	No flow	S 1300ft W 965ft from the N4 cor.	A 12-1 (31bac)		
153	25-5963	90.9	S 365ft E 180ft from the NW cor.	A 12-1 (32bbb)	427622.56	4621327.04
154	25-5577	Found in conjunction with #153	S 330ft E 165ft from the NW cor.	A 12-1 (32)		

155*	25-5965	Cannot verify	N 1075ft W 2410ft from the E4 cor.	A 12-1 (32)		
156*	25-5974	No flow	S 1680ft E 1335ft from the NW cor.	A 12-1 (32bdb)		
157	25-5955	14.8	S 1045ft W 450ft from the E4 cor.	A 12-1 (32dad)		
158	25-5957	9.2	S 875ft W 660ft from the E4 cor.	A 12-1 (32)	428944.33	4620389.53
159	25-5961	175.4	S 1125ft W 1135ft from the E4 cor.	A 12-1 (32dbd)	428772.66	4620299.33
160	25-5962	Cannot verify, area has been developed	S 850ft E 360ft from the W4 cor.	A 12-1 (33)		
161	25-5574	Diffuse flow	N 275ft E 205ft from the SW cor.	A 12-1 (33)		
162	25-5756	Diffuse flow	N 35ft E 150ft from the SW cor.	A 12-1 (33)		
163	25-6522	15	N 520ft W 1270ft from the E4 cor.	A 12-1 (34)	431961.20	4620793.99
	thru 25-6532					
164	25-5895	26.5	N 450ft E 110ft from the E4 cor.	A 12-1 (34)	432318.52	4620799.81
	25-5897					
	25-5293					
165	25-2994	31.3	S 865ft E 140ft from the N4 cor.	A 12-1 (35)		
166	25-4189	15.34	S 1460ft W 475ft from the N4 cor.	A 12-1 (35)		
167	25-6418	157.57	SLN1) S 1445ft E 1475ft from the NW cor.	A 12-1 (35)		
			SLN2) S 1690ft E 995ft "			
			SLN3) S 1520ft E 1790ft "			
			SLN4) S 1410ft E 2145ft "			
168	25-6237	15.1	N 865ft E 675ft from the W4 cor.	A 12-1 (35)		
	25-6238					

169	25-3064	Cannot verify	1) N 1090ft E 1462ft from the SW cor.	A 12-1 (35)		
			2) N 785ft E 855ft from the SW cor.			
172	25-6603	1.2	N 1415ft W 1245ft from the SE cor.	A 13-1 (15)	431983.31	4634814.19
173	25-6054	10.58	N 1550ft E 130ft from the S4 cor.	A 13-1 (15)	431631.23	4634840.38
174	25-5317	Dry	N 1655ft W 35ft from the S4 cor.	A 13-1 (15)		
	6291thru6293					
175	25-6396	No flow	N 350ft E 535ft from the W4 cor.	A 13-1 (16bcc)		
176	25-6313	No flow	S 380ft E 865ft from the W4 cor.	A 13-1 (16)		
177	25-6619	No flow	1) S 1140ft E 1070ft from the W4 cor.	A 13-1 (16cbd)		
	25-6314		2) S 1170ft E 850ft from the W4 cor.			
178	25-6621	No flow	1) S 1040ft E 1070ft from the W4 cor.	A 13-1 (16)		
			2) S 1170ft E 620ft from the W4 cor.			
179	25-6474	10.58	N 1210ft E 380ft from the Sw cor.	A 13-1 (16)		
	25-6475					
180		Dry		A 13-1 (16cca)		
181		Dry		A 13-1 (16cc)		
182	25-6476	142.6	N 950ft E 1045ft from S4 cor.	A 13-1 (17dca)	428692.93	4634743.775
	6477, 6478					
183	25-6479	60.3	POD N65ft E605ft from S4 cor.	A 13-1 (17dcc)		
184	25-6308	Found in conjunction with 183	N 70ft E 635ft from the S4 cor.	A 13-1 (17dcc)		

185	25-6307	3.7	N 25ft E 1055ft from the S4 cor.	A 13-1 (17dcd)		
186	25-6311	Found in conjunction with 183	N 190ft E 600ft from the S4 cor.	A 13-1 (17dcc)		
187	25-6114	185.8	S 220ft E 700ft from N4 cor.	A 13-1 (20aba)	428626.0046	4634368.413
	6120, 6123, 6125					
	6127, 6129, 6130					
188		25.3		A 13-1 (20cca)	427898.5592	4633065.995
189	25-5314	1286.7	N 2390ft E2140ft from SW cor.	A 13-1 (20dbb)	428243.0512	4633512.31
190	25-6392	Canal/ditch water	N1055ft E1400ft from SW cor.	A 13-1 (20d)		
	25-6393					
191		Cannot verify		A 13-1 (20)		
192	25-6118	38.6	S 1090ft E 175ft from the N4 cor.	A 13-1 (20abc)	428451.4177	4634030.878
	25-6124					
193	25-6388	51.36	1) N 2170ft E 50ft from the S4 cor.	A 13-1 (20)		
	25-6389		2) N 2070ft W 515ft from the S4 cor.			
	25-6390					
	25-6391					
	25-3000					
194	25-6712	4	S 300ft W 1750ft from the E4 cor.	A 13-1 (20dba)		
195	25-6711	No flow	N 955ft W 775ft from the E4 cor.	A 13-1 (20adb)		
196	25-4336	Cannot verify	N 715ft W 720ft from the E4 cor.	A 13-1 (27)		
197		No flow		A 13-1 (27)		

198		127.5		A 13-1 (29bab)	427956.7548	4632641.167
199		No flow		A 13-1 (29acb)		
200	25-6502	31.4	S 1135ft W 785ft from the N4 cor.	A 13-1 (29bac)	428137.1613	4632450.576
201		4861.8		A 13-1 (29bac)	428032.4091	4632462.215
202		Found in conjunction with #201		A 13-1 (29bca)		
203		337.9		A 13-1 (29bcd)	427805.4462	4632127.59
204	25-6133	6.35	N 2630 ft W 1135 ft from S1/4 cor.	A 13-1 (29bdc)		
	25-6133					
205	25-6133	Cannot verify	N 3130 ft W 1020 ft from S1/4 cor.	A 13-1 (29bdc)		
206	25-6506	Cannot verify	S 335 ft W 465 ft from N1/4 cor.	A 13-1 (29baa)		
	25-6507, 6508					
207	25-6509	No flow	S 510ft W 1475ft from N1/4 cor.	A 13-1 (29bba)		
	25-6510,6511					
208		Found in conjunction with #221	16.25 chains S and 35.8 Rods W of the NE cor. SW1/4	A 13-1 (29)		
209	25-6385	Cannot verify	S 370ft W 1975ft from the E4 cor.	A 13-1 (29dba)		
	25-6401					
210	25-6419	42.6	S 490ft E 1295ft from the W4 cor.	A 13-1 (29cab)		
211	25-2987	Found in conjunction with #221	N 1490ft W 515ft from the S4 cor.	A 13-1 (29cad)		
	25-6404					
212	25-6421	127.4	N 1710ft W 780ft from the S4 cor.	A 13-1 (29)	428144.7267	4631625.071

213	25-6402	274.3	N 1595ft E 1425ft from the SW cor.	A 13-1 (29)		
214	25-6408	No flow	N 1485ft W 380ft from the S4 cor.	A 13-1 (29)		
	25-6411					
	25-6407					
215	25-6405	Diffuse flow	N 1340ft E 1375ft from the SW cor.	A 13-1 (29cac)	427849.5793	4631470.525
216	25-6412	Found in conjunction with #221	N 1290ft W 325ft from the S4 cor.	A 13-1 (29)		
217	25-6413	Found in conjunction with #221	N 1185ft W 430ft from the S4 cor.	A 13-1 (29)		
218	25-6406	Cannot verify	N 1165ft E 1595ft from the S4 cor.	A 13-1 (29)		
	25-3473					
219	25-3464	93.3	1)N 1775ft E 35ft from the S4 cor.	A 13-1 (29)	428071.9822	4631691.996
	25-3465		2) N 1845ft W 565ft from the S4 cor.			
	25-3466		3) N 1710ft W 790ft from the S4 cor.			
	25-3467		4) N 1735ft W 690ft from the S4 cor.			
	25-3469		5) N 1595ft E 1425ft from the SW cor.			
	25-3471		6) N 1340ft E 1375ft from the SW cor.			
	25-3472		7) N 1250ft E 1025ft from the S4 cor.			
	25-3470		8) N 1405ft E 945ft from the SW cor.			
	25-6403		"			
	25-3468		9) N 1580ft W 660ft from the S4 cor.			
220	25-6416	Spring (Winn)	N 1250ft E 1025ft from the SW cor.	A 13-1 (29)		
221	25-3474	223.4	N640ft E625ft from SW cor.	A 13-1 (29ccd)	427761.2175	4631322.454
222	25-9261	50.56	1) S 1800ft W 680 ft from the N4 cor.	A 13-1 (29)	428020.77	4632142.139
			2) S 2210 ft W 1345 ft from the N4 cor.			
223	25-6539	Cannot verify	N 125ft W 570ft from the E4 cor.	A 13-1 (31)		

224	25-5172	405.3	N 270ft W1220ft from E4 cor.	A 13-1 (32adc)	428872.1721	4630445.446
	25-6485		N 20ft W 740ft from E4 cor.			
			N 212ft W 2100ft from E4 cor.			
225	25-6538	Diffuse flow	N70ft E745ft from W1/4 cor.	A 13-1 (32b)		
			N945ft E355ft from W1/4 cor.			

Appendix B: Discharge/status and basic chemistry for springs located above the principal aquifer

Table 23: Discharge/status and basic chemistry for springs located above the principal aquifer.
*: Report from June-August 2004; all other data collected May-June 2005.

Spring #	Discharge (gpm)/comment	pH	Alkalinity	Temp	EC
8*	No flow	7.3	320	12.4	590
13*	7.4	7.37	300	11.6	750
14*	77.04	9.32	320	15.2	836
23	17.8	7.13	420	11.9	715
31*	No flow	7.18	340	16	830
35	237.1	7.25	280	10.4	655
36	50.4	6.97	320	8.7	1010
37	495.3	8.04	420	15.5	867
38	511.9	8.18	420	16.8	855
39	39	7.81	280	18.5	530
43*	No flow	7.69	300	14.1	725
44	2.5	7.37	300	10.1	553
46*	No flow	7.34	360	15.4	713
50*	No flow	7.22	340	13.4	656
51	No flow	7.98	320	19	504
52*	No flow	7.32	280	12.8	580
56*	3.8	7.35	420	10.4	970
57	4990	7.67	340	16.2	425
58	3736	8.79	300	17.1	570
60	Not measured	7.29	460	10	910
63*	No flow	7.13	320	17.4	656
67*	No flow	7.11	300	11.7	557
70*	No flow	7.01	320	12.4	702
71*	Diffuse flow	7.29	280	13.4	802
87	0.5	7.44	260	12	635
89	4.65	7.47	340	11.8	690
95	160.2	8.27	420	19.5	770
97	Diffuse/low flow	7.35	480	11.5	748
102	No flow	NM	NM	9.6	546
105	Diffuse flow	7.9	260	8.9	520
114	79.4	8.85	240	27	466
116	118.31	7.51	350	19.6	484.3
118	233.59	NM	NM	NM	NM
119	45.2	7.24	400	17.1	508
120	23.5	7.34	350	19.6	477.5
121	5.46	7.24	300	19.4	466
129	28.6	7.31	340	12.7	665

130	114.8	7.26	320	12.6	655
131	87.2	7.72	360	13.7	726
134	123.2	8.95	320	21.5	588
135	55.28	8.65	300	23.8	465
136	32.2	8.29	240	29.1	587
137	23.78	7.48	260	22	448
138	61.6	8.47	260	22.3	453.5
139	186.6	8.47	260	22.3	453.5
140	145.61	7.73	260	22.8	453
143	4.1	7.25	240	20.6	468
144*	No flow	7.67	360	20.1	933
145	292.3	8.4	280	26.9	601
148	75	8.48	380	21.6	748
149	159.3	8.37	320	19.8	470
153	90.9	7.99	340	24.8	570
157	14.8	7.15	300	15.2	495
158	9.2	7.33	220	15	734
159	175.4	8.82	400	19.9	837
163	15	7.43	320	11.4	933
164	26.5	7.92	220	12.2	690
164a	7.94	8.22	240	12.1	618
164b	6.35	8.23	220	12.2	606
165	17.4	NM	NM	NM	NM
165a	2.9	NM	NM	NM	NM
165b	11	NM	NM	NM	NM
166	4.5	NM	NM	NM	NM
166a	6.34	NM	NM	NM	NM
166b	4.5	NM	NM	NM	NM
167	91.17	NM	NM	NM	NM
167a	56.4	NM	NM	NM	NM
167b	10	NM	NM	NM	NM
168	6.3	NM	NM	NM	NM
168a	5.3	NM	NM	NM	NM
168b	3.5	8.06	200	11.2	553
172	1.2	7.69	340	18.9	529
173	10.58	7.16	380	10.4	531
179	10.58	8.54	360	24.6	572
182	142.6	7.8	400	23	589
183	60.3	7.8	380	22.1	570
185	3.7	7.68	420	17.1	570
187	185.8	NM	NM	NM	NM
187a	15.87	7.97	340	25.8	586
187b	41.08	8.09	400	26.1	588
187c	103.24	7.84	440	19	576.5
188	25.3	7.02	440	10.8	546
188a	742.6	NM	NM	NM	NM

189	1286.7	7.6	380	15.2	479
192	6.4	7.61	520	11	640
192a	32.2	8.4	320	25.9	553
193	51.36	7.7	300	16	460.1
194	4	8.09	560	17	628
198	127.5	6.97	360	11.4	503
200	31.4	7.27	360	11.9	527
200a	54.55	7.74	300	17.7	504
200b	14.29	7.88	280	16.8	460
201	4861.8	7.3	360	11.6	506
201a	18.75	7.22	260	12.7	504
203	337.9	7.37	300	10.9	486
203a	47.8	7.34	340	11.9	525
204	6.35	7.86	340	14.7	486.7
207	No flow	7.35	360	11.2	493.7
210	42.6	8.1	NM	15.1	467
212	127.4	7.48	320	11.3	508
213	274.3	8.25	320	12.7	485
213a	78.3	7.86	360	12.4	498.7
214	No flow	7.38	340	12.1	499.5
219	93.3	7.19	360	11.2	496.5
220	53.5	7.89	340	10.7	509
221	223.4	7.97	260	9.8	496.5
222	50.56	7.13	340	12.2	521
222a	8.21	7.13	360	11.2	545
224	405.3	7.05	340	10.5	522

Appendix C: Discharge data

Table 24: Spring discharge monitoring data (date of measurement in parentheses; highest measurement in bold; directions are abbreviated N = North, S = South, E = East, W= West).

#	Name	Discharge (gpm) and date				
13	John Nielsen Spring	7.4 (11-Jun-04)	**27 (12-Jul-05)**	11.6 (18-Aug-05)	15.3 (15-Sep-05)	11.4 (23-Oct-05)
14	W. Camp Hollow Spring	77.04 (21-Jun-04)	49.8 (26-Jul-05)	62.6 (18-Aug-05)	**77.9 (15-Sep-05)**	54.4 (23-Oct-05)
23	Libbie Spring	17.8 (23-Jun-05)	**39.3 (12-Jul-05)**	38.6 (18-Aug-05)	9.9 (15-Sep-05)	14.3 (23-Oct-05)
35	Hansen Spring	237.1 (18-May-05)	277 (13-Jul-05)	288.9 (18-Aug-05)	295.7 (15-Sep-05)	249.2 (21-Oct-05)
36	Parker Spring	50.4 (18-May-05)	337.8 (13-Jul-05)	**419.8 (18-Aug-05)**	158.5 (15-Sep-05)	63.7 (21-Oct-05)
37	Davis Spring	495.3 (18-May-05)	516.5 (12-Jul-05)	**1595.5 (18-Aug-05)**	233.6 (15-Sep-05)	NM (October)
38	S.W. Field Irr. Co. Spring	511.9 (19-May-05)	284.4 (12-Jul-05)	**636.1 (18-Aug-05)**	183.3 (15-Sep-05)	NM (October)
39	Fredrick Spring	**39 (19-May-05)**	NM (July)	NM (August)	NM (September)	NM (October)
44	Ditch Spring	2.5 (18-May-05)	2.1 (12-Jul-05)	**2.9 (18-Aug-05)**	6 (15-Sep-05)	1.4 (23-Oct-05)
46	Little Ballard Spring	0 (19-Jun-04)	674.6 (12-Jul-05)	846.6 (18-Aug-05)	795.1 (15-Sep-05)	605.2 (23-Oct-05)
47	Banellis Spring	NM (18-May-05)	8.8 (13-Jul-05)	5.1 (18-Aug-05)	8.3 (15-Sep-05)	12.8 (23-Oct-05)
50	Big Ballard Spring	0 (19-Jun-04)	230.9 (12-Jul-05)	224 (18-Aug-05)	391.6 (15-Sep-05)	522.5 (23-Oct-05)
56	Campbell Spring	3.8 (22-Jun-04)	5.3 (13-Jul-05)	**7.9 (18-Aug-05)**	5.3 (15-Sep-05)	4.5 (23-Oct-05)
57	Spring Creek #1	4990.5 (23-Jun-05)	4248.4 (13-Jul-05)	**6131.1 (18-Aug-05)**	4693 (15-Sep-05)	3967.7 (21-Oct-05)
58	Spring Creek #3	3736 (19-May-05)	4702.2 (13-Jul-05)	4251.8 (18-Aug-05)	4732.4 (15-Sep-05)	5014.2 (21-Oct-05)

#	Name	Discharge (gpm) and date				
13	John Nielsen Spring	8 (23-Nov-05)	16.4 (13-Dec-05)	5.2 (19-Jan-06)	10.2 (16-Feb-06)	13.2 (23-Mar-06)
14	W. Camp Hollow Spring	43.9 (23-Nov-05)	34.8 (13-Dec-05)	45.1 (19-Jan-06)	47.1 (16-Feb-06)	60.3 (23-Mar-06)
23	Libbie Spring	20.1 (23-Nov-05)	13.9 (13-Dec-05)	34.1 (19-Jan-06)	36.7 (16-Feb-06)	31.54 (23-Mar-06)
35	Hansen Spring	76.8 (23-Nov-05)	**358 (13-Dec-05)**	277.9 (18-Jan-06)	193.1 (16-Feb-06)	208.8 (23-Mar-06)
36	Parker Spring	41.2 (23-Nov-05)	37.9 (12-Dec-05)	186.9 (18-Jan-06)	104.7 (16-Feb-06)	281.6 (23-Mar-06)
37	Davis Spring	219 (23-Nov-05)	214.9 (12-Dec-05)	467.7 (18-Jan-06)	389.1 (16-Feb-06)	583.6 (23-Mar-06)
38	S.W. Field Irr. Co. Spring	141.3 (23-Nov-05)	274.3 (12-Dec-05)	421.2 (18-Jan-06)	336.7 (16-Feb-06)	563.8 (23-Mar-06)
39	Fredrick Spring	6.8 (23-Nov-05)	28.4 (13-Dec-05)	17.5 (18-Jan-06)	27.1 (16-Feb-06)	10.3 (23-Mar-06)
44	Ditch Spring	1.2 (23-Nov-05)	1 (13-Dec-05)	1.1 (19-Jan-06)	1.3 (16-Feb-06)	1.7 (23-Mar-06)
46	Little Ballard Spring	1049.6 (23-Nov-05)	1117.4 (13-Dec-)05	**1324.4 (19-Jan-06)**	697.7 (16-Feb-06)	225 (23-Mar-06)
47	Banellis Spring	6.6 (23-Nov-05)	19.2 (13-Dec-05)	20.6 (19-Jan-06)	14.9 (16-Feb-06)	**31.2 (23-Mar-06)**
50	Big Ballard Spring	455.5 (23-Nov-05)	537.5 (13-Dec-05)	**593.2 (19-Jan-06)**	421.7 (16-Feb-06)	519.6 (23-Mar-06)
56	Campbell Spring	5.8 (23-Nov-05)	5.8 (13-Dec-05)	6.4 (18-Jan-06)	4.9 (16-Feb-06)	6.35 (23-Mar-06)
57	Spring Creek #1	3478 (23-Nov-05)	4134.7 (13-Dec-05)	5272.2 (18-Jan-06)	2144.9 (16-Feb-06)	4060 (23-Mar-06)
58	Spring Creek #3	3719.4 (23-Nov-05)	4913.6 (13-Dec-05)	4497.6 (18-Jan-06)	NM (16-Feb-06)	**5071.5 (23-Mar-06)**

#	Name	Discharge (gpm) and date				
60	Del Hansen Spring	NM (19-May-05)	NM (13-Jul-05)	NM (18-Aug-05)	NM (15-Sep-05)	NM (23-Oct-05)
89	Barn Yard Spring	4.65 (17-Jun-05)	4.5 (12-Jul-05)	4 (18-Aug-05)	3.5 (15-Sep-05)	**4.9 (23-Oct-05)**
93	S. Blue Spring	NM (June)	NM (July)	117.5(18-Aug-05)	47.4 (15-Sep-05)	30.1 (23-Oct-05)
95	Spring Creek #4	160.2 (19-May-05)	NM (13-Jul-05)	NM (August)	181.9 (15-Sep-05)	134.6 (21-Oct-05)
114	N. Bodrero Spring	79.4 (24-May-05)	NM (July)	NM (August)	NM (September)	**150 (21-Oct-05)**
130	Sheep Spring	114.8 (25-May-05)	NM (July)	NM (August)	NM (September)	NM (October)
134	Snider Spring	123.2 (9-Jun-05)	**1257.8 (14-Jul-05)**	133.5 (18-Aug-05)	343.8 (15-Sep-05)	112.6 (21-Oct-05)
145	Jensen Spring	292.3 (23-May-05)	NM (July)	NM (August)	NM (September)	NM (October)
149	N. Blue Spring	159.3 (9-Jun-05)	106.7 (14-Jul-05)	132.8 (18-Aug-05)	172.5 (15-Sep-05)	91.7 (21-Oct-05)
158	Road Spring	9.2 (23-May-05)	24.6 (14-Jul-05)	18.1 (18-Aug-05)	16.7 (15-Sep-05)	14.8 (21-Oct-05)
159	Merrill Spring	**175.4 (20-May-05)**	26.7 (14-Jul-05)	66.4 (18-Aug-05)	27.3 (15-Sep-05)	36.4 (21-Oct-05)
163	Johnson Spring	15 (18-May-05)	46.6 (18-Jul-05)	29.9 (19-Aug-05)	**55.7 (15-Sep-05)**	44.9 (23-Oct-05)
164	Blair Spring	26.5 (17-May-05)	16.1 (18-Jul-05)	27.3 (19-Aug-05)	15.4 (15-Sep-05)	13 (23-Oct-05)
172	N. Corbett Spring	**1.2 (15-Jun-05)**	0.4 (18-Jul-05)	0.2 (19-Aug-05)	0 (September)	0 (October)

#	Name	Discharge (gpm) and date				
60	Del Hansen Spring	418.1 (23-Nov-05)	337 (13-Dec-05)	481.9 (18-Jan-06)	437.1 (16-Feb-06)	**544.2 (23-Mar-06)**
89	Barn Yard Spring	4.8 (23-Nov-05)	4 (13-Dec-05)	2 (19-Jan-06)	4.3 (16-Feb-06)	**4.9 (23-Mar-06)**
93	S. Blue Spring	49.9 (23-Nov-05)	70.3 (13-Dec-05)	61.6 (18-Jan-06)	73 (16-Feb-06)	**127.4 (23-Mar-06)**
95	Spring Creek #4	157 (23-Nov-05)	182.6 (13-Dec-05)	**241.1 (18-Jan-06)**	202.9 (16-Feb-06)	211.2 (23-Mar-06)
114	N. Bodrero Spring	133.3 (23-Nov-05)	120 (12-Dec-05)	**150 (18-Jan-06)**	120 (15-Feb-06)	**150 (23-Mar-06)**
130	Sheep Spring	**370.4 (23-Nov-05)**	285.3 (14-Dec-05)	302.8 (19-Jan-06)	292.4 (16-Feb-06)	339.4 (23-Mar-06)
134	Snider Spring	137 (23-Nov-05)	219.4 (12-Dec-05)	310.2 (18-Jan-06)	236.6 (15-Feb-06)	441.1 (23-Mar-06)
145	Jensen Spring	327.3 (23-Nov-05)	354.2 (12-Dec-05)	**450.7 (18-Jan-06)**	373.7 (15-Feb-06)	444.1 (23-Mar-06)
149	N. Blue Spring	107 (23-Nov-05)	176.1 (12-Dec-05)	179.9 (18-Jan-06)	193.5 (15-Feb-06)	**194 (23-Mar-06)**
158	Road Spring	20.2 (23-Nov-05)	25.3 (12-Dec-05)	21.2 (18-Jan-06)	25 (15-Feb-06)	**55.6 (23-Mar-06)**
159	Merrill Spring	4.6 (23-Nov-05)	44.3 (12-Dec-05)	79.6 (18-Jan-06)	48.9 (15-Feb-06)	135.9 (23-Mar-06)
163	Johnson Spring	25 (23-Nov-05)	18.2 (14-Dec-05)	28 (19-Jan-06)	17.5 (16-Feb-06)	26.9 (23-Mar-06)
164	Blair Spring	**30 (23-Nov-05)**	22.2 (14-Dec-05)	20 (19-Jan-06)	23.1 (16-Feb-06)	24 (23-Mar-06)
172	N. Corbett Spring	0 (November)	0 (December)	0 (January)	0 (February)	0 (22-Mar-06)

#	Name	Discharge (gpm) and date				
182	Joseph Smith Spring	**142.6 (14-Jun-05)**	134.8 (18-Jul-05)	116.9 (19-Aug-05)	116.9 (14-Sep-05)	121 (21-Oct-05)
187	William Smith Spring	185.8 (14-Jun-05)	137 (18-Jul-05)	149.5 (19-Aug-05)	166.2 (14-Sep-05)	189.4 (21-Oct-05)
188	Mathers Spring	25.3 (14-Jun-05)	5.6 (15-Jul-05)	91.3 (19-Aug-05)	**184.2 (14-Sep-05)**	34.1 (21-Oct-05)
188a	Mathers Spring Outlet	742.6 (14-Jun-05)	NM (15-Jul-05)	NM (19-Aug-05)	495.4 (14-Sep-05)	606.7 (21-Oct-05)
189	Corbett Spring	1286.7 (14-Jun-05)	1222 (15-Jul-05)	1147.5 (19-Aug-05)	1200.8 (14-Sep-05)	1358.4 (21-Oct-05)
200	Anderson Spring	31.4 (13-Jun-05)	64.1 (15-Jul-05)	75.1 (19-Aug-05)	45.1 (14-Sep-05)	**82.2 (21-Oct-05)**
201	Outlet Spring	**4861.8 (13-Jun-05)**	3197.8 (15-Jul-05)	920.8 (19-Aug-05)	1785 (14-Sep-05)	1295.6 (21-Oct-05)
203	S. Erickson Spring	337.9 (13-Jun-05)	464.8 (15-Jul-05)	**551.2 (19-Aug-05)**	537.5 (14-Sep-05)	488.4 (21-Oct-05)
212	Low Spring	**127.4 (8-Jun-05)**	100.6 (15-Jul-05)	64.5 (19-Aug-05)	68.3 (14-Sep-05)	93.9 (21-Oct-05)
215	Sorenson Spring	NM (8-Jun-05)	33.3 (15-Jul-05)	98.6 (19-Aug-05)	93.9 (14-Sep-05)	93.8 (21-Oct-05)
221	Gittens Spring	223.4 (8-Jun-05)	571.1 (15-Jul-05)	198.9 (19-Aug-05)	326.6 (14-Sep-05)	340.9 (21-Oct-05)
222	Small Seep Spring	50.56 (13-Jun-05)	43.1 (15-Jul-05)	34.4 (19-Aug-05)	35.1 (14-Sep-05)	50.1 (21-Oct-05)
224	Hopkins Spring	405.3 (7-Jun-05)	440.3 (15-Jul-05)	401.8 (19-Aug-05)	**468.3 (14-Sep-05)**	398.4 (21-Oct-05)

#	Name	Discharge (gpm) and date				
182	Joseph Smith Spring	24.8 (16-Nov-05)	12 (12-Dec-05)	102.9 (18-Jan-06)	NM (15-Feb-06)	36 (22-Mar-06)
187	William Smith Spring	328.9 (16-Nov-05)	387.2 (12-Dec-05)	433 (18-Jan-06)	NM (15-Feb-06)	**484.4 (22-Mar-06)**
188	Mathers Spring	38.7 (16-Nov-05)	47.2 (12-Dec-05)	65.7 (18-Jan-06)	36.3 (15-Feb-06)	64 (22-Mar-06)
188a	Mathers Spring Outlet	517.5 (16-Nov-05)	513.3 (12-Dec-05)	**753.7 (18-Jan-06)**	590.1 (15-Feb-06)	664 (22-Mar-06)
189	Corbett Spring	**1508.8 (16-Nov-05)**	1084.1 (12-Dec-05)	1325.2 (18-Jan-06)	1200.2 (15-Feb-06)	1276.6 (22-Mar-06)
200	Anderson Spring	48.9 (16-Nov-05)	38.1 (12-Dec-05)	72.4 (18-Jan-06)	63.1 (15-Feb-06)	57.9 (22-Mar-06)
201	Outlet Spring	941.2 (16-Nov-05)	346.9 (12-Dec-05)	433.8 (18-Jan-06)	443.7 (15-Feb-06)	439.3 (22-Mar-06)
203	S. Erickson Spring	199.1 (16-Nov-05)	316.3 (12-Dec-05)	499.1 (18-Jan-06)	438 (15-Feb-06)	331.6 (22-Mar-06)
212	Low Spring	77.4 (23-Nov-05)	88.4 (12-Dec-05)	59.7 (18-Jan-06)	44.4 (15-Feb-06)	111.5 (22-Mar-06)
215	Sorenson Spring	89.7 (23-Nov-05)	38.4 (12-Dec-05)	56 (18-Jan-06)	43 (15-Feb-06)	**150.4 (22-Mar-06)**
221	Gittens Spring	**619.9 (23-Nov-05)**	354.5 (12-Dec-05)	602.8 (18-Jan-06)	482.9 (15-Feb-06)	416.7 (22-Mar-06)
222	Small Seep Spring	36 (16-Nov-05)	33.1 (12-Dec-05)	**51.5 (18-Jan-06)**	35.6 (15-Feb-06)	49.6 (22-Mar-06)
224	Hopkins Spring	458.5 (23-Nov-05)	391.7 (12-Dec-05)	388.4 (18-Jan-06)	385.1 (15-Feb-06)	392 (22-Mar-06)

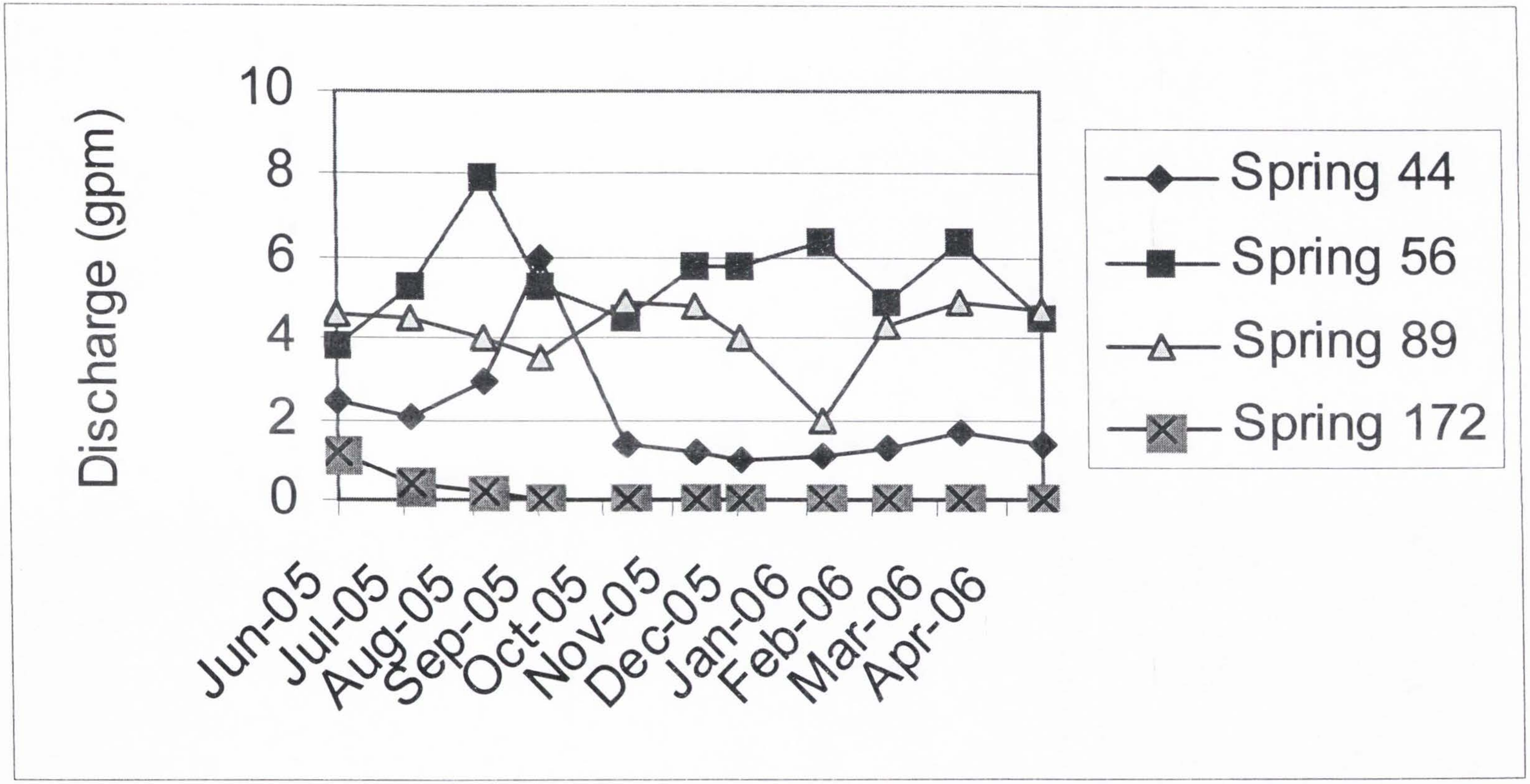

Figure 23: Graph of springs 44, 56, 89, and 172 with discharges less than 10 gallons per minute.

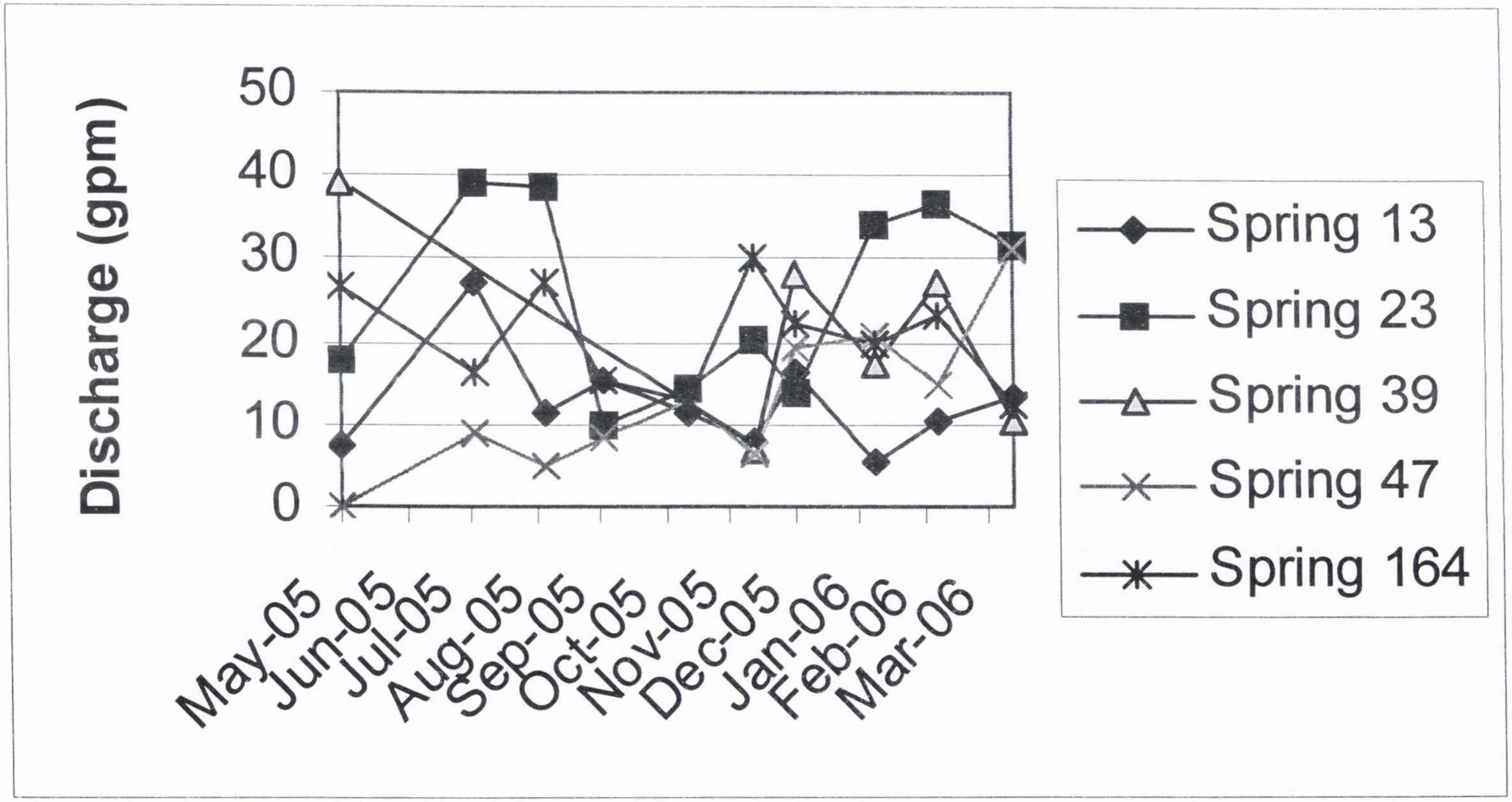

Figure 24: Graph of springs 13, 23, 39, 47, and 164 with discharges between 10 and 50 gallons per minute.

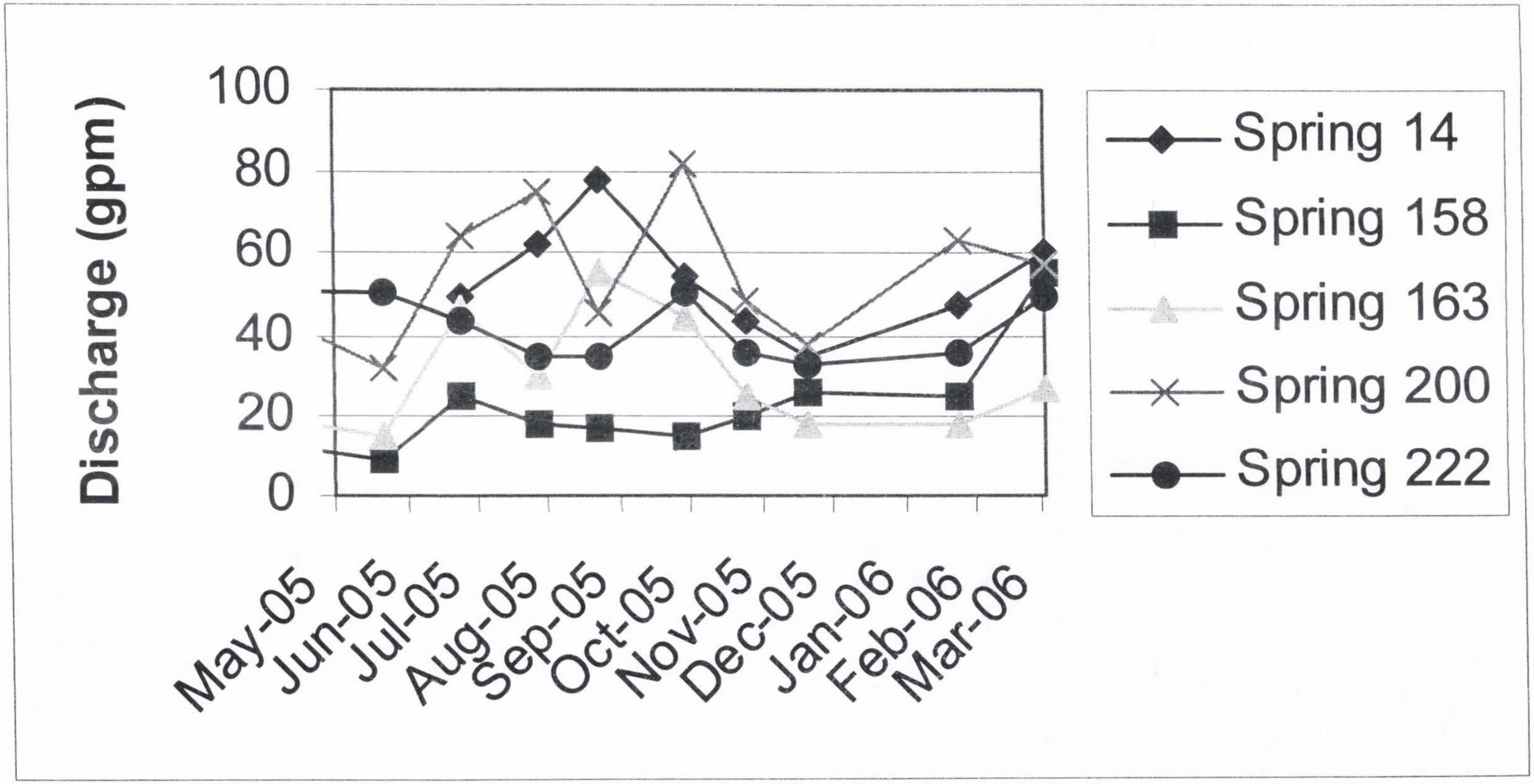

Figure 25: Graph of springs 14, 158, 163, 200, and 222 with discharges between 50 and 100 gallons per minute.

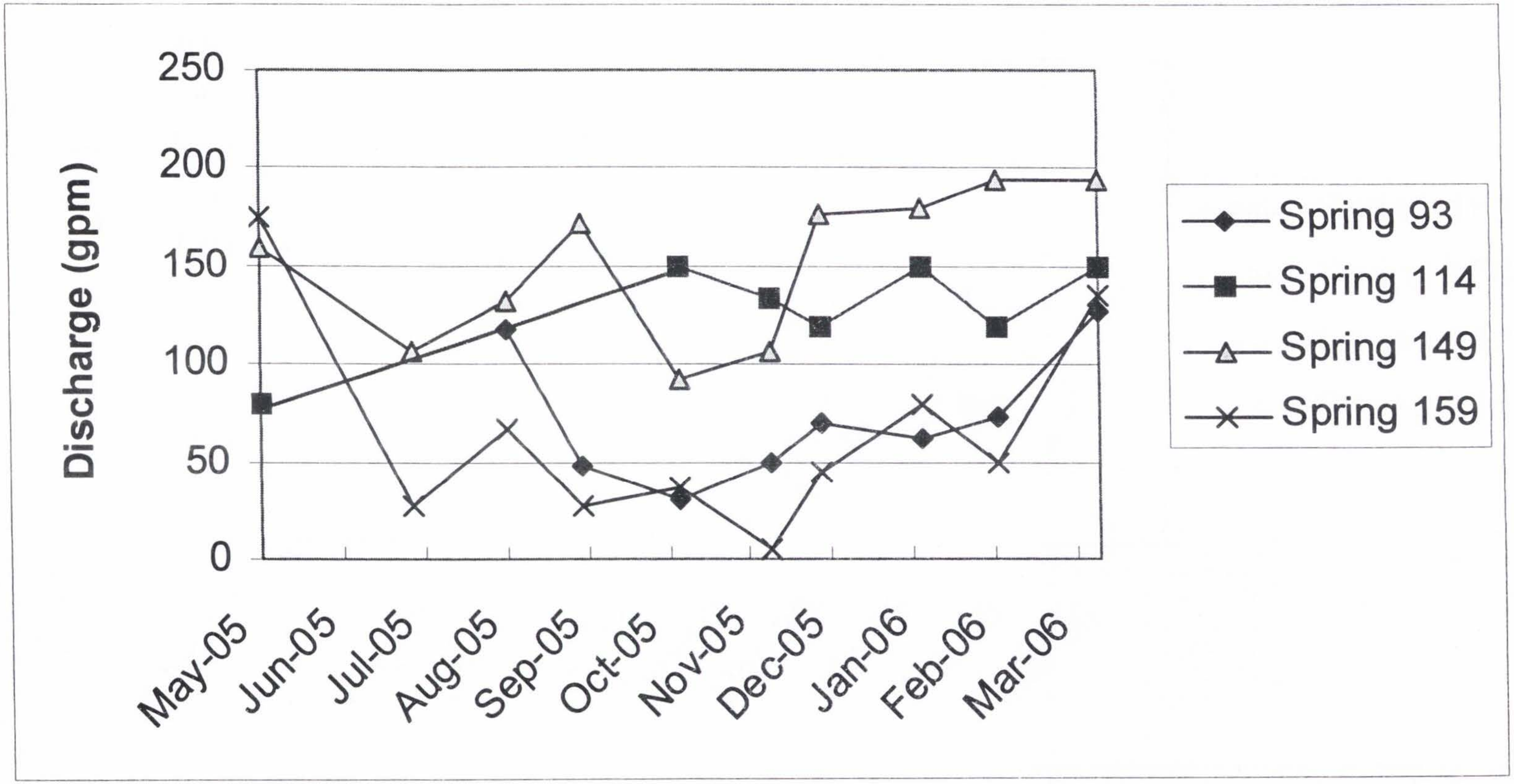

Figure 26: Graph of springs 93, 114, 149, and 159 with discharges between 100 and 200 gallons per minute.

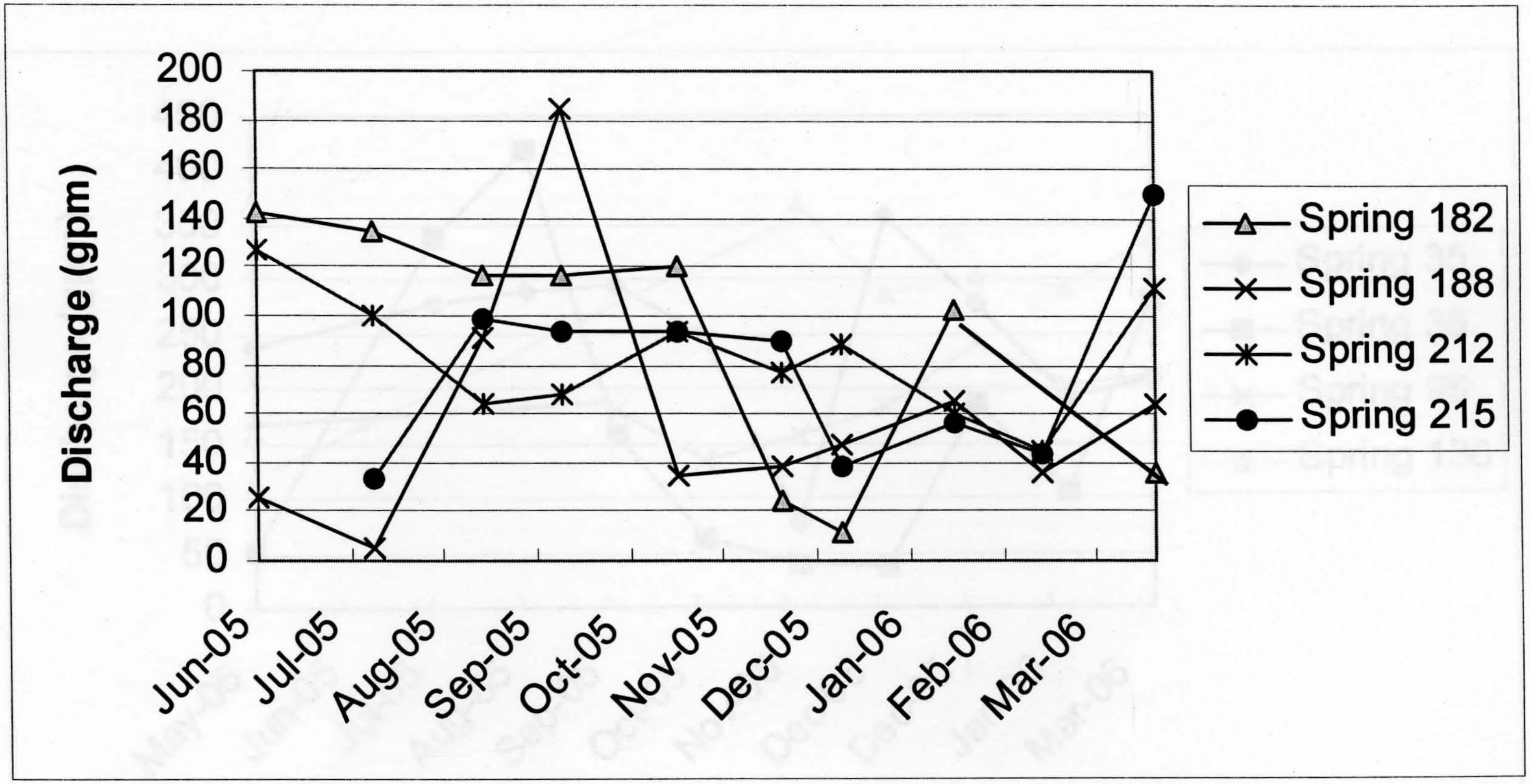

Figure 27: Graph of springs 182, 188, 212, and 215 with discharges between 100 and 200 gallons per minute.

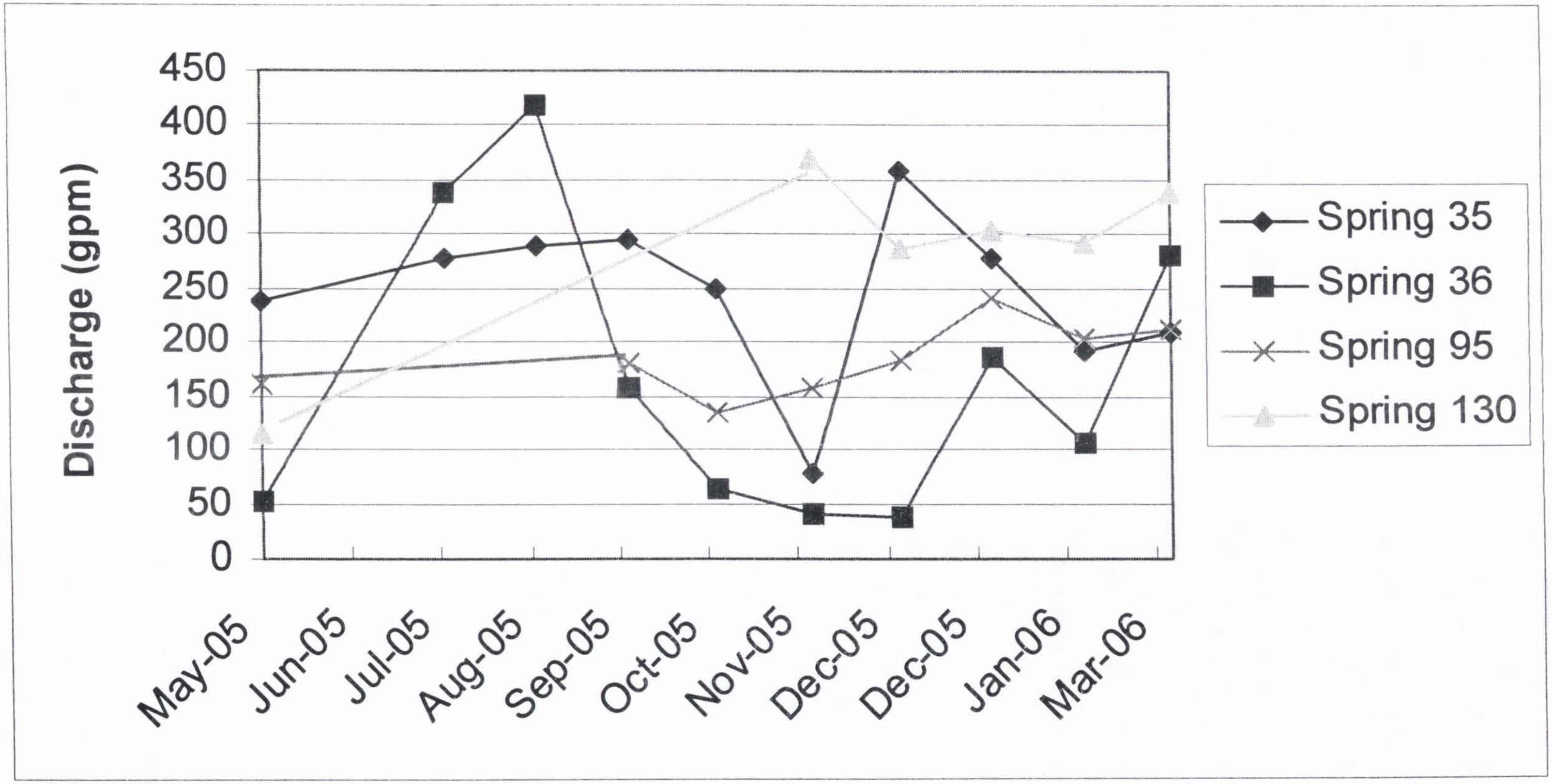

Figure 28: Graph of springs 35, 36, 95 and 130 with discharges between 200 and 500 gallons per minute.

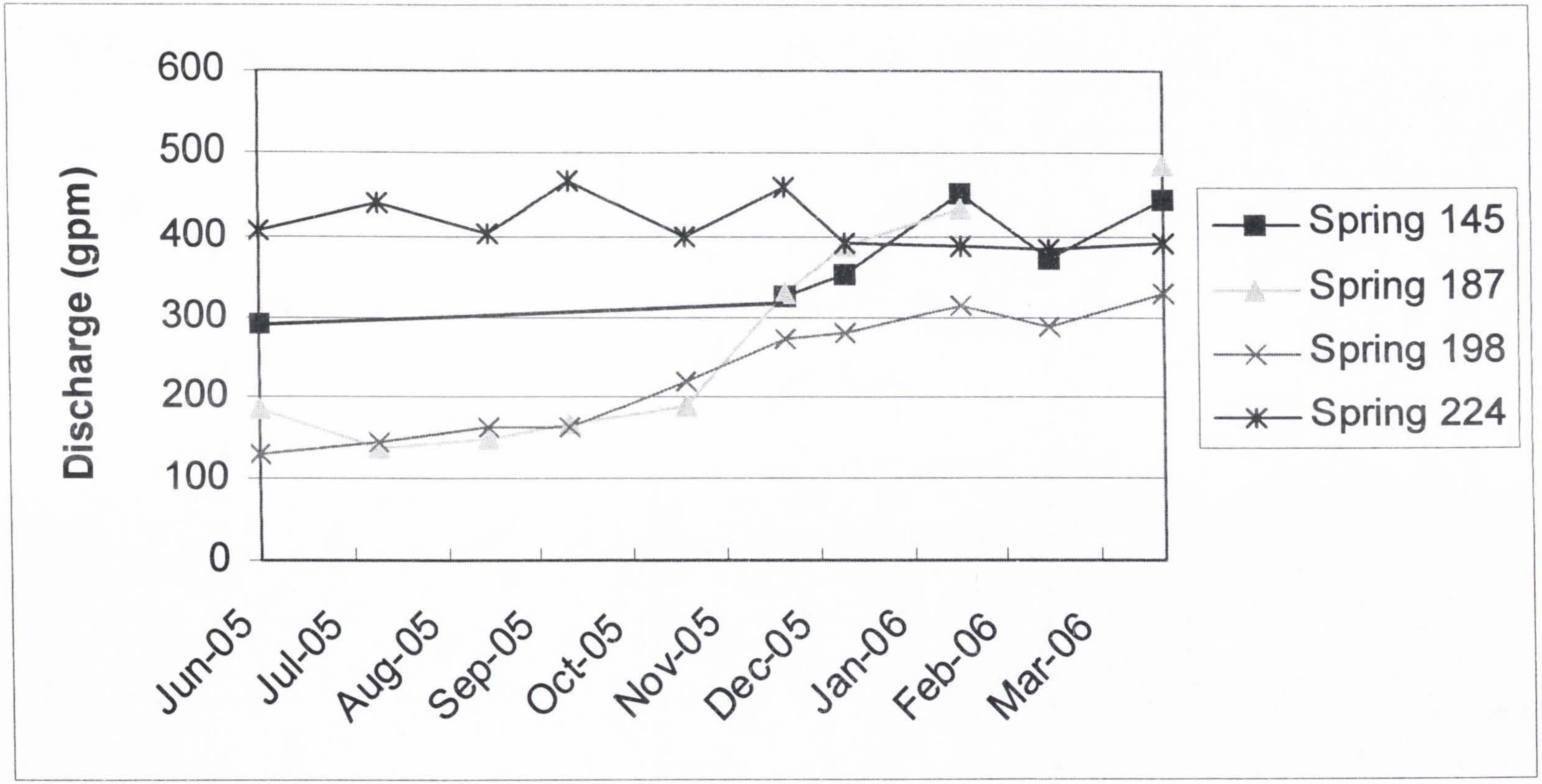

Figure 29: Graph of springs 145, 187, 198, and 224 with discharges between 200 and 500 gallons per minute.

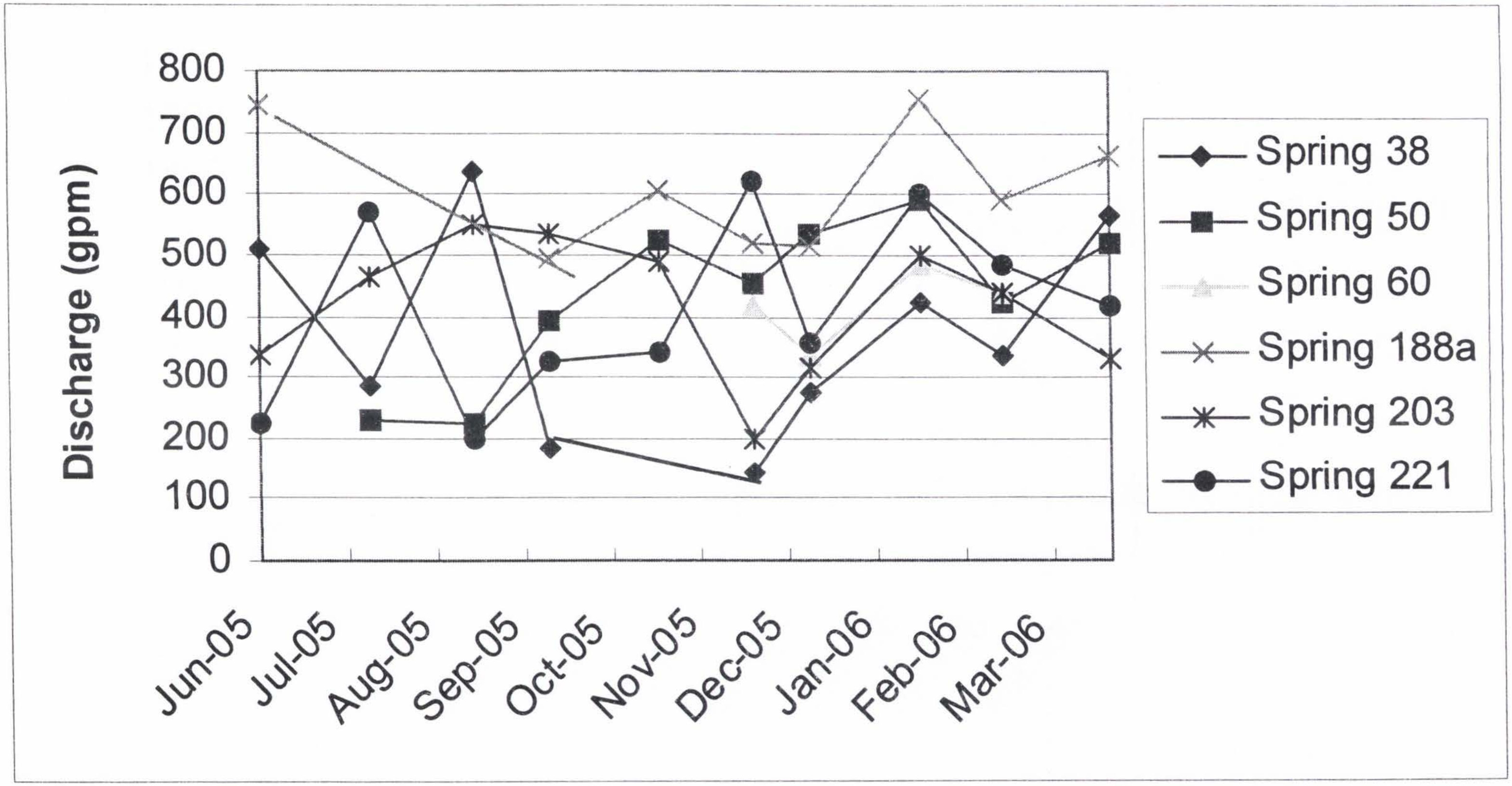

Figure 30: Graph of springs 38, 50, 60, 188a, 203, and 221 with discharges between 500 and 1000 gallons per minute.

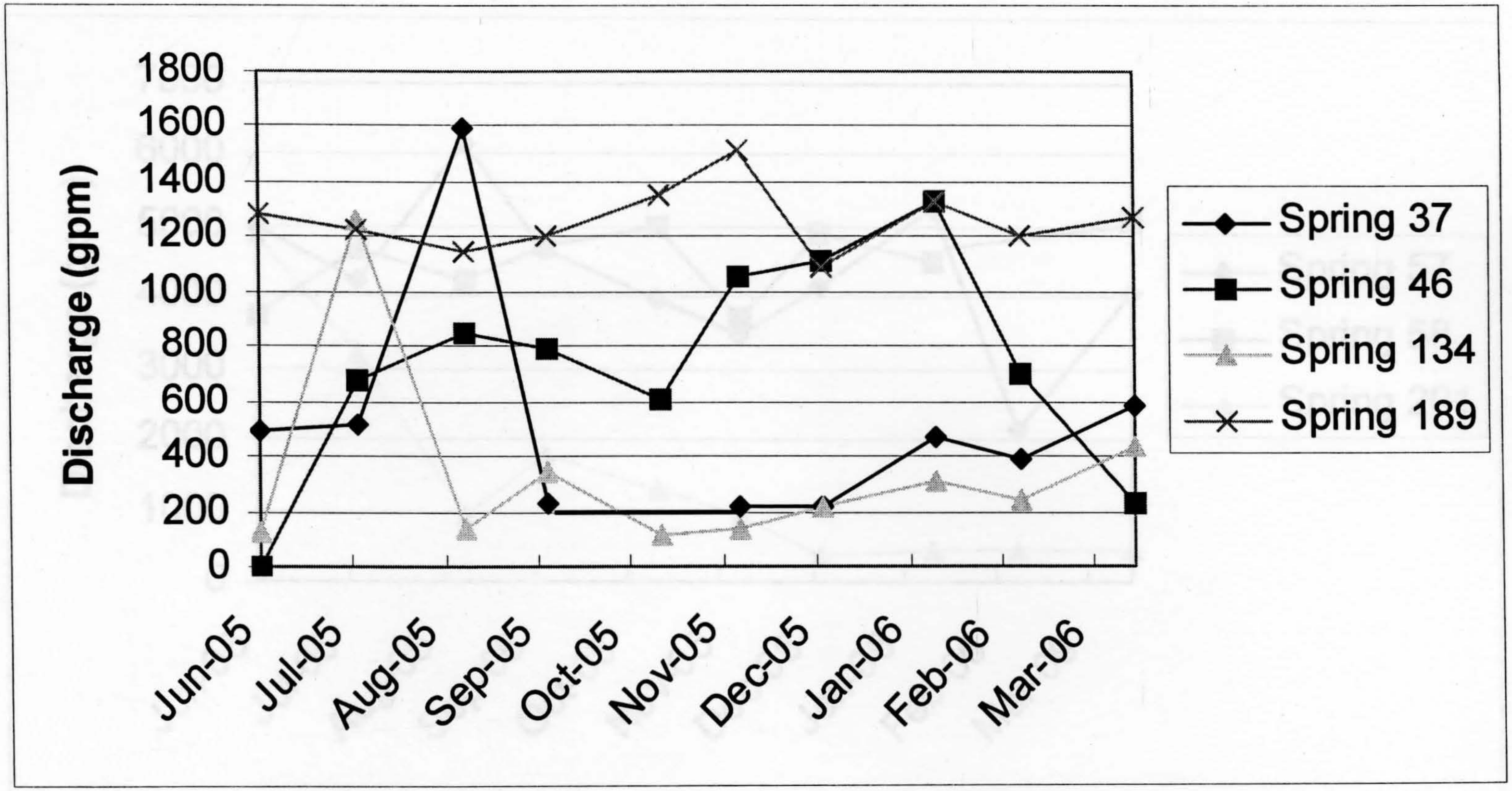

Figure 31: Graph of springs 37, 46, 134, and 189 with discharges between 1000 and 2000 gallons per minute.

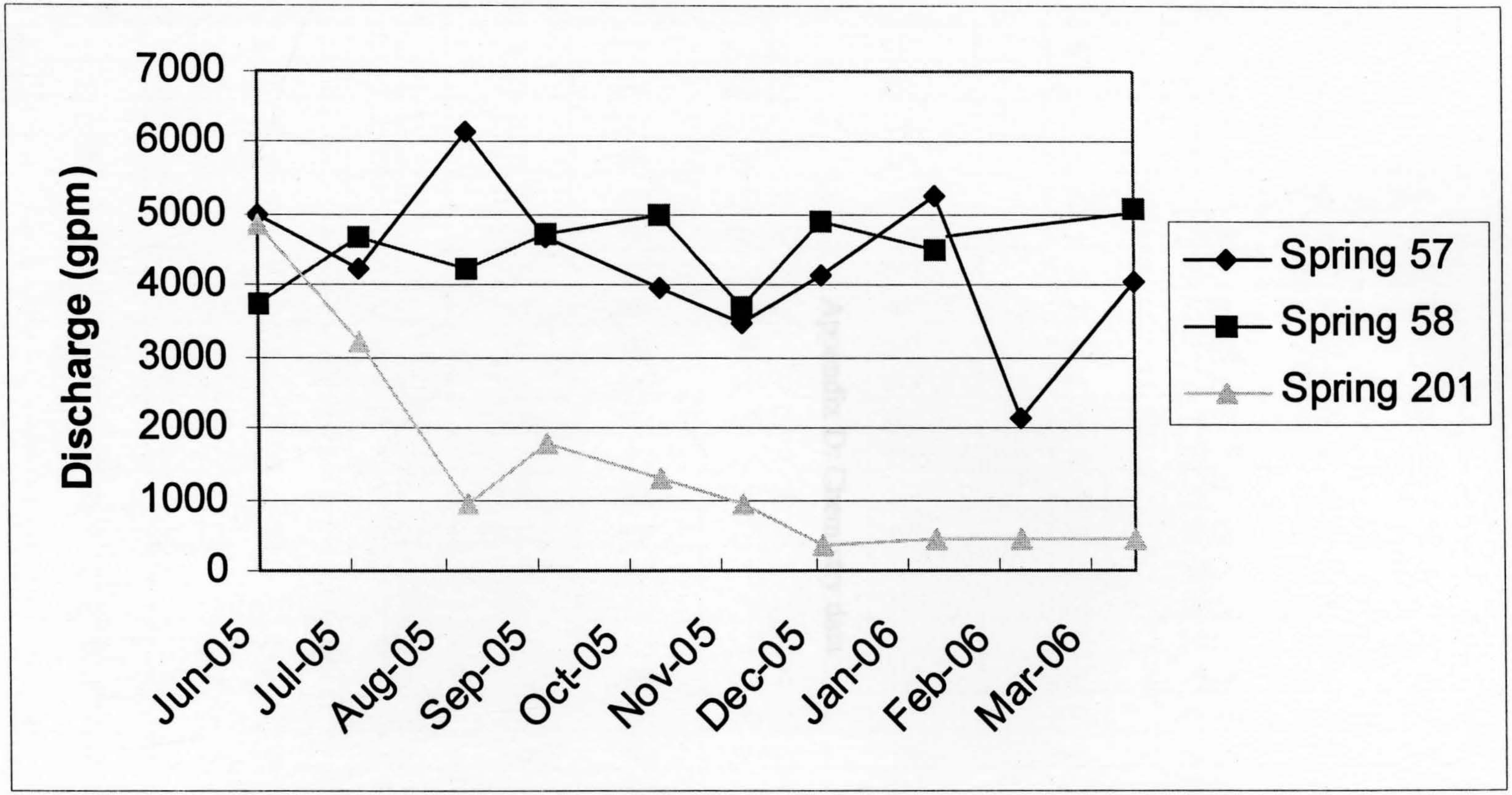

Figure 32: Graph of springs 57, 58, and 201 with discharges greater than 2000 gallons per minute.

Appendix D: Chemistry data

Table 25: Concentrations (mg/L) of major ions and trace metals in spring water.

Spring #	Date sampled	Temp (°C)	pH	EC (ųS)	TDS	Alkalinity ($CaCO_3$)	Ba	Ca	Cl	Cu
13	12-Jul-05	15.0	7.41	527	332.22	340	0.08	99.22	84.64	0.03
14	26-Jul-05	12.1	7.23	541	288.72	380	0.08	89.83	58.20	<0.01
14	16-Feb-06	11.0	7.66	790	334.47	300	0.17	79.50	56.40	<0.01
23	12-Jul-05	13.8	7.27	608	395.46	400	0.11	97.35	21.78	0.02
35	13-Jul-05	11.2	7.23	460	177.42	260	0.05	73.09	19.68	<0.01
36	13-Jul-05	12.8	6.94	545	284.05	400	0.11	100.50	34.64	0.03
36	16-Feb-06	7.5	7.60	877	324.13	340	0.58	84.30	58.50	<0.01
37	12-Jul-05	21.4	7.87	566	234.46	400	0.09	57.85	20.89	<0.01
38	12-Jul-05	27.1	7.89	583	206.16	300	0.08	60.38	19.03	<0.01
44	12-Jul-05	12.8	7.31	445	166.77	300	0.08	71.08	13.47	0.02
46	15-Sep-05	14.8	7.29	890	285.19	400	0.16	106.50	42.64	0.06
46a	12-Jul-05	11.6	6.63	469	270.04	460	0.27	103.50	33.00	<0.01
47	13-Jul-05	10.8	7.02	530	207.66	300	0.18	76.75	42.40	0.03
50	12-Jul-05	16.9	7.72	447	222.72	380	0.07	87.09	18.54	0.02
56	13-Jul-05	12.6	7.06	666	306.21	460	0.10	114.70	35.33	0.02
57	13-Jul-05	16.8	7.90	471	195.21	320	0.06	68.21	18.29	0.03
58	13-Jul-05	18.0	7.79	479	176.59	300	0.06	64.83	12.51	0.01
60	13-Jul-05	16.5	7.22	588	274.42	440	0.08	74.49	19.89	0.04
71	12-Jul-05	14.2	7.05	493	261.65	320	0.12	95.30	24.36	0.03
87	12-Jul-05	12.8	7.49	482	254.81	280	0.08	83.02	27.19	0.03
89	12-Jul-05	12.6	7.53	460	246.24	380	0.14	69.97	17.60	0.02
93	23-Aug-05	15.6	7.51	576	195.08	280	0.61	66.23	13.32	<0.01
95	13-Jul-05	22.3	7.45	472	243.57	320	0.05	56.96	12.88	<0.01
105	18-Jul-05	11.9	7.34	473	126.68	300	0.04	67.31	2.42	0.02
134	14-Jul-05	24.6	7.97	459	183.04	300	0.06	48.91	11.40	0.02
147	14-Jul-05	20.8	7.40	452	182.52	240	0.09	51.74	9.62	0.03
149	14-Jul-05	24.4	7.68	548	236.54	260	0.08	43.68	20.87	0.02

Spring #	Fe	K	Mg	Mn	Na	Ni	PO$_4$	SiO$_2$	SO$_4$	Sr	Zn
13	<0.01	7.56	31.66	<0.01	42.40	<0.01	P<0.1	127.97	19.72	0.20	0.02
14	<0.01	3.17	33.67	<0.01	28.33	<0.01	P<0.1	138.02	31.90	0.26	0.01
14	<0.01	3.00	29.40	<0.01	28.30	<0.01	P<0.1	118.73	18.75	0.22	<0.01
23	<0.01	10.25	50.89	<0.01	25.93	<0.01	P<0.1	373.93	41.91	0.32	0.02
35	<0.01	3.66	23.34	<0.01	16.11	<0.01	P<0.1	79.58	12.44	0.11	0.03
36	<0.01	16.87	38.14	<0.01	19.92	<0.01	P<0.1	138.92	25.95	0.22	0.02
36	<0.01	7.10	30.00	<0.01	33.30	<0.01	0.40	88.78	20.94	0.23	<0.01
37	<0.01	4.20	44.43	<0.01	17.54	<0.01	P<0.1	179.05	16.51	0.23	0.02
38	<0.01	2.53	28.01	<0.01	15.93	<0.01	P<0.1	160.76	14.53	0.17	0.02
44	<0.01	0.83	19.35	<0.01	16.16	<0.01	P<0.1	91.58	8.50	0.11	0.02
46	<0.01	3.32	44.02	<0.01	13.68	<0.01	P<0.1	140.84	25.90	0.24	0.07
46a	0.01	5.06	41.31	<0.01	14.25	<0.01	P<0.1	135.43	27.18	0.24	0.02
47	<0.01	2.15	22.29	<0.01	16.94	<0.01	P<0.1	90.83	12.93	0.13	0.01
50	<0.01	2.41	34.74	<0.01	10.05	<0.01	P<0.1	128.82	27.83	0.26	0.03
56	<0.01	5.07	42.00	<0.01	24.00	<0.01	P<0.1	136.16	63.06	0.28	0.02
57	<0.01	3.64	32.84	<0.01	13.29	<0.01	P<0.1	100.99	34.15	0.22	0.02
58	<0.01	3.16	29.69	<0.01	10.16	<0.01	P<0.1	81.12	53.77	0.28	0.02
60	<0.01	10.71	48.40	<0.01	16.03	<0.01	P<0.1	194.92	39.72	0.39	0.02
71	<0.01	32.77	27.72	<0.01	16.23	<0.01	0.73	117.85	28.67	0.20	0.02
87	<0.01	1.73	32.79	<0.01	11.89	<0.01	P<0.1	197.47	16.60	0.20	0.03
89	<0.01	3.19	31.18	<0.01	11.94	<0.01	P<0.1	221.83	24.82	0.19	0.03
93	0.45	2.31	26.33	0.01	17.07	0.01	P<0.1	111.07	49.07	0.39	0.04
95	0.02	10.23	28.39	0.03	12.34	<0.01	1.15	244.72	22.93	0.20	0.03
105	0.05	0.60	21.11	0.01	2.24	<0.01	P<0.1	67.06	4.24	0.09	0.01
134	0.01	5.54	20.98	0.02	18.47	<0.01	P<0.1	156.42	12.45	0.34	0.01
147	<0.01	3.50	20.43	<0.01	12.68	<0.01	P<0.1	165.85	19.32	0.43	0.02
149	<0.01	8.47	21.43	0.04	29.26	<0.01	P<0.1	223.55	23.01	0.49	0.02

Spring #	Date sampled	Temp (°C)	pH	EC (ųS)	TDS	Alkalinity ($CaCO_3$)	Ba	Ca	Cl	Cu
153	14-Jul-05	16.2	7.78	447	129.12	260	0.05	54.78	8.80	0.01
158	14-Jul-05	18.7	7.45	636	199.16	340	0.10	70.44	16.47	0.02
158	15-Feb-06	6.8	7.51	667	249.77	240	0.27	65.00	37.70	<0.01
159	14-Jul-05	21.0	7.81	644	260.80	420	0.16	74.27	29.49	<0.01
163	18-Jul-05	14.0	7.49	630	318.82	340	0.08	77.74	87.30	<0.01
164	19-Aug-05	13.3	7.71	543	229.13	260	0.10	67.65	61.55	<0.01
172	18-Jul-05	22.4	7.96	596	390.87	340	0.17	54.01	22.29	0.02
173	18-Jul-05	11.5	7.08	512	370.98	380	0.22	76.41	12.52	<0.01
182	18-Jul-05	21.1	7.57	625	249.93	420	0.12	66.56	10.34	0.02
188	15-Jul-05	16.6	7.01	535	237.53	460	0.07	87.02	17.28	<0.01
188	15-Feb-06	4.2	7.51	993	475.21	420	0.06	86.00	65.30	0.01
188a	14-Sep-05	12.5	7.34	591	192.68	340	0.29	71.30	11.97	<0.01
189	15-Jul-05	17.2	7.92	461	190.22	320	0.05	66.72	10.41	<0.01
192	15-Jul-05	15.6	7.73	614	273.84	460	0.08	65.78	13.57	<0.01
198	15-Jul-05	14.0	7.20	503	206.13	380	0.07	81.14	14.45	0.02
200	15-Jul-05	12.7	7.16	512	232.22	380	0.10	94.53	19.16	<0.01
203	15-Jul-05	10.9	7.44	462	165.91	280	0.06	69.10	8.62	<0.01
212	15-Jul-05	13.4	6.99	487	169.25	320	0.06	81.38	5.82	<0.01
215	15-Jul-05	13.8	7.53	479	167.00	320	0.06	69.17	7.33	<0.01
219	15-Jul-05	12.4	7.60	450	149.58	260	0.05	63.93	6.70	<0.01
221	15-Jul-05	16.0	7.68	486	164.33	300	0.06	69.47	7.53	<0.01
222	15-Jul-05	14.5	7.22	502	214.14	320	0.08	82.78	19.79	<0.01
224	15-Jul-05	12.2	7.10	569	223.87	380	0.10	90.64	15.60	0.01
224	15-Feb-06	10.0	7.87	974	303.25	340	0.31	93.90	19.40	<0.01

Spring #	Fe	K	Mg	Mn	Na	Ni	PO_4	SiO_2	SO_4	Sr	Zn
153	<0.01	2.03	19.83	<0.01	7.15	<0.01	P<0.1	71.30	8.97	0.12	0.02
158	0.04	3.10	27.53	0.03	15.74	<0.01	P<0.1	132.29	10.98	0.15	0.03
158	<0.01	3.0	22.9	0.02	26.6	<0.01	0.55	84.28	9.29	0.16	<0.01
159	0.02	7.43	38.79	0.03	23.21	<0.01	P<0.1	174.86	16.25	0.22	0.01
163	<0.01	2.52	34.33	<0.01	37.42	<0.01	P<0.1	155.63	19.38	0.21	<0.01
164	<0.01	2.03	25.65	<0.01	22.73	<0.01	P<0.1	96.52	12.41	0.15	<0.01
172	<0.01	5.87	34.56	<0.01	43.60	<0.01	P<0.1	475.33	23.47	0.33	<0.01
173	<0.01	5.96	37.78	<0.01	23.37	<0.01	P<0.1	447.73	15.27	0.32	<0.01
182	<0.01	5.81	45.40	0.01	13.93	<0.01	P<0.1	222.48	10.41	0.26	<0.01
188	<0.01	3.26	37.07	0.02	17.84	<0.01	P<0.1	148.85	15.56	0.19	<0.01
188	<0.01	4.00	45.30	<0.01	71.90	<0.01	0.40	108.67	93.16	0.41	<0.01
188a	<0.01	2.64	30.56	<0.01	11.16	<0.01	P<0.1	130.38	10.90	0.16	0.02
189	<0.01	2.59	32.86	<0.01	9.62	<0.01	P<0.1	138.36	9.39	0.16	<0.01
192	<0.01	13.24	52.62	0.01	21.43	<0.01	P<0.1	220.55	11.15	0.28	<0.01
198	<0.01	2.76	34.62	<0.01	11.06	<0.01	P<0.1	124.44	11.00	0.16	0.01
200	<0.01	4.37	36.66	<0.01	11.97	<0.01	P<0.1	131.41	11.40	0.18	0.02
203	<0.01	2.08	24.43	<0.01	8.14	<0.01	P<0.1	108.33	7.87	0.18	0.02
212	<0.01	1.28	25.00	<0.01	6.15	<0.01	P<0.1	100.37	7.47	0.13	0.02
215	0.02	2.64	25.09	0.04	6.45	<0.01	P<0.1	114.96	6.91	0.15	0.02
219	<0.01	2.44	22.77	0.02	5.87	<0.01	P<0.1	97.03	6.86	0.13	0.01
221	<0.01	2.76	26.35	<0.01	6.78	<0.01	P<0.1	103.99	7.84	0.14	0.01
222	<0.01	1.96	32.22	<0.01	15.52	<0.01	P<0.1	123.24	11.96	0.18	0.01
224	<0.01	7.54	34.81	<0.01	10.83	<0.01	P<0.1	127.75	13.12	0.22	0.01
224	<0.01	8.40	36.50	<0.01	13.10	<0.01	0.40	114.87	16.06	0.31	<0.01

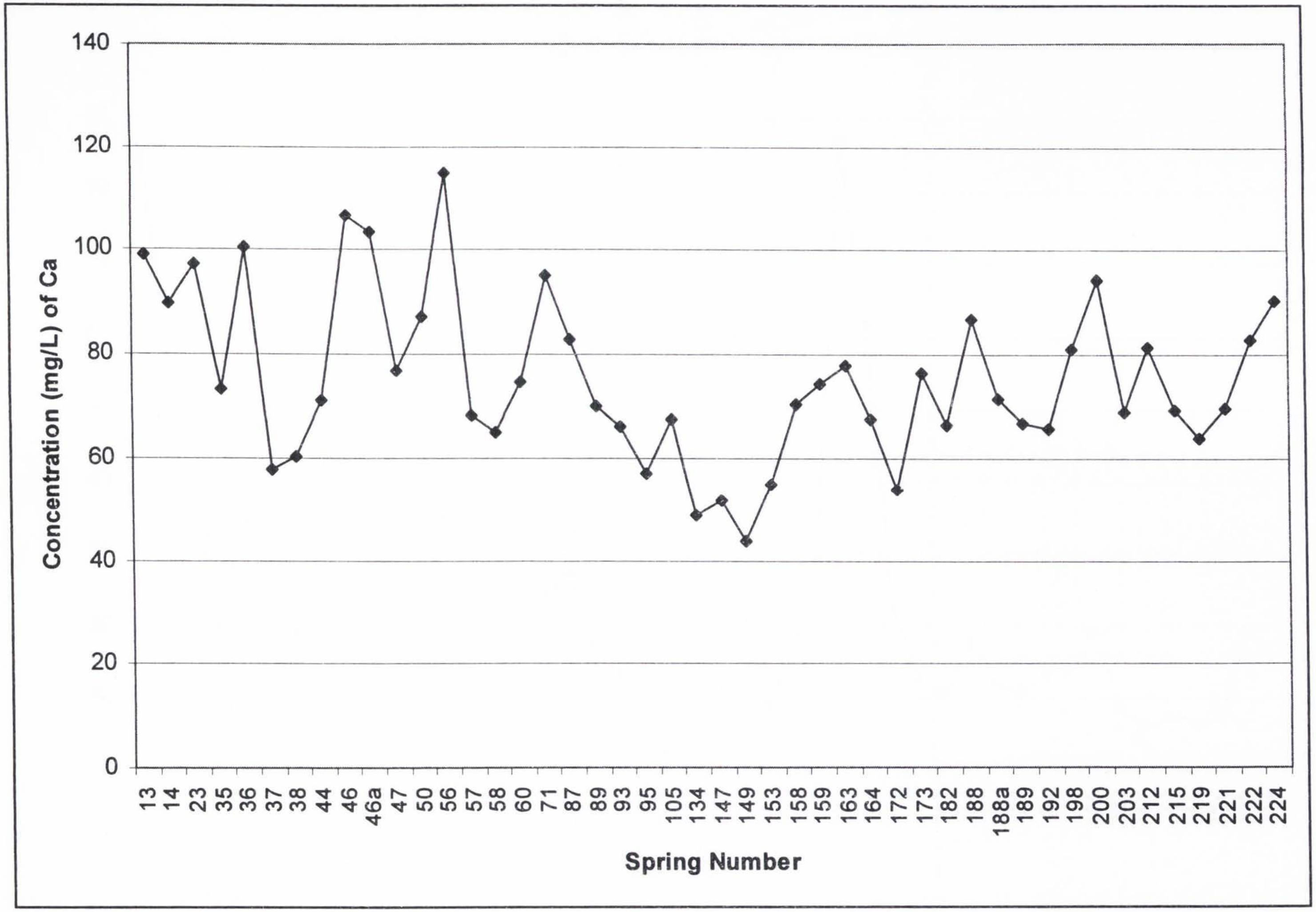

Figure 33: Concentrations of Ca in spring samples.

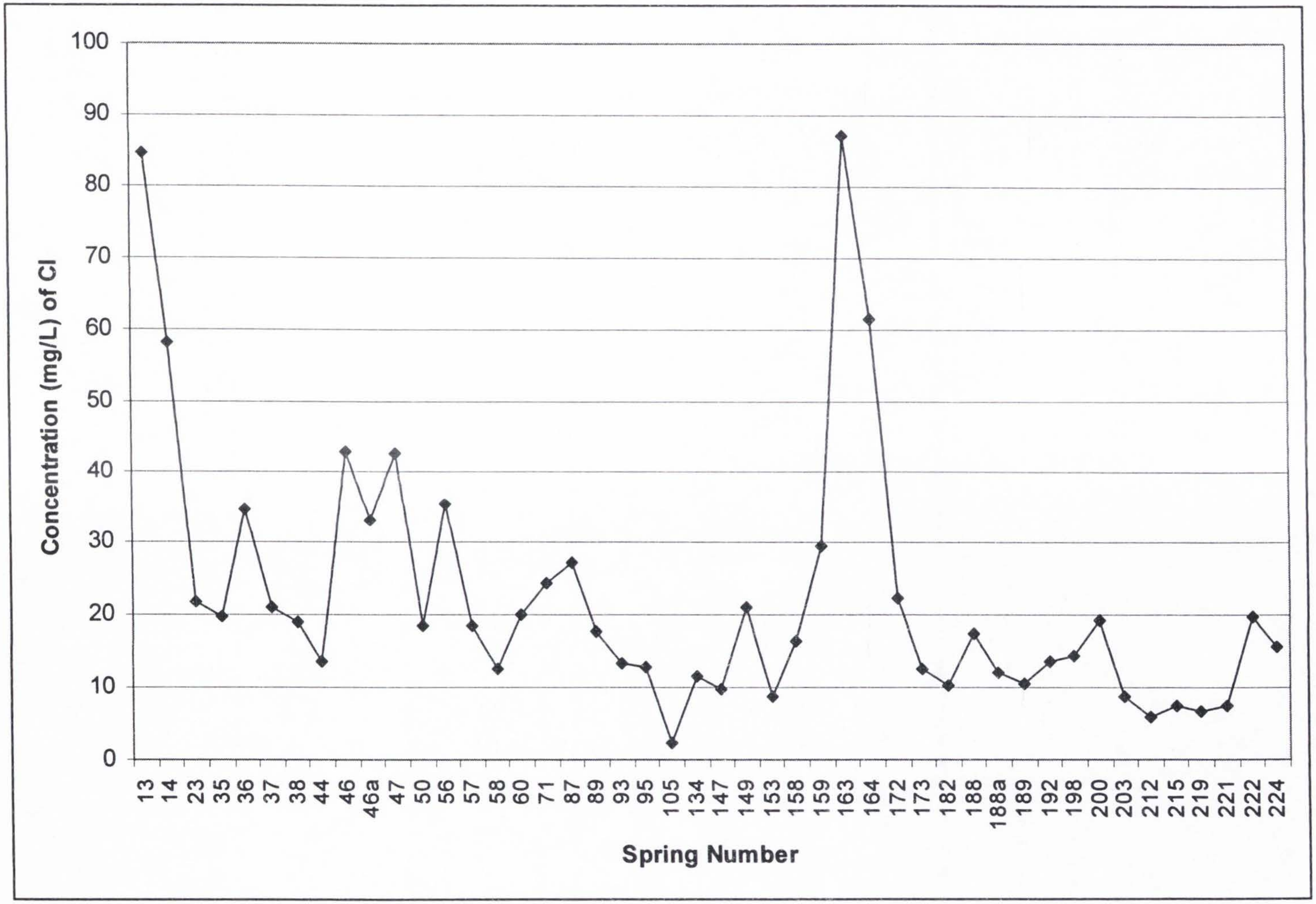

Figure 34: Concentrations of Cl in spring samples.

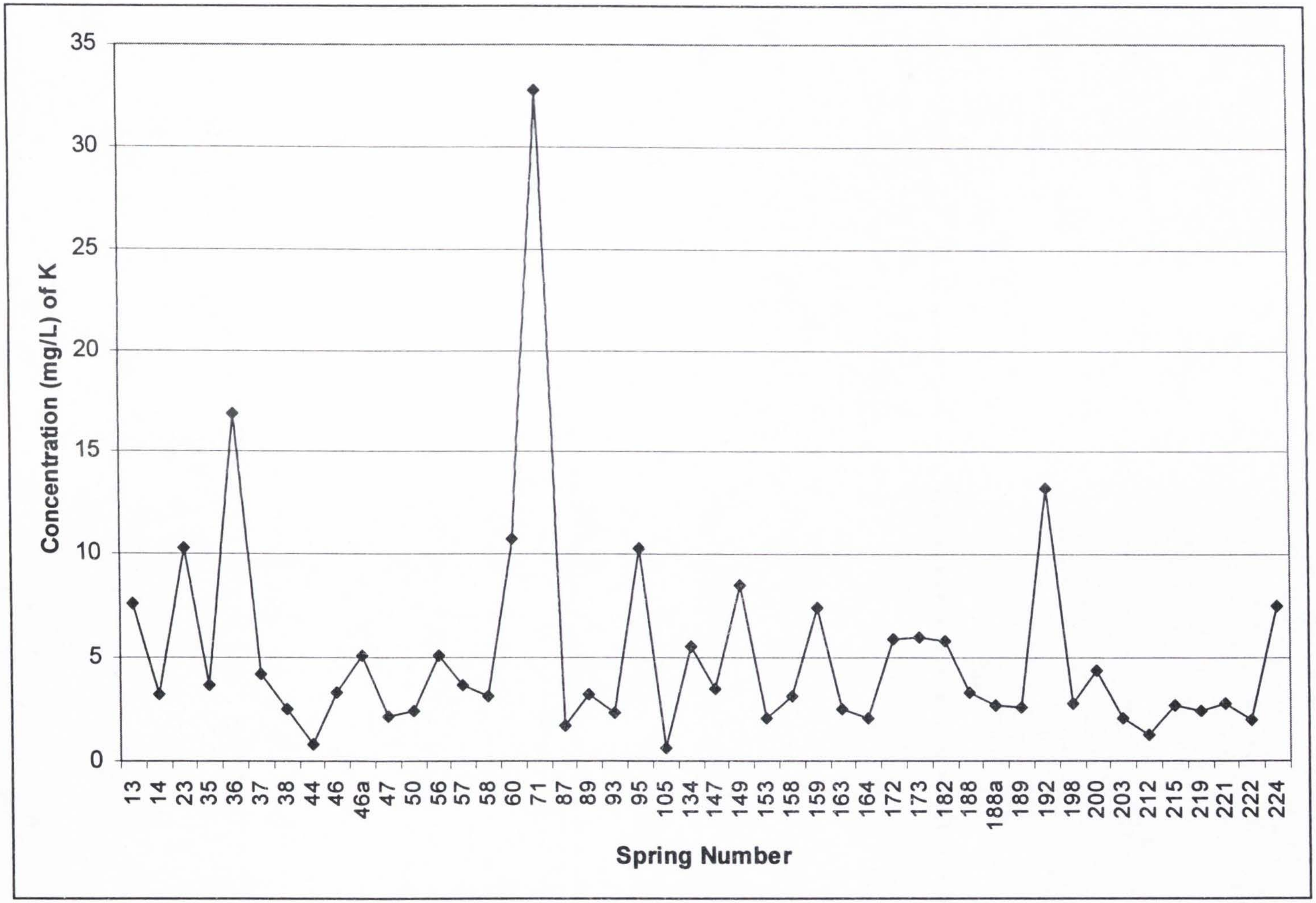

Figure 35: Concentrations of K in spring samples.

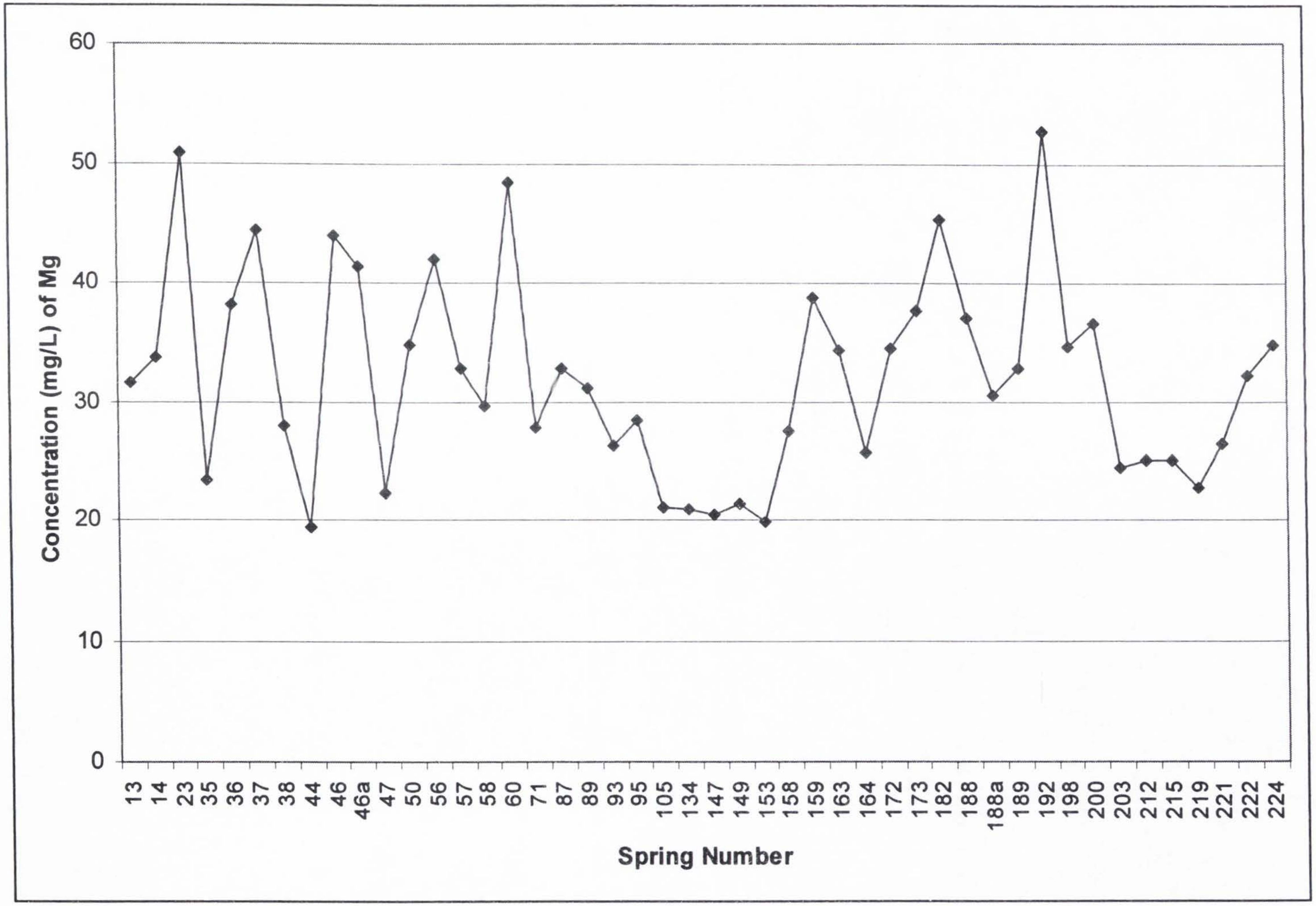

Figure 36: Concentrations of Mg in spring samples.

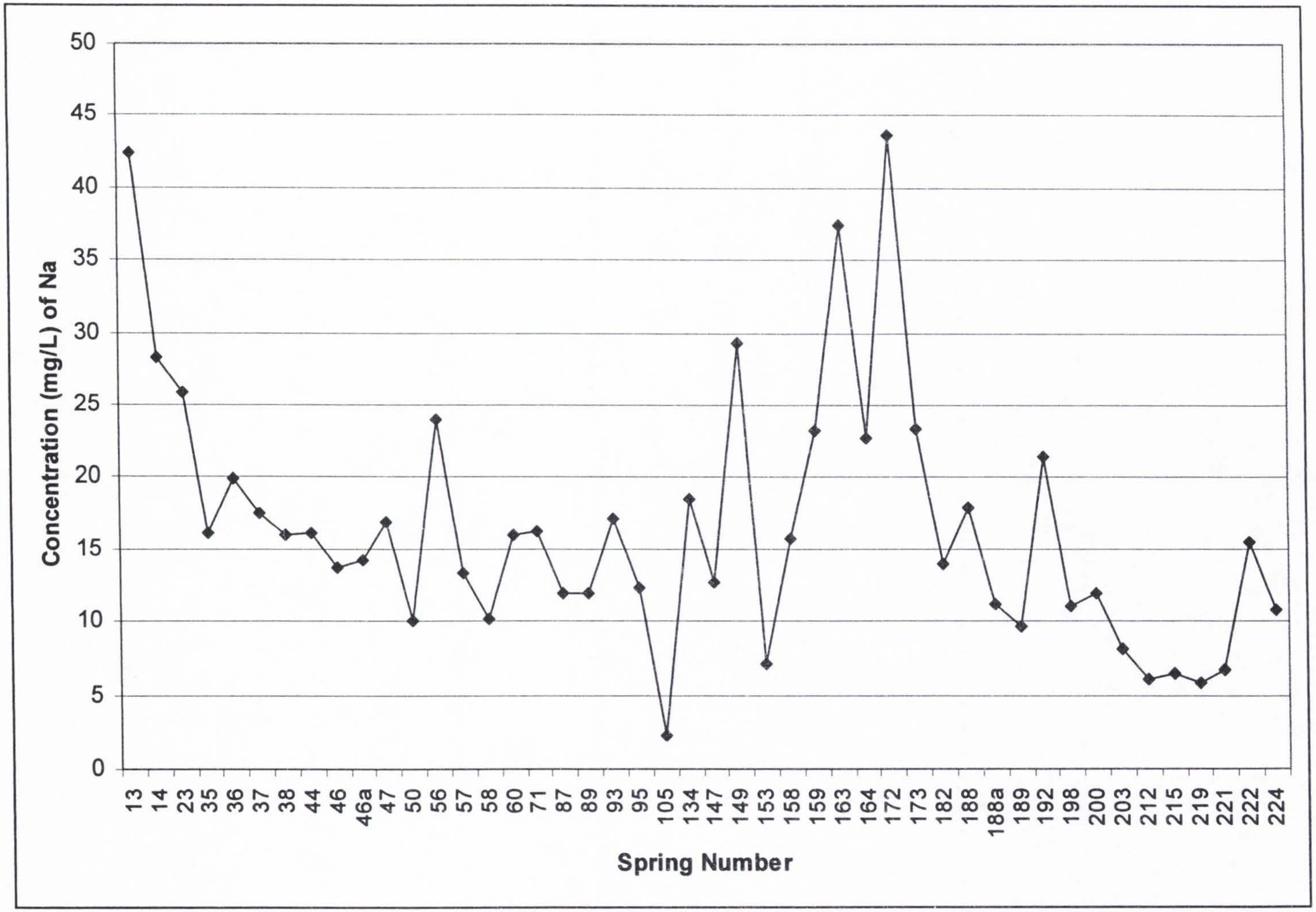

Figure 37: Concentrations of Na in spring samples.

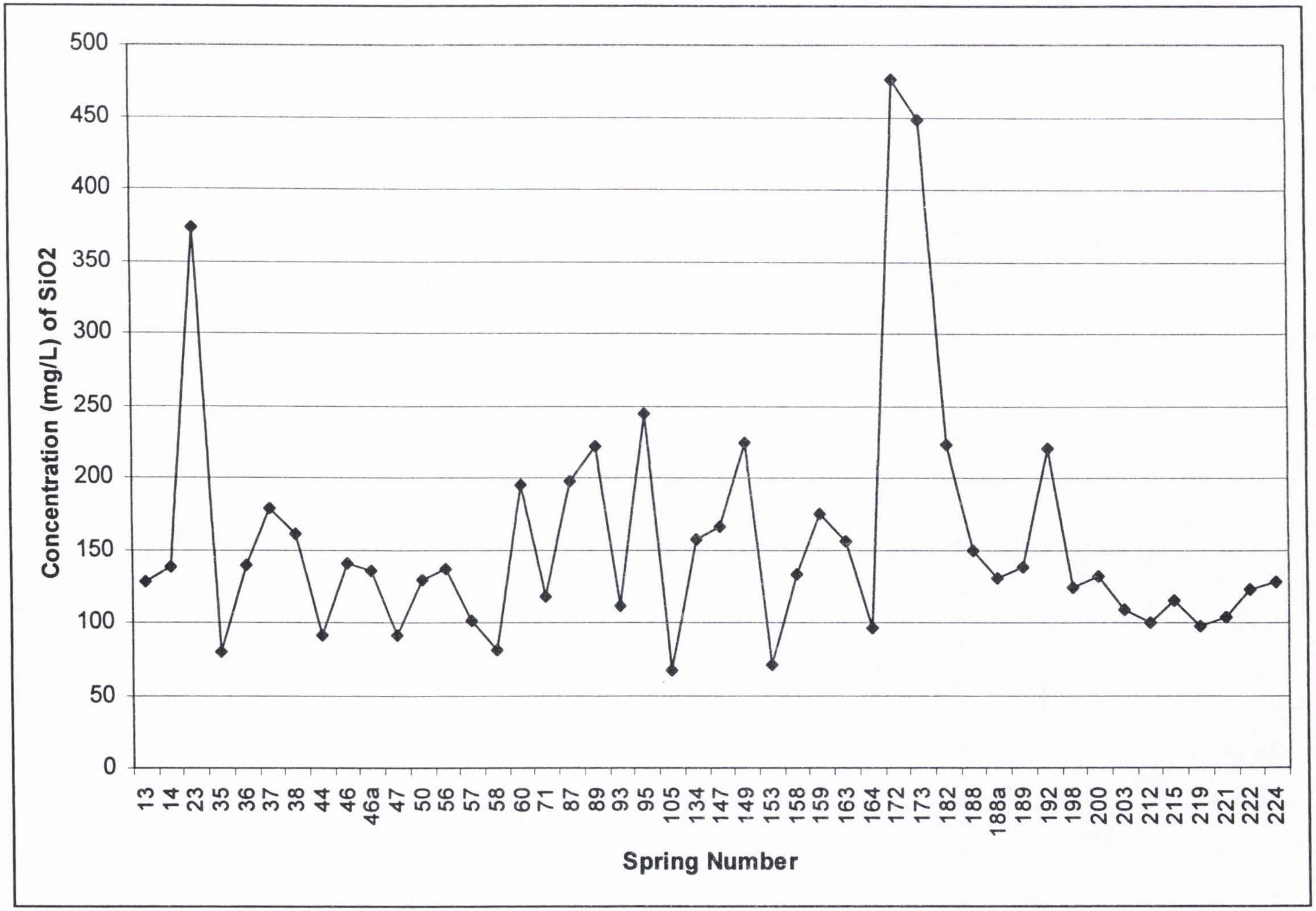

Figure 38: Concentrations of SiO_2 in spring samples.

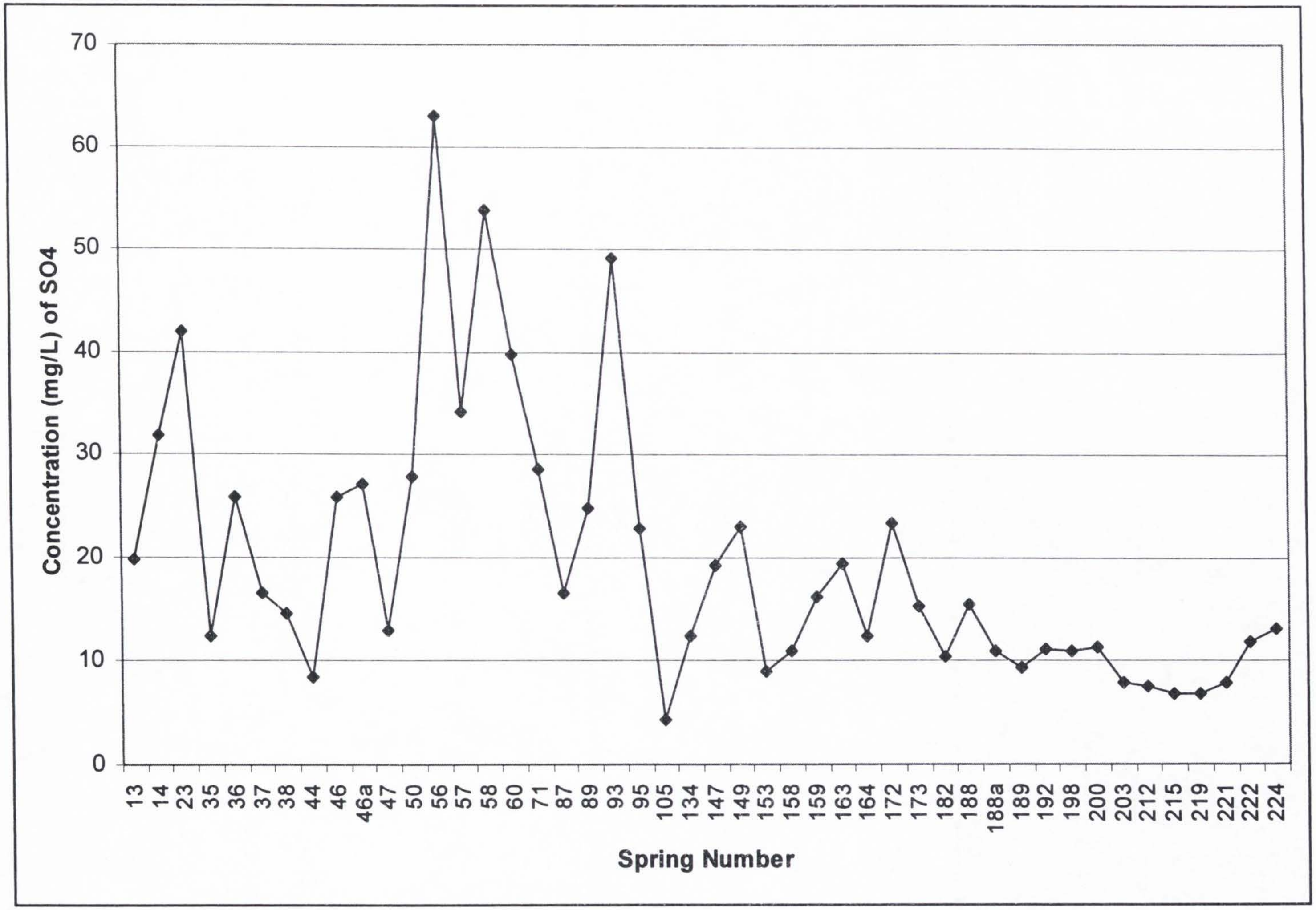

Figure 39: Concentrations of SO_4 in spring samples.

PLATE 1

U.S. Geological Survey Topographic Quadrangles
with Spring Locations Plotted

N
W E
S

0 0.5 1 2
Miles

1 inch equals 0.38 miles

● Springs

Compilation of the Smithfield, Logan,
and Wellsville USGS Topographic Quadrangles

Contour Intervals: 40 feet

NAD 1927 UTM Zone 12N Projection