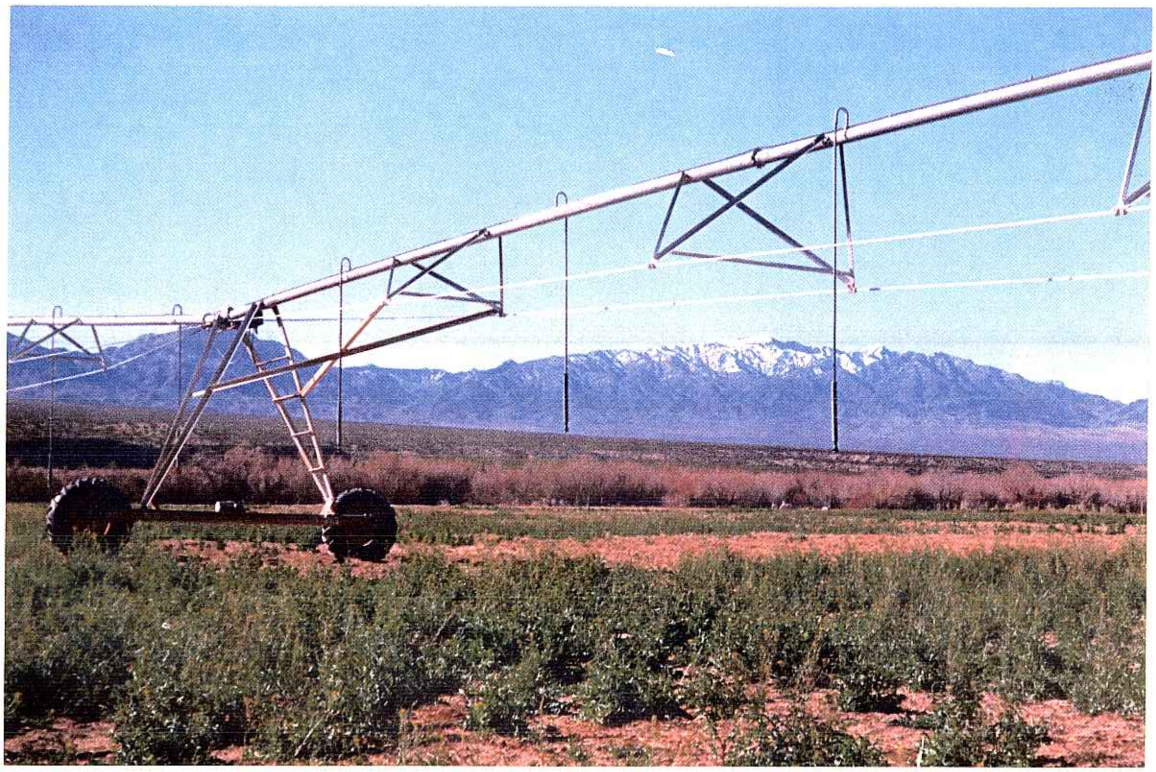
Ambient Groundwater Quality of the Virgin River Basin: A 1997 Baseline Study



Prepared by

Hydrologic Support and Assessment Section
Water Quality Division
Arizona Department of Environmental Quality

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Final Report of:
Ambient Groundwater Quality of the Virgin River Basin:
A 1997 Baseline Study

Prepared by
Douglas C. Towne
Groundwater Monitoring Unit
Hydrologic Support & Assessment Section
Water Quality Division
Arizona Department of Environmental Quality

Sampling Assistance Thanks to
Donald Hall, Robert Hanus, Shauna Leaym, and Rich Ratliffe (Mohave County)

Report Preparation Assistance Thanks to
Warren Elting, Maureen Freark, Gloria Koroghlanian,
Marianne Gilbert, Shauna Leaym and Wang K. Yu

Report Review Assistance Thanks to
Jeanette Black, Elizabeth Boettcher, Stephanie Ellingham (BLM), Wayne Hood III,
Tom Merrifield, Nicole Spence (ADWR), Scott Steinhagen, Moncef Tihami, and Bob Wallin

3033 North Central Avenue
Phoenix, Arizona 85012
(602) 207-4412
In Arizona 1-800-234-5677 ext. 4412

VISION

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- Be innovative and supportive
- Provide quality services to our customers
- Align our jobs with the Department's mission, and
- Promote a sustainable environment and economy.

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The Arizona Department of Environmental Quality shall preserve, protect and enhance the environment and public health, and shall be a leader in the development of public policy to maintain and improve the quality of Arizona's air, land and water resources.

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Cover Photo: Situated in the floodplain of the Virgin River is a center pivot irrigation unit, with the river's riparian area and the snow-capped Virgin River Mountains in the background.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

Ambient Groundwater Quality of the Douglas Basin: A 1996 Baseline Study. ADEQ Publication Forthcoming Spring, 1999.

Ground-water Quality in the Sierra Vista Subbasin, Arizona, 1996-97. Joint ADEQ-USGS Publication Forthcoming Spring, 1999.

Ambient Groundwater Quality of the Yuma Basin: A 1995 Baseline Study. ADEQ Publication OFR 98-7

The Impacts of Septic Systems on Water Quality of Shallow Perched Aquifers: A Case Study of Fort Valley, Arizona. ADEQ Publication OFR 97-7.

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Part I

Abstract

1. ABSTRACT

The Groundwater Monitoring Unit of the Arizona Department of Environmental Quality (ADEQ) completed a baseline groundwater quality study of the Virgin River Groundwater Basin (VRGB) in 1997. Located in the arid northwest corner of Arizona, the VRGB consists mainly of undeveloped public lands punctuated by small areas of private land, some of which contain densely-settled residences utilizing septic systems for wastewater treatment. A total of 38 groundwater samples were collected for the study including 33 stratified random samples from four aquifers: Beaver Dam, Littlefield, Virgin River alluvial, and Virgin River basin. All groundwater samples were analyzed for Safe Drinking Water (SDW) inorganics, 10 samples were analyzed for radionuclides, and 3 samples were analyzed for Groundwater Protection List (GWPL) pesticides. Laboratory results revealed no detections of GWPL pesticides, while only one radionuclide sample exceeded the Primary Maximum Contaminant Levels (MCLs) for gross alpha. Inorganic parameter levels of the VRGB samples did not exceed any health-based Primary MCLs, though aesthetics-based Secondary MCLs for chloride, iron, manganese, field pH, sulfate, and total dissolved solids were exceeded, especially in the Littlefield and Virgin River alluvial aquifers. These results suggest that regional groundwater quality conditions generally support drinking water uses; however, some residents may prefer to use treated water for domestic purposes because of aesthetic reasons.

Piper trilinear diagrams revealed each aquifer in the VRGB had a characteristic water chemistry: Beaver Dam aquifer had bicarbonate-calcium water, Littlefield and Virgin River alluvial aquifers had sulfate-calcium water, and Virgin River basin aquifer had a mixed water chemistry. Statistical analyses indicated that many significant differences exist in groundwater quality parameter levels among aquifers in the VRGB. Generally, inorganic parameters in the Littlefield and Virgin River alluvial aquifers have significantly higher levels than the Beaver Dam and Virgin River basin aquifers.

A strong correlation existed among the levels of most groundwater quality parameters in the VRGB, perhaps indicating a common natural source for most parameters. Exceptions to this trend include nitrate, fluoride, iron, and manganese; parameters which may come from other natural or cultural sources. There is also a significant relationship between decreasing groundwater quality parameter levels and increasing groundwater depth below land surface in the VRGB; however, when examined by individual aquifer few of these statistical relationships are present. Thus, these VRGB depth-dependent parameter levels may be more the result of parameter level differences among aquifers and the accompanying groundwater depth variations than by any actual relationships within aquifers.

The groundwater quality of the Beaver Dam and Littlefield aquifers may be impacted by cultural factors as evidenced by the comparison of upgradient, control samples to the 95% confidence interval established for each aquifer. The presence of poorer-quality groundwater beneath the Beaver Dam aquifer and better-quality groundwater beneath the Virgin River alluvial aquifer was also indicated by results of limited sampling of deeper aquifers.

Part II

Background

2. OBJECTIVES

The Groundwater Monitoring Unit (GMU) of the Arizona Department of Environmental Quality (ADEQ) conducted an extensive regional groundwater quality study of the Virgin River Groundwater Basin (VRGB) in 1997. The impetus for this groundwater study was fourfold:

- Requests by both the Northern Regional Office (NRO) of ADEQ and Mohave County, Arizona for additional groundwater quality data in the VRGB because of groundwater contamination concerns from septic systems;
- An ADEQ report (Hood, 1991) which, in evaluating the need for ambient monitoring in each of the 50 designated groundwater basins in Arizona, noted a lack of groundwater quality data collection alternatives in the VRGB such as public water systems and other organizations collecting groundwater quality data;
- Because of recent population growth and the associated increase in well drilling in the previously sparsely-populated VRGB, an opportunity to collect groundwater samples from areas that could not be sampled by prior studies;
- The opportunity to conduct a baseline groundwater quality study in a relatively undeveloped area before explosive population growth in the VRGB; and

This groundwater study had four objectives:

- To obtain baseline data throughout the VRGB on the occurrence, concentrations, and ranges of a wide variety of groundwater quality parameters including the identification and delineation of any areas with groundwater quality problems.
- With the sampling sites determined through means of stratified random selection, to examine aquifers within the VRGB for statistically significant groundwater quality differences.
- Using the sampling sites determined through means of stratified random selection, examine relationships with groundwater quality parameter levels and indices such as groundwater depth and other groundwater quality parameter levels.
- To establish a statistically designed ambient groundwater quality index well monitoring network for the VRGB.

Meeting these objectives in a reproducible, scientific study that utilizes statistical analysis to make broad statements concerning groundwater quality will provide many benefits, some of which are listed below:

- Residents in the VRGB utilizing water supplied by a public water system for domestic purposes have the assurance that this resource is tested regularly and meets water quality standards set by the Safe Drinking Water (SDW) Act. However, many rural residents are served by private wells whose water is usually not tested for a wide array of possible pollutants. Although Arizona statutes require well drilling contractors to disinfect new wells, which are used for human consumption, for potential bacteria contamination, many wells are not further tested for other types of groundwater quality problems. Thus, contamination affecting groundwater pumped from private wells may go undetected for years and have adverse health effects on users of this resource. Collecting and analyzing groundwater samples from all these private wells would be prohibitively expensive. However, a statistically-based ambient groundwater study to estimate groundwater quality conditions on a regional scale and identify possible associations with landscape attributes to help explain impaired groundwater conditions offers an affordable alternative.

- Determining whether groundwater in the VRGB is currently suitable for domestic uses;

- Determining whether septic system effluent has impacted groundwater quality in the VRGB, especially at groundwater depths at which domestic wells are commonly perforated. Levels of nitrate, considered the most important septage indicator, will be an important factor in making this determination;

- Provides a scientific basis for distinguishing pollution impacts to aquifers;

- Assessing the effectiveness of groundwater protection efforts such as industry Best Management Practices (BMPs) by tracking groundwater quality changes;

- Be a useful tool with which to guide VRGB planning such as construction of new public water supply well locations and determination of wellhead protection areas.

3. INTRODUCTION

Physical Setting - Located within the Basin and Range Physiographic Province in the northwestern corner of Arizona, the VRGB encompasses a total area of approximately 433 square miles within Arizona. The basin's boundaries are formed by two natural hydrologic barriers and two artificial political boundaries. The northeast-southwest trending Virgin and Beaver Dam Mountains form the VRGB's boundaries on the east and south while the Arizona-Utah and Arizona-Nevada state lines are the basin's boundaries to the north and west (**Figure 1**). Elevations above mean sea level range from 8012 feet at Mt. Bangs in the Virgin Mountains to 1600 feet along the Virgin River at the Arizona-Nevada state line.

Climate - The VRGB is located in an arid region, with an average annual precipitation of approximately seven inches at Littlefield, Arizona. Temperatures in Littlefield range from an average daily minimum of 29°F in January to an average daily maximum of 106°F in July (Sellers and others, 1985). Vegetation varies from salt cedar, cottonwood, and willow trees in the riparian areas to creosote bush, yucca, and joshua trees through the broad valleys while juniper trees are found in the highest elevations of the basin.

Surface Water - The Virgin River, a major tributary of the Colorado River, has its headwaters on the Markagunt Plateau above Cedar City, Utah. This river flows through the canyons of Zion National Park before cutting across 35 miles of the northwest corner of Arizona. The Virgin River then enters Nevada, eventually discharging into Lake Mead on the Colorado River.

The course of the Virgin River stretches through the VRGB from the northeast to the southwest, extending from the Arizona-Utah state line to the Arizona-Nevada state line. Where the Virgin River cuts through the Beaver Dam Mountains at an area known as "The Narrows," numerous springs are present that maintain the river's perennial baseflow through Arizona. Most of the springs are along the banks of the Virgin River and cannot be easily identified or measured (USGS, 1976). Downstream of "The Narrows", the Virgin River flows through a broad alluvial valley to the Nevada border. Average annual discharge of the Virgin River at Littlefield is approximately 174,000 acre-feet per year (USGS, 1990). Beaver Dam Wash is the largest tributary within the VRGB and is perennial for approximately a mile above its confluence with the Virgin River.

Average annual discharge of Beaver Dam Wash to the Virgin River is approximately 5,400 acre-feet per year (ADWR, 1991). Numerous washes drain the upland and mountain areas with springs occasionally providing small perennial reaches in some washes.

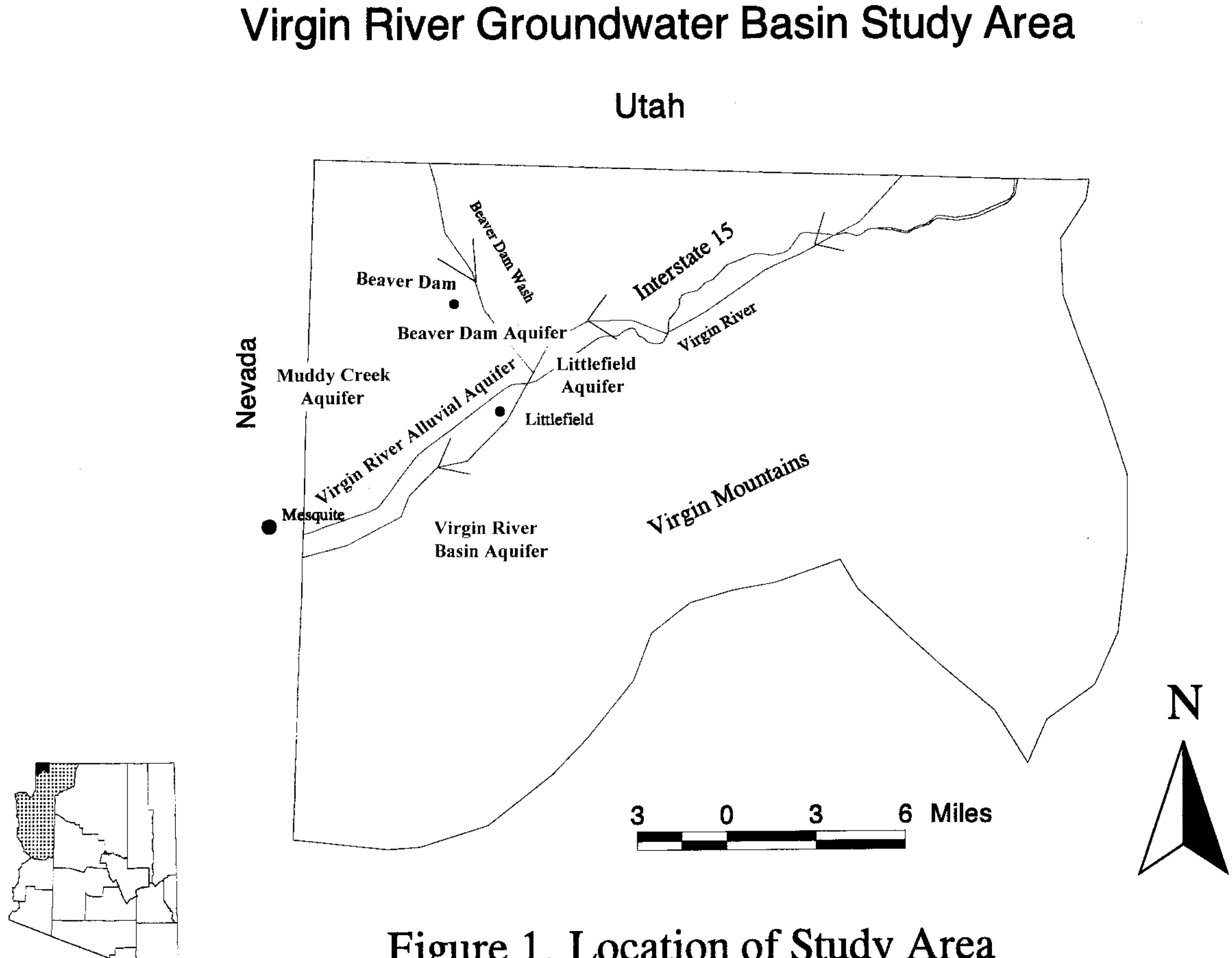


Figure 1. Location of Study Area

The Virgin River exhibits highly saline water quality while the surface flow of Beaver Dam Wash is characterized by relatively good water quality. Water quality parameter levels of each stream are provided in **Appendix I**. The U.S. Geological Survey collected the Virgin River data, which is a mean of six samples collected between November, 1996, and August, 1997, near Littlefield, AZ. The ADEQ Surface Water Quality Unit collected the Beaver Dam Wash data, which is a mean of six samples collected between November, 1993, and August, 1994, near Beaver Dam, AZ.

Cultural Development - The VRGB in 1990 had a population of approximately 800 (ADWR, 1991); however, this lightly populated and relatively undeveloped basin has been rapidly growing. The current population of approximately 5000 Arizona residents are mainly located in the communities of Beaver Dam, Desert Springs, Littlefield, and Scenic (Mesquite Chamber of Commerce, 1997). Similar population increases have occurred along the Virgin River in neighboring Nevada and Utah. St. George, Utah is the fastest growing city in that state, with a population of about 45,000. Similarly Mesquite, located just across the state line in Nevada, has a rapidly growing population of 8,800 (Mesquite Chamber of Commerce, 1997).

Economic activities in these communities include farming, ranching, and service industries. Irrigated farmland on which crops are raised mainly for livestock consumption, is located along the river floodplains. In 1976, about 5,000 acre-feet of groundwater was withdrawn mainly for irrigation purposes along the Virgin River (USGS, 1976). Ranching is the predominant economic use of the large tracts of public land in the basin. While ranching and farming are still active in the basin, they have declined in economic importance. Service businesses catering to tourists are located along Highway 91 and Interstate 15. With the construction of gambling casinos in Mesquite and the popularity of the general area to those seeking a second or retirement home, the service industry is now the chief economic activity in the basin.

4. HYDROGEOLOGY

4.1 Aquifer Characteristics

The hydrogeology of the VRGB is complex with groundwater occurring in at least four aquifers (**Figure 1**) that share various levels of interconnection (Black and Rascona, 1991):

1) Beaver Dam aquifer,
2) Virgin River aquifer,
3) Littlefield aquifer, and
4) Muddy Creek aquifer.

The Beaver Dam Wash aquifer consists of unconsolidated silts, sands, and gravels deposited between steep terraces created by the incision of Beaver Dam Wash into the relatively impermeable units of the Littlefield and Muddy Creek Formations. Thus, the aquifer is largely isolated from other water-bearing units in the basin. Groundwater is unconfined and the direction of flow is from northwest to the southeast, where it eventually discharges into and mixes with the groundwater in the stream alluvium of the Virgin River aquifer. Wells completed in the Beaver Dam Wash aquifer are generally less than 150 feet deep below land surface (bls). Depths to groundwater are typically less than 65 feet bls, with well discharges ranging from 30 - 5,000 gallons per minute (gpm) (Black and Rascona, 1991).

The Virgin River aquifer includes the floodplain and terrace alluvium of the Virgin River southwest of Littlefield, and broadens to include alluvial-fan deposits of the Virgin Mountains south of the Virgin River. The floodplain deposits consist of silt, sand, and gravel; while the alluvial fan and terrace deposits consist of unconsolidated and semi-consolidated clay, silt, sand, gravel, and boulders (Moore, 1972). While the total thickness of the aquifer is unknown, well logs indicate deposits of sand, silt, and gravel to a depth of 1,020 feet. Measured depths to water range from 15 feet bls in the stream alluvium near Littlefield to 320 feet bls in the alluvial fan deposits. Depth to water in the alluvial fan deposits increases with distance south from the river. Reported discharges from wells in the Virgin River aquifer range from 10 to 1,620 gpm. Groundwater in the aquifer is unconfined and the general direction of flow is toward the southwest, parallel to the river (Black and Rascona, 1991).

The Littlefield aquifer, located south of the Virgin River between the town of Littlefield and the Virgin River Mountains, consists of alluvial-fan deposits that overlie a 50 - 75 foot thick limestone formation. The alluvial-fan deposits also increase in thickness with distance from the Virgin River. Depths to water in this aquifer range from 15 to 52 feet bls, increasing with distance from the river. Although few wells are completed in this shallow water table aquifer, many springs originate from groundwater flowing over or through the limestone. Discharges from springs range from 10 to 50 gpm and well discharges have been reported from 30 to 1,500 gpm (Black and Rascona, 1991).

The Muddy Creek aquifer is located north of Mesquite, Nevada and extends partially into Arizona. Available information suggests that this aquifer consists of Pliocene lake deposits and is separate from the nearby Virgin River aquifer. Direction of flow and source of water in this aquifer are unknown. Groundwater is also available in limited quantities in the hardrock areas including the Beaver Dam Mountains and Virgin Mountains, both composed of sedimentary rocks (Black and Rascona, 1991).

Generally, the VRGB is a remote, undeveloped basin with large areas having few, if any, wells and/or springs from which to obtain groundwater samples. Wells have only been drilled in limited portions of the Beaver Dam, Virgin River, and Littlefield aquifers where residential development has occurred.

4.2 Groundwater Quality

Since groundwater is a significant source of municipal, domestic, and irrigation water in the VRGB and also contributes to surface water flow in the basin, groundwater quality is important from both a public health and environmental perspective. Two limited water quality studies of the VRGB have been previously conducted by the US Geologic Survey (USGS) in 1976 and by the Arizona Department of Water Resources (ADWR) in 1991.

The USGS conducted a limited hydrologic investigation of the VRGB in 1976. The electrical conductivity (EC) was measured in eight groundwater quality samples, fluoride (F) was measured in five samples, and more detailed chemical analyses were conducted on five groundwater quality samples. EC values ranged from 900 - 3500 micromhos/cm, while F values ranged from 0.4 - 1.1 milligrams per liter (mg/l). Total dissolved solids (TDS) concentrations in samples from five wells ranged from 670 - 2870 mg/l; sulfate (SO_4) and chloride (Cl) concentrations from eight sites ranged from 950 - 1,300 mg/l and 29 - 430 mg/l, respectively.

A 1991 study was conducted by the Basic Data Section of the ADWR in which 19 water-quality samples were collected for EC and F. Based on EC value conversion to TDS levels (multiplied by 0.6), of the 19 samples collected, 13 exceeded the TDS Secondary MCL of 500 mg/l. Meanwhile, F levels in the 19 samples ranged from 0.5 to 1.5 mg/l, all below the Secondary MCL of 2.0 mg/l. Of these 19 samples, seven had detailed chemical analyses performed with four exceeding the Secondary MCL for both Cl and SO_4 (250 mg/l), while one exceeded the Secondary MCL for only SO_4. This ADWR study also found groundwater chemistry of the Littlefield and terrace portions of the Beaver Dam aquifer to be Ca-SO_4, Virgin River aquifer was Na-SO_4, and floodplain portions of the Beaver Dam aquifer to be Ca-HCO_3.

Additional VRGB groundwater quality sampling was conducted by the USGS in the 1990s (ADEQ Groundwater Quality Database, 1997) that indicated elevated levels of radionuclides.

5. METHODS AND MATERIALS

5.1 Sampling Strategy

The quantitative estimation of regional groundwater quality conditions requires the selection of sampling locations that follow scientific principles for probability sampling. Thus, sampling in the VRGB conducted by ADEQ follows a stratified random site-selection approach. This statistically-designed sampling plan is very efficient because it requires sampling relatively few wells to make valid statistical statements about the groundwater conditions of large areas. This strategy also reduces the possibility of biased well selection and ensures adequate spatial coverage throughout both each aquifer and the study area as a whole. Because of the limited development within the VRGB and the associated scarcity of wells outside these areas, the systematic grid overlay sometimes used to produce regional groundwater quality studies was determined to be an inadequate study design method. Instead, to determine the stratified random well locations, sampling within the VRGB was divided into three aquifers: Beaver Dam Wash, Littlefield, and Virgin River. Upon the receipt of preliminary laboratory results for Virgin River samples, it was determined that there were actually two aquifers: Virgin River alluvial (wells generally north of the Virgin River located in floodplain deposits) and Virgin River basin (wells generally south of the Virgin River located in alluvial-fan deposits), and the study was expanded to include four aquifers. Since no wells were located within Arizona that tapped the Muddy Creek formation, this aquifer was not sampled for this study. No initial effort was made to stratify the selection of wells based on well depth since previous hydrologic studies indicated no vertical layering of aquifers existed in the basin.

For this VRGB study, a total of 33 samples were collected utilizing this strategy. Stuart (1976) notes that a sample number exceeding 30 is typically large enough for the distribution of the sample mean to be approximated by the normal distribution if that population is normally-distributed. Sampling sites were selected from a randomized list of ADWR-registered wells as well as during field reconnaissance within the VRGB. In addition, five targeted wells were sampled to collect groundwater quality information from either very shallow or very deep depths to vertically examine groundwater quality in the study area. Wells constructed for several uses - domestic, municipal, irrigation, and stock - were used for groundwater quality sampling. The location, well depth, water depth, open intervals, and driller logs for each well sampled in the study were compiled (**Appendix A**).

5.2 Sample Parameters

Each VRGB groundwater sample was analyzed for SDW inorganic compounds. In addition, limited samples for radionuclides, GWPL pesticides, and bacteria (fecal coliform) were collected from wells deemed most likely to have radionuclide, pesticide, and/or bacteria contamination. The primary groundwater quality parameters sampled in this study are inorganic, with Safe Drinking Water (SDW) parameters serving as the focus of analysis.

During sample collection in the field, the following field parameters were analyzed for:

- temperature - field
- pH - field
- EC - field

From each of the 38 wells sampled as part of this study, an inorganic groundwater sample was collected for analytical analysis for SDW parameters. These groundwater quality parameters. analyzed by contract laboratories include:

- total alkalinity
- chloride (Cl)
- hardness
- pH
- total dissolved solids (TDS)
- aluminum (Al)
- barium (Ba)
- calcium (Ca)
- copper (Cu)
- lead (Pb)
- manganese (Mn)
- selenium (Se)
- sodium (Na)
- electrical conductivity (EC)
- nitrite as N (NO_2-N)
- phenolphthalein alkalinity
- fluoride (F)
- nitrate as N (NO_3-N)
- sulfate (SO_4)
- turbidity
- arsenic (As)
- cadmium (Cd)
- chromium (Cr)
- iron (Fe)
- magnesium (Mg)
- mercury (Hg)
- silver (Ag)
- zinc (Zn)
- bicarbonate (HCO_3)

Five other inorganic constituents whose presence is considered indicative of human impacts were also sampled for:

- ammonia-nitrogen (NH_3-N)
- phosphorus (P)
- total Kjeldahl nitrogen (TKN)
- boron (B)
- potassium (K)

Of the 38 wells that were sampled for inorganic parameters as part of this study, 10 wells also had groundwater samples collected from them for radionuclide analysis. The sampling strategy for radionuclides was similar to that outlined for inorganic samples, except because of fiscal reasons, a much lower number of samples were collected: Beaver Dam - 3, Littlefield - 3, Virgin River alluvial - 3, and Virgin River basin - 1.

Of the 38 wells sampled, 9 bacteria samples for fecal coliform were collected to further investigate possible septic system impacts on the aquifers. These bacteria samples were incubated and counted in the field using procedures developed by ADEQ's Surface Water Monitoring Program (ADEQ, 1995). The number of bacteria samples collected from wells located in the following aquifers are as follows: Beaver Dam - 4, Littlefield - 1, Virgin River alluvial - 3, Virgin River basin - 1.

Of the 38 wells that were sampled as part of this study, 3 wells also had groundwater samples collected from them for analysis of Groundwater Protection List (GWPL) pesticides with the assistance of the ADEQ Pesticide Contamination Prevention Program (PCPP). These pesticides are synthetic organic compounds used to control weeds, insects, and other organisms for a variety of agriculture and non-agriculture purposes. The targeted sampling sites were typically chosen from wells located in agricultural portions of the VRGB. One GWPL sample was collected from each of the following aquifers: Beaver Dam, Virgin River alluvial, and Virgin River basin. These GWPL pesticide samples were collected to extend the coverage of pesticide sampling by the ADEQ PCPP, even though assessing the 1995 1080 Commercial Pesticide Application Database from the Arizona Department of Agriculture indicated there were no such pesticide applications within the VRGB.

No samples were collected for volatile organic compounds (VOCs) for the VRGB study as, based on the level of industrial and commercial development in the area, the threat to groundwater quality from these compounds appeared to be low.

5.3 Sample Collection

The sample collection methods for this study conformed to the *Quality Assurance Project Plan (QAPP)* (ADEQ, 1991) and the *Field Manual For Water Quality Sampling* (Arizona Water Resources Research Center, 1994). While these sources should be consulted as references to specific sampling questions, a brief synopsis of the procedures involved in collecting a groundwater sample for this study is provided.

Whenever possible, wells were selected which met three criteria:

- well construction information was available,
- the well had a dedicated pump and adequate surface seal, and
- a spigot was located at the wellhead before a storage tank.

After obtaining permission from the owner to sample the well, the water level was measured with a probe where access permitted. The volume of water needed to purge the well of one and three bore hole volumes was calculated from well log and on-site information. Physical parameters (temperature, pH, and electrical conductivity) were monitored at least every five minutes using a Hydrolab multi-parameter instrument. After three bore volumes had been pumped and the physical parameters had stabilized within ten percent, it was determined that a sample representative of the aquifer could be collected from a point as close to the wellhead as possible.

At each sampling site, groundwater was collected for analyses by laboratories for four possible groups of parameters in the following order:

1. GWPL Pesticides
2. Safe Drinking Water (SDW) Inorganic Compounds
3. Radionuclides
4. Bacteria (fecal coliform)

GWPL pesticides were collected in one gallon, amber glass containers. The inorganic constituents were collected in three one-liter polyethylene bottles. Samples to be analyzed for dissolved metals were collected in bottles preserved with nitric acid. An on-site positive pressure filtering apparatus fitted with a 0.45 μM pore size groundwater capsule filter was used to filter metals only. Unfiltered groundwater was then collected in the sulfuric acid preserved container for nutrients and in the unpreserved bottle for physical parameters. Radionuclide samples were collected in two collapsible one-liter plastic containers. Bacteria samples were collected in two, pre-sterilized, 100-milliliter (ml) Whirl-Pak bags which contained a pre-added dechlorinating agent, sodium thiosulfate. With the exception of the radionuclide samples, all groundwater samples were kept at 4^0C by packing them on ice in an insulated picnic cooler during transport to the laboratory. Chain of custody procedures were followed in sample handling including keeping the samples in a locked truck camper shell.

Equipment blanks were collected to ensure the filter apparatus and/or deionized water were not impacting the groundwater quality sampling. Duplicate and split samples are identical sets of samples collected from the same source at the same time that are used to check for laboratory differences. Duplicate samples are submitted to the same lab while split samples are submitted to 2 different laboratories.

The Arizona Department of Health Services (ADHS) Laboratory in Phoenix conducted most of the inorganic and pesticide analyses for this study, the only exceptions being: VR-02, VR-16, and VR-42. These SDW inorganic analyses were submitted to Del Mar Laboratory in Phoenix, which performed the testing, with the exception of NH_3-N and TKN analyses which were analyzed by Del Mar Laboratory in Colton, California. The radionuclide samples were analyzed by the Arizona Radiation Regulatory Agency located in Phoenix while the bacteria samples were incubated in the field by ADEQ personnel using procedures developed by ADEQ's Surface Water Monitoring Program (ADEQ, 1995).

5.4 Statistical Considerations

There were several considerations in selecting whether parametric or nonparametric statistical tests were appropriate for this study. Parametric statistical methods are often used to analyze data sets, but may present problems since groundwater quality data usually doesn't meet the assumptions of normality, linearity, and independence. Other problems with water quality data include limited data points, missing values, censoring (detection limits), and seasonality. Higher numbers of samples help compensate for these problems; 30 is often large enough (Stuart, 1976) for a normally distributed population to be recognized as such. Depending on how skewed, fat, or skinny the data population is, it may still be appropriate to use parametric tests. But as a result of these factors, the use of parametric statistical methods may at times not be the most appropriate tests to analyze groundwater quality data.

Nonparametric methods are more flexible and can handle such problems more easily. As a result, agencies such as USGS have decided that nonparametric statistical methods give better results with groundwater quality data; albeit, they are a less "powerful" analytical tool. However, Wilkinson and Hill (1994) note that nonparametric procedures were in most cases designed to apply to data that were categorical or ranked in the first place, such as rank judgements and binary data. These authors suggest that data that violate distributional assumptions for liner models should consider transformations or robust models before retreating to nonparametric tests.

With the absence of a universally accepted statistical method with which to treat all types of groundwater quality data, the decision was made to analyze the data utilizing three different types of statistical analyses:

- Analysis of Variance (ANOVA) - is a parametric test used to test the difference in means of 2 or more groups. The test compares the variability among group means to the variability within each group. Nontransformed data was used which was not necessarily normally-distributed.

- ANOVA - same test as above, using logarithmically transformed data in an attempt to have more normally-distributed data.

- Kruskal-Wallis - is a nonparametric test used for measuring differences of a single variable across 2 or more independent groups of cases. This test transforms the values of a variable to ranks, using these to test that there is no shift in the center of the groups. Kruskal-Wallis is the nonparametric analog of the one-way ANOVA using non-transformed data (Wilkinson and Hill, 1994).

Results of the three statistical analyses were very similar; consequently, only the results of the nonparametric Kruskal-Wallis test are presented in this report. All statistical tests were conducted using a personal computer with SYSTAT software.

Part III

Groundwater Sampling Results

6. ANALYTICAL RESULTS

For the VRGB study, ADEQ personnel collected and transported to State-certified laboratories for analyses: 38 SDW inorganic samples, 10 radionuclide samples, and 3 GWPL pesticide samples. For QA/QC purposes, 3 duplicates, 3 splits, and 3 equipment blanks were collected for SDW inorganic analysis. No duplicates, splits, and/or blanks were collected with either radionuclide or GWPL Pesticides samples. Groundwater sampling in the VRGB occurred over the course of 3 field trips from March - April 1997. The specific dates of the 1997 field trips were: 3/3 - 3/7, 3/24 - 3/28, and 4/21 - 4/23.

Characteristics describing the 38 wells from which a groundwater sample was collected for this study are provided in **Appendix A**. Well information includes:

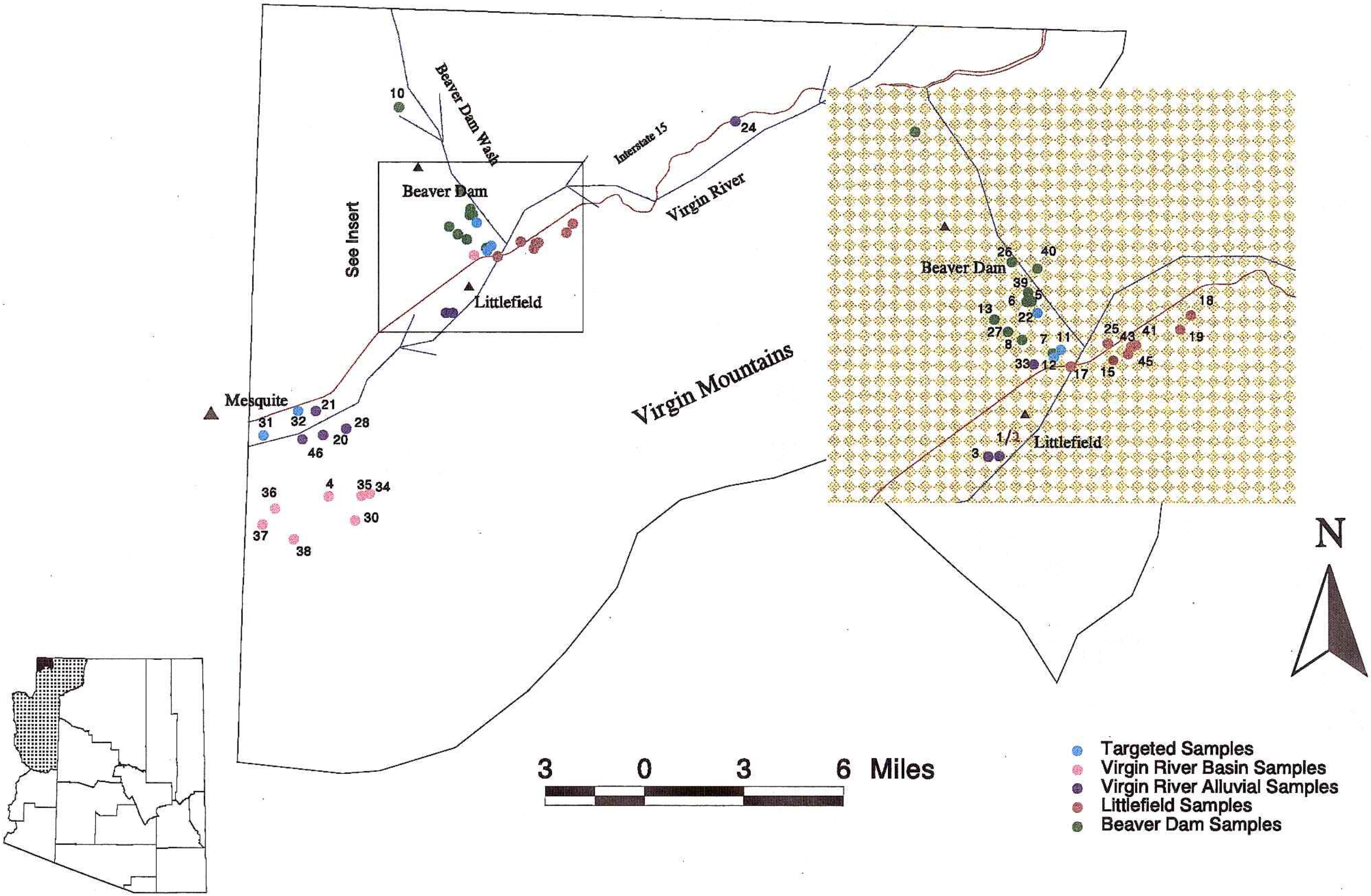
- ADWR registration number,
- sample name,
- well location (cadastral),
- well owner,
- well use,
- well depth,
- well casing diameter,
- well perforation interval,
- water depth, and
- well surface elevation.

Information concerning each of the 47 groundwater samples collected for this study is provided in **Appendix B**. Sample information includes:

- sample name,
- well Global Positioning System (GPS) location (latitude & longitude),
- ADEQ well number,
- sample date,
- type of samples collected, and
- factors related to sample location.

The locations of groundwater quality samples collected as part of this study are provided in **Figure 2**. As the map shows, although the VRGB covers the northwest corner of Arizona, most of the basin consists of rugged, undeveloped public land; therefore, the groundwater samples are clustered in the few developed areas of the basin in which wells have been drilled. Since this study was funded by the State of Arizona, no groundwater samples were collected in either of the Nevada or Utah portions of the groundwater basin.

Figure 2. Location of VRGB Groundwater Samples



6.1 Evaluation of Analytical Data

Overall, the analytical work conducted for this study was considered valid based on the 8 different QA/QC correlations presented in **Figure 3**. Each of these QA/QC correlations is described below:

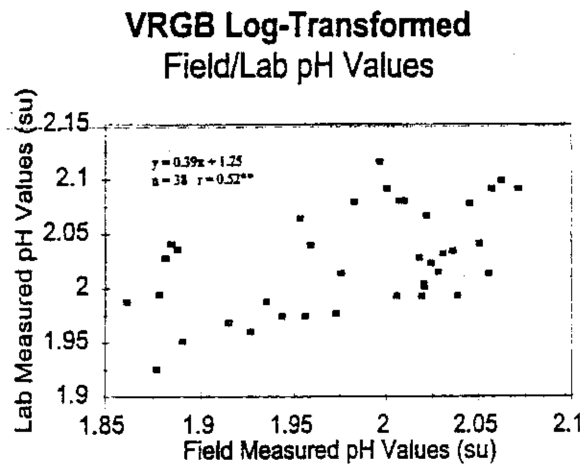
pH - The pH values measured in the field using a Hydrolab at the time of sampling were significantly correlated at $p = 0.01$ (the p-value is also called the attained significance level) with the pH values determined by the contract laboratories even though pH is closely related to the environment of the water and is likely to be altered by sampling and storage (Hem, 1970). Log-transforming both field and laboratory pH values again resulted in a significant correlation at $p = 0.01$ and a better graphical relationship (**Graph 1**).

Cation/Anion Balances - Cation/anion balances of groundwater samples were significantly correlated at $p = 0.01$ (**Graph 2**). Cation/anion balances were conducted for all inorganic analyses and, with the exception of four samples (VR-11, VR-12, VR-16, and VR-33), all balanced within acceptable limits (90 - 110%). There are various reasons for imbalances. Samples VR-11 and VR-12 are probably influenced by the underdevelopment of these Bureau of Land Management (BLM) monitoring wells and their related very high turbidity levels (1730 and 430 NTU). Sample VR-16, a split analyzed by Del Mar Laboratory, also had an unacceptable balance although the balance of the original sample analyzed by the ADHS Laboratory was within the acceptable range. In comparing the two samples, it appeared as though the SO_4 level of VR-16 was too low, though Del Mar Laboratory could not locate an error. The last sample with an unacceptable balance, VR-33, was brought to the attention of ADHS Laboratory but no error was located. The cation/anion balance graph shows that the overall cation-anion balance variation for the study was within 1%.

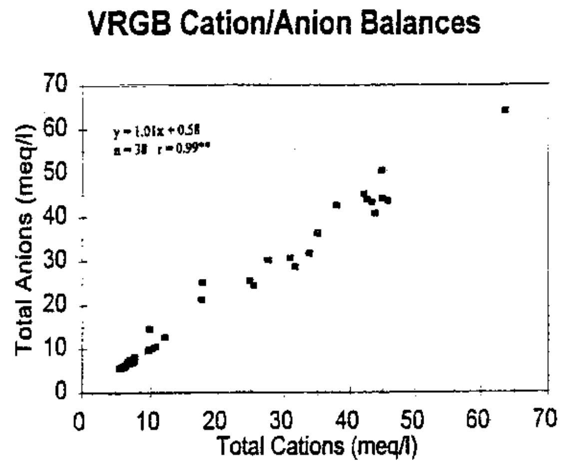
EC - The electrical conductivity (EC) measured in the field using a Hydrolab at the time of sampling and converted to 25^0 C values was significantly correlated at $p=0.01$ with the EC measured by contract laboratories (**Graph 3**). The field/lab EC graph shows that the overall EC variation for the study was within 5%. Similarly, the laboratory-measured EC was significantly correlated at $p = 0.01$ with the Total Dissolved Solids (TDS) levels determined by contract laboratories (**Graph 4**). Groundwater high in HCO_3 will provide a low TDS/EC ratio while groundwater high in SO_4 will provide a high TDS/EC ratio. Likewise, groundwater with very high or very low TDS and EC levels can provide variable results.

Cation/Anion - TDS Relationships - The levels of major anions - bicarbonate, Cl, and SO_4 - were correlated with TDS levels at $p = 0.01$. Similarly, the levels of major cations - Ca, Mg, Na, and K - were correlated with TDS levels at $p = 0.01$. All the major cation/anion - TDS comparisons revealed a strong linear relationship.

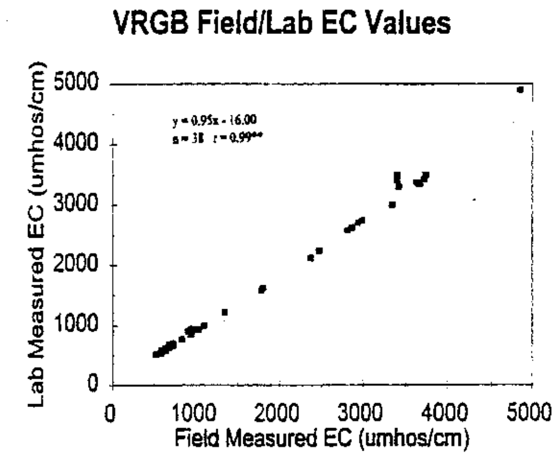
Figure 3. VRGB Study QA/QC Correations



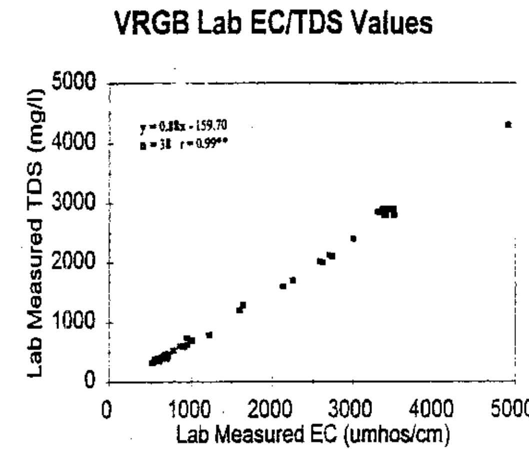
Graph #1



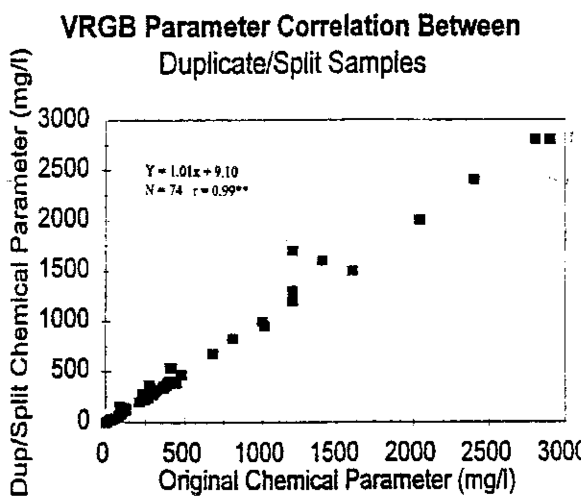
Graph #2



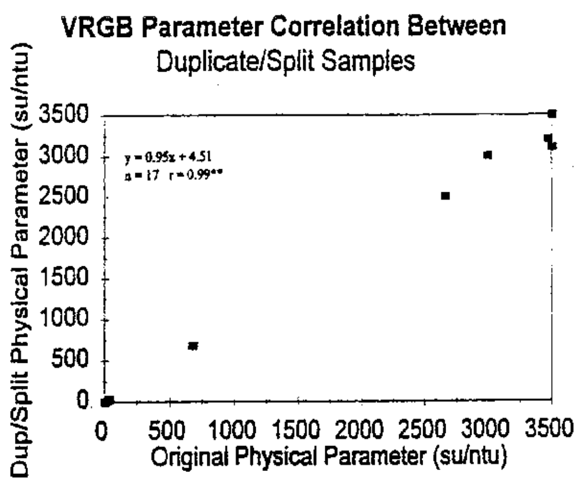
Graph #3



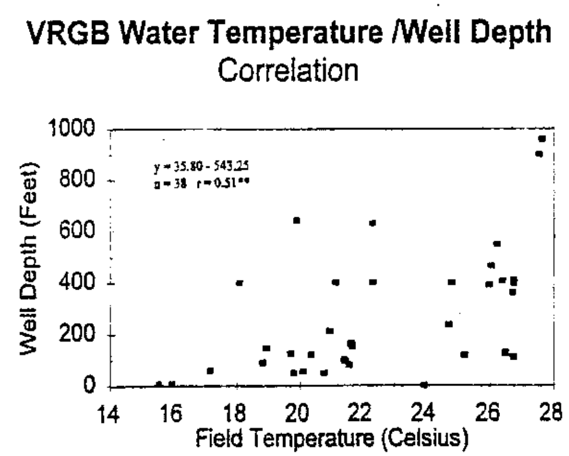
Graph #4



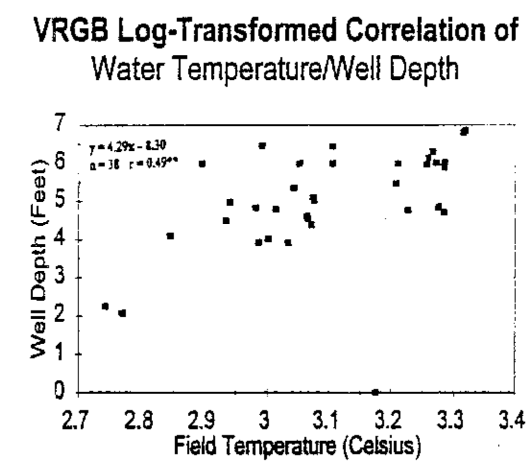
Graph #5



Graph #6



Graph #7



Graph #8

Duplicate/Split Samples - The six pair of original and duplicate/split samples collected as part of the study were significantly correlated with the original samples at the p = 0.01 level. There was an overall 1% variation with respect to all physical and chemical inorganic parameters measured in mg/l (**Graph 5**), while those physical and chemical parameters measured in SU/NTU/umhos had only an overall 5% variation (**Graph 6**).

Groundwater Temperature/Well Depth - Groundwater temperature measured in the field was compared to well depth to examine the relationship that exists between temperature and depth. Groundwater temperature should increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet (Bitten and Gerba, 1994). Using either the non-transformed (**Graph 7**) or log-transformed data (**Graph 8**), groundwater temperature and well depth were significantly correlated at the p = 0.01 level, though the log-transformed data showed a better graphic relationship. The only sample to deviate from the trend shown on the graph was the one spring that was sampled as part of the study. Furthermore, plumbing differences in wells probably prevented a stronger graphical relationship between groundwater temperature and well depth.

Equipment Blanks - The three equipment blanks (VR-09, VR-23, and VR-46) collected as part of this study exhibited excellent results with respect to the corresponding non-detection of all the analyzed chemical parameters. The only exceptions to this were:

VR-09 - TDS (20 mg/l), turbidity (0.05 NTU), EC (2.4 umhos/cm), and B (0.39 mg/l);
VR-23 - turbidity (0.18 NTU) and EC (21.1 umhos/cm); and
VR-47 - turbidity (0.06 NTU) and EC (2.2 umhos/cm).

Of these detections, B is a parameter which has also been found in equipment blanks run by other ADEQ programs and whose presence is attributed to its use in many detergents (The Main Water Line, 1996).

Based on these results, the analytical work conducted in this study was considered excellent.

6.2 Groundwater Chemistry

Piper trilinear diagrams were used to illustrate the chemical composition of groundwater samples collected in the VRGB. These groundwater samples were plotted on 5 Piper trilinear diagrams (**Figure 4**) to show the water chemistry of:

#1) The Virgin River Groundwater Basin;
#2) The Beaver Dam Aquifer;
#3) The Littlefield Aquifer;
#4) The Virgin River Aquifers; and
#5) Beaver Dam Wash and Virgin River surface water samples.

The water chemistry of these aquifers and streams is summarized in **Table 1**.

Virgin River Groundwater Basin - The 34 groundwater samples (all except the three deep samples and one upgradient sample in the Virgin River Gorge) collected from wells located in the Virgin River Groundwater Basin were divided into four aquifers: Beaver Dam aquifer (twelve samples symbolized by o), Littlefield aquifer (eight samples symbolized by □), Virgin River basin aquifer (seven samples symbolized by +), and Virgin River alluvial aquifer (seven samples symbolized by ◇). This figure (**Piper Diagram #1**) illustrates how two predominant clusters are formed: a tight cluster formed by groundwater samples collected from both the Littlefield aquifer and the Virgin River alluvial aquifer as well as a looser cluster formed by groundwater samples collected from both the Beaver Dam aquifer and the Virgin River basin aquifer. The Littlefield - Virgin River alluvial aquifers exhibit a Ca-SO_4 water chemistry while the Beaver Dam - Virgin River basin aquifers exhibit similar mixed water chemistry with the Beaver Dam samples tending towards Ca-bicarbonate and south of Virgin River samples tending towards Na-SO_4 water chemistry. Interestingly, the deep aquifer sample from the Beaver Dam aquifer has a water chemistry similar to both the Littlefield and Virgin River alluvial aquifers, while the deep aquifer samples from the Virgin River alluvial aquifer have water chemistries similar to the Beaver Dam and Virgin River basin aquifers.

Beaver Dam Aquifer - The 13 groundwater samples collected from wells located in the Beaver Dam aquifer were divided into four categories (**Piper Diagram #2**): west of Beaver Dam Wash (four samples symbolized by ◇), east of Beaver Dam Wash (seven samples symbolized by +), upgradient (one sample symbolized by □) and deep groundwater (one sample symbolized by o). The Piper trilinear diagram illustrates how this aquifer exhibits mixed water chemistry of the Ca-bicarbonate type, with water chemistry to the east of Beaver Dam Wash tending towards water with higher SO_4 concentrations. The upgradient sample collected from the west of Beaver Dam Wash is chemically similar to other samples from this area. Finally, the one deep groundwater sample collected from the Beaver Dam aquifer is very dissimilar from other samples from this aquifer. This deep sample has a Ca-SO_4 water chemistry that is similar to groundwater samples collected from both the Littlefield and the Virgin River North aquifers.

Figure 4. Water Chemistry Diagrams of VRGB Aquifers and Rivers

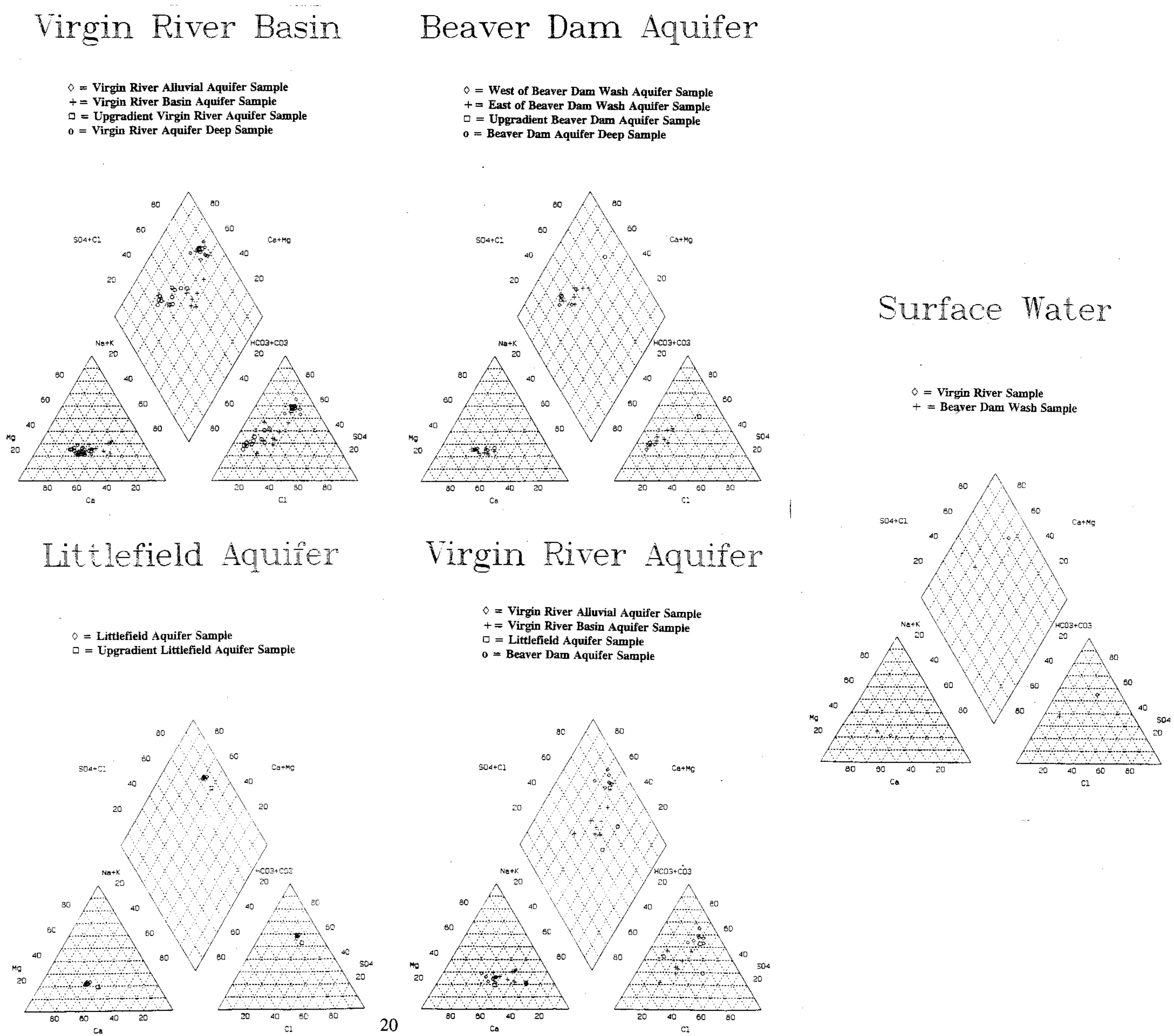


Table 1. Summary of Water Chemistry of VRGB Aquifers and Streams

AQUIFER/STREAM	DOMINANT CHEMISTRY	COMMENTS
Beaver Dam aquifer	calcium-bicarbonate	Deeper aquifer has sulfate-bicarbonate chemistry
Beaver Dam Wash	calcium-bicarbonate	Surface water sample
Littlefield aquifer	calcium-sulfate	
Virgin River	calcium-sulfate	Surface water sample
Virgin River alluvial aquifer	calcium-sulfate	Deeper aquifer has sodium-bicarbonate/chloride chemistry
Virgin River basin aquifer	mixed	sodium-sulfate, sodium-bicarbonate, and calcium-bicarbonate chemistries predominate

Littlefield Aquifer - There were eight groundwater samples (symbolized by ◇) collected from wells and a spring in the Littlefield aquifer (**Piper Diagram #3**). The Piper trilinear diagram illustrates how this aquifer exhibits a very consistent Ca-SO_4 water chemistry. An upgradient sample (symbolized by □) collected from a well in the Virgin River Gorge also exhibits a Ca-SO_4 water chemistry, but with greater Cl and Na concentrations.

Virgin River Alluvial and Basin Aquifers - There were 17 groundwater samples collected from wells in the Virgin River aquifer, divided into four categories (**Piper Diagram #4**): floodplain deposits north of Virgin River (seven samples symbolized by ◇), alluvial-fan deposits south of Virgin River (seven samples symbolized by +), upgradient (one sample symbolized by □) and deep groundwater (two samples symbolized by o). The Piper trilinear diagram illustrates how the water chemistry of this aquifer varies both spatially and vertically. All the groundwater samples collected north of Virgin River (or in the Virgin River alluvial aquifer) - as well as the upgradient sample collected in the Virgin River Gorge - exhibit a Ca-SO_4 water chemistry in a clustered pattern. The similarity of the upgradient sample to north of Virgin River samples suggests these groundwater samples may be from an alluvial aquifer strongly influenced by water from the Virgin River.

The water chemistry of the two deep groundwater samples also collected north of Virgin River are of Na-Cl and Na-bicarbonate types, indicating these wells may be withdrawing water from a different aquifer than the more shallow wells in this area. The groundwater samples collected south of the Virgin River (or in the Virgin River basin aquifer) exhibit a clustered pattern with a mixed water chemistry of the Na-SO_4, Na-bicarbonate, and Ca-bicarbonate varieties. The water chemical differences between these samples and those collected north of the Virgin River suggests the groundwater south of the Virgin River may be more strongly influenced by recharge from the Virgin Mountains than flow of the Virgin River. Thus, based on this data, south of the Virgin River area is termed the Virgin River basin aquifer and north of Virgin River area is termed the Virgin River alluvial aquifer for the remainder of the study.

Surface Water Samples - For comparison purposes, surface water samples from Beaver Dam Wash and the Virgin River were also plotted (**Piper Diagram #5**). The Beaver Dam Wash sample (symbolized by +) is a mean of 5 samples collected near Beaver Dam, AZ by the ADEQ Surface Water Monitoring Unit in 1996. The surface water of the Beaver Dam Wash is of Ca-bicarbonate chemistry, very similar to groundwater samples collected from the underlying Beaver Dam aquifer. The Virgin River sample (symbolized by ◇) is a mean of 6 samples collected near Littlefield, AZ by the USGS between November, 1996 and August, 1997 (USGS, 1998). The surface water of the Virgin River is of Ca-SO_4 chemistry, very similar to groundwater samples collected from the underlying Virgin River alluvial aquifer.

In summary, the unique water chemistry characteristic of each aquifer in the Virgin River Basin provides an excellent method of differentiating these four aquifers (**Figure 4**). The chemistry of the Beaver Dam and Virgin River alluvial aquifers appears to be strongly influenced by the surface flow of Beaver Dam Wash and the Virgin River, respectively.

6.3 Inorganic Parameter Levels

The 38 groundwater samples collected in this study were analyzed for various SDW inorganic parameters. The analytical results indicated that groundwater in the VRGB generally supports drinking water uses as health-based water quality standards were rarely exceeded. However, some aquifers within the VRGB have groundwater that frequently exceeded aesthetics-based water quality standards. During field work, ADEQ personnel noted that many residents in these areas commonly used treated water for some domestic uses. For discussion purposes, the inorganic parameters in this section are divided into three groups: parameters having health-based water quality standards or SDW Primary Maximum Contaminant Levels (MCLs), parameters having aesthetic-based water quality standards or SDW Secondary MCLs, and parameters without SDW water quality standards.

For easy visual comparison between sample locations, any inorganic parameter regularly detected in VRGB groundwater had its levels summarized in box plot statistical displays. For boxplot display, sample locations were divided into the following categories with the following numbers:

BD Beaver Dam aquifer - 10 samples
BDD Beaver Dam aquifer, deep sample - 1 sample
BDS Beaver Dam, shallow sample - 2 samples
LTF Littlefield aquifer - 8 samples
UPG Upgradient, Virgin River Gorge - 1 sample
VRD Virgin River alluvial aquifer, deep sample - 2 samples
VRN Virgin River alluvial aquifer - 7 samples
VRS Virgin River basin aquifer - 7 samples

In these box plot displays, the center vertical line marks the median of the sample levels while the edges of the box mark the first and third quantiles. The whiskers show the range of parameter levels that fall within 1.5 Hspreads (or the absolute value of the difference between the values of the two hinges). Parameter levels outside the inner fences (or the hinge +/- 1.5 x Hspread) are termed outside values and are shown as asterisks. Parameter levels outside the outer fences (or the hinge +/- 3 x Hspread) are termed far outside values and are shown as empty circles.

The analytical results of all groundwater samples collected as part of this study can be found in **Appendices C, D, E, F, and G**, as well as accessed in the ADEQ Water Quality Database.

6.4 Inorganic Parameters with SDW Primary MCLs

Included in the SDW inorganic analyses of VRGB groundwater samples were 10 chemical parameters having Primary MCLs: As, Ba, Be, Cd, Cr, F, Hg, NO_3 - N, NO_2 - N, NO_3 - N/ NO_2 - N, Se, and Tl. Of the 38 samples collected from VRGB wells by ADEQ for SDW inorganic parameters, none contained a parameter whose concentration was in excess of a Primary MCL Standard. Each Primary MCL and the extent of its occurrence within the VRGB is individually discussed below. Boxplots for As, F, and nitrate (as N) are provided in **Figure 5**.

Arsenic (As) - Of the 38 groundwater samples collected in the VRGB, only 10 groundwater samples had As levels above the ADHS Laboratory Minimum Reporting Level (MRL) of 0.010 mg/l (**Figure 5**). The highest detected level of As was 0.02 mg/l, below the Primary MCL of 0.05 mg/l. Detections of As occurred only in Beaver Dam, Littlefield, and Virgin River basin aquifers. The As concentrations of most potable waters seldom exceeds 0.010 mg/l, although values as high as 0.1 mg/l have been reported. The occurrence of As in water may be as a result of mineral dissolution, industrial discharges, or the application of insecticides (Franson, 1989).

Barium (Ba) - There was not a confirmed detection of Ba above the ADHS Laboratory MRL of 0.01 mg/l in any of the 38 groundwater samples collected in the VRGB. Ba has a Primary MCL of 2.0 mg/l.

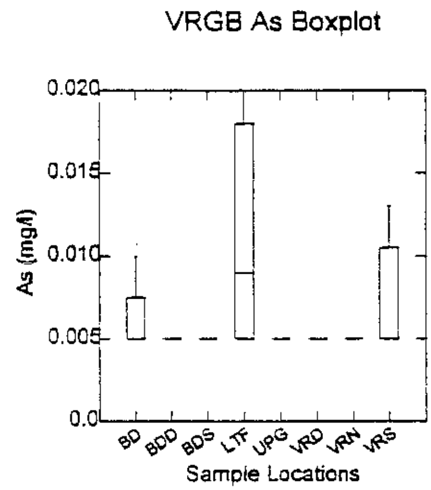
Beryllium (Be) - There was not a confirmed detection of Be above the ADHS Laboratory MRL of 0.0005 mg/l in any of the 38 groundwater samples collected in the VRGB. Be has a Primary MCL of 0.004 mg/l.

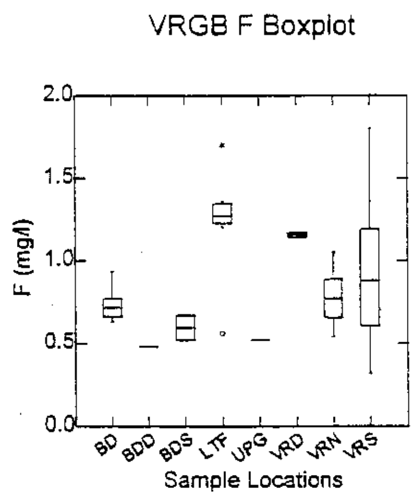
Cadmium (Cd) - Of the 38 groundwater samples collected in the VRGB, none had Cd levels above the ADHS Laboratory MRL of 0.0010 mg/l. Cd has a Primary MCL of 0.005 mg/l.

Chromium (Cr) - Of the 38 groundwater samples collected in the VRGB, only one sample had Cr levels above the ADHS Laboratory MRL of 0.010 mg/l. This sample, collected on the flanks of the Virgin Mountains, had a Cr level of 0.016 mg/l, below the 0.1 mg/l Primary MCL. The Cr concentration of U.S. drinking waters has been reported to vary between 0.003 and 0.04 mg/l, with a mean of 0.0032 mg/l (Franson, 1989).

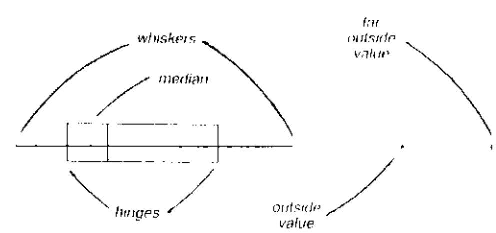
Fluoride (F) - Of the 38 groundwater samples collected in the VRGB, all had F levels above the ADHS Laboratory MRL of 0.20 mg/l (**Figure 5**). The highest detected level of F was 1.80 mg/l, below both the Primary MCL of 4.0 mg/l and Secondary MCL of 2.0 mg/l. Other VRGB F statistics include: median = 0.77 mg/l, mean = 0.89 mg/l, and 95% Confidence Intervals (CIs) = 0.77 - 1.01 mg/l. Generally the highest F levels were found in the Littlefield aquifer.

Figure 5. Boxplots of Selected Parameters with SDW Primary MCLs

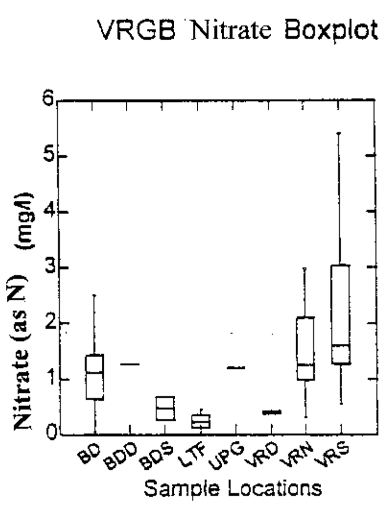




BD = Beaver Dam Aquifer Sample
BDD = Beaver Dam Aquifer Deep Sample
BDS = Beaver Dam Aquifer Shallow Sample
LTF = Littlefield Aquifer Sample
UPG = Upgradient Virgin River Gorge Sample
VRD = Virgin River Alluvial Deep Sample
VRN = Virgin River Alluvial Sample
VRS = Virgin River Basin Sample



Box Plot Legend



Mercury (Hg) - Of the 38 groundwater samples collected in the VRGB, only one sample had Hg levels above the ADHS Laboratory MRL of 0.0005 mg/l. This sample, collected near the Virgin Mountains, had a Hg level of 0.0005 mg/l, well below the 0.002 mg/l Primary MCL.

Nitrate (as N) **(NO_3- N)** - Of the 38 groundwater samples collected in the VRGB, all but 4 had detections of nitrate above the ADHS Laboratory MRL of 0.10 mg/l (**Figure 5**). The highest detected level of nitrate was 5.4 mg/l, below the 10.0 mg/l Primary MCL. Other VRGB nitrate statistics include: median = 1.03 mg/l, mean = 1.17 mg/l, and 95% CIs = 0.81 - 1.54 mg/l. The highest nitrate levels were found in the Virgin River alluvial and basin aquifers.

Nitrite (as N) (NO_2- N) - Of the 38 groundwater samples collected in the VRGB, none had nitrite levels above the ADHS Laboratory MRL of 0.10 mg/l. Nitrite has a Primary MCL of 1 mg/l.

Nitrate/Nitrite (NO_3-N/NO_2-N) - A Primary MCL of 10.0 mg/l. See Nitrate and/or Nitrite.

Selenium (Se) - Of the 38 groundwater samples collected in the VRGB, only one sample had Se levels above the ADHS Laboratory MRL of 0.005 mg/l. This sample, collected from the Virgin River alluvial aquifer, had a Se level of 0.006 mg/l, below the Primary MCL of 0.05 mg/l. The Se concentration of most U.S. drinking waters is less than 0.010 mg/l (Franson, 1989).

Thallium (Tl) - There was not a confirmed detection of Tl above the ADHS Laboratory MRL of 0.005 mg/l in any of the 38 groundwater samples collected in the VRGB. Tl has a Primary MCL of 0.002 mg/l.

6.5 Inorganic Parameters with SDW Secondary MCLs

Included in the SDW inorganic analyses of VRGB groundwater samples were 10 chemical parameters having Secondary MCLs. Of the 38 samples collected and analyzed for SDW inorganic parameters, 25 contained a parameter whose concentration was in excess of a Secondary MCL Standard. This indicates that approximately two-thirds of the groundwater samples in the VRGB have aesthetic problems with indices such as taste, odor, and/or color. The inorganic constituents with Secondary MCLs and the number of groundwater samples which exceeded these standards are as follows: Al - 0, Cl - 15, F - 0, Fe - 7, Mn - 5, field pH - 1, lab pH - 0, Ag - 0, SO_4 - 17, TDS - 25, and Zn - 0. These exceedances are shown by aquifer in **Table 2**. Each Secondary MCL and the extent of its occurrence within the VRGB is individually discussed below. Boxplots for Cl, Fe, field pH, lab pH, Mn, SO_4 and TDS are provided in **Figure 6**.

Aluminum (Al) - Of the 38 groundwater samples collected in the VRGB, none had Al concentrations above the ADHS Laboratory MRL of 0.50 mg/l. Al has a Primary MCL of 0.05 mg/l.

Chloride (Cl) - The 38 groundwater samples collected in the VRGB had Cl levels ranging from 7.4 - 560 mg/l with 15 groundwater samples exceeding the Cl Secondary MCL of 250 mg/l. Other VRGB Cl statistics include: median = 137.5 mg/l, mean = 193.3 mg/l, and 95% CIs = 138.0 - 248.7 mg/l. Generally Cl levels were highest in Littlefield and Virgin River alluvial aquifers and lowest in Beaver Dam and Virgin River basin aquifers (**Figure 6**).

Fluoride (F) - see the discussion on F in the "Inorganic Constituents with SDW Primary MCLs" section (**Figure 5**).

Iron (Fe) - Of the 38 groundwater samples collected in the VRGB, 8 samples had Fe levels above the ADHS Laboratory MRL of 0.10 mg/l (**Figure 6**). Concentrations of Fe in 7 groundwater samples exceeded the Secondary MCL of 0.3 mg/l, with 18 mg/l the highest level detected. Other VRGB Fe statistics include: median = 0.05 mg/l, mean = 0.90 mg/l, and 95% CIs = -0.12 - 1.93 mg/l. Generally Fe levels were highest in the Littlefield aquifer.

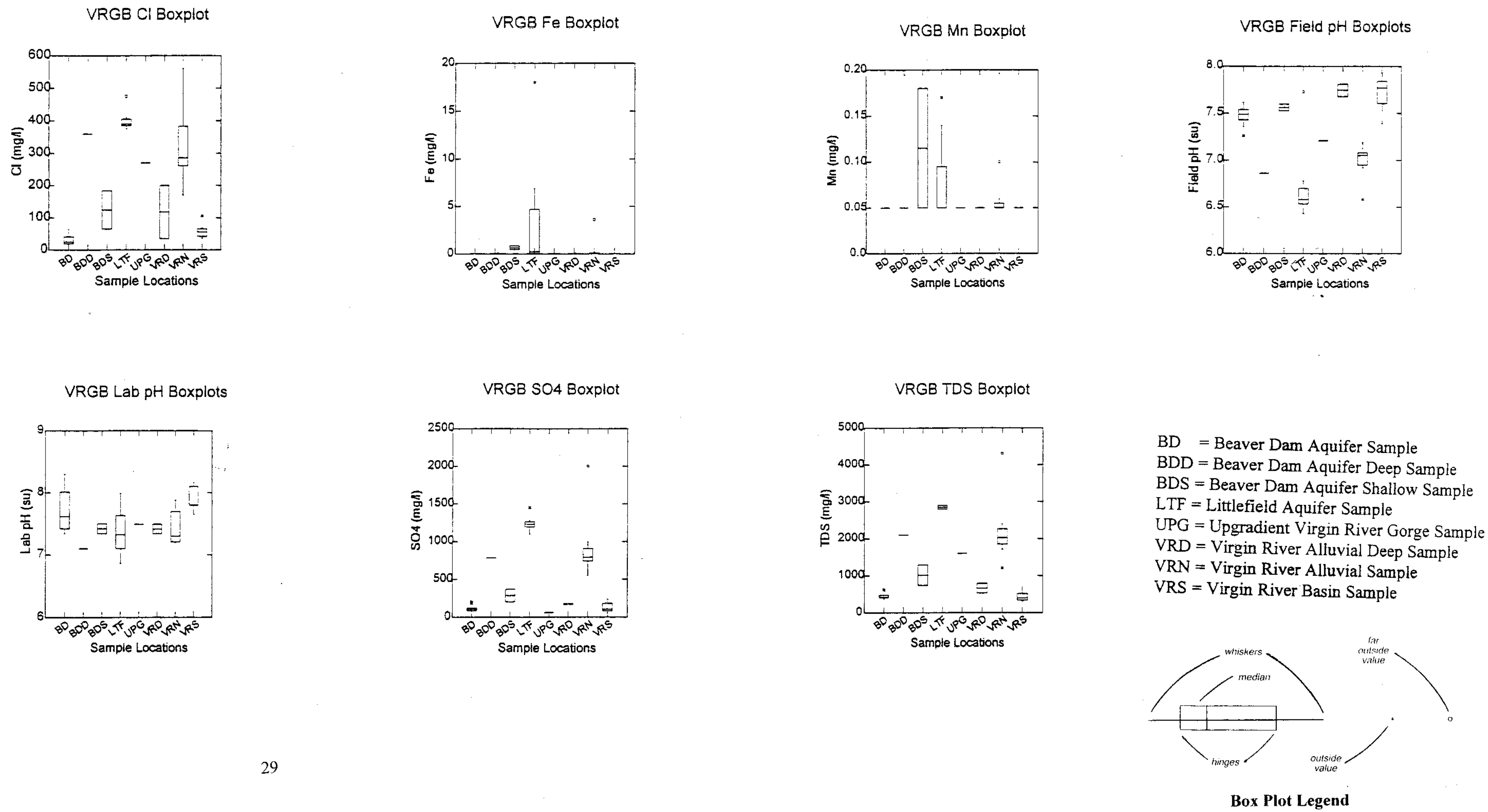
Manganese (Mn) - Of the 38 groundwater samples collected in the VRGB, 5 samples had Mn levels above the ADHS Laboratory MRL and the Secondary MCL of 0.05 mg/l (**Figure 6**). The highest Mn level of 0.18 mg/l occurred in a shallow Beaver Dam aquifer monitoring well.

pH (field measured) - Of the 38 groundwater samples collected in the VRGB, all but one sample had pH values between 6.5 and 8.5 standard units and therefore, were within Secondary MCL guidelines (**Figure 6**). VRGB field-measured pH values include: median = 7.41 SU, mean = 7.27 SU, and 95% CIs = 7.12 - 7.41 SU. Generally the lowest pH values were in the Littlefield aquifer, while the Virgin River basin aquifer had the highest pH values.

Table 2. Secondary MCL Exceedances by VRGB Aquifer

Parameter	Exceedances	Exceedances by Aquifer
Cl	15	8 - Littlefield 6 - Virgin River alluvial 1 - Beaver Dam (deep well)
Fe	7	4 - Littlefield 2 - Beaver Dam (shallow wells) 1 - Virgin River alluvial
Mn	5	2 - Littlefield 2 - Virgin River alluvial 1 - Beaver Dam (shallow well)
pH - field	1	1 - Littlefield
SO_4	17	8 - Littlefield 7 - Virgin River alluvial 1 - Beaver Dam (shallow well) 1 - Beaver Dam (deep well)
TDS	25	8 - Littlefield 8 - Virgin River alluvial 2 - Beaver Dam 2 - Virgin River basin 2 - Virgin River alluvial (deep wells) 2 - Beaver Dam (shallow wells) 1 - Beaver Dam (deep well)

Figure 6. Boxplots of Selected Parameters with SDW Secondary MCL s



pH is closely related to the environment of the water and is likely to be altered by sampling and storage, so that a meaningful value can be obtained only in the field (Hem, 1970).

pH (laboratory measured) - Of the 38 groundwater samples collected in the VRGB, all had pH values between 6.5 and 8.5 standard units and therefore, were within Secondary MCL guidelines though all exceeded the 15 minute holding time for pH (**Figure 6**). Other VRGB lab-measured pH values include: median = 7.58 SU, mean = 7.59 SU, and 95% CIs = 7.47 - 7.71 SU. Generally the Virgin River basin aquifer had the highest pH values. Sampling and storage of groundwater typically producces pH values that are higher or more alkaline than those values measured in the field (Hem, 1970).

Silver (Ag) - Of the 38 groundwater samples collected in the VRGB, none had silver concentrations above the ADHS Laboratory MRL of 0.001 mg/l. Ag has a Secondary MCL level of 0.1 mg/l.

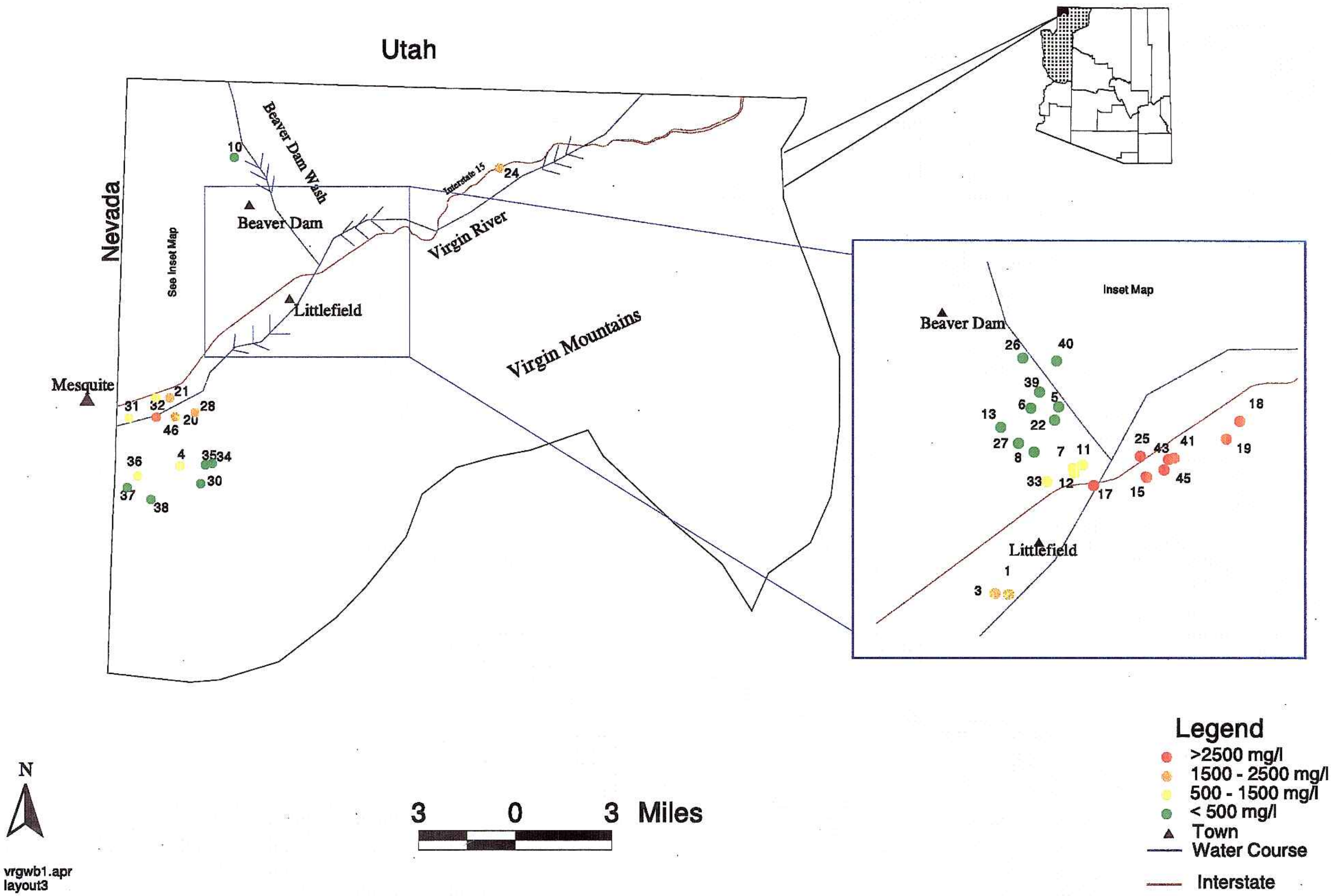
Sulfate (SO_4) - Of the 38 groundwater samples collected in the VRGB, 17 had SO_4 levels exceeding the 250 mg/l Secondary MCL as SO_4 levels ranged from 58 - 2000 mg/l. A Primary MCL of 400 mg/l for SO_4 has been proposed (Crockett, 1995). Using this level as a potential Primary MCL, 17 groundwater samples collected in the VRGB would exceed this limit. Other VRGB SO_4 statistics include: median = 212 mg/l, mean = 538 mg/l, and 95% CIs = 365 - 711 mg/l (**Figure 6**). SO_4 levels were greatly elevated in the Littlefield aquifer and moderately elevated in the Virgin River alluvial aquifer.

Total Dissolved Solids (TDS) - The 38 groundwater samples collected in the VRGB had TDS levels ranging from 320 - 4300 mg/l (**Figure 6**). Twenty-five of these samples had TDS levels exceeding the Secondary MCL of 500 mg/l. Other VRGB TDS statistics include: median = 765 mg/l, mean = 1403 mg/l, and 95% CIs = 1040 - 1765 mg/l. The 38 VRGB groundwater samples fall into the following TDS categories denoted by Hem (1970): Fresh (< 1000 mg/l) - 20, Slightly saline (1000 - 3000 mg/l) - 17, Moderately saline (3000 - 10,000) - 1, and Very saline (10,000 - 35,000) - 0 (**Figure 6a**).

In California, groundwater is designated as a potential drinking water source unless TDS values exceed 3000 mg/l, which only occurs with 1 VRGB groundwater sample (Barlow and Spencer, 1996). The concentration of TDS is one indicator of how potable water is: water low in TDS might taste bland; water very high in TDS may taste saline. TDS is the total amount of solids left when a filtered groundwater sample is evaporated to dryness and is an indication of mineralization. The major contributors to TDS are common ions: calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride, fluoride, sulfate, and silica.

Zinc (Zn) - Of the 38 groundwater samples collected in the VRGB, 10 had Zn concentrations above the ADHS Laboratory MRL of 0.05 mg/l. The highest detected Zn concentration was 1.18 mg/l, well below the Secondary MCL of 5.0 mg/l. In comparison, Zn in U.S. drinking waters typically varies between 0.06 and 7.0 mg/l, with a mean of 1.33 mg/l (Franson, 1989).

Figure 6a. TDS Levels of VRGB Groundwater Samples



6.6 Other Inorganic Parameters

Included in the SDW inorganic analyses of VRGB groundwater samples were 18 chemical parameters for which there are no recommended contaminant levels. Some of these parameters do have other water quality standards such as SDW Action Levels or Health-Based Guidance Levels (HBGLs). Each parameter and its occurrence within the VRGB is discussed below. Boxplots for total alkalinity, HCO_3, B, Ca, EC-field, EC-lab, hardness, Mg, TKN, total phosphorus, K, Na, temperature - field, and turbidity are provided in **Figure 7**.

Alkalinity, Phenolphthalein - Of the 38 groundwater samples collected in the VRGB, none had phenolphthalein alkalinity above the ADHS Laboratory MRL of 2.0 mg/l.

Alkalinity, Total - This parameter, which is a measure of a water's acid-neutralizing capacity, ranged from 110 - 612 mg/l in the 38 groundwater samples. Other VRGB total alkalinity statistics include: median = 201 mg/l, mean = 244 mg/l, and 95% CIs = 210 - 278 mg/l (**Figure 7**). Total alkalinity levels are generally highest in the Littlefield aquifer and lowest in the Virgin River basin aquifer.

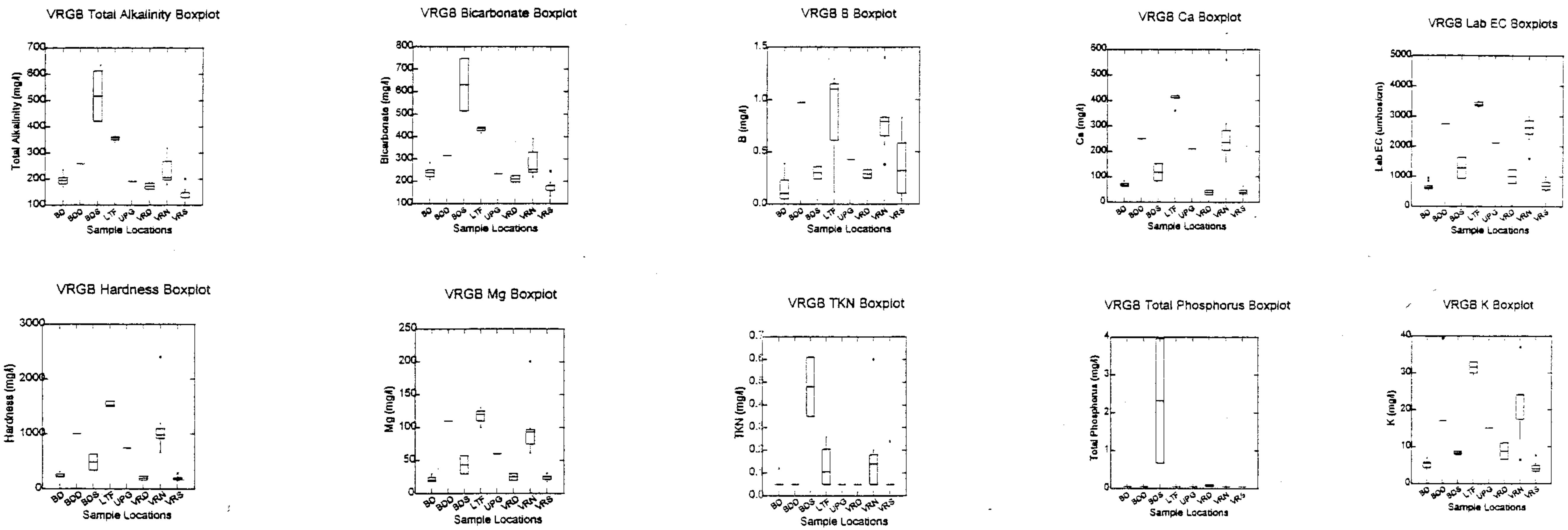
Ammonia (NH_3 - N) - Of the 38 groundwater samples collected in the VRGB, none had levels above the ADHS Laboratory MRL of 0.10 mg/l. In comparison, NH_3 - N concentrations have been reported to vary from less than 0.010 mg/l in groundwater to more than 30 mg/l in some wastewaters (Franson, 1989).

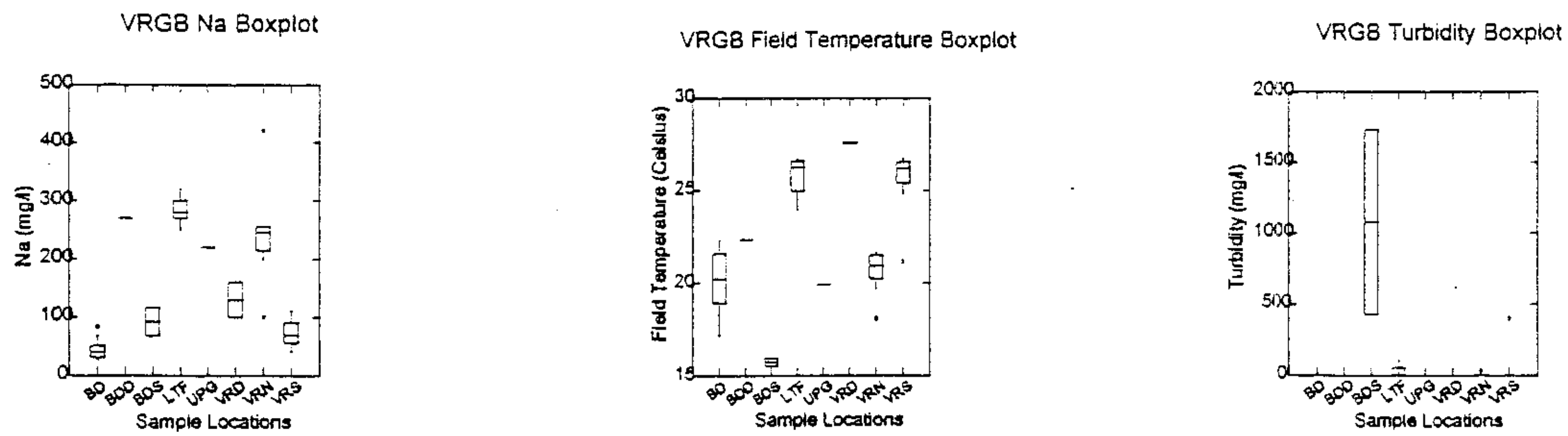
Bicarbonate (HCO_3) - The 38 groundwater samples collected in the VRGB had concentrations of HCO_3 ranging from 134 - 747 mg/l. Other VRGB HCO_3 statistics include: median = 245 mg/l, mean = 297 mg/l, and 95% CIs = 256 -339 mg/l (**Figure 7**). Generally, the highest HCO_3 levels were found in the Littlefield aquifer, and to a lesser extent, in the Virgin River alluvial aquifer. The lowest HCO_3 levels were found in the Virgin River basin aquifer.

Boron (B) - Of the 38 groundwater samples collected in the VRGB, 32 had B levels above the ADHS Laboratory MRL of 0.10 mg/l ranging up to 1.40 mg/l (**Figure 7**). Other VRGB B statistics include: median = 0.36 mg/l, mean = 0.50 mg/l, and 95% CIs = 0.37 - 0.64 mg/l. B has a Health Based Guidance Level (HBGL) of 0.63 mg/l, a level exceeded in 17 VRGB samples. B levels were highest in the Littlefield aquifer, and to a lesser extent, in the Virgin River alluvial aquifer. The lowest levels were found in the Beaver Dam aquifer. B may occur naturally in some waters or may be impacted by industrial waste effluents (Franson, 1989).

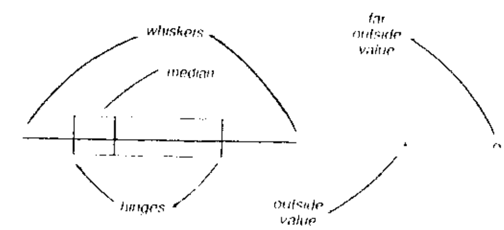
Calcium (Ca) - The 38 groundwater samples collected in the VRGB had concentrations of Ca ranging from 26 - 560 mg/l (**Figure 7**). Other VRGB Ca statistics include: median = 83.8 mg/l, mean = 182.7 mg/l, and 95% CIs = 131 - 234 mg/l. Generally, the highest Ca levels were found in the Littlefield aquifer, and to a lesser extent, in the Virgin River alluvial aquifer. The lowest levels were found in the Virgin River basin aquifer.

Figure 7. Boxplots of Selected Parameters without SDW Standards





BD = Beaver Dam Aquifer Sample
BDD = Beaver Dam Aquifer Deep Sample
BDS = Beaver Dam Aquifer Shallow Sample
LTF = Littlefield Aquifer Sample
UPG = Upgradient Virgin River Gorge Sample
VRD = Virgin River Alluvial Deep Sample
VRN = Virgin River Alluvial Sample
VRS = Virgin River Basin Sample



Box Plot Legend

Copper (Cu) - Of the 38 groundwater samples collected in the VRGB, only one had a concentration of Cu above the ADHS Laboratory MRL of 0.010 mg/l. This Cu level (0.016 mg/l) was well below the 1.3 mg/l SDW Recommended Action Level, a water quality standard which indicates the need for water or distribution treatment.

Electrical Conductivity - field-measured (EC) - The 38 groundwater samples collected in the VRGB had EC concentrations ranging from 520 - 4850 umhos/cm. Other VRGB EC statistics include: median = 1213 umhos/cm, mean = 1898 umhos/cm, and 95% CIs = 1463 -2332 umhos/cm. Generally, the highest EC levels were found in the Littlefield aquifer, and to a lesser extent, in the Virgin River alluvial aquifer.

Electrical Conductivity - laboratory-measured (EC) - The 38 groundwater samples collected in the VRGB had EC concentrations ranging from 510 - 4900 umhos/cm (**Figure 7**). Other VRGB EC statistics include: median = 1108 umhos/cm, mean = 1784 umhos/cm, and 95% CIs = 1371 - 2198 umhos/cm. Generally, the highest EC levels were found in the Littlefield aquifer, and to a lesser extent, in the Virgin River alluvial aquifer.

Hardness - Hardness, a measure of calcium and magnesium concentrations, had levels in the VRGB ranging from 150 - 2400 mg/l, all above the ADHS Laboratory MRL of 10 mg/l (**Figure 7**). Other VRGB hardness statistics include: median = 326 mg/l, mean = 719 mg/l, and 95% CIs = 518 - 919 mg/l. Hardness levels are commonly subdivided into soft (< 75 mg/l), moderately hard (75 - 150 mg/l), hard (150 - 300 mg/l), and very hard (> 300 mg/l) (Crockett, 1995). Of the 38 groundwater samples collected in the VRGB, none were in the soft range, 1 was in the moderately hard range, 18 were in the hard range, and 19 were in the very hard range. While high hardness levels do not have negative health implications, they can be a nuisance to cleaning laundry and dishes as well as impacting plumbing fixtures.

Lead (Pb) - Of the 38 groundwater samples collected in the VRGB, none had a concentration of Pb above the ADHS Laboratory MRL of 0.005 mg/l. There is a SDW Recommended Action Level of 0.015 mg/l for Pb.

Magnesium (Mg) - The 38 groundwater samples collected in the VRGB had Mg concentrations ranging from 18 - 200 mg/l (**Figure 7**). Other VRGB Mg statistics include: median = 30.4 mg/l, 61.2 mg/l, and 95% CIs = 45.8 - 76.6 mg/l. Mg concentrations greater than 125 mg/l may have potentially cathartic and diuretic effects (Franson, 1989). Three of the VRGB samples exceeded this 125 mg/l limit.

Nitrogen, Total Kjeldahl (TKN) - Of the 38 groundwater samples collected in the VRGB, 12 had TKN concentrations (organic nitrogen and ammonia) above the ADHS Laboratory MRL of 0.10 mg/l, with 0.61 mg/l the highest TKN level. Other VRGB Mg statistics include: median = 0.05 mg/l, mean = 0.12 mg/l, and 95% CIs = 0.07 - 0.17 mg/l (**Figure 7**). TKN concentrations were typically lowest in the Beaver Dam and Virgin River basin aquifers.

Phosphorus, Total (Total P) - Of the 38 groundwater samples collected in the VRGB, 3 had total P concentrations above the ADHS Laboratory MRL of 0.10 mg/l, with 3.96 mg/l the highest level (**Figure 7**). Total P was typically detected only in the very shallow Beaver Dam aquifer monitoring wells.

Potassium (K) - The 38 groundwater samples collected in the VRGB had K concentrations ranging from 3 - 37 mg/l; thus, all K concentrations exceeded the ADHS Laboratory MRL of 0.50 mg/l (**Figure 7**). Other VRGB K concentrations include: median = 7.71 mg/l, mean = 14.54 mg/l, 95% CIs = 10.7 - 18.3 mg/l. In most drinking waters, K seldom reaches 20 mg/l (Franson, 1989). Generally, K concentrations were highest in the Littlefield aquifer, and to a lesser extent, the Virgin River alluvial aquifer.

Sodium (Na) - The 38 groundwater samples collected in the VRGB had Na concentrations ranging from 27 - 420 mg/l (**Figure 7**). Other VRGB Na statistics include: median = 109 mg/l, mean = 155 mg/l, and 95% CIs = 119 - 191 mg/l. Although no water quality standards exist for sodium, 20 mg/l is the EPA cautionary limit for sodium-risk individuals to bring to the attention of their physician (Crockett, 1995). Generally, Na levels were highest in the Littlefield and Virgin River alluvial aquifers and lowest in the Beaver Dam aquifers.

Temperature - field - The 38 groundwater samples collected in the VRGB had temperatures ranging from 15.5 - 27.6 degrees Celsius (°C). Other VRGB temperature statistics include: median = 21.6 °C, mean = 22.6°C, and 95% CIs = 21.5 - 23.7°C (**Figure 7**). Generally, the highest temperatures were found in the Littlefield and the Virgin River basin aquifers, while the Beaver Dam and Virgin River alluvial aquifers had lower temperatures.

Turbidity - The 38 groundwater samples collected in the VRGB had turbidity concentrations ranging from 0.03 - 1730 nephelometric turbidity units (NTU), all above the ADHS Laboratory MRL of 0.01 NTU (**Figure 7**). Other VRGB turbidity statistics include: median = 0.36 NTU, mean = 75.5 NTU, and 95% CIs = -20.3 - 171.3 NTU. The turbidity standard, which applies only to water systems using surface water, is < 1 NTU as a monthly average or 5 NTU as an average of two consecutive days readings. Two shallow Beaver Dam monitoring wells had very high turbidity levels probably due to the underdevelopment of the wells. Turbidity levels were generally highest in the Littlefield aquifer.

6.7 Pesticides

GWPL Pesticides - There were no detections of organic pesticides in the 3 VRGB wells sampled for GWPL pesticides. For a complete list of pesticides on the GWPL as well as VRGB pesticide sampling results, consult **Appendices F and G**.

6.8 Radionuclides

SDW Radionuclides - At 10 wells, samples were collected for radionuclide analysis with only one sample exceeding the SDW Primary MCLs for Gross α; no samples exceeded SDW Primary MCLs for Gross ß and Combined Radium-226 + Radium - 228. Gross α levels ranged from 1.6 - 20.0 picocuries per liter (pCi/L), with only one sample above the Primary MCL of 15 pCi/L. Four groundwater samples possessing high Gross α values were tested for Combined Radium-226 + Radium-228, with these latter levels ranging from < LLD - 1.2 pCi/L, below the 5.0 pCi/L Primary MCL. One sample, with a Gross α level of 20.0 pCi/L, was tested for mass uranium with a 3.5 μg/l result. Gross ß levels ranged from < LLD - 35 pCi/L, well below the 50 pCi/l Primary MCL. Refer to **Appendix E** for a complete list of radionuclide sampling results.

Part IV

Analytical Analysis

7. STATISTICAL TESTS

Of the 39 inorganic parameters sampled, 23 were subjected to further statistical analysis. These parameters included: As, HCO_3, B, Ca, Cl, EC (field-measured), EC (laboratory-measured), F, hardness, Fe, Mg, nitrate (NO_3 - N), pH (field-measured), pH (laboratory-measured), K, Na, SO_4, temperature (field-measured), total alkalinity, TDS, TKN, turbidity, and Zn. Not subjected to further statistical analysis were inorganic parameters which were only rarely - if ever - detected in groundwater samples: Al, NH_3 - N, Ba, Be, Cd, Cr, Cu, Pb, Mn, Hg, NO_2 - N, phenolphthalein alkalinity, Se, Ag, Tl, and Total P.

Inorganic parameters were analyzed using a variety of statistical tests in an attempt to answer a wide range of questions concerning groundwater quality in the VRGB. The groundwater quality data was initially tested to see if the data had a normal distribution in **Section 7.1**. Groundwater quality parameter levels in different VRGB aquifers were tested for significant differences in **Section 7.2**. The degree of association among levels of different groundwater quality parameters in the VRGB is provided in **Section 7.3**; the same information for specific VRGB aquifers is shown in **Section 7.4**. The relationship between groundwater quality parameter levels and groundwater depth is examined in **Section 7.5**; the same information for specific VRGB aquifers is shown in **Section 7.6**. **In Section 7.7**, the parameter levels of individual VRGB aquifers are compared with upgradient, control samples to examine for potential impacts. Finally, groundwater quality parameter levels in 2 aquifers are compared with parameter levels of samples collected from deeper groundwater levels in an effort to determine whether separate aquifers exist in the areas (**Section 7.8**).

7.1 Groundwater Quality Parameter Level Population Distribution

The inorganic parameters subjected to further statistical analysis were tested for normality using the Kolmogorov-Smirnov (KS) one sample test with the Lilliefors option (Conover, 1980). The Lilliefors option is considered to be more powerful than the chi-square goodness-of-fit test for normality since it does not require a particular or standard deviation for the distribution. The null hypothesis to be tested was:

0 H_0: The population was normally distributed.

vs.

0 H_A: The population was not normally distributed.

The parameter is regarded to be normally distributed when the null hypothesis H_0 is accepted. Whether or not the null hypothesis H_0 is rejected is reflected by the level of significance generated by the test. In this study, the probability level of less than or equal to 0.05 was used to determine the significance. The probability level of 0.05 or larger will indicate the test result is not significantly different from the null hypothesis H_0; therefore, H_0 is accepted and the parameter is normally distributed.

The results shown in **Table 3** indicate that, with the exception of pH - field and pH - lab, none of the parameters were normally distributed. This is not uncommon as the distribution of many groundwater quality parameters is not Gaussian or normal but skewed to the right (Montgomery, et al, 1987). Available sources indicate that data that violate distributional assumptions for linear models should be transformed before retreating to nonparametric tests since these procedures were in most cases designed to apply to data that were initially categorical or ranked, such as rank judgements and binary data (Wilkinson and Hill, 1994). These parameters were then logarithmically transformed and again tested for normality using the KS one sample test with the Lilliefors option. The null hypothesis to be tested was:

0 H_0: The population was lognormally distributed.

vs.

0 H_A: The population was not lognormally distributed.

The logarithmically transformed parameter is regarded to be normally distributed when the null hypothesis H_0 is accepted. Whether or not the null hypothesis H_0 is rejected is reflected by the level of significance generated by the test. In this study, the probability level of less than or equal to 0.05 was used to determine the significance. The probability level of 0.05 or larger will indicate the test result is not significantly different from the null hypothesis H_0; therefore, H_0 is accepted and the logarithmically transformed parameter is normally distributed.

The results, again shown in **Table 3**, indicate that none of the parameters were lognormally distributed with the exception of F, pH - field, and pH - lab. Many parameters such as bicarbonate, Ca, Cl, EC - field, EC - lab, hardness, K, Mg, SO_4, temperature - field, total alkalinity, TDS, and turbidity while not becoming normally distributed at $p=0.05$, were nevertheless "more" normally distributed than the non-transformed one as indicated by a significance at a higher probability level. A few parameters such as B, Na, and nitrate became "less" normally distributed after log-transformation while parameters such as As, Fe, Mn, TKN, and Zn had an "unchanged" normality after log-transformation.

Based on the above observations, the groundwater quality data was analyzed using both the logarithmically-transformed database with the parametric ANOVA test as well as using the non-transformed database with the nonparametric Kruskal-Wallis test as has been recommended (Helsel and Hirsch, 1997). Remarkably similar results occurred with each test. Twenty-two of the 24 (or 92%) groundwater quality parameters had similar results to both the Kruskal-Wallis test and the ANOVA test when examining groundwater quality parameter level differences between aquifers. Only the Kruskal-Wallis results are presented in this report because recent and comprehensive statistical references specifically recommend the use of nonparametric test when the nonnormality assumption is violated (Helsel and Hirsch, 1997). These authors note that if the assumptions of parametric tests are violated, the consequence is an inability to detect differences which are truly present. The value of nonparametric approaches here is that they are relatively powerful for a wide range of situations.

Table 3. Distribution of Inorganic Parameters in VRGB Samples

Parameter	Non-Transformed Data KS Test	Log-transformed Data KS Test
As	ns	ns
B	ns	ns
Ca	ns	ns
Cl	ns	ns
EC - field	ns	ns
EC - lab	ns	ns
F	ns	*
HCO_3	ns	ns
Hardness	ns	ns
Fe	ns	ns
Mg	ns	ns
Mn	ns	ns
Total N	ns	ns
pH - field	*	*
pH - lab	*	*
K	ns	ns
Na	ns	ns
SO_4	ns	ns
Temp - field	ns	ns
T. Alkalinity	ns	ns
TDS	ns	ns
TKN	ns	ns
Turbidity	ns	ns
Zn	ns	ns

ns = Data not normally distributed
* = Data normally distributed

7.2 Groundwater Quality Parameter Level Variations Among Aquifers

A major objective of this study was to assess the variation of groundwater quality parameter levels between four aquifers located within the VRGB:

- Beaver Dam aquifer (BD);
- Littlefield aquifer (LT);
- Virgin River alluvial aquifer (VA); and
- Virgin River basin aquifer (VB).

While empirically, groundwater quality parameter levels in the Littlefield and Virgin River alluvial aquifers were generally higher than those in the Beaver Dam and Virgin River basin aquifers, the Kruskal-Wallis test was used to statistically assess whether significant parameter level variations exist between these four aquifers. The results are shown in **Table 4** and indicate the levels of all the 24 analyzed groundwater quality parameters - with the exception of As, Mn, TKN, turbidity, and Zn - differed significantly between aquifers.

Of parameters that differed significantly among aquifers, there emerged an atypical pattern:

- Littlefield > Virgin River alluvial > Beaver Dam >, =, or < Virgin River basin

Nine parameters followed this specific pattern - Ca, EC - field, EC - lab, hardness, Mg, K, Na, SO_4, and TDS - while four other parameters - B, Cl, HCO_3, and total alkalinity - had similar patterns. Other patterns involving significant differences in parameter levels among aquifers are as follows:

- Field temperature was significantly lower in those aquifers (Beaver Dam and Virgin River alluvial) having direct contact with perennial surface water flow than those aquifers (Littlefield and Virgin River basin) not having direct contact with perennial surface water flow.

- Nitrate was significantly lower in the Littlefield aquifer than the other three aquifers.

- F and Fe were significantly higher in the Littlefield aquifer than two of the other aquifers.

- Field pH was highest in the Virgin River basin aquifer and lowest in the Littlefield aquifer.

Table 4. Variation in Groundwater Quality Parameter Levels in Four VRGB Aquifers Using Kruskal-Wallis

Parameter	Significance	Aquifer Comparison
As	ns	
B	**	LT=VA>VB=BD
Ca	**	LT>VA>BD>VB
Cl	**	LT=VA>VB>BD
EC-field	**	LT>VA>VB=BD
EC-lab	**	LT>VA>VB=BD
F	*	LT>VA=BD (VB not significantly different from other aquifers)
HCO_3	**	LT>VA=BD>VB
Hardness	**	LT>VA>BD>VB
Fe	*	LT>BD=VB (VA not significantly different from other aquifers)
Mg	**	LT>VA>VB=BD
Mn	ns	
NO_3-N	**	BD=VA= VB>LT
pH-field	**	VB>BD>VA>LT
pH-lab	**	VB=BD>VA=LT
K	**	LT>VA>BD=VB
Na	**	LT>VA>VB>BD
SO_4	**	LT>VA>BD=VB
Temperature-field	**	LT=VB>VA=BD
Total Alkalinity	**	LT>VA=BD>VB
TDS	**	LT>VA>BD=VB
TKN	ns	
Turbidity	ns	
Zn	ns	

ns Not significant
* Significant at p = 0.05
** Significant at p = 0.01

VA=Virgin River alluvial aquifer
VB=Virgin River basin aquifer
LT=Littlefield aquifer
BD=Beaver Dam aquifer

7.3 Overall Correlation of Groundwater Quality Parameter Levels

In order to assess the degree of association among levels of different groundwater quality parameters in the VRGB, the parameter levels of each of the 33 randomly sampled wells were compared with the other groundwater quality parameters. The Pearson correlation coefficient was used to measure the degree of association among groundwater quality parameters. The Pearson correlation coefficient varies between -1 and +1, with a value of +1 indicating that one variable can be predicted perfectly by a positive linear function of the other, and vice versa. A value of -1 indicates the same, except that the function has a negative sign for the slope of the line. Finally, a Pearson correlation of 0 indicates that neither of two variables can be predicted from the other by using a linear equation (Wilkinson and Hill, 1994).

The results of the Pearson correlation coefficient analysis were then subjected to a probability test to determine which of the individual pairwise correlations were significant. In addition, a Bartlett chi-square test was computed for each grouping which tests a global hypothesis concerning the significance of all the correlations in the matrix. The Bartlett chi-square test is sensitive to nonnormality and its significance can be used only as a rough guide to determine whether there may be some real correlations among the variables (Wilkinson and Hill, 1994).

The results of the probability test of the Pearson correlation coefficient using non-transformed data show that the Bartlett chi-square test was significant at $p=0.01$, allowing the preliminary acceptance of the correlations among the groundwater quality parameter levels as being true probabilities. These correlation probabilities are provided in **Table 5** and indicate a remarkably good overall correlation between most parameter levels. In other words, as the levels of one groundwater quality parameter rise, the levels of other groundwater quality parameters tend to also increase. This is particularly true with TDS, its major ion components of HCO_3, Ca, Mg, Na, K, Cl, SO_4, as well as EC, total alkalinity, hardness, TKN, B, and to a lesser extent Fe and Mn. A mixed pattern was exhibited by F, while temperature and turbidity seldom had significant correlations. Only pH and nitrate had negative correlations in which as the groundwater quality parameter tended to increase, these two parameter levels tended to decrease. Parameter levels and the number of significant correlations with the other 19 parameter levels are as follows: total alkalinity, HCO_3, and K - 17, EC, Ca, hardness, and B - 16, TDS, Cl, and SO_4 - 15, pH and Na - 14, Mg and TKN - 13, nitrate - 12, Mn - 11, F - 8, Fe - 7, temperature and turbidity - 1. These correlations may indicate that most parameters occur from a common source, while nitrate, F, Mn, and Fe occur naturally and/or from different sources.

Table 5. Correlation Among Overall Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	Temp	pH-f	EC-f	TDS	Talk	Bic	Ca	Mg	Hard	Na	K	Cl	SO_4	F	NO_3	TKN	B	Fe	Mn
pH-f	ns																		
EC-f	ns	$\underline{**}$																	
TDS	ns	$\underline{**}$	**																
Talk	ns	$\underline{**}$	**	**															
Bicarbonate	ns	$\underline{**}$	**	**	**														
Ca	ns	$\underline{**}$	**	**	**	**													
Mg	ns	$\underline{**}$	**	**	**	**	**												
Hard	ns	$\underline{**}$	**	**	**	**	**	**											
Na	ns	$\underline{**}$	**	**	**	**	**	**	**										
K	ns	$\underline{**}$	**	**	**	**	**	**	**	**									
Cl	ns	$\underline{**}$	**	**	**	**	**	**	**	**	**								
SO_4	ns	$\underline{**}$	**	**	**	**	**	**	**	**	**	**							
F	*	ns	ns	ns	*	*	*	ns	ns	ns	*	ns	ns						
NO_3	ns	*	$\underline{*}$	$\underline{*}$	$\underline{**}$	$\underline{**}$	$\underline{**}$	ns	$\underline{*}$	$\underline{*}$	$\underline{**}$	$\underline{*}$	$\underline{*}$	$\underline{*}$					
TKN	ns	$\underline{**}$	**	**	*	*	**	**	**	**	**	**	**	ns	ns				
B	ns	$\underline{**}$	**	**	**	**	**	**	**	**	**	**	**	**	ns	**			
Fe	ns	ns	**	ns	*	*	ns	ns	*	ns	*	ns	ns	ns	ns	ns	*		
Mn	ns	ns	**	*	*	*	*	ns	*	ns	*	*	*	ns	ns	ns	**	**	
Turbidity	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns

ns Not Significant
* Significant Positive Correlation at p=0.05
** Significant Positive Correlation at p=0.01

Bartlett Chi-square statistic = = 0.00
$\underline{*}$ Significant Negative Correlation at p=0.05
$\underline{**}$ Significant Negative Correlation at p=0.01

7.4 Correlation of Groundwater Quality Parameter Levels by Aquifer

In order to assess the degree of association among levels of different groundwater quality parameters in the Beaver Dam, Littlefield, Virgin River alluvial, and Virgin River basin aquifers, parameter levels of each aquifer group of randomly sampled wells were compared with one another. This analysis was conducted in order to establish patterns or more precise relationships than could be found in the overall groundwater quality database.

Beaver Dam Aquifer - The results of the Beaver Dam aquifer probability test of the Pearson correlation coefficient using non-transformed data show that the Bartlett chi-square test was not positively definite as individual significant tests were suspect. Nonetheless, these correlation probabilities are provided in **Table 6** and they indicated a weak correlation between most parameter levels except some major ions. All significant correlations were positive except with the temperature - pH relationship. Parameter levels and the number of significant correlations with the other 19 parameter levels are as follows: EC, TDS, Mg, and SO_4 - 9, Ca, hardness, Na, and Cl - 8, nitrate - 7, K - 6, F - 3, total alkalinity and HCO_3 - 2, temperature, pH, and B - 1, and TKN, Fe, Mn, and turbidity - 0.

Littlefield Aquifer - The results of the Littlefield aquifer probability test of the Pearson correlation coefficient using non-transformed data show that the Bartlett chi-square test was not positively definite as individual significant tests were suspect. Nonetheless, these correlation probabilities are provided in **Table 7** and they indicated a weak correlation between most parameter levels. The majority of significant correlations were negative. Parameter levels and the number of significant correlations with the other 19 parameter levels are as follows: Mg, Fe, and Mn - 4, nitrate - 3, EC, TDS, Ca, Na, K, Cl, and TKN - 2, temperature, total alkalinity, HCO_3, hardness, SO_4, F, and B and turbidity - 1, and pH - 0. Of particular interest is the significant Fe-Mn positive relationship, as well as those metals significant negative relationship with the Ca-Mg water chemistry.

Virgin River Alluvial Aquifer - The results of the Virgin River alluvial aquifer probability test of the Pearson correlation coefficient using non-transformed data show that the Bartlett chi-square test was not positive definite as individual significant tests were suspect. Nonetheless, these correlation probabilities are provided in **Table 8** and they indicated strong correlations between most major ion parameter levels while metals and physical parameters in general have rather weak correlations with other parameters. The majority of significant correlations were positive except for pH. Parameter levels and the number of significant correlations with the other 19 parameter levels are as follows: TDS, Ca, Mg, hardness, and SO_4 - 11, EC, Na, K, and B - 10, Cl and TKN - 9, pH - 7, total alkalinity and HCO_3 - 2, Fe and Mn - 1, and temperature, F, nitrate, and turbidity - 0. Of particular interest is the complete lack of significant relationships involving the following parameters: temperature, turbidity, Fe, Mn, F, and nitrate. This may indicate that the source of these parameters is different from the major ions.

Table 6. Correlation Among BD Aquifer Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	Temp	pH-f	EC-f	TDS	Talk	Bic	Ca	Mg	Hard	Na	K	Cl	SO_4	F	NO_3	TKN	B	Fe	Mn
pH-f	*̲*̲																		
EC-f	ns	ns																	
TDS	ns	ns	**																
Talk	ns	ns	ns	ns															
Bicarbonate	ns	ns	ns	ns	**														
Ca	ns	ns	**	**	ns	ns													
Mg	ns	ns	**	**	ns	ns	**												
Hard	ns	ns	**	**	ns	ns	**	**											
Na	ns	ns	**	**	ns	ns	*	**	**										
K	ns	ns	**	**	ns	ns	**	*	**	ns									
Cl	ns	ns	**	**	ns	ns	**	**	**	**	ns								
SO_4	ns	ns	**	**	ns	ns	**	**	**	**	*	**							
F	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns						
NO_3	ns	ns	*	*	ns	ns	ns	*	ns	*	ns	**	*	ns					
TKN	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns				
B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns			
Fe	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Mn	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	
Turbidity	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns Not Significant
* Significant Positive Correlation at p=0.05
** Significant Positive Correlation at p=0.01

Bartlett Chi-square probability for Pearson correlation is not positive definite, individual significance tests are suspect.
*̲ Significant Negative Correlation at p=0.05
̲̲ Significant Negative Correlation at p=0.01

Table 7. Correlation Among LTL Aquifer Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	Temp	pH-f	EC-f	TDS	Talk	Bic	Ca	Mg	Hard	Na	K	Cl	SO_4	F	NO_3	TKN	B	Fe	Mn
pH-f	ns																		
EC-f	ns	ns																	
TDS	$\underline{*}$	ns	*																
Talk	ns	ns	ns	ns															
Bicarbonate	ns	ns	ns	ns	**														
Ca	ns	ns	ns	ns	ns	ns													
Mg	ns	ns	ns	ns	ns	ns	ns												
Hard	ns	ns	ns	ns	ns	ns	ns	ns											
Na	ns	ns	ns	ns	ns	ns	ns	**	ns										
K	ns	ns	ns	ns	ns	ns	ns	**	ns	ns									
Cl	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns								
SO_4	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**							
F	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	$\underline{**}$	ns						
NO_3	ns	ns	ns	ns	ns	ns	ns	ns	$\underline{*}$	ns	ns	ns	ns	ns					
TKN	ns	ns	$\underline{*}$	ns	ns	ns	ns	ns	ns	ns	$\underline{**}$	ns	ns	ns	ns				
B	ns	ns	ns	ns	ns	ns	ns	ns	ns	$\underline{*}$	ns	ns	ns	ns	ns	ns			
Fe	ns	ns	ns	ns	ns	ns	$\underline{**}$	$\underline{**}$	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Mn	ns	ns	ns	ns	ns	ns	$\underline{**}$	$\underline{**}$	ns	ns	ns	ns	ns	ns	$\underline{*}$	ns	ns	**	
Turbidity	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	$\underline{*}$	ns	ns	ns	ns

ns Not Significant
* Significant Positive Correlation at p=0.05
** Significant Positive Correlation at p=0.01

Bartlett Chi-square probability for Pearson correlation is not positive definite, individual significance tests are suspect.
$\underline{*}$ Significant Negative Correlation at p=0.05
$\underline{**}$ Significant Negative Correlation at p=0.01

Table 8. Correlation Among VRA Aquifer Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	Temp	pH-f	EC-f	TDS	Talk	Bic	Ca	Mg	Hard	Na	K	Cl	SO_4	F	NO_3	TKN	B	Fe	Mn
pH-f	ns																		
EC-f	ns	ns																	
TDS	ns	$\underline{**}$	**																
Talk	ns	$\underline{**}$	ns	ns															
Bicarbonate	ns	$\underline{**}$	ns	ns	**														
Ca	ns	$\underline{*}$	**	**	ns	ns													
Mg	ns	$\underline{*}$	**	**	ns	ns	**												
Hard	ns	$\underline{*}$	**	**	ns	ns	**	**											
Na	ns	ns	**	**	ns	ns	**	**	**										
K	ns	ns	**	**	ns	ns	**	*	**	**									
Cl	ns	ns	**	**	ns	ns	**	**	**	**	**								
SO_4	ns	$\underline{*}$	**	**	ns	ns	**	**	**	**	**	**							
F	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns						
NO_3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns					
TKN	ns	ns	**	**	ns	ns	**	**	**	*	*	ns	**	ns	ns				
B	ns	ns	**	**	ns	ns	**	**	**	**	**	**	**	ns	ns	*			
Fe	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Mn	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	
Turbidity	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns Not Significant
* Significant Positive Correlation at p=0.05
** Significant Positive Correlation at p=0.01

Bartlett Chi-square probability for Pearson correlation is not positive definite, individual significance tests are suspect.
$\underline{*}$ Significant Negative Correlation at p=0.05
$\underline{**}$ Significant Negative Correlation at p=0.01

Virgin River Basin Aquifer - The results of the probability test of the Pearson correlation coefficient using non-transformed data show that the Bartlett chi-square test was not positive definite as individual significant tests were suspect. Nonetheless, these correlation probabilities are provided in **Table 9** and they generally indicate weak correlations between most parameter levels. The majority of significant correlations were positive except for temperature, pH, and nitrate. Parameter levels and the number of significant correlations with the other 19 parameter levels are as follows: TDS - 9, EC and Na - 8, Mg, hardness, SO_4, and TKN - 7, Ca - 5, K - 4, temperature, Cl, and nitrate - 3, pH, total alkalinity, and HCO_3 - 2, B - 1, and F, Fe, Mn, and turbidity - 0.

Table 9. Correlation Among VRB Aquifer Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	Temp	pH-f	EC-f	TDS	Talk	Bic	Ca	Mg	Hard	Na	K	Cl	SO_4	F	NO_3	TKN	B	Fe	Mn
pH-f	ns																		
EC-f	ns	ns																	
TDS	*̲	ns	**																
Talk	ns	*̲	ns	ns															
Bicarbonate	ns	*̲	ns	ns	**														
Ca	ns	ns	**	*	ns	ns													
Mg	ns	ns	**	**	ns	ns	ns												
Hard	ns	ns	**	**	ns	ns	**	*											
Na	ns	ns	**	**	ns	ns	ns	**	*										
K	ns	ns	*	*	ns	ns	ns	ns	ns	**									
Cl	*̲*̲	ns	ns	ns	ns	ns	ns	*	ns	ns	ns								
SO_4	ns	ns	**	**	ns	ns	*	*	**	**	**	ns							
F	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns						
NO_3	ns	ns	ns	ns	ns	ns	ns	*̲	ns	*̲	ns	ns	ns	ns					
TKN	*̲*̲	ns	*	*	ns	ns	*	ns	*	*	ns	**	ns	ns	ns				
B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns			
Fe	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Mn	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	
Turbidity	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns Not Significant
* Significant Positive Correlation at p=0.05
** Significant Positive Correlation at p=0.01

Bartlett Chi-square probability for Pearson correlation is not positive definite, individual significance tests are suspect.
*̲ Significant Negative Correlation at p=0.05
̲̲ Significant Negative Correlation at p=0.01

7.5 Overall Groundwater Quality Parameter Level Variations With Groundwater Depth

In order to assess the impact of groundwater depth on the levels of groundwater quality parameters in the VRGB, the parameter levels of each of the 33 randomly sampled wells were compared to the corresponding groundwater depth. Depth was determined using a sounder in the field or data from ADWR well registration records. Comparisons were done using three distinct methods:

#1 - Linear Model	$[P] = md + b$	[P] vs d
#2 - Exponential Model	$[P]_d = [P]_{d=0}e^{-rd}$	ln[P] vs d
#3 - Biphasic Model	$[P] = a(d)^{-b}$	ln[P] vs ln d

where [P] is the level of the groundwater quality parameter, d is the groundwater depth in feet below land surface, r = rate of change, and a and b are integers.

The overall results indicate that 18 of the 24 groundwater quality parameters examined had one or more mathematical equations significantly relating changing parameter levels to increasing groundwater depth below land surface (bls): temperature-f, pH-f, pH-lab, nitrate, Zn, and turbidity had levels that increased significantly with increasing groundwater depth while EC-f, EC-lab, TDS, total alkalinity, HCO_3, Ca, Mg, hardness, Na, K, Cl, and SO_4 had levels that decreased significantly with increasing groundwater depth (**Table 10**). The linear model most adequately described the relationship of four parameters (temperature, pH-f, pH-lab, and NO_3-N), the exponential model offered the best solution in 11 cases (EC-f, EC-lab, TDS, total alkalinity, HCO_3, Ca, Mg, hardness, K, SO_4, and Zn), and the biphasic model most adequately described the relationship with turbidity.

Previously in this report, it was determined that significant differences exist in groundwater quality parameter levels among aquifers in the VRGB. How these parameter level differences - and potential associated groundwater level differences - between aquifers might impact the determination that approximately 75% of the groundwater quality parameters have decreasing parameter levels significantly related to increasing groundwater depth bls was investigated. A Kruskal-Wallis test was used to examine whether groundwater levels among the four aquifers were significantly different from one another (**Table 11**). The results reveal that groundwater depth bls in the Virgin River basin aquifer is significantly greater than the groundwater depth bls in the other three aquifers.

From this finding, it may be inferred that the decreasing parameter levels with increasing groundwater depth relationship is influenced by the significantly different groundwater depth bls among the aquifers. This relationship is presented in **Table 12** which shows that the Virgin River basin aquifer has significantly lower parameter levels of B, Ca, EC, HCO_3, hardness, Fe, Mg, K, SO_4, total alkalinity, and TDS than the other three aquifers as well as having

Table 10. Relationship Between Overall Groundwater Quality Parameter Levels and Groundwater Depth Using Three Mathematical Models

Parameter	Significance	Type of Relationship	Most Significant Model
Temperature - f	**	Increasing with depth bls	Linear
pH - f	**	Increasing with depth bls	Linear
pH - lab	*	Increasing with depth bls	Linear
EC - f	**	Decreasing with depth bls	Exponential
EC - lab	*	Decreasing with depth bls	Exponential
TDS	**	Decreasing with depth bls	Exponential
Talk	**	Decreasing with depth bls	Exponential
HCO_3	**	Decreasing with depth bls	Exponential
Ca	**	Decreasing with depth bls	Exponential
Mg	*	Decreasing with depth bls	Exponential
Hardness	**	Decreasing with depth bls	Exponential
Na	*	Decreasing with depth bls	Linear
K	**	Decreasing with depth bls	Exponential
Cl	*	Decreasing with depth bls	Linear
SO_4	*	Decreasing with depth bls	Exponential
F	ns		
NO_3 - N	**	Increasing with depth bls	Linear
TKN	ns		
B	ns		
As	ns		
Fe	ns		
Mn	ns		
Zinc	*	Increasing with depth bls	Exponential
Turbidity	*	Increasing with depth bls	Biphasic

ns Not significant * Significant at $p = 0.05$ ** Significant at $p = 0.01$

Table 11. Comparison of Groundwater Depth Levels Among VRGB Aquifers Using Kruskal-Wallis

AQUIFER	MEAN GROUNDWATER DEPTH (feet bls)
Beaver Dam	44.3 b
Littlefield	61.1 b
Virgin River alluvial	47.0 b
Virgin River basin	303.7 a
Significance	**

** Significant at $p = 0.01$
Row Values followed by the same letter (a, b) are not significantly different at $p = 0.05$

Table 12. Comparison of Groundwater Depth Levels Among VRGB Aquifers Using Kruskal-Wallis

Parameter	Beaver Dam	Littlefield	Virgin River alluvial	Virgin River basin
GW Depth	44 b	61 b	47 b	304 a
As	0.01a	0.01a	0.01a	0.01a
B	0.14 a	0.88 b	0.81 b	0.37 a
Ca	69 b	408 d	273 c	41 a
Cl	31 a	401 c	333 c	59 b
EC - field	709 a	3580 c	3003 b	715 a
EC - lab	667 a	3397 c	2796 b	701 a
F	0.73 a	1.24 b	0.74 a	0.94 ab
HCO_3	239 b	434 c	290 b	174 a
Hardness	244 b	1544 d	1134 c	193 a
Fe	0.05 a	3.50 b	0.50 ab	0.05 a
Mg	21.4 a	117 c	101 b	24.1 a
Mn	0.05	0.08	0.06	0.05
NO_3-N	1.15 b	0.24 a	1.49 b	2.30 b
pH - field	7.47 c	6.72 a	6.97 b	7.71 d
pH - lab	7.73 b	7.37 a	7.41 a	7.96 b
K	5.31 a	31.4 c	20.9 b	4.44 a
Na	45.5 a	284 d	247 c	73.4 b
SO_4	118 a	1241 c	927 b	132 a
Temperature - field	20.2 a	25.8 b	20.8 a	25.4 b
Total alkalinity	196 b	356 c	237 b	142 a
TDS	460 a	2850 c	2230 b	446 a
TKN	0.06a	0.13a	0.16a	0.08a
Turbidity	2.2a	29.1a	5.6a	58.6a
Zn	0.03a	0.08a	0.11a	0.14a

Row Values followed by the same letter (a, b, and c) are not significantly different at $p = 0.05$
All units mg/l except EC (micromhos/cm), Temperature (°C), pH (standard units), and GW Depth (feet bls)

significantly greater groundwater depth bls than the other aquifers. This finding is further reinforced by the comparatively few decreasing parameter level - increasing groundwater depth relationships found when each aquifer is individually examined in the next section.

7.6 Groundwater Parameter Level Variations With Groundwater Depth By Aquifer

In order to assess the impact of groundwater depth on the levels of groundwater quality parameters in the VRGB, the parameter levels of each of the 33 randomly sampled wells were subdivided into four aquifers - Beaver Dam, Littlefield, Virgin River alluvial, and Virgin River basin - and compared to the corresponding groundwater depth determined from ADWR well registration records or sounder readings taken in the field. Comparisons were again done using three models: linear, exponential, and biphasic. This additional analysis was conducted in order to establish patterns or more precise relationships than could be found in the overall database. The results are provided in **Table 13**.

Beaver Dam Aquifer - Temperature was the only parameter in the Beaver Dam aquifer which had a mathematical equation significantly relating its levels to groundwater depth bls. Temperature was significantly related to groundwater bls using all three models, though the biphasic model best described the relationship.

Littlefield Aquifer - Nine of the 24 parameters examined had 1 or more mathematical equations significantly relating these parameter levels to groundwater depth (bls). These parameters include pH-f, pH-lab, Ca, hardness, NO_3-N, As, Fe, Mn, and turbidity. The linear model best described the relationship with three parameters: Ca, hardness, and turbidity; the exponential model offered the best solution for NO_3-N, As, Fe, and Mn, while the biphasic model offered the best solution for pH-f and pH-lab. Thus, in comparing the groundwater quality parameter levels in the lower, coarse-gravel zone to groundwater depths, 38% of the parameters examined exhibited a pattern in which the concentration of the groundwater quality parameter would decrease with increasing groundwater depth.

Virgin River Alluvial Aquifer - None of the 24 parameters examined had a mathematical equation significantly relating these parameter levels to groundwater depth (bls).

Virgin River Basin Aquifer - Only 3 parameters - K, SO_4, and Zn - in the Virgin River Basin aquifer had one or more mathematical equations significantly relating these parameter levels to groundwater depth bls. The three parameters were significantly related to groundwater bls using all models, though the biphasic model best described each relationship.

Table 13. Relationship Between Aquifer Groundwater Quality Parameter Levels and Groundwater Depth Using Three Mathematical Models

Parameter	Beaver Dam Aquifer			Littlefield Aquifer		
	Significance	Most Significant Model	Type of Relationship	Significance	Most Significant Model	Type of Relationship
Temp - f	*	Biphasic	Increasing w/ depth bls	ns		
pH - f	ns			**	Biphasic	Decreasing w/ depth bls
pH - lab	ns			*	Biphasic	Decreasing w/ depth bls
EC - f	ns			ns		
EC - lab	ns			ns		
TDS	ns			ns		
Talk	ns			ns		
HCO_3	ns			ns		
Ca	ns			*	Linear	Decreasing w/ depth bls
Mg	ns			ns		
Hardness	ns			**	Linear	Increasing w/ depth bls
Na	ns			ns		
K	ns			ns		
Cl	ns			ns		
SO_4	ns			ns		
F	ns			ns		
NO_3-N	ns			**	Exponential	Decreasing w/ depth bls
TKN	ns			ns		
B	ns			ns		
As	ns			*	Exponential	Decreasing w/ depth bls
Fe	ns			**	Exponential	Increasing w/ depth bls
Mn	ns			**	Exponential	Increasing w/ depth bls
Zinc	ns			ns		
Turbidity	ns			**	Linear	Increasing w/ depth bls

ns Not significant * Significant at $p = 0.05$ ** Significant at $p = 0.01$

Table 13. Relationship Between Aquifer Groundwater Quality Parameter Levels and Groundwater Depth Using Three Mathematical Models--Continued

Parameter	Virgin River Alluvial Aquifer			Virgin River Basin Aquifer		
	Significance	Most Significant Model	Type of Relationship	Significance	Most Significant Model	Type of Relationship
Temp - f	ns			ns		
pH - f	ns			ns		
pH - lab	ns			ns		
EC - f	ns			ns		
EC - lab	ns			ns		
TDS	ns			ns		
Talk	ns			ns		
HCO_3	ns			ns		
Ca	ns			ns		
Mg	ns			ns		
Hardness	ns			ns		
Na	ns			ns		
K	ns			*	Biphasic	Decreasing w/ depth bls
Cl	ns			ns		
SO_4	ns			*	Biphasic	Decreasing w/ depth bls
F	ns			ns		
NO_3-N	ns			ns		
TKN	ns			ns		
B	ns			ns		
As	ns			ns		
Fe	ns			ns		
Mn	ns			ns		
Zinc	ns			*	Biphasic	Increasing w/ depth bls
Turbidity	ns			ns		

ns Not significant * Significant at p = 0.05 ** Significant at p = 0.01

7.7 Potential Cultural Impacts on Groundwater Quality

To examine whether cultural development and/or natural factors may have impacted groundwater quality of the 4 aquifers in the VRGB, it is helpful to compare the aquifer's groundwater quality parameter levels with those from an upgradient or control sample. The 4 upgradient or control samples are located in what are thought to be relatively pristine areas:

VR-10 - Beaver Dam aquifer sample, well located 3 miles upgradient of Beaver Dam;
VR-19 - Littlefield aquifer sample, most upgradient of all wells located in aquifer;
VR-24 - Virgin River alluvial aquifer sample, well located 8 miles upgradient in Virgin River Gorge;
VR-30 - Virgin River basin aquifer sample, most upgradient of all wells located in aquifer.

The groundwater quality parameter levels associated with the upgradient or control samples were compared with the corresponding Confidence Intervals ($CI_{0.95}$). $CI_{0.95}$ for the respective aquifers were determined using the non-transformed data from the 33 randomly sampled wells in this study. $CI_{0.95}$ indicates that 95% of the population lies within the stated interval. In general, the level of groundwater quality parameters of the 4 upgradient or control samples were within the corresponding $CI_{0.95}$ established for the other samples collected within the respective aquifers (**Table 14**). The following parameters were exceptions to this trend, having levels below the lower limit of the corresponding $CI_{0.95}$ established from the data of other Beaver Dam, Littlefield, Virgin River alluvial aquifer samples:

- Beaver Dam aquifer- Ca, Cl, EC-field, EC-lab, F, HCO_3, Mg, Na, NO_3-N, pH - lab, SO_4, temperature-field, total alkalinity, and TDS;
- Littlefield aquifer - Ca, HCO_3, Mg, Na, NO_3-N, total alkalinity, and TDS; and
- Virgin River Alluvial aquifer - B and F.

Thus, some upgradient parameter levels are lower than would be expected from the corresponding $CI_{0.95}$ in the Beaver Dam and Littlefield aquifers. This may indicate that these aquifers are impacted to some degree from either cultural and/or natural sources downgradient from these upgradient locations where control samples were collected.

Table 14. Comparison of Groundwater Quality Parameters of Various Aquifers and the Upgradient, Control Samples

Parameter	Beaver Dam $CI_{0.95}$ (mg/l)	Beaver Dam Control (mg/l)	Littlefield $CI_{0.95}$ (mg/l)	Littlefield Control (mg/l)	VR Alluvial $CI_{0.95}$ (mg/l)	VR Alluvial Control (mg/l)	VR Basin $CI_{0.95}$ (mg/l)	VR Basin Control (mg/l)
As	.0047 - .0081	ND	0.06 - 0.018	ND	ND	ND	0.004 - 0.012	ND
B	.0053 - 0.166	ND	0.38 - 1.29	1.2	0.50 - 1.08	**0.43**	0.04 - 0.77	0.16
Ca	63.4 - 75.7	**62.5**	410 - 420	**360**	152 - 400	210	27.9 - 57.4	33
Cl	20.2 - 45.1	**17.4**	3 072 - 434	390	211 - 447	270	31.2 - 85.2	61
EC - field	622 - 823	**585**	3427 - 3719	3630	2131 - 3881	2370	472 - 957	721
EC - lab	583 - 780	**538**	3329 - 3472	3370	1855 - 3753	2120	489 - 914	703
F	0.67 - 0.81	**0.66**	0.93 - 1.56	1.25	0.61 - 0.95	**0.52**	0.33 - 1.54	0.98
Fe	ND	ND	-0.95 - 3.80	18	-0.67 - 1.81	ND	ND	ND
Hardness	215.5 - 275.4	231	1492 - 1580	1600	624 - 1682	740	145 - 248	170
HCO_3	223 - 258	**221**	429 - 444	**415**	225 - 347	233	134 - 216	166
K	4.56 - 6.04	5.38	29.8 - 32.6	33	12.4 - 30.6	15	2.67 - 6.36	4
Mg	18.6 - 25.0	**18.4**	112 - 128	**100**	56.6 - 142.4	60	19.1 - 28.8	25
Mn	ND	ND	0.03 - 0.09	0.17	0.04 - 0.08	ND	ND	ND
Na	33.4 - 61.6	**27.3**	271 - 307	**250**	156 - 332	220	43.5 - 104.8	69
pH - field	7.38 - 7.55	7.54	6.30 - 7.13	6.78	6.80 - 7.17	7.21	7.48 - 7.89	7.86
pH - lab	7.51 - 8.01	**7.40**	7.04 - 7.76	7.16	7.19 - 7.72	7.49	7.71 - 8.15	8.16

Bold numbers = Upgradient sample level below 95% Confidence Level   ND = Parameter not detected within aquifer at Minimum Reporting Level
All units are mg/l with the exception of EC (umhos/cm), pH (SU), and turbidity (NTU)

Table 14. Comparison of Groundwater Quality Parameters of Various Aquifers and the Upgradient, Control Samples--Continued

Parameter	Beaver Dam $CI_{0.95}$ (mg/l)	Beaver Dam Control (mg/l)	Littlefield $CI_{0.95}$ (mg/l)	Littlefield Control (mg/l)	VR Alluvial $CI_{0.95}$ (mg/l)	VR Alluvial Control (mg/l)	VR Regional $CI_{0.95}$ (mg/l)	VR Regional Control (mg/l)
SO_4	89.7 - 154.3	**85.4**	1151 - 1346	1190	502 - 1395	61	57 - 215	105
Temp. - field	19.1 - 21.6	**18.8**	24.7 - 26.6	26.7	19.4 - 21.8	19.89	23.0 - 27.5	26.18
Total Alkalinity	183 - 212	**181**	352 - 364	**340**	185 - 283	191	109 - 177	136
TDS	401 - 537	**377**	2816 - 2899	**2800**	1342 - 3155	1600	284 - 610	440
TKN	0.040 - 0.076	ND	0.06 - 0.22	ND	0.00 - 0.36	ND	0.00 - 0.16	ND
Nitrate (as N)	0.68 - 1.75	**0.58**	0.13 - 0.40	**ND**	0.67 - 2.38	1.20	0.34 - 4.19	2.56
Turbidity	-0.85 - 5.55	0.44	-9.65 - 44.72	110	-5.14 - 17.97	0.37	-103 - 239	1.41
Zn	ND	ND	-0.07 - 0.25	ND	-0.11 - 0.34	ND	0.02 - 0.16	0.41

Bold numbers = Upgradient sample level below 95% Confidence Level ND = Parameter not detected within aquifer at Minimum Reporting Level
All units are mg/l with the exception of EC (umhos/cm), pH (SU), and turbidity (NTU)

7.8 Beaver Dam and Virgin River Alluvial Aquifer Deep Samples

In analyzing the 4 distinct aquifers in the VRGB, 3 samples were collected from depths that appeared to be very dissimilar from other samples collected from the aquifers, based on both groundwater chemistry and groundwater quality parameter levels. An examination of well construction records revealed the samples were collected from far deeper levels in the Beaver Dam or Virgin River Alluvial aquifers than were other groundwater samples. These 3 deep samples include:

- VR-22 - groundwater sample collected from a deep, 643 foot well located in the Beaver Dam aquifer, which incidently, is an ADWR Water Quality Index well;

- VR-31/32 - groundwater samples collected from two deep (960 foot and 900 foot) wells located in the Virgin River alluvial aquifer.

To further quantify that these 3 samples are not representative of the aquifers they were collected from, groundwater quality parameter levels associated with these samples were compared with the corresponding Confidence Intervals ($CI_{0.95}$) established for the other samples collected within the respective aquifers. $CI_{0.95}$ indicates that 95% of the population lies within the stated interval. In general, the level of groundwater quality parameters of these 3 deep samples were not within the corresponding $CI_{0.95}$ established for the other samples collected within the respective aquifers (**Table 15**).

Levels of B, Ca, Cl, EC-field, EC-lab, hardness, HCO_3, K, Mg, Na, pH - field, pH - lab, SO_4, temperature-field, total alkalinity, and TDS in the Beaver Dam deep sample (VR-22) were above the upper limit of the corresponding $CI_{0.95}$ established from the data of other Beaver Dam aquifer samples, while levels of F were below the lower limit of the corresponding $CI_{0.95.}$ This indicates that a deep aquifer with poorer quality water may exist in the Beaver Dam area.

In the Virgin River deep alluvial samples (VR-31 & VR-32) levels of B, Ca, Cl, EC - field, EC - lab, hardness, HCO_3, K, Mg, nitrate, Na, SO_4, total alkalinity, and TDS were below the lower limit of the corresponding $CI_{0.95}$ established from the data of other Virgin River alluvial aquifer samples, while levels of F, pH - field, and temperature - field were above the upper limit of the corresponding $CI_{0.95}$. This indicates that a deep aquifer with better quality water probably exists in the Virgin River alluvial area and may be hydrologically linked to the Virgin River basin aquifer.

Since these 3 samples appear to have come from deeper aquifers they were not included in any other statistical analyses involving examining groundwater quality differences between various aquifers in the VRGB.

Table 15. Comparison of Groundwater Quality Parameters of Three Deep Wells and 95% Confidence Intervals Established for Aquifers

Parameter	Beaver Dam $CI_{0.95}$ (mg/l)	Beaver Dam Deep Sample (mg/l)	VR Alluvial $CI_{0.95}$ (mg/l)	VR Alluvial Deep Samples (mg/l)
As	.0047 - .0081	ND	ND	ND / ND
B	.0053 - 0.166	**0.97**	0.50 - 1.08	**0.33 / 0.25**
Ca	63.4 - 75.7	**250**	152 - 400	**47 / 30**
Cl	20.2 - 45.1	**360**	211 - 447	**200 / 35**
EC - field	622 - 823	**2980**	2131 - 3881	**1338 / 831**
EC - lab	583 - 780	**2740**	1855 - 3753	**1220 / 771**
F	0.67 - 0.81	**0.48**	0.61 - 0.95	**1.14 / 1.17**
Fe	ND	ND	-0.67 - 1.81	ND / ND
Hardness	215.5 - 275.4	**1000**	624 - 1682	**230 / 160**
HCO_3	223 - 258	**315**	225 - 347	**196 / 224**
K	4.56 - 6.04	**17**	12.4 - 30.6	**11 / 6.6**
Mg	18.6 - 25.0	**110**	56.6 - 142.4	**30 / 20**
Mn	ND	ND	0.04 - 0.08	ND / ND
Na	33.4 - 61.6	**270**	156 - 332	160 / **100**
pH - field	7.38 - 7.55	**6.86**	6.80 - 7.17	**7.68 / 7.81**
pH - lab	7.51 - 8.01	**7.10**	7.19 - 7.72	7.34 / 7.49
SO_4	89.7 - 154.3	**782**	502 - 1395	**177 / 166**
Temp. - field	19.1 - 21.6	**22.3**	19.4 - 21.8	**27.6 / 27.5**
Total Alkalinity	183 - 212	**258**	185 - 283	**161 / 184**
TDS	401 - 537	**2100**	1342 - 3155	**790 / 530**
TKN	0.040 - 0.076	ND	0.00 - 0.36	ND / ND
Nitrate (as N)	0.68 - 1.75	1.27	0.67 - 2.38	**0.37 / 0.43**
Turbidity	-0.85 - 5.55	0.19	-5.14 - 17.97	0.17 / 0.25
Zn	ND	ND	-0.11 - 0.34	ND / ND

Bold = sample level not within $CI_{0.95}$
Regular = sample level within $CI_{0.95}$

Part V

Final Analysis

8. AMBIENT MONITORING INDEX WELL NETWORK

An ambient monitoring index well network was established in the VRGB consisting of 16 index wells. Index well networks are important tools in evaluating regional water quality allowing for efficient groundwater quality checks that are representative of a large area. The establishment of a VRGB ambient monitoring index well network is predicated on the concept that it is easier and less expensive to prevent groundwater contamination than to clean the aquifer up afterward. Thus, the development of early warning groundwater quality systems is justified (Bitton and Gerba, 1994). Trend analysis of this type is usually most useful in the uppermost portion of the aquifer which is at a higher risk of contamination.

A precursor to the successful establishment of an ambient monitoring index well network is a statistically-designed groundwater quality study. A study of this type provides a comprehensive overview of the groundwater quality of a basin as well as the selection of wells that accurately reflect the regional groundwater quality. In comparison, using a single well without the advantage of a comprehensive groundwater study can provide a skewed picture of the area's groundwater quality. An example of this is the ADWR VRGB index well that taps a deeper aquifer than is commonly used in the Beaver Dam area. This groundwater sample's poorer quality inaccurately reflects the upper aquifer's more representative groundwater quality which generally meets SDW standards.

With the index well network in place, groundwater quality data can be collected from a small number of wells over a long period of time. The results of these temporal trend analyses can be used to predict the impacts of widespread, low-level contamination on groundwater resources. Long-term trends in groundwater quality reflect variations in the rate and quality of recharge. These trends can be used to ascertain time-intervals for well sampling needed to adequately monitor long-term groundwater quality trends in the VRGB.

The 16 ambient groundwater quality monitoring index wells are shown in **Figure 8** and listed in **Table 16**. They were selected on the following criteria:

1) Four wells were located in and evenly distributed throughout the following aquifers: Beaver Dam, Littlefield, Virgin River alluvial, and Virgin River basin that are representative of the rapidly developing portions of the VRGB;

2) One well within each aquifer will be a "control" well, located upgradient of potential cultural impacts and other wells as much as possible;

3) Wells should be properly constructed, have a sampling port near the wellhead, and have well construction information such as casing perforation depths;

4) Current well owners should be willing to participate in the program.

Figure 8. Location of Groundwater Quality Index Wells Selected for the Ambient Monitoring Network

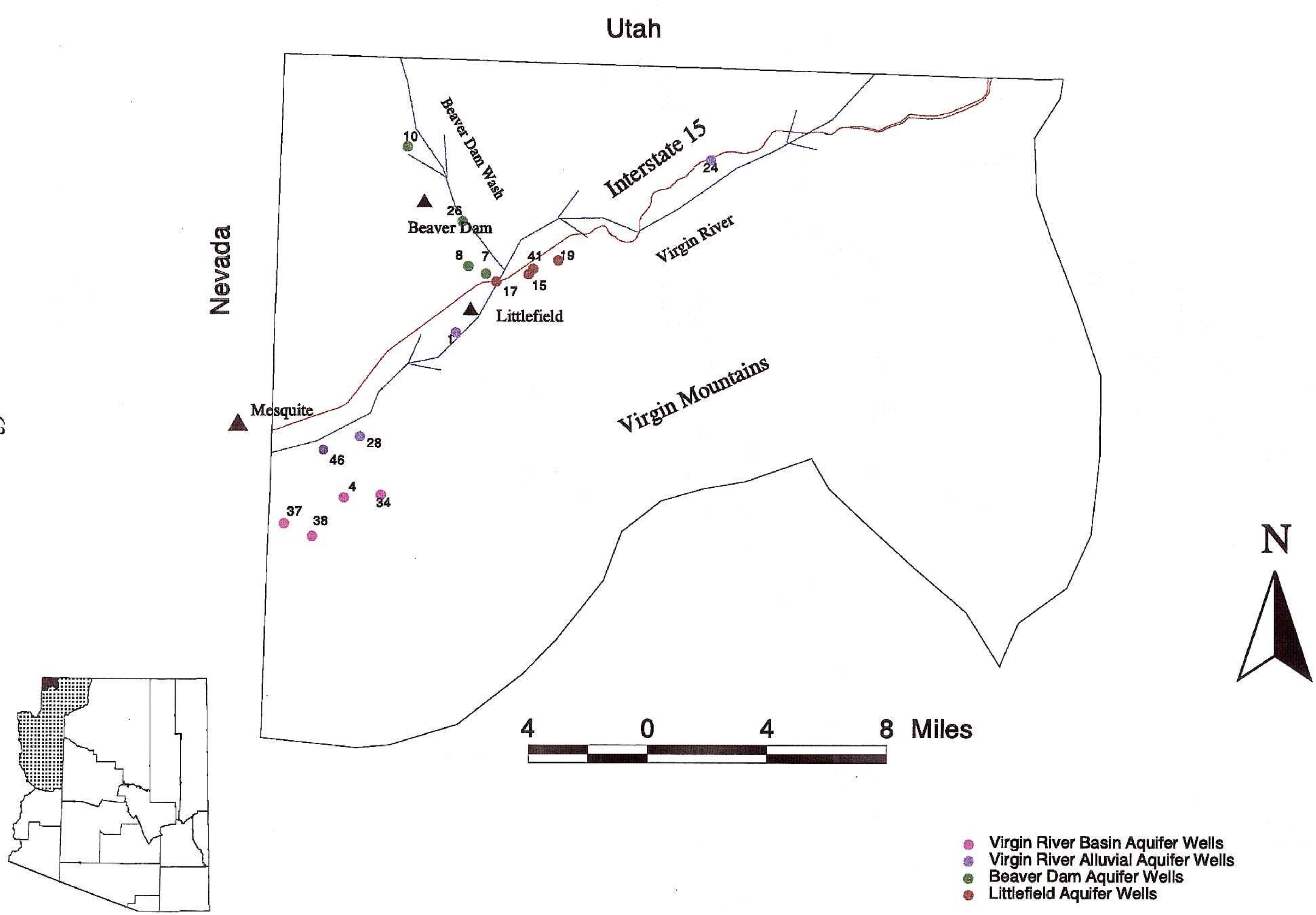


Table 16. Index Wells Selected for VRGB Ambient Groundwater Quality Monitoring Network

Well Registry #	ADEQ #	Owner	Location	Aquifer	Comments
55-614932	56392	ASLD/Hays	(B-41-16)13aab	Beaver Dam	Control Sample
55-523201	56403	Biasi	(B-41-15)29dac	Beaver Dam	
55-512262	48793	Sodell Co.	(B-40-15)04bca	Beaver Dam	
55-607608	22590	BD Store/Evans	(B-40-15)05abd	Beaver Dam	
55-532721	56400	Smith	(B-41-15)36ccb	Littlefield	Control Sample
55-535547	56417	Hindman (Munson)	(B-40-15)03aac	Littlefield	
55-651070	56397	Bell	(B-40-15)03acd	Littlefield	
None	56398	Ltl Jamaica Spring	(B-40-15)04dbb	Littlefield	
55-535702	56401	ADOT	(B-41-14)14cca	Virgin River alluvial	Control Sample
55-621577	48806	Lee (Tanner)	(B-40-15)17bdc	Virgin River alluvial	
55-533675	56405	Jacobson	(B-39-16)02baa	Virgin River alluvial	
55-520894	48779	Davis	(B-39-16)03bab	Virgin River alluvial	
55-519683	48789	Pulsiphor	(B-39-16)21daa	Virgin River basin	Control Sample
55-513105	48783	Frehner	(B-39-16)11ddd	Virgin River basin	
55-533606	56414	Evans	(B-39-16)17ddc	Virgin River basin	
55-539135	56389	Barnes	(B-39-16)15aba	Virgin River basin	

A qualitative recommendation is made that the ADEQ monitoring well network should be resampled at least every 5 years, a time period based upon time trend analyses conducted in other basin and range areas of Arizona. With the rapid pace of residential and commercial development within the VRGB, this schedule will serve to alert the agency of changing groundwater quality conditions as well as fiscally and logistically possible. Since all the VRGB wells were originally sampled as part of this study in 1997, these same wells are scheduled to be resampled approximately in 2002.

9. CONCLUSION

This 1997 ADEQ regional study to assess the groundwater quality of the VRGB had four major objectives: obtain baseline data throughout the basin, examine groundwater quality differences between various aquifers, examine relationships with groundwater quality parameter levels and indices such as groundwater depth and other groundwater quality parameter levels, and establish an ambient monitoring index well network. The results of the study indicated the following key findings for each objective:

A) Obtain baseline data on the occurrence, concentrations, and ranges of a wide-array of groundwater quality parameters:

- Generally groundwater quality in the VRGB meets SDW standards and is acceptable for drinking and other domestic uses. Some residents, however, prefer to use treated or filtered water because of poor aesthetic characteristics (taste, smell, and/or color) of the groundwater. The Littlefield and Virgin River alluvial aquifers are especially saline and this discourages their more extensive use as a water supply.

- There were no exceedances of any health-based, inorganic Primary MCLs in the 38 groundwater samples that were collected and analyzed in the VRGB. The samples were tested for 10 inorganic parameters (see **Figure 5**).

- There were many aesthetics-based, inorganic Secondary MCL exceedances in the 38 groundwater samples. Of the 10 inorganic parameters having Secondary MCLs, the following exceedances occurred: Cl - 15, Fe - 7, Mn - 5, pH-field - 1, SO_4 - 17, and TDS - 25 (see **Table 2** and **Figure 6**). The majority of the exceedances occurred in samples from the Littlefield and Virgin River alluvial aquifers.

- The potential for currently-registered pesticides to contaminate the groundwater was also a component of this study. As a result, groundwater samples were collected in areas of agricultural activity for GWPL analysis. This analysis consists of the 152 pesticides used in Arizona that are considered most likely to leach to the groundwater through normal agricultural use (see **Appendix H**). There were no detections of any pesticides in the samples tested (see **Appendix G**).

- Radionuclide levels in groundwater were also examined in this study. Ten samples were analyzed for gross alpha, radium-226, and radium-228. Only one sample from the Littlefield aquifer exceeded the gross alpha Primary MCL (see **Appendix F**).

B) Examine groundwater quality differences among various aquifers:

- Previous groundwater studies indicated the existence of four aquifers within the VRGB: Beaver Dam, Littlefield, Muddy Creek, and a single Virgin River aquifer. This study was unable to locate any wells in Arizona to sample that tapped the Muddy Creek aquifer. Based on groundwater sampling conducted for this study, the Virgin River aquifer appears to consist of not one but two distinct aquifers - an alluvial and basin. The Virgin River alluvial aquifer consists of floodplain deposits generally located north of the Virgin River while the Virgin River basin aquifer consists of alluvial-fan deposits generally located south of the Virgin River.

- Piper trilinear diagrams reveal the groundwater chemistry in the VRGB varies greatly between aquifers, with each aquifer having a distinctive chemical fingerprint. Groundwater samples collected from the Beaver Dam aquifer exhibit a mixed water chemistry of the Ca-HCO_3 type, with samples to the east of Beaver Dam Wash tending towards higher SO_4 concentrations. Groundwater samples from Littlefield and Virgin River alluvial aquifers exhibit a very consistent Ca-SO_4 water chemistry as did the deep groundwater sample collected from beneath the Beaver Dam aquifer. Groundwater samples collected from the Virgin River basin aquifer exhibit a clustered pattern with a mixed water chemistry of Na-SO_4, Na-HCO_3, and Ca-HCO_3 varieties while the water chemistry of the two deep samples collected from beneath the Virgin River alluvial aquifer were Na-Cl and Na-HCO_3 (see **Table 1** and **Figure 4**).

- The variation in groundwater quality parameter levels was assessed among four aquifers in the VRGB: Beaver Dam Wash, Littlefield, Virgin River alluvial, and Virgin River basin. Statistical results indicate numerous significant differences exist in the levels of groundwater quality parameters in the four aquifers. Many inorganic parameters, especially major ions, in the Littlefield and Virgin River alluvial aquifers have significantly higher levels than those in the Beaver Dam and Virgin River basin aquifers. Other interesting patterns include: temperature - field was significantly lower in those aquifers having a direct contact with perennial surface water flow (Beaver Dam and Virgin River alluvial), and nitrate was significantly lower in the Littlefield aquifer than the other three aquifers (see **Table 4**).

- Two groundwater samples collected from great depths in the Virgin River alluvial aquifer and one from beneath the Beaver Dam aquifer appear to be tapping deeper aquifers of different groundwater quality than the surficial aquifers. The groundwater quality parameter levels associated with these deep samples were compared with the corresponding 95% Confidence Intervals established for the respective aquifers. Results indicate the deep Beaver Dam aquifer parameter levels were frequently above the upper 95% Confidence Interval while the deep Virgin River alluvial parameter levels were frequently below the lower 95% Confidence Interval. Thus, the Beaver Dam aquifer appears to have lower groundwater quality parameter levels than the deep Beaver Dam aquifer sample; in contrast, the Virgin River alluvial aquifer appears to have higher groundwater quality parameter levels than the deeper Virgin River alluvial aquifer (see **Table 15**).

- Groundwater quality parameter levels of an upgradient, control sample were compared to the 95% Confidence Intervals established for each respective aquifer. The results indicate that the control samples for the Beaver Dam and Littlefield aquifers were often below the lower 95% Confidence Interval, indicating the groundwater quality of these aquifers may already be impacted by residential and commercial development (see **Table 14**).

C) Examine relationships with groundwater quality parameter levels and indices such as groundwater depth and other groundwater quality parameter levels:

- The levels of most groundwater quality parameter levels in the VRGB are statistically strongly correlated, probably indicating a common natural source for most parameters. Exceptions to this trend include F, temperature-field, and turbidity, which seldom had significant correlations; pH and nitrate had negative correlations in which these parameter levels tended to decrease as other groundwater quality parameter levels tended to increase. This may indicate that nitrate is from a different source than other parameters and may be related to human activities (see **Table 5** thru **Table 9**).

- Decreasing levels of numerous groundwater quality parameters are also significantly related to increasing groundwater depth below land surface in the VRGB. Few of these statistical relationships are present when individual aquifers are examined. Thus, these VRGB parameter level - groundwater depth relationships may be influenced more by differences in average parameter level and groundwater depth between aquifers than any actual relationship within aquifers (see **Table 10**, **Table 11**, **Table 12**, and **Table 13**).

D) Establish an ambient groundwater monitoring well network in the VRGB:

- An ambient groundwater monitoring well network of 16 index wells was established in the VRGB. The wells follow a statistical-design with equal numbers of wells located in the four distinct aquifers. One well in each aquifer was designated a "control" well and located upgradient of residential and commercial development as much as possible. With the rapid population growth in the VRGB, a qualitative estimation is that resampling of the index wells should occur in a five-year intervals based on studies conducted by the Ambient Groundwater Monitoring Program in other areas of Arizona (see **Figure 8** and **Table 16**).

10. DISCUSSION AND RECOMMENDATIONS

There were 2 major findings in this ADEQ VRGB groundwater quality study:

- Although prior literature (Black and Rascona, 1981) stated that there was 1 Virgin River aquifer, the data from this study suggests the Virgin River aquifer actually consists of 2 distinct aquifers with very different groundwater quality characteristics. These 2 aquifers are referred to in this study as the Virgin River alluvial aquifer and the Virgin River basin aquifer. This distinction was made on the basis of dissimilar groundwater quality chemistries and significantly different groundwater quality parameter levels.

- The four VRGB sampled aquifers - Beaver Dam, Littlefield, Virgin River alluvial, and Virgin River basin - have very dissimilar groundwater quality conditions. These groundwater quality differences appear to stem from localized hydrologic and geologic conditions within the aquifers.

Hydrologic conditions seem to be the chief factor affecting the groundwater quality in the Beaver Dam and Virgin River alluvial aquifers. The relatively low groundwater quality parameter levels reflective of the Beaver Dam aquifer are likely the result of recharge by good-quality surface water along the length of Beaver Dam Wash (Black and Rascona, 1991). Surface water quality also seems to be a major factor in the groundwater quality of the Virgin River alluvial aquifer. The relatively high groundwater quality parameter levels characteristic of the Virgin River alluvial aquifer are probably due to recharge by highly saline surface water along the length of the Virgin River. Factors influencing the poor-quality surface water in the Virgin River, which overlies the Virgin River alluvial aquifer, include an initial high concentration of salt, spring discharges around Littlefield, and irrigation returns (Black and Rascona, 1991).

In contrast, geologic conditions seem to be the main influence impacting groundwater quality of the Littlefield and Virgin River basin aquifers. The relatively high groundwater quality parameter levels found in the Littlefield aquifer could be due to groundwater contact with limestone known as the "Littlefield Formation" (Meissner Engineers, 1960). This flat-lying, fresh-water limestone unit is overlain by the alluvial fan deposits and is the likely cause of the high Ca levels found in the Littlefield aquifer groundwater. Recharge from the Virgin Mountains is thought to largely dictate the groundwater quality of the Virgin River basin aquifer. The Virgin Mountains consist primarily of granite and sedimentary rocks and recharge through these formations seems to yield water of generally potable quality.

Although regional groundwater quality conditions support drinking water uses in the VRGB, there are several indications that groundwater quality in the area should be closely monitored to avoid future problems. Of particular concern is the impact of the many recently-constructed residences and their use of septic systems for wastewater treatment. Although nitrate is present at only low levels in the VRGB, this parameter exhibits several unique patterns. Judging from parameter level correlations, nitrate appears to stem from a different source - perhaps septic systems - than most other parameters. Nitrate levels in areas of residential development overlaying the Beaver Dam and Littlefield aquifers are elevated when compared to upgradient, control samples. Nitrate levels in the Beaver Dam, Virgin River alluvial, and Virgin River basin aquifers are significantly higher than those in the Littlefield aquifer, contrary to the patterns of other groundwater quality parameters. Despite these trends, nitrate levels do not currently pose a problem as the highest sampled nitrate (as N) level was 5.4 mg/l, approximately half the 10.0 mg/l Primary MCL although nitrate (as N) levels above 3 mg/l are thought to be an indicator of land use impacts (Madison and Brunett, 1984). Nevertheless, the previously-mentioned patterns illustrate the need to closely monitor nitrate levels in the VRGB.

Because of the report's scope and timing, this study is a valuable foundation upon which to build future groundwater quality monitoring efforts in the VRGB. Previous groundwater quality studies by the USGS in 1976 and ADWR in 1991 had very limited numbers of groundwater samples subjected to detailed chemical analysis. In the intervening period of time, rapid, clustered population growth occurred in this relatively-undeveloped area. This growth allowed for a much larger number of wells located over a greater spatial expanse in which to sample for this report. Thus, the greater comprehensiveness of this study should provide important groundwater quality baseline information in which to help track any VRGB groundwater quality trends as the area continues its rapid residential and commercial growth.

Future groundwater quality sampling should not only resample ADEQ index wells but also attempt to sample recently-drilled wells in areas of the VRGB where previously no wells existed. This strategy would attempt to overcome perhaps the chief weakness of this study. Although a greater spatial area was covered by this ADEQ study than by previous groundwater quality studies, groundwater samples could not be collected from large areas of the VRGB that lacked wells and/or springs. Thus, specific groundwater quality information is still lacking from large areas of the VRGB.

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Part VI

Appendices

Appendix A. Characteristics of Wells Selected for Groundwater Monitoring in the Virgin River Groundwater Basin (VRGB)

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth bls (ft)	Casing Diameter (in)	Perforation Interval bls (ft)	Water Depth bls (ft)	Surface Elevation of Well (ft)
55-621577	VR-01/VR-02	(B-40-15)17bdc	Lee (Tanner)	Irrigation	125'	16"	N/A	16'	1740'
55-621578	VR-03	(B-40-15)17bcc	Lee (Tanner)	Irrigation	50'	16"	N/A	10'	1740'
55-539135	VR-04	(B-39-16)15aba	Barnes	Domestic	400'	6"	325'-400'	285'	1853'
55-510501	VR-05	(B-41-15)33cdd	Walton, et al.	Domestic	145'	8"	80'-90'	63'	1900'
unknown	VR-06	(B-41-15)33caa	Lindsay	Domestic	120'	6"	N/A	63.8'	1900'
55-512262	VR-07	(B-40-15)04bca	Sodell Co.	Public	51'	8"	20'-50'	10'	1800'
55-607608	VR-08	(B-40-15)05abd	Evans	Domestic	60'	12"	N/A	10'	1850'
55-614932	VR-10	(B-41-16)13aab	ASLD/Hays	Irrigation	90'	14"	N/A	18'	2021'
None	VR-11	(B-40-15)04bda	BLM	Monitoring	9.5'	1"	7 - 9.5'	3.2'	1789'
None	VR-12	(B-40-15)04bdc	BLM	Monitoring	7.9'	1"	5.5 - 7.9'	2.8'	1787'
55-613831	VR-13/VR-14	(B-41-15)32cda	Pratt (Jones)	Irrigation	56'	12"	N/A	18.6'	1875'
55-651070	VR-15/VR-16	(B-40-15)03acd	Bell	Domestic	117'	8"	N/A	51'	1960'
None	VR-17	(B-40-15)04dbb		Recreation	0'	None		0'	1820'
55-532546	VR-18	(B-41-15)36cbb	Chaney	Domestic	235'	8"	195 - 235'	148'	1969'
55-532721	VR-19	(B-41-15)36ccb	Smith	Domestic	360'	8"	260 - 360'	150'	2040'
55-517695	VR-20	(B-39-16)03abd	Felshaw	Domestic	160'	8"	60'-160'	118'	1689'

N/A = Information Not Available

Appendix A. Characteristics of Wells Selected for Groundwater Monitoring in the VRGB--Continued

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth bls (ft)	Casing Diameter (in)	Perforation Interval bls (ft)	Water Depth bls (ft)	Surface Elevation of Well (ft)
55-604108	VR-21	(B-40-16)34bcc	Hughes	Irrigation	400'	16"	N/A	140'	1761'
None	VR-22	(B-41-15)33cab	ADOT	Domestic	N/A	8"	N/A	53.6'	1900'
55-535702	VR-24	(B-41-14)14cca	ADOT	Domestic	643'	8"	N/A	317'	2320'
55-520102	VR-25	(B-40-15)03abb	Reber	Domestic	465'	5"	N/A	30'	1916'
55-523201	VR-26	(B-41-15)29dac	Biasi	Public	630'	18"	90'-600'	100'	1955'
55-539947	VR-27	(B-40-15)05baa	Baker	Domestic	100'	8"	N/A	30'	1847'
55-533675	VR-28/VR-29	(B-39-16)02baa	Jacobson	Domestic	210'	8"	N/A	30'	1755'
55-550826	VR-30	(B-39-16)14dbc	Murray	Domestic	550'	5"	N/A	336'	1880'
55-543355	VR-31	(B-39-16)05aac	Redd	Irrigation	960'	20"	440'-920'	380'	1640'
55-543357	VR-32	(B-40-16)33dba	Redd	Irrigation	900'	14"	N/A	300'	1771'
None	VR-33	(B-40-15)05dad	Peterson	Public	80'	8"	N/A	N/A	1880'
55-513105	VR-34	(B-39-16)11ddd	Frehner	Domestic	400'	8"	360'-400'	330'	1909'
None	VR-35	(B-39-16)11ddc	Frehner	Irrigation	390'	16"	N/A	290'	1905'
55-535197	VR-36	(B-39-16)16bcd	Cushen	Domestic	407'	6"	360'-400'	260'	1837'
55-533606	VR-37	(B-39-16)17ddc	Evans	Domestic	395'	8"	325'-395'	290'	1899'

N/A = Information Not Available

Appendix A. Characteristics of Wells Selected for Groundwater Monitoring in the VRGB--Continued

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth bls (ft)	Casing Diameter (in)	Perforation Interval bls (ft)	Water Depth bls (ft)	Surface Elevation of Well (ft)
55-519683	VR-38	(B-39-16)21daa	Pulsiphor	Domestic	410'	8"	340'-405'	335'	1994'
55-516122	VR-39	(B-41-15)32aaa	Hardy	Domestic	150'	6"	N/A	N/A	1942'
55-510598	VR-40	(B-41-15)33aad	Olsen	Domestic	163'	8"	9-115' 155-160'	60'	2000'
55-535547	VR-41 VR-42	(B-40-15)03aac	Hindman (Munson)	Domestic	110'	8"	61'-97'	50'	1962'
55-555195	VR-43 VR-44	(B-40-15)03aad	Krause (Grimes)	Domestic	125'	8"	N/A	50'	1970'
55-544038	VR-45	(B-40-15)03aad	Hall (Romero)	Domestic	128'	6"	108'-128'	65'	1999'
55-520894	VR-46	(B-39-16)03bab	Davis	Domestic	94'	8"	50'-75'	33'	1640'

N/A = Information Not Available

Appendix B. Characteristics of VRGB Groundwater Samples

Sample Name	Latitude & Longitude	ADEQ Well Number	Sample Date	Type of Sample	Factors Related to Sample Location	Sample MCL Exceedances
VR-01	36°52'05.694" 113°56'26.708"	48806	03/04/97	SDW Inorganic + 6 Fecal Coliform	- Virgin River alluvial aquifer	Secondary = TDS, Cl, SO_4
VR-02	36°52'05.694" 113°56'26.708"	48806	03/04/97	SDW Inorganic + 6	- QA/QC = Split of VR-01	Secondary = TDS, Cl, SO_4
VR-03	36°52'04.832" 113°56'40.180"	48805	03/04/97	SDW Inorganic + 6 Fecal Coliform	- Virgin River alluvial aquifer	Secondary = TDS, Cl, SO_4
VR-04	36°47'11.711" 114°00'16.007"	56389	03/04/97	SDW Inorganic + 6 Fecal Coliform	- Virgin River basin aquifer	Secondary = TDS
VR-05	36°54'40.724" 113°55'58.886"	56390	03/04/97	SDW Inorganic + 6 Fecal Coliform	- Beaver Dam aquifer	None
VR-06	36°54'50.100" 113°55'57.747"	56391	03/04/97	SDW Inorganic + 6 Fecal Coliform	- Beaver Dam aquifer	None
VR-07	36°53'49.578" 113°55'24.653"	48793	03/05/97	SDW Inorganic + 6	- Beaver Dam aquifer	Secondary = TDS
VR-08	36°54'02.054" 113°56'03.346"	22590	03/05/97	SDW Inorganic + 6	- Beaver Dam aquifer	
VR-09			03/05/97	SDW Inorganic + 6	- QA/QC = Equipment Blank	
VR-10	36°57'25.944" 113°58'23.507"	56392	03/05/97	SDW Inorganic + 6	- Beaver Dam aquifer - Control Sample	
VR-11	36°53'53.197" 113°55'15.110"	56393	03/06/97	SDW Inorganic + 6	- Beaver Dam aquifer - shallow - Targeted sample	Secondary = TDS, SO_4, Fe, Mn
VR-12	36°53'45.418" 113°55'23.109"	56394	03/06/97	SDW Inorganic + 6	- Beaver Dam aquifer - shallow - Targeted sample	Secondary = TDS, Fe
VR-13	36°54'21.571" 113°56'38.513"	56396	03/06/97	SDW Inorganic + 6	- Beaver Dam aquifer	
VR-14	36°54'21.571" 113°56'38.513"	56396	03/06/97	SDW Inorganic + 6	- QA/QC = Duplicate of VR-13	

Appendix B. Characteristics of VRGB Groundwater Samples--Continued

Sample Name	Latitude & Longitude	ADEQ Well Number	Sample Date	Type of Sample	Factors Related to Sample Location	Sample MCL Exceedances
VR-15	36°53'51.146" 113°53'51.885"	56397	03/25/97	SDW Inorganic + 6 Radionuclides	- Littlefield aquifer	Primary = Gross α Secondary = TDS, Cl, SO_4
VR-16	36°53'51.146" 113°53'51.885"	56397	03/25/97	SDW Inorganic + 6	- QA/QC = Duplicate of VR-15	Secondary = TDS, Cl, SO_4
VR-17	36°53'37.014" 113°55'02.302"	56398	03/25/97	SDW Inorganic + 6 Radionuclides Fecal Coliform	- Littlefield aquifer	Secondary = TDS, Cl, SO_4
VR-18	36°54'32.604" 113°52'36.576"	56399	03/25/97	SDW Inorganic + 6 Radionuclides	- Littlefield aquifer	Secondary = TDS, Cl, SO_4, Fe, Mn
VR-19	36°54'17.661" 113°52'48.973"	56400	03/25/97	SDW Inorganic + 6	- Littlefield aquifer - Control Sample	Secondary = TDS, Cl, SO_4, Fe, Mn
VR-20	36°48'46.661" 114°00'31.784"	48776	03/25/97	SDW Inorganic + 6 Radionuclides	- Virgin River alluvial aquifer	Secondary = TDS, Cl, SO_4
VR-21	36°49'23.863" 114°00'47.035"	48809	03/25/97	SDW Inorganic + 6 Radionuclides	- Virgin River alluvial aquifer	Secondary = TDS, SO_4
VR-22	36°54'29.496" 113°55'45.014"	22696	03/26/97	SDW Inorganic + 6 Radionuclides Fecal Coliform	- Beaver Dam aquifer - deep - Targeted sample	Secondary = TDS, Cl, SO_4
VR-23			03/26/97	SDW Inorganic + 6	- QA/QC = Equipment Blank	None
VR-24	36°57'20.131" 113°47'22.965"	56401	03/26/97	SDW Inorganic + 6 Radionuclides Fecal Coliform	- Virgin River alluvial aquifer - Control Sample	Secondary = TDS, Cl
VR-25	36°54'01.515" 113°54'17.509"	56402	03/26/97	SDW Inorganic + 6 Fecal Coliform	- Littlefield aquifer	Secondary = TDS, Cl, SO_4
VR-26	36°55'19.691" 113°56'19.149"	56403	03/26/97	SDW Inorganic + 6 Radionuclides	- Beaver Dam aquifer	None
VR-27	36°54'09.841" 113°56'21.113"	56404	03/27/97	SDW Inorganic + 6 Radionuclides	- Beaver Dam aquifer	None

Appendix B. Characteristics of VRGB Groundwater Samples--Continued

Sample Name	Latitude & Longitude	ADEQ Well Number	Sample Date	Type of Sample	Factors Related to Sample Location	Sample MCL Exceedances
VR-28	36°48'57.993" 113°59'46.521"	56405	03/27/97	SDW Inorganic + 6	- Virgin River alluvial aquifer	Secondary = TDS, Cl, SO_4, Fe, Mn
VR-29	36°48'57.993" 113°59'46.521"	56405	03/27/97	SDW Inorganic + 6	- QA/QC = Duplicate of VR-28	Secondary = TDS, Cl, SO_4, Fe, Mn
VR-30	36°46'35.247" 113°59'23.541"	56406	03/27/97	SDW Inorganic + 6 Radionuclides	- Virgin River basin aquifer - Control Sample	None
VR-31	36°48'42.834" 114°02'27.421"	56407	03/27/97	SDW Inorganic + 6	- Virgin River alluvial aq - deep - Targeted sample	Secondary = TDS
VR-32	36°49'23.369" 114°01'21.811"	56408	03/27/97	SDW Inorganic + 6	- Virgin River alluvial aq - deep - Targeted sample	Secondary = TDS
VR-33	36°53'37.938" 113°55'48.490"	56409	03/27/97	SDW Inorganic + 6	- Virgin River alluvial aquifer	Secondary = TDS, SO_4
VR-34	36°47'17.935" 113°58'56.483"	48783	04/22/97	SDW Inorganic + 6	- Virgin River basin aquifer	None
VR-35	36°47'13.775" 113°59'12.234"	22545	04/22/97	SDW Inorganic + 6 GWPL Pesticides	- Virgin River basin aquifer	None
VR-36	36°46'49.705" 114°02'00.602"	56413	04/22/97	SDW Inorganic + 6	- Virgin River basin aquifer	Secondary = TDS
VR-37	36°46'23.783" 114°02'23.944"	56414	04/22/97	SDW Inorganic + 6	- Virgin River basin aquifer	None
VR-38	36°46'03.004" 114°01'22.447"	48789	04/22/97	SDW Inorganic + 6	- Virgin River basin aquifer	None
VR-39	36°54'41.267" 113°55'52.949"	56415	04/22/97	SDW Inorganic + 6 GWPL Pesticides	- Beaver Dam aquifer	Secondary = TDS
VR-40	36°54'43.761" 113°55'56.983"	56416	04/22/97	SDW Inorganic + 6	- Beaver Dam aquifer	None

Appendix B. Characteristics of VRGB Groundwater Samples--Continued

Sample Name	Latitude & Longitude	ADEQ Well Number	Sample Date	Type of Sample	Factors Related to Sample Location	Sample MCL Exceedances
VR-41	36°54'00.821" 113°53'42.570"	56417	04/22/97	SDW Inorganic + 6	- Littlefield aquifer	Secondary = TDS, Cl, SO_4, Fe
VR-42	36°54'00.821" 113°53'42.570"	56417	04/22/97	SDW Inorganic + 6	- QA/QC = Split of VR-41	Secondary = TDS, Cl, SO_4, Fe
VR-43	36°53'59.191" 113°53'46.463"	56418	04/22/97	SDW Inorganic + 6	- Littlefield aquifer	Secondary = pH(f),TDS, Cl, SO_4
VR-44	36°53'59.191" 113°53'46.463"	56418	04/22/97	SDW Inorganic + 6	- QA/QC = Duplicate of VR-43	Secondary = pH(f),TDS, Cl, SO_4
VR-45	36°53'59.253" 113°53'48.037"	56419	04/22/97	SDW Inorganic + 6	- Littlefield aquifer	Secondary = TDS, Cl, SO_4, Fe
VR-46	36°48'51.874" 114°00'44.626"	48779	04/22/97	SDW Inorganic + 6 GWPL Pesticides	- Virgin River alluvial aquifer	Secondary = TDS, Cl, SO_4, Mn
VR-47			04/22/97	SDW Inorganic + 6	- QA/QC = Equipment Blank	None

Appendix C. Summary of Field & Lab-Measured Physical Parameters and Nutrients in VRGB Samples

Sample ID	Sample Date	Fecal cfu	NH_3-N mg/l	NO_3/NO_2 mg/l	pH-f SU	pH SU	Sp Cond-f umhos/cm	Sp Cond umhos/c	Temp-f ^{0}C	TDS mg/l	TKN mg/l	T. Phos mg/l	Trbdty mg/l
Minimum Reporting Levels (MRL)			0.10	0.10		0.1				10	0.10	0.10	0.01
Maximum Contaminant Levels (MCL)				10.0	(6.50 to 8.50)	(6.50 to 8.50)				(500)			
VR-01	03/04/97	0	ND	0.85	6.98	*7.01*	2810	2660	19.70	**2040**	0.23	ND	*0.34*
VR-02	03/04/97	N/A	ND	0.75	6.98	7.4	2810	2500	19.70	**2000**	ND	ND	N/A
VR-03	03/04/97	0	ND	2.98	7.19	*7.22*	2930	2700	20.75	**2120**	0.20	ND	*0.07*
VR-04	03/04/97	0	ND	1.04	7.66	7.65	1088	996	21.13	**690**	0.24	ND	*3.6*
VR-05	03/04/97	0	ND	1.05	7.57	7.56	683	632	18.92	434	0.12	ND	*1.26*
VR-06	03/04/97	0	ND	1.85	7.54	7.42	714	662	20.34	457	ND	ND	*11.0*
VR-07	03/05/97	N/A	ND	1.17	7.52	7.60	941	850	19.79	**606**	ND	ND	*0.06*
VR-08	03/05/97	N/A	ND	0.64	7.62	7.63	635	585	17.17	410	ND	ND	*0.10*
VR-09	03/05/97	N/A	ND	ND	N/A	5.63	N/A	2.4	N/A	20	ND	ND	*0.05*
VR-10	03/05/97	N/A	ND	0.58	7.54	7.40	585	538	18.80	377	ND	ND	*0.44*
VR-11	03/06/97	N/A	< 0.20	0.69	7.53	7.34	1800	1630	15.53	**1290**	0.61	3.96	1730
VR-12	03/06/97	N/A	ND	0.27	7.60	*7.50*	1024	932	15.96	**740**	0.35	0.67	*430*

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time
ND = None Detected at Lab Minimum Reporting Level (MRL)
Bold = SDW Standard Exceedance
f - field measured

Appendix C. Summary of Field & Lab-Measured Physical Parameters and Nutrients in VRGB Groundwater Samples--Continued

Sample ID	Sample Date	Fecal cfu	NH_3-N mg/l	NO_3/NO_2 mg/l	pH-f SU	pH SU	Sp Cond-f umhos/cm	Sp Cond umhos/c	Temp-f ^{0}C	TDS mg/l	TKN mg/l	T. Phos mg/l	Trbdty mg/l
Minimum Reporting Levels (MRL)			0.10	0.10		0.1				10	0.10	0.10	0.01
Maximum Contaminant Levels (MCL)				10.0	(6.50 to 8.50)	(6.50 to 8.50)				(500)			
VR-13	03/06/97	N/A	ND	1.49	7.43	7.18	733	677	20.10	472	ND	ND	*8.2*
VR-14	03/06/97	N/A	ND	1.37	7.43	7.55	733	679	20.10	474	ND	ND	8.0
VR-15	03/25/97	N/A	ND	0.21	6.53	*7.03*	3660	3470	25.19*	**2900**	ND	ND	*0.06*
VR-16			ND	0.18	6.53	6.7	3660	3200	25.19*	**2800**	ND	ND	ND
VR-17	03/26/97	100	ND	0.46	7.73	*7.99*	3670	3350	23.92	**2900**	ND	ND	*0.08*
VR-18	03/26/97	N/A	ND	ND	6.62	*7.04*	3740	3490	24.71	**2900**	ND	ND	76.8
VR-19	03/26/97	N/A	ND	ND	6.78	*7.16*	3630	3370	26.67	**2800**	ND	ND	*110*
VR-20	03/26/97	N/A	ND	1.25	7.05	*7.88*	2860	2620	21.63	**2000**	ND	ND	*0.09*
VR-21	03/26/97	N/A	ND	2.29	7.07	*7.20*	2470	2240	18.07	**1700**	0.14	ND	*3.6*
VR-22	03/27/97	0	ND	1.27	6.86	*7.10*	2980	2740	22.32	**2100**	ND	ND	*0.19*
VR-23	03/27/97	N/A	< 0.20	ND	N/A	5.7	N/A	21.1	N/A	ND	ND	ND	*0.18*
VR-24	03/27/97	0	ND	1.20	7.21	*7.49*	2370	2120	19.89	**1600**	ND	ND	*0.37*

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time

ND = None Detected at Lab Minimum Reporting Level (MRL)
Bold = SDW Standard Exceedance

f - field measured

Appendix C. Summary of Field & Lab-Measured Physical Parameters and Nutrients in VRGB Groundwater Samples--Continued

Sample ID	Sample Date	F. Col cfu	NH_3-N mg/l	NO_3/NO_2 mg/l	pH-f SU	pH SU	Sp Cond-f umhos/cm	Sp Cond umhos/c	Temp-f °C	TDS mg/l	TKN mg/l	T. Phos mg/l	Trbdty mg/l
Minimum Reporting Levels (MRL)			0.10	0.10		0.1				10	0.10	0.10	0.01
Maximum Contaminant Levels (MCL)				10.0	(6.50 to 8.50)	(6.50 to 8.50)				(500)			
VR-25	03/27/97	0	ND	0.46	6.60	*7.66*	3720	3430	26.01	**2900**	0.17	ND	*0.20*
VR-26	03/28/97	N/A	ND	1.02	7.46	*8.01*	598	580	22.31	390	ND	ND	*0.05*
VR-27	03/27/97	N/A	ND	ND	7.44	*8.01*	629	578	21.39	410	ND	ND	0.15
VR-28	03/27/97	N/A	ND	0.63	7.09	*8.01*	3340	3000	20.93	**2400**	ND	ND	31.8
VR-29	03/27/97	N/A	ND	ND	7.09	*7.37*	3340	3000	20.93	**2400**	ND	ND	36.8
VR-30	03/27/97	N/A	ND	2.56	7.86	*8.16*	721	703	26.18	440	ND	ND	*1.41*
VR-31	03/27/97	N/A	ND	0.37	7.68	*7.34*	1338	1220	27.60	**790**	ND	0.11	0.17
VR-32	03/27/97	N/A	<0.20	0.43	7.81	7.49	831	771	27.51	**530**	ND	ND	0.25
VR-33	03/27/97	N/A	ND	1.16	6.92	7.30	1780	1590	21.54	**1200**	ND	ND	0.11
VR-34	04/22/97	N/A	ND	1.5	7.93	8.1	580	590	24.80	350	ND	ND	1.4
VR-35	04/22/97	N/A	ND	1.6	7.82	*8.1*	669	680	25.95	400	ND	ND	*400*
VR-36	04/22/97	N/A	ND	0.55	7.39	*8.1*	901	900	26.35	**590**	ND	ND	*3.00*
VR-37	04/22/97	N/A	ND	5.4	7.77	*7.7*	528	530	26.70	330	ND	ND	*0.20*

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time

ND = None Detected at Lab Minimum Reporting Level (MRL)
Bold = SDW Standard Exceedance

f - field measured

Appendix C. Summary of Field & Lab-Measured Physical Parameters and Nutrients in VRGB Groundwater Samples--Continued

Sample ID	Sample Date	F. Col cfu	NH_3-N mg/l	NO_3/NO_2 mg/l	pH-f SU	pH SU	Sp Cond-f umhos/cm	Sp Cond umhos/c	Temp-f °C	TDS mg/l	TKN mg/l	T. Phos mg/l	Trbdy mg/l
Minimum Reporting Levels (MRL)			0.10	0.10		0.1				10	0.10	0.10	0.01
Maximum Contaminant Levels (MCL)				10.0	(6.50 to 8.50)	(6.50 to 8.50)				(500)			
VR-38	04/22/97	N/A	ND	3.5	7.55	*7.9*	520	510	26.70	320	ND	ND	*0.23*
VR-39	04/22/97	N/A	ND	2.5	7.26	*8.0*	938	940	21.65	**630**	ND	ND	*0.18*
VR-40	04/22/97	N/A	ND	1.2	7.36	*8.3*	629	630	21.60	410	ND	ND	*0.23*
VR-41	04/22/97	N/A	ND	0.26	6.54	*7.8*	3420	3500	26.67	**2800**	0.22	ND	*39*
VR-42			ND	0.23	6.54	*6.9*	3420	3100	26.67	**2900**	ND	ND	*35*
VR-43	04/22/97	N/A	ND	0.24	**6.43**	*7.2*	3400	3500	26.44	**2800**	0.30	ND	*0.36*
VR-44		N/A	ND	0.24	**6.43**	*7.4*	3400	3500	26.44	**2800**	0.23	ND	*0.09*
VR-45	04/22/97	N/A	ND	0.22	6.56	*7.6*	3400	3400	26.44	**2800**	0.24	ND	*8.4*
VR-46	04/22/97	N/A	ND	1.9	6.58	*7.7*	4850	4900	21.42	**4300**	0.60	ND	*6.5*
VR-47	04/22/97	N/A	ND	ND	N/A	5.8	N/A	2.2	N/A	ND	ND	ND	*0.06*

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time

ND = None Detected at Lab Minimum Reporting Level (MRL)
Bold = SDW Standard Exceedance

f - field measured

Appendix D. Summary of Lab-Measured Major Ions in Virgin River Groundwater Basin Samples

Sample ID #	Date Sampled	Alk- Phnl mg/l	Alk-Total mg/l	Ca mg/l	Cl mg/l	F mg/l	Hardness mg/l	K mg/l	Mg mg/l	Na mg/l	SO_4 mg/l
Minimum Reporting Levels (MRL)		2.0	2.0	1.0	1.0	0.20	10	0.50	1.0	5.0	10.0
Maximum Contaminant Levels (MCL)					(250)	4.0 & (2.0)					(250)
VR-01	03/04/97	ND	292	230	**281**	0.94	1010	27.5	N/A	232	**804**
VR-02		N/A	280	281	**290**	1.1	950	21	93.2	260	**830**
VR-03	03/04/97	ND	199	236	**281**	1.05	991	22.9	98.5	257	**793**
VR-04	03/04/97	ND	130	65	105	0.88	279	5.51	30.8	108	234
VR-05	03/04/97	ND	187	61.6	28.9	0.73	207	5.39	18.1	51.7	103
VR-06	03/04/97	ND	170	72.8	41.3	0.69	239	5.75	19.9	42.9	109
VR-07	03/05/97	ND	207	83.8	51.5	0.70	311	6.95	26.2	69.4	183
VR-08	03/05/97	ND	205	68.3	19.8	0.76	232	5.61	20.4	31.5	98.2
VR-09	03/05/97	ND	ND	< 5.0	ND	ND	ND	ND	ND	ND	ND
VR-10	03/05/97	ND	181	62.5	17.4	0.66	231	5.38	18.4	27.3	85.4
VR-11	03/06/97	ND	612	152	184	0.52	6.33	8.72	57.3	117	**369**
VR-12	03/06/97	ND	421	83.8	65.2	0.67	340	7.82	29.8	68.3	204

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time

ND = None Detected at Lab Minimum Reporting Level (MRL)
Bold = SDW Standard Exceedance

Appendix D. Summary of Lab-Measured Major Ions in VRGB Groundwater Samples--Continued

Sample ID #	Date Sampled	Alk- Phnl mg/l	Alk-Total mg/l	Ca mg/l	Cl mg/l	F mg/l	Hardness mg/l	K mg/l	Mg mg/l	Na mg/l	SO_4 mg/l
Minimum Reporting Levels (MRL)		2.0	2.0	1.0	1.0	0.20	10	0.50	1.0	5.0	10.0
Maximum Contaminant Levels (MCL)					(250)	4.0 & (2.0)					(250)
VR-13	03/06/97	ND	244	76.0	21.5	0.93	263	5.66	24.7	39.5	86.2
VR-14		ND	229	70.8	21.3	0.94	278	5.58	24.0	38.4	154
VR-15	03/25/97	ND	363	440	**410**	1.33	1600	32	120	280	**1200**
VR-16		N/A	340	390	**540**	ND	1500	33	120	340	**1700**
VR-17	03/25/97	ND	348	420	**410**	1.29	1500	33	110	270	**1220**
VR-18	03/25/97	ND	361	410	**400**	1.36	1600	33	110	270	**1280**
VR-19	03/25/97	ND	340	360	**390**	1.25	1600	33	100	250	**1190**
VR-20	03/25/97	ND	196	220	**360**	0.80	940	24	72	230	**766**
VR-21	03/25/97	ND	179	190	240	0.67	900	12	77	200	**718**
VR-22	03/26/97	ND	258	250	**360**	0.48	1000	17	110	270	**782**
VR-23	03/26/97	ND	ND	< 5.0	ND	ND	ND	ND	ND	ND	ND
VR-24	03/26/97	ND	191	210	**270**	0.52	740	15	60	220	61
VR-25	03/26/97	< 1	364	420	**390**	1.33	1500	30	130	290	**1240**

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time

ND = None Detected at Lab Minimum Reporting Level (MRL)
Bold = SDW Standard Exceedance

Appendix D. Summary of Lab-Measured Major Ions in VRGB Groundwater Samples--Continued

Sample ID #	Date Sampled	Alk- Phnl mg/l	Alk-Total mg/l	Ca mg/l	Cl mg/l	F mg/l	Hardness mg/l	K mg/l	Mg mg/l	Na mg/l	SO_4 mg/l
Minimum Reporting Levels (MRL)		2.0	2.0	1.0	1.0	0.20	10	0.50	1.0	5.0	10.0
Maximum Contaminant Levels (MCL)					(250)	4.0 & (2.0)					(250)
VR-26	03/27/97	ND	181	61	20	0.77	210	3.9	18	31	78.0
VR-27	03/27/97	ND	202	65	18	0.77	220	4.3	20	32	86.4
VR-28	03/27/97	ND	209	310	**400**	0.54	1200	24	95	260	**997**
VR-29		ND	203	310	**410**	0.54	1200	24	95	250	**996**
VR-30	03/27/97	ND	136	33	61	0.98	170	4.0	25	69	105
VR-31	03/27/97	ND	161	47	200	1.14	230	11	30	160	177
VR-32	03/27/97	ND	184	30	35	1.17	160	6.6	20	100	166
VR-33	03/27/97	ND	249	160	170	0.64	660	6.4	61	100	**548**
VR-34	04/22/97	ND	130	26	56	1.4	150	3.5	23	64	81
VR-35	04/22/97	ND	130	32	68	1.8	180	4.2	26	73	140
VR-36	04/22/97	ND	200	52	42	0.84	230	7.6	26	110	220
VR-37	04/22/97	ND	110	39	42	0.32	160	3.3	18	49	85
VR-38	04/22/97	ND	160	42	36	0.37	180	3.0	20	41	58

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time

ND = None Detected at Lab Minimum Reporting Level (MRL)
Bold = SDW Standard Exceedance

Appendix D. Summary of Lab-Measured Major Ions in VRGB Groundwater Samples--Continued

Sample ID #	Date Sampled	Alk- Phnl mg/l	Alk-Total mg/l	Ca mg/l	Cl mg/l	F mg/l	Hardness mg/l	K mg/l	Mg mg/l	Na mg/l	SO_4 mg/l
Minimum Reporting Levels (MRL)		2.0	2.0	1.0	1.0	0.20	10	0.50	1.0	5.0	10.0
Maximum Contaminant Levels (MCL)					(250)	4.0 & (2.0)					(250)
VR-39	04/22/97	ND	200	78	64	0.63	300	5.9	30	84	200
VR-40	04/22/97	ND	190	62	29	0.66	220	4.3	19	46	120
VR-41	04/22/97	ND	360	420	**380**	1.2	1400	31	120	270	**1200**
VR-42	04/22/97	ND	350	400	**370**	**2.2**	1600	28	140	370	**1300**
VR-43	04/22/97	ND	370	410	**390**	1.3	1400	31	120	280	**1200**
VR-44	04/22/97	ND	360	410	**390**	1.2	1600	30	120	280	**1200**
VR-45	04/22/97	ND	360	420	**380**	1.2	1600	30	120	280	**1100**
VR-46	04/22/97	ND	320	560	**560**	0.77	2400	37	200	420	**2000**
VR-47	04/22/97	ND	ND	< 5.0	ND	ND	ND	ND	ND	ND	ND

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time

ND = None Detected at Lab Minimum Reporting Level (MRL)
Bold = SDW Standard Exceedance

Appendix E. Summary of Lab-Measured Metal Concentrations in VRGB Groundwater Samples

Sample ID #	Sample Date	Al mg/l	As mg/l	B mg/l	Ba mg/l	Be mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Mn mg/l	Hg mg/l	Se mg/l	Sb mg/l	Ag mg/l	Tl mg/l	Zn mg/l
Minimum Reporting Levels (MRL)		0.50	.010	0.10	0.10	.0005	.0010	0.010	0.010	.10	0.005	.05	.0005	.005	.005	.001	.005	0.05
Maximum Contaminant Levels (MCL)		(0.05 to 0.20)	.05	0.63*	2.0		.005	0.1	{1.3}	(0.3)	{.015}	(.05)	.002	.05		(0.1)		(5.0)
VR-01	03/04/97	ND	ND	0.83	ND	ND	ND	ND	0.020	ND	ND	ND	ND	.006	.005	ND	ND	ND
VR-02		N/A	ND	0.82	ND	ND	ND	.0065	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-03	03/04/97	ND	ND	0.84	ND	ND	ND	ND	ND	ND	ND	ND	ND	.006	ND	ND	ND	ND
VR-04	03/04/97	ND	.010	0.32	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.09
VR-05	03/04/97	ND	ND	0.10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-06	03/04/97	ND	ND	0.12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-07	03/05/97	ND	ND	0.23	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-08	03/05/97	ND	.010	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-09	03/05/97	ND	ND	0.39	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-10	03/05/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-11	03/06/97	ND	ND	0.36	ND	ND	ND	ND	ND	**0.46**	ND	**0.18**	ND	ND	ND	ND	ND	0.52
VR-12	03/06/97	ND	ND	0.24	ND	ND	ND	ND	ND	**0.84**	ND	ND	ND	ND	ND	ND	ND	1.18
VR-13	03/06/97	ND	.010	0.11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-14		ND	ND	0.10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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ND = None Detected at Lab Minimum Reporting Level (MRL)

{ } = Action Levels for Copper and Lead
Italics # = Exceeded Recommended Holding Time

* = Human Health Based Guidance Level
Bold = SDW Standard Exceedance

Appendix E. Summary of Lab-Measured Metal Concentrations in VRGB Groundwater Samples--Continued

Sample ID #	Sample Date	Al mg/l	As mg/l	B mg/l	Ba mg/l	Be mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Mn mg/l	Hg mg/l	Se mg/	Sb mg/l	Ag mg/l	Tl mg/l	Zn mg/l
Minimum Reporting Levels (MRL)		0.50	.010	0.10	0.10	.0005	.0010	0.010	0.010	.10	0.005	.05	.0005	.005	.005	.001	.005	0.05
Maximum Contaminant Levels (MCL)		(0.05 to 0.20)	.05	0.63*	2.0		.005	0.1	{1.3}	(0.3)	{.015}	(.05)	.002	.05		(0.1)		(5.0)
VR-15	03/25/97	ND	.020	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-16		N/A	.014	1.2	0.015	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-17	03/25/97	ND	.020	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-18	03/25/97	ND	ND	1.2	<.20	ND	ND	ND	ND	**6.9**	ND	**0.14**	ND	ND	ND	ND	ND	0.49
VR-19	03/25/97	ND	ND	1.2	ND	ND	ND	ND	ND	**18**	ND	**0.17**	ND	ND	ND	ND	ND	ND
VR-20	03/25/97	ND	ND	0.74	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-21	03/25/97	ND	ND	0.57	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-22	03/26/97	ND	ND	0.97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-23	03/26/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-24	03/26/97	ND	ND	0.43	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-25	03/26/97	ND	.013	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-26	03/27/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-27	03/27/97	ND	.010	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-28	03/27/97	ND	ND	0.78	ND	ND	ND	ND	ND	**3.6**	ND	**0.10**	ND	ND	ND	ND	ND	0.65
VR-29		ND	ND	0.80	ND	ND	ND	ND	ND	**3.6**	ND	**0.10**	ND	ND	ND	ND	ND	0.68

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Italics # = Exceeded Recommended Holding Time

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Bold = SDW Standard Exceedance

Appendix E. Summary of Lab-Measured Metal Concentrations in VRGB Groundwater Samples--Continued

Sample ID #	Sample Date	Al mg/l	As mg/l	B mg/l	Ba mg/l	Be mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Mn mg/l	Hg mg/l	Se mg/	Sb mg/l	Ag mg/l	Tl mg/l	Zn mg/l
Minimum Reporting Levels (MRL)		0.50	.010	0.10	0.10	.0005	.0010	0.010	0.010	.10	0.005	.05	.0005	.005	.005	.001	.005	0.05
Maximum Contaminant Levels (MCL)		(0.05 to 0.20)	.05	0.63*	2.0		.005	0.1	{1.3}	(0.3)	{.015}	(.05)	.002	.05		(0.1)		(5.0)
VR-30	03/27/97	ND	ND	0.16	ND	ND	ND	ND	ND	ND	ND	ND	.0005	ND	ND	ND	ND	0.41
VR-31	03/27/97	ND	ND	0.33	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-32	03/27/97	ND	ND	0.25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-33	03/27/97	ND	ND	0.38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-34	04/22/97	ND	0.013	0.81	ND	ND	ND	0.016	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.10
VR-35	04/22/97	ND	0.011	0.83	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-36	04/22/97	ND	ND	0.36	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.072
VR-37	04/22/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.12
VR-38	04/22/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.19
VR-39	04/22/97	ND	ND	0.23	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-40	04/22/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VR-41	04/22/97	ND	ND	1.1	ND	ND	ND	ND	ND	**2.3**	ND	ND	.0005	ND	.007	ND	ND	ND
VR-42	04/22/97	ND	ND	1.4	0.013	ND	ND	ND	ND	**2.6**	ND	ND	ND	.005	ND	ND	ND	ND

( ) = Secondary SDW Maximum Contaminant Level
ND = None Detected at Lab Minimum Reporting Level (MRL)

{ } = Action Levels for Copper and Lead
Italics # = Exceeded Recommended Holding Time

* = Human Health Based Guidance Level
Bold = SDW Standard Exceedance

Appendix E. Summary of Lab-Measured Metal Concentrations in VRGB Groundwater Samples--Continued

Sample ID #	Sample Date	Al mg/l	As mg/l	B mg/l	Ba mg/l	Be mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Mn mg/l	Hg mg/l	Se mg/	Sb mg/l	Ag mg/l	Tl mg/l	Zn mg/l
Minimum Reporting Levels (MRL)		0.50	.010	0.10	0.10	.0005	.0010	0.010	0.010	.10	0.005	.05	.0005	.005	.005	.001	.005	0.05
Maximum Contaminant Levels (MCL)		(0.05 to 0.20)	.05	0.63*	2.0		.005	0.1	{1.3}	(0.3)	{.015}	(.05)	.002	.05		(0.1)		(5.0)
VR-43	04/22/97	ND	.019	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.007	ND	ND	ND
VR-44	04/22/97	ND	.019	**1.1**	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.006	ND	ND	ND
VR-45	04/22/97	ND	ND	1.1	ND	ND	ND	ND	ND	**0.43**	ND	ND	ND	ND	.007	ND	ND	ND
VR-46	04/22/97	ND	ND	1.4	ND	ND	ND	ND	ND	**0.14**	ND	**0.06**	ND	ND	.008	ND	ND	ND
VR-47	04/22/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

( ) = Secondary SDW Maximum Contaminant Level
ND = None Detected at Lab Minimum Reporting Level (MRL)
{ } = Action Levels for Copper and Lead
Italics # = Exceeded Recommended Holding Time
* = Human Health Based Guidance Level
Bold = SDW Standard Exceedance

Appendix F. Summary of Radionuclide Levels in VRGB Groundwater Samples

Sample ID #	Date Sampled	Gross Alpha (pCi/L) (Activity) + (Error)	Gross Beta (pCi/L) (Activity) + (Error)	Ra-226 (pCi/L) (Activity) + (Error)	Mass Uranium (µg/l) (Activity) + (Error)
Maximum Contaminant Levels (MCLs)		15	50	5	
VR-15	03/25/97	**2.0E+001 + 1.5E+000**	2.8E+001 + 1.6E+000	1.2E+000 + 4.0E-001	3.5E+000 + 8.0E-002
VR-17	03/25/97	4.6E+000 + 1.0E+000	3.3E+001 + 2.0E+000		
VR-18	03/25/97	5.3E+000 + 1.1E+000	3.5E+001 + 2.0E+000	7.0E-001 + 4.0E-001	
VR-20	03/25/97	2.9E+000 + 9.8E-001	1.8E+001 + 1.6E+000		
VR-21	03/25/97	3.2E+000 + 1.0E+000	1.6E+001 + 1.4E+000		
VR-22	03/26/97	9.8E+000 + 1.2E+000	8.2E+000 + 1.5E+000	< LLD (3.0E-001)	
VR-24	03/26/97	7.4E+000 + 1.2E+000	1.3E+000 + 1.6E+000	< LLD (3.0E-001)	
VR-26	03/26/97	1.9E+000 + 1.2E+000	< LLD (1.8E+000)		
VR-27	03/27/97	2.1E+000 + 1.5E+000	< LLD (1.9E+000)		
VR-30	03/27/97	1.6E+000 + 1.5E+000	< LLD (2.0E+000)		

Bold = SDW Standard Exceedance

Appendix G. Summary of Groundwater Protection List Pesticides in VRGB Samples

Sample Number	Sample Date	Pesticides Detected
VR-35	04/22/97	None
VR-39	04/22/97	None
VR-46	04/22/97	None

Appendix H. Pesticides on the ADEQ Groundwater Protection List (GWPL)

Compound	Minimum Reporting Limit (MRLs) µg/l	Health-Based Guidance Levels (HBGLs) µg/l	Maximum Contaminant Levels (MCLs) µg/l
ACEPHATE	N.R.	4	
ALACHLOR	10	0.44	2.0
ALDICARB	2	7	3.0
ARSENIC ACID			
AMETRYN	10	63	
ATRAZINE	10	0.16	3.0
AZINPHOS-METHYL	5	18	
BROMACIL	20	91	
BUTYLATE	5	350	
CACODYLIC ACID			
CAPTAN	30	10	
CARBARYL	2	700	
CARBOFURAN	2	35	
CARBOXIN	10	700	
CHLOROTHALNIL	10	3.2	
CHLORSULFURON	N.R.	350	
COPPER SULFATE			
CYANAZINE	10	0.04	
CYCLOATE	8		
CYROMAZINE	N.R.	53	
DCPA	5	70	
DIAZINON	10	6.3	
DICAMBA	0.5	210	
DICHLORAN	10	180	
DIETHATHYL ETHYL	5		

N.R. = Compound recovered at less than 30% in the extraction process

Appendix H. Pesticides on the ADEQ Groundwater Protection List (GWPL)--Continued

Compound	Minimum Reporting Limit (MRLs) µg/l	Health-Based Guidance Levels (HBGLs) µg/l	Maximum Contaminant Levels (MCLs) µg/l
DIMETHOATE	10	1.4	
DIPHENAMID	10	210	
DIRUON	20	14	
DPX-M6316	20	91	
DSMA			
ENDOSULFAN	10	42	
EPTC	10	180	
ETHOFUMESATE	10		
ETHOPROP	10		
FENAMIPHOS	10	1.8	
FENARIMOL	10	460	
FLUAZIFOP-P-BUTYL	5		
FLUCYTHRINATE	10		
FLUOMETURON	30	91	
FLURIDONE	10	560	
HEXAZINONE	5	230	
IMMAZALIL	15	91	
ISAZOPHOS	10		
LINDANE	5	0.03	0.20
LINURON	50	1.4	
MAA			
METALAXYL	5	420	
METALDEHYDE	20		
METHIOCARB	2	8.8	
METHOMYL	2	180	
METHYL PARATHION	10	1.8	

Appendix H. Pesticides on the ADEQ Groundwater Protection List (GWPL)--Continued

Compound	Minimum Reporting Limit (MRLs) µg/l	Health-Based Guidance Levels (HBGLs) µg/l	Maximum Contaminant Levels (MCLs) µg/l
METOLACHLOR	5	110	
METRIBUZIN	10	180	
METSULFURON-METHYL	N.R.	1800	
MEVINPHOS	10		
MONOCROTOPHOS	N.R.	0.32	
MSMA			
MYCLOBUTANIL	10	180	
NAPROPAMIDE	10	700	
NORFLURAZON	10	280	
OXAMYL	1	180	200
PARATHION	10	4.2	
PEBULATE	5		
PERMETHRIN	5	350	
PHOSMET	10	140	
PHOSPHAMIDON	10	1.2	
PIPERONYL BUTOXIDE	5		
PROFENOFOS	10	0.35	
PROMETON	5	110	
PROMETRYN	10	28	
PRONAMIDE	5	53	
PROPICONAZOLE	10	91	
PYRAZON	20		
SETHOXYDIM	10	630	
SIMAZINE	10	0.29	1
SULFOMETURON-METHYL	30		

N.R. = Compound recovered at less than 30% in the extraction process

Appendix H. Pesticides on the ADEQ Groundwater Protection List (GWPL)--Continued

Compound	Minimum Reporting Limit (MRLs) µg/l	Health-Based Guidance Levels (HBGLs) µg/l	Maximum Contaminant Levels (MCLs) µg/l
SULPROFUS	10	18	
TEBUTHIURON	30	490	
TERBACIL	10	91	
TERBUFOS	5	0.18	
THIDIAZURON	40		
TRIADIMEFON	5	210	
2,4-D	0.5	70	70
VERNOLATE	5	7	
VINCLOZOLIN	5	180	

Appendix I. Summary of Surface Water Parameter Levels in the VRGB

Parameter	Beaver Dam Wash	Virgin River
As	ND	ND
B	1.32	ND
Ca	88	288.3
Cl	32.6	348
EC-field	804.8	2995
EC-lab	766.8	-
F	0.665	0.8
HCO_3	256.7	346
Hardness	328.3	1071.7
Fe	ND	ND
Mg	26.2	87.7
Mn	ND	ND
NO_3-N	0.908	0.585
pH-field	7.84	7.78
pH-lab	8.32	-
K	5.32	24.3
Na	45.1	256.7
SO_4	153.7	901.6
Temperature-field	20.7	18.8
Total Alkalinity	214.5	283.8
TDS	541	2236.7
TKN	.16	.15
Turbidity	1.14	14.1
Zn	ND	ND

ND = Not detected at MRL - = Not sampled for
All units mg/l except pH (SU), EC (umhos/cm), & turbidity (NTU)
Beaver Dam Wash parameter levels are average of 4 samples collected by ADEQ between 11/93 - 9/94
Virgin River parameter levels are average of 6 samples collected by USGS between 11/96 - 8/97