

THESIS

WATER QUALITY CHANGES AT A
STREAMFLOW AUGMENTATION PROJECT,
LOWER SOUTH PLATTE RIVER, COLORADO

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR
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ABSTRACT OF THESIS

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Flow augmentation projects utilizing managed groundwater recharge serve as a management tool for the conjunctive use of groundwater and surface water. The projects emphasize providing adequate water quantity at the right place and at the right time. However, water quality must be addressed. Mixing of different qualities within such a system can affect water quality both in the river and in the alluvial aquifer.

The Tamarack Ranch Groundwater Recharge Project (Project) operates adjacent to the South Platte River in northeastern Colorado. The Project re-times excess flows in the South Platte River using managed groundwater recharge. Surface water, groundwater, and extraction water samples from the site were analyzed for water quality parameters and ionic composition. Water chemistry from the different sample locations determined the spatial and temporal influence of managed recharge activities.

Two primary and distinct source waters are present in the system – groundwater and river water. The groundwater is dominated by calcium and bicarbonate. The river water is dominated by sodium / calcium and sulfate. The extraction water is a mixture of these two sources. The application of a simple batch mixing technique determined that the extraction water was about 80% groundwater.

This research found that a streamflow augmentation project using managed groundwater recharge does affect water quality. As the system continues to operate, alluvial aquifer water quality will be affected by the surface water quality. A space for time substitution shows how groundwater quality is changing due to the effects of additional river water entering the alluvial aquifer system.

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TABLE OF CONTENTS

ABSTRACT OF THESIS	iii
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS.....	vi
LIST OF TABLES	viii
LIST OF FIGURES	ix
CHAPTER 1: INTRODUCTION	1
1.1 Hypothesis and Objective	4
CHAPTER 2: BACKGROUND	6
2.1 Colorado Water Law	6
2.2 Streamflow Augmentation Projects	7
2.3 Mixing Analysis	10
CHAPTER 3: METHODS	12
3.1 Project / Site Description	12
3.2 Sample Analysis.....	21
3.3 Sample Collection	26
3.4 Data Analysis	31
3.5 Previous Site Specific Water Quality Findings	34
CHAPTER 4: RESULTS and DISCUSSION.....	38
4.1 Water Level Analysis.....	38
4.2 Sample Location Groups.....	43
4.3 Water Quality Parameters	44
4.4 Groundwater / Surface Water Mixing.....	60
4.5 Differences between Sloughs.....	77
CHAPTER 5: SUMMARY and CONCLUSIONS.....	79

5.1 Future Recommendations	81
CHAPTER 6: LITERATURE CITED.....	83
APPENDICES	88

LIST OF TABLES

Table 1. Pumping History Summary at Tamarack.....	21
Table 2. Sample Collection Points Summary Table.	29
Table 3. Sample Locations by Group.	43
Table 4. Water Quality Data Summary by Sample Location Group.	45
Table 5. Numerical Assignment for Each Sample Collection Date.....	61

LIST OF FIGURES

Figure 1. Tamarack Ranch State Wildlife Area General Location and Layout.....	13
Figure 2. Tamarack Ranch Groundwater Recharge Project Sampling Locations.	15
Figure 3. Example of a Groundwater Extraction Pump and Recharge Pond.....	16
Figure 4. Simplified Geologic Cross-Section of the Project.....	20
Figure 5. Sample Collection Points in Recharge Pond Area.	28
Figure 6. Depiction of Water Table on November 13, 2002 (216 Days OFF).....	40
Figure 7. Depiction of Water Table on March 11, 2003 (42 Days ON).....	41
Figure 8. Temperature Changes with Time.	47
Figure 9. pH Changes with Time.....	49
Figure 10. Specific Conductivity Changes with Time.....	51
Figure 11. Nitrate Changes with Time.....	53
Figure 12. Sulfate Changes with Time.	55
Figure 13. Hardness Changes with Time.....	57
Figure 14. Alkalinity Changes with Time.....	59
Figure 15. Mixing Diagram of Sodium vs. Sulfate.....	62
Figure 16. Mixing Diagram of Sodium vs. Chloride.....	63
Figure 17. Mixing Diagram of Magnesium vs. Chloride.....	64
Figure 18. Chemical Composition Comparisons of Groundwater and River Water.	68
Figure 19. Piper Diagram of Source Waters and Extraction Waters.	69
Figure 20. Lower Shallow Well Group Compositions.	70
Figure 21. Compositional Changes in DOW 5 over Time.....	72
Figure 22. Compositional Changes in DOW 4 over Time.....	74
Figure 23. Compositional Changes in T 13 Deep over Time.	75
Figure 24. Compositional Changes in SPR 1 and SPR 2 over Time.	76
Figure 25. Compositional Differences between SL 1 and SL 2.	78

CHAPTER 1: INTRODUCTION

Throughout the western United States, rapidly growing populations and agricultural demands stretch surface water resources to the limit. In Colorado, snow high in the Rocky Mountains feeds rivers that flow to the Atlantic and Pacific Oceans. While Colorado has an abundance of river headwaters, it is also a state that is dealing with serious water shortages. The effects of surface water over-appropriation have negative impacts within Colorado as well as states downstream. Streamflow augmentation projects utilizing managed groundwater recharge are being employed to minimize the downstream impacts as well as to continue meeting the water resource needs of Colorado (Warner et al., 1986).

Conjunctive use strategies involving both groundwater and surface water resources are becoming increasingly popular. The use of managed groundwater recharge in augmenting river flows is one such example of conjunctive use (Fairchild, 1987). Streamflow augmentation projects re-regulate, or redistribute, river flows in time. The strategy is to take water out of the river during high flow, low-demand periods. This “excess” water, termed extraction water in this text, is pumped away from the river to recharge ponds designed to allow the water to quickly infiltrate into the alluvial aquifer system. The aquifer acts as storage. The aquifer, via subsurface flow, releases water back to the river at a later time. The optimal locations for the recharge ponds result in the

recharge water augmenting the river during critical, low-flow, high-demand periods (Warner et al., 1986).

It has been said that water in the South Platte River is used and reused seven times before it reaches the Nebraska State line. The two biggest demands placed on the river come from urban and agricultural sources. Nearly two-thirds of Colorado's population lives in Front Range cities like Denver and Greeley, which rely heavily on surface water from the South Platte River. Further east, out on the high plains, Colorado farmers depend on irrigation water from the river to nourish one of the most productive agricultural regions in the country (Dennehy et al., 1993).

The effectiveness of streamflow augmentation depends on the design and operation of the managed groundwater recharge system. As these systems increase base flows in the river, they may also modify the alluvium hydrology. This modification could have a significant impact on water quality in the alluvial aquifer and in the river (Asano, 1985). In particular, water quality represents a critical issue for the South Platte River Basin in northeastern Colorado, as the river ranks in the upper 25th percentile of nitrate-impacted rivers in the United States (USGS, 1998).

Managed groundwater recharge as a water management method in the South Platte River Basin is still a relatively new concept. First started about 20 years ago, initial research interests focused mainly on water quantity (Burns, 1985; Warner et al., 1986). Many questions concerning water quality effects still remain. How does recharge water quality

affect water quality in the alluvial aquifer and surface water? Can return flows flush nitrates and salts from the alluvial aquifer to the river and improve water quality in the alluvium? If so, how does flushing impact river water quality? What are the mixing dynamics of different source waters within the system? These are the questions that the following research investigates.

The Tamarack Ranch Groundwater Recharge Project (Project) is a part of the State of Colorado's efforts in addressing multiple resource demands. This Project is located in northeastern Colorado. By studying the mixing dynamics and resulting effects on water quality at the Project, one can understand how streamflow augmentation projects using managed groundwater recharge influence water quality.

In order to explain the hypothesis and research objective, a brief summary of the Project design and layout is presented here. The Methods section includes a detailed description of the Project. The South Platte River in northeastern Colorado flows in a northeasterly direction. On the floodplain, approximately 0.4 km (0.25 mi.) south of the main river channel, groundwater extraction pumps have been installed into the alluvial aquifer. These pumps connect to a series of pipes that lead to a recharge pond area. The recharge ponds are located in a hydraulically and topographically up-gradient direction approximately 1.6 km (1 mi.) south of the river. The recharge ponds are unlined and sited in highly permeable areas to allow for rapid infiltration. When extraction water is pumped to the ponds, it enters the subsurface and travels down-gradient towards the

river. Groundwater monitoring wells are installed throughout the area to monitor water levels and collect samples for water quality.

1.1 Hypothesis and Objective

The hypothesis for this research is that a streamflow augmentation project using managed groundwater recharge affects water quality. The hypothesis will be answered through a series of five tasks designed to accomplish one objective. The objective is to determine what effects a streamflow augmentation project using managed groundwater recharge has on water quality.

Spatial and temporal effects are considered. The Tamarack recharge system is very dynamic. Not all extraction pumps operate at the same time and extraction water can be pumped to different areas of the project depending on need. The Results and Discussion section will account for these dynamics so that the results of this research can be applied to other streamflow augmentation projects.

Task 1. The first task requires water chemistry measurements. This task involves designing and implementing a water quality sampling program at the Project. The sampling program incorporates all areas of the site to account for any spatial effects and will be maintained for a period of time long enough to identify temporal changes and trends.

Task 2. Similar sample locations are grouped qualitatively to identify the distinct source waters required in Task 3.

Task 3. Chemically distinct source waters are identified and defined.

Task 4. The fourth task determines the mixing dynamics over space and time. If there are distinct chemistry differences between the river water and the groundwater in the alluvial aquifer, the extraction water chemistry may indicate the proportion of water that is coming from each source.

Task 5. The final task draws conclusions on the expected long-term changes that a streamflow augmentation project has on water quality. Can a “space for time” substitution be made that leads to accurate water quality predictions for the future? Since managed groundwater recharge projects are becoming increasingly popular in the West, the predictions formulated from this research could have an impact on future operations.

CHAPTER 2: BACKGROUND

The research presented below focuses on the effects of managed groundwater recharge on water quality in the alluvial aquifer and the South Platte River at the Tamarack Ranch Groundwater Recharge Project. First, several critical background conditions are discussed to familiarize the reader with the importance of the tasks. The Background section begins with a brief description of Colorado water law. From there, the role of streamflow augmentation plans is examined. The section concludes with a review of previous research on groundwater / surface water mixing.

2.1 Colorado Water Law

Colorado water law is founded on the Prior Appropriation Doctrine, which summarizes as “first in time, first in right”. The first person or entity to appropriate and beneficially use water and adjudicate a water right for that intended or perfected use has the first right to use that water within a particular surface water system. If a senior appropriator cannot divert their water because of low river flows, a “call” is placed on the river. A call on the river requires all upstream junior appropriators to cease or replace (augment) diversions impacting the senior user (Vranesh, 1989).

In Colorado, recharge programs act as a major source of augmentation water due to their relatively low costs. Recharge programs continue to grow and expand as the demand for

water increases. Maintaining and improving managed groundwater recharge projects is vital in protecting the water resources upon which irrigated agriculture depends (Warner et al., 1986).

Present-day water use along the South Platte River is a result of the combined effects of agricultural and urban demands, limited water supply, and legal, economic and engineering constraints. Before irrigation development, the South Platte River was dry in the summer (Eschner et al., 1983). In 1865, an early settler described the South Platte River as “too thick to drink, too thin to plow, too shallow to sail on and too broad to shoot a rifle across” (Jackson, 2000). Today, the South Platte River is a gaining stream, with most of the return flow coming from deep percolation of applied irrigation water (Warner et al., 1986).

2.2 Streamflow Augmentation Projects

Augmentation projects allow irrigation wells to be pumped at times and in amounts that Colorado law would otherwise prohibit. Groundwater extracted by wells from the alluvial aquifer and used for irrigation during the summer months causes a depletion of streamflow in the river, which results in injury to senior water rights. Almost all surface water rights are senior to those of groundwater appropriators – considered junior simply due to the fact of “first in time, first in right” (Cech, 1990). However, if alluvial aquifer wells were shut down because of surface water needs, farmers in northeastern Colorado would face serious, negative economic impacts (Warner et al., 1986).

Augmentation projects raise streamflow levels by increasing the volume of discharge originating from the hydraulically connected alluvial aquifer. The key is to have that recharge water return to the river during the critical low-flow, high-demand irrigation season so that the senior surface water rights holders and the junior groundwater appropriators can meet their irrigation needs without conflict (Cech, 1990).

2.2.1 Three-States Agreement

The Cooperative Agreement for the Platte River Research and Other Efforts Relating to Endangered Species Habitat along the Central Platte River, Nebraska was signed by the Governors of Colorado, Wyoming, and Nebraska, and the Secretary of the Interior on July 1, 1997. This agreement, commonly referred to as the Three-States Agreement, has two main objectives. First and foremost, the agreement establishes a recovery plan to conserve and improve the habitat of four endangered or threatened species using the Platte River Basin in central Nebraska. The four targeted species are the whooping crane, piping plover, interior least tern, and pallid sturgeon. Second, the agreement enables existing and new water uses in the Platte River Basin to proceed without additional actions required for the four species under the Endangered Species Act.

As part of this agreement, Colorado committed to augment river flows in the South Platte River at the Colorado-Nebraska border by $1.2 \times 10^7 \text{ m}^3$ (10,000 acre-feet) annually. Recently, Colorado's commitment increased to $3.3 \times 10^7 \text{ m}^3$ (27,000 acre-feet) annually.

A major portion of this amount is expected to come from flow augmentation projects like Tamarack (U.S. Department of the Interior, 1997).

The success of Colorado's commitment to the Three-States Agreement is critical in protecting irrigated agricultural practices in the South Platte River Basin in Colorado. Without a successful commitment, Federal regulations under the Endangered Species Act could have severe negative consequences.

2.2.2 Stream Depletion Factors

The timing of the return flows and their amount of river augmentation depend on the alluvium properties and the distance between the recharge basin and the river. Currently, the quantity and timing of return flows to the river from recharge activities are determined by U.S. Geological Survey Stream Depletion Factor (SDF) methodology (Warner et al., 1986). SDF factors have units of days and represent the lag time it takes for recharge to return to the river. Mathematically, the SDF represents the time in days when 28 percent of the total amount of water extracted from a well in the alluvial aquifer is from the river (Jenkins, 1968). Conversely, it is also used to estimate when 28 % of the recharge water returns to the river. The remaining 72% returns to the river in the time following the SDF day period. The SDF for the Tamarack recharge basins ranges from 60 days to 270 days (U.S. Department of the Interior, 1997).

A degree of uncertainty inherently exists with any streamflow augmentation project. The SDF method calculates return flow to the river based on Glover's analytical solution for a well near a stream, but uses a numerical groundwater model to account for varying aquifer properties and boundary conditions. Warner et al. (1986) outlines several highly idealized assumptions used in Glover's analytical solutions.

2.3 Mixing Analysis

The concepts of hydrogeochemical mixing were first developed to identify the major processes controlling stream water chemistry. End-Member Mixing Analysis (EMMA) is one procedure developed to link catchment scale processes to the identifiability of stream water composition (Kleissen et al., 1990; Christophersen and Neal, 1990). Stream water composition was explained as a conservative mixture of soil water and groundwater end-members. By plotting different chemical solutes against one another, the stream water chemistries plotted between the boundaries created by the end-members (Christophersen et al., 1990; Hooper et al., 1990).

This approach will be applied to the Tamarack system in a very qualitative process. The chemistry of the extraction water entering the ponds is investigated as a mixture of distinct source waters. The source waters are treated as the "end-members". Hooper et al. (1990) explains the process of creating mixing diagrams with water chemistry data. Through these mixing diagrams, plotting the extraction water chemistry in relation to

source water chemistries determines the proportion of each source water's influence on the system.

CHAPTER 3: METHODS

This research studied one part of a larger project designed to quantify the impacts a streamflow augmentation project has on water quality and quantity. Ultimately, water quality is a result of the chemical mixing dynamics. By identifying the different source waters available for mixing and by analyzing the extraction water composition, one can determine how the source waters interact.

3.1 Project / Site Description

The Tamarack Ranch State Wildlife Area (Tamarack SWA) is located in northeastern Colorado near the town of Crook in Logan County (Figure 1). The Colorado Division of Wildlife (CDOW), Department of Natural Resources owns and operates the approximately 43 km² (17 mi.²) wildlife area to maintain migratory bird habitat and provide opportunities for recreation, education, and research. The area covers 25.7 km (16 mi.) of the South Platte River and land on either side to the north and south. The South Platte River drains 50,000 km² (19,000 mi.²) of land as it flows under the bridge at Crook, Colorado. The bridge designates the western boundary of the Tamarack SWA (Burns, 1985).

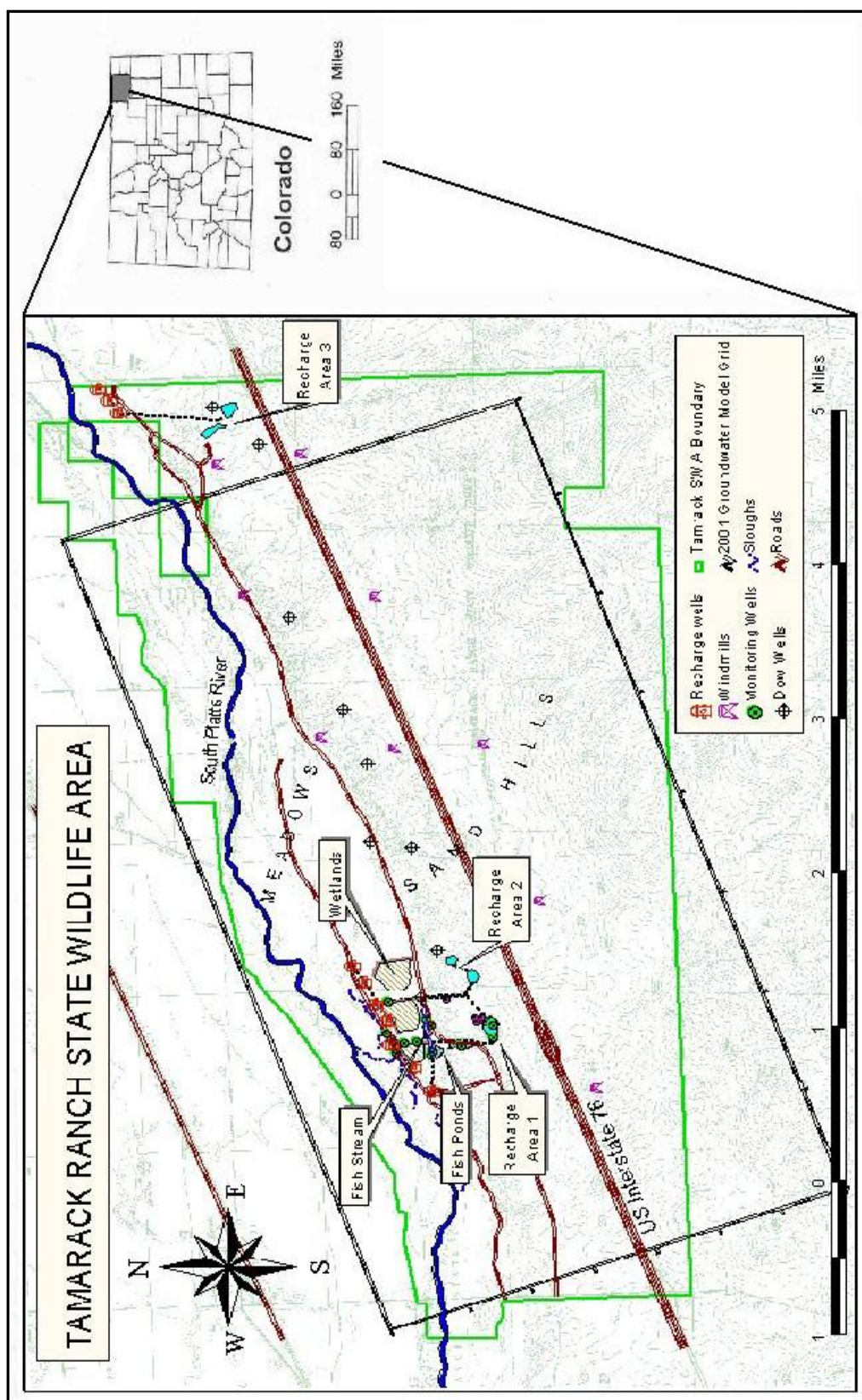


Figure 1. Tamarack Ranch State Wildlife Area General Location and Layout.

The Project re-regulates excess flows in the South Platte River through managed groundwater recharge. The Project is designed to pump groundwater from the alluvial aquifer next to the South Platte River when there is no call on the river. Through a network of pipes, this extraction water empties into recharge ponds constructed in upland areas approximately 1 km (0.6 mi.) from the river (Figure 2). The extraction water infiltrates and becomes part of the alluvial groundwater system. Over time, the water travels back to the South Platte River providing accretion water when additional river flows are needed (Flory and Halstead, 2002).

Currently, the Project facilities include 10 groundwater extraction pumps located next to the South Platte River, 3 recharge ponds constructed in the sandhill area 1 km (0.6 mi.) south of the river, and underground pipelines connecting the pumps to the ponds (Figure 2). Examples of an extraction pump and a recharge pond at the Project are shown in Figure 3. At build-out, the Project is proposed to have 20 to 30 groundwater extraction pumps with additional recharge ponds that receive an average total of $3.7 \times 10^7 \text{ m}^3$ (30,000 acre-ft.) of extraction water. A portion of that water will return back to the river during times of shortage to provide flow to benefit native fish species in Colorado, and incidentally provide flow for threatened and endangered species in central Nebraska. A pipeline also connects one extraction pump to a series of three lined fishponds, which flows into a 536 m (1,760 ft.) artificial minnow stream, which then flows into a series of three wetland areas providing for wildlife habitat (Flory and Halstead, 2002).

Water Quality Sampling Locations



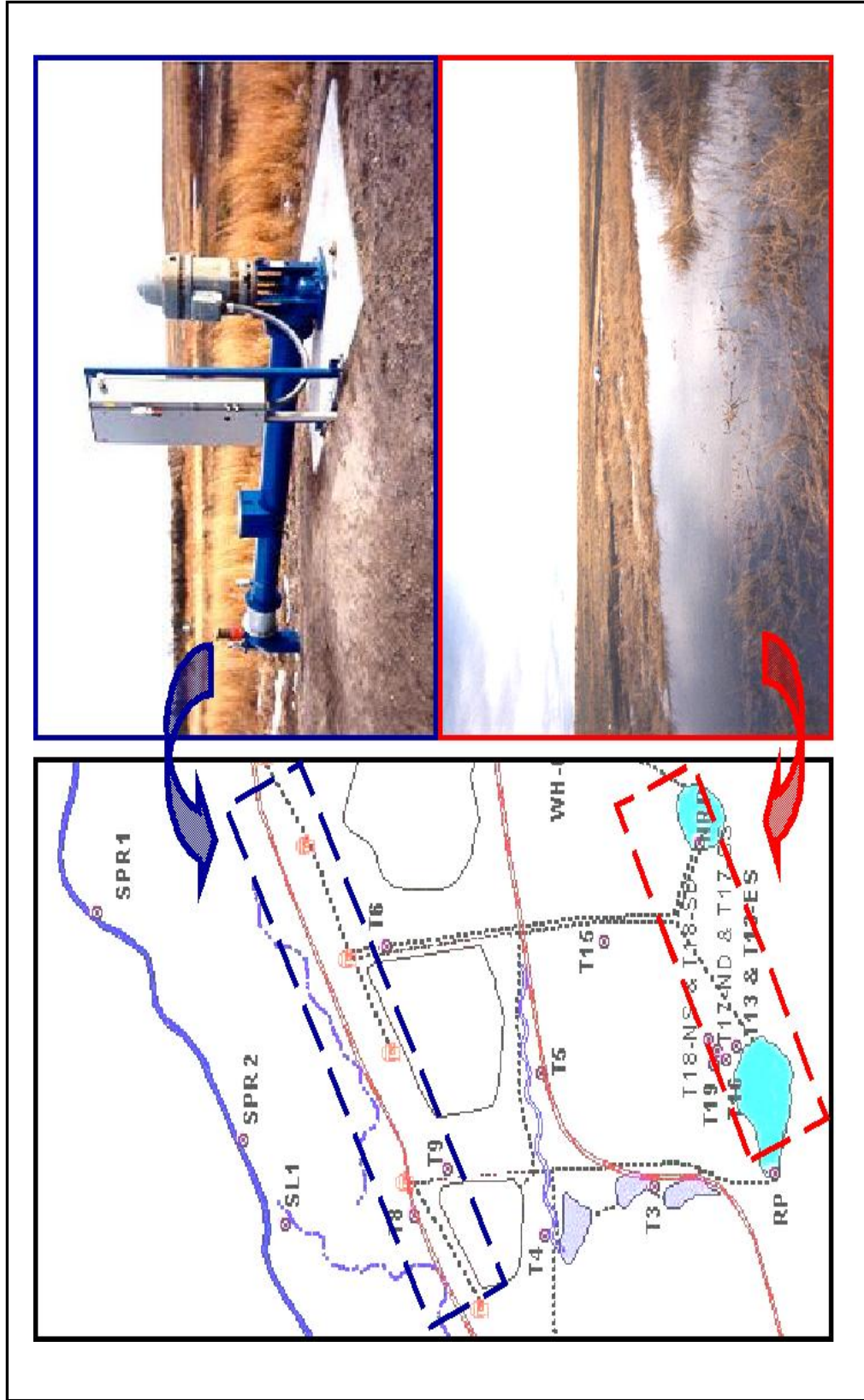


Figure 3. Example of a Groundwater Extraction Pump and Recharge Pond. The groundwater extraction pumps are located adjacent to the river and pump water to the recharge ponds. The recharge ponds are located in the sandhill area.

The study area consists of two primary physiographic features – the Valley Fill aquifer and the sandhill area. The extraction pumps are located in the Valley Fill aquifer near the river (Figure 3). The recharge ponds are located in the sandhill area approximately 0.2 to 1.2 km (500 to 4000 ft.) southeast of the river (Burns, 1985). Numerous studies describe the hydrogeological parameters of both features. Dennehy et al. (1993) provides a comprehensive report on the environmental setting of the entire South Platte River Basin.

3.1.1 Valley Fill Aquifer

The Valley Fill aquifer is an alluvial aquifer consisting of Pleistocene and recently deposited alluvium of the South Platte River. The alluvium is composed of highly permeable braided stream deposits consisting of clay, silt, sand, and gravel. The alluvium thickness ranges from 0.3 m (1 ft.) at the valley edges to 90 m (300 ft.) in the center near the river. The water table in the Valley Fill aquifer ranges from 0 to 24 m (0 to 80 ft.) below ground surface (bgs). The water table dips downstream at a rate of approximately 1.4 m/km (7.5 ft./mi.) (Bjorklund et al., 1957). Past aquifer testing in the Project area indicates a range of hydraulic conductivity values from 46 to 213 m/day (150 to 700 ft./day) and a range of specific yield values from 0.1 to 0.2 (Flory and Halstead, 2002). The relatively impermeable Brule shale underlies the alluvial aquifer at a depth ranging from 15 to 90 m bgs (50 to 300 ft. bgs) (Bjorklund et al., 1957).

Additional references provide further details of the aquifer setting. Hurr and Schneider (1973) show the hydrogeologic properties of the Valley Fill aquifer by mapping such

characteristics as transmissivity and stream depletion factors. The Soil Survey of Logan County, Colorado (Amen et al., 1977) characterizes the uppermost soil layers from the surface to 1.5 m bgs (0 to 60 in. bgs). Burns (1985) and Flory and Halstead (2002) discuss aquifer characteristics specific to the Tamarack SWA.

3.1.2 Sandhill Area

The sandhill area serves as an excellent recharge area because highly permeable soils overlie the alluvium of the Valley Fill aquifer, which is hydraulically connected to the river (Warner et al., 1986). The area is composed of eolian deposits of fine to medium sand located primarily along the southern edge of the valley. The sandhill area forms a terrace of sand dune deposits 15 to 30 m (50 to 100 ft.) above the river floodplain (Bjorklund and Brown, 1957). The Soil Survey of Logan County, Colorado classifies the soils in this area as either Dailey or Valent loamy sands with a permeability ranging between 15 to 51 cm/hr. (6 to 20 in./hr.) (Amen et al., 1977).

Burns (1985) and Flory and Halstead (2002) discuss the presence of a paleo-river channel. At the west end of the Tamarack SWA, which is near the Project, the paleo-river channel is located south of the present South Platte River under the sandhill area. At the east end of the Tamarack SWA, the paleo-river channel aligns with the current river location. A simplified geologic cross-section highlights the different characteristics of the Project area (Figure 4 – not to scale).

3.1.3 Pumping Schedule

To date, the typical groundwater pumping schedule at Tamarack begins in January when there is less demand on the river. The extraction pumps operate continuously through the winter and spring until a call is put on the river. In dry years, calls are put on the river as early as mid-April due to irrigation demands. When this happens, the pumps are sometimes turned on again in June / July during snowmelt runoff. Regardless, the extraction pumps are cut off for good by mid-June or July. The Northern Colorado Water Conservancy District (NCWCD) operates the pumps. According to their information, the pumping schedule since January 2001 is summarized in Table 1. A detailed history for each of the 10 extraction pumps is included in Appendix 1.

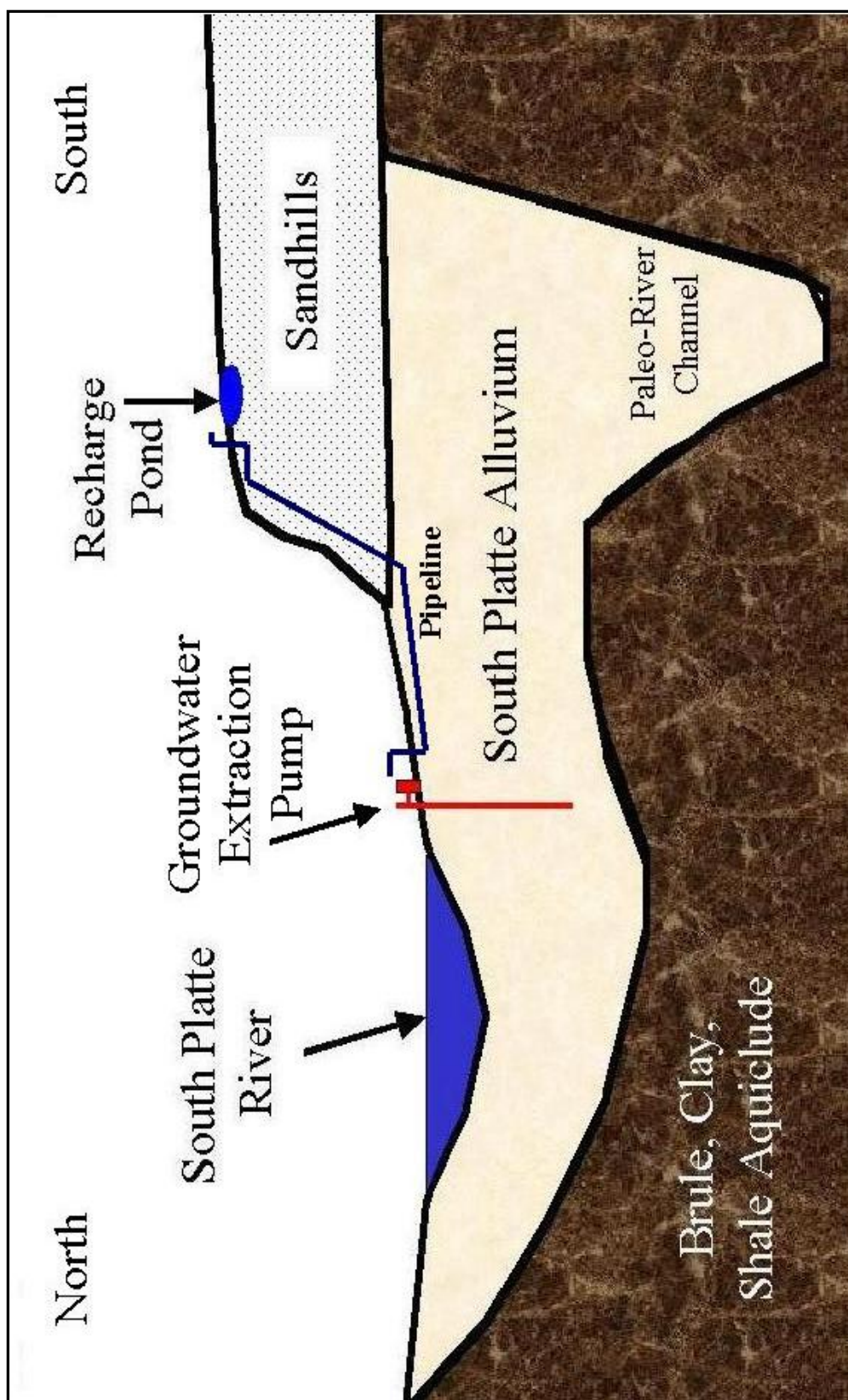


Figure 4. Simplified Geologic Cross-Section of the Project. This figure (not to scale) depicts the hydrogeological setting at the site. A paleo-river channel is located underneath the sandhills in the area of the Project.

Table 1. Pumping History Summary at Tamarack. The pumps operate when there is not a call on the river. The longest periods of operation, identified as “Days ON” in the table, occur from January to mid-spring.

Pumps ON	Pumps OFF	Days ON
January 10, 2001	May 24, 2001	124 days
June 2, 2001	June 21, 2001	19 days
July 16, 2001	July 21, 2001	5 days
September 17, 2001	November 27, 2001	71 days
January 27, 2002	April 12, 2002	75 days
January 29, 2003	Through June 1, 2003	123 days

3.2 Sample Analysis

This research analyzed nine water quality data parameters. The data parameters are water level, temperature, pH, specific conductivity, dissolved oxygen, nitrate, sulfate, hardness and alkalinity. The first five are field-measured parameters. The last four require laboratory analysis. In addition to these parameters, cation – anion analysis was performed on samples collected from April 26, 2002 to March 11, 2003.

The present research is a continuation of the protocol set forth in Kazbekov’s (2001) investigation of water chemistry at the Project. The nine parameters stated above were initially included in Kazbekov’s research. Kazbekov collected five sampling rounds of

water quality data during June and July of 2001. The data analysis performed from the current research includes Kazbekov's data when applicable.

A quality assurance / quality control (QA / QC) plan established the guidelines for sample collection and sample analysis both in the field and in the laboratory. These guidelines follow the recommendations set forth in *Water Quality Inventory Protocol: Riverine Environments* (Stednick, 1991).

3.2.1 Field Measured Parameters

Water level was measured before sample collection. Temperature, pH, specific conductivity, and dissolved oxygen were measured in the field immediately after sample collection. Field duplicates, field blanks, and bottle blanks were used every ten sampling locations to insure proper field collection techniques and field instrument calibration as per Stednick and Gilbert (1998).

Water Level

Water level was measured using a Heron Instruments, Inc. (Ontario, Canada) 'Dipper T' model water level meter.

Temperature

Temperature was measured using the 'YSI 58 Dissolved Oxygen Meter' by Yellow Springs Instrument Co., Inc. (Yellow Springs, Ohio). Temperature readings are reported to the nearest 0.1 °C. Temperature is important as it affects most physical, chemical, and biological processes. Temperature differences can determine seasonal variations and distinguish different water sources for mixing purposes.

pH

The pH parameter was measured in the field using an Oakton Instruments (Vernon Hills, Illinois) 'pHTestr 1' (Model 35624-00 Microprocessor Based Pocket Size pH Tester). pH is reported to the nearest 0.1 Standard Unit of pH.

Specific Conductivity

Specific conductivity was measured using a 'DiST 3 Pocket Tester' by HANNA Instruments (Woonsocket, Rhode Island). Specific conductivity values are reported in units of $\mu\text{S}/\text{cm}$.

Dissolved Oxygen

Dissolved oxygen measurements were made in the field using a 'YSI 58 Dissolved Oxygen Meter' by Yellow Springs Instrument Co., Inc. Temperature and pressure

calibrations were made prior to fieldwork and the calibration was checked after every tenth sample to avoid distortion. Dissolved oxygen readings are reported to the nearest 0.1 mg/L.

3.2.2 Laboratory Measured Parameters

Nitrate, sulfate, hardness, and alkalinity were determined in the Water Quality Laboratory of the Department of Forest, Rangeland, and Watershed Stewardship at Colorado State University, Fort Collins, CO. Samples did not exceed the appropriate holding time for each parameter. Laboratory duplicates and blanks were used every ten samples to check the calibration and precision of the laboratory analytical equipment (Stednick and Gilbert, 1998).

Nitrate as NO_3^- - Nitrogen

Nitrate concentrations were determined in the lab using the cadmium reduction method as stated in Hach Method 8171 (Hach, 1996). Direct readings were recorded from the Hach ‘Spectrophotometer DR/2000’ (Loveland, Colorado) using NitraVer 5 powder pillows (Stednick, 1991). Concentrations are reported as mg/L NO_3^- - N.

Sulfate (SO_4^{2-}), dissolved

The turbidimetric method, Hach Method 8051, using the Hach ‘Spectrophotometer DR/2000’ with SulfaVer 4 powder pillows determined the sulfate concentrations (Hach,

1996). Concentrations are reported as mg/L SO_4^{2-} , dissolved (Stednick, 1991). All sampling locations except DOW 4 and DOW 5 were diluted to a 1:10 ratio. DOW 4 and DOW 5 were analyzed without dilution.

Hardness

Total hardness concentrations were determined using the EDTA titrimetric method, Hach Method 8213 (Hach, 1996). A Hach ‘Digital Titrator Model 16900’ was used in the analysis. Concentrations are reported as mg/L CaCO_3 with two significant figures.

Alkalinity

Total alkalinity was measured in the lab using the phenolphthalein titration method, Hach Method 8203 (Hach, 1996), using the bromcresol green-methyl red indicator powder pillows. The samples were titrated using a 1.6 N H_2SO_4 solution with the Hach ‘Digital Titrator Model 16900’. Concentrations are reported in mg/L CaCO_3 .

3.2.3 Cation - Anion Analysis

Cation – anion analyses were performed in the Soils, Water, and Plant Testing Laboratory at Colorado State University. The samples were analyzed for four major cations, Ca^{2+} , Mg^{2+} , Na^+ , and K^+ , and four major anions, NO_3^- , SO_4^{2-} , Cl^- , and HCO_3^- . Base cations were measured using inductively coupled plasma emission spectroscopy. Anions were measured using ion chromatography. All samples were first filtered through

0.45-micron paper before analysis. Standards, blanks, and duplicates were used during analysis for QA/QC checks.

Concentrations in mg/L were converted to meq/L following the protocol in Hem (1985).

HCO_3^- was not measured directly in the laboratory. HCO_3^- concentrations in meq/L were calculated by dividing the alkalinity by 50 as per Stednick and Gilbert (1998).

Theoretically, the sum of cation equivalents should equal the sum of anion equivalents for each water sample. However, this does not typically occur due to the presence of ions that are not measured. Stednick and Gilbert (1998) outline acceptable percent differences according to the sum of cations and anions.

3.3 Sample Collection

Sample collection of water quality parameters began in June 2001 and continued through March 2003. Kazbekov (2001) describes the water quality sampling program in detail. His research included two sampling rounds in June 2001 and three sampling rounds in July 2001. After a three-month interval of no sample collection, sample collection began again in November 2001 and continued through March 2003.

Kazbekov's (2001) work began with 20 sample collection points. These points included 14 monitoring wells, 2 recharge ponds, 2 sloughs, and 2 points along the South Platte River. In August 2001, three new monitoring wells, T-19, T-17 SS, and T-18 NS, were

installed near the recharge pond identified as RP (Figure 5). The total number of sample locations increased to 23 in November 2001. All sample collection points are listed in Table 2 with their respective sample type, well screen depth, collection dates, and location description. All sample collection points are identified in Figure 2. A synopsis of field and laboratory data for every sample collection point on every sample collection date is provided in Appendix 2.

Near the recharge ponds, monitoring wells are completed at three different depths to cover shallow, intermediate, and deep hydrogeological interactions. The shallow wells, T-13 ES, T-15, T-16, T-17 SS, T-18 NS, and T-19, range in depth from 8 to 14 m bgs (26 to 46 ft. bgs) with the bottom 1.5 m (5 ft.) screened. The two intermediate wells, T-17 ND and T-18 SD, range in depth from 18 to 21 m bgs (59 to 70 ft. bgs) with the bottom 1.5 m (5 ft.) screened. The deep wells, T-13 Deep, DOW 4, and DOW 5, range in depth from 43 to 84 m bgs (142 to 274 ft. bgs) with bottom screen lengths of 6 m (20 ft.), 27 m (90 ft.), and 18 m (60 ft.) respectively.

Three monitoring wells, T-3, T-4, and T-5, are located in a transition area between the base of the sandhills and the floodplain. The wells range in depths from 3 to 10 m bgs (9 to 33 ft. bgs). Three other monitoring wells, T-6, T-8, T-9, are in the floodplain near the extraction pumps and completed to depths ranging from 3 to 4 m bgs (12 to 14 ft. bgs). These six wells are not screened and open only at the bottom.

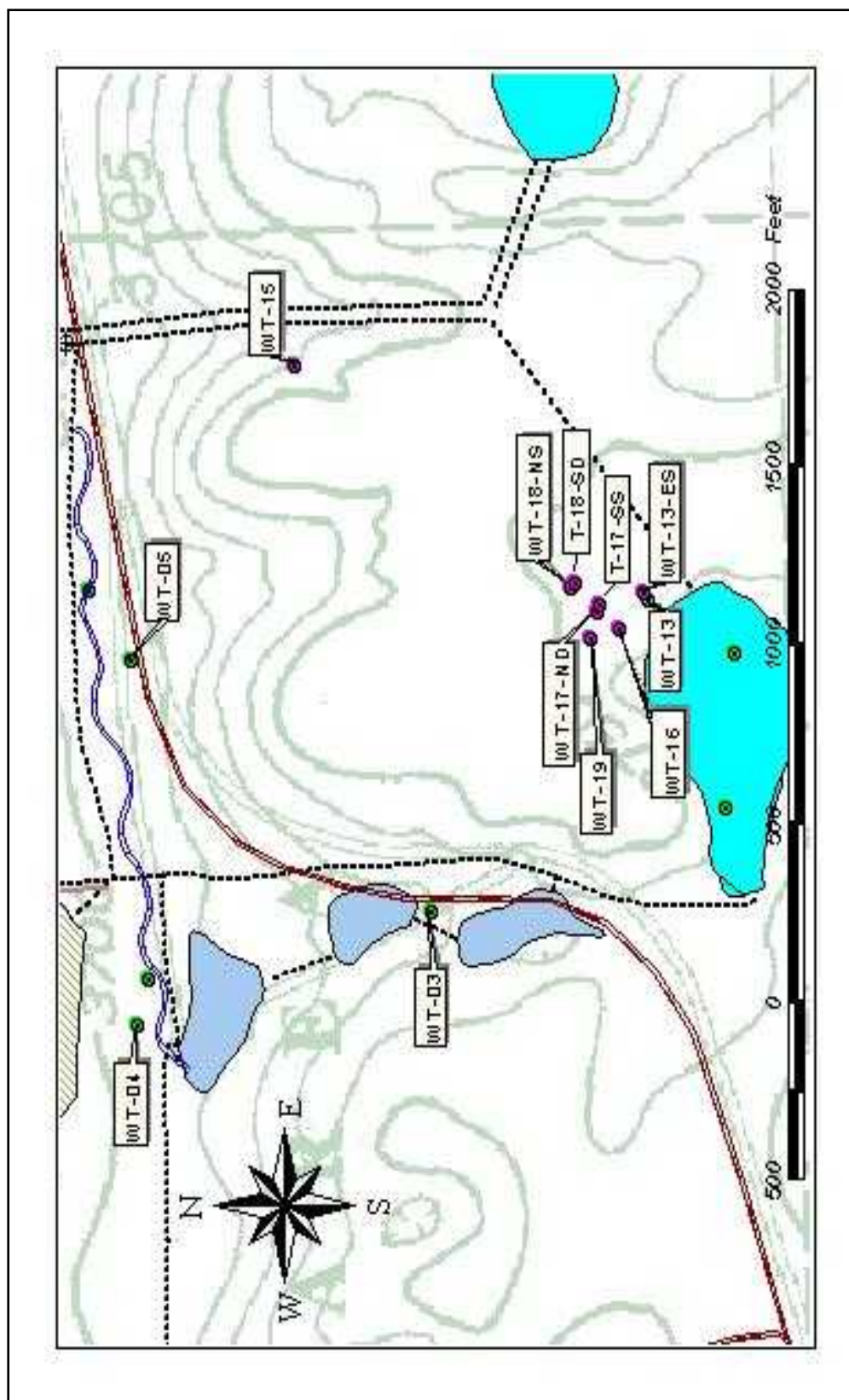


Figure 5. Sample Collection Points in Recharge Pond Area. T-19, T-17 SS, and T-18 NS were installed in August 2001.

Table 2. Sample Collection Points Summary Table. All 23 sample locations are provided with a description of the sample type, screen depth, collection date, and location importance. A single screen depth value indicates a groundwater monitoring well open only at the end. Recharge pond samples are actually collected from the outlet pipe into the pond.

Sample ID	Sample Type	Collection Date															Location / Description / Importance
		6/15/01	6/25/01	7/8/01	7/17/01	7/24/01	11/1/01	12/14/01	2/22/02	3/7/02	4/26/02	6/5/02	7/19/02	10/10/02	11/13/02	2/4/03	
	Screen Depth BGS, ft.																
DOW5	GW (142.0-202.0)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Division of Wildlife well (old windmill location) in sandhills
DOW4	GW (184.0-274.0)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Division of Wildlife well (old windmill location) in sandhills
T-13 Deep	GW (179.0-199.0)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	located just east of RP
T-17 ND	GW (64.7-69.7)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	"intermediate" depth near RP
T-18 SD	GW (59.4-64.4)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	"intermediate" depth near RP
T-13 ES	GW (39.0-44.0)	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	N	N	Y	Y	"east shallow" near RP
T-15	GW (26.3-31.3)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N	N	N	N	Y	furthest upper well from RP
T-16	GW (29.4-34.4)	Y	Y	N	N	N	N	Y	Y	N	N	N	N	N	Y	Y	near RP
T-17 SS	GW (38.0-43.0)	N	N	N	N	N	N	Y	Y	Y	N	N	N	N	Y	Y	near RP
T-18 NS	GW (41.6-46.6)	N	N	N	N	N	N	Y	Y	Y	N	N	N	N	N	Y	near RP
T-19	GW (38.2-43.2)	N	N	N	N	N	N	Y	Y	Y	N	N	N	N	Y	Y	near RP
T-3	GW (33.4)	Y	Y	Y	N	N	Y	Y	Y	N	Y	N	N	N	N	N	in transition zone near cooling ponds, obstructed with bailer
T-4	GW (9.2)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	in transition zone near cooling ponds
T-5	GW (23.8)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	in transition zone near mirrow stream
T-6	GW (13.2)	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	N	in floodplain near recharge pumps
T-8	GW (14.4)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	in floodplain near recharge pumps
T-9	GW (12.7)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	in floodplain near recharge pumps
SPR1	SW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	South Platte River (downstream location)
SPR2	SW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	South Platte River (upstream location)
SL1	SW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Slough 1
SL2	SW	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Slough 2
RP	SW	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	Y	Recharge Pond
NRP	SW	Y	N	N	Y	N	N	N	N	Y	N	N	N	N	N	Y	New Recharge Pond (constructed in 2002)

GW = Groundwater Sample, SW = Surface Water Sample, Y = Sample Collected, N = Sample Not Collected

All monitoring wells, except T-13 Deep, DOW 4, and DOW 5, were installed using a Giddings rig and constructed of 2.54 cm (1 in.) inner diameter PVC pipe. T-13 Deep is constructed of PVC pipe with a 10.6 cm (4 in.) inner diameter. DOW 4 and DOW 5 have a 43 cm (17 in.) diameter. Additional monitoring well specifics are provided in Table 2 and Appendix 2.

Beginning July 2002, all monitoring wells were purged three well volumes and allowed to recharge overnight before sample collection. Water level was measured prior to purging. Well purging and sample collection from monitoring wells used a 0.61 m (2 ft.) long stainless steel bailer with a 1.27 cm (0.5 in.) inner diameter. Every effort was made to minimize the effects of aeration and volatilization during transfer from the bailer to the sample container. T-13 Deep, DOW 4, and DOW 5 were purged three well volumes and sampled using a down-hole Grundfos 'Redi-Flo Variable Performance Pump' (SI/MP-1-115/230V) (Fresno, California).

Four of the surface water sample locations, SPR 1, SPR 2, SL 1, and SL 2, were sampled as outlined in Stednick and Gilbert (1998). The two extraction water samples from RP and NRP were collected from their respective outlet pipe before entering the recharge pond.

Sample containers consisted of Nalgene HDPE 250mL wide-mouth bottles. The bottles were labeled with waterproof ink on label tape. During sample collection and transport,

the bottles were stored upright in a closed cooler containing ice. The temperature remained as close to 4 °C as possible during collection, transport, and storage.

3.4 Data Analysis

3.4.1 Water Level

Water levels were measured before every sample collection. The NCWCD provided latitude, longitude, and elevation data for each monitoring well location. A 3-D graphing application “smoothed” the coordinate data using the inverse distance method to create both contour plots and 3-D mesh plots of the water table.

3.4.2 Sample Groups

For ease in data interpretation, the sample locations were grouped together on a very qualitative level. For the most part, water chemistry similarities coincided with sample locations and sample depths. The groups are as follows: the extraction water, the upper deep wells, the upper intermediate wells, the upper shallow wells, the lower shallow wells (including three transition wells), the sloughs, and the river. The extraction water samples were collected at the mouth of the outlet pipe discharging water into the recharge ponds. The upper classification is for all of the monitoring wells located on the sandhills, which are predominantly near one of the recharge ponds. The upper grouping has three

sub-groupings based on the screen depth of the monitoring wells. The upper shallow wells are located closest to the recharge pond and have a screen length of 1.5 m (5 ft.) at depths ranging between 8 to 14 m bgs (26 to 47 ft. bgs). The two upper intermediate wells are co-located with their shallow counterparts and are screened at the bottom 1.5 m (5 ft.) at depths ranging from 18 to 21 m bgs (59 to 70 ft. bgs). The screen length varies on each of the upper deep wells, but they range in depth from 43 m to 84 m bgs (142 ft. to 274 ft. bgs). The lower shallow wells, located in the river floodplain, are not screened. They are only open at the bottom at depths ranging between 3 m – 10 m bgs (9 ft. – 33 ft. bgs). Table 2 lists the depth and screen interval for each monitoring well.

3.4.3 Mixing Diagrams

As mentioned earlier, mixing diagrams are the starting point for any investigation into mixing dynamics. These diagrams are x-y plots of all species analyzed in the system (Hooper et al., 1990). The cation – anion analysis provided analytical results for four cations and four anions at every sample collection point. Thus, from these eight different species a total of 28 different mixing diagrams were constructed. Mixing diagrams help to determine visually the separate and distinct source waters in the system. The source waters will plot at the extreme ends of the mixing diagram.

Conservative mixing throughout the system is a critical assumption, as it defines the batch-like mixing process. The process means extraction water chemistry will plot within the boundaries formed by the source waters. For example, if there are two source

waters mixing conservatively to form the extraction water composition, then the extraction water chemistry will plot linearly between the two source water chemistries. If three source waters are present within the system and mixing conservatively, then the extraction water chemistry will plot within the triangular boundary created by the three different source water chemistries (Hooper et al., 1990). This concept works only if the source water chemistries are sufficiently different from one another and if the solutes within each source remain constant over space and time. Chemistries that plot non-linearly and/or outside of the source water boundaries imply a non-conservative mixing process (Christophersen et al., 1990).

3.4.4 Piper Diagrams

Trilinear Piper diagrams are a visual classification of ion ratios. Triangular portions at the bottom of the diagram compare the relative proportion of cations (left side) and anions (right side). The diamond portion above reflects the combined information from the two triangles (Piper, 1944). Piper diagrams are useful tools in classifying different water types. In this research, the diagrams will be used to define the different source waters within the system.

Hem (1985) and Drever (1997) explain how Piper diagrams are applied to mixing between two end-members. If a water is a mixture of two end-members, then the water plots on a straight line between the two end-members in each of the fields of the diagram.

3.5 Previous Site Specific Water Quality Findings

The final part of this section will highlight the previous findings from the Lower South Platte River and site-specific research at Tamarack. These findings will transition into the current research results presented in the next section.

3.5.1 Lower South Platte River Research

The South Platte River was one of the original sites picked for the U. S. Geological Survey's National Water Quality Assessment Program (NAWQA) (Dennehy et al., 1993). While research from the NAWQA studies takes into account the South Platte River Basin as a whole, some study results provide applicable information for the current research at Tamarack SWA.

Bruce and McMahon (1998) describe an 'agricultural-alluvium' water quality study that served as one of the subset settings in the NAWQA study. They indicate that most waters in the lower South Platte River plot in the Ca^{2+} Mg^{2+} SO_4^{2-} Cl^- part of the trilinear diagram. The median nitrate concentration was 9.35 mg/L as nitrogen; the median sulfate concentration was 695 mg/L; and alkalinity levels had a median of 302.5 mg/L as CaCO_3 . Tritium concentrations in the water samples indicate that the water in the alluvial aquifer is from "recent" recharge or modern water.

Additionally, the NAWQA study reports that concentrations of dissolved solids increased in a downstream direction. Water reuse and evaporative concentration of salts lead to increasing dissolved solids as water flows through the basin. This increase in dissolved solids correlated with an increase in the sulfate anion. Sulfate replaces bicarbonate as the dominant anion in groundwater in the alluvial aquifer in the plains. This is mainly due to fertilizer applications and urban wastewater discharge and partly due to interactions with sulfur-bearing rock units (Bruce and McMahon, 1998).

About 2.7×10^8 kg (300,000 tons) of nitrogen enters the South Platte River Basin every year from waste-water treatment plants, precipitation, fertilizer, and manure (USGS, 1995). McMahon et al. (1996) determined that naturally occurring processes in the South Platte alluvial aquifer can reduce nitrate concentrations in the groundwater prior to discharge to the river. The study found that the alluvial aquifer in lowland areas near the river had lower levels of dissolved oxygen than in the upland, irrigated areas, which enhanced microbial denitrification processes converting nitrate to nitrogen gas.

In a related study, McMahon and Bohlke (1996) indicated the importance of mixing between groundwater and surface water in reducing nitrate concentrations. At their site, mixing between South Platte River water and groundwater in the floodplain and riverbed sediments accounted for 70% to 85% of the difference between nitrate concentrations in the agricultural recharge areas versus the river.

3.5.2 Tamarack-Specific Research

Kazbekov (2001) examined the spatial and temporal variability of water quality parameters according to upland, lowland, and river locations. Although his data collection only covered two months, he concluded from his limited sampling that significant variability in water quality is attributable to the different sampling locations. It is much of his research that is referenced in the following review of Tamarack-specific water quality parameters.

Kazbekov (2001) determined spatial and temporal variations in temperature at the site. Surface water temperatures followed the seasonal changes in air temperature. Groundwater temperature variations were much less variable over time. Among the groundwater locations, temperatures were slightly lower with increasing depth.

From Kazbekov's data, slough SL 2 appears to be fed by groundwater due to its similarity in temperatures with other groundwater sample locations. Temperatures in slough SL 1 coincided with the surface water in the South Platte River.

Spatial variability affected pH more than temporal variability (Kazbekov, 2001). Three surface water locations, the two river points and SL 1, had the highest pH values. The values ranged between 8.2 and 8.5. The upper deep wells (T-13 Deep, DOW 4 and DOW 5), along with SL 2, had pH values slightly lower at 7.8. The upper shallow wells were slightly lower still with values ranging from 7.5 to 7.7. The lowest pH values came from the lower shallow wells, which ranged between 7.1 and 7.4.

Kazbekov's (2001) study found that surface water sample locations had higher specific conductivity than groundwater sample locations. The two river points and slough SL 1 had values from 1500 $\mu\text{S}/\text{cm}$ to 1800 $\mu\text{S}/\text{cm}$, which is typical for surface water. The groundwater points and slough SL 2 had lower values ranging from 300 $\mu\text{S}/\text{cm}$ to 600 $\mu\text{S}/\text{cm}$.

Kazbekov (2001) found spatial and temporal variations in sulfate concentrations. The surface water locations, SPR 1, SPR 2, and SL 1, had higher sulfate concentrations (420 mg/L to 630 mg/L) on average than the groundwater locations and SL 2 (9 mg/L to 120 mg/L).

Kazbekov (2001) found that the hardness in the river was similar to SL 1. Surface water sample locations ranged from 500 to 600 mg/L. Most of the groundwater locations and SL 2 ranged from 200 to 250 mg/L. All of the waters are considered to be "very hard" (Hem, 1985).

CHAPTER 4: RESULTS AND DISCUSSION

The physical attributes of the managed recharge system are presented before the chemical attributes. The water level data represents the physical changes in the water table under different pumping conditions. The transition from focusing on the physical to the chemical begins by grouping the sample collection points by location. Initially, the water quality parameters are discussed individually. From there, the individual parameters meld to reveal separate and distinct source waters. Ultimately, it is the analysis of the mixing dynamics between the different source waters that reveals the effects on the system as a whole.

4.1 Water Level Analysis

Visualizing the physical dynamics of the system now will help to understand the chemical dynamics of water quality and mixing that follow. The water table and flow gradients vary depending upon the operation of the extraction pumps. When the extraction pumps have been off for a period of time, the water table is smooth and shows only a slight gradient in the northeast direction back to the river. However, during operation of the extraction pumps distinct physical changes to the water table and flow gradients occur. Noticeable cones of depression form around the extraction pumps and a groundwater mound forms under the recharge pond area. This relationship shows clearly in Figure 6 and Figure 7. The x-coordinates and y-coordinates for each of the monitoring

wells were provided by the NCWCD. The coordinates are in feet and based on the NAD 27 coordinate system. In each of these figures, the South Platte River is included only as a directional reference.

On November 13, 2002, the extraction pumps have been off for 216 days. This sample collection date represents the longest time period that the pumps were off during the research. The water table shows a smooth, gradual decline in the northeast direction (Figure 6). The highest groundwater elevation is under the recharge pond at 1127 m (3696 ft.). The lowest groundwater elevation is near the South Platte River at 1124 m (3688 ft.). The overall gradient between the recharge pond and the river is 2 m (8 ft.).

In contrast, March 11, 2003 represents the 42nd day that the extraction pumps have been operating. A groundwater mound formed underneath the recharge pond area (Figure 7). Here is the highest water table elevation at 1131 m (3712 ft.). The extraction pumps created a distinct cone of depression in the alluvial aquifer near the river. Near monitoring well T-6 (Figure 2), the water table reaches its lowest elevation at 1123 m (3685 ft.). The gradient from the recharge pond area to the river is 8 m (27 ft.) and is in a more northerly direction than when the pumps are not operating.

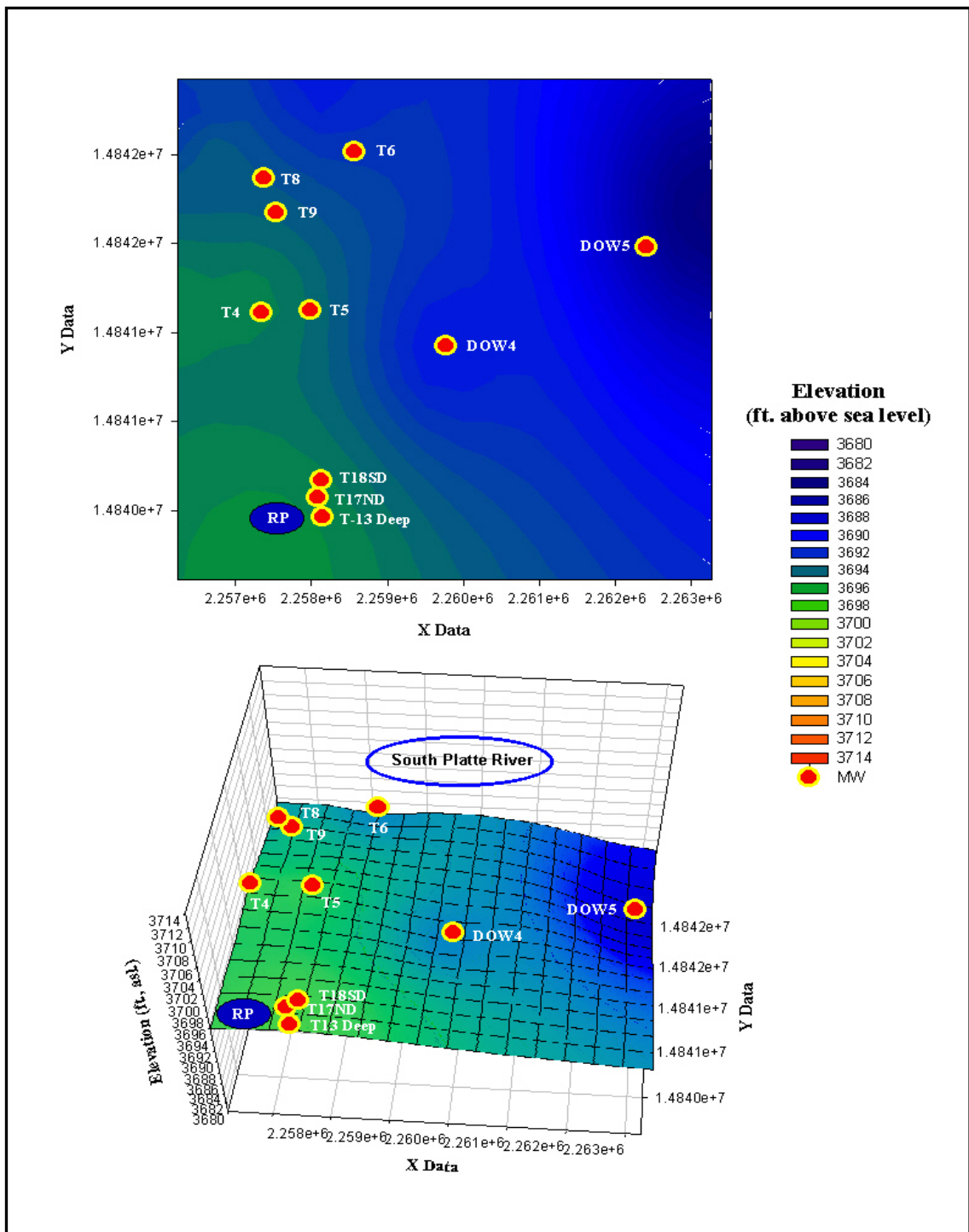


Figure 6. Depiction of Water Table on November 13, 2002 (216 Days OFF). When the extraction pumps have been off, the water table has a smooth, gradual gradient to the northeast toward the South Platte River. ‘MW’ in the legend stands for monitoring well. The locations are based on the NAD 27 coordinate system in feet.

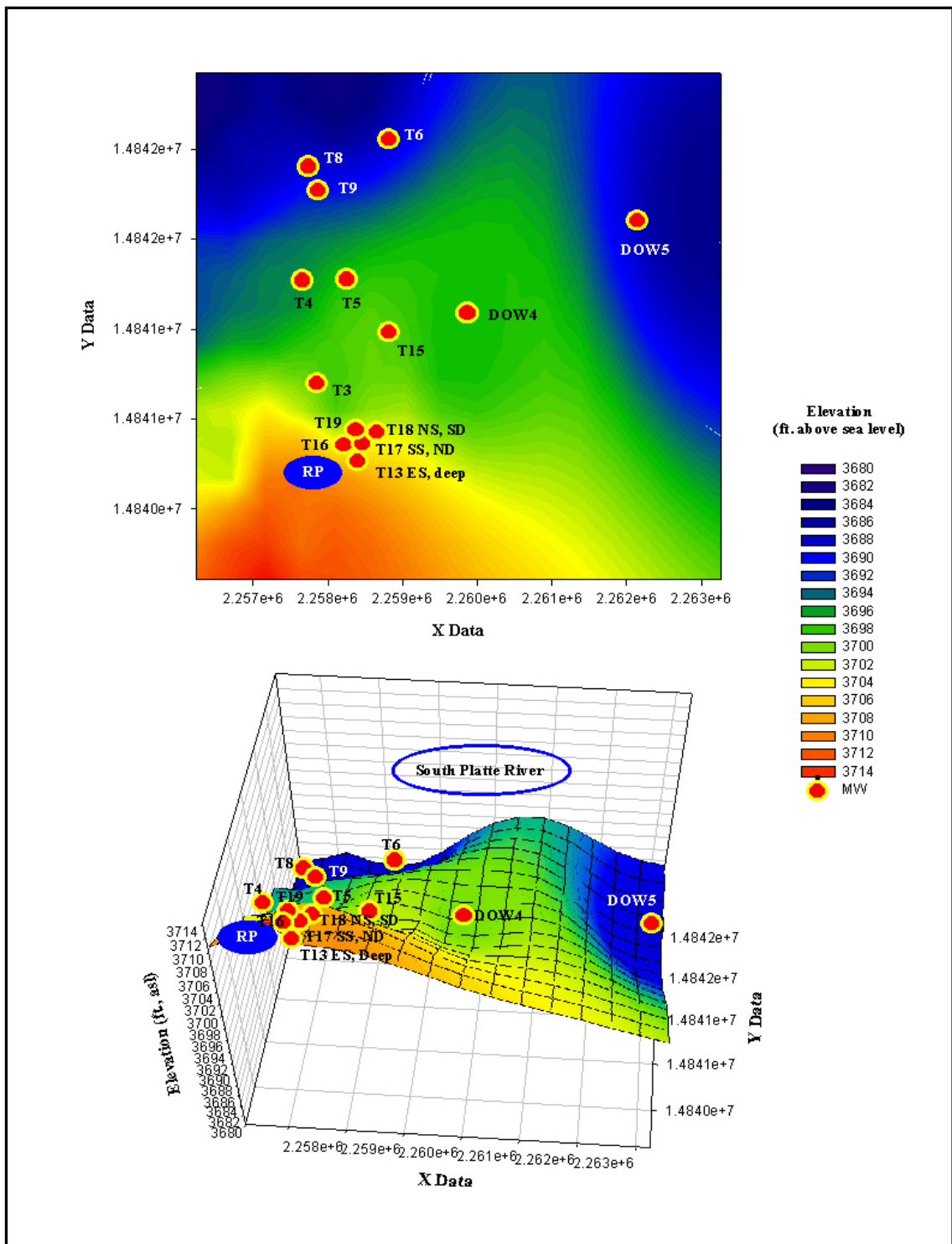


Figure 7. Depiction of Water Table on March 11, 2003 (42 Days ON). A ground-water mound has formed under the recharge pond area. A cone of depression has formed under the extraction pumps near T-6, T-8, and T-9.

In comparing the two dates, the water table is 5 m (16 ft.) higher under the recharge pond area and 1 m (3 ft.) lower in the groundwater extraction area when the pumps are operating. This creates a difference in gradient of 6 m (19 ft.). The almost due north gradient during groundwater extraction is explained by the drawdown created by the pumps. Seven extraction pumps for the Project are located along a line that begins 820 m (900 yds.) southwest of T-8 and ends 640 m (700 yds.) northeast of T-6 (Figure 2). This line of pumps in relation to the recharge pond area, which is located much further to the south, represents an almost due north direction. The northeast gradient direction occurring when the pumps are off (Figure 6) depicts a relatively natural, or at least undisturbed, condition (Bjorklund et al., 1957).

In Figure 7, a groundwater rise appears between sample locations T-6 and DOW 5. The water table elevation for DOW 5 remains unchanged between the two dates at 1124 m above sea level (asl) (3688 ft. asl). On the other hand, T-6 is very close to the extraction pumps. When the pumps are operating, T-6 is one of the first wells to show drawdown effects. These drawdown effects in T-6 are one reason why the groundwater rise appears so prominently. Another potential factor may be the beginning contributions of recharge water coming from the recharge pond area. On March 11, 2003, the new recharge pond, NRP, was in operation and located near DOW 4. After 42 days of groundwater extraction, any initial contribution of recharge water coming from the ponds would be influenced more by the artificial gradient created by drawdown from the extraction

pumps than the natural gradient that would cause recharge water to flow in the direction of DOW 5.

4.2 Sample Location Groups

For ease of data interpretation and presentation, the sample locations are grouped by common location. There are seven sample location groups: the South Platte River, the sloughs, the lower shallow wells, the upper shallow wells, the upper intermediate wells, the upper deep wells, and the recharge ponds. The sample collection points within each group are listed in Table 3. Each group is color coded to facilitate data interpretation.

Table 3. Sample Locations by Group.

GROUP NAME	SAMPLE COLLECTION POINTS GROUPED	COLOR
RIVER	SPR1, SPR2	BLUE
SLOUGH	SL1, SL2	YELLOW
LOWER SHALLOW WELL	T3, T4, T5, T6, T8, T9	GREEN
UPPER SHALLOW WELL	T13ES, T15, T16, T17SS, T18NS, T19	ORANGE
UPPER INTERMEDIATE WELL	T17ND, T18SD	GREY
UPPER DEEP WELL	T13 Deep, DOW4, DOW5	RED
RECHARGE POND	RP (west), NRP (east)	BLACK

The water quality results presented in the following sections utilize the group classifications. Every sample collection point is plotted within each group. This approach allows for the analysis of different sample locations within a group, as well as between the groups themselves.

4.3 Water Quality Parameters

The parameters varying by time and / or location are temperature, pH, specific conductivity, nitrate, sulfate, hardness, and alkalinity. The mean and standard deviation for each sample location group are listed in Table 4. The sample location groups in Table 4 differ slightly from Table 3. The sloughs are presented individually to show their differences in water chemistry. The three transition wells, T 3, T 4, and T 5, are not included in the lower shallow well group due to their locations near the fishponds and the minnow stream. The extraction water locations, RP and NRP, are plotted in every graph to show the similarities and differences between them and the different sample location groups. Appendix 2 contains all of the water quality parameter data.

Table 4. Water Quality Data Summary by Sample Location Group. The mean and standard deviation are given for each group. The two slough locations are listed separately. Wells T3, T4, and T5 are separated from the Lower Shallow Well Group due to their proximity to the fishponds and minnow stream.

Sample Location Group	Temp. (Celsius)	pH	Spec. Cond. (microS/cm)	DO (mg/L)	Nitrate (mg/L NO3-N)	Sulfate (mg/L)	Hardness (mg/L as CaCO3)	Alkalinity (mg/L as CaCO3)
River (SPR1, SPR2)	17.7	7.8	1875	7.0	1.9	671	632	189
Standard Deviation	10.5	0.6	214	4.7	1.6	92	78	48
Slough 1	16.7	7.8	1399	6.6	0.7	495	461	183
Standard Deviation	9.9	0.7	477	5.4	0.7	239	143	78
Slough 2	15.4	7.6	420	5.5	1.3	34	159	143
Standard Deviation	7.4	0.5	85	4.1	0.8	41	22	34
Lower Shallow Wells near pumps (T6, T8, T9)	14.0	7.2	785	3.8	1.2	140	236	158
Standard Deviation	4.1	0.4	256	2.3	0.7	69	55	49
Transition Well (T3)	11.1	7.3	605	3.5	0.5	57	197	166
Standard Deviation	3.9	0.3	164	1.9	0.5	44	16	27
Transition Well (T4)	13.5	7.3	1568	4.0	3.6	335	412	419
Standard Deviation	4.4	0.3	423	2.3	1.0	179	97	209
Transition Well (T5)	14.1	7.3	818	3.6	0.8	146	256	182
Standard Deviation	3.6	0.2	192	2.5	0.7	27	42	58
Upper Shallow Wells (T13ES, T15, T16, T17-SS, T18-NS, T19)	13.3	7.3	785	4.5	2.5	158	205	229
Standard Deviation	4.7	0.3	264	3.0	1.2	124	56	183
Upper Intermediate Wells (T17-ND, T18-SD)	12.9	7.3	772	4.9	2.0	139	237	159
Standard Deviation	3.2	0.2	243	3.0	0.9	54	48	22
Upper Deep Wells (T13-Deep, DOW4, DOW5)	15.2	7.4	526	5.9	1.8	64	183	128
Standard Deviation	3.2	0.4	250	4.5	0.6	68	76	34
Recharge Ponds (RP, NRP)	12.0	7.4	808	5.1	1.7	167	270	141
Standard Deviation	2.6	0.4	214	3.3	0.4	63	44	41

4.3.1 Temperature

Temperature fluctuates temporally and spatially (Table 4 and Figure 8). The South Platte River sample group has the highest mean temperature at 17.7 °C and the greatest standard deviation. The sloughs are slightly cooler. The changes in temperature of these two surface water groups correspond to changes in the seasonal air temperature. The lower shallow wells have a mean temperature of 14.0 °C. This group also appears to be seasonally influenced by air temperature. The lower standard deviation of this group as compared to the two surface water groups indicates the dampening effect of the shallow depth bgs. The upper deep and upper intermediate wells have mean temperatures of 15.2 °C and 12.9 °C, respectively. Only a slight influence of the seasonal air temperature is noticeable and the standard deviation in these two groups is the lowest of all sampling locations that have water to sample year round. It is difficult to analyze the upper shallow wells and the recharge ponds due to a lack of water at these locations except during periods of recharge. The extraction water mean temperature is 12.0 °C, which is more representative of groundwater temperatures than river water.

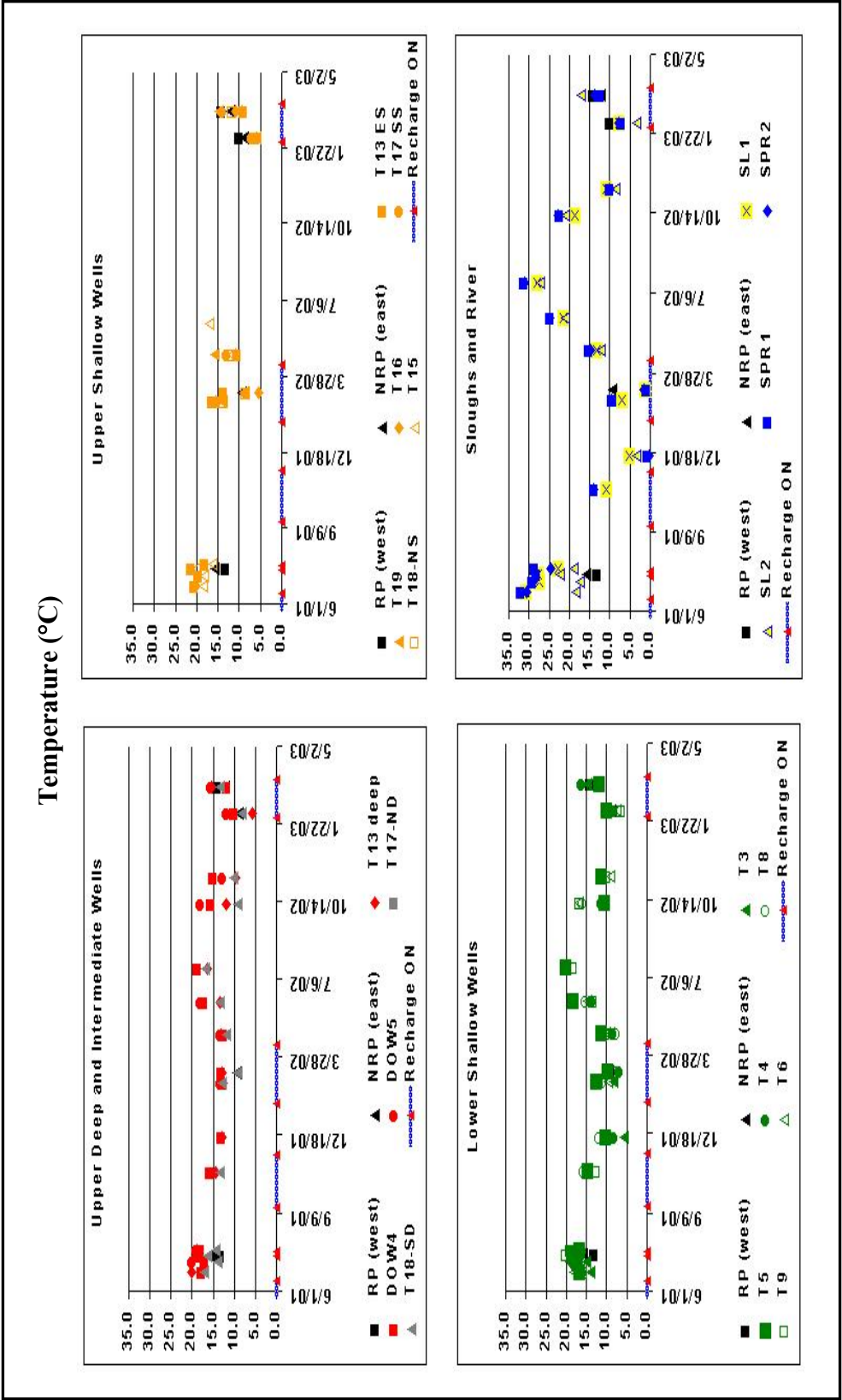


Figure 8. Temperature Changes with Time. Temperature changes temporally and spatially. The sloughs and river group shows temporal changes affected by seasonal air temperature. This is contrasted spatially with the Upper Deep and Intermediate Well Group that shows only slight changes over time.

4.3.2 pH

Spatially, the three highest mean pH values are in the surface waters of the river group, SL 1, and SL 2 at 7.8, 7.8, and 7.6 respectively (Table 4 and Figure 9). The lowest mean pH is in the lower shallow well group at 7.2. The mean pH of the recharge ponds is 7.4, which is between the river group and the lower shallow well group. There does not appear to be a distinct temporal variation in any of the groups.

pH

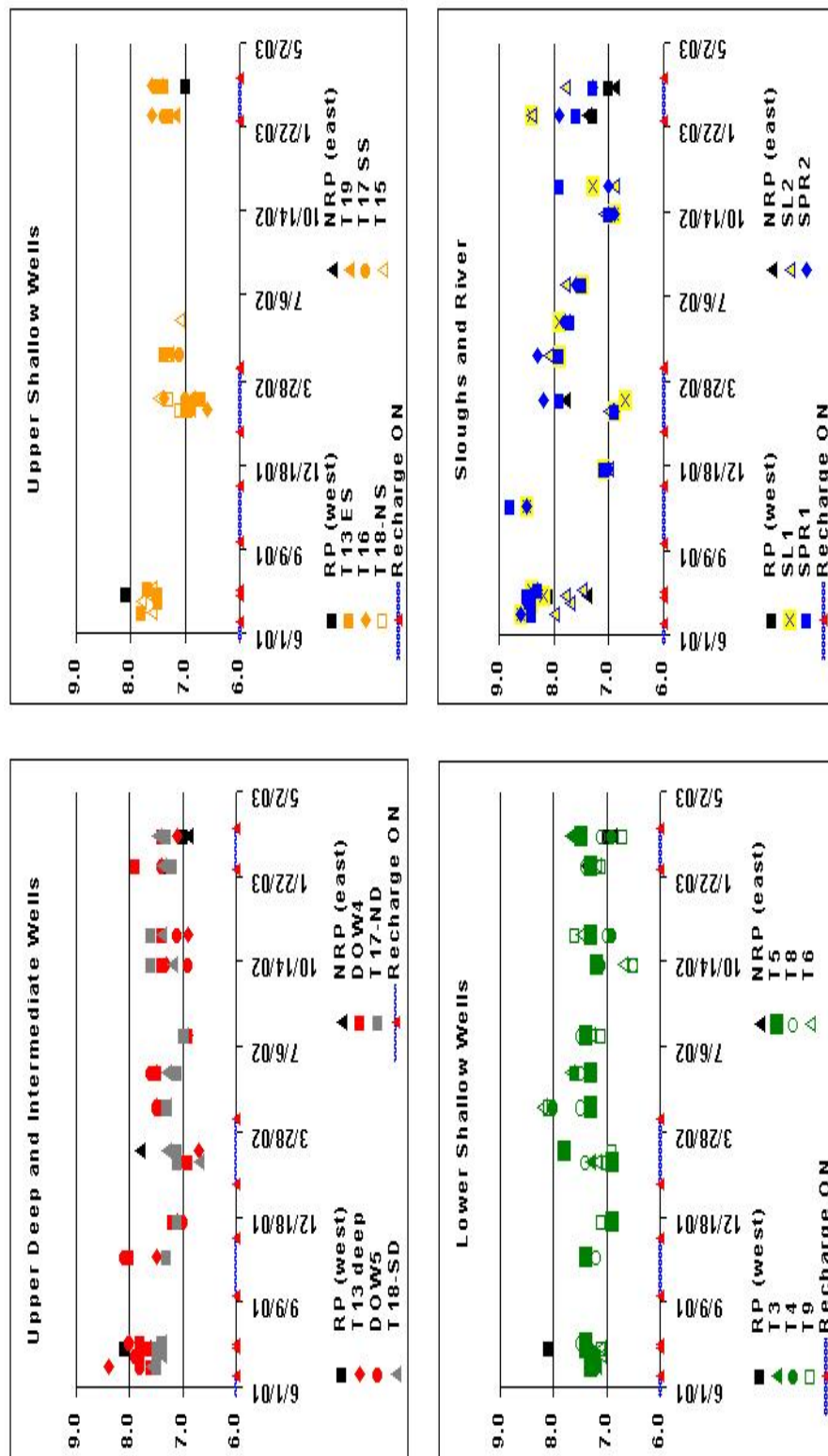


Figure 9. pH Changes with Time. The highest mean pH values are in the surface water locations of the river and sloughs. The lowest mean pH is in the lower shallow well group.

4.3.3 Specific Conductivity

Mean specific conductivity values are different between surface water and groundwater sample locations (Table 4 and Figure 10). The river group and SL 1 have the highest mean specific conductivities at 1875 $\mu\text{S}/\text{cm}$ and 1399 $\mu\text{S}/\text{cm}$ respectively. The extraction water has a mean specific conductivity of 808 $\mu\text{S}/\text{cm}$. The next highest mean is 785 $\mu\text{S}/\text{cm}$ found in the lower shallow wells and the upper shallow wells. The upper intermediate well group is slightly lower still at 772 $\mu\text{S}/\text{cm}$. While the upper deep well group has the lowest mean specific conductivity at 526 $\mu\text{S}/\text{cm}$.

With a mean specific conductivity of 1399 $\mu\text{S}/\text{cm}$, SL 1 appears to be fed by water from the South Platte River. On the other hand, SL 2, at 420 $\mu\text{S}/\text{cm}$, appears to be predominately fed by a groundwater source.

A slight temporal effect in specific conductivity is noticeable in the groundwater sampling locations (Figure 10). In all of the groundwater well groups it is apparent that specific conductivity values are increasing over time. There does not appear to be much seasonal variation with specific conductivity.

Specific Conductivity ($\mu\text{S}/\text{cm}$)

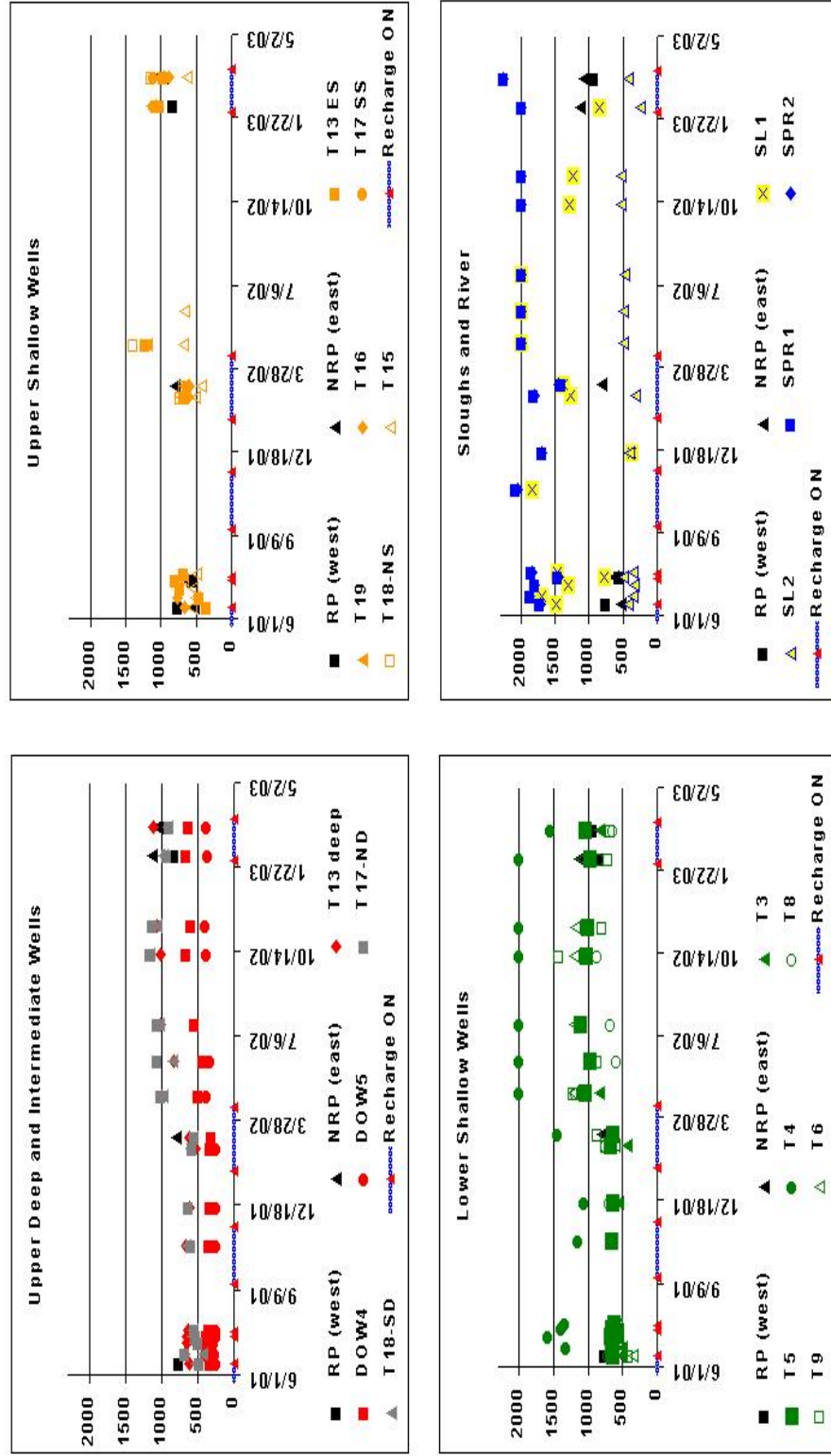


Figure 10. Specific Conductivity Changes with Time. Specific conductivities in the river and SL 1 are greater than at groundwater locations. Within the groundwater groups, there appears to be a gradual increase in specific conductivity over time.

4.3.4 Nitrate

The mean nitrate concentration in the river is 1.9 mg/L $\text{NO}_3^- \text{N}$ (Table 4). This concentration is higher than in the lower shallow wells at 1.2 mg/L $\text{NO}_3^- \text{N}$. The mean nitrate concentration for the extraction water falls between the first two groups at 1.7 mg/L $\text{NO}_3^- \text{N}$ (Figure 11).

It appears that the extraction water gains nitrate while residing in the recharge pond as surface water. The extraction water mean concentration is 1.7 mg/L $\text{NO}_3^- \text{N}$, while water in the upper shallow well group is 2.5 mg/L $\text{NO}_3^- \text{N}$ (Table 4). When the ponds are present during the recharge period, they serve as waterfowl habitat and quickly show an abundance of algae and vegetation.

Within the upper well groups, the mean nitrate concentration for each group decreases with increasing depth bgs. The upper shallow, upper intermediate, and upper deep well groups have mean concentrations of 2.5 mg/L, 2.0 mg/L, and 1.8 mg/L $\text{NO}_3^- \text{N}$ respectively (Table 4).

Nitrate (mg/L)

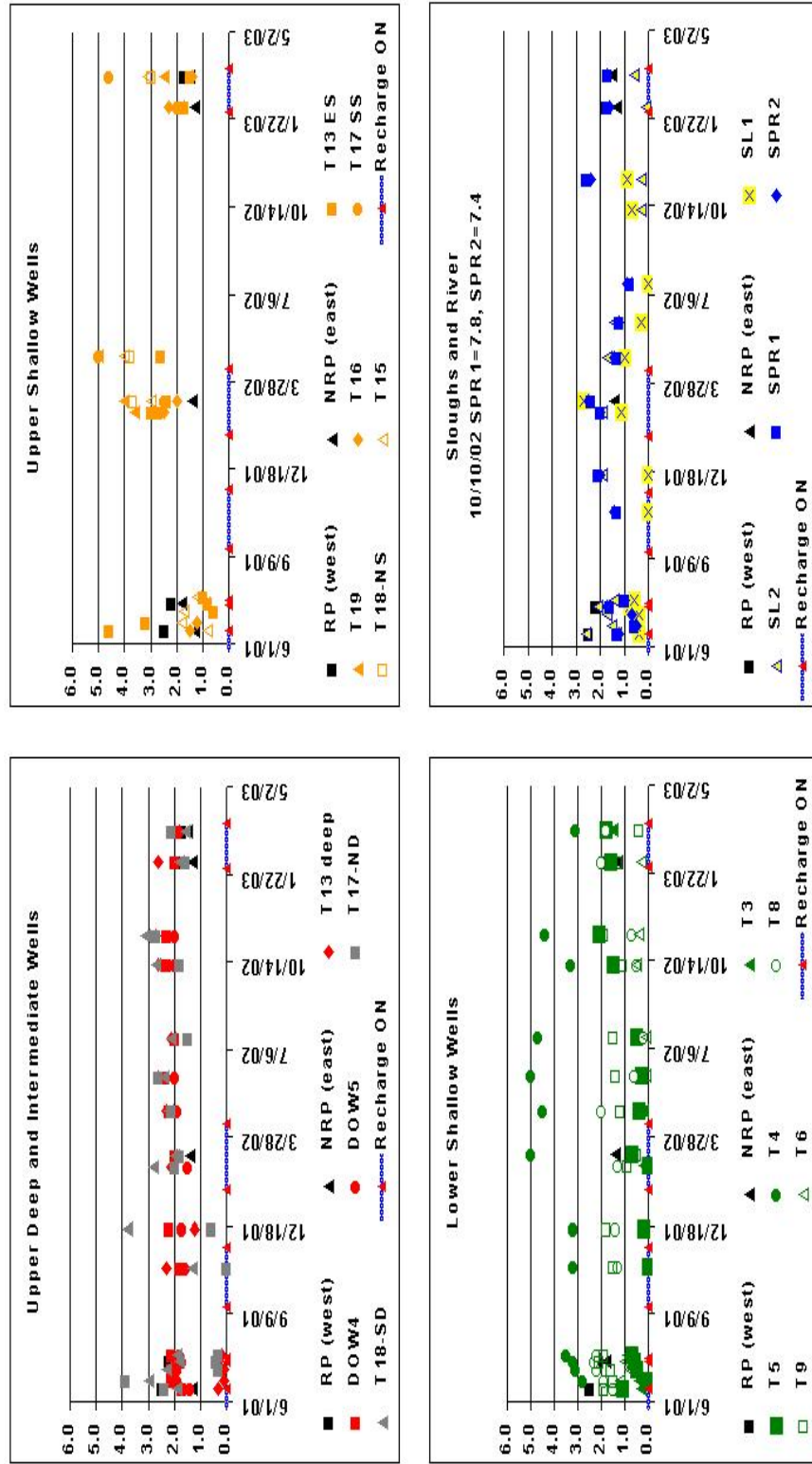


Figure 11. Nitrate Changes with Time. The greatest mean nitrate concentration is in the upper shallow well group. The lower shallow well group has one of the lowest mean nitrate concentrations.

4.3.5 Sulfate

Sulfate concentrations vary spatially (Table 4 and Figure 12). The mean river water sulfate concentration is 671 mg/L and all of the groundwater groups are much lower. The lower shallow wells, the upper shallow wells, and the upper intermediate wells have similar mean concentrations at 140 mg/L, 158 mg/L, and 139 mg/L respectively. The two lowest mean sulfate concentrations are 64 mg/L in the upper deep wells and 34 mg/L in SL 2. In contrast, SL 1 is similar to the river water with a mean sulfate concentration of 495 mg/L. At 167 mg/L, the mean concentration of extraction water is greater than all of the groundwater groups, but lower than the river water.

Within the three upper well groups, the mean sulfate concentration decreases with increasing depth. The mean sulfate concentration in the upper shallow wells is 158 mg/L. The upper intermediate wells decrease to 139 mg/L. Accordingly, the decrease continues to 64 mg/L in the upper deep wells. Unlike nitrate, the mean sulfate concentration of the extraction water is greater than the upper shallow wells. Therefore, there does not appear to be an additional source of sulfate in the recharge pond area.

Sulfate (mg/L)

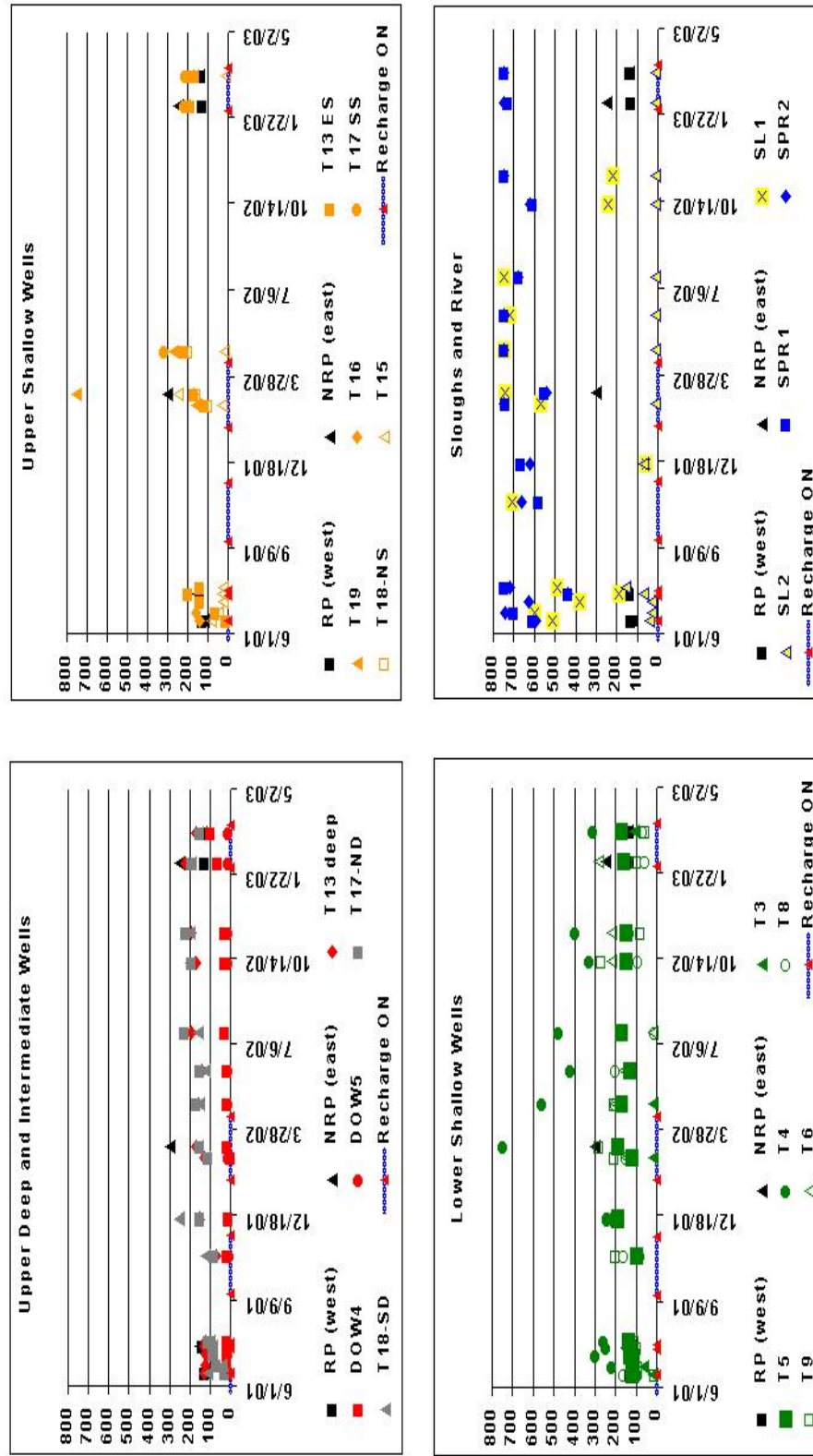


Figure 12. Sulfate Changes with Time. Sulfate varies spatially between groundwater and surface water locations. The extraction water mean concentration is slightly greater than the lower shallow wells and much lower than the river water.

4.3.6 Hardness

Similar to specific conductivity and sulfate, hardness concentrations vary spatially over the Project between groundwater and surface water locations (Table 4 and Figure 13).

The greatest mean hardness concentration is from the river group at 632 mg/L CaCO₃.

The lower shallow wells, the upper shallow wells, the upper intermediate wells, and the upper deep wells all have lower mean concentrations at 236 mg/L, 205 mg/L, 237 mg/L, and 183 mg/L CaCO₃ respectively. The extraction water is slightly greater than any of the groundwater groups and much lower than the river water at 270 mg/L CaCO₃.

SL 1, at 461 mg/L CaCO₃, more closely resembles river water. SL 2, at 159 mg/L CaCO₃, is similar to groundwater.

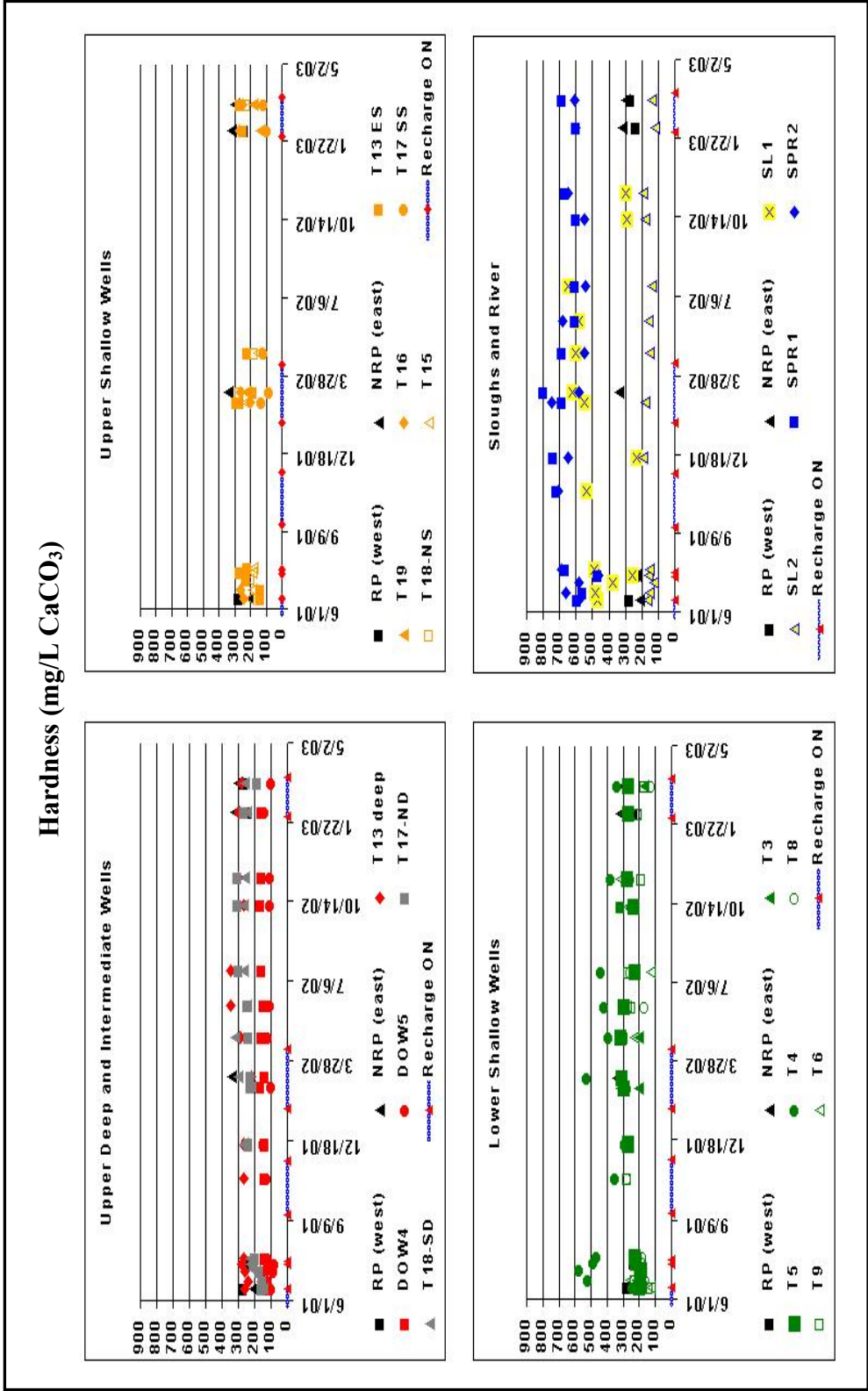


Figure 13. Hardness Changes with Time. Hardness concentrations exhibit spatial variability over the Project. Mean surface water concentrations are greater than groundwater concentrations.

4.3.7 Alkalinity

Mean alkalinity in the river group is greater than in the lower shallow well group at 189 mg/L and 158 mg/L CaCO₃ respectively. However, the extraction water has an even lower mean concentration than either of the first two groups at 141 mg/L CaCO₃ (Table 4 and Figure 14).

The greatest mean alkalinity concentration, not accounting for the transition wells, is in the upper shallow well group at 229 mg/L CaCO₃. Within the upper groups, mean alkalinity decreases with increasing depth. Mean concentrations for the upper, intermediate, and upper lower well groups are 159 mg/L and 128 mg/L mg/L CaCO₃ respectively.

Mean alkalinity in SL 1 is 183 mg/L CaCO₃. SL 2 has a mean concentration of 143 mg/L CaCO₃. Again, the similarity with river water in the first and groundwater in the latter is apparent (Table 4 and Figure 14).

Alkalinity (mg/L CaCO₃)

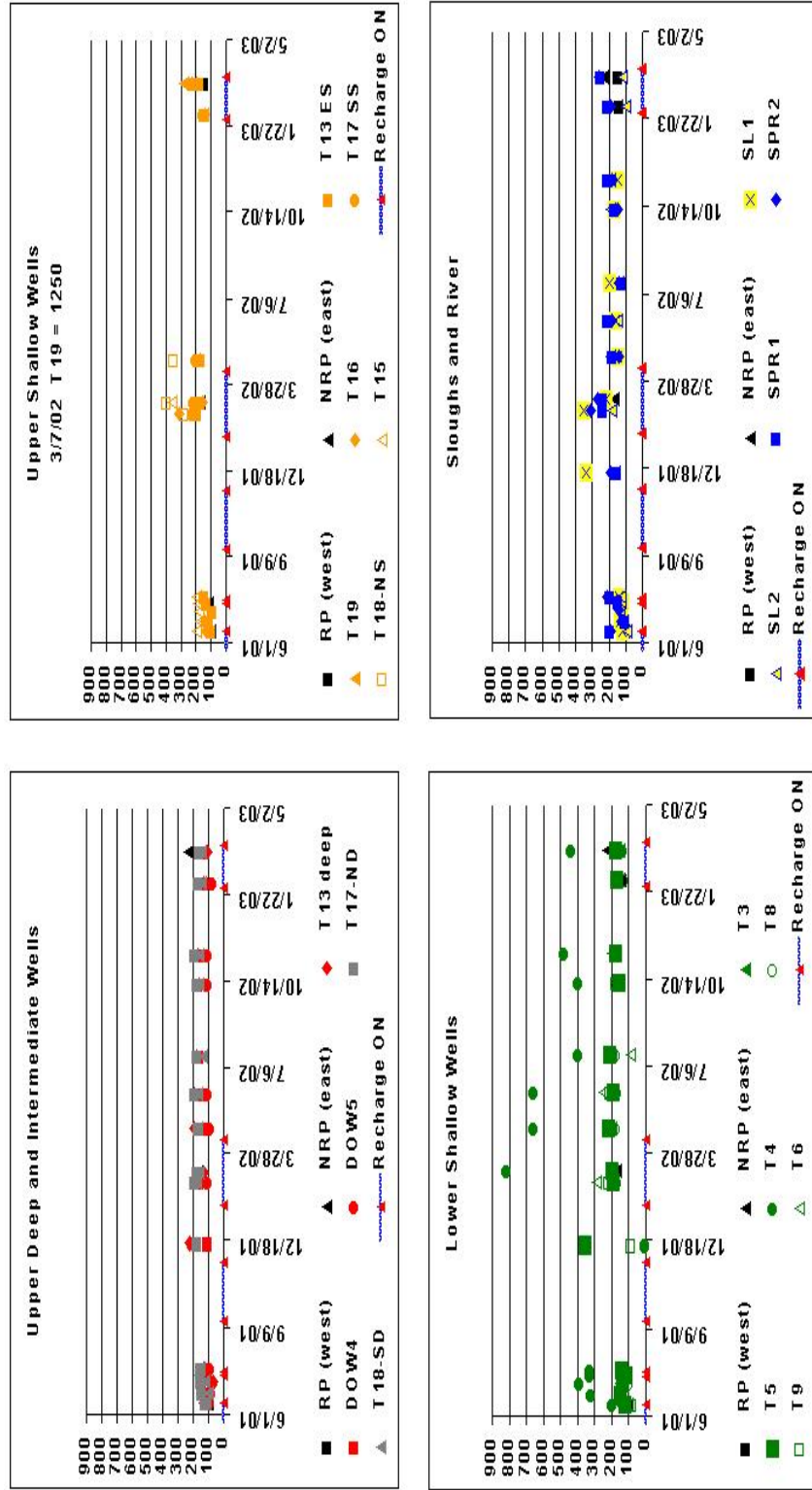


Figure 14. Alkalinity Changes with Time. The greatest mean alkalinity concentrations are in the upper shallow well group. The extraction water and the lower shallow well group have very similar concentrations.

4.4 Groundwater / Surface Water Mixing

Results from the cation – anion laboratory analyses are used in creating mixing diagrams (Appendix 3 and Appendix 4). Mixing diagrams are plots of one ion versus another. During conservative mixing, the mixing diagrams reveal linear relationships between distinct source waters and waters that are mixtures of the distinct source waters.

Samples from the last seven sampling events, beginning on April 26, 2002 and ending on March 11, 2003, were assigned a number from 1 to 7 (Table 5). Using the analytical results for eight ions, Ca^{2+} , K^+ , Mg^{2+} , Na^+ , NO_3^- , SO_4^{2-} , HCO_3^- , and Cl^- , 28 different mixing diagrams were created to examine all possible combinations. The ions that show the clearest relationships are Na^+ , Mg^{2+} , SO_4^{2-} , and Cl^- . Examples of three mixing diagrams are included as Figure 15, Figure 16, and Figure 17.

Table 5. Numerical Assignment for Each Sample Collection Date.

Sample Collection Date	Assigned Number
April 26, 2002	1
June 5, 2002	2
July 19, 2002	3
October 10, 2002	4
November 13, 2002	5
February 4, 2003	6
March 11, 2003	7

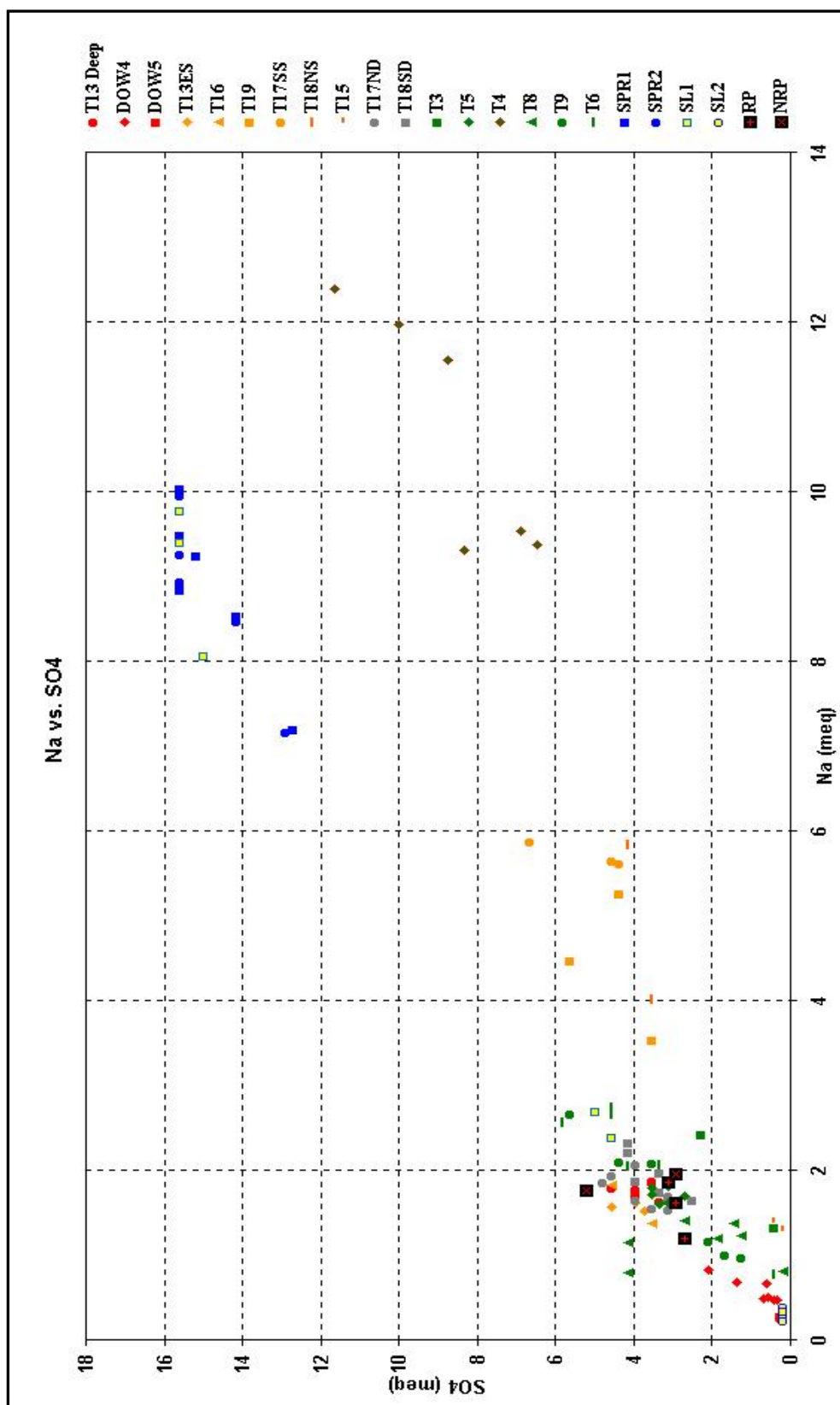


Figure 15. Mixing Diagram of Sodium vs. Sulfate. Two separate and distinct source waters are apparent. The groundwater source water is best characterized by DOW 4 and DOW 5, which plot in the extreme lower left of the diagram. The two river water samples, SPR 1 and SPR 2, plot in the upper right portion of the diagram.

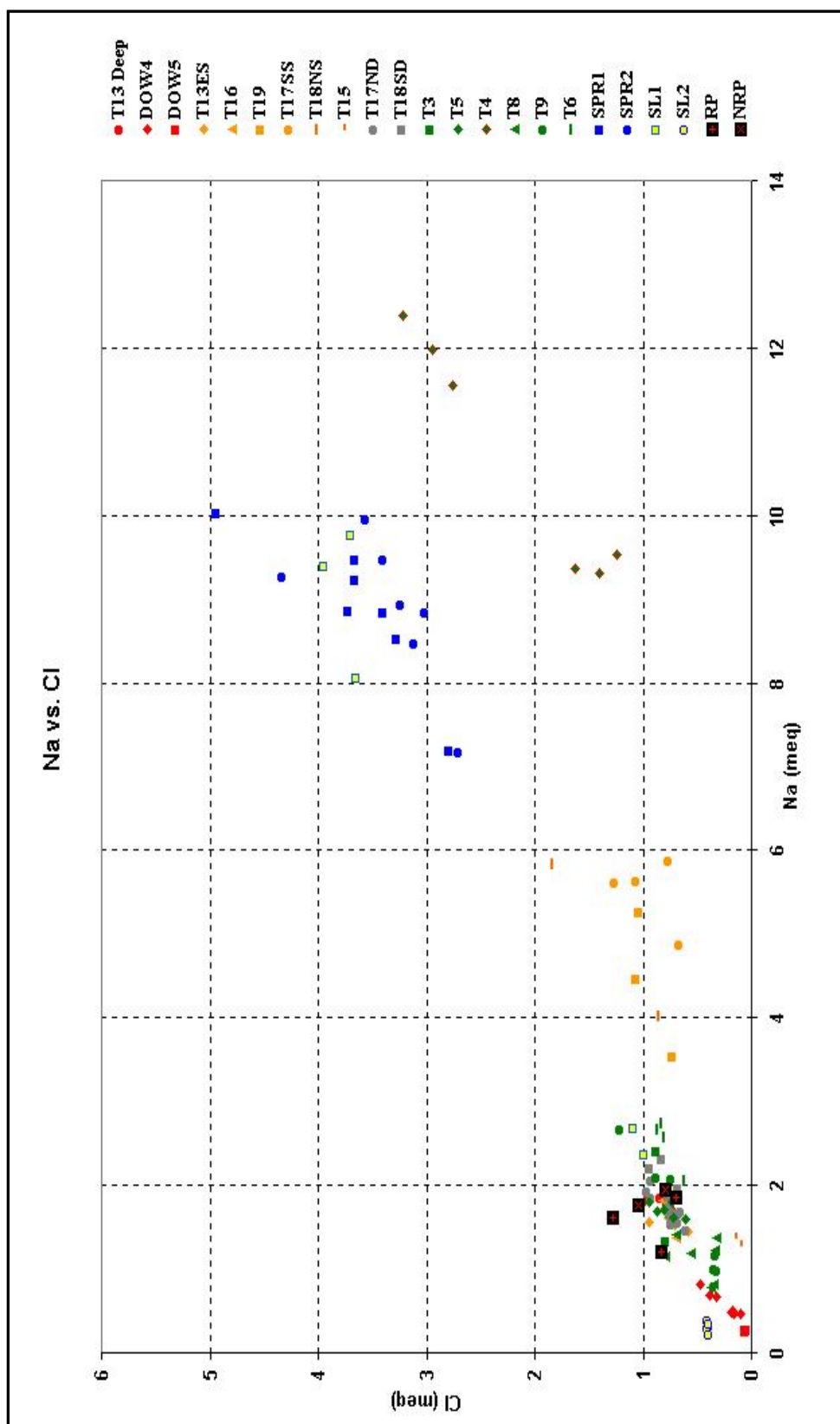


Figure 16. Mixing Diagram of Sodium vs. Chloride. Notice how the groundwater source (DOW 4 and DOW 5) and the river water source (SPR 1 and SPR 2) act as end-members to many of the other sample compositions. T-13 Deep shows a slight influence from the river water as it plots above and to the right of DOW 4 and DOW 5.

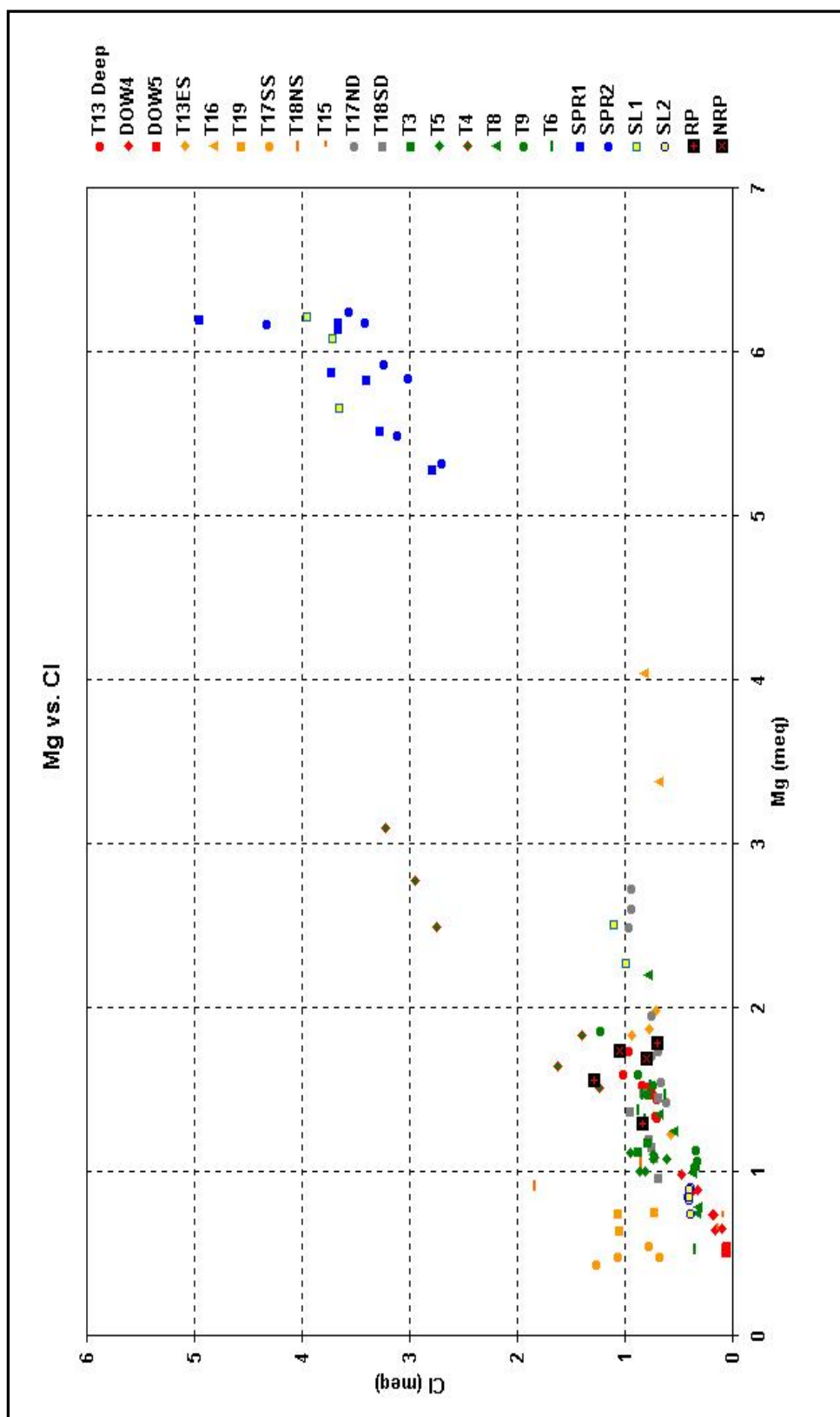


Figure 17. Mixing Diagram of Magnesium vs. Chloride. The lower shallow wells (green), upper intermediate wells (gray), and extraction water (black) show signs of conservative mixing as they plot in a linear fashion between the two source waters. The upper shallow wells (orange) and well T-4 (green diamond with red border) show signs of non-conservative mixing as they do not plot linearly between the two source waters.

The mixing diagrams reveal two distinct source waters – groundwater and river water. The groundwater source is best characterized by the two upper deep sampling locations, DOW 4 and DOW 5. The surface water from the two river sampling locations, SPR 1 and SPR 2, best characterizes the other source. These two source waters comprise the “end points” on the mixing diagrams. Groundwater from DOW 4 and DOW 5 typically plots in the extreme lower left portion of the mixing diagram. The river water plots in the upper right of the mixing diagrams (Figures 15 – 17).

T-13 Deep is not included in the characterization of the groundwater source. T-13 Deep is grouped with DOW 4 and DOW 5. However, T-13 Deep shows signs of mixing with the river water. As seen on the mixing diagrams, T-13 Deep plots closer to the river water and is not at the extreme lower left like DOW 4 and DOW 5. Of the three wells in the upper deep group, T-13 Deep is the closest to the recharge ponds. Therefore, it is beginning to show signs of mixing with the new recharge water entering the system through the ponds.

Three sample groups show signs of conservative mixing between the two source waters. The lower shallow wells, the upper intermediate wells, and the extraction water plot in a linear fashion between the groundwater source and the river water source. These three groups plot closer to the groundwater source than the river water source (Figures 15 – 17).

There are two exceptions to the conservative mixing assumption. The upper shallow well group, identified as the dark yellow symbols on the mixing diagrams, does not plot linearly between the two source waters. This is a characteristic of non-conservative mixing. Due to their close proximity to the recharge ponds, many factors could lead to non-conservative mixing in this area. The wells in this group are dry during the times of the year when the extraction pumps are not operating. Additionally, potential vadose zone reactions in the shallow subsurface soils around the pond, as well as effects from waterfowl and vegetation growth in the ponds are all distinct possibilities. Well T4 is the other exception. T-4 is identified on the mixing diagrams as a green diamond with a red border. In all of the mixing diagrams, T-4 plots in a different location from the other sample points. This well is located near the three-fishponds and the minnow stream. T-4 is the main reason why T-3 and T-5 were also pulled out of the lower shallow well group and their results reported individually in Table 4 as “transition” wells.

Now that two separate and distinct source waters have been identified in the Tamarack system, their chemical composition will be determined. Groundwater samples from DOW 4 and DOW 5 are used to characterize the composition of the groundwater source. River water samples from SPR 1 and SPR 2 are used for the composition of the river water source. The averaged chemical composition of the two sources is presented in Figure 18. For the groundwater source, Ca^{2+} is the dominant cation at 2.28 meq/. The concentrations of Mg^{2+} , Na^+ , and K^+ are 0.66 meq/L, 0.44 meq/L, and 0.12 meq/L respectively. HCO_3^- , at 2.49 meq/L, is the dominant anion in the groundwater source. SO_4^{2-} , Cl^- , and NO_3^- comprise the other anions at 0.57 meq/L, 0.16 meq/L, and 0.03

meq/L respectively. The groundwater source has an average composition of 3.4 meq/L of cations and anions each. For the river water source, Na^+ , at 8.88 meq/L, and Ca^{2+} , at 8.31 meq/L, are the two dominant cations. Mg^{2+} and K^+ have concentrations of 5.87 meq/L and 0.35 meq/L respectively. The dominant anion in the river water source is SO_4^{2-} , at 15.0 meq/L. HCO_3^- , Cl^- , and NO_3^- have concentrations of 3.71 meq/L, 3.48 meq/L, and 0.04 meq/L respectively. The average cation and anion concentration for the river water is 22.8 meq/L each.

The groundwater and river water source compositions are plotted on a Piper diagram (Figure 19). Plots of the individual extraction water compositions are also included to show that the extraction water compositions are conservative mixtures of the two source waters. By measuring the distance between the extraction water plots and the two source water plots in the mixing diagrams (Figures 15 – 17), it appears that 80% of the extraction water is from the groundwater source. River water composes 20% of the extraction water.

The same characteristics are shown in the lower shallow well group (Figure 20). Groundwater composition in the alluvial aquifer near the river is not the same as the groundwater composition further away in the upper deep wells, especially in DOW 4 and DOW 5. This indicates that managed groundwater recharge operations in the alluvial aquifer near the river affect local groundwater quality.

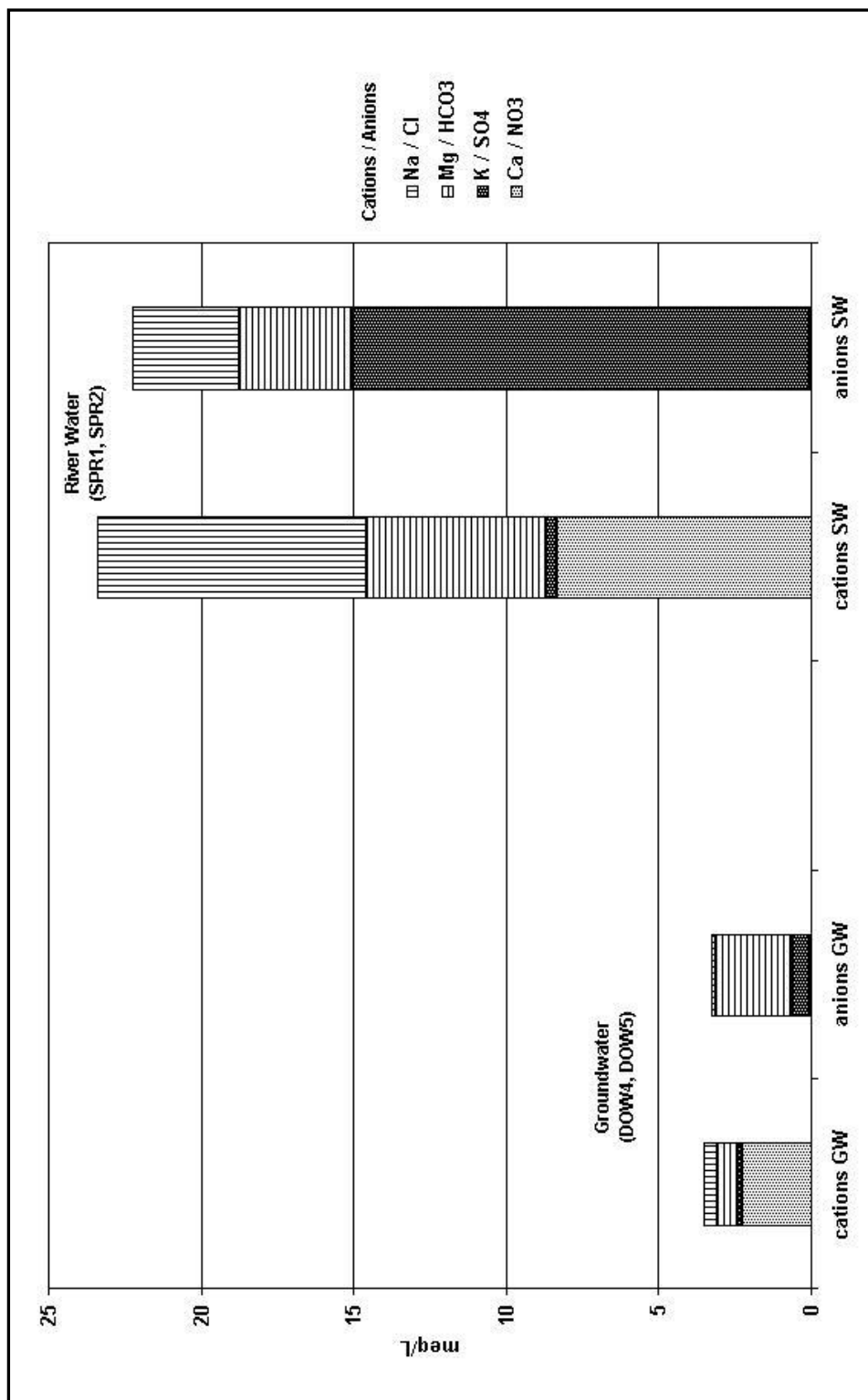


Figure 18. Chemical Composition Comparisons of Groundwater and River Water.

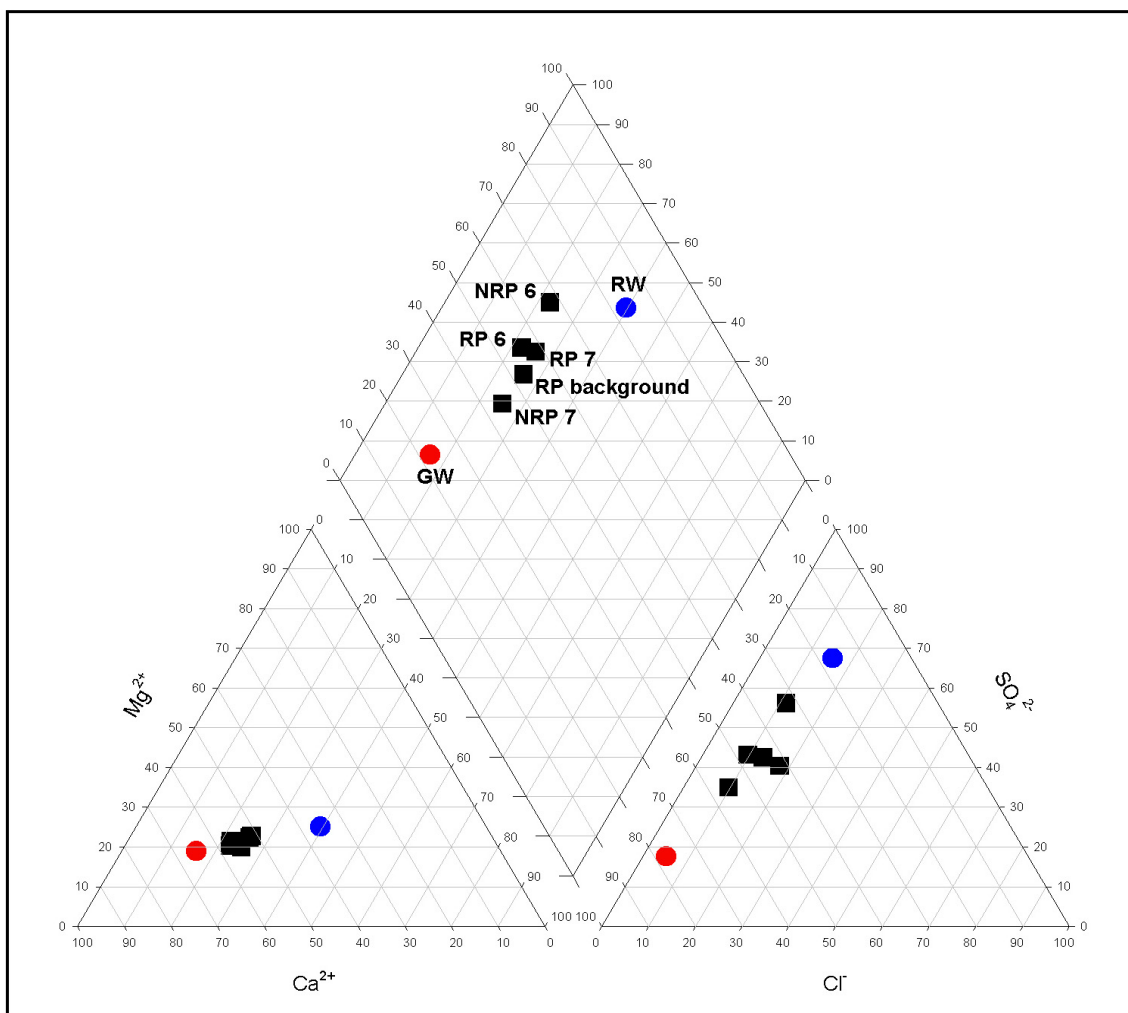


Figure 19. Piper Diagram of Source Waters and Extraction Waters. The groundwater (GW) source and river water (RW) source compositions as plotted on a Piper diagram. Also included are the extraction water (RP and NRP) water compositions to show that they are mostly conservative mixtures of the two source waters. The RP background sample was collected in March 2002.

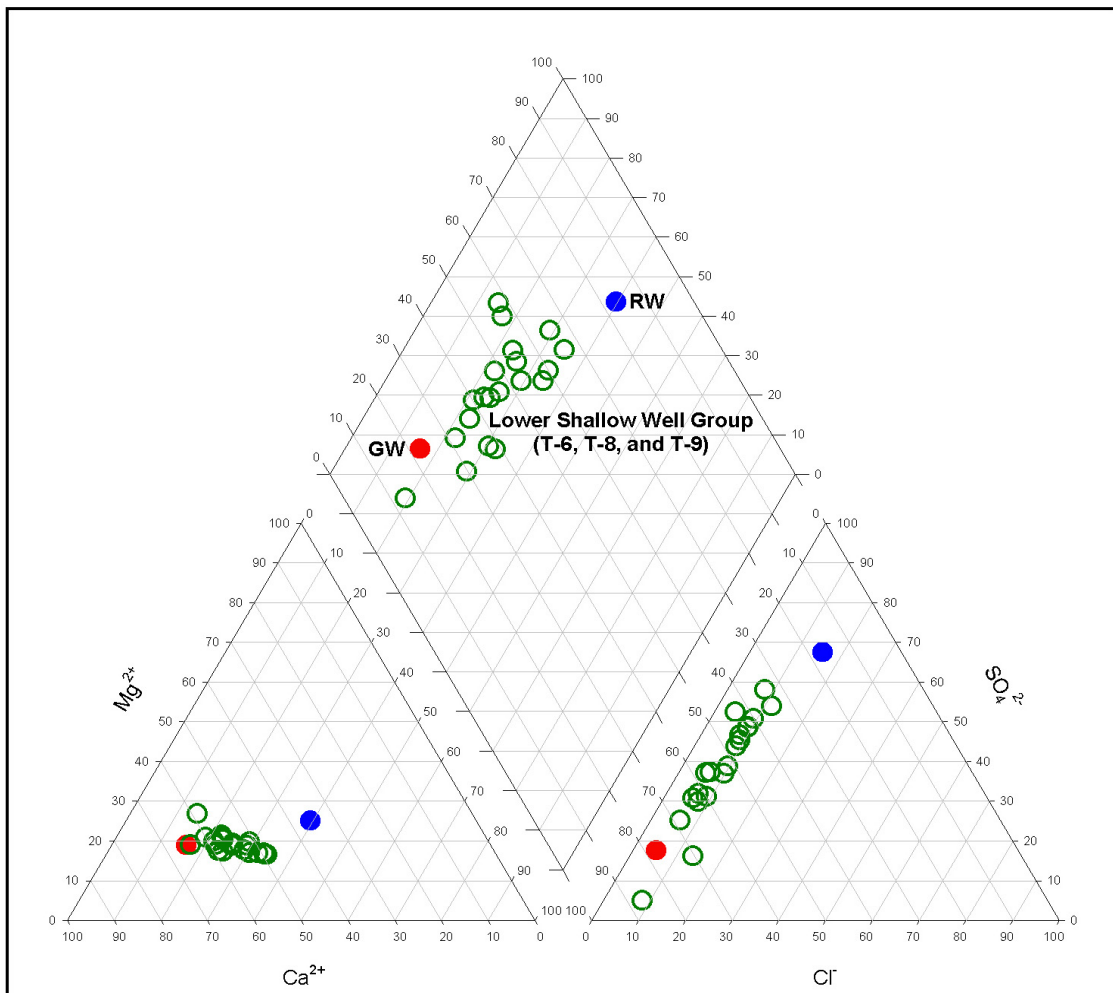


Figure 20. Piper Diagram of Lower Shallow Well Group Waters. The lower shallow well group compositions are plotted along with the two source waters. In general, the water in the shallow alluvial aquifer near the river is a conservative mixture of the two sources. This diagram also shows that groundwater in the alluvial aquifer near the river is different from groundwater further away, like in DOW 4 and DOW 5 represented by the GW symbol.

4.4.1 Local Effects of Mixing over Time

Now that the general mixing dynamics on a project-wide scale have been discussed, one can investigate the local effects of mixing over time at individual sample locations. The upper deep well group, which characterizes one of the source waters at the site, will be the focus of attention. When viewing the following figures, refer to Table 5 for the sample collection date that is assigned to numbers 1 through 7. The numbers progress toward the most recent sample collection date.

DOW 5 is one of the deepest wells and also the furthest away from the recharge pond area. There appears to be no changes in the water composition over time at this location as seen in the Piper diagram (Figure 21). DOW 5 serves as a benchmark in comparing the compositional changes viewed in the other two wells in the upper deep well group. The fact that there are no apparent changes in composition over time in DOW 5 means that the groundwater at this location is not mixing with other sources. The effects of the recharge ponds are minimal at this location.

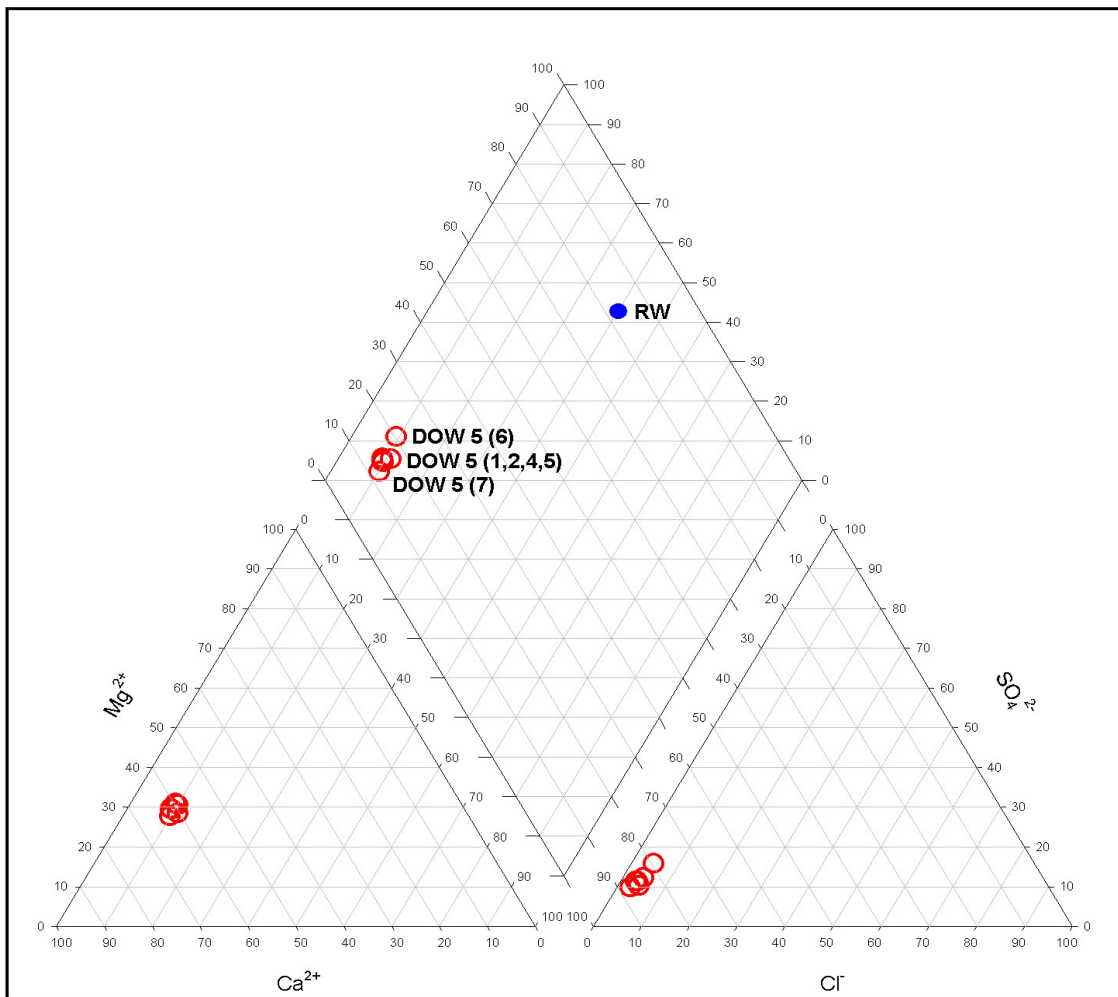


Figure 21. Compositional Changes in DOW 5 over Time. Groundwater composition in DOW 5 remains relatively constant over time. The lack of change at this location indicates a lack of mixing with other waters.

DOW 4 is closer to the recharge pond area than DOW 5. The recharge pond identified as RP is the initial pond constructed for the Project. It began receiving extraction water in January 2000. A newer recharge pond, identified as NRP, was brought on-line in January 2002. This pond is closer to DOW 4. The Piper diagram of DOW 4 shows the beginning effects of mixing with recharge water (Figure 22). The composition of DOW 4 (1) is similar to all of the DOW 5 compositions. The next four samples, DOW 4 (2) – DOW 4 (5), progress slightly in the direction of the river water source. DOW 4 (6) and DOW 4 (7) progress more dramatically toward the river water source. The first five sample collection dates were at times of no groundwater extraction. The last two sample collection dates correspond to times of groundwater extraction.

T-13 Deep is the closest of the upper deep wells to the recharge pond area. Similar to the effects in DOW 4, T-13 Deep shows a progression in composition towards the river water source over time (Figure 23). The groundwater chemistry of T-13 Deep shows the greatest influence from the extraction water entering the recharge ponds. The chemistries indicate a longer time of mixing relative to the other two upper deep locations because the plots begin and end much closer to the river water source.

The river water chemistry in SPR 1 and SPR 2 remains relatively constant during the sample collection period (Figure 24). The seven sample collection dates span almost a one year time frame. No significant chemistry changes are apparent during times of snow-melt runoff or low water flow.

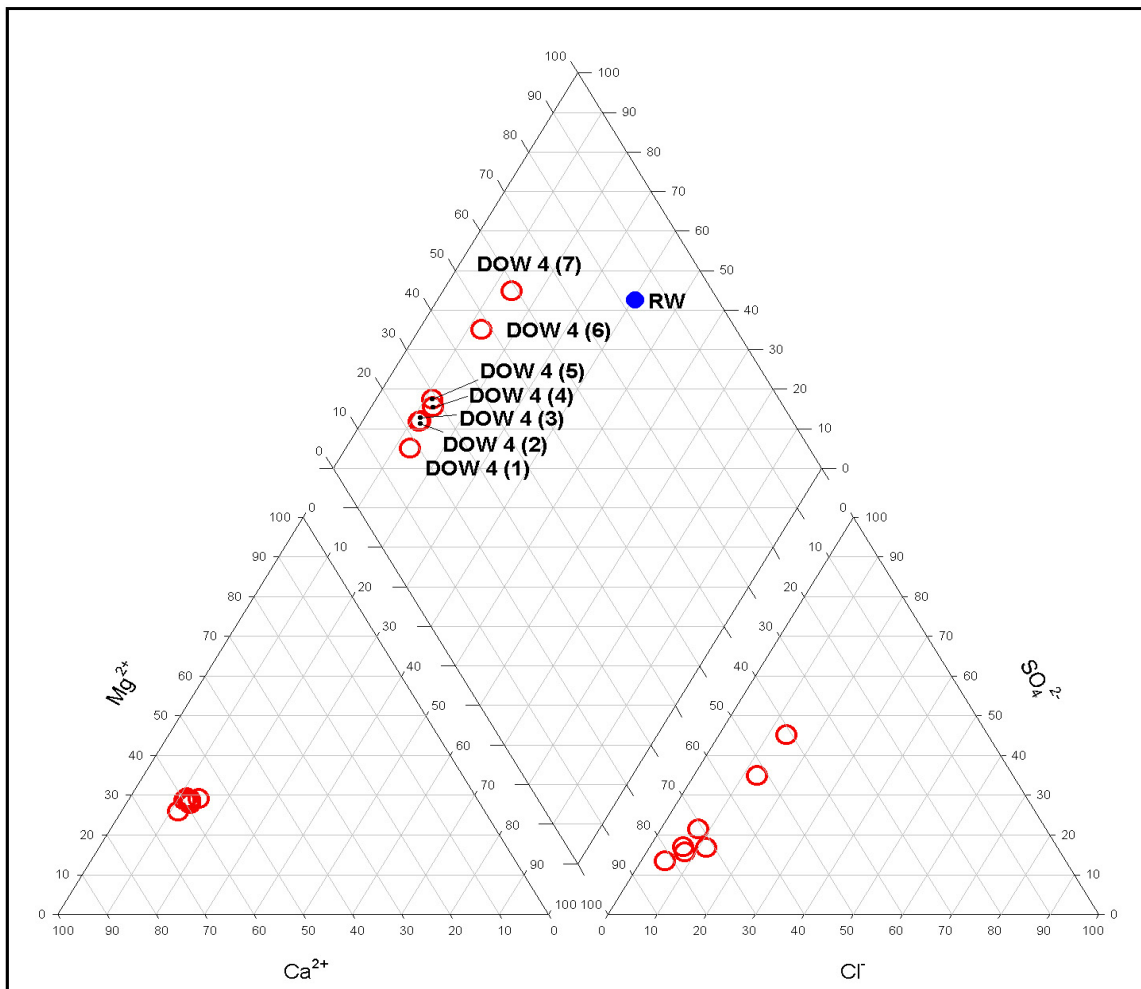


Figure 22. Compositional Changes in DOW 4 over Time. DOW 4 shows signs of mixing with the river water source. The first five sample collection dates (1 – 5) show only slight progression toward the river water source. These five dates correspond to times of no groundwater extraction. The last two sample collection dates (6 – 7) show greater effects from the recharge pond area. The last two dates were during times of groundwater extraction.

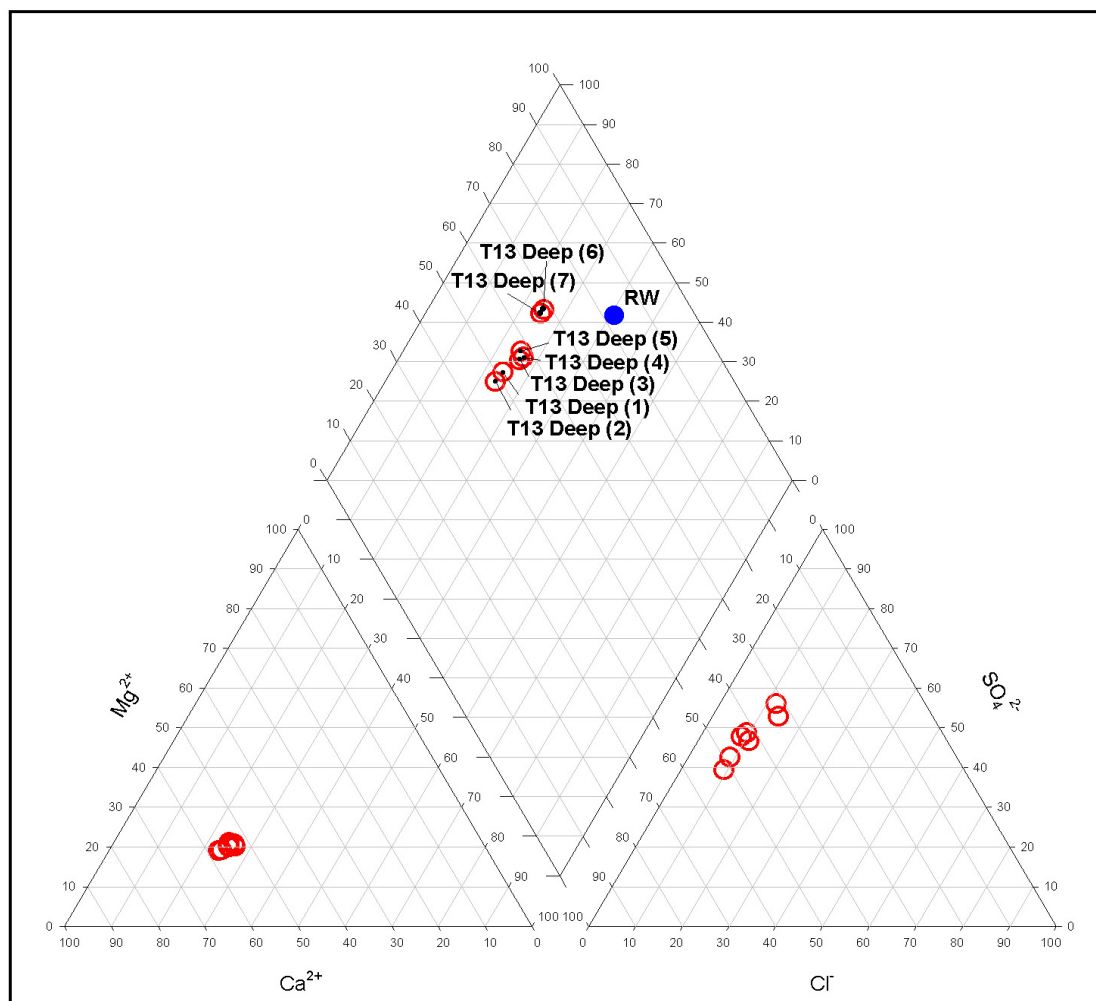


Figure 23. Compositional Changes in T 13 Deep over Time. Of the three upper deep wells, T 13 Deep shows the greatest effects of mixing with the river water source. This well is the closest to the recharge pond area. Therefore, the influence of the river water coming to the recharge ponds as part of the extraction water has affected this well greater than DOW 5 or DOW 4.

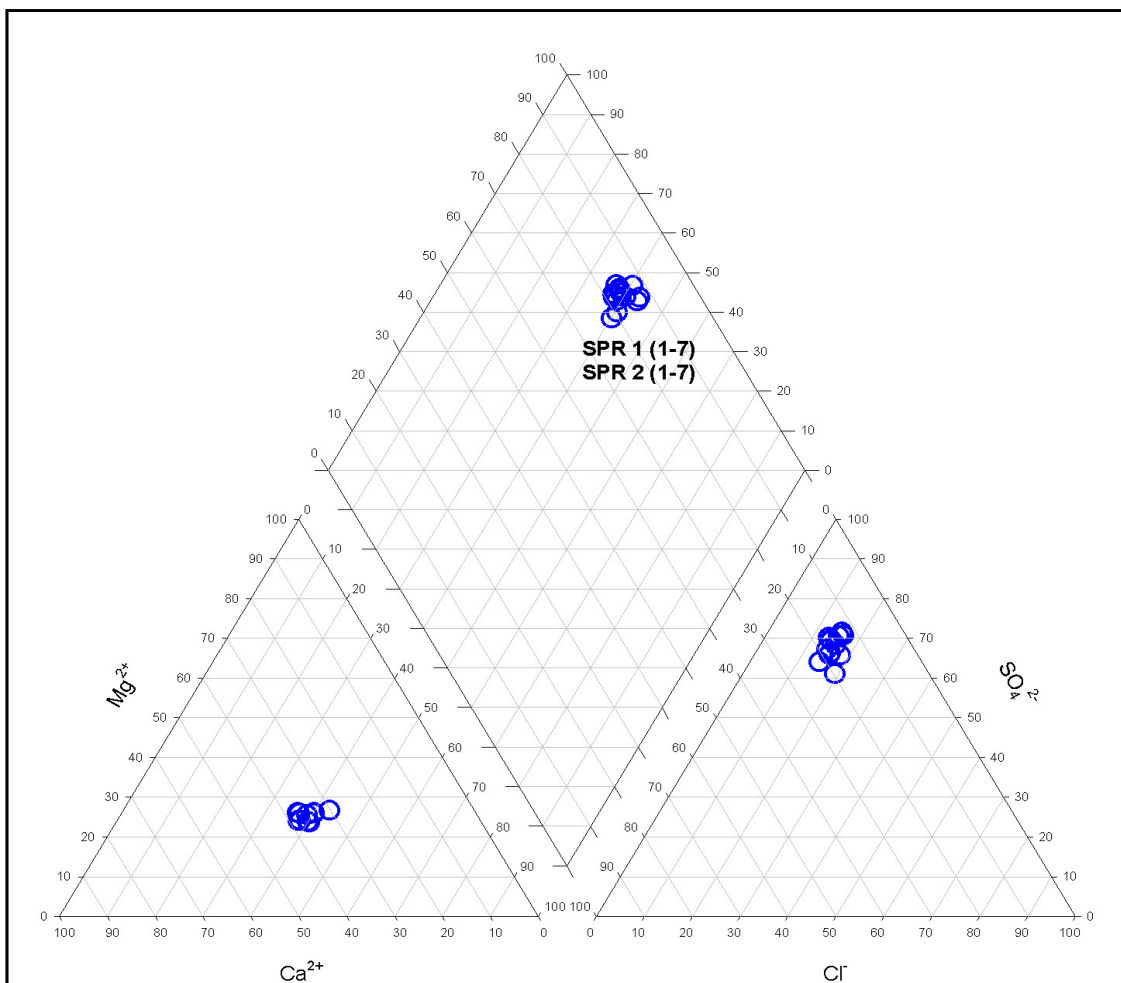


Figure 24. Compositional Changes in SPR 1 and SPR 2 over Time. The river water samples show no signs of change over the one year sample collection period.

4.5 Differences between Sloughs

Even in the initial stages of analyzing the water quality parameters, the compositions of SL 1 and SL 2 suggested that a different source water fed each. Kazbekov (2001) concluded that SL 1 was fed by river water and groundwater fed SL 2. The following Piper diagram of the slough compositions confirms Kazbekov's conclusions (Figure 25). On the Piper diagram, SL 1 plots close to the river water source. SL 2 plots close to the groundwater source. In fact, SL 2 shows less influence from mixing than DOW 4 shows in Figure 22. For future source water characterizations, the SL 2 composition may characterize the groundwater end-member better than DOW 4.

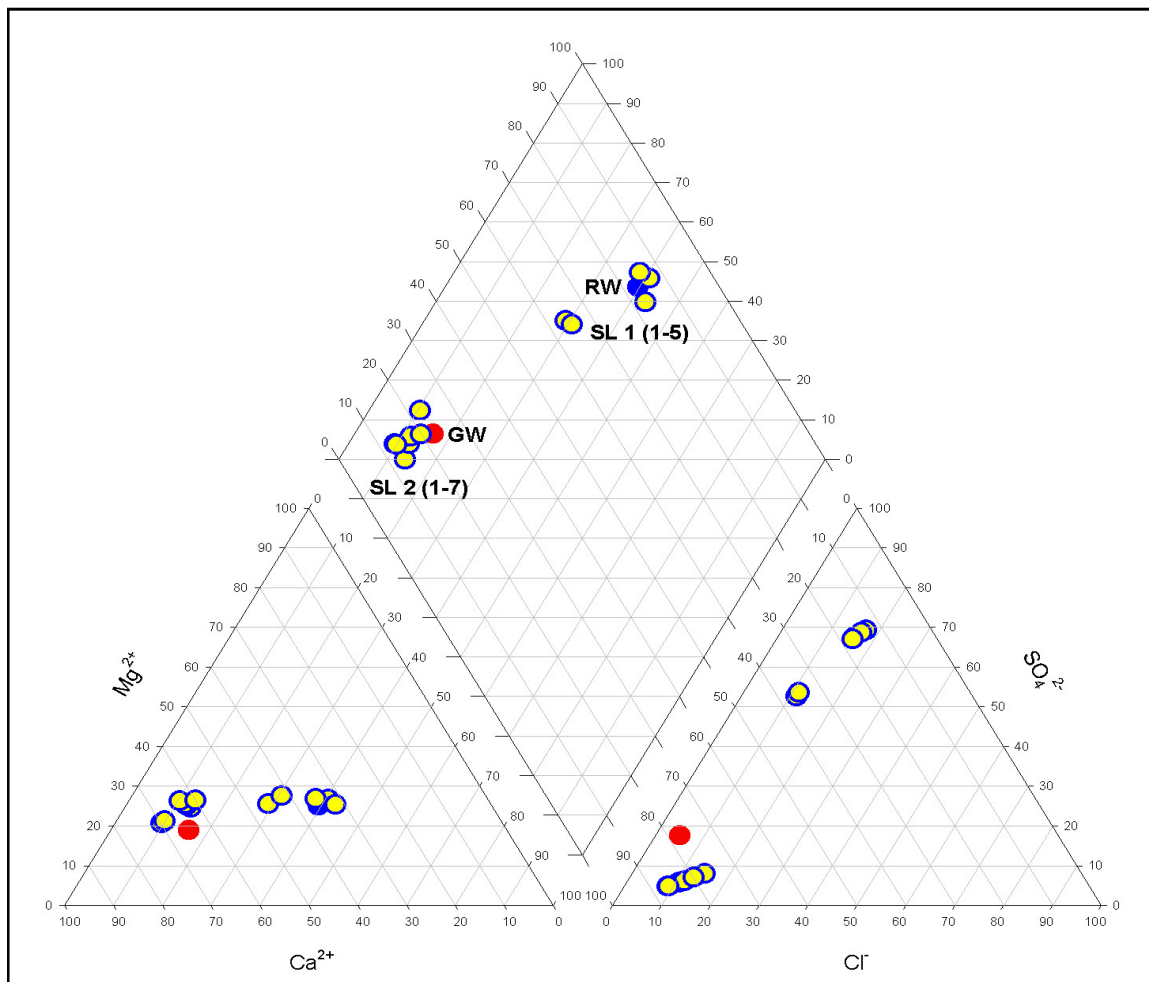


Figure 25. Compositional Differences between SL 1 and SL 2. SL 1 plots close to the river water source. This indicates that SL 1 is predominantly fed by surface water from the river. The water composition of SL 2 is very similar to the groundwater source. SL 2 is predominantly fed by a groundwater source.

CHAPTER 5: SUMMARY AND CONCLUSIONS

The research suggests that groundwater and river water serve as two distinct source waters for mixing at the Tamarack Ranch Groundwater Recharge project (Figure 18). Groundwater chemistry varies over time and space. Groundwater in the alluvial aquifer near the river does not have the same chemistry as groundwater collected further away from the river. The groundwater chemistry in two upper deep wells, DOW 4 and DOW 5, and one slough, SL 2, should be considered the background groundwater source at the site. The groundwater is primarily dominated by Ca^{2+} and HCO_3^- ions. Groundwater chemistry varies over time due to the effects of managed groundwater recharge operations. The Piper diagrams of DOW 4 and T-13 Deep show a distinct progression in water chemistry toward that of the river water source (Figure 22 and Figure 23). In contrast, the river water chemistry varies only slightly over time and space (Figure 24). At the site, the dominant ions in the South Platte River water are Na^+ , Ca^{2+} , and SO_4^{2-} .

In terms of mixing dynamics, one could consider that two big mixing pots operate at the site. The first mixing pot is the alluvial aquifer near the river. The groundwater extraction pumps operate in this area. As the pumps pump extraction water up to the recharge ponds, groundwater and river water enters from the surrounding area. The mixing diagrams and piper diagrams of the extraction water and the lower shallow well group indicate that the water in this area mixes conservatively between the groundwater source and the river water source (Figures 15 – 17 and Figures 19 - 20). The extraction water is estimated to be composed of 80% groundwater and 20% river water.

The recharge ponds are the second mixing pot. In the recharge pond area, there seems to be an element of non-conservative mixing. The water chemistry changes from when the extraction water enters into the pond to when it is next sampled again in the upper shallow wells located nearby. The water chemistries from the upper shallow wells do not show a linear relationship between the groundwater source and the river water source (Figures 15 – 17). One example is that nitrate concentrations in the upper shallow wells increased from when the extraction water entered the pond (Table 4). Several factors could cause this effect. The ponds and nearby areas are very dynamic environments. The ponds are present only during periods of groundwater extraction. At all other times of the year, the ponds are dry. When the ponds are present, they provide habitat to waterfowl. Significant amounts of algae and vegetation grow in the ponds. Transition well T-4 also exhibits non-conservative mixing behavior (Figures 15 - 17). There is no current explanation for this effect other than the fact that this well is located near bodies of surface water.

In terms of the overall effectiveness of this Project and other similar flow augmentation projects, the potential exists for these projects to decrease nitrate concentrations in the river. At Tamarack, the lower shallow wells in the alluvial aquifer near the river exhibit the lowest mean nitrate concentrations (Table 4). Since this water will be the recharge water returning to the river under flow augmentation conditions, the potential exists for a positive impact on the river. Also in the upper well groups, nitrate concentrations decrease with increasing depth. Even though it appears that the recharge ponds

contribute additional sources of nitrate to the extraction water, the circulation process overall may decrease concentrations. However, the magnitude and groundwater / stream water interactions in these areas need further study.

Streamflow augmentation projects will affect the water quality of the alluvial aquifer. River water quality has a significant impact. Even though river water only composes about 20% of the extraction water coming into the recharge ponds at Tamarack, the Piper diagrams show that sulfate concentrations in the upper deep wells are increasing over time (Figures 22 – 23). The overall significance of this impact remains to be determined.

5.1 Future Recommendations

It would be interesting to use chemical water quality parameters to calibrate groundwater models that have traditionally only incorporated physical, hydrogeological parameters. The idea of calibrating a purely mathematical model to water quality parameters provides a unique way to compare the mathematical against the physical. For example, does a modeling program, such as MODFLOW, accurately predict the changes in water quality over time in managed groundwater recharge systems?

Additional research should focus on determining the exact proportion of groundwater and river water that is in the extraction water being pumped to the recharge ponds.

Considering that the river should have an efficient hydraulic connection with the alluvial aquifer and the close proximity of the extraction pumps in the alluvial aquifer to the river,

how do the compositional percentages of the source water change over the time that the pumps are operating? Additional information in this area will greatly benefit how managers operate streamflow augmentation projects to maintain a balance between water quality and water quantity both in the river and the surrounding aquifer.

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APPENDICES

Appendix 1. Detailed Pumping History at Tamarack (7 pages).

Appendix 2. Field / Laboratory Data Log for Each Sampling Location (12 pages).

Appendix 3. Cation / Anion Concentrations in mg/L (2 pages).

Appendix 4. Cation / Anion Concentrations in meq/L and Balance (2 pages).

APPENDIX 1. DETAILED PUMPING HISTORY AT TAMARACK (Year 2000)

Well ID Pumping rates for Tamarack wells average between 3.2 and 3.4 cfs.	R1 on 1/18; 3.45 cfs						
Date	19-Jan-00	18-May-00	25-May-00	20-Oct-00	25-Oct-00	26-Oct-00	28-Nov-00
WR-01 Pump to Original Pond	ON	ON		ON	ON		
WR-02	ON	ON					ON
WR-03 Pump to New Pond							
WR-04							
WR-05	ON	ON					
WR-06							
WR-07							
WR-08							
WR-09							
WR-10							

* Pumping rates for Tamarack wells average between 3.2 and 3.4 cfs.

** WR-04, -09, and -10 pump to a recharge area on the eastern side of Tamarack SWA and are not involved in the current research.

APPENDIX 1. DETAILED PUMPING HISTORY AT TAMARACK (Year 2001)

Well ID Pumping rates for Tamarack wells average between 3.2 and 3.4 cfs.		Pumps turned on right after this reading	Pumps R4, R9 and R10 turned on today		Pumps R6, R3 R7 & R8 turned on 5/11; R6 & R8 turned off 5/15		
Date	5-Jan-01	10-Jan-01	17-Apr-01	11-May-01	16-May-01	21-May-01	22-May-01
WR-01 Pump to Original Pond		ON	ON	ON	ON	ON	
WR-02	ON	ON	ON	ON		ON	
WR-03 Pump to New Pond				ON	ON	ON	
WR-04			ON	ON	ON	ON	
WR-05		ON	ON	ON	ON	ON	
WR-06				ON			
WR-07				ON	ON	ON	
WR-08				ON			
WR-09			ON	ON	ON	ON	
WR-10			ON	ON	ON	ON	

* Pumping rates for Tamarack wells average between 3.2 and 3.4 cfs.

** WR-04, -09, and -10 pump to a recharge area on the eastern side of Tamarack SWA and are not involved in the current research.

(Year 2001 cont.)

All wells off 5/22 5:00pm, all wells on 5/24 9:30am	All wells off 5/24 8:30pm		On AM		All wells off end of 6/21		On AM	Off PM
24-May-01	24-May-01	25-May-01	2-Jun-01	4-Jun-01	21-Jun-01	22-Jun-01	16-Jul-01	20-Jul-01
ON	ON		ON	ON	ON		ON	ON
ON	ON		ON				ON	ON
ON	ON		ON	ON	ON		ON	ON
ON	ON		ON	ON	ON		ON	ON
ON	ON		ON	ON	ON		ON	ON
ON	ON		ON	ON	ON		ON	ON
ON	ON		ON	ON	ON		ON	ON
ON	ON		ON				ON	ON
ON	ON		ON	ON	ON		ON	ON
ON	ON		ON	ON	ON		ON	ON

(Year 2001 cont.)

	well to fish pond	wells split between fish stream and the west meadow		WR-02 and west wetland turned off AM	
21-Jul-01	23-Aug-01	17-Sep-01	27-Nov-01	28-Nov-01	20-Dec-01
	ON	ON	ON	ON	ON
		ON	ON		
					ON
					ON
					ON

APPENDIX 1. DETAILED PUMPING HISTORY AT TAMARACK (Year 2002)

Well ID Pumping rates for Tamarack wells average between 3.2 and 3.4 cfs.				
Date	27-Jan-02	11-Feb-02	27-Feb-02	11-Mar-02
WR-01 Pump to Original Pond	ON	ON	ON	ON
WR-02	ON	ON	ON	ON
WR-03 Pump to New Pond	ON	ON	ON	ON
WR-04	ON	ON	ON	ON
WR-05	ON	ON	ON	ON
WR-06	ON	ON	ON	ON
WR-07	ON			ON
WR-08	ON			ON
WR-09	ON	ON	ON	ON
WR-10	ON	ON		ON

* Pumping rates for Tamarack wells average between 3.2 and 3.4 cfs.

** WR-04, -09, and -10 pump to a recharge area on the eastern side of Tamarack SWA and are not involved in the current research.

(Year 2002 cont.)

	Call at state line					3 & 10 on btwn 3 and 6 pm
9-Apr-02	12-Apr-02	5-Aug-02	27-Aug-02	31-Aug-02	4-Sep-02	6-Dec-02
ON	ON	ON		ON		
ON	OFF				ON	ON
ON	OFF					ON
ON	OFF					
ON	OFF					
ON	OFF					
ON	OFF					
ON	OFF					
ON	OFF					
ON	OFF					ON

APPENDIX 1. DETAILED PUMPING HISTORY AT TAMARACK (Year 2003)

Well ID Pumping rates for Tamarack wells average between 3.2 and 3.4 cfs.		
Date	29-Jan-03	15-Mar-03
WR-01 Pump to Original Pond	ON	ON
WR-02	ON	ON
WR-03 Pump to New Pond	ON	ON
WR-04	ON	ON
WR-05	ON	ON
WR-06	ON	ON
WR-07	ON	ON
WR-08	ON	ON
WR-09	ON	ON
WR-10	ON	ON

* Pumping rates for Tamarack wells average between 3.2 and 3.4 cfs.

** WR-04, -09, and -10 pump to a recharge area on the eastern side of Tamarack SWA and are not involved in the current research.

Appendix 2. Field / Lab Data Log

"Upper Deep Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T13 Deep	6/15/2001	36.58	199	2.79	20			621		0.3	130	260	128
	6/25/2001	39.80	199	2.79	20	20.0	8.4	689	2.6	0.1	120	240	108
	7/8/2001	44.25	199	2.79	20	20.0	7.8	642	2.0	0.1	120	260	72
	7/17/2001	45.12	199	2.79	20	19.1	7.6	654	1.8	0.3	130	280	144
	7/24/2001	42.43	199	2.79	20	18.9	8.0	630	2.7	0.2	120	270	128
	11/1/2001	46.60	199	2.79	20	14.4	7.5	675	7.3	2.3	70	270	
	12/14/2001	46.70	199	2.79	20	12.8	7.1	614	1.9	1.2	150	270	220
	2/22/2002	39.90	199	2.79	20	12.6	7.0	530	2.9	2.1	130	230	160
	3/7/2002	39.07	199	2.79	20	12.8	6.7	618	6.2	1.9	170	220	130
	4/26/2002	43.07	199	2.79	20	13.1	7.5	996		2.3	160	290	190
	6/5/2002	46.81	199	2.79	20	13.5	7.5	830	8.2	2.6	140	350	190
	7/19/2002	47.07	199	2.79	20	16.5	6.9	1016	1.2	2.1	190	350	180
	10/10/2002	47.88	199	2.79	20	11.9	7.3	1022	8.9	2.6	170	270	160
	11/13/2002	47.82	199	2.79	20	9.7	6.9	1072	7.9	2.7	190	300	170
	2/4/2003	42.66	199	2.79	20	5.8	7.4	968		2.6	220	300	130
	3/11/2003	37.86	199	2.79	20	15.5	7.1	1111	6.6	1.8	170	280	110
	ci					2.1	0.2	102	1.6	0.5	18	18	20
	stddev					4.0	0.5	202	2.9	1.0	36	36	39
	mean					14.4	7.4	793	4.6	1.6	149	278	148

"Upper Deep Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
DOW4	6/15/2001	72.25	274.00	1.00	90			334		1.7	13	120	112
	6/25/2001	73.40	274.00	1.00	90	17.8	7.6	388	4.9	2.1	18	130	100
	7/8/2001	75.33	274.00	1.00	90	17.1	7.8	359	6.2	2.1	19	140	144
	7/17/2001	76.82	274.00	1.00	90	18.2	7.7	386	9.4	1.9	19	120	108
	7/24/2001	74.94	274.00	1.00	90	18.2	7.8	353	2.7	2.1	20	140	112
	11/1/2001	76.90	274.00	1.00	90	15.8	8.0	348	16.3	1.8	15	140	
	12/14/2001	76.85	274.00	0.25	90	13.2	7.2	334	1.6	2.2	10	140	110
	2/22/2002	73.72	274.00	0.25	90	12.9	6.9	333	3.4	2.0	0	170	160
	3/7/2002	73.15	274.00	0.25	90	13.2	7.1	309	5.2	2.0	17	140	150
	4/26/2002	74.31	274.00	0.25	90	12.7	7.4	498		2.2	16	160	130
	6/5/2002	76.12	274.00	0.25	90	17.4	7.5	440	18.1	2.4	20	150	130
	7/19/2002	77.30	274.00	0.25	90	18.8	6.9	555	1.0	2.0	27	160	160
	10/10/2002	77.73	274.00	0.25	90	15.7	7.4	661	8.5	2.3	30	170	170
	11/13/2002	77.47	274.00	0.25	90	15.1	7.4	602	2.7	2.3	32	160	140
	2/4/2003	77.92	274.00	0.25	90	10.2	7.9	659	0.7	2.0	66	160	130
	3/11/2003	72.23	274.00	0.25	90	11.9	7.4	631	8.1	2.0	100	190	120
	ci					1.4	0.2	66	2.9	0.1	12	10	11
	stddev					2.7	0.3	130	5.4	0.2	24	19	22
	mean					15.2	7.5	449	6.3	2.1	26	149	132

Appendix 2. Field / Lab Data Log

"Upper Deep Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
DOW5	6/15/2001	90.00	202.00	1.00	60			248		1.4	8	100	96
	6/25/2001	90.00	202.00	1.00	60	17.7	7.8	265	4.5	1.9	16	120	88
	7/8/2001	90.35	202.00	1.00	60	20.2	7.9	283	5.6	1.9	11	90	68
	7/17/2001	90.53	202.00	1.00	60	18.0	7.8	255	9.4	1.7	11	80	104
	7/24/2001	90.55	202.00	1.00	60	19.1	8.0	250	2.1	1.8	11	120	92
	11/1/2001	91.05	202.00	1.00	60	15.3	8.1	252	15.1	1.6	7	120	
	12/14/2001	90.88	202.00	0.25	60	13.1	7.0	248	1.7	1.7	10	150	110
	2/22/2002	90.30	202.00	0.25	60	13.5	6.9	243	3.1	1.5	10	100	110
	3/7/2002					not collected because of darkness							
	4/26/2002	89.78	202.00	0.25	60	13.3	7.5	383		1.9	10	120	90
	6/5/2002	90.33	202.00	0.25	60	18.2	7.6	330	16.0	2.0	10	110	110
	7/19/2002					not collected because of darkness							
	10/10/2002	92.54	202.00	0.25	60	18.1	6.9	389	9.0	2.0	11	110	110
	11/13/2002	91.43	202.00	0.25	60	12.8	7.1	396	6.8	2.0	11	110	110
	2/4/2003	91.33	202.00	0.25	60	11.8	7.4	368	0.6	1.6	12	140	80
	3/11/2003	90.80	202.00	0.25	60	15.7	7.4	385	7.5	1.8	12	100	140
	ci					1.7	0.2	35	2.9	0.1	1	10	10
	stddev					2.8	0.4	64	5.0	0.2	2	18	18
	mean					15.9	7.5	307	6.8	1.8	11	112	101

"Upper Intermediate Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T17-ND	6/15/2001	32.62	69.70	0.70	5			482		2.4	30	160	124
	6/25/2001	37.87	69.70	0.70	5	18.8	7.5	688	2.9	3.9	70	160	148
	7/8/2001	44.84	69.70	0.70	5	15.6	7.5	508	3.1	0.3	90	180	156
	7/17/2001	46.05	69.70	0.70	5	15.5	7.5	541	1.7	0.4	90	210	156
	7/24/2001	41.62	69.70	0.70	5	13.4	7.4	553	3.4	0.3	110	200	152
	11/1/2001	47.85	69.70	0.70	5	14.1	7.3	600	4.2	0.0	80		
	12/14/2001	47.95	69.70	0.70	5	8.3	7.1	633	0.2	0.6	150	240	180
	2/22/2002	38.37	69.70	0.70	5	12.4	7.1	578	1.0	2.0	110	230	190
	3/7/2002	37.45	69.70	0.70	5	9.6	7.1	551	8.0	1.8	150	230	180
	4/26/2002	43.43	69.70	0.70	5	13.0	7.3	1021		2.1	170	240	170
	6/5/2002	47.23	69.70	0.70	5	13.7	7.1	1060	8.0	2.6	150	250	190
	7/19/2002	48.44	69.70	0.70	5	18.4	7.0	1064	3.2	1.5	230	300	180
	10/10/2002	49.17	69.70	0.70	5	9.5	7.6	1175	9.5	1.8	190	310	180
	11/13/2002	49.12	69.70	0.70	5	10.3	7.6	1135	8.0	2.7	220	310	190
	2/4/2003	45.52	69.70	0.70	5	6.9	7.2	930	0.2	1.6	190	270	170
	3/11/2003	34.13	69.70	0.70	5	14.1	7.3	893	6.4	2.1	150	190	160
	ci					1.8	0.1	128	1.7	0.5	29	26	10
	stddev					3.5	0.2	253	3.2	1.1	57	50	19
	mean					12.9	7.3	776	4.3	1.6	136	232	168

Appendix 2. Field / Lab Data Log

"Upper Intermediate Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T18-SD	6/15/2001	37.84	64.40	0.80	5			537		1.9	110	150	116
	6/25/2001	41.24	64.40	0.80	5	17.2	7.6	441	2.4	3.0	40	160	100
	7/8/2001	47.50	64.40	0.80	5	14.0	7.4	545	4.5	2.3	90	200	124
	7/17/2001	48.73	64.40	0.80	5	16.5	7.5	586	1.8	1.8	90	230	160
	7/24/2001	45.03	64.40	0.80	5	14.5	7.4	565	3.9	1.9	100	230	156
	11/1/2001	50.40	64.40	0.80	5	13.3		661	5.6	1.3	120		
	12/14/2001	50.53	64.40	0.80	5					3.8	250	270	
	2/22/2002	42.50	64.40	0.80	5	12.9	6.7	608	3.5	2.8	120	220	180
	3/7/2002	41.70	64.40	0.80	5	9.2	7.3	568	7.3	2.0	160	300	160
	4/26/2002	46.06	64.40	0.80	5	11.9	7.3	978		2.2	150	320	170
	6/5/2002	49.84	64.40	0.80	5	13.3	7.3	850	7.2	2.4	120	250	170
	7/19/2002	51.04	64.40	0.80	5	16.9	7.0	1039	3.0	2.1	160	270	140
	10/10/2002	51.76	64.40	0.80	5	9.3	7.2	1168	10.4	2.7	200	270	160
	11/13/2002	51.67	64.40	0.80	5	10.1	7.4	1073	8.9	3.1	200	260	160
	2/4/2003	45.55	64.40	0.80	5	8.1	7.4	983		1.8	190	250	150
	3/11/2003	39.11	64.40	0.80	5	13.5	7.5	924	8.2	1.6	160	260	150
	ci					1.6	0.1	126	1.7	0.3	27	24	12
	stddev					2.9	0.2	240	2.8	0.6	53	47	22
	mean					12.9	7.3	768	5.6	2.3	141	243	150

"Upper Shallow Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T13-ES	6/15/2001	23.27	44	0.50	5			364		4.6	10	140	104
	6/25/2001	32.53	44	0.50	5	20.8	7.8	454	2.5	3.2	60	140	120
	7/8/2001	41.01	44	0.50	5	19.8	7.5	730	2.5	0.6	140	230	96
	7/17/2001	42.18	44	0.50	5	21.5	7.5	794	2.0	0.8	200	270	136
	7/24/2001	36.35	44	0.50	5	18.2	7.7	675	2.9	1.0	140	220	148
	11/1/2001					dry							
	12/14/2001					dry							
	2/22/2002	33.71	44	0.50	5	16.6	7.0	686	0.3	2.7	120	290	200
	3/7/2002	32.72	44	0.50	5	13.9	6.7	623	6.4	2.4	170	190	170
	4/26/2002	39.69	44	0.50	5	10.5	7.4	1223		2.6	220	220	170
	6/5/2002	43.58	44	0.50	5	dry							
	7/19/2002		44	0.50	5	dry							
	10/10/2002		44	0.50	5	plugged							
	11/13/2002		44	0.50	5	plugged							
	2/4/2003	30.40	44	0.50	5	6.1	7.3	1025		1.7	190	250	150
	3/11/2003	26.37	44	0.50	5	9.0	7.4	977	7.2	1.5	180	270	180
	ci					3.9	0.2	171	2.0	0.8	43	34	22
	stddev					5.6	0.3	261	2.5	1.2	65	52	34
	mean					15.2	7.4	755	3.4	2.1	143	222	147

Appendix 2. Field / Lab Data Log

"Upper Shallow Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T15	6/15/2001	26.47	31.30	0.20	5			562		0.8	80	210	192
	6/25/2001	27.00	31.30	0.20	5	18.5	7.6	505	2.5	1.8	50	190	176
	7/8/2001	29.05	31.30	0.20	5	18.3	7.8	542	4.5	1.7	20	210	180
	7/17/2001	29.86	31.30	0.20	5	20.1	7.7	681	2.3	0.9	30	190	184
	7/24/2001	28.77	31.30	0.20	5	16.2	7.6	494	2.8	1.2	30	180	196
	11/1/2001	30.70	31.30	0.20	5	dry							
	12/14/2001		31.30	0.20	5	dry							
	2/22/2002	27.88	31.30	0.20	5	13.7	6.9	505	3.4	3.0	30	230	200
	3/7/2002	27.12	31.30	0.20	5	8.9	7.5	434	4.8	3.0	250	220	360
	4/26/2002	27.95	31.30	0.20	5	11.8	7.3	690		4.0	20	150	200
	6/5/2002	30.50	31.30	0.20	5	16.9	7.1	660	7.8				
	7/19/2002	31.11	31.30	0.20	5	dry							
	10/10/2002		31.30	0.20	5	dry							
	11/13/2002		31.30	0.20	5	dry							
	2/4/2003	30.72	31.30	0.20	5	dry							
	3/11/2003	26.75	31.30	0.20	5	10.3	7.5	623	7.0	3.1	10	180	230
	ci					2.7	0.2	58	1.5	0.8	52	17	40
	stddev					4.0	0.3	89	2.1	1.1	75	25	57
	mean					15.0	7.4	570	4.4	2.2	58	196	213

"Upper Shallow Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T16	6/15/2001	20.95	34.40	3.60	5			664		1.5	140	240	136
	6/25/2001	33.30	34.40	3.60	5	20.2	7.8	763	3.3	1.2	160	270	144
	7/8/2001		34.4			dry							
	7/17/2001		34.4			dry							
	7/24/2001		34.4			dry							
	11/1/2001		34.4			dry							
	12/14/2001		34.4			dry							
	2/22/2002	32.20	34.40	3.60	5	15.5	6.6	615	0.4	2.5	130	200	310
	3/7/2002	31.30	34.40	3.60	5	5.4	7.4	600	7.4	2.0	170	260	160
	4/26/2002		34.4	3.60	5	dry							
	6/5/2002		34.4	3.60	5	dry							
	7/19/2002		34.40	3.60	5	dry							
	10/10/2002		34.40	3.60	5	dry							
	11/13/2002		34.40	3.60	5	dry							
	2/4/2003	28.21	34.40	3.60	5	5.9	7.6	1073		2.3	220	270	140
	3/11/2003	20.05	34.40	3.60	5	10.8	7.6	889	8.9	1.4	170	250	230
	ci					6.2	0.5	162	4.4	0.5	28	23	61
	stddev					6.3	0.5	184	3.9	0.5	31	26	70
	mean					11.6	7.4	767	5.0	1.8	165	248	187

Appendix 2. Field / Lab Data Log

"Upper Shallow Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T17-SS	6/15/2001							not yet installed					
	6/25/2001							not yet installed					
	7/8/2001							not yet installed					
	7/17/2001							not yet installed					
	7/24/2001							not yet installed					
	11/1/2001												
	12/14/2001												
	2/22/2002	38.33	43.00	0.55	5	15.3	6.9		0.9	3.0	120	130	230
	3/7/2002	37.35	43.00	0.55	5	8.3	7.0	615	7.0	2.5	170	80	220
	4/26/2002	42.84	43.00	0.55	5	13.1	7.1	1199		5.0	320	120	200
	6/5/2002												
	7/19/2002												
	10/10/2002												
	11/13/2002												
	2/4/2003	41.91	43.00	0.55	5	7.1	7.4	1109	0.3	2.0	220	100	160
	3/11/2003	33.66	43.00	0.55	5	14.0	7.5	1113	8.1	4.6	210	120	220
	ci					3.6	0.3	301	4.6	1.3	72	20	27
	stddev					3.6	0.3	266	4.1	1.3	74	20	28
	mean					11.6	7.2	1009	4.0	3.4	208	110	206

"Upper Shallow Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T18-NS	6/15/2001							not collected					
	6/25/2001							not collected					
	7/8/2001							not collected					
	7/17/2001							not collected					
	7/24/2001							not collected					
	11/1/2001							not collected					
	12/14/2001							not collected (when was this well installed?)					
	2/22/2002	42.54	46.60	0.80	5	14.1	7.1	735	1.3	3.0	100	270	280
	3/7/2002	41.72	46.60	0.80	5	8.7	7.3	684	7.8	3.7	160	270	400
	4/26/2002	45.55	46.60	0.80	5	12.4	7.3	1403		3.8	200	180	350
	6/5/2002	47.17	46.60	0.80	5								
	7/19/2002	47.27	46.60	0.80	5								
	10/10/2002		46.60	0.80	5								
	11/13/2002		46.60	0.80	5								
	2/4/2003	46.51	46.60	0.80	5								
	3/11/2003	39.17	46.60	0.80	5	11.8	7.5	1147	9.2	3.0	170	230	230
	ci					2.6	0.2	389	5.9	0.5	47	48	85
	stddev					2.3	0.2	343	4.2	0.4	42	43	75
	mean					11.8	7.3	992	6.1	3.4	158	238	315

Appendix 2. Field / Lab Data Log

"Upper Shallow Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T19	6/15/2001							not collected					
	6/25/2001							not collected					
	7/8/2001							not collected					
	7/17/2001							not collected					
	7/24/2001							not collected					
	11/1/2001							not collected					
	12/14/2001							not collected (when was this well installed?)					
	2/22/2002	38.69	43.20	1.00	5	14.1	6.9	724	0.5	3.6	160	280	230
	3/7/2002	37.60	43.20	1.00	5	8.7	6.9	683	7.4	4.0	750	230	1250
	4/26/2002	43.60	43.20	1.00	5	15.7	7.3	1198		5.0	270		
	6/5/2002		43.20	1.00	5					dry			
	7/19/2002		43.20	1.00	5					dry			
	10/10/2002		43.20	1.00	5					dry			
	11/13/2002		43.20	1.00	5					dry			
	2/4/2003	42.31	43.20	1.00	5	5.9	7.2	1141		1.9	210	140	150
	3/11/2003	33.82	43.20	1.00	5	14.9	7.5	1030	8.0	2.5	170	180	280
	ci					4.2	0.3	233	5.7	1.2	244	69	586
	stddev					4.3	0.3	238	4.1	1.2	249	61	518
	mean					11.9	7.2	955	5.3	3.4	312	208	478

"Transition Well (Lower Shallow Well)"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T3	6/15/2001	26.44	33.38	1.92	0			502		0.3	20	190	148
	6/25/2001	26.75	33.38	1.92	0	14.0	7.3	510	3.0	0.4	60	220	144
	7/8/2001	28.65	33.38	1.92	0	15.0	7.4	567		0.5	110	200	152
	7/17/2001	29.40	33.38	1.92	0					bailer stuck in well			
	7/24/2001	no data	33.38	1.92	0					bailer stuck in well			
	11/1/2001	28.05	33.38	1.92	0					not enough water to collect			
	12/14/2001	29.25	33.38	1.92	0	5.7	6.9	557	0.6				
	2/22/2002	27.50	33.38	1.92	0	8.3	7.3	429	5.3	0.1	20	200	200
	3/7/2002							not collected because of darkness					
	4/26/2002	27.25	33.38	1.92	0	9.1	7.3	842		0.2	20	200	200
	6/5/2002	29.80	33.38	1.92	0					dry			
	7/19/2002	30.78	33.38	1.92	0					dry			
	10/10/2002	31.24	33.38	1.92	0					dry			
	11/13/2002	dry	33.38	1.92	0					dry			
	2/4/2003	29.89	33.38	1.92	0					bailer stuck in well			
	3/11/2003	26.98	33.38	1.92	0	14.7	7.7	831	5.3	1.5	110	170	150
	ci					3.5	0.2	131	1.9	0.4	39	14	23
	stddev					3.9	0.3	164	1.9	0.5	44	16	27
	mean					11.1	7.3	605	3.5	0.5	57	197	166

Appendix 2. Field / Lab Data Log

"Transition Well (Lower Shallow Well)"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T4	6/15/2001	10.19	9.17	1.83	0			674		1.4	90	250	200
	6/25/2001	8.63	9.17	1.83	0	17.1	7.2	1331	2.6	2.8	220	520	324
	7/8/2001	8.02	9.17	1.83	0	18.4	7.2	1578	3.6	3.1	300	575	392
	7/17/2001	9.21	9.17	1.83	0	17.7	7.3	1398	3.3	3.2	250	490	328
	7/24/2001	9.05	9.17	1.83	0	16.0	7.4	1343	2.8	3.5	260	470	332
	11/1/2001	6.90	9.17	1.83	0	14.3		1149	3.3	3.2	80	350	
	12/14/2001	7.43	9.17	1.83	0	8.2	6.9	1061	0.5	3.2	240	290	10
	2/22/2002	11.06	9.17	1.83	0	dry							
	3/7/2002	10.26	9.17	1.83	0	6.9	7.8	1440	6.4	5.0	750	530	820
	4/26/2002	7.16	9.17	1.83	0	8.5	8.0	2000		4.5	560	390	660
	6/5/2002	8.57	9.17	1.83	0	13.8	7.6	2000	6.8	5.0	420	420	660
	7/19/2002	9.24	9.17	1.83	0	20.2	7.4	2000	2.0	4.7	480	440	400
	10/10/2002	8.67	9.17	1.83	0	11.5	7.1	2000	7.4	3.3	330	320	400
	11/13/2002	8.79	9.17	1.83	0	11.3	6.9	2000	7.0	4.4	400	380	480
	2/4/2003	11.23	9.17	1.83	0	8.3	7.3	2000	0.9	not enough water to collect			
	3/11/2003	10.81	9.17	1.83	0	16.4	6.9	1550	4.8	3.1	310	340	440
	ci					2.4	0.2	222	1.3	0.5	97	53	118
	stddev					4.4	0.3	423	2.3	1.0	179	97	209
	mean					13.5	7.3	1568	4.0	3.6	335	412	419

"Transition Well (Lower Shallow Well)"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T5	6/15/2001	17.85	23.80	2.00	0			653		1.1	120	210	124
	6/25/2001	16.95	23.80	2.00	0	16.8	7.3	657	3.3	0.1	120	200	152
	7/8/2001	17.02	23.80	2.00	0	17.3	7.3	678	3.2	0.5	130	190	140
	7/17/2001	17.83	23.80	2.00	0	18.7	7.4	668	2.1	0.6	130	220	116
	7/24/2001	17.68	23.80	2.00	0	16.9	7.4	625	2.4	0.7	140	230	142
	11/1/2001	16.20	23.80	2.00	0	14.9	7.4	669	3.2	0.0	100		
	12/14/2001	16.75	23.80	2.00	0	10.3	6.9	650	0.5	0.2	190	270	360
	2/22/2002	17.49	23.80	2.00	0	12.8	6.9	672	2.9	0.0	120	300	190
	3/7/2002	17.03	23.80	2.00	0	9.8	7.8	640	4.3	0.7	190	310	200
	4/26/2002	15.73	23.80	2.00	0	11.4	7.3	1041		0.4	170	320	220
	6/5/2002	17.52	23.80	2.00	0	18.5	7.3	970	4.5	0.3	130	300	190
	7/19/2002	18.62	23.80	2.00	0	20.1	7.4	1108	2.2	0.5	170	230	210
	10/10/2002	17.66	23.80	2.00	0	10.7	7.2	1027	8.8	1.5	150	240	160
	11/13/2002	17.26	23.80	2.00	0	11.3	7.3	1011	8.3	2.1	150	280	180
	2/4/2003	18.71	23.80	2.00	0	10.2	7.3	983	0.8	1.6	160	270	170
	3/11/2003	17.34	23.80	2.00	0	11.9	7.5	1043		1.8	170	270	180
	ci					1.9	0.1	97	1.4	0.3	14	22	30
	stddev					3.6	0.2	192	2.5	0.7	27	42	58
	mean					14.1	7.3	818	3.6	0.8	146	256	182

Appendix 2. Field / Lab Data Log

"Lower Shallow Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T6	6/15/2001	12.31	13.17	1.83	0			342		0.3	20	130	104
	6/25/2001	8.05	13.17	1.83	0	18.2	7.2	622	2.3	1.2	110	260	148
	7/8/2001	5.94	13.17	1.83	0	19.1	7.1	555	3.0	0.8	110	220	152
	7/17/2001	7.72	13.17	1.83	0	18.6	7.1	605	4.2	1.0	130	230	144
	7/24/2001	7.58	13.17	1.83	0	17.1	7.4	610	2.4	0.9	130	240	144
	11/1/2001		13.17	1.83	0	not collected because of darkness							
	12/14/2001		13.17	1.83	0	not collected because of darkness							
	2/22/2002	10.61	13.17	1.83	0	9.5	7.2	602	4.0	0.2	150	320	290
	3/7/2002		13.17	1.83	0	not collected because of darkness							
	4/26/2002	4.53	13.17	1.83	0	10.1	8.2	1227		0.2	200	230	200
	6/5/2002	5.67	13.17	1.83	0	14.8	7.7	970	7.0	0.1	160	280	250
	7/19/2002	6.89	13.17	1.83	0	20.0	7.3	1195	1.3	0.1	20	130	90
	10/10/2002	6.17	13.17	1.83	0	16.8	6.7	1205	4.9	0.5	220	270	180
	11/13/2002	5.35	13.17	1.83	0	9.0	7.5	1186	9.4	0.4	220	320	200
	2/4/2003	11.65	13.17	1.83	0	7.5	7.2	1090	0.9	0.3	280	300	170
	3/11/2003	12.61	13.17	1.83	0	not enough sample to collect							
	ci					2.8	0.2	183	1.6	0.2	44	36	32
	stddev					4.7	0.4	323	2.6	0.4	78	63	57
	mean					14.6	7.3	851	3.9	0.5	146	244	173

"Lower Shallow Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T8	6/15/2001	12.45	14.37	2.00	0			713		1.5	160	240	116
	6/25/2001	8.95	14.37	2.00	0	16.2	7.3	659	3.4	1.9	120	170	136
	7/8/2001	6.71	14.37	2.00	0	16.3	7.2	661	4.2	2.2	130	190	104
	7/17/2001	8.93	14.37	1.83	0	16.9	7.3	546	6.4	2.3	110	180	140
	7/24/2001	8.26	14.37	1.83	0	16.8	7.5	550	2.0	2.2	120	180	116
	11/1/2001	6.00	14.37	1.83	0	15.9	7.2	660	3.4	1.3	160	277	
	12/14/2001	8.80	14.37	1.83	0	11.9	6.9	704	0.5	1.4	200	260	10
	2/22/2002	13.25	14.37	1.83	0	11.1	7.4	749	2.9	1.3	150	280	170
	3/7/2002		14.37	1.83	0	not collected because of darkness							
	4/26/2002	9.48	14.37	1.83	0	7.9	7.5	1182		2.0	200	310	180
	6/5/2002	12.40	14.37	1.83	0	15.4	7.5	590	6.5	0.6	200	170	170
	7/19/2002	12.91	14.37	1.83	0	20.2	7.5	683	1.4	0.2	10	260	180
	10/10/2002	6.98	14.37	1.83	0	16.1	6.5	872	4.4	0.5	90	250	180
	11/13/2002	6.97	14.37	1.83	0	11.0	7.0	1037	6.8	0.7	130	260	180
	2/4/2003	14.27	14.37	1.83	0	8.6	7.4	832	0.9	2.0	60	210	130
	3/11/2003	15.82	14.37	1.83	0	13.2	7.1	649	5.4	1.8	70	130	140
	ci					1.9	0.2	93	1.2	0.4	29	27	25
	stddev					3.5	0.3	177	2.2	0.7	55	52	46
	mean					14.1	7.2	739	3.7	1.5	127	224	139

Appendix 2. Field / Lab Data Log

"Lower Shallow Well"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
T9	6/15/2001	11.18	12.65	2.00	0			418		1.9	10	150	84
	6/25/2001	8.00	12.65	2.00	0	15.8	7.3	555	3.5	1.5	90	230	144
	7/8/2001	5.80	12.65	2.00	0	17.5	7.2	654	3.7	1.6	120	200	142
	7/17/2001	7.38	12.65	2.00	0	20.2	7.1	548	4.9	2.1	100	210	124
	7/24/2001	7.51	12.65	2.00	0	19.1	7.4	562	2.3	1.9	110	210	132
	11/1/2001	5.10	12.65	2.00	0	12.6		670	3.6	1.5	200	280	
	12/14/2001	7.30	12.65	2.00	0	9.3	7.1	646	0.5	1.8	200	270	90
	2/22/2002	11.73	12.65	2.00	0	11.8	7.0	752	3.7	0.9	210	300	220
	3/7/2002	11.11	12.65	2.00	0	7.6	6.9	867	5.9	0.5	280	300	200
	4/26/2002	7.56	12.65	2.00	0	10.3	8.1	1214		1.2	210	300	220
	6/5/2002	8.33	12.65	2.00	0	13.5	7.6	870	8.8	1.4	140	250	210
	7/19/2002	9.02	12.65	2.00	0	18.3	7.1	1098	1.4	1.5	170	270	190
	10/10/2002	5.10	12.65	2.00	0	16.9	6.5	1429	4.2	1.1	270	320	180
	11/13/2002	4.85	12.65	2.00	0	10.2	7.6	800	6.5	1.9	80	190	170
	2/4/2003	10.62	12.65	2.00	0	6.5	7.1	712	0.7	1.3	100	210	160
	3/11/2003	11.89	12.65	2.00	0	13.7	6.7	672	4.2	0.4	60	170	170
	ci					2.3	0.2	135	1.2	0.3	39	26	23
	stddev					4.3	0.4	267	2.3	0.5	76	52	43
	mean					13.6	7.2	779	3.8	1.4	147	241	162

"South Platte River"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
SPR1	6/15/2001							1726		1.3	610	600	196
	6/25/2001					32.1	8.4	1882	11.2	0.6	700	570	108
	7/8/2001					29.2	8.4	1797	11.6				
	7/17/2001					28.2	8.5	1463	9.2	1.6	440	470	148
	7/24/2001					28.7	8.3	1864	9.1	1.0	750	670	200
	11/1/2001					14.1	8.8	2080	15.5	1.3	580	720	
	12/14/2001					0.8	7.1	1696	0.9	2.1	670	740	160
	2/22/2002					9.5	6.9	1820	4.9	2.0	740	690	240
	3/7/2002					1.0	7.9	1423	10.8	2.4	550	800	240
	4/26/2002					15.2	7.9	2000		1.3	750	690	180
	6/5/2002					25.0	7.7	2000		1.2	750	610	210
	7/19/2002					31.4	7.5	2000	0.9	0.8	680	610	130
	10/10/2002					22.5	7.0	2000	7.2	7.8	610	600	170
	11/13/2002					10.1	7.9	2000	4.4	2.6	750	670	210
	2/4/2003					7.2	7.6	2000	1.1	1.7	730	600	210
	3/11/2003					12.5	7.3	2260	8.8	1.7	750	690	250
	ci					5.7	0.3	111	2.6	0.9	49	42	23
	stddev					11.0	0.6	219	4.6	1.7	94	80	42
	mean					17.8	7.8	1876	7.3	2.0	671	649	189

Appendix 2. Field / Lab Data Log

"South Platte River"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
SPR2	6/15/2001							1718		1.2	590	590	188
	6/25/2001					30.6	8.6	1880	17.0	0.5	740	660	128
	7/8/2001					29.0	8.5	1801	10.4	0.7	630	580	144
	7/17/2001					28.4	8.4	1458	9.2	1.7	435	460	156
	7/24/2001					24.7	8.3	1841	3.7	1.0	720	690	208
	11/1/2001					14.0	8.5	2050		1.4	660	710	
	12/14/2001					0.2	7.0	1706	0.6	2.0	620	650	190
	2/22/2002					9.6	6.9	1804	4.9	2.0	750	750	310
	3/7/2002					1.6	8.2	1452	11.2	2.5	540	580	270
	4/26/2002					14.8	8.3	2000		1.4	750	550	140
	6/5/2002					24.8	7.8	2000		1.2	750	680	180
	7/19/2002					31.2	7.6	2000	0.8	0.9	680	540	140
	10/10/2002					22.8	6.9	2000	7.9	7.4	620	550	150
	11/13/2002					10.2	7.0	2000	4.8	2.4	750	650	180
	2/4/2003					7.9	7.9	2000	1.2	1.6	750	600	190
	3/11/2003					13.8	7.3	2270	8.8	1.7	750	610	260
	ci					5.5	0.3	109	2.9	0.8	47	38	28
	stddev					10.5	0.6	216	5.0	1.6	93	74	53
	mean					17.6	7.8	1874	6.7	1.9	671	616	189

"Slough"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3	
SL1	6/15/2001							1492		0.4	510	470	120	
	6/25/2001					30.9	8.6	1706	18.0	0.5	600	490	132	
	7/8/2001					27.5	8.4	1305	11.4	0.4	380	380	124	
	7/17/2001					27.8	8.2	778	10.1	0.8	190	260	120	
	7/24/2001					22.9	8.4	1471	4.3	0.6	490	490	140	
	11/1/2001					11.0	8.5	1833		0.0	710	540		
	12/14/2001					5.2	7.1	373	1.5	0.0	60	230	340	
	2/22/2002					6.9	6.9	1280	6.7	1.1	570	550	350	
	3/7/2002					1.2	6.7	1373	10.8	2.7	740	620	220	
	4/26/2002					13.3	7.9	2000		1.0	750	600	150	
	6/5/2002					21.6	7.9	2000		0.3	720	580	160	
	7/19/2002					28.0	7.5	2000	1.0	0.0	750	650	200	
	10/10/2002					18.7	6.9	1292	3.5	0.7	240	290	170	
	11/13/2002					11.0	7.3	1245	4.6	0.9	220	300	150	
	2/4/2003					7.7	8.4	844	0.9	too dry to collect lab samples				
	3/11/2003					dry								
	ci						5.2	0.4	241	3.2	0.4	125	75	42
	stddev						9.9	0.7	477	5.4	0.7	239	143	78
mean						16.7	7.8	1399	6.6	0.7	495	461	183	

Appendix 2. Field / Lab Data Log

"Slough"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
SL2	6/15/2001							427		2.6	42	170	92
	6/25/2001					18.4	8.0	348	11.5	1.5	29	150	112
	7/8/2001					17.5	7.7	338	10.2	1.7	26	130	132
	7/17/2001					22.2	7.8	492	8.6	2.1	71	160	128
	7/24/2001					18.8	7.5	355	2.8	1.4	155	160	124
	11/1/2001												
	12/14/2001					3.5	7.0	408	0.8	1.9	70	190	160
	2/22/2002					9.7	7.0	321	3.5	1.9	10	180	180
	3/7/2002					not collected because of darkness							
	4/26/2002					12.1	8.1	493		1.7	10	150	190
	6/5/2002					20.9	7.8	490		1.4	10	160	150
	7/19/2002					27.2	7.8	475	0.8	0.9	10	140	140
	10/10/2002					21.1	7.1	529	7.1	0.3	10	180	190
	11/13/2002					8.5	6.9	525	4.8	0.3	10	190	190
	2/4/2003					3.4	8.4	255	0.5	0.1	10	120	100
	3/11/2003					17.0	7.8	425	9.6	0.6	10	140	120
	ci					4.2	0.3	46	2.5	0.4	22	12	18
	stddev					7.4	0.5	85	4.1	0.8	41	22	34
	mean					15.4	7.6	420	5.5	1.3	34	159	143

"Recharge Water"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
RP (west)	6/15/2001							765		2.5	130	280	102
	6/25/2001												
	7/8/2001												
	7/17/2001					13.3	8.1	565	7.4	2.2	140	240	112
	7/24/2001												
	11/1/2001	no sample collected											
	12/14/2001	no sample collected											
	2/22/2002	no sample collected											
	3/7/2002	no sample collected											
	4/26/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	6/5/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	7/19/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	10/10/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	11/13/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	2/4/2003					10.2	7.3	832	0.7	1.8	130	240	140
	3/11/2003					14.2	7.0	933	9.4	1.7	140	270	150
	ci					2.9	0.8	176	6.3	0.4	7	23	26
	stddev					2.1	0.6	155	4.5	0.4	6	21	23
	mean					12.6	7.5	774	5.8	2.1	135	258	126

Appendix 2. Field / Lab Data Log

"Recharge Water"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
NRP (east)	6/15/2001							522		1.3	120	210	103
	6/25/2001												
	7/8/2001												
	7/17/2001					15.7	7.4	637	5.0	1.8	150	230	116
	7/24/2001												
	11/1/2001	no sample collected											
	12/14/2001	no sample collected											
	2/22/2002	no sample collected											
	3/7/2002					9.4	7.8	807	6.6	1.4	300	340	170
	4/26/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	6/5/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	7/19/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	10/10/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	11/13/2002	dry (recharge wells cut off first week of 04/2002 due to call on river)											
	2/4/2003					8.9	7.4	1138	0.7	1.3	250	320	150
	3/11/2003					12.2	6.9	1071	6.2	1.5	140	300	230
	ci					3.5	0.4	262	3.0	0.2	77	56	49
	stddev					3.1	0.4	267	2.7	0.2	79	57	50
	mean					11.6	7.4	835	4.6	1.5	192	280	154

"Miscellaneous Sampling Points Collected on March 11, 2003"

Location	Date	Water Level from TOC, ft.	Well Depth from BGS, ft.	Casing Height AGS, ft.	Screen length, ft.	Temp, °C	pH	Specific Cond., microS/cm	DO, mg/L	NO3-N, mg/L-N	SO4, dissolved, mg/L	Hardness, mg/L CaCO3	Alkalinity, mg/L CaCO3
RP (water)	3/11/2003					13.3	7.6	933	13.7	1.0	170	250	160
NRP (water)	3/11/2003					10.1	7.1	1102	7.3	0.9	200	320	210
T-3 Pond	3/11/2003					12.7	7.8	829	12.1	1.4	140	210	130
Minnow Strm	3/11/2003					12.2	7.5	854	8.2	0.7	150	230	220

Appendix 3. Cation / Anion Concentrations in mg/L.

Sample Name	B 2496 (mg/L)	Ca1840 (mg/L)	K 7664 (mg/L)	Mg2795 (mg/L)	Na AVG (mg/L)	NO3 (mg/L)	SO4 (mg/L)	Alkalinity (mg/L)	Cl from IC (mg/L)	Ca:SO4	Na:SO4
DOW4 1	0.0298	45.54	7.556	7.90	10.78	2.2	16	130	3.401	2.85	0.67
DOW4 2	0.0222	51.23	5.758	7.78	10.61	2.4	20	130	5.712	2.56	0.53
DOW4 3	0.0273	48.81	4.316	8.91	11.39	2.0	27	160	6.156	1.81	0.42
DOW4 4	0.0312	59.37	5.184	10.75	15.18	2.3	30	170	11.583	1.98	0.51
DOW4 5	0.0163	50.54	4.670	8.89	11.27	2.3	32	140	6.427	1.58	0.35
DOW4 6	0.0307	61.15	5.176	10.71	15.63	2.0	66	130	13.447	0.93	0.24
DOW4 7	0.0246	62.88	5.701	11.88	18.82	2.0	100	120	16.821	0.63	0.19
DOW5 1	0.0172	35.29	6.160	6.14	6.46	1.9	10	90	2.037	3.53	0.65
DOW5 2	0.0060	37.58	4.841	6.15	6.22	2.0	10	110	2.420	3.76	0.62
DOW5 4	0.0164	35.06	3.125	6.67	6.34	2.0	11	110	1.812	3.19	0.58
DOW5 5	0.0023	35.68	3.145	6.38	5.99	2.0	11	110	2.026	3.24	0.54
DOW5 6	0.0191	36.76	3.192	6.50	6.37	1.6	12	80	2.028	3.06	0.53
DOW5 7	0.0000	32.93	3.174	6.23	6.38	1.8	12	140	1.917	2.74	0.53
MS 7	0.0535	68.22	5.998	18.55	36.30	0.7	150	220	19.283	0.45	0.24
NRP 6	0.0363	97.80	5.876	21.15	40.51	1.3	250	150	37.158	0.39	0.16
NRP 7	0.0446	92.88	6.239	20.57	44.81	1.5	140	230	28.358	0.66	0.32
NRP not outlet	0.0398	95.44	6.289	21.27	44.54	0.9	200	210	26.521	0.48	0.22
RP 6	0.0587	67.98	5.093	15.76	27.61	1.8	130	140	29.645	0.52	0.21
RP 7	0.0611	72.12	6.041	18.87	37.12	1.7	140	150	45.573	0.52	0.27
RP background	0.0550	80.21	6.165	21.68	42.65	1.8	150	170	24.750	0.53	0.28
RP near T13 7	0.0649	72.33	6.784	19.23	40.59	1.0	170	160	22.539	0.43	0.24
SL1 1	0.3311	152.30	5.648	75.56	216.10	1.0	750	150	140.008	0.20	0.29
SL1 2	0.3038	149.30	0.837	68.83	185.25	0.3	720	160	129.580	0.21	0.26
SL1 3	0.3652	153.40	21.710	73.97	224.80	0.0	750	200	131.395	0.20	0.30
SL1 4	0.0913	90.08	6.944	30.55	61.78	0.7	240	170	38.874	0.38	0.26
SL1 5	0.5773	68.91	6.277	27.65	54.71	0.9	220	150	35.024	0.31	0.25
SL2 1	0.0129	45.40	4.726	10.91	8.80	1.7	10	190	14.333	4.54	0.88
SL2 2	0.0094	44.71	4.667	10.95	7.55	1.4	10	150	13.915	4.47	0.76
SL2 3	0.0161	40.63	3.442	10.07	6.92	0.9	10	140	14.344	4.06	0.69
SL2 4	0.0000	60.65	3.871	10.89	7.34	0.3	10	190	14.278	6.07	0.73
SL2 5	0.0000	55.67	4.402	10.35	6.68	0.3	10	190	14.498	5.57	0.67
SL2 6	0.0065	35.91	2.732	9.08	5.28	0.1	10	100	13.926	3.59	0.53
SL2 7	0.0099	38.46	3.610	10.28	7.93	0.6	10	120	14.267	3.85	0.79
SPR1 1	0.3331	160.80	4.185	74.63	217.85	1.3	750	180	129.855	0.21	0.29
SPR1 2	0.3081	162.10	2.032	70.81	203.15	1.2	750	210	120.604	0.22	0.27
SPR1 3	0.2904	125.10	16.840	67.10	196.05	0.8	680	130	116.303	0.18	0.29
SPR1 4	0.2445	150.40	15.260	64.15	165.45	7.8	610	170	98.879	0.25	0.27
SPR1 5	0.3291	184.80	18.950	71.45	203.80	2.6	750	210	132.011	0.25	0.27
SPR1 6	0.3177	193.20	18.390	75.11	212.40	1.7	730	210	129.701	0.26	0.29
SPR1 7	0.3225	187.80	20.910	75.33	230.70	1.7	750	250	175.428	0.25	0.31
SPR2 1	0.3291	160.50	4.509	75.07	217.85	1.4	750	140	120.780	0.21	0.29
SPR2 2	0.3080	162.30	2.075	70.95	203.40	1.2	750	180	106.882	0.22	0.27
SPR2 3	0.2865	123.90	16.560	66.76	194.65	0.9	680	140	110.407	0.18	0.29
SPR2 4	0.2471	152.30	15.350	64.68	164.80	7.4	620	150	95.832	0.25	0.27
SPR2 5	0.3241	185.30	18.910	72.05	205.45	2.4	750	180	114.785	0.25	0.27
SPR2 6	0.3369	194.50	18.400	75.00	212.95	1.6	750	190	153.505	0.26	0.28
SPR2 7	0.3292	189.00	20.630	75.89	228.95	1.7	750	260	126.456	0.25	0.31
T13 Deep 1	0.0536	79.67	2.526	16.26	37.33	2.3	160	190	25.234	0.50	0.23
T13 Deep 2	0.0548	81.06	2.856	16.16	36.66	2.6	140	190	24.970	0.58	0.26
T13 deep 3	0.0606	75.73	5.878	17.86	39.27	2.1	190	180	26.158	0.40	0.21
T13 deep 4	0.0590	81.12	6.512	18.54	42.54	2.6	170	160	29.887	0.48	0.25
T13 deep 5	0.0606	83.36	6.423	18.44	40.64	2.7	190	170	27.588	0.44	0.21
T13 deep 6	0.0553	86.13	6.669	19.34	41.18	2.6	220	130	35.816	0.39	0.19
T13 deep 7	0.0459	89.17	6.436	21.08	43.12	1.8	170	110	34.001	0.52	0.25
T13 deep background	0.0463	78.03	6.406	17.52	36.70	no value	no value	no value	24.937	no value	no value
T13 ES 1	0.0516	83.00	65.370	22.21	35.94	2.6	220	170	33.330	0.38	0.16
T13ES 6	0.0639	73.39	26.430	22.69	37.22	1.7	190	150	27.363	0.39	0.20
T13ES 7	0.0524	72.18	21.040	24.02	34.89	1.5	180	180	25.168	0.40	0.19
T13ES background	0.0884	66.30	40.980	14.88	33.23	no value	no value	no value	20.482	no value	no value
T15 1	0.0661	53.17	18.100	7.96	31.74	4.0	20	200	4.714	2.66	1.59
T15 7	0.0464	49.67	10.230	8.84	29.55	3.1	10	230	3.242	4.97	2.96

Appendix 3. Cation / Anion Concentrations in mg/L.

Sample Name	B_2496 (mg/L)	Ca1840 (mg/L)	K_7664 (mg/L)	Mg2795 (mg/L)	Na AVG (mg/L)	NO3 (mg/L)	SO4 (mg/L)	Alkalinity (mg/L)	Cl from IC (mg/L)	Ca:SO4	Na:SO4
T16 6	0.0767	42.72	26.460	49.01	41.74	2.3	220	140	29.040	0.19	0.19
T16 7	0.0187	37.10	18.300	41.07	31.34	1.4	170	230	24.464	0.22	0.18
T17ND 1	0.0514	76.33	7.266	21.15	35.61	2.1	170	170	24.288	0.45	0.21
T17ND 2	0.0566	79.41	7.171	23.68	35.34	2.6	150	190	26.488	0.53	0.24
T17ND 3	0.0688	83.15	9.862	31.66	42.62	1.5	230	180	33.237	0.36	0.19
T17ND 4	0.0633	91.87	11.670	33.08	47.45	1.8	190	180	33.165	0.48	0.25
T17ND 5	0.0531	76.48	10.740	30.28	44.44	2.7	220	190	34.254	0.35	0.20
T17ND 6	0.0531	75.16	7.457	20.73	37.96	1.6	190	170	26.686	0.40	0.20
T17ND 7	0.0388	69.93	6.838	18.84	38.81	2.1	150	160	23.441	0.47	0.26
T17ND background	0.0284	65.85	11.310	17.32	33.80	no value	no value	no value	21.593	no value	no value
T17SS 1	0.1394	48.20	24.680	6.68	135.15	5.0	320	200	27.489	0.15	0.42
T17SS 6	0.1291	32.80	11.840	5.80	129.60	2.0	220	160	37.763	0.15	0.59
T17SS 7	0.1233	29.00	12.220	5.22	128.95	4.6	210	220	44.781	0.14	0.61
T17SS background	0.1000	34.61	13.380	5.80	112.30	no value	no value	no value	23.837	no value	no value
T18NS 1	0.3717	61.18	29.350	11.14	134.25	3.8	200	350	65.021	0.31	0.67
T18NS 7	0.1147	64.30	16.040	12.79	92.38	3.0	170	230	30.239	0.38	0.54
T18SD 1	0.0654	80.02	8.432	11.70	38.21	2.2	150	170	24.376	0.53	0.25
T18SD 2	0.0639	79.13	7.281	13.13	37.75	2.4	120	170	25.751	0.66	0.31
T18SD 3	0.0729	78.31	9.483	14.00	40.09	2.1	160	140	26.807	0.49	0.25
T18SD 4	0.0676	84.45	13.290	18.02	53.37	2.7	200	160	29.403	0.42	0.27
T18SD 5	0.0608	81.12	12.740	16.62	50.83	3.1	200	160	33.589	0.41	0.25
T18SD 6	0.0839	80.20	12.390	14.60	43.04	1.8	190	150	27.445	0.42	0.23
T18SD 7	0.0379	71.34	11.790	17.62	45.39	1.6	160	150	24.189	0.45	0.28
T19 1	0.1443	62.18	31.840	9.09	102.85	5.0	270	no sample	37.697	0.23	0.38
T19 6	0.1303	44.94	16.480	7.81	121.05	1.9	210	150	37.015	0.21	0.58
T19 7	0.1045	49.85	17.370	9.21	81.34	2.5	170	280	25.828	0.29	0.48
T3 1	0.0549	62.94	22.400	14.29	30.50	0.2	20	200	28.028	3.15	1.52
T3 7	0.0740	43.44	14.220	13.66	55.63	1.5	110	150	31.174	0.39	0.51
T3 POND 7	0.0504	66.43	5.890	19.06	35.94	1.4	140	130	18.634	0.47	0.26
T4 1	0.3341	209.60	0.000	37.57	284.65	4.5	560	660	114.224	0.37	0.51
T4 2	0.3513	66.48	20.170	30.22	265.40	5.0	420	660	97.559	0.16	0.63
T4 3	0.3884	100.80	18.040	33.65	275.30	4.7	480	400	104.368	0.21	0.57
T4 4	0.4370	114.80	14.680	18.33	219.05	3.3	330	400	44.044	0.35	0.66
T4 5	0.4560	145.30	14.050	22.24	213.80	4.4	400	480	49.731	0.36	0.53
T4 7	0.3306	122.10	15.610	19.91	215.45	3.1	310	440	57.750	0.39	0.70
T5 1	0.0582	89.60	4.555	12.17	39.15	0.4	170	220	28.732	0.53	0.23
T5 2	0.0725	89.51	5.248	12.20	38.82	0.3	130	190	30.723	0.69	0.30
T5 3	0.0728	83.11	8.613	13.56	41.20	0.5	170	210	33.583	0.49	0.24
T5 4	0.0636	81.92	8.215	13.10	41.50	1.5	150	160	26.021	0.55	0.28
T5 5	0.0742	86.20	7.718	13.20	36.94	2.1	150	180	25.729	0.57	0.25
T5 6	0.0594	84.29	7.141	13.03	36.70	1.6	160	170	21.747	0.53	0.23
T5 7	0.0617	83.88	7.531	13.43	41.33	1.8	170	180	26.070	0.49	0.24
T6 1	0.0579	102.70	0.627	18.54	46.98	0.2	200	200	26.873	0.51	0.23
T6 2	0.0591	98.71	1.545	17.87	47.36	0.1	160	250	22.066	0.62	0.30
T6 3	0.0269	31.83	3.676	6.38	17.73	0.1	20	90	12.551	1.59	0.89
T6 4	0.0758	86.39	7.347	17.85	63.00	0.5	220	180	29.634	0.39	0.29
T6 5	0.0947	83.13	6.994	16.78	61.25	0.4	220	200	30.998	0.38	0.28
T6 6	0.0880	78.82	7.660	16.09	59.11	0.3	280	170	28.831	0.28	0.21
T8 1	0.0424	96.33	1.948	26.75	26.30	2.0	200	180	27.995	0.48	0.13
T8 2	0.0243	67.43	4.328	12.09	18.03	0.6	200	170	13.134	0.34	0.09
T8 3	0.0318	58.92	5.146	12.46	18.69	0.2	10	180	12.397	5.89	1.87
T8 4	0.0499	73.32	5.735	15.12	27.41	0.5	90	180	19.663	0.81	0.30
T8 5	0.0729	83.94	6.939	16.37	32.42	0.7	130	180	24.442	0.65	0.25
T8 6	0.0609	46.33	4.279	9.08	28.32	2.0	60	130	11.847	0.77	0.47
T8 7	0.0429	47.02	4.767	9.49	31.57	1.8	70	140	11.374	0.67	0.45
T9 1	0.0534	90.88	1.671	19.36	48.06	1.2	210	220	31.185	0.43	0.23
T9 2	0.0504	86.82	2.317	17.83	45.38	1.4	140	210	27.885	0.62	0.32
T9 3	0.0655	79.32	7.028	18.59	47.83	1.5	170	190	26.268	0.47	0.28
T9 4	0.1209	102.90	8.157	22.62	61.33	1.1	270	180	43.230	0.38	0.23
T9 5	0.0471	55.88	5.414	12.50	22.99	1.9	80	170	12.276	0.70	0.29
T9 6	0.0645	63.28	5.424	13.73	26.86	1.3	100	160	11.858	0.63	0.27
T9 7	0.0406	55.76	5.140	12.93	22.41	0.4	60	170	11.616	0.93	0.37

Appendix 4. Cation / Anion Concentrations in meq/L and Balance.

Sample Name	Ca (meq/L)	K (meq/L)	Mg (meq/L)	Na (meq/L)	CATIONS (meq/L)	NO3 (meq/L)	SO4 (meq/L)	HCO3 (meq/L)	Cl (meq/L)	ANIONS (meq/L)	BALANCE	CATIONS + ANIONS	% DIFFERENCE
DOW4 1	2.27	0.193	0.65	0.47	3.585	0.04	0.3	2.6	0.10	3.06	0.52	6.65	7.8
DOW4 2	2.56	0.147	0.64	0.46	3.805	0.04	0.4	2.6	0.16	3.2	0.59	7.02	8.4
DOW4 3	2.44	0.110	0.73	0.50	3.774	0.03	0.6	3.2	0.17	4.0	-0.19	7.74	-2.5
DOW4 4	2.96	0.133	0.88	0.66	4.640	0.04	0.6	3.4	0.33	4.4	0.25	9.03	2.8
DOW4 5	2.52	0.119	0.73	0.49	3.863	0.04	0.7	2.8	0.18	3.7	0.18	7.55	2.4
DOW4 6	3.05	0.132	0.88	0.68	4.745	0.03	1.4	2.6	0.38	4.4	0.36	9.13	3.9
DOW4 7	3.14	0.146	0.98	0.82	5.080	0.03	2.1	2.4	0.47	5.0	0.09	10.07	0.9
DOW5 1	1.76	0.158	0.51	0.28	2.704	0.03	0.2	1.8	0.06	2.1	0.61	4.80	12.7
DOW5 2	1.88	0.124	0.51	0.27	2.776	0.03	0.2	2.2	0.07	2.5	0.27	5.28	5.1
DOW5 4	1.75	0.080	0.55	0.28	2.654	0.03	0.2	2.2	0.05	2.5	0.14	5.17	2.7
DOW5 5	1.78	0.080	0.52	0.26	2.646	0.03	0.2	2.2	0.06	2.5	0.13	5.16	2.5
DOW5 6	1.83	0.082	0.53	0.28	2.727	0.03	0.2	1.6	0.06	1.9	0.79	4.66	17.0
DOW5 7	1.64	0.081	0.51	0.28	2.515	0.03	0.2	2.8	0.05	3.1	-0.62	5.65	-10.9
MS 7	3.40	0.153	1.53	1.58	6.663	0.01	3.1	4.4	0.54	8.1	-1.42	14.74	-9.6
NRP 6	4.88	0.150	1.74	1.76	8.533	0.02	5.2	3.0	1.05	9.3	-0.74	17.81	-4.2
NRP 7	4.63	0.160	1.69	1.95	8.436	0.02	2.9	4.6	0.80	8.3	0.10	16.78	0.6
NRP not outlet 7	4.76	0.161	1.75	1.94	8.611	0.01	4.2	4.2	0.75	9.1	-0.52	17.74	-2.9
RP 6	3.39	0.130	1.30	1.20	6.020	0.03	2.7	2.8	0.84	6.4	-0.35	12.39	-2.8
RP 7	3.60	0.155	1.55	1.61	6.921	0.03	2.9	3.0	1.29	7.2	-0.31	14.15	-2.2
RP background	4.00	0.158	1.78	1.86	7.800	0.03	3.1	3.4	0.70	7.3	0.55	15.05	3.6
RP near T13 7	3.61	0.174	1.58	1.77	7.131	0.02	3.5	3.2	0.64	7.4	-0.26	14.52	-1.8
SL1 1	7.60	0.000	0.00	0.00	23.362	0.02	15.6	3.0	3.95	22.6	0.78	45.94	1.7
SL1 2	7.45	0.021	5.66	8.06	21.194	0.00	15.0	3.2	3.66	21.9	-0.66	43.04	-1.5
SL1 3	7.65	0.555	6.09	9.78	24.076	0.00	15.6	4.0	3.71	23.3	0.75	47.40	1.6
SL1 4	4.49	0.178	2.51	2.69	9.874	0.01	5.0	3.4	1.10	9.5	0.37	19.38	1.9
SL1 5	3.44	0.161	2.28	2.38	8.254	0.01	4.6	3.0	0.99	8.6	-0.33	16.84	-2.0
SL2 1	2.27	0.121	0.90	0.38	3.667	0.03	0.2	3.8	0.40	4.4	-0.77	8.11	-9.5
SL2 2	2.23	0.119	0.90	0.33	3.580	0.02	0.2	3.0	0.39	3.6	-0.04	7.20	-0.6
SL2 3	2.03	0.088	0.83	0.30	3.245	0.01	0.2	2.8	0.40	3.4	-0.18	6.67	-2.7
SL2 4	3.03	0.099	0.90	0.32	4.341	0.00	0.2	3.8	0.40	4.4	-0.07	8.76	-0.9
SL2 5	2.78	0.113	0.85	0.29	4.033	0.00	0.2	3.8	0.41	4.4	-0.39	8.45	-4.6
SL2 6	1.79	0.070	0.75	0.23	2.839	0.00	0.2	2.0	0.39	2.6	0.24	5.44	4.3
SL2 7	1.92	0.092	0.85	0.34	3.202	0.01	0.2	2.4	0.40	3.0	0.18	6.22	2.9
SPR1 1	8.02	0.107	6.14	9.48	23.749	0.02	15.6	3.6	3.66	22.9	0.85	46.65	1.8
SPR1 2	8.09	0.052	5.83	8.84	22.805	0.02	15.6	4.2	3.40	23.2	-0.43	46.04	-0.9
SPR1 3	6.24	0.431	5.52	8.53	20.723	0.01	14.2	2.6	3.28	20.1	0.67	40.77	1.6
SPR1 4	7.50	0.390	5.28	7.20	20.371	0.13	12.7	3.4	2.79	19.0	1.36	39.39	3.4
SPR1 5	9.22	0.485	5.88	8.87	24.451	0.04	15.6	4.2	3.72	23.6	0.87	48.03	1.8
SPR1 6	9.64	0.470	6.18	9.24	25.531	0.03	15.2	4.2	3.66	23.1	2.45	48.62	5.0
SPR1 7	9.37	0.535	6.20	10.04	26.140	0.03	15.6	5.0	4.95	25.6	0.55	51.73	1.1
SPR2 1	8.01	0.115	6.18	9.48	23.778	0.02	15.6	2.8	3.41	21.8	1.93	45.62	4.2
SPR2 2	8.10	0.053	5.84	8.85	22.838	0.02	15.6	3.6	3.02	22.2	0.59	45.09	1.3
SPR2 3	6.18	0.424	5.49	8.47	20.567	0.01	14.2	2.8	3.11	20.1	0.48	40.65	1.2
SPR2 4	7.60	0.393	5.32	7.17	20.484	0.12	12.9	3.0	2.70	18.7	1.75	39.21	4.5
SPR2 5	9.25	0.484	5.93	8.94	24.596	0.04	15.6	3.6	3.24	22.5	2.10	47.09	4.5
SPR2 6	9.71	0.471	6.17	9.26	25.611	0.03	15.6	3.8	4.33	23.8	1.84	49.38	3.7
SPR2 7	9.43	0.528	6.24	9.96	26.163	0.03	15.6	5.2	3.57	24.4	1.75	50.57	3.5
T13 Deep 1	3.98	0.065	1.34	1.62	7.002	0.04	3.3	3.8	0.71	7.9	-0.88	14.88	-5.9
T13 Deep 2	4.04	0.073	1.33	1.59	7.042	0.04	2.9	3.8	0.70	7.5	-0.42	14.50	-2.9
T13 deep 3	3.78	0.150	1.47	1.71	7.107	0.03	4.0	3.6	0.74	8.3	-1.22	15.43	-7.9
T13 deep 4	4.05	0.167	1.53	1.85	7.590	0.04	3.5	3.2	0.84	7.6	-0.03	15.21	-0.2
T13 deep 5	4.16	0.164	1.52	1.77	7.609	0.04	4.0	3.4	0.78	8.2	-0.57	15.79	-3.6
T13 deep 6	4.30	0.171	1.59	1.79	7.851	0.04	4.6	2.6	1.01	8.2	-0.38	16.08	-2.4
T13 deep 7	4.45	0.165	1.73	1.88	8.224	0.03	3.5	2.2	0.96	6.7	1.50	14.95	10.0
T13 deep background	3.89	0.164	1.44	1.60	7.096	no value	no value	no value	0.70	no value	no value	no value	no value
T13 ES 1	4.14	1.672	1.83	1.56	9.205	0.04	4.6	3.4	0.94	9.0	0.24	18.17	1.3
T13ES 6	3.66	0.676	1.87	1.62	7.824	0.03	4.0	3.0	0.77	7.8	0.07	15.58	0.4
T13ES 7	3.60	0.538	1.98	1.52	7.634	0.02	3.7	3.6	0.71	8.1	-0.45	15.72	-2.8
T13ES background	3.31	1.048	1.22	1.45	7.026	no value	no value	no value	0.58	no value	no value	no value	no value
T15 1	2.65	0.463	0.65	1.38	5.152	0.06	0.4	4.0	0.13	4.6	0.54	9.77	5.5
T15 7	2.48	0.262	0.73	1.29	4.753	0.05	0.2	4.6	0.09	4.9	-0.20	9.70	-2.0

Appendix 4. Cation / Anion Concentrations in meq/L and Balance.

Sample Name	Ca (meq/L)	K (meq/L)	Mg (meq/L)	Na (meq/L)	CATIONS (meq/L)	NO3 (meq/L)	SO4 (meq/L)	HCO3 (meq/L)	Cl (meq/L)	ANIONS (meq/L)	BALANCE	CATIONS + ANIONS	% DIFFERENCE
T16 6	2.13	0.677	4.03	1.82	8.657	0.04	4.6	2.8	0.82	8.2	0.42	16.89	2.5
T16 7	1.85	0.468	3.38	1.36	7.062	0.02	3.5	4.6	0.69	8.9	-1.79	15.91	-11.2
T17ND 1	3.81	0.186	1.74	1.55	7.284	0.03	3.5	3.4	0.69	7.7	-0.37	14.94	-2.5
T17ND 2	3.96	0.183	1.95	1.54	7.632	0.04	3.1	3.8	0.75	7.7	-0.08	15.34	-0.5
T17ND 3	4.15	0.252	2.61	1.85	8.861	0.02	4.8	3.6	0.94	9.4	-0.49	18.21	-2.7
T17ND 4	4.58	0.299	2.72	2.06	9.669	0.03	4.0	3.6	0.94	8.5	1.15	18.19	6.3
T17ND 5	3.82	0.275	2.49	1.93	8.516	0.04	4.6	3.8	0.97	9.4	-0.87	17.91	-4.9
T17ND 6	3.75	0.191	1.71	1.65	7.298	0.03	4.0	3.4	0.75	8.1	-0.84	15.43	-5.4
T17ND 7	3.49	0.175	1.55	1.69	6.903	0.03	3.1	3.2	0.66	7.0	-0.12	13.92	-0.8
T17ND background	3.29	0.289	1.43	1.47	6.471	no value	no value	no value	0.61	no value	no value	no value	no value
T17SS 1	2.41	0.631	0.55	5.88	9.465	0.08	6.7	4.0	0.78	11.5	-2.05	20.98	-9.8
T17SS 6	1.64	0.303	0.48	5.64	8.055	0.03	4.6	3.2	1.07	8.9	-0.82	16.93	-4.9
T17SS 7	1.45	0.313	0.43	5.61	7.798	0.07	4.4	4.4	1.26	10.1	-2.31	17.91	-12.9
T17SS background	1.73	0.342	0.48	4.89	7.431	no value	no value	no value	0.67	no value	no value	no value	no value
T18NS 1	3.05	0.751	0.92	5.84	10.560	0.06	4.2	7.0	1.83	13.1	-2.50	23.62	-10.6
T18NS 7	3.21	0.410	1.05	4.02	8.690	0.05	3.5	4.6	0.85	9.0	-0.35	17.73	-2.0
T18SD 1	3.99	0.216	0.96	1.66	6.834	0.04	3.1	3.4	0.69	7.2	-0.41	14.08	-2.9
T18SD 2	3.95	0.186	1.08	1.64	6.857	0.04	2.5	3.4	0.73	6.7	0.19	13.52	1.4
T18SD 3	3.91	0.243	1.15	1.74	7.046	0.03	3.3	2.8	0.76	6.9	0.12	13.97	0.9
T18SD 4	4.21	0.340	1.48	2.32	8.358	0.04	4.2	3.2	0.83	8.2	0.12	16.60	0.7
T18SD 5	4.05	0.326	1.37	2.21	7.952	0.05	4.2	3.2	0.95	8.4	-0.41	16.31	-2.5
T18SD 6	4.00	0.317	1.20	1.87	7.392	0.03	4.0	3.0	0.77	7.8	-0.37	15.15	-2.4
T18SD 7	3.56	0.302	1.45	1.97	7.286	0.03	3.3	3.0	0.68	7.0	0.25	14.33	1.7
T19 1	3.10	0.814	0.75	4.47	9.140	0.08	5.6	no sample	1.06	no value	no value	no value	no value
T19 6	2.24	0.422	0.64	5.27	8.572	0.03	4.4	3.0	1.04	8.4	0.12	17.02	0.7
T19 7	2.49	0.444	0.76	3.54	7.228	0.04	3.5	5.6	0.73	9.9	-2.68	17.14	-15.6
T3 1	3.14	0.573	1.18	1.33	6.216	0.00	0.4	4.0	0.79	5.2	1.01	11.43	8.8
T3 7	2.17	0.364	1.12	2.42	6.075	0.02	2.3	3.0	0.88	6.2	-0.12	12.27	-1.0
T3 POND 7	3.31	0.151	1.57	1.56	6.597	0.02	2.9	2.6	0.53	6.1	0.53	12.66	4.2
T4 1	10.46	0.000	3.09	12.38	25.933	0.07	11.7	13.2	3.22	28.2	-2.22	54.09	-4.1
T4 2	3.32	0.516	2.49	11.54	17.865	0.08	8.7	13.2	2.75	24.8	-6.91	42.64	-16.2
T4 3	5.03	0.461	2.77	11.98	20.236	0.08	10.0	8.0	2.94	21.0	-0.78	41.25	-1.9
T4 4	5.73	0.376	1.51	9.53	17.141	0.05	6.9	8.0	1.24	16.2	0.97	33.31	2.9
T4 5	7.25	0.359	1.83	9.30	18.740	0.07	8.3	9.6	1.40	19.4	-0.66	38.14	-1.7
T4 7	6.09	0.399	1.64	9.37	17.503	0.05	6.5	8.8	1.63	16.9	0.57	34.44	1.7
T5 1	4.47	0.117	1.00	1.70	7.292	0.01	3.5	4.4	0.81	8.8	-1.46	16.05	-9.1
T5 2	4.47	0.134	1.00	1.69	7.293	0.00	2.7	3.8	0.87	7.4	-0.08	14.67	-0.6
T5 3	4.15	0.220	1.12	1.79	7.275	0.01	3.5	4.2	0.95	8.7	-1.42	15.97	-8.9
T5 4	4.09	0.210	1.08	1.81	7.181	0.02	3.1	3.2	0.73	7.1	0.10	14.26	0.7
T5 5	4.30	0.197	1.09	1.61	7.192	0.03	3.1	3.6	0.73	7.5	-0.29	14.67	-2.0
T5 6	4.21	0.183	1.07	1.60	7.057	0.03	3.3	3.4	0.61	7.4	-0.31	14.43	-2.2
T5 7	4.19	0.193	1.11	1.80	7.281	0.03	3.5	3.6	0.74	7.9	-0.62	15.19	-4.1
T6 1	5.12	0.016	1.53	2.04	8.710	0.00	4.2	4.0	0.76	8.9	-0.22	17.64	-1.2
T6 2	4.93	0.040	1.47	2.06	8.496	0.00	3.3	5.0	0.62	9.0	-0.46	17.45	-2.6
T6 3	1.59	0.094	0.52	0.77	2.978	0.00	0.4	1.8	0.35	2.6	0.41	5.55	7.3
T6 4	4.31	0.188	1.47	2.74	8.708	0.01	4.6	3.6	0.84	9.0	-0.32	17.73	-1.8
T6 5	4.15	0.179	1.38	2.66	8.372	0.01	4.6	4.0	0.87	9.5	-1.09	17.83	-6.1
T6 6	3.93	0.196	1.32	2.57	8.024	0.00	5.8	3.4	0.81	10.0	-2.02	18.07	-11.2
T8 1	4.81	0.050	2.20	1.14	8.202	0.03	4.2	3.6	0.79	8.6	-0.38	16.79	-2.3
T8 2	3.36	0.111	0.99	0.78	5.255	0.01	4.2	3.4	0.37	7.9	-2.69	13.20	-20.4
T8 3	2.94	0.132	1.03	0.81	4.910	0.00	0.2	3.6	0.35	4.2	0.75	9.07	8.3
T8 4	3.66	0.147	1.24	1.19	6.242	0.01	1.9	3.6	0.55	6.0	0.21	12.28	1.7
T8 5	4.19	0.177	1.35	1.41	7.123	0.01	2.7	3.6	0.69	7.0	0.12	14.13	0.8
T8 6	2.31	0.109	0.75	1.23	4.400	0.03	1.2	2.6	0.33	4.2	0.18	8.62	2.1
T8 7	2.35	0.122	0.78	1.37	4.622	0.03	1.5	2.8	0.32	4.6	0.01	9.23	0.2
T9 1	4.53	0.043	1.59	2.09	8.261	0.02	4.4	4.4	0.88	9.7	-1.41	17.93	-7.9
T9 2	4.33	0.059	1.47	1.97	7.833	0.02	2.9	4.2	0.79	7.9	-0.09	15.76	-0.6
T9 3	3.96	0.180	1.53	2.08	7.748	0.02	3.5	3.8	0.74	8.1	-0.36	15.85	-2.2
T9 4	5.13	0.209	1.86	2.67	9.872	0.02	5.6	3.6	1.22	10.5	-0.59	20.33	-2.9
T9 5	2.79	0.138	1.03	1.00	4.955	0.03	1.7	3.4	0.35	5.4	-0.49	10.40	-4.7
T9 6	3.16	0.139	1.13	1.17	5.595	0.02	2.1	3.2	0.33	5.6	-0.04	11.23	-0.4
T9 7	2.78	0.131	1.06	0.97	4.953	0.01	1.2	3.4	0.33	5.0	-0.03	9.94	-0.3