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# Identification of geochemical facies through major ion data and additional parameters from shallow groundwater utilizing a comparison of geomathematics and traditional methods in Las Vegas Valley, Nevada

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# IDENTIFICATION OF GEOCHEMICAL FACIES THROUGH MAJOR ION DATA AND ADDITIONAL PARAMETERS FROM SHALLOW GROUNDWATER UTILIZING A COMPARISON OF GEOMATHEMATICS AND TRADITIONAL METHODS IN LAS VEGAS VALLEY, NEVADA

by

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Bachelor of Science in Geology
University of Nevada, Las Vegas
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A thesis submitted in partial fulfillment
of the requirements for the

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We recommend the thesis prepared under our supervision by

**Eric L. Dano**

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# Identification of Geochemical Facies through Major Ion Data and Additional Parameters from Shallow Groundwater Utilizing a Comparison of Geomathematics and Traditional Methods in Las Vegas Valley, Nevada

be accepted in partial fulfillment of the requirements for the degree of

**Master of Science in Geoscience**

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**August 2010**

# ABSTRACT

## Identification of Geochemical Facies through Major Ion Data and Some Additional Parameters from Shallow Groundwater Utilizing a Comparison of Geomathematics and Traditional Methods in Las Vegas Valley, Nevada

by

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There has been little exploration to identify geochemical facies in shallow groundwater in the Las Vegas Valley in Clark County, Nevada. Identification of hydrochemical facies in Las Vegas Valley is important for assessing the extent and nature of a potential groundwater resource. The identification of facies could be complicated by the possibility that secondary recharge constitutes a hydrochemical facies of its own. To identify geochemical facies, groundwater samples for major ions, stable isotopes and some municipal tracers were collected from 35 wells in an established network of monitor wells. Wells were purged with a bailer or 12V pump and EC, pH, and Temperature were collected in the field. Collected samples were submitted to SNWS laboratory for analysis. Total dissolved solids ranged from 997 to 9121 mg/l with a standard deviation of 1981. PCA was run with a Statistica and the resulting in 90% of the variance associated with the first five components. The results were then kriged with Surfer and projected as a raster grid in ArcMap. A successful attempt was made to identify facies utilizing PCA and a comparison of the results to traditional trilinear diagram methods supported the findings. Identified facies ranged from a Mg-Ca-$SO_4$-$HCO_3$ water in the northwest to a Na-Mg-$SO_4$-Cl water in the southeast. Facies occur roughly perpendicular to the general direction of flow in the basin. An attempt to identify secondary recharge as a distinct facies was unsuccessful. This was either due to a uniform impact throughout the shallow groundwater system, or the impact of secondary recharge is less significant and more localized.

TABLE OF CONTENTS

## LIST OF FIGURES

# LIST OF TABLES

# ACRONYMS AND ABBREVIATIONS

## ACRONYMS

| | |
|---|---|
| CCRFCD | Clark County Regional Flood Control District |
| DRI | Desert Research Institute |
| EC | electroconductivity |
| EPA | Environmental Protection Agency |
| ESRI | Environmental Systems Research Institute, Inc. |
| ET | evapotranspiration |
| GIS | geographical information system |
| LVVWD | Las Vegas Valley Water District |
| NEL | Nevada Environmental Laboratories |
| PCA | principal component analysis |
| PC | principal components |
| PDC | Pacific Disaster Center |
| SNWA | Southern Nevada Water Authority |
| SNWS | Southern Nevada Water System |
| TDS | total dissolved solids |
| THM | trihalomethane |
| VOA | volatile organic analyte |
| WGS | world geodetic system |

## ABBREVIATIONS

| | |
|---|---|
| asl | above sea level |
| bgs | below ground surface |
| cm | centimeter |
| ft | foot |
| gpm | gallons per minute |
| in. | inch |
| µm | micron |
| ml | milliliter |
| m | meter |
| µs | microsiemen |
| mg/l | milligram per liter (ppm) |
| sec | second |
| V | volt |

# CHAPTER 1

# PURPOSE AND SCOPE

Hydrochemical facies describe groundwater masses within an aquifer that differ in their chemical composition. For the purposes of the present study, to constitute a facies, a chemical regime must be both spatially significant and continuous at the geographic scale under investigation. This thesis first investigates the geochemical similarity of shallow groundwater from different areas in the Las Vegas Valley, then assesses spatial continuity.

A detailed analysis of the chemical composition of groundwater in Las Vegas can benefit resource managers; however, identifying geochemical facies in shallow groundwater is potentially complicated by the impacts of infiltration of excess irrigation water (secondary recharge). While much has been done to identify geochemical facies in the deeper aquifer systems in Las Vegas (Dettinger, 1987; Brothers and Katzer, 1989; Hines et al, 1993; Leising, 2004), there has been little recent exploration to identify shallow groundwater geochemical facies. Also, little has been done to understand the potential degree to which secondary recharge has impacted the area's shallow groundwater system and influenced the shallow groundwater geochemistry. A better understanding of geochemical facies and irrigation impacted areas in shallow groundwater could potentially aid both in resource evaluations and nuisance water investigations.

The quality of shallow groundwater in Las Vegas Valley has important implications, as quality affects the groundwater's potential as a resource, and can also indicate where negative impacts may be mitigated. Shallow groundwater constitutes a potential resource through desalination, a nuisance in the urbanized area, and even a potential way to evaluate the efficacy of water conservation programs. For example, identifying geochemical facies could aid in site selection for desalination facilities, based on expected water quality and expected recovery.

Little has been done to put shallow groundwater to beneficial use given the costs of infrastructure, cost of brine disposal, and difficulty of extraction in significant quantities. Putting shallow groundwater to beneficial use is encouraged in that pumping water to mitigate nuisance water conditions has been declared a beneficial use in the Las Vegas basin (NRS 534.025). Nuisance water is shallow groundwater that emanates in undesirable locations such as basements and landscaping. In 1948 Maxey and Jameson described a 3406 l/m (900 gpm) gain to the city sewer system and near surface water that caused problems with construction projects and basements “especially within the city limits of Las Vegas” (Maxey and Jameson, 1948). These workers may have been the first to describe nuisance water in Las Vegas. Because of poor quality, shallow groundwater can also damage landscape plants (SNWA, 2002). In some areas the presence of high sulfate in the water makes it aggressive toward concrete, leading to weakened foundations and footings and potential damage to structures (Boyd and Mindness, 2004). With the knowledge of the extent of geochemical facies, the potential damage to infrastructure could be assessed and remediation plans more readily developed. Similarly, resource development efforts could be aided by identifying target sites for desalination facilities based on expected water quality and expected recovery. Mitigation of nuisance water usually requires a discharge permit that places restrictions on the quality of the water that can be discharged; therefore, putting shallow groundwater to beneficial use is a more desirable form of mitigation (NRS 445A.465, NRS 445A.565). On a planning level, recognizing geochemical facies could provide a way to evaluate the efficacy of water conservation programs.

Identification of geochemical facies in the shallow system that are analogous to or derived from facies identified by previous investigators in deeper aquifer systems in Las Vegas would aid in determining the sources and evolution of shallow groundwater. Identifying similarities and differences of physically adjacent waters in the basin would support test assumptions regarding connection and direction of flow between aquiformations. Earlier investigations have proposed secondary recharge, mineral dissolution, and concentration through evapotranspiration as the causes for increased dissolved solids in the shallow system (Dinger, 1977; Dettinger, 1987; Hines et al, 1993; Bernholtz, 1993; and Zikmund, 1996). A shift in the relative proportions of normally conservative ions during transport might suggest mineral dissolution or mixing with other waters. The research in this thesis explores the ability of Principal Component Analysis (PCA) to provide a better understanding of geochemical facies and irrigation impacted areas.

PCA is a form of data exploration used as an aid to simplify a dataset by identifying as few variables [dimensions] as possible that control most of the variance in the dataset (Everitt and Dunn, 1992). The actual variability in many real sets of data is generally constrained to a few dimensions (Wickens, 1995). This simplification method will fail if roughly 75% of the variance is not associated with the first four variables because the interpretation will likely not be meaningful and might be impossible altogether (Morrison, 1967).

PCA is often used when dealing with complex trace metals data (Kreamer et al., 1996; Stetzenbach et al., 2001). PCA has also been used to determine mixing proportions and mass balance calculations (Laaksoharju et al.,1999). PCA was utilized recently to differentiate between groundwater and surface water on the Gangetic Plain in India (Singh et al., 2005). PCA, in conjunction with cluster analysis, has been utilized in surface water studies to identify spatial and temporal patterns in water chemistry (Momen et. al., 1996). A similar approach was also utilized in Spain to identify spatial and temporal patterns on a stream over the duration of a year (Elosegui, 1994). The diversity of applications regarding PCA demonstrates the utility of a tool that is based on relatively simple mathematical concepts. One objective of the present thesis is to test whether this method can readily substitute for traditional methods such as Piper diagrams in identifying geochemical facies.

Piper trilinear diagrams are a graphical representation of major ion chemistry. Suites of samples from waters with similar chemistry tend to plot in clustered groups. Mixed waters and evolved chemistries plot as aligned points between clusters from the end members (Piper, 1944). Research for the present thesis initially assumed that in trilinear plots, ionic ratios of shallow groundwater significantly impacted by the infiltration of irrigation water should cluster closer to those of the municipal supply; similarly, shallow groundwater derived from the upward migration of deeper water should cluster closer to water from wells that draw from deeper aquifer systems. Piper trilinear diagrams will therefore also be utilized to illustrate geochemical regimes within the shallow groundwater system. Analyses of mixed waters with differing degrees of mixing were expected to plot as a compositional trend between the two regimes. For example, compositional trend between a water that plots in the regime of deep groundwater and a water that plots in the regime of shallow groundwater for the valley could suggest an evolution from one to the other.

## 1.1 Hypotheses

For the present study, the following hypotheses are proposed:

1. PCA can substitute for Piper trilinear diagrams to identify geochemical facies that are defined using major ion concentrations.
2. PCA can also identify geochemical facies by supplementing major ion data with parameters not generally utilized in trilinear diagrams.
3. PCA can identify an irrigation leaching fraction and determine if it constitutes a distinct spatially significant facies.

The main hypothesis is that Principal Component Analysis (PCA), conducted with major ion data and some additional parameters, can substitute for Piper trilinear diagrams to identify geochemical facies in shallow groundwater in the Las Vegas Valley. The approach used for the present study was similar to that of Dalton and Upchurch (1978) in Florida where factor analysis, a similar process, was used to augment Piper trilinear diagrams in interpreting multiple mixing trends. Secondarily to the use of major ion data, PCA can identify geochemical facies by incorporating major cation and anion data with supplemental parameters not generally utilized in trilinear diagrams. Unlike the work of Kreamer et al. (1996) or Stetzenbach et al. (1999), where PCA was performed on trace metals data, the present study will utilize major ion data as well as less often used parameters such as trihalomethanes (THMs), perchlorate ($ClO_4^-$), deuterium (D) and oxygen$^{18}$ ($^{18}O$) in distinguishing like and unlike waters.

Trihalomethane and $ClO_4^-$ function as municipal tracers. Both are present in Las Vegas Valley treated municipal drinking water. THM are disinfection byproducts that result from the chlorination process during treatment of water for the potable supply. Perchlorate is an industrial contaminant found in Lake Mead and subsequently in the potable water supply (ITRC, 2005). D and $^{18}O$ are isotopes present in water molecules. The ratios of these isotopes with respect to a known standard can vary due to processes of evaporation and condensation. These variations reflect the seasonal timing of precipitation, and subsequent natural recharge. Variations can also result in a shift in isotopic ratio from a meteoric trend that reflects the degree to which evaporation has impacted a water.

The third hypothesis was tested using PCA to identify the leaching fraction from the infiltration of irrigation water, and the results incorporated into GIS analysis to determine whether the leaching fraction constitutes a distinct geochemical facies. The leaching fraction is the component of shallow groundwater derived from irrigation using the municipal supply. Differentiating the irrigation leaching fraction from native groundwater requires distinguishing geochemically distinct source waters that have been acted upon by two processes. The chemical makeup of the leaching fraction has been impacted by evapotranspiration and possibly by dissolution or precipitation of pedic mineral phases prior to its entry into the saturated part of the shallow groundwater system. Native groundwater can dissolve or precipitate soluble minerals when passing through sediment in the valley fill to enter the shallow system (Leisiing,2004; Malmberg, 1965).

PCA was used to reduce the data to the components that most represent the variance within the dataset. The principal component scores were represented in an x-y scatter-plot and then utilized for a graphic representation of the data by relating the two groups of data with the most variance to each other. Like waters should then cluster within the plot in much the fashion observed in trilinear diagrams. These clusters will then have to be further examined for intuitive associations including similar geography or source water dominance as associated with specific site details.

Additionally, it is hypothesized that PCA can distinguish the irrigation leaching fraction from shallow groundwater of a different origin. This third hypothesis was tested by determining if the irrigation leaching fraction constitutes a distinct spatially significant facies. If the leaching fraction is neither spatially significant nor continuous, then its not a facies but its presence locally within the shallow system may hinder efforts to identify existing natural geochemical facies. The present study will attempt to use PCA analysis to identify such cases, and to determine which data to sequester to better identify natural geochemical facies. The results of the PCA scenarios will be compared to trilinear diagrams to determine if the results are consistent with traditional methods for identifying geochemical facies.

The first task of this project involved the collection of data from selected shallow wells in the Las Vegas Valley. Laboratory analytical results were quality assured, and the data were supplemented with previously published water concentrations from the study area. After quality assurance and compilation was conducted, Piper trilinear diagrams were constructed and Principal Component Analysis was performed

## 1.2 Background

The city of Las Vegas Valley, located in Clark County, Nevada, was named after a campsite on the Old Spanish Trail. The name signifies fertile or marshy plains (Carlson, 1974). Las Vegas steadily grew from a population of 30 in 1855 (Jones and Cahlan, 1975) to an estimated 2 million at the end of 2007 (Brean, 2007). The population increase has led to an extensive urbanized area within the Las Vegas Valley.

### 1.2.1 Physiography

The Las Vegas Basin is approximately 48 km (30 miles) long and 80 km (50 miles) wide (Plume, 1986) comprising a total area of about 4000 km^2 or 1600 square miles. Relief ranges from approximately 3658 m asl (12,000 ft asl) in the Spring Mountains to the west, 3048 m asl (10,000 ft asl) in the Las Vegas Range and Sheep Mountains to the north, and 457 m asl (1,500 ft asl) in the southeast (Zikmund, 1997). This point is where the Las Vegas Wash discharges to the Colorado River basin.

### 1.2.2 Climate

The climate in the Las Vegas Valley is classified as hot arid desert (BWh) in the Köppen–Geiger system (Peel et al., 2007). The valley floor receives approximately 10 cm (4 in.) of precipitation a year (Donovan and Katzer, 2000) with an average evapotranspiration of 218 cm (86 in.) and potential evapotranspiration greater than 240 cm (94 in.) (Shevenell, 1996). The valley floor is classified as E – arid under the Thornthwaite climate regions classification based on a moisture index of -95.8 (Gabler et al., 2009 after Thornthwaite, 1948). The mountains receive approximately 48 cm (19 in.) of water equivalent precipitation per year above 1219 m asl (4,000 ft asl), mostly as snow (Donovan and Katzer, 2000) over a recharge area of 399,654 hectares (987,564 acres). Natural recharge estimates range from about 3.58 x $10^{\wedge 7}$ $m^3$ (29,000 acre-ft) (Harrill,1976) to approximately 6.29 x $10^{\wedge 7}$ $m^3$ (51,000 acre-ft) (Donovan and Katzer, 2000).

### 1.2.3 Structural Setting

The Las Vegas Valley is a structurally controlled graben situated in the Basin and Range province of western North America. The basin was created by a combination of right lateral shearing in the Las Vegas Shear zone and Cenezoic normal faulting and underwent greater than 100% extension in the Miocene (Wernicke, 1984). Basin fill consists of coarse grained alluvial fan deposits derived from the adjacent mountain blocks that become finer towards the basin center where the alluvium is interbedded with fine-grained playa and paludal deposits. Figure 1 (after Malmberg, 1965) depicts a vertically exaggerated cross section illustrating the interaction between basin geometry, geology, and groundwater flow.

### 1.2.4 Hydrogeology

Donovan (1996) formally described three aquiformations in the basin fill. The uppermost unit is the Las Vegas Wash Aquitard, which ranges from 60 to 135 meters (196 to 443 ft), and is host to the shallow groundwater system. Though locally capable of small-scale water production, the hydraulic conductivity of this unit is generally low, so on a regional scale it is considered to be an aquitard. An aquitard is “a confining bed …

and does not readily yield water to wells or springs, but may serve as a storage unit for groundwater" (Bates and Jackson, 1984).

In contrast, an aquifer is defined as a geologic unit "sufficiently permeable to yield economically significant quantities of water to wells and springs" (Bates and Jackson, 1984). Most of the groundwater used in the Las Vegas Valley comes from the Las Vegas Springs Aquifer, which underlies the Las Vegas Wash Aquitard and is between 200 and 350 meters (656 and 1148 ft) thick (Donovan, 1996). The deepest aquiformation, the Duck Creek Aquifer, is largely untapped due to its depth, poorer water quality, and lower transmissivity. The maximum thickness of the Duck Creek aquifer is not defined (Donovan, 1996). According to Donovan, deeper aquiformations contribute groundwater recharge to the shallow groundwater system.

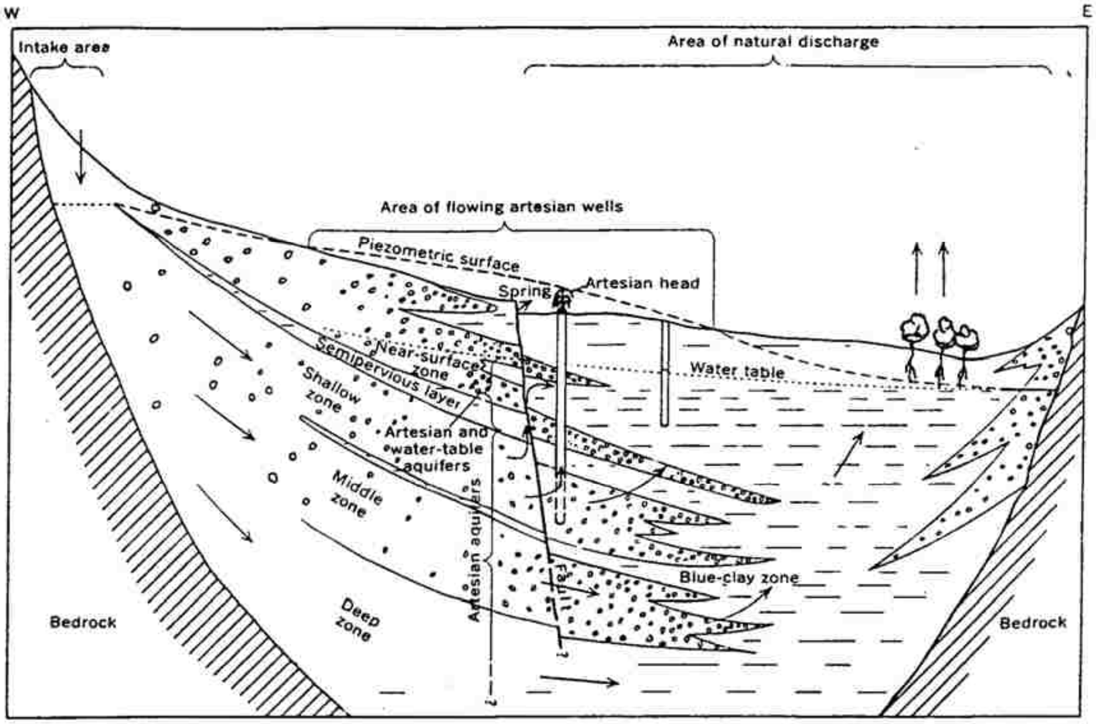


**Figure 1 Cartoon crossection depicting groundwater conditions in the Las Vegas Valley after Malmberg, 1965.**

The shallow groundwater system is the focus of the research described in this thesis, and has historically had several different definitions. The shallow system was first discussed by Maxey and Jameson (1948), who described the portion of the Valley with "near surface water" as the area to the south of Tule Springs Ranch (near present-day Rancho and US95) extending southeast toward downtown Las Vegas, east to the Las Vegas Wash, and south to an area west of Whitney, located near Russell and Boulder Hwy (Fig.2). Kaufmann (1978) further described the shallow system in an analysis of the effects of land and water use on groundwater quality; Brothers and Katzer, (1988) described the "Shallow Aquifer" as being that portion of the water table within 9 m (30 ft) of land surface. Hines, Cole and Donovan, (1993), refer to a "shallow/intermediate zone" of unspecified depth. These earlier attempts to define the shallow system relied on depth and location based definitions.

Using a different approach, Donovan (1996) defined his aquiformations based on hydraulic properties, independent of the presence of saturated groundwater. In this context, previous workers references to the shallow system or "shallow aquifer(s)" actually refer to the saturated portion of the Las Vegas Wash Aquitard (Leising 2004). Although portions of the shallow system can produce more water than others, to refer to the entire shallow system as an aquifer is a misnomer, because relative to the underlying primary aquifers the productivity of the shallow groundwater system is low. The present study will likewise take the approach that the shallow system is a region within the larger saturated flow system that occurs within 30 m (100 ft) of land surface and is contained within the Las Vegas Wash Aquitard per Leising (2004).

Movement through this saturated flow system is controlled for the most part by topography. Overall flow is from the northwest to the southeast toward the Las Vegas Wash. There are numerous small discharge points to washes throughout the shallow system that sustain base flows within the Las Vegas Wash tributary network. Spring/seep flow and evapotranspiration (ET) are significant discharges in areas with the depth to groundwater less than 3 m (10 ft) (Devitt et al., 2002). The rate of movement toward the washes is largely restricted by the typically low hydraulic conductivity of the Las Vegas Wash Aquitard (Donovan, 1996). Horizontal hydraulic conductivity in the downtown Las Vegas area ranges from $3.28 \times 10^{-4}$ cm/sec ($1.08 \times 10^{-5}$ ft/sec) to $5.49 \times 10^{-3}$ cm/sec ($1.8 \times 10^{-4}$ ft/sec) (Western Technologies, 1991).

### 1.2.5 Lithology of the Las Vegas Wash Aquitard

In the Las Vegas Valley, the typically low hydraulic conductivity within the Las Vegas Wash Aquitard is due to the presence of strongly cemented, coarse grained sediments in the western portions and silt-clay dominated, fine grained sediments in the eastern portions (Donovan, 1996). The dominant units are Tertiary Muddy Creek Formation and Quaternary to Tertiary fine grained sediments. Unit thicknesses range from less than 300m (1000 ft) for the Muddy Creek Formation to as much as 4000 to 6000m (13,000 to 19,000 ft). The Muddy Creek Formation is a gypsiferous mudstone and sandstone composed of finely-bedded sand, silt, and calcareous mudstone with minor gravels (Page et al., 2005). The majority of the Quaternary units form thin veneers on the surface that range in thickness from .5 to 5m (1.5 to 16 ft) (Page et al., 2005). The surficial deposits include lithologies associated with aeolian, fluvial, alluvial and spring mound deposits. A more detailed description of the lithologic units can be found in Appendix 1.

The wells used in this study intercept a number of Quaternary and Tertiary geologic units that comprise the Las Vegas Wash Aquitard. Many of these wells are part of a shallow groundwater monitoring network currently maintained by SNWA, from which a subset of representative wells was selected. Samples collected from these wells provide data for the PCA and Piper analysis used in this research.

# CHAPTER 2

# METHODOLOGY

The following section will discuss the methodology for acquiring, preparing, and interpreting data necessary to test the hypothesis that PCA can be used as a surrogate for trilinear diagrams in identifying geochemical facies. Methods described include selection of a subset of wells from the SNWA shallow groundwater monitoring network, procedures for groundwater sample collection, a listing of the sample parameters to be used in this research, a brief discussion of the laboratory analytical methods used to generate the groundwater quality data. There will be discussion of the quality assurance process to determine the viability of these data. Additional methods discussed will cover the statistical methods used to generate visualizations of these data. Data visualization methods will include the generation of Piper trilinear diagrams, the PCA process, kriging of datasets for the purpose of spatial visualization, and GIS applications for the purpose of map based comparisons of the dataset.

## 2.1 Well Selection

Sites were selected from the existing Southern Nevada Water Authority (SNWA) shallow groundwater monitoring network.

The SNWA shallow groundwater monitoring network originated through a Desert Research institute (DRI) reconnaissance and investigation into the hydrology and hydrochemistry of the shallow alluvuial aquifer zone (Wild et. al, 1991). From there the network was monitored by DRI until SNWA took responsibility in the late 1990's. The network was expanded to include data from wells observed by outside agencies and consultants working on groundwater contamination sites. These data are periodically accesed from reports submitted to the Nevada Division of Environmental Protection, or direct contact with the agencies as is the case with the City of Henderson. These date are mostly used by SNWA in the generation of the depth to water contour map (SNWA, 2003).

Sites selected fit three criteria including the existence of past water quality data, diversity among site conditions, and the spatial distribution of wells in an effort to minimize long distances between sample locations to effectively characterize the chemical variability within the shallow groundwater system.

The primary site selection criterion was the existence of previous water quality data, which served to assess the degree of variability and functioned as a consistency check for analytical results. The selection process identified 35 wells suitable for analysis that can be grouped into five settings, or site conditions. The grouping was intended to aid determining whether secondary recharge constituted its own facies or a separate impact. Settings include wells located in gravel areas or native desert landscape, areas immediately adjacent to perennially active streams, parks or golf courses in areas of irrigated turf, paved streets in residential areas, and paved areas in commercial settings. The diversity of site conditions was based on the assumption that land use or conditions immediately surrounding a well could influence groundwater chemistry.

Sites were geographically distributed throughout the shallow system to ensure that facies would not be defined by small groupings of wells. The sites selected for groundwater sampling are described in detail in Appendix 2. The following sites were selected for groundwater sampling (Figure 2).

## 2.2 Groundwater Sampling Methodology

Upon selection of representative or available wells, groundwater sample collection commenced. Water samples were collected from 35 wells intersecting the shallow groundwater system. The sampling methodology involved purging all wells prior to sample collection in order to ensure sample collection occurred from fresh well water. A standard of either three well volumes or stable electrical conductivity (EC) in the well discharge was used to indicate that a sample was representative of the surrounding groundwater and not impacted by stagnation or reaction with well materials. Wells were purged with a 12V submersible pump, disposable bailer, or a Grundfos 220V Variflow submersible pump. During the well purge, discharge water volume was measured using five-gallon plastic buckets.

In situations where the purge volume was small or the time and effort to set up a pump exceeded the effort to bail the well then a disposable bailer was the preferred method for water sample collection. Purging with a disposable bailer was especially desirable as there was reduced risk of contamination from pump equipment. The purging method was recorded for each site, and is reported in Appendix 2.

## 2.3 Field Analysis

Field chemistry was collected at the time of sample collection. Parameters included EC, pH, and temperature. The EC was measured in the field with a Cole Parmer model 1481-61 conductivity meter using a platinum probe. The EC meter was calibrated (typically daily before going into the field, with some exceptions) with 500 μs/cm and 1000 μs/cm conductivity standards prepared by the SNWA water quality lab.

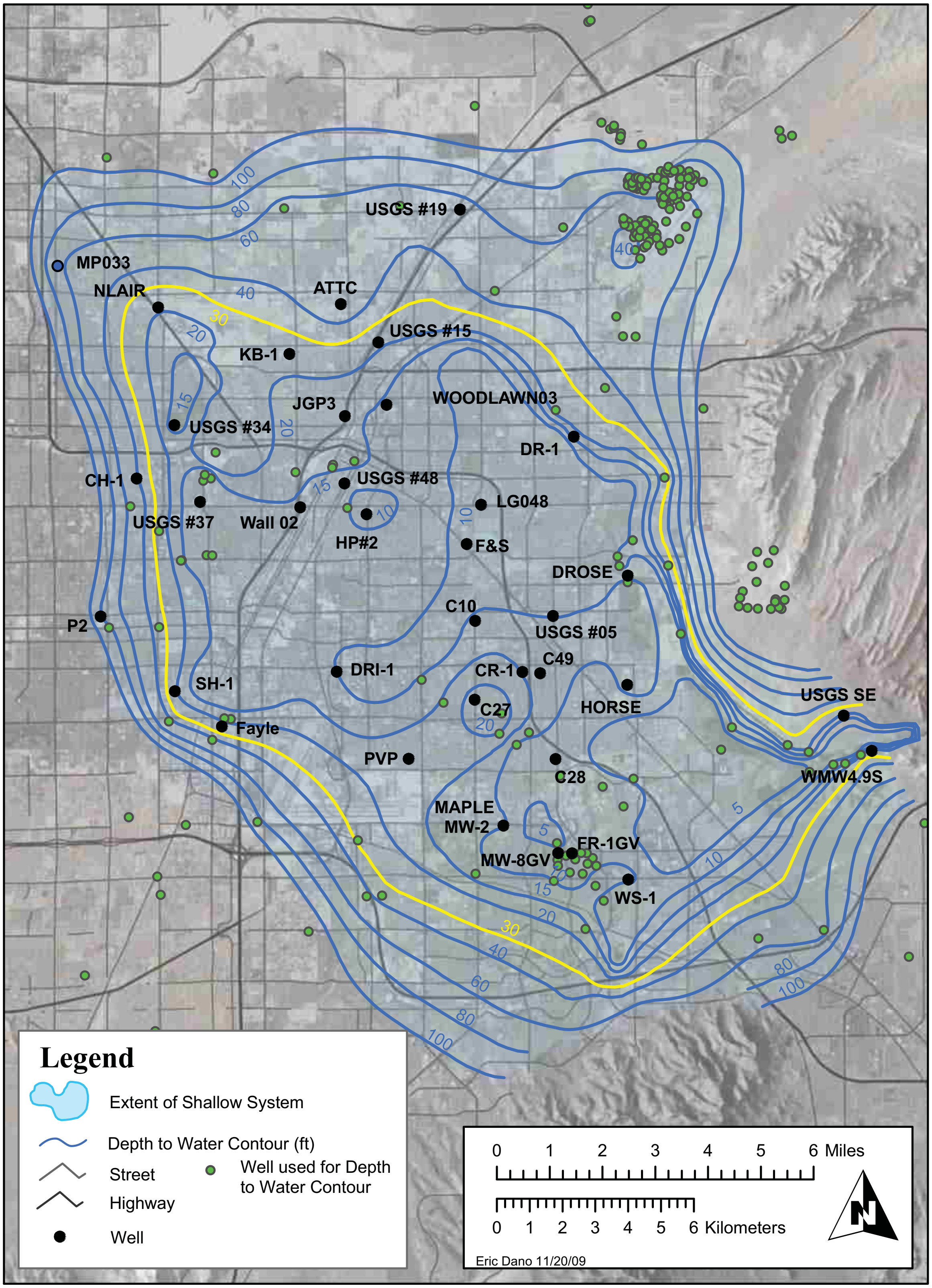


**Figure 2** Map of sites used in the SNWA shallow groundwater monitoring network. The water contours were made with the use of additional wells portrayed in green.

The field measurements for pH and temperature were made with a Beckman model Φ250 pH/Temp/mV meter. The pH and temperature meter were calibrated daily with pH standards from Fischer Scientific. A three point calibration was conducted using buffered standards of pH 4.00, pH 7.00 and pH 10.00. The Beckman model Φ250 pH/Temp/ mV meter is temperature compensating.

### 2.4 Major Ion, Trihalomethane, and Perchlorate Analyses

Samples for major cations and anions, and $ClO_4^-$ were collected in clean styrene one pint bottles. THM samples were preserved at pH 2 using 10% HCl and collected in 40ml VOA vials with no headspace. The $\delta D$-$\delta^{18}O$ stable isotope samples were collected in 20 ml borosilicate vials with caps that sealed sufficiently to prevent evaporation of the sample water. Per analytical protocols, samples were placed in iced coolers while in the field and subsequently refrigerated prior to transport to the lab. Delivery took place within analytical hold times, and chain-of-custody procedures were followed.

Analyses included major cations (sodium ($Na^+$), potassium ($K^+$), calcium ($Ca^{2+}$), and magnesium ($Mg^{2+}$)); major anions (chloride ($Cl^-$), nitrate ($NO_3^-$), and sulfate ($SO_4^{2-}$)); alkalinity as bicarbonate ($HCO_3^{2-}$); and additionally silica ($SiO_2$) total dissolved solids (TDS), $ClO_4^-$ and THMs. Analysis was performed at either of two certified laboratories: the Southern Nevada Water System (SNWS) or the Nevada Environmental Laboratories (NEL) in Las Vegas. Cations were analyzed by the EPA 200.8 method at SNWS or according to the EPA 200.7 ICP/OES method at NEL. Both facilities used the EPA 300 method for anions and M2320B for $HCO_3^{2-}$. The THM samples were analyzed following the EPA524.2 method for the following constituents: Chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), chlorodibromomethane ($CHBr_2Cl$), bromoform ($CHBr_3$), and total trihalomethanes (TTHM). The TTHM is a sum of components from the previously listed analytes. All THM results are reported in micrograms per liter (µg/l). Perchlorate was analyzed at NEL by the EPA314 method. TDS was calculated by the method M2540C.

## 2.5 Stable Isotopes -Sampling and Analysis

Twenty-eight samples collected for this research were supplemented with $\delta D$-$\delta^{18}O$ stable isotope data from 26 samples previously collected by SNWA. These data were then compared to an additional 153 samples obtained by SNWA from deeper aquifers both as part of a separate study and during artificial recharge and recovery activities within the Las Vegas Valley.

Development of a $\delta D$-$\delta^{18}O$ stable isotope dataset was an effort to associate a stable isotope value with as many of the 35 well locations as possible and to create a representative set of values on a scatter plot for characterizing the isotopic signature of shallow groundwater. Because the isotopic analyses were conducted by different laboratories at different times, it was assumed that samples are sufficiently comparable for the purposes of this research.

Fifty-four data points for 51 sites were assembled to represent stable isotope values associated with shallow groundwater in Las Vegas. A total of 28 $\delta D$-$\delta^{18}O$ samples collected by SNWA were sent to the Department of Earth and Environmental Science at the New Mexico Institute of Mining and Technology in 2005, and analysis conducted in August of 2005. The isotope values for 10 sites are from a shallow groundwater study conducted on the Whitney mesa area in Henderson (SEA, 1994). The purpose of the SEA study was to determine the source of nuisance water in the vicinity of a Holocene fault in the Whitney Mesa. An additional 10 stable isotope samples were collected in 1999 and analyzed at the Desert Research Institute (DRI) in Las Vegas for the SNWA valley wide groundwater sampling program (Leising, 2004). Three isotope samples were collected in 2002 in association with other shallow groundwater investigations regarding and were analyzed in 2004 at Waterloo University. Two data points included were collected from uppermost zone of the LVVWD multi-level monitoring well MP33. The samples solely represent the shallow groundwater in northwest region of the shallow groundwater system. An additional data point associated with the well UP03, collected in 1986, was included in the interest of geographic completeness of the primary data set for PCA analysis.

## 2.6 Quality Assurance

Quality assurance (QA) beyond that of the analytical laboratories was necessary because suspended acid-soluble phases were present in some shallow groundwater samples. Preservation for cation analysis involved acidification, while anion/alkalinity preservation did not. Thus, additional cations could be reported without compensating quantities of anions. Calculating cation-anion molar charge ratio provided a QA methodology.

To calculate the cation to anion ratio, the sum of the milliequivalents for anions is divided by the sum of the milliequivalents for the cations (Equation 1). The milliequivelents are calculated by dividing the concentration by the atomic mass of the ion, and multiplying the result by the ionic charge. By electroneutrality, anion charge and cation charge should balance, giving a cation to anion ratio of 1.0 in the absence of analytical errors.

$$\left(\sum_{\text{Anions}} \frac{\mathrm{NO_3^-}}{62.01}+\frac{\mathrm{Cl^-}}{35.45}+\frac{2(\mathrm{SO_4^{2-}})}{96.07}+\frac{(\mathrm{CaCO_3})*1.22}{61.018}\right)\Bigg/\left(\sum_{\text{Cations}} \frac{\mathrm{Na^+}}{62.01}+\frac{\mathrm{K^+}}{39.1}+\frac{2*\left(\mathrm{Ca^{2+}}\right)}{40.08}+\frac{2(\mathrm{Mg^{2+}})}{24.31}\right) \quad (1)$$

The amount of deviation from that figure was used to indicate the presence of outliers in the dataset. Though data contained in outliers might not be suitable for calculations of mineral stability, some proved statistically adequate for the purposes of this research.

The statistical method used to identify outliers was the Cook's Distance (Cook's D). Cook's D is combination of the leverage and t-test influence parameters used to describe how a single point affects a statistical model measuring how much a predictive model is impacted if a data point is removed (Kleinbaum et al., 1998). Large Cook's D values are generally associated with large Student's t-test residuals and high leverage values (Anderson and Whitcomb, 2000). A large Cook's D is not reason enough to exclude a data point; however, a large relative Cook's D value may indicate an outlier and should be examined further.

## 2.7 Data Visualization Methodology

Once QA has been conducted on a dataset, visualization methods become useful tools for interpretation. Visual data comparison methods included Piper trilinear diagrams, kriged PCA results, and spatial representation of data using geographic information system (GIS) software. PCA has been included with the data visualizations as the ultimate output is a rasterized map of the PC scores.

### 2.7.1 Piper Diagrams

Piper diagrams graphically represent some of the multiple variables associated with major cation and anion data and aid rapid determinations of similarities and differences in waster samples (Piper, 1944). A piper diagram is composed of two triangles and a rhombus. The two triangles depict milliequivalent percentages of three sets of components, totaling 100%. The components are displayed at the corners of the triangle. Typically, components of one triangle are cations with one corner representing Na +K, while components of the other are $SO_4^{2-}$+ $Cl^-$ and $HCO_3^-$. Piper diagrams for this research were produced using the software product Aquachem (Waterloo Hydrogeologic, Inc., 2008). Results from the Piper plots were compared against PCA results.

### 2.7.2 Principal Component Analysis

PCA is a common method of multivariate data analysis because of its straightforward approach, the simplicity of the mathematical process, and the ability to simplify the significant variability of a data set into a few dimensions. Complex sets of variables are can be reduced to their most variable components, facilitating further analysis. A description of the mathematical process behind PCA is included in this research.

The concept behind PCA is to describe variation within a set of data in terms of uncorrelated variables derived from linear combinations of a set of original variables. The goal is to find linear combinations of the original data that can summarize the data with as little information loss as possible (Everitt and Dunn, 1992).

The result of PCA is a set of loadings for the analytes (variables) and PC scores for the sites studied (cases). The PC scores (loadings) represent the influence the analyte has on particular eigenvectors. A large positive loading (relative to the set of loadings) suggest positive correlation to the eigenvector. Large negative loadings mean negative correlation. Small positive or negative values suggest little influence on the eigenvector.

PCA requires the calculation of a covariance matrix of the samples (Jackson, 1991). To produce a covariance matrix the data are first normalized against the respective means of the components producing a normalized matrix Z (Wackernagel, 1995).

$$Z = [Z_{\alpha i}] = \begin{bmatrix} Z_{1,1} & Z_{1,i} & Z_{1,N} \\ Z_{\alpha,1} & Z_{\alpha,i} & Z_{\alpha,N} \\ Z_{n,1} & Z_{n,i} & Z_{n,N} \end{bmatrix} \qquad (2)$$

In a transpose matrix the rows become the columns. The transpose of an orthogonal matrix [$A^T$] multiplied by the matrix itself [A] form the identity matrix, and additionally the transpose of the matrix equals the inverse of the matrix [$A^TA=I$, and $A^T= A^{-1}$ ]. Thus, the components represent unit normal vectors (Wackernagel, 1995).

In the PCA methodology, a covariance matrix V or ( $\sigma_{ij}$ ) is produced from [Z] by multiplying the normalized matrix Z by $\frac{1}{n}$, where n is the number of components, and by the transpose of matrix Z , $Z^T$ (Wackernagel, 1995).

$$V = [\sigma_{ij}] = \frac{1}{n} Z^T Z \qquad (3)$$

The ultimate objective is to produce an orthogonal, square diagonal matrix [D] from the covariance matrix. That matrix [D] contains n rows of n factors that are correlated and have zero mean (Wackernagel, 1995).

$$D = \frac{1}{n}\gamma^T\gamma = \begin{bmatrix} d_{1,1} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & d_{n,n} \end{bmatrix} \qquad (4)$$

To develop the orthogonal matrix requires changing the measured variables to synthesized factors. Using Equation 4, the matrix D is related to a matrix γ and its transpose such that

$$\gamma = \mathrm{ZA} \quad \text{where} \quad \mathrm{A}^{\mathrm{T}}\mathrm{A} = \mathrm{I} \qquad (5)$$

where A is a matrix of eigenvectors that are used to diagonalize the covariance matrix [V].

$$\mathrm{D} = \mathrm{A}^{\mathrm{T}}\mathrm{VA} \qquad (6)$$

Where

$$\mathrm{VA} = \mathrm{AD} \qquad (7)$$

From (4) (5) and (6), the relationship between γ and the normalized matrix [Z] is as follows:

$$\frac{1}{n}\gamma^T\gamma = \frac{1}{n}\gamma^T\mathrm{ZA} \qquad (8)$$

Multiply by $\frac{1}{n}$ and $\gamma^{\mathrm{T}}$ (Wackernagel, 1995).

$$\mathrm{D} = \frac{1}{n}(\mathrm{ZA})^{\mathrm{T}}(\mathrm{ZA}) \qquad (9)$$

$$\mathrm{D} = \frac{1}{n}\mathrm{A}^{\mathrm{T}}\mathrm{Z}^{\mathrm{T}}\mathrm{ZA} \qquad (10)$$

$$\mathrm{D} = \mathrm{A}^{\mathrm{T}}\frac{1}{n}\left(\mathrm{Z}^{\mathrm{T}}\mathrm{Z}\right)\mathrm{A} \qquad (11)$$

This expression has the same form as (6), where the middle terms correspond to [V]. The column vector terms in the eigenvalue matrix [A] are paired to column vectors in the eigenvalue matrix [D] of variances. In the PCA process, the eigenvalues are ordered diagonally from the strongest to least correlation while maintaining the appropriate pairings. Eigenvalue and eigenvector terms for which eigenvalue correlations are strongest are then used to form a new matrix [Q]. In essence, this procedure consolidates the most correlated variables into single factors and simplifies the dataset. The matrix [Q] is used as a basis onto which the data from the original normalized matrix [Z] (see Equation 2) are projected using the dot product:

$$[\mathrm{M}] = [\mathrm{Q}] \bullet [Z] \qquad (12)$$

The total variance in the new matrix [M] is calculated. Once the eigenvectors have been determined, these must be related to the original dataset from which the variance matrix [Z] was determined.

PCA analysis was conducted with a commercial software product called Statistica, Version 7.1.30.0. (StatSoft, Inc., 2005). There is a requirement that there be no blanks or zeros within the dataset as these values will very heavily bias deviation and correlation processes. Statistica was first used to normalize the data in the array. Eigenvectors were then calculated from the normalized data. From the eigenvectors, PC scores were then assessed. To spatially represent the results, the PC scores were associated with the sites and site coordinates to be rasterized for more meaningful visualization.

### 2.7.3 Kriging

Kriging was the statistical method used to generate a rasterized dataset of most likely PC scores based on a geographically sparse dataset. The process estimates point values between sampled locations in a grid using an inverse-distance weighing of nearby sample points and allowing for variance of each sample (Isaaks, 1989). The final product was a raster grid was at a 91 m (300 ft) discretization. A commercial software was used to perform the kriging (Surfer, version 8.05, Golden Software, Inc., 2004).

In order to properly present rasterized data in Geographical information system (GIS) utilities, an amount of manipulation of the datasets must be conducted for compatibility. The raster datasets generated by Surfer as Surfer grids are not directly compatible in most GIS utilities. While the data in the grid is retained, the overall grid format from Surfer must undergo a format conversion in order to be properly portrayed with ArcMap, the GIS utility that will be used for spatial representations. A freeware product called Grid Convert, version 1.0, from Geospatial Designs is used to convert Surfer girds from a proprietary grid format into an ASCII grid format compatible with ArcMap (Geospatial Designs, 2004). The ASCII grid is then recognizable to Environmental Systems Research Institute (ESRI), based tools available through ArcMap.

Initial attempts to graphically represent krigged PCA data were unsuccessful because the low numerical values of the PC scores prevented meaningful differentiation among the various sample sites, which in turn prevented effective inverse-distance correlation. The failure was tracked to the software handling the conversion from a Surfer grid to an ESRI ASCII grid. The low values were truncated and the resultant grid was of essentially uniform value. To correct this problem, the PC scores were increased by two orders of magnitude and the subsequent results made for a better representation with more distinction in values apparent.

### 2.7.4 Geographical Information Systems and Mapping

Geographical information system (GIS) software utilities are used to spatially represent datasets for the purpose of generating maps and making spatial comparisons of data. A commercial product from ESRI called ArcMap®, version 9.3, is used for all GIS visualizations in this research (ESRI, Inc., 2008). The base coordinate system used is the State plane coordinate system in US survey feet based on the North American datum from 1983 (NAD 83) for locations in Eastern Nevada (SPCS 83 Zone 2701) (Stem, 1989). ArcMap was the primary tool used to produce maps that aided analysis. The maps spatially integrated Valley physiography, kriged PCA results, geologic mapping, water levels, drainages, and the results of geochemical sampling.

# CHAPTER 3

# RESULTS

Results discussed in this section begin with the measured field parameters and proceed to the laboratory analytical results for the major ions, municipal tracers (THM and $ClO_4^-$), and stable isotopes. Further discussion addresses quality assurance, after which Piper trilinear diagrams are presented to graphically demonstrate the similarities and differences in groundwater chemistry between the sites. These are then compared to the results from the PCA-kriging statistical analyses. Averages and standard deviations are included with the following datasets. These values, however, represent arithmetic products, and in the absence of spatial weighting do not represent generalized conditions within the shallow groundwater system.

## 3.1 Field Analytical Results

Field chemistry measurements were collected at every sampling event. Results for field EC ranged from 1,155 µs/cm to 10,560 µs/cm with an average of 3,598 µs/cm and a standard deviation of 2,227 (Table 1). Field pH ranged from 6.83 to 7.59 with an average of 7.17 and a standard deviation of 0.18 The field temperature ranged from 17.4 ˚C to 26.7 ˚C with an average of 22.69 ˚C and a standard deviation of 2.16.

## 3.2 Major Ion Analytical Results

Following field chemistry are the results for groundwater samples analyzed by the water quality laboratory at the Southern Nevada Water System (SNWS) and Nevada

Environmental Laboratories (NEL) in Las Vegas. NEL and SNWS provided analytical results for major cations, anions, $SiO_2$, TDS, and municipal tracers.

| Site Identification | Field EC us/cm | Field pH | Field Temp. (°C) |
|---|---|---|---|
| ATTC | 1344 | 7.26 | 25.3 |
| C10 | 4730 | 7.27 | 21.3 |
| C27 | 4630 | 7.22 | 23.8 |
| C28 | 5420 | 7.06 | 23.5 |
| C49 | 3110 | 7.13 | 22.2 |
| CH-1 | 1847 | 7.16 | 23.2 |
| CR-1 | 4350 | 7.03 | 21.5 |
| DR-1 | 2530 | 7.44 | 25.1 |
| DRI-1 | 4290 | 6.84 | 22.3 |
| DROSE | 5950 | 7.27 | 19.0 |
| F&S | 4440 | 7.01 | 22.7 |
| Fayle | 1580 | 7.36 | 22.6 |
| FR-1GV | 5160 | 6.93 | 22.2 |
| HORSE | 10560 | 7.34 | 23.3 |
| HP#2 | 3380 | 7.31 | 19.2 |
| JGP3 | 2190 | 7.34 | 22.9 |
| KB-1 | 2320 | 7.20 | 23.3 |
| LG048 | 4930 | 7.21 | 23.7 |
| MAPLE MW-2 | 6600 | 7.16 | 24.0 |
| MW-8GV | 7610 | 6.83 | 17.4 |
| NLAIR | 1362 | 7.23 | 24.3 |
| P2 | 2160 | 6.96 | 23.6 |
| PVP | 3050 | 7.05 | 22.3 |
| SH-1 | 1684 | 7.41 | 24.6 |
| USGS #05 | 4030 | 7.14 | 18.0 |
| USGS #15 | 1343 | 7.20 | 26.7 |
| USGS #19 | 1155 | 7.55 | 24.9 |
| USGS #34 | 1899 | 7.17 | 25.5 |
| USGS #37 | 2290 | 7.07 | 19.6 |
| USGS #48 | 2550 | 7.31 | 23.3 |
| USGS SE | 8550 | 7.59 | 24.5 |
| Wall 02 | 1775 | 7.41 | 20.0 |
| WMW4.9S | 2570 | 7.38 | 22.0 |
| WOODLAWN03 | 2570 | 7.00 | 21.9 |
| WS-1 | 1954 | 7.28 | 24.6 |

**Table 1 Electrical conductivity, pH, and temperature field analytical results.**

3.2.1 Analytical Results for Cations

The results for $Na^+$ ranged from 19 mg/l to 940 mg/l with an average of 273 mg/l and a standard deviation of 247. Potassium ranged from 0.01 mg/l (used to replace a non-detect value) to 180 mg/l with an average of 37.84 mg/l and a standard deviation of 41.13. The results for $Ca^{2+}$ ranged from 79 mg/l to 742 mg/l with an average of 323.43 mg/l and a standard deviation of 198.11. Magnesium ranged from 64 mg/l to 480 mg/l with an average of 210.66 mg/l and a standard deviation of 116.16. Results are presented in Table 2.

| Site Identification | Na | K | Ca | Mg |
|---|---|---|---|---|
| ATTC | 22 | 3.9 | 150 | 98 |
| C10 | 550 | 52 | 700 | 370 |
| C27 | 400 | 67 | 570 | 380 |
| C28 | 600 | 56 | 570 | 360 |
| C49 | 200 | 23 | 300 | 170 |
| CH-1 | 120 | 7.8 | 130 | 120 |
| CR-1 | 340 | 15 | 460 | 320 |
| DR-1 | 140 | 16 | 120 | 200 |
| DRI-1 | 280 | 28 | 380 | 170 |
| DROSE | 282 | 43.9 | 332 | 181 |
| F&S | 360 | 71 | 330 | 260 |
| Fayle | 58 | 6.2 | 170 | 95 |
| FR-1GV | 372 | 96.3 | 687 | 237 |
| HORSE | 860 | 180 | 430 | 320 |
| HP#2 | 200 | 20 | 330 | 310 |
| JGP3 | 140 | 18 | 130 | 160 |
| KB-1 | 96 | 7.5 | 190 | 160 |
| LG048 | 470 | 86 | 290 | 420 |
| MAPLE MW-2 | 470 | 98 | 590 | 410 |
| MW-8GV | 918 | 115 | 742 | 334 |
| NLAIR | 40 | 3.4 | 130 | 87 |
| P2 | 110 | 5.8 | 190 | 130 |
| PVP | 180 | 19 | 330 | 150 |
| SH-1 | 130 | 8.6 | 140 | 97 |
| USGS #05 | 250 | 52 | 430 | 260 |
| USGS #15 | 84 | 9.4 | 170 | 110 |
| USGS #19 | 19 | 2.9 | 79 | 120 |
| USGS #34 | 32 | 0.01 | 100 | 64 |
| USGS #37 | 150 | 8.6 | 180 | 160 |
| USGS #48 | 160 | 28 | 390 | 200 |
| USGS SE | 940 | 100 | 710 | 480 |
| Wall 02 | 110 | 10 | 170 | 85 |
| WMW4.9S | 140 | 19 | 180 | 85 |
| WOODLAWN03 | 170 | 27 | 330 | 180 |
| WS-1 | 150 | 20 | 190 | 90 |

**Table 2 Analytical results for cations in mg/l.**

### 3.2.2 Analytical Results for Anions

The results for $Cl^-$ ranged from 21 mg/l to 1500 mg/l with an average of 348.43 mg/l and a standard deviation of 347.33. Nitrate ranged from 1.18 mg/l to 970.6 mg/l with an average of 52.78 mg/l and a standard deviation of 161.50. Bicarbonate ranged from 104.188 mg/l to 1201.7 mg/l with an average of 340.01 mg/l and a standard deviation of 201.27. The results for $SO_4^{2-}$ ranged from 24 mg/l to 5600 mg/l with an average of 1422.11mg/l and a standard deviation of 1246.75. Results are presented in Table 3.

### 3.2.3 Analytical Results for Silica and Total Dissolved Solids

Results for $SiO_2$ ranged from 14 mg/l to 77.6 mg/l with an average of 36 mg/l and a standard deviation of 19.11. TDS ranged from 996.64 mg/l to 9121.38 mg/l with an average of 2998.80 mg/l and a standard deviation of 1981.51. Results are presented in Table 4.

| Site Identification | Cl | **$NO_3$** | $SO_4$ | $HCO_3$ |
|---|---|---|---|---|
| ATTC | 120 | 3 | 440 | 439 |
| C10 | 270 | 40 | 3000 | 537 |
| C27 | 250 | 11 | 3300 | 232 |
| C28 | 820 | 11 | 2200 | 354 |
| C49 | 220 | 17 | 1500 | 243 |
| CH-1 | 160 | 6 | 470 | 342 |
| CR-1 | 320 | 21 | 2100 | 232 |
| DR-1 | 220 | 15 | 860 | 220 |
| DRI-1 | 550 | 23 | 1500 | 305 |
| DROSE | 484 | 55 | 2549 | 284 |
| F&S | 340 | 14 | 200 | 323 |
| Fayle | 120 | 24 | 510 | 207 |
| FR-1GV | 733 | 18 | 1088 | 1202 |
| HORSE | 1500 | 97 | 5600 | 122 |
| HP#2 | 230 | 8 | 1800 | 268 |
| JGP3 | 160 | 20 | 800 | 339 |
| KB-1 | 200 | 51 | 870 | 237 |
| LG048 | 410 | 9 | 2800 | 293 |
| MAPLE MW-2 | 1100 | 22 | 2800 | 375 |
| MW-8GV | 351 | 92 | 523 | 767 |
| NLAIR | 130 | 42 | 390 | 244 |
| P2 | 21 | 971 | 24 | 270 |
| PVP | 210 | 22 | 1500 | 235 |
| SH-1 | 120 | 11 | 600 | 183 |
| USGS #05 | 300 | 11 | 2200 | 293 |
| USGS #15 | 64 | 1 | 340 | 439 |
| USGS #19 | 64 | 3 | 450 | 268 |
| USGS #34 | 130 | 25 | 580 | 354 |
| USGS #37 | 160 | 49 | 810 | 415 |
| USGS #48 | 150 | 15 | 1100 | 622 |
| USGS SE | 1300 | 76 | 4100 | 104 |
| Wall 02 | 48 | 7 | 730 | 244 |
| WMW4.9S | 360 | 25 | 780 | 228 |
| WOODLAWN03 | 270 | 30 | 770 | 477 |
| WS-1 | 310 | 1 | 490 | 204 |

**Table 3 Analytical results for anions in mg/l.**

| Site Identification | TDS | $SiO_2$ |
|---|---|---|
| ATTC | 1215.95 | 19.0 |
| C10 | 5494.28 | 72.0 |
| C27 | 5190.62 | 23.0 |
| C28 | 4956.30 | 49.0 |
| C49 | 2665.88 | 37.0 |
| CH-1 | 1309.00 | 15.0 |
| CR-1 | 3793.40 | 27.6 |
| DR-1 | 1787.05 | 36.0 |
| DRI-1 | 3211.02 | 30.0 |
| DROSE | 4233.60 | 73.5 |
| F&S | 1899.35 | 59.0 |
| Fayle | 1169.10 | 16.0 |
| FR-1GV | 4283.98 | 67.2 |
| HORSE | 9121.37 | 34.0 |
| HP#2 | 3144.97 | 27.0 |
| JGP3 | 1734.83 | 29.0 |
| KB-1 | 1789.14 | 21.0 |
| LG048 | 4748.29 | 23.0 |
| MAPLE MW-2 | 5858.37 | 61.0 |
| MW-8GV | 3781.98 | 77.6 |
| NLAIR | 1038.89 | 16.0 |
| P2 | 2302.40 | 63.0 |
| PVP | 2631.52 | 28.0 |
| SH-1 | 1271.22 | 15.0 |
| USGS #05 | 3796.00 | 53.0 |
| USGS #15 | 1162.58 | 24.0 |
| USGS #19 | 996.64 | 39.0 |
| USGS #34 | 1237.23 | 16.0 |
| USGS #37 | 1873.29 | 16.0 |
| USGS #48 | 2598.05 | 45.0 |
| USGS SE | 7810.36 | 19.0 |
| Wall 02 | 1373.64 | 14.0 |
| WMW4.9S | 1814.32 | 38.0 |
| WOODLAWN03 | 2205.96 | 38.0 |
| WS-1 | 1457.39 | 39.0 |

**Table 4 Analytical results for TDS and $SiO_2$ in mg/l.**

## 3.3 Analytical Results for Municipal Tracers

Chloroform ($CHCl_3$) was evident in 15 samples. Results for $CHCl_3$ ranged from 1.1 μg/l to 7 μg/l with an average of 2.6 μg/l and a standard deviation of 1.70. One sample only (Well DROSE) was the only well with analytical results above non-detect for brominated THM. The sample contained 1.4 μg/l bromodichloromethane ($CHBrCl_2$) and 0.1 μg/l chlorodibromomethane ($CHBr_2Cl$). The $ClO_4^-$ ion is a contaminant present in the municipal water supply. Perchlorate was only detected in 12 samples. Results above detection for $ClO_4^-$ ranged from 3.9 μg/l to 440 μg/l with an average of 56.0 μg/l and a standard deviation of 126.69. Results are presented in Table 5.

| Site Identification | $CHCl_3$ | TTHM | $ClO_4$ |
|---|---|---|---|
| ATTC | | | |
| C10 | | | |
| C27 | | | n |
| C28 | | | |
| C49 | 4.3 | 4.3 | n |
| CH-1 | | | 12 |
| CR-1 | 1.1 | 1.1 | n |
| DR-1 | | | 3.9 |
| DRI-1 | 1.1 | 1.1 | |
| DROSE | 1.7 | 4.1 | <4 |
| F&S | <5 | <5 | 9.9 |
| Fayle | 2.5 | 2.5 | |
| FR-1GV | 2.3 | 2.3 | 18.18 |
| HORSE | <0.5 | <0.5 | |
| HP#2 | | | n |
| JGP3 | 1.9 | 1.9 | 4.9 |
| KB-1 | 1.3 | 1.3 | 4.3 |
| LG048 | | | n |
| MAPLE MW-2 | <.5 | <.5 | 8.8 |
| MW-8GV | 1.2 | 12 | <4 |
| NLAIR | 1.8 | 1.8 | |
| P2 | 4.3 | 4.3 | < 4 |
| PVP | 7 | 7 | 15 |
| SH-1 | | | 7.2 |
| USGS #05 | | | n |
| USGS #15 | <0.5 | <0.5 | n |
| USGS #19 | <0.5 | <0.5 | |
| USGS #34 | <0.5 | <0.5 | |
| USGS #37 | | | n |
| USGS #48 | | | n |
| USGS SE | <5 | <5 | 440 |
| Wall 02 | 2.2 | 2.2 | |
| WMW4.9S | <5 | <5 | 140 |
| WOODLAWN03 | 1.8 | 1.8 | 8.4 |
| WS-1 | <5 | <5 | <4 |

**Table 5 Analytical results for chlorform ($CHCl_3$), TTHM, and $ClO_4^-$ all units in μg/l.**

Data paucity for the exotic parameters makes inclusion into PCA problematic as the presence of blanks or zero value is not compatible with the analytical method. Only half of the sites had values above the detection level for these parameters. The reduced size of the available data set was therefore assumed to be less representative with regard to the spatial distribution in the shallow groundwater system.

## 3.4 Analytical Results for Stable Isotopes

Samples for stable isotopes were collected and analyzed for every site. The results of the 35 stable isotope samples for D and $^{18}O$ analysis are presented in Table 6 and plotted in Figure 3 with a comparison to the global meteoric water line and the local meteoric waterline. The results are presented as delta values, the parts per thousand of the ratio of the measured isotope ratio divided by the same isotopic ratio found in a standard sample. Historically, this is taken as standard mean ocean water (SMOW) Craig (1961).

The equation for calculating delta values, where R is the isotopic ratio, $R^+$ is the ratio of the same isotope in SMOW (Equation 13) (Craig, 1961).

$$\delta = \left[\left(R/R^{+}\right)-1\right]\cdot 1000 \quad (13)$$

The equation for the meteoric water line was established by Craig (Equation 14) (1961).

$$\delta D = 8\delta O^{18} + 10 \qquad (14)$$

The straight line equation for the global meteoric water line (Equation 15) (Craig, 1961).

$$\delta D = 6.87\delta O^{18} - 6.5 \qquad (15)$$

The straight line equation for the local meteoric water line (Ingraham et al., 1991).

The values for the shallow system D data ranged from -62 to -102 with an average of -95.5 and a standard deviation of 5.9. The values ranged from -5.2 to -13.8 with an average of -12.2 and a standard deviation of 1.2 for $^{18}O$.

## 3.5 Quality Assurance

Major ion data were evaluated using the cation to anion ratio, which is based on molar charge and electroneutrality. In an electrically neutral solution, this ratio is 1.0. Deviations from this figure represent analytical error. Results of the cation and anion molar charges as well as the ratio of the two are presented in Table 7. The ratios range from 0.325 to 1.884. The standard deviation for the cation to anion ratios is 0.302.

| Site Identification | d$^{18}$O | dD |
|---|---|---|
| ATTC | -12.16 | -94.68 |
| C10 | -12.25 | -95.49 |
| C27 | -12.47 | -99.38 |
| C28 | -12.35 | -97.67 |
| C49 | -13.21 | -99.80 |
| CH-1 | -12.50 | -99.13 |
| CR-1 | -13.30 | -98.47 |
| DR-1 | -12.42 | -95.35 |
| DRI-1 | -12.14 | -97.80 |
| DROSE | -11.54 | -96.33 |
| F&S | -11.97 | -96.66 |
| Fayle | -12.53 | -97.01 |
| FR-1GV | -12.22 | -99.36 |
| HORSE | -11.20 | -90.00 |
| HP#2 | -13.66 | -101.10 |
| JGP3 | -13.30 | -101.12 |
| KB-1 | -13.04 | -102.02 |
| LG048 | -13.00 | -100.00 |
| MAPLE MW-2 | -12.37 | -95.29 |
| MW-8GV | -9.84 | -90.03 |
| NLAIR | -13.29 | -97.93 |
| P2 | -11.97 | -95.03 |
| PVP | -12.43 | -98.41 |
| SH-1 | -12.51 | -98.10 |
| USGS #05 | -12.65 | -102.12 |
| USGS #15 | -13.60 | -100.00 |
| USGS #19 | -12.82 | -91.19 |
| USGS #34 | -13.02 | -96.61 |
| USGS #37 | -12.20 | -96.00 |
| USGS #48 | -12.95 | -102.20 |
| USGS SE | -5.20 | -62.00 |
| Wall 02 | -12.30 | -97.00 |
| WMW4.9S | -11.82 | -96.32 |
| WOODLAWN03 | -12.47 | -100.69 |
| WS-1 | -12.46 | -97.23 |

**Table 6 Analytical results for D and $^{18}$O expressed as enrichments in mills relative to standard mean ocean water (SMOW).**

The average major cation to anion ratio for the dataset is 1.026. In a plot of cation against anion molar charge four datapoints appear to deviate markedly from the other points in the dataset (Figure 4). A Cook's D influence test suggests that two of the deviant datapoints (HORSE and MW-8GV) should be considered outliers. These data might not be suitable for calculations of mineral stability, but are adequate for the purposes of this research.

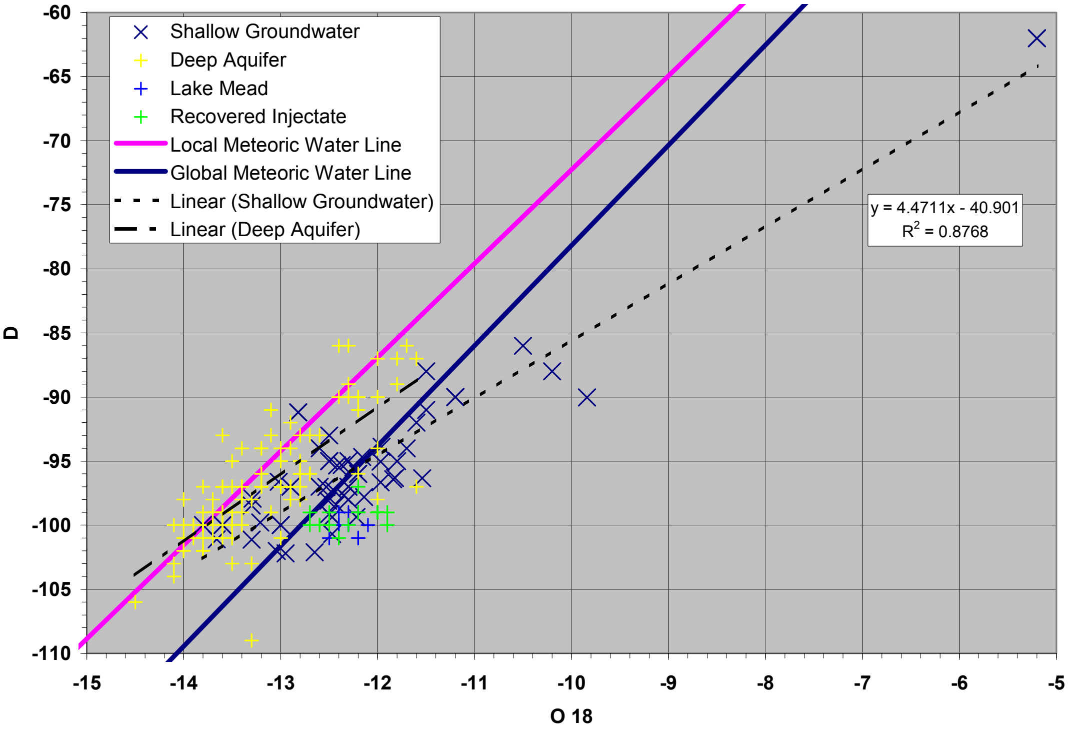


**Figure 3 Chart detailing the results of D and $^{18}$O analysis expressed as enrichments in mills relative to SMOW and the relationship with the global meteoric water line (Craig, 1961) and the local meteoric water line (Ingraham et al., 1991).**

| Site Identification | Total Anions | Total Cations | Anions/ Cations |
|---|---|---|---|
| ATTC | 19.792 | 16.604 | 1.192 |
| C10 | 79.518 | 90.624 | 0.877 |
| C27 | 79.722 | 78.818 | 1.011 |
| C28 | 74.912 | 85.591 | 0.875 |
| C49 | 41.684 | 38.244 | 1.090 |
| CH-1 | 19.996 | 21.779 | 0.918 |
| CR-1 | 56.879 | 64.453 | 0.882 |
| DR-1 | 27.951 | 28.941 | 0.966 |
| DRI-1 | 52.112 | 45.843 | 1.137 |
| DROSE | 72.267 | 44.847 | 1.611 |
| F&S | 19.284 | 55.332 | 0.349 |
| Fayle | 17.787 | 18.980 | 0.937 |
| FR-1GV | 63.319 | 72.423 | 0.874 |
| HORSE | 162.464 | 89.795 | 1.809 |
| HP#2 | 48.488 | 51.182 | 0.947 |
| JGP3 | 27.046 | 26.200 | 1.032 |
| KB-1 | 28.449 | 27.012 | 1.053 |
| LG048 | 74.805 | 71.668 | 1.044 |
| MAPLE MW-2 | 95.819 | 86.122 | 1.113 |
| MW-8GV | 34.855 | 107.376 | 0.325 |
| NLAIR | 16.470 | 15.471 | 1.065 |
| P2 | 21.163 | 25.109 | 0.843 |
| PVP | 41.357 | 37.123 | 1.114 |
| SH-1 | 19.046 | 20.841 | 0.914 |
| USGS #05 | 59.239 | 55.052 | 1.076 |
| USGS #15 | 16.100 | 21.427 | 0.751 |
| USGS #19 | 15.616 | 14.715 | 1.061 |
| USGS #34 | 21.947 | 11.648 | 1.884 |
| USGS #37 | 28.959 | 28.890 | 1.002 |
| USGS #48 | 37.571 | 43.591 | 0.862 |
| USGS SE | 124.958 | 118.364 | 1.056 |
| Wall 02 | 20.657 | 20.516 | 1.007 |
| WMW4.9S | 30.541 | 22.551 | 1.354 |
| WOODLAWN03 | 31.947 | 39.361 | 0.812 |
| WS-1 | 22.307 | 23.921 | 0.933 |

**Table 7 Cation and anion sums in milliequivalents and the calculated cation to anion ratio.**

## 3.6 Piper Trilinear Diagram

Major ion analytical results were plotted in a piper trilinear diagram (Figure 5). The dataset covers a large portion of the Trilinear diagram with no obvious clustering.

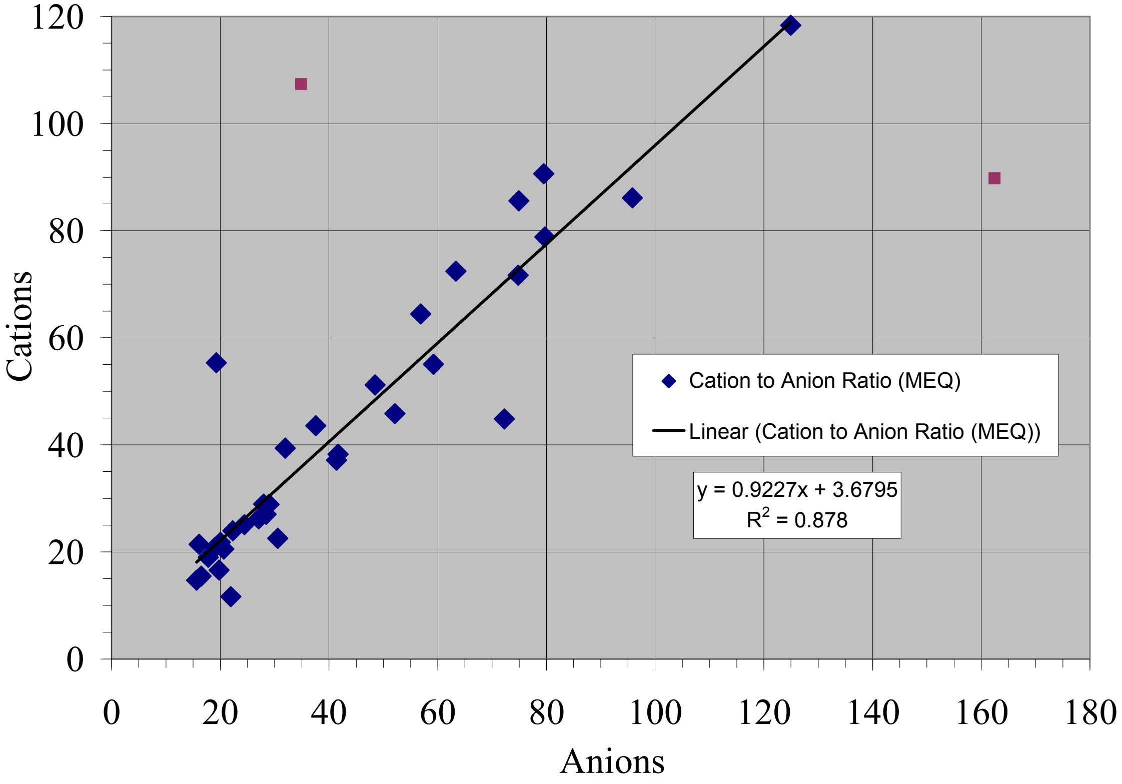


**Figure 4 Plot of the Cation to Anion Ratio, Outliers highlighted in red.**

## 3.7 Principal Component Analysis

The following 18 parameters were set up for PCA: $Ca^{2+}$ (mg/l), $Mg^{2+}$ (mg/l), $Na^+$ (mg/l), $K^+$ (mg/l), GW-Chart- $CO_3^-$ (a calculated value for carbonate) (mg/l), $HCO_3^{2-}$ (mg/l), $Cl^-$ (mg/l), $SO_4^{2-}$ (mg/l), TDS (mg/l), $NO_3^-$ as N (mg/l), $NO_3^-$ (mg/l), LAB EC (µs/cm), $SiO_2$ (mg/l), FIELD_EC reported in µs/cm, FIELD_PH, FIELD_TEMP (˚C), D per mill enrichment relative to SMOW (δD), and $O^{18}$ per mill enrichment relative to SMOW

($\delta O^{18}$). These items were selected because the data represented were assumed to be spatially correlable.

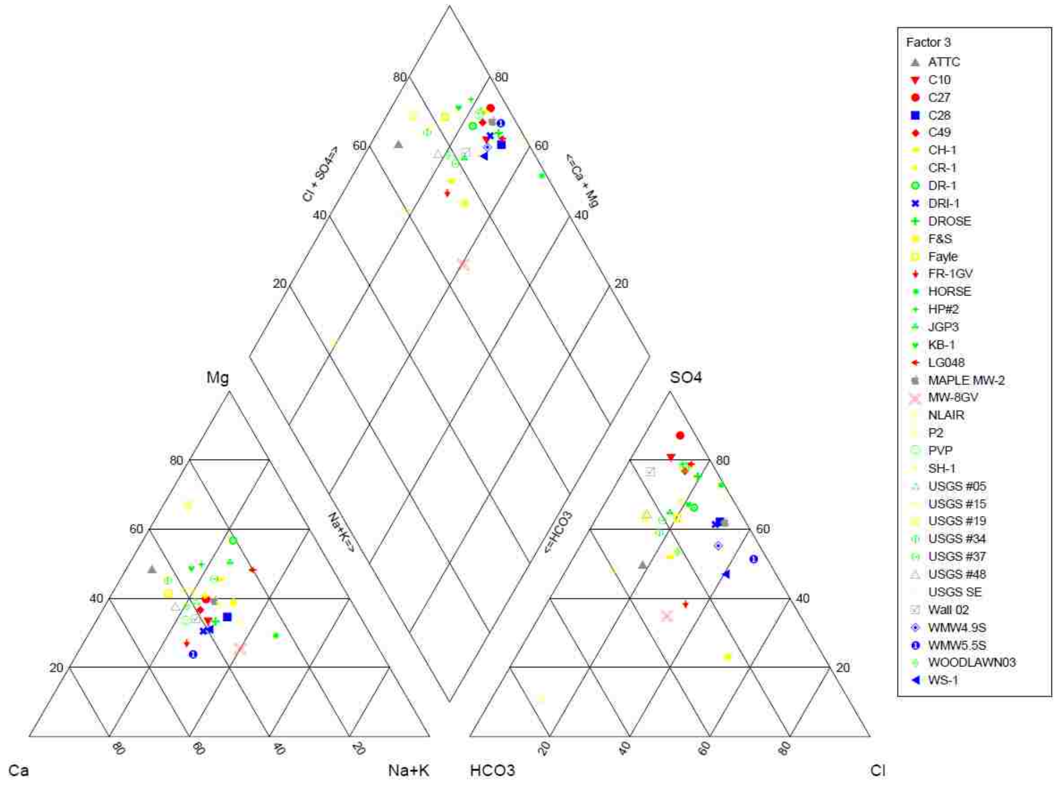


**Figure 5 Piper trilinear diagram of major ion geochemical results.**

PCA analysis indicated over 90% of the variance to be in the first five principal components. The resulting eigenvectors and a summary of their percent of the total variance both independently and cumulatively are presented in Table 8.

The correlations between the first five principal components and the 18 variables used is presented in Table 9, the first three are also represented on Figure 6. Analytes that are of similar magnitude have a similar influence on the PC scores calculated for the sites.

|  | Eigenvalue | % Total variance | Cumulative Eigenvalue | Cumulative % |
|---|---|---|---|---|
| 1 | 8.394 | 46.635 | 8.394 | 46.635 |
| 2 | 3.193 | 17.740 | 11.588 | 64.375 |
| 3 | 2.254 | 12.522 | 13.842 | 76.897 |
| 4 | 1.480 | 8.220 | 15.321 | 85.117 |
| 5 | 0.974 | 5.412 | 16.295 | 90.529 |
| 6 | 0.732 | 4.068 | 17.028 | 94.598 |
| 7 | 0.418 | 2.324 | 17.446 | 96.922 |
| 8 | 0.207 | 1.147 | 17.652 | 98.069 |
| 9 | 0.103 | 0.572 | 17.755 | 98.641 |
| 10 | 0.078 | 0.432 | 17.833 | 99.073 |
| 11 | 0.066 | 0.365 | 17.899 | 99.438 |
| 12 | 0.038 | 0.211 | 17.937 | 99.650 |
| 13 | 0.029 | 0.163 | 17.966 | 99.812 |
| 14 | 0.024 | 0.134 | 17.990 | 99.946 |
| 15 | 0.009 | 0.048 | 17.999 | 99.994 |
| 16 | 0.001 | 0.006 | 18.000 | 100.000 |
| 17 | 0.000 | 0.000 | 18.000 | 100.000 |

**Table 8 Presentation of the resulting eigenvalues and the percentage of the total variance.**

| Analyte | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 |
|---|---|---|---|---|---|
| Ca | -0.853776 | 0.300489 | -0.196267 | 0.073094 | 0.063904 |
| Mg | -0.857583 | 0.003580 | -0.108806 | -0.072949 | -0.130677 |
| Na | -0.962383 | 0.012331 | 0.000115 | 0.022124 | 0.090279 |
| K | -0.916711 | 0.057745 | -0.098470 | -0.003651 | -0.139298 |
| CO3 | 0.185444 | 0.058428 | -0.499943 | 0.769559 | -0.209113 |
| Total Alkalinity | -0.112376 | 0.685597 | -0.454903 | 0.435776 | 0.013066 |
| Cl | -0.869308 | -0.220870 | 0.009382 | -0.008312 | -0.139917 |
| SO4 | -0.822985 | -0.311073 | -0.047543 | -0.213875 | -0.275253 |
| TDS | -0.953381 | -0.085187 | 0.017604 | -0.071135 | -0.216063 |
| NO3 as N | 0.005797 | 0.403230 | 0.870713 | 0.161034 | -0.181991 |
| NO3 | 0.004360 | 0.402171 | 0.870918 | 0.159779 | -0.183408 |
| Lab EC | -0.983086 | 0.067162 | -0.033155 | -0.075184 | 0.001540 |
| SiO2 | -0.433380 | 0.696903 | -0.025405 | 0.233411 | -0.061108 |
| Field EC | -0.980136 | 0.013907 | 0.003349 | -0.084359 | -0.016847 |
| Field pH | 0.094135 | -0.791822 | -0.041897 | 0.359106 | -0.100098 |
| Field Temp | 0.246505 | -0.478341 | 0.157879 | 0.302538 | -0.528685 |
| D | -0.565589 | -0.452585 | 0.354926 | 0.435653 | 0.352481 |
| O18 | -0.659326 | -0.266134 | 0.314008 | 0.373199 | 0.474338 |

**Table 9 PC loadings for the first 5 principal components and the variables.**

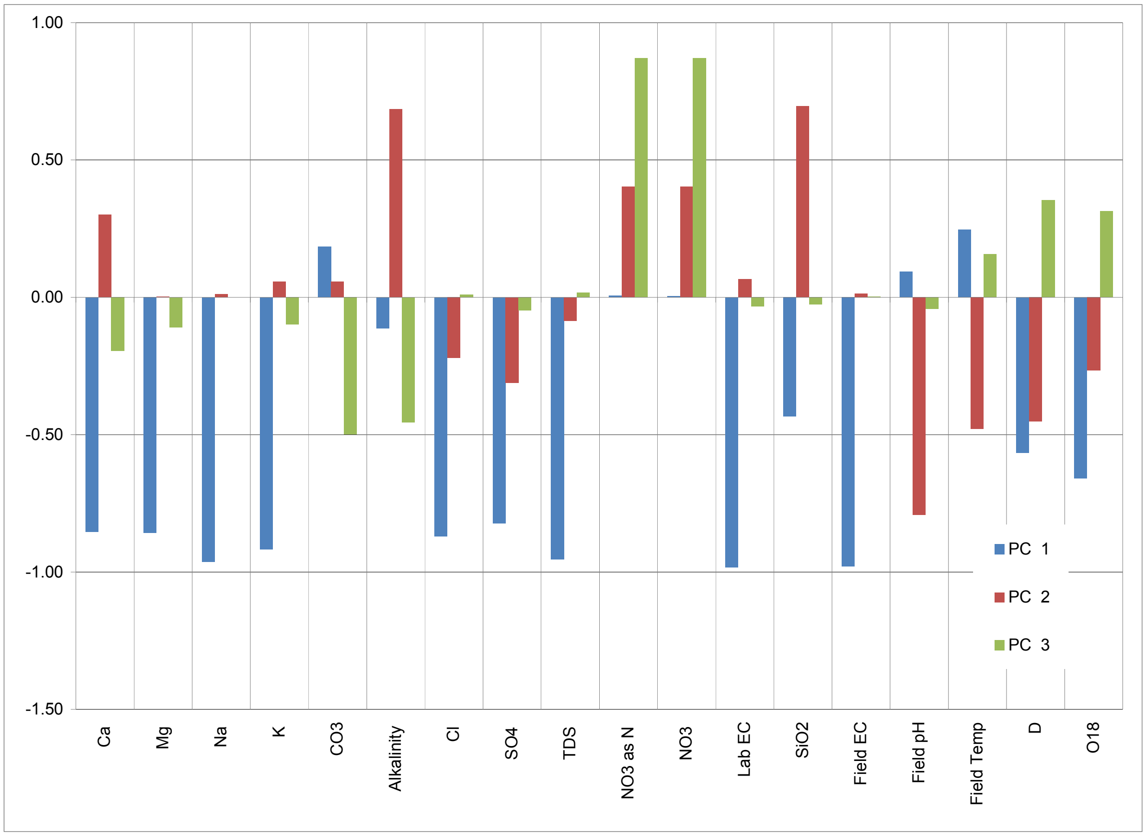


**Figure 6 PC loadings for the analytical parameters.**

To demonstrate the clustering of data points and discern outliers, the relationship between the first two principal components is presented on a scatter plot in Figure 7. This plot represents the principal axes that contain the most total variance associated with the dataset. This is often representative of more variance than any of the original variables (Davis, 1986). Points on the plot that are grouped or cluster represent sites that are similar in some fashion. Points that represent outliers on this plot represent wells that are especially distinct to the data set as a whole.

Because this thesis emphasizes identifying geochemical facies in a spatial setting, the analysis will focus on the PC coordinates associated to the well sites. Theese PC coordinates are in respect to the data associated with the physical well locations. The PC coordinates of the variables might be more telling of the geochemical processes that evolved the waters into what is observed, but that analysis is not part of this research. The first three principal components associated with sample locations are presented in Table 10 and Figure 8. Values represented in Figure 8 that are of similar magnitude represent wells that are identified through PCA as being similar or related in some way. This is similar in fashion to the clustering previously discussed for Figure 7.

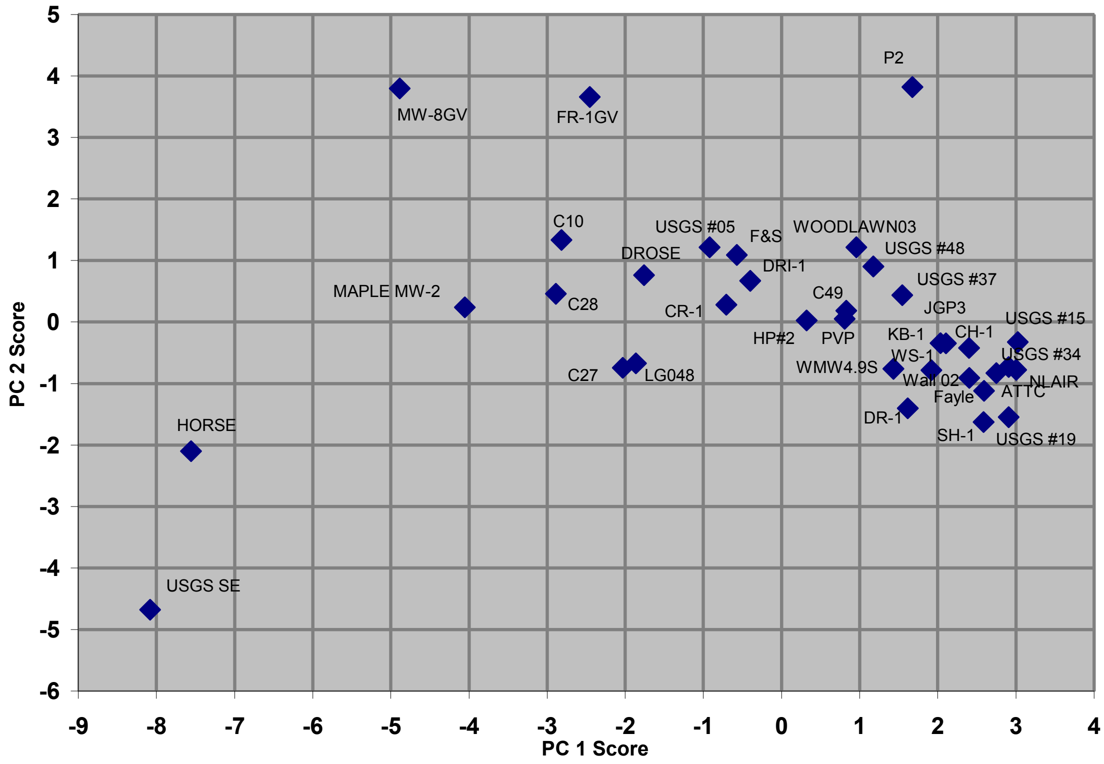


**Figure 7 Projection of the first two principal component scores.**

| Site Identification | PC 1 | PC 2 | PC 3 |
|---|---|---|---|
| ATTC | 2.74938 | -0.83185 | -0.43947 |
| C10 | -2.81646 | 1.33183 | -1.40996 |
| C27 | -2.03272 | -0.74588 | -0.24445 |
| C28 | -2.88741 | 0.45826 | -0.49210 |
| C49 | 0.82983 | 0.18166 | -0.02363 |
| CH-1 | 2.40075 | -0.42213 | -0.07079 |
| CR-1 | -0.70736 | 0.28099 | -0.06492 |
| DR-1 | 1.61710 | -1.40266 | 0.05128 |
| DRI-1 | -0.40148 | 0.66981 | 0.28758 |
| DROSE | -1.76083 | 0.76015 | -0.00116 |
| F&S | -0.57057 | 1.08986 | 0.01496 |
| Fayle | 2.59246 | -1.12130 | 0.27656 |
| FR-1GV | -2.45431 | 3.65760 | -2.54519 |
| HORSE | -7.55766 | -2.09968 | 0.87698 |
| HP#2 | 0.32044 | 0.02438 | -0.78502 |
| JGP3 | 2.10503 | -0.34639 | -0.56573 |
| KB-1 | 2.03486 | -0.34245 | 0.23335 |
| LG048 | -1.86346 | -0.67291 | -0.59815 |
| MAPLE MW-2 | -4.05408 | 0.23683 | -0.67076 |
| MW-8GV | -4.88562 | 3.79723 | -0.44684 |
| NLAIR | 3.00278 | -0.77825 | 0.36243 |
| P2 | 1.67611 | 3.81904 | 7.37771 |
| PVP | 0.80751 | 0.04982 | 0.28517 |
| SH-1 | 2.58545 | -1.62534 | 0.22216 |
| USGS #05 | -0.92167 | 1.21641 | -0.66206 |
| USGS #15 | 3.02381 | -0.32597 | -0.65928 |
| USGS #19 | 2.90751 | -1.54722 | -0.42078 |
| USGS #34 | 2.90752 | -0.73151 | 0.11296 |
| USGS #37 | 1.54520 | 0.43535 | 0.04662 |
| USGS #48 | 1.17580 | 0.90206 | -2.06351 |
| USGS SE | -8.08195 | -4.67802 | 2.34609 |
| Wall 02 | 2.40174 | -0.90967 | -0.39079 |
| WMW4.9S | 1.43289 | -0.76168 | 0.21993 |
| WOODLAWN03 | 0.95940 | 1.21584 | -0.39628 |
| WS-1 | 1.92003 | -0.78423 | 0.23706 |

**Table 10 PC scores for the first three principal components associated with sample locations.**

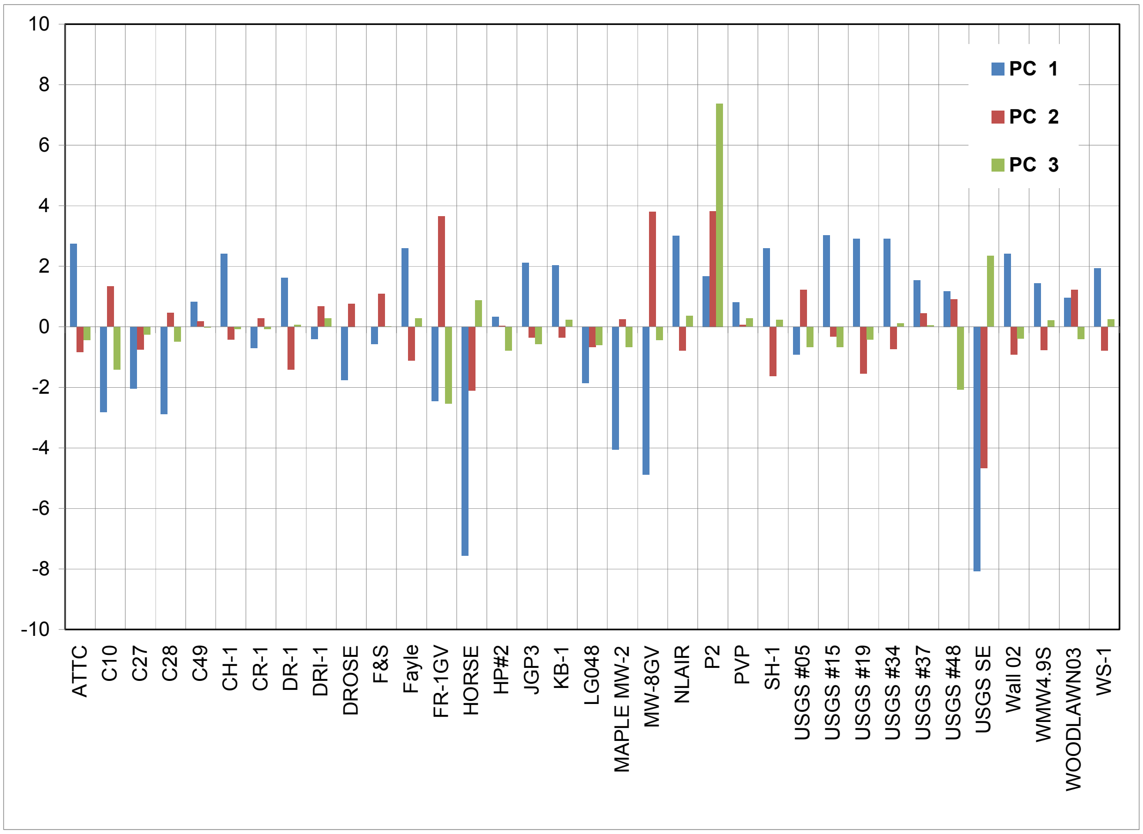


**Figure 8 PC scores for the sites.**

# CHAPTER 4

# DISCUSSION

## 4.1 Field Chemistry

Field chemistry results vary spatially within the shallow groundwater system. The lowest values of EC are located in the north and northwest with a few other low values along the fringes of the shallow system. These low values along the fringes might represent water that is borderline for inclusion in the shallow groundwater system. These sites likely represent the transition from shallow groundwater to what is considered intermediate groundwater that would be associated with domestic well use. The values increase gradually toward the southeast portion of the shallow system along an axis in the center of the Valley trending roughly in the same direction as the land surface topography and general groundwater flow direction according to Plume (1984). Locally within the the shallow system, EC values deviate from the trend, particularly along drainages comprising the Las Vegas Wash tributary network.

The highest values of field EC are centered around the well HORSE, with a field EC value of 10,560 µs/cm. And the second highest is at well USGS-SE about 6.8 km (4.25 mi) southeast of HORSE. Variations in field EC may possibly be attributed to localized effects from secondary recharge of water with a lower EC.

A narrow range pH in values coupled with variability at each site suggests that variations in pH will generally have less obvious causes and interpretation is not likely to be very meaningful. The majority of the pH values in the shallow system are slightly above neutral suggesting both the influence of alkaline water from bicarbonate dominated source water, and the alkaline nature of water sourced from Lake Mead and applied as landscape irrigation. Some of the lowest pH values are from the southeastern portions of the shallow system on top of Whitney Mesa. These might be attributed to organic decay affecting secondary recharge as it percolates through suburban landscapes (Smith and Guitjens, 1998). One of the lowest values is located on the western margin of the shallow system at well P2. Well P2 is located adjacent to the highest density of septic systems in the Las Vegas Valley (Dano, 2003). The high density of septic systems likely contributes hypoxic groundwater to the shallow system and locally lowers the pH (Patterson, 2003).

## 4.2 Major Ions

Water accumulates ions during recharge from basin margins to the basin fill aquifer due to mineral dissolution of within the country rock and vadose zone salts deposited by ET (Thomas et al. 1989). In arid basins, much of the precipitation on the valley floor does not result in recharge to groundwater; any meteoric ions added to the soil will remain there (Smith and Drever, 1976). Some salts that are evapoconcentrated in the vadose zone are later transported to the water table when sufficient precipitation results in recharge and transport of remobilized minerals to the water table (Thomas et al. 1989). Excess irrigation will behave in much the same way as significant precipitation and may serve as an analogy to climatic change to wetter conditions. The major ion signature in secondary recharge thus may be heavily masked by dissolution of vadose zone salts derived from phreatic sources or precipitation during evaporation within the capillary fringe.

Dinger (1977) recognized that $SO_4^{2-}$ to $Cl^-$ and $Ca^{++}$ to $Mg^{++}$ ratios in shallow groundwater mirror those of deeper aquifers in the Las Vegas Valley, supporting the idea that the shallow system is connected to deeper aquifers and that at low concentrations both sets of ions are conservative. This observation suggests that the ions are concentrated by evaporation, because the stoichiometric proportions remain constant. Stoichiometrically proportionate dissolution of the multiple mineral phases necessary to add these ions is highly unlikely.

The $SO_4^{2-}$ to $Cl^-$ ratio illustrated in Figure 9 exhibits a positive correlation, with a correlation coefficient of 0.7779. Although there is some scatter, the plot demonstrates that the ratios are generally maintained with increased concentrations of dissolved ions. The highest concentrations presented are from samples collected farthest down the flow path to the southeast, and the lowest concentrations are from samples collected in the northwest and western portions of the shallow system. Some of the lower concentration sites are located adjacent to washes. These are possibly impacted by municipal runoff with a lower overall TDS than the native shallow groundwater.

The $Ca^{2+}$ vs $Mg^{2+}$ chart (Figure 10) also shows a positive correlation coefficient of 0.8181. There is again some scatter; however, position within this chart appears less dependent on overall TDS. Each wells' location within the flow system does appear to influence placement on figure 8. With the exception of a couple of points, the sites with values that plot less than 200 on both axes are all located in the Northwest or in the fringes of the shallow groundwater system.

Nitrate values demonstrate little variation associated with evolution along the shallow groundwater flow path. Lower $NO_3^-$ concentrations are represented by ATTC in the north, WS-1 in the south, and along some of the fringes, (Figure 11). Wells P2 and DROSE represent the highest values. Well P2 likely exhibits elevated $NO_3^-$ due to its

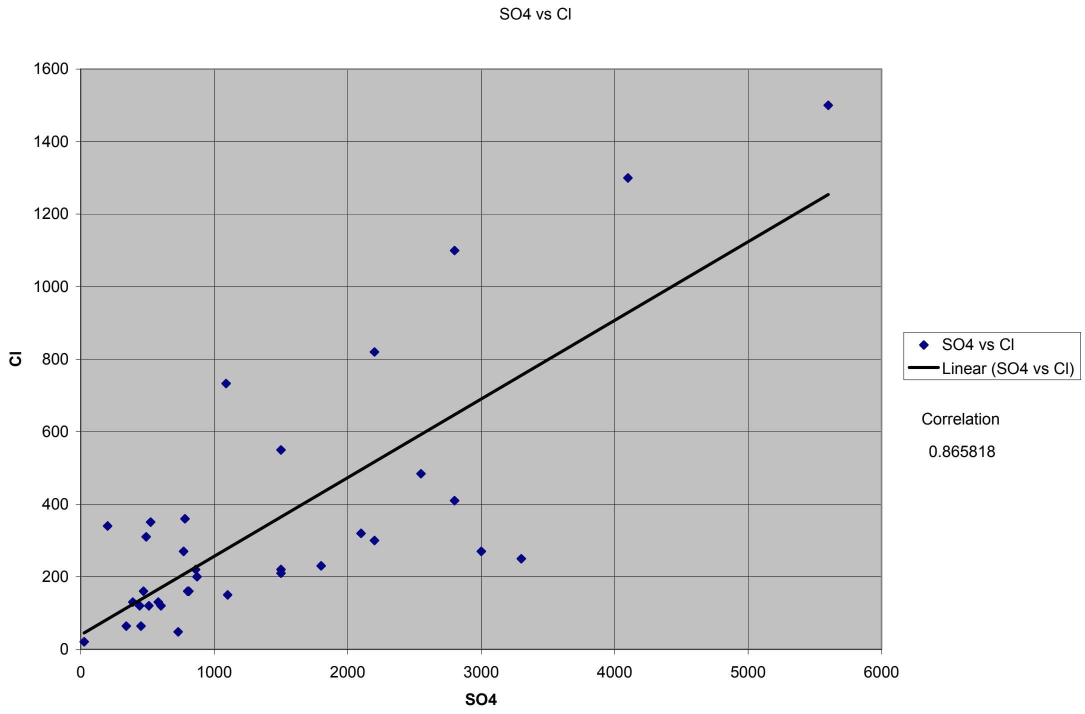


Figure 9 Scatter plot depicting the relationship between $Cl^-$ and $SO_4^{2-}$.

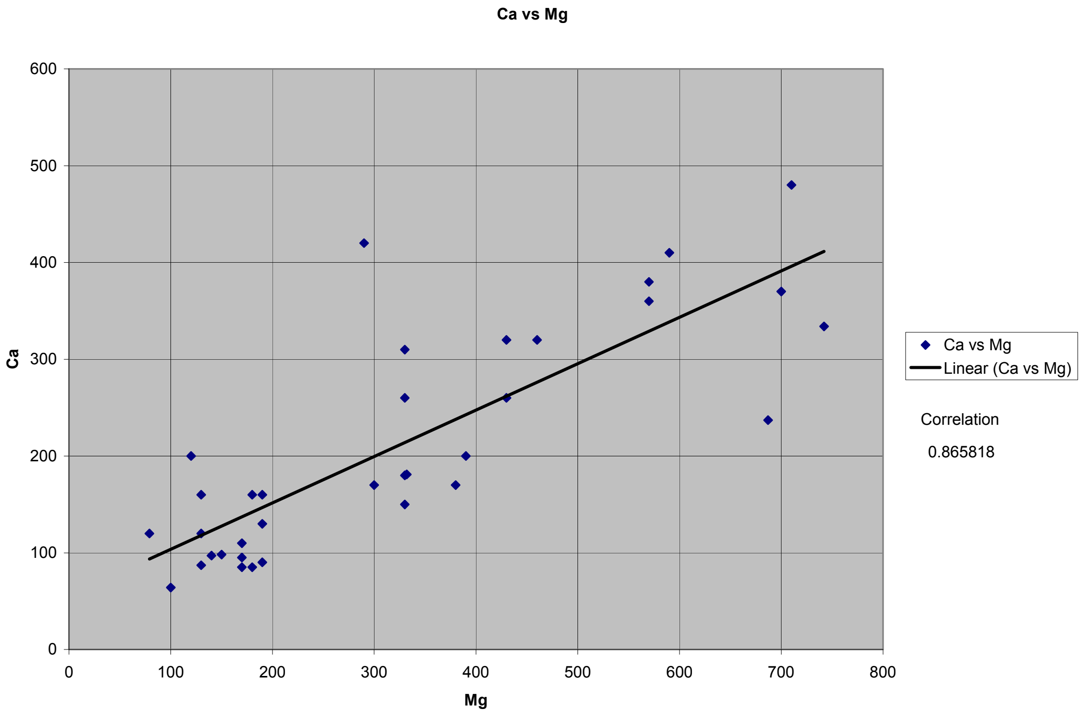


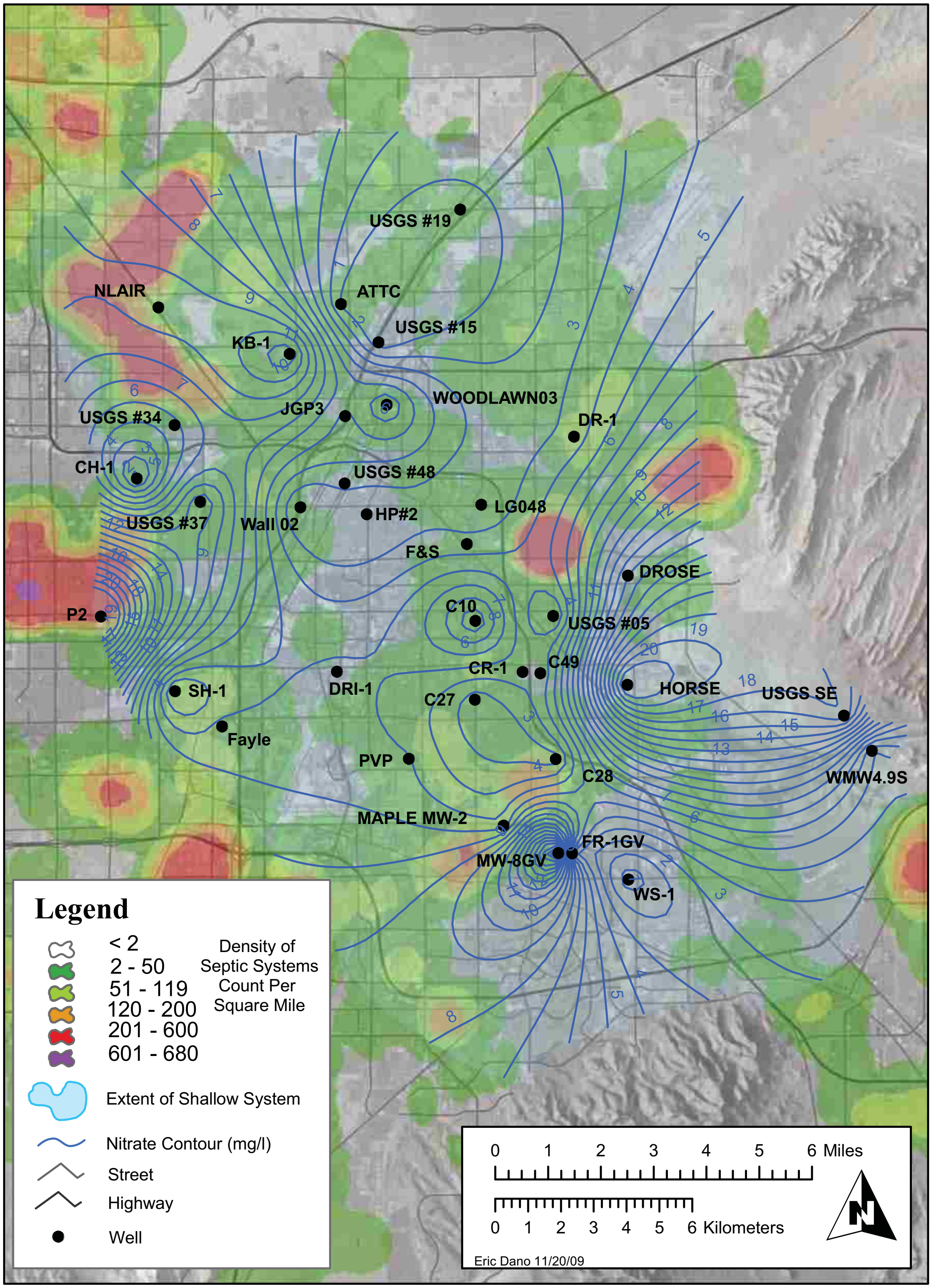
Figure 10 Scatter plot depicting the relationship between $Ca^{2+}$ and $Mg^{2+}$.

proximity to the highest density of septic systems in the Las Vegas Valley. At Well DROSE, there is a high concentration of septic systems upgradient in close proximity to the well site; additionally, the site is within a golf course that has been irrigating with treated municipal waste water (reuse water) since 1948 (Dinger, 1977; Zikmund, 1996).

## 4.3 Municipal Tracers

Municipal tracers, notably $ClO_4^-$ and THM, have proven effective in qualitatively identifying nuisance water that originated from the municipal distribution system. Challenges arise due to the localized distribution of secondary recharge and low concentrations. The absence of municipal tracers at many of the sites suggests that the impact of secondary recharge is not uniform. Additionally there are no spatially connected areas that appear to have correlable values of the municipal tracers.

The difficulties in utilizing THMs could be attributed to many factors. In posing the testable hypotheses for this thesis, it initially was assumed there is a municipal component to most of the water in the shallow groundwater system. This assumption is likely false. THMs were not detected in all of the samples analyzed, and where encountered concentrations were often low. These low concentrations may be attributable to hydrologic processes such as dispersion, degradation, sorption, and dilution within the shallow groundwater system. Moreover, THMs are volatile compounds; chloroform for example has a vapor pressure of 197 mm Hg (.26 bar) (Du, 2001). A portion of these VOCs may therefore be lost to the atmosphere during the application of irrigation water. The combined effect of these processes is currently poorly understood. The THM data were therefore left out of the PCA process.



Eric Dano 11/20/09

**Figure 11** Map detailing the contoured values from the nitrate analysis overlaying the calculated density of septic systems in relation to the extent of the shallow groundwater system in Las Vegas.

The number of samples with no detection would have significantly reduced the dataset and may have biased the data toward sites with a significant influence from secondary recharge.

The $ClO_4^-$ ion was also examined as a possible municipal tracer. This was complicated by the low and variable concentrations found in municipal water and the local potential for non-municipal sources of the ion. The $ClO_4^-$ ion occurs in high concentrations in portions of the shallow groundwater system. These levels may have arisen due to evapoconcentration or from environmental contamination associated with its industrial manufacture in Henderson, Nevada from 1945 to 2002 (ITRC, 2005). Perchlorate may also be present locally as a result of an explosion at an amonium perchlorate factory (Routley, unknown date, roughly 1988). Fallout from the explosion in the form of unoxidized ammonium perchlorate may impact the water cycle in much of the southeast portion of the Valley. In addition to this industrial accident, $ClO_4^-$ is a common ingredient in fireworks (Takeo, 1981). Fallout from Fourth of July celebrations throughout the Valley may affect shallow system $ClO_4^-$ levels. The multiplicity of potential sources, variable input concentrations, and highly variable concentration in the shallow groundwater system negated the utility of $ClO_4^-$ concentrations to this research. Perchlorate was also left out of the PCA process. The number of samples with no detection would have further reduced the dataset and may have biased the data toward only sites with a significant influence from secondary recharge.

## 4.4 Stable Isotopes

Stable isotopes provide an additional way of examining groundwater recharge and transport. Examining the ratios of D and $^{18}O$, their distribution in the watershed, and their placement in relation to the meteoric waterline allows inferences as to what environmental processes impact the fate and transport of ground water.

Mineral dissolution should not impact the D and $^{18}O$ isotopic makeup of groundwater, evaporation should make the isotopic composition of remaining water heavier (Thomas et al. 1989). Transpiration can increase dissolved ion concentration with minimal effect on isotopic composition (Thomas et al. 1989; Ehleringer, 1992; Yepez et al. 2003).

The isotope data suggest much of the water is derived from similar sources and has undergone evaporation. Overlap of some of the data from shallow groundwater samples and data points from deeper aquifer sources suggests a degree of commonality of source for some sites (Smith and Guitjens, 1998). Both shallow and deep groundwater datasets have trends that diverge from the LMWL and GMWL by a shallower slope suggestive of an evaporative component to the water. It is difficult to determine if evaporation has occurred during precipitation in the summer months, if evaporation occurred prior to infiltration, or if the evaporation has occurred as a process within the vadose zone (Kendall, 2001).

Only some of the shallow groundwater appears to be sourced from depth. In Figure 3, points symbolized by blue +'s cluster near a group of shallow groundwater points, these blue points are from samples of artificial recharge water. The artificial recharge (AR) water is treated water from Lake Mead that is water injected into deep municipal wells. Points symbolized by green +'s are recovered water from deeper wells that received artificial recharge. The similarity in isotopic composition in shallow wells that cluster near the AR water and recovered water suggest that water from Lake Mead in the form of secondary recharge is a source of some of the water in the shallow groundwater system.

## 4.5 Quality Assurance

The results of the quality assurance demonstrate that much of the data falls within a close cation to anion ratio. Two sites represented outliers as suggested by the Cook's D. The cation to anion ratio in HORSE had a Cook's D of 0.823. The cation to anion ratio for well MW-8GV had a Cook's D of 1.23. If chemical equilibrium calculations were to be conducted, those data would be considered suspect and removed; however, those data will be retained for the purposes of this study. The data were also examined for values that would seem out of place, there were no non-detects for any of the major ions and all of the results appeared to be in the same order of magnitude or the correct concentration units.

## 4.6 Piper Trilinear Diagrams

Data from some of the wells plot on a Piper diagrams proximal to other documented groundwater regimes (Figure 12). Examples are Wells ATTC, USGS #15 and P2. Well P2 is a deeper well, relative to the rest of the shallow system, on the western fringe of the shallow system. Its chemical makeup appears closer to that of deeper groundwater that has little of the evaporative effect to which shallower groundwater is commonly subjected. Despite its similarity to deeper aquifer water, P2 is in an area of high septic tank density, and may be impacted by septic system leachate and perhaps secondary recharge from irrigation. This is supported by the presence of high $NO_3^-$ in relation to much of the shallow groundwater system and trace pharmaceuticals. The derivation of shallow water from deeper groundwater is a likely explanation for attributes of ATTC as well, as it is also located on the northern fringe of the shallow system. Unlike Well P2, at ATTC there is little evidence of a strong influence of anthropogenic recharge from septic systems. USGS#15 is geographically close to ATTC and likely represents similar groundwater conditions.

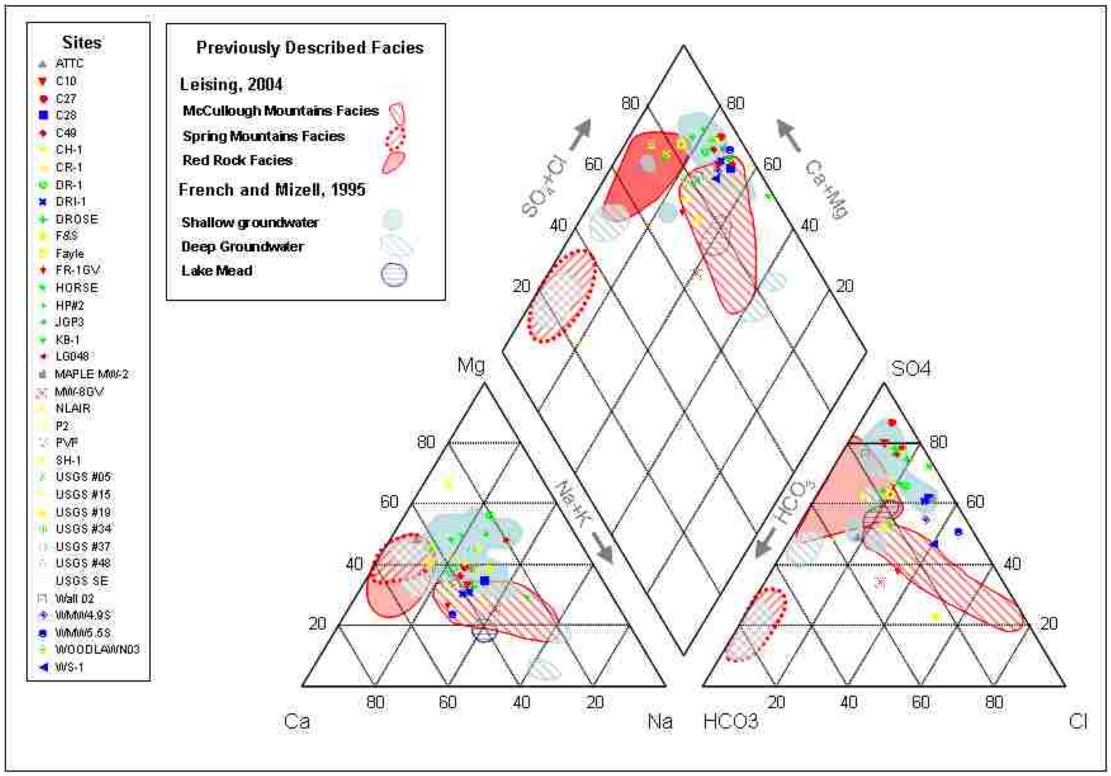


**Figure 12. Trilinear diagram comparing the results of this research and waters and facies identified by other researchers in Las Vegas Valley. (Leising, 2004; Mizell, 1995)**

Locally, shallow groundwater sites bear resemblance to surface water conditions as well as to deeper water. This may suggest the upward migration of deep aquifer water into the shallow system and from there to surface flows. Alternatively, surface water contributions along losing reaches may enter the deeper aquifers through the shallow system. Water in Duck Creek near MAPLE MW-2 is chemically similar to nearby shallow groundwater found in MAPLE MW-2, and plots between the McCullough Mountains facies and the Red Rock facies of the Las Vegas Springs Aquifer as defined by Leising (2004). Surface water flows in Duck Creek drain the geographic area that lies between these two facies. Wells MAPLE MW-2, C28, DRI-1 also plot within this area on the $HCO_3$ – Cl – $SO_4$ ternary diagram. These wells are all adjacent to washes that have perennial baseflow as identified in Dano (2003).

Similarities exist not only between shallow groundwater and surface water chemistries, but with deeper geochemical facies that are not spatially proximal to the shallow groundwater sites. The data from P2 plot on the Piper diagram adjacent to the Spring Mountain facies, yet the well is physically located in the area of the Red Rock geochemical facies. This is likely an impact of irrigation and septic infiltration of water delivered from the municipal system. This water is delivered in the summer mostly from wells producing water from the Spring Mountains facies in the Las Vegas Springs Aquifer (per Leising, 2004), and mixed with Lake Mead water the rest of the year.

Similar situations are common. Most of the wells geographically within the area of the Red Rock geochemical facies plot in a Piper diagram like waters from the McCullough Mountains facies. Similarly, most of the wells that physically lie within the area of the Spring Mountains facies plot in the Red Rock facies on a Piper diagram. Examples include JGP03, USGS#37, USGS#34, USGS#48, and Wall 02. These wells all physically lie within the geographic region encompassed by the Spring Mountains facies of the Las Vegas Springs Aquifer and plot on a Piper diagram in the transition between the Redrock and McCollough  Mountains geochemical facies (Leising, 2004).

This supports the premise that shallow groundwater is evolved or derived from adjacent waters in deeper aquifers.  Just as water, moving along the flow path in deeper groundwater, evolves into the adjacent facie through groundwater-rock interactions and mixing with waters derived from recharge in different geologic settings (Leising, 2004), it does the same during upward migration.  Some of the wells appear more transitional and plot with more similarity to physically adjacent deeper geochemical facies.

## 4.7 Principal Component Analysis

A rasterized dataset was created from each of the first three PC scores (PC1, PC2, and PC3) (Figures 13, 14, and 15).  The resulting grids were mapped, grouped into 10 categories using the "natural breaks" methodology of ArcView® software, and color coded.  The color breaks corresponding to PC1 are oriented roughly perpendicular to the groundwater flow direction within the study area.  The PC2 color breaks produce a less cohesive pattern that suggests that the PC 2 values are dominated by a more localized variable.  The PC3 plot has color breaks that are again perpendicular to the natural flow paths and has a pattern that is suggestive of a natural variability of the constituents.

PC1 correlates strongly with electroconductivity values, field EC, lab EC,  and TDS (see Table 9).  Correlations of -0.980 and –0.983 for the conductivities respectively and  –0.953 for TDS.  There is also a strong negative correlation with $Na^+$ and $K^+$, with correlation coefficients of –0.962 and –0.917 respectively.  There are strong secondary negative correlations with PC1 of  –0.854 and  –0.858 for $Ca^{2+}$ and $Mg^{2+}$ respectively and

–0.869 and –0.823 for $Cl^-$ and $SO_4^{2-}$ respectively. The contours of the PC1 scores very closely mimic the contours for $K^+$, $Na^+$, EC and TDS (Figure 13). The contours of the $Mg^{2+}$ and $Cl^-$ data also bear similar patterns to the PC 1 contours. It would be expected that these major ions would determine both TDS and EC, and would closely correlate.

The second principal component has a moderate positive correlation with $SiO_2$ 0.697 and a moderate negative correlation with pH –0.792 (Figure 14).

The third principal component has its strongest correlation with $NO_3^-$. There is a positive correlation of 0.871 with $NO_3^-$ the next weaker positive correlation is between the stable isotopes D and O18 with moderate positive correlations of 0.355 and 0.314 respectively (Figure 15). The third principal component might be most indacitave of the influence of septics on shallow groundwater quality. The weaker but positive correlation with D and $^{18}O$ supports this. The D and $^{18}O$ values for recovered water plot amongst many of the shallow groundwater samples (Green +'s on Figure 3).

To further study the results, a comparison between the PC scores and the trilinear plots must be made. Visualization was aided by color-coding the points on the trilinear diagrams to match the PC scores. These are displayed in Figures 17 through 19. To improve the comparison between PC scores and placement on trilinear diagrams, a series of trilinear diagrams have been produced with a color coding to match the rasterized factor scores. By color-coding the points on the trilinear diagrams to the PC scores, especially as they are mapped, a comparison of first PC scores and the trilinear plots can be more easily made.

The Principal component scores plotted on the trilinear diagram have been color shaded to represent positive versus negative values for the PC 1 scores (Figure 16). The

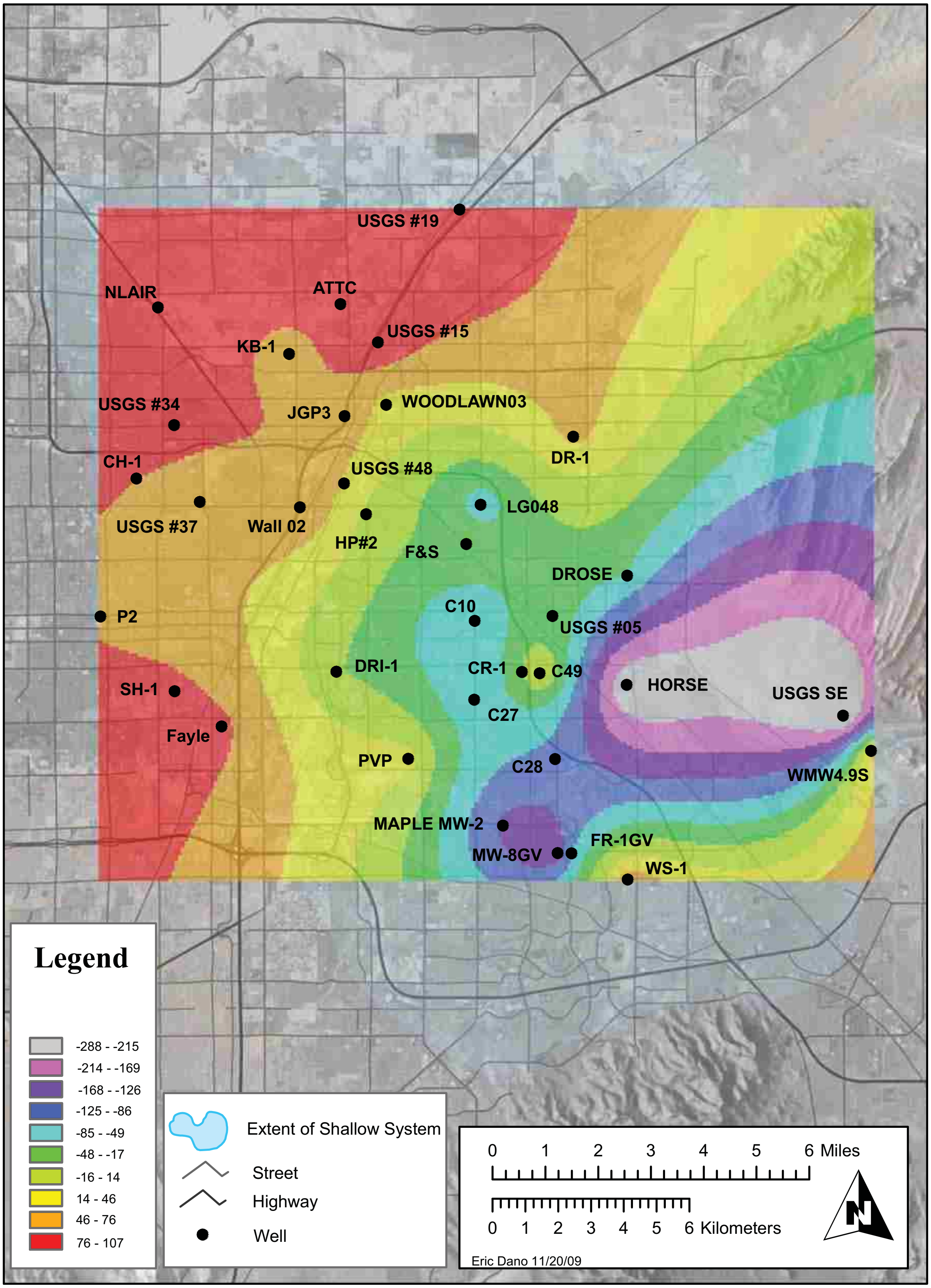


**Figure 13 Rasterized results of PC 1 scores presented in spatial relation to sample locations in Las Vegas Valley.**

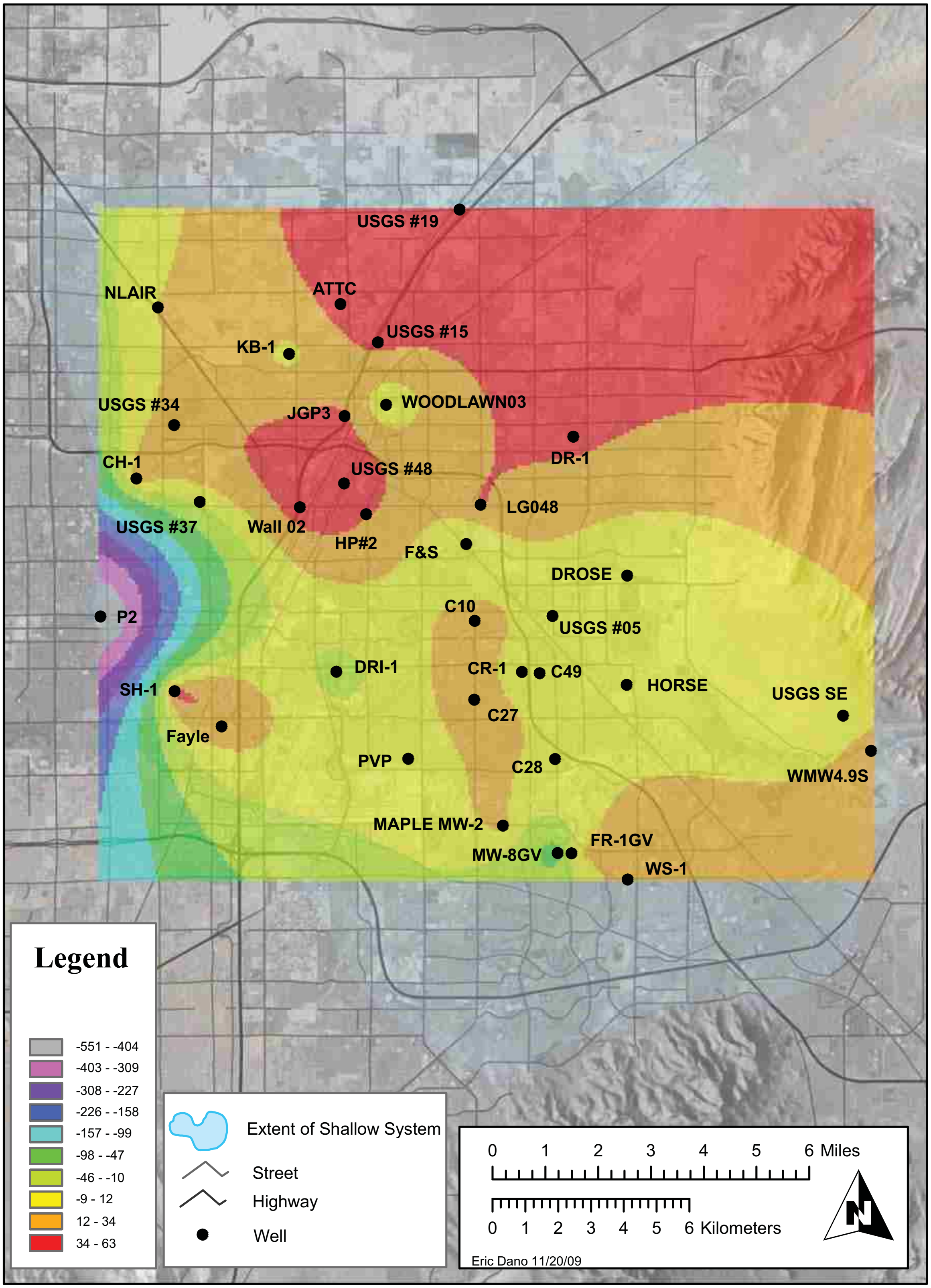


**Figure 14 Rasterized results of PC 2 scores presented in spatial relation to sample locations in Las Vegas Valley.**

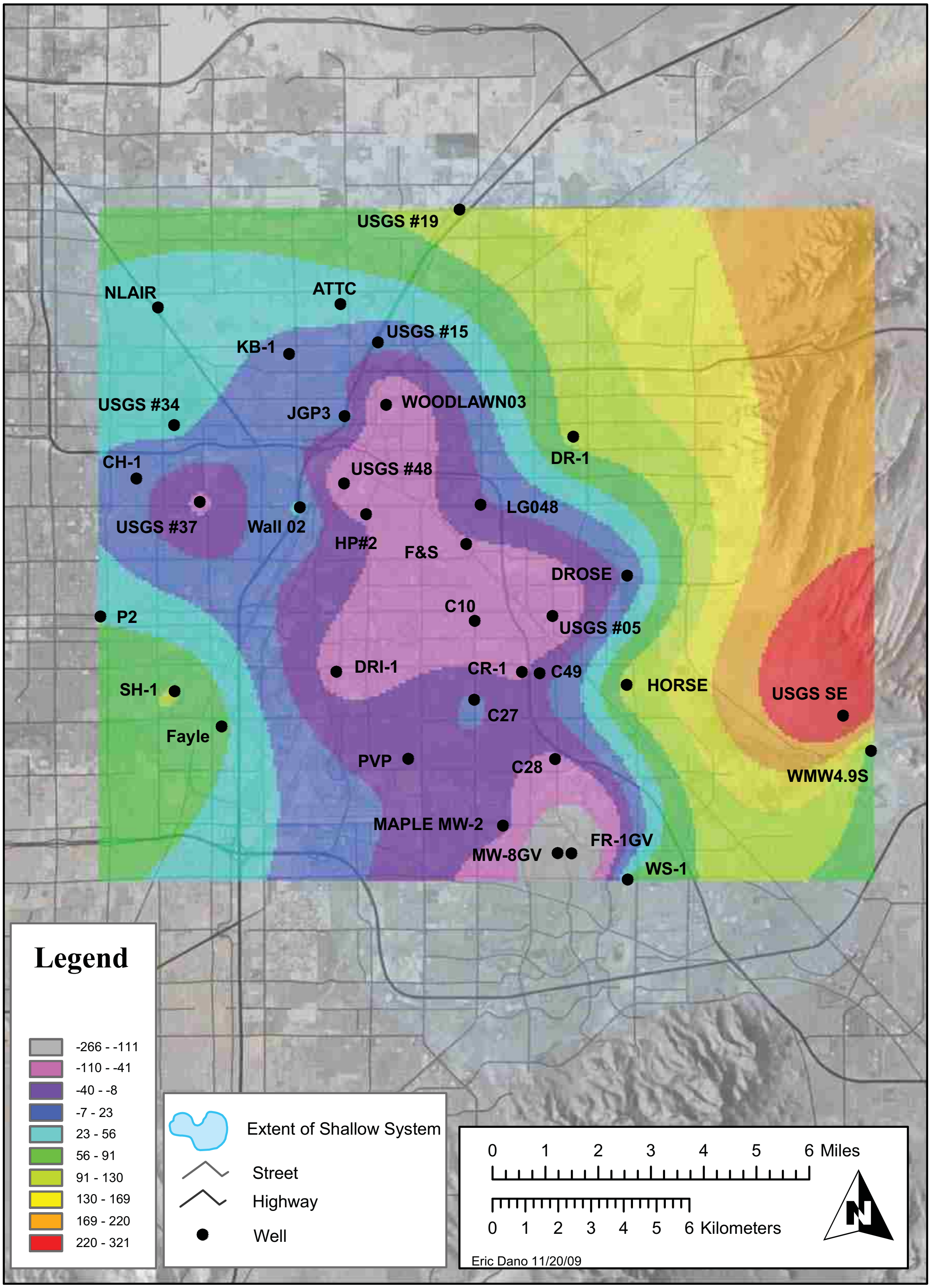


**Figure 15 Rasterized results of PC 3 scores presented in spatial relation to sample locations in Las Vegas Valley.**

scores shift from positive to negative along the general flow path that follows topographic gradient in the Valley. The shift from positive to negative along flow path is best demonstrated by the grouping of the data points into two mostly distinct sets. This does not necessarily imply that in the region where the values are close to zero the correlation between those variables and PC1 breaks down, this region represents the datapoints nearest the overlap of the two groups.

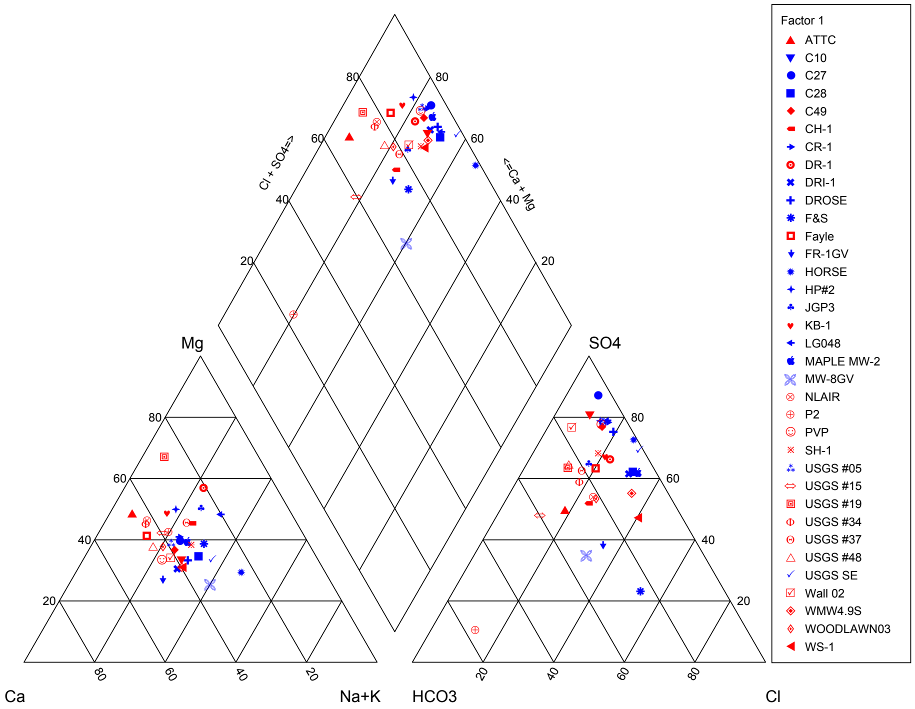


**Figure 16 Trilinear diagram with point color shaded to relate to positive or negative values of the PC 1 scores.**

Wells ATTC, NLAIR, USGS #19, USGS #15, USGS #34, CH-1, SH-1 and Fayle group together with positive PC scores. These wells also plot close together on the trilinear diagram with values for Cl+SO$_4$ above 60% MEQ and Ca+Mg above 80 % MEQ. The shallow groundwater in the northwest portion of the shallow system is a Mg-

Ca-$SO_4$-$HCO_3$ water. This progresses to a Ca-Mg-$SO_4$-$HCO_3$ intermediate water as found in USGS #48. Along the flow path the water further evolves from the carbonate sulfate water to a more sulfate dominated water Mg-Ca-Na-$SO_4$ as encountered in well C27. The Na-Mg-$SO_4$-Cl water encountered in HORSE effectively represents the end of the general flow path that follows topographic gradient in the Valley. This is also evident as HORSE has the highest TDS encountered in the shallow wells.

The high TDS found in water samples from HORSE is likely associated with soluble salts located in the soils surrounding the well. Dinger (1977) identified the salts glauberite ($Na_2Ca(SO_4)_2$), mirabilite ($Na_2SO_4 \cdot 10\ H_2O$), and thenardite ($Na_2SO_4$) present in the soil in the area near HORSE (Dinger, 1977). As was noted by Dinger (1977) the change from Ca-Mg-bicarbonate water to a Na-Mg-$SO_4$-Cl is associated with the presence of sodium sulfate species in the soils. PCA results describe the spatial association but can not indicate whether the salts influence the groundwater chemistry or are a result of it. Well USGS-SE produces a similar water (Na-Mg-Ca-$SO_4$-Cl) with the lower TDS and additional $Ca^{2+}$ that probably derives from the abundant gypsum present in sediments on the far eastern side of the basin. It should be noted that HORSE and USGS-SE are close to each other in the southeast part of the Las Vegas Valley, but they are not on the same flow path. Flow in the shallow groundwater system in this area is generally toward the Wash or at least tangential to it. The similarities in chemistry between the two sites may be indicative of the influence of groundwater from depth that is not hindered by the wash. This correlation with the evolution of the water is consistent with the evolution of waters flowing through basins in arid environments such as Smith Creek Valley (Thomas et al. 1989).

In addition to the evolution of the shallow groundwater some indication of the influence of secondary recharge is evident where water samples differ significantly from nearby waters. For example. MW-8GV is often an outlier when plotted on the trilinear diagrams. The Na-Ca-Mg-$SO_4$-Cl-$HCO_3$ water is possibly the result of a combination of the influence of geology on the Whitney Mesa and the influence of Lake Mead water mixed through secondary recharge. Calcium carbonate cemented soil and the presence of gypsum could account for some of the ions dominating this water (Smith and Guitjens, 1998).

Water samples collected from the three wells located adjacent to active washes fall into the same Ca-Mg-Na-$SO_4$-Cl water type that is also shared by two sites in areas dominated by irrigated turf, WOODLAWN 03 and DROSE. These wells are not proximal to each other within the shallow system DROSE is located in the Desert Rose golf course near the confluence of the Las Vegas Wash and Flamingo Wash. The water type encountered might indicate a mixture of surface water with the most urban impact and native shallow groundwater. Desert Rose golf course has been irrigated with reclaimed waste water since 1948 (Dinger, 1977). In contrast to sites potentially impacted by reuse irrigation well WOODLAWN 03 is located in an irrigated cemetery north of downtown Las Vegas. As there are no active washes in the immediate area, this would suggest that the water type is more likely influenced by Lake Mead water through secondary recharge.

Additional to the color shading to demonstrate positive and negative values, color shading of points has been conducted for other comparisons. A comparison can be made by color shading The PC 1 scores on a trilinear plot to match the colors used on Figure 13 that represent the PC 1 scores mapped in relation to the shallow wells (Figure 17). These colors also group in correlation to both location along the general flow path and the physical proximity of the wells. Figure 18 is a similar color shading for the PC 2 scores resulted in a less robust but still reasonable grouping when contrasted to the spatial extents of the PC scores as grouped in the map in Figure 14. The PC 3 scores as color shaded in a trilinear diagram to match Figure 15 were far less convincing of the use of PCA as a surrogate for trilinear diagrams (Figure 19). The results presented in Figure 19 suggest that only the most variable principal components bear significant relation to geochemical facies as they would be defined through trilinear diagrams.

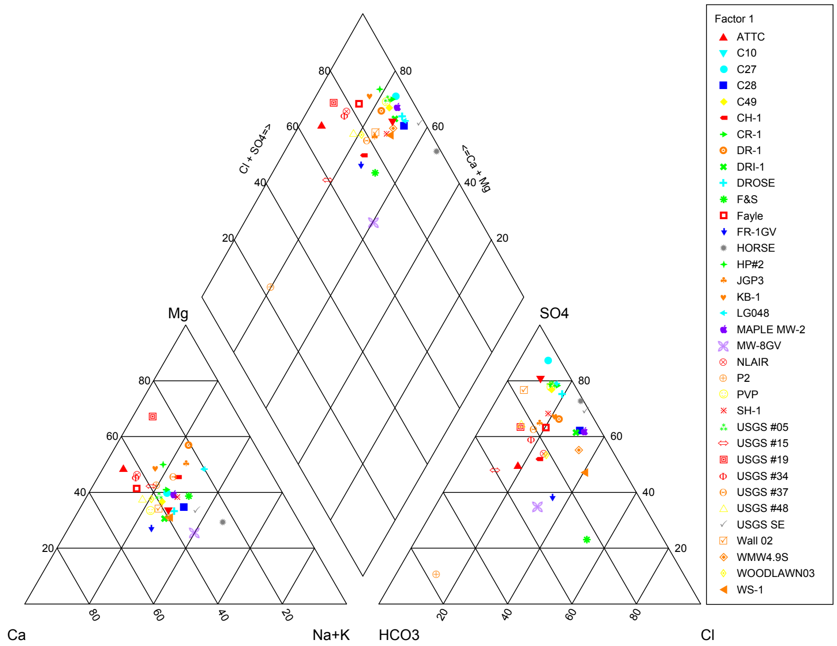


**Figure 17 Trilinear diagram with point color shaded to relate to the values of the PC 1 scores**

A map of facies separations based on PC 1 scores and Mg-Ca-$SO_4$-$HCO_3$, Ca-Mg-$SO_4$-$HCO_3$, Mg-Ca-Na-$SO_4$, and Na-Mg-$SO_4$-Cl waters is presented in Figure 20.

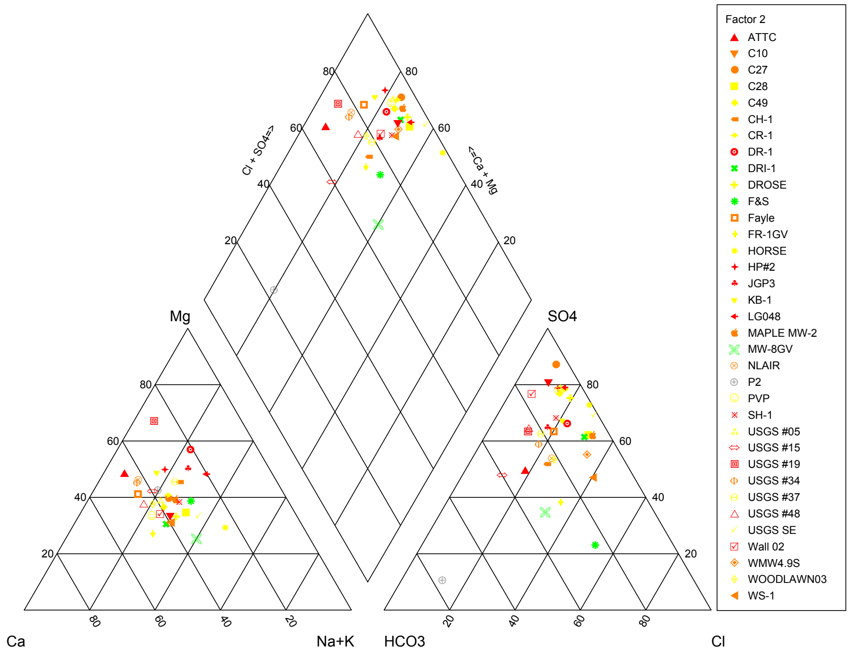


Figure 18 Trilinear diagram with point color shaded to relate to the values of the PC 2 scores.

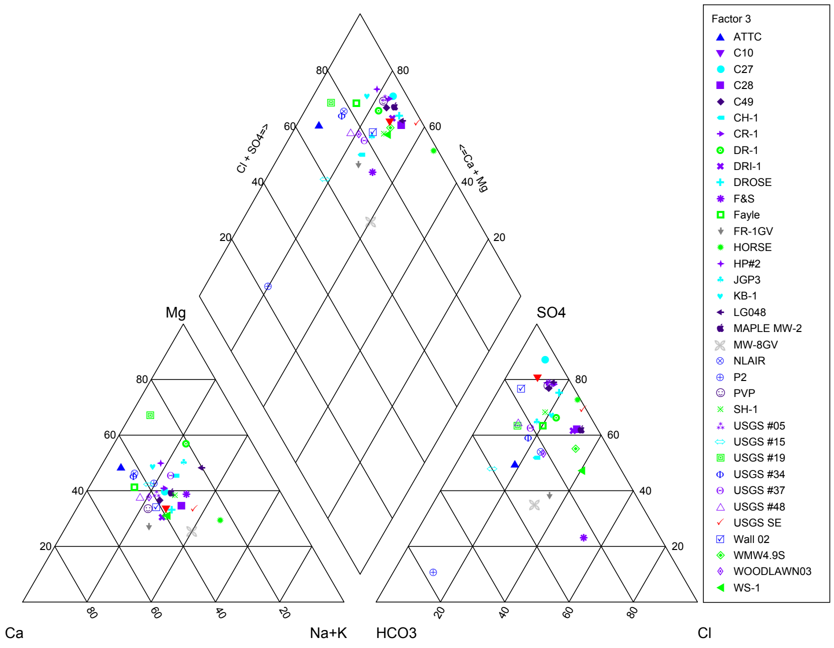


Figure 19 Trilinear diagram with point color shaded to relate to the values of the PC 3 scores.

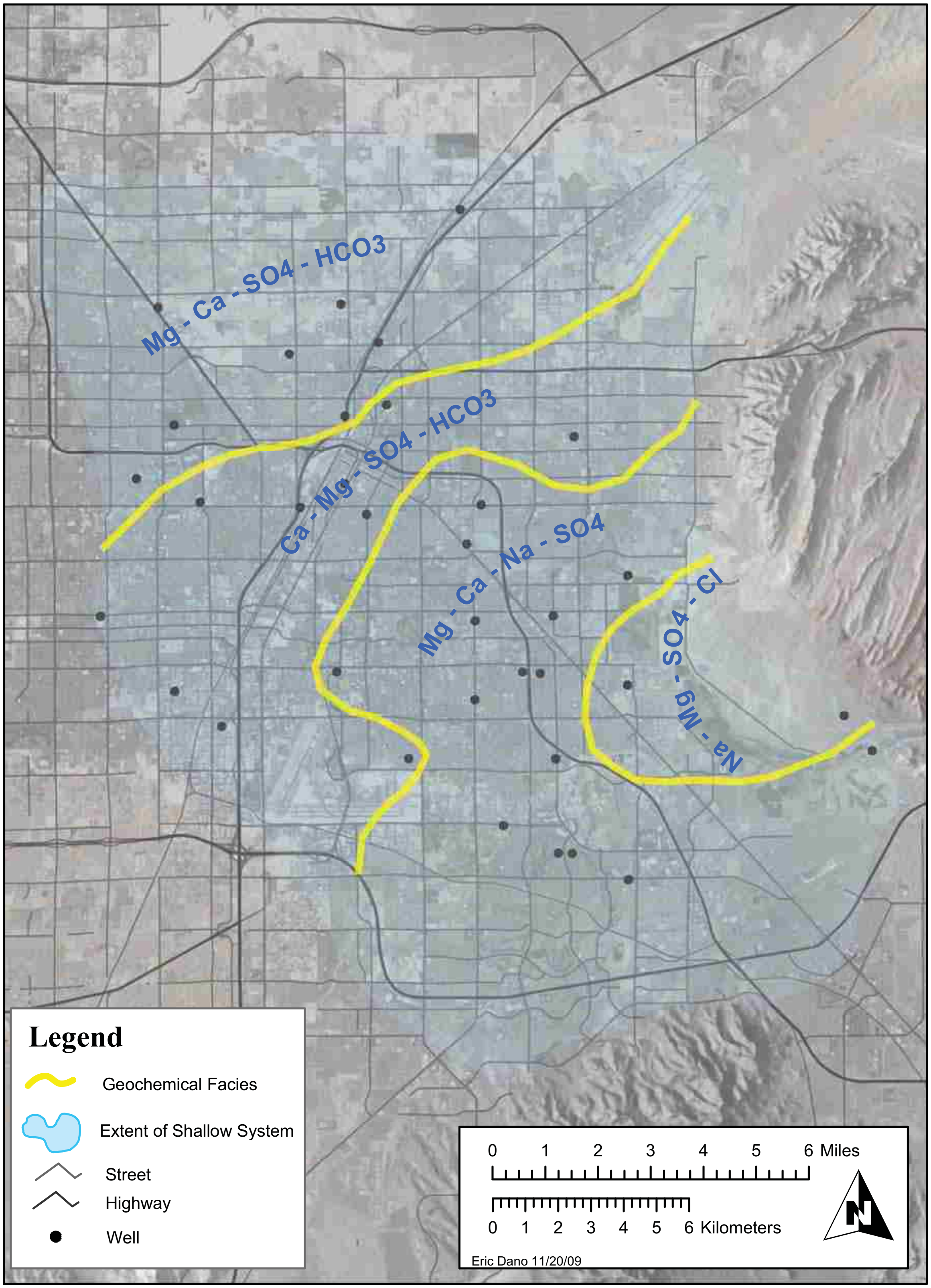


**Figure 20 Contours of PC 1 scores presented with geochemical water types in Las Vegas Valley.**

# CHAPTER 5

# CONCLUSIONS

Characterization of groundwater chemistry has the potential to help resource managers: shallow groundwater constitutes a potential resource through desalination; areas potentially sourcing corrosive nuisance water can be identified; possibly the efficacy of water conservation programs can be evaluated by understanding the extent to which secondary recharge has chemically impacted shallow groundwater. In terms of understanding basin groundwater dynamics, geochemical facies in the shallow system that are analogous to facies identified by previous investigators in deeper aquifer systems are instrumental in determining the sources and evolution of shallow groundwater. A shift in conservative ion proportions during transport might suggest mineral dissolution or mixing with secondary recharge. Better understanding of the sources of shallow groundwater is needed for water balance estimates and to observe and document the impact of conservation efforts on shallow groundwater in Las Vegas Valley.

This research set out to test three hypotheses:

1. PCA can substitute for Piper trilinear diagrams to identify geochemical facies that are defined using major ion concentrations.
2. PCA can also identify geochemical facies by supplementing major ion data with parameters not generally utilized in trilinear diagrams.
3. PCA can identify an irrigation leaching fraction and determine if it constitutes a distinct spatially significant facies.

The data presented in the previous chapters supports the main hypothesis that Principal Component Analysis (PCA), conducted with major ion data and some additional parameters, can substitute for Piper trilinear diagrams. The data also supports the ability to identify geochemical facies in shallow groundwater in the Las Vegas Valley. Secondary to the use of major ion data, PCA has been demonstrated capable to identify geochemical facies by incorporating major cation and anion data with supplemental parameters not generally utilized in trilinear diagrams.

PCA was not successfully applied to identify an irrigation leaching fraction. The scarcity of data with regard to the municipal tracers likely led to the failure of this method. Based on major ions, the irrigation leaching fraction does not appear to be geographically continuous, which may have contributed to failure of the method..

Sites were selected over a sufficient geographic area to provide samples representative of most chemical constituents within the shallow groundwater system. The samples were sent to laboratories for chemical and isotopic analysis. The results were assessed for data quality. Piper trilinear diagrams were constructed of the major ion analytical results. Principal component analysis was conducted to determine the PC scores associated with the groundwater chemistry from each of the sites. Rasterized datasets were then produced and visually inspected to determine if PCA yielded a spatially relevant result. PCA was used to reduce the data to the components that most represent the variance within the dataset. Clusters observed on the Piper trilinear diagrams were further examined to identify associations such as similar geography or source water chemistry. The PCA results were then applied to trilinear diagrams to determine whether PCA groupings matched groupings in the aqueous geochemistry.

Along the general topographic gradient from the northwest to southeast in the Valley, shallow groundwater chemistry changes from a Ca-Mg-$HCO_3$ -$SO_4$ water to a water with proportionally more $SO_4^-$, in parallel with a bulk water salinity and EC increase. This is evident by the dominance of concentration driven metrics in the first principal component and secondarily the strong correlations with $Ca^{2+}$ and $SO_4^{2-}$ and also with $Mg^{2+}$ and $Cl^-$.

Future research could include additional sampling at locations assumed to be impacted by irrigation with an emphasis on different tracers. Processes that could potentially mask simple mixing would include mineral dissolution or precipitation. A study of geochemical equilibrium throughout the shallow system could be conducted to determine if mineral precipitation is likely to occur that might mask what this research has assumed to be a simple binary mixing of native shallow groundwater and municipal water. Modeling or field studies could also be conducted mixing native groundwater from different chemical facies with municipal water. The product waters could then be subjected to a bench top soil column experiments to examine the impact soil chemistry and vadose processes have on the infiltration of irrigation water and the formation of irrigation derived leachate.

# APPENDIX 1

## LITHOLOGIC DESCRIPTIONS

The following lithology will be discussed in approximate chronological age of oldest to youngest. The following order is not meant fully imply superposition, as some of these units are syngenetic.

Tertiary Muddy Creek formation (Tm) is a gypsiferous red-brow to green- gray mudstone and sandstone with little exposure in the southeast portion of the Valley (Page et al., 2005). The thickness is described as less than 300 m (1,000 ft); significantly thicker than many of the other units described in this research; therefore it likely underlies many of the younger sediments in the southeastern area of the Valley (Page et al., 2005).

Quaternary to Tertiary undivided fine-grained sediments (QTs) dominate the lithology within the area of the shallow groundwater system (Page et al., 2005). QTs is light colored and composed of fine sand, silt and calcareous clay with minor gravels that are more abundant toward the west (Donovan, 1996; Page et al., 2005). The unit is calcareous, with variable weak to strong cementation of beds, interbeds, and locally capping caliche; locally gypsiferous (Page et al., 2005). The thickness is estimated to be as much as 4000 m (13,000 ft) to 6000 m (19,000 ft) (Langenheim et al., 1997; Page et al., 2005).

Pleistocene old alluvium (Qao) is composed of cemented gravel and sand from remnants of partly eroded alluvial-fans and terraces (Page et al., 2005). The unit contains well developed degraded soils, and is around 4 m (13 ft) thick (Page et al., 2005).

Middle Pleistocene old fine-grained spring deposits (Qso) are light colored weakly to strongly cemented sand, silt and calcareous clay associated with past ground-water discharge (Page et al., 2005). The unit contains reddish-brown silty, gypserfous interbeds with a blocky structure and overall thickness greater than 5 m (16 ft) (Page et al., 2005).

Middle Pleistocene fine-grained sediments of Whitney Mesa (Qfw) are light colored weakly to strongly cemented reddish-brown fine sands, silts, and calcareous clays with some interstratified gravels with no reported unit thickness (Page et al., 2005).

Late and middle Pleistocene intermediate fan alluvium (Qai) is composed of massive to well bedded cemented alluvial-fan gravel with interbedded sands, the unit ranges from clast to matrix supported with angular to sub-rounded gravel ranging in size from fine gravel to boulders, unit thickness is from less than 1 m (3 ft) to more than 5 m (16 ft) (Page et al., 2005).

Late Pleistocene intermediate fine-grained deposits associated with past ground-water discharge (Qscd) are light-gray partially cemented calcareous silts with trace fossils of cicada burrows (Quade, 1986; Page et al., 2005) over tan-brown fine sandy silt and mud, overall unit thickness is from 2 m (6 ft) to 6 m (20 ft) (Page et al., 2005).

Early Holocene to latest Pleistocene young fine-grained deposits associated with past ground-water discharge (Qse) contain light-gray to light-brown unconsolidated sand, silt and mud, and locally contains dark-gray peat, charcoal and organic rich black mats (Quade et al., 1998; Page et al., 2005), unit thickness is greater than 4 m (13 ft) (Page et al., 2005).

Holocene and late Pleistocene undivided young spring deposits (Qsy) contains units Qse and Qsyy to form and overall unit thickness from 1 m (3 ft) to 4 m (13 ft) (Page et al., 2005).

Holocene and late Pleistocene undivided young and intermediate alluvium (Qau) forms thin veneers of variably cemented, clast to matrix supported, poor to moderately sorted angular to subrounded alluvial-fan gravel with interbedded sand, grain size ranges from sand to boulder and usually occurs over Qai, unit thickness is less than 1 m (3 ft) (Page et al., 2005).

Holocene and latest Pleistocene older young alluvium (Qayo) usually occurs over Qse as noncemented gravel and sand with weakly developed soil derived from alluvial fan remnants, unit thickness is from 1 m (3 ft) to 3 m (9 ft) (Page et al., 2005).

Predominately Holocene and latest Pleistocene young fan alluvium (Qay) is composed of noncemented gravel and sand with weakly developed soil deposited with a bar and swale morphology with eolian sediment between channels (Page et al., 2005). The unit thickness is from 1 m (3 ft) to 3 m (9 ft) (Page et al., 2005).

Holocene older fine-grained deposits (Qfo) form thin veneers of noncemented fluvial sand and mud deposited in fluvial bars and channels with thickness from less than .5 m (1.5 ft) to 1.5 m (5 ft) (Page et al., 2005).

Holocene youngest alluvium (Qayy) noncemented alluvial-fan composed of gravel and sand deposited in a bar and swale morphology including minor modern channels and some weakly developed desert pavement (Page et al., 2005). The unit thickness is from 1 m (3 ft) to 2 m (6 ft) (Page et al., 2005).

Late Holocene youngest spring deposits (Qsyy) are spring mounds and areas of historic and pre-historic groundwater discharge composed of fine-grained organic rich to calcareous silt, clay and mud with a  thickness from 1 m (3 ft) to 4 m (13 ft)  (Page et al., 2005).

Late Holocene dune sand (Qd) is noncemented eolian sand deposited in active to inactive partially vegetated dunes with an overall thickness from 1 m (3 ft) to 5 m (16 ft) (Page et al., 2005).

Late Holocene intermittently active fluvial fine-grained alluvium (Qfy) is a thin veneer of brown to gray sand, silt, mud and gravel interbeds deposited in a fluvial bar and channel system with an overall thickness from .5 m (1.5 ft) to 1.5 m (5 ft) (Page et al., 2005).

# APPENDIX 2

## SITE DESCRIPTIONS

The 35 wells used in this research are found in five settings. Settings include wells located in gravel areas or native desert landscape, areas immediately adjacent to perennially active streams, parks or golf courses in areas of irrigated turf, paved streets in residential areas, and paved areas in commercial settings. The names of the wells are as they appear in the Southern Nevada Water Authority (SNWA) database. The inconsistent style of nomenclature reflects the diverse array of studies and projects that the wells were originally drilled for. The following sites, listed here in alphabetical order, were selected for groundwater sampling. Some of the sites are referred to in the present sense and some are referred to in the past sense, this reflects the current state of existence for these wells. Some wells have been lost to construction in the time since samples were collected.

Well ATTC is located in the parking lot of the Area Technical Trade Center at the corner of Brooks Avenue and Commerce Street. The State plane coordinates for the well are 785296 ft east, and 26779957 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 666689.935 m east, 4009323.273 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 12' 51.84" north, and 115° 8' 44.08" west, WGS 84 PDC mercator projection. There is little irrigated turf nearby. Well ATTC has a period of water-level record from 3/28/1994 to 9/18/2008 with 86 measurements. Depth to water measurements range from 15.62 m (51.26 ft) to 19.69 m (64.6 ft) below ground surface (bgs), and the measurements average 17.28 m (56.69 ft) bgs. ATTC is a 7.6 cm (3 in.) diameter well, drilled to 24 m (80 ft) bgs with a perforated interval from 20.4 m (67 ft) to 21.9 m (72 ft) bgs. To collect a groundwater sample, a volume of approximately 76 liters (20 gallons) was purged on 6/3/2002 with a Grundfos 220V Variflow pump. The well is up gradient from a fault scarp that trends north south near Losee Road. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well C10 site was in located a paved street in a residential area on Wingrove Avenue near the corner of Pecos Road and Desert Inn Road. The State plane coordinates for the well are 798736 ft east, and 26748275 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 670927.103 m east, 3999727.117 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 7' 37.9" north, and 115° 6' 1.98" west, WGS 84 PDC mercator projection. Residential irrigation typical of suburbs in the arid southwest occurs nearby. Well C10 has a period of water-level record from 4/1/1985 to 10/18/2002 with 69 measurements and was lost in 2002 during road construction. Depth to water measurements ranged from 1.64 m (5.37 ft) to 4.03 m (13.22 ft) bgs, and the average was 2.64 m (8.65 ft) bgs. C10 is a 5 cm (2 in.) diameter well, drilled to 5.2 m (17 ft) bgs with a perforated interval from 3.4 m (11 ft) to 4.3 m (14 ft) bgs. To collect a groundwater sample, a volume of approximately 19 liters (5 gallons) was purged on 5/9/2002 with a disposable bailer. The mapped surface geology is Holocene youngest alluvium (Qayy) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well C27 is located on Billman Avenue and Pecos Road, in a residential area. The State plane coordinates for the well are 798693 ft east, and 26740388 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 670949.044 m east, 3997323.131 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 6' 19.9" north, and 115° 6' 2.98" west, WGS 84 PDC mercator projection. Turf irrigation occurs nearby. Well C27 has a period of water-level record from 4/1/1985 to 2/13/2007 with 91 measurements. C27 is a 5 cm (2 in.) diameter well, drilled to 9 m (29.5 ft) bgs with a perforated interval from 7 m (23 ft) to 9 m (29.5 ft) bgs. Depth to water measurements range from 4.69 m (15.38 ft) to 6.96 m (22.83 ft) bgs, and the measurements average 6 m (19.7 ft) bgs. To collect a groundwater sample, a volume of approximately 38 liters (10 gallons) was purged on 5/9/2002 with a 12V submersible pump. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well C28 is located on Rawhide Street near the corner of Rawhide Street and Mountain Vista Street adjacent to the Clark County Regional Flood Control District (CCRFCD) Rawhide channel. The State plane coordinates for the well are 806767 ft east, and 26734463 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 673436.160 m east, 3995553.166 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 5' 20.9" north, and 115° 4' 24.96" west, WGS 84 PDC mercator projection. Well C28 has a period of water-level record from 4/1/1985 to 6/13/2007 with 89 measurements. Depth to water measurements range from 2.05 m (6.71 ft) to 3.11 m (10.2 ft) bgs, and the measurements average 2.37 m (7.76 ft) bgs. C28 is a 5 cm (2 in.) diameter well, drilled to 6 m (20 ft) bgs with a perforated interval from 4.3 m (14 ft) to 5.8 m (19 ft) bgs. To collect a groundwater sample, a volume of approximately 57 liters (15 gallons) was purged on 5/9/2002 with a 12V submersible pump. The mapped surface geology is Holocene and latest Pleistocene young fan alluvium (Qay) (Page et al., 2005). The soils mapped are composed of a combination of silt, poorly graded gravel, silty sand, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well C49 is located in a residential area at the corner of Toledo Avenue and Seville Street, irrigation typical of suburbs in the arid Southwest occurs nearby. The State plane coordinates for the well are 805245 ft east, and 26743049 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 672934.143 m east, 3998163.261 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 6' 45.89" north, and 115° 4' 42.96" west, WGS 84 PDC mercator projection. The site is located down gradient from a north-south trending fault scarp that is approximately adjacent to US highway 515 (93/95) and the Las Vegas Valley Water District (LVVWD) Campbell Reservoir. Well C49 has a period of water-level record from 4/1/1985 to 11/19/2008 with 93 measurements. Depth to water measurements range from 2.32 m (7.61 ft) to 3.64 m (11.95 ft) bgs, and the measurements average 2.93 m (9.61 ft) bgs. C49 is a 5 cm (2 in.) diameter well, drilled to7.6 m (25 ft) bgs with a perforated interval from 6.1 m (20 ft) to 7.6 m (25 ft) bgs. To collect a groundwater sample, a volume of approximately 26 liters (7 gallons) was purged on 3/30/2005 with a disposable bailer. The mapped surface geology is Holocene older fine-grained deposits (Qfo) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well CH-1 is located on a disused LVVWD reservoir site named after the Charleston Heights neighborhood in a residential area at the corner of Falcon Lane and Alta Drive. The State plane coordinates for the well are 764869 ft east, and 26762514 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 660541.994 m east, 4003916.206 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 10' 0.18" north, and 115° 12' 54.17" west, WGS 84 PDC mercator projection. Well CH-1 has a period of water-level record from 8/14/1995 to 9/15/2008 with 29 measurements. Depth to water measurements range from 9.85 m (32.31 ft) to 13.24 m (43.45 ft) bgs, and the measurements average 11.26 m (36.94 ft) bgs. CH-1 is a 10 cm (4 in.) diameter well, drilled to 13.7 m (45 ft) bgs with a perforated interval from 9.1 m (30 ft) to 13.7 m (45 ft) bgs. To collect a groundwater sample, a volume of approximately 49 liters (13 gallons) was purged on 5/17/2002 with a 12V submersible pump. The site is located on a north-south trending fault scarp approximately between Decatur Boulevard and Upland Boulevard. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of silty sand, clayey sand, silt, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well CR-1 is located in the LVVWD Campbell reservoir site near Flamingo Road and US highway 515 (93/95). The State plane coordinates for the well are 803471 ft east, and 26743185 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 672392.857 m east, 3998196.829 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 6' 47.32" north, and 115° 5' 4.58" west, WGS 84 PDC mercator projection. Well CR-1 has a period of water-level record from 3/21/1996 to 1/6/2006 with 17 measurements. Depth to water measurements range from 3.37 m (11.05 ft) to 3.61 m (11.85 ft) bgs, and the measurements average 3.47 m (11.4 ft) bgs. CR-1 is a 10 cm (4 in.) diameter well, drilled to 14.0 m (46 ft) bgs with a perforated interval from 6.4 m (21 ft) to 12.5 m (41 ft) bgs. To collect a groundwater sample, a volume of approximately 265 liters (70 gallons) was purged on 10/29/2002 with a 12V submersible pump. The well is situated near a fault scarp. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well DR-1 is located in the Dell Robinson Middle School yard at the corner of Harris avenue and Greenbrook Street. The well is located in an area of irrigated turf. The State plane coordinates for the well are 808595 ft east, and 26766712 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 673849.939 m east, 4005390.207 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 10' 39.73" north, and 115° 4' 0.6" west, WGS 84 PDC mercator projection. The area is irrigated turf. The well is located approximately .40 km

(¼ mile) from the Las Vegas Wash near the intersection of Bonanza Road and Nellis Boulevard. DR-1 is a 7.6 cm (3 in.) diameter well, drilled to 18.3 m (60 ft) bgs with a perforated interval from12.2 m (40 ft) to 18.3 m (60 ft) bgs. Well DR-1 has a period of water-level record from 6/3/1994 to 9/16/2008 with 39 measurements. Depth to water measurements range from 5.45 m (17.89 ft) to 7.85 m (25.77 ft) bgs, and the measurements average 6.43 m (21.08 ft) bgs. To collect a groundwater sample, a volume of approximately 170 liters (45 gallons) was purged on 5/30/2002 with a Grundfos 220V Variflow pump. The mapped surface geology is Holocene youngest alluvium (Qayy) (Page et al., 2005). The soils mapped are composed of a combination of silt, poorly graded gravel, silty sand, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well DRI-1 is located in a gravel area hosting a solar panel array at the Desert Research institute near the intersection of Swenson Street and Flamingo Road. The State plane coordinates for the well are 784872 ft east, and 26743192 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 666724.258 m east, 3998116.323 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 6' 48.27" north, and 115° 8' 51.26" west, WGS 84 PDC mercator projection. DRI-1 is a 10 cm (4 in.) diameter well, drilled to 5.5 m (18 ft) bgs with a perforated interval from 2.4 m (8 ft) to 5.5 m (18 ft) bgs. Well DRI-1 has a period of water-level record from 7/9/1999 to 9/15/2008 with 31 measurements. Depth to water measurements range from 2.75 m (9.01 ft) to 3.32 m (10.89 ft) bgs, and the measurements average3.06 m (10.04 ft) bgs. To collect a groundwater sample, a volume of approximately 72 liters (19 gallons) was purged on 6/6/2002 with a 12V submersible pump.  The well is located adjacent to the Tropicana Wash.  The mapped surface geology is Holocene youngest alluvium (Qayy) (Page et al., 2005).  The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well DROSE is located in the Desert Rose municipal golf course near Vegas Valley Drive, just below the confluence of Las Vegas Wash and Flamingo Wash.  The State plane coordinates for the well are 813987 ft east, and 26752804 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989).  The UTM easting and northing for the well are 675555.194 m east, 4001175.270 m north, NAD 83 Zone 11 North.  The latitude and longitude for the well are 36° 8' 21.89" north, and 115° 2' 55.76" west, WGS 84 PDC mercator projection.  The area is turf that is irrigated with reuse water.  DROSE is a 10 cm (4 in.) diameter well, drilled to 14.9 m (49 ft) bgs with a perforated interval from 13.7 m (45 ft) to 14.9 m (49 ft) bgs.  Well DROSE has a period of water-level record from 7/28/1994 to 9/16/2008 with 48 measurements.  Depth to water measurements range from 4.57 m (14.98 ft) to 6.25 m (20.5 ft) bgs, and the measurements average 5.45 m (17.87 ft) bgs.  To collect a groundwater sample, a grab sample was collected on 4/23/2003 with a disposable bailer.  The mapped surface geology is Holocene youngest alluvium (Qayy) (Page et al., 2005).  The soils mapped are composed of a combination of silt, poorly graded gravel, silty sand, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well F&S is located in the median in Boulder Highway/ Fremont Street between the intersections with E. St Louis Avenue and Sahara Avenue across from the Lucky

Cuss Motel. The State plane coordinates for the well are 797877 ft east, and 26755956 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 670631.150 m east, 4002064.307 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 8' 53.9" north, and 115° 6' 11.99" west, WGS 84 PDC mercator projection. Little irrigation occurs in the vicinity of the well. F&S is a 5 cm (2 in.) diameter well, drilled to 7.6 m (25 ft) bgs with a perforated interval from 6.1 m (20 ft) to 7.6 m (25 ft) bgs. Well F&S has a period of water-level record from 4/26/1994 to 9/16/2008 with 55 measurements. Depth to water measurements range from 1.88 m (6.18 ft) to 2.95 m (9.67) ft bgs, and the measurements average 2.30 m (7.55 ft) bgs. To collect a groundwater sample, a volume of approximately 26 liters (7 gallons) was purged on 3/30/2005 with a disposable bailer. The mapped surface geology is Holocene and latest Pleistocene young fan alluvium (Qay) (Page et al., 2005). The soils mapped are composed of a combination of lean clay, silty sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well FAYLE is located at the LVVWD Fayle reservoir site near Dean Martin Drive and Tropicana Avenue. The State plane coordinates for the well are 773410 ft east, and 26737735 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 663255.182 m east, 3996402.256 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 5' 54.79" north, and 115° 11' 11.24" west, WGS 84 PDC mercator projection. There is little irrigation that occurs nearby. There is physical water level evidence that the well is influenced from deeper aquifer systems. The hydrograph exhibits a signal that corresponds to artificial recharge activities at LVVWD well AR018 located at Decatur Boulevard and Warm Springs Road. This signal indicates connectivity with the deeper aquifer systems. Well FAYLE has a period of water-level record from 6/3/1994 to 9/15/2008 with 37 measurements. Depth to water measurements range from 6.25 m (20.5 ft) to 10.71 m (35.15 ft) bgs, and the measurements average 8.22 m (26.98 ft) bgs. FAYLE is a 7.6 cm (3 in.) diameter well, drilled to 14.6 m (48 ft) bgs with a perforated interval from 13.1 m (43 ft) to 14.6 m (48 ft) bgs. To collect a groundwater sample, a volume of approximately 341 liters (90 gallons) was purged on 5/7/2002 with a 12V submersible pump. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well FR-1GV is located in a street in the Fox Ridge residential area on Whitney Mesa, domestic irrigation occurs nearby. The State plane coordinates for the well are 808408 ft east, and 26725030 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 673978.184 m east, 3992685.441 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 3' 47.52" north, and 115° 4' 5.58" west, WGS 84 PDC mercator projection. FR-1GV is a 5 cm (2 in.) diameter well, drilled to 3.31 m (10.85 ft) bgs. Well FR-1GV has a period of water-level record from 1/31/1999 to 1/26/2007 with 82 measurements. Depth to water measurements range from 1.04 m (3.40 ft) to (6.30 ft) bgs, and the measurements average 1.52 m (4.99 ft) bgs. To collect a groundwater sample, a volume of approximately 19 liters (5 gallons) was purged on 4/23/2003 with a disposable bailer.

The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well HORSE is located in a gravel area between Horseman's Park and Dog Fanciers Park, near the Clark County Water Reclamation Districts Waste Water treatment facility south of Flamingo Road and west of Stephanie Street. The State plane coordinates for the well are 813956 ft east, and 26741895 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 675594.232 m east, 3997850.245 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 6' 34.01" north, and 115° 2' 56.87" west, WGS 84 PDC mercator projection. HORSE is a 30.5 cm (12 in.) diameter well, drilled to 24.4 m (80 ft) bgs with a perforated interval from 6.1 m (20 ft) to 24.4 m (80 ft) bgs. Well HORSE has a period of water-level record from 4/27/1994 to 9/16/2008 with 37 measurements. Depth to water measurements range from 3.72 m (12.2 ft) to 5.04 m (16.54 ft) bgs, and the measurements average 4.46 m (14.62 ft) bgs. To collect a groundwater sample, a volume of approximately 1495 liters (395 gallons) was purged on 6/5/2002 with a Grundfos 220V Variflow pump. The park landscape is a mix of bare soil and irrigated turf. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) and Holocene and latest Pleistocene young fan alluvium (Qay) (Page et al., 2005). The soils mapped are composed of a combination of silt, poorly graded gravel, silty sand, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well HP#2 is located in Huntridge Park near Maryland Parkway and Charleston Boulevard. The State plane coordinates for the well are 787857 ft east, and 26758940 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 667564.007 m east, 4002929.202 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 9' 23.88" north, and 115° 8' 14" west, WGS 84 PDC mercator projection. The area was irrigated turf at the time of sample collection. HP#2 is a 10 cm (4 in.) diameter well, drilled to 12.2 m (40 ft) bgs with a perforated interval from 10.7 m (35 ft) to 12.2 m (40 ft) bgs. Well HP#2 has a period of water-level record from 7/7/1993 to 9/15/2008 with 44 measurements. Depth to water measurements range from 1.74 m (5.71 ft) to 2.72 m (8.92 ft) bgs, and the measurements average 2.18 m (7.14 ft) bgs. To collect a groundwater sample, a volume of approximately 76 liters (20 gallons) was purged on 5/13/2002 with a 12V submersible pump. The mapped surface geology is Holocene and latest Pleistocene young fan alluvium (Qay) (Page et al., 2005). The soils mapped are composed of a combination of lean clay, silty sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well JGP03 was located in a xeriscaped area adjacent to James Gay III park near Interstate 15 and Owens Avenue, on B Street between Madison Avenue and Jefferson Avenue. The State plane coordinates for the well are 785705 ft east, and 26768753 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 666864.471 m east, 4005910.392 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 11' 1.02" north, and 115° 8' 39.7" west, WGS 84 PDC mercator projection. The area was formerly all irrigated turf. A portion of the turf was converted to xeriscape after a storm drain project necessitated the replacement of the well.  JGP03 was a 5 cm (2 in.) diameter well, drilled to 10.1 m (33 ft) bgs with a perforated interval from 8.5 m (28 ft) to 10.1 m (33 ft) bgs.  Well JGP03 has a period of water-level record from 4/28/1994 to 9/18/2008 with 27 measurements.  Depth to water measurements range from 3.30 m (10.83 ft) to 5.12 m (16.80 ft) bgs, and the measurements average 4.14 m (13.59 ft) bgs.  To collect a groundwater sample, a volume of approximately 38 liters (10 gallons) was purged on 3/10/2005 with a disposable bailer. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005).  The soils mapped are composed of a combination of lean clay, silty sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well KB-1 is located in a school yard at Kermit Booker elementary near Martin Luther King Boulevard and Carey Avenue.  The State plane coordinates for the well are 780154 ft east, and 26774989 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989).  The UTM easting and northing for the well are 665144.908 m east, 4007786.256 m north, NAD 83 Zone 11 North.  The latitude and longitude for the well are 36° 12' 2.94" north, and 115° 9' 47.09" west, WGS 84 PDC mercator projection.  At the time of sample collection the well was located in an irrigated turf area.  The school has since been replaced and the land use has been reconfigured.  KB-1 is a 7.6 cm (3 in.) diameter well, drilled to 15.2 m (50 ft) bgs with a perforated interval from 10.7 m (35 ft) to 15.2 m (50 ft) bgs.  Well KB-1 has a period of water-level record from 3/28/1994 to 9/18/2008 with 146 measurements.  Depth to water measurements range from 5.92 m (19.41 ft) to 10.53 m (34.56 ft) bgs, and the measurements average 7.28 m (23.87 ft) bgs.

To collect a groundwater sample, a volume of approximately 114 liters (30 gallons) was purged on 3/10/2005 with a 12V submersible pump. The mapped surface geology is Holocene and latest Pleistocene young fan alluvium (Qay) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well LG048 is located in an apartment complex parking lot near the intersection of Charleston Boulevard between Pecos Road and Pecos Street. The State plane coordinates for the well are 799332 ft east, and 26759908 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 671057.027 m east, 4003275.266 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 9' 32.91" north, and 115° 5' 54.01" west, WGS 84 PDC mercator projection. There is minimal turf irrigation in the vicinity of the well. LG048 is a 15.2 cm (6 in.) diameter well, drilled to 12.2 m (40 ft) bgs with a perforated interval from 11.0 m (36 ft) to 11.9 m (39 ft) bgs. Well LG048 has a period of water-level record from 6/9/1971 to 9/16/2008 with 85 measurements. Depth to water measurements range from 2.06 m (6.75 ft) to 4.30 m (14.11 ft) bgs, and the measurements average 3.25 m (10.60 ft) bgs. To collect a groundwater sample, a volume of approximately 420 liters (111 gallons) was purged on 5/16/2002 with a 12V submersible pump. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of lean clay, silty sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well MAPLE MW-2 is located in a mini-mall parking lot at the intersection of Sunset Road and Sandhill Road. The State plane coordinates for the well are 801562 ft east, and 26727800 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 671879.356 m east, 3993499.301 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 4' 15.27" north, and 115° 5' 28.79" west, WGS 84 PDC mercator projection. There is little irrigated turf in the area of the well. This well is located approximately .40 km (¼ mile) from a gaining reach of Duck Creek (Dano, 2003). MAPLE MW-2 is a 5 cm (2 in.) diameter well, drilled to 8.4 m (27.5 ft) bgs with a perforated interval from 3.8 m (12.5 ft)to 8.4 m (27.5 ft) bgs. Well MAPLE-MW-2 has a period of water-level record from 5/21/2003 to 9/17/2008 with 16 measurements. Depth to water measurements range from 3.32 m (10.89 ft) to 3.90 m (12.81 ft) bgs, and the measurements average 3.73 m (12.25 ft) bgs. To collect a groundwater sample, a volume of approximately 26 liters (7 gallons) was purged on 3/30/2005 with a disposable bailer. The mapped surface geology is Holocene and latest Pleistocene young fan alluvium (Qay) (Page et al., 2005). The soils mapped are composed of a combination of silt, poorly graded gravel, silty sand, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well MW-8GV is located in a street in a residential area on Whitney Mesa, domestic irrigation occurs nearby. The State plane coordinates for the well are 807044 ft east, and 26725059 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 673562.332 m east, 3992688.226 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 3' 47.88" north, and 115° 4' 22.19" west, WGS 84 PDC mercator projection. MW-8GV is a 5 cm (2 in.)

diameter well, drilled to 3.4 m (11 ft). Well MW-8GV has a period of water-level record from 1/31/1999 to 1/26/2007 with 79 measurements. Depth to water measurements range from 1.07 m (3.5 ft) to 1.80 m (5.9 ft) bgs, and the measurements average 1.42 m (4.65 ft) bgs. To collect a groundwater sample, a volume of approximately 15 liters (4 gallons) was purged on 4/23/2003 with a disposable bailer. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well NLAIR is located in a gravel area at the North Las Vegas Airport near the fence line at Rancho Drive and Decatur Boulevard. The State plane coordinates for the well are 767025 ft east, and 26779636 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 661122.867 m east, 4009144.068 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 12' 49.43" north, and 115° 12' 27.07" west, WGS 84 PDC mercator projection. There is little irrigated turf in the area of the well. NLAIR is a 5 cm (2 in.) diameter well, drilled to 11.6 m (38 ft) bgs with a perforated interval from 10.1 m (33 ft) to 11.6 m (38 ft) bgs. Well NLAIR has a period of water-level record from 7/13/1999 to 9/18/2008 with 36 measurements. Depth to water measurements range from 5.41 m (17.76 ft) to 6.67 m (21.87 ft) bgs, and the measurements average 5.82 m (19.08 ft) bgs. To collect a groundwater sample, a volume of approximately 57 liters (15 gallons) was purged on 6/4/2002 with a 12V submersible pump. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). This site falls on the boundary between two soil association groups. The soils mapped are composed of a combination of silty sand, clayey sand, silt, lean clay, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well P2 is located at the LVVWD Pico reservoir site near Desert Inn Road and Jones Boulevard. The State plane coordinates for the well are 761266 ft east, and 26748710 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 659505.291 m east, 3999693.155 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 7' 43.8" north, and 115° 13' 38.74" west, WGS 84 PDC mercator projection. The well was drilled prior to the abandonment of two LVVWD artificial recharge wells. The wells were constructed in a fashion that permitted cascading water. P-2 is a 10 cm (4 in.) diameter well, drilled to 32.6 m (107 ft) bgs with a perforated interval from 26.5 m (87 ft) to 32.6 m (107 ft) bgs. The hydrograph demonstrates the rapid recovery of the shallow groundwater system after the cascading water was stopped. Well P-2 has a period of water-level record from 6/29/2005 to 11/19/2008 with 8 measurements. Depth to water measurements range from 22.34 m (73.31 ft) to 29.89 m (98.06 ft) bgs, and the measurements average 25.38 m (83.28 ft) bgs. To collect a groundwater sample, a volume of approximately 19 liters (5 gallons) was purged on 8/1/2005 with a disposable bailer. The mapped surface geology is late and middle Pleistocene intermediate fan alluvium (Qai) (Page et al., 2005). The soils mapped are composed of a combination of silty sand, clayey sand, silt, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well PVP is located in an irrigated turf area in Roan Park near Eastern Avenue and Russell Road at the corner of Stirrup Street and Roan Avenue. The State plane coordinates for the well are 792075 ft east, and 26734490 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 668958.216 m east, 3995496.153 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 5' 21.89" north, and 115° 7' 23.97" west, WGS 84 PDC mercator projection. PVP is a 10 cm (4 in.) diameter well, drilled to 9.1 m (29.7 ft) bgs with a perforated interval from 7.8 m (25.7 ft) to 9.1 m (29.7 ft) bgs. Well PVP has a period of water-level record from 2/26/1986 to 9/15/2008 with 107 measurements. Depth to water measurements range from 3.90 m (12.79 ft) to 5.98 m (19.61 ft) bgs, and the measurements average 4.97 m (16.31 ft) bgs. To collect a groundwater sample, a volume of approximately 57 liters (15 gallons) was purged on 3/30/2005 with a 12V submersible pump. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). This site falls on the boundary between two soil association groups. The soils mapped are composed of a combination of silty sand, clayey sand, silt, lean clay, fat clay, and silty organic clay or organic silt (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well SH-1 is located in a median adjacent to a paved school bus facility near the Sunrise Horizon High School on Harmon Avenue between Arville Street and Cameron Street. The State plane coordinates for the well are 768687 ft east, and 26741258 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 661800.098 m east, 3997454.987 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 6' 29.82" north, and 115° 12' 8.62" west, WGS 84 PDC mercator projection. SH-1 is a 5 cm (2 in.) diameter well, drilled to 11.4 m (37.5 ft) bgs with a perforated interval from 9.9 m (32.5 ft) to 11.4 m (37.5 ft) bgs. Water levels might be influenced by nearby remediation activities. Well SH-1 has a period of water-level record from 5/18/1999 to 9/15/2008 with 41 measurements. Depth to water measurements range from 5.06 m (16.59 ft) to 6.41 m (21.03 ft) bgs, and the measurements average 5.79 m (18.98 ft) bgs. To collect a groundwater sample, a volume of approximately 136 liters (36 gallons) was purged on 5/8/2002 with a 12V submersible pump. The mapped surface geology is Pleistocene old alluvium (Qao) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well USGS #05 was located in an irrigated turf area in a small residential park located near Desert Inn Road and Nellis Boulevard on Encina Drive. The State plane coordinates for the well are 806523 ft east, and 26748772 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 673298.220 m east, 3999913.205 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 7' 42.42" north, and 115° 4' 27.02" west, WGS 84 PDC mercator projection. USGS #05 is a 10 cm (4 in.) diameter well, drilled to 3.4 m (11 ft) bgs with a perforated interval from 2.1 m (7 ft) to 3.4 m (11 ft) bgs. Well USGS #05 has a period of water-level record from 3/2/1981 to 1/31/2007 with 89 measurements. Depth to water measurements range from 1.59 m (5.21 ft) to 3.56 m (11.71 ft) bgs, and the measurements average 2.51 m (8.23 ft) bgs. To collect a groundwater sample, a volume of approximately 12 liters (3.25 gallons) was purged on 5/14/2002 with a disposable bailer. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of lean clay, silty sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well USGS #15 was located near Interstate 15 and Carey Avenue in a gravel area. The State plane coordinates for the well are 789043 ft east, and 26776129 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 667848.977 m east, 4008173.278 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 12' 13.82" north, and 115° 7' 58.57" west, WGS 84 PDC mercator projection. There is little irrigation nearby. There is however likely influence from a nearby groundwater remediation area. USGS #15 was a 10 cm (4 in.) diameter well, drilled to 14 m (46 ft) bgs with a perforated interval from 13.1 m (43 ft) to 14 m (46 ft) bgs. Well USGS #15 has a period of water-level record from 10/22/1981 to 9/18/2008 with 166 measurements. Depth to water measurements range from 5.72 m (18.75 ft) to 9.33 m (30.60 ft) bgs, and the measurements average 7.14 m (23.44 ft) bgs. To collect a groundwater sample, a volume of approximately 110 liters (29 gallons) was purged on 5/31/2002 with a Grundfos 220V Variflow pump. The mapped surface geology is Holocene and latest Pleistocene young fan alluvium (Qay) (Page et al., 2005). The soils mapped are composed of a combination of lean clay, silty sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well USGS #19 is located near the interchange at Craig Road and Interstate 15 between Interstate 15 and Donovan Way. The State plane coordinates for the well are 797220 ft east, and 26789422 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 670281.926 m east, 4012261.110 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 14' 24.89" north, and 115° 6' 17.99" west, WGS 84 PDC mercator projection. The well has little irrigated landscaping around it. Water chemistry and water levels might be influenced from deeper aquifer systems, or from recharge of storm water. USGS #19 is a 10 cm (4 in.) diameter well, drilled to 25.6 m (84 ft) bgs with a perforated interval from 25 m (82 ft) to 25.6 m (84 ft) bgs. Well USGS #19 has a period of water-level record from 9/20/1979 to 9/18/2008 with 138 measurements. Depth to water measurements range from 14.51 m (47.61 ft) to 19.75 m (64.80 ft) bgs, and the measurements average 18.36 m (60.23 ft) bgs. To collect a groundwater sample, a volume of approximately 189 liters (50 gallons) was purged on 6/4/2002 with a Grundfos 220V Variflow pump. The mapped surface geology is Middle Pleistocene old fine-grained spring deposits (Qso) (Page et al., 2005). This site falls on the boundary between two soil association groups. The soils mapped are composed of a combination of silt, poorly graded gravel, silty sand, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well USGS #34 is located in a municipal golf course near Washington Avenue and Decatur Boulevard. The State plane coordinates for the well are 768635 ft east, and 26767860 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 661665.971 m east, 4005562.262 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 10' 52.91" north, and 115° 12' 7.99" west, WGS 84 PDC mercator projection. The area is dominated by irrigated turf. USGS #34 is a 10 cm (4 in.) diameter well, drilled to 9.1 m (30 ft) bgs with a perforated interval from 7.6 m (25 ft) to 9.1 m (30 ft) bgs. Well USGS #34 has a period of water-level record from 3/2/1981 to 9/17/2008 with 110 measurements. Depth to water measurements range from 2.26 (7.40 ft) to 5.46 m (17.92 ft) bgs, and the measurements average 3.09 m (10.13 ft) bgs. To collect a groundwater sample, a volume of approximately 95 liters (25 gallons) was purged on 6/19/2002 with a Grundfos 220V Variflow pump. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) and Holocene and latest Pleistocene young fan alluvium (Qay) (Page et al., 2005). The soils mapped are composed of a combination of silty sand, clayey sand, silt, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well USGS #37 is located in an area of irrigated turf in a small residential park near Charleston Boulevard and Valley View Boulevard on Hinson Street. The State plane coordinates for the well are 771204 ft east, and 26760184 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 662483.078 m east, 4003234.271 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 9' 36.89" north, and 115° 11' 37.02" west, WGS 84 PDC mercator projection. USGS #37 is a 10 cm (4 in.) diameter well, drilled to 5.5 m (18 ft) bgs with a perforated interval from 4.3 m (14 ft) to 5.5 m (18 ft) bgs. Well USGS #37 has a period of water-level record from 3/2/1981 to 9/15/2008 with 114 measurements. Depth to water measurements range from 1.97 m (6.47 ft) to 4.03 m (13.21 ft) bgs, and the measurements average 3.08 m (10.11 ft) bgs. To collect a groundwater sample, a volume of approximately 38 liters (10 gallons) was purged on 5/17/2002 with a 12V submersible pump. The mapped surface geology is Quaternary to Tertiary undivided fine-grained sediments (QTs) (Page et al., 2005). The soils mapped are composed of a combination of silty sand, clayey sand, silt, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well USGS #48 was located in the downtown area in the corner of a parking lot at 4th Street and Clark Avenue. The State plane coordinates for the well are 785651 ft east, and 26762020 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 666877.972 m east, 4003858.098 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 9' 54.44" north, and 115° 8' 40.73" west, WGS 84 PDC mercator projection. There is little irrigated turf in the area. USGS #48 is a 10 cm (4 in.) diameter well, drilled to 6.7 m (22 ft) bgs with a perforated interval from 5.5 m (18 ft) to 6.7 m (22 ft) bgs. Well USGS #48 has a period of water-level record from 4/15/1981 to 8/5/2005 with 96 measurements. Depth to water measurements range from 1.59 m (5.23 ft) to 3.13 m (10.28 ft) bgs, and the measurements average 2.27 m (7.44 ft) bgs. To collect a groundwater sample, a volume of approximately 397 liters (105 gallons) was purged on 5/13/2002 with a 12V submersible pump. The mapped surface geology is Holocene and late Pleistocene undivided young spring deposits (Qsy) (Page et al., 2005). The soils mapped are composed of a combination of lean clay, silty sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well USGS-SE is located in an area of open desert on the east side of the Las Vegas Valley approximately .80 km (¾ mile) northeast of the Las Vegas Wash. The State plane coordinates for the well are 835611 ft east, and 26738794 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 682208.173 m east, 3997001.306 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 6' 2.09" north, and 114° 58' 33.19" west, WGS 84 PDC mercator projection. USGS-SE is a 10 cm (4 in.) diameter well, drilled to 24.4 m (80 ft) bgs with a perforated interval from 23.2 m (76 ft) to 24.4 m (80 ft) bgs. Well USGS-SE has a period of water-level record from 10/1/1997 to 9/16/2008 with 60 measurements. Depth to water measurements range from 4.31 m (14.13 ft) to 17.25 m (56.60 ft) bgs, and the measurements average 7.18 m (23.54 ft) bgs. To collect a groundwater sample, a volume of approximately 19 liters (5 gallons) was purged on 5/25/2005 with a 12V submersible pump. The mapped surface geology is Holocene and late Pleistocene undivided young and intermediate alluvium (Qau) over Tertiary Muddy Creek formation (Tm) (Page et al., 2005). This site is located out side of the extent of the soils map in Kaufmann, 1978.

Well WALL 02 located on Western Avenue at Charleston Boulevard and Interstate 15 adjacent to the Charleston Boulevard east off ramp. The State plane coordinates for the well are 781240 ft east, and 26759634 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 665544.223 m east, 4003111.285 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 9' 31.04" north, and 115° 9' 34.66" west, WGS 84 PDC mercator projection. There is little irrigated turf nearby. WALL 02 is a 5 cm (2 in.) diameter well, drilled to 9.1 m (30 ft) bgs. Well WALL 02 has a period of water-level record from 10/25/2001 to 9/18/2008 with 13 measurements. Depth to water measurements range from 4.44 m (14.58 ft) to 4.62 m (15.17 ft) bgs, and the measurements average 4.50 m (14.76 ft) bgs. To collect a groundwater sample, a volume of approximately 38 liters (10 gallons) was purged on 6/4/2002 with a disposable bailer. The mapped surface geology is Holocene and late Pleistocene undivided young spring deposits (Qsy) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well WMW4.9S is located adjacent to the Las Vegas Wash. The State plane coordinates for the well are 838418 ft east, and 26735286 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 683079.302 m east, 3995944.569 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 5' 27.22" north, and 114° 57' 59.26" west, WGS 84 PDC mercator projection. Water levels and water quality are likely influenced by wash water. WMW4.9S is a 10 cm (4 in.) diameter well, drilled to 15.5 m (51 ft) bgs with a perforated interval from 6.1 m (20 ft) to 15.2 m (50 ft) bgs. Well WMW4.9S has a period of water-level record from 3/27/2002 to 9/16/2008 with 27 measurements. Depth to water measurements range from 6.05 m (19.86 ft) to 9.61 m (31.52 ft) bgs, and the measurements average 8.58 m (28.16 ft) bgs. To collect a groundwater sample, a volume of approximately 125 liters (33 gallons) was purged on 5/25/2005 with a 12V submersible pump. The mapped surface geology is Holocene youngest alluvium (Qayy) (Page et al., 2005). This site is located out side of the extent of the soils map in Kaufmann, 1978.

Well WOODLAWN 03 was located in a municipal cemetery located at Owens Avenue and Las Vegas Boulevard. The State plane coordinates for the well are 789871 ft east, and 26769902 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 668129.054 m east, 4006279.121 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 11' 12.2" north, and 115° 7' 48.82" west, WGS 84 PDC mercator projection. The landscape in the cemetery is dominated by irrigated turf. There are two deeper SNWA monitor wells located in the cemetery. The deeper wells have screened intervals in zones with artesian head above land surface. WOODLAWN 03 was a 5 cm (2 in.) diameter well, drilled to 5.8 m (19 ft) bgs. Well WOODLAWN 03 has a period of water-level record from 5/19/2000 to 9/18/2008 with 47 measurements. Depth to water measurements range from 3.91 m (12.82 ft) to 4.64 m (15.22 ft) bgs, and the measurements average 4.43 m (14.54 ft) bgs. To collect a groundwater sample, a volume of approximately 11 liters (3 gallons) was purged on 3/10/2005 with a disposable bailer. The mapped surface geology is Holocene and latest Pleistocene young fan alluvium (Qay) (Page et al., 2005). The soils mapped are composed of a combination of silt, poorly graded gravel, silty sand, and lean clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

Well WS-1 is located in a dry landscaped area adjacent top the Pittman Wash near Warm Springs Road and Stephanie Street. The State plane coordinates for the well are 814046 ft east, and 26722418 ft north, U.S. survey feet, NAD 83, zone 2701 (Stem,1989). The UTM easting and northing for the well are 675708.143 m east, 3991914.367 m north, NAD 83 Zone 11 North. The latitude and longitude for the well are 36° 3' 21.39" north, and 115° 2' 57.08" west, WGS 84 PDC mercator projection. There is little irrigated turf nearby. WS-1 is a 5 cm (2 in.) diameter well, drilled to 13.9 m (45.5 ft) bgs with a perforated interval from 10.7 m (35.1 ft) to 11.5 m (37.6 ft) bgs. Well WS-1 has a period of water-level record from 6/29/1993 to 9/17/2008 with 34 measurements. Depth to water measurements range from 3.42 m (11.24 ft) to 4.09 m

(13.42 ft) bgs, and the measurements average 3.82 m (12.53 ft) bgs. To collect a groundwater sample, a volume of approximately 26 liters (7 gallons) was purged on 5/25/2005 with a disposable bailer. The mapped surface geology is late and middle Pleistocene intermediate fan alluvium (Qai) (Page et al., 2005). The soils mapped are composed of a combination of silty organic clay or organic silt, lean clay, clayey sand, and fat clay (Kaufmann, 1978 after Langan et al., 1967, and U.S. Bureau of Reclamation, 1998).

# APPENDIX 3

# PCA TABLES

# Normalized Data for PCA

| ID | Calcium (Ca) mg/l | Magnesium (Mg) mg/l | Sodium (Na) mg/l | Potassium (K) mg/l | GW-Chart-Calced CO3 |
|---|---|---|---|---|---|
| ATTC | -0.875426 | -0.969848 | -1.013034 | -0.825212 | 1.256962 |
| C10 | 1.900842 | 1.371758 | 1.120885 | 0.344373 | 1.641754 |
| C27 | 1.244633 | 1.457846 | 0.514658 | 0.709108 | -0.981043 |
| C28 | 1.244633 | 1.285669 | 1.322960 | 0.441635 | -0.392964 |
| C49 | -0.118262 | -0.350011 | -0.293645 | -0.360782 | -0.872963 |
| CH-1 | -0.976381 | -0.780453 | -0.616966 | -0.730381 | -0.250853 |
| CR-1 | 0.689380 | 0.941316 | 0.272167 | -0.555308 | -1.169022 |
| DR-1 | -1.026858 | -0.091746 | -0.536136 | -0.530992 | 0.440874 |
| DRI-1 | 0.285559 | -0.350011 | 0.029676 | -0.239204 | -1.308851 |
| DROSE | 0.043267 | -0.255314 | 0.037759 | 0.147416 | -0.117816 |
| F&S | 0.033171 | 0.424785 | 0.352997 | 0.806371 | -0.860505 |
| Fayle | -0.774470 | -0.995674 | -0.867540 | -0.769286 | -0.320586 |
| FR-1GV | 1.835221 | 0.226782 | 0.401495 | 1.421557 | 1.728728 |
| HORSE | 0.537947 | 0.941316 | 2.373754 | 3.456780 | -0.977832 |
| HP#2 | 0.033171 | 0.855227 | -0.293645 | -0.433729 | -0.047899 |
| JGP3 | -0.976381 | -0.436099 | -0.536136 | -0.482361 | 0.677999 |
| KB-1 | -0.673515 | -0.436099 | -0.713962 | -0.737675 | -0.523549 |
| LG048 | -0.168739 | 1.802200 | 0.797564 | 1.171106 | -0.104751 |
| MAPLE MW-2 | 1.345588 | 1.716112 | 0.797564 | 1.462894 | 0.174475 |
| MW-8GV | 2.112848 | 1.061839 | 2.608161 | 1.876261 | -0.157121 |
| NLAIR | -0.976381 | -1.064545 | -0.940287 | -0.837370 | -0.358727 |
| P2 | -0.673515 | -0.694365 | -0.657381 | -0.779012 | -1.066041 |
| PVP | 0.033171 | -0.522188 | -0.374475 | -0.458045 | -1.109856 |
| SH-1 | -0.925903 | -0.978457 | -0.576551 | -0.710928 | -0.123575 |
| USGS #05 | 0.537947 | 0.424785 | -0.091569 | 0.344373 | -0.586062 |
| USGS #15 | -0.774470 | -0.866542 | -0.762460 | -0.691476 | 0.823999 |
| USGS #19 | -1.233817 | -0.780453 | -1.025159 | -0.849527 | 1.899753 |
| USGS #34 | -1.127814 | -1.262548 | -0.972619 | -0.919800 | 0.098626 |
| USGS #37 | -0.723993 | -0.436099 | -0.495720 | -0.710928 | -0.274855 |
| USGS #48 | 0.336037 | -0.091746 | -0.455305 | -0.239204 | 3.235032 |
| USGS SE | 1.951319 | 2.318731 | 2.697075 | 1.511525 | -0.396651 |
| Wall 02 | -0.774470 | -1.081763 | -0.657381 | -0.676886 | 0.855984 |
| WMW4.9S | -0.723993 | -1.081763 | -0.536136 | -0.458045 | -0.050641 |
| WOODLAWN03 | 0.033171 | -0.263923 | -0.414890 | -0.263519 | -0.313499 |
| WS-1 | -0.673515 | -1.038719 | -0.495720 | -0.433729 | -0.468526 |

# Normalized Data for PCA

| ID | Total Alkalinity mg/l | Chloride (Cl) mg/l | Sulfate (SO4) mg/l | TDS | Nitrate (NO3) as N |
|---|---|---|---|---|---|
| ATTC | 0.492825 | -0.657670 | -0.787740 | -0.899741 | -0.305167 |
| C10 | 0.977752 | -0.225804 | 1.265600 | 1.259382 | -0.085469 |
| C27 | -0.537646 | -0.283386 | 1.506226 | 1.106138 | -0.260496 |
| C28 | 0.068513 | 1.357704 | 0.623931 | 0.987883 | -0.256316 |
| C49 | -0.483092 | -0.369760 | 0.062471 | -0.168013 | -0.218698 |
| CH-1 | 0.007897 | -0.542506 | -0.763678 | -0.852785 | -0.286619 |
| CR-1 | -0.537646 | -0.081849 | 0.543723 | 0.401009 | -0.200412 |
| DR-1 | -0.598262 | -0.369760 | -0.450864 | -0.611529 | -0.234372 |
| DRI-1 | -0.173950 | 0.580346 | 0.062471 | 0.107098 | -0.187350 |
| DROSE | -0.276997 | 0.390325 | 0.903859 | 0.623160 | 0.018503 |
| F&S | -0.083026 | -0.024267 | -0.980241 | -0.554855 | -0.234372 |
| Fayle | -0.658878 | -0.657670 | -0.731594 | -0.923386 | -0.182125 |
| FR-1GV | 4.281320 | 1.107222 | -0.267988 | 0.648588 | -0.208771 |
| HORSE | -1.083189 | 3.315497 | 3.351024 | 3.089852 | 0.251524 |
| HP#2 | -0.355798 | -0.340968 | 0.303097 | 0.073766 | -0.276170 |
| JGP3 | -0.004226 | -0.542506 | -0.498989 | -0.637880 | -0.200412 |
| KB-1 | -0.513400 | -0.427342 | -0.442843 | -0.610473 | -0.009710 |
| LG048 | -0.234566 | 0.177271 | 1.105183 | 0.882910 | -0.268333 |
| MAPLE MW-2 | 0.171560 | 2.163854 | 1.105183 | 1.443125 | -0.184738 |
| MW-8GV | 2.123393 | 0.007403 | -0.721167 | 0.395242 | 0.248651 |
| NLAIR | -0.477030 | -0.628879 | -0.827844 | -0.989098 | -0.072407 |
| P2 | -0.349737 | -0.942702 | -1.121408 | -0.351449 | 5.685207 |
| PVP | -0.519461 | -0.398551 | 0.062471 | -0.185352 | -0.189962 |
| SH-1 | -0.780110 | -0.657670 | -0.659406 | -0.871848 | -0.260496 |
| USGS #05 | -0.234566 | -0.139431 | 0.623931 | 0.402320 | -0.258406 |
| USGS #15 | 0.492825 | -0.818900 | -0.867949 | -0.926676 | -0.315878 |
| USGS #19 | -0.355798 | -0.818900 | -0.779719 | -1.010419 | -0.306996 |
| USGS #34 | 0.068513 | -0.628879 | -0.675448 | -0.889004 | -0.174288 |
| USGS #37 | 0.371593 | -0.542506 | -0.490968 | -0.568007 | -0.035834 |
| USGS #48 | 1.402064 | -0.571297 | -0.258363 | -0.202245 | -0.234372 |
| USGS SE | -1.171689 | 2.739675 | 2.147895 | 2.428229 | 0.147030 |
| Wall 02 | -0.477030 | -0.864966 | -0.555135 | -0.820162 | -0.284007 |
| WMW4.9S | -0.555831 | 0.033315 | -0.515031 | -0.597766 | -0.166451 |
| WOODLAWN03 | 0.680734 | -0.225804 | -0.523052 | -0.400118 | -0.137715 |
| WS-1 | -0.677063 | -0.110640 | -0.747636 | -0.777895 | -0.314571 |

Normalized Data for PCA

| ID | Nitrate (NO3) mg/l | LAB EC umho/cm | SiO2 | FIELD_EC | FIELD_PH |
|---|---|---|---|---|---|
| ATTC | -0.307910 | -0.994229 | -0.324729 | -1.011880 | 0.309465 |
| C10 | -0.077426 | 0.675458 | 0.193708 | 0.508512 | 0.364168 |
| C27 | -0.261046 | 0.640764 | -0.285601 | 0.463610 | 0.090651 |
| C28 | -0.256852 | 0.961691 | -0.031274 | 0.818338 | -0.784603 |
| C49 | -0.222301 | -0.282986 | -0.148656 | -0.218905 | -0.401679 |
| CH-1 | -0.288452 | -0.794734 | -0.363856 | -0.786021 | -0.237569 |
| CR-1 | -0.198012 | 0.289479 | -0.240605 | 0.337883 | -0.948713 |
| DR-1 | -0.233640 | -0.517176 | -0.158438 | -0.479338 | 1.294126 |
| DRI-1 | -0.184309 | 0.194068 | -0.217129 | 0.310942 | -1.988078 |
| DROSE | 0.014955 | 0.887964 | 0.208381 | 1.056320 | 0.364168 |
| F&S | -0.237979 | 0.293815 | 0.066544 | 0.378295 | -1.058120 |
| Fayle | -0.178828 | -0.898819 | -0.354074 | -0.905910 | 0.856499 |
| FR-1GV | -0.212372 | 0.848932 | 0.146755 | 0.701592 | -1.495747 |
| HORSE | 0.276109 | 2.878579 | -0.178001 | 3.126316 | 0.747092 |
| HP#2 | -0.277489 | -0.022775 | -0.246474 | -0.097669 | 0.582982 |
| JGP3 | -0.204011 | -0.647281 | -0.226910 | -0.632006 | 0.747092 |
| KB-1 | -0.013265 | -0.577892 | -0.305165 | -0.573633 | -0.018755 |
| LG048 | -0.269267 | 0.783880 | -0.285601 | 0.598317 | 0.035948 |
| MAPLE MW-2 | -0.188333 | 1.182870 | 0.086108 | 1.348185 | -0.237569 |
| MW-8GV | 0.245157 | 2.158662 | 0.248486 | 1.801698 | -2.042781 |
| NLAIR | -0.063724 | -0.994229 | -0.354074 | -1.003797 | 0.145355 |
| P2 | 5.682981 | -0.681976 | 5.651969 | -0.645477 | -1.331637 |
| PVP | -0.193559 | -0.309007 | -0.236692 | -0.245846 | -0.839306 |
| SH-1 | -0.261046 | -0.843307 | -0.363856 | -0.859212 | 1.130016 |
| USGS #05 | -0.258709 | 0.298152 | 0.007853 | 0.194196 | -0.346976 |
| USGS #15 | -0.319503 | -1.054945 | -0.275820 | -1.012329 | -0.018755 |
| USGS #19 | -0.309828 | -1.080966 | -0.129092 | -1.096745 | 1.895863 |
| USGS #34 | -0.170606 | -0.872798 | -0.354074 | -0.762672 | -0.182866 |
| USGS #37 | -0.025355 | -0.547534 | -0.354074 | -0.587104 | -0.729900 |
| USGS #48 | -0.233640 | -0.478144 | -0.070401 | -0.470358 | 0.582982 |
| USGS SE | 0.143512 | 2.076261 | -0.324729 | 2.223780 | 2.114677 |
| Wall 02 | -0.285711 | -0.838103 | -0.373638 | -0.818351 | 1.130016 |
| WMW4.9S | -0.170042 | -0.504165 | -0.138874 | -0.461377 | 0.965906 |
| WOODLAWN03 | -0.141300 | -0.443449 | -0.138874 | -0.461377 | -1.112823 |
| WS-1 | -0.318197 | -0.786061 | -0.129092 | -0.737976 | 0.418872 |

Normalized Data for PCA

| ID | FIELD TEMP | D | O18 |
|---|---|---|---|
| ATTC | 1.203740 | 0.270178 | 0.071561 |
| C10 | -0.644106 | 0.150083 | 0.008242 |
| C27 | 0.510798 | -0.427375 | -0.146540 |
| C28 | 0.372209 | -0.173656 | -0.062114 |
| C49 | -0.228341 | -0.489970 | -0.667170 |
| CH-1 | 0.233621 | -0.390472 | -0.167647 |
| CR-1 | -0.551714 | -0.292148 | -0.730490 |
| DR-1 | 1.111348 | 0.170874 | -0.111363 |
| DRI-1 | -0.182145 | -0.193526 | 0.085633 |
| DROSE | -1.706618 | 0.024790 | 0.507765 |
| F&S | 0.002640 | -0.024380 | 0.205237 |
| Fayle | -0.043556 | -0.075822 | -0.188753 |
| FR-1GV | -0.228341 | -0.424390 | 0.029348 |
| HORSE | 0.279817 | 0.965371 | 0.746973 |
| HP#2 | -1.614226 | -0.683025 | -0.983770 |
| JGP3 | 0.095032 | -0.686441 | -0.730490 |
| KB-1 | 0.279817 | -0.819649 | -0.547566 |
| LG048 | 0.464601 | -0.519671 | -0.519424 |
| MAPLE MW-2 | 0.603190 | 0.179116 | -0.076185 |
| MW-8GV | -2.445757 | 0.960916 | 1.703807 |
| NLAIR | 0.741778 | -0.212267 | -0.723455 |
| P2 | 0.418405 | 0.218395 | 0.205237 |
| PVP | -0.182145 | -0.282881 | -0.118398 |
| SH-1 | 0.880367 | -0.236993 | -0.174682 |
| USGS #05 | -2.168580 | -0.834054 | -0.273180 |
| USGS #15 | 1.850486 | -0.519671 | -0.941556 |
| USGS #19 | 1.018955 | 0.788651 | -0.392784 |
| USGS #34 | 1.296132 | -0.016242 | -0.533495 |
| USGS #37 | -1.429441 | 0.074346 | 0.043419 |
| USGS #48 | 0.279817 | -0.846231 | -0.484246 |
| USGS SE | 0.834171 | 5.123486 | 4.968298 |
| Wall 02 | -1.244657 | -0.074158 | -0.026936 |
| WMW4.9S | -0.320733 | 0.026825 | 0.310770 |
| WOODLAWN03 | -0.366929 | -0.621693 | -0.146540 |
| WS-1 | 0.880367 | -0.108314 | -0.139505 |

# PC Coordinates of Variables

| PC -coords-Var | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 | PC 6 |
|---|---|---|---|---|---|---|
| Calcium (Ca) mg/l | -0.8538 | 0.3005 | -0.1963 | 0.0731 | 0.0639 | 0.0389 |
| Magnesium (Mg) mg/l | -0.8576 | 0.0036 | -0.1088 | -0.0729 | -0.1307 | -0.0752 |
| Sodium (Na) mg/l | -0.9624 | 0.0123 | 0.0001 | 0.0221 | 0.0903 | 0.0596 |
| Potassium (K) mg/l | -0.9167 | 0.0577 | -0.0985 | -0.0037 | -0.1393 | 0.0793 |
| GW-Chart- Calced CO3 | 0.1854 | 0.0584 | -0.4999 | 0.7696 | -0.2091 | -0.2091 |
| Total Alkalinity mg/l | -0.1124 | 0.6856 | -0.4549 | 0.4358 | 0.0131 | 0.2453 |
| Chloride (Cl) mg/l | -0.8693 | -0.2209 | 0.0094 | -0.0083 | -0.1399 | 0.1785 |
| Sulfate (SO4) mg/l | -0.8230 | -0.3111 | -0.0475 | -0.2139 | -0.2753 | -0.2071 |
| TDS | -0.9534 | -0.0852 | 0.0176 | -0.0711 | -0.2161 | -0.0845 |
| Nitrate (NO3) as N | 0.0058 | 0.4032 | 0.8707 | 0.1610 | -0.1820 | -0.0957 |
| Nitrate (NO3) mg/l | 0.0044 | 0.4022 | 0.8709 | 0.1598 | -0.1834 | -0.0961 |
| LAB EC umho/cm | -0.9831 | 0.0672 | -0.0332 | -0.0752 | 0.0015 | -0.0062 |
| SiO2 | -0.4334 | 0.6969 | -0.0254 | 0.2334 | -0.0611 | -0.2233 |
| FIELD_EC | -0.9801 | 0.0139 | 0.0033 | -0.0844 | -0.0168 | 0.0020 |
| FIELD_PH | 0.0941 | -0.7918 | -0.0419 | 0.3591 | -0.1001 | -0.4390 |
| FIELD_TEMP | 0.2465 | -0.4783 | 0.1579 | 0.3025 | -0.5287 | 0.5223 |
| D | -0.5656 | -0.4526 | 0.3549 | 0.4357 | 0.3525 | 0.0969 |
| O18 | -0.6593 | -0.2661 | 0.3140 | 0.3732 | 0.4743 | 0.0960 |

| PC -coords-Var | PC 7 | PC 8 | PC 9 | PC 10 | PC 11 | PC 12 |
|---|---|---|---|---|---|---|
| Calcium (Ca) mg/l | -0.2689 | -0.0818 | -0.1486 | 0.0818 | -0.1097 | 0.0880 |
| Magnesium (Mg) mg/l | -0.3970 | -0.1357 | 0.1174 | -0.1745 | -0.0018 | -0.0635 |
| Sodium (Na) mg/l | -0.0508 | -0.0319 | 0.1718 | 0.0605 | 0.0489 | 0.1279 |
| Potassium (K) mg/l | 0.2111 | 0.0791 | 0.2231 | 0.0290 | -0.0861 | -0.0505 |
| GW-Chart- Calced CO3 | -0.0354 | 0.1114 | 0.0113 | -0.0229 | 0.1070 | 0.0453 |
| Total Alkalinity mg/l | -0.0229 | 0.2083 | -0.0157 | -0.0034 | -0.0636 | -0.0633 |
| Chloride (Cl) mg/l | 0.2585 | 0.0535 | -0.1766 | -0.1924 | -0.0317 | 0.0685 |
| Sulfate (SO4) mg/l | -0.0599 | 0.1195 | -0.1487 | 0.1054 | 0.0477 | -0.0718 |
| TDS | -0.0516 | 0.0902 | -0.1069 | 0.0360 | 0.0097 | -0.0172 |
| Nitrate (NO3) as N | -0.0441 | 0.0909 | 0.0157 | -0.0116 | -0.0138 | 0.0147 |
| Nitrate (NO3) mg/l | -0.0430 | 0.0934 | 0.0159 | -0.0106 | -0.0123 | 0.0155 |
| LAB EC umho/cm | 0.0805 | 0.0268 | 0.0864 | 0.0254 | 0.0375 | 0.0056 |
| SiO2 | 0.2332 | -0.3951 | -0.0690 | 0.0173 | 0.0139 | -0.0400 |
| FIELD_EC | 0.1363 | 0.0244 | 0.0389 | 0.0113 | 0.0611 | -0.0007 |
| FIELD_PH | 0.0637 | -0.0302 | 0.0597 | 0.0034 | -0.1335 | 0.0168 |
| FIELD_TEMP | -0.0421 | -0.1862 | 0.0118 | 0.0673 | 0.0015 | -0.0106 |
| D | -0.0386 | -0.0343 | -0.0362 | -0.0212 | 0.0754 | -0.0392 |
| O18 | -0.0022 | 0.0050 | -0.0394 | 0.0341 | -0.0374 | -0.0488 |

PC Coordinates of Variables

| PC -coords-Var | PC 13 | PC 14 | PC 15 | PC 16 | PC 17 | PC 18 |
|---|---|---|---|---|---|---|
| Calcium (Ca) mg/l | -0.0009 | 0.0489 | 0.0369 | 0.0003 | -0.0002 | 0.0001 |
| Magnesium (Mg) mg/l | -0.0133 | -0.0132 | -0.0008 | -0.0012 | -0.0002 | 0.0000 |
| Sodium (Na) mg/l | 0.0185 | -0.0363 | -0.0654 | -0.0044 | -0.0003 | 0.0001 |
| Potassium (K) mg/l | -0.0392 | 0.0887 | -0.0106 | -0.0005 | -0.0001 | 0.0000 |
| GW-Chart- Calced CO3 | -0.0622 | 0.0273 | 0.0129 | 0.0016 | 0.0000 | 0.0000 |
| Total Alkalinity mg/l | 0.0715 | -0.0504 | -0.0167 | -0.0026 | -0.0002 | 0.0001 |
| Chloride (Cl) mg/l | -0.0100 | -0.0021 | -0.0145 | 0.0017 | -0.0004 | 0.0001 |
| Sulfate (SO4) mg/l | -0.0032 | -0.0033 | -0.0269 | 0.0000 | -0.0014 | 0.0005 |
| TDS | 0.0021 | -0.0045 | -0.0258 | -0.0003 | 0.0023 | -0.0008 |
| Nitrate (NO3) as N | 0.0003 | -0.0012 | 0.0043 | -0.0001 | 0.0011 | 0.0012 |
| Nitrate (NO3) mg/l | 0.0015 | -0.0002 | 0.0034 | 0.0000 | -0.0014 | -0.0011 |
| LAB EC umho/cm | 0.0273 | -0.0408 | 0.0494 | 0.0256 | 0.0000 | 0.0000 |
| SiO2 | 0.0051 | -0.0061 | -0.0200 | 0.0001 | 0.0000 | 0.0000 |
| FIELD_EC | 0.0166 | -0.0289 | 0.0749 | -0.0214 | 0.0000 | 0.0000 |
| FIELD_PH | 0.0523 | -0.0364 | 0.0063 | -0.0016 | 0.0000 | 0.0000 |
| FIELD_TEMP | -0.0040 | -0.0189 | 0.0093 | 0.0005 | 0.0000 | 0.0000 |
| D | 0.0959 | 0.0708 | -0.0051 | 0.0009 | 0.0000 | 0.0000 |
| O18 | -0.1146 | -0.0520 | -0.0030 | 0.0001 | 0.0000 | 0.0000 |

# PC Coordinates of Cases

| PC -Coords-Cases | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 | PC 6 |
|---|---|---|---|---|---|---|
| ATTC | 2.749 | -0.832 | -0.439 | 1.530 | -0.016 | 0.783 |
| C10 | -2.816 | 1.332 | -1.410 | 1.397 | -0.675 | -1.538 |
| C27 | -2.033 | -0.746 | -0.244 | -1.446 | -0.976 | 0.015 |
| C28 | -2.887 | 0.458 | -0.492 | -0.647 | -0.712 | 0.694 |
| C49 | 0.830 | 0.182 | -0.024 | -1.271 | 0.063 | -0.055 |
| CH-1 | 2.401 | -0.422 | -0.071 | -0.371 | 0.490 | 0.679 |
| CR-1 | -0.707 | 0.281 | -0.065 | -1.962 | 0.069 | 0.051 |
| DR-1 | 1.617 | -1.403 | 0.051 | 0.798 | -0.450 | -0.232 |
| DRI-1 | -0.401 | 0.670 | 0.288 | -1.672 | 0.617 | 1.387 |
| DROSE | -1.761 | 0.760 | -0.001 | -0.250 | 0.592 | -1.868 |
| F&S | -0.571 | 1.090 | 0.015 | -0.516 | 0.657 | 0.826 |
| Fayle | 2.592 | -1.121 | 0.277 | -0.223 | 0.644 | -0.233 |
| FR-1GV | -2.454 | 3.658 | -2.545 | 2.220 | -0.514 | 1.437 |
| HORSE | -7.558 | -2.100 | 0.877 | -1.257 | -1.941 | -0.131 |
| HP#2 | 0.320 | 0.024 | -0.785 | -1.184 | 0.100 | -1.638 |
| JGP3 | 2.105 | -0.346 | -0.566 | 0.247 | -0.396 | -0.517 |
| KB-1 | 2.035 | -0.342 | 0.233 | -0.890 | -0.170 | 0.182 |
| LG048 | -1.863 | -0.673 | -0.598 | -1.004 | -1.427 | 0.020 |
| MAPLE MW-2 | -4.054 | 0.237 | -0.671 | 0.022 | -1.568 | 0.341 |
| MW-8GV | -4.886 | 3.797 | -0.447 | 0.742 | 2.611 | 0.357 |
| NLAIR | 3.003 | -0.778 | 0.362 | -0.354 | -0.014 | 0.581 |
| P2 | 1.676 | 3.819 | 7.378 | 1.113 | -1.271 | -0.464 |
| PVP | 0.808 | 0.050 | 0.285 | -1.368 | 0.543 | 0.442 |
| SH-1 | 2.585 | -1.625 | 0.222 | 0.054 | 0.025 | 0.112 |
| USGS #05 | -0.922 | 1.216 | -0.662 | -1.520 | 0.615 | -1.554 |
| USGS #15 | 3.024 | -0.326 | -0.659 | 0.806 | -0.985 | 1.191 |
| USGS #19 | 2.908 | -1.547 | -0.421 | 2.274 | -0.332 | -0.845 |
| USGS #34 | 2.908 | -0.732 | 0.113 | 0.212 | -0.214 | 1.144 |
| USGS #37 | 1.545 | 0.435 | 0.047 | -0.601 | 1.462 | -0.061 |
| USGS #48 | 1.176 | 0.902 | -2.064 | 2.482 | -1.140 | -0.790 |
| USGS SE | -8.082 | -4.678 | 2.346 | 2.561 | 1.955 | 0.529 |
| Wall 02 | 2.402 | -0.910 | -0.391 | 0.329 | 1.117 | -1.321 |
| WMW4.9S | 1.433 | -0.762 | 0.220 | 0.254 | 0.691 | -0.605 |
| WOODLAWN03 | 0.959 | 1.216 | -0.396 | -0.466 | 0.454 | 0.619 |
| WS-1 | 1.920 | -0.784 | 0.237 | -0.039 | 0.095 | 0.462 |

PC Coordinates of Cases

| PC -Coords-Cases | PC 7 | PC 8 | PC 9 | PC 10 | PC 11 | PC 12 |
|---|---|---|---|---|---|---|
| ATTC | -0.112 | 0.357 | -0.133 | 0.084 | 0.269 | -0.220 |
| C10 | -1.060 | -0.590 | -0.396 | 0.596 | 0.200 | 0.099 |
| C27 | -1.479 | -0.090 | 0.185 | 0.733 | -0.534 | -0.292 |
| C28 | -0.350 | -0.679 | -0.280 | -0.336 | 0.129 | 0.634 |
| C49 | 0.066 | -0.340 | -0.243 | 0.265 | 0.017 | -0.026 |
| CH-1 | -0.006 | 0.423 | 0.131 | -0.087 | 0.036 | -0.041 |
| CR-1 | -1.129 | -0.160 | -0.323 | -0.135 | 0.326 | 0.188 |
| DR-1 | 0.198 | -0.797 | 0.359 | -0.203 | 0.019 | -0.225 |
| DRI-1 | 0.136 | 0.130 | -0.758 | 0.012 | 0.457 | 0.122 |
| DROSE | 1.366 | -0.454 | -0.670 | 0.229 | 0.311 | -0.410 |
| F&S | 0.598 | -1.331 | 0.815 | -0.265 | -0.023 | -0.241 |
| Fayle | 0.103 | 0.183 | 0.050 | 0.030 | -0.437 | 0.141 |
| FR-1GV | 0.450 | 0.960 | -0.510 | -0.139 | -0.615 | -0.247 |
| HORSE | 1.885 | 1.206 | 0.381 | 0.329 | 0.161 | 0.154 |
| HP#2 | -0.741 | 0.412 | 0.129 | -0.647 | -0.149 | 0.082 |
| JGP3 | 0.189 | 0.177 | 0.397 | -0.203 | -0.013 | 0.076 |
| KB-1 | -0.112 | 0.061 | 0.012 | -0.106 | -0.147 | 0.087 |
| LG048 | -0.762 | 0.315 | 1.168 | -0.264 | 0.196 | -0.409 |
| MAPLE MW-2 | 0.281 | -0.733 | -0.421 | -0.781 | -0.124 | 0.055 |
| MW-8GV | 0.140 | -0.171 | 1.265 | 0.340 | 0.159 | 0.274 |
| NLAIR | 0.076 | 0.067 | 0.031 | 0.031 | -0.077 | 0.105 |
| P2 | -0.310 | 0.197 | 0.007 | -0.065 | -0.057 | 0.009 |
| PVP | -0.149 | -0.060 | -0.462 | 0.429 | 0.052 | -0.089 |
| SH-1 | 0.119 | -0.082 | 0.307 | 0.281 | -0.374 | 0.274 |
| USGS #05 | 0.118 | -0.048 | -0.278 | -0.039 | -0.266 | -0.261 |
| USGS #15 | -0.159 | -0.141 | 0.183 | 0.302 | 0.152 | 0.040 |
| USGS #19 | 0.328 | -0.648 | 0.172 | -0.128 | 0.337 | -0.143 |
| USGS #34 | 0.167 | 0.271 | -0.131 | 0.259 | 0.369 | -0.147 |
| USGS #37 | -0.289 | 1.142 | -0.068 | -0.423 | 0.305 | -0.240 |
| USGS #48 | -0.395 | 0.450 | -0.063 | 0.075 | 0.245 | 0.283 |
| USGS SE | -0.943 | 0.020 | -0.401 | -0.173 | -0.105 | -0.113 |
| Wall 02 | 0.098 | 0.960 | 0.194 | 0.009 | -0.072 | 0.364 |
| WMW4.9S | 0.975 | -0.201 | -0.233 | -0.051 | -0.327 | 0.145 |
| WOODLAWN03 | -0.064 | 0.095 | -0.290 | -0.118 | -0.121 | -0.183 |
| WS-1 | 0.767 | -0.902 | -0.128 | 0.161 | -0.298 | 0.153 |

# PC Coordinates of Cases

| PC -Coords-Cases | PC 13 | PC 14 | PC 15 | PC 16 | PC 17 | PC 18 |
|---|---|---|---|---|---|---|
| ATTC | -0.147 | 0.049 | 0.059 | 0.062 | 0.002 | 0.000 |
| C10 | 0.142 | 0.039 | -0.294 | -0.033 | -0.005 | -0.001 |
| C27 | -0.083 | 0.037 | 0.161 | 0.034 | 0.000 | -0.001 |
| C28 | -0.023 | -0.260 | -0.170 | 0.072 | 0.003 | -0.001 |
| C49 | 0.177 | 0.098 | -0.074 | -0.041 | 0.003 | 0.003 |
| CH-1 | -0.113 | -0.195 | -0.120 | -0.024 | 0.003 | -0.001 |
| CR-1 | 0.347 | -0.015 | 0.174 | -0.045 | 0.002 | -0.001 |
| DR-1 | 0.086 | -0.270 | 0.050 | -0.003 | -0.002 | -0.004 |
| DRI-1 | -0.236 | 0.063 | 0.069 | 0.029 | 0.002 | -0.002 |
| DROSE | 0.011 | -0.383 | 0.183 | 0.002 | 0.001 | 0.001 |
| F&S | -0.218 | 0.227 | 0.081 | -0.065 | 0.000 | -0.003 |
| Fayle | 0.114 | 0.088 | 0.080 | 0.011 | -0.003 | -0.002 |
| FR-1GV | 0.301 | -0.074 | 0.018 | -0.001 | 0.003 | -0.001 |
| HORSE | 0.087 | 0.120 | -0.038 | -0.012 | -0.002 | -0.001 |
| HP#2 | 0.307 | -0.014 | 0.144 | -0.005 | 0.003 | 0.000 |
| JGP3 | 0.026 | -0.203 | -0.087 | -0.050 | 0.001 | 0.003 |
| KB-1 | -0.129 | -0.239 | 0.141 | 0.016 | -0.008 | 0.005 |
| LG048 | -0.164 | -0.127 | -0.164 | 0.032 | 0.003 | 0.001 |
| MAPLE MW-2 | -0.079 | 0.270 | 0.131 | -0.012 | -0.002 | 0.002 |
| MW-8GV | 0.122 | -0.021 | 0.098 | 0.034 | -0.001 | 0.002 |
| NLAIR | 0.225 | 0.172 | 0.021 | 0.037 | -0.009 | 0.000 |
| P2 | -0.020 | 0.014 | -0.005 | 0.001 | 0.001 | 0.000 |
| PVP | -0.096 | 0.131 | 0.018 | -0.007 | 0.002 | 0.002 |
| SH-1 | -0.003 | -0.184 | 0.032 | -0.004 | 0.001 | -0.002 |
| USGS #05 | -0.229 | 0.200 | -0.115 | 0.044 | 0.001 | -0.001 |
| USGS #15 | 0.096 | 0.004 | -0.034 | -0.048 | 0.003 | 0.002 |
| USGS #19 | 0.306 | 0.327 | -0.015 | 0.069 | 0.002 | 0.002 |
| USGS #34 | 0.227 | -0.031 | 0.118 | -0.005 | 0.000 | -0.001 |
| USGS #37 | 0.073 | 0.041 | -0.227 | -0.008 | -0.006 | -0.002 |
| USGS #48 | -0.560 | 0.018 | 0.200 | -0.026 | -0.003 | -0.001 |
| USGS SE | -0.060 | -0.042 | -0.002 | -0.024 | 0.000 | 0.001 |
| Wall 02 | -0.166 | 0.236 | 0.034 | -0.024 | 0.006 | 0.000 |
| WMW4.9S | -0.082 | -0.129 | -0.072 | 0.019 | 0.000 | 0.001 |
| WOODLAWN03 | -0.216 | 0.000 | -0.177 | -0.021 | -0.004 | 0.003 |
| WS-1 | -0.024 | 0.051 | -0.217 | -0.005 | 0.002 | 0.000 |

# PC Scores

| | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 | PC 6 |
|---|---|---|---|---|---|---|
| ATTC | 0.90755 | 0.43250 | 0.39125 | 1.29879 | 0.01817 | -0.75792 |
| C10 | -0.87628 | 0.23371 | -0.81335 | 1.22074 | -0.78728 | 1.80465 |
| C27 | -0.75094 | 0.24742 | -0.00664 | -1.01602 | -1.11811 | 0.17758 |
| C28 | -0.97104 | 0.08929 | -0.47628 | -0.42326 | -0.73770 | -0.88124 |
| C49 | 0.28996 | 0.07250 | -0.16681 | -1.07769 | 0.04250 | -0.07598 |
| CH-1 | 0.77671 | 0.21833 | 0.03099 | -0.23014 | 0.49431 | -0.63351 |
| CR-1 | -0.26962 | 0.00511 | -0.51074 | -1.46625 | -0.01358 | 0.09915 |
| DR-1 | 0.55131 | 0.40175 | 1.05401 | 0.41788 | -0.43679 | -0.02348 |
| DRI-1 | -0.15377 | -0.19891 | -0.59336 | -1.26247 | 0.68749 | -1.56753 |
| DROSE | -0.51152 | -0.06951 | -0.03930 | -0.50258 | 0.58459 | 1.69356 |
| F&S | -0.13314 | -0.14354 | -0.45115 | -0.53205 | 0.76848 | -1.29576 |
| Fayle | 0.84100 | 0.26038 | 0.63928 | -0.27760 | 0.63158 | 0.29908 |
| FR-1GV | -0.74269 | 0.10196 | -2.67800 | 2.39307 | -0.49234 | -1.29120 |
| HORSE | -2.65656 | 0.00243 | 1.12840 | -1.10010 | -1.97836 | -0.10675 |
| HP#2 | 0.08662 | 0.35935 | -0.44239 | -0.82802 | -0.12482 | 2.14179 |
| JGP3 | 0.71185 | 0.38538 | 0.07943 | 0.21540 | -0.46149 | 0.59125 |
| KB-1 | 0.66528 | 0.07375 | 0.11853 | -0.73400 | -0.15849 | -0.22888 |
| LG048 | -0.69054 | 0.35638 | -0.11688 | -0.60107 | -1.58076 | 0.16184 |
| MAPLE MW-2 | -1.34717 | 0.18100 | -0.22051 | 0.05196 | -1.59957 | -0.66776 |
| MW-8GV | -1.56277 | -0.70610 | -2.17765 | 0.80292 | 2.77291 | -0.16404 |
| NLAIR | 0.98641 | 0.14047 | 0.44963 | -0.34266 | 0.04123 | -0.70942 |
| P2 | 0.72568 | -5.55995 | 0.54559 | 0.50500 | -0.83018 | 0.40755 |
| PVP | 0.25771 | -0.02848 | -0.12973 | -1.12044 | 0.56095 | -0.51669 |
| SH-1 | 0.83192 | 0.38872 | 0.94520 | -0.07238 | 0.01654 | -0.18465 |
| USGS #05 | -0.27017 | 0.07245 | -0.89136 | -1.21268 | 0.46993 | 1.76195 |
| USGS #15 | 1.01901 | 0.41055 | 0.02661 | 0.75652 | -0.95427 | -1.37939 |
| USGS #19 | 1.00949 | 0.63668 | 1.22519 | 1.58871 | -0.33924 | 0.71572 |
| USGS #34 | 0.95398 | 0.21151 | 0.36736 | 0.18266 | -0.13749 | -1.31447 |
| USGS #37 | 0.48881 | -0.04790 | -0.51519 | -0.34257 | 1.45592 | 0.46769 |
| USGS #48 | 0.44309 | 0.60972 | -0.83825 | 2.28966 | -1.26048 | 1.15346 |
| USGS SE | -2.89531 | 0.00767 | 3.23981 | 1.68429 | 2.11044 | -0.39103 |
| Wall 02 | 0.77254 | 0.45505 | 0.31346 | 0.28702 | 0.98980 | 1.81778 |
| WMW4.9S | 0.49725 | 0.21429 | 0.68439 | -0.03101 | 0.71294 | 0.45311 |
| WOODLAWN03 | 0.34731 | -0.04337 | -0.87298 | -0.25177 | 0.48937 | -0.63360 |
| WS-1 | 0.66804 | 0.22940 | 0.70147 | -0.26984 | 0.16381 | -0.92289 |

## PC Scores

| | PC 7 | PC 8 | PC 9 | PC 10 | PC 11 | PC 12 |
|---|---|---|---|---|---|---|
| ATTC | 0.02488 | -0.50512 | 0.57409 | 1.22221 | -0.13038 | -0.99486 |
| C10 | -1.73594 | -0.66335 | 1.62749 | -0.35149 | 1.18476 | 0.73370 |
| C27 | -2.11260 | 0.22236 | 2.32197 | -1.38367 | -1.99199 | -0.63637 |
| C28 | -0.99558 | -0.30058 | -1.50455 | -0.73345 | 2.21674 | 0.49094 |
| C49 | -0.19042 | -0.39154 | 0.64047 | -0.37180 | 0.23867 | 0.73311 |
| CH-1 | 0.21564 | 0.04717 | 0.02577 | 0.69249 | -0.50120 | -0.38541 |
| CR-1 | -1.70480 | -0.75166 | -0.32397 | 0.80388 | 1.18333 | 1.78307 |
| DR-1 | -0.26585 | 1.13516 | -0.74822 | 0.21226 | -0.35395 | 0.20928 |
| DRI-1 | 0.10262 | -1.72267 | 0.03752 | 0.89662 | 1.55535 | -1.26226 |
| DROSE | 1.62988 | -1.05998 | 0.37558 | 0.37521 | 0.48292 | -0.61424 |
| F&S | -0.12194 | 2.39918 | -1.22954 | -0.35384 | -0.07191 | -1.64241 |
| Fayle | 0.26856 | 0.05117 | -0.05548 | -1.36042 | -0.69349 | 0.76695 |
| FR-1GV | 1.26507 | -1.43836 | -0.36846 | -0.89914 | -2.49202 | 1.47893 |
| HORSE | 3.44936 | 0.46589 | 1.35043 | 0.48717 | 0.48658 | 0.63436 |
| HP#2 | -0.59794 | 0.09941 | -1.81746 | 0.33053 | -0.64365 | 1.71182 |
| JGP3 | 0.44982 | 0.81623 | -0.48986 | 0.27672 | -0.12425 | 0.40188 |
| KB-1 | -0.13126 | -0.02100 | -0.26212 | -0.25469 | -0.23398 | -0.32920 |
| LG048 | -0.77675 | 2.23156 | -0.01311 | 2.26778 | -1.54402 | -0.88364 |
| MAPLE MW-2 | -0.12950 | -0.47967 | -2.90258 | -0.59320 | 0.29731 | -0.56957 |
| MW-8GV | 0.19596 | 2.85256 | 1.04995 | -0.20387 | 1.25174 | 0.77170 |
| NLAIR | 0.09300 | 0.01254 | 0.16486 | -0.17621 | -0.02604 | 1.28444 |
| P2 | -0.14025 | -0.04297 | -0.11706 | -0.03356 | -0.13678 | -0.04695 |
| PVP | -0.35159 | -1.03765 | 1.26153 | -0.19717 | 0.13482 | -0.69409 |
| SH-1 | 0.09645 | 0.70721 | 0.61348 | -1.67508 | -0.04189 | 0.33122 |
| USGS #05 | 0.20451 | -0.51829 | -0.31496 | -0.63030 | -1.12284 | -1.44796 |
| USGS #15 | -0.38509 | 0.38418 | 1.00468 | 0.21378 | 0.48106 | 0.47550 |
| USGS #19 | 0.06786 | 0.71204 | -0.52426 | 0.75770 | 0.76570 | 1.04229 |
| USGS #34 | 0.30097 | -0.46695 | 1.12858 | 1.30185 | 0.34286 | 0.92252 |
| USGS #37 | 0.36815 | -0.72810 | -0.43279 | 2.64143 | -1.03310 | 0.51780 |
| USGS #48 | -0.07771 | -0.27941 | 0.23543 | 0.11612 | 1.53315 | -2.62874 |
| USGS SE | -1.40163 | -1.02863 | -0.36954 | 0.29358 | -0.86962 | -0.25583 |
| Wall 02 | 0.91218 | 0.07477 | 0.10584 | -0.42667 | 0.54198 | -0.51562 |
| WMW4.9S | 1.21113 | -0.26813 | -0.62088 | -1.52507 | -0.03797 | -0.24841 |
| WOODLAWN03 | -0.08945 | -0.70309 | -0.25337 | 0.19263 | -0.97204 | -1.04240 |
| WS-1 | 0.35226 | 0.19568 | -0.16945 | -1.91233 | 0.32413 | -0.09152 |

PC Scores

| | PC 13 | PC 14 | PC 15 | PC 16 | PC 17 |
|---|---|---|---|---|---|
| ATTC | 0.51938 | -0.23271 | -0.14659 | 1.83549 | 0.26755 |
| C10 | -0.04179 | 1.04484 | -1.39561 | -1.05154 | -1.74548 |
| C27 | 0.60783 | -0.64302 | 0.78381 | 1.04063 | -0.15411 |
| C28 | -2.26946 | 0.37189 | -1.32700 | 2.08614 | -0.19769 |
| C49 | 0.81275 | 0.24950 | -0.89570 | -1.24347 | 1.64746 |
| CH-1 | -1.49927 | 0.14120 | -0.95957 | -0.73352 | -0.04206 |
| CR-1 | 0.45894 | -0.82218 | 0.66769 | -1.27443 | -0.10582 |
| DR-1 | -0.41016 | -1.95158 | -0.60654 | -0.13472 | -2.19602 |
| DRI-1 | 0.25154 | 0.03967 | -0.00020 | 0.88516 | -0.54587 |
| DROSE | 0.21017 | -3.85667 | -1.11277 | -0.02923 | 0.18397 |
| F&S | 1.95250 | -0.35480 | -0.40748 | -1.97146 | -1.66280 |
| Fayle | 0.19251 | 0.39265 | 1.18294 | 0.36870 | -1.16830 |
| FR-1GV | 0.02980 | -0.52306 | -0.44824 | -0.02790 | 0.08443 |
| HORSE | 0.04292 | 1.10982 | 0.63041 | -0.31516 | -0.67462 |
| HP#2 | 0.07609 | -0.37702 | 0.78748 | -0.07778 | 0.50111 |
| JGP3 | -1.43169 | -0.06850 | -0.18273 | -1.47854 | 1.19894 |
| KB-1 | -1.50296 | -0.91315 | 2.54456 | 0.55156 | 1.03608 |
| LG048 | -1.00203 | 0.35738 | -1.08989 | 0.92333 | 1.10728 |
| MAPLE MW-2 | 1.64082 | 0.20662 | 1.08753 | -0.35279 | 0.84583 |
| MW-8GV | -0.08308 | -0.29042 | 0.88853 | 1.03290 | 0.78789 |
| NLAIR | 0.60477 | 0.86363 | 1.73286 | 1.12354 | -1.38440 |
| P2 | -0.02924 | 0.11870 | -0.08359 | 0.02242 | 0.08776 |
| PVP | 0.83827 | 0.19950 | -0.07278 | -0.22165 | 1.36186 |
| SH-1 | -1.30849 | -0.34114 | 0.11328 | -0.08285 | -0.53094 |
| USGS #05 | 0.98530 | 0.86259 | -1.08508 | 1.26035 | -0.54523 |
| USGS #15 | 0.06680 | 0.10322 | -0.41485 | -1.41619 | 1.24830 |
| USGS #19 | 2.60405 | 0.29477 | -0.96065 | 1.97254 | 0.88489 |
| USGS #34 | 0.61699 | -0.98635 | 0.31042 | -0.13091 | -0.25612 |
| USGS #37 | -0.62347 | 1.60908 | 0.13022 | -0.23521 | -1.80620 |
| USGS #48 | -0.54367 | -0.02962 | 2.00280 | -0.67525 | -0.69340 |
| USGS SE | -0.40623 | 0.06936 | 0.27553 | -0.68120 | 0.52599 |
| Wall 02 | 0.14363 | 1.71033 | 0.47211 | -0.63509 | 1.42721 |
| WMW4.9S | -0.88830 | -0.12648 | -0.57021 | 0.51784 | 0.14998 |
| WOODLAWN03 | -0.60544 | 0.92281 | -0.01235 | -0.63317 | 0.41697 |
| WS-1 | -0.00979 | 0.84912 | -1.83835 | -0.21854 | -0.05444 |

# PC Score Coefficients

| PC Score Coefficients | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 | PC 6 |
|---|---|---|---|---|---|---|
| Calcium (Ca) mg/l | -0.0998 | 0.1127 | -0.0857 | 0.0483 | 0.0677 | 0.0515 |
| Magnesium (Mg) mg/l | -0.1002 | 0.0013 | -0.0475 | -0.0482 | -0.1384 | -0.0996 |
| Sodium (Na) mg/l | -0.1124 | 0.0046 | 0.0001 | 0.0146 | 0.0956 | 0.0789 |
| Potassium (K) mg/l | -0.1071 | 0.0217 | -0.0430 | -0.0024 | -0.1475 | 0.1050 |
| GW-Chart-Calced CO3 | 0.0217 | 0.0219 | -0.2184 | 0.5088 | -0.2215 | -0.2769 |
| Total Alkalinity mg/l | -0.0131 | 0.2571 | -0.1987 | 0.2881 | 0.0138 | 0.3248 |
| Chloride (Cl) mg/l | -0.1016 | -0.0828 | 0.0041 | -0.0055 | -0.1482 | 0.2364 |
| Sulfate (SO4) mg/l | -0.0962 | -0.1167 | -0.0208 | -0.1414 | -0.2915 | -0.2743 |
| TDS | -0.1114 | -0.0320 | 0.0077 | -0.0470 | -0.2288 | -0.1119 |
| Nitrate (NO3) as N | 0.0007 | 0.1512 | 0.3803 | 0.1065 | -0.1927 | -0.1267 |
| Nitrate (NO3) mg/l | 0.0005 | 0.1508 | 0.3804 | 0.1056 | -0.1943 | -0.1272 |
| LAB EC umho/cm | -0.1149 | 0.0252 | -0.0145 | -0.0497 | 0.0016 | -0.0082 |
| SiO2 | -0.0506 | 0.2614 | -0.0111 | 0.1543 | -0.0647 | -0.2957 |
| FIELD_EC | -0.1145 | 0.0052 | 0.0015 | -0.0558 | -0.0178 | 0.0026 |
| FIELD_PH | 0.0110 | -0.2970 | -0.0183 | 0.2374 | -0.1060 | -0.5813 |
| FIELD_TEMP | 0.0288 | -0.1794 | 0.0690 | 0.2000 | -0.5599 | 0.6916 |
| D | -0.0661 | -0.1697 | 0.1550 | 0.2880 | 0.3733 | 0.1283 |
| O18 | -0.0770 | -0.0998 | 0.1372 | 0.2468 | 0.5024 | 0.1271 |

PC Score Coefficients

| PC Score Coefficients | PC 7 | PC 8 | PC 9 | PC 10 | PC 11 | PC 12 |
|---|---|---|---|---|---|---|
| Calcium (Ca) mg/l | -0.6078 | -0.2519 | -0.7389 | 0.8261 | -1.5388 | 1.6521 |
| Magnesium (Mg) mg/l | -0.8973 | -0.4179 | 0.5841 | -1.7613 | -0.0258 | -1.1923 |
| Sodium (Na) mg/l | -0.1148 | -0.0983 | 0.8544 | 0.6111 | 0.6856 | 2.3994 |
| Potassium (K) mg/l | 0.4770 | 0.2438 | 1.1096 | 0.2929 | -1.2076 | -0.9469 |
| GW-Chart-Calced CO3 | -0.0800 | 0.3430 | 0.0563 | -0.2315 | 1.5014 | 0.8497 |
| Total Alkalinity mg/l | -0.0517 | 0.6418 | -0.0779 | -0.0340 | -0.8924 | -1.1881 |
| Chloride (Cl) mg/l | 0.5843 | 0.1647 | -0.8784 | -1.9421 | -0.4454 | 1.2851 |
| Sulfate (SO4) mg/l | -0.1355 | 0.3682 | -0.7393 | 1.0637 | 0.6691 | -1.3474 |
| TDS | -0.1166 | 0.2777 | -0.5318 | 0.3631 | 0.1364 | -0.3233 |
| Nitrate (NO3) as N | -0.0996 | 0.2802 | 0.0778 | -0.1172 | -0.1932 | 0.2759 |
| Nitrate (NO3) mg/l | -0.0972 | 0.2877 | 0.0788 | -0.1068 | -0.1726 | 0.2901 |
| LAB EC umho/cm | 0.1818 | 0.0825 | 0.4295 | 0.2564 | 0.5265 | 0.1049 |
| SiO2 | 0.5271 | -1.2171 | -0.3431 | 0.1742 | 0.1944 | -0.7502 |
| FIELD_EC | 0.3079 | 0.0753 | 0.1934 | 0.1143 | 0.8580 | -0.0127 |
| FIELD_PH | 0.1440 | -0.0932 | 0.2969 | 0.0340 | -1.8729 | 0.3144 |
| FIELD_TEMP | -0.0950 | -0.5735 | 0.0587 | 0.6792 | 0.0209 | -0.1988 |
| D | -0.0872 | -0.1058 | -0.1802 | -0.2139 | 1.0579 | -0.7356 |
| O18 | -0.0049 | 0.0155 | -0.1961 | 0.3444 | -0.5246 | -0.9166 |

PC Score Coefficients

| PC Score Coefficients | PC 13 | PC 14 | PC 15 | PC 16 | PC 17 | PC 18 |
|---|---|---|---|---|---|---|
| Calcium (Ca) mg/l | -0.0240 | 1.8113 | 2.2445 | 0.2349 | -21.8325 | 22.4376 |
| Magnesium (Mg) mg/l | -0.3574 | -0.4891 | -0.0506 | -1.0384 | -13.8290 | 12.5810 |
| Sodium (Na) mg/l | 0.4966 | -1.3440 | -3.9773 | -3.8259 | -25.0248 | 29.3001 |
| Potassium (K) mg/l | -1.0513 | 3.2823 | -0.6470 | -0.4110 | -4.8294 | 6.0479 |
| GW-Chart-Calced CO3 | -1.6685 | 1.0115 | 0.7869 | 1.3536 | 0.0024 | 0.6277 |
| Total Alkalinity mg/l | 1.9180 | -1.8669 | -1.0146 | -2.2214 | -17.1858 | 18.2032 |
| Chloride (Cl) mg/l | -0.2686 | -0.0775 | -0.8800 | 1.4887 | -37.6748 | 40.2018 |
| Sulfate (SO4) mg/l | -0.0861 | -0.1206 | -1.6364 | -0.0247 | -132.8596 | 143.4790 |
| TDS | 0.0568 | -0.1677 | -1.5698 | -0.2566 | 212.2173 | -225.3336 |
| Nitrate (NO3) as N | 0.0091 | -0.0434 | 0.2629 | -0.0499 | 99.8372 | 325.4759 |
| Nitrate (NO3) mg/l | 0.0400 | -0.0065 | 0.2078 | -0.0355 | -127.1988 | -295.9840 |
| LAB EC umho/cm | 0.7336 | -1.5096 | 3.0028 | 22.2879 | -0.1114 | -0.4055 |
| SiO2 | 0.1372 | -0.2242 | -1.2162 | 0.0642 | -2.4834 | 1.9011 |
| FIELD_EC | 0.4442 | -1.0713 | 4.5552 | -18.6137 | 1.8987 | -3.2425 |
| FIELD_PH | 1.4033 | -1.3479 | 0.3818 | -1.3552 | -0.0259 | -0.9260 |
| FIELD_TEMP | -0.1066 | -0.7012 | 0.5636 | 0.4029 | -0.3918 | -0.3639 |
| D | 2.5734 | 2.6206 | -0.3120 | 0.8072 | 0.9198 | 1.4436 |
| O18 | -3.0751 | -1.9255 | -0.1816 | 0.0609 | -0.8492 | -2.2164 |

Correlation Matrix

| | PC 1 | PC 2 | PC 3 | Calcium (Ca) mg/l | Magnesium (Mg) mg/l | Sodium (Na) mg/l | Potassium (K) mg/l |
|---|---|---|---|---|---|---|---|
| PC 1 | 1.0000 | | | | | | |
| PC 2 | 0.0000 | 1.0000 | | | | | |
| PC 3 | 0.0000 | 0.0000 | 1.0000 | | | | |
| Calcium (Ca) mg/l | -0.8538 | 0.3005 | -0.1963 | 1.0000 | | | |
| Magnesium (Mg) mg/l | -0.8576 | 0.0036 | -0.1088 | 0.8181 | 1.0000 | | |
| Sodium (Na) mg/l | -0.9624 | 0.0123 | 0.0001 | 0.8324 | 0.8336 | 1.0000 | |
| Potassium (K) mg/l | -0.9167 | 0.0577 | -0.0985 | 0.7282 | 0.7389 | 0.8879 | 1.0000 |
| Cal CO3 | 0.1854 | 0.0584 | -0.4999 | -0.0169 | -0.1159 | -0.1853 | -0.1112 |
| Total Alkalinity mg/l | -0.1124 | 0.6856 | -0.4549 | 0.4229 | 0.0798 | 0.1267 | 0.2131 |
| Cl/NO3 | 0.0086 | -0.0843 | -0.1133 | 0.0022 | -0.0051 | 0.0048 | 0.0413 |
| Chloride (Cl) mg/l | -0.8693 | -0.2209 | 0.0094 | 0.6169 | 0.6480 | 0.7829 | 0.8303 |
| Sulfate (SO4) mg/l | -0.8230 | -0.3111 | -0.0475 | 0.6016 | 0.7533 | 0.7213 | 0.7302 |
| TDS | -0.9534 | -0.0852 | 0.0176 | 0.7842 | 0.8457 | 0.8741 | 0.8642 |
| Nitrate (NO3) as N | -0.5187 | 0.1899 | 0.5786 | 0.3216 | 0.2403 | 0.5336 | 0.4537 |
| Nitrate (NO3) mg/l | -0.5211 | 0.1807 | 0.5717 | 0.3188 | 0.2406 | 0.5354 | 0.4591 |
| LAB EC umho/cm | -0.9831 | 0.0672 | -0.0332 | 0.8220 | 0.8225 | 0.9577 | 0.9383 |
| SiO2 | -0.4334 | 0.6969 | -0.0254 | 0.5641 | 0.3371 | 0.3992 | 0.4333 |
| FIELD EC | -0.9801 | 0.0139 | 0.0033 | 0.7842 | 0.7937 | 0.9393 | 0.9323 |
| FIELD PH | 0.0941 | -0.7918 | -0.0419 | -0.3160 | -0.0749 | -0.1219 | -0.1203 |
| FIELD TEMP | 0.2465 | -0.4783 | 0.1579 | -0.3479 | -0.1900 | -0.2401 | -0.1754 |
| D | -0.5656 | -0.4526 | 0.3549 | 0.3437 | 0.3792 | 0.5798 | 0.3929 |
| O18 | -0.6593 | -0.2661 | 0.3140 | 0.4887 | 0.4289 | 0.6752 | 0.4960 |

# Correlation Matrix

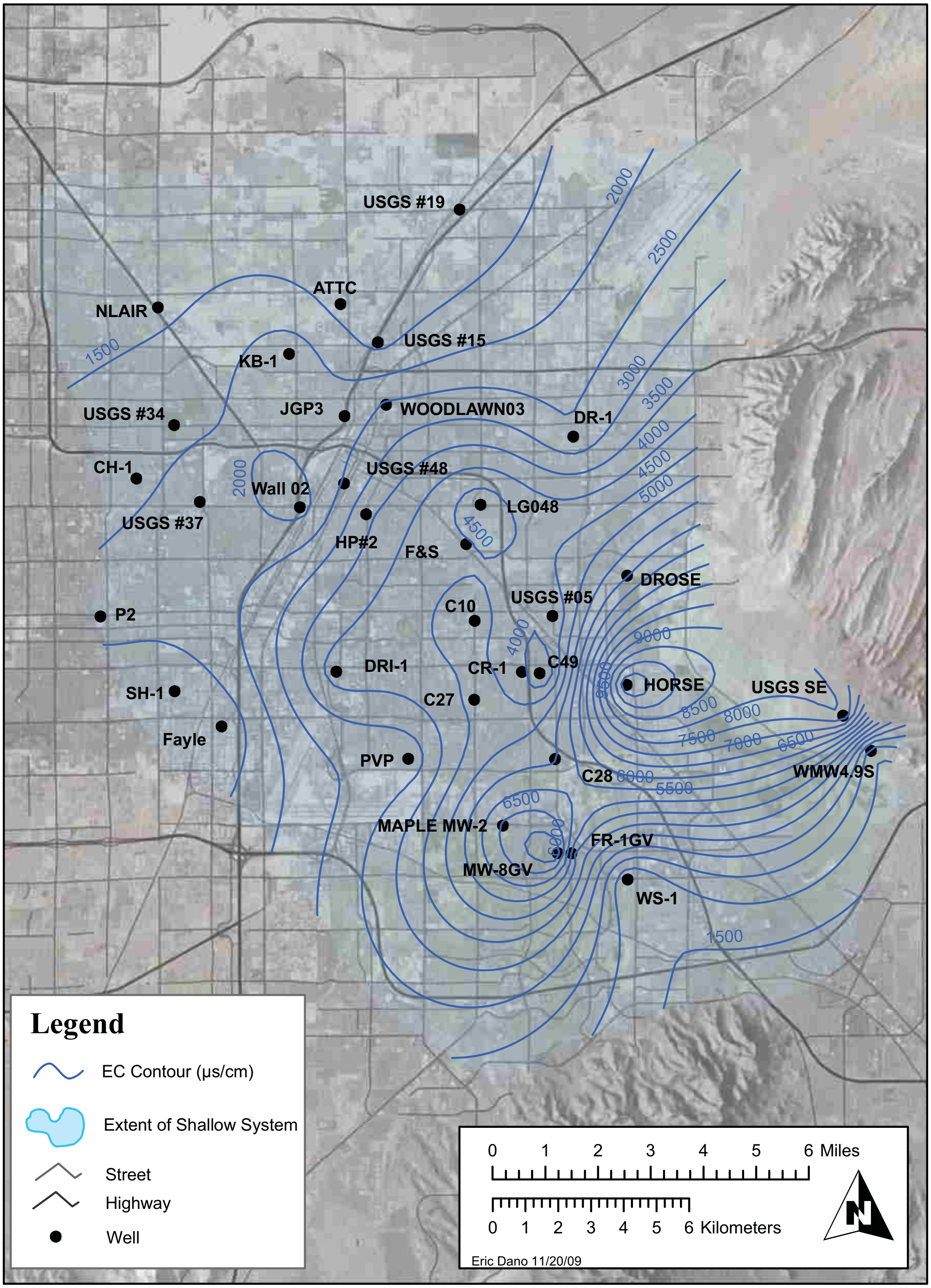
| | GW-Chart-Calced CO3 | Total Alkalinity mg/l | Cl/NO3 | Chloride (Cl) mg/l | Sulfate (SO4) mg/l | TDS | Nitrate (NO3) as N |
|---|---|---|---|---|---|---|---|
| PC 1 | | | | | | | |
| PC 2 | | | | | | | |
| PC 3 | | | | | | | |
| Calcium (Ca) mg/l | | | | | | | |
| Magnesium (Mg) mg/l | | | | | | | |
| Sodium (Na) mg/l | | | | | | | |
| Potassium (K) mg/l | | | | | | | |
| Cal CO3 | 1.0000 | | | | | | |
| Total Alkalinity mg/l | 0.5362 | 1.0000 | | | | | |
| Cl/NO3 | -0.0256 | -0.0259 | 1.0000 | | | | |
| Chloride (Cl) mg/l | -0.1940 | -0.0137 | 0.1301 | 1.0000 | | | |
| Sulfate (SO4) mg/l | -0.1978 | -0.2166 | -0.0333 | 0.7779 | 1.0000 | | |
| TDS | -0.1730 | 0.0090 | -0.0172 | 0.8658 | 0.9384 | 1.0000 | |
| Nitrate (NO3) as N | -0.2906 | -0.0038 | -0.3523 | 0.3973 | 0.3062 | 0.4571 | 1.0000 |
| Nitrate (NO3) mg/l | -0.2908 | -0.0094 | -0.3546 | 0.4035 | 0.3182 | 0.4641 | 0.9995 |
| LAB EC umho/cm | -0.2160 | 0.1400 | -0.0378 | 0.8392 | 0.7950 | 0.9257 | 0.5408 |
| SiO2 | 0.1576 | 0.5002 | 0.0616 | 0.2344 | 0.1092 | 0.3306 | 0.3241 |
| FIELD EC | -0.2407 | 0.0806 | -0.0373 | 0.8767 | 0.8156 | 0.9331 | 0.5532 |
| FIELD PH | 0.3585 | -0.4827 | 0.0208 | 0.0338 | 0.1888 | -0.0036 | -0.1694 |
| FIELD TEMP | 0.1519 | -0.2116 | 0.2607 | 0.0209 | -0.1027 | -0.1563 | -0.2514 |
| D | -0.0677 | -0.1946 | -0.0499 | 0.5519 | 0.3865 | 0.4721 | 0.4975 |
| O18 | -0.1280 | -0.0573 | -0.0678 | 0.5818 | 0.3927 | 0.5262 | 0.5688 |

# Correlation Matrix

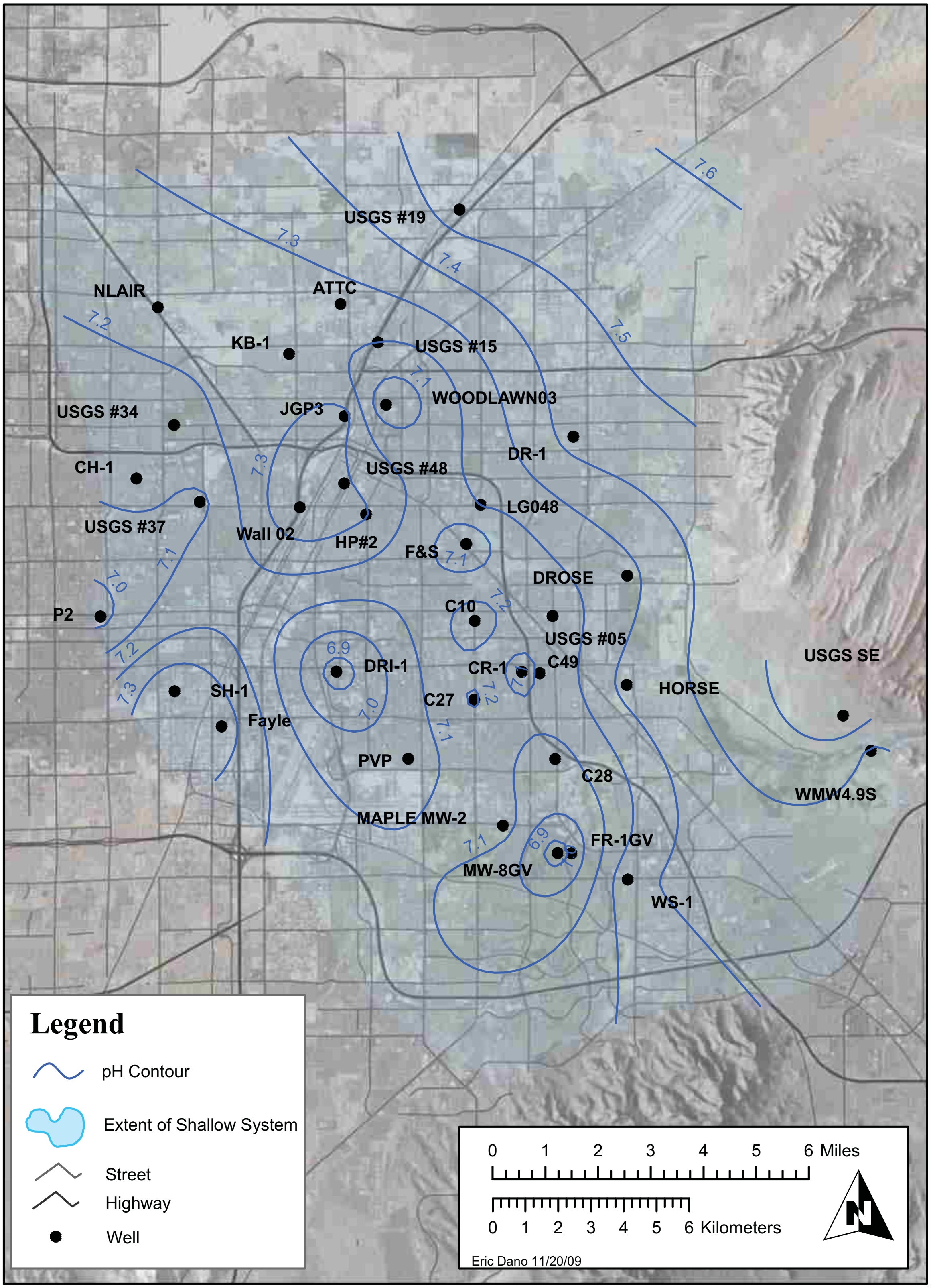
| | Nitrate (NO3) mg/l | LAB EC umho/cm | SiO2 | FIELD EC | FIELD PH | FIELD TEMP | D | O18 |
|---|---|---|---|---|---|---|---|---|
| PC 1 | | | | | | | | |
| PC 2 | | | | | | | | |
| PC 3 | | | | | | | | |
| Calcium (Ca) mg/l | | | | | | | | |
| Magnesium (Mg) mg/l | | | | | | | | |
| Sodium (Na) mg/l | | | | | | | | |
| Potassium (K) mg/l | | | | | | | | |
| Cal CO3 | | | | | | | | |
| Total Alkalinity mg/l | | | | | | | | |
| Cl/NO3 | | | | | | | | |
| Chloride (Cl) mg/l | | | | | | | | |
| Sulfate (SO4) mg/l | | | | | | | | |
| TDS | | | | | | | | |
| Nitrate (NO3) as N | | | | | | | | |
| Nitrate (NO3) mg/l | 1.0000 | | | | | | | |
| LAB EC umho/cm | 0.5441 | 1.0000 | | | | | | |
| SiO2 | 0.3142 | 0.4598 | 1.0000 | | | | | |
| FIELD EC | 0.5571 | 0.9930 | 0.4345 | 1.0000 | | | | |
| FIELD PH | -0.1646 | -0.1609 | -0.3830 | -0.1283 | 1.0000 | | | |
| FIELD TEMP | -0.2492 | -0.3110 | -0.3934 | -0.2711 | 0.3317 | 1.0000 | | |
| D | 0.4937 | 0.4755 | -0.0113 | 0.5028 | 0.3569 | 0.1341 | 1.0000 | |
| O18 | 0.5611 | 0.5866 | 0.1310 | 0.6001 | 0.1774 | -0.0705 | 0.9289 | 1.0000 |

# APPENDIX 4

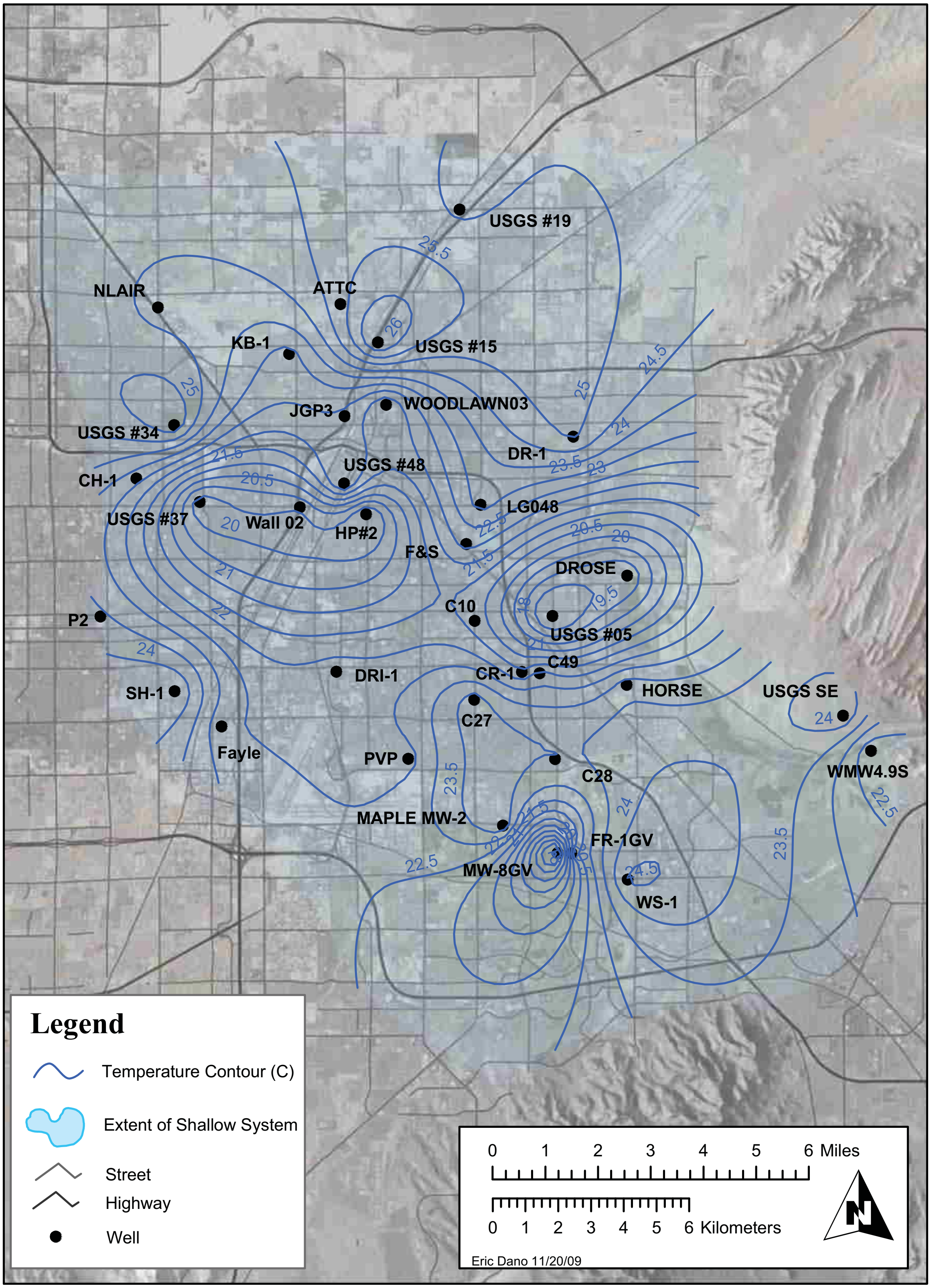
# CONTOUR MAPS



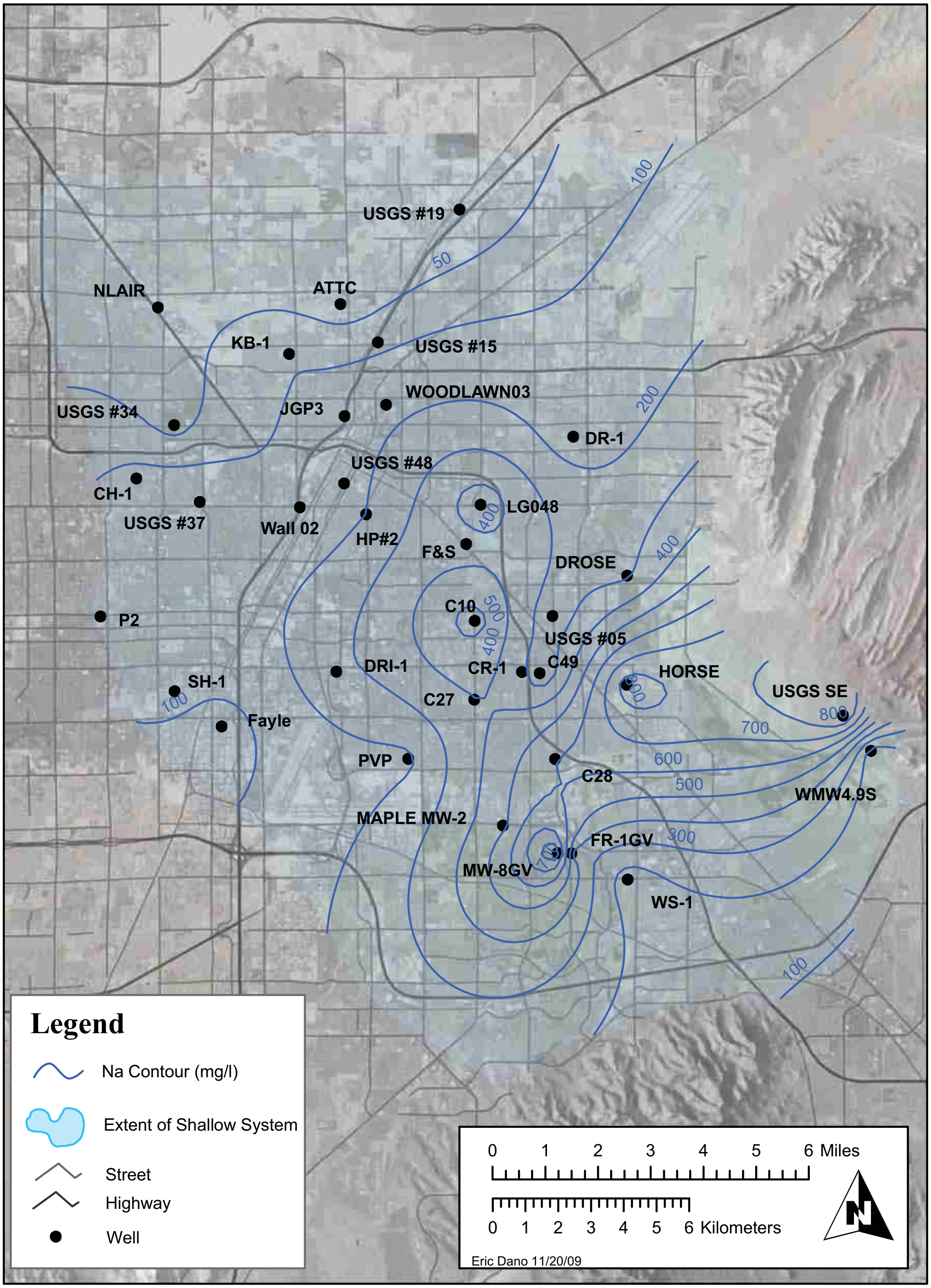
**Appendix 4-1 Contour Map of Electroconductivity (EC) values in microsiemens per centimeter (µs/cm).**



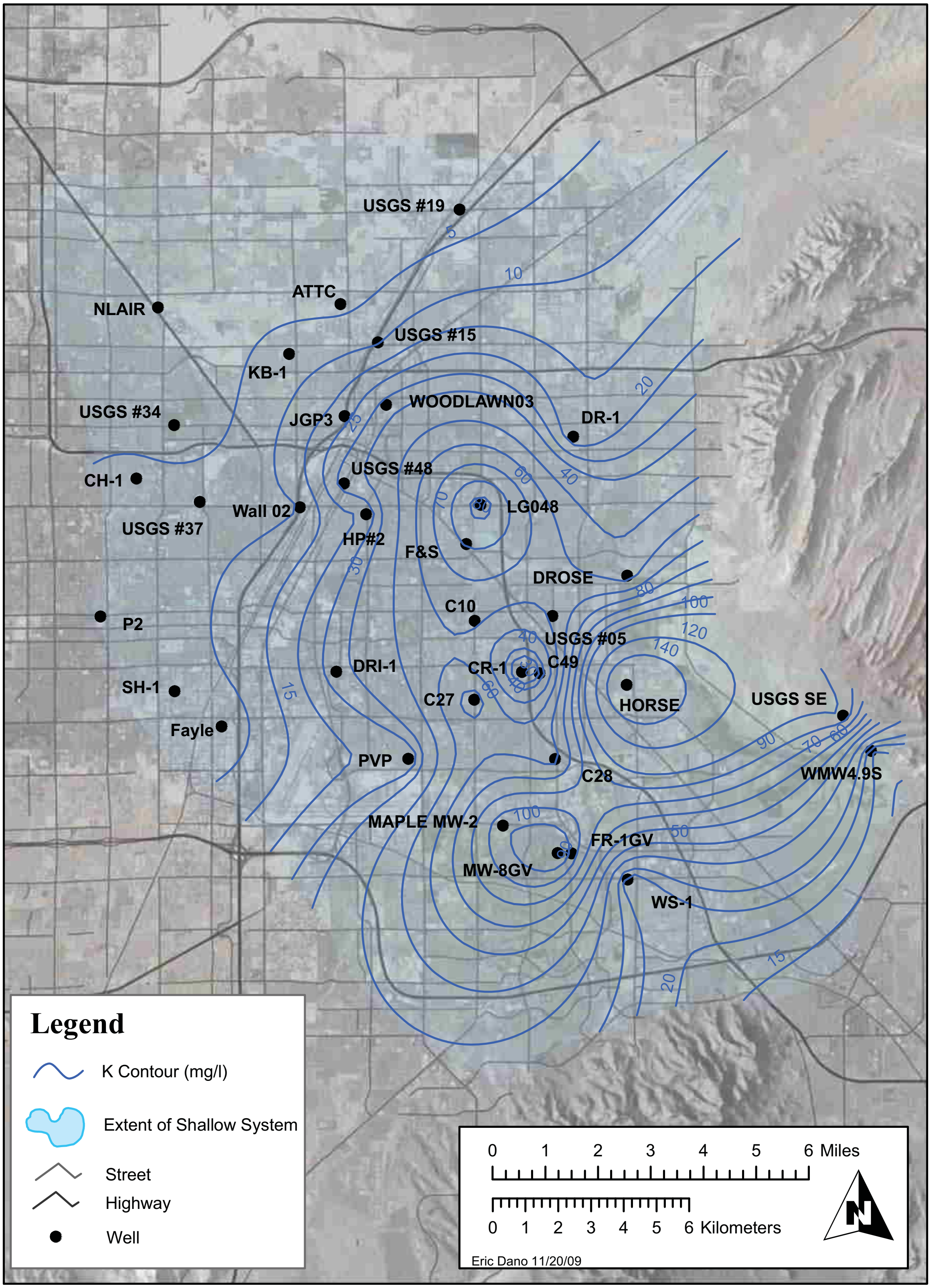
Appendix 4-2 Contour Map of pH values.



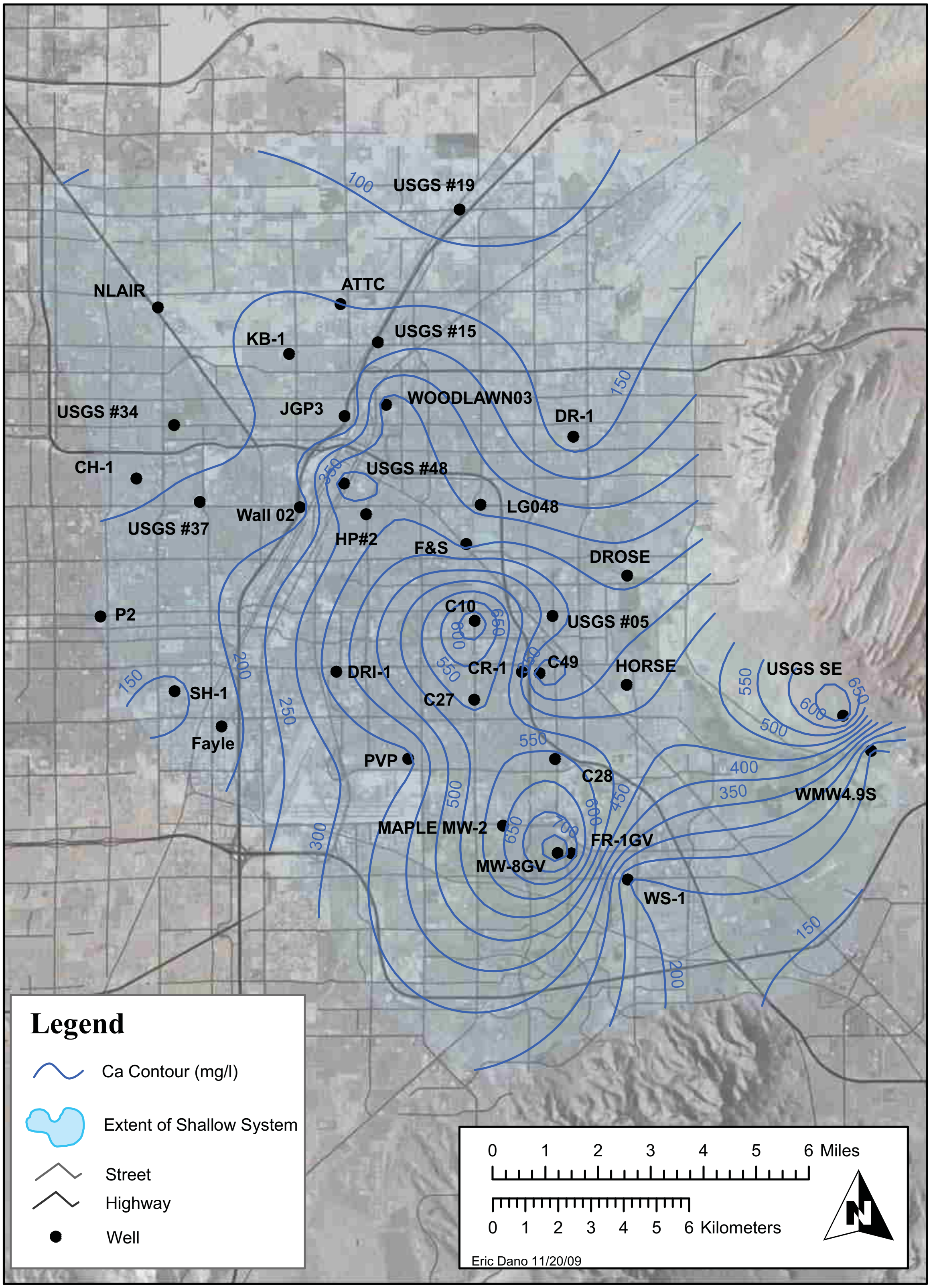
Appendix 4-3 Contour map of temperature values (C). 5° contour interval



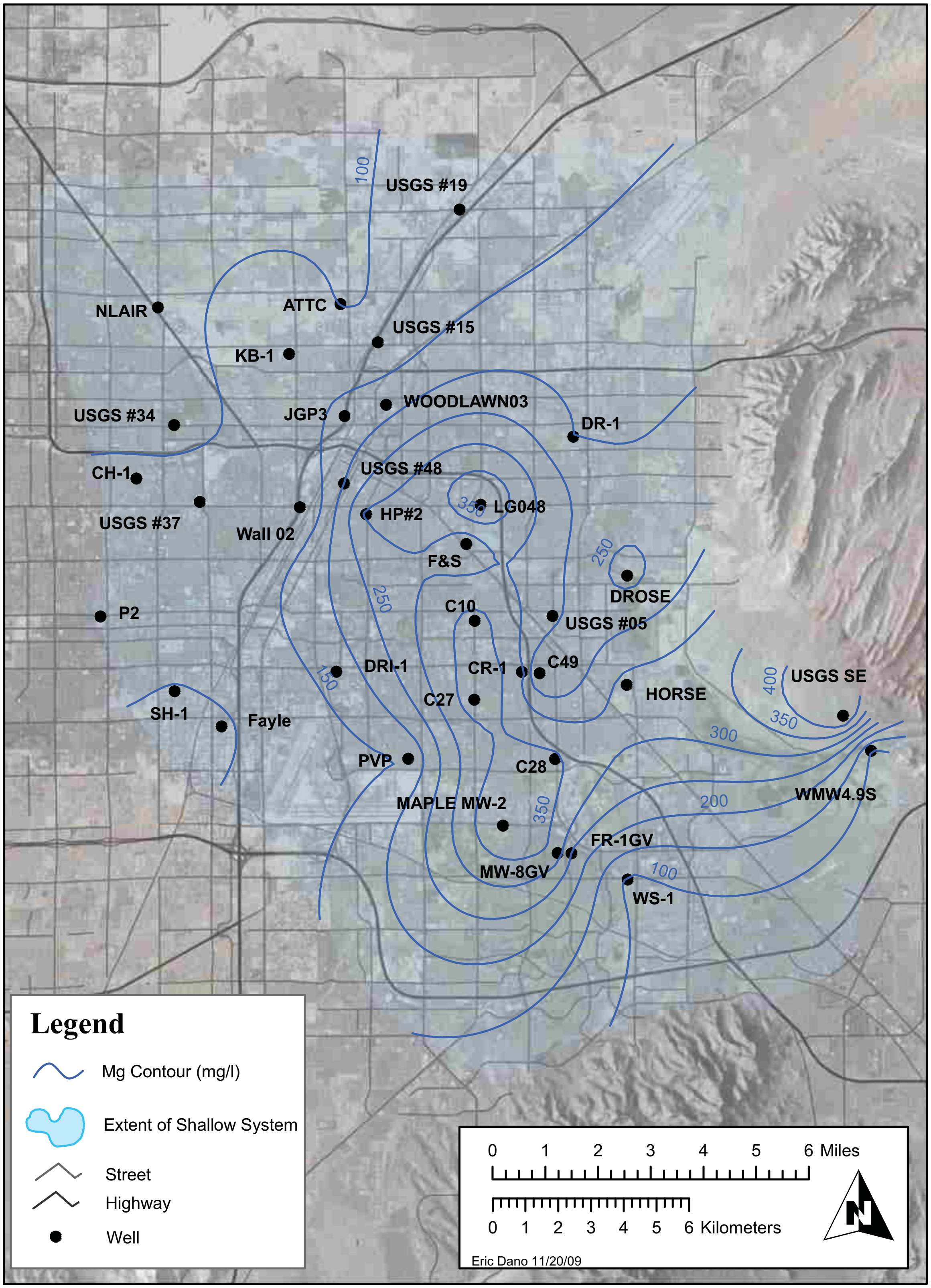
Appendix 4-4 Contour Map of Sodium (Na) values (mg/l).



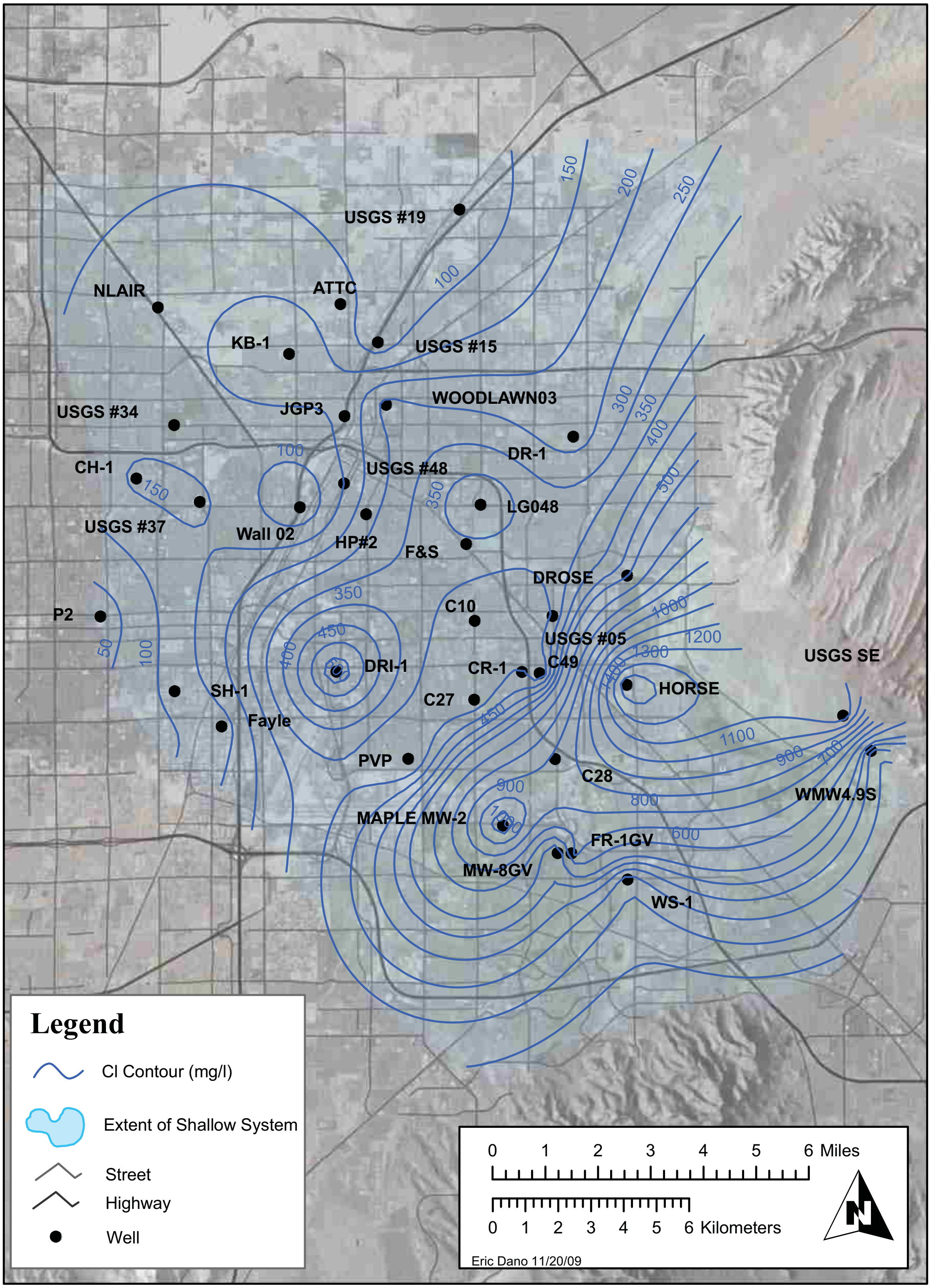
**Appendix 4-5 Contour Map of Potassium (K) values (mg/l). Variable contour interval, 5 to 25 mg /l in 5 unit increments, 30 to 100 mg /l in 10 unit increments, 100 to 140 mg /l in 20 unit increments.**



**Appendix 4-6 Contour Map of Calcium (Ca) values (mg/l). Contour interval, 100 to 700 mg /l in 50 unit increments.**



**Appendix 4-7 Contour Map of Magnesium (Mg) values (mg/l). Contour interval, 100 to 400 mg /l in 50 unit increments.**



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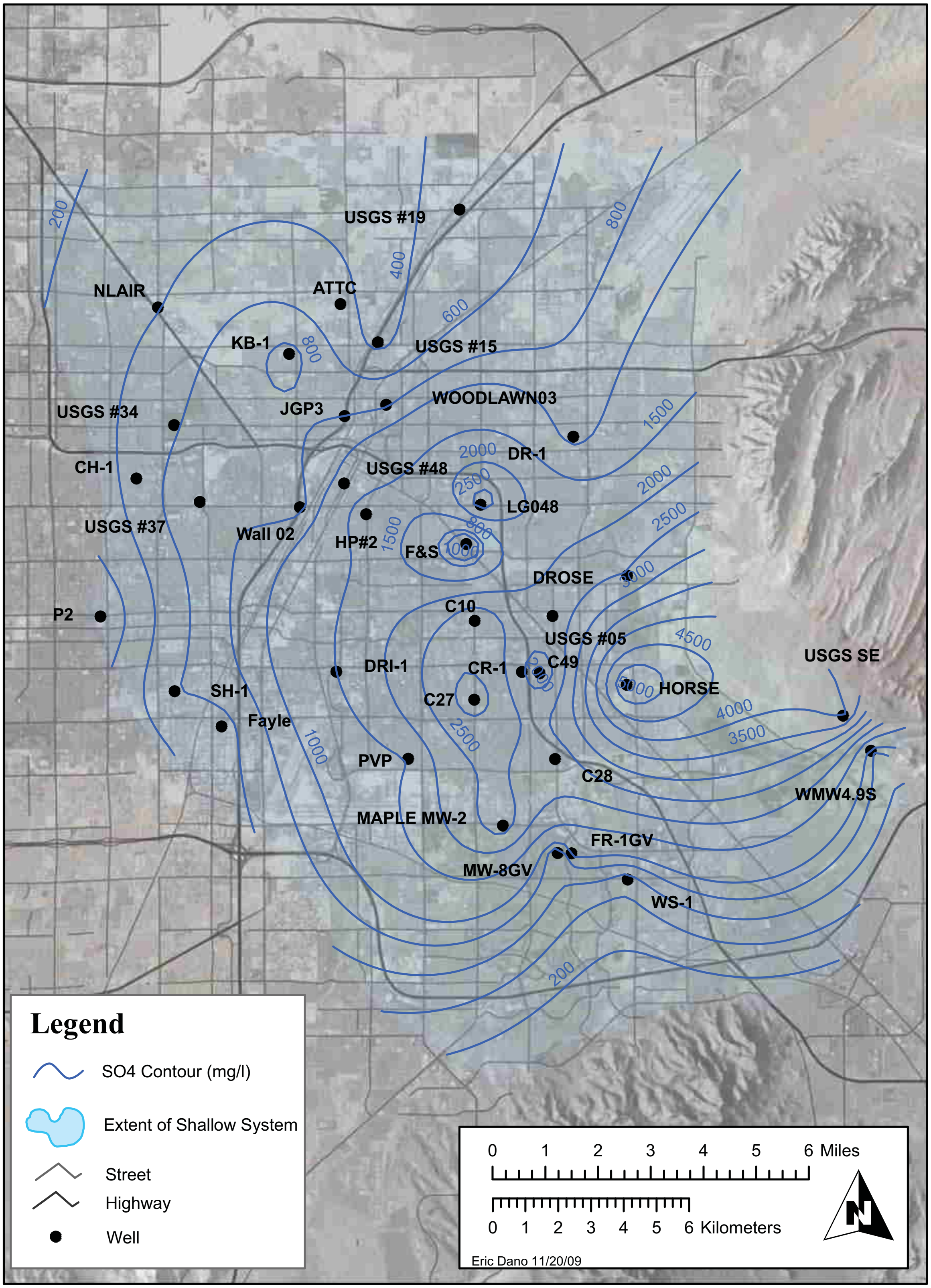
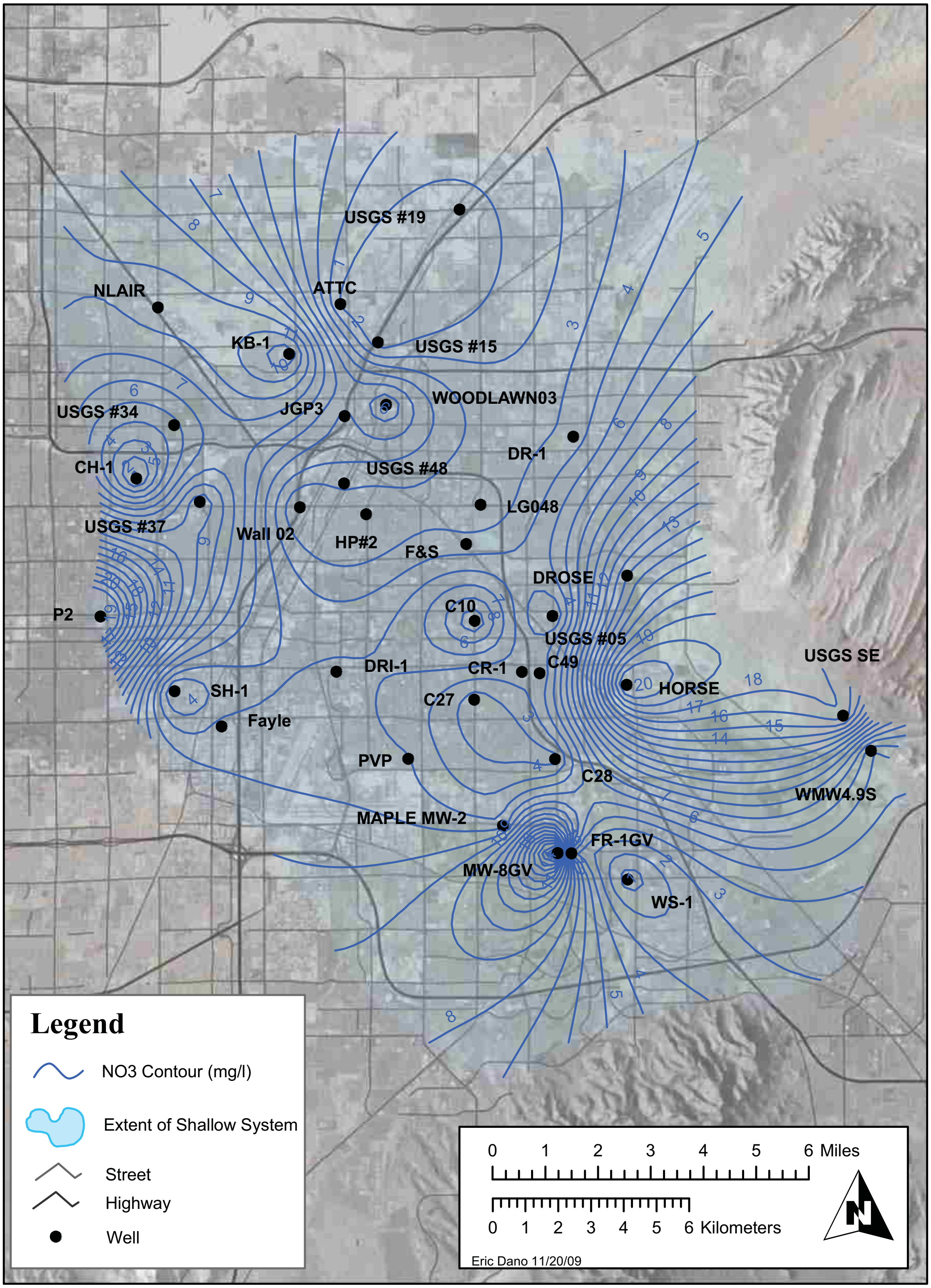
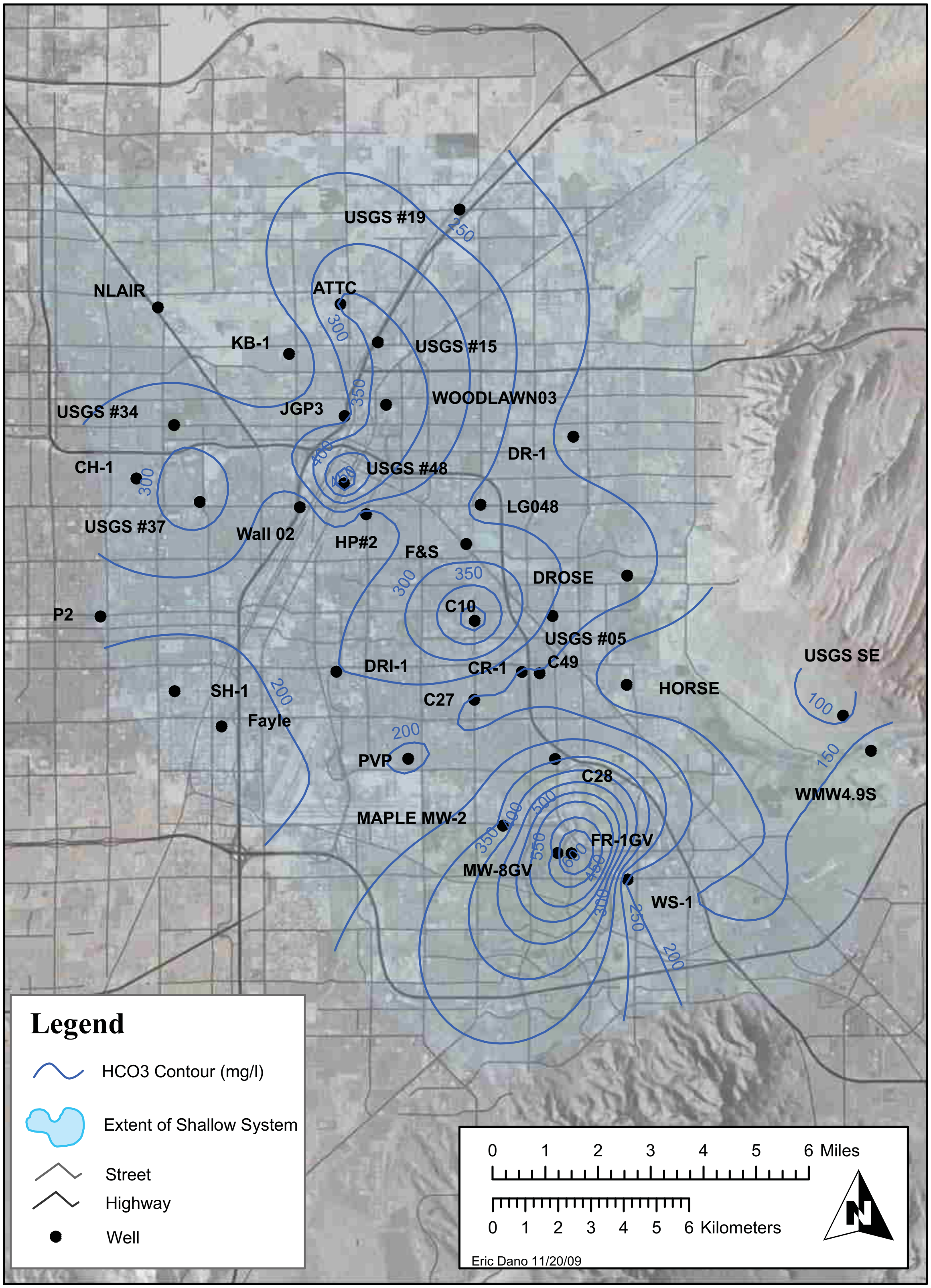
**Appendix 4-8 Contour Map of Chloride (Cl) values (mg/l). Variable contour interval, 50 to 500 mg /l in 50 unit increments, 500 to 1400 mg /l in 100 unit increments.**



**Appendix 4-9 Contour Map of Sulfate (SO4) values (mg/l). Variable contour interval, 200 to 1000 mg /l in 200 unit increments, 1000 to 5000 mg /l in 500 unit increments.**



Appendix 4-10 Contour Map of Nitrate (NO3 as N) values (mg/l).



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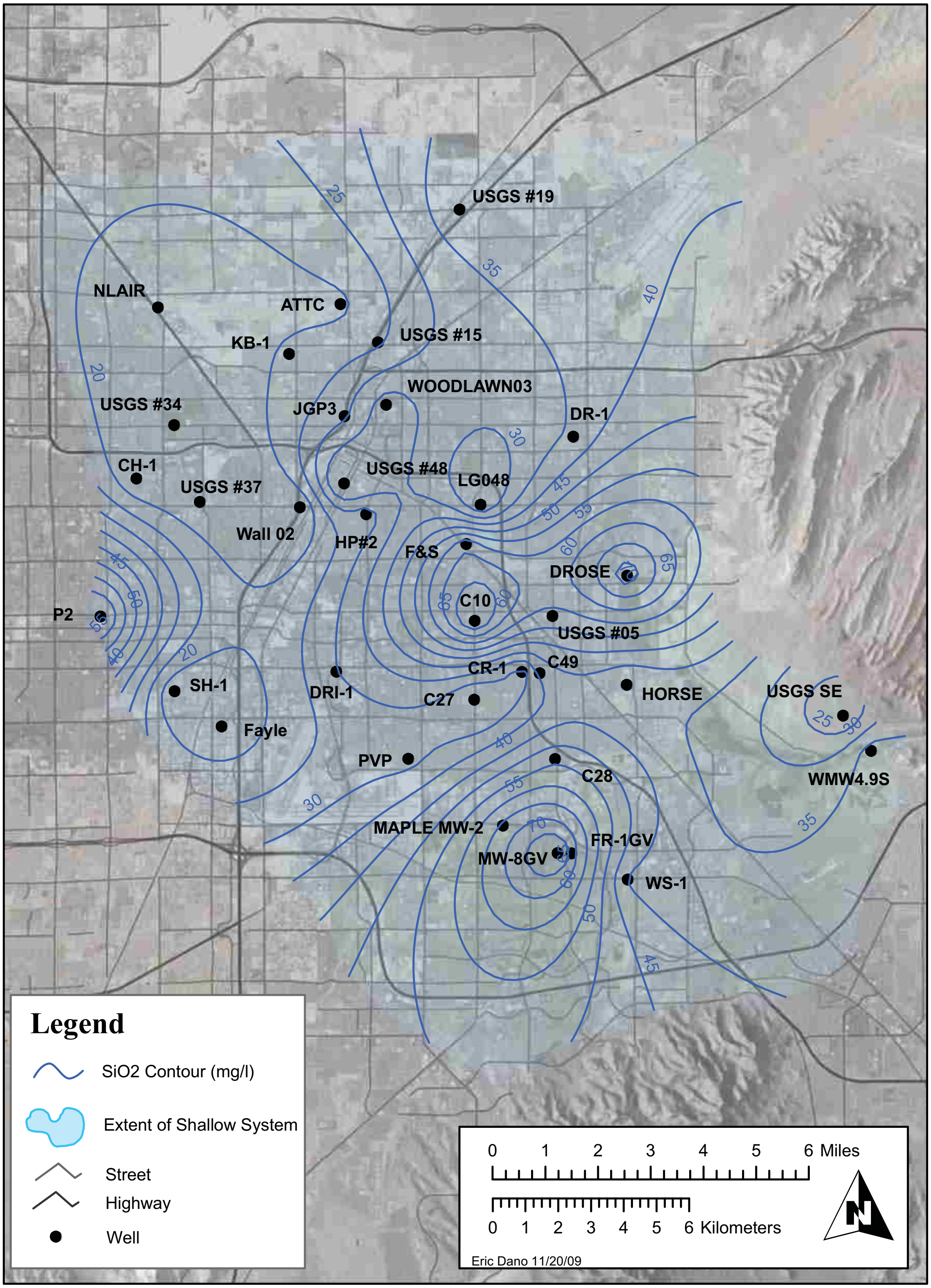
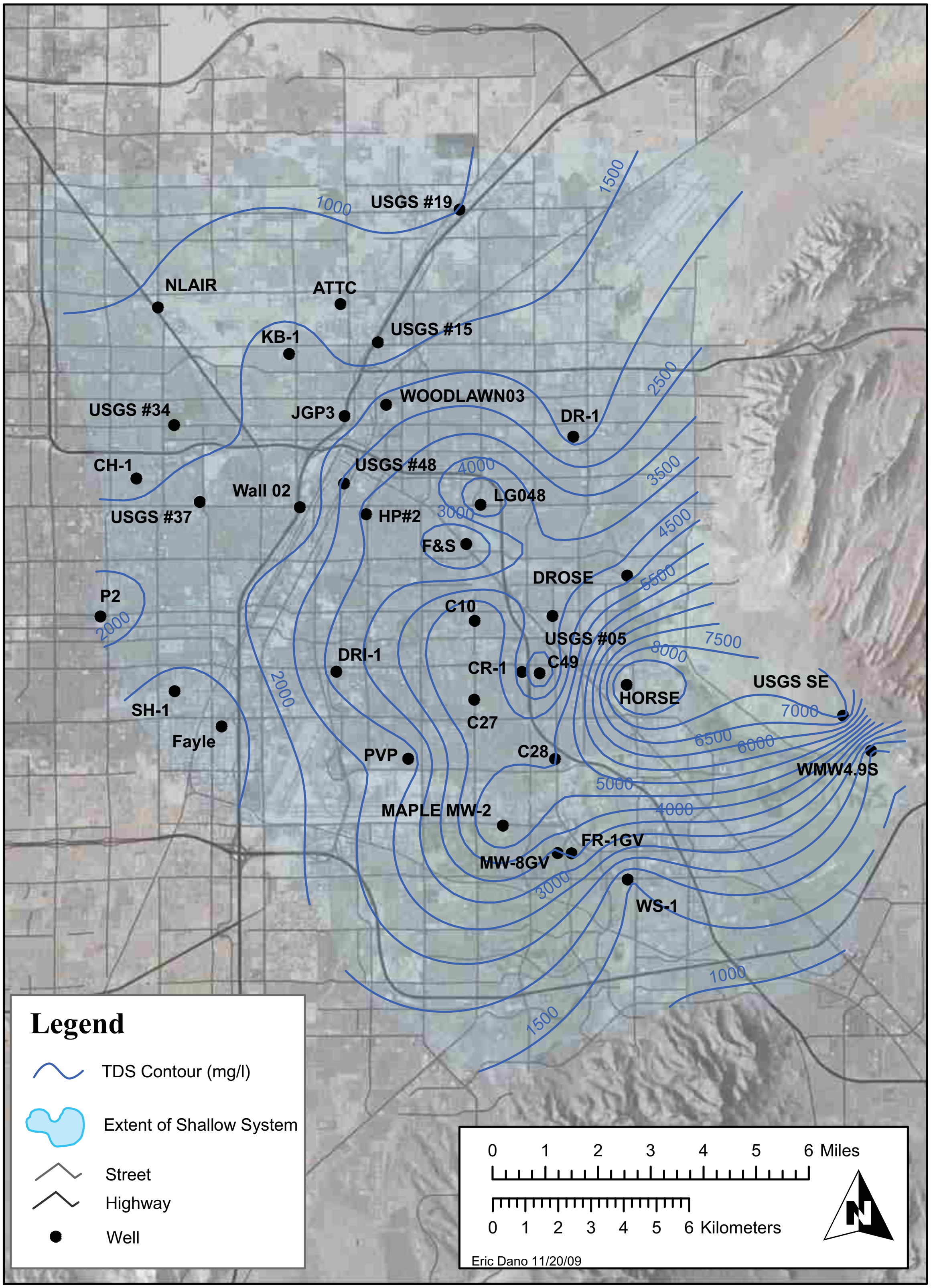
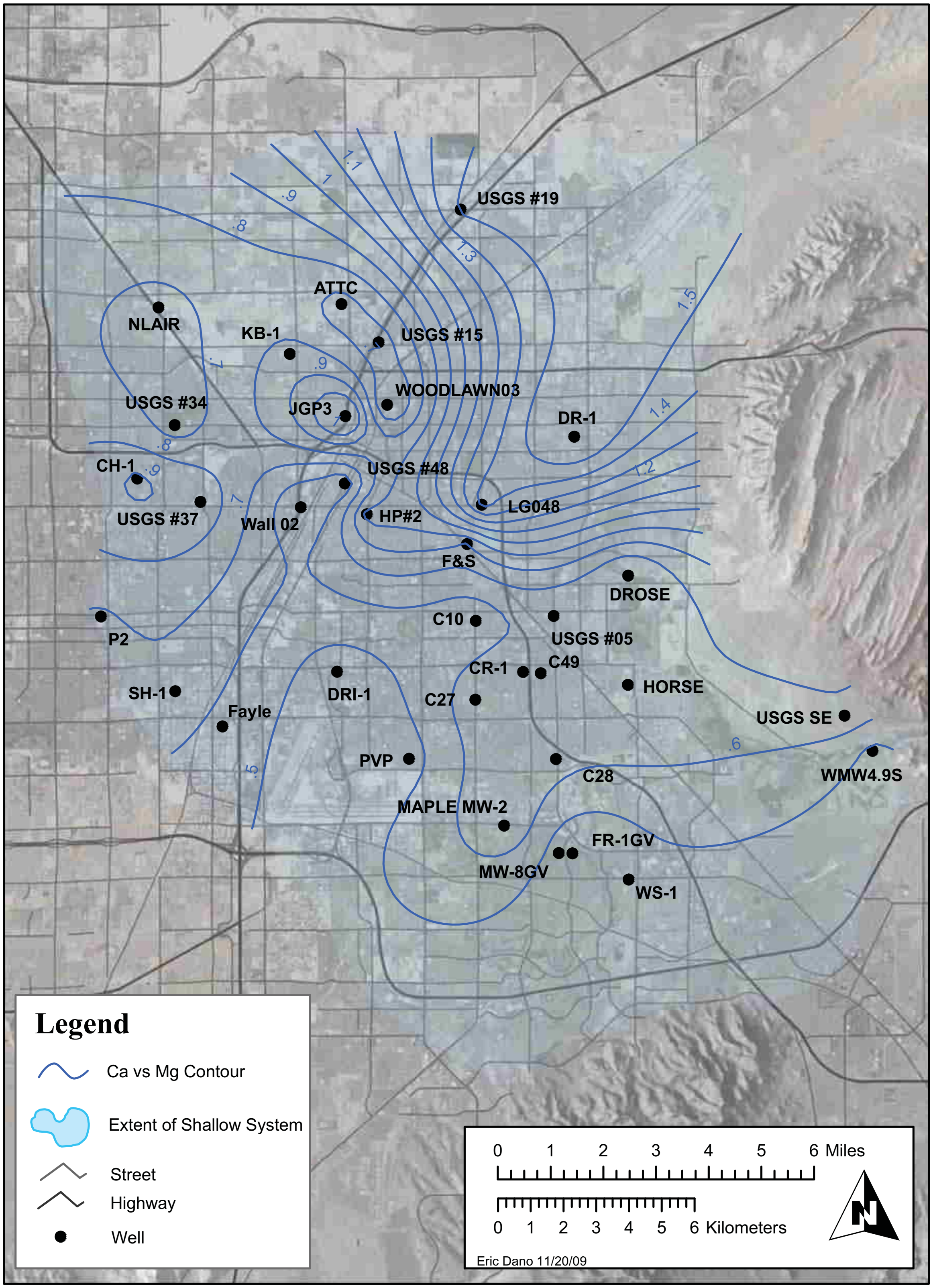
**Appendix 4-11 Contour Map of Bicarbonate (HCO3) values (mg/l). Contour interval from 100 mg/l to 600 mg/l in 50 unit increments.**



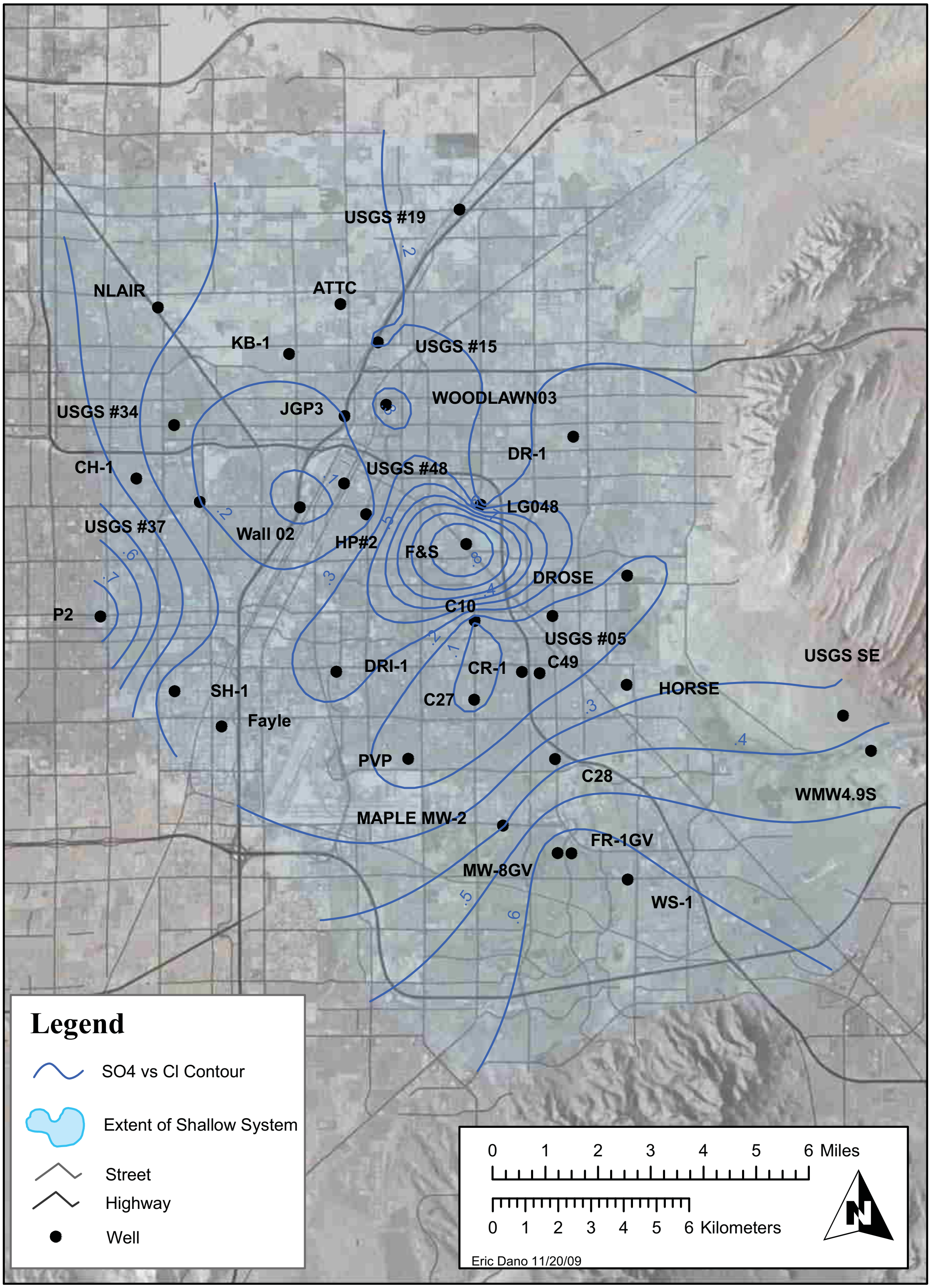
**Appendix 4-12 Contour Map of Silicate (SiO2) values (mg/l). Contour interval from 20 mg/l to 70 mg/l in 5 unit increments.**



**Appendix 4-13 Contour Map of Total Dissolved Solids (TDS) values (mg/l). Contour interval from 1000 mg/l to 8000 mg/l in 500 unit increments.**



**Appendix 4-14 Contour Map of Ratio between Calcium (Ca) and Magnesium (Mg). Contour interval in .1 ratio unit from .5 to 1.5.**



**Appendix 4-15 Contour Map of Ratio between Sulfate (SO4) and Chloride (Cl). Contour interval in .1 ratio unit from .1 to .8.**

# APPENDIX 5

## PHARMACEUTICAL RESULTS

| SPE Batch ID # | 031506-2B | 031506-5B |
|---|---|---|
| **Description** | **08-01-05 P2** | **08-01-05 AR002** |
| **Analyte** | **ppt** | **ppt** |
| Hydrocodone | <71 | <71 |
| Trimethoprim | <71 | <71 |
| Acetaminophen | <71 | <71 |
| Caffeine | <710 | <710 |
| Erythromycin-$H_2O$ | <71 | <71 |
| Sulfamethoxazole | 124 | 130 |
| Fluoxetine | <71 | <71 |
| Pentoxifylline | <71 | <71 |
| Meprobamate | <71 | <71 |
| Dilantin | <71 | <71 |
| TCEP | <710 | <710 |
| Carbamazepine | <71 | <71 |
| DEET | <71 | <71 |
| Atrazine | <71 | <71 |
| Diazepam | <71 | <71 |
| Oxybenzone | <71 | <71 |
| Estriol | <355 | <355 |
| Ethynylestradiol | <71 | <71 |
| Estrone | <71 | 103 |
| Estradiol | <71 | 1560 |
| Testosterone | <71 | <71 |
| Progesterone | <71 | <71 |
| Androstenedione | <71 | <71 |
| Iopromide | <71 | <71 |
| Naproxen | <71 | <71 |
| Ibuprofen | <71 | <71 |
| Diclofenac | <71 | <71 |
| Triclosan | <71 | <71 |
| Gemfibrozil | <71 | <71 |

Samples were collected for pharmaceutical analysis on 8-15-05. Samples were from well P2 and cascading water from the nearby recharge well AR002 Prior to its abandonment.

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Publications:

**Dano, E.** 2003. Septic System Tributary Interaction Study Las Vegas, Nevada, Las Vegas, NV: Southern Nevada Water Authority.

Leising, J.F., **Dano, E.**, 2006, Experimental investigation to limit trihalomethane production, Southwest Hydrology, v.5 No. 6, November/December p24-25.

Thesis Title: Identification of Geochemical Facies Through Major Ion Data and Additional Parameters From Shallow *Groundwater* Utilizing a Comparison of Geomathematics and Traditional Methods in Las Vegas Valley, Nevada

Thesis Examination Committee:
Chairperson, Dr. David Kreamer, Ph.D.
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