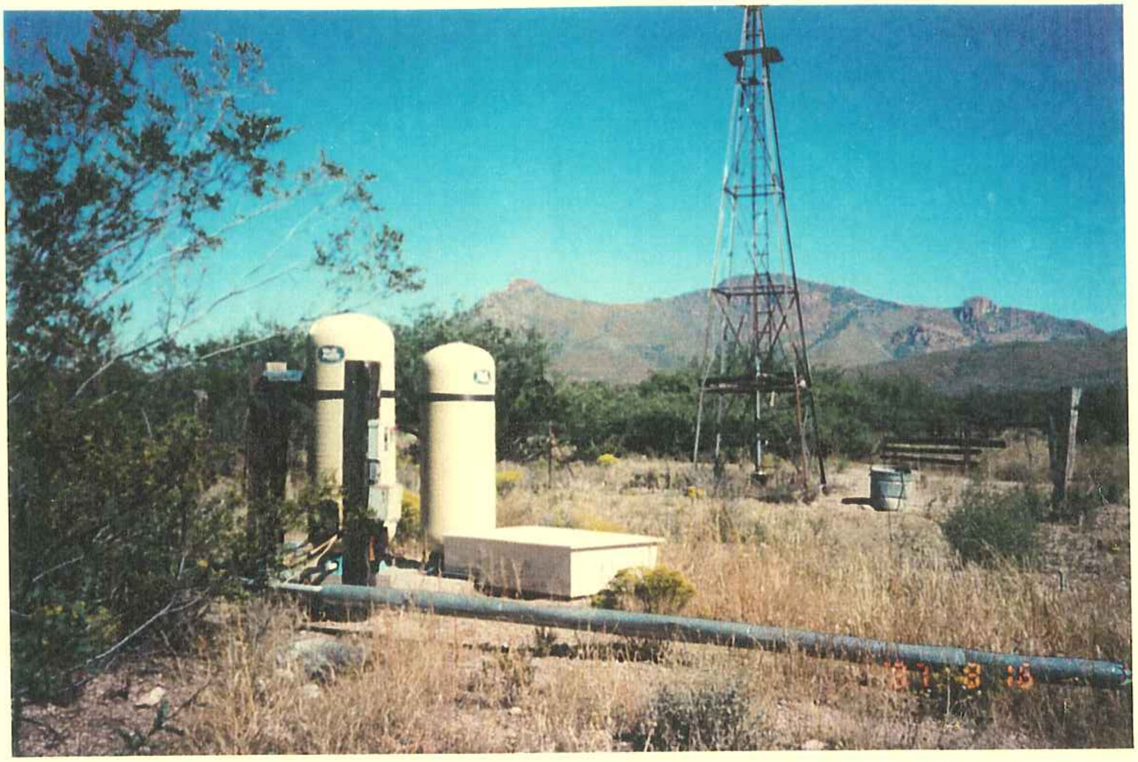
AMBIENT GROUNDWATER QUALITY OF THE DOUGLAS BASIN:

A 1995-96 BASELINE STUDY



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Final Report of:
Ambient Groundwater Quality of the Douglas Basin:
A 1995-96 Baseline Study

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VISION

The Arizona Department of Environmental Quality will be the best environmental agency in the nation. We will be a well trained, motivated team that will:

~ 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.

MISSION

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: Both an older windmill and newer well with an electric, submersible pump are visible at this site located west of the Pedregosa Mountains.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

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

Ambient Groundwater Quality of the Virgin River Basin: A 1997 Baseline Study. ADEQ Publication OFR 99-4.

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

Collection and Analysis of Ground-Water Samples in the Sierra Vista Basin, Arizona, 1996 (A Cooperative Program Between the USGS and the Arizona Department of Environmental Quality). USGS Fact Sheet FS-107-97.

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

TABLE OF CONTENTS

PART IV ANALYTICAL ANALYSIS

PART V FINAL ANALYSIS

PART VI REFERENCES

PART VII APPENDICES

LIST OF TABLES

LIST OF FIGURES

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 Douglas Groundwater Basin (DGB) in 1995-96. A total of 51 groundwater samples were collected for the study, whose design included 29 grid-based, stratified random samples and 21 targeted samples. All groundwater samples were analyzed for Safe Drinking Water (SDW) inorganics, 12 samples were analyzed for SDW Volatile Organic Compounds (VOCs), 7 samples were analyzed for Groundwater Protection List (GWPL) pesticides, and 6 samples were analyzed for radionuclides. Laboratory results revealed no detections of any GWPL pesticides while the only SDW VOC detected was chloroform in 1 sample. Radionuclide samples did not exceed Primary Maximum Contaminant Levels (MCLs) for any parameter. With inorganic parameters, levels of arsenic, beryllium, and nitrate each exceeded their respective health-based Primary MCLs in 1 sample apiece. Aesthetics-based Secondary MCLs were exceeded in 16 samples: 8 times by fluoride and total dissolved solids (TDS), twice by pH and sulfate, and once by chloride, iron, and manganese. These results suggest that regional groundwater quality conditions generally support drinking water uses, but because of aesthetic factors, some residents may prefer to use treated water for domestic purposes.

Piper trilinear diagrams reveal that of the 2 major aquifers in the DGB, bedrock aquifer samples tend to exhibit a calcium-bicarbonate chemistry; alluvial aquifer samples also typically exhibit a calcium-bicarbonate chemistry though sodium-bicarbonate, sodium-sulfate, and calcium-sulfate varieties are also present in this aquifer. Statistical analyses found that many significant differences exist in inorganic groundwater quality parameter levels between aquifers while fewer differences existed between groundwater management areas, and between various divisions (East-West, North-South) of the DGB. A strong positive correlation existed between the levels of most major ions and nitrate; in contrast, fluoride and pH tend to be negatively correlated with other groundwater quality parameters while trace elements have few significant correlations. Many parameter levels also significantly increased or decreased with increasing groundwater depth below land surface in the DGB.

Comparing parameter levels from targeted samples with 95% confidence intervals established for the DGB indicated several potential impacts. Nitrate appears to be elevated in the Elfrida area perhaps from agricultural practices and/or septic systems. Near the City of Douglas, high sodium and pH levels in combination with low calcium and magnesium levels appear to indicate groundwater is being subjected to natural softening by cation exchange. Elevated sulfate levels in the Mule Gulch area might be the result of mine tailings in the area. Finally, a geothermal anomaly appears to exist east of the Bisbee-Douglas Airport resulting in TDS levels reaching 14,000 mg/l and elevated levels of temperature, arsenic, and other parameters.

A time-trend analysis was conducted using groundwater quality data collected by ADWR from 7 wells in 1987. The results indicated while many of the 12 parameters appeared to have higher levels in 1995-96 than 1987, only nitrate and potassium were significantly higher.

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 Douglas Groundwater Basin (DGB) in 1995-96. The impetus for this groundwater study was threefold:

- An ADEQ report (Hood, 1991) which, in evaluating the need for ambient monitoring in each of the 50 designated groundwater basins in Arizona, ranked the DGB as the 8th highest basin priority for the collection of groundwater quality data;
- Because of recent population growth and the associated increase in well drilling, an opportunity to collect groundwater samples from portions of the basin that could not be sampled by previous studies; and
- Support the data collection and hydrologic analysis requirements of the ADEQ Watershed Program for the Upper San Pedro Watershed.

This groundwater study had five objectives:

- To obtain baseline data throughout the DGB on the occurrence, concentrations, and ranges of a wide array of groundwater quality parameters including the identification and delineation of any areas with elevated groundwater quality parameter levels.
- With the sampling sites determined through means of stratified random selection, to examine particular geographic areas and aquifers within the DGB 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.
- Using groundwater quality data collected during previous studies by other government agencies, resample some of the same wells in order to examine temporal groundwater quality trends in the DGB.
- To establish a statistically designed ambient groundwater quality index well monitoring network for the DGB.

Meeting these objectives in a reproducible, scientific study that utilizes statistical analysis to make broad statements concerning groundwater quality will provide many benefits.

- Residents in the DGB 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 seldom tested for a wide variety of possible pollutants. While 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. While collecting and analyzing groundwater samples from all these private wells would be prohibitively expensive, 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 DGB is currently suitable for domestic and municipal uses.

- 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 DGB planning and new public water supply well locations and determine wellhead protection areas.

- Provide reliable and consistent information on the status and trends in the quality of the groundwater resources of the DGB.

3. INTRODUCTION

3.1 Physical Setting

Located in the southeast corner of Arizona, the Douglas Groundwater Basin (DGB) spans approximately 950 square miles and is considered part of the Mexican Highland section of the Basin and Range physiographic province (**Figure 1**). The DGB is the southern part of the Sulphur Springs Valley, a northwest-southeast trending structural trough that extends from the central portion of Aravaipa Canyon to the northeastern section of the State of Sonora, Mexico. The DGB consists of a broad alluvial valley, approximately 15 miles wide and 35 miles long which is isolated by elongated mountain chains (ADWR, 1994). The valley slopes are gentle and concave upward from the axis to the sharply defined mountain fronts (Coates and Cushman, 1955).

The basin's boundaries include the Swisshelm, Pedregosa, and Perilla Mountains to the east, the Mule and Dragoon Mountains to the west, and to the north, a series of small ridges and buttes the most prominent of which are Six Mile Hill, Township Butte, the Pearce Hills, Turkey Creek Ridge, and Squaretop Hills that are remnants of an older landscape now largely buried by alluvium (Coates and Cushman, 1955). Although the basin extends south into Mexico, for the purposes of this report, the international border - an artificial political boundary - serves as an arbitrary groundwater divide to the south (**Figure 1**). Bedrock structures are effective in controlling groundwater movement, though some groundwater inflow may occur in the small ridges and hills that denote the DGB's northeast boundary (Coates and Cushman, 1955). Bedrock elevations generally lie above 4,700 feet and range up to 6,390 feet in the Perilla Mountains to 7,185 feet in the Swisshelm Mountains. The basin's alluvial valley slopes southward with elevations ranging from 4,350 feet above mean sea level in the hills that form the basin's northern boundary to 3,900 feet above mean sea level along the international boundary (Coates and Cushman, 1955).

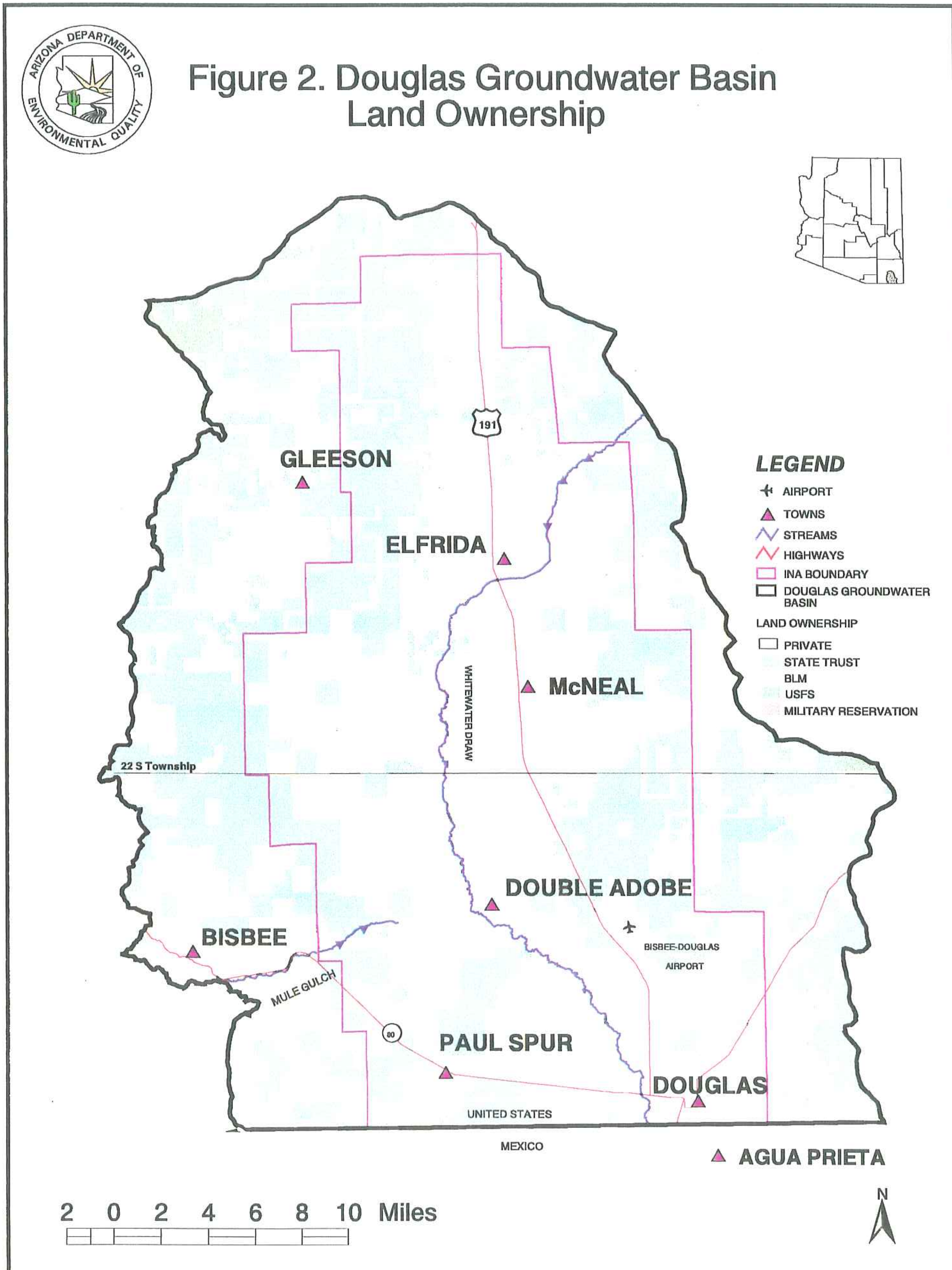
Unusual for Arizona, the DGB is largely composed of private land and State Trust land, both comprising the majority of holdings in the Sulphur Springs Valley, though both also are found in upland areas. Finally, small portions of land managed by the Bureau of Land Management and the Forest Service are found within the DGB, usually in the higher upland areas (**Figure 2**).

3.2 Surface Water

With the exception of small stockponds, residents of the DGB are dependent on groundwater for their various water needs (ADWR, 1994). The basin is drained by Whitewater Draw, an ephemeral watercourse. Tributary watercourses to the Whitewater Draw are also ephemeral and most disappear before reaching the central portion of the valley floor (Coates and Cushman, 1955).

Figure 1. Douglas Groundwater Basin Study Area

Figure 2. Douglas Groundwater Basin Land Ownership



The Whitewater Draw heads in Rucker Canyon in the Chiricahua Mountains which is actually in the adjacent Willcox Groundwater Basin, an example of where a groundwater basin cuts across a surface water divide (ADWR, 1994). This watercourse derives its name from the white caliche deposits along its banks (Coates and Cushman, 1955). Whitewater Draw proceeds westward around the north end of the Swisshelm Mountains at which point it enters the DGB. The channel of this watercourse loses its identity for several miles around Elfrida, before emerging as an arroyo and continuing southeast through the center of the Sulphur Springs Valley (**Figure 1**). The Whitewater Draw continues through the Douglas Reduction Works (DRW) mining slag site until eventually discharging into the Aqua Prieta River, a tributary of the Rio Yaqui that drains into the Gulf of California.

The other portions of the Whitewater Draw flow only for short periods in response to major precipitation events. There are only 2 perennial stretches, the upper 3 miles in Rucker Canyon and the 2-mile reach immediately north of the international border (Coates and Cushman, 1955) though more recent information suggests this lower stretch is now intermittent (Rascona, 1993). This stretch above the international border may be maintained by the presence of a perched aquifer in the area as suggested by several sources (Castaneda, 1998) (Coates and Cushman, 1955). The Whitewater Draw surface water quality parameter levels collected in 1998 downgradient of the DRW mining slag site at the International Border are provided in **Appendix K**. Total annual discharge of Whitewater Draw, measured 1.5 miles north of the international border, averages about 6,730 acre-feet (Rascona, 1993).

3.3 Climate

The climate in the valley portion of the DGB is characterized by low precipitation, high evaporation, and large daily fluctuations in temperature. The hot summer days are tempered by winds and low humidity, and the nights are cool. Winter temperatures are mild, although freezing temperatures occasionally occur during the evening. Climate conditions in the surrounding mountains are cooler and snow is common at the higher elevations during the winter (Coates and Cushman, 1955).

Average annual precipitation in the DGB ranges from approximately 11 inches at the Town of McNeal in the central portion of the basin to 14 inches at the City of Douglas situated along the International Border. The majority of this precipitation falls from July through September during thunderstorms, while the remainder consists of gentle rain and occasionally snow from October through March. The average daily maximum temperature at Douglas is approximately 79 degrees Fahrenheit, and the average daily minimum temperature is 44 degrees Fahrenheit (Sellers et al., 1985).

3.4 Cultural Setting

The largest urban areas within the DGB are the Cities of Douglas and Bisbee, having 1995 populations of 14,800 and 6,500, respectively (**Figure 1**). Bisbee actually lies on the groundwater basin divide with portions of the urban area situated within the Upper San Pedro Groundwater Basin. Copper production was formerly the main industry of both cities; mining occurred at the ore source near Bisbee while Douglas was the site of ore smelting operations. The copper industry in this area is now largely inactive. Mining of copper ore in Bisbee was halted in 1975 and mining activity is now limited to leaching operations in the Mule Gulch area (Castaneda, 1998) while the Copper Queen Smelter in Douglas was closed and demolished in 1988, leaving behind the DRW mining slag site. This 2,000 acre site located one-half mile to the west of Douglas, was entered into the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) in 1979 because of potential hazardous substance contamination of the groundwater and air from the huge on-site waste slag heaps and/or heavy metal particulate from smelter operations (Castaneda, 1998). The DRW site was also used by the City of Douglas during the 1980s as the sites for 4 sanitary landfills (Castaneda, 1998).

Douglas and Bisbee now largely serve as government, retail, and service centers. Bisbee serves as the county seat of Cochise County while the City of Douglas is part of a larger urban area. To the south, across the international border in Mexico, lies the sister city of Agua Prieta with a 1995 population of approximately 56,000. Pirtleville is a small community on the northwestern outskirts of Douglas.

Communities within the DGB include the agricultural towns of Elfrida and McNeal located in the heart of the Sulphur Springs Valley (**Figure 1**). Farming, almost completely dependent on irrigation in this area, started around 1910 when the first irrigation wells were drilled in the DGB (Coates and Cushman, 1955). Agriculture is an important sector of the economy in the DGB as over 38,000 acres of land were irrigated in 1978 with most of the acreage located in the north and central portions of the basin. The economic impact of farming in the DGB is decreasing from it peak in the early 1970s as over 10,000 acres went out of production between 1976 and 1986 (Regan, 1986). Spatially, the greatest land use consists of grazing with many cattle ranches located in the basin.

Other small communities within the DGB include three founded on mining, Gleason, Pearce, and Paul Spur. Gleason, located in the Dragoon Mountains, and Pearce, located at the northern boundary of the basin, are former mining towns. Paul Spur, located to the west of Douglas, is located adjacent to a large limestone deposit which is currently being mined. Other settlements in the DGB include Bisbee Junction, formerly a railroad town, is now predominately a residential area of Bisbee, and Sunizona, a retirement community located in the northeast portion of the basin. In addition, isolated rural residences are becoming an increasingly common part of the DGB landscape.

3.5 Wastewater Treatment

Communities within the DGB that utilize wastewater treatment plants include those in the communities of Bisbee and Douglas. The smaller communities of Elfrida, McNeal, and Pirtleville - as well as many other developments, domestic residences, and commercial enterprises dispersed throughout the basin - use septic systems as a means of wastewater disposal (ADHS, 1977). Bisbee has 3 wastewater plants: Warren, San Jose that releases effluent into the San Pedro Watershed and Mule Gulch, in operation since 1954, discharges effluent into Mule Gulch within the DGB. The Douglas wastewater treatment plant, constructed in 1946, releases effluent literally at the international border which is later used for irrigation in Mexico. Elfrida, McNeal, and Pirtleville are considered to be located in soils considered unsuitable for septic system operation because of very low permeability rates (ADHS, 1977). Septic systems continue to be operated in these communities because of relatively low population densities that may limit impacts as well as the lack of economical alternatives in these small communities.

4. HYDROGEOLOGY

4.1 Aquifer Characteristics

The geology of the DGB consists of mountains composed primarily of sedimentary and igneous rocks, with local outcrops of metamorphic rocks that surround an alluvial valley composed largely of eroded sediments from the adjacent mountain areas (**Figure 3**). The basin-fill consists of coarse deposits near the mountain fronts and fine-grained near the center of the basin, though varying conditions of transportation and deposition make the actual grain-size distribution much more complex (Coates and Cushman, 1955). The basin-fill consists of both upper and lower alluvial deposits (Rascona, 1993):

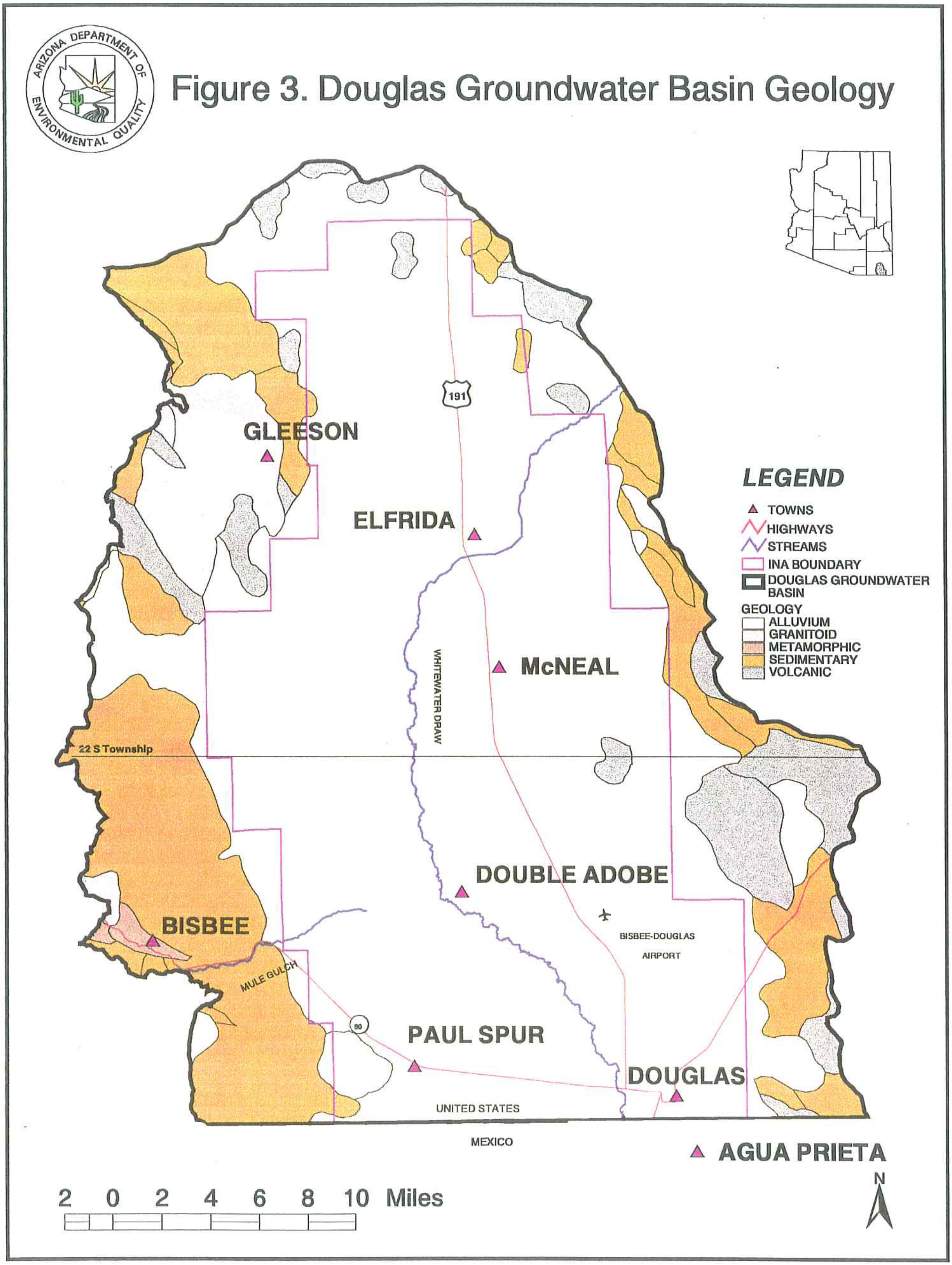
- The upper alluvial deposits consist of unconsolidated to poorly consolidated gravel, sand, and silt with a maximum thickness of about 1,000 feet.

- The lower alluvial deposits consist of conglomerate, gravel, and sand derived from the underlying or nearby rhyolitic rocks. These deposits occur below the upper alluvial deposits at depths beginning at about 650 feet and extending up to 2,200 feet.

Although groundwater is found in both basin-fill deposits and in the mountain bedrock, the principal water-bearing unit in the DGB is the upper alluvial deposits. Alluvial deposits below the water table contain groundwater, but there are considerable differences in water storage, water transmitting, and water movement capabilities (Coates and Cushman, 1955). Water is drawn from sand and gravel lenses which are interconnected; however, the connections may be indirect. Each lense may have a different ability to store and transmit water. The water-bearing zones in this unit are unconfined to semi-confined and, for the most part, are interconnected to form a single groundwater reservoir. The interbedded clay and silt layers in the basin-fill result in both localized, confined conditions, and perched water tables. These confined conditions are more common in the southern portion of the basin. Water levels in wells in this area rise above the regional water table but don't reach the surface (Rascona, 1993).

Groundwater is also found in the mountain bedrock. Sedimentary and granitic bedrock provide most of the groundwater found in the mountains while the schist and volcanic rocks are generally non-water-bearing. The water-bearing ability of the bedrock is related to the degree of fracturing or weathering the rock has undergone which act as both minute conduits and areas of water storage (Coates and Cushman, 1955). Another, albeit limited, source of groundwater are small perched aquifers. These are formed by relatively impervious zones of caliche, clay, and/ or lava that collect small bodies of unconfined water above and separate from the main alluvial aquifer. Perched aquifers occur in small isolated areas near mountain fronts, mainly along major washes immediately downstream from the bedrock-alluvium contact (Coates and Cushman, 1955). Perched aquifers have a limited storage capacity and are apt to go dry during periods of drought.

Figure 3. Douglas Groundwater Basin Geology



4.2 Groundwater Production

Well yields from the basin-fill range from a few gallons per minute in small-diameter stock and domestic wells to 2,000 gallons per minute in large-capacity irrigation wells. With adequate amounts and quality of groundwater generally available in the upper alluvial deposits, groundwater situated in the lower alluvial deposits are typically not withdrawn for use in the DGB. Alluvium below depths of 300 - 400 feet, because of consolidation and the consequent decrease in permeability, have generally not yielded water to wells in sufficient quantities to justify the cost of the drilling below those depths (Coates and Cushman, 1955).

Well yields in the bedrock usually range from several gallons per minute up to 50 gallons per minute; however, highly fractured and cavernous limestone in Bisbee reportedly yields up to several million gallons per day (Rascona, 1993). Typically, the mountain bedrock provides relatively minor amounts from localized sources, usually only enough for low-capacity stock and domestic wells. The Mule, Perilla and Swisshelm Mountains - as well as the northern portion of the Dragoon Mountains - consist predominantly of sedimentary bedrock, the southern portion of the Dragoon Mountains are typically granitic bedrock, while volcanic rocks are common along the northern drainage divide and in the Pedregosa Mountains (Coates and Cushman, 1955).

4.3 Groundwater Recharge, Flow, and Use

Groundwater recharge in the DGB occurs mainly through precipitation in the surrounding mountains with mountain-front recharge estimated at 20,000 acre-feet per year (Coates and Cushman, 1955). Recharge is especially great along washes in a narrow zone along the mountain fronts. Very little rainfall on the valley floor is recharged into the basin-fill aquifer because of use by vegetation, high evaporation rates, and layers of clay and caliche which impede downward percolation of water. Irrigation recharge is also thought to be negligible because of these same factors. The small amount of groundwater recharge that does occur in the valley floor occurs over the coarse-grained materials along the washes (Rascona, 1993). Finally, recharge also occurs with groundwater underflow through the course of Whitewater Draw and other ephemeral streams entering the basin along its northern boundary. In contrast, groundwater is discharged from the DGB by evapotranspiration, flow southward out of the basin, and pumping from wells, with the latter the most significant (Coates and Cushman, 1955).

Historically, groundwater flowed into the DGB from recharge areas in the mountains toward the center of the basin and then south towards Mexico. The gradient of the water table is greatest near the mountains and becomes progressively less toward the valley center (Coates and Cushman, 1955). Groundwater pumpage for irrigation, which began on a large-scale in the late 1940's, altered the regional groundwater flow by creating several cones of depression. The largest cone of depression is located north of Elfrida and groundwater now flows north from this town, reversing the historic direction of groundwater movement. Water levels in the valley ranged from 50 feet below land surface to 296 feet below land surface (ADWR, 1992). Generally, water-level declines have occurred since the late 1940's when groundwater pumpage began exceeding groundwater recharge, though an increase in pumping costs in the late 1970s has reduced water usage and groundwater elevations have increased in many areas (Regan, 1986).

The rate of groundwater movement depends upon the groundwater gradient and upon the type of sediments the groundwater moves through. In general, the groundwater gradient is greatest near the mountains and becomes progressively less toward the valley (Coates and Cushman, 1955). Groundwater movement rates are thought to be highly variable, ranging from a few inches to several feet per day with the slower rates typically occurring in the central portion of the valley where silt and clay compromise up to 80% of the alluvium in many areas (Coates and Cushman, 1955).

Groundwater in the DGB is used for irrigation, municipal, domestic, and stock purposes. The majority of groundwater pumped in the DGB is used for irrigation. In comparison, municipal, industrial, domestic, and stock utilize relatively minor amounts of this resource. Total groundwater pumpage was less than 5,000 acre-feet prior to 1939. Annual pumpage increased steadily from the mid 1940's to the mid 1970's and peaked at 138,000 acre-feet in 1974. Groundwater withdrawals increased especially in the early 1960s, when withdrawals doubled from 60,000 acre-feet in 1964 to 120,000 in 1967, a period when many farmers relocated from the High Plains of Texas to the Sulphur Springs Valley (Regan, 1986). This migration occurred because many farmers in the High Plains, as their groundwater resource dwindled, began to search for other areas for agricultural development. Southern Arizona was attractive because of its similarities to the High Plains; it had little surface water, relatively high elevations with hot summers, groundwater sources adequate for irrigation, and an overall lack of restrictive groundwater legislation (Regan, 1986). Rising energy costs in the late 1970s caused many farmers to reduce groundwater pumping and by 1990, groundwater pumpage totaled only approximately 43,000 acre-feet (Rascona, 1993).

4.4 Groundwater Management

The DGB has a history of groundwater quantity concerns. With the advent of heavy groundwater pumping for irrigation, the DGB became severely overdrafted in the late 1940's (ADWR, 1994). In 1965, responding to local farmers concerned with the amount of acreage recently brought into production by farmers from Texas, the central alluvial portion of the DGB containing approximately 546 square miles was designated as the Douglas Critical Groundwater Area (CGA) (Regan, 1986). This occurred as the result of legislation contained in the 1948 Arizona Critical Groundwater Code and prohibited the drilling of new irrigation wells within the Douglas CGA, though new irrigated agricultural land could be brought into production when supplied with water from previously existing wells (Regan, 1986). During the 2 year period before the Douglas Basin was declared a CGA, 170 wells were drilled, 25% of all the registered non-exempt (having a pump capacity greater than 35 gallons per minute) wells in the area at the time (Regan, 1986).

The Douglas CGA designation became the Douglas Irrigation Non-expansion Area (INA) with the passage of the Arizona Groundwater Management Act in 1980 (**Figure 1**). The INA grandfathered rights to irrigated land, thus limiting the acreage in the DGB that could be irrigated rather than merely limiting the number of irrigated wells. The INA designation in the Douglas Basin was designed to reduce the negative effects of declining groundwater levels such as higher pumping costs, lower quality water, and subsidence (Regan, 1986). All users of non-exempt wells, those with greater than 35 gallons per minute (gpm), are required to use a water-measuring device and report annual pumpage to the ADWR (Rascona, 1993).

4.5 Groundwater Quality

Although a comprehensive study examining a wide range of groundwater quality parameters of the DGB has not been undertaken, currently available data suggests that much of the groundwater is of suitable quality for human consumption. Studies that have been conducted within the DGB are summarized below.

A USGS study conducted from the late 1940s to the early 1950s collected samples from 112 wells mostly located in the alluvial aquifer (Coates and Cushman, 1955). Results indicated that 98 of the 112 samples had total dissolved solids (TDS) levels less than 500 mg/l consisting mostly of calcium, sodium and bicarbonate. Of the remaining 14 samples with TDS levels greater than 500 mg/l, wells in the vicinity of the Whitewater Draw consisted mainly of sodium, chloride, and sulfate whereas the water from wells east of Douglas contained mainly calcium and sulfate. The study also noted that most samples had hardness levels over 100 mg/l, with the exception of the Douglas area. Fluoride levels greater than 1.5 mg/l were common while nitrate (as N) exceeded 10 mg/l in only 1 sample.

A 1978 groundwater investigation conducted in the DGB by the USGS examined the concentrations of, TDS, anions and cations, and fluoride. In 7 water samples, TDS concentrations ranged from 229 to 680 mg/l and averaged about 390 mg/l. TDS values of 800 mg/l were present in the basin, when estimated from specific conductance values obtained at other wells. TDS values were generally higher in the southern area of the basin than the northern. Of the 9 groundwater samples which were analyzed for ions, 7 were of the sodium-bicarbonate type, 1 was of the sodium-chloride type, and 1 was of the calcium-chloride type. Fluoride concentrations ranged from 0.3 - 8.5 mg/l and averaged about 1.1 mg/l in the 37 samples collected.

The Arizona Department of Water Resources (ADWR) collected additional groundwater quality data from 1986 - 1991. Results similar to the 1978 USGS study were obtained. Specific conductance values ranged from 210 to 2,380 microsiemens per centimeter (μS/cm) and averaged around 500 μS/cm. Specific conductance levels increased southward along Whitewater Draw but remained fairly constant throughout the basin away from this watercourse. A total of 36 groundwater samples were analyzed for ions. Two types of water dominated these samples: sodium-bicarbonate characterized 18 groundwater samples and calcium-bicarbonate characterized 14 groundwater samples. Sodium-chloride and calcium-sulfate water each characterized 2 groundwater samples. Values for fluoride ranged from 0.2 to 15 mg/l and averaged around 2.0 mg/l and were higher in the northern part of the basin. In addition, Primary Maximum Contaminant Level (MCL) exceedances for nitrate and arsenic were also discovered in groundwater samples.

Another study (Littin, 1987) conducted mainly outside the basin, though overlapping the southwest corner of the DGB, noted elevated sulfate levels (650 - 850 mg/l) in the groundwater between the towns of Bisbee and Warren, and also northeast of the town of Naco. The study hypothesized that these elevated sulfate levels might be resulting from groundwater recharge through an upgradient mine-tailings pond. While this area is generally outside the basin, the elevated sulfate levels have the potential to impact the DGB.

The Environmental Protection Agency (EPA) collected groundwater samples in the DRW mining slag site during 1995-96 which did not reveal inorganic contaminants above background levels except with selenium, gross alpha, and gross beta. VOCs detected in the DRW mining slag site were thought to be from City of Douglas landfills in the area (Castaneda, 1998).

5. METHODS AND MATERIALS

5.1 Sampling Strategy

The regional portion of the DGB study will focus on groundwater quality conditions that are prevalent or large in scale and persistent in time. The study is designed to identify regional degradation of groundwater quality such as occurs from nonpoint sources of pollution or a high density of point sources. In contrast, targeted sampling will focus on groundwater degradation resulting from a specific point source.

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 DGB conducted by ADEQ follows a systematic grid-based, random site-selection approach that is very efficient because it requires sampling relatively few wells to make valid statistical statements about the conditions of large areas. This systematic element causes the selected wells to be spatially spread out while the random element ensures that every well has an equal chance of being sampled. A statistically-designed sampling plan such as this one allows much greater assumptions to be made on the groundwater quality of the DGB based on statistics than would be allowable with a non-statistical approach. This strategy also reduces the possibility of biased well selection and ensures adequate spatial coverage throughout both aquifers and the study area as a whole. The grid overlay for the study will use township/range lines, with each township considered a cell within which a random well will be selected for sampling. The selection of the well within each township will be randomized based on the ADWR well registration; if no registered wells exist which are able to be sampled within a township, an unregistered well and/or spring will instead be sampled where possible.

Several factors were considered as to how many samples were collected for the DGB groundwater study. Aside from administrative limitations on funding and personnel, this decision was based on three factors related to the conditions in the area (Hem, 1970):

- Amount of groundwater quality data already available;
- Hydrologic complexity and variability of the area; and
- Extent to which groundwater of impacted quality is known or believed likely to occur.

A total of 29 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. In addition, 22 targeted wells were sampled to collect groundwater quality information in specific portions of the study area.

5.2 Sample Parameters

Each groundwater sample collected within the DGB was analyzed for SDW inorganic compounds. In addition, limited targeted sampling was conducted for radionuclides, volatile organic compounds (VOCs), and GWPL pesticides from wells in areas deemed most likely to have the respective contaminants. No bacteria sampling was conducted since microbiological contamination problems in groundwater are often transient (Graf, 1990).

The primary groundwater quality parameters sampled for in this study are inorganic, with Safe Drinking Water (SDW) parameters serving as the focus of analysis. During sample collection, the following field parameters were collected:

- temperature
- pH
- EC

From each of the 51 wells sampled as part of this study, an inorganic groundwater sample was collected for analytical analysis for the above-listed groundwater quality parameters. SDW 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 51 wells sampled as part of this study:

- SDW inorganic samples were collected from 51 wells;
- SDW VOC samples were collected from 12 wells;
- Groundwater Protection List (GWPL) pesticide samples were collected from 7 wells;
- SDW Radionuclide samples were collected from 6 wells.

The Groundwater Protection List (GWPL) pesticides, synthetic organic compounds used to control weeds, insects, and other organisms for a variety of agricultural and nonagricultural purposes, were collected with the assistance of the ADEQ Pesticide Contamination Prevention Program (PCPP). These targeted sampling sites were chosen from wells located in agricultural portions of the DGB and focused in areas with the highest concentration of pesticide applications as determined by assessing the 1995 1080 Commercial Pesticide Application Database from the Arizona Department of Agriculture. Three sections of land (Township 18 South, Range 26 East, Section 34; Township 19 South, Range 26 East, Section 28; and Township 18 South, Range 26 East, Section 34) accounted for approximately 50% of the total pesticide applications that occurred within the DGB (Hanus, 1995).

5.3 Sample Collection

Wells constructed for many types of uses - domestic, municipal, irrigation, and stock - were used for groundwater quality sampling. Well data, such as location, depth of well casing, depth of perforated openings, casing size, pump capacity, water level, drawdown, well type, water uses, watershed, county, owner, and driller logs for each well sampled in the study were compiled from the ADWR well registry. When the well is registered, this information is provided to ADWR by the well owner. Sometimes data is omitted from the application and or data input errors occur, leaving incomplete and/or incorrect well records (Regan, 1986).

As recommended by Cohen and others (1988), the same persons who designed the study were also responsible for the collection and interpretation of data. This helps ensure that the data are consistently of high quality and relevant and meaningful interpretations are drawn from the collected information.

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 multiparameter 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. SDW VOCs
2. GWPL Pesticides
3. SDW Inorganic Compounds
4. Radionuclides

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 laboratory while split samples are submitted to 2 different laboratories.

5.4 Sample Containers

SDW VOC samples were collected in duplicate, 40-ml amber glass vials with Teflon caps which contain 10 drops 1:1 hydrochloric (HCl) acid preservative. The vials were prepared by the laboratory. Before sealing the glass vial, litmus paper is used to affirm the sample's pH is below 2; additional HCl is added if need be to bring pH sample to below 2. GWPL pesticides were collected in 1 gallon, amber glass containers. The inorganic constituents were collected in 3 1-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 micron (μM) pore size groundwater capsule filter was used only for metals. 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 collapsible 1-liter plastic containers. With the exception of the radionuclide samples, all groundwater samples were kept at 4^0C by packing on ice in an insulated picnic cooler during transport to the laboratory. Chain of custody procedures were followed in sample handling.

5.5 Laboratories

The Arizona Department of Health Services (ADHS) Laboratory in Phoenix conducted all the inorganic, VOC, and pesticide analyses for this study, the only exceptions being 4 inorganic splits. Sample DGB-24 was analyzed by Analytical Technology Laboratory in Phoenix, DGB-35a and DGB-47 were analyzed by McKenzie Laboratory in Phoenix, and DGB-49 was analyzed by 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.

5.6 Statistical Considerations

There were several considerations in selecting whether parametric or nonparametric statistical tests were more 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 such as Analysis of Variance (ANOVA). But as a result of these factors, the use of parametric statistical methods such as ANOVA to analyze groundwater quality data may at times be flawed.

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. In USGS studies such as Berndt's (1996), the nonparametric Kruskal-Wallis test was used to examine differences in parameter concentrations in groundwater between groups of data typically not normally or log-normally distributed. The Kruskal-Wallis test uses the differences, but also incorporates information about the magnitude of each difference. 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 linear models should consider transformations or robust models before retreating to nonparametrics.

With the absence of a universally accepted statistical method with which to treat groundwater quality data, the decision was made to analyze the data utilizing three different types of statistical analyses: ANOVA, ANOVA using logarithmically transformed data, and Kruskal-Wallis test. For time-trend comparisons conducted between 2 groups of groundwater quality data collected by different government agencies, the nonparametric Wilcoxon test was considered the most suitable for statistical analysis. All statistical tests were conducted using on a personal computer using SYSTAT software.

Part III

GROUNDWATER SAMPLING RESULTS

6. ANALYTICAL RESULTS

For the DGB study, ADEQ personnel collected and transported to State-certified laboratories for analyses: 51 SDW inorganic samples, 12 SDW VOC samples, 7 GWPL pesticide samples, and 6 radionuclide samples. For QA/QC purposes, 4 splits, 2 duplicates and 2 equipment blanks were collected for SDW inorganic analysis. No duplicates, splits, and/or blanks were collected with VOCs, GWPL pesticides, and radionuclides except for 3 VOC travel blanks and 1 duplicate GWPL pesticide sample. Groundwater sampling in the DGB occurred over the course of 6 field trips from October 1995 to June 1996.

Characteristics describing the 51 wells from which a groundwater sample was collected for this study are provided in **Appendix A**. Well information includes:

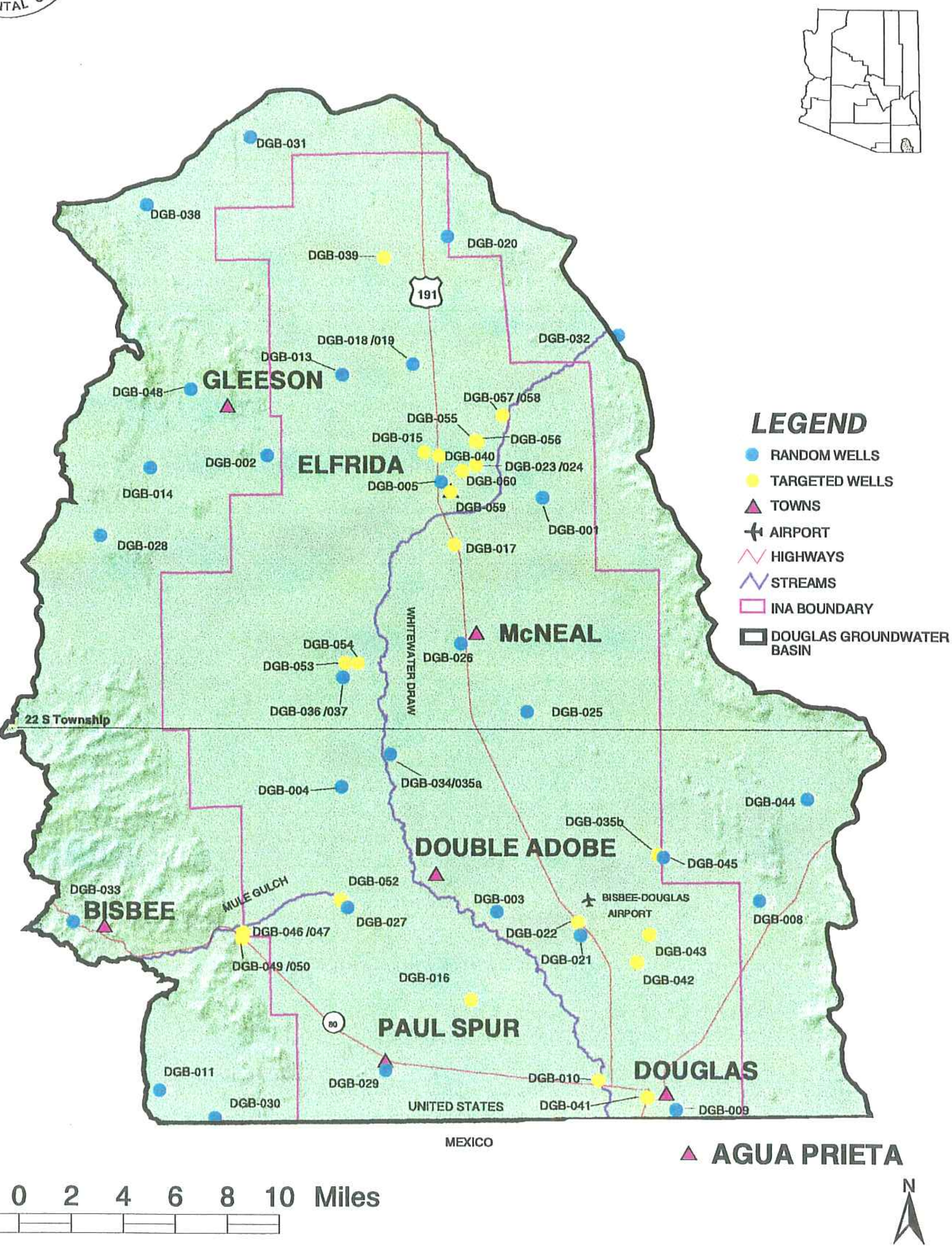
- ADWR registration number,
- sample name,
- well location (cadastral),
- well owner,
- well use,
- well depth,
- well casing diameter,
- well perforation interval,
- water depth, and
- well surface elevation.

Information concerning each of the 60 groundwater samples collected for this study is provided in **Appendix B**. Sample information includes:

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

The groundwater quality samples collected as part of the DGB study, divided into random and targeted samples, are shown in **Figure 4**.

Figure 4. Location of Douglas Groundwater Basin Wells Sampled by ADEQ



6.1 Evaluation of Analytical Data

Overall, the analytical work conducted under the auspices of this study was considered valid based on the 9 different QA/QC correlations presented in **Figure 5**. Each of these QA/QC correlations is described below:

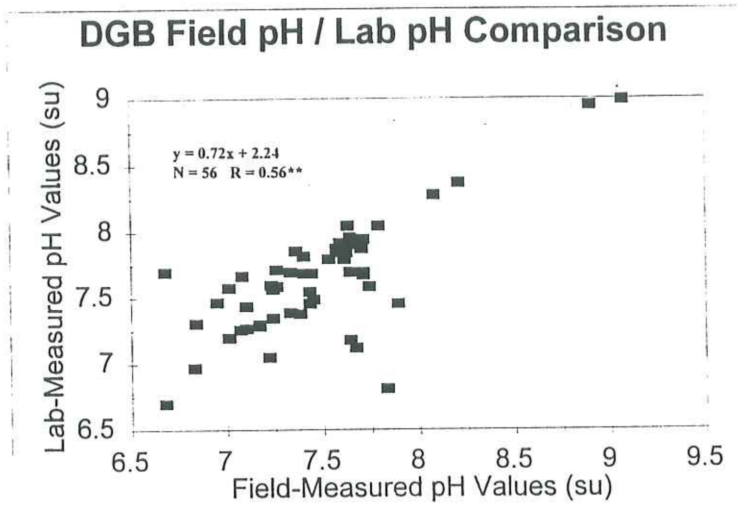
- **pH** - The pH values measured in the field using a Hydrolab at the time of sampling were significantly correlated at $p = 0.01$ with the pH values determined by the contract laboratories (**Graph 1**)even though pH is closely related to the environment of the water and is likely to be altered by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

- **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 2**). The field/lab EC graph shows that the overall EC variation for the study was within 7%.

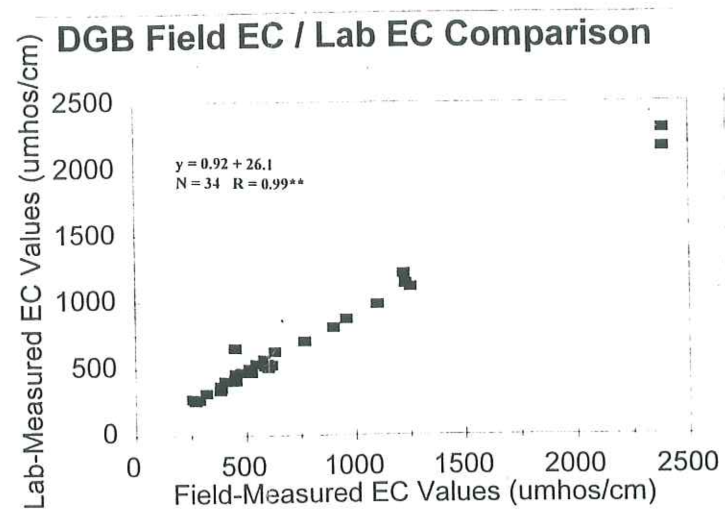
- **EC/TDS** - The electrical conductivity (EC) measured in the field using a Hydrolab at the time of sampling and converted to 25^0 C values was significantly correlated at $p=0.01$ with the TDS measured by contract laboratories (**Graph 3**). The field EC/TDS graph shows that the overall EC/TDS variation for the study was within 11%. Typically, the TDS value in mg/l should be from 0.55 to 0.75 times the EC in micromhos/cm for groundwater up to several thousand mg/l. Groundwater in which the ions are mostly HCO_3 and Cl will have a factor near the lower end of this range and groundwater high in SO_4 may reach or even exceed the upper end (Hem, 1970). The relationship of TDS to EC becomes indefinite for groundwater both with very high and low concentrations of dissolved solids (Hem, 1970).

- **Cation/Anion Balances** - Cation/anion balances is an analysis such that, if found to be within acceptable limits, it can be assumed there are no important errors in concentrations reported for major constituents though minor constituents are not necessarily adequately evaluated (Hem, 1970). Overall, cation/anion balances of DGB groundwater samples were significantly correlated at $p = 0.01$ (**Graph 4**). Cation/anion balances, with the exception of five samples (DGB-01, DGB-29, DGB-34, DGB-35a, and DGB-35b), all balanced within acceptable limits (90 - 110%). Sample DGB-01 is barely out of range (113%), while DGB-29 has a greater error (79%). Two of these samples, DGB-34 (119%) and DGB-35a (123%), are splits and both had similiar sample results. The unacceptable balance on sample DGB-35b (119%) is probably due to the very high parameter levels (TDS = 14,200 mg/l). All these unacceptable balances were brought to the attention of either the ADHS or McKenzie Laboratory but no analytical errors were found.

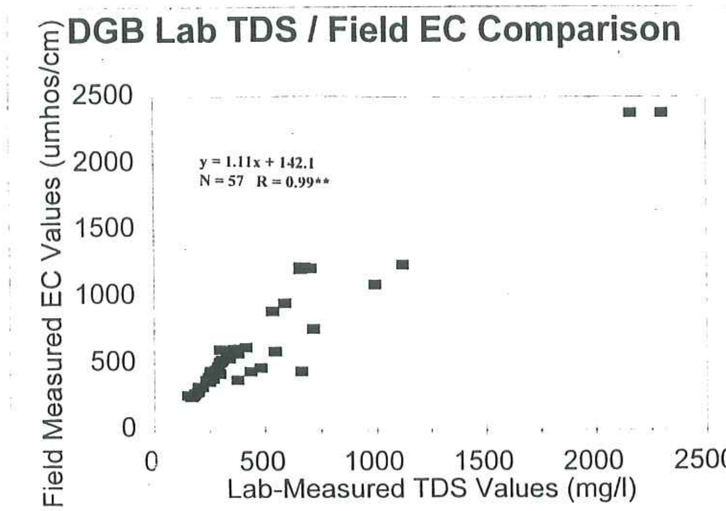
Figure 5. DGB Study QA/QC Correlations



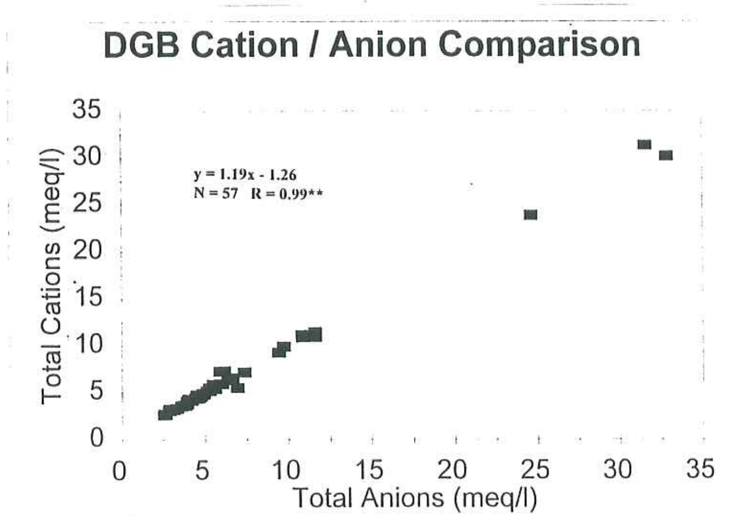
Graph 1



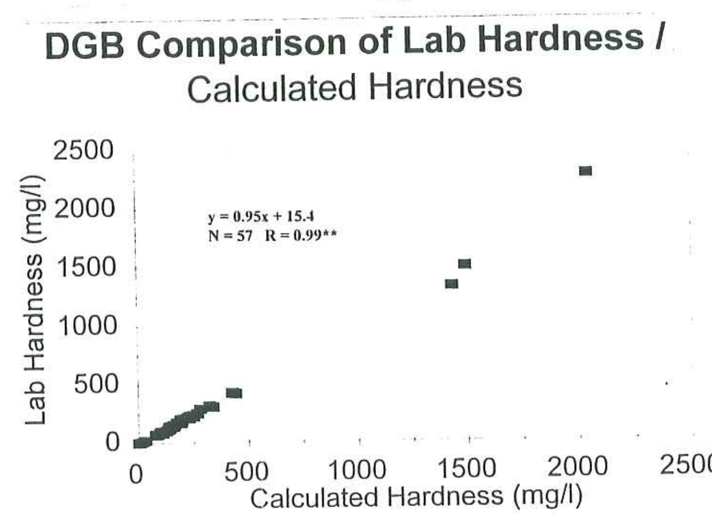
Graph 2



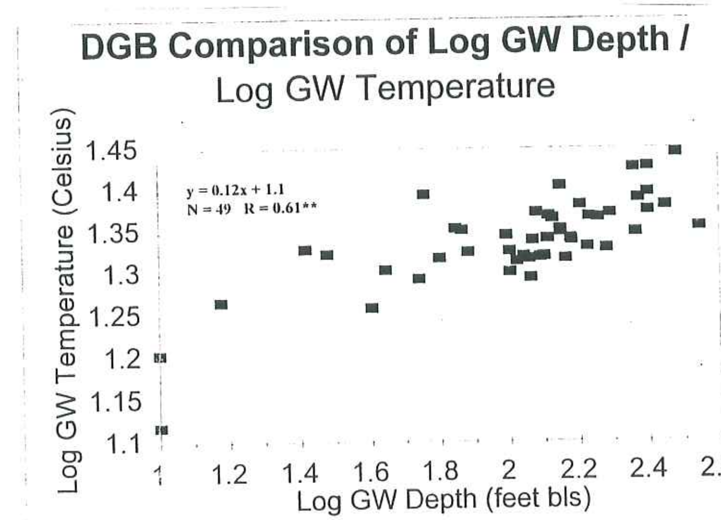
Graph 3



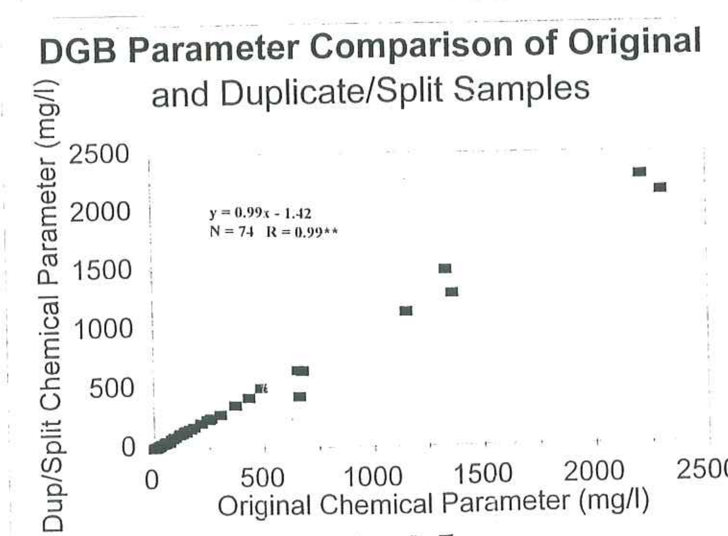
Graph 4



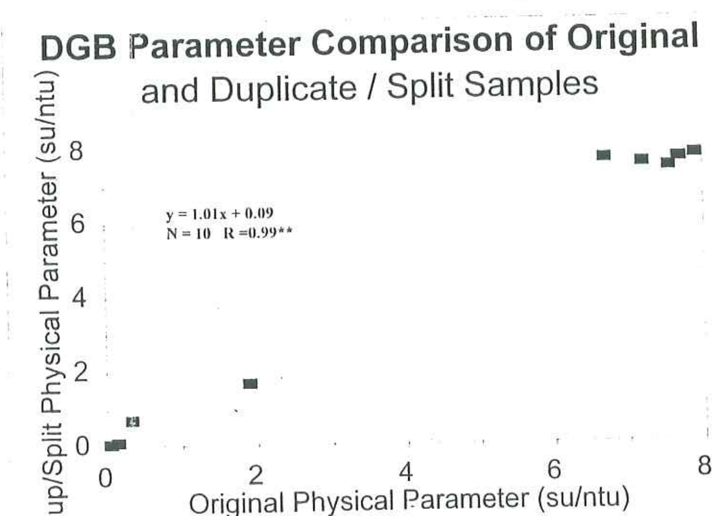
Graph 5



Graph 6



Graph 7



Graph 8

- **Hardness** - The levels of laboratory-measured hardness levels were significantly correlated with calculated hardness levels at p = 0.01 (**Graph 5**). Hardness was calculated using the following formula: [(Ca x 2.497) + (Mg x 4.118)]. The hardness graph shows that the overall hardness variation for the study was within 5%.

- **Groundwater Temperature/Groundwater Depth** - Groundwater temperature measured in the field was compared to groundwater 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 or log-transformed data, groundwater temperature and well depth were significantly correlated at the p = 0.01 level, though the log-transformed data showed a better graphic relationship (**Graph 6**). Furthermore, plumbing differences in wells probably prevented a stronger graphical relationship between groundwater temperature and groundwater depth.

- **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 7**), those physical and chemical parameters measured in su/ntu/umhos also had only an overall 1% variation (**Graph 8**).

- **Equipment Blanks** - The two equipment blanks 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: DGB-12 - EC (1.989 umhos/cm) and B (0.30 mg/l); and DGB-58 - TDS (16 mg/l), turbidity (0.08 NTU), EC (2.24 umhos/cm), Sb (0.0112 mg/l), B (0.21 mg/l), and K (0.26 mg/l).

- **Overall Evaluation** - Based on these QA/QC correlations, the analytical work conducted for this study was excellent and the results were judged suitable for further statistical analysis with the exception of the Sb. Sb was detected both in a DGB study equipment blank as well as in equipment blanks submitted by other ADEQ programs using the same type of water filters. A conversation with the company manufacturing the water filters confirmed that they were contaminated with Sb. Thus, the water filters were thought to be the cause of most, if not all, of the Sb detections in the DGB. Of the other DGB equipment blank detections, B is a parameter which has also been found in equipment blanks submitted by other ADEQ programs. The presence of B may be attributed to its use in many detergents used to clean the deionized (DI) carboys (The Main Water Line, 1996). The EC detections may be explained in two ways: water passed through a deionizing exchange unit will normally have an EC value of at least 1 umhos/cm while carbon dioxide from the air can dissolve in distilled water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity (Hem, 1970).

6.2 Groundwater Chemistry

Piper trilinear diagrams were used to illustrate the chemical composition of groundwater samples collected in the DGB. These groundwater samples were plotted on 8 Piper trilinear diagrams (**Figure 6**) to show the water chemistry of:

#1) Douglas Groundwater Basin (DGB) samples;
#2) DGB Samples by Valley (divided by Whitewater Draw);
#3) DGB Samples by Basin (divided by town of McNeal);
#4) DGB Samples by Geology (alluvial vs bedrock aquifers);
#5) DGB Samples by Irrigation Nonexpansion Area (INA) Boundary;
#6) DGB Samples by Targeted Areas (Mule Gulch, Douglas, McNeal, Elfrida, and Bisbee-Douglas Airport);
#7) DGB Surface Water Samples; and
#8) DGB Samples by TDS Levels.

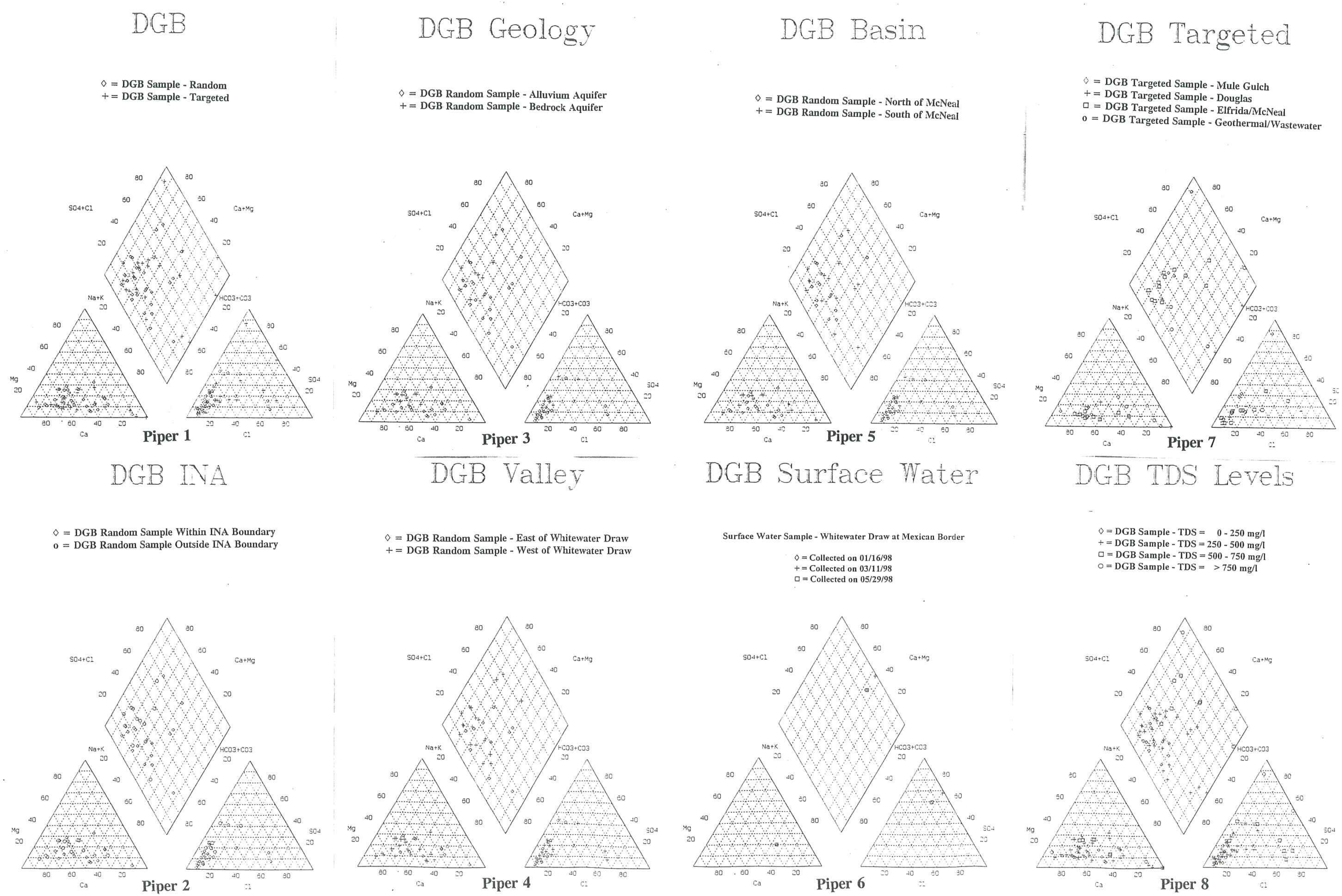
DGB Samples - In this diagram (**Piper 1**), the 51 groundwater samples collected from wells located in the DGB were divided into two groups: random (29 samples symbolized by ◇) and targeted (22 samples symbolized by +). The Piper trilinear diagram illustrates that the majority (34) of DGB samples are of Ca-HCO_3 chemistry, 8 samples are of Na-HCO_3 chemistry, 6 samples are of Na-SO_4 chemistry, and 3 are of Ca-SO_4 chemistry. The samples exhibiting Ca-SO_4 chemistry are generally from the Mule Gulch area. The samples having either Na-SO_4 or Na-HCO_3 chemistry are from the southern portion of the DGB, with the strongest Na-SO_4 chemistries coming from samples in the Douglas area.

DGB Samples by Valley - In this diagram (**Piper 2**), the 29 random samples collected in the DGB were divided into two groups: 19 samples collected west (symbolized by +) of the Whitewater Draw and 10 samples (symbolized by ◇) collected east of the Whitewater Draw. The Piper trilinear diagram illustrates that no valley groundwater chemistry patterns were apparent and that most samples exhibit a Ca-HCO_3 chemistry.

DGB Samples by Basin - In this diagram (**Piper 3**), the 29 random samples collected in the DGB were divided into two groups: 15 samples collected north (symbolized by ◇) of the town of McNeal and 14 samples (symbolized by +) collected south of McNeal. The Piper trilinear diagram illustrates that no basin groundwater chemistry patterns were apparent and that most samples exhibit a Ca-HCO_3 chemistry.

DGB Samples by Geology - In this diagram (**Piper 4**), the 29 random samples collected in the DGB were divided into two groups: 19 samples (symbolized by ◇) collected in the alluvial aquifer and 10 samples (symbolized by +) collected in the bedrock aquifer. The Piper trilinear diagram illustrates that alluvial aquifer samples tend to exhibit Ca-HCO_3 and Na-HCO_3 groundwater chemistries while most bedrock aquifer samples exhibit a Ca-HCO_3 chemistry.

Figure 6. DGB Water Chemistry Diagrams



DGB Samples by INA - In this diagram (**Piper 5**), the 29 random samples collected in the DGB were divided into two groups: 17 samples (symbolized by ◇) collected within the INA and 12 samples (symbolized by o) collected outside the INA. Similiar to the geology patterns, the Piper trilinear diagram illustrates that INA samples tend to exhibit Ca-HCO_3 and Na-HCO_3 groundwater chemistries while most non-INA samples exhibit a Ca-HCO_3 chemistry.

DGB Samples by Targeted Area - In this diagram (**Piper 6**), the 22 groundwater samples collected from targeted wells located in the DGB were divided into four groups: Mule Gulch, Douglas, Elfrida/McNeal, and Bisbee-Douglas Airport. Of the 3 Mule Gulch-area targeted samples (symbolized by ◇), one exhibits a strong Ca-SO_4 water chemistry while the other two samples exhibit a more typical Ca-HCO_3 water chemistry. Of the 3 Douglas-area targeted samples (symbolized by +), two exhibit a strong Na-HCO_3 water chemistry while the other sample exhibits a more typical Ca-HCO_3 water chemistry. Of the 12 Elfrida/McNeal-area targeted samples (symbolized by □), 10 have a Ca-HCO_3 water chemistry while 2 have a Na-SO_4 water chemistry. Of the 4 Bisbee-Douglas Airport targeted samples (symbolized by o), the geothermal area sample has a strong Ca-SO_4 water chemistry while those in the wastewater area have Na-HCO_3 water chemistry.

DGB Samples by TDS Levels - In this diagram (**Piper 7**), the 51 groundwater samples collected from wells located in the DGB were divided into 4 groups according to TDS concentration: 0 - 250 mg/l (14 samples symbolized by ◇), 250 - 500 mg/l (27 samples symbolized by +), 500 - 750 mg/l (8 samples symbolized by □), and > 750 mg/l (2 samples symbolized by o). The Piper trilinear diagram illustrates that while the majority of Ca-SO_4 and Na-SO_4 samples exceed the 500 mg/l Secondary MCL level (7 out of 9 samples), only a few Na-HCO_3 and Ca-HCO_3 samples exceeded the Secondary MCL (2 out of 42). Thus, groundwater with Ca-SO_4 and Na-SO_4 chemistry in the DGB is more likely to have TDS Secondary MCL exceedences than groundwater with Na-HCO_3 and Ca-HCO_3 chemistry.

Surface Water Samples - For comparison purposes, 3 surface water samples from the Whitewater Draw at the International Border with Mexico collected in 1998 were plotted on a trilinear diagram (**Piper 8**). The 3 samples were collected in January (symbolized by ◇), March (symbolized by +), and May (symbolized by □) by the ADEQ Surface Water Monitoring Unit. The surface water of the Whitewater Draw shows a seasonally-consistent Na-SO_4 chemistry, with a particularly strong SO_4-Cl anion component. This strong SO_4 value may be influenced by the contribution of Mule Gulch which flows through an area of mine tailings.

In summary, the Ca-HCO_3 water chemistry is characteristic of groundwater in the DGB. Those groundwater samples that differ greatly from the Ca-HCO_3 water chemistry are indicative of unique processes acting on the groundwater chemistry and will be individually explored in this report.

6.3 Inorganic Parameter Levels

The 51 wells from which groundwater samples were collected in this study were analyzed for various inorganic parameters some of which had SDW standards that reflect the best current scientific and technical judgment available. The analytical results indicated that groundwater in the DGB generally supports drinking water uses as health-based water quality standards were rarely exceeded. Groundwater is also generally acceptable for domestic uses as aesthetics-based water quality standards were typically not exceeded. Each well of the 51 wells sampled are provided in **Figure 7**, with the color indicating whether a parameter from the respective well exceeded either a Primary Maximum Contaminant Level (MCL), Secondary MCL, or neither a Primary or Secondary MCL.

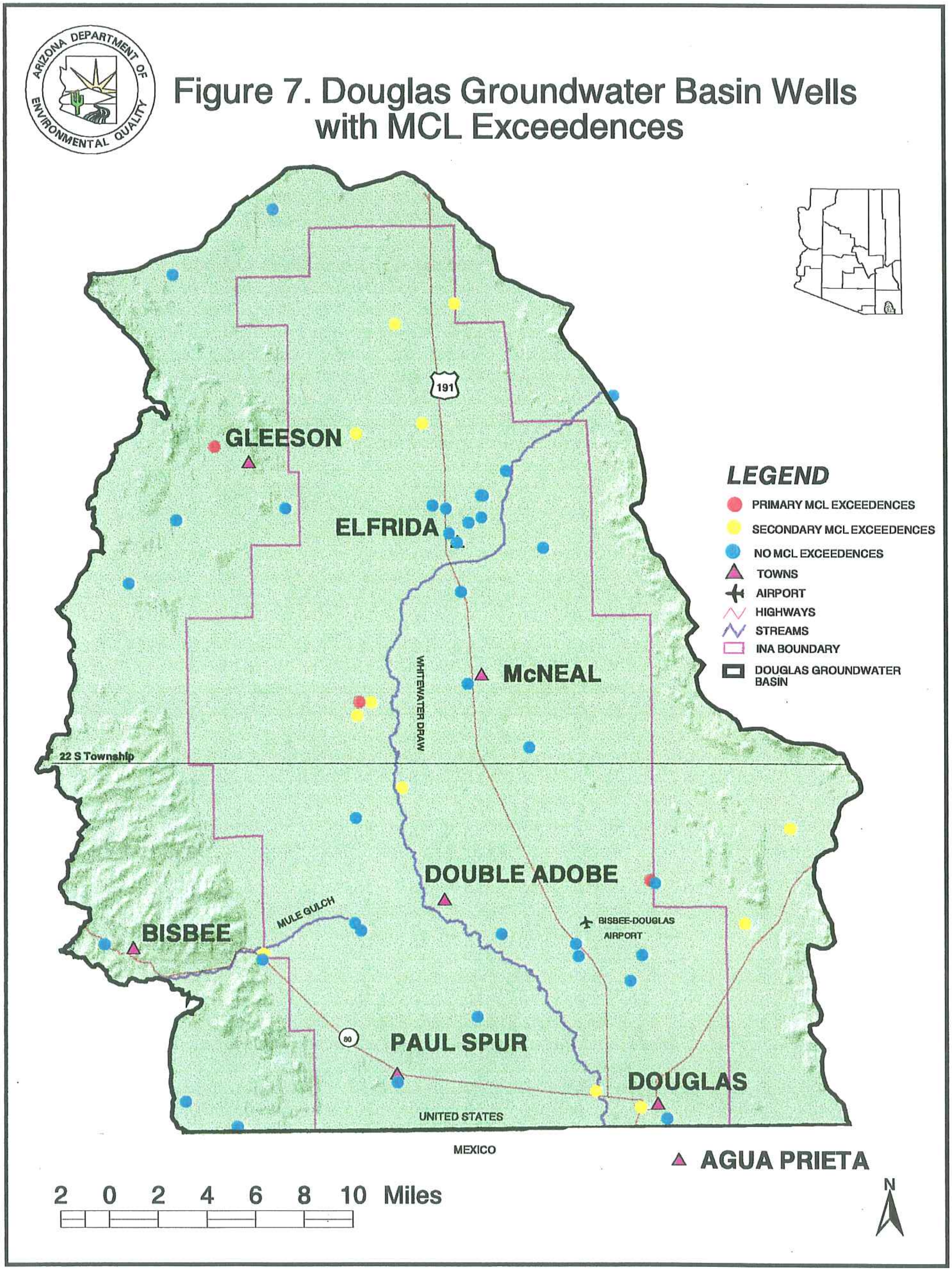
For discussion purposes, the inorganic parameters in this section are divided into three groups: parameters having health-based water quality standards or SDW Primary MCLs, parameters having aesthetic-based water quality standards or SDW Secondary MCLs, and parameters without SDW water quality standards.

For easy visual comparison between sample locations, inorganic parameters regularly detected in DGB groundwater had their levels summarized in box plot statistical displays. For box plot display, groundwater sample locations were divided into two categories: alluvium samples and bedrock samples. There were 39 groundwater samples collected from the alluvial aquifer and 12 groundwater samples collected from the bedrock aquifer. Generally these box plots reflect all 51 groundwater samples; however, one alluvium sample (DGB-35b) was taken out in 5 of the box plots because its levels were an extreme outlier. The box plots in which DGB-35b is not reflected include field EC, TDS, Na, Cl, and SO_4.

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 Groundwater Quality Database.

Figure 7. Douglas Groundwater Basin Wells with MCL Exceedences



6.4 Inorganic Parameters with SDW Primary MCLs

SDW Primary MCLs are based on a lifetime daily consumption of 2 liters of liquid; thus, there should be negligible health effects if the level of a parameter in a groundwater sample slightly exceeds the MCL for a short time. With the exception of hazardous spills and accidents, an immediate health threat is typically only posed by nitrate to children under six months of age (ADEQ, undated).

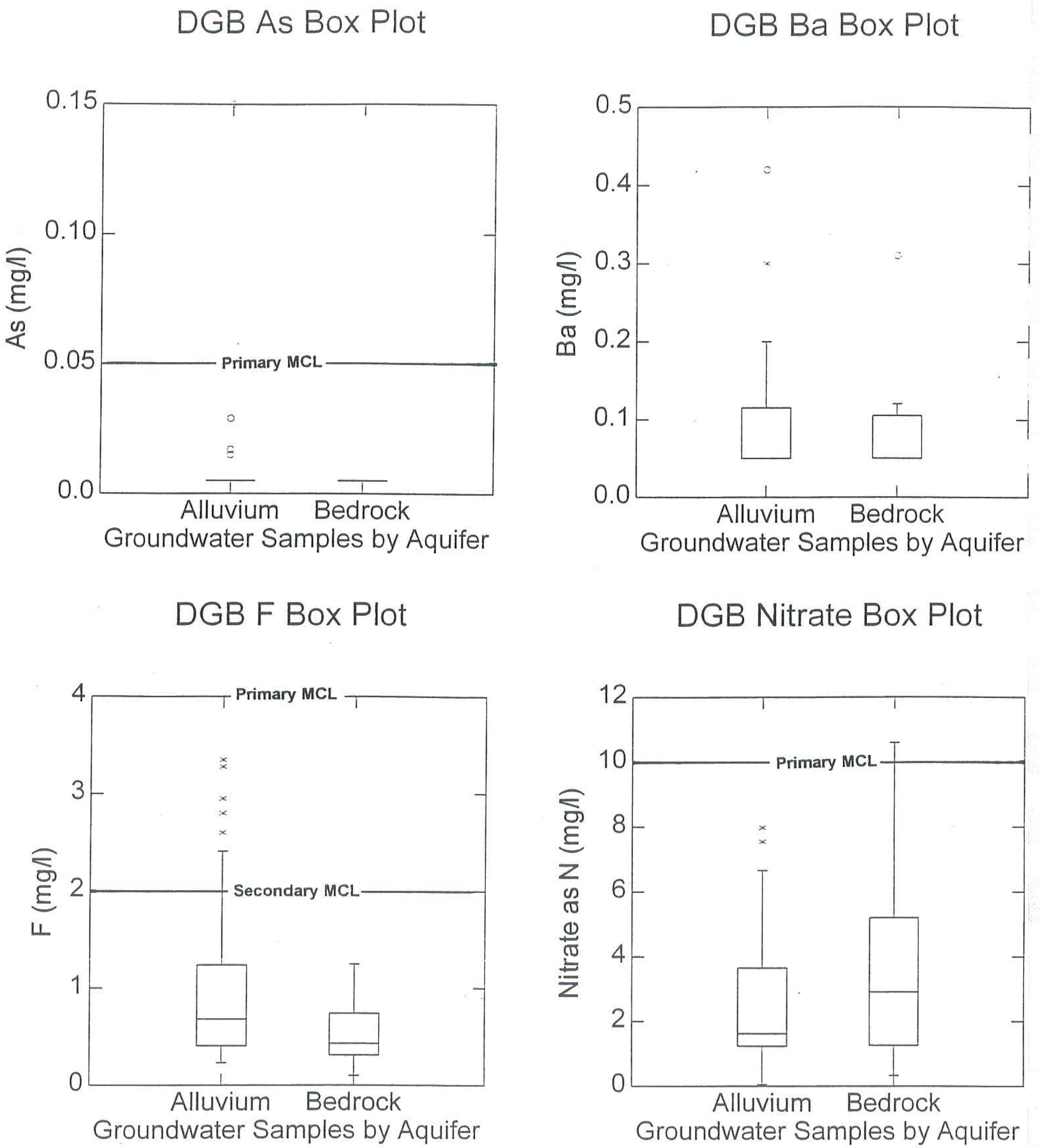
Included in the SDW inorganic analyses of DGB groundwater samples were 13 chemical parameters having Primary MCLs: As, Ba, Be, Cd, Cr, F, Hg, NO_3 - N, NO_2 - N, NO_3 - N/ NO_2 - N, Sb, Se, and Tl. Disregarding the Sb results because of groundwater filter contamination problems, of the 51 samples collected from DGB wells by ADEQ for SDW inorganic parameters, only 3 samples contained a parameter whose concentration was in excess of a Primary MCL Standard. Of the 3 samples, As, Be, and NO_3 - N each exceeded its respective Primary MCL in 1 sample. Each Primary MCL and the extent of its occurrence within the DGB is individually discussed below. Boxplots for As, Ba, F, and nitrate (as N) are provided in **Figure 8**.

Arsenic (As) - Of the 51 groundwater samples collected in the DGB, only 5 groundwater samples had As levels above the ADHS Laboratory Minimum Reporting Level (MRL) of 0.010 mg/l (**Figure 8**). The only As level above the Primary MCL of 0.05 mg/l was in DGB-35b which had a level of 0.15 mg/l. This sample, collected to the east of the Bisbee-Douglas Airport, seemed to be the result of a geothermal anomaly as As is commonly present in areas of geothermal activity (Hem, 1970). Detections of As occurred sporadically in only the south-central portion of the DGB from McNeal to Douglas. Nationwide, 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 (Franson, 1989). As may occur in water as a result of mineral dissolution, industrial discharges, or the application of insecticides.

Barium (Ba) - Of the 51 groundwater samples collected in the DGB, 14 groundwater samples had Ba levels above the ADHS Laboratory MRL of 0.01 mg/l, though none exceeded the 2.0 mg/l Primary MCL (**Figure 8**). The highest Ba level was 0.42 mg/l collected in the south-central portion of the basin; most Ba detections occurred in the southern portion of the DGB.

Beryllium (Be) - Of the 51 groundwater samples collected in the DGB, only 1 had Be levels above the ADHS Laboratory MRL of 0.0005 mg/l. This sample, DGB-53 collected near McNeal, had a Be level of 0.007 which exceeded the Primary MCL of 0.004 mg/l. Hem (1970) notes that the chemical properties of Be seem highly unfavorable for the occurrence of any but extremely low concentrations in natural water.

Figure 8. Boxplots of Selected Parameters with SDW Primary MCLs



Cadmium (Cd) - Of the 51 groundwater samples collected in the DGB, none had Cd levels above the ADHS Laboratory MRL of 0.0010 mg/l. Cd has a Primary MCL of 0.005 mg/l. Background literature suggests that concentrations of Cd that have been found in groundwater are very small except in water polluted by metal plating industries (Hem, 1970).

Chromium (Cr) - Of the 51 groundwater samples collected in the DGB, none had Cr levels above the ADHS Laboratory MRL of 0.010 mg/l. Cr has a Primary MCL of 0.1 mg/l. Nationwide, the Cr concentration of 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) while other sources (Hem, 1970) note that Cr is not often encountered except in groundwater impacted by industrial pollution.

Fluoride (F) - Of the 51 groundwater samples collected in the DGB, 50 had F levels above the ADHS Laboratory MRL of 0.20 mg/l. Eight samples exceeded the Secondary MCL of 2.0 mg/l with 3.35 mg/l the highest detected F level. Thus, no samples exceeded the Primary MCL of 4.0 mg/l (**Figure 8**). Other DGB F statistics include: median = 0.56 mg/l, mean = 0.94 mg/l, and 95% CIs = 0.70 - 1.18 mg/l. These F levels support the assertion by Hem (1970) that the concentration of F in most natural waters is less than 1 mg/l. A map showing F levels in the DGB is provided in **Figure 9**.

Hem (1970) notes that some of the highest concentrations of F ever reported occur in southeastern Arizona, particularly around San Simon located to the north of the DGB. Thus, it is not surprising that the Secondary MCL sample exceedences tended to be in the north-central portion of the DGB.

Mercury (Hg) - Of the 51 groundwater samples collected in the DGB, none had Hg levels above the ADHS Laboratory MRL of 0.0005 mg/l. Hg has a Primary MCL of 0.002 mg/l. Background literature suggests that very few natural waters contain detectable concentrations of Hg (Hem, 1970).

Nitrate (as N) (NO_3 - N) - Of the 51 groundwater samples collected in the DGB, 50 had detections of nitrate (as N) above the ADHS Laboratory MRL of 0.10 mg/l (**Figure 8**). The only nitrate level above the Primary MCL of 10.0 mg/l was 10.6 mg/l in DGB-48. This sample was collected in the bedrock of the Dragoon Mountains. Other DGB nitrate statistics include: median = 1.65 mg/l, mean = 2.82 mg/l, and 95% CIs = 2.18 - 3.46 mg/l. A map showing nitrate levels in the DGB is provided in **Figure 10**.

Qualitative nitrate groundwater quality categories have been suggested by Madison and Brunett (1984): < 0.2 mg/l =natural background, 0.2 - 3.0 mg/l may or may not indicate human influence, 3.1 - 10 mg/l may result from human activites, and > 10 mg/l indicate human activities. Of the 51 wells sampled in this study, 1 well is in the < 0.2 mg/l category, 29 wells are in the 0.2 - 3.0 mg/l category, 20 wells are in the 3.1 - 10 mg/l category, and 1 well is in the > 10 mg/l category.

Figure 9. Levels of Fluoride in Douglas Groundwater Basin Wells

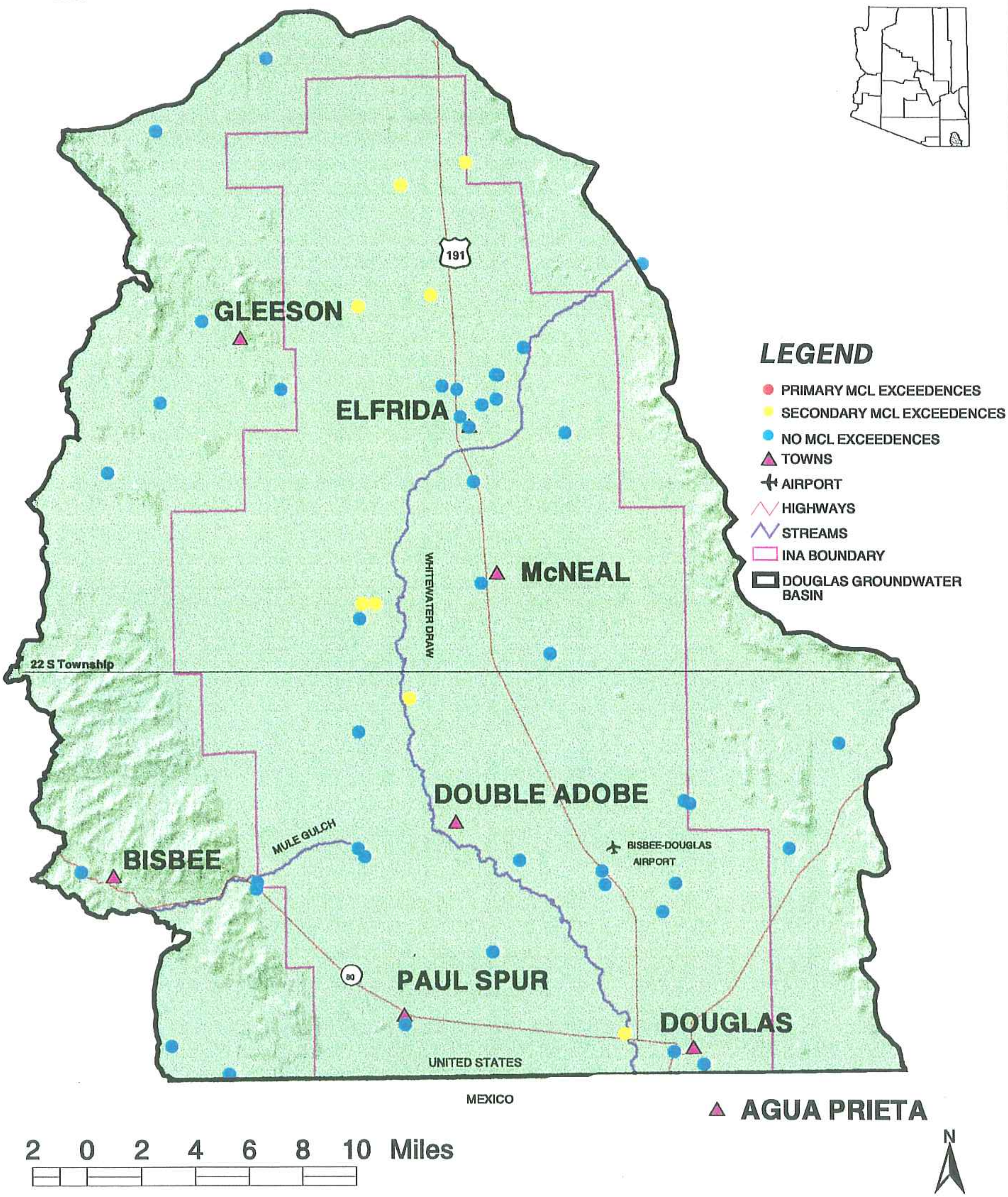
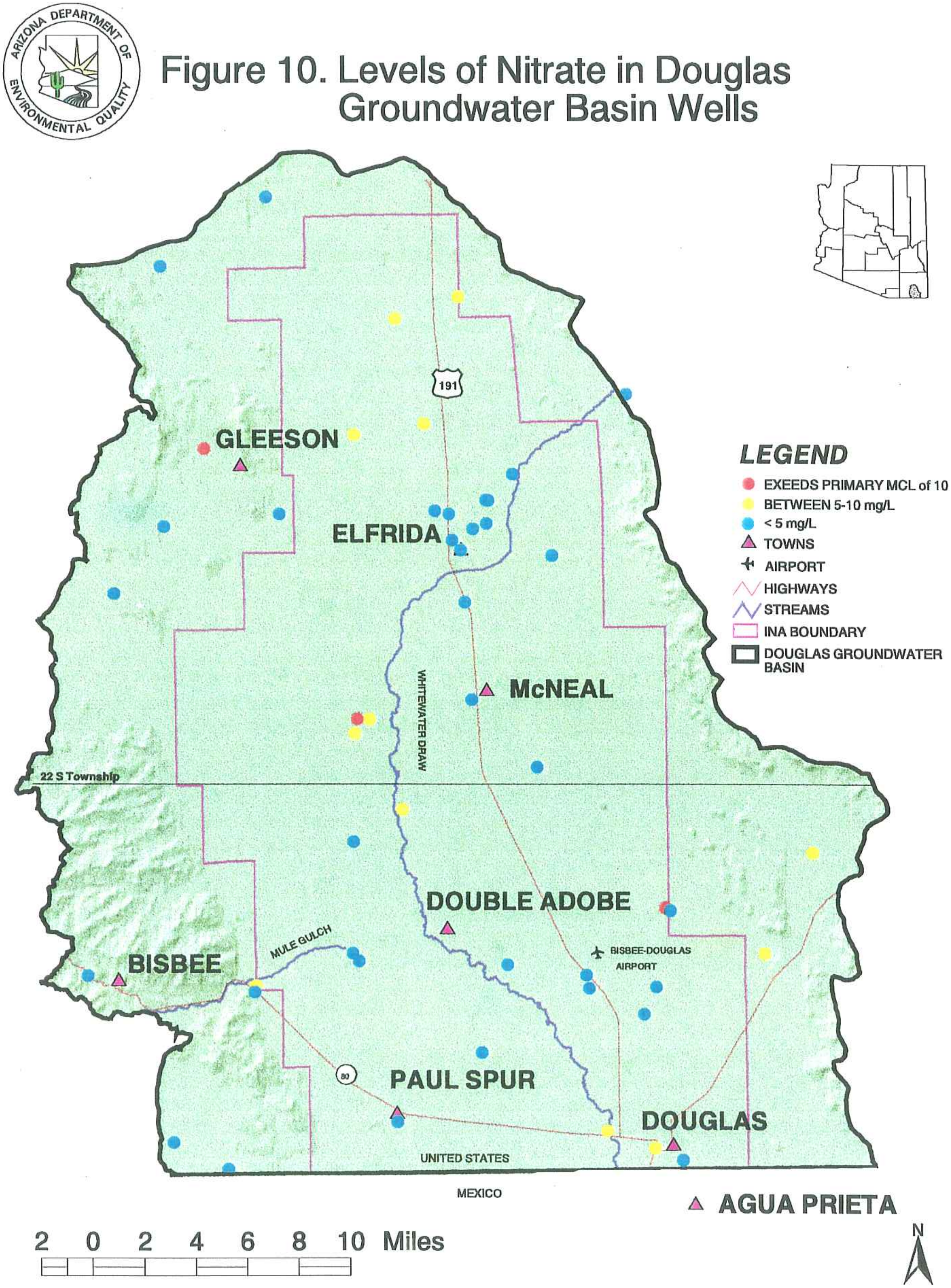


Figure 10. Levels of Nitrate in Douglas Groundwater Basin Wells



Nitrite (as N) (NO_2- N) - Of the 51 groundwater samples collected in the DGB, none had nitrite levels above the ADHS Laboratory MRL of 0.10 mg/l. The Primary MCL for nitrite is 1.0 mg/l. For further discussion of nitrite levels, see nitrate/nitrite.

Total N (NO_3 - N/NO_2 - N) - see Nitrate and/or Nitrite. Total N has a Primary MCL of 10.0 mg/l.

Selenium (Se) - Of the 51 groundwater samples collected in the DGB, only one sample had Se levels above the ADHS Laboratory MRL of 0.005 mg/l. This sample, collected from near McNeal, 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).

Antimony (Sb) - The Sb analytical results for the DGB study should be disregarded because of QA/QC problems. Sb was detected in equipment blanks and other samples collected for this study as well as by other ADEQ programs. A subsequent communication to the water filter manufacturer revealed that a batch of groundwater filters had been contaminated with Sb. Thus, the Sb levels in DGB groundwater are very suspect and are not considered reflective of actual Sb levels in the basin.

Thallium (Tl) - Of the 51 groundwater samples collected in the DGB, none had Tl levels above the ADHS Laboratory MRL of 0.002 mg/l. Tl has a Primary MCL of 0.002 mg/l.

6.5 Inorganic Parameters with SDW Secondary MCLs

Standards for Secondary MCLs are established on the basis of the physical characteristics which selected parameters impart to the water and are not based on health effects (ADEQ, undated). Included in the SDW inorganic analyses of DGB groundwater samples were 10 chemical parameters having Secondary MCLs. Of the 51 samples collected and analyzed for SDW inorganic parameters, 16 contained a parameter whose concentration was in excess of a Secondary MCL Standard. This indicates that approximately one-third of the groundwater samples in the DGB have aesthetic problems with indices such as taste, odor, or color. The inorganic constituents with Secondary MCLs and the number of groundwater samples which exceeded these standards are as follows: Al - 0, Cl - 1, F - 8, Fe - 1, Mn - 1, field pH - 2, lab pH - 2, Ag - 0, SO_4 - 2, TDS - 8, and Zn - 0. Each Secondary MCL and the extent of its occurrence within the DGB is individually discussed below. Boxplots for Cl, field pH, lab pH, SO_4 and TDS are provided in **Figure 11**.

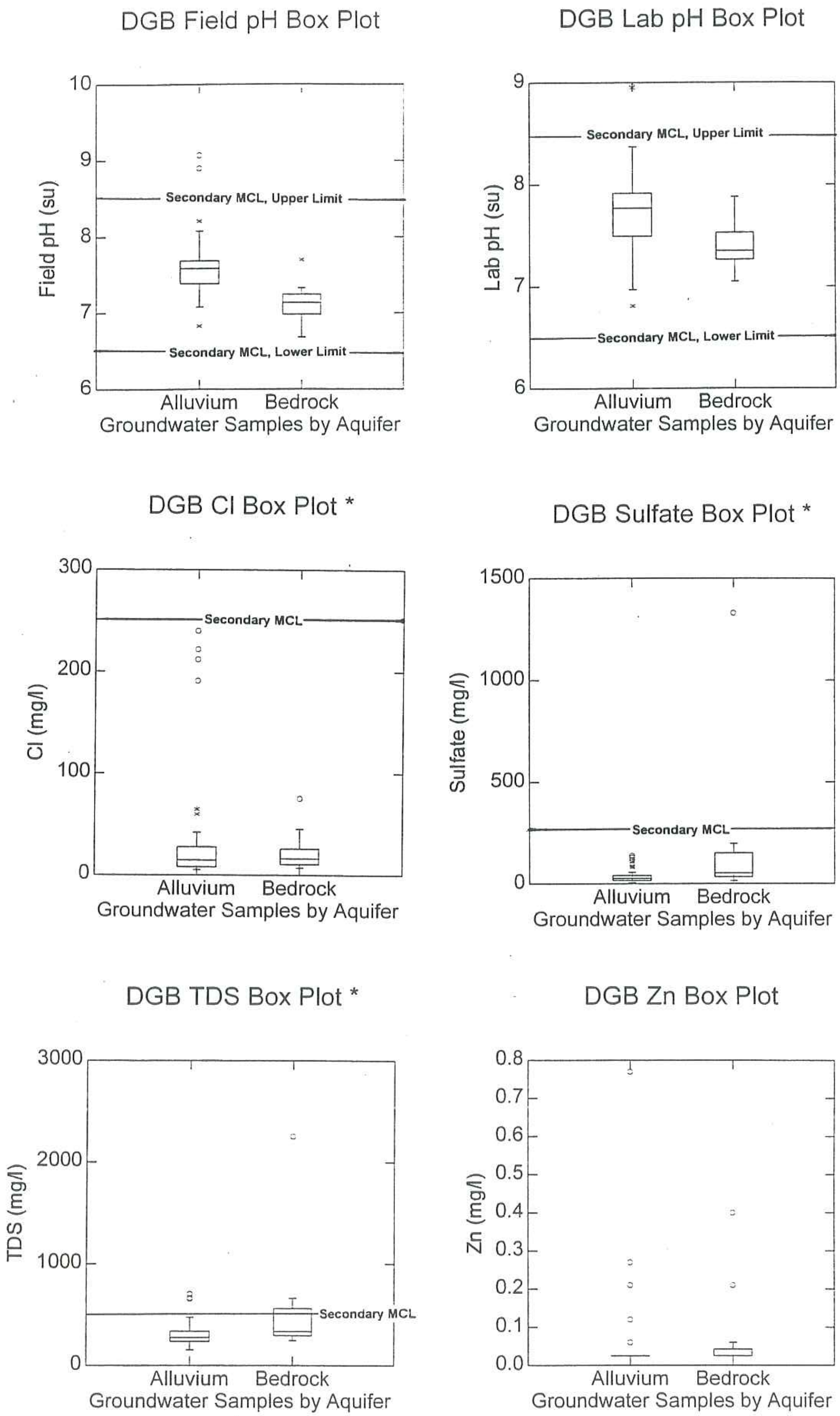
Aluminum (Al) - Of the 51 groundwater samples collected in the VRGB, none had Al concentrations above the ADHS Laboratory MRL of 0.50 mg/l. Al has a Secondary MCL of 0.05 mg/l. Although Al is the third most abundant of the elements in the earth's outer crust, it rarely occurs in natural waters except in very low pH waters such as which occur around mines (Hem, 1970).

Chloride (Cl) - The 51 groundwater samples collected in the DGB had Cl levels ranging from 5.2 - 3160 mg/l (**Figure 11**). The only Cl level above the Secondary MCL of 250 mg/l was 3160 mg/l in DGB-35b. This sample, collected to the east of the Bisbee-Douglas Airport, seemed to be the result of a geothermal anomaly based on temperature and other parameter levels. Other DGB Cl statistics include: median = 15.9 mg/l, mean = 95.7 mg/l, and 95% CIs = -28.4 - 219.8 mg/l.

Fluoride (F) - see the discussion on F in the "Inorganic Constituents with SDW Primary MCLs" section and **Figure 8** and **Figure 9**.

Iron (Fe) - Of the 51 groundwater samples collected in the DGB, 3 samples had Fe levels above the ADHS Laboratory MRL of 0.10 mg/l, with 2 of these samples above the 0.3 mg/l Secondary MCL. Groundwater sample DGB-35b, collected in the vicinity of the Bisbee Douglas Airport, had the highest Fe concentration of 13.9 mg/l, a Fe level which is indicative of hot springs in volcanic areas (Hem, 1970). Two other samples (DGB-46/47 - 0.33 mg/l and DGB-27 - 0.10 mg/l), near Mule Gulch and downgradient of the Bisbee mines, also had Fe detections. Water of low pH, which may result from acid drainage from mining operations, often carries high Fe concentrations (Hem, 1970), which may explain these other Fe detections as both samples also had low field pH levels.

Figure 11. Boxplots of Selected Parameters with SDW Secondary MCLs



* = Indicates an extreme outlier is missing from boxplot

Manganese (Mn) - Of the 51 groundwater samples collected in the DGB, only 1 sample had Mn levels above the ADHS Laboratory MRL and the Secondary MCL of 0.05 mg/l. Sample DGB-35a, collected to the east of the Bisbee-Douglas Airport, had a Mn level of 1.52 mg/l. As with Fe, geothermal activity usually results in high Mn concentrations which are often related to manganese oxide deposits (Hem, 1970).

pH (field measured) - 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). Of the 51 groundwater samples collected in the DGB, all but 2 samples had pH values between 6.5 and 8.5 standard units (su) and therefore, were within Secondary MCL guidelines. Other DGB field-measured pH values include: median = 7.45 su, mean = 7.49 su, and 95% CIs = 7.37 - 7.62 su (**Figure 11**).

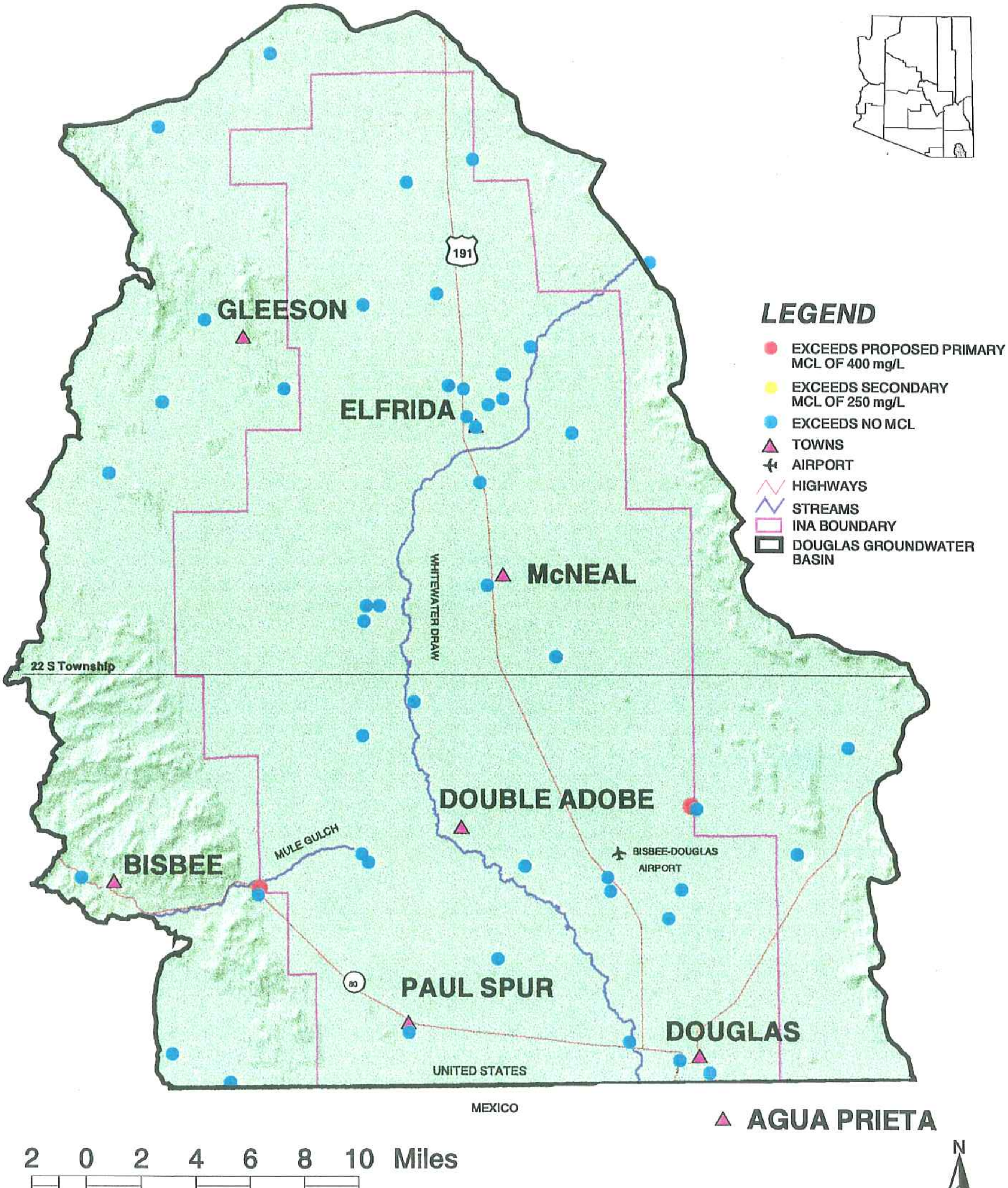
The two samples outside Secondary MCL guidelines were DGB-10 (8.90 su) and DGB-41 (9.07 su) which are both located in the Douglas area. The high pH of these two groundwater samples is probably due to natural softening by cation exchange. Both groundwater samples have replaced most of their Ca and Mg ions with Na ions by cation exchange. The pH of such a solution can rise to rather high levels because buffering by calcium carbonate precipitation becomes relatively ineffective (Hem, 1970).

pH (laboratory measured) - Of the 51 groundwater samples collected in the DGB, all but 2 samples had pH values between 6.5 and 8.5 standard units (su) and therefore, were within Secondary MCL guidelines. The two samples outside Secondary MCL guidelines were DGB-10 (8.95 su) and DGB-41 (8.99 su) which are both located in the Douglas area. Other DGB lab-measured pH values include: median = 7.69 su, mean = 7.67 su, and 95% CIs = 7.55 - 7.78 su (**Figure 11**). Sampling and storage of groundwater typically produces pH values that are higher or more alkaline than those values measured in the field.

Silver (Ag) - Of the 51 groundwater samples collected in the DGB, none had Ag concentrations above the ADHS Laboratory MRL of 0.001 mg/l. Ag has a Secondary MCL of 0.1 mg/l. A rather rare element, Ag would not be expected to occur in groundwater in anything but minor concentrations (Hem, 1970).

Sulfate (SO_4) - Of the 51 groundwater samples collected in the DGB, 2 had SO_4 levels exceeding the 250 mg/l Secondary MCL as well as the proposed Primary MCL of 400 mg/l (Crockett, 1995). The highest SO_4 level (5020 mg/l) was in DGB-35b, a sample collected to the east of the Bisbee-Douglas Airport which seemed to be the result of a geothermal anomaly. The other elevated SO_4 level (1330 mg/l) was in DGB-46/47, a sample collected where Mule Gulch enters the basin alluvium. The elevated SO_4 level in the Mule Gulch area may be due to many mine tailings in the area as sulfides are often associated with ores of economic importance and these are oxidized to yield SO_4 ions (Hem, 1970). Other DGB SO_4 statistics include: median = 31 mg/l, mean = 168 mg/l, and 95% CIs = -34 - 370 mg/l (**Figure 11**). A map showing SO_4 levels in the DGB is provided in **Figure 12**.

Figure 12. Levels of Sulfate in Douglas Groundwater Basin Wells

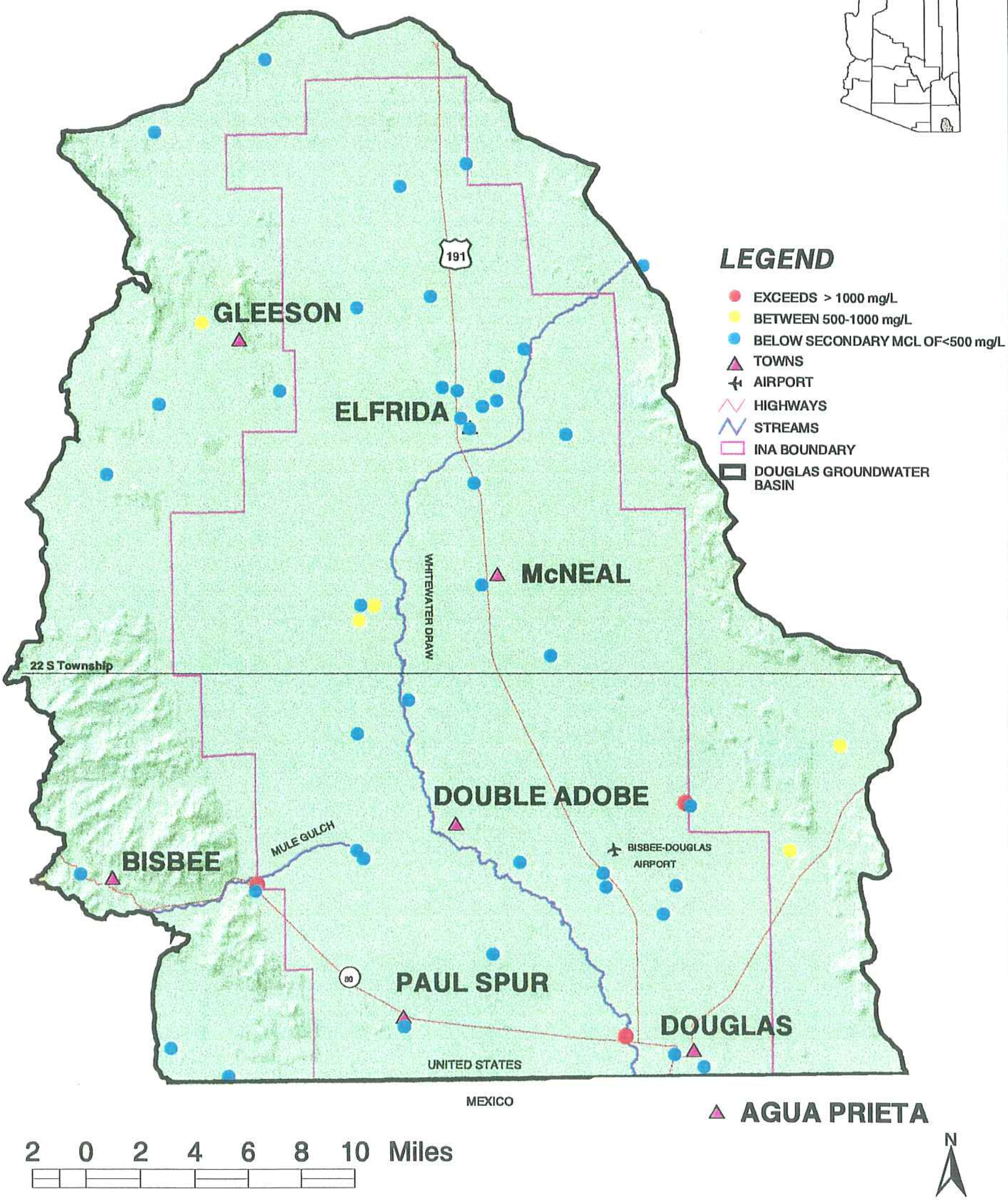


Total Dissolved Solids (TDS) - The 51 groundwater samples collected in the DGB had TDS levels ranging from 154 - 14200 mg/l (**Figure 11**). Nine of these samples had TDS levels exceeding the Secondary MCL of 500 mg/l. Other DGB TDS statistics include: median = 288 mg/l, mean = 640 mg/l, and 95% CIs = 89 - 1192 mg/l. The 51 DGB groundwater samples fall into the following TDS categories denoted by Hem (1970): Fresh (< 1000 mg/l) - 49, Slightly saline (1000 - 3000 mg/l) - 1, Moderately saline (3000 - 10,000) - 0, and Very saline (10,000 - 35,000) - 1. A map showing TDS levels in the DGB is provided in **Figure 13**.

For comparison purposes, groundwater in California is designated as a potential drinking water source unless TDS values exceed 3000 mg/l, which only occurs with 1 DGB 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. These ions are often natural constituents of groundwater, though they can be elevated through human sources.

Zinc (Zn) - Of the 51 groundwater samples collected in the DGB, 8 had Zn concentrations above the ADHS Laboratory MRL of 0.05 mg/l (**Figure 11**). The highest detected Zn concentration was 0.77 mg/l, well below the Secondary MCL of 5.0 mg/l. Many of the Zn detections occurred in the southwest portion of the basin. For comparison purposes, the Zn concentration of U.S. drinking waters typically varies between 0.06 and 7.0 mg/l, with a mean of 1.33 mg/l (Franson, 1989) while Hem (1970) notes concentrations of Zn in water from nonmineralized areas are generally considerably below 0.01 mg/l.

Figure 13. Levels of TDS in Douglas Groundwater Basin Wells



6.6 Other Inorganic Parameters

Included in the SDW inorganic analyses of DGB groundwater samples were 17 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 DGB is discussed below. Boxplots for total alkalinity, HCO_3, B, Ca, EC-field, hardness, Mg, TKN, K, Na, temperature - field, and turbidity are provided in **Figure 14**.

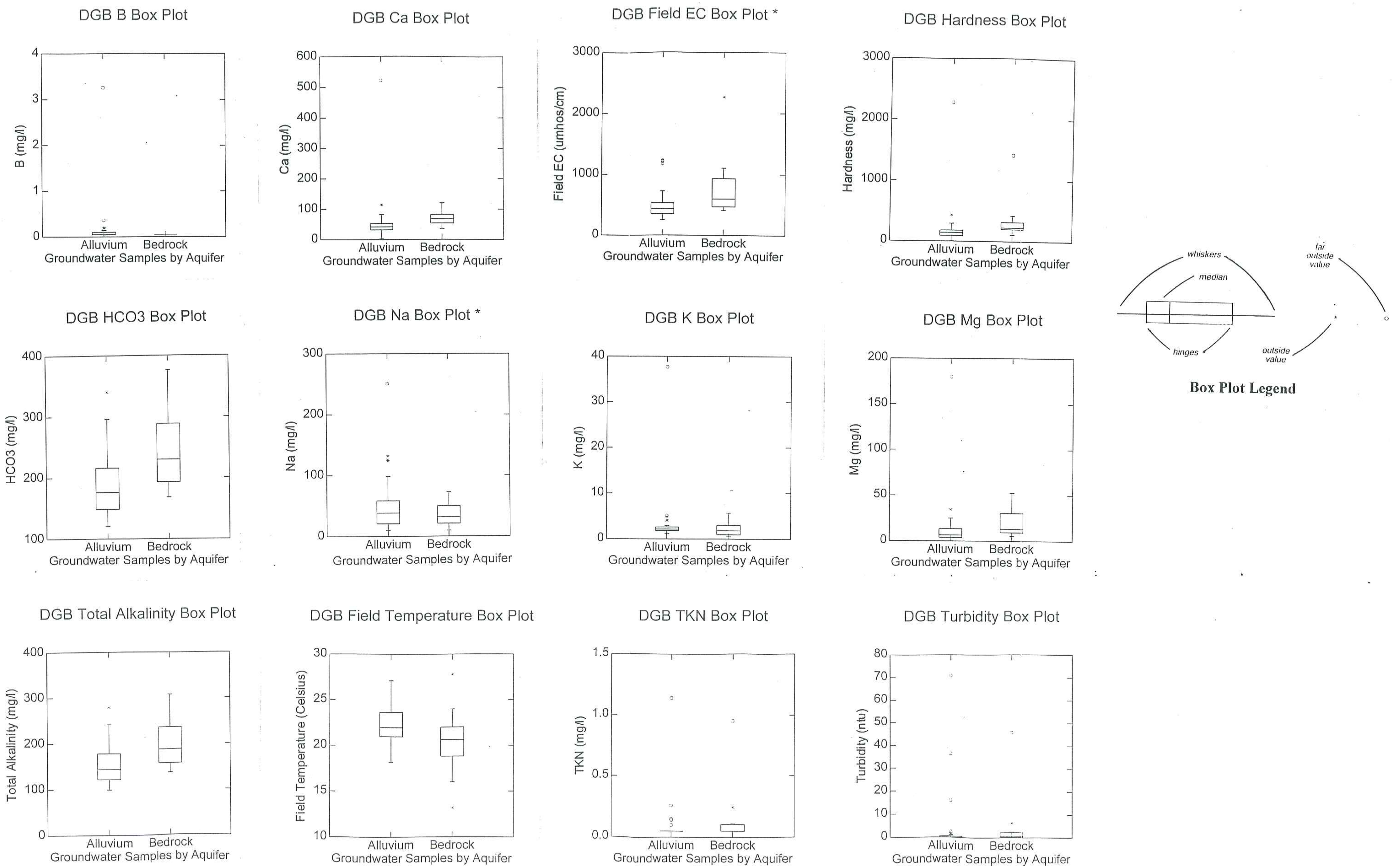
Alkalinity, Phenolphthalein - This parameter is a measure of a water's acid neutralizing capacity above the phenolphthalein end point of about pH 8.3. Of the 51 groundwater samples collected in the DGB, only two had phenolphthalein alkalinity levels above the ADHS Laboratory MRL of 2.0 mg/l. Both samples, DGB-10 (11.3 mg/l) and DGB-41 (13.5 mg/l), were located in the Douglas area.

Alkalinity, Total - This parameter is a measure of a water's acid-neutralizing capacity by chemical buffering. In most waters, alkalinity is caused primarily by the presence of bicarbonate (HCO_3) and carbonate (CO_3) ions with important noncarbonate contributors including hydroxide, silicate, borate, and organic ligands (Hem, 1985). This alkalinity is a "capacity" function which; therefore, has a different chemical basis than the "intensity" function, pH (Hem, 1970). In other words, it is a measurement of how much acid can be added to a liquid without changing the pH.

Total alkalinity ranged from 99 - 308 mg/l in the 51 groundwater samples, all above the recommended 60 mg/l level (**Figure 14**). Alkalinity levels below 60 mg/l can cause deterioration of plumbing and increases the chance for heavy metals in water that are present in pipes, soldering, and/or plumbing fixtures. Other DGB total alkalinity statistics include: median = 151 mg/l, mean = 165 mg/l, and 95% CIs = 152 - 179 mg/l. Field determination of total alkalinity, HCO_3, and CO_3 is preferred over laboratory determination because because degasification, precipitation, and other chemical and physical reactions may cause the concentrations of HCO_3, and CO_3 for some groundwater to change significantly within hours after sample collection (Hem, 1985).

Ammonia (NH_3 - N) - Of the 51 groundwater samples collected in the DGB, only 1 had levels above the ADHS Laboratory MRL of 0.10 mg/l. The detected NH_3 - N level was 1.09 mg/l in DGB-35b. This sample, collected to the east of the Bisbee-Douglas Airport, seemed to be the result of a geothermal anomaly based on temperature and other parameter levels. The presence of NH_3 - N in this sample (along with the high Fe level) suggest it had been exposed to a reducing compound (Hem, 1970). 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).

Figure 14. Boxplots of Selected Parameters Without SDW Standards



Box Plot Legend

Bicarbonate (HCO_3) - The 51 groundwater samples collected in the DGB had concentrations of HCO_3 ranging from 121 - 376 mg/l (**Figure 14**). Other DGB HCO_3 statistics include: median = 184 mg/l, mean = 201 mg/l, and 95% CIs = 184 - 218 mg/l.

Boron (B) - Of the 51 groundwater samples collected in the DGB, 11 had B levels above the ADHS Laboratory MRL of 0.10 mg/l (**Figure 14**). Detections of B predominately occurred in two areas: around Douglas and to the west of the town of McNeal. The highest B level was 3.26 mg/l in sample DGB-35b, the geothermal anomaly east of the Bisbee-Douglas Airport. This was the only DGB sample with B levels above the Health Based Guidance Level (HBGL) of 0.63 mg/l. Groundwater in geothermal areas typically contains considerable concentrations of B because this element is often liberated in volcanic gases (Hem, 1970). Franson (1989) notes that B may occur naturally in some waters or may be impacted by industrial effluents.

Some caution should be exercised in using the B data collected in this study because of several B detections in equipment blanks. However, available information indicates the B contamination may stem from the DI water rather than the groundwater filters. Sodium tetraborate is widely used as a cleaning aid and detergent (Hem, 1970) and this residue may have been present in DI carboys.

Calcium (Ca) - The 51 groundwater samples collected in the DGB had concentrations of Ca ranging from non-detect - 521 mg/l (**Figure 14**). Other DGB Ca statistics include: median = 47.6 mg/l, mean = 58.8 mg/l, and 95% CIs = 40 - 79 mg/l. In most natural fresh water, Ca is the principal cation (Hem, 1970).

Copper (Cu) - Of the 51 groundwater samples collected in the DGB, only one had a concentration of Cu above the ADHS Laboratory MRL of 0.010 mg/l. The Cu level (0.01 mg/l) in DGB-43 located north of Douglas 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-f) - EC is the ability of a substance to conduct an electrical current and this value changes with temperature (Hem, 1970). The 51 groundwater samples collected in the DGB had EC concentrations ranging from 250 - 16490 umhos/cm (**Figure 14**). Other DGB EC statistics include: median = 448 umhos/cm, mean = 887 umhos/cm, and 95% CIs = 252 - 1521 umhos/cm.

Electrical Conductivity - laboratory-measured (EC-lab) - Only 31 groundwater samples collected in the DGB were analyzed for lab-measured EC because of miscommunications with the ADHS laboratory. Using these partial results, lab-measured EC concentrations ranged from 263 - 2230 umhos/cm. Other DGB EC statistics include: median = 518 umhos/cm, mean = 621 umhos/cm, and 95% CIs = 475 - 767 umhos/cm.

Hardness - Hardness, a measure of the effect of the alkaline-earth cations calcium and magnesium, had levels in the DGB ranging from non-detect at the ADHS Laboratory MRL of 10 mg/l to 2280 mg/l (**Figure 14**). Other DGB hardness statistics include: median = 144 mg/l, mean = 228 mg/l, and 95% CIs = 128 - 327 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 51 groundwater samples collected in the DGB, 6 were in the soft range, 21 were in the moderately hard range, 18 were in the hard range, and 6 were in the very hard range (**Figure 15**). While high hardness levels have no negative health implications, they can be a nuisance to cleaning laundry and dishes and impact plumbing fixtures.

Lead (Pb) - Of the 51 groundwater samples collected in the DGB, only one had a concentration of Pb above the ADHS Laboratory MRL of 0.005 mg/l. Sample DGB-05 located near the town of Elfrida had a Pb level of 0.008 mg/l. There is a SDW Recommended Action Level of 0.015 mg/l for Pb.

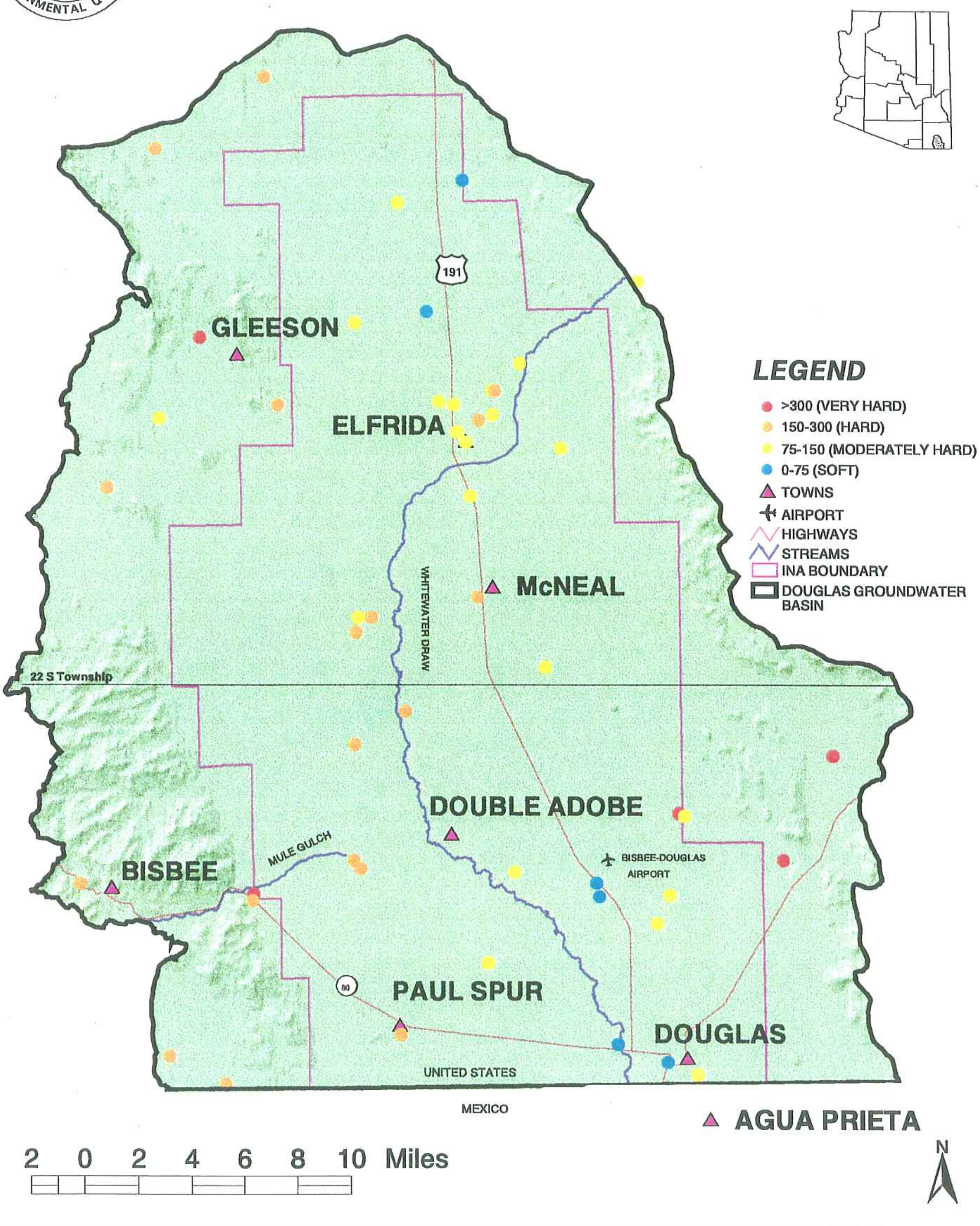
Magnesium (Mg) - The 51 groundwater samples collected in the DGB had Mg concentrations ranging from nondetect - 180 mg/l (**Figure 14**). Other DGB Mg statistics include: median = 8.2 mg/l, 14.5 mg/l, and 95% CIs = 7.3 - 21.8 mg/l. Mg concentrations greater than 125 mg/l may have potentially cathartic and diuretic effects (Franson, 1989). Only one sample, the geothermal anomaly DGB-35b, exceeded this 125 mg/l limit. In most natural fresh water, the Mg concentration is much lower than the Ca concentration (Hem, 1970).

Nitrogen, Total Kjeldahl (TKN) - Of the 51 groundwater samples collected in the DGB, 5 had TKN (organic nitrogen and ammonia) concentrations above the ADHS Laboratory MRL of 0.10 mg/l (**Figure 14**). The highest TKN level was 1.14 mg/l in sample DGB-35b, the geothermal anomaly east of the Bisbee-Douglas Airport. Detections of TKN predominately occurred in the southern portion of the DGB.

Phosphorus, Total (P) - Of the 51 groundwater samples collected in the DGB, none had total P concentrations above the ADHS Laboratory MRL of 0.10 mg/l.

Potassium (K) - The 51 groundwater samples collected in the DGB had K concentrations ranging from 0.52 - 37.7 mg/l; thus, all K concentrations exceeded the ADHS Laboratory MRL of 0.50 mg/l (**Figure 14**). Other DGB K concentrations include: median = 2.13 mg/l, mean = 3.04 mg/l, 95% CIs = 1.6 - 4.5 mg/l. In most drinking waters, K seldom reaches 20 mg/l (Franson, 1989) and is typically only elevated in water with very high TDS concentrations or in water from hot springs (Hem, 1970). This geothermal reason is probably the cause of the extreme K concentration outlier of DGB-35b (37.7 mg/l) collected from east of the Bisbee-Douglas Airport. The next highest K concentration was 5.68 mg/l in DGB-11 collected near Bisbee Junction. An alkali metal like Na, in most natural the concentration of K is much lower than that of Na (Hem, 1970).

Figure 15. Levels of Hardness in Douglas Groundwater Basin Wells



Sodium (Na) - The 51 groundwater samples collected in the DGB had Na concentrations ranging from 9.6 - 420 mg/l (**Figure 14**). Other DGB Na statistics include: median = 36.7 mg/l, mean = 134.4 mg/l, and 95% CIs = -38 - 307 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). Levels of Na in 41 samples in the DGB exceeded this cautionary limit.

Temperature - field - The 51 groundwater samples collected in the DGB had temperature concentrations ranging from 13.2 - 27.8 degrees Celsius (**Figure 14**). Other DGB temperature statistics include: median = 21.6°, mean = 22.0°, and 95% CIs = 21.2 - 22.7°.

Turbidity - The 51 groundwater samples collected in the DGB had turbidity concentrations ranging from non-detect - 71 NTU (**Figure 14**). Other DGB turbidity statistics include: median = 0.14 NTU, mean = 3.89 ntu, and 95% CIs = 0.31 - 7.47 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.

6.7 VOCs

SDW VOCs - There were no detections of VOCs in the 12 wells sampled for SDW VOCs except for DGB-09 where chloroform was detected at the MRL of 0.5 μg/l. This sample was a municipal well for the City of Douglas that was powered by a turbine pump. Lubricants are added to these type of wells for normal maintenance, which may be the cause of the VOC detection. For a complete list of DGB VOC results as well as a listing of the SDW VOCs and their respective Primary MCLs, consult **Appendices G and I**. No VOCs were detected in any of the 3 VOC travel blanks.

6.8 Pesticides

GWPL Pesticides - There were no detections of organic pesticides in the 7 wells sampled for GWPL pesticides. For a complete list of pesticides on the GWPL as well as DGB results, consult **Appendices H and J**.

6.9 Radionuclides

SDW Radionuclides - Six wells were sampled for radionuclide analysis. None of the sample results exceeded the SDW Primary MCLs for Gross α, Gross ß, and Combined Radium-226 + Radium-228. Gross α levels ranged from 2.9 - 15 pCi/L, with a 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 - 1.0 pCi/L, below the 5.0 pCi/L Primary MCL. One sample, with a Gross α level of 15.0 pCi/L, was tested for mass uranium with a 9.3 μg/l result, a level below the proposed Primary MCL of 20 μg/l. Gross ß levels ranged from < LLD - 26 pCi/L, well below the 50 pCi/l Primary MCL. For complete radionuclide results, consult **Appendix F**.

Part IV

ANALYTICAL ANALYSIS

7. STATISTICAL TESTS

Of the 40 inorganic parameters sampled for, 22 were subjected to further statistical analysis. These parameters included: HCO_3, B, Ba, Ca, Cl, EC (field-measured), EC (laboratory-measured), F, hardness, 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 18 inorganic parameters which were only rarely - if ever - detected in groundwater samples: Al, As, Be, NH_3 - N, Cd, Cr, Cu, Fe, Pb, Mn, Hg, NO_2 - N, phenolphthalein alkalinity, Se, Sb, Tl, Ag, 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 were tested for significant differences between different aquifers (**Section 7.2**), groundwater management zones (**Section 7.3**), valley-sides (**Section 7.4**), and basin areas (**Section 7.5**). The degree of association among levels of different groundwater quality parameters in the DGB is provided in **Section 7.6**; the same information for specific DGB aquifers is shown in **Section 7.7** and **Section 7.8**. The relationship between groundwater quality parameter levels and groundwater depth is examined in **Section 7.9**; the same information for specific DGB aquifers is shown in **Section 7.10** and **Section 7.11**. Groundwater depth variations by area are provided in **Section 7.12**. In **Section 7.13**, 95% Confidence Intervals for parameter levels are provided, which are then compared to targeted sampling results collected near the Town of Elfrida (**Section 7.15**), the City of Douglas (**Section 7.16**), Mule Gulch (**Section 7.17**), the Town of McNeal (**Section 7.18**), Northern Sulphur Springs Valley (**Section 7.19**), and a geothermal area (**Section 7.20**). A time-trend analysis is groundwater quality is provided in **Section 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 1** indicate that 9 of the 22 parameters were normally distributed including Ca, EC-lab, HCO_3, hardness, Mg, pH-field, pH-lab, Na, and temperature. 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 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 1**, indicate that the parameters generally fall into four categories:

- Lognormally-distributed parameters - 14 of the 22 parameters were lognormally distributed at $p=0.05$ including Ca, EC-field, EC-lab, HCO_3, hardness, Mg, pH-field, pH-lab, K, Na, SO_4, temperature, total alkalinity, and turbidity.

- "Almost" lognormally-distributed parameters - 3 of the 22 parameters, while not becoming normally distributed at $p=0.05$, were nevertheless "more" normally distributed than the non-transformed parameter as indicated by a significance at a higher probability level. These parameters which were "almost" log-normally distributed and their significance include: ln TDS (0.0441), ln NO_3-N (0.0429), and ln F (0.0250).

- Non-lognormally distributed parameters - 4 of the 22 parameters had a probability level of 0.0000 before and after log-transformation. These parameters include B, Ba, TKN, and Zn. The normality of these parameters was not aided by logarithmic transformation which may be related to the large number of non-detections (hence, a "censored" data set) as well as outliers associated with these 4 parameters.

Table 1. Distribution of Inorganic Parameters in DGB Samples

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

* = Non-transformed data normally distributed
** = Log-transformed data normally distributed

- Non-lognormally distributed parameters - 1 of the 22 parameters, Cl, had a probability level of before log-transformation of 0.0000 which remained largely unchanged after log-transformation (0.0002). The normality of Cl was not aided by logarithmic transformation which seems to be related to two large outliers in the data set.

Based on the above observations, using the logarithmically-transformed database with parametric tests such as ANOVA appears to be the most appropriate method to analyze the groundwater quality data. However, the groundwater quality data was also analyzed using the non-transformed database with nonparametric tests such as Kruskal-Wallis, which has been recommended by some statisticians (Helsel and Hirsch, 1997).

Remarkably similar results occurred with each test in the comparison of 4 sub-areas within the DGB. Eighty of the 88 (or 91%) groundwater quality parameters had similar results when using either the ANOVA test with log-transformed data or the Kruskal-Wallis test using non-transformed data. Of the 8 cases where the two tests were in nonagreement, 5 cases involved lognormally-distributed parameters (Ca, Na, HCO_3, and twice, EC-f), 2 cases involved "almost" lognormally-distributed parameters (F and TDS), and 1 case involved a non lognormally-distributed parameter (Zn). In these 8 cases where the two tests were in nonagreement, often the test that showed non-significance barely missed being significant at the $p = 0.05$ level. Thus, it may be summarized that the two tests were largely in agreement and when they were not, the $p = 0.05$ confidence level that, somewhat arbitarily, often divided findings that both showed strong trends toward significance. An example of this is with Zn, which was significant at the $p = 0.05$ level with the Kruskal-Walis test with a 0.0519 p value but not significant at the $p = 0.05$ level with the ANOVA test with a 0.0619 p value.

While the most recent and comprehensive statistical references specifically recommend the use of nonparametric tests when the nonnormality assumption is violated (Helsel and Hirsch, 1997), this is not the case with this study. These authors also note that if the assumptions of parametric tests are violated, the consequence is an inability to detect differences which are truly present. Again, this does not appear to be the case with this study as with the 8 cases where the ANOVA and Kruskal-Wallis tests were in nonagreement, ANOVA found significance in 3 cases when Kruskal-Wallis failed to while Kruskal-Wallis found significance in 5 cases when ANOVA failed to. A result of these findings was that only parametric tests such as ANOVA using the log-transformed data were reported in this study.

7.2 Groundwater Quality Parameter Level Variations Between Aquifers

A critical factor in understanding groundwater quality is the ability to make comparisons among different areas (Cohen and others, 1988). As such, a major objective of this study was to assess the variation of groundwater quality parameter levels between the two aquifers (**Figure 3**) located within the DGB as documented by Rascona (1993):

- **Alluvial aquifer** - the principal water-bearing unit in the DGB that encompasses the valley floor; and

- **Bedrock aquifer** - a limited water-bearing unit in areas of hard rock surrounding the DGB. The bedrock aquifer includes a series of ranges that, stretching clockwise from the southwest, include the Mule Mountains, Dragoon Mountains, Squaretop Hills, Swisshelm Mountains, Pedregosa Mountains, and Perilla Mountains. These ranges are composed primarily of sedimentary and igneous rocks with local outcrops of metamorphic rocks (Rascona, 1993).

The results of the 29 stratified random samples showed that with half of the groundwater quality parameters, the mean levels of the 10 bedrock aquifer samples were higher than the mean levels of the 19 alluvial aquifer samples. The 11 parameters following this pattern include Ca, EC - field, EC - lab, HCO_3, hardness, Mg, NO_3-N, SO_4, total alkalinity, TDS, and turbidity. In contrast, B, Ba, Cl, F, pH-field, pH-lab, K, Na, temperature-field, TKN and Zn had mean levels in the 19 alluvial aquifer samples higher than the mean levels in the 10 bedrock samples.

To determine whether these differences in mean groundwater quality parameter levels between the two aquifers were due to chance or statistically significant, additional more advanced statistical work was conducted. The results are shown in **Table 2** and indicate the levels of 10 of the 22 analyzed groundwater quality parameters differed significantly between aquifers. Three of these 10 parameters, pH - field, pH - lab, and temperature - field, have significantly higher levels in the alluvial aquifer than the bedrock aquifer while 7 parameters - Ca, hardness, HCO_3, Mg, SO_4, total alkalinity, and turbidity - have significantly higher levels in the bedrock aquifer than the alluvial aquifer.

Table 2. Variation in Groundwater Quality Parameter Levels Between Two Aquifers Using ANOVA with Log-Transformed Data

Parameter	Significance	Aquifer Comparison
B	ns	
Ba	ns	
Ca	**	Bedrock > Alluvial
Cl	ns	
EC-field	ns	
EC-lab	ns	
F	ns	
HCO_3	*	Bedrock > Alluvial
Hardness	**	Bedrock > Alluvial
Mg	*	Bedrock > Alluvial
NO_3-N	ns	
pH-field	**	Alluvial > Bedrock
pH-lab	**	Alluvial > Bedrock
K	ns	
Na	ns	
SO_4	*	Bedrock > Alluvial
Temperature-field	*	Alluvial > Bedrock
Total Alkalinity	**	Bedrock > Alluvial
TDS	ns	
TKN	ns	
Turbidity	**	Bedrock > Alluvial
Zn	ns	

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

7.3 Groundwater Quality Parameter Level Variations Between Groundwater Management Zones

Another important spatial groundwater quality comparison in this study is between the different groundwater management zones within the DGB (**Figure 1**) as documented by Rascona (1993):

- **Irrigation Non-Expansion Area (INA)** - the central portion of the DGB consisting of approximately 540 square miles in which the drilling of new irrigation wells is prohibited in order to halt the expansion of irrigated farmland; and

- **Outside INA** - this area, which is outside the INA boundary and still within the DGB, consists of the outer peripheries of the groundwater basin. Included in this area are the majority of hard rock areas as well as some alluvial areas.

The results of the 29 stratified random samples showed that with approximately half of the groundwater quality parameters, the mean levels of the 12 samples collected outside the INA were higher than the mean levels of the 17 samples collected within the INA. The 12 parameters following this pattern include Ca, EC - field, EC - lab, HCO_3, hardness, Mg, NO_3-N, SO_4, total alkalinity, TDS, turbidity, and Zn. In contrast, B, Ba, Cl, F, pH-field, pH-lab, K, Na, temperature-field, and TKN had mean levels in the 17 samples collected within the INA higher than the mean levels of the 12 samples collected outside the INA boundary.

To determine whether these differences in mean groundwater quality parameter levels between the two groundwater management areas were due to chance or statistically significant, additional more advanced statistical work was conducted. The results are shown in **Table 3** and indicate the levels of 6 of the 22 analyzed groundwater quality parameters differed significantly between aquifers. Four of these 10 parameters, F, pH - field, pH - lab, and temperature - field, have significantly higher levels within the INA while 2 parameters - Ca and turbidity - have significantly higher levels outside the INA.

Table 3. Variation in Groundwater Quality Parameter Levels Between Two Groundwater Management Zones Using ANOVA with Log-Transformed Data

Parameter	Significance	GW Management Zone Comparison
B	ns	
Ba	ns	
Ca	*	Outside INA > Inside INA
Cl	ns	
EC-field	ns	
EC-lab	ns	
F	*	Inside INA > Outside INA
HCO_3	ns	
Hardness	ns	
Mg	ns	
NO_3-N	ns	
pH-field	**	Inside INA > Outside INA
pH-lab	**	Inside INA > Outside INA
K	ns	
Na	ns	
SO_4	ns	
Temperature-field	*	Inside INA > Outside INA
Total Alkalinity	ns	
TDS	ns	
TKN	ns	
Turbidity	**	Outside INA > Inside INA
Zn	ns	

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

7.4 Groundwater Quality Parameter Level Variations Between Valley-Sides

Another spatial groundwater quality comparison that is made in this study is between the valley sides of the DGB as divided by the Whitewater Draw, the principal watercourse in the basin. The Whitewater Draw is a mostly ephemeral stream, except in its extreme southern reach, stretching from its source in the Chiricahua Mountains to the International Border with Mexico (Rascona, 1993). The two valley-sides (**Figure 1**) in which the groundwater quality is compared are as follows:

- **East Valley Side** - the smaller portion of the DGB situated east of the Whitewater Draw. The dividing line between the valley-sides, the Whitewater Draw, stretches from the Squaretop Hills through the communities of Elfrida, Double Adobe, and finally to the International Boundary several miles west of Douglas.

- **West Valley Side** - the larger portion of the DGB situated west of the Whitewater Draw as described above.

The results of the 29 stratified random samples showed that with the majority of groundwater quality parameters, the mean levels of the 19 samples collected in the West valley side were higher than the mean levels of the 10 samples collected in the East valley side. The 14 parameters following this pattern include Ba, Ca, Cl, EC-field, EC-lab, F, HCO_3, hardness, K, NO_3-N, total alkalinity, TDS, turbidity, and Zn. In contrast 8 parameters, B, pH-field, pH-lab, Mg, Na, SO_4, temperature-field, and TKN, had mean levels in the 10 samples collected in the East valley side higher than the mean levels of the 19 samples collected in the West valley side.

To determine whether these differences in mean groundwater quality parameter levels between the two valley sides were due to chance or were statistically significant, additional more advanced statistical work was conducted. The results are shown in **Table 4** and indicate the levels of 2 of the 22 analyzed groundwater quality parameters differed significantly between aquifers. While pH-field had significantly higher levels in the East valley side, Ca had significantly higher levels in the West valley side.

Table 4. Variation in Groundwater Quality Parameter Levels Between Two Valley Sides Using ANOVA with Log-Transformed Data

Parameter	Significance	Valley Side Comparison
B	ns	
Ba	ns	
Ca	*	West > East
Cl	ns	
EC-field	ns	
EC-lab	ns	
F	ns	
HCO_3	ns	
Hardness	ns	
Mg	ns	
NO_3-N	ns	
pH-field	*	East > West
pH-lab	ns	
K	ns	
Na	ns	
SO_4	ns	
Temperature-field	ns	
Total Alkalinity	ns	
TDS	ns	
TKN	ns	
Turbidity	ns	
Zn	ns	

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

7.5 Groundwater Quality Parameter Level Variations Between Basin Areas

Another spatial groundwater quality comparison that is made in this study is between portions of the basin latitudinally-divided. The basin portions of the DGB were divided, somewhat arbitrarily, by the 22 South Township line. Although there is no specific physical boundary at this township line, it can be defended as a way to divide the basin latitudinally: this township line divides the random samples into almost equal numbers for the north and south areas of the basin (15 random samples vs 14 random samples). In addition, the north portion contains the majority of the irrigated agricultural land in the DGB. The two basin areas in which the groundwater quality is compared (**Figure 1**) are further described below:

- **North Basin Area** - this consists of the upper, northern area of the DGB located north of the 22 South Township line. This area includes the communities of Elfrida, Gleeson, and McNeal and includes most of the irrigated farmland found within the DGB.

- **South Basin Area** - this consists of the lower, southern area of the DGB south of the 22 South Township line. This area includes the communities of Bisbee, Bisbee Junction, Double Adobe, Douglas, Paul Spur, and Pirtleville.

The results of the 29 stratified random samples showed that with the majority of groundwater quality parameters, the mean levels of the 14 samples collected in the lower, South basin area were higher than the mean levels of the 15 samples collected in the upper, North basin area. The 15 parameters following this pattern include Ba, Ca, Cl, EC-field, EC-lab, HCO_3, hardness, K, Mg, Na, NO_3-N, SO_4, total alkalinity, and TDS. In contrast 7 parameters, B, F, pH-field, pH-lab, temperature-field, turbidity, and Zn, had mean levels in the 15 samples collected in the upper, North basin area higher than the mean levels of the 14 samples collected in the lower, South basin area.

To determine whether these differences in mean groundwater quality parameter levels between the two basin areas were due to chance or were statistically significant, additional statistical work was conducted. The results are shown in **Table 5** and indicate the levels of 3 of the 22 analyzed groundwater quality parameters differed significantly between aquifers. While F had significantly higher levels in the upper, North basin area, Ba and HCO_3 had significantly higher levels in the lower, South basin area.

Table 5. Variation in Groundwater Quality Parameter Levels Between Two Basin Areas Using ANOVA with Log-Transformed Data

Parameter	Significance	Basin Area Comparison
B	ns	
Ba	*	South > North
Ca	ns	
Cl	ns	
EC-field	ns	
EC-lab	ns	
F	*	North > South
HCO_3	*	South > North
Hardness	ns	
Mg	ns	
NO_3-N	ns	
pH-field	ns	
pH-lab	ns	
K	ns	
Na	ns	
SO_4	ns	
Temperature-field	ns	
Total Alkalinity	ns	
TDS	ns	
TKN	ns	
Turbidity	ns	
Zn	ns	

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

7.6 Correlation Among DGB Groundwater Quality Parameter Levels

In order to assess the strength of association between levels of different groundwater quality parameters in the DGB, the log-transformed parameter levels of each of the 29 randomly sampled wells were compared with the other groundwater quality parameters. The Pearson correlation coefficient was used to measure the strength of association between 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 a perfect inverse relationship. Finally, a Pearson correlation of 0 indicates that neither of the 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 log-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 6** and indicate a fair overall correlation between most of the 21 parameter levels; out of 210 correlations of different parameter levels, 66 pairs had significant correlations at the $p=0.05$ level. Of the 66 significant correlations between different parameters, 56 were positively correlated. In other words, as the levels of one of these parameters rise, the levels of other significantly related groundwater quality parameters tend to also increase. Ten parameters were negatively correlated with each other so that as the level of one of these parameters rise, the level of the other significantly related parameters tend to decrease.

Most significantly-correlated parameters tended to have positive correlations one another with only pH and F typically showing significant negative correlations. Parameter levels and the number of significant correlations with the other 21 parameter levels are as follows: Ca - 13, hardness - 12, nitrate - 11, EC-field - 10, TDS and Mg - 9, Cl, HCO_3, and SO_4 - 8, pH-lab, total alkalinity, and Na - 7, pH-lab and F - 6, temperature-field - 3, B and turbidity - 2, Ba, K, and Zn - 1, and TKN - 0.

Most of the correlations (53%) involved major ions. Cations were positively correlated with the anions to form common water chemistries, except that Na was not correlated with total alkalinity and HCO_3. TDS and EC-field were also correlated with the major ions. Interestingly, pH-field was positively significantly correlated with Na and negatively

Table 6. Correlation Among DGB 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	Ba	Zn
pH-f	*																		
EC-f	ns	ns																	
TDS	ns	ns	**																
Talk	ns	ns	**	ns															
Bicarbonate	ns	ns	**	*	**														
Ca	ns	$\underline{**}$	**	**	*	*													
Mg	ns	ns	**	**	**	**	**												
Hard	ns	$\underline{**}$	**	**	**	**	**	**											
Na	ns	*	**	**	ns	ns	ns	ns	ns										
K	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns									
Cl	ns	ns	**	**	ns	ns	**	**	**	**	*								
SO_4	ns	ns	**	**	ns	ns	**	**	**	**	ns	ns							
F	ns	*	ns	ns	$\underline{*}$	$\underline{**}$	$\underline{*}$	ns	$\underline{*}$	ns	ns	ns	ns						
NO_3	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			
Ba	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Zn	ns	$\underline{*}$	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	$\underline{*}$	ns	ns	ns	ns

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

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

signficantly correlated with Ca and hardness. These correlations are probably due to natural softening by cation exchange with some Ca and Mg ions replaced with Na ions. The pH of such a solution can rise to rather high levels because buffering by calcium carbonate precipitation becomes relatively ineffective (Hem, 1970).

Very interesting correlations were found with F. This parameter was significantly positively correlated with both pH-field and pH-lab which suggests that exchange reactions are a source of control of F levels in solution (Robertson, 1985). This relationship is probably the result of mineral surfaces that are capable of absorbing anions, and if such a surface carried F ions, they could be available for release by substitution of hydroxide ions from water of high pH (Hem, 1970). Some high F concentrations in groundwater may result from this effect since high F concentrations in groundwater typically also have a high pH (Hem, 1970). Significantly negatively correlated relationships were found between F and Ca, hardness, HCO_3, and total alkalinity. Hem (1970) also noted this relationship, that higher concentrations of F generally are in groundwater that is relatively low in Ca. This may be due to Ca levels being an important control on higher levels of F through precipitation of the mineral, fluorite. Under closed conditions, calcite precipitation, secondary clay mineral formation, and ion exchange along the hydraulic flow path deplete the groundwater of Ca and HCO_3 (Robertson, 1985). Under equilibrium conditions, with low Ca levels, F levels may increase and permit relatively high levels of F in the groundwater.

Nitrate was positively significantly correlated with all the major ions (HCO_3, Ca, Mg, Na, Cl, and SO_4) as well as TDS and EC-field and negatively significantly correlated with turbidity. Some of these correlations, such as the nitrate-TDS-Cl relationship, can perhaps be explained by possible impacts from septic systems, as each parameter is an indication of septage (Bedient, et al., 1994). Na, SO_4, Ca, and Mg are also possible indicators of septic impacts (Pye, et al., 1983).

A significant positive correlation was found between B and both Na and Cl. A possible explanation for the B-Na relationship is the presence of evaporite deposits containing B in closed basins (Hem, 1970). Although the DGB is not a closed basin, it is near several, including the Wilcox Playa and several in New Mexico near Lordsburg. Kernite ($Na_2B_4O_74H_2O$), which contains both B and Na is common in evaporate boron deposits and could be a reason for the correlation between these two parameters (Robertson, 1985).

In this study, the only significant correlation involving Ba was with Ca. The positive correlation between these two parameters may be due to the similar solubilities of both Ba carbonate and calcite or Ca carbonate (Hem, 1970). The correlation of Ba with Ca occurs frequently in the alluvial basins of Arizona. The weathering of feldspars is the major dissolution reaction that controls groundwater chemistry in these areas; Ba and Ca correlated because they are alkaline earths and are geochemically similar (Robertson, 1985).

7.7 Correlation Among Alluvial Aquifer Groundwater Quality Parameter Levels

In order to assess the strength of association between levels of different groundwater quality parameters in the alluvial and hard rock aquifers, parameter levels of each 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.

The alluvial aquifer results of the probability test of the Pearson correlation coefficient using log-transformed data show that the Bartlett chi-square test was not significant at $p=0.05$. This means that the correlation matrix is not positive definite and individual significance tests may be suspect. Nonetheless, these correlation probabilities are provided in **Table 7** and indicate a fair overall correlation between most parameter levels; out of 210 correlations of different parameter levels, 56 pairs had significant correlations at the $p=0.05$ level. Of the 56 significant correlations between different parameters, 50 were positively correlated. In other words, as the levels of one of these parameters rise, the levels of other significantly related groundwater quality parameters tend to also increase. Six parameters were negatively correlated with each other so that as the level of one of these parameters rise, the level of the other significantly related parameters tend to decrease.

Most significantly-correlated parameters tended to have positive correlations one another; only F, pH, and temperature typically showed significant negative correlations. Parameter levels and the number of significant correlations with the other 21 parameter levels are as follows: EC-field - 11, Mg and TDS - 10, hardness, K, Na, and NO_3-N - 9, Ca and Cl - 8, pH-field and SO_4 - 7, B - 4, Ba, HCO_3, pH-lab, temperature-field, total alkalinity, and Zn - 3, turbidity - 2, F and TKN - 0.

Most of the correlations (59%) involved major ions, expecially in common water chemistry combinations. Examples include HCO_3 with Ca and Mg, Cl with Ca, Mg, Na, and K, and SO_4 with Na. Many of the other relationships outlined in the overall correleation section were present in the alluvial aquifer correlation section.

Table 7. **Correlation Among Alluvial 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	Ba	Zn
pH-f	ns																		
EC-f	ns	ns																	
TDS	ns	ns	**																
Talk	ns	ns	ns	ns															
Bicarbonate	ns	ns	ns	ns	**														
Ca	ns	$\underline{**}$	**	**	ns	*													
Mg	ns	ns	**	**	*	**	**												
Hard	ns	$\underline{*}$	**	**	ns	**	**	**											
Na	ns	*	**	**	ns	ns	ns	ns	ns										
K	ns	ns	**	**	ns	ns	**	**	**	*									
Cl	ns	ns	**	**	ns	ns	**	**	**	**	**								
SO_4	ns	ns	**	**	ns	ns	ns	ns	ns	**	ns	ns							
F	ns	ns	ns	ns	ns	$\underline{**}$	ns	ns	ns	ns	ns	ns	ns						
NO_3	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			
Ba	ns	ns	*	ns	ns	ns	**	ns	**	ns	ns	ns	ns	ns	ns	ns	ns		
Zn	$\underline{*}$	$\underline{*}$	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	
Turbidity	$\underline{*}$	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

7.8 Correlation Among Bedrock Aquifer Groundwater Quality Parameter Levels

In order to assess the strength of association between levels of different groundwater quality parameters in the alluvial and hard rock aquifers, parameter levels of each 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.

The hardrock aquifer results of the probability test of the Pearson correlation coefficient using log-transformed data show that the Bartlett chi-square test was not significant at $p=0.05$. This means that the correlation matrix is not positive definite and individual significance tests may be suspect. Nonetheless, these correlation probabilities are provided in **Table 8** and indicate a weaker overall correlation between most parameter levels than with overall or alluvial aquifer results; out of 210 correlations of different parameter levels, 34 pairs had significant correlations at the $p=0.05$ level. Of the 34 significant correlations between different parameters, 33 were positively correlated. In other words, as the levels of one of these parameters rise, the levels of other significantly related groundwater quality parameters tend to also increase. Only 1 parameter was negatively correlated with another so that as the level of this parameter rises, the level of the other significantly related parameter tends to decrease.

Most significantly-correlated parameters tended to have positive correlations one another with only the NO_3-N - turbidity siginificant correlation was negative. Parameter levels and the number of significant correlations with the other 21 parameter levels are as follows: EC-field, Mg, and TDS - 8, Ca, hardness, and SO_4 - 7, Cl - 6, NO_3-N - 5, Na - 4, turbidity - 2, HCO_3, temperature-field, and total alkalinity - 1, and B, Ba, F, K, pH-field, pH-lab, TKN, and Zn - 0.

Most of the correlations (77%) involved major ions such as with common water chemistry combinations. Examples include Ca and Mg with Cl and SO_4, and Na with SO_4. Some cations were significantly correlated (Mg - Ca and Mg - Na) as well as anions (Cl - SO_4). TDS and EC-field were also correlated with the major ions except with HCO_3 and K. Also of interest was that NO_3-N was correlated with both Ca and Mg, indicating hard water was much more likely have higher NO_3-N levels.

Table 8. Correlation Among Bedrock 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	Ba	Zn
pH-f	ns																		
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	ns	**	ns										
K	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns									
Cl	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					
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	ns			
Ba	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Zn	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 Not Significant
* Significant Positive Correlation at p=0.05
** Significant Positive Correlation at p=0.01

Bartlett Chi-square statistic = = 0.00
*̲ Significant Negative Correlation at p=0.05
̲̲ Significant Negative Correlation at p=0.01

7.9 DGB 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 DGB, the parameter levels of each of the 29 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 DGB results indicate that 7 of the 21 (or 33%) groundwater quality parameters examined had a mathematical equation relating increasing parameter levels to increasing groundwater depth bls: B, F, pH-field, pH-lab, K, Na, and temperature-field. In contrast, 14 of the 21 (or 67%) groundwater quality parameters examined had a mathematical equation relating decreasing parameter levels to increasing groundwater depth bls: Ba, Ca, Cl, EC-field, HCO_3, hardness, Mg, NO_3-N, SO_4, total alkalinity, TDS, TKN, turbidity, and Zn. These parameter level - groundwater depth relationships were then examined to see which were significant at the 95% confidence interval.

The DGB results indicate that 10 of the 21 (or 48%) groundwater quality parameters examined had one or more mathematical equations significantly relating changing parameter levels to increasing groundwater depth bls: B, pH-field, pH-lab, K, and temperature-field had levels that increased significantly with increasing groundwater depth while Ca, EC-field, hardness, SO_4, and turbidity had levels that decreased significantly with increasing groundwater depth (**Table 9**). The linear model most adequately described the relationship of two parameters (Ca and temperature-field), the biphasic model most adequately described the relationship with 8 parameters (B, EC-field, hardness, pH-field, pH-lab, K, SO_4, and turbidity) while the exponential model did not offer the best solution with any parameters.

Table 9. Relationship Between DGB Groundwater Quality Parameter Levels and Groundwater Depth Using Three Mathematical Models

Parameter	Significance	Type of Relationship	Most Significant Model
B	*	Increasing with depth bls	Biphasic
Ba	ns		
Ca	**	Decreasing with depth bls	Linear
Cl	ns		
EC - f	*	Decreasing with depth bls	Biphasic
F	ns		
HCO_3	ns		
Hardness	**	Decreasing with depth bls	Biphasic
Mg	ns		
NO_3-N	ns		
pH-field	**	Increasing with depth bls	Biphasic
pH-lab	**	Increasing with depth bls	Biphasic
K	*	Increasing with depth bls	Biphasic
Na	ns		
SO_4	*	Decreasing with depth bls	Biphasic
Temperature-field	**	Increasing with depth bls	Linear
Total Alkalinity	ns		
TDS	ns		
TKN	ns		
Turbidity	*	Decreasing with depth bls	Biphasic
Zn	ns		

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

A general pattern is revealed in which many of the parameter levels that significantly decrease with increasing groundwater depth are major ions or related to major ions (Ca, EC-field, hardness, and SO_4); the only exception is turbidity, a physical parameter. In contrast, parameter levels that significantly increase with increasing groundwater depth tend to be physical parameters (pH-field, pH-lab, and temperature-field) with only B and K not following this pattern. Some of these parameter level differences with groundwater depth were expected from examining prevous studies. As occurred in the DGB, groundwater temperature should increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet (Bitten and Gerba, 1994).

These significant relationships suggest that groundwater more suitable to a wide variety of domestic uses may be obtained at greater depths bls, since parameters that significantly decrease with groundwater depth bls such as EC-field, hardness, SO_4, and turbidity would tend to have a larger effect on groundwater quality than the parameters that increase with groundwater depth.

7.10 Alluvial Aquifer 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 DGB, the parameter levels of each of the 19 randomly sampled wells located in the alluvial aquifer were compared to the corresponding groundwater depth. As in the previous section, depth was determined using a sounder in the field or data from ADWR well registration records. Comparisons were done using three distinct methods: linear model, exponential model, and biphasic model.

The alluvial aquifer results indicate that 11 of the 21 (or 52%) groundwater quality parameters examined had a mathematical equation relating increasing parameter levels to increasing groundwater depth bls: B, F, HCO_3, Mg, NO_3-N, pH-field, pH-lab, K, Na, temperature-field, and total alkalinity. In contrast, 10 of the 21 (or 48%) groundwater quality parameters examined had a mathematical equation relating decreasing parameter levels to increasing groundwater depth bls: Ba, Ca, Cl, EC-field, hardness, SO_4, TDS, TKN, turbidity, and Zn. These parameter level - groundwater depth relationships were then examined to see which were significant at the 95% confidence interval.

The alluvial aquifer results indicate that only 2 of the 21 (10%) groundwater quality parameters examined had one or more mathematical equations significantly relating changing parameter levels to increasing groundwater depth bls: temperature-field levels increased significantly with increasing groundwater depth while turbidity levels decreased significantly with increasing groundwater depth (**Table 10**). The biphasic model most adequately described the relationship with the 2 parameters, temperature-field and turbidity.

Both temperature-field and turbidity have the same significant relationships with groundwater depth in the alluvial aquifer as these parameters have with the overall groundwater quality results. Again, the temperature-field level differences of approximately 3 degrees Celsius with every 100 meters or 328 feet with groundwater depth were expected from examining prevous studies (Bitten and Gerba, 1994).

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

Parameter	Significance	Type of Relationship	Most Significant Model
B	ns		
Ba	ns		
Ca	ns		
Cl	ns		
EC - f	ns		
F	ns		
HCO_3	ns		
Hardness	ns		
Mg	ns		
NO_3-N	ns		
pH-field	ns		
pH-lab	ns		
K	ns		
Na	ns		
SO_4	ns		
Temperature-field	**	Increasing with depth bls	Biphasic
Total Alkalinity	ns		
TDS	ns		
TKN	ns		
Turbidity	**	Decreasing with depth bls	Biphasic
Zn	ns		

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

7.11 Bedrock Aquifer 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 DGB, the parameter levels of each of the 10 randomly sampled wells located in the bedrock aquifer were compared to the corresponding groundwater depth. As in the previous section, depth was determined using a sounder in the field or data from ADWR well registration records. Comparisons were done using three distinct methods: linear model, exponential model, and biphasic model.

The bedrock aquifer results indicate that 6 of the 20 (30%) groundwater quality parameters examined had a mathematical equation relating increasing parameter levels to increasing groundwater depth bls: F, pH-field, pH-lab, K, temperature-field, and turbidity. In contrast, 14 of the 20 (70%) groundwater quality parameters examined had a mathematical equation relating decreasing parameter levels to increasing groundwater depth bls: Ba, Ca, Cl, EC-field, HCO_3, hardness, Mg, NO_3-N, Na, SO_4, total alkalinity, TDS, TKN, turbidity, and Zn. B was not detected in any bedrock aquifer groundwater quality samples. These parameter level - groundwater depth relationships were then examined to see which were significant at the 95% confidence interval.

The overall results indicate that only 3 of the 21 (14%) groundwater quality parameters examined had one or more mathematical equations significantly relating changing parameter levels to increasing groundwater depth bls: temperature-field and turbidity levels increased significantly with increasing groundwater depth while TKN levels decreased significantly with increasing groundwater depth (**Table 11**). The linear model most adequately described the relationship with the 2 parameters temperature-field and turbidity, while the biphasic model most adequately described the relationship with TKN.

Temperature-field has the same significant relationship with groundwater depth in the bedrock aquifer as in the overall results and the alluvial aquifer. As previously mentioned, a difference of approximately 3 degrees Celsius with every 100 meters or 328 feet with groundwater depth is expected from temperature-field levels based on previous studies (Bitten and Gerba, 1994). Turbidity also has increasing levels as depth bls increases in the bedrock aquifer in direct contrast to how this physical parameter behaves with both the overall DGB results and alluvial aquifer. TKN levels decrease with increasing groundwater depth bls, a relationship which isn't present in either the alluvial aquifer or the overall DGB results.

Table 11. Relationship Between Bedrock Aquifer Groundwater Quality Parameter Levels and Groundwater Depth Using Three Mathematical Models

Parameter	Significance	Type of Relationship	Most Significant Model
B	ns		
Ba	ns		
Ca	ns		
Cl	ns		
EC - f	ns		
F	ns		
HCO_3	ns		
Hardness	ns		
Mg	ns		
NO_3-N	ns		
pH-field	ns		
pH-lab	ns		
K	ns		
Na	ns		
SO_4	ns		
Temperature-field	**	Increasing with depth bls	Linear
Total Alkalinity	ns		
TDS	ns		
TKN	*	Decreasing with depth bls	Biphasic
Turbidity	**	Increasing with depth bls	Linear
Zn	ns		

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

7.12 Groundwater Depth Variations by Area

Previously in this report, it was determined that significant differences exist in groundwater quality parameter levels among various areas in the DGB divided by geologic, drainage, and political boundaries. These areas were then compared to one another to determine whether groundwater levels bls were significantly different by using an ANOVA test with log-transformed data. The results **(Table 12)** reveal that groundwater depth bls in the DGB differed significantly between geologic areas (alluvial vs. hardrock) and between political groundwater boundaries (inside the INA vs. outside the INA) while not differing significantly between valleys (East vs. West) and basins (North vs. South). In the two cases where groundwater levels differed significantly, the alluvial aquifer had significantly greater depth to groundwater bls than the hardrock aquifer; similarly, the area inside the INA had significantly greater depth to groundwater bls than the area outside the INA.

7.13 Groundwater Parameter Level 95% Confidence Intervals

Confidence intervals at the 95% ($CI_{0.95}$) were determined based on the 29 randomly sampled wells in this study **(Table 13)**. A $CI_{0.95}$ indicates that 95% of the population lies within the stated interval. This statistical index is a useful tool with which to compare targeted groundwater samples to expose possible impacts to groundwater from specific land uses. This which will be done in the following section.

Table 12. Comparison of Groundwater Depth Levels Among Various DGB Areas Using ANOVA with Log-Transformed Data

DGB Area	Significance	Area Comparison
Aquifer	**	Alluvial > Bedrock
INA	**	Inside INA > Outside INA
Valley	ns	
Basin	ns	

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

Table 13. 95% Confidence Interval ($CI_{0.95}$) for Groundwater Quality Parameter Levels in the DGB

Parameter	$CI_{0.95}$
B	0.051 - 0.077
Ba	0.062 - 0.134
Ca	45.32 - 65.48
Cl	10.86 - 53.40
EC-field	471.5 - 670.5
F	0.554 - 1.164
HCO_3	197.5 - 245.8
Hardness	147.9 - 222.4
Mg	9.12 - 16.57
NO_3-N	1.71 - 3.51
pH-field	7.28 - 7.51
pH-lab	7.49 - 7.72
K	1.97 - 2.95
Na	33.5 - 55.0
SO_4	28.5 - 66.5
Temperature-field	20.4 - 22.6
Total Alkalinity	161.7 - 201.2
TDS	287.4 - 395.8
TKN	0.052 - 0.095
Turbidity	-1.10 - 5.35
Zn	0.02 - 0.13

All units are mg/l with the exception of EC (umhos/cm), pH (SU), and turbidity (NTU)

7.14 Targeted Groundwater Sampling

A total of 22 targeted samples were collected for the DGB study as the result of groundwater quality concerns expressed by local residents, local government officials, and ADEQ employees in other programs. There were 6 targeted areas where varying numbers of targeted samples were collected:

- **Town of Elfrida Area** - 9 samples. Targeted samples were collected in the vicinity of Elfrida to examine for potential impacts from several possible sources of groundwater contamination including a landfill operated by Cochise County located just northeast of town, septic systems used by Elfrida residents, and the surrounding irrigated agricultural land.

- **City of Douglas Area** - 6 samples. Targeted samples were collected to determine possible impacts from municipal activities in Douglas, the former site of the Copper Queen Smelter, and from complaints of wastewater discharges exceeding water quality standards, to the southwest of the Bisbee-Douglas Airport.

- **Mule Gulch Area** - 3 samples. Targeted samples were collected in an attempt to determine any groundwater quality impacts stemming from mine tailings in the area.

- **Town of McNeal Area** - 2 samples. Targeted samples were collected to determine if the high F levels found near McNeal in the 1990 ADWR study were reflective of the area or the result of instrument malfunctioning.

- **Northern Sulphur Springs Valley** - 1 sample. A single targeted sample was collected in the intensively irrigated agricultural lands of Sulphur Springs Valley, located in the north central portion of the DGB.

- **Geothermal Area** - 1 sample. A targeted sample was collected in response to reports of poor groundwater quality located to the east of the airport.

Since these targeted samples were collected in a non-random manner, statistical methods utilized in previous sections of this report could not be appropriately applied to this data. In order to use quantitative methods in determining potential groundwater quality impacts from various land uses and/or localized natural conditions, analytical results from targeted samples were compared with $CI_{0.95}$ determined from the 29 random groundwater quality samples collected during the study. Any targeted sample parameter levels exceeding the $CI_{0.95}$ should be viewed as potentially being impacted by a land use and/or a localized natural condition. These comparisons will use natural, nontransformed data.

7.15 Elfrida Area Targeted Sampling Results

Nine targeted groundwater quality samples were collected in the Elfrida area; 7 samples surrounding the landfill located just to the northeast of town and 2 samples located in Elfrida. Although groundwater flow appears to be to the southwest in the vicinity of the landfill (Rascona, 1993), seasonal groundwater flow during periods of heavy agricultural pumping may be to the north. For this reason, groundwater quality samples were collected around the landfill in an attempt to locate any potential impacts from this land use. Water that has percolated through a landfill is known as leachate and may contain large amounts of inorganic and organic contaminants (Driscoll, 1986). Many inorganic parameters are indicative of leachate contamination, including TDS, total alkalinity, Ca, Cl, Mg, Na, K, SO_4, Mn, Zn, Fe, Cu, Pb, Hg, P, NO_3-N, and NH_4 (Driscoll, 1986). These Elfrida-area targeted samples also served to expose potential groundwater quality impacts from septic systems used in Elfrida residences and from agricultural practices in the surrounding irrigated farmland. Soil types in the Elfrida area are considered unsuitable for septic system operation due to their low permeability (ADHS, 1977). Parameters indicative of impacts from septic systems include bacteria, NO_3-N, Cl, and TDS (Alhajjar, et al., 1990). Nitrate from nitrogen fertilizer are the most common kind of agricultural contamination (Henderson, 1984).

The 9 targeted groundwater quality samples collected in the Elfrida area were compared with 95% Confidence Intervals developed for the DGB. The results, shown in **Table 14**, indicate that with the exception of NO_3-N, pH-field, and pH-lab, groundwater quality parameter levels of the targeted samples rarely exceed the $CI_{0.95}$ upper level. These inorganic results, along with the VOC non-detections in the area, appear to indicate that the recently-constructed landfill located northeast of the Town of Elfrida has not impacted groundwater quality. Numerous citizens expressed concern during the course of this study over possible groundwater quality impacts from this landfill operated by Cochise County. While no such link between the landfill and groundwater quality was established by this study, these targeted sampling results will provide good baseline data with which to compare future groundwater quality sampling in the Elfrida area.

These data do reveal an interesting pattern in which 6 of the 9 NO_3-N levels of the targeted samples exceed the upper $CI_{0.95}$ with these 6 samples also exceeding 3 mg/l, a NO_3-N level often indicative of land use impacts. There is no apparent pattern formed by the NO_3-N levels of the 9 targeted wells with high and low values interspersed with one another (**Figure 16**). There is also an almost complete absence of upper $CI_{0.95}$ exceedences by Cl and TDS levels, which are commonly associated with septic systems, as well as by SO_4 and TDS levels, which are commonoly associated with impacts from agricultural return flows (ITFM Technical Appendix, 1994) with the targeted samples. Thus, it is difficult to discern whether the NO_3-N impacts were stemming from septic systems or agricultural practices, the 2 most likely sources in the area. Other possible explanations might be a localized, natural source of NO_3-N such as the weathering deoxidation of ammonium chloride-bearing (NH_4-Cl) volcanic sediments (tuffaceous sandstones) and subsequent migration in the aquifer (Hastings and Hood III, 1989).

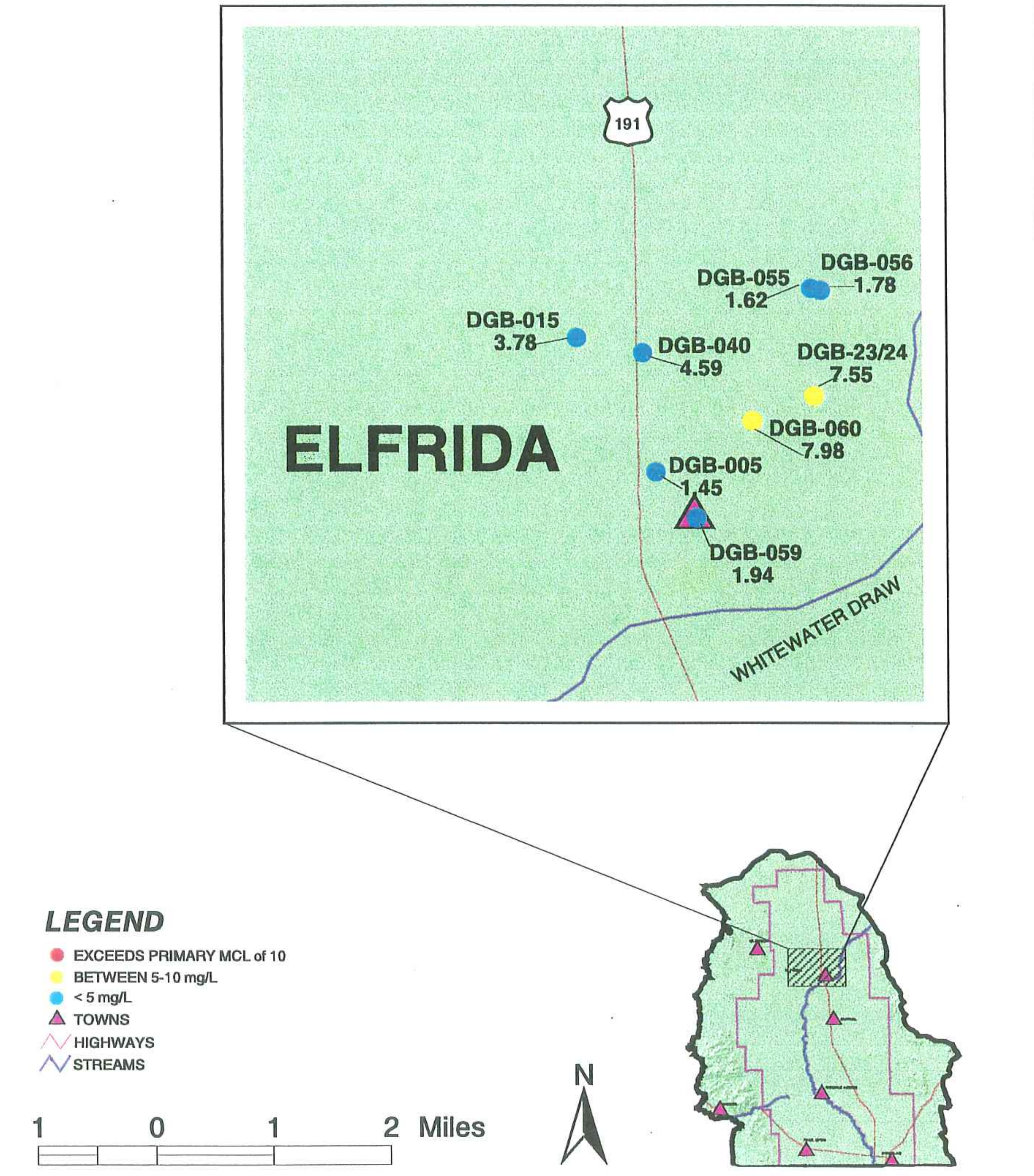
Table 14. Comparison of Groundwater Quality Parameter Levels of Elfrida Area Targeted Samples and DGB 95% Confidence Intervals

Parameter	DGB-15	DGB-17	DGB-23/24	DGB-40	DGB-55	DGB-56	DGB-57	DGB-59	DGB-60
B									
Ba									
Ca						>			
Cl									
EC-field									
F									
HCO_3						>			
Hardness							>		
NO_3-N	>	>	>	>			>		>
pH-field	>	>	>	>	>			>	
pH-lab	>	>	>	<	>			>	
K									
Na									
SO_4									
Temp-f					>				
Total Alk						>			
TDS									
TKN						>			
Turbidity		>				>			
Zn									

\> Above Upper 95% Confidence Level

< Below Lower 95% Confidence Level (for pH only)

Figure 16. Nitrate Levels Near the Town of Elfrida



7.16 City of Douglas Area Targeted Sampling Results

Six targeted groundwater quality samples were collected in the greater Douglas area to examine for potential impacts from various land uses including septic systems, the slag waste pile formed by the Copper Queen Smelter, and from a private citizen's complaint. The complaint concerned wastewater discharges exceeding Hg water quality standards from the prison located at the Bisbee-Douglas Airport. The groundwater flow in that area appears to be to the south although heavy groundwater pumping suggests a groundwater depression may have formed in the Douglas area (Rascona, 1993).

The 6 targeted groundwater quality samples collected in the greater Douglas area were compared with 95% Confidence Intervals developed for the DGB. The results, shown in **Table 15**, indicate that parameter levels in these 6 targeted samples occasionally exceeded the $CI_{0.95}$. The most frequent exceedences were of pH-field (5), temperature-field (5), pH-lab (4), and Na (4) with no other parameter exceeding the $CI_{0.95}$ with more than 2 of the 6 groundwater quality samples.

These patterns of elevated pH and Na levels - along with the very low levels of Ca (6 of the 6 samples are below the $CI_{0.95}$) and Mg (3 of the 6 samples are below the $CI_{0.95}$) - suggest that groundwater is being subjected to natural softening by cation exchange, probably within the saturated zone (Coates and Cushman) and (Hem, 1970). These targeted groundwater samples appear to have had most of their Ca and Mg ions replaced with Na ions by cation exchange and then participated in chemical reactions that raise the pH. The pH of such a solution can rise to rather high levels because buffering by calcium carbonate precipitation becomes relatively ineffective (Hem, 1970). The 2 random samples collected in the greater Douglas area (DGB-9 and DGB-21) support this assertion by showing a similar pattern characterized by levels of pH-field, pH-lab, and Na above the $CI_{0.95}$ and levels of Ca and Mg below the $CI_{0.95}$ (except with Mg in DGB-9). The cation exchange occurring in the Douglas area may indicate there are high levels of clays and soil organic materials in the soils since these are the primary ion-exchange sites (Fetter, 1994).

According to this study, there appears to be no link between the septic systems, slag heaps from smelters, and/or wastewater discharges high in Hg and impacted groundwater quality. However, these targeted sampling results will provide good baseline data with which to compare future groundwater quality sampling in the greater Douglas area.

Table 15. **Comparison of Groundwater Quality Parameter Levels of City of Douglas Area Targeted Samples and DGB 95% Confidence Intervals**

Parameter	DGB-10	DGB-16	DGB-22	DGB-41	DGB-42	DGB-43
B			>	>		
Ba	>	>				
Ca						
Cl	>					
EC-field	>					
F	>					
HCO_3						
Hardness						
Mg						>
NO_3-N			>			
pH-field	>		>	>	>	>
pH-lab	>	>	>	>		
K						
Na	>		>	>	>	
SO_4	>					
Temperature-field	>		>	>	>	>
Total Alkalinity						
TDS	>					
TKN				>		
Turbidity						
Zn						

> Above Upper 95% Confidence Level
< Below Lower 95% Confidence Level (for pH only)

7.17 Mule Gulch Area Targeted Sampling Results

Three targeted groundwater quality samples were collected near where Mule Gulch runs from the hardrock of the Mule Mountains into the alluvium of the Sulphur Springs Valley. These targeted samples were collected in an attempt to discern any groundwater quality impacts stemming from both mine tailing dumps and the Bisbee Sewage Disposal Plant which is located upgradient along the hardrock portion of Mule Gulch. Besides these 3 wells, there were no other wells in the area which ADEQ personnel were able to sample to assist in examining the Mule Gulch area. Groundwater movement appears to be east, following the direction of the flow of Mule Gulch (Rascona, 1993).

Groundwater quality impacts from mine tailing dumps typically have elevated levels of SO_4, radioactive materials, and low, acidic pH values which in turn can also leach heavy metals (Henderson, 1984). Although sulfur is not a major constituent of the earth's crust, it is widely distributed in reduced form both in igneous and sedimentary rocks as metallic sulfides. Concentrations of these sulfides often constitute ores of economic importance. As a result of weathering and contact with aerated water, the sulfides are oxidized to yield SO_4 ions which are carried off in the water (Hem, 1970). This oxidation process of sulfur species produces hydrogen ions in considerable quantity which helps explain why water of very low pH may result from drainage of active mines as well as continuing long after mining has ceased (Hem, 1985). Lower pH and metal concentrations can also occur in mine drainage water.

Groundwater quality impacts from mining activites have been documented from Bisbee-area mines outside the DGB. Portions of the alluvial aquifer located south of Bisbee have been impacted from infiltration of leachate from a mine tailings pond (Littin, 1987). This impoundment, located northeast of the multi-national town of Naco, is considered the source of the elevated SO_4 levels in a number of wells in the area.

The 3 targeted groundwater quality samples collected in the Mule Gulch area were compared with 95% Confidence Intervals developed for the DGB. The results, shown in **Table 16**, indicate that parameter levels in DGB-46/47 generally exceeded $CI_{0.95}$ while DGB-49/50 and DGB-52 only occasionally exceeded $CI_{0.95}$. More importantly, all 3 samples had acidic pH-field values below the $CI_{0.95}$ and 2 samples exceeded the SO_4 $CI_{0.95}$. In addition, DGB-46/47 exceeded the $CI_{0.95}$ for NO_3-N and had a detection of Fe over the Secondary MCL, 1 of only 3 detections of Fe in this DGB study.

Sampling results from these 3 targeted wells appear to indicate that the Mule Gulch area to the east of Bisbee has similar groundwater quality impacts stemming from mine wastes as have occurred to the south of Bisbee, as documented by the USGS (Littin, 1987). DGB-46/47, located where groundwater would likely be affected by impacts upgradient along Mule Gulch, shows an extremely high SO_4 level (1330 mg/l), low pH level (6.68 su), and a 0.33 mg/l level of Fe, all indicators of impacts from mine wastes. DGB-52 also has SO_4 exceeding the $CI_{0.95}$ and pH-field values lower than $CI_{0.95}$, but located 4 miles downgradient of DGB-46/47,

Table 16. Comparison of Groundwater Quality Parameter Levels of Mule Gulch Area Targeted Samples and DGB 95% Confidence Intervals

Parameter	DGB-46/47	DGB-49/50	DGB-52
B			
Ba			>
Ca	>		>
Cl			
EC-field	>		
F			
HCO_3			
Hardness	>		
Mg	>		
NO_3-N	>		
pH-field	<	<	<
pH-lab	<	<	
K			
Na			
SO_4	>		>
Temperature-field		>	
Total Alkalinity			
TDS	>		
TKN	>	>	
Turbidity	>		
Zn			

\> Above Upper 95% Confidence Level
< Below Lower 95% Confidence Level (for pH only)

these respective parameter values show much more minor effects of potential impacts from mine wastes. DGB-49/50 has a pH-field level below the $CI_{0.95}$ but otherwise shows few effects of mine waste impacts. As **Figure 17** shows, DGB-49/50 appears to receive groundwater recharge from the eastern flank of the Mule Mountains rather than drainage from Mule Gulch, which would help explain the fewer mine waste impacts found in this well.

The SO_4 levels of 4 wells - 2 targeted (DGB-46/47 and DGB-52), 1 random (DGB-27), and 1 sampled in August, 1988 by the ADEQ Safe Drinking Water Section (Mike's Corral & Steakhouse) - were compared with distance between the various wells using 3 mathematical models: linear, exponential, and biphasic. Both the exponential and the biphasic models were highly correlated at $p=0.01$, though the exponential model most adequately described the relationship (**Figure 18**).

Using this exponential model the spatial extent of the elevated SO_4 levels in the groundwater, specifically at levels above the 250 mg/l Secondary MCL was determined. Based on this targeted sampling, groundwater would have to travel a distance of 2.48 miles in a downgradient, easterly direction from the well where sample DGB-46/47 was collected in order to obtain levels below the SO_4 Secondary MCL.

Another potential impact on the groundwater quality of this area is the Bisbee Sewage Disposal Plant which is located upgradient along the hardrock portion of Mule Gulch. Municipal wastewater systems such as this may impact groundwater quality from leakage from sewer lines, wastewater holding ponds, and/or land spreading of wastewater at excessive rates. Contamination may include NO_3-N, phosphates, heavy metals, pathogens, hydrocarbons, and other inorganic and organic substances (Henderson, 1984). Since nitrate occurs naturally, its presence is not always indicative of contamination though NO_3-N levels over 3 mg/l are generally considered to be influenced by anthropogenic sources (Madison and Burnett, 1984).

To examine impacts from this municipal wastewater system, the 3 targeted groundwater quality samples collected in the Mule Gulch area were compared with 95% Confidence Intervals developed for the DGB. The results, shown in **Table 16**, indicate that only DGB-46/47 had a NO_3-N parameter level exceeding the $CI_{0.95}$. This sample had a NO_3-N level of 6.32 mg/l. This sample, with a NO_3-N level elevated above the $CI_{0.95}$, may indicate potential impacts from the Bisbee Sewage Disposal Plant or other upgradient sources.

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Figure 17. Sulfate Levels Near Mule Gulch

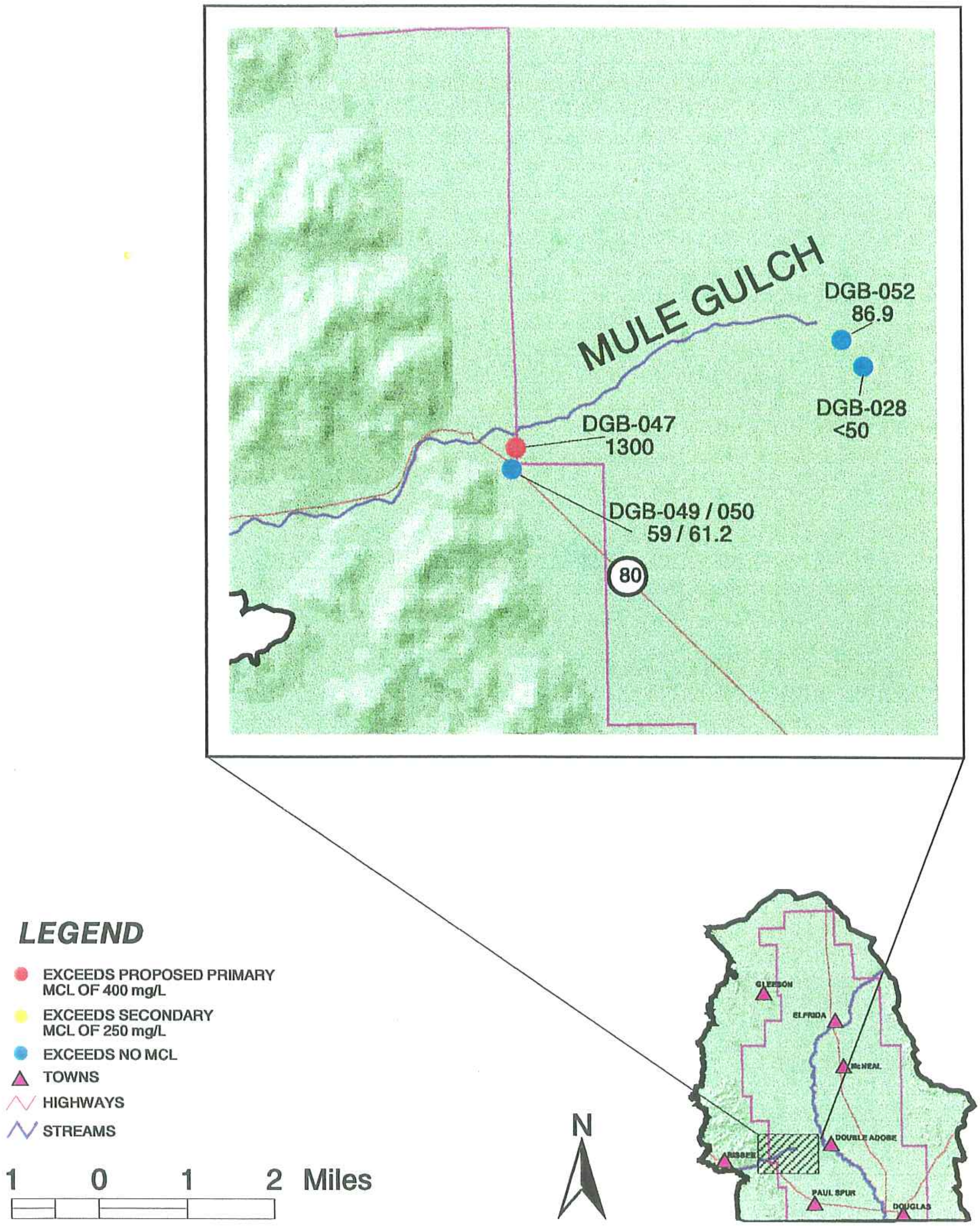
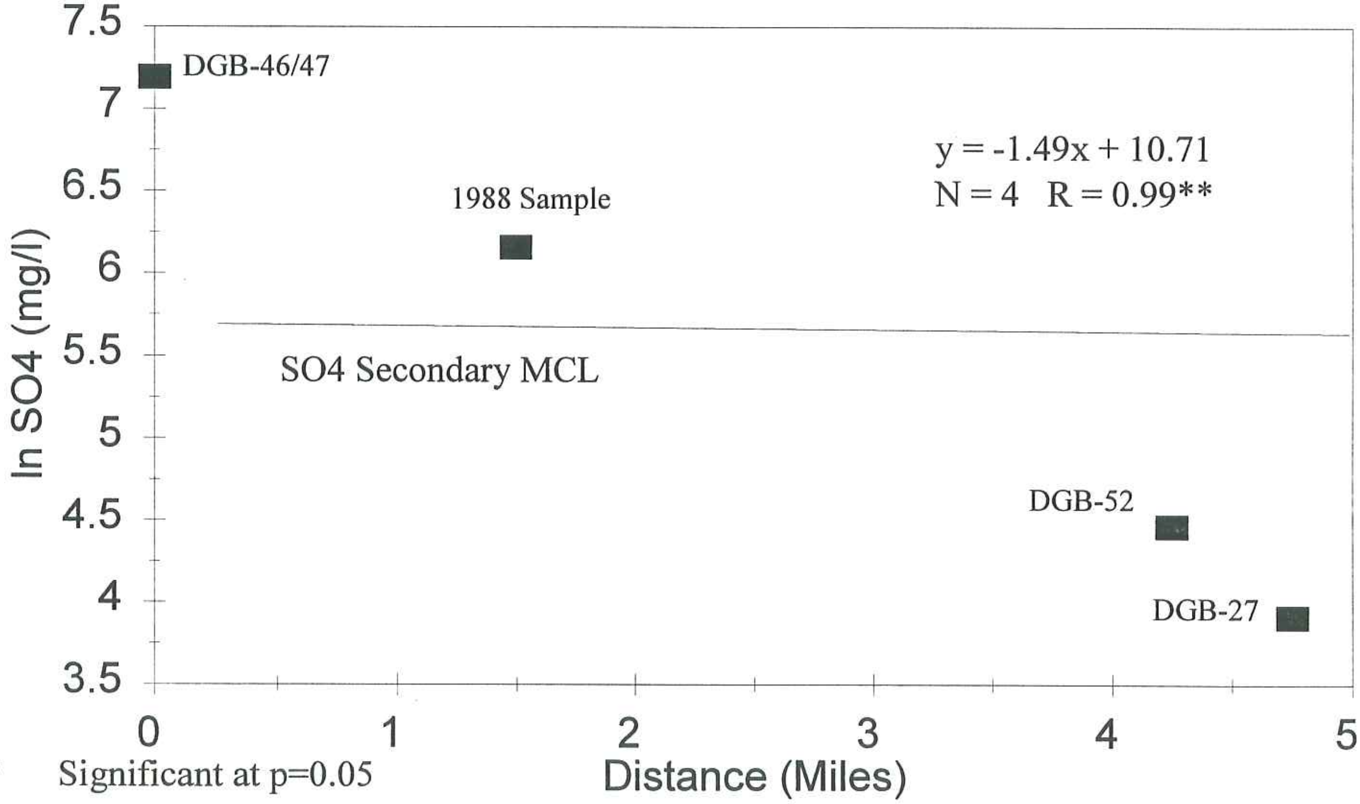


Figure 18. Relationship Between SO4 and Distance in Mule Gulch Area



* Significant at p=0.05

** Significant at p=0.01

7.18 McNeal Area Targeted Sampling Results

Two targeted groundwater quality samples were collected to the west of the Town of McNeal in order to determine F levels in the area. A 1990 ADWR study in this area found elevated F levels, often over the Primary MCL level of 4 mg/l. The 5 groundwater samples nearest to McNeal had F levels of 5.6, 6.2, 7.0, 9.2, and 15 mg/l, all exceeding the Primary MCL. During a conversation conerning this study, the author noted that the high F levels in the McNeal area may have been due to a malfunctioning F meter (Rascona, 1995). These two targeted samples were collected in an attempt to determine whether the elevated F levels found in the 1990 ADWR report are representative of the area.

The analytical results from the two targeted groundwater samples show F levels over the 2.0 mg/l Secondary MCL but not over the 4.0 mg/l Primary MCL; DGB-53 had a F level of 2.95 mg/l while DGB-54 had a 3.28 mg/l F level. In comparison, F $CI_{0.95}$ for the DGB ranged from 0.554 - 1.164 mg/l, well below the F levels of the 2 targeted samples. In addition, 4 random groundwater samples were collected in the McNeal area. The F levels of these samples were DGB-25 - 0.27 mg/l, DGB-26 - 1.18 mg/l, DGB-34/35a - 2.60 mg/l, and DGB-36/37 - 1.30 mg/l.

These results suggest that F levels in the McNeal area are elevated in comparison to other areas of the DGB and sometimes exceed the Secondary MCL. Therefore, the F levels measured by ADWR in their 1990 study, all of which exceeded the Primary MCL sometimes by up to 3 magnitudes, may have been accurate. This conclusion is based on ADEQ sampling results as well as conversations with ADWR personnel involved in the 1990 ADWR study (Rascona, 1995).

7.19 Northern Sulphur Springs Valley Targeted Sample Results

A single targeted groundwater quality sample was collected in the Northern Sulphur Springs Valley to examine potential impacts from intensely irrigated agricultural lands. The groundwater flow in the area appears to be to the south (Rascona, 1993).

The sample collected in this area was compared with 95% Confidence Intervals developed for the DGB. The results, shown in **Table 17**, indicate that only F and pH-field parameter levels in this targeted sample exceeded the $CI_{0.95}$. This pattern suggests that irrigated agriculture in the Northern Sulphur Springs Valley has not impacted groundwater quality. Results from this targeted sample will provide important baseline data with which to compare future groundwater quality sampling in this agricultural area.

Table 17. Comparison of Groundwater Quality Parameter Levels of Northern Sulphur Springs Targeted Sample and DGB 95% Confidence Intervals

Parameter	DGB-39
B	
Ba	
Ca	
Cl	
EC-field	
F	>
HCO_3	
Hardness	
Mg	
NO_3-N	
pH-field	>
pH-lab	
K	
Na	
SO_4	
Temperature-field	
Total Alkalinity	
TDS	
TKN	
Turbidity	
Zn	

> Above Upper 95% Confidence Level
< Below Lower 95% Confidence Level (for pH only)

7.20 Geothermal Targeted Sample Results

A single targeted groundwater quality sample was collected to the east of the Bisbee-Douglas International Airport in what was rumored to be an area of poor groundwater quality. Groundwater flow appears to be to the southwest in the vicinity of the well (Rascona, 1993).

This sample was compared with 95% Confidence Intervals developed for the DGB. The results, shown in **Table 18**, indicate that the majority of groundwater quality parameters had levels exceeding the $CI_{0.95}$ upper level, including B, Ca, Cl, EC-field, hardness, Mg, K, Na, SO_4, temperature-field, TDS, TKN, and turbidity. In many cases, these parameter levels exceeded the $CI_{0.95}$ upper level by several orders of magnitude as well as exceeding the respective Secondary MCLs for Cl, SO_4, and TDS. In addition, groundwater quality parameters rarely - if ever - encountered in the DGB such as As, Fe, Mn, and NH_3-N were detected in the sample from this well, sometimes exceeding their respective Primary (As) or Secondary MCLs (Fe and Mn).

Results from sample DGB-35b appear to indicate that this well is located in a very limited geothermal anomaly. Elevated groundwater temperatures such as exhibited by DGB-35b (27.1^0 Celsius) raise both the solubility and the rate of dissolution of most rock minerals (Hem, 1970). The solute content of such groundwater is commonly higher than nonthermal water, with higher levels of TDS and various metals. As such, the extremely high levels of many groundwater quality parameters collected from this well are indicative of geothermal activity. These include physical parameters: EC-field (16,490 umhos/cm) and turbidity (71 ntu), nutrients: NH_3-N(1.09 mg/l) and TKN (1.14 mg/l), major ions: Ca (521 mg/l), Cl (3,160 mg/l), K (37.7 mg/l), Mg (180 mg/l), Na (4,420 mg/l), SO_4 (5,020 mg/l), and TDS (14,200 mg/l), and trace elements: As (0.15 mg/l), B (3.26 mg/l), Fe (13.9 mg/l), and Mn (1.52 mg/l).

In an attempt to delineate this area of supposed geothermal activity, other wells were sought from which to collect groundwater samples. A largely undeveloped area, very few wells had been drilled in the area. The only well from which ADEQ could collect a groundwater sample from was DGB-45 which was used as a random sample. This well was less than 200 meters from where DGB-35b was collected. The only indication of geothermal activity associated with sample DGB-45 was a field temperature of 24.1^0 Celsius that exceeded the DGB $CI_{0.95}$; all other parameter levels were below the DGB $CI_{0.95}$. The difference in groundwater quality between the 2 wells may be related to different hydrologic conditions. DGB-35b has a well depth of 600', a water depth of 250', and a perforated interval from 560' to 600' while DGB-45 is a much shallower well at 340', has a water depth of 160', and an unknown perforated interval.

Any future well development in this area east of the Bisbee-Douglas International Airport should - if possible - avoid obtaining groundwater from depths > 550 bls. As evidenced by sample DGB-35b, groundwater exceeding SDW standards could be encountered.

Table 18. Comparison of Groundwater Quality Parameter Levels of Geothermal Targeted Sample and DGB 95% Confidence Intervals

Parameter	DGB-35b
B	>
Ba	
Ca	>
Cl	>
EC-field	>
F	
HCO_3	
Hardness	>
Mg	>
NO_3-N	
pH-field	
pH-lab	
K	>
Na	>
SO_4	>
Temperature-field	>
Total Alkalinity	
TDS	>
TKN	>
Turbidity	>
Zn	

> Above Upper 95% Confidence Level
< Below Lower 95% Confidence Level (for pH only)

8. TIME-TREND ANALYSIS

A groundwater quality time-trend analysis was conducted using baseline groundwater quality data previously collected by the ADWR and the USGS in the summer of 1987. This data was compared with ADEQ sampling results collected in 1995 and 1996. Seven of the 35 wells sampled by ADWR/USGS were resampled by ADEQ for this study. These resampled wells include DGB-2, DGB-4, DGB-10, DGB-14, DGB-16, DGB-21, and DGB-22. The locations of the 7 wells are generally spread throughout the DGB and are shown in **Figure 19**.

The nonparametric Wilcoxon test was used to determine any significant differences between these 2 groups of groundwater quality samples with respect to parameter levels. Wilcoxon uses the rank order of the differences between 2 variables and is the nonparametric analog of the paired t test (Wilkinson and Hill, 1994). A nonparametric test was considered more appropriate than a parameteric test because the accuracy of these data sets is inherently less dependable since it was collected at different times by different government agencies and analyzed by different laboratories.

Examining the mean levels of the 7 groundwater quality samples, parameters such as EC-field, NO_3-N, hardness, Ca, Mg, Na, K, Cl, and B were higher in the ADEQ samples than the ADWR samples; the opposite is the case with temperature-field, pH-field, and SO_4. These parameters were then tested to examine which of these parameter level differences were significant at the 95% confidence level.

Differences between the 2 data sets were tested for the following 12 parameters: temperature-field, EC-field, pH-field, NO_3-N, hardness, Ca, Mg, Na, K, Cl, SO_4, and F. The results of the Wilcoxon test, provided in **Table 19**, show that 3 parameters (pH-field, NO_3-N, and K) are significantly different between the two data sets. The parameter levels of NO_3-N and K were significantly higher in the groundwater samples collected by ADEQ than those collected by ADWR/USGS; the pH-field values measured by ADWR/USGS were significantly higher than those measured by ADEQ.

The variations in 12 groundwater quality parameters, temperature-field, EC-field, pH-field, NO_3-N, hardness, Ca, Mg, Na, K, Cl, SO_4, and F, were compared between the ADWR/USGS and the ADEQ samples collected from the same 7 wells. Linear regression indicates that the overall composite variation between 84 sets of parameters was approximately 1.04% and significantly correlated at $p = 0.01$ (**Figure 20**). Linear regression also indicates that each of the 7 sets of 12 groundwater quality parameters, except temperature-field, were also significantly correlated at $p = 0.01$. In addition, the two groundwater quality data sets had different MRLs for trace elements such as As, B, and Ba. Thus, although this limited the usefulness of linear regression to quantify these relationships, both data sets exhibited similar peaks with respect to these trace elements.

Figure 19. Location of Wells Used in the Time-Trend Analysis

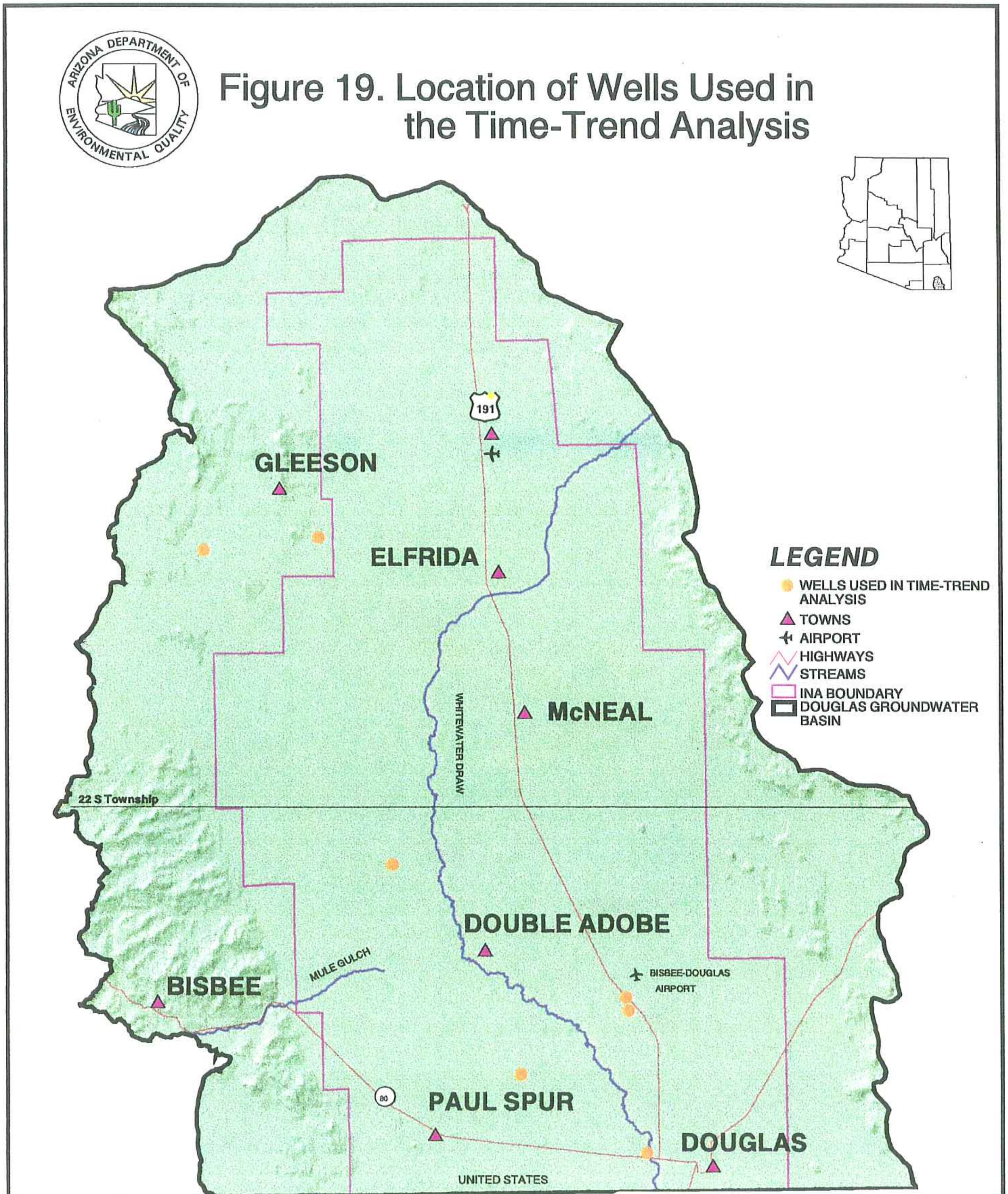
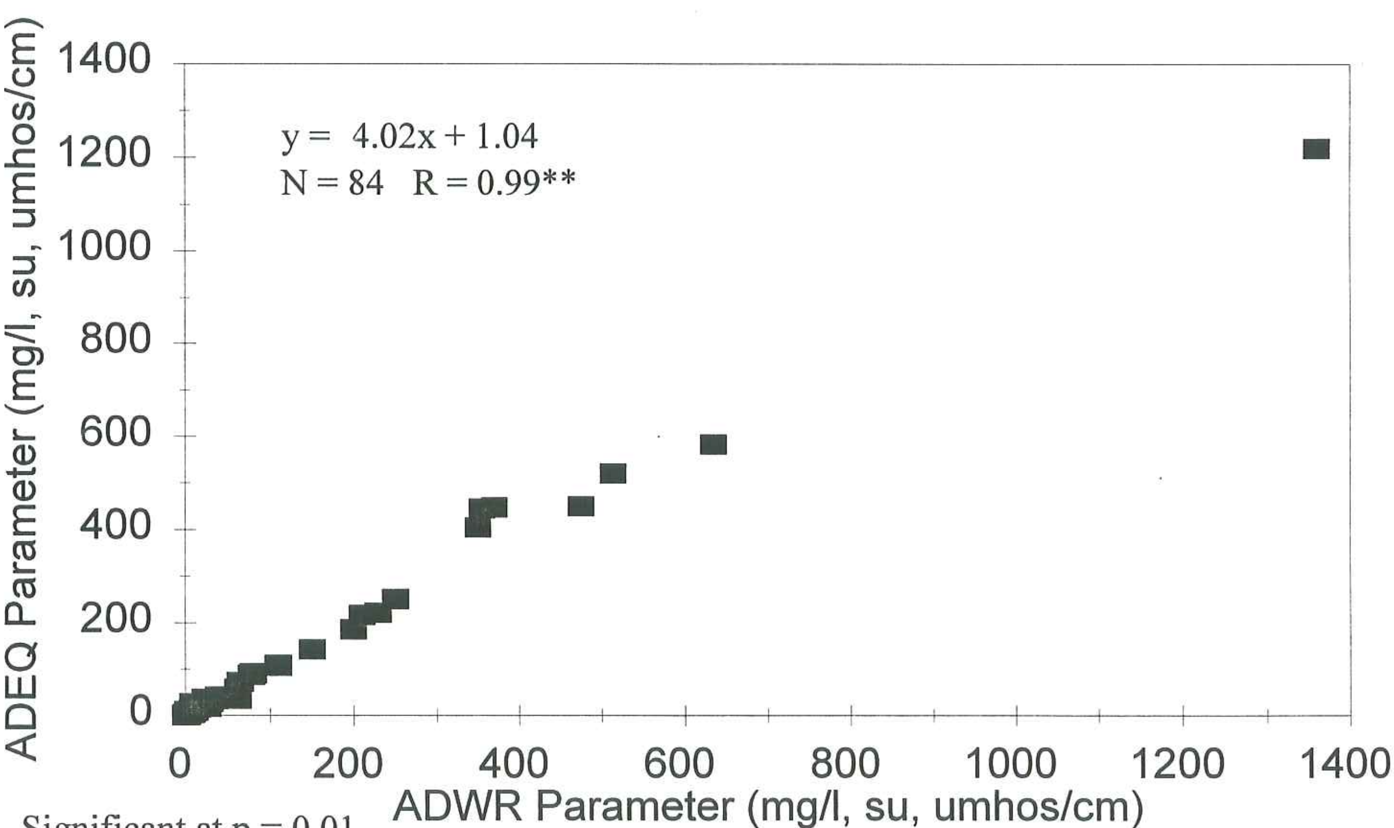


Table 19. Variation in Groundwater Quality Parameter Levels Between 1987 ADWR/USGS and 1995/96 ADEQ Sampling Results for 7 Wells Using Wilcoxon Test with Natural Data

Parameter	Significance	Sampling Comparison
Ca	ns	
Cl	ns	
EC-field	ns	
F	ns	
Hardness	ns	
Mg	ns	
NO_3-N	*	1995/96 > 1987
pH-field	*	1987 > 1995/96
K	*	1995/96 > 1987
Na	ns	
SO_4	ns	
Temperature-field	ns	

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

Figure 20. Correlation of Parameter Levels Between ADWR/ADEQ Samples



* Significant at p = 0.01
** Significant at p = 0.05

Another limited time-trend analysis was conducted using a well sampled in 1910, 1946, as well as in 1995 by ADEQ (Coates and Cushman, 1955). This well, located at the railroad siding of Kelton Junction several miles to the northwest of Elfrida, supplied the now-abandoned El Paso & Southwestern Railroad line that ran through the Sulphur Springs Valley. The well, once utilized for both domestic and industrial (for steam locomotives) purposes is currently used only for domestic purposes. The well is 650 feet deep; groundwater depth in 1995 was approximately 270 feet. Although only limited parameters were sampled for in 1910 (HCO_3 and Cl) and 1946, (temperature, EC, HCO_3, Cl, and F), it is nonetheless an interesting though qualitative comparison since the sampling events span 85 and 50 years, respectively. Comparisons of the 3 sampling events are as follows:

- Temperature - 25.5^0 C (1946), 24.0^0 C (1995)
- EC - 347 umhos/cm (1946), 434 unhos/cm (1995)
- HCO_3 - 180 mg/l (1910), 182 mg/l (1946), 207 mg/l (1995)
- Cl - 7 mg/l (1910), 7 mg/l (1946), 12.4 mg/l (1995)
- F - 4.4 mg/l (1946), 2.2 mg/l (1995)

Although relatively few parameters are examined, a qualitative analysis seems to indicate that parameter levels have not increased dramatically in this deep well.

Part V

FINAL ANALYSIS

9. AMBIENT MONITORING INDEX WELL NETWORK

For groundwater studies, time variability is usually less important than spatial variation in the composition of an aquifer (Hem, 1970). Nonetheless, a critical factor in understanding groundwater quality is the ability to make comparisons over time, and consistent information is necessary to make valid comparisons (Cohen and others, 1988). Although changes in groundwater quality with time are usually comparatively slow, studies have documented both long-term and short-term trends (Hem, 1970). Deep wells that obtain water from aquifers which are not too extensively exploited may yield groundwater of constant chemical composition for many years while shallow wells and/or seasonal springs may exhibit shorter term chemical composition flucuations (Hem, 1970).

Index well networks are important tools in evaluating regional water quality, as they allow for efficient groundwater quality checks that are representative of a large area. The establishment of an ambient monitoring index well network in the DGB is predicated on the concept that it is better - and less expensive - to prevent groundwater contamination than to attempt to clean the aquifer up afterward; 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. This presents a comprehensive background of the groundwater quality of the basin as well as the selection of wells that accurately reflect the regional groundwater quality. 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 and the results of the 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 DGB. For effective time-trend analysis, consistent field sampling protocols are required to minimize errors and maximize quality assurance of monitoring data over time.

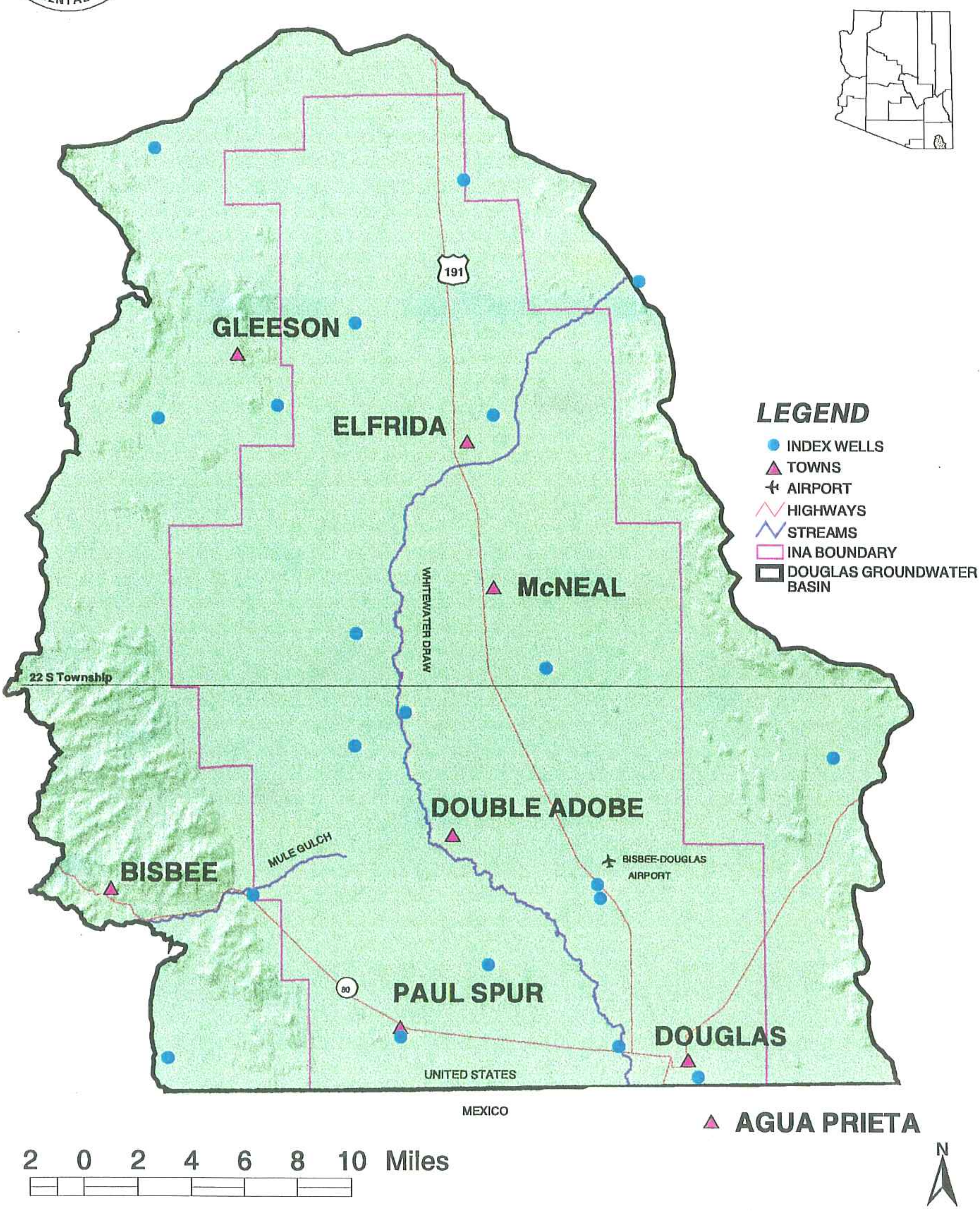
The 16 ambient groundwater quality monitoring index wells established for the DGB are listed in **Table 20** and are shown in **Figure 21**. They were selected on the following basis:

- The 16 index wells are located in every other township, forming a "checkerboard" pattern across the DGB. This provides wide spatial coverage across the basin, and a variety of aquifers, land uses, and well types are encompassed by the monitoring well network;
- Of the 16 index wells, 7 were previously sampled by the ADWR/USGS in 1987 and used in the time trend analysis of this 1995-96 ADEQ study. These wells were chosen as part of the ambient index network to "jump start" the groundwater quality comparisons over time in the DGB;

Table 20. Index Wells Selected for DGB Ambient Groundwater Quality Monitoring Network

Well Registry #	ADEQ #	Sample #	Location	Comments
55-633368	41315	DGB-38	(D-18-24)09cdc	
55-606653	41405	DGB-20	(D-18-26)34aad	
55-613647	41807	DGB-13	(D-19-25)25acc	
55-513430	50395	DGB-32	(D-19-27)14cdc	
55-641453	42442	DGB-14	(D-20-24)10ddd	Sampled in 1987
55-633786	42452	DGB-02	(D-20-25)09bdd	Sampled in 1987
55-606926	51621	DGB-23/24	(D-20-26)11cdd	
55-800205	42996	DGB-36/37	(D-21-25)25aaa	
55-624487	50733	DGB-25	(D-21-27)31add	
55-645369	43491	DGB-04	(D-22-25)13adb	Sampled in 1987
55-532818	51697	DGB-34/35a	(D-22-26)08aba	
None	55056	DGB-44	(D-22-28)13dcb	
55-624566	55055	DGB-46/47	(D-23-25)08ddd	
55-633420	44074	DGB-16	(D-23-26)26acd	Sampled in 1987
None	44095	DGB-21	(D-23-27)16aaa	Sampled in 1987
55-617653	44088	DGB-22	(D-23-27)09dab	Sampled in 1987
55-805643	44355	DGB-11	(D-24-24)11dcd	
55-633419	44393	DGB-29	(D-24-26)08baa	
55-603979	44411	DGB-10	(D-24-27)10daa	Sampled in 1987
55-603988	51175	DGB-09	(D-24-28)18cad	

Figure 21. Index Wells Selected for Ambient Monitoring Network



- The 16 DGB index wells typically consist of random samples collected during the 1995-96 study, though targeted wells were sometimes included if their sampling history and well characteristics were more appropriate for the ambient monitoring network.

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

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

The ADEQ ambient index well groundwater monitoring network in the DGB should be resampled more frequently than every 8 years. This recomendation is based upon an earlier finding in this report that 3 parameters have changed significantly in 7 wells between 1987 sampling by ADWR/USGS and 1995-96 sampling by ADEQ. One of the parameters with significantly higher levels in the second round of sampling was NO_3-N, which has a health-based Primary MCL. Nitrate is often associated with impacts from human activities such as wastewater systems and agriculture. Since levels of this potentially-harmful groundwater quality parameter appear to be significantly increasing, this sampling schedule will serve to alert both ADEQ and DGB residents of continued area trends in NO_3-N levels. Given the continued residential and commercial development taking place within the DGB, keeping abreast of NO_3-N levels will be an especially important trend.

10. CONCLUSION

This 1995-96 ADEQ regional study to assess the groundwater quality of the DGB had 6 major objectives:

- Obtain baseline data throughout the basin on the occurrence, concentrations, and ranges of a wide array of groundwater quality parameters;
- Characterize groundwater quality differences between various spatial areas;
- Examine relationships with groundwater quality parameter levels and indices such as groundwater depth and other groundwater quality parameter levels;
- Assess the impact on groundwater quality from potential contaminant sources related to specific land uses and/or management practices;
- Conduct a groundwater quality time-trend analysis using results from previous studies for baseline data; and
- Establish an ambient monitoring index well network for long-term examination of temporal groundwater quality trends.

The results of the study indicated the following key findings for each objective:

Obtain baseline data throughout the basin on the occurrence, concentrations, and ranges of a wide array of groundwater quality parameters

Overall, the groundwater quality of the DGB is generally acceptable for drinking and other domestic uses based on the results of this study. Some residents may prefer to use treated or filtered water because of poor aesthetic characteristics such as taste, smell, and/or color of the groundwater occasionally encountered in the DGB. This conclusion is based on the following findings:

- Only 3 of the 51 groundwater samples collected for the DGB study had exceedences of health-based, inorganic Primary MCLs (**Figure 7**). These 3 exceedences were for As, Be, and NO_3-N (**Figure 8**, **9**, and **10**), with each exceeding its respective Primary MCL in 1 sample. The DGB groundwater samples were tested for 13 inorganic parameters having Primary MCLs, though Sb results were considered invalid due to groundwater filter contamination problems.

- Sixteen of the 51 DGB groundwater samples had exceedences of aesthetics-based, inorganic Secondary MCLs (**Figure** 7). This indicates that approximately one-third of the groundwater samples collected for this study had aesthetic problems with indices such as taste, odor, and/or color. The groundwater samples were tested for 10 inorganic parameters having Secondary MCLs and the following exceedences occurred: Cl - 1, F - 8, Fe - 1, Mn - 1, pH-field - 2, pH-lab - 2, SO_4 - 2, and TDS - 8 (**Figure 9, 11, 12**, and and **13**).

- Results from the 29 randomly sampled wells were used to created 95% Confidence Intervals ($CI_{0.95}$) for most inorganic parameters (**Table 13**).

- There were no detections of any pesticides in the 7 samples tested for GWPL analysis (see **Appendix H**). The GWPL consists of the 152 pesticides used in Arizona that are considered most likely to leach to the groundwater through normal agricultural use (see **Appendix J**). The 7 groundwater samples tested for pesticides were collected in areas of agricultural activity within the DGB.

- Of the 12 SDW VOC samples collected within the DGB, only chloroform was detected in a single sample at the MRL (**Appendix G**). The sample having this VOC detection was collected at a turbine well; therefore, the detection may have been the result of lubricants that are normally added to the well pump. The SDW VOC list is comprised of 58 VOCs that are considered the most likely potential threats to public drinking supplies (**Appendix I**). The limited sampling conducted for VOCs in the DGB was focused in likely areas of contamination such as landfills and industrial areas.

- Of the 6 groundwater quality samples collected for radionuclide analysis, none exceeded SDW Primary MCLs for Gross α, Gross ß, and Combined Radium-226+Radium-228 (see **Appendix F**). The radionuclide samples were collected in areas thought to contain elevated levels of these constituents.

Characterize groundwater quality differences between various spatial areas

Groundwater quality differences between various physical and cultural areas in the DGB were examined using 4 spatial comparisons: aquifer (alluvial - bedrock), Irrigation Non-Expansion Area (INA) Boundary (inside - outside), valley (east - west), and basin (north - south). Although significant groundwater quality parameter level differences were found with all the spatial comparisons, aquifer differences were by far the most numerous with bedrock parameter levels generally significantly greater than alluvial parameter levels. INA differences followed a similar pattern as the aquifers, while there were few valley and basin differences. Depth to groundwater bls is significantly greater in the both the alluvial aquifer and inside the INA than the bedrock aquifer and outside the INA; there are no significant differences between valley- sides and/or basin portions. These conclusions are based on the following findings:

- Significant groundwater quality parameter level differences were most numerous in comparisons between aquifers in the DGB. Generally, parameter levels were higher in the bedrock aquifer than the alluvial aquifer. Parameters such as Ca, HCO_3, hardness, Mg, SO_4, total alkalinity, and turbidity were significantly higher in the bedrock than the alluvial aquifer. In contrast, pH-field, pH-lab, and temperature-field were significantly higher in the alluvial aquifer than the bedrock aquifer (**Table 2**). Piper trilinear diagrams illustrate the different groundwater quality chemistry of the two aquifers. Bedrock groundwater samples tend to exhibit a Ca-HCO_3 chemistry while alluvial groundwater samples tend to be of either Na-HCO_3 or Ca-HCO_3 chemistries (**Figure 6**).

- Spatial patterns of groundwater quality parameter levels between INA boundaries were similar to those found with aquifers, as both the aquifer and INA demarcation lines divide the DGB into similar areas. Parameters such as Ca and turbidity were significantly higher outside the INA than inside the INA. In contrast, F, pH-field, pH-lab, and temperature-field were significantly higher inside the INA than outside the INA (**Table 3**). Groundwater samples collected outside the INA tend to exhibit a Ca-HCO_3 chemistry while groundwater samples collected inside the INA tend to be of either Na-HCO_3 or Ca-HCO_3 chemistries (**Figure 6**).

- Only 2 significant groundwater quality parameter level differences were found when using the Whitewater Draw to divide the DGB into East and West valleys; Ca was significantly higher in the West valley, pH-field was significantly higher in the East valley (**Table 4**). No water chemistry differences between valleys were apparent in plotting these groundwater samples onto Piper trilinear diagrams (**Figure 6**).

- Only 3 significant groundwater quality parameter level differences were found when dividing the DGB into North and South basins, somewhat arbitarily, at the 22 South Township line. Levels of F were significantly higher in the northern part of the DGB, while Ba and HCO_3 were significantly higher in the southern part of the DGB (**Table 5**). No water chemistry differences between basins were apparent in plotting these groundwater samples onto Piper trilinear diagrams (**Figure 6**).

- Differences in depth to groundwater bls were examined using the 4 DGB spatial comparisons previously discussed. The alluvial aquifer and the area inside the INA had significantly greater depths to groundwater bls than the bedrock aquifer and areas outside the INA, respectively (**Table 12**). There were no significant differences between valley-sides (east - west), and basin portions (north - south).

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

The levels of some groundwater quality parameters in the DGB, especially major ions and NO_3-N, are positively correlated with one another. An exception to this trend is F and pH-field whose levels are often negatively correlated with other parameter levels. Most trace elements have few, if any, correlations with other groundwater quality parameters. Levels of many groundwater quality parameters tended to either significantly decrease or increase with increasing groundwater depth below land surface (bls) in the DGB. These conclusions are based on the following findings:

- The levels of many of the 21 groundwater quality parameter levels (56 of 210 parameter pairings) in the DGB are significantly positively correlated, especially major ions and NO_3-N. In other words, as the levels of one parameter rise, the levels of other parameters also tend to rise. There were fewer significant negative correlations (10 of 210 parameter pairings), most involving F and pH-field, in which parameter levels tended to decrease as other groundwater quality parameter levels tended to increase. Trace elements had far fewer significantly-correlated relationships with other parameters than did major ions (**Table 6**).

- In the alluvial aquifer, the levels of many of the 21 groundwater quality parameter levels (50 of 210 parameter pairings) are significantly positively correlated, especially major ions and NO_3-N. There were fewer significant negative correlations (6 of 210 parameter pairings), most involving pH-field, temperature-field, and F (**Table 7**). In the bedrock aquifer, some of the 21 groundwater quality parameter levels (33 of 210 parameter pairings) are significantly positively correlated, especially major ions and NO_3-N. There was only 1 significant negative correlation (NO_3-N - turbidity) among the parameter pairings. The only trace element with a significant correlation was Zn-K (**Table 8**).

- Ten of the 21 groundwater quality parameters examined had levels that significantly decreased or increased with increasing groundwater depth bls in the DGB. The parameters that decreased with groundwater depth bls include Ca, EC-field, hardness, SO_4, and turbidity while parameters increasing with groundwater depth bls include B, pH-field, pH-lab, K, and temperature-field (see **Table 9**). All these parameter level - groundwater depth relationships were most adequately described by a biphasic model except for Ca and temperature-field which were linear relationships.

- When analyzed by aquifer, few groundwater quality parameters examined had levels that significantly decreased or increased with increasing groundwater depth bls in the DGB. In the alluvial aquifer, turbidity decreased with groundwater depth bls while temperature-field increased with groundwater depth bls (see **Table 10**). Both of these parameter level - groundwater depth relationships were most adequately described by a biphasic model and were similar to relationships found with the overall DGB results.

- In the bedrock aquifer, the parameter that significantly decreased with groundwater depth bls was TKN while the parameters that significantly increased with groundwater depth bls were temperature-field and turbidity (see **Table 11**). While the temperature-field relationship is the same as found in both the alluvial aquifer and overall DGB results, the turbidity results are opposite what were found in both the alluvial aquifer and overall DGB results. A linear model most adequately described temperature-field and turbidity parameter level - groundwater depth relationships while TKN was described best by the biphasic model.

Assess the impact on groundwater quality from potential contaminant sources related to specific land uses and/or management practices:

Within the DGB, 6 areas were selected for additional targeted sampling to determine potential impacts from specific land uses. These areas included the Town of Elfrida, City of Douglas, Mule Gulch, Town of McNeal, Bisbee-Douglas International Airport, and northern Sulphur Springs Valley. Results from targeted samples were compared with $CI_{0.95}$ determined from stratified random sampling in the DGB. Targeted sample parameter level exceedences of the $CI_{0.95}$ were viewed as potentially being impacted. All studied areas showed potential impacts except with the intensively irrigated farmland of the northern Sulphur Springs Valley. These conclusions are based on the following findings:

- To examine for impacts from a nearby landfill, irrigated agriculture, and septic systems, 9 targeted groundwater samples were collected in the Elfrida area. As NO_3-N and pH-field were the only parameters typically exceeding the $CI_{0.95}$, there appeared to be no groundwater quality impacts from the landfill (**Table 14**). However, the NO_3-N levels in the Elfrida area indicate that septic systems and/or agricultural practices may have impacted groundwater quality in the area (**Figure 16**).

- To examine for impacts from the slag heap formed by the former Copper Queen smelter and septic systems, 6 targeted groundwater samples were collected in the City of Douglas area. Since pH-field, temperature-field, and Na were the only parameters typically exceeding the $CI_{0.95}$, there appeared to be no groundwater quality impacts from these land uses (**Table 15**). However, these $CI_{0.95}$ exceedances, along with very low levels of Ca and Mg, suggest that groundwater in the Greater Douglas area is being subjected to natural softening by cation exchange with Na ions.

- Three targeted groundwater quality samples were collected in the vicinity of Mule Gulch in an attempt to discern any impacts stemming from mine tailing dumps and the Bisbee Sewage Disposal Plant (**Figure 17**). With 2 SO_4 levels exceeding the $CI_{0.95}$ and 3 pH-field levels below the $CI_{0.95}$, it appears that mine tailings may be impacting groundwater quality in the area (**Table 16**). This relationship was further supported by a significant correlation (p=0.01) by comparing the SO_4 levels of 4 wells with distance from the well closest to the mine tailings (**Figure 18**). In addition, potential impacts are shown from the Bisbee Sewage Disposal Plant as the well closest to the facility had a NO_3-N level exceeding the $CI_{0.95}$.

- Two targeted groundwater quality samples were collected near the Town of McNeal because a 1990 ADWR study found F levels above the Primary MCL. ADEQ sampling results suggest that F levels in the McNeal area are elevated in comparison to $CI_{0.95,}$ sometimes exceeding Secondary MCL levels. As such, the 1990 ADWR results that exceeded Primary MCL levels may be an accurate reflection of F levels in the McNeal area (Rascona, 1995).

- A single targeted sample was collected to the east of the Bisbee-Douglas International Airport. This sample had 13 parameter levels that exceeded the DGB $CI_{0.95}$, many by several magnitudes (**Table 18**). The TDS level of 14,200 mg/l indicates that this well may be pumping groundwater from what appears to be a limited geothermal anomaly.

Conduct a groundwater quality time-trend analysis using results from previous studies for baseline data:

A limited groundwater quality time-trend analysis based on historical data from 7 wells sampled by ADWR/USGS in 1987 and ADEQ in 1995/96 was conducted in the DGB (**Figure 19**). The results indicated that many of the 12 parameters had higher levels in 1995-96 than 1987, though only NO_3-N and K were significantly higher. In contrast, pH-field was significantly lower in 1995-96 than 1987 (**Table 19**). Using linear regression, the two data sets were significantly correlated at $p = 0.01$ and the variation was approximately 1% (**Figure 20**).

Establish an ambient monitoring index well network for long-term examination of temporal groundwater quality trends:

An ambient groundwater monitoring well network of 16 index wells, 1 located in every other township forming a "checkerboard" pattern, was established in the DGB (**Table 20** and **Figure 21**). Of the 16 wells, 7 were previously sampled by ADWR in 1987 in order to "jump start" the groundwater quality comparisons over time in the DGB. The ADEQ ambient index well groundwater monitoring network in the DGB should be resampled more frequently than every 8 years, based on the time-trend analysis provided in this report. Of particular concern are the significantly increasing NO_3-N levels in conjunction with the continued development taking place in the basin.

11. DISCUSSION

Although regional groundwater quality conditions generally support drinking water uses in the DGB, there are several indications that groundwater quality should be closely monitored to avoid future problems. There are 4 areas of particular concern:

- TDS levels in the DGB;
- SO_4 levels in the Mule Gulch area;
- F levels in the DGB, particularly in the McNeal area; and
- Nitrate levels in the DGB, particularly in the Elfrida and Mule Gulch areas.

TDS levels in the DGB. The source of most of the dissolved solids contained in the DGB groundwater are thought to be a result of the alluvium minerals that comprise the valley fill. The cations especially, are likely to be derived directly from solution of minerals in rocks and soil; anions may, in a large part, come from nonlithologic sources (Hem, 1970). The opportunity for groundwater to dissolve minerals from rock and soil increases with time, so TDS levels in groundwater should be expected to increase uniformly with depth and distance from recharge areas. Such TDS levels are difficult to predict, however, since the alluvium is not homogenous and contains materials with different compositions and solubilities (Coates and Cushman, 1955). The occasionally high TDS levels found in the alluvial aquifer may be related to the presence of evaporite beds, such as the gypsum deposits that are sometimes encountered in the DGB.

SO_4 levels near Mule Gulch. Elevated SO_4 levels were found where Mule Gulch leaves the bedrock and enters the alluvium of the DGB. It appears that the mining wastes in the Mule Gulch area are impacting the groundwater in a similar manner as has been documented in the Bisbee-Naco area within the Upper San Pedro Groundwater Basin. The USGS hypothesized that the elevated SO_4 levels (650 - 850 mg/l) sampled in the aquifer between the communities of Bisbee and Naco might be the result of groundwater recharging through an upgradient mine-tailings pond (Litten, 1987). The mine tailings dumps found along the upper reaches of Mule Gulch could have a similar negative recharge affect on groundwater quality. Low pH values in this area support this conclusion.

F levels in the DGB. Fluoride is another concern in the DGB. A recent study by ADWR found many F levels over the Primary MCL of 4 mg/l, especially in the vicinity of McNeal (Rascona, 1993). The 5 wells sampled nearest this community had F levels ranging from 5.6 - 15 mg/l, all of which exceeded the Primary MCL, some by several magnitudes. A conversation with the author of the ADWR report revealed that the instrument ADWR had used to measure F levels in the study may have malfunctioned. The author was concerned with the accuracy of some measurements, particularly the elevated F levels around McNeal. ADEQ results of wells sampled in the McNeal area revealed F levels frequently exceeded the Secondary MCL of 2.0

mg/l but no samples exceeded the Primary MCL. Furthermore, F levels in the DGB were generally acceptable with 8 of the 51 wells sampled by ADEQ exceeding Secondary MCL levels and none exceeding Primary MCL levels. ADEQ sample results suggest that the F levels collected by ADWR in their 1993 study might be an accurate reflection of F levels in the McNeal area. Future studies should carefully examine F levels, particularly in the McNeal area.

Nitrate levels in the DGB. Nitrate levels in the DGB are another concern. Although only 1 of the 51 wells sampled had a nitrate (as N) level over the 10.0 mg/l Primary MCL, 2 trends suggest this parameter is becoming a greater threat to the groundwater quality in the DGB. A time-trend statistical analysis conducted on samples collected from 7 wells by ADWR in 1987 and resampled by ADEQ in 1995-96 indicated that nitrate levels have significantly increased. Furthermore, an examination of potential impacts from septic systems and irrigated agricultural practices in the Elfrida area revealed that nitrate level samples collected from targeted wells frequently exceeded the nitrate upper 95% Confidence Intervals established from random sampling within the DGB. Previous studies indicate that nitrate levels in the DGB have historically been low; only 1 out of 112 wells sampled in the late 1940s/early 1950s exceeded the nitrate (as N) Primary MCL (Coates and Cushman, 1955). These authors thought that the nitrate present in the groundwater of the DGB probably was derived from sources other than contamination by human and animal wastes, and this theory should be considered in future DGB nitrate studies. The positive nitrate parameter level correlation with levels of major ions in the DGB may support this non-human/animal waste source of nitrate, as nitrate levels in other studies usually are negatively-correlated with major ions (Towne and Yu, 1998). Nitrate isotope analysis could be used in future studies to assist in determining the source of nitrate in the groundwater.

Part VI

REFERENCES

12. REFERENCES

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Part VII

APPENDICES

Appendix A. Characteristics of DGB Wells Selected for Groundwater Sampling

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth (ft)	Casing Diamtr (in)	Perforation Interval	Water Depth (ft)	Surface Elevation of Well (ft)
55-546800	DGB-001	(D-20-27)20bbb	Kennedy	Irrigation	300'	8"	150' - 300'	195'	4220'
55-633786	DGB-002	(D-20-25)09bdd	McMahon - Kennedy	Domestic/ Stock	500'	6"	N/A	360'	4570'
55-515363	DGB-003	(D-23-26)12aba	Nordhagen	Domestic	130'	6"	90' - 130'	60'	4002'
55-645369	DGB-004	(D-22-25)13adb	Tanner	Domestic	200'	12"	75' - 200'	76'	4095'
55-608012	DGB-005	(D-20-26)15bca	Hunt	Domestic	250'	16"	N/A	150'	4150'
55-527495	DGB-006/07	(D-24-27)05bbb	Dees	Domestic	126'	6"	62' - 121'	73'	4000'
55-643076	DGB-008	(D-23-28)03dac	Hopkins	Domestic/ Stock	55'	6"	N/A	26'	4381'
55-603988	DGB-009	(D-24-28)18cad	City of Douglas	Municipal	500'	16"	N/A	228'	4025'
55-603979	DGB-010	(D-24-27)10daa	City of Douglas	Municipal	334'	16"	N/A	57'	3920'
55-805643	DGB-011	(D-24-24)11dcd	Epple	Domestic	165'	2"	N/A	30'	4630'
55-613647	DGB-013	(D-19-25)25acc	Grizzle	Domestic	650'	12"	N/A	270'	4300'
55-641453	DGB-014	(D-20-24)10ddd	Telles Enterprises	Domestic/ Stock	42'	8"	N/A	15'	4893'
55-612619	DGB-015	(D-20-26)09bdd	Gural	Irrigation/ Domestic	276'	18"	N/A	110'	4166'

N/A = Information Not Available

Appendix A. Characteristics of DGB Wells Selected for Groundwater Sampling--Continued

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth (ft)	Casing Diamtr (in)	Perforation Interval	Water Depth (ft)	Surface Elevation of Well (ft)
55-633420	DGB-016	(D-23-26)26acd	Christiansen	Domestic	200'	6"	N/A	98'	4045'
55-605489	DGB-017	(D-20-26)27dcc	McAllister	Irrigation	453'	12"	N/A	123'	4134'
55-609516	DGB-018/19	(D-19-26)28bba	Mitchell/Noble	Irrigation	400'	16"	N/A	150'	4201'
55-606653	DGB-020	(D-18-26)34aad	AZ Farm Assoc.	Irrigation	400'	16"	N/A	170'	4282'
None	DGB-021	(D-23-27)16aaa	Statler/Place	Irrigation	500'	16"	130' - 496'	129'	4040'
55-617653	DGB-022	(D-23-27)09dab	Place	Irrigation	500'	16"	N/A	120'	4055'
55-606926	DGB-023/24	(D-20-26)11cdd	Reddell/Brand	Domestic	250'	8"	N/A	145'	4186'
55-624487	DGB-025	(D-21-27)31add	Double E Ranch	Domestic	225'	6"	N/A	180'	4295'
55-505139	DGB-026	(D-21-26)14cdc	McLaughlin	Domestic	300'	8"	175' - 297'	168'	4160'
55-530875	DGB-027	(D-23-25)01ddd	Richardson	Domestic	200'	6"	137' - 195'	105'	4120'
55-629300	DGB-028	(D-20-24)29aaa	Davis	Stock	625'	8"	N/A	52'	4700'
55-633419	DGB-029	(D-24-26)08baa	Christiansen	Stock	232'	6"	N/A	190'	4190'
55-620593	DGB-030	(D-24-25)18ddd	Giacoletti	Domestic	200'	10"	N/A	44.3'	4560'
55-505828	DGB-031	(D-18-25)05dda	Koch	Domestic	450'	6"	AT ADWR	302'	4420'
55-513430	DGB-032	(D-19-27)14cdc	Panka	Domestic	100'	6"	80' - 100'	40'	4605'

N/A = Information Not Available

Appendix A. Characteristics of DGB Wells Selected for Groundwater Sampling--Continued

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth (ft)	Casing Diamtr (in)	Perforation Interval (ft)	Water Depth (ft)	Surface Elevation of Well (ft)
55-648364	DGB-033	(D-23-24)08ac	Edwards	Irrigation	25'	3/4"	N/A	10'	5700'
55-532818	DGB-034 DGB-035a	(D-22-26)08aba	Wright	Stock	126'	6"	71' - 121'	53'	4040'
55-518704	DGB-035b	(D-22-27)25ddc	Jumper	Domestic	600'	6"	560' - 600'	250'	4220'
55-800205	DGB-036/37	(D-21-25)25aaa	Keen	Domestic	125'	6"	N/A	100'	4100'
55-633368	DGB-038	(D-18-24)09cdc	Garey	Stock	25'	8"	N/A	10'	4960'
55-625656	DGB-039	(D-19-26)05abb	Shoenfelder	Irrigation	403'	16"	N/A	140'	4269'
55-611345	DGB-040	(D-20-26)10cbb	Zamora	Domestic	203'	8"	N/A	115'	4177'
55-603985	DGB-041	(D-24-27)13bdb	City of Douglas	Municipal	554'	16"	N/A	130'	4370'
55-618539	DGB-042	(D-23-27)24bbb	La Costa Water Co.	Municipal	700'	16"	N/A	235'	4110'
55-608033	DGB-043	(D-23-27)13abc	Leslie Canyon Water	Municipal	500'	9"	N/A	250'	4150'
None	DGB-044	(D-22-28)13dcb	Cureton	Domestic	460'	4"	N/A	4'	4700'
55-512073	DGB-045	(D-22-28)30ccc	Laursen	Domestic	340'	6"		160'	4230'
55-624566	DGB-046/47	(D-23-25)08ddd	Cornelius	Domestic	484'	6"	N/A	350'	4520'
None	DGB-048	(D-19-24)25ddd	Cowan	Stock	250'	6"	N/A	50'	5170'
None	DGB-049/50	(D-23-25)07aaa	Penick	Domestic	600'	9"	N/A	320'	4500'

N/A = Information Not Available

Appendix A. Characteristics of DGB Wells Selected for Groundwater Sampling--Continued

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth (ft)	Casing Diamtr (in)	Perforation Interval (ft)	Water Depth (ft)	Surface Elevation of Well (ft)
55-537632	DGB-052	(D-23-25)01dca	McNeely	Municipal	240'	6"	must obtain	117'	4120'
55-609584	DGB-053	(D-21-26)19bcc	Mitchell	Irrigation/ Domestic	400'	16"	N/A	140'	4118'
55-609585	DGB-054	(D-21-26)19add	Mitchell	Irrigation	225'	16"	N/A	151'	4095'
55-600855	DGB-055	(D-20-26)02cdd	Mortenson/Swigart - Robertson	Domestic	200'	7"	N/A	133'	4212'
55-631065	DGB-056	(D-20-26)11abb	Campbell	Domestic	250'	8"	N/A	125'	4212'
55-618918	DGB-057	(D-20-26)01baa	White	Domestic	390'	6"	N/A	230'	4275'
55-538995	DGB-059	(D-20-26)15cdd	Thompson	Domestic	220'	8"	N/A	114'	4150'
55-603837	DGB-060	(D-20-26)15aad	Mortenson	Domestic	200'	12"	N/A	100'	4170'

N/A = Information Not Available

Appendix B. Characteristics of DGB Groundwater Samples

Sample Name	Latitude - Longitude	ADEQ Well Number	Sample Date	Type of Sample	Factors Related to Sample Location	SDW MCL Exceedances
DGB-001	31°40'57.378" 109°37'04.280"	50570	10/11/95	SDW Inorganic + 5	- Random sample - Cell 11	
DGB-002	31°42'28.564" 109°47'52.549"	42452	10/11/95	SDW Inorganic + 5	- Random sample - Cell 9 - ADWR previously sampled	
DGB-003	31°27'02.674" 109°39'04.095"	51594	10/11/95	SDW Inorganic + 5	- Random sample - Cell 22	
DGB-004	31°31'17.274" 109°45'06.274"	43491	10/12/95	SDW Inorganic + 5	- Random sample - Cell 16 - USGS previously sampled	
DGB-005	31°41'31.453" 109°41'02.830"	51595	10/12/95	SDW Inorganic + 5 SDW VOCs	- Random sample - Cell 10	
DGB-006	31°22'41.426" 109°37'39.304"	51565	10/12/95	SDW Inorganic + 5 SDW VOCs	- Random sample - Cell 28 - Cancer cluster in area	TDS
DGB-007		51565	10/12/95	SDW Inorganic + 5	- QA/QC Duplicate of DGB-6	TDS
DGB-008	31°27'19.512" 109°28'51.224"	51074	10/12/95	SDW Inorganic + 5	- Random sample - Cell 24	TDS
DGB-009	31°20'20.415" 109°32'13.310"	51175	10/12/95	SDW Inorganic + 5 SDW VOCs	- Random sample - Cell 29	
DGB-010	31°21'21.743" 109°35'12.822"	44411	10/12/95	SDW Inorganic + 5 SDW VOCs	- Douglas Targeted sample - ADWR previously sampled	pH-f, pH-lab, F, TDS
DGB-011	31°21'08.830" 109°52.'21.756"	44355	10/13/95	SDW Inorganic + 5	- Random sample - Cell 25	
DGB-012			10/13/95	SDW Inorganic + 5	- QA/QC Equipment Blank	
DGB-013	31°45'09.540" 109°44'53.193"	41807	10/13/95	SDW Inorganic + 5	- Random sample - Cell 5	F
DGB-014	31°42' 05" 109°52' 25"	42442	10/24/95	SDW Inorganic + 5	- Random sample - Cell 8 - ADWR previously sampled	

Appendix B. Characteristics of DGB Groundwater Samples--Continued

Sample Name	Latitude - Longitude	ADEQ Well Number	Sample Date	Type of Sample	Factors Related to Sample Location	SDW MCL Exceedances
DGB-015	31°42'32.206" 109°41'43.143"	50464	10/24/95	SDW Inorganic + 5 GWPL Pesticides	- Elfrida targeted sample - Irrigated agricultural area	
DGB-016	31°24'05.013" 109°40'07.930"	44074	10/24/95	SDW Inorganic + 5 GWPL Pesticides	- Douglas targeted sample - ADWR previously sampled	
DGB-017	31°39'24.429" 109°40'34.078"	42576	10/24/95	SDW Inorganic + 5 GWPL Pesticides	- Elfrida targeted sample - Irrigated agricultural area	
DGB-018	31°45'29.592" 109°42'06.082"	41898	10/24/95	SDW Inorganic + 5 GWPL Pesticides	- Random sample - Cell 6	F
DGB-019		41898	10/24/95	GWPL Pesticides	- QA/QC Duplicate of DGB-18	
DGB-020	31°49'47.597" 109°40'39.861"	41405	10/24/95	SDW Inorganic + 5 GWPL Pesticides	- Random sample - Cell 3	F
DGB-021	31°26'12.941" 109°35'50.282"	44095	10/24/95	SDW Inorganic + 5	- Random sample - Cell 23	
DGB-022	31°26'39.720" 109°35'56.408"	44088	10/24/95	SDW Inorganic + 5	- BD Airport targeted sample - ADWR previously sampled	
DGB-023	31°42'04.532" 109°39'39.760"	51621	10/25/95	SDW Inorganic + 5 GWPL Pesticides	- Elfrida targeted sample - Irrigated agricultural area	
DGB-024		51621	10/25/95	SDW Inorganic + 5	- QA/QC Split of DGB-023	
DGB-025	31°33'45.651" 109°37'47.097"	50733	10/25/95	SDW Inorganic + 5	- Random sample - Cell 15	
DGB-026	31°36'04.625" 109°40'20.303"	51696	12/18/95	SDW Inorganic + 5 SDW Radionuclides	- Random sample - Cell 14	
DGB-027	31°39'49.464" 109°54'28.725"	42450	12/18/95	SDW Inorganic + 5 SDW Radionuclides	- Random sample - Cell 21	
DGB-028	31°27'13.477" 109°44'56.673"	50987	12/18/95	SDW Inorganic + 5 SDW Radionuclides	- Random sample - Cell 12	

Appendix B. Characteristics of DGB Groundwater Samples--Continued

Sample Name	Latitude - Longitude	ADEQ Well Number	Sample Date	Type of Sample	Factors Related to Sample Location	SDW MCL Exceedances
DGB-029	31°21'44.939" 109°43'30.700"	44393	12/19/95	SDW Inorganic + 5 SDW Radionuclides	- Random sample - Cell 27 - Near major limestone mine	
DGB-030	31°20'12.418" 109°50'12.254"	51112	12/19/95	SDW Inorganic + 5	- Random sample - Cell 26	
DGB-031	31°54'05.453" 109°49'29.779"	51698	12/19/95	SDW Inorganic + 5 SDW Radionuclides	- Random sample - Cell 2	
DGB-032	31°46'24.440" 109°34'01.503"	50395	12/19/95	SDW Inorganic + 5 SDW Radionuclides	- Random sample - Cell 7	
DGB-033	31°26'49.713" 109°55'40.035"	51695	12/20/95	SDW Inorganic + 5	- Random sample - Cell 20	
DGB-034	31°32'22.331" 109°43'10.336"	51697	12/20/95	SDW Inorganic + 5	- Random sample - Cell 17	F
DGB-035a		51697	12/20/95	SDW Inorganic + 5	- QA/QC Split of DGB-034	F
DGB-035b	31°28'54.217" 109°32'48.031"	50919	12/20/95	SDW Inorganic + 5	- BD Airport - Targeted sample - Geothermal area	TDS, Cl, SO_4, As, Fe, Mn
DGB-036	31°34'58.638" 109°44'59.943"	42996	12/20/95	SDW Inorganic + 5	- Random sample - Cell 13	TDS
DGB-037		42996	12/20/95	SDW Inorganic + 5	- QA/QC Duplicate of DGB-036	TDS
DGB-038	31°52'41.637" 109°54'20.983"	41315	02/26/96	SDW Inorganic + 5	- Random sample - Cell 1	
DGB-039	31°49'05.138" 109°43'11.613"	41833	02/26/96	SDW Inorganic + 5 SDW VOCs	- Agricultural targeted sample	F

Appendix B. Characteristics of DGB Groundwater Samples--Continued

Sample Name	Latitude - Longitude	ADEQ Well Number	Sample Date	Type of Sample	Factors Related to Sample Location	SDW MCL Exceedances
DGB-040	31°42'25.020" 109°41'08.762"	55052	02/26/96	SDW Inorganic + 5 SDW VOCs	- Elfrida targeted sample - Proximity to county landfill	
DGB-041	31°20'45.307" 109°33'19.938"	51158	02/27/96	SDW Inorganic + 5 SDW VOCs	- Douglas targeted sample - Proximity to urban area	pH-f, pH-lab
DGB-042	31°25'17.974" 109°33'40.279"	44113	02/27/96	SDW Inorganic + 5 SDW VOCs	- BD Airport targeted sample - Proximity to high TDS levels	
DGB-043	31°26'13.539" 109°33'10.373"	55053	02/27/96	SDW Inorganic + 5	- BD Airport targeted sample - Proximity to high TDS levels	
DGB-044	31°30'43.037" 109°26'52.882"	55056	02/27/96	SDW Inorganic + 5	- Random sample - Cell 19	TDS
DGB-045	31°28'49.147" 109°32'35.259"	55054	02/27/96	SDW Inorganic + 5	- Random sample - Cell 18	
DGB-046	31°26'26.166" 109°49'02.103"	55055	02/28/96	SDW Inorganic + 5 SDW VOCs	- Mule Gulch targeted sample - ADWR previously sampled	TDS, SO_4, Fe
DGB-047		55055	02/28/96	SDW Inorganic + 5 SDW VOCs	- QA/QC Split of DGB-046	TDS, SO_4, Fe
DGB-048	31°44'43.529" 109°50'50.554"	55057	02/28/96	SDW Inorganic + 5	- Random sample - Cell 4	NO_3-N, TDS
DGB-049	31°26'13.339" 109°49'04.861"	55121	06/03/96	SDW Inorganic + 5	- Mule Gulch targeted sample	
DGB-050		55121	06/03/96	SDW Inorganic + 5	- QA/QC Duplicate of DGB-49	
DGB-052	31°27'29.835" 109°45'12.155"	50986	06/04/96	SDW Inorganic + 5	- Mule Gulch targeted sample	
DGB-053	31°35'27.702" 109°44'54.813"	55123	06/05/96	SDW Inorganic + 5	- McNeal targeted sample - proximity to high F levels	F,
DGB-054	31°35'27.513" 109°44'25.040"	43050	06/05/96	SDW Inorganic + 5	- McNeal targeted sample - proximity to high F levels	TDS, F

Appendix B. Characteristics of DGB Groundwater Samples--Continued

Sample Name	Latitude - Longitude	ADEQ Well Number	Sample Date	Type of Sample	Factors Related to Sample Location	SDW MCL Exceedances
DGB-055	31°42' 55" 109°39' 40"	42478	06/24/96	SDW Inorganic + 5	- Elfrida targeted sample - Proximity to landfill	
DGB-056	31°42'51.951" 109°39'35.163"	55128	06/25/96	SDW Inorganic + 5 SDW VOCs	- Elfrida targeted sample - Proximity to landfill	
DGB-057	31°43'45.029" 109°38'35.942"	55129	06/25/96	SDW Inorganic + 5	- Elfrida targeted sample - Proximity to landfill	
DGB-058		55129	06/25/96	SDW Inorganic + 5	- QA/QC Equipment Blank	
DGB-059	31°41'10.628" 109°40'42.085"	55130	06/25/96	SDW Inorganic + 5	- Elfrida targeted sample - Proximity to septic systems	
DGB-060	31°41'53.922" 109°40'12.263"	55131	06/25/96	SDW Inorganic + 5 SDW VOCs	- Elfrida targeted sample - Proximity to landfill	

Appendix C. Levels of Nutrients and Physical Parameters in DGB Groundwater Samples

Sample ID	Sample Date	HCO_3 mg/l	NH_3-N mg/l	NO_3/NO_2 mg/l	pH-f SU	pH SU	Sp Cond-f US/CM	Sp Cond US/CM	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)			
DGB-001	10/11/95	151	ND	0.34	7.57	7.85	285	273	23.66	183	ND	ND	*0.35*
DGB-002	10/11/95	296	ND	5.00	7.40	7.69	583	579	25.41	358	ND	ND	*0.04*
DGB-003	10/11/95	163	ND	0.96	7.58	*7.86*	387	360	22.39	238	ND	ND	*0.22*
DGB-004	10/12/95	293	ND	1.29	7.10	7.44	522	481	21.19	300	ND	ND	*0.03*
DGB-005	10/12/95	170	ND	1.45	7.53	7.80	383	345	21.27	234	ND	ND	*0.05*
DGB-006	10/12/95	199	ND	6.65	7.33	7.70	1227	1150	22.48	**676**	0.26	ND	*0.14*
DGB-007	10/12/95	198	ND	6.68	7.33	7.70	1227	1145	22.48	**655**	0.14	ND	*0.12*
DGB-008	10/12/95	376	ND	3.89	6.95	7.47	899	820	21.57	**535**	ND	ND	*0.07*
DGB-009	10/12/95	184	ND	1.65	7.64	7.91	630	637	26.71	414	ND	ND	*0.01*
DGB-010	10/12/95	148	ND	0.80	**8.90**	**8.95**	1220	1221	24.85	**702**	ND	ND	*0.03*
DGB-011	10/13/95	277	ND	6.20	7.23	7.60	586	529	21.07	329	ND	ND	*0.06*
DGB-012	10/13/95	ND	ND	ND	-	*5.62*	-	1.98	-	*ND*	ND	ND	*ND*
DGB-013	10/13/95	207	ND	4.39	7.62	7.85	434	416	24.01	280	ND	ND	*0.02*

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

ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%

f - Field Measured
bold = MCL Exceedance

Appendix C. Levels of Nutrients and Physical Parameters in DGB Groundwater Samples--Continued

Sample ID	Sample Date	HCO_3 mg/l	NH_3-N mg/l	NO_3/NO_2 mg/l	pH-f SU	pH SU	Sp Cond-f US/CM	Sp Cond US/CM	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)			
DGB-014	10/24/95	173	ND	1.16	6.84	*7.31*	405	-	18.5	245	ND	ND	*2.6*
DGB-015	10/24/95	124	ND	3.78	7.57	*7.88*	461	-	21.01	279	ND	ND	*1.57*
DGB-016	10/24/95	217	ND	1.22	7.36	*7.86*	451	-	22.17	257	ND	ND	*0.06*
DGB-017	10/24/95	149	ND	3.54	7.59	*7.92*	380	-	20.88	237	ND	ND	*37.*
DGB-018	10/24/95	146	ND	0.99	7.63	*8.05*	333	-	21.97	215	ND	ND	*0.02*
DGB-020	10/24/95	148	ND	0.78	7.64	*7.96*	295	-	23.36	197	ND	ND	*ND*
DGB-021	10/24/95	196	ND	3.47	8.08	*8.28*	448	-	21.97	289	ND	ND	*ND*
DGB-022	10/24/95	171	ND	3.57	8.21	*8.37*	446	-	23.61	286	ND	ND	*ND*
DGB-023	10/25/95	144	ND	7.41	7.61	*7.90*	372	-	20.78	248	ND	ND	*0.04*
DGB-024	10/25/95	125	ND	7.7	7.61	7.8	372	-	20.78	240	< 0.2	< 0.05	0.07
DGB-025	10/25/95	190	ND	1.36	7.40	*7.82*	395	-	23.26	265	ND	ND	*0.05*
DGB-026	12/18/95	229	ND	1.34	7.64	*7.70*	438	N/A	21.46	252	*<0.2*	ND	*0.10*
DGB-027	12/18/95	240	ND	1.10	7.38	*7.38*	455	N/A	20.64	271	ND	ND	*1.65*

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

ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%

f - Field Measured
bold = MCL Exceedance

Appendix C. Levels of Nutrients and Physical Parameters in DGB Groundwater Samples--Continued

Sample ID	Sample Date	HCO_3 mg/l	NH_3-N mg/l	NO_3/NO_2 mg/l	pH-f SU	pH SU	Sp Cond-f US/CM	Sp Cond US/CM	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)			
DGB-028	12/18/95	332	ND	1.57	7.70	*7.88*	584	-	20.85	378	ND	ND	*1.27*
DGB-029	12/19/95	340	ND	4.67	7.24	*7.35*	532	-	21.38	306	ND	ND	*ND*
DGB-030	12/19/95	228	ND	3.08	7.10	*7.27*	488	-	20.25	286	ND	ND	*0.25*
DGB-031	12/19/95	211	ND	0.33	7.33	*7.39*	430	-	27.81	295	ND	ND	*46*
DGB-032	12/19/95	122	ND	0.63	6.83	*6.97*	334	-	18.20	200	ND	ND	*0.68*
DGB-033	12/20/95	220	ND	0.84	7.07	7.26	613	-	13.12	298	< 0.2	ND	1.95
DGB-034	12/20/95	176	ND	1.13	7.71	7.68	616	-	19.94	369	ND	ND	2.6
DGB-035a	12/20/95	183	ND	1.6	7.71	7.7	616	536	19.94	360	0.53	ND	-
DGB-035b	12/20/95	174	1.09	ND	7.17	7.30	15995	-	27.10	**14200**	1.14	ND	71
DGB-036	12/20/95	176	ND	3.69	7.43	7.55	1212	-	20.30	**656**	ND	ND	1.90
DGB-037		176	ND	3.78	7.43	7.46	1212	-	20.30	**658**	ND	ND	1.70
DGB-038	02/26/96	234	ND	1.36	7.26	*7.59*	601	518	16.03	339	ND	ND	*0.97*
DGB-039	02/26/96	121	ND	2.55	7.83	*6.81*	269	263	21.56	177	ND	ND	*0.10*
DGB-040	02/26/96	137	ND	4.59	7.64	*7.18*	452	420	19.74	271	ND	ND	*0.07*

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

ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%

f - Field Measured
bold = MCL Exceedance

Appendix C. Levels of Nutrients and Physical Parameters in DGB Groundwater Samples--Continued

Sample ID	Sample Date	HCO_3 mg/l	NH_3-N mg/l	NO_3/NO_2 mg/l	pH-f SU	pH SU	Sp Cond-f US/CM	Sp Cond US/CM	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)			
DGB-041	02/27/96	190	ND	1.49	**9.07**	***8.99***	551	545	23.30	338	0.15	ND	*0.36*
DGB-042	02/27/96	233	ND	1.06	7.67	*7.12*	404	413	24.53	254	ND	ND	*0.41*
DGB-043	02/27/96	236	ND	1.55	7.74	*7.59*	454	470	25.41	288	ND	ND	*0.03*
DGB-044	02/27/96	300	ND	4.20	7.17	*7.29*	959	884	19.20	**587**	0.11	ND	*0.44*
DGB-045	02/27/96	218	ND	1.25	7.89	*7.46*	385	377	24.09	262	ND	ND	*0.09*
DGB-046	02/28/96	165	ND	5.94	6.68	6.70	2384	2300	22.50	**2210**	0.26	ND	6.4
DGB-047	02/28/96	171	ND	6.7	6.68	7.7	2384	2160	22.50	**2300**	0.23	ND	N/A
DGB-048	02/28/96	232	ND	**10.6**	7.22	7.05	1100	994	20.48	**663**	ND	ND	0.12
DGB-049	06/03/96	171	1.2	2.8	7.01	7.2	450	660	24.02	300	1.9	0.36	0.33
DGB-050		178	ND	2.68	7.01	*7.58*	450	437	24.02	282	ND	ND	*0.73*
DGB-052	06/04/96	215	ND	3.42	7.08	*7.67*	610	544	21.09	375	ND	ND	*0.61*
DGB-053	06/05/96	173	ND	1.31	7.67	7.92	762	716	22.41	475	ND	ND	*0.03*
DGB-054	06/05/96	179	ND	3.48	7.26	*7.72*	1250	1119	21.91	**707**	ND	ND	*0.55*

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

ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%

f - Field Measured
bold = MCL Exceedance

Appendix C. Levels of Nutrients and Physical Parameters in DGB Groundwater Samples--Continued

Sample ID	Sample Date	HCO_3 mg/l	NH_3-N mg/l	NO_3/NO_2 mg/l	pH-f SU	pH SU	Sp Cond-f US/CM	Sp Cond US/CM	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)			
DGB-055	06/24/96	142	ND	1.62	7.71	7.95	257	278	25.20	169	ND	ND	1.10
DGB-056	06/25/96	277	ND	1.78	7.45	*7.49*	515	511	20.92	295	0.14	ND	16.4
DGB-057	06/25/96	129	ND	5.59	7.44	*7.69*	319	323	22.22	199	ND	ND	0.20
DGB-058	06/25/96	ND	ND	ND	-	5.43	-	2.24	-	16	ND	ND	0.08
DGB-059	06/25/96	134	ND	1.94	7.79	8.05	270	271	20.80	154	ND	ND	0.14
DGB-060	06/25/96	167	ND	7.98	7.24	7.57	478	482	20.95	286	ND	ND	0.02

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

ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%

f - Field Measured
bold = MCL Exceedance

Appendix D. Levels of Major Ions in DGB Groundwater 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)
DGB-001	09/12/95	ND	124	34.5	6.9	1.48	87	2.09	5.4	23.9	ND
DGB-002	09/12/95	ND	243	34.7	17	0.46	186	2.64	25.0	57.4	37.3
DGB-003	09/12/95	ND	134	33.7	9.1	0.68	101	2.27	4.8	39.0	41.7
DGB-004	09/12/95	ND	240	71.9	12.8	0.29	217	1.70	10.9	21.8	ND
DGB-005	09/12/95	ND	139	49.2	16.1	0.39	135	2.21	4.3	19.4	15.9
DGB-006	09/12/95	ND	163	114	241	0.38	430	4.81	34.6	58.5	40.5
DGB-007	09/12/95	ND	162	114	240	0.38	426	4.92	34.4	58.3	40.4
DGB-008	09/12/95	ND	308	80.0	25.4	0.36	320	0.97	29.7	65.5	108
DGB-009	09/12/95	ND	151	34.7	27.7	0.48	141	4.02	13.8	84.3	129
DGB-010	09/12/95	11.3	144	< 5.0	222	**2.41**	10	2.09	ND	251	109
DGB-011	09/13/95	ND	227	68.7	16.5	0.36	242	5.68	18.6	18.3	< 30
DGB-012	09/13/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-013	09/13/95	ND	170	32.8	12.4	**2.20**	95	2.72	4.0	56.3	21.3

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

ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%

bold = MCL Exceedance

Appendix D. Levels of Major Ions in DGB 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)
DGB-014	09/12/95	ND	142	35.8	7.1	0.82	107	2.18	8.3	36.7	36.4
DGB-015	09/12/95	ND	102	46.1	42.0	1.08	118	2.20	3.7	38.4	31.6
DGB-016	09/12/95	ND	178	41.8	13.9	1.03	143	2.93	13.0	33.0	20.0
DGB-017	09/12/95	ND	122	43.2	17.1	1.03	122	2.54	7.7	19.0	27.2
DGB-018	09/12/95	ND	120	29.0	10.4	**2.19**	73	2.33	2.2	38.2	21.9
DGB-020	09/12/95	ND	121	27.2	6.5	**3.35**	70	2.12	2.4	34.3	< 20.0
DGB-021	09/12/95	ND	161	9.8	17.8	0.24	27	1.49	1.6	87.4	24.0
DGB-022	09/12/95	ND	140	7.9	26.8	0.23	18	1.88	ND	91.5	29.5
DGB-023	09/12/95	ND	118	48.7	5.4	0.35	142	2.04	4.8	16.8	23.9
DGB-024	09/12/95	< 1	125	47	5.7	0.33	138	2.	5.	17	21
DGB-025	09/13/95	ND	156	50.5	7.8	0.27	142	1.98	6.9	24.4	33.0
DGB-026	12/18/95	ND	188	47.6	16.8	1.18	185	1.85	16.6	22.0	< 20
DGB-027	12/18/95	ND	187	52.1	10.1	1.03	153	2.59	6.8	38.9	< 50

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

ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%

bold = MCL Exceedance

Appendix D. Levels of Major Ions in DGB 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)
DGB-028	12/18/95	ND	272	68.9	10.3	0.45	216	1.15	12.2	46.2	< 50
DGB-029	12/19/95	ND	279	63.2	17.2	0.41	235	2.92	17.4	19.7	< 50
DGB-030	12/19/95	ND	187	79.0	10.0	ND	225	1.96	5.4	9.6	30.8
DGB-031	12/19/95	ND	173	57.2	11.0	0.66	207	3.81	11.4	23.6	53.4
DGB-032	12/19/95	ND	100	48.3	5.72	0.41	133	1.30	4.3	10.2	33.9
DGB-033	12/20/95	ND	180	54.3	26.4	0.51	190	5.22	14.1	28.4	40.7
DGB-034	12/20/95	ND	144	38.3	66.5	**2.59**	160	2.29	16.0	92.9	56.3
DGB-035a	12/20/95	N/A	150	37	53	**2.6**	160	2.2	16	93	56
DGB-035b	12/20/95	ND	143	521	**3160**	0.77	2280	37.7	180	4420	**5020**
DGB-036	12/20/95	ND	144	80.1	212	1.29	257	4.21	16.0	126	78.7
DGB-037	12/20/95	ND	144	80.2	212	1.30	255	4.11	16.0	126	81.6
DGB-038	02/26/96	ND	192	86.0	18.0	1.18	228	0.93	8.4	16.4	51.6
DGB-039	02/26/96	ND	99.3	30.6	10.0	**2.80**	80	1.82	3.0	19.8	ND
DGB-040	02/26/96	ND	112	52.7	32.4	0.66	144	2.17	4.9	26.1	31.2

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time
ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%
bold = MCL Exceedance

Appendix D. Levels of Major Ions in DGB 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)
DGB-041	02/27/96	13.5	183	ND	29.2	0.84	ND	1.14	ND	124	46.6
DGB-042	02/27/96	ND	191	24.5	8.0	0.26	97	2.13	10.4	55.4	15.8
DGB-043	02/27/96	ND	193	30.5	15.2	0.39	141	1.58	17.5	50.8	32.7
DGB-044	02/27/96	ND	246	83.8	15.9	0.26	309	0.61	31.4	72.7	194
DGB-045	02/27/96	ND	179	22.0	9.7	0.46	80.2	1.56	6.2	58.6	10.4
DGB-046	02/28/96	ND	135	487	48.4	0.25	1332	2.34	52.6	34.6	**1360**
DGB-047	02/28/96	N/A	140	510	42	0.20	1500	2.0	53	35	**1300**
DGB-048	02/28/96	ND	190	120	75.3	0.41	421	1.72	33.9	53.4	198
DGB-049	06/03/96	ND	140	54	12	1.1	180	0.45	10	27	59
DGB-050	06/03/96	ND	146	52.0	9.7	1.39	177	0.59	10.4	26.8	61.2
DGB-052	06/04/96	ND	176	68.6	14.2	0.85	211	1.70	8.2	41.3	86.9
DGB-053	06/05/96	ND	142	42.8	64.6	**2.95**	150	3.99	8.5	98.5	116
DGB-054	06/05/96	ND	147	82.4	191	**3.28**	291	5.12	18.2	132	137

( ) = Secondary SDW Maximum Contaminant Level
Italics # = Exceeded Recommended Holding Time
ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%
bold = MCL Exceedance

Appendix D. Levels of Major Ions in DGB 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)
DGB-055	06/24/96	ND	116	36.5	5.2	0.55	107	1.67	3.3	14.8	ND
DGB-056	06/25/96	ND	227	78.5	5.2	0.40	214	2.25	7.9	20.9	22.0
DGB-057	06/25/96	ND	106	39.4	5.2	0.71	108	1.92	5.5	16.8	18.5
DGB-058	06/25/96	ND	ND	<5.0	ND	ND	ND	0.26	ND	ND	ND
DGB-059	06/25/96	ND	110	35.0	6.2	0.56	88.6	1.66	2.7	16.2	ND
DGB-060	06/25/96	ND	137	64.6	19.2	0.41	172	2.36	6.5	22.2	31.0

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

ND = None Detected at Lab Minimum Reporting Level (MRL)
Shadow # = Spike Recovery Not Between 90 - 110%

bold = MCL Exceedance

Appendix E. Levels of Trace Elements in DGB 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	.004	.005	0.1	{1.3}	(0.3)	{.015}	(.05)	.002	.05	.006	(0.1)	.002	(5.0)
DGB-001	10/11/95	ND	ND	ND	ND	ND	ND	<.02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-002	10/11/95	ND	ND	0.14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.009**	ND	ND	ND
DGB-003	10/11/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-004	10/12/95	ND	ND	ND	0.42	ND	ND	ND	ND	ND	ND	ND	ND	ND	.005	ND	ND	ND
DGB-005	10/12/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.008	ND	ND	ND	ND	ND	ND	ND
DGB-006	10/12/95	ND	ND	ND	0.31	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-007	10/12/95	ND	ND	ND	0.30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-008	10/12/95	ND	ND	ND	0.11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-009	10/12/95	ND	ND	0.11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-010	10/12/95	ND	0.029	0.36	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-011	10/13/95	ND	ND	ND	0.31	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.21
DGB-012	10/13/95	ND	ND	0.30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-013	10/13/95	ND	ND	ND	0.13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.27
DGB-014	10/24/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.009**	ND	ND	ND
DGB-015	10/24/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.008**	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 = MCL Exceedance

Appendix E. Levels of Trace Elements in DGB 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	.004	.005	0.1	{1.3}	(0.3)	{.015}	(.05)	.002	.05	.006	(0.1)	.002	(5.0)
DGB-016	10/24/95	ND	ND	ND	0.15	ND	ND	ND	ND	ND	ND	ND	ND	ND	.006	ND	ND	ND
DGB-017	10/24/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.009**	ND	ND	ND
DGB-018	10/24/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.008**	ND	ND	ND
DGB-020	10/24/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-021	10/24/95	ND	ND	0.12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.006	ND	ND	ND
DGB-022	10/24/95	ND	ND	0.10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.006	ND	ND	ND
DGB-023	10/25/95	ND	ND	ND	ND	ND	ND	ND	<.02	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-024	10/25/95	ND	.003	0.03	ND	ND	.0006	ND	ND	ND	< .002	ND	.0002	ND	ND	ND	ND	ND
DGB-025	10/25/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-026	12/18/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	< 0.10	ND	ND	ND	ND	ND	ND	ND
DGB-027	12/18/95	ND	ND	ND	0.20	ND	ND	ND	ND	0.10	ND	ND	ND	ND	ND	ND	ND	0.21
DGB-028	12/18/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.005	ND	ND	ND
DGB-029	12/19/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-030	12/19/95	ND	ND	ND	0.12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-031	12/19/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.009**	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 = MCL Exceedance

Appendix E. Levels of Trace Elements in DGB 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	.004	.005	0.1	{1.3}	(0.3)	{.015}	(.05)	.002	.05	.006	(0.1)	.002	(5.0)
DGB-032	12/19/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.77
DGB-033	12/19/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.008**	ND	ND	0.06
DGB-034	12/20/95	ND	ND	ND	0.14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-035a	12/20/95	N/A	.010	ND	0.13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-035b	12/20/95	ND	**.150**	3.26	ND	ND	.0025	ND	ND	**13.9**	ND	**1.52**	ND	ND	ND	ND	.025	0.06
DGB-036	12/20/95	ND	ND	0.19	0.12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.16
DGB-037	12/20/95	ND	ND	0.18	0.12	ND	ND	ND	ND	ND	ND	ND	ND	ND	.006	ND	ND	0.08
DGB-038	02/26/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.008**	ND	ND	ND
DGB-039	02/26/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.006	ND	ND	ND
DGB-040	02/26/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-041	02/27/96	ND	.017	0.21	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.007**	ND	ND	ND
DGB-042	02/27/96	ND	ND	ND	0.13	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.007**	ND	ND	ND
DGB-043	02/27/96	ND	ND	ND	0.20	ND	ND	ND	0.010	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-044	02/27/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**.008**	ND	ND	ND
DGB-045	02/27/96	ND	ND	0.10	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 = MCL Exceedance

Appendix E. Levels of Trace Elements in DGB 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	.004	.005	0.1	{1.3}	(0.3)	{.015}	(.05)	.002	.05	.006	(0.1)	.002	(5.0)
DGB-046	02/28/96	ND	ND	ND	ND	ND	ND	ND	ND	0.33	ND	ND	ND	ND	0.01	ND	ND	ND
DGB-047	02/28/96	ND	ND	ND	ND	ND	ND	ND	ND	0.33	ND	ND	ND	ND	ND	ND	ND	ND
DGB-048	02/28/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.009	ND	ND	ND
DGB-049	06/03/96	ND	ND	ND	0.20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.41
DGB-050	06/03/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.39
DGB-052	06/04/96	ND	ND	ND	0.14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-053	06/05/96	ND	.015	0.19	ND	**0.007**	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-054	06/05/96	ND	.015	0.21	ND	ND	ND	ND	ND	ND	ND	ND	ND	.006	.006	ND	ND	ND
DGB-055	06/24/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-056	06/25/96	ND	ND	ND	0.11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-057	06/25/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-058	06/25/96	ND	ND	ND	0.21	ND	ND	ND	ND	ND	ND	ND	ND	ND	.011	ND	ND	ND
DGB-059	06/25/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DGB-060	06/25/96	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 = MCL Exceedance

Appendix F. Levels of SDW Radionuclides in DGB Groundwater Samples

Sample ID #	Date Sampled	Gross Alpha (pCi/L) (Activity) + (Error)	Gross Beta (pCi/L) (Activity) + (Error)	Ra-226 (pCi/L) + (Activity) (Error)	Ra-228 (pCi/L) (Activity) (Error)	Mass Uranium (µg/l) (Activity) + (Error)
Maximum Contaminant Levels (MCLs)		15	50	Combined	5	
DGB-26	12/18/95	6.4E+000 + 1.6E+000	2.2E+000 + 1.0E+000	< LLD (3.0E-001)	< LLD (9.0E-001)	
DGB-27	12/18/95	3.7E+000 + 1.4E+000	2.6E+001 + 1.0E+000			
DGB-28	12/18/95	1.5E+001 + 1.6E+000	< LLD (1.6E+000)	< LLD (2.0E-001)	< LLD (1.0E+000)	9.3E+000 + 4.0E-001
DGB-29	12/19/95	6.4E+000 + 1.8E+000	1.8E+000 + 1.0E+000	< LLD (3.2E-001)	< LLD (9.0E-001)	
DGB-31	12/19/95	1.3E+001 + 2.0E+000	7.5E+000 + 1.2E+000	< LLD (3.0E-001)	1.0E+000 + 4.0E-001	
DGB-32	12/19/95	2.9E+000 + 1.2E+000	1.7E+000 + 1.0E+000			

Appendix G. Summary of SDW VOCs Detected in DGB Groundwater Samples

Sample Number	Sample Date	VOCs Detected
DGB-05	10/12/95	None
DGB-06	10/12/95	None
DGB-09	10/12/95	Chloroform - 0.5 μg/l
DGB-10	10/12/95	None
DGB-39	10/26/95	None
DGB-40	10/26/95	None
DGB-41	10/27/95	None
DGB-42	10/27/95	None
DGB-46	10/28/95	None
DGB-47	10/28/95	None
DGB-56	06/25/96	None
DGB-60	06/25/96	None

Appendix H. Summary of GWPL in DGB Groundwater Samples

Sample Number	Sample Date	Pesticides Detected
DGB-015	10/24/95	None
DGB-016	10/24/95	None
DGB-017	10/24/95	None
DGB-018	10/24/95	None
DGB-019	10/24/95	None
DGB-020	10/24/95	None
DGB-023	10/25/95	None

Appendix I. VOCs on the EPA 502.2 Safe Drinking Water (SDW) List

Compound	Minimum Reporting Limit (MRLs) μg/l	Maximum Contaminant Levels (MCLs) μg/l
Benzene	0.5	5.0
Bromozene	0.5	
Bromochloromethane	0.5	
Bromodichloromethane	0.5	
Bromoform	0.5	
Bromomethane	0.5	
n-Butylbenzene	0.5	
sec-Butylbenzene	0.5	
tert-Butylbenzene	0.5	
Carbon Tetrachloride	0.5	5.0
Chlorobenzene	0.5	100
Chloroethane	0.5	
Chloroform	0.5	
Chloromethane	0.5	
2-Chlorotoluene	0.5	
4-Chlorotoluene	0.5	
Dibromochloromethane	0.5	
1,2-Dibromo-3-chloropropane	0.5	
1,2-Dibromoethane	0.5	
Dibromomethane	0.5	
1,2-Dichlorobenzene	0.5	600
1,3-Dichlorobenzene	0.5	
1,4-Dichlorobenzene	0.5	75
Dichlorodifluormethane	0.5	
1,1-Dichloroethane	0.5	7

Appendix I. VOCs on the EPA 502.2 Safe Drinking Water (SDW) List--Continued

Compound	Minimum Reporting Limit (MRLs) µg/l	Maximum Contaminant Levels (MCLs) µg/l
1,2-Dichloroethene	0.5	5.0
1,1-Dichloroethene	0.5	
cis-1,2-Dichloroethene	0.5	70
trans-1,2-Dichlorothene	0.5	100
1,2-Dichloropropane	0.5	5.0
1,3-Dichloropropane	0.5	
2,2-Dichloropropane	0.5	
1,1-Dichloropropene	0.5	
c-1,3-Dichloropropene	0.5	
t-1,3-Dichloropropene	0.5	
Ethylbenzene	0.5	700
Hexachlorobutadiene	0.5	
Isopropylbenzene	0.5	
p-Isopropyltoluene	0.5	
Methylene Chloride	0.5	
Naphthalene	0.5	
n-Propylbenzene	0.5	
Styrene	0.5	100
1,1,1,2-Tetrachloroethane	0.5	
1,1,2,2-Tetrachloroethane	0.5	
Tetrachloroethene	0.5	5.0
Toluene	0.5	1000
1,2,3-Trichlorobenzene	0.5	
1,2,4-Trichlorobenzene	0.5	70
1,1,1-Trichloroethane	0.5	200

Appendix I. VOCs on the EPA 502.2 Safe Drinking Water (SDW) List--Continued

Compound	Minimum Reporting Limit (MRLs) µg/l	Maximum Contaminant Levels (MCLs) µg/l
1,1,2-Trichloroethane	0.5	5.0
Trichloroethene	0.5	5.0
Trichlorofluormethane	0.5	
1,2,3-Trichloropropane	0.5	
1,2,4-Trimethylbenzene	0.5	70
1,3,5-Trimethylbenzene	0.5	
Vinyl Chloride	0.5	2.0
Total Xylenes	1.5	10000

Appendix J. 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 J. 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	
METHOMLY	2	180	
METHYL PARATHION	10	1.8	

Appendix J. 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 J. 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 K. Summary of Surface Water Parameter Levels in the Whitewater Draw

Parameter	January 1998	March 1998	May 1998
As	ND	ND	ND
Be	ND	ND	ND
Ca	192	206	210
Cl	352	376	355
EC	N/A	4360	4420
F	N/A	1	N/A
HCO_3	340	340	330
Hardness	850	889	928
Fe	ND	ND	ND
Mg	92	100	103
Mn	0.75	0.33	0.55
NO_3-N	0.5	N/A	N/A
pH-lab	7.7	7.6	7.4
K	11	12	9
Na	473	472	494
SO_4	1059	1116	1089
Total Alkalinity	362	342	350
TDS	4000	2410	2400
Zn	ND	0.3	ND

ND = Not detected at MRL
N/A = Not Sampled For
All units mg/l except pH (SU) & EC (umhos/cm)
Whitewater Draw samples were collected by the ADEQ Surface Water Monitoring Unit at the International Border