AMBIENT GROUNDWATER QUALITY OF THE YUMA BASIN:

A 1995 BASELINE STUDY

Prepared by

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

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Ambient Groundwater Quality of the Yuma Basin: A 1995 Baseline Study

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Cover Photo: South Gila Project Drainage Well #6 furiously pumping groundwater with Yuma Mesa and Gila Mountains in the background. March, 1995.

VISION

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

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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DISCLAIMER

This groundwater quality study of the Yuma Groundwater Basin (YGB) was not designed to evaluate water quality in specific localized areas. Even though limited sampling was targeted to demonstrate a link between land uses and deteriorating water quality, these linkages could not be established even when water quality standards violations were documented. This is a regional study which contains conclusions based upon statistical representations of water quality throughout the YGB. The localized groundwater quality standard exceedences in the YGB which have been documented by other ADEQ programs were not necessarily included in this study due to the sampling design. Localized groundwater quality impacts may exist and continue to appear even though the overall regional groundwater quality indicators appear both largely acceptable and stable.

1. ABSTRACT

The Groundwater Monitoring Unit of the Arizona Department of Environmental Quality (ADEQ) conducted a baseline groundwater quality study of the Yuma Groundwater Basin (YGB) in 1995. Fifty-five wells were sampled for Safe Drinking Water (SDW) inorganics, with a lesser number of samples collected for the banned-pesticides DBCP and EDB (41 samples), Groundwater Protection List pesticides (21 samples), and radionuclides (7 samples). A stratified random sampling design was used to select 42 wells that are equally distributed in three physiographic areas (Gila Valley, Yuma Mesa, and Yuma Valley) and two groundwater zones (upper, fine-grained and lower, coarse-gravel). Also sampled were 13 wells targeted around land uses and/or an area of high nitrate levels.

Laboratory results revealed no detection of any pesticides. Of the inorganic and radionuclide parameters with health-based Primary Maximum Contaminant Levels (MCLs), only nitrate exceeded the water quality standard in five wells - four of which are located in the eastern South Gila Valley. In this area of high nitrate levels, one nitrate sample exceeded the Primary MCL by a factor of twelve. Of inorganic parameters with aesthetics-based Secondary MCLs, chloride, iron, manganese, sulfate, and total dissolved solids frequently exceeded water quality standards. This data suggests that regional groundwater quality conditions in the YGB generally support drinking water uses but because of aesthetic factors, residents may prefer to use treated water for some domestic purposes.

YGB groundwater has no dominant water chemistry and is chemically fairly uniform and similar to Colorado River water. Many groundwater quality parameter levels are positively correlated with one another which may indicate a common source of salts and minerals. These findings support the assertion made by previous studies (Olmstead and others, 1973) that groundwater in the YGB consists largely of recharged Colorado River water.

Statistical analyses comparing the upper, fine-grained and lower, coarse-gravel groundwater zones indicate no significant differences exist between groundwater quality parameter levels; however, when groundwater quality parameter levels are compared with groundwater depth below land surface (bls), many parameters have decreasing levels significantly related to increasing groundwater depth bls. Numerous statistically-significant differences exist in groundwater quality parameter levels among physiographic areas, with many inorganic parameters having higher levels in Gila Valley than Yuma Mesa and Yuma Valley. These spatial groundwater quality differences may be due to unique histories involving how long an area has been irrigated, depth to groundwater, and - especially - the source of irrigation water. The irrigation source in Gila Valley has predominately been groundwater with this resource being constantly recycled and degraded; in contrast, "fresher" Colorado River water has been chiefly applied for agriculture in the Yuma Mesa and Yuma Valley. A time trend analysis conducted on 14 wells sampled by both the U.S. Bureau of Reclamation in 1989-90 and ADEQ in 1995 showed few significant groundwater quality parameter level differences indicating that groundwater quality has been relatively unchanged during this time period.

2. OBJECTIVES

The Groundwater Monitoring Unit (GMU) of the Arizona Department of Environmental Quality (ADEQ) conducted an extensive regional groundwater quality study of the Yuma Groundwater Basin (YGB) in 1995. The impetus for this groundwater study was an ADEQ report (Hood, 1991) which evaluated the need for ambient monitoring in each of the 50 designated groundwater basins in Arizona. In an effort to provide a scientific basis for prioritizing areas of the State for research activities, criteria such as groundwater quality data collection alternatives, dependence of the population on the groundwater supply, and aquifer characteristics and vulnerability to contamination were examined. Based on this methodology, of all the groundwater basins in Arizona, the YGB had the highest priority for an ambient groundwater monitoring study and accompanying index well network.

This groundwater study had six objectives:

1) To obtain baseline data throughout the YGB on the occurrence, concentrations, and ranges of a wide array of groundwater quality parameters including the identification and delineation of any areas with groundwater quality problems.

2) With the sampling sites determined through means of stratified random selection, examine various spatial areas within the YGB for statistically significant groundwater quality differences, including those between:

   A) Two groundwater zones: the upper, fine-grained (FG) and the lower, coarse-gravel (CG);

   B) Three physiographic areas: Gila Valley (GV), Yuma Mesa (YM), and Yuma Valley (YV);

   C) Six groundwater zone/physiographic areas: GVFG - Gila Valley fine-grained, GVCG - Gila Valley coarse-gravel, YMFG - Yuma Mesa fine-grained, YMCG - Yuma Mesa coarse-gravel, YVFG - Yuma Valley fine-grained, and YVCG - Yuma Valley coarse-gravel;

   D) Different well types (domestic, irrigation, municipal, industrial, and drainage) which are indicative of different land uses.

3) 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.

4) By the use of upgradient and downgradient sampling, assess the impact on groundwater from potential contaminant sources related to specific land uses or management practices such as biosolids, a landfill, septic systems, and an urban area.

5) To identify statistically significant changes and trends in groundwater quality within the YGB by comparing 1995 sampling results collected by ADEQ with 1989 - 1990 sampling results collected by the United States Bureau of Reclamation (USBR) from the same wells.

6) To establish a statistically-designed ambient groundwater quality index well monitoring network for the YGB.

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

- Yuma-area residents utilizing water supplied by a public water system for domestic use 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 rarely - if ever - tested for possible pollutants. 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 private wells would be prohibitively expensive, an ambient groundwater study that emphasizes evaluating physiographic areas and groundwater zones by using scientific principles to accurately estimate groundwater quality conditions offers an affordable alternative.

- Determine whether groundwater in the YGB is currently suitable for domestic use;

- Provide a scientific basis for distinguishing pollution impacts and determining clean-up criteria for groundwater contamination sites;

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

- Be a useful tool with which to guide Yuma-area planning and especially the establishment of new public water supply well locations and wellhead protection areas.

3. INTRODUCTION

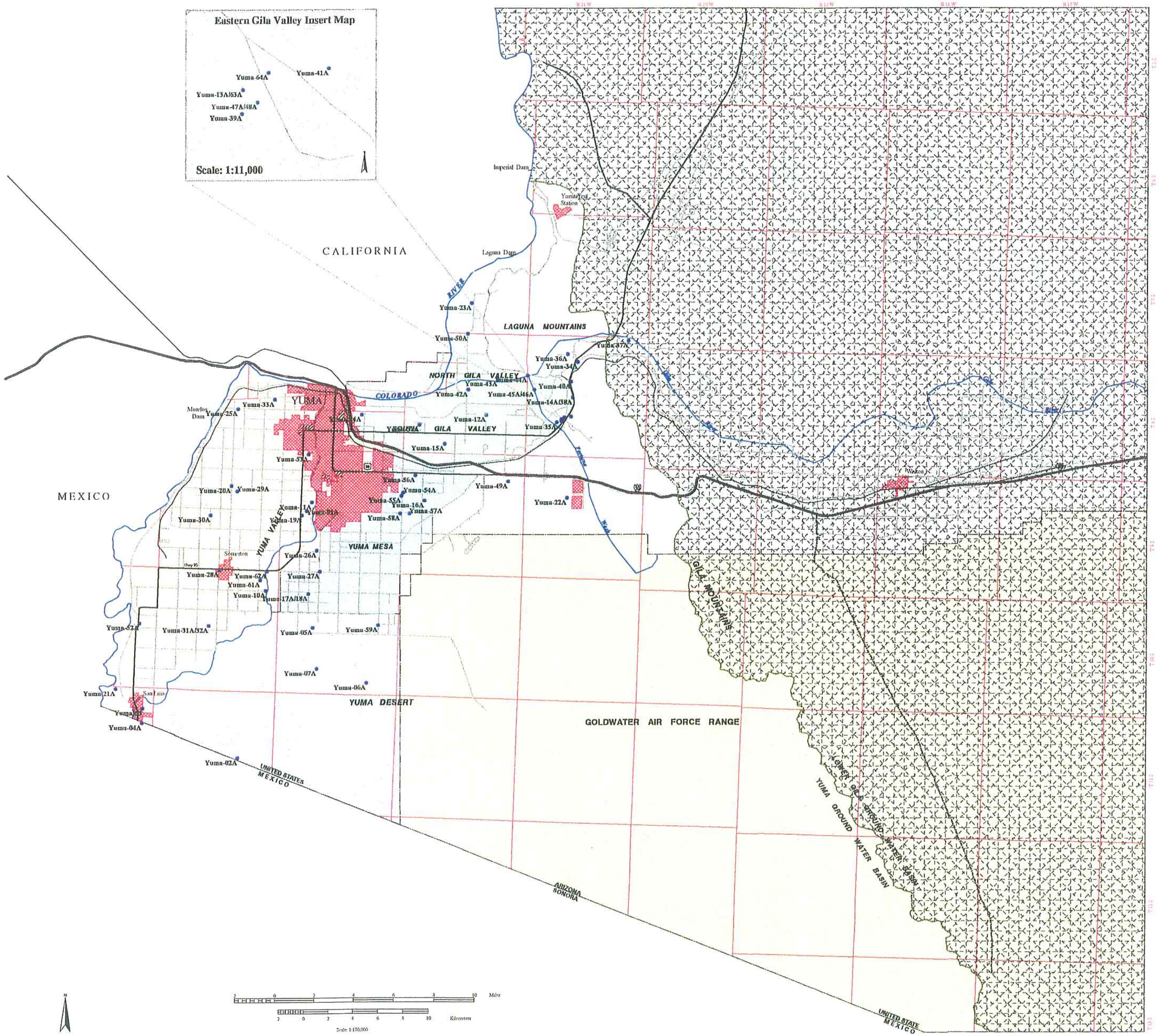
3.1 Physical Setting: Geography, Physiography, and Climate

The YGB is located in the extreme southwest corner of Arizona at the apex of the Colorado River delta, approximately 70 miles north of the Gulf of California (**Figure 1a**). Situated in one of the driest desert areas in North America, the YGB covers approximately 750 square miles. The basin boundaries are formed by two hydrologic barriers: the Laguna Mountains to the northeast and the Gila and Tinajas Atlas Mountains to the east, and two political boundaries: the International Border with Mexico to the south, and the Colorado River to the west and northwest. In reality, the YGB extends past these political boundaries for considerable distances into the State of California and the Mexican States of Baja California and Sonora.

The YGB lies within the Lower Colorado Sonoran Desert section of the Basin and Range physiographic province. Elevations within the YGB range from 3156 feet above mean sea level in the Gila Mountains to about 80 feet above mean sea level where the Colorado River crosses into Mexico. The basin is characterized by elongated, north to northwest trending mountains separated by extensive, broad desert plains through which are cut the present valleys of the Colorado and Gila Rivers. Because of the arid conditions, no perennial streams originate in the area. Though regulated upstream by dams, the Colorado River is perennial through the Yuma area as far as the Morelos Dam, a diversion dam operated by Mexico approximately 11 miles downstream of Yuma. The Gila River is also perennial through the YGB, typically serving as a natural drain for excess irrigation water in the area. Important physiographic areas and their extent within the YGB include two river valleys: Gila Valley - 27,000 acres and Yuma Valley - 65,000 acres, and a river terrace, Yuma Mesa - 300,000 acres (Olmstead and others, 1973). The largely uninhabited and undeveloped Yuma Desert occupies the remainder of the YGB.

Climatically, the YGB is one of the driest areas in North America with an annual precipitation of only 2.57 inches. This precipitation is sporadic and occurs mainly as thunderstorms from July to December. Temperatures range from moderate in the winter to extremely hot during the summer. In January, the mean daily maximum temperature is 69 degrees F and the mean daily minimum is 37 degrees F. July has a mean daily maximum temperature of 107 degrees F and a mean daily minimum of 73 degrees F (Sellers and Hill, 1974). Creosote bush and mesquite are the dominant types of natural vegetation in the low desert portion of the YGB, while riparian areas along the Colorado and Gila Rivers are composed of salt cedar, cottonwood, and willow.

Figure 1. Location of Groundwater Samples Collected by ADEQ in the YGB



4. HYDROGEOLOGY

4.1 Aquifer Characteristics

Groundwater in the YGB exists primarily in unconfined conditions and consists mainly of alluvial deposits of the ancestral Colorado and Gila Rivers. These alluvial deposits contain loose and unconsolidated sand, gravel, silt, and clay of several aggradational and degradational cycles. Based on water-bearing characteristics, Olmstead and others (1973) divided the basin-fill into two major subdivisions:

> 1) The deeper subdivision - this is not typically used as a water source and consists of four zones which are listed in descending order: the Bouse Formation, marine sedimentary rocks, volcanic rocks, and nonmarine sedimentary rocks. With the exception of the Bouse Formation and nonmarine sedimentary rocks, these deep and highly mineralized units are not considered to be potentially significant sources of groundwater.
>
> 2) The shallower subdivision - a frequently used and hydrologically important water source because it is extremely transmissive and yields good quantities of water to wells (Hill, 1993). The shallower subdivision generally extends to a depth of 3,000 feet below land surface (bls) and, in descending order, consists of three water-bearing units: the upper fine-grained zone, the coarse-gravel zone, and the wedge zone. These deposits are saturated except for the top few feet or tens of feet in most of the area and there exists a close hydraulic connection between these water-bearing zones (Mock and others, 1988).

The upper, fine-grained zone is the shallowest water bearing unit in the YGB. Although limited water is pumped from this zone, it is important hydrologically because groundwater is recharged vertically through this uppermost layer. The fine-grained zone ranges in thickness from about 70 - 240 feet and averages about 100 feet beneath the river valleys and 170 - 180 feet beneath the Yuma Mesa (Olmstead and others, 1973). In the river valleys, the upper portion of the fine-grained zone consists of a relatively thin layer of silt and clay, approximately 5 - 15 feet thick, with the remainder of the zone consisting of sand and silt. Most groundwater discharge from the zone is through evapotranspiration to the atmosphere or through surface drains, while a smaller amount is pumped out for domestic or irrigation uses (USBR, 1991).

Underlying the fine-grained zone is the coarse-gravel zone, the principally-used aquifer beneath the river valleys and Yuma Mesa. The coarse-gravel zone is the most permeable of the alluvial sediments in the YGB and its outstanding characteristic is its ability to transmit large volumes of water. These alluvial deposits consist of fluvial and deltaic sediments from the Colorado and Gila Rivers and range in thickness from 0 to 100 feet within the YGB. Depth to the coarse-gravel zone ranges from approximately 100 feet in the river valleys to approximately 180 feet beneath Yuma Mesa. Most water production wells are constructed with screened openings completed in this zone (Olmstead and others, 1973).

The wedge zone, while constituting the major part of the water-bearing deposits beneath the river valleys and the Yuma Mesa, is only occasionally utilized for groundwater withdrawals because of the presence of shallower productive aquifers (Olmstead and others, 1973). Its dimensions vary from a depth of 160 - 300 feet from north to south in the YGB. The lower extent of the wedge zone generally pinches out laterally beneath the coarse-gravel zone against the adjacent Laguna and Gila Mountains as well as the buried bedrock ridge under Yuma Mesa, hence the water unit's name. To the south, the wedge zone extends to a depth of approximately 2500 feet near San Luis, Arizona. Consisting of interbedded sands and gravels, the lithologic break between the wedge zone and the overlying coarse-gravel zone is sometimes vague and the two zones are undifferentiated in many locations. The wedge zone is not a highly used water-bearing zone at this time, only a few wells penetrate more than a few feet into it (Mock and others, 1988).

In general, the movement of groundwater parallels the flows of the Gila and Colorado Rivers, moving west, then southwest. The exception to this trend is the Yuma Mesa where a large water mound has formed due to percolating irrigation water. Groundwater moves out from this mound in all directions with a gradient ranging from 2 to 60 feet per mile. The hydraulic gradient in Yuma Valley ranges from about 1 to 10 feet per mile, but is strongly influenced by the stages of the Colorado River (Olmstead and others, 1973). Under normal conditions, when the stage is low, groundwater feeds the Colorado River. However, at high stages, the river recharges the groundwater, causing local flow gradients to reverse.

The Gila and Yuma Valleys have very shallow depths to groundwater ranging from 2 to 20 feet below land surface. On the Yuma Mesa, depth to groundwater ranges from about 40 feet to approximately 200 feet below land surface. The Algodones Fault, which runs in a northwest - southeast direction through the YGB, alters groundwater elevations as much as 50 feet within one-half mile on either side of the fault (Olmstead and others, 1973).

4.2 Water Budget

A water surplus exists in the basin which is the result of groundwater recharge caused by several factors including:

1) Irrigation - By far the largest recharge component is from 700,000 acre-feet of water diverted from the Colorado River north of Yuma at Imperial Dam and applied to farmland in the basin through unlined canals.

2) Flooding - Another recharge source is from the Colorado and Gila Rivers during flood conditions. While the Colorado River has become a gaining stream since the construction of upstream dams starting in the 1930's, it was

once a losing stream in the Yuma area. Currently it acts as a drain for the Yuma Basin under normal surface-water flow and groundwater conditions, only providing recharge during flood conditions.

3) Underflow - Recharge is also provided by subsurface inflows into the YGB, though they are of a limited nature as the basin is closed to the north and east, except for the Colorado and Gila River channels. Approximately 1,000 acre-feet of groundwater enter the basin annually as underflow along the Gila River (USBR, 1991).

4) Precipitation - A very minor amount of recharge also occurs from precipitation and local runoff.

Discharge from the groundwater system is predominately to surface drains, the Colorado and Gila Rivers at normal stage levels, phreatophyte growth in riparian areas, and groundwater pumpage.

Shallow groundwater creates numerous problems such as the reduced efficiency of septic systems, stability problems for structures, inability to flush soils of salt build-up, and difficulty in harvesting crops when fields are too saturated for heavy machinery to operate properly (Mock and others, 1988). Extensive drainage facilities are necessary to keep the water table below the root zones of crops, the leach fields of septic tanks, and the base of constructed facilities in both Gila and Yuma Valleys. To keep these valleys from becoming water logged, this water surplus must be moved out of the basin. Drainage is accomplished with tile drains installed in fields as well as numerous high-capacity wells perforated in the coarse-gravel zone and located at the interface between Yuma Mesa and the valleys. These drainage wells discharge water into nearby surface drains to move the water south into Mexico. Parts of the drainage system date from as early as 1916, and by 1981, the system had 42 operating drainage wells and 80 miles of open gravity drains that export an annual average of 235,000 acre-feet of water (USBR, 1991).

An estimated 49 million acre-feet of groundwater are in storage in the YGB, to a depth of 1,200 feet (ADWR, 1994). Altogether, approximately 226,000 acre-feet were pumped in the YGB in 1984 (U.S. Geological Survey, 1986). Over 12,000 acres of farmland are irrigated using groundwater in private developments outside the USBR projects (USBR, 1991). The communities of Somerton, San Luis, and Gadsden, as well as the many subdivisions and individual homes located throughout the YGB, are examples of municipal and domestic groundwater consumers. A significant amount of groundwater is also withdrawn for regulatory use at the "242 Well Field" along the Mexican border east of San Luis, Arizona. These wells, which became operational in 1981, are designed to intercept groundwater naturally flowing south and discharge it into the "242 Lateral" to help the United States meet Colorado River water obligations to Mexico.

5. GROUNDWATER QUALITY

Since groundwater is a significant source of water supply in the YGB, groundwater quality in the YGB is important from both a public health and environmental perspective. A growing segment of the population in the Yuma area is dependent on this resource for domestic and irrigation uses. Groundwater is also a significant component of the hydrologic cycle as it contributes to surface water flow in the basin. However, the increasing use of groundwater in the Yuma area is not without drawbacks. Based on levels of total dissolved solids (TDS), groundwater in the YGB is generally of lower quality than surface water derived from the Colorado River. This is due to the leaching of soil and subsoil saline material, fertilizers, and soil amendments. Constituents commonly occurring in the groundwater such as TDS, chloride, and sulfate often cause the water to have an unpleasant taste and/or odor. As a result, many domestic residences served by groundwater have treated water delivered to their homes by truck for supplemental household purposes such as drinking and cooking. There are also health concerns stemming from contamination of groundwater by agricultural pesticides and nitrates.

Previous groundwater quality studies suggest each water-bearing zone in the YGB possesses different water quality characteristics. The chemistry of the upper, fine-grained zone fluctuates greatly because the extremely shallow water table is not well protected from changes brought about by events occurring at land surface or from human-induced contamination. Olmstead and others (1973) reported that water in this zone is exceedingly variable in chemical characteristics and concentrations of dissolved solids, which was attributed to factors such as depth to groundwater, proximity of canals, laterals, or surface drains, irrigation regimen, and upward or downward movement of water. The groundwater quality in the coarse-gravel zone also is variable. While TDS concentrations typically range from 900 - 1500 milligrams per liter (mg/l), somewhat saline water with TDS levels in excess of 1800 mg/l occurs in scattered areas in the northern portion of the YGB. Less saline water is found close to the Colorado River and presumably is the result of local recharge of river water. The water in the wedge zone has a smaller range in chemical characteristics than that in the overlying coarse-gravel zone and much less than that in the upper, fine-grained zone. The TDS concentration in wedge zone water generally ranges from 700 - 1500 mg/l (Olmstead and others, 1973).

Studies have shown groundwater in the YGB to be at high risk from contamination. Maps which spatially quantify potential pollution threats to groundwater resources, termed Drastic Index Maps, have been developed for the YGB (Woodward-Clyde Consultants, 1987). The most developed areas of the YGB, the Gila Valley, Yuma Valley, and Yuma Mesa, are categorized by these maps as possessing physical characteristics indicative of the highest vulnerability of groundwater to pollution from both agricultural activities and other sources.

Groundwater contamination stemming from agricultural, industrial, and landfill sources has been documented in the YGB. Agricultural-related contamination has resulted from pesticide applications to cropland in Yuma Mesa and the Gila and Yuma Valleys. The Yuma Marine

Corps Air Station, located on the Yuma Mesa, has been the source of contamination from pipeline spills, underground storage tanks (USTs), and other industrial uses. Fuel leaks from USTs have also occurred in the communities of Yuma and Somerton. The Somerton Landfill has been a contamination source of metals and other constituents.

5.1 Previous Groundwater Quality Studies

Several groundwater studies have been conducted in the YGB to both characterize the groundwater quality and examine the aquifer for contaminants; these studies are summarized below.

An Arizona Department of Water Resources (ADWR, undated) study examined statewide TDS concentrations in groundwater. The TDS levels in the YGB ranged from less than 1000 mg/l to greater than 10,000 mg/l. Generally, TDS levels were less than 1000 mg/l in the Yuma Desert and the western portions of the Yuma Valley, 1000 - 3000 mg/l in the Yuma Mesa, while Yuma Valley and Gila Valleys had TDS levels in excess of 3000 mg/l.

A United States Geological Survey (USGS) study (Wilkins, 1978) examined specific conductance and fluoride levels in groundwater within the YGB. Specific conductance, which is strongly linked to TDS levels, was found to be highest (greater than 3330 micromhos per centimeter at 25 degrees C) in Gila Valley. Relatively high levels (1670 - 2,500) were also found in areas of Yuma Mesa and Yuma Valley. Fluoride levels were all less than the 4.0 mg/l Primary Maximum Contaminant Level (MCL) and the 2.0 mg/l Secondary MCL, with the average reading about 0.7 mg/l. The highest fluoride level, 1.4 mg/l, was recorded in the Yuma Mesa.

An Arizona Department of Health Services (ADHS) Yuma County study was conducted in 1979 to determine any presence of dibromochloropropane (DBCP) in the groundwater. DBCP is a constituent in several pesticides used since the mid-1950's to control nematodes in citrus groves and was banned by the Environmental Protection Agency (EPA) in 1979. Of the 76 groundwater samples collected from wells for this study, 33 tested positive for DBCP with values ranging from 0.07 - 137 micrograms per liter (μg/l), with this latter level the highest recorded DBCP concentration in groundwater in the United States (Mumme, 1988). The majority of DBCP detections were found within the Yuma Mesa, an area of extensive citrus orchards and in wells with depths ranging from 150 - 200 feet, though some well depths were as great as 400 feet.

Similarly, another ADHS study examined the statewide occurrence of ethylene dibromide (EDB) in groundwater. This chemical has been used for decades as a soil fumigant to control nematodes, particularly on cotton, citrus, and vegetable crops in Arizona as well as being a gasoline additive before being banned by the EPA in 1984. Of the nine wells sampled within Yuma County, eight had EDB detections ranging from 0.002 to 0.019 μg/l (ADHS, 1984). The study concluded that additional sampling was necessary to characterize the spatial and vertical distribution of EDB in the Yuma area.

A follow-up to these two studies conducted by ADEQ in 1987 found only three DBCP and two EDP positive detections out of 43 well samples collected in Yuma County (Williams, 1987). The DBCP concentrations ranged from 0.026 - 0.220 μg/l, while only trace amounts of EDB were detected.

The USBR collected water samples from approximately 304 wells in the Greater Yuma-area, which included portions of California, during a groundwater study conducted from 1984 through 1991 (USBR, 1991). All the wells sampled were perforated in the coarse grained zone and consisted of most of the drainage, regulatory, irrigation, and municipal wells located in the YGB, with only a few domestic wells included in the study. Despite the large numbers of samples collected in this study, the sampling density varied tremendously in different areas of the YGB because of a lack of statistical sampling design. As a result, some areas had a very high sampling density while other large areas of the YGB had relatively few representative samples. The cumulative results of the USBR groundwater sampling study are summarized in **Table 1**.

Comparing chemical constituent levels obtained from USBR samples with Safe Drinking Water (SDW) Maximum Contaminant Levels (MCLs) levels indicates that while few Primary MCLs are exceeded, many Secondary MCLs are regularly exceeded in YGB groundwater samples. Generally, levels of constituents such as nitrate (NO_3), fluoride, iron, and pH only occasionally exceeded their respective MCLs, while chloride, manganese, and sulfate levels typically exceeded their MCLs, and TDS always exceeded its MCL.

Table 1. Yuma-area Groundwater Parameter Levels Collected by the USBR from 1984 - 1991.

Constituent	# of Wells Sampled	Average	Minimum	Maximum	Standard Deviation
EC	304	2604	872	7730	1181
TDS	303	1670	518	4725	772
Temperature	287	25.2	19.0	36.0	3.3
pH	304	7.9	7.4	8.9	0.2
Sodium	303	339	88	1130	175
Potassium	303	5.8	2.5	15.3	2.0
Calcium	304	152	37	520	79
Magnesium	304	49	11	177	29
Chloride	303	272	72	2064	314
Bicarbonate	303	270	66	590	97
Sulfate	304	436	70	1200	243
Nitrate (NO_3)	274	4.3	0.0	69.9	8.3
Silica	273	25.7	14.5	46.1	4.8
Boron	271	0.42	0.07	2.74	0.30
Fluoride	275	0.6	0.2	2.7	0.3
Iron	271	0.15	0.0	1.11	0.21
Manganese	271	0.72	0.0	3.78	0.82
Barium	271	0.06	0.0	0.50	0.06
Strontium	271	1.47	0.0	5.66	0.92

All units mg/l except EC (micromhos/cm), Temperature (^{0}C), and pH (standard units)

6. METHODS AND MATERIALS

6.1 Sampling Strategy

The quantitative estimation of regional groundwater quality conditions requires the selection of sampling locations that follow scientific principles for probability sampling. To meet the different objectives of the YGB ambient study, a two-pronged approach as suggested by Alley (1993) was deemed the most appropriate. This strategy includes stratified random sampling in a split-plot design as well as targeted sampling. Utilizing this groundwater sampling strategy, both point and nonpoint sources of aquifer contamination were examined.

Stratified random sampling in a split-plot design was conducted by dividing the YGB into three subpopulations based both upon landforms and irrigation histories: Gila Valley, Yuma Mesa, and Yuma Valley. Fourteen random samples were collected from each subpopulation; seven from the upper fine-grained water bearing zone and seven from the deeper, coarse-gravel water bearing zone. These water zones were chosen for study because the upper fine-grained aquifer - being the uppermost water zone - is generally most susceptible to contamination and thus, serves as an early warning of potential contamination of the more extensively used deeper water zones such as the coarse gravel zone. A total of 42 samples were collected in utilizing this strategy. This number exceeded 30, which Stuart (1976) notes is often a large enough population for the sampling distribution of the sample mean to be approximated by the normal distribution (or anotherwords, there is enough data to determine if the data is normally distributed). Sampling sites were randomly selected from a listing of all groundwater wells registered within the YGB by the Arizona Department of Water Resources (ADWR) as well as field reconnaissance. Targeted sites constituted the remainder of the groundwater samples collected for this baseline investigation. Targeted sampling is useful in identifying water-quality problems that would be missed or underrated by survey sampling (Alley, 1993). Targeted sites were chosen using two different strategies:

1) Land Use Activities - Some targeted groundwater sample sites were chosen on the basis of land use activities in the immediate area: biosolid applications, landfills, septic waste disposal systems, and urban areas. These targeted sites were selected from discussions with local officials and residents, previously documented sources of contamination, and traditional sources of pollution. Six targeted samples utilizing this type of strategy were collected during the course of the study.

2) Groundwater Quality Data - The second source of information used for targeting sites was groundwater quality data obtained from earlier random and targeted samples collected as part of this ADEQ study. Intensive monitoring efforts were then conducted in an attempt to quantify the spatial extent of the high parameter levels as well as locate any potential sources. Seven such targeted samples were collected during the course of the groundwater study.

6.2 Sample Parameters

Inorganic groundwater quality parameters are the main focus of the various parameters sampled for in this study, with Safe Drinking Water (SDW) parameters serving as the basis of analysis. SDW parameters 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)
- phenolphthalein alkalinity
- fluoride (F)
- nitrate (NO_3-N)
- sulfate (SO_4)
- turbidity
- arsenic (As)
- cadmium (Cd)
- chromium (Cr)
- iron (Fe)
- magnesium (Mg)
- mercury (Hg)
- silver (Ag)
- zinc (Zn)

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

- ammonia-nitrogen (NH_4)
- phosphorus (P)
- total Kjeldahl nitrogen (TKN)
- boron (B)
- potassium (K)

Thus, from each of the 55 wells sampled as part of this study - whether a stratified random sample or a targeted sample - an inorganic groundwater sample was collected for analytical analysis for the above-listed groundwater quality parameters.

Of the 55 wells that were sampled for inorganic parameters as part of this study, 41 wells also had groundwater samples collected from them for analysis of currently-banned pesticides 1,2-dibromo-3-chloropropane (DBCP) and 1,2-dibromoethane or ethylene dibromide (EDB). These 41 sample sites were not evenly distributed throughout the YGB, but located in several targeted areas based on previous studies. These targeted areas had previous pesticide detections, usually in the vicinity of citrus orchards where they had been used as a soil fumigant and/or nematocide.

Of the 55 wells that were sampled for inorganic parameters as part of this study, 21 wells also had groundwater samples collected from them for analysis of Groundwater Protection List (GWPL) pesticides. These targeted sampling sites were typically chosen from wells pumping groundwater from relatively shallow depths in areas such as the Yuma Valley, where previous pesticide detections have occurred. The ADEQ Pesticide Prevention Program (PPP) assisted in collecting GWPL pesticide samples. Those samples were included in this study because of the extensive pesticide use which occurs within the YGB. In 1995, 78 different pesticides were used within the study area with the dozen most commonly applied pesticides in descending order: methomyl, cypermethrin, permethrin, bacillus thuringiensis var. israelensis, maneb, fosetyl-al, mevinphos, dimethoate, endosulfan, acephate, and diazinon. In addition, the currently-registered pesticides dicamba and 2,4-D were previously detected in the area by the PPP in 1994, which suggested continued study was needed to investigate the potential presence of these parameters in the groundwater.

Seven of the 55 wells that were sampled for inorganic parameters as part of this study also had groundwater samples collected from them for radionuclide analysis. The sampling strategy for radionuclides was similar to that outlined for inorganic samples, except that a much lower number of samples were collected. Two random stratified samples were collected in Gila Valley, Yuma Mesa, and Yuma Valley, while one targeted sample was collected from the eastern Gila Valley near the Gila Mountains.

6.3 Sample Collection

The sample collection methods for this study conformed to the *Quality Assurance Project Plan (Q.A.P.P.)* (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 any storage or holding 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 either a Cambridge Meter or Hydrolab. After three bore volumes had been pumped and the physical parameters had stabilized within ten percent, it was determined that a sample representative of the aquifer could be collected from a point as close to the wellhead as possible.

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

1. GWPL Pesticides
2. DBCP and EDB pesticides
3. Safe Drinking Water (SDW) Inorganic Compounds
4. Radionuclides

GWPL pesticide samples were collected in one gallon, amber glass containers. Samples for the banned pesticide samples for DBCP and EDB were collected in one liter, amber glass containers, in two 40 ml clear glass vials with Teflon septums, or extracted from the GWPL pesticide container depending on which laboratory was used for analysis. The inorganic constituents were collected in three one-liter poly bottles. The sample in the nitric acid preservative container for dissolved metals was collected using an on-site, positive-pressure filtering apparatus fitted with a 0.45 μM pore size groundwater capsule filter. Unfiltered groundwater was then collected in the sulfuric acid container for nutrients and in the unpreserved bottle for physical parameters. Radionuclide samples were collected in two collapsible one-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.

The Arizona Department of Health Services (ADHS) Laboratory in Phoenix conducted the majority of the analyses for this study. The only exceptions were two SDW inorganic analyses, Yuma-048A and Yuma-064A samples, the DBCP/EDB samples, Yuma-017A through Yuma-023A and Yuma-031A through Yuma-033A, and the radionuclide samples. The SDW inorganic analyses were submitted to Analytical Technologies, Inc. (ATI) in Phoenix, which performed the testing, with the exception of metals analyses which were analyzed by the ATI laboratory in Fort Collins, Colorado. The previously-noted DBCP/EDB samples were submitted to McKenzie Laboratories in Phoenix which subcontracted the work to Pace Incorporated Environmental Laboratories in Camarillo, California. The radionuclide samples were analyzed by the Arizona Radiation Regulatory Agency located in Phoenix.

6.4 Statistical Considerations

There were several considerations in selecting appropriate statistical tests 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 are helpful in determining whether a data set is normally distributed; 30 is often a large enough sample size (Stuart, 1976). Depending on how skewed, the data population is, it may still be appropriate to use parametric tests. But as a result of these factors, the use of parametric statistical methods 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 the United States Geological Survey (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 Wilcoxon rank sum test was used to examine differences in parameter concentrations in groundwater between groups of data typically not normally or log-normally distributed. The Wilcoxon signed rank test not only examines for 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.

As a result of testing the YGB groundwater quality data for normality using the Kolmogorov-Smirnov One Sample Test with the Lilliefors option, the use of log-transformed data with parametric tests was considered the most powerful and valid method with which to analyze the data from this study. The level of significance used in the study was 95% (designated by *) while the 99% level of significance is also provided (designated by **). Systat software was used for all statistical computations.

7. RESULTS

For the YGB study, ADEQ personnel collected and transported for analysis to State-certified laboratories a wide variety of groundwater samples: 63 SDW inorganic, 41 DBCP and EDB pesticide, 21 GWPL pesticide, and 7 radionuclide. Included in the 63 SDW inorganic samples were three duplicates, one split, one equipment blank, and one combination nitrate spike/equipment blank. In addition, two wells were resampled making a total of 55 wells in the YGB having SDW inorganic samples collected from them. The 41 DBCP and EDB samples included two DBCP/EDB duplicates and three DBCP/EDB travel blanks. No duplicates, splits, blanks and/or spikes were collected for GWPL Pesticides or radionuclides. Groundwater sampling in the YGB occurred over the course of five field trips stretching from February - September 1995. The specific dates of the 1995 field trips were: 2/28 - 3/2, 3/20 - 3/22, 4/10 - 4/12, 6/7 - 6/8, and 9/11- 9/13.

Characteristics describing each of the 55 wells which were sampled for this study are provided in **Appendix A**. Various well information contained in this appendix includes, ADWR registration number, well location, well owner, well use, and well construction information. Information concerning each of the 63 groundwater samples collected in this study are provided in **Appendix B**: sample name, well name and location, sample date, type of samples collected, and factors related to sample location. Locations of wells sampled as part of this study and the accompanying sample identification numbers are provided in **Figure 1b**. Finally, the analytical results of all groundwater samples collected as part of this study can be found in **Appendices C, D, E,** and **F**, as well as accessed in the ADEQ Groundwater Quality Database.

7.1 Evaluation of Analytical Data

Overall, the analytical work conducted under the auspices of this study was considered excellent and valid for statistical analysis. This conclusion is based on the following QA/QC comparisons and correlations:

- pH values measured in the field using either a Cambridge Meter or Hydrolab at the time of sampling were significantly correlated at $P = 0.01$ with the pH values determined by the contract laboratories (**Figure 2**). The variability between the field and lab pH values is attributed to chemical changes groundwater undergoes when withdrawn from its natural environment. The ADHS laboratory has a 15 minute holding time for pH.

- Electrical conductivity (EC) measured in the field using either a YSI Meter or Hydrolab at the time of sampling and converted to 25^0 C values were significantly correlated at $P = 0.01$ with the Total Dissolved Solids (TDS) levels determined by contract laboratories (**Figure 3**).

- Cation-anion balances for all inorganic analyses were within acceptable limits (90 - 110%) except for one sample, Yuma-042A. The unacceptable balance was brought to

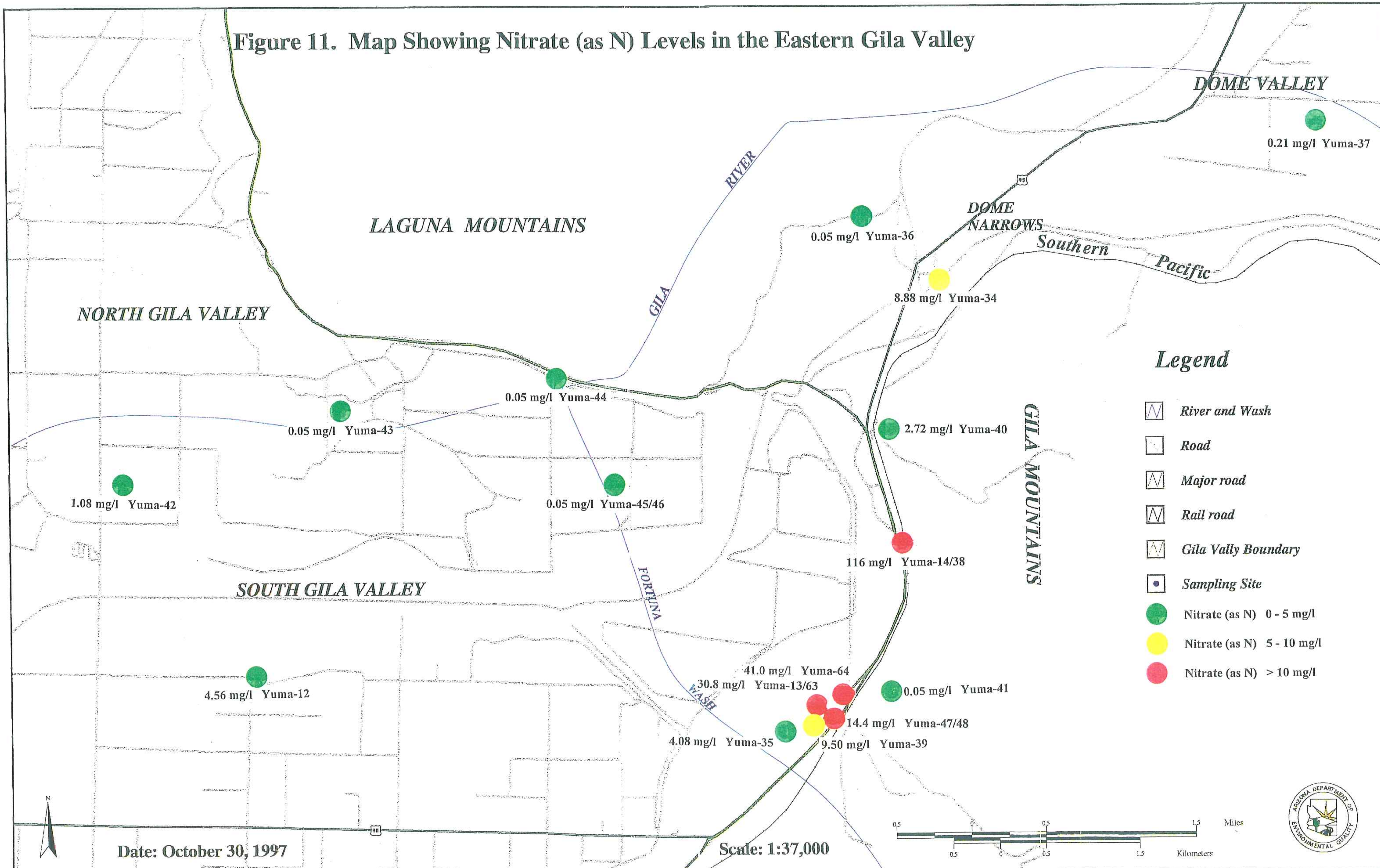
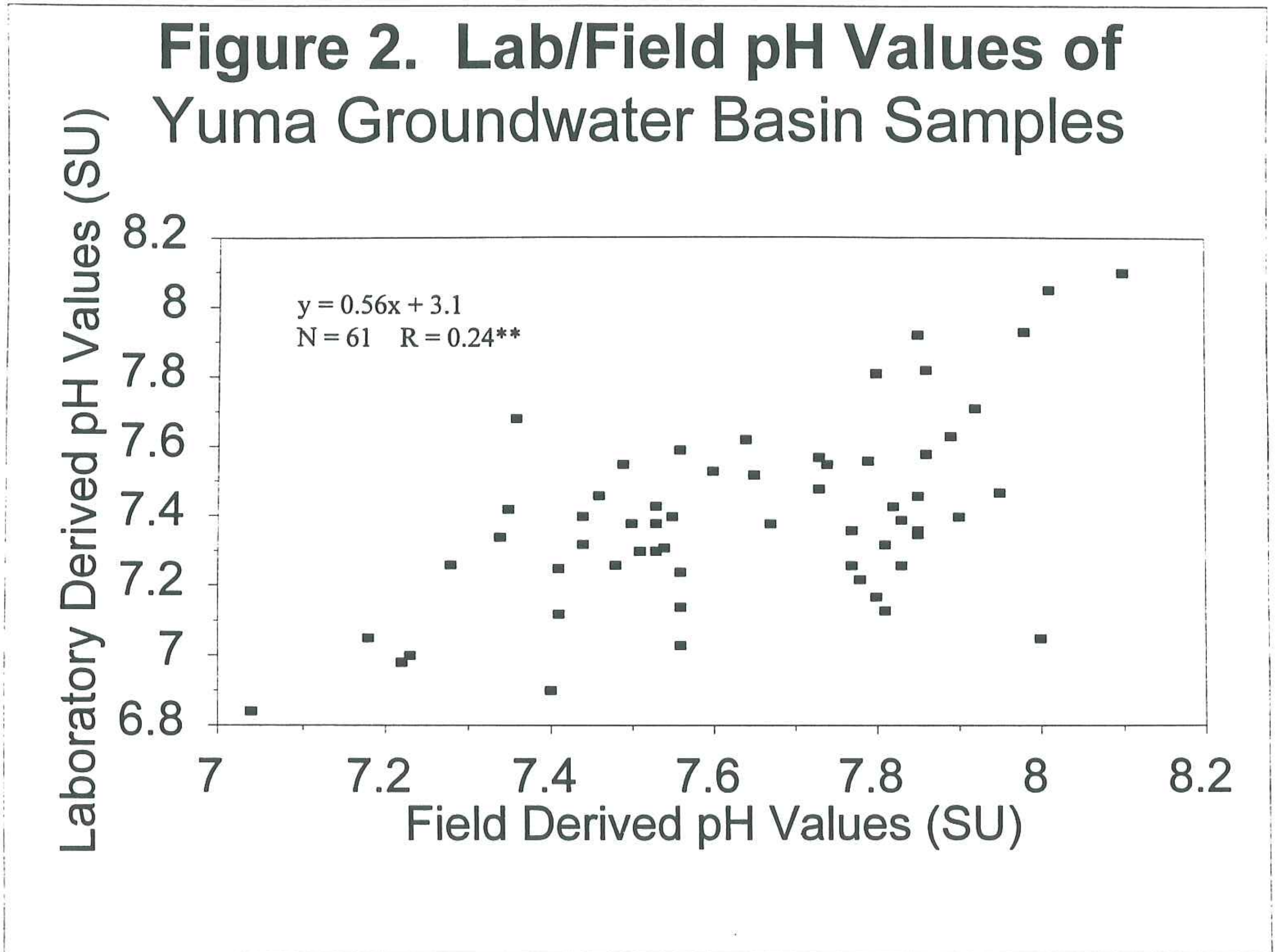


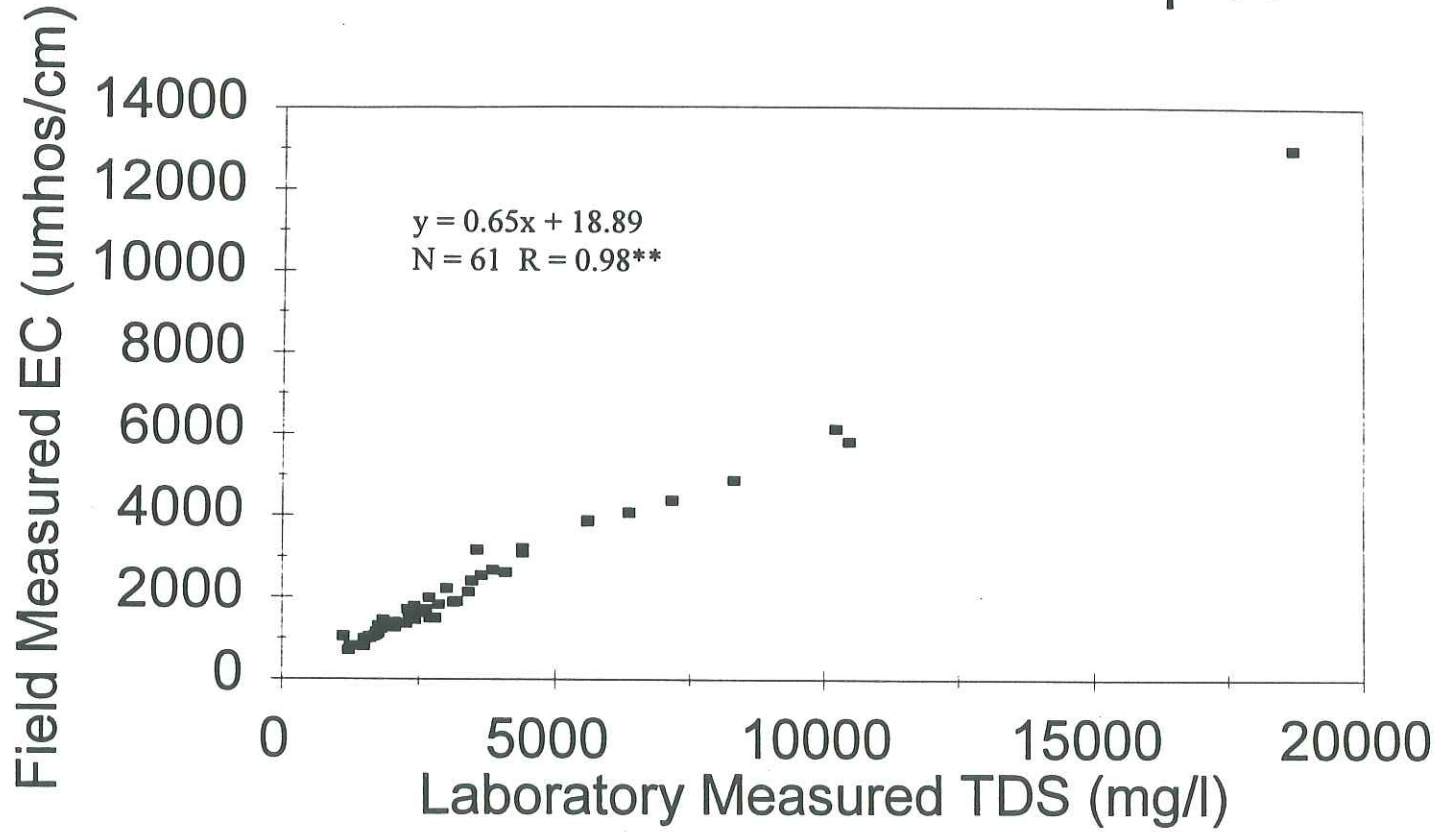
Figure 11. Map Showing Nitrate (as N) Levels in the Eastern Gila Valley
DOME VALLEY
0.21 mg/l Yuma-37
RIVER
GILA
LAGUNA MOUNTAINS
0.05 mg/l Yuma-36
DOME NARROWS
Southern Pacific
8.88 mg/l Yuma-34
NORTH GILA VALLEY
Legend
0.05 mg/l Yuma-44
0.05 mg/l Yuma-43
2.72 mg/l Yuma-40
GILA MOUNTAINS
River and Wash
Road
Major road
Rail road
Gila Vally Boundary
Sampling Site
Nitrate (as N) 0 - 5 mg/l
Nitrate (as N) 5 - 10 mg/l
Nitrate (as N) > 10 mg/l
1.08 mg/l Yuma-42
0.05 mg/l Yuma-45/46
116 mg/l Yuma-14/38
FORTUNA
SOUTH GILA VALLEY
41.0 mg/l Yuma-64
30.8 mg/l Yuma-13/63
0.05 mg/l Yuma-41
4.56 mg/l Yuma-12
WASH
14.4 mg/l Yuma-47/48
4.08 mg/l Yuma-35
9.50 mg/l Yuma-39
N
Date: October 30, 1997
Scale: 1:37,000
Miles
Kilometers
ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY



* Significant at p = 0.05

** Significant at p = 0.01

Figure 3. Field EC/Lab TDS Balances of Yuma Groundwater Basin Samples



* Significant at p = 0.05

** Significant at p = 0.01

the attention of ADHS Laboratory but no error was located. **Figure 4** graphically shows that the overall cation-anion balance variation for the study was within 2% and were significantly correlated at P = 0.01.

- Four pairs of original and duplicate/split samples collected as part of the study had only an overall 1% variation with respect to all physical and chemical inorganic parameters (**Figure 5** and **Figure 6**). With the exception of pH, nitrate, and TKN, all individual inorganic parameters had less than a 5% variation and were significantly correlated at P = 0.01. Similarly, the two pairs of DBCP/EDB sample duplicates both had non-detections of the pesticides.

- 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 with the exception in one blank of the detection of boron (0.41 mg/l), a parameter which has also been found in equipment blanks run by other ADEQ programs and which may be due to detergents used to clean the deionized water carboys (The Main Water Line, 1996). Similarly, the three DBCP/EDB travel blanks all had non-detections for the analyzed pesticides.

- The sample spiked with 10.0 mg/l of nitrate (as N) resulted in an analysis of 10.1 mg/l of total N by the ADHS Laboratory.

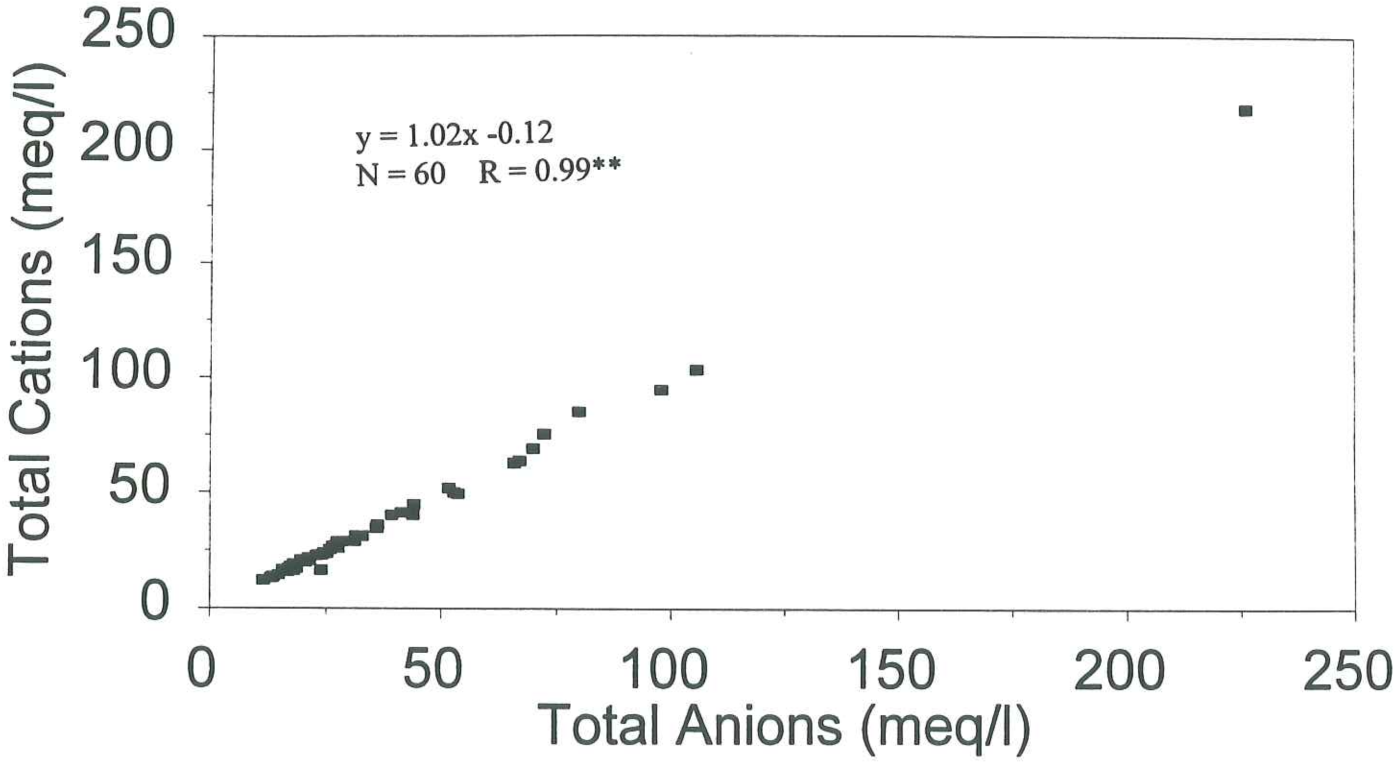
Again, based on these QA/QC measurements, the analytical work conducted under the auspices of this study was considered excellent and valid for further analysis.

7.2 Groundwater Chemistry

To visually show their chemical composition, groundwater samples collected in the YGB were plotted on Piper trilinear diagrams (**Figure 7**). These trilinear diagrams reveal that the groundwater samples form a clustered, linear pattern, indicating chemically, the groundwater throughout the YGB is both fairly uniform and similar to surface water samples collected from both the Gila River near Dome, AZ as well as the Colorado River above Morelos Dam. These plotted surface water samples are an average of six bi-monthly samples collected in 1994 (USGS, 1995). These Piper trilinear diagrams support the assertion made by previous studies (Olmstead and others, 1973) that groundwater in the YGB consists largely of recharged Colorado River water.

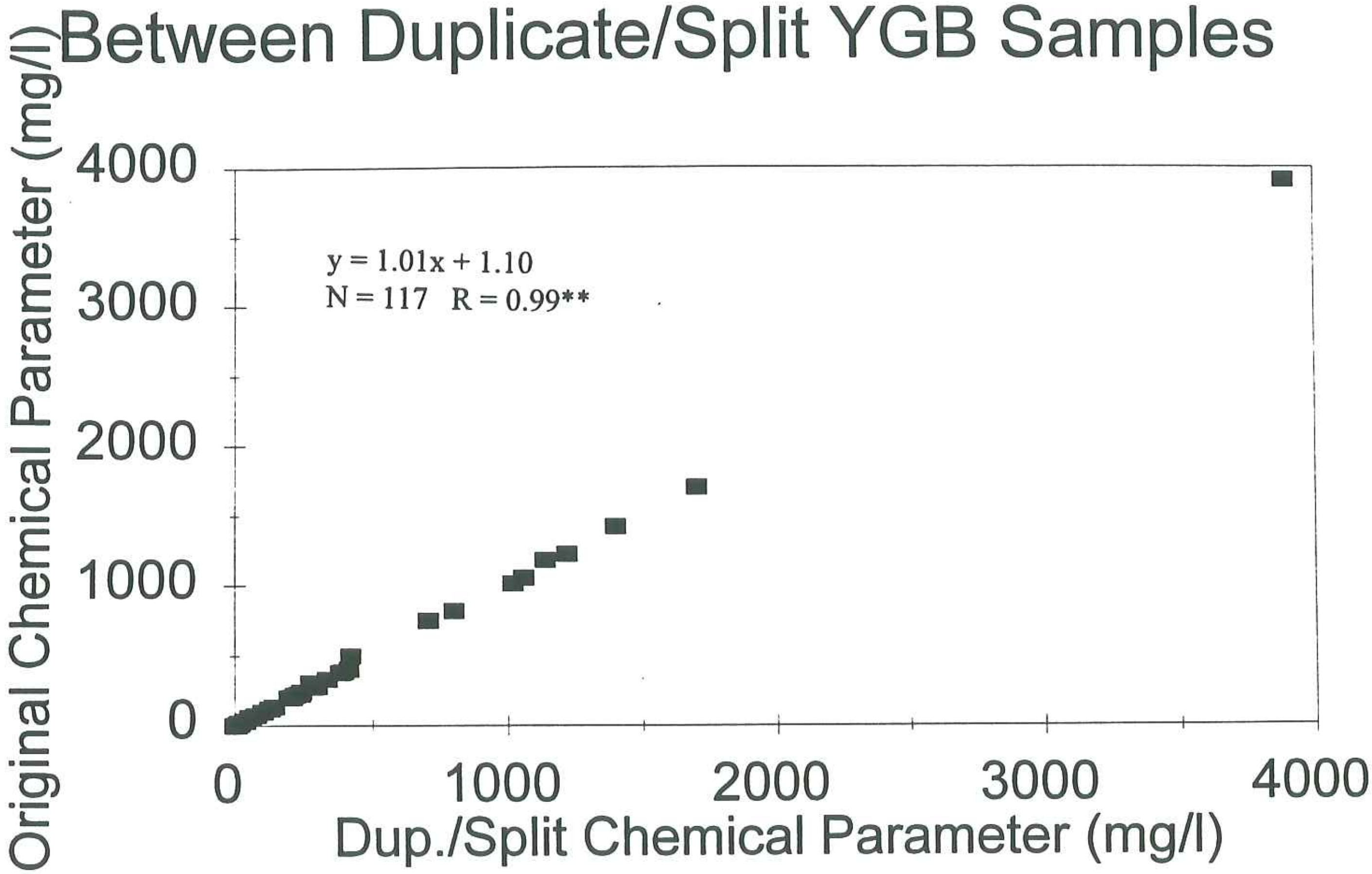
The major anions form a clustered, linear pattern trending from sulfate to chloride with the majority having no dominant anion when plotted on the trilinear diagrams. Thus, no bicarbonate dominant water was sampled in the YGB. Similarly, the major cations from these groundwater samples form a clustered, linear pattern with approximately half having sodium-dominant water and half having no dominant type though trending to either sodium or calcium. Thus, no magnesium dominant water was sampled during the YGB study. In summary, the 55

Figure 4. Cation/Anion Balances of Yuma Groundwater Basin Samples



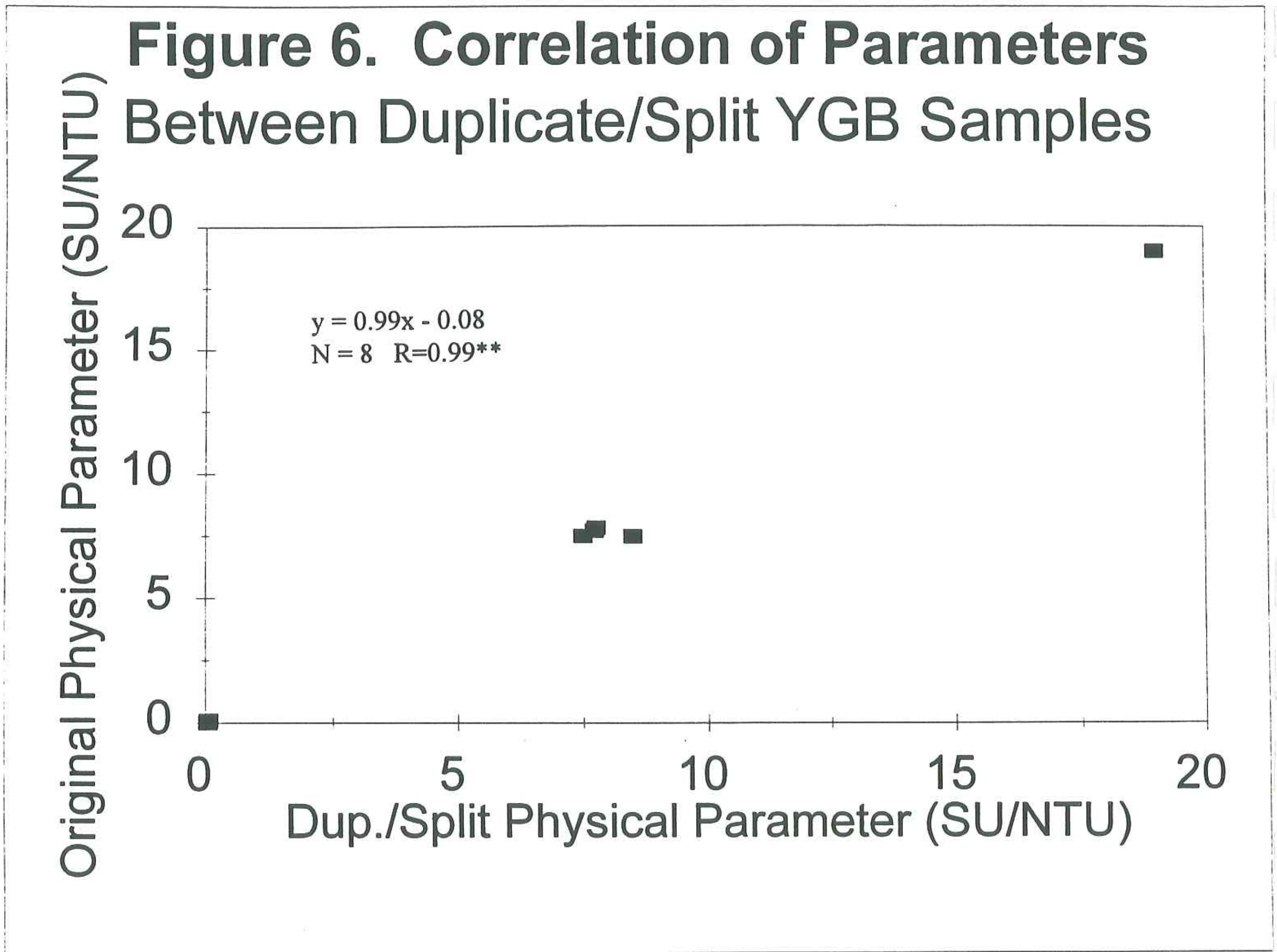
* Significant at p = 0.05
** Significant at p = 0.01

Figure 5. Correlation of Parameters
Between Duplicate/Split YGB Samples



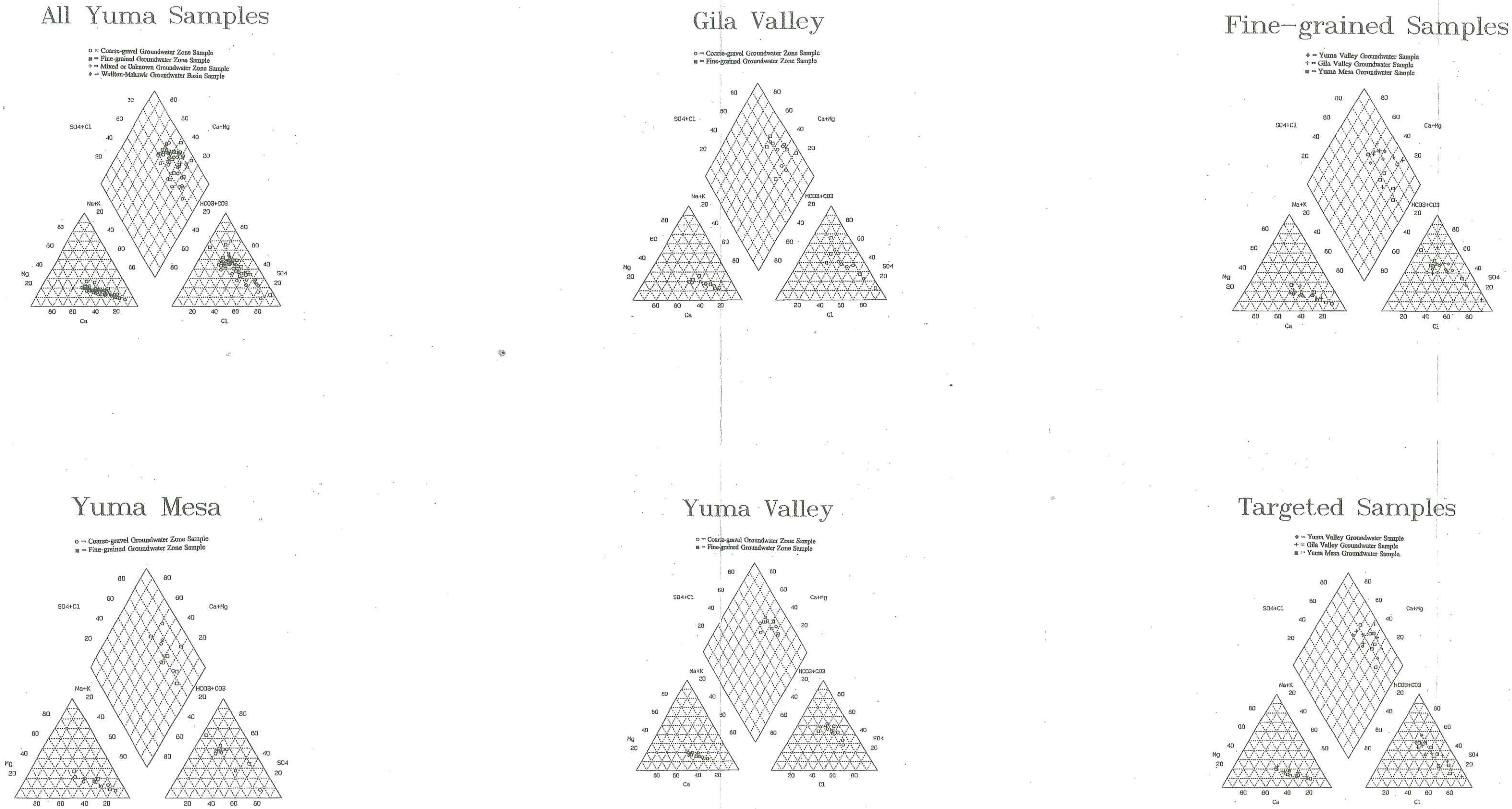
* Significant at p = 0.05

** Significant at p = 0.01

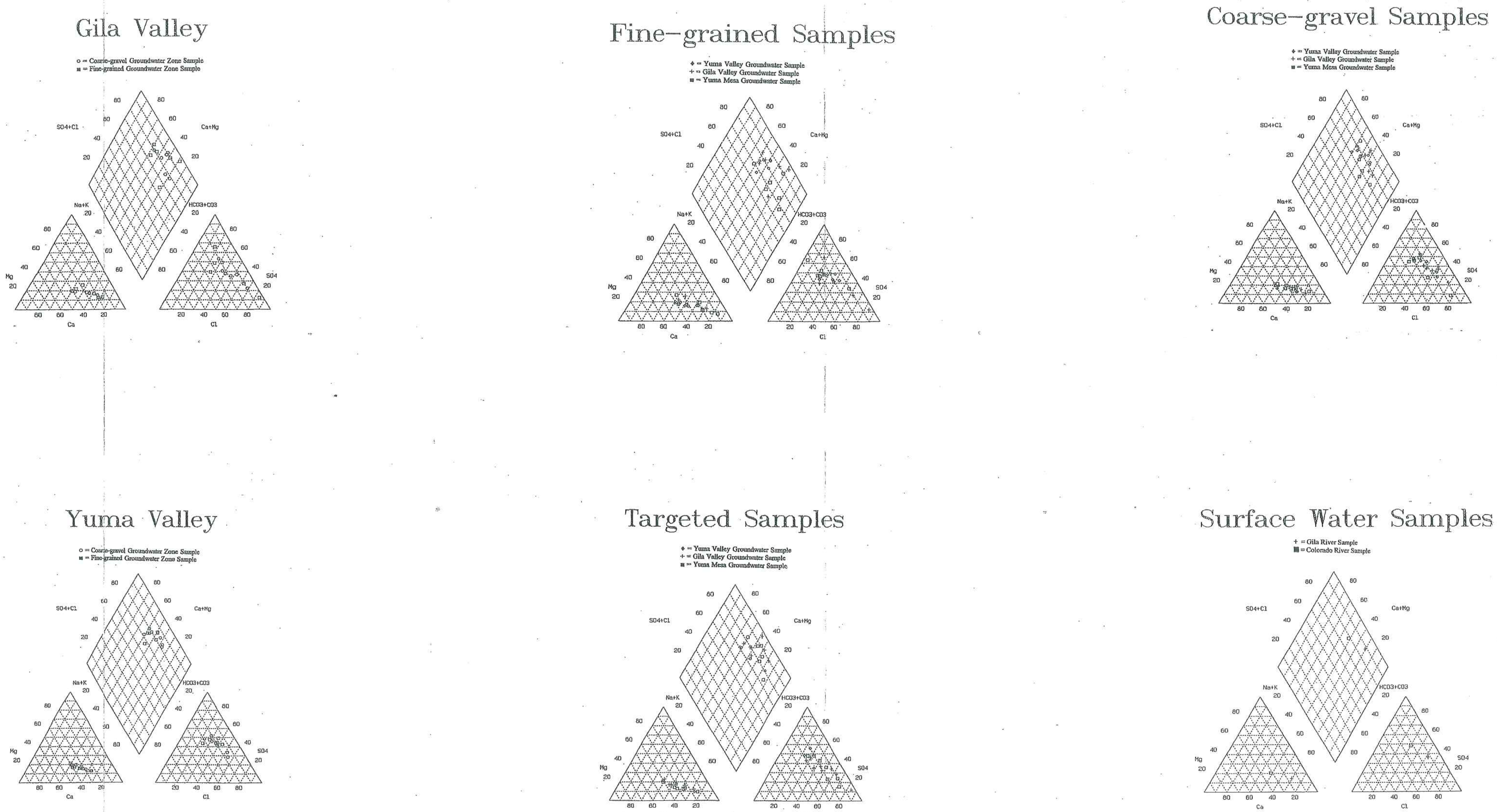


* Significant at p = 0.05
** Significant at p = 0.01

Figure 7. Piper Trilinear Diagrams of YGB Groundwater Samples.



igure 7. Piper Trilinear Diagrams of YGB Groundwater Samples.



groundwater samples consisted of a variety of water chemistry types:

- 25 samples had sodium-sulfate type water,
- 24 samples had sodium-chloride type water, and
- 6 samples had calcium-sulfate type water.

Despite the three different chemical types of groundwater found in the YGB, the chemical differences of the groundwater are not great, as the dominant anion and cation were typically contributing less than 50 percent to the ions in solution. The groundwater samples were also divided into both groundwater zones and geographic areas, then plotted on Piper trilinear diagrams. Examining the randomly collected groundwater samples geographically, the trilinear chemical diagrams for Gila Valley, Yuma Mesa, and Yuma Valley, all show clustered, linear patterns with slightly different characteristics:

- Yuma Mesa samples show the greatest variation, perhaps because Colorado River irrigation water is applied to only portions of this physiographic area while other portions nearer the Yuma Desert have never been irrigated;

- Yuma Valley groundwater samples show the most tightly clustered pattern because the majority of groundwater consists of recharged Colorado River irrigation water; and

- Gila Valley groundwater sample patterns fall between these two having both areas of applied Colorado River irrigation water and areas of where groundwater is the source of irrigation water.

Similarly, plotting coarse-gravel groundwater samples, fine-grained groundwater samples, and targeted groundwater samples on trilinear chemical diagrams also exhibit clustered, linear patterns with no obvious empirical differences between the groups.

7.3 Inorganic Parameter Levels

The groundwater samples collected in this study were analyzed for various SDW inorganic parameters. Generally, the analytical results associated with these parameters for the 57 samples indicated that, upon comparison with health-based Primary MCLs, the groundwater in the YGB generally supports drinking water uses except with one parameter in a very limited area. In contrast, upon comparison with aesthetic-based Secondary MCLs, groundwater in the YGB suffers from aesthetic drawbacks which may lead residents to instead use treated water for some domestic purposes. Many parameters such as total alkalinity, hardness, pH, TDS, turbidity, Ca, Cl, F, Mg, Na, nitrate (NO_3- N), TKN, SO_4, B, Fe, Mn, and K, had their various levels summarized in box plot statistical displays. Those parameters having Primary MCLs are shown in **Figure 8**, parameters having Secondary MCLs are shown in **Figure 9**, while the other inorganic parameters are displayed in **Figure 10**.

Figure 8. Boxplots of YGB Inorganic Parameters with SDW PMCLS

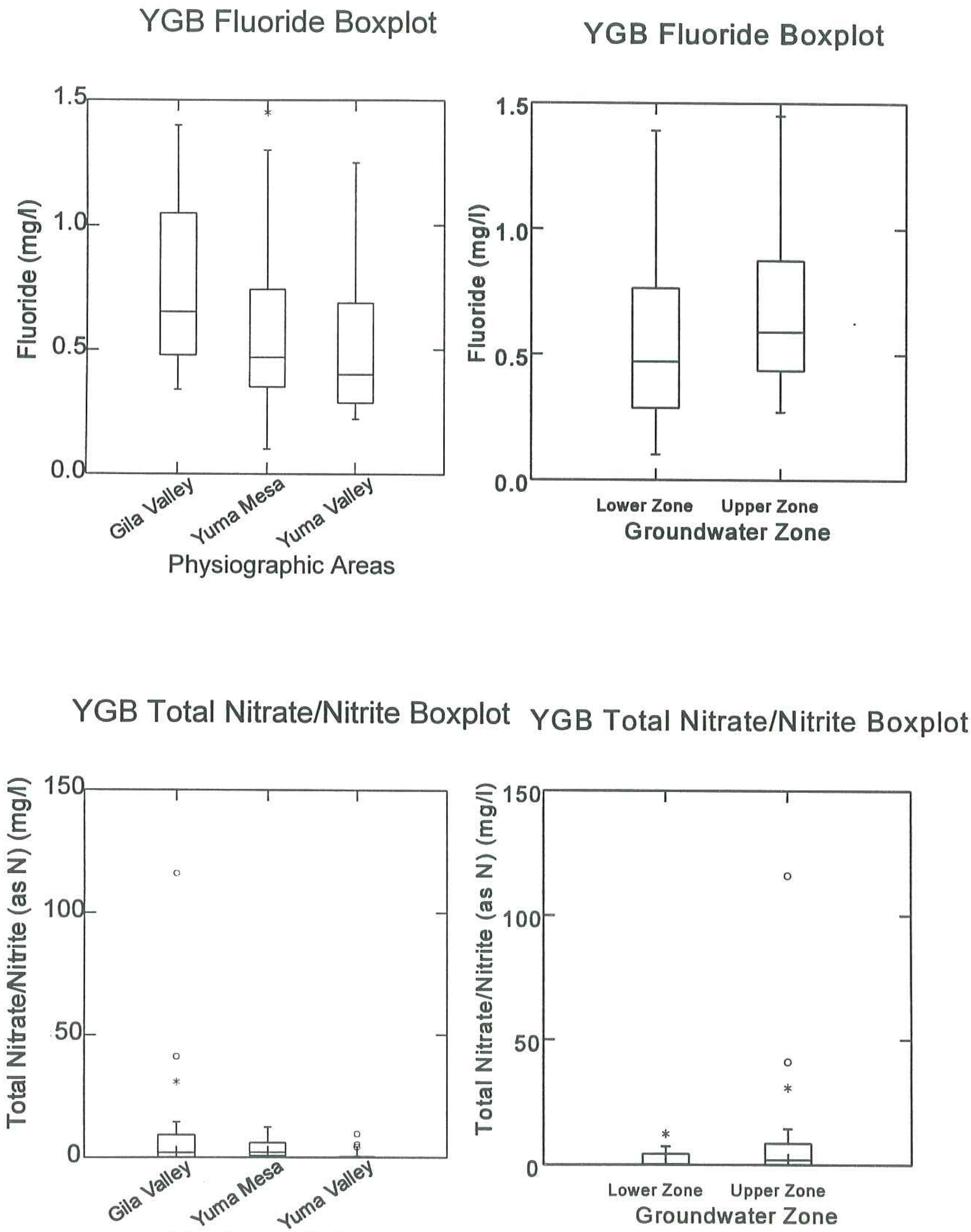


Figure 9. Boxplots of YGB Inorganics Parameters with SDW SMCLS

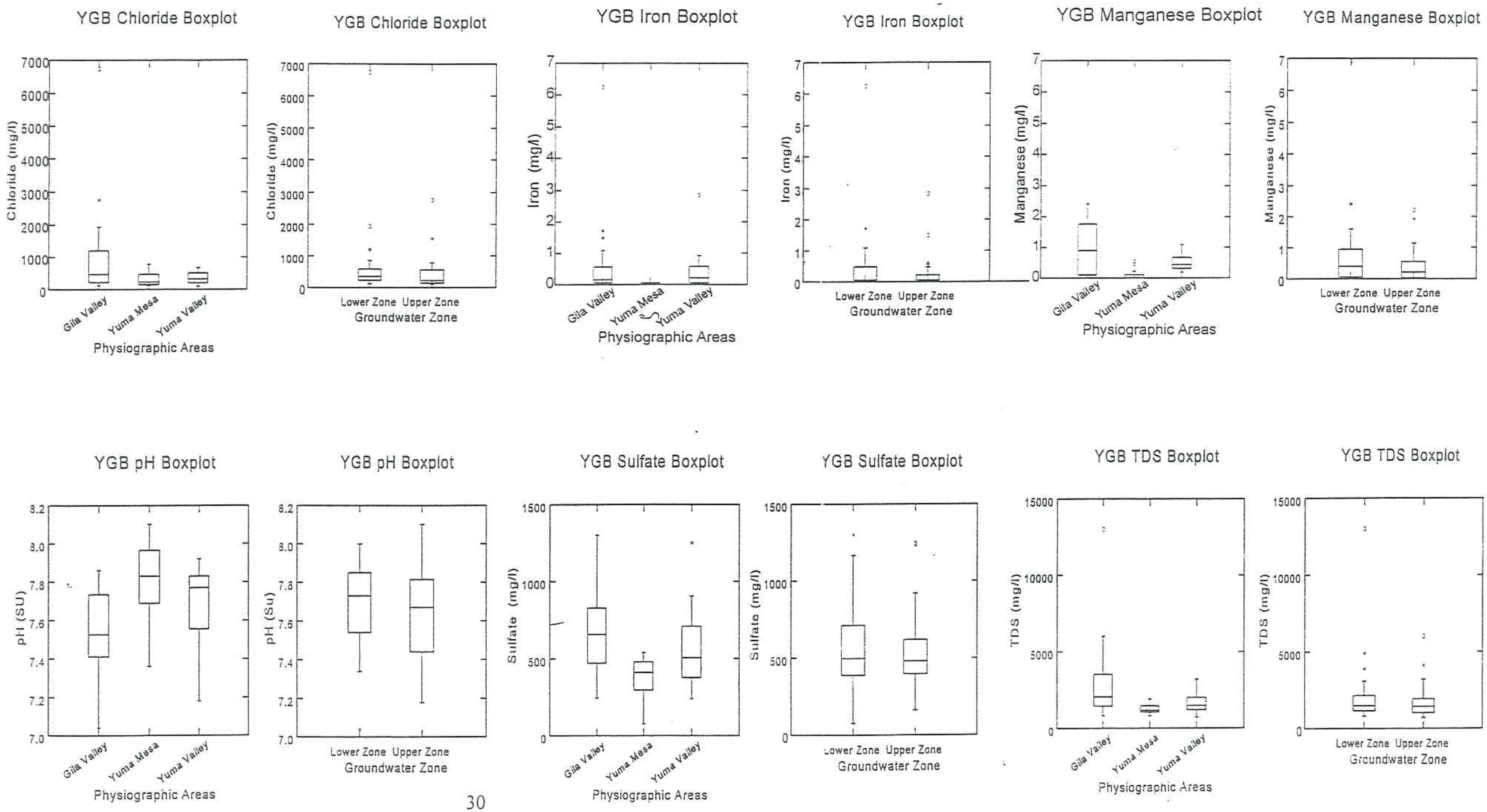
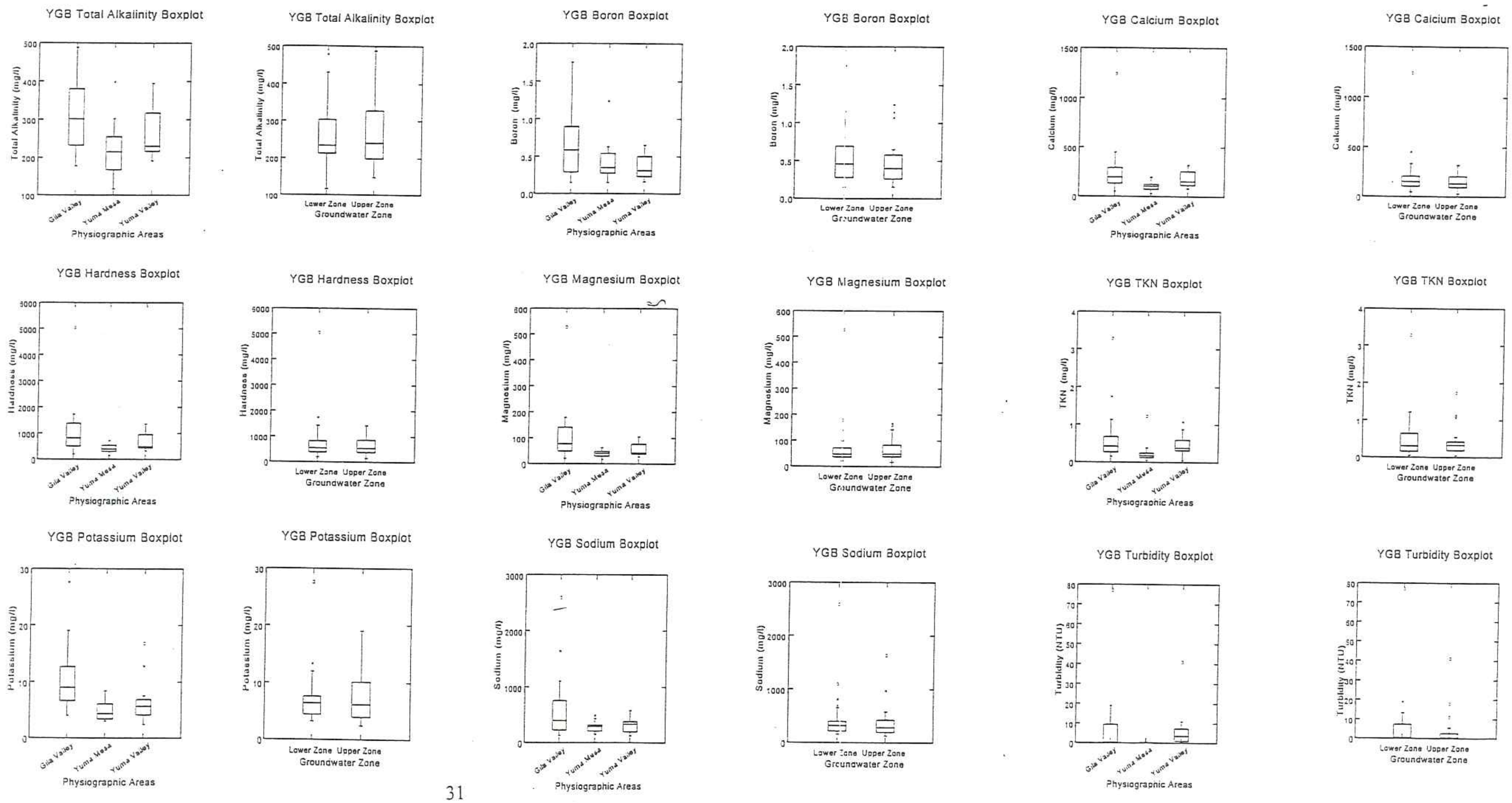


Figure 10. Boxplots of YGB Inorganic Parameters with no SDW MCLS



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, and parameter levels outside the outer fences (or the hinge +/- 3 x Hspread) are termed far outside values and are shown as empty circles.

7.4 Inorganic Parameters with SDW Primary MCLs

Ten chemical parameters having Primary MCLs were included in the SDW inorganic analyses of YGB groundwater samples. The inorganic constituents with Primary MCLs and the number of groundwater samples which exceeded these standards are as follows: arsenic - 0, barium - 0, cadmium - 0, chromium - 0, fluoride - 0, mercury - 0, nitrate - 7, nitrite - 0, and selenium - 0. Of the 55 wells sampled by ADEQ for SDW inorganic parameters, only five wells had groundwater samples collected from them that exceeded a Primary MCL Standard. Of the seven groundwater samples collected from these five wells (two wells were sampled twice), nitrate was the only constituent exceeded. With a nitrate (as N) 10.0 mg/l Primary MCL, exceedences ranged from 12.3 mg/l to 122 mg/l. Each Primary MCL and the extent of its occurrence within the YGB is individually discussed below while the analytical results of each groundwater sample are found in **Appendices D** and **E**.

Arsenic (As) - Of the 57 groundwater samples collected in the YGB, ten groundwater samples had As levels above the ADHS Laboratory Minimum Reporting Level (MRL) of 0.010 mg/l. The highest detected level of As was 0.019 mg/l, well below the Primary MCL of 0.05 mg/l. Eight of ten As detections occurred in groundwater samples collected in Gila Valley, with the remaining two in close proximity to this area. Approximately one-third of the groundwater samples obtained in the Gila Valley tested positive for As. 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. Arsenic may occur in water as a result of mineral dissolution, industrial discharges, or the application of insecticides (Franson, 1989), though these As concentrations are probably naturally occurring stemming from the nearby Gila and Laguna Mountains (Robertson, 1986).

Barium (Ba) - Of the 57 groundwater samples collected in the YGB, five groundwater samples had Ba levels above the ADHS Laboratory MRL of 0.01 mg/l. The highest detected level of Ba was 0.34 mg/l, well below the Primary MCL of 2.0 mg/l. The positive detections of Ba were located in two geographic areas: in the southern portion of the Yuma Mesa and near hardrock areas of the Gila and Laguna Mountains. The Ba concentration of U.S. drinking waters ranges between 0.0007 - 0.9 mg/l, with a mean of 0.049 mg/l. Higher concentrations in drinking water often signal undesirable industrial waste pollution (Franson, 1989).

Cadmium (Cd) - Of the 57 groundwater samples collected in the YGB, none had Cd levels above the ADHS Laboratory MRL of 0.0010 mg/l.

Chromium (Cr) - Of the 57 groundwater samples collected in the YGB, only one sample had Cr levels above the ADHS Laboratory MRL of 0.010 mg/l. This sample, collected on the flanks of the Gila Mountains, had a Cr level of 0.012 mg/l, below the 0.1 mg/l Primary MCL. The Cr concentration of U.S. drinking waters has been reported to vary between 0.003 and 0.04 mg/l, with a mean of 0.0032 mg/l (Franson, 1989).

Fluoride (F) - Of the 57 groundwater samples collected in the YGB, 56 groundwater samples had F levels above the ADHS Laboratory MRL of 0.20 mg/l. The highest detected level of F was 1.47 mg/l, below both the Primary MCL of 4.0 mg/l and Secondary MCL of 2.0 mg/l. The median F level was 0.55 mg/l, while the mean F level was 0.64 mg/l. Boxplots reveal F levels were generally higher in the Gila Valley, especially near the Gila and Laguna Mountains, than in the Yuma Mesa and Yuma Valley and were also higher in the upper, fine-grained zone than in the lower, coarse-gravel zone.

Mercury (Hg) - Of the 57 groundwater samples collected in the YGB, none had Hg levels above the ADHS Laboratory MRL of 0.0005 mg/l.

Nitrate (NO_3 - N) - The 57 groundwater samples collected in the YGB had a median value of 0.82 mg/l and a mean of 5.95 mg/l. Thirty-eight samples had nitrate (as N) levels above the ADHS Laboratory MRL of 0.10 mg/l, with seven of the groundwater samples above the Primary MCL of 10.0 mg/l. The seven groundwater samples exceeding the Primary MCL had levels ranging from 12.3 - 122 mg/l, with six samples collected from Gila Valley and one from Yuma Mesa. Generally, nitrate levels were highest in eastern Gila Valley and lowest in Yuma Valley, while Yuma Mesa had nitrate levels in between these two extremes.

Nitrite (NO_2- N) - Of the 57 groundwater samples collected in the YGB, four samples had nitrite levels above the ADHS Laboratory MRL of 0.10 mg/l. Nitrite levels in these four groundwater samples ranged from 0.12 - 0.30 mg/l, well below the Primary MCL of 1.0 mg/l.

Selenium (Se) - Of the 57 groundwater samples collected in the YGB, six samples had Se levels above the ADHS Laboratory MRL of 0.005 mg/l. The highest detected level of Se was 0.036 mg/l, below the Primary MCL of 0.05 mg/l. This sample was collected in the southern portion of the Yuma Mesa. The other Se detections were located predominantly in the eastern Gila River Valley with levels ranged from < 0.010 - 0.016 mg/l. The Se concentration of most U.S. drinking waters is less than 0.010 mg/l (Franson, 1989).

7.5 Inorganic Parameters with SDW Secondary MCLs

Ten chemical parameters that had Secondary MCLs were included in the SDW inorganic analyses of YGB groundwater samples. Of the 57 groundwater samples collected from 55 wells by ADEQ for SDW inorganic parameters, all exceeded at least one Secondary MCL Standard, indicating that groundwater in the YGB has taste, odor, and/or color aesthetic problems. The inorganic constituents with Secondary MCLs and the number of groundwater samples which exceeded these standards are as follows: aluminum - 0, chloride - 33, fluoride - 0, iron - 14, manganese - 39, pH - 0, silver - 0, sulfate - 51, TDS - 57, and zinc - 0. Each Secondary MCL and the extent of its occurrence within the YGB is individually discussed below while analytical results for each groundwater sample can be found in **Appendices C, D,** and **E.**

Aluminum (Al) - Of the 57 groundwater samples collected in the YGB, none had Al concentrations above the ADHS Laboratory MRL of 0.50 mg/l.

Chloride (Cl) - The 57 groundwater samples collected in the YGB had Cl levels ranging from 95.6 - 6750 mg/l, with a median of 322 mg/l and a mean of 600 mg/l. Cl concentrations of 33 groundwater samples exceeded the Secondary MCL of 250 mg/l, with 6750 mg/l the highest level detected in a groundwater sample collected from eastern Gila Valley. Boxplots indicate Cl levels were higher in Gila Valley than Yuma Mesa and Yuma Valley and similar levels of Cl were found in both water-bearing zones.

Fluoride (F) - see the discussion on F in the "Inorganic Paramters with SDW Primary MCLs" section.

Iron (Fe) - The 57 groundwater samples collected in the YGB had a median Fe level of 0.05 mg/l and a mean level of 0.40 mg/l. Twenty-one samples had Fe levels above the ADHS Laboratory MRL of 0.10 mg/l. Fourteen samples had concentrations above the Secondary MCL of 0.3 mg/l, with 6.25 mg/l the highest level detected from a well in the eastern Gila Valley. All the Fe detections occurred in groundwater samples collected from either Gila or Yuma Valleys, with eight of the Secondary MCL exceedences occurring in samples collected in Gila Valley and six from samples collected in Yuma Valley. The high levels of Fe found in the Gila and Yuma Valleys is probably caused by interaction with iron-bearing clay minerals and oxides, while in the Yuma Mesa there is little contribution of Fe to percolating irrigation waters with the quartz-rich sandy soils there (Olmstead and others, 1973). The presence of Fe in the groundwater was often noted in the valleys during field sampling by the telltale signs of orange staining on rocks and irrigation pipes.

Manganese (Mn) - The 57 groundwater samples collected in the YGB had Mn levels ranging from 0.05 - 6.92 mg/l, with a median value of 0.30 mg/l and a mean value of 0.67 mg/l. Thirty-nine samples had Mn concentrations above the Secondary MCL of 0.05 mg/l. Boxplots reveal Mn levels highest in Gila Valley and lowest in Yuma Mesa; similarly Mn levels were higher in the lower, coarse-gravel water zone than in the upper, fine-grained water zone. Typically Mn levels are less than half that of Fe in natural waters, which is not the case in the Yuma area. Since the Colorado River is deficient in both Mn and Fe, the elevated Mn levels might be due to local weathering and leaching of volcanics such as those found in the Laguna Mountains (USBR, 1991).

pH - Of the 57 groundwater samples collected in the YGB, all had pH values between 6.5 and 8.5 standard units and therefore, were within Secondary MCL guidelines. The median pH level was 7.73 SU while the mean pH level was 7.66 SU. However, 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). All the field measured pH values were also within Secondary MCL guidelines. Boxplots reveal levels of pH were highest in Yuma Mesa and lowest in Gila Valley; pH levels were also higher in the lower, coarse-gravel water zone than the upper, fine-grained water zone.

Silver (Ag) - Of the 57 groundwater samples collected in the YGB, none had Ag concentrations above the ADHS Laboratory MRL of 0.001 mg/l.

Sulfate (SO_4) - The 57 groundwater samples collected in the YGB had SO_4 levels ranging from 77.7 - 1300 mg/l, with a median value of 493 mg/l and a mean of 553 mg/l. SO_4 concentrations of 52 groundwater samples exceeded the Secondary MCL of 250 mg/l, with 1300 mg/l the highest level detected in a sample collected from the eastern Gila Valley. A Primary MCL of 400 mg/l for SO_4 has been proposed (Crockett, 1995); using this level, 42 groundwater samples collected in the YGB would exceed this potential Primary MCL. Boxplots show SO_4 levels highest in Gila Valley and lowest in Yuma Mesa, with similar SO_4 concentrations found in each water-bearing zone.

Total Dissolved Solids (TDS) - 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 processes. The 57 groundwater samples collected in the YGB had TDS levels ranging from 720 - 13,000 mg/l, with a median value of 1500 mg/l and a mean value of 2057 mg/l. As such, all YGB samples were at levels above the Secondary MCL of 500 mg/l. The highest TDS level of 13,000 mg/l was from a groundwater sample collected from the eastern Gila Valley. The 57 YGB groundwater samples fall into the following TDS categories denoted by Hem (1970): Fresh (< 1000 mg/l) - 6, Slightly saline (1000 - 3000 mg/l) - 41, Moderately saline (3000 - 10,000) - 9, and Very saline (10,000 - 35,000) - 1. In California, groundwater is designated as a potential drinking water source unless TDS values exceed 3000 mg/l (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. Boxplots show TDS levels are highest in Gila Valley, lowest in Yuma Mesa, while water-bearing zones have similar concentrations.

Zinc (Zn) - Of the 57 groundwater samples collected in the YGB, three had Zn concentrations above the ADHS Laboratory MRL of 0.05 mg/l. The highest Zn concentration was 0.85 mg/l, well below the Secondary MCL of 5.0 mg/l. The Zn concentration of U.S. drinking waters varies between 0.06 and 7.0 mg/l, with a mean of 1.33 mg/l (Franson, 1989).

7.6 Other Inorganic Parameters

Alkalinity, Phenolphthalein - Of the 57 groundwater samples collected in the YGB, none had phenolphthalein alkalinity above the ADHS Laboratory MRL of 2.0 mg/l.

Alkalinity, Total - This parameter is a measure of a water's acid-neutralizing capacity. The 57 groundwater samples collected in the YGB had concentrations of total alkalinity ranging from 116 - 488 mg/l, with a median of 238 mg/l and a mean of 267 mg/l. Boxplots show the highest total alkalinity levels were in Gila Valley and the lowest in Yuma Mesa, while water-bearing zone total alkalinity concentrations were similar.

Ammonia (NH_3 - N) - Of the 57 groundwater samples collected in the YGB, 22 had levels above the ADHS Laboratory MRL of 0.10 mg/l, with 1.13 mg/l the highest ammonia concentration recorded. Ammonia 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).

Boron (B) - The 57 groundwater samples collected in the YGB had B levels ranging from 0.15 - 1.75 mg/l, with a median level of 0.45 mg/l and a mean level of 0.51 mg/l. Thus, all samples had B levels above the ADHS Laboratory MRL of 0.10 mg/l. B has a Health Based Guidance Level (HBGL) of 0.63 mg/l, a boron level exceeded in 13 YGB samples. B may occur naturally in some waters or may be impacted by industrial waste effluents (Franson, 1989). Boxplots reveal B levels were highest in Gila Valley, lowest in Yuma Valley; B levels in the lower, coarse-gravel zone were higher than in the upper, fine-grained zone.

Calcium (Ca) - The 57 groundwater samples collected in the YGB had concentrations of Ca ranging from 30.2 - 1240 mg/l, with a median value of 136 mg/l and a mean value of 184 mg/l. Boxplots reveal Ca levels were highest in the Gila Valley, lowest in Yuma Mesa and also higher in the lower, coarse-gravel zone than the upper, fine-grained zone.

Copper (Cu) - Of the 57 groundwater samples collected in the YGB, three had concentrations of Cu above the ADHS Laboratory MRL of 0.010 mg/l. Cu levels ranged from non-detect to 0.016 mg/l, all well below the 1.3 mg/l SDW Recommended Action Level, a water quality standard which triggers the need for water or distribution treatment.

Hardness - Hardness is a measure of calcium and magnesium concentrations. While high hardness levels have no negative health implications, they can impact plumbing fixtures and be a nuisance to cleaning laundry and dishes. Of the 57 groundwater samples collected in the YGB, all had hardness concentrations above the ADHS Laboratory MRL of 10 mg/l with levels ranging from 146 - 5040 mg/l, with a median value of 536 mg/l and a mean level of 737 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 57 groundwater samples collected in the YGB, none were in the soft range, one was in the moderately hard range, five were in the hard range, and 51 were in the very hard range. Boxplots indicate the highest hardness levels are found in Gila Valley while the lowest are found in Yuma Mesa; similar hardness concentrations were found in each water-bearing zone.

Lead (Pb) - Of the 57 groundwater samples collected in the YGB, one had a concentration of Pb above the ADHS Laboratory MRL of 0.005 mg/l. This Pb detection was at a level of 0.009 mg/l, well below the SDW Recommended Action Level of 0.015 mg/l.

Magnesium (Mg) - The 57 groundwater samples collected in the YGB had Mg concentrations ranging from 16.1 - 527 mg/l, with a median value of 47.6 mg/l and a mean level of 69.9 mg/l. Mg concentrations greater than 125 mg/l may potentially have cathartic and diuretic effects (Franson, 1989). Boxplots reveal similar Mg levels in each water-bearing zone, while the highest levels were found in Gila Valley and the lowest levels in Yuma Mesa.

Nitrogen, Total Kjeldahl (TKN) - Of the 57 groundwater samples collected in the YGB, 51 had TKN concentrations above the ADHS Laboratory MRL of 0.10 mg/l, with 3.28 mg/l the highest TKN level. TKN concentrations in YGB samples had a median value of 0.33 mg/l and a mean value of 0.46 mg/l. TKN is analytically defined as both organic nitrogen and ammonia. Boxplots reveal TKN levels are similar in each water-bearing zone, while samples from the Gila Valley exhibit higher TKN levels than the Yuma Mesa and Yuma Valley.

Phosphorus, Total (P) - Of the 57 groundwater samples collected in the YGB, seven had total phosphorus concentrations above the ADHS Laboratory MRL of 0.10 mg/l. Total phosphorus levels ranged from non-detect to 0.24 mg/l.

Potassium (K) - The 57 groundwater samples collected in the YGB had K concentrations ranging from 2.45 - 27.6 mg/l, with a median value of 9.26 mg/l and a mean value of 7.43 mg/l. Thus, all K concentrations exceeded the ADHS Laboratory MRL of 0.50 mg/l. K in most drinking waters seldom reaches 20 mg/l (Franson, 1989). Boxplots reveal K levels are highest in Gila Valley and lowest in Yuma Mesa; groundwater zones had similar levels of K.

Sodium (Na) - The 57 groundwater samples collected in the YGB had Na concentrations ranging from 124 - 2590 mg/l, with a median value of 310 mg/l and a mean value of 425 mg/l. Although no water quality standards exist for Na, 20 mg/l is the EPA cautionary limit for sodium-risk individuals to bring to the attention of their physician (Crockett, 1995). Boxplots reveal Na levels are higher in Gila Valley than Yuma Mesa and Yuma Valley; groundwater zones had similar levels of Na.

Turbidity - Of the 57 groundwater samples collected in the YGB, 54 had turbidity concentrations above the ADHS Laboratory MRL of 0.01 NTU. Turbidity levels ranged from non-detect - 77 NTU, with a median of 0.53 NTU and a mean of 4.88 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. Boxplots reveal turbidity levels are highest in Gila Valley and Yuma Valley as well as in the lower, coarse-gravel zone.

7.7 Pesticides

DBCP and EDB - Of the 36 wells from which groundwater samples were collected for DBCP and EDB analysis, there were no detections of either pesticide above the ADHS Laboratory MRL of 0.01 mg/l with the possible exception of EDB in one well. Groundwater sample Yuma-056A collected from a well serving the Lemon Tree Trailer Park located on Yuma Mesa had the "presence of EDB suspected but cannot be confirmed" by the ADHS laboratory. This laboratory further noted that there were "several unidentified peaks occurring in the chromatogram, some of which interfere in determining that EDB is present." Refer to **Appendix F** for a complete list of pesticide sampling results.

GWPL Pesticides - Of the 21 wells from which groundwater samples were collected for GWPL pesticide analyses, there were no detections of organic pesticides in any groundwater sample. Refer to **Appendix G** for a complete list of the MRLs, HBGLs, and MCLs for the 85 pesticides on the Groundwater Protection List and **Appendix F** for a complete list of pesticide sampling results.

7.8 Radionuclides

Of the seven wells from which groundwater samples were collected for radionuclide analysis, no samples exceeded the SDW Primary MCLs for Gross α, Gross β, and Combined Radium-226 + Radium - 228. Gross α levels ranged from < 1.4 - 10.7 picocurie per liter (pCi/L), with a Primary MCL of 15 pCi/L. Two groundwater samples possessing high Gross α values were tested for Combined Radium-226 + Radium 228, with these latter levels at 3.3 and 3.7 pCi/L, below the 5.0 pCi/L Primary MCL. Gross β levels ranged from 7.7 - 11.7 pCi/L, well below the 50 pCi/l Primary MCL. Refer to **Appendix F** for a complete list of radionuclide sampling results.

8. STATISTICAL ANALYSES

Of the 32 inorganic parameters sampled for by ADEQ, 19 were detected frequently enough to be subjected to further statistical analysis. These parameters included: As, B, Ca, Cl, F, hardness, Fe, Mg, Mn, NH_3-N, nitrate, pH, K, Na, SO_4, total alkalinity, TDS, TKN, and turbidity. Not subject to further statistical analysis were inorganic parameters which were only rarely - if ever - detected in groundwater samples: Al, Ba, Cd, Cr, Cu, Pb, Hg, nitrite, phenolphthalein alkalinity, Se, Ag, total P, and Zn.

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:

H_0: The population was normally distributed.
vs.
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 2** indicated that with the exception of F and pH, none of the parameters were normally distributed. This is not uncommon as the distribution of many groundwater quality parameters is not Gaussian or normal but skewed to the right (Montgomery and others, 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. As before, the null hypothesis to be tested was:

H_0: The population was lognormally distributed.
vs.
H_A: The population was not lognormally distributed.

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

The results shown in **Table 2** indicated that all the parameters were lognormally distributed with the exception of As, Cl, Fe, Mn, nitrate, and NH_3-N. Moreover, although the lognormally transformed Cl was not normally distributed at $p=0.05$, it is nevertheless "more" normally distributed than the non-transformed one as indicated by a significance at a higher probability level (0.0216 and 0.0000 corresponding to ln Cl and Cl, respectively). The normality of the other parameters, As, Fe, Mn, NO_3-N, and NH_3-N, were not aided by logarithmic transformation, which may be related to the large number of outliers as well as non-detections (hence, a "censored data set") associated with these 5 parameters.

Data compiled during this study was examined using both the parametric ANOVA test on log-transformed data and the nonparametric Wilcoxon test on non-transformed data. The violations related to the assumptions of normality with six of the log-transformed groundwater quality parameters suggest that a parametric test such as ANOVA may not be applied validly to these parameters as violations of normality result in a loss of ability to see differences between means (Helsel and Hirsch, 1997). However, other parametric tests such as Student t-tests are considered to be robust or valid even when some of the assumptions such as normality are violated (Harris and others, 1987). Based on the results of both ANOVA and Wilcoxon tests, there were few differences in findings of significance so it was decided to only present the results of the more powerful ANOVA test in this report. Thus, it was decided that the most defensible and rigorous statistical analysis of this data set would be to utilize parametric tests conducted using the logarithmically-transformed database.

8.1 Groundwater Parameter Level Variations Among Groundwater Zones

One of the objectives of this study was to assess the variation of groundwater quality parameter levels between the two most widely used water bearing zones in the YGB: the upper, fine-grained zone and the lower, coarse gravel zone. Therefore, of the 42 randomly selected wells in the YGB, 21 wells were perforated solely in the fine-grained zone and an equal number perforated solely in the coarse-gravel zone. ANOVA was used to statistically assess whether the parameter level variations between the two groundwater zones were significantly different. The results are shown in **Table 3** and indicate that no significant differences exist in the levels of groundwater quality parameters in the two groundwater zones.

Table 2. Distribution of Inorganic Parameters in the YGB Using the Kolmogorov-Smirnov One Sample Test With the Lilliefors Option.

Parameter	Non-transformed Data	Log-transformed Data
As	ns	ns
B	ns	*
Ca	ns	*
Cl	ns	ns
F	*	*
Hardness	ns	*
Fe	ns	ns
Mg	ns	*
Mn	ns	ns
NH_3-N	ns	ns
Nitrate	ns	ns
pH	*	*
K	ns	*
Na	ns	*
SO_4	ns	*
Total Alkalinity	ns	*
TDS	ns	*
TKN	ns	*
Turbidity	ns	*

* = Data normally distributed
ns = Data not normally distributed

Table 3. **Variation in Groundwater Quality Parameter Levels in Two YGB Groundwater Zones Using ANOVA**

Parameter	Significance
As	ns
B	ns
Ca	ns
Cl	ns
F	ns
Hardness	ns
Fe	ns
Mg	ns
Mn	ns
NH_3-N	ns
Nitrate	ns
pH	ns
K	ns
Na	ns
SO_4	ns
Total Alkalinity	ns
TDS	ns
TKN	ns
Turbidity	ns

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

8.2 Groundwater Parameter Level Variations Among Physiographic Areas

Another objective of this study was to assess the variation of groundwater quality parameter levels among the three major physiographic areas in the YGB: Gila Valley, Yuma Mesa, and Yuma Valley. This was accomplished by sampling 14 randomly selected wells in each physiographic area, for a total of 42 randomly selected groundwater samples collected within the YGB. While empirically, parameter levels seemed highest in Gila Valley and lowest in Yuma Mesa, ANOVA was used to statistically assess whether the parameter level variations between the physiographic areas were significantly different. The ANOVA results provided in **Table 4** indicate the levels of groundwater quality parameters, with the exception of NH_3-N, pH, and total alkalinity, differed significantly between physiographic areas.

In order to determine what significant differences existed between groundwater quality parameter levels of the three physiographic areas, ANOVA with the Tukey option was used to determine pairwise differences. The results of the Tukey analysis are also provided in **Table 4** and revealed that groundwater quality parameters such as Ca, Cl, Fe, hardness, Mg, Mn, K, Na, SO_4, TDS, TKN, and turbidity were significantly higher in Gila Valley than Yuma Mesa while B, F, Mn, and Na were significantly higher in Gila Valley than Yuma Valley. In addition Ca, Fe, and turbidity were significantly higher in Yuma Valley than Yuma Mesa while nitrate was significantly higher in Yuma Mesa than Yuma Valley.

8.3 Groundwater Parameter Level Variations Among Groundwater Zone/Physiographic Areas

Another objective of this study was to assess the variation of groundwater quality parameter levels among the six groundwater zone/physiographic areas in the YGB:

- Gila Valley coarse-gravel zone (GVCG),
- Gila Valley fine-grained zone (GVFG),
- Yuma Mesa coarse-gravel zone (YMCG),
- Yuma Mesa fine-grained zone (YMFG),
- Yuma Valley coarse-gravel zone (YVCG), and
- Yuma Valley fine-grained zone (YVFG).

This was accomplished by sampling 7 randomly selected wells in each groundwater zone/physiographic area, for a total of 42 randomly selected groundwater samples collected within the YGB. ANOVA was used to statistically assess whether the parameter level variations between the groundwater zone/physiographic areas were significantly different. The ANOVA results, provided in **Table 5**, indicate the levels of groundwater quality parameters such as Ca, hardness, Mg, Mn, nitrate, K, and TKN differed significantly between groundwater zone/physiographic areas.

Table 4. Variation in Groundwater Quality Parameter Levels in Three YGB Physiographic Areas Using ANOVA With Tukey Option

Parameter	Significance	Physiographic Area Significant Differences
As	*	
B	*	GV>YV
Ca	**	GV=YV>YM
Cl	*	GV>YM
F	**	GV>YV
Hardness	*	GV>YM
Fe	**	YV=GV>YM
Mg	*	GV>YM
Mn	**	GV>YV=YM
NH_3-N	ns	
Nitrate	*	YM>YV
pH	ns	
K	**	GV>YM
Na	*	GV>YV=YM
SO_4	*	GV>YM
Total Alkalinity	ns	
TDS	*	GV>YM
TKN	*	GV>YM
Turbidity	**	YV=GV>YM

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

GV Gila Valley
YM Yuma Mesa
YV Yuma Valley

Table 5. Variation in Groundwater Quality Parameter Levels in Six Groundwater Zone/Physiographic Areas Using ANOVA with Tukey Option

Parameter	Significance	Groundwater Zone/Physiographic Area Significant Differences
As	ns	
B	ns	
Ca	*	GVCG=YVCG>YMFG
Cl	ns	
F	ns	
Hardness	*	GVCG>YMFG
Fe	**	
Mg	*	GVCG>YMFG
Mn	**	GVCG=GVFG=YVCG=YVFG>YMCG=YMFG
NH_3-N	ns	
Nitrate	*	YMCG>YVCG
pH	ns	
K	**	GVCG>YMFG=YMCG
Na	ns	
SO_4	ns	
Total Alkalinity	ns	
TDS	ns	
TKN	**	GVFG=GVCG>YMFG
Turbidity	ns	

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

GVCG Gila Valley coarse-gravel
GVFG Gila Valley fine-grained
YMCG Yuma Mesa coarse-gravel
YMFG Yuma Mesa fine-grained
YVCG Yuma Valley coarse-gravel
YVFG Yuma Valley fine-grained

In order to determine what significant differences existed between groundwater quality parameter levels of the six groundwater zone/physiographic areas, ANOVA with the Tukey option was used to determine pairwise differences. The results of the Tukey analysis are also provided in **Table 5** and revealed that groundwater quality parameters such as Ca, hardness, Mg, Mn, K, and TKN were significantly higher in GVCG than YMFG. Other significant groundwater quality parameter level differences were found between groundwater zone/physiographic areas with the following parameters: Ca, Mn, NO_3-N, K, and TKN.

8.4 Groundwater Parameter Level Variations Among Land Uses as Typified by Well Types

The 42 randomly sampled wells in this study consisted of the following types: 28 domestic, 5 industrial, 4 drainage, 3 irrigation, and 2 municipal wells. Using ANOVA with the Tukey option, the variation of groundwater parameter levels among different land uses, as typified by the chief purpose the sampled well's water is used for, was analyzed for significant differences. The results are provided in **Table 6** and show that F and Mn were the only parameters having significant differences between wells. Tukey analysis also showed that domestic, drainage, and industrial wells had levels of F significantly higher than in municipal wells.

8.5 Groundwater Parameter Level 95% Confidence Intervals

Confidence intervals at the 95% level ($CI_{0.95}$) were determined for the 42 randomly sampled wells in this study. A $CI_{0.95}$ indicates that 95% of the population lies within the stated interval. A $CI_{0.95}$ was determined for each groundwater zone, physiographic area, and groundwater zone/physiographic area. Because of the number of samples, the $CI_{0.95}$ groundwater zone has the smallest parameter level range while the $CI_{0.95}$ groundwater zone/physiographic area has the largest parameter level range. The results are provided in **Table 7**.

Table 6. Variation in Groundwater Quality Parameter Levels Between Well Types (Domestic, Drainage, Irrigation, Industrial, and Municipal) Using ANOVA

Parameter	Significance
B	ns
Ca	ns
Cl	ns
F	**
Hardness	ns
Fe	ns
Mg	ns
Mn	*
NH_3-N	ns
Nitrate	ns
pH	ns
K	ns
Na	ns
SO_4	ns
Total Alkalinity	ns
TDS	ns
TKN	ns
Turbidity	ns

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

Table 7. 95% Confidence Intervals for Groundwater Quality Parameter Levels in Two Groundwater Zones, Three Physiographic Areas, and Six Groundwater Zone/Physiographic Areas.

Parameter	Groundwater Zone	Physiographic Area	Zone / Area
As	-0.059 - 0.258	-0.0926 - 0.3052	-0.2898 - 0.4293
B	0.370 - 0.537	0.356 - 0.569	0.314 - 0.749
Ca	138.1 - 229.5	131.3 - 250.5	112.4 - 385.9
Cl	328.2 - 577.6	310.6 - 647.1	263.1 - 1053.0
F	0.511 - 0.677	0.496 - 0.706	0.448 - 0.850
Hardness	529.5 - 853.6	504.8 - 923.3	434.9 - 1352.0
Fe	0.159 - 0.461	0.144 - 0.595	0.112 - 1.025
Mg	49.5 - 80.4	47.2 - 87.2	40.6 - 130.6
Mn	0.236 - 0.729	0.216 - 0.927	0.167 - 3.985
NH_3-N	0.124 - 0.332	0.110 - 0.406	0.086 - 1.313
Nitrate	2.53 - 131.3	2.00 - 301.7	4.27 - 488.1
pH	7.699 - 7.777	7.577 - 7.814	7.517 - 7.925
K	5.47 - 7.29	5.30 - 7.60	4.79 - 9.11
Na	302.5 - 433.8	291.2 - 458.2	262.9 - 577.1
SO_4	464.4 - 739.2	442.8 - 797.0	391.6 - 1114.5
Total Alkalinity	239.3 - 311.7	232.5 - 324.3	214.4 - 376.4
TDS	1513.7 - 2160.7	1457.7 - 2286.0	1292.8 - 2931.9
TKN	0.376 - 0.746	0.322 - 0.863	0.271 - 1.800
Turbidity	2.43 - 58.81	2.00 - 123.22	1.27 - 331.3

All units mg/l with the exception of pH (SU) and turbidity (NTU)

8.6 Overall Groundwater Parameter Level Variations With Groundwater Depth

In order to assess the impacts of groundwater depth on the levels of groundwater quality parameters in the YGB, the parameter levels of each of the 42 randomly sampled wells were compared to the corresponding groundwater depth determined either in the field using a sounder or 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 (bls), r = rate of change, and both a and b are integers.

The overall results indicate that 9 of 18 parameters examined, including total alkalinity, hardness, turbidity, Ca, nitrate, TKN, SO_4, Fe, and Mn had one or more mathematical equations significantly relating decreasing parameter levels to increasing groundwater depth bls (**Table 8**). In six of these parameters (hardness, turbidity, Ca, nitrate, Fe, and Mn), the biphasic model most adequately describes the relationship, while in three cases (total alkalinity, TKN, and SO_4), the exponential model offered the best solution. In no cases did the linear model most adequately describe the relationship. Thus, in comparing the overall groundwater quality parameter levels to groundwater depths, 50% of the parameters examined exhibited a pattern in which the concentration of the groundwater quality parameter would decrease with increasing groundwater depth with this relationship mathematically best described by either an exponential or biphasic model.

8.7 Groundwater Parameter Level Variations With Groundwater Depth By Zone

In order to assess the impacts of groundwater depth on the levels of groundwater quality parameters in the YGB, the parameter levels of each of the 42 randomly sampled wells were subdivided into two groundwater zones - the upper, fine-grained and the lower, coarse-gravel - and compared to the corresponding groundwater depth determined either in the field using a sounder or from ADWR well registration records. Comparisons were again done using three models: linear, exponential, and biphasic. This additional analysis was conducted in order to establish patterns or more precise relationships than could be found in the overall database.

The results are provided in **Table 9** and indicate that 8 of the 18 parameters examined in the upper, fine-grained zone had one or more mathematical equations significantly relating these parameter levels to groundwater depth bls. These parameters include total alkalinity, hardness, turbidity, Ca, TKN, SO_4, Fe, and Mn. In seven of these parameters, the biphasic

Table 8. Relationship Between Groundwater Quality Parameter Levels and Overall Groundwater Depth Using Three Mathematical Models

Parameter	Significance	Most Significant Model
Total alkalinity	**	Exponential
Hardness	*	Biphasic
pH	ns	
TDS	ns	
Turbidity	**	Biphasic
Ca	**	Biphasic
Cl	ns	
F	ns	
Mg	ns	
Na	ns	
Nitrate	*	Biphasic
TKN	**	Exponential
SO_4	**	Exponential
As	ns	
B	ns	
Fe	**	Biphasic
Mn	**	Biphasic
K	ns	

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

Table 9. **Relationship Between Groundwater Quality Parameter Levels and Groundwater Depth By Groundwater Zone Using Three Mathematical Models**

Parameter	Upper Fine-grained Groundwater Zone		Lower Coarse-gravel Groundwater Zone	
	Significance	Most Significant Model	Significance	Most Significant Model
Total Alk	*	Biphasic	*	Exponential
Hardness	*	Biphasic	ns	
pH	ns		ns	
TDS	ns		ns	
Turbidity	**	Biphasic	**	Biphasic
Ca	**	Biphasic	ns	
Cl	ns		ns	
F	ns		ns	
Mg	ns		ns	
Na	ns		ns	
Nitrate	ns		*	Biphasic
TKN	**	Exponential	**	Exponential
SO_4	*	Biphasic	**	Exponential
As	ns		ns	
B	ns		ns	
Fe	*	Biphasic	*	Biphasic
Mn	**	Biphasic	**	Exponential
K	ns		ns	

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

model best described the relationship, while in one instance (TKN), the exponential model offered the best solution. In no cases did the linear model offer the best fit. Thus, in comparing the upper, fine-grained groundwater quality parameter levels to groundwater depths, 44% of the parameters examined exhibited a pattern in which the concentration of the groundwater quality parameter would decrease with increasing groundwater depth with this relationship mathematically typically best described by a biphasic model.

Similar results for the lower, coarse-gravel zone are provided in **Table 9**. Seven of the 18 parameters examined had one or more mathematical equations significantly relating these parameter levels to groundwater depth (bls). These parameters include total alkalinity, turbidity, nitrate, TKN, SO_4, Fe, and Mn. The biphasic model best described the relationship in four of these parameters: turbidity, nitrate, Fe, and Mn, while the exponential model offered the best solution for total alkalinity, TKN, and SO_4. In no cases did the linear model offer the best fit. Thus, in comparing the groundwater quality parameter levels in the lower, coarse-gravel zone to groundwater depths, 39% of the parameters examined exhibited a pattern in which the concentration of the groundwater quality parameter would decrease with increasing groundwater depth with this relationship mathematically typically best described by either a biphasic or exponential model.

8.8 Groundwater Parameter Level Variations With Groundwater Depth By Area

In order to assess the impacts of groundwater depth on the levels of groundwater quality parameters in the YGB, the parameter levels of each of the 42 randomly sampled wells were subdivided into three physiographic areas - Gila Valley, Yuma Mesa, and Yuma Valley - and compared to the corresponding groundwater depth determined either in the field using a sounder or from ADWR well registration records. Comparisons were again done using three models: linear, exponential, and biphasic. This additional analysis was conducted in order to establish patterns or more precise relationships than could be found in the overall database.

The results are provided in **Table 10** and indicate that none of the 18 parameters examined in either the Gila Valley or Yuma Valley had one or more mathematical equations significantly relating these parameter levels to groundwater depth (bls). However, 5 of the 18 parameters examined in the Yuma Mesa had one or more mathematical equations significantly relating these parameter levels to groundwater depth (bls). These parameters include total alkalinity, Cl, F, SO_4, and K. The biphasic model best described the relationship with total alkalinity, Cl, and F; the exponential model offered the best solution for SO_4; and the linear model best described the relationship with K. Thus, in comparing the groundwater quality parameter levels in the physiographic areas, 28% of the Yuma Mesa parameters examined exhibited a pattern in which the concentration of the groundwater quality parameter would decrease with increasing groundwater depth with this relationship mathematically typically best described by either a biphasic or exponential model. There were no significant relationships between groundwater quality parameter levels in Gila Valley and Yuma Valley with groundwater depth.

Table 10. Relationship Between Groundwater Quality Parameter Levels and Groundwater Depth By Physiographic Area Using Three Mathematical Models

Parameter	Gila Valley Physiographic Area		Yuma Mesa Physiographic Area		Yuma Valley Physiographic Area	
	Significance	Most Significant Model	Significance	Most Significant Model	Significance	Most Significant Model
Total Alk.	ns		*	Biphasic	ns	
Hardness	ns		ns		ns	
pH	ns		ns		ns	
TDS	ns		ns		ns	
Turbidity	ns		ns		ns	
Ca	ns		ns		ns	
Cl	ns		*	Biphasic	ns	
F	ns		*	Biphasic	ns	
Mg	ns		ns		ns	
Na	ns		ns		ns	
Nitrate	ns		ns		ns	
TKN	ns		ns		ns	
SO_4	ns		**	Exponential	ns	
As	ns		ns		ns	
B	ns		ns		ns	
Fe	ns		ns		ns	
Mn	ns		ns		ns	
K	ns		**	Linear	ns	

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

8.9 Overall Correlation of Groundwater Quality Parameter Levels

In order to assess the strength of association between levels of different groundwater quality parameters in the YGB, the parameter levels of each of the 42 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 the same, except that the function has a negative sign for the slope of the line. Finally, a Pearson correlation of 0 indicates that neither of two variables can be predicted from the other by using a linear equation (Wilkinson and Hill, 1994).

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

The results of the probability test of the Pearson correlation coefficient using 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 11** and indicate a good overall correlation between most parameter levels. In other words, as the levels of one groundwater quality parameter rise, the levels of other groundwater quality parameters tend to either rise or decline. Generally, only pH and nitrate had negative correlations in which as the groundwater quality parameter tended to increase, these two parameter levels tended to decrease. Parameter levels and the number of significant correlations with the other 18 parameter levels are as follows: hardness, Ca, and Mg - 15, TDS - 14, SO_4, Fe, and Mn - 13, turbidity, Cl, and TKN - 12, Total alkalinity and Band Na - 11, K - 10, NH_3-N - 9, pH - 7, nitrate - 6, F - 3, and As - 0. With the exception of pH, nitrate, F, and As, parameter levels tend to rise together in unison in 50% or more of the pairwise cases. These correlations may indicate that most parameters occur from a common source, while nitrate, F, and As occur naturally and/or from different sources.

8.10 Groundwater Zone Correlation of Groundwater Quality Parameter Levels

In order to assess the strength of association between levels of different groundwater quality parameters in the YGB, the parameter levels of each of the 42 randomly sampled wells were divided into groundwater zones. These parameters were then compared with the other groundwater quality parameters located within either the upper, fine-grained or lower, coarse-gravel groundwater zone. This additional analysis was conducted in order to establish patterns or more precise relationships than could be found in the overall database.

Table 11. Overall Correlation Between Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	Hard	pH	TDS	Turb	Ca	Cl	F	Mg	Na	Nitrate	TKN	SO_4	B	Fe	Mn	K	NH_3-N	As
Total Alk.	**	ns	**	*	**	ns	ns	**	**	ns	**	**	**	**	**	ns	ns	ns
Hardness		<u>**</u>	**	**	**	**	ns	**	**	ns	**	**	**	**	**	**	**	ns
pH			<u>**</u>	ns	<u>**</u>	<u>*</u>	ns	<u>**</u>	<u>**</u>	ns	ns	ns	<u>*</u>	ns	ns	ns	ns	ns
TDS				*	**	**	ns	**	**	ns	**	**	**	**	**	**	ns	ns
Turbidity					**	*	ns	*	ns	<u>**</u>	*	**	ns	**	**	ns	**	ns
Ca						**	ns	**	**	ns	**	**	**	**	**	**	**	ns
Cl							ns	**	**	ns	ns	**	**	*	*	**	ns	ns
F								ns	ns	**	ns	ns	**	ns	ns	ns	<u>**</u>	ns
Mg									**	ns	**	**	**	**	**	**	**	ns
Na										ns	*	**	**	ns	ns	**	ns	ns
Nitrate											<u>*</u>	ns	ns	<u>**</u>	<u>**</u>	ns	<u>**</u>	ns
TKN												**	ns	**	**	ns	**	ns
SO_4													**	**	**	**	ns	ns
B														ns	ns	**	ns	ns
Fe															**	**	**	ns
Mn																**	**	ns
K																	ns	ns
NH_3-N																		ns

ns Not Significant
* Significant Positive Correlation at p=0.05
** Significant Positive Correlation at p=0.01
<u>*</u> Significant Negative Correlation at p=0.05
<u>**</u> Significant Negative Correlation at p=0.01
Bartlett Chi-square probability for Pearson correlation - p = 0.00

The results of the probability test of the Pearson correlation coefficient using log-transformed data from the coarse-gravel zone 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 12** and indicate a good overall correlation between most parameter levels. In other words, as the levels of one groundwater quality parameter rise, the levels of other groundwater quality parameters tend to either rise or decline. Generally, only pH and nitrate had negative correlations in which as the groundwater quality parameter tended to increase, these two parameter levels tended to decrease. Parameter levels and the number of significant correlations with the other 18 parameter levels are as follows: hardness and Mg - 14, Ca, Cl, Mn, and K - 13, TDS, SO_4, and Fe - 12, - 11, Na and NH_3-N - 10, nitrate and TKN - 9, total alkalinity and B - 7, turbidity - 6, pH - 5, F - 3, and As - 1. Thus, 12 of the 18 groundwater quality parameters are significantly correlated with other groundwater quality parameter levels in 50% or more of the pairwise cases.

The results of the probability test of the Pearson correlation coefficient using log-transformed data from the fine-grained zone show that the Bartlett chi-square test was not "positive definite with individual significance tests suspect". These correlation probabilities are provided in **Table 13** and indicate a good overall correlation between most parameter levels. In other words, as the levels of one groundwater quality parameter vary, the levels of other groundwater quality parameters tend to either rise or decline. Generally, only pH and nitrate had negative correlations in which as the groundwater quality parameter tended to increase, these two parameter levels tended to decrease. Parameter levels and the number of significant correlations with the other 18 parameter levels are as follows: hardness and Ca - 12, Mg, and SO_4 - 11, TDS - 10, TKN - 9, total alkalinity, Cl, Na, Fe, B, and K - 8, Mn - 6, pH and nitrate - 4, turbidity and NH_3-N - 3, F - 1, and As - 0. Thus, only 5 of the 18 groundwater quality parameters are significantly correlated with other groundwater quality parameter levels in 50% or more of the pairwise cases.

8.11 Physiographic Area Correlation of Groundwater Quality Parameter Levels

In order to assess the strength of association between levels of different groundwater quality parameters in the YGB, the parameter levels of each of the 42 randomly sampled wells were seperated among three physiographic areas: Gila Valley, Yuma Mesa, and Yuma Valley. The correlation between fluctuations of parameter levels were then compared to one another within these physiographic areas. This additional analysis was conducted in order to establish patterns or more precise relationships than could be found in the overall database. The results of the probability test of the Pearson correlation coefficient using log-transformed data from each physiographic area shows that each Bartlett chi-square test was not significant at $p=0.01$, making each correlation matrix not "positive definite with individual significance tests suspect".

Table 12. Correlation Between Coarse-gravel Zone Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	T. Alk	Hard	pH	TDS	Turb	Ca	Cl	F	Mg	Na	Nitrate	TKN	SO_4	B	Fe	Mn	K	NH_3-N	As
Total Alk.		*	ns	**	ns	ns	ns	ns	**	**	ns	*	**	**	ns	ns	*	ns	ns
Hardness			$\underline{**}$	**	ns	**	**	ns	**	**	$\underline{**}$	*	**	ns	**	**	**	**	ns
pH				$\underline{**}$	ns	ns	$\underline{**}$	ns	$\underline{**}$	ns	ns	ns	ns	ns	ns	ns	$\underline{**}$	ns	ns
TDS					ns	**	**	ns	**	**	ns	ns	**	**	**	**	**	ns	ns
Turbidity						**	*	ns	ns	ns	$\underline{**}$	ns	ns	ns	**	*	ns	*	ns
Ca							**	ns	**	*	$\underline{*}$	*	*	ns	**	**	**	**	ns
Cl								ns	**	**	ns	*	*	ns	**	**	**	**	ns
F									ns	ns	**	ns	ns	**	ns	ns	ns	$\underline{**}$	ns
Mg										**	$\underline{*}$	*	**	ns	**	**	**	*	ns
Na											ns	ns	**	**	ns	**	**	ns	ns
Nitrate												ns	ns	ns	$\underline{**}$	$\underline{**}$	$\underline{*}$	$\underline{**}$	ns
TKN													**	ns	*	*	ns	*	ns
SO_4														*	*	**	*	ns	ns
B															ns	ns	**	ns	*
Fe																**	**	*	ns
Mn																	**	**	ns
K																		ns	ns
NH_3-N																			ns

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

Bartlett Chi-square probability for Pearson correlation - p = 0.00
$\underline{*}$ Significant Negative Correlation at p=0.05
$\underline{**}$ Significant Negative Correlation at p=0.01

Table 13. **Correlation Between Fine-grained Zone Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities**

Parameter	T. Alk	Hard	pH	TDS	Turb	Ca	Cl	F	Mg	Na	Nitrate	TKN	SO_4	B	Fe	Mn	K	NH_3-N	As
Total Alk.		**	ns	*	ns	**	ns	ns	**	ns	ns	**	**	ns	**	*	ns	ns	ns
Hardness			$\underline{\ast}$	**	ns	**	**	ns	**	**	ns	**	**	**	*	ns	*	ns	ns
pH				ns	ns	$\underline{\ast}$	ns	$\underline{\ast}$	$\underline{\ast}$	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TDS					ns	**	**	ns	**	**	ns	*	**	**	ns	ns	**	ns	ns
Turbidity						ns	ns	ns	ns	ns	$\underline{\ast}$	ns	ns	ns	**	**	ns	ns	ns
Ca							**	ns	**	**	ns	*	**	**	*	ns	*	ns	ns
Cl								ns	**	**	ns	ns	**	**	ns	ns	**	ns	ns
F									ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Mg										**	ns	**	**	**	ns	ns	*	ns	ns
Na											ns	ns	**	**	ns	ns	**	ns	ns
Nitrate												ns	ns	ns	$\underline{\ast\ast}$	$\underline{\ast\ast}$	ns	$\underline{\ast\ast}$	ns
TKN													**	ns	**	**	ns	**	ns
SO_4														**	*	ns	*	ns	ns
B															ns	ns	*	ns	ns
Fe																**	ns	ns	ns
Mn																	ns	**	ns
K																		ns	ns
NH_3-N																			ns

ns Not Significant
* Significant Positive Correlation at p=0.05
** Significant Positive Correlation at p=0.01
$\underline{\ast}$ Significant Negative Correlation at p=0.05
$\underline{\ast\ast}$ Significant Negative Correlation at p=0.01

Bartlett Chi-square probability for Pearson correlation is not positive definite, individual significance test are suspect.

Correlation probabilities for the Gila Valley are provided in **Table 14** and indicate a good overall correlation between most parameter levels. In other words, as the levels of one groundwater quality parameter rise, the levels of other groundwater quality parameters tend to either rise or decline. Generally, only pH, F, and nitrate had negative correlations in which as the groundwater quality parameter tended to increase, the levels of these three parameters tended to decrease. Parameter levels and the number of significant correlations with the other 18 parameter levels in Gila Valley are as follows: hardness, Mg, SO_4, and Mn - 13, Ca - 12, TKN and Fe - 11, TDS and K - 10, turbidity, Cl, and B - 9, Na - 8, total alkalinity - 7, F - 6, NH_3-N - 5, nitrate - 3, and pH and As - 0. Thus, 12 of the 18 groundwater quality parameters are significantly correlated with other groundwater quality parameter levels in 50% or more of the pairwise cases.

Correlation probabilities for the Yuma Mesa are provided in **Table 15** and indicate a weak overall correlation between most parameter levels. In other words, as the levels of one groundwater quality parameter rise, the levels of other groundwater quality parameters tend not to either rise or decline significantly. Parameter levels and the number of significant correlations with the other 18 parameter levels in Yuma Mesa are as follows: hardness and K - 6, NH_3-N - 5, pH and TDS - 4, Cl, F, Mg, and SO_4 - 3, total alkalinity, turbidity, nitrate, B and Mn - 2, Ca, Na, and TKN - 1, and Fe and As - 0. Thus, none of the 18 groundwater quality parameters are significantly correlated with other groundwater quality parameter levels in 50% or more of the pairwise cases.

Correlation probabilities for the Yuma Valley are provided in **Table 16** and indicate a moderate overall correlation between most parameter levels. In other words, as the levels of one groundwater quality parameter rise, the levels of other groundwater quality parameters tend to either rise or decline. Generally, only pH, F, and nitrate had negative correlations in which as the groundwater quality parameter tended to increase, the levels of these three parameters tended to decrease. Parameter levels and the number of significant correlations with the other 18 parameter levels in Yuma Valley are as follows: total alkalinity and Mn - 10, hardness, TDS, Cl, Mg, and SO_4 - 9, Ca, Na, and B - 8, nitrate - 5, NH_3-N - 4, F and TKN - 3, pH, turbidity, and Fe - 2, K and As - 0. Thus, 7 of the 18 groundwater quality parameters are significantly correlated with other groundwater quality parameter levels in 50% or more of the pairwise cases.

Table 14. Correlation Between Gila Valley Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	T. Alk	Hard	pH	TDS	Turb	Ca	Cl	F	Mg	Na	Nitrate	TKN	SO_4	B	Fe	Mn	K	NH_3-N	As
Total Alk.		*	ns	ns	ns	ns	ns	ns	*	ns	ns	*	**	*	*	*	ns	ns	ns
Hardness			ns	*̲*̲	*	**	**	ns	**	**	ns	**	**	**	*	*	**	ns	ns
pH				ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TDS					ns	**	**	ns	**	**	ns	*	**	**	ns	*	**	ns	ns
Turbidity						**	ns	*̲*̲	*	ns	ns	*	*	ns	**	*	*	ns	ns
Ca							**	ns	**	**	ns	**	**	*	*	*	**	ns	ns
Cl								ns	**	**	ns	ns	*	**	ns	*	**	ns	ns
F									ns	ns	**	*̲	ns	ns	*̲*̲	*̲	ns	*̲*̲	ns
Mg										**	ns	**	**	**	*	*	**	ns	ns
Na											ns	ns	*	**	ns	ns	**	ns	ns
Nitrate												ns	ns	ns	ns	*̲*̲	ns	*̲*̲	ns
TKN													*	ns	**	**	ns	**	ns
SO_4														*	*	*	**	ns	ns
B															ns	ns	**	ns	ns
Fe																**	*	*	ns
Mn																	ns	*	ns
K																		ns	ns
NH_3-N																			ns

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

Table 15. Correlation Between Yuma Mesa Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	T. Alk	Hard	pH	TDS	Turb	Ca	Cl	F	Mg	Na	Nitrate	TKN	SO_4	B	Fe	Mn	K	NH_3-N	As
Total Alk.		ns	ns	ns	ns	ns	*̲	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
Hardness			*̲*̲	*	*̲	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	*	*	ns
pH				*̲	ns	ns	ns	ns	*̲*̲	ns	ns	ns	ns	ns	ns	ns	*̲	ns	ns
TDS					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
Ca							**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cl								ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
F									ns	ns	ns	ns	*	ns	ns	ns	*̲*̲	*̲	ns
Mg										ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Na											ns	ns	ns	**	ns	ns	ns	ns	ns
Nitrate												ns	ns	*	ns	*̲*̲	ns	ns	ns
TKN													*	ns	ns	ns	ns	ns	ns
SO_4														ns	ns	ns	ns	ns	ns
B															ns	ns	ns	ns	ns
Fe																ns	ns	ns	ns
Mn																	ns	**	ns
K																		*	ns
NH_3-N																			ns

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

Table 16. Correlation Between Yuma Valley Groundwater Quality Parameter Levels Using Pearson Correlation Probabilities

Parameter	T. Alk	Hard	pH	TDS	Turb	Ca	Cl	F	Mg	Na	Nitrate	TKN	SO_4	B	Fe	Mn	K	NH_3-N	As
Total Alk.		**	*̲	**	ns	**	*	ns	**	**	ns	ns	**	*	ns	**	ns	ns	ns
Hardness			ns	**	ns	**	**	ns	**	**	ns	ns	**	*	ns	**	ns	ns	ns
pH				ns	ns	ns	ns	*̲*̲	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TDS					ns	**	**	ns	**	**	ns	ns	**	**	ns	**	ns	ns	ns
Turbidity						ns	ns	ns	ns	ns	*̲*̲	ns	ns	ns	**	ns	ns	ns	ns
Ca							**	ns	**	**	ns	ns	**	ns	ns	**	ns	ns	ns
Cl								ns	**	**	ns	ns	**	**	ns	*	ns	ns	ns
F									ns	ns	ns	ns	ns	*	ns	ns	ns	*̲*̲	ns
Mg										**	ns	ns	**	*	ns	**	ns	ns	ns
Na											ns	ns	**	**	ns	ns	ns	ns	ns
Nitrate												*̲	ns	ns	*̲*̲	*̲	ns	*̲*̲	ns
TKN													ns	ns	ns	**	ns	**	ns
SO_4														**	ns	*	ns	ns	ns
B															ns	ns	ns	ns	ns
Fe																ns	ns	ns	ns
Mn																	ns	*	ns
K																		ns	ns
NH_3-N																			ns

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

8.12 Groundwater Quality Impacts From Specific Land Uses

Limited targeted groundwater sampling was conducted as part of this study as the result of groundwater quality concerns expressed by ADEQ employees in other programs, local government officials, and Yuma-area residents. Specific land uses such as a biosolids application area, a landfill, a housing development utilizing septic systems for wastewater disposal, and an urban area were the focus of groundwater sampling to determine if any groundwater quality impacts could be discerned. The specific land uses targeted included:

- Ag Tech Farm located in the southern Yuma Mesa, which is a permitted biosolids application area;

- Cocopah Landfill located on the border of the East Cocopah Indian Reservation on Yuma Mesa;

- Yuma County Septic Advisory Area located in the Yuma Valley near the Padre Ranchettes subdivision, so designated as a result of high groundwater levels recorded during the winter/spring of 1995;

- City of San Luis located along the International Border with Mexico on Yuma Mesa.

For these targeted samples, a groundwater quality sample was collected from the well which was considered to be in the best location - both vertically and horizontally - to show impacts from potential contamination from the selected land use. Three such wells perforated in the coarse-gravel zone were sampled for the biosolids investigation (Yuma-5A, Yuma-6A, and Yuma-7A), while the other land uses had a single well sampled for their assessment. The land uses and their associated targeted samples include the Cocopah Landfill (Yuma-62A), Yuma Valley Septic Advisory Area (Yuma-11A), and the City of San Luis (Yuma-4A). The results are provided in **Table 17** and indicate that with only a few exceptions, groundwater quality parameter levels of the targeted land uses did not exceed the log-transformed $CI_{0.95}$ upper limits. The exceptions included:

B - for two land uses (landfill, and septic);
F - for one land use (septic); and
pH - for two land uses (biosolids and landfill).

Based on these results, no further targeted land use groundwater samples were collected.

Table 17. Comparison of Groundwater Quality Parameters of Wells Potentially Impacted by Specific Land Uses and 95% Confidence Intervals Established for Groundwater Zones

Parameter	Biosolids Area Average Sample Level	Landfill Area Sample Level	Septic Area Sample Level	Urban Area Sample Level
B	-	>	>	-
Ca	-	-	-	-
Cl	-	-	-	-
F	-	-	>	-
Hardness	-	-	-	-
Fe	-	-	-	-
Mg	-	-	-	-
Mn	-	-	-	-
NH_3-N	-	-	-	-
Nitrate	-	-	-	-
pH	>	>	-	-
K	-	-	-	-
Na	-	-	-	-
SO_4	-	-	-	-
Alkalinity	-	-	-	-
TDS	-	-	-	-
TKN	-	-	-	-
Turbidity	-	-	-	-

\> Above the Upper 95% Confidence Interval
\- Below the Upper 95% Confidence Interval

8.13 Eastern Gila Valley Targeted Nitrate Sampling

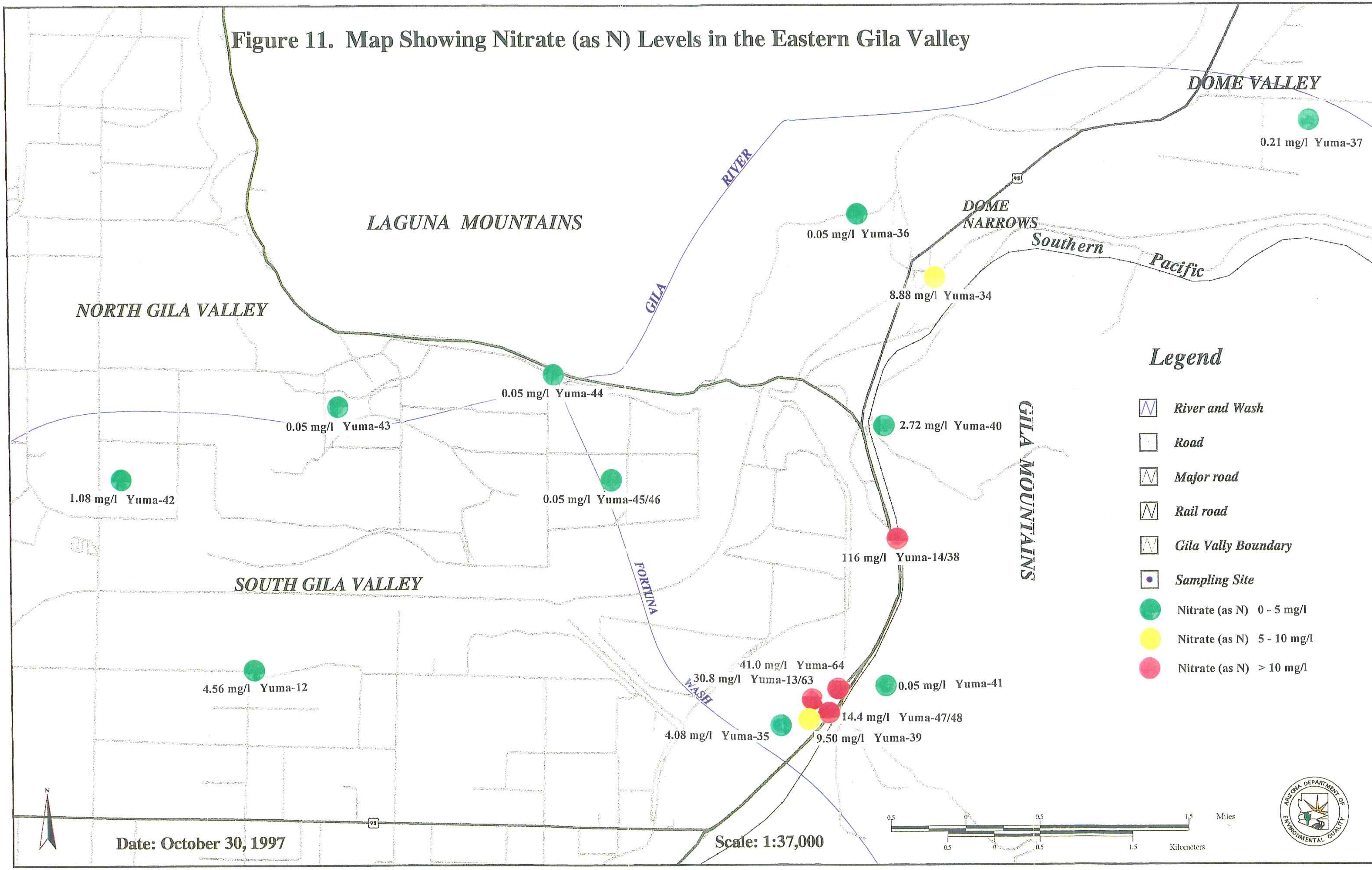
A well belonging to the Veterans of Foreign Wars (VFW) Post in the Eastern Gila Valley downgradient of the Dome Narrows was selected for sampling as the result of random selection. The groundwater sample collected from this well had a nitrate (as N) level of 122 mg/l during the initial sampling in March, 1995. The high nitrate levels in this well were confirmed when, in June, 1995, an additional groundwater sample collected from this same well had a nitrate (as N) level of 110 mg/l. These nitrate levels - with concentrations over ten times the Primary MCL - precipitated the targeted sampling of other wells in the vicinity to determine if they also had elevated levels of this parameter.

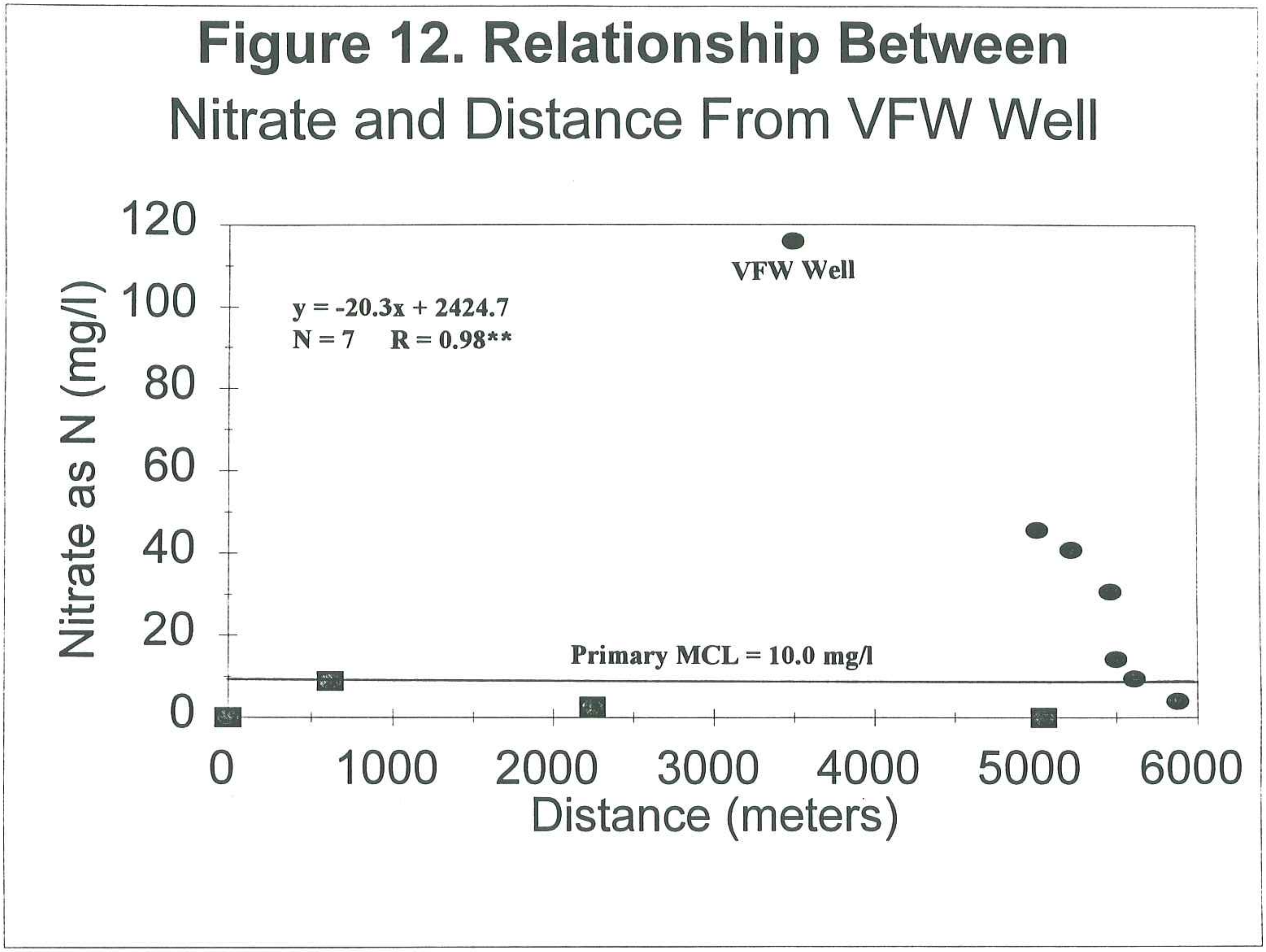
Groundwater movement in the area generally follows the path of the Gila River, flowing in a southerly, and then southwestern direction, though localized groundwater movement may be influenced by recharge from unlined canals, ditches, and cones of depression caused by high-capacity wells (Olmstead and others, 1973). The limited number of wells in this area made adequately assessing the nitrate levels in groundwater difficult; however, limited targeted sampling did reveal three additional wells in the area having nitrate (as N) levels over the Primary MCL. **Figure 11** illustrates the location of wells having groundwater samples collected from them and the associated nitrate (as N) levels. The source of the extremely high nitrate levels appears to be in the general vicinity of the VFW Post. An upgradient well located approximately a mile to the north, which belonged to a sand and gravel operation, had a nitrate (as N) level of 2.72 mg/l. On the other hand, the nearest downgradient well which was sampled as part of another study, an Arizona Department of Agriculture monitoring well located approximately a mile to the south, had a nitrate (as N) level of 46.5 mg/l. Three other wells located to the south and downgradient of the VFW Post well had nitrate (as N) levels exceeding the Primary MCL.

The nitrate levels of the VFW Well and five downgradient wells were then compared with distance between the various wells using three mathematical models: linear, exponential, and biphasic. Both the linear and exponential models were highly correlated at $p=0.01$, though the linear model most adequately described the relationship. With the addition of nitrate data from an Arizona Department of Agriculture monitoring well sampled by ADEQ in January 1997, an even more significant correlation at $p=0.01$ was revealed in comparing distance between wells and nitrate (as N) levels **(Figure 12)**.

To determine the spatial extent of the elevated nitrate (as N) levels in the groundwater, specifically at levels above the 10.0 mg/l Primary MCL, three mathematical models were used: linear, exponential, and biphasic. Both the linear and exponential models were highly correlated at $p=0.01$, though the linear model most adequately described the relationship. Solving the linear regression equation, it was also determined that a distance of 2148 meters would have to be traveled in a downgradient, southerly direction from the VFW Well in order to obtain groundwater below the Primary MCL, based on sampling results from this 1995 study.

Figure 11. Map Showing Nitrate (as N) Levels in the Eastern Gila Valley





■ **Upgradient well located to north or east of VFW Well**

● **Downgradient well located to south of VFW Well**

* **Significant at p = 0.05**

** **Significant at p = 0.01**

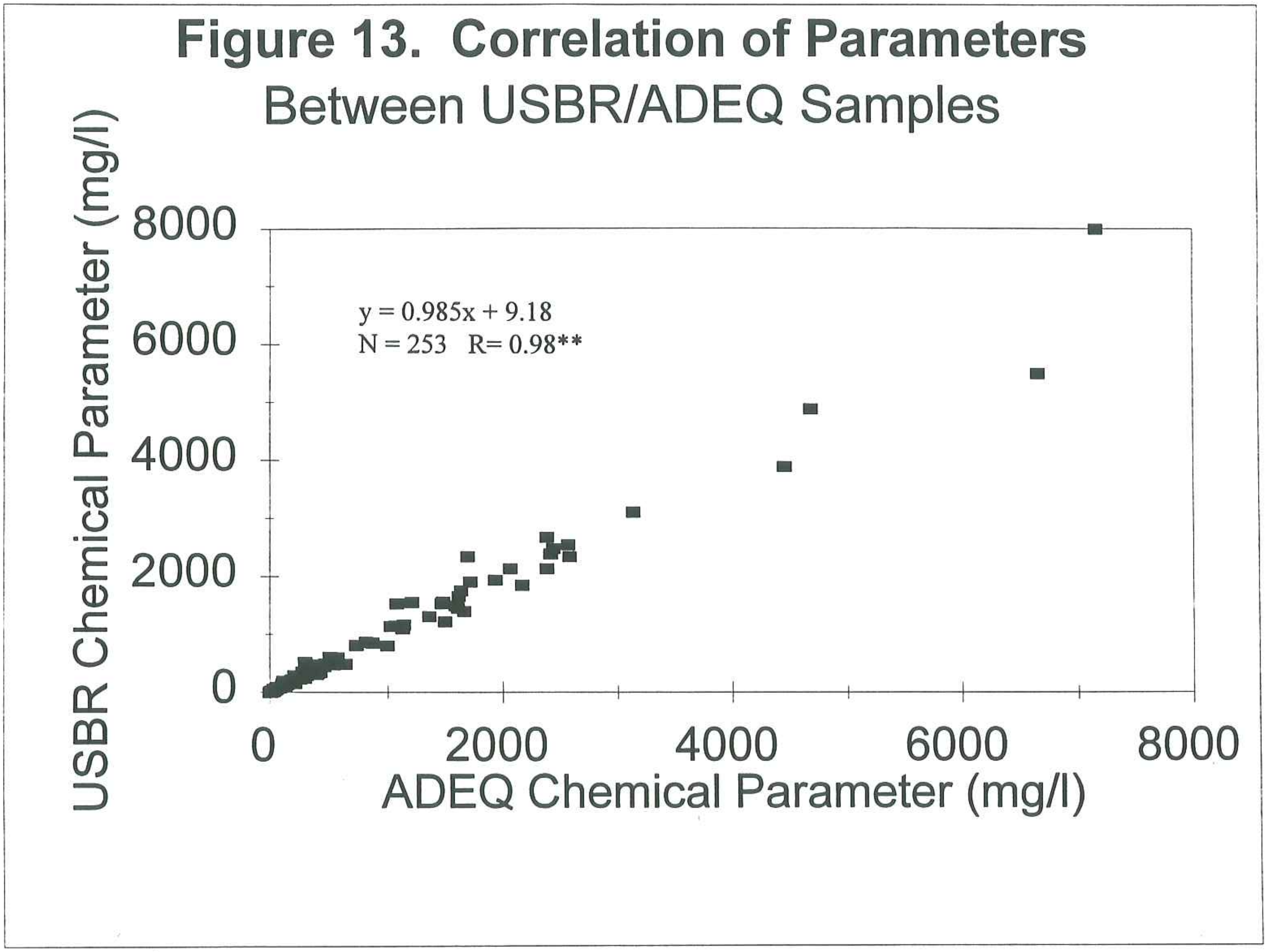
There has been no identified source of the eastern Gila Valley elevated nitrate levels, though ADEQ will continue to investigate this area in an effort to determine the source. Although there is sparse historical groundwater quality data in the immediate vicinity of the VFW Well, a 1991 USBR sample collected from a well located about a half mile to the northwest and slightly upgradient, was below the nitrate Primary MCL though it did exhibit nitrate (as N) levels of 8.3 mg/l. This historical groundwater quality data suggests that elevated nitrate levels may have existed in this area for some time.

8.14 Time Trend Analysis

A groundwater quality time-trend analysis was conducted using the ADEQ groundwater sampling results. The baseline used for the time-trend analysis was groundwater quality data collected by the U.S. Bureau of Reclamation (USBR) in 1989-90. Fourteen of the 304 wells sampled by the USBR were resampled by ADEQ in 1995. The majority of the 14 resampled wells withdraw groundwater from the lower, coarse-gravel zone and these wells were not located in a statistically-designed manner.

The variations in 15 groundwater quality parameters (Na, K, Ca, Mg, Cl, SO_4, NO_3 - N, B, F, Fe, Mn, Ba, TDS, EC, and temperature) were compared between samples collected by these agencies from 14 wells sampled by each study. The results are provided in **Figure 13.** Linear regression indicates that the overall composite variation between 253 sets of parameters was only 1.5%. The locations of the 14 wells sampled by each agency is provided in **Figure 14.**

In order to determine if there was a significant difference between these two groups of 15 groundwater samples with respect to the levels of various groundwater quality parameters, the nonparametric Wilcoxon test was selected instead of the parametric ANOVA test. The nonparametric test was considered more appropriate because the accuracy of the data set was inherently less dependable since it was collected by two different agencies at different times. The results, provided in **Table 18**, show that only K and SO_4 of the groundwater quality parameter levels from the 1995 ADEQ samples were significantly different from parameter levels recorded from the 1989-90 USBR samples. An examination of the data shows that both the K and SO_4 levels significantly increased from 1989-90 to 1995.



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

Figure 14. Location of Groundwater Samples Used By ADEQ for Time Trend Analysis

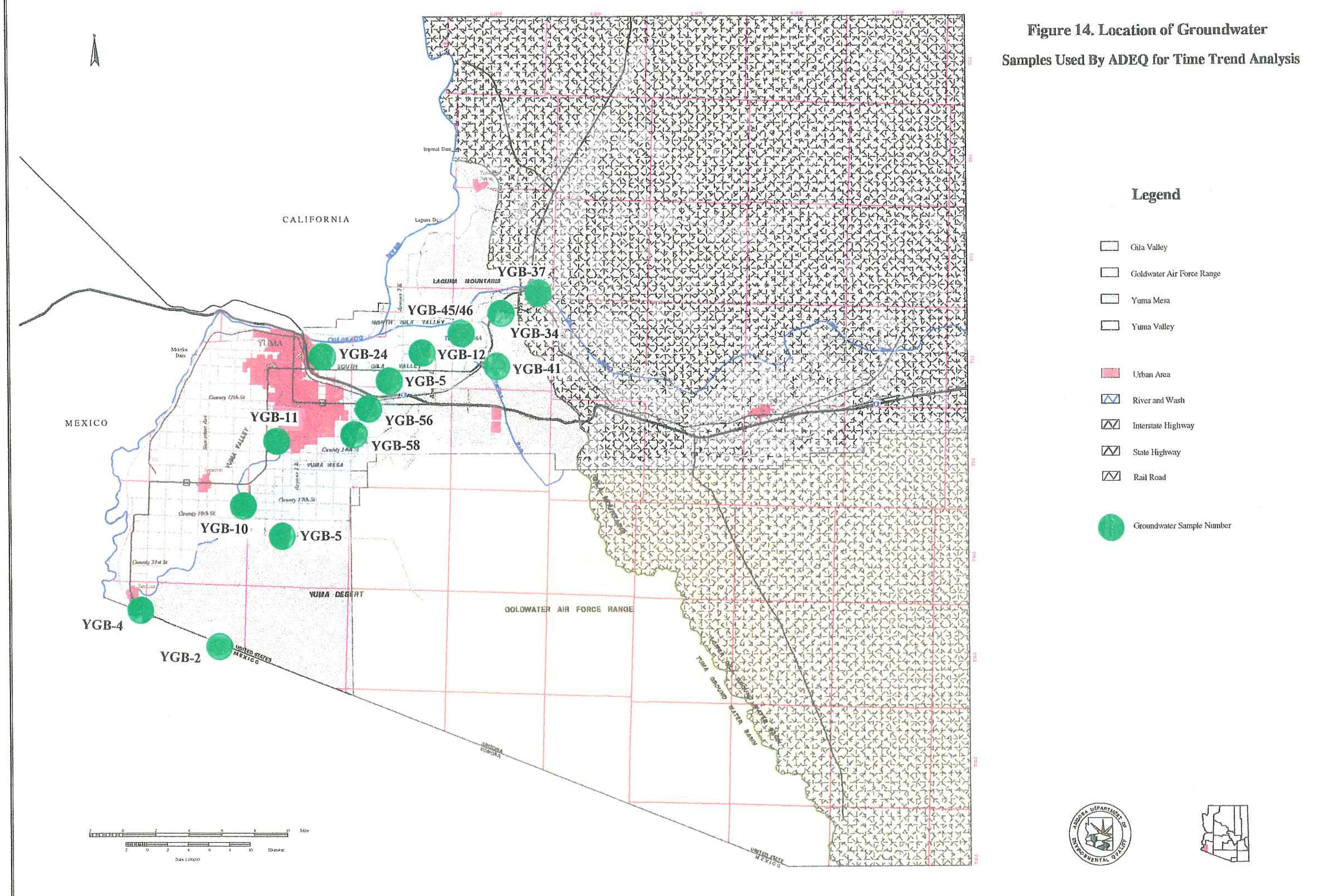


Table 18. Variation in Groundwater Quality Parameter Levels Between 1989-90 USBR and 1995 ADEQ Sampling Results for 14 Wells Using Wilcoxon

Parameter	Significance of Non-transformed Data
Na	ns
K	**
Ca	ns
Mg	ns
Cl	ns
HCO_3	ns
SO_4	*
NO_3 - N	ns
B	ns
F	ns
Fe	ns
Mn	ns
Ba	ns
TDS	ns
EC	ns
Temp.	ns

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

8.15 Groundwater Depth Variations In the YGB

A component of this groundwater quality study was to examine the variation in groundwater depth levels between groundwater zones and physiographic areas. ANOVA was used to statistically assess, using log-transformed data, whether the groundwater depth level variation was significantly different between zones and areas. The results are shown in **Table 19** and indicate that the only significant differences exist in depth to groundwater levels between physiographic areas at the $p=0.01$ level. Exploring this relationship further using the Tukey option revealed that groundwater depth levels were significantly greater in the Yuma Mesa than in either Gila Valley or Yuma Valley at the $p=0.01$ level. This finding is predictable as Yuma Mesa is a river terrace and thus, higher in elevation than either of the two river valleys.

It is relevant to prove this significant difference between groundwater depth levels among physiographic areas because this study has earlier determined that area has a significant impact on levels of groundwater quality parameters. Thus, it is likely that groundwater depth may be one of the factors influencing the variation in groundwater quality parameter levels among areas. With a deeper groundwater depth, water recharging through the vadose zone takes longer to impact the aquifer. In addition, although the Yuma Mesa has deeper groundwater depths, groundwater elevations are nonetheless higher than those found in either Gila Valley or Yuma Valley. Thus, groundwater in the Yuma Mesa is being continually flushed by groundwater movement from the aquifer's upper reaches to these two valleys.

Table 19. Variation in Groundwater Depth Levels in YGB Groundwater Zones and Physiographic Areas Using ANOVA

Source	Significance Using Log-transformed Groundwater Depth
Groundwater Zone	ns
Physiographic Area	**

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

9. AMBIENT MONITORING INDEX WELL NETWORK

The establishment of an ambient monitoring index well network in the YGB is predicated on the concept that because it is easier and less expensive to prevent groundwater pollution than to clean the aquifer after contamination, 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 the highest risk of contamination. 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 of groundwater resources. Long-term trends in groundwater quality reflect variations in the rate and quality of recharge, and can be used to ascertain adequate sampling intervals to determine long-term YGB groundwater quality trends.

The 18 ambient groundwater quality monitoring index wells were listed in **Table 20** and are selected on the following basis:

1) Six wells were located in and distributed throughout each of the following physiographic areas: Gila Valley, Yuma Mesa, and Yuma Valley;

2) Nine wells were located in and distributed throughout each of the following water zones: upper, fine-grained and lower, coarse-gravel;

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

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

5) Monitoring wells constructed for joint Arizona Department of Agriculture/ADEQ use in the YGB will be incorporated into the well network.

The time-trend analysis conducted from groundwater quality data complied by ADEQ in 1995 and the USBR in 1989-1990 supports the conclusion that groundwater quality in the YGB, at least within the lower, coarse-gravel zone, is not rapidly changing. Therefore, the recommendation is made that resampling of the ADEQ groundwater quality index monitoring wells should be conducted at intervals greater than five years. As such, perhaps an interval of seven to eight years would be an adequate resampling time to allow potential or measurable groundwater quality changes to appear in water quality index wells.

Table 20. Wells Selected for YGB Ambient Groundwater Quality Monitoring Network.

Well Registry #	ADEQ #	Owner	Well Name	Location	Water Zone	Physiographic Area
55-560072	56257	ADA-ADEQ	Well #1	(C-08-21)21ccc	Fine-grained	Gila Valley
55-560073	56258	ADA-ADEQ	Well #2	(C-08-22)34aaa	Fine-grained	Gila Valley
55-560074	56259	ADA-ADEQ	Well #3	(C-08-23)27daa	Fine-grained	Gila Valley
55-503291	51304	H & H Seed Co.		(C-08-23)27add	Coarse-gravel	Gila Valley
55-626998	24557	USBR	SG-714	(C-08-22)26bbb	Coarse-gravel	Gila Valley
55-500899	000999	Yuco Gin Co.		(C-08-21)29acc	Coarse-gravel	Gila Valley
55-518119	46806	Swainn		(C-09-22)17bcb	Fine-grained	Yuma Mesa
55-86900	51572	Edenburn		(C-09-22)12bbd	Fine-grained	Yuma Mesa
55-631482	51579	McElvain		(C-10-23)14dda	Fine-grained	Yuma Mesa
55-536951	46807	Webb		(C-10-23)08baa	Coarse-gravel	Yuma Mesa
55-522880	000441	Woodman		(C-09-23)13aad	Coarse-gravel	Yuma Mesa
55-511849	51455	Far West Water Co		(C-09-21)09ccc	Coarse-gravel	Yuma Mesa
55-560075	56260	ADA-ADEQ	Well #5	(C-09-24)01aaa	Fine-grained	Yuma Valley
55-560077	56270	ADA-ADEQ	Well #8	(C-10-24)10bbb	Fine-grained	Yuma Valley
55-560079	56268	ADA-ADEQ	Well #10	(C-10-25)36ccc	Fine-grained	Yuma Valley
55-504513	51295	YCWUA	13th Street Well	(C-09-23)20bab	Coarse-gravel	Yuma Valley
55-84812	25580	City of San Luis	Central Well Field	(C-11-25)12bdb	Coarse-gravel	Yuma Valley
55-615593	51301	EMCO Livestock		(C-10-24)16dca	Coarse-gravel	Yuma Valley

10. CONCLUSION

This regional study to assess the groundwater quality of the Yuma Groundwater Basin (YGB) was conducted by ADEQ during 1995. The study had six major objectives: obtain baseline data throughout the basin, examine groundwater quality differences between various 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 specific land uses, investigate groundwater quality changes over time, and establish an ambient monitoring index well network. The results of the study indicated the following key findings for each objective:

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

- Piper trilinear water chemistry diagrams revealed the groundwater throughout the YGB is fairly uniform and is similar to water in the Colorado River and Gila River. Most groundwater samples collected in this study exhibited sodium-sulfate, sodium-chloride, or calcium-sulfate type water, though the chemical differences were not great as the dominant anion and cation typically contributed less than 50% to the ions in solution.

- Ten of the inorganic groundwater quality parameters sampled for have associated health-based Primary MCLs. Of these 10 parameters, only one - nitrate - was detected above the Primary MCL and/or Arizona Aquifer Water Quality Standards (AWQS) in seven groundwater samples from five wells. Elevated nitrate concentrations were only detected in four wells located in the eastern Gila Valley and one well located in the Yuma Mesa in this study.

- This study discovered elevated nitrate levels in the eastern Gila Valley within the following boundaries: the Southern Pacific Railroad tracks to the east, US Highway 95 to the north, the Wellton-Mohawk Canal/Gila Gravity Main Canal to the west, and US Highway 95 to the south. Within this area, groundwater samples often exceeded the 10.0 mg/l Primary MCL, with one sample having a nitrate (as N) concentration of 122 mg/l.

- Ten of the inorganic groundwater parameters sampled for have associated aesthetics-based Secondary MCLs. All groundwater samples collected in the YGB exceeded at least one Secondary MCL with TDS, Cl, SO_4, Fe, and Mn exceedences especally common. The results from this study indicate that although most groundwater in the YGB meets standards for use as a potable resource, with the high levels of many Secondary MCL parameters, the water may not taste very palatable and/or be a good cleaning agent. As a result, most households use their well water only for non-potable purposes.

- The presence of the banned pesticides, DBCP and EDB, was also examined in this study. These pesticides were detected in some YGB groundwater samples during the late 1970s and early 1980s. In groundwater samples collected by ADEQ from 36 wells in this study, there were no confirmed detections of either pesticide.

- The presence of currently-registered pesticides in groundwater was also a component of this study. As a result, groundwater samples were collected for GWPL analysis. This analysis consists of the 152 pesticides used in Arizona that are considered most likely to leach to the groundwater through normal agricultural use. In 21 groundwater samples collected in this study, there were no detections of any of the 152 pesticides.

- Radionuclide levels in groundwater were also examined in this study. In seven samples collected throughout the YGB, none exceeded the Primary MCLs established for either gross alpha or radium-226 and radium-228.

B) Examine various spatial areas within the YGB for statistically significant groundwater quality differences:

- The variation in groundwater quality parameter levels was assessed between the two shallowest groundwater zones in the YGB: the upper, fine-grained zone and the lower, coarse-gravel zone. The results of ANOVA analysis indicated no significant differences existed in the levels of any groundwater quality parameters between the two groundwater zones.

- The variation in groundwater quality parameter levels was assessed among three physiographic areas in the YGB: Gila Valley, Yuma Mesa, and Yuma Valley. The results of ANOVA analysis indicated many significant differences exist in the levels of groundwater quality parameters among the three physiographic areas. Parameters such as Ca, Cl, Fe, hardness, Mg, Mn, K, Na, SO_4, TDS, TKN, and turbidity were significantly higher in Gila Valley than Yuma Mesa, while B, F, Mn, and Na were significantly higher in Gila Valley than Yuma Valley. Finally,Ca, Fe, and turbidity were significantly higher in Yuma Valley than Yuma Mesa while nitrate was higher in Yuma Mesa than Yuma Valley.

- The variation in groundwater quality parameter levels was assessed among groundwater zone/physiographic areas in the YGB. The results of ANOVA analysis indicated that parameters such as Ca, hardness, Fe, Mg, Mn, nitrate, K, and TKN differed significantly between groundwater zone/physiographic areas. Many of these groundwater quality parameters were significantly higher in Gila Valley coarse-gravel than Yuma Mesa fine-grained, though other differences in groundwater zone/physiographic areas occurred.

- The variation in groundwater quality parameter levels was assessed among well types in the YGB. This was conducted as a rough method for examining for groundwater quality differences stemming from land use. Well types sampled for the study include domestic, municipal, drainage, irrigation, and industrial. The results of ANOVA analysis indicated that the only groundwater quality parameters that differed significantly among well types were F and Mn. Tukey analysis showed that domestic, drainage, and industrial wells had levels of F significantly higher than in municipal wells.

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

- Groundwater quality parameter level variations with groundwater depth were examined using three methods: linear, exponential, and biphasic. Using analytical results from the 42 randomly sampled wells indicated that 9 of the 18 parameters examined had one or more mathematical equations significantly relating these parameter levels to groundwater depth. These parameters included total alkalinity, hardness, turbidity, Ca, nitrate, TKN, SO_4, Fe, and Mn. A pattern emerged in which the concentration of these 9 groundwater quality parameters would decrease with increasing groundwater depth below land surface (bls). Using the same methods, parameter levels within each groundwater zone and physiographic area were also examined for relationships with groundwater depth. Generally groundwater zone results were similar to the overall results, while fewer significant relationships were found within physiographic areas.

- Groundwater quality parameter levels were compared to one another using the Pearson correlation coefficient to determine their strength of association. There were many significant positive correlations using the overall analytical results, indicating that as the levels of one groundwater quality parameter vary, the levels of many other groundwater quality parameters tend to have a corresponding change in concentration. Of the 18 parameters in the matrix, hardness, Ca, Mg, TDS, SO_4, Fe, Mn, turbidity, Cl, TKN, total alkalinity, B, Na, K, and NH_3-N had significant correlations with at least 50% of the other parameters while pH, nitrate, F, and As had significant correlations with less than 50% of the other parameters. The correlations between parameter levels were typically positive (except generally for pH and nitrate), indicating that with most parameters, as the concentration of a parameter rises, other parameters tend to have a corresponding increase. Similar results occurred when the data base was divided into groundwater zones, while fewer significant groundwater quality parameter level correlations were found when using only physiographic areas.

D) By the use of targeted sampling, assess the impact on groundwater from potential contaminant sources related to specific land uses:

- Limited targeted groundwater sampling was conducted near the permitted biosolids application area (Yuma Mesa), the Cocopah Landfill (Yuma Mesa), the Yuma County Septic Advisory Area (Yuma Valley), and the City of San Luis (Yuma Mesa). Groundwater quality sampling results from targeted wells considered most likely to have impacts from these potential contaminant sources were compared with 95% Confidence Intervals developed for the area to investigate possible influences. Few parameter levels from the targeted samples exceeded the upper 95% Confidence Levels; therefore based on this approach, no groundwater quality impacts were discerned from any of these land uses.

E) To identify trends in groundwater quality:

- A time-trend analysis was conducted using groundwater quality collected by ADEQ in 1995 and the USBR in 1989-90 from the same 15 YGB wells, the majority of which are located in the lower, coarse-gravel zone. Linear regression revealed less than a 2% overall variation between 15 parameters in the two data sets while a Wilcoxon test showed only K and SO_4 had significant higher parameter levels for the 1995 ADEQ samples than the 1989-90 USBR samples. Based on data collected for these two studies, it does not appear that groundwater quality in the YGB has significantly changed during the five years between the studies.

F) Establish an ambient groundwater monitoring well network in the YGB:

- An ambient groundwater quality monitoring index well network composed of 18 wells has been established in the YGB. Similar to this study, the well selection follows a statistical design with the wells being equally divided between the two upper groundwater zones and three physiographic areas. The ambient index well network will be resampled at intervals greater than five years based on the few significant groundwater quality parameter level changes between the 1989-90 USBR study and the 1995 ADEQ study.

11. DISCUSSION AND RECOMMENDATIONS

This regional study to assess the groundwater quality of the Yuma Groundwater Basin (YGB) had six major objectives: obtain baseline data throughout the basin, examine groundwater quality differences between various spatial areas, assess the impact on groundwater quality from specific land uses, investigate groundwater quality changes over time, and establish an ambient monitoring index well network. The results of the study indicated the following key discussion and recommendations for each objective:

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

- ADEQ's 1995 sampling results of inorganic parameters met Primary MCLs standards and AWQS - except in very limited areas due to nitrate levels - and therefore, is an acceptable resource for domestic purposes. However, based on Secondary MCLs standards, aesthetic qualities of the groundwater such as taste, odor, and color impact its usefulness for tasks such as drinking, cooking, and other domestic needs. As a result, most domestic households use their well water only for non-potable purposes and have drinking water trucked in for use. The intensive irrigation that occurs in the basin may have contributed to these groundwater characteristics; in regions of high agricultural use, Cl and nitrate are parameters which can be used to assess groundwater quality. High SO_4 and TDS levels, which are commonly associated with agricultural return flows, may also impact groundwater (ITFM Technical Appendix, 1994).

- The nitrate source for eastern Gila Valley is presently unknown as the area consists primarily of unimproved desert land there is little agricultural activity, residential development, or industrial operations. The limited historical groundwater quality data in this area suggests the elevated nitrate levels may have existed for at least five years. A more detailed targeted study in this area would be difficult without the drilling of monitoring wells as most of the available wells around the VFW Post were sampled as part of this study. The nitrate source in the Yuma Mesa may be due to a combination of much greater quantities of irrigation water needed to grow crops there because of the porous sands (Yuma Mesa Irrigation District, 1997) and the consequential leaching of fertilizers through these porous sands (USBR, 1991). This process may be especially prevalent in areas of Yuma Mesa not underlain by the Clay B soil layer.

- Based on ADEQ's 1995 sampling results of the banned pesticides DBCP and EDB, it appears these compounds may no longer be present in detectable levels in the YGB. Historically, these pesticides were detected with great frequency in studies conducted in the Yuma area in 1979 and 1984 respectively, after which the pesticides were subsequently banned. These pesticides were still being detected in groundwater at the time of a 1987 ADEQ study. Available information on these pesticides suggests DBCP is very persistent in soil (Howard, 1991). Another publication noted that because of the compound's hydrolytic stability and the limited biological activity in subsurface soils, DBCP leached to the groundwater is expected to persist for years (Clement Associates, Inc., 1990b). EDB also appears to be potentially very persistent in the groundwater, with a reported hydrolysis half-life in sterilized water at pH 7 reported to be 14 years (Ali and Richard, 1984), though the authors note that information on EDB degradation in soil and water is fragmentary and conflicting. From the lack of confirmed detections of these pesticides in the groundwater sampling conducted in 1995, it appears that the movement and mixing of groundwater may be the reason the levels of these compounds are below detection levels.

- Typically, once groundwater contains chemicals such as DBCP and EDB, aquifers tend to remain contaminated because of insufficient dilution and the slow movement of groundwater in most aquifers. From the data available on these compounds, it is not definitive whether the non-detections of DBCP and EDB in the YGB is due to the rapid movement and mixing of groundwater that occurs in the Yuma aquifer or from biological breakdown. However, based on the results of this study, levels of these pollutants are below laboratory detection limits. Thus, an interesting follow-up study would be to resample sites in the Phoenix area where DBCP and EDB were detected in the groundwater in 1979 and 1984 to determine if these pesticides are still present. The results from this sampling may provide a better indication if movement and mixing of the groundwater or biological breakdown was more important in the disappearance of DBCP and EDB below detection limits from groundwater in the Yuma-area.

- Although some currently registered pesticides on the GWPL, such as dicamba and 2,4-D, were detected in shallow groundwater elevation observation wells in the Yuma-area during sampling by the ADEQ Pesticide Contamination Prevention Program in 1994-95, sampling of production wells conducted as part of this study failed to detect any of these pesticides. Groundwater pesticide sampling in the area by the ADEQ Pesticide Contamination Prevention Program is an on-going process.

- Public health threats to groundwater by radionuclides in the Yuma-area was suggested by the occurrence of Tertiary sedimentary rocks with above average uranium concentrations in the YGB (Jenkins, 1989). This potential impact to Yuma-area groundwater from nearby uranium-bearing rocks was also recognized in a 1993 joint USGS-ADEQ radionuclide study (Duncan and others, 1993). Limited groundwater sampling for radionuclides in this study did not indicate any exceedences of Primary MCLs.

B) Examine various spatial areas within the YGB for statistically significant groundwater quality differences:

- Data from this study has shown that no significant differences exist in groundwater quality parameter levels between the uppermost water zones (fine-grained and coarse-gravel) in the YGB. This finding contradicts popularly-held thought that groundwater quality of the upper, fine-grained zone is poorer than that associated with the lower, coarse-gravel zone. Wells are most often developed in the coarse-gravel zone because of greater water production in that zone - not because of better groundwater quality. However, the levels of many groundwater quality parameters do significantly decrease with groundwater depth as was statistically determined in another section of this report. This finding - along with the similar water chemistry of the groundwater samples collected - supports the statement that the majority of groundwater in both the upper, fine-grained zone and the lower, coarse-gravel zone in the Yuma area is largely recharged irrigation water from the Colorado River (Olmstead and others, 1973).

- Many significant differences exist in groundwater quality parameter levels among physiographic areas within the YGB, with parameter levels generally significantly higher in the Gila Valley than the Yuma Mesa, with parameter levels in Yuma Valley generally falling between these two extremes and not significantly different from either. The higher groundwater quality parameter levels present in Gila Valley have been noted by previous studies (Olmstead and others, 1973). Reasons for these groundwater quality differences appear to be explained by examining the historical development of irrigated farmland in each physiographic area; however, this cannot be confirmed because of the lack of Gila Valley pre-irrigation groundwater quality data.

Although irrigation on Yuma Mesa began in 1923 with the construction of the Unit B-Yuma Auxiliary Project (Hill, 1993), agricultural development of land in the Yuma Mesa was largely a post World War II phenomenon, as only 2000 acres of farmland were irrigated as late as 1943. Irrigated acreage increased to about 20,000 acres chiefly in citrus orchards and alfalfa, by 1959, at which time it stabilized (Olmstead and others, 1973). Irrigation on Yuma Mesa was provided by Colorado River water; thus a fresh source of water was continually recharging the aquifer. In contrast, although farmland in the North Gila Valley has historically been irrigated with Colorado River water, farmland in the South Gila Valley was irrigated exclusively with groundwater from the earliest agricultural developments in the 1910s until 1965, when almost 10,000 acres were in agricultural production. Colorado River water became available in 1965 and is now the chief source of irrigation water, although substantial quantities of groundwater are still pumped from depths as great as 600 feet to obtain water of better quality (Olmsted and others, 1973). Farmland in the Yuma Valley, although intensively farmed since about 1897, has always had irrigation needs predominately provided by Colorado River water, thus also continually recharging the aquifer with a fresh water source.

Based on the results of this study and this historical data, it appears that the source of irrigation water is an an important factor in the prediction of groundwater quality in the YGB. Deterioration of groundwater quality is often observed in areas of irrigation development because of the increase in concentration of salts as a result of evapotranspiration (Olmstead and others, 1973). Moreover, the rate of deterioration is increased when water pumped from the wells is reused in the vicinity for irrigation; this practice increases the intensity of recycling and eventually results in groundwater too saline/sodic for domestic or irrigation use (Hem, 1986). In areas where the water table beneath the irrigated land can be kept far below the surface and thus not be affected by the percolating, recycled water, temporarily using groundwater for irrigation can be reasonably effective. However, continually using groundwater for irrigation tends to degrade the quality of water found in an aquifer, particularly where the groundwater is very shallow as in Gila Valley. Continually recharging the aquifer with fresh surface water, such as from the Colorado River, tends to have less of a negative impact on groundwater quality.

The water needs of cotton, a common crop the Yuma-area, can be used to illustrate this process. The irrigation needed to grow an acre of cotton is about 5 acre-feet of water per year; four acre-feet are used by the crop for evapotranspiration and the remaining 1 acre-foot is used for salt leaching and percolates downward through the root zone (Bouwer, 1997). Since the portion of irrigation water that is actually consumed by plants or lost to evaporation is virtually free of dissolved material, the percolating water carries the vast majority of salts that were in the irrigation water, plus residues of fertilizer and pesticides that may have been applied. This mineral and salt-rich water eventually recharges the underlying aquifer (Hem, 1986). Concentrations of nitrate and pesticides in this deep percolation water can be reduced by utilizing best management practices, but salt loadings on the groundwater cannot be reduced (Bouwer, 1997).

If the cotton is grown with water supplied from the Colorado River, as is the case in Yuma Mesa, Yuma Valley, and parts of Gila Valley, this water source has TDS levels averaging about 750 mg/l just above Imperial Dam (USGS, 1995). The deep percolation from this irrigation is of low-quality water, carrying with it 3750 mg/l (750 mg /l x 5 acre-feet) salt concentration. In other words, the 1 acre-foot used for salt leaching carries with it all the salt contained within the original 5 acre-feet irrigation application. For comparison purposes, groundwater pumped to irrigate cotton from Gila Valley has TDS levels averaging 2600 mg/l. The deep percolation from this irrigation is of very low-quality water, carrying with it 13,000 mg/l (2600 mg/l x 5 acre-feet) salt concentration. Thus, the source of irrigation water can have a very important influence on the groundwater quality in the YGB. Based on continued reuse of groundwater in portions of the Gila Valley, it's not surprising that groundwater quality parameter levels are often significantly higher in Gila Valley than in Yuma Mesa and Yuma Valley.

Other factors which may influence groundwater quality include duration of irrigation, groundwater depth, and groundwater movement. While most groundwater parameter levels are significantly higher in Gila Valley than the Yuma Mesa, this relationship does not exist between Gila Valley and Yuma Valley even though both Yuma Mesa and Yuma Valley both predominantly utilize Colorado River water for irrigation. The low-quality, deep percolation water discussed above may help explain this difference. This deep-percolation water typically moves downward at a velocity of 6.7 ft/yr in unconfined aquifers (Bouwer, 1997) and appears to affect groundwater quality in Yuma Valley to a larger extent than Yuma Mesa. For instance, at the rate of recharge of 6.7 ft/yr and with an average groundwater depth of 15 feet bls in the Yuma Valley, this salt-laden recharge may take approximately 2.3 years to reach the groundwater as compared with approximately 12 years on the Yuma Mesa, which has an average groundwater depth of 80 feet bls. This recharge has been occurring on a large scale in Yuma Valley since 1897 as compared with since approximately 1959 in Yuma Mesa. Thus, a combination of Yuma Valley having been intensively irrigated for a much longer period of time as well as having a much shallower groundwater level than that in Yuma Mesa are potential factors which may explain the groundwater quality parameter level differences between Yuma Valley and Yuma Mesa.

Another potential influence on the different groundwater quality parameter levels among physiographic areas is the movement of groundwater. Although groundwater depths are greatest in the Yuma Mesa, groundwater elevations are also the highest in this area since it is a river terrace. The continued recharge of imported surface water from the Colorado River has created a groundwater "mound" on the Yuma Mesa, with groundwater continually moving to the north and west from this mound towards Gila Valley and Yuma Valley. With this movement, groundwater beneath the Yuma Mesa - particularly recharged water - is continually flushed from the area towards the lower valleys.

- No significant groundwater quality differences existed among well types (and the associated land use). One should use caution in interpreting this result as irrigated cropland, urban development, and industrial development are largely interspersed throughout the YGB, with urban and industrial development often located in formerly irrigated agricultural areas. Without definitive, long-term geographic areas of land use, the impacts from particular land uses are difficult to assess. Using well types rather than land uses for analysis further masks any impacts from specific land uses since, as an example, a domestic well could be located in an agricultural area.

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

- Although there were no significant differences in groundwater quality parameter levels between groundwater zones, mathematical models revealed approximately half of the examined parameters exhibited a pattern in which the level of a groundwater quality parameter would decrease with increasing groundwater depth. This is an important finding for those seeking to locate and screen a well that would provide a generally better source of groundwater and/or seek to minimize the levels of particular groundwater quality parameters. Thus, even while there were no significant differences between groundwater quality parameter levels between the two groundwater zones, this observation indicates that groundwater pumped from deeper depths of the aquifer may generally provide a less saline source of water.

- The level of many groundwater quality parameters, especially major ions, are positively correlated with the level of other groundwater quality parameters regardless of whether it was based on groundwater zone, physiographic area, or the overall results. As such, this correlation can be a valuable tool in interpolating probable levels of certain groundwater quality parameters where only partial analytical analyses are available. These statistically-significant correlations may also be used to monitor for only an "indicator" parameter instead of an entire suite of parameters, thus saving money especially if a field parameter is used (Nyer and Stauss, 1997). Also of interest are the many significant positive correlations between the majority of parameters (including major ions, nutrients, and trace elements) compared with nitrate, F, and As levels which had either no significant correlations or significant negative correlations with other parameter levels. This finding suggests that there may be a common source for most groundwater quality parameters such as recharged irrigation water from the Colorado River. In contrast, F and As may be naturally occurring while nitrate might have another source other than recharged Colorado River irrigation water.

D) By the use of targeted sampling to assess the impact on groundwater from potential contaminant sources related to specific land uses:

- This was a regional study and was not designed to extensively evaluate water quality in specific local areas. It should be emphasized that these targeted samples were reconnaissance-type samples rather than extensive studies of each land use and may be insufficient in both numbers of samples and well perferation depths for any broad conclusions to be drawn from them.

E) To identify trends in groundwater quality:

- In this study, few statistical differences were observed in groundwater quality temporal trends. Although a study by Hill (1993) indicates there is a great deal of groundwater movement within the YGB, only K and SO_4 had significant parameter level increases between the groundwater sampled by the USBR 1989-90 and ADEQ in 1995. This indicates the composition of the water has not changed widely over this time period. There are several caveats to this conclusion: the 15 wells are predominantly screened in the lower, coarse-gravel zone which may not show water quality changes in the upper, fine-grained zone; at the same time, the wells were not selected on a random basis.

F) Establish an ambient groundwater monitoring well network in the YGB:

- Groundwater quality change is typically a relatively slow process. Statistical analysis has revealed few significant differences among groundwater samples collected from the same wells in 1989-90 and 1995; thus, the composition of the water has remained relatively stable during this period. On this basis, it is recommended that the ambient groundwater monitoring index wells be resampled at an interval greater than five years. This recommendation goes along with Nyer and Stauss (1997) who note that groundwater monitoring programs should be based upon the rate of groundwater movement, the physical and geochemical properties of the aquifer, and the biogeochemistry of any contaminants in the aquifer. These authors also laud the utility of performing statistical analysis of the variation in existing data to evaluate and set the frequency of sampling events. Finally, this sampling frequency is flexible and could be altered by the occurrence of an unusual event such as a hundred-year flood in order to determine its impacts on groundwater quality.

12. REFERENCES

Ali, Syed M. and Richard, Nancy Jo., 1984. *Ethylene Dibromide (EDB): A Water Quality Assessment.* California State Water Resources Control Board Special Projects Report No. 84-8SP, p. 35.

Alley, William M., ed, 1993. *Regional Groundwater Quality.* Van Nostrand Reinhold: New York, NY.

Arizona Department of Environmental Quality, 1989. *Quality Assurance Project Plan.* ADEQ: Water Quality Standards Unit: Phoenix, AZ.

Arizona Department of Environmental Quality, 1996. *The Main Water Line: October 14, 1996.* ADEQ: Phoenix, AZ, p. 4.

Arizona Department of Health Services, 1984. *Results of 1984 Ethylene Dibromide (EDB) Sampling in Arizona.* ADHS: Phoenix, AZ.

Arizona Department of Water Resources, undated. *Total Dissolved Solids Content of Aquifers of the Basin and Range and the C-Aquifer.* ADWR: Phoenix, AZ.

Arizona Department of Water Resources, 1994. *Arizona Water Resources Assessment - Volume II Hydrologic Summary.* ADWR: Phoenix, AZ.

Arizona Water Resources Research Center, 1995. *Field Manual for Water Quality Sampling.* University of Arizona: Tucson, AZ.

Barlow, Gregory W. And Spencer, Linda L, 1996. *A New Method for Designating Beneficial Uses of Groundwater: A San Francisco Area Application.* National Groundwater Association Convention Abstracts, p. 57.

Bitton, Gabriel and Gerba, Charles P., 1994. *Groundwater Pollution Microbiology.* Krieger Publishing Company: Malabar, Fl.

Bouwer, Herman, 1997. *Arizona's Long-Term Water Outlook: From NIMTO to AMTO - Part II.* Arizona Hydrologic Society Newsletter, Volume 14, Issue 5.

Clement Associates, Inc., 1990a. *(Draft) Toxicological Profile for 1,2-Dibromo-3 Chloropropane.* U.S. Public Health Service Agency for Toxic Subtances and Disease Registry: Contract No. 205-88-0608, p. 83.

Clement Associates, Inc., 1990b. *(Draft) Toxicological Profile for 1,2-Dibromothane.* U.S. Public Health Service Agency for Toxic Substances and Disease Registry: Contract No. 205-88-0608, p. 94.

Conover, W.J., 1980. *Practical Non-Parametric Statistics.* 2nd Edition, John Wiley & Sons: New York, NY.

Crockett, Janet K., 1995. *Idaho Statewide Groundwater Quality Monitoring Program-Summary of Results, 1991 Through 1993.* Idaho Department of Water Resources: Boise, ID.

Daniel, Debra L., Munson, Brian E., and Graf, Charles G., 1988. *Groundwater Contamination by Pesticides in Arizona: An Overview.* ADEQ: Phoenix, AZ.

Duncan, J.T., Spencer, J.E., Eshraghi, P., and Emrick, S., 1993. *A Reconnaissance Study of Radon and Other Radionuclides in Arizona Well Water.* ADEQ: Phoenix, AZ.

Fransom, Mary, Ed., 1989. *Standard Methods for the Examination of Water and Wasterwater.* American Public Health Association: Washington, D.C.

Hadeed, Samuel J., 1979. *Dibromochloropropane (DBCP) Well Sampling Program for Yuma County, Arizona.* ADHS: Phoenix, AZ.

Harris, J., Loftis, J.C., and Montgomery, R.H., 1987. *Statistical Methods for Characterizing Groundwater Quality.* Ground Water, v. 25, p.185-193.

Helsel, D.R., and Hirsch, R.M. 1997. *Statistical Methods in Water Resources.* Elsevier Publishing: New York, NY.

Hem, John D., 1986. *Study and Interpretation of the Chemical Characteristics of Natural Water.* USGS Water-Supply Paper 1473: Washington, D.C.

Hill, Bradley M., 1993. *Hydrogeology, Numerical Model and Scenario Simulations of the Yuma Area Groundwater Flow Model, Arizona, California, and Mexico.* ADWR: Phoenix, AZ.

Hood, Wayne K, III., 1991. *A Plan To Establish Ambient Groundwater Quality Monitoring Networks in Arizona.* ADEQ: Phoenix, AZ.

Howard, Philip H., ed., 1991. *Handbook of Environmental Fate of and Exposure Data for Organic Chemicals.* Lewis Publishers, Inc: Chelsea, MI, p. 223.

Jenkins, Robin D., 1989. *Radionuclides in Groundwater and Their Occurrance in Arizona.* Paper presented at the Annual Symposium of the Arizona Hydrologic Society, Casa Grande, AZ, September 14-16, 1989.

Mock, Peter A, Burnett, Earl E., Hammett, B.A., 1988. *Digital Computer Model Study of Yuma Area Groundwater Problems: Associated with Increased River Flows in the Lower Colorado River From January 1983 to June 1984.* ADWR Open-File Report No. 6: Phoenix, AZ.

Mumme, Stephen P., 1988. *Apportioning Groundwater Beneath the U.S.-Mexico Border.* UCSD Center for U.S.-Mexican Studies: San Diego, CA.

Munson, Brian E., 1995. *Professional Letter to Joyce Wilson, Yuma City Administrator.* ADEQ: Phoenix, AZ.

Nyer, Evan K., and Stauss, Lynne, 1997. *Monitoring Plans.* Ground Water Monitoring Research, Fall 1997, p.67-70.

Olmstead, F.H., Loeltz, O.J., and Irelan, Burdge, 1973. *Geohydrology of the Yuma Area, Arizona and California.* USGS Professional Paper 486-H: Washington, D.C.

Robertson, F.N., 1986. "Occurrence and solubility controls of trace elements in groundwater in alluvial basins of Arizona" in Anderson, T.W., and Johnson, A.I., eds., *Regional Aquifer Systems of the United States, Southwest Alluvial Basins of Arizona.* American Water Resources Association Monography Series No. 7, p. 69-80.

Sellers, W.D., Hill, R.H., and Sanderson-Rae, Margaret, eds., 1985. *Arizona Climate - the First Hundred Years: 1885-1985.* University of Arizona Press: Tucson, AZ.

United States Geological Survery, 1995. *Water Resources Data, Arizona, Water Year 1995.* U.S. Geological Survery: Tucson, AZ.

United States Bureau of Reclamation, 1991. *Ground-Water Status Report 1989 Yuma Area - Arizona, California.* Yuma Projects Office: Yuma, AZ.

Wilkins, D.W., 1978. *Maps Showing Ground-Water Conditions in the Yuma Area, Yuma County, Arizona - 1975.* USGS Water Resources Investigations 78-62: Tucson, AZ.

Wilkinson, Leland and Hill, MaryAnn, 1994. *Using Systat.* Systat, Inc: Evanston, IL.

Williams, Roland, 1987. *Yuma Basin Pesticide Monitoring Team Groundwater Sampling Summary Report.* ADEQ: Phoenix, AZ.

Woodward-Clyde Consultants, 1987. *Agricultural Drastic Map of Ground Water Pollution Potential: Yuma County.* ADEQ: Phoenix, AZ.

Woodward-Clyde Consultants, 1987. *General Drastic Map of Ground Water Pollution Potential: Yuma County.* ADEQ: Phoenix, AZ.

Yuma Daily Sun, 1995. *All is Not Well in Soggy Yuma: USBR's Solution to Groundwater Problems Carries $10.3 Million Pricetag.* June 28, 1995.

Yuma Mesa Irrigation District, 1997. Verbal communication.

Appendix A. Characteristics of Wells Selected for Groundwater Monitoring in the Yuma Groundwater Basin (YGB)

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Depth Wl (ft)	Casing Dia (in)	Perforation Interval (ft)	Depth Wtr-ft	Aquifer Zone(s)
55-504513	Yuma-001A	(C-09-23)20bab	13th Street - Yuma County Water Users	Drainage	234'	24"	142'-169' 204'-227'	20.8'	coarse-gravel
None	Yuma-002A	(C-11-24)23bca	International Cattle Exchange	Stock, Domestic	N/A	N/A	N/A	80'	fine-grained
55-522655	Yuma-003A	(C-11-25)12baa	North Well Field - City of San Luis	Municipal	203'	8"	101'-201'	59'	coarse-gravel
55-84812	Yuma-004A	(C-11-25)12bdb	Central Well Field - City of San Luis	Municipal	210'	8"	160'-200'	58'	coarse-gravel
None	Yuma-005A	(C-10-23)17dca	State of AZ - Evans	Irrigation	N/A	N/A	N/A	N/A	coarse-gravel
55-85073	Yuma-006A	(C-10-23)35bdc	Evans	Irrigation	455'	16"	299'-455'	179'	coarse-gravel wedge
55-505548	Yuma-007A	(C-10-23)28ccb	Kofa Jojoba - Evans	Irrigation	403'	16"	282'-403'	105'	coarse-gravel wedge
55-627019	Yuma-010A	(C-10-24)01cdc	YV-23 - USBR	Drainage	179'	24"	N/A	100.5'	coarse-gravel
55-646366	Yuma-011A	(C-09-23)17dcc	Moorhead - Hunter	Domestic	30'	4"	N/A	5'	fine-grained
55-626998	Yuma-012A	(C-08-22)26bbb	SG-714 - USBR	Drainage	135'	20"	N/A	41'	coarse-gravel
55-518336	Yuma-013A Yuma-063A	(C-08-21)29abb	Morris	Domestic	80'	6"	60'-80'	40'	fine-grained
55-538381	Yuma-014A Yuma-038A	(C-08-21)21bab	VFW	Domestic	85'	5"	65'-85'	32'	fine-grained
55-626986	Yuma-015A	(C-08-22)33cbb	SG-6 - USBR	Drainage	204'	20"	N/A	27'	coarse-gravel

N/A = Information Not Available

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

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth (ft)	Casing Diamtr (in)	Perforation Interval (ft)	Water Depth (ft)	Aquifer Zone(s)
55-518119	Yuma-016A	(C-09-22)17bcb	Ford - Swainn	Domestic	125'	5"	105'- 125'	52.5'	fine-grained
55-536951	Yuma-017A Yuma-018A	(C-10-23)08baa	Webb	Domestic	205'	5"	185'- 205'	77.5'	coarse-gravel
None	Yuma-019A	(C-09-23)20bbc	Bierman	Irrigation	14'	2"	N/A	9'	fine-grained
None	Yuma-020A	(C-09-24)10dcb	Garcia	Irrigation	N/A	N/A	N/A	N/A	fine-grained
55-604925	Yuma-021A	(C-11-25)02bba	Brown	Irrigation	240'	20"	N/A	20'	coarse-gravel
55-511849	Yuma-022A	(C-09-21)09ccc	Far West Water Co.	Municipal	268'	8"	N/A	208'	coarse-gravel
55-522783	Yuma-023A	(C-07-22)27bbd	Ott	Domestic	105'	5"	85'- 105'	13'	coarse-gravel
55-503291	Yuma-024A	(C-08-23)27add	H & H Seed Company	Domestic	120'	6"	82'- 112'	11'	coarse-gravel
55-618702	Yuma-025A	(C-08-24)27aba	U of AZ Valley Ag	Domestic	125'	6"	N/A	6'	coarse-gravel
55-512706	Yuma-026A	(C-09-23)29ddc	U of AZ Mesa Ag Station	Domestic	233'	6"	173'- 233'	30'	coarse-gravel
55-514819	Yuma-027A	(C-09-23)33ccc	Unit "B" Irr Office	Domestic	220'	6"	200'- 220'	80'	coarse-gravel
55-505855	Yuma-028A	(C-09-24)15aab	Main St Park - City of Somerton	Irrigation	67'	9"	N/A	7'	fine-grained
55-629173	Yuma-029A	(C-09-24)15aab	Schmit Aviation - Ogram	Domestic	32'	2"	N/A	8'	fine-grained
55-647154	Yuma-030A	(C-09-24)21acb	Smart - Valley Meat	Domestic	24'	2"	N/A	15'	fine-grained

N/A = Information Not Available

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

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth (ft)	Casing Diamtr (in)	Perforation Interval (ft)	Water Depth (ft)	Aquifer Zone(s) Tapped
55-615593	Yuma-031A Yuma-032A	(C-10-24)16dca	State of AZ - EMCO Livestock	Domestic Stock	24'	8"	N/A	12'	coarse-gravel
55-640999	Yuma-033A	(C-08-24)24dbb	Combs	Domestic	106'	2"	N/A	10'	fine-grained
55-636181	Yuma-034A	(C-08-21)09bad	Nickerson	Domestic	34'	6"	N/A	12'	fine-grained
55-500899	Yuma-035A	(C-08-21)29acc	Yuco Gin Co.	Industrial	180'	8"	140' - 180'	38'	coarse-gravel
55-536882	Yuma-036A	(C-08-21)04dda	Adair Ranges	Domestic	70'	5"	50' - 70'	12'	fine-grained
55-590250	Yuma-037A	(C-08-21)01bbb	Wltn-Mhwk Ir	Irrigation	150'	20"	85' - 145'	14'	coarse-gravel
55-648483	Yuma-039A	(C-08-21)29abd	Daily	Domestic	60'	6"	N/A	30'	fine-grained
55-625464	Yuma-040A	(C-08-21)16bbd	Tanner Company	Industrial	396'	16"	30'- 396'	51'	fine-grained coarse-gravel
55-539941	Yuma-041A	(C-08-21)21cdc	Gowan Company	Industrial	268'	10"	192' - 238'	41'	coarse-gravel
55-611670	Yuma-042A	(C-08-22)15cca	Czajkowski	Domestic	35'	2"	N/A	30'	fine-grained
55-603775	Yuma-043A	(C-08-22)14abc	Bean - Yuma Lakes	Domestic	100'	4"	N/A	18'	coarse-gravel
55-606747	Yuma-044A	(C-08-22)12ddd	Sturges Farm	Domestic	50'	8"	N/A	20'	fine-grained
55-606742	Yuma-045A Yuma-046A	(C-08-21)18cad	Sturges Farm	Irrigation	130'	24"	N/A	30'	coarse-gravel
55-630032	Yuma-047A Yuma-048A	(C-08-21)29adb	Bowman	Domestic	55'	6"	N/A	40'	fine-grained
55-86900	Yuma-049A	(C-09-22)12bbd	Edenburn	Domestic	165'	6"	125' - 165'	76'	fine-grained

N/A = Information Not Available

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

ADWR Well #	Sample Name	Well Location	Well Name - Owner	Well Use	Well Depth (ft)	Casing Diamtr (in)	Perforation Interval (ft)	Water Depth (ft)	Aquifer Zone(s) Tapped
55-630410	Yuma-050A	(C-08-22)03bbb	Crump	Domestic	95'	4"	N/A	15'	fine-grained
55-508044	Yuma-051A	(C-08-22)30bad	Hartley	Domestic	95'	3"	82'- 90'	8'	fine-grained
55-525843	Yuma-052A	(C-10-25)13cca	Corona - Juarez	Domestic	172'	5"	152'-172'	15'	coarse-gravel
55-627046	Yuma-053A	(C-09-23)05bcb	Klein	Irrigation	25'	2"	N/A	4'	fine-grained
None	Yuma-054A	(C-09-22)07ccc	Woodman	Domestic	110'	6"	N/A	58'	fine-grained
55-522880	Yuma-055A	(C-09-23)13aad	Woodman	Domestic	164'	8"	144'- 164'	58'	coarse-gravel
55-646243	Yuma-056A	(C-09-22)07aba	Haile	Domestic	160'	8"	N/A	57'	coarse-gravel
55-646584	Yuma-057A	(C-09-22)19baa	Brown	Domestic	125'	2"	N/A	53'	fine-grained
55-601146	Yuma-058A	(C-09-23)24aaa	Gunlock	Domestic	162'	4"	N/A	55'	coarse-gravel
55-631482	Yuma-059A	(C-10-23)14dda	McElvain	Domestic	134'	6"	N/A	98'	fine-grained
55-505541	Yuma-061A	(C-10-24)01bcc	Johnson	Domestic	159'	6"	147'- 157'	9'	coarse-gravel
None	Yuma-062A	(C-10-24)01bab	N/A	N/A	N/A	8"	N/A	N/A	N/A
55-651206	Yuma-064A	(C-08-21)29aaa	Gonzales	Domestic	70'	4"	N/A	25'	fine-grained

N/A = Information Not Available

Appendix B. Characteristics of Groundwater Samples Collected in the YGB

Sample Name	Well Name	Well Location	Sample Date	Type of Sample	Factors Related to Sample Location	MCL Exceedences
Yuma-001A	YCWUA 13th St. Drainage	(C-09-23)20bab	02/28/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Valley coarse-grained zone - USBR previously sampled	TDS, Cl, SO_4, Mn
Yuma-002A	International Cattle Exchange	(C-11-24)23bca	03/01/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Mesa fine-grained zone - Animal feedlot - USBR previously sampled	TDS, Cl, Mn
Yuma-003A	City of San Luis North Well Field	(C-11-25)12baa	03/01/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Mesa coarse-gravel zone	TDS, Cl, SO_4, Mn
Yuma-004A	City of San Luis Central Well Field	(C-11-25)12bdb	03/01/95	SDW Inorganic + 5 EDB & DBCP	- Urban area - Near Mexico - USBR previously sampled	TDS, Mn
Yuma-005A	Kenny Evans "I"	(C-10-23)17dca	03/02/95	SDW Inorganic + 5 EDB & DBCP	- Biosolids project area - Near EDB & DBCP area - USBR previously sampled	TDS, SO_4, Mn
Yuma-006A	Kenny Evans "II"	(C-10-23)35bdc	03/02/95	SDW Inorganic + 5 EDB & DBCP	- Biosolids project area	TDS, Cl, Mn
Yuma-007A	Kofa Jojoba	(C-10-23)28ccb	03/02/95	SDW Inorganic + 5 EDB & DBCP	- Biosolids project area	TDS, Cl, SO_4, Mn
Yuma-010A	USBR - YV23	(C-10-24)01cdc	03/20/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Valley coarse-grained zone - USBR previously sampled	TDS, Cl, SO_4, Mn
Yuma-011A	Hunter	(C-09-23)17dcc	03/20/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- In YCHD Groundwater Septic Advisory Area	TDS, SO_4, Mn
Yuma-012A	South Gila Drainage #714	(C-08-22)26bbb	03/21/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Gila Valley coarse-grained zone - USBR previously sampled	TDS, Cl, SO_4, Fe, Mn

Appendix B. Characteristics of Groundwater Samples Collected in the YGB--Continued

Sample Name	Well Name	Well Location	Sample Date	Type of Sample	Factors Related to Sample Location	MCL Exceedences
Yuma-013A	Morris	(C-8-21)29abb	03/21/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Near industrial plant - Response to citizen complaint	TDS, SO_4, NO_3-N, Mn
Yuma-014A	VFW	(C-08-21)21bab	03/21/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Gila Valley fine-grained zone	TDS, Cl, SO_4, NO_3-N
Yuma-015A	South Gila Drainage #6	(C-08-22)33cbb	03/21/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Gila Valley coarse-grained zone - USBR previously sampled	TDS, Cl, SO_4, Mn
Yuma-016A	Swainn	(C-09-22)17bcb	03/21/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Mesa fine-grained zone	TDS, SO_4
Yuma-017A	Webb	(C-10-23)08baa	03/21/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Mesa coarse-grained zone	TDS, SO_4
Yuma-018A	Webb	(C-10-23)08baa	03/21/95	SDW Inorganic + 5 EDB & DBCP	- QA/QC = Duplicate of Yuma-017A	TDS, SO_4
Yuma-019A	Bierman	(C-09-23)20bbc	03/21/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Valley fine-grained zone - Near Septic Advisory Area	TDS, Cl, SO_4, Mn
Yuma-020A	Garcia	(C-09-24)10dcb	03/22/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Valley fine-grained zone	TDS, SO_4, Fe, Mn
Yuma-021A	Brown	(C-11-25)02bba	03/22/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Valley coarse-grained zone	TDS, Cl, SO_4, Fe, Mn
Yuma-022A	Far West Water Company # 18	(C-09-21)09ccc	04/10/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Mesa coarse-grained zone	TDS, SO_4
Yuma-023A	Ott	(C-07-22)27bbd	04/10/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Gila Valley coarse-grained zone	TDS, Cl, SO_4, Fe, Mn

Appendix B. Characteristics of Groundwater Samples Collected in the YGB--Continued

Sample Name	Well Name	Well Location	Sample Date	Type of Sample	Factors Related to Sample Location	MCL Exceedences
Yuma-024A	H & H Seed Co.	(C-08-23)27add	04/10/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Gila Valley coarse-grained zone - USBR previously sampled	TDS, Cl, SO_4, Fe, Mn
Yuma-025A	U of AZ Valley Ag. Station	(C-08-24)27aba	04/10/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Valley coarse-gravel zone	TDS, SO_4, Mn
Yuma-026A	U of AZ Mesa Ag. Station	(C-09-23)29ddd	04/11/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Mesa coarse-gravel zone - DBCP & EDB area	TDS, SO_4
Yuma-027A	Unit "B" Irrigation Office	(C-09-23)33ccc	04/11/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Mesa coarse-grained zone	TDS, SO_4, NO_3-N
Yuma-028A	Somerton Main Street Park	(C-10-24)03bbb	04/11/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Valley fine-grained zone	TDS, Cl, SO_4, Fe, Mn
Yuma-029A	Schmit Aviation	(C-09-24)15aab	04/11/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Valley fine-grained zone	TDS, SO_4, Mn
Yuma-030A	Valley Meat Co.	(C-09-24)21acb	04/11/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Valley fine-grained zone	TDS, Cl, SO_4, Mn
Yuma-031A	EMCO Livestock	(C-10-24)16dca	04/11/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Valley coarse-gravel zone	TDS, SO_4, Fe, Mn
Yuma-032A	EMCO Livestock	(C-10-24)16dca	04/11/95	SDW Inorganic + 5 EDB & DBCP	- QA/QC = Duplicate of Yuma-031A	TDS, SO_4, Mn
Yuma-033A	Combs	(C-08-24)24dbb	04/12/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Valley fine-grained zone	TDS, Mn
Yuma-034A	Nickerson	(C-08-21)09bad	06/07/95	SDW Inorganic + 5	- Random sample for Gila Valley fine-grained zone - USBR previously sampled	TDS, SO_4

Appendix B. Characteristics of Groundwater Samples Collected in the YGB--Continued

Sample Name	Well Name	Well Location	Sample Date	Type of Sample	Factors Related to Sample Location	MCL Exceedences
Yuma-035A	Yuco Gin Co.	(C-08-21)29acc	06/07/95	SDW Inorganic + 5	- Random sample for Gila Valley coarse-gravel zone	TDS, Cl, SO_4, Mn
Yuma-036A	Adair Ranges	(C-08-21)04dda	06/07/95	SDW Inorganic + 5	- Proximity to high nitrate levels	TDS, Cl, SO_4, Fe, Mn
Yuma-037A	Wltn-Mohawk Ir	(C-08-21)01bbb	06/07/95	SDW Inorganic + 5	- Proximity to high nitrate levels - USBR previously sampled	TDS, Cl, SO_4, Fe, Mn
Yuma-038A	VFW Post	(C-08-21)21bab	06/07/95	SDW Inorganic + 5	- Resampling of well with high nitrate levels	TDS, Cl, SO_4, NO_3-N
Yuma-039A	Daily	(C-08-21)29abd	06/07/95	SDW Inorganic + 5	- Proximity to high nitrate levels	TDS, SO_4
Yuma-040A			06/07/95	SDW Inorganic + 5	- QA/QC = Equipment Blank	
Yuma-040A	Tanner Co.	(C-08-21)16bbd	06/08/95	SDW Inorganic + 5	- Proximity to high nitrate levels	TDS, Cl, SO_4
Yuma-041A	Gowan Co.	(C-08-21)21cdc	06/08/95	SDW Inorganic + 5	- Random sample for Gila Valley coarse-gravel zone - USBR previously sampled	TDS, Cl, SO_4, Mn
Yuma-042A	Czajkowski	(C-08-22)15cca	06/08/95	SDW Inorganic + 5	- Random sample for Gila Valley fine-grained zone	TDS, SO_4, Mn
Yuma-043A	Bean	(C-08-22)14abc	06/08/95	SDW Inorganic + 5	- Random sample for Gila Valley fine-grained zone	TDS, Mn
Yuma-044A	Sturges Farm	(C-08-22)12ddd	06/08/95	SDW Inorganic + 5	- Random sample for Gila Valley fine-grained zone	TDS, SO_4, Mn
Yuma-045A	Sturges Farm	(C-08-21)18cad	06/08/95	SDW Inorganic + 5	- Random sample for Gila Valley coarse-gravel zone - USBR previously sampled	TDS, Cl, SO_4, Fe, Mn
Yuma-046A	Sturges Farm	(C-08-21)18cad	06/08/95	SDW Inorganic + 5	- QA/QC = Duplicate of Yuma- 045A	TDS, Cl, SO_4, Fe, Mn
Yuma-047A	Bowman	(C-08-21)29adb	09/11/95	SDW Inorganic + 5 EDB & DBCP	- Proximity to high nitrate levels	TDS, Cl, SO_4, NO_3-N

Appendix B. Characteristics of Groundwater Samples Collected in the YGB--Continued

Sample Name	Well Name	Well Location	Sample Date	Type of Sample	Factors Related to Sample Location	MCL Exceedences
Yuma-048A	Bowman	(C-08-21)29adb	09/11/95	SDW Inorganic + 5	- QA/QC = Split of Yuma-047A	TDS, Cl, SO_4, NO_3-N
Yuma-049A	Edenburn	(C-09-22)12bbd	09/11/95	SDW Inorganic + 5 EDB & DBCP	- Random sample for Yuma Mesa fine-grained zone	TDS, Cl, SO_4
Yuma-050A	Crump	(C-08-22)03bbb	09/11/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticdes Radionuclides	- Random sample for Gila Valley fine-grained zone	TDS, Cl, SO_4, Fe, Mn
Yuma-051A	Hartly	(C-08-22)30dab	09/11/95	SDW Inorganic + 5 GWPL Pesticides Radionuclides	- Random sample for Gila Valley fine-grained zone	TDS, Cl, SO_4, Fe, Mn
Yuma-052A	Corona	(C-10-25)13cca	09/11/95	SDW Inorganic + 5 GWPL Pesticides Radionuclides	- Random sample for Yuma Valley coarse-gravel zone	TDS, Cl, SO_4, Fe, Mn
Yuma-053A	Klein	(C-09-23)05bcb	09/12/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides Radionuclides	- Random sample for Yuma Valley fine-grained zone	TDS, Cl, SO_4, Fe, Mn
Yuma-054A	Woodman	(C-09-22)07ccc	09/12/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Mesa fine-grained	TDS, SO_4
Yuma-055A	Woodman	(C-09-23)13aad	09/12/95	SDW Inorganic + 5	- Random sample for Yuma Mesa coarse-gravel zone	TDS, SO_4
Yuma-056A	Haile	(C-09-22)07aba	09/12/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides Radionuclides	- Random sample for Yuma Mesa coarse-gravel zone - USBR previously sampled	TDS, SO_4
Yuma-057A	Brown	(C-09-22)19baa	09/12/95	SDW Inorganic + 5 EDB & DBCP GWPL Pesticides	- Random sample for Yuma Mesa fine-grained zone	TDS, SO_4

Appendix B. Characteristics of Groundwater Samples Collected in the YGB--Continued

Sample Name	Well Name	Well Location	Sample Date	Type of Sample	Factors Related to Sample Location	MCL Exceedences
Yuma-058A	Gunlock	(C-09-23)24aaa	09/12/95	SDW Inorganic + 5	- Random sample for Yuma Mesa coarse-gravel zone - USBR previously sampled	TDS, SO_4
Yuma-059A	McElvain	(C-10-23)14daa	09/12/95	SDW Inorganic + 5 Radionucides	- Random sample for Yuma Mesa fine-grained zone	TDS, Cl, SO_4
Yuma-060A			09/12/95	SDW Inorganic + 5	- QA/QC = Travel Blank / Nitrate Spike	
Yuma-061A	Johnson	(C-10-24)01bcc	09/12/95	SDW Inorganic + 5	- Random sample for Yuma Valley coarse-gravel zone - ADHS previously sampled	TDS, Cl, SO_4, Fe, Mn
Yuma-062A	Not Available	(C-10-24)01bab	09/13/95	SDW Inorganic + 5	- Proximity to Cocopah Landfill	TDS, Cl, SO_4, Mn
Yuma-063A	Morris	(C-08-21)29abb	09/13/95	SDW Inorganic + 5 Radionuclides	- Resampling of well with high nitrate levels	TDS, SO_4, Mn, NO_3-N
Yuma-064A	Gonzales	(C-08-21)29aaa	09/13/95	SDW Inorganic + 5	- Proximity to high nitrate levels	TDS, Cl, SO_4, Mn, NO_3-N

Appendix C. Summary of Certain Parameters in YGB Groundwater Samples

Sample ID #	ADWR #	Date Sampled	Phnl. Alk. mg/l	Total Alk. mg/l	Hardness mg/l	pH SU	TDS mg/l	Turbidity NTU
Minimum Reporting Levels (MRL)			2.0	2.0	10	0.1	10	0.01
Maximum Contaminant Levels (MCL)						(6.50 to 8.50)	(500)	
Yuma-001A	55-504513	02/28/95	ND	225	425	7.85	***1500***	*0.86*
Yuma-002A	None	03/01/95	ND	147	261	8.02	***873***	*1.89*
Yuma-003A	55-605204	03/01/95	ND	216	724	7.65	***1530***	*0.34*
Yuma-004A	55-84812	03/01/95	ND	176	323	7.85	***812***	*0.11*
Yuma-005A	None	03/02/95	ND	215	371	7.81	**1310**	0.24
Yuma-006A	55-85073	03/02/95	ND	116	388	7.83	**1140**	0.55
Yuma-007A	55-505548	03/02/95	ND	127	543	7.86	**1560**	0.19
Yuma-010A	55-627019	03/20/95	ND	208	448	7.64	**1500**	*1.94*
Yuma-011A	55-646366	03/20/95	ND	238	315	7.67	**1490**	*0.62*
Yuma-012A	55-626998	03/21/95	ND	323	849	7.53	**2140**	*8.50*
Yuma-013A	55-518336	03/21/95	ND	337	846	7.28	**1690**	*0.06*
Yuma-014A	55-538381	03/21/95	ND	175	1370	7.41	**5850**	*1.16*
Yuma-015A	55-626986	03/21/95	ND	258	330	7.80	**1460**	*0.02*
Yuma-016A	55-518119	03/21/95	ND	268	533	7.46	**1050**	*0.03*
Yuma-017A	55-536951	03/21/95	ND	243	331	7.73	**1020**	*0.10*
Yuma-018A	55-536951	03/21/95	ND	239	330	7.73	**1020**	*0.07*
Yuma-019A	None	03/21/95	ND	394	1110	7.23	**2420**	*1.31*
Yuma-020A	None	03/22/95	ND	309	647	7.18	**1280**	41.0
Yuma-021A	55-604925	03/22/95	ND	284	850	7.55	**1660**	6.30
Yuma-022A	55-511849	04/10/95	ND	141	566	7.48	**1370**	*0.05*
Yuma-023A	55-522783	04/10/95	ND	280	795	7.83	**1790**	*10.4*
Yuma-024A	55-503291	04/10/95	ND	384	1728	7.56	**4890**	*13.3*
Yuma-025A	55-618702	04/10/95	ND	207	487	7.90	**1150**	*0.92*
Yuma-026A	55-618703	04/11/95	ND	225	200	7.95	**1120**	*0.08*
Yuma-027A	55-514819	04/11/95	ND	210	443	8.00	**1180**	*0.07*

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

Italics # = Exceeded Recomended Holding Time
Bold = SDW Standard Exceedence

Appendix C. Summary of Certain Parameters in YGB Groundwater Samples--Continued

Sample ID #	ADWR #	Date Sampled	Phnl Alk mg/l	Total Alk mg/l	Hardness mg/l	pH SU	TDS mg/l	Turbidity NTU
Minimum Reporting Levels (MRL)			2.0	2.0	10	0.1	10	0.01
Maximum Contaminant Levels (MCL)						(6.50 to 8.50)	(500)	
Yuma-028A	55-505855	04/11/95	ND	325	1056	7.78	**2690**	*11.0*
Yuma-029A	55-629173	04/11/95	ND	192	442	7.80	**1000**	*0.65*
Yuma-030A	55-647154	04/11/95	ND	225	476	7.77	**1330**	*0.07*
Yuma-031A	55-615593	04/11/95	ND	228	379	7.85	**1060**	*7.5*
Yuma-032A	55-615593	04/11/95	ND	227	380	7.77	**1060**	*8.5*
Yuma-033A	55-640999	04/12/95	ND	191	314	7.92	**720**	3.5
Yuma-034A	55-636181	06/07/95	ND	224	416	7.44	**1170**	*0.03*
Yuma-035A	55-500899	06/07/95	ND	478	682	7.73	**2550**	*0.06*
Yuma-036A	55-536882	06/07/95	ND	430	5040	7.04	**13000**	77.
Yuma-037A	55-590250	06/07/95	ND	387	1570	7.41	**4400**	*6.7*
Yuma-038A	55-538381	06/07/95	ND	179	1430	7.22	**6160**	*0.20*
Yuma-039A	55-648483	06/07/95	ND	347	676	7.4	**1450**	*ND*
Yuma-040A	Equip. Blank	06/07/95	ND	ND	ND	5.94	ND	*0.03*
Yuma-040A	55-625464	06/08/95	ND	234	556	7.35	**2640**	0.23
Yuma-041A	55-539941	06/08/95	ND	237	949	7.34	**3110**	0.27
Yuma-042A	55-611670	06/08/95	ND	208	456	7.44	**983**	5.5
Yuma-043A	55-603775	06/08/95	ND	230	200	7.86	**818**	0.44
Yuma-044A	55-606747	06/08/95	ND	177	365	7.74	**821**	0.18
Yuma-045A	55-606742	06/08/95	ND	388	1430	7.53	**3910**	19.
Yuma-046A	55-606742	06/08/95	ND	392	1400	7.51	**3890**	19.
Yuma-047A	55-630032	09/11/95	ND	279	752	7.53	**1710**	*0.02*
Yuma-048A	55-630032	09/11/95	< 1	277	707	7.5	**1700**	0.06
Yuma-049A	55-86900	09/11/95	ND	162	604	7.82	**1900**	*ND*
Yuma-050A	55-630410	09/11/95	ND	488	1420	7.56	**3180**	*5.1*
Yuma-051A	55-508044	09/11/95	ND	360	1350	7.79	**4110**	*17.9*

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

Italics # = Exceeded Recomended Holding Time
Bold = SDW Standard Exceedence

Appendix C. Summary of Certain Parameters in YGB Groundwater Samples--Continued

Sample ID #	ADWR #	Date Sampled	Phnl. Alk mg/l	Total Alk mg/l	Hardness mg/l	pH SU	TDS mg/l	Turbidity NTU
Minimum Reporting Levels (MRL)			2.0	2.0	10	0.1	10	0.01
Maximum Contaminant Levels (MCL)						(6.50 to 8.50)	(500)	
Yuma-052A	55-525843	09/11/95	ND	371	1080	7.89	**2220**	*6.7*
Yuma-053A	55-627046	09/12/95	ND	395	1350	7.54	**3220**	*4.1*
Yuma-054A	None	09/12/95	ND	271	388	7.85	**1230**	*ND*
Yuma-055A	55-522880	09/12/95	ND	302	146	8.10	**1080**	*ND*
Yuma-056A	55-646243	09/12/95	ND	272	272	7.98	**1150**	*0.13*
Yuma-057A	55-646584	09/12/95	ND	240	204	8.01	**1040**	*0.72*
Yuma-058A	55-601146	09/12/95	ND	399	490	7.49	**1400**	*0.53*
Yuma-059A	55-631482	09/12/95	ND	173	534	7.36	**1920**	*0.15*
Yuma-060A	Travel Blank	09/12/95	ND	ND	ND	5.99	22	*0.12*
Yuma-061A	55-505541	09/12/95	ND	230	686	7.56	**1830**	*10.0*
Yuma-062A	None	09/13/95	ND	204	536	7.81	**1630**	0.06
Yuma-063A	55-518336	09/13/95	ND	322	868	7.56	**1710**	0.09
Yuma-064A	55-651206	09/13/95	< 1	378	854	7.6	**2000**	0.09

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

Italics # = Exceeded Recomended Holding Time
Bold = SDW Standard Exceedence

Appendix D. Summary of Additional Inorganics in YGB Groundwater Samples

Sample ID	Date Sampled	Ca mg/l	Cl mg/l	F mg/l	Mg mg/l	Na mg/l	NH_3-N mg/l	NO_3-N mg/l	NO_2-N mg/l	Total N mg/l	TKN mg/l	T. Phos. mg/l	SO_4 mg/l
Minimum Reporting Levels (MRL)		1.0	1.0	0.20	1.0	5.0	0.10	0.10	0.10	0.10	0.10	0.10	10.0
Maximum Contaminant Levels (MCL)			(250)	4.0 & (2.0)				10.0	1.0	10.0			(250)
Yuma-001A	02/28/95	115	**322**	0.75	37.1	344	ND	0.45	*ND*	0.45	0.13	ND	**527**
Yuma-002A	03/01/95	74.0	**297**	0.38	22.2	205	ND	ND	ND	ND	ND	ND	163
Yuma-003A	03/01/95	196	**359**	0.26	58.6	213	0.32	ND	ND	ND	0.31	ND	**520**
Yuma-004A	03/01/95	91.0	225	0.35	27.9	157	ND	ND	ND	ND	0.13	ND	180
Yuma-005A	03/01/95	106	244	0.67	30.3	295	ND	0.53	ND	0.53	ND	ND	**498**
Yuma-006A	03/01/95	116	**452**	0.24	30.7	210	ND	0.23	ND	0.23	0.12	ND	132
Yuma-007A	03/01/95	158	**608**	0.23	39.7	322	ND	1.00	ND	1.00	ND	ND	**299**
Yuma-010A	03/20/95	117	***483***	*0.47*	37.0	337	0.11	ND	*ND*	ND	0.30	ND	**342**
Yuma-011A	03/20/95	79.5	*211*	*0.92*	27.0	384	ND	ND	*ND*	ND	0.15	ND	**648**
Yuma-012A	03/21/95	196	**590**	*0.65*	76.4	420	ND	4.56	ND	4.56	0.65	ND	**611**
Yuma-013A	03/21/95	212	219	*0.69*	77.5	244	ND	**32.2**	ND	**32.2**	0.57	ND	**593**
Yuma-014A	03/21/95	294	**2620**	*1.31*	151	1560	ND	**122.**	ND	**122**	0.36	ND	**574**

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

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

Appendix D. Summary of Additional Inorganics in YGB Groundwater Samples--Continued

Sample ID	Date Sampled	Ca mg/l	Cl mg/l	F mg/l	Mg mg/l	Na mg/l	NH_3-N mg/l	NO_3-N mg/l	NO_2-N mg/l	Total N mg/l	TKN mg/l	T. Phos. mg/l	SO_4 mg/l
Minimum Reporting Levels (MRL)		1.0	1.0	0.20	1.0	5.0	0.10	0.10	0.10	0.10	0.10	0.10	10.0
Maximum Contaminant Levels (MCL)			(250)	4.0 & (2.0)				10.0	1.0	10.0			(250)
Yuma-015A	03/21/95	79.5	**342**	*1.07*	31.5	381	ND	4.45	0.14	4.59	**0.23**	ND	433
Yuma-016A	03/21/95	122	137	*0.47*	57.6	150	ND	1.75	ND	1.75	0.23	ND	389
Yuma-017A	03/21/95	74.5	124	*0.78*	34.9	221	ND	5.47	ND	5.47	0.24	ND	383
Yuma-018A	03/21/95	74.9	123	*0.78*	34.9	215	ND	5.55	ND	5.55	0.19	ND	385
Yuma-019A	03/21/95	285	**534**	*1.25*	96.5	414	ND	5.07	0.12	5.19	**0.48**	ND	771
Yuma-020A	03/22/95	165	173	*0.88*	53.7	183	ND	ND	ND	ND	0.38	ND	499
Yuma-021A	03/22/95	228	**352**	*0.27*	65.9	228	0.38	ND	ND	ND	0.68	ND	526
Yuma-022A	04/10/95	154	**536**	ND	54.3	194	< 0.20	0.82	*ND*	0.82	ND	ND	77.7
Yuma-023A	04/10/95	219	**260**	0.35	65.8	281	0.33	ND	*ND*	ND	0.71	ND	703
Yuma-024A	04/10/95	451	**1940**	0.43	178	1103	0.66	ND	*ND*	ND	1.06	0.12	852
Yuma-025A	04/10/95	153	199	0.28	38.1	187	0.35	ND	*ND*	ND	0.88	ND	397
Yuma-026A	04/11/95	51.6	143	0.77	20.9	314	ND	7.35	*ND*	7.35	**0.25**	ND	396

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

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

Appendix D. Summary of Additional Inorganics in YGB Groundwater Samples--Continued

Sample ID	Date Sampled	Ca mg/l	Cl mg/l	F mg/l	Mg mg/l	Na mg/l	NH_3-N mg/l	NO_3-N mg/l	NO_2-N mg/l	Total N mg/l	TKN mg/l	T. Phos. mg/l	SO_4 mg/l
Minimum Reporting Levels (MRL)		1.0	1.0	0.20	1.0	5.0	0.10	0.10	0.10	0.10	0.10	0.10	10.0
Maximum Contaminant Levels (MCL)			(250)	4.0 & (2.0)				10.0	1.0	10.0			(250)
Yuma-027A	04/11/95	116	156	0.82	46.4	216	ND	**12.3**	*ND*	**12.3**	1.22	ND	**433**
Yuma-028A	04/11/95	303	**673**	0.27	97.6	516	0.49	ND	*ND*	ND	1.07	< 0.20	**903**
Yuma-029A	04/11/95	129	133	0.29	38.7	155	ND	9.17	*0.30*	9.47	ND	< 0.20	**360**
Yuma-030A	04/11/95	136	**263**	0.62	41.1	259	ND	4.11	*ND*	4.11	0.37	0.23	**445**
Yuma-031A	04/11/95	101	229	0.41	37.4	206	0.33	ND	*ND*	ND	0.36	ND	**284**
Yuma-032A	04/11/95	99.5	232	0.39	36.4	204	0.13	ND	*ND*	ND	0.29	ND	**295**
Yuma-033A	04/11/95	93.4	95.6	0.34	25.8	124	0.39	ND	*ND*	ND	0.55	ND	240
Yuma-034A	06/07/95	117	171	1.18	38.5	222	ND	8.88	ND	8.88	0.30	ND	**410**
Yuma-035A	06/07/95	158	**525**	1.03	76.5	622	ND	4.08	0.28	4.36	0.38	ND	**804**
Yuma-036A	06/07/95	1240	**6750**	0.44	527	2590	1.13	ND	ND	ND	*3.28*	0.16	**1300**
Yuma-037A	06/07/95	406	**1650**	0.83	150	984	0.29	0.21	ND	0.21	0.97	ND	**877**
Yuma-038A	06/07/95	317	**2900**	1.47	162	1710	ND	**110.**	ND	**110.**	0.35	ND	**600**

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

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

Appendix D. Summary of Additional Inorganics in YGB Groundwater Samples--Continued

Sample ID #	Date Sampled	Ca mg/l	Cl mg/l	F mg/l	Mg mg/l	Na mg/l	NH_3-N mg/l	NO_3-N mg/l	NO_2-N mg/l	Total N mg/l	TKN mg/l	T.Phos. mg/l	SO_4 mg/l
Minimum Reporting Levels (MRL)		1.0	1.0	0.20	1.0	5.0	0.10	0.10	0.10	0.10	0.10	0.10	10.0
Maximum Contaminant Levels (MCL)			(250)	4.0 & (2.0)				10.0	1.0	10.0			(250)
Yuma-039A	06/07/95	192	200	0.42	57.2	189	ND	9.50	ND	9.5	0.33	ND	**483**
Yuma-040A	06/07/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Yuma-040A	06/08/95	134	**855**	1.39	60.6	659	ND	2.72	ND	2.72	0.15	ND	**723**
Yuma-041A	06/08/95	221	**1190**	0.76	99.4	700	0.24	ND	ND	ND	0.61	ND	**737**
Yuma-042A	06/08/95	134	141	0.55	39.4	148	ND	1.08	ND	1.08	0.21	0.24	**760**
Yuma-043A	06/08/95	52.2	119	0.87	20.4	204	0.15	ND	ND	ND	0.43	ND	247
Yuma-044A	06/08/95	96.7	120	0.52	36.1	129	0.15	ND	ND	ND	0.41	ND	**317**
Yuma-045A	06/08/95	334	**1230**	0.67	137	824	0.14	ND	ND	ND	0.50	ND	**1190**
Yuma-046A	06/08/95	332	**1220**	0.66	139	802	0.12	ND	ND	ND	0.53	ND	**1140**
Yuma-047A	09/11/95	200	**407**	0.35	60.3	308	ND	**13.6**	*ND*	**13.8**	0.40	ND	**500**
Yuma-048A	09/11/95	193	**410**	0.34	54.7	271	< 0.03	N/A	N/A	**15**	< 0.02	< .05	**420**
Yuma-049A	09/11/95	137	**782**	0.72	61.7	438	ND	2.00	*ND*	2.0	0.20	ND	**294**

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

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

Appendix E. Summary of Metal Concentrations in YGB Groundwater Samples

Sample ID #	Date Sampled	Al mg/l	As mg/l	B mg/l	Ba mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Mn mg/l	Hg mg/l	K mg/l	Se mg/l	Ag mg/l	Zn mg/l
Minimum Reporting Levels (MRL)		0.50	0.010	0.10	0.10	0.0010	0.010	0.010	0.10	0.005	0.05	0.0005	0.50	0.005	0.001	0.05
Maximum Contaminant Levels (MCL)		(0.05 to 0.20)	0.05	0.63*	2.0	0.005	0.1	{1.3}	(0.3)	{0.015}	(0.05)	0.002		0.05	(0.1)	(5.0)
Yuma-001A	02/28/95	ND	ND	0.47	ND	ND	ND	ND	ND	ND	**0.30**	ND	5.18	ND	ND	ND
Yuma-002A	03/01/95	ND	ND	0.19	ND	ND	ND	ND	ND	ND	**0.12**	ND	4.72	ND	ND	ND
Yuma-003A	03/01/95	ND	ND	0.17	ND	ND	ND	ND	ND	ND	**0.54**	ND	5.36	ND	ND	ND
Yuma-004A	03/01/95	ND	ND	0.15	ND	ND	ND	ND	ND	ND	**0.23**	ND	4.54	ND	ND	ND
Yuma-005A	03/02/95	ND	ND	0.63	ND	ND	ND	ND	ND	ND	**0.15**	ND	4.20	ND	ND	ND
Yuma-006A	03/02/95	ND	ND	0.29	0.13	ND	ND	ND	ND	ND	**0.10**	ND	8.40	ND	ND	ND
Yuma-007A	03/02/95	ND	ND	0.62	0.11	ND	ND	ND	ND	ND	**0.09**	ND	6.60	0.036	ND	ND
Yuma-010A	03/20/95	ND	ND	0.53	ND	ND	ND	ND	0.17	ND	**0.39**	ND	6.44	ND	ND	ND
Yuma-011A	03/20/95	ND	ND	0.65	ND	ND	ND	ND	ND	ND	**0.24**	ND	4.43	ND	ND	ND
Yuma-012A	03/21/95	ND	0.015	0.54	ND	ND	ND	ND	**0.57**	ND	**1.05**	ND	9.70	ND	ND	ND
Yuma-013A	03/21/95	ND	0.012	0.47	ND	ND	ND	0.010	ND	ND	**0.25**	ND	10.00	ND	ND	ND
Yuma-014A	03/21/95	ND	0.014	1.10	ND	ND	ND	0.016	ND	ND	ND	ND	14.90	ND	ND	ND
Yuma-015A	03/21/95	ND	0.019	0.76	ND	ND	ND	ND	ND	ND	**0.62**	ND	4.87	ND	ND	ND
Yuma-016A	03/21/95	ND	0.010	0.27	ND	ND	ND	ND	ND	ND	ND	ND	3.67	ND	ND	ND
Yuma-017A	03/21/95	ND	ND	0.31	ND	ND	ND	0.011	ND	ND	ND	ND	3.43	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 Recomended Holding Time
* = Human Health Based Guidance Level
Bold = SDW Standard Exceedence

Appendix E. Summary of Metal Concentrations in YGB Groundwater Samples--Continued

Sample ID #	Date Sampled	Al mg/l	As mg/l	B mg/l	Ba mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Mn mg/l	Hg mg/l	K mg/l	Se mg/l	Ag mg/l	Zn mg/l
Minimum Reporting Levels (MRL)		0.50	0.010	0.10	0.10	0.0010	0.010	0.010	0.10	0.005	0.05	0.0005	0.5	0.005	0.001	0.05
Maximum Contaminant Levels (MCL)		(0.05 to 0.20)	0.05	0.63*	2.0	0.005	0.1	{1.3}	(0.3)	{0.015}	(0.05)	0.002		0.05	(0.1)	(5.0)
Yuma-018A	03/21/95	ND	ND	0.31	ND	ND	ND	ND	ND	ND	ND	ND	3.47	ND	ND	ND
Yuma-019A	03/21/95	ND	ND	0.53	ND	ND	ND	ND	ND	ND	**0.59**	ND	2.45	ND	ND	0.08
Yuma-020A	03/22/95	ND	ND	0.29	ND	ND	ND	ND	**2.84**	ND	**0.32**	ND	3.92	ND	ND	ND
Yuma-021A	03/22/95	ND	ND	0.24	ND	ND	ND	ND	**0.42**	ND	**0.79**	ND	5.72	ND	ND	ND
Yuma-022A	04/10/95	ND	ND	0.24	0.34	ND	ND	ND	ND	ND	ND	*ND*	7.32	ND	ND	ND
Yuma-023A	04/10/95	ND	ND	0.31	ND	ND	ND	ND	**0.54**	ND	**1.03**	*ND*	7.42	ND	ND	ND
Yuma-024A	04/10/95	ND	0.014	0.91	ND	ND	ND	ND	**1.09**	ND	**2.42**	*ND*	12.0	ND	ND	ND
Yuma-025A	04/10/95	ND	ND	0.20	ND	ND		ND	ND	ND	**0.61**	*ND*	4.75	ND	ND	ND
Yuma-026A	04/11/95	ND	ND	0.35	ND	ND	ND	ND	ND	ND	ND	*ND*	3.56	ND	ND	ND
Yuma-027A	04/11/95	ND	ND	0.28	ND	ND	ND	ND	ND	ND	ND	*ND*	3.46	ND	ND	ND
Yuma-028A	04/11/95	ND	ND	0.40	ND	ND	ND	ND	**0.60**	ND	**0.99**	*ND*	7.58	ND	ND	ND
Yuma-029A	04/11/95	ND	ND	0.20	ND	ND	ND	ND	ND	ND	**0.19**	*ND*	7.22	ND	ND	ND
Yuma-030A	04/11/95	ND	ND	0.31	ND	ND	ND	ND	0.10	ND	**0.21**	*ND*	16.8	ND	ND	ND
Yuma-031A	04/11/95	ND	ND	0.22	ND	ND	ND	ND	**0.33**	ND	**0.33**	*ND*	3.79	ND	ND	ND
Yuma-032A	04/11/95	ND	ND	0.22	ND	ND	ND	ND	0.26	ND	**0.32**	*ND*	3.80	ND	ND	ND

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Italics # = Exceeded Recomended Holding Time
* = Human Health Based Guidance Level
Bold = SDW Standard Exceedence

Appendix E. Summary of Metal Concentrations in YGB Groundwater Samples--Continued

Sample ID #	Date Sampled	Al mg/l	As mg/l	B mg/l	Ba mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Mn mg/l	Hg mg/l	K mg/l	Se mg/l	Ag mg/l	Zn mg/l
Minimum Reporting Levels (MRL)		0.50	0.010	0.10	0.10	0.0010	0.010	0.010	0.10	0.005	0.05	0.0005	0.50	0.005	0.001	0.05
Maximum Contaminant Levels (MCL)		(0.05 to 0.20)	0.05	0.63*	2.0	0.005	0.1	{1.3}	(0.3)	{.015}	(0.05)	0.002		0.05	(0.1)	(5.0)
Yuma-033A	04/12/95	ND	ND	0.16	ND	ND	ND	ND	0.21	ND	**0.44**	ND	3.20	ND	ND	ND
Yuma-034A	06/07/95	ND	ND	0.36	ND	ND	ND	ND	ND	ND	ND	ND	5.74	ND	ND	ND
Yuma-035A	06/07/95	ND	ND	1.15	ND	ND	ND	ND	ND	ND	**0.85**	ND	8.30	ND	ND	ND
Yuma-036A	06/07/95	ND	ND	1.75	0.11	ND	ND	ND	**6.25**	ND	**6.92**	ND	27.6	0.007	ND	ND
Yuma-037A	06/07/95	ND	0.012	1.24	ND	ND	ND	ND	**0.54**	ND	**2.81**	ND	10.8	ND	ND	ND
Yuma-038A	06/07/95	ND	0.012	1.03	ND	ND	ND	ND	ND	ND	ND	ND	14.3	ND	ND	ND
Yuma-039A	06/07/95	ND	ND	0.27	ND	ND	ND	ND	ND	ND	ND	ND	17.4	<0.010	ND	ND
Yuma-040A	06/07/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Yuma-040A	06/08/95	ND	ND	0.88	ND	ND	ND	ND	ND	ND	ND	ND	7.09	ND	ND	ND
Yuma-041A	06/08/95	ND	ND	0.82	ND	ND	0.012	ND	ND	0.009	**1.60**	ND	7.86	ND	ND	ND
Yuma-042A	06/08/95	ND	ND	0.17	ND	ND	ND	ND	0.18	ND	**0.19**	ND	7.26	ND	ND	ND
Yuma-043A	06/08/95	ND	0.012	0.22	ND	ND	ND	ND	0.12	ND	**0.50**	ND	4.03	ND	ND	ND
Yuma-044A	06/08/95	ND	ND	0.15	ND	ND	ND	ND	ND	ND	**0.94**	ND	4.85	0.016	ND	ND
Yuma-045A	06/08/95	ND	ND	0.87	ND	ND	ND	ND	**1.80**	ND	**2.40**	ND	13.2	ND	ND	ND
Yuma-046A	06/08/95	ND	ND	0.88	ND	ND	ND	ND	**1.64**	ND	**2.38**	ND	13.5	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 Recomended Holding Time
* = Human Health Based Guidance Level
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Appendix E. Summary of Metal Concentrations in YGB Groundwater Samples--Continued

Sample ID #	Date Sampled	Al mg/l	As mg/l	B mg/l	Ba mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Mn mg/l	Hg mg/l	K mg/l	Se mg/l	Ag mg/l	Zn mg/l
Minimum Reporting Levels (MRL)		0.50	0.010	0.10	0.10	0.0010	0.010	0.010	0.10	0.005	0.05	0.0005	0.50	0.005	0.001	0.05
Maximum Contaminant Levels (MCL)		(0.05 to 0.20)	0.05	0.63*	2.0	0.005	0.1	{1.3}	(0.3)	{.015}	(0.05)	0.002		0.05	(0.1)	(5.0)
Yuma-047A	09/11/95	ND	ND	0.25	ND	ND	ND	ND	ND	ND	ND	ND	19.8	<0.010	ND	ND
Yuma-048A	09/11/95	N/A	<.003	0.25	0.024	<.0005	0.005	0.008	0.036	<0.002	<0.005	<.0002	18.3	<0.005	<0.005	0.028
Yuma-049A	09/11/95	ND	ND	0.56	ND	ND	ND	ND	ND	ND	ND	ND	7.38	ND	ND	ND
Yuma-050A	09/11/95	ND	ND	0.58	ND	ND	ND	<0.02	**0.47**	ND	**1.13**	ND	10.3	ND	ND	ND
Yuma-051A	09/11/95	ND	ND	1.14	0.11	ND	ND	ND	**1.49**	ND	**2.20**	ND	10.8	ND	ND	ND
Yuma-052A	09/11/95	ND	ND	0.28	ND	ND	ND	ND	**0.82**	ND	**1.09**	ND	6.54	<0.010	ND	ND
Yuma-053A	09/12/95	ND	ND	0.65	ND	ND	ND	ND	**0.54**	ND	**0.73**	ND	12.8	ND	ND	ND
Yuma-054A	09/12/95	ND	ND	0.46	ND	ND	ND	ND	ND	ND	ND	ND	3.38	ND	ND	ND
Yuma-055A	09/12/95	ND	ND	0.52	ND	ND	ND	ND	ND	ND	ND	ND	3.03	ND	ND	ND
Yuma-056A	09/12/95	ND	ND	0.48	ND	ND	ND	ND	ND	ND	ND	ND	3.27	ND	ND	ND
Yuma-057A	09/12/95	ND	ND	0.29	ND	ND	ND	ND	ND	ND	ND	ND	3.34	ND	ND	ND
Yuma-058A	09/12/95	ND	ND	0.46	ND	ND	ND	ND	ND	ND	ND	ND	4.39	ND	ND	0.85
Yuma-059A	09/12/95	ND	ND	1.24	ND	ND	ND	ND	ND	ND	ND	ND	5.96	ND	ND	ND
Yuma-060A	09/12/95	ND	ND	0.41	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Yuma-061A	09/12/95	ND	ND	0.37	ND	ND	ND	ND	**0.92**	ND	**0.61**	ND	6.58	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 Recomended Holding Time

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

Appendix E. Summary of Metal Concentrations in YGB Groundwater Samples--Continued

Sample ID #	Date Sampled	Al mg/l	As mg/l	B mg/l	Ba mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Mn mg/l	Hg mg/l	K mg/l	Se mg/l	Ag mg/l	Zn mg/l
Minimum Reporting Levels (MRL)		0.50	0.010	0.10	0.10	0.0010	0.010	0.010	0.10	0.005	0.05	0.0005	0.50	0.005	0.001	0.05
Maximum Contaminant Levels (MCL)		(0.05 to 0.20)	0.05	0.63*	2.0	0.005	0.1	{1.3}	(0.3)	{.015}	(0.05)	0.002		0.05	(0.1)	(5.0)
Yuma-062A	09/13/95	ND	ND	0.58	ND	ND	ND	ND	ND	ND	**0.45**	ND	6.26	ND	ND	ND
Yuma-063A	09/13/95	ND	0.012	0.43	ND	ND	ND	ND	ND	ND	**0.24**	ND	9.84	ND	ND	ND
Yuma-064A	09/13/95	N/A	0.006	0.59	0.023	<.0005	ND	.008	.025	<0.002	**1.92**	<.0002	6.2	<0.005	<0.005	<.025

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

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

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

Appendix F. Summary of Pesticide and Radionuclide Levels in YGB Groundwater Samples

Sample ID #	GWPL	DBCP µg/l	EDB µg/l	Alpha pCi/l	Beta pCi/l	R-226 pCi/l	R-228 pCi/l
Minimum Reporting Levels (MRLs)	see Appendix G	0.01	0.01	varies	varies	0.1	0.2
Maximum Contaminant Levels (MCLs)				15.0		5.0 (w/ R-228)	5.0 (w/ R-226)
Yuma-001A		ND	ND				
Yuma-002A		ND	ND				
Yuma-003A		ND	ND				
Yuma-004A		ND	ND				
Yuma-005A		ND	ND				
Yuma-006A		ND	ND				
Yuma-007A		ND	ND				
Yuma-010A		ND	ND				
Yuma-011A	ND	ND	ND				
Yuma-012A		ND	ND				
Yuma-013A	ND	ND	ND				
Yuma-014A	ND	ND	ND				
Yuma-015A	ND	ND	ND				
Yuma-016A	ND	ND	ND				
Yuma-017A	ND	ND	ND				
Yuma-018A		ND	ND				
Yuma-019A	ND	ND	ND				
Yuma-020A		ND	ND				
Yuma-021A		ND	ND				
Yuma-022A		ND	ND				
Yuma-023A		ND	ND				

Appendix F. Summary of Pesticide and Radionuclide Levels in YGB Groundwater Samples--Continued

Sample ID #	GWPL	DBCP µg/l	EDB µg/l	Alpha pCi/l	Beta pCi/l	R-226 pCi/l	R-228 pCi/l
Minimum Reporting Levels (MRLs)	see Appendix G	0.01	0.01	varies	varies	0.1	0.2
Maximum Contaminant Levels (MCLs)	see Appendix G			15		5.0 (w/ R-228)	5.0 (w/ R-226)
Yuma-024A	ND	ND	ND				
Yuma-025A	ND	ND	ND				
Yuma-026A	ND	ND	ND				
Yuma-027A	ND	ND	ND				
Yuma-028A	ND	ND	ND				
Yuma-029A	ND	ND	ND				
Yuma-030A	ND	ND	ND				
Yuma-031A		ND	ND				
Yuma-032A		ND	ND				
Yuma-033A		ND	ND				
Yuma-047A		ND	ND				
Yuma-049A		ND	ND				
Yuma-050A	ND	ND	ND	3.1	11.1		
Yuma-051A	ND			< 1.4	10.3		
Yuma-052A	ND			< 1.9	10.9		
Yuma-053A	ND	ND	ND	8.7	10.0	< 0.1	3.7
Yuma-054A	ND	ND	ND				
Yuma-056A	ND	ND	<0.01	10.7	7.7	< 0.1	3.3
Yuma-057A	ND	ND	ND				
Yuma-059A				4.8	9.2		
Yuma-063A				3.3	11.7		

Appendix G. 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 G. 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 G. 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 G. 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 H. EPA Methods Used to Determine Inorganic Constituent Concentration Levels In YGB Groundwater Samples.

Parameter	EPA Method	Parameter	EPA Method
Alkalinity, Total	310.1	B	200.7
Alkalinity, Phenol	310.1	Ba	200.7
Ammonia-Nitrogen	350.1	Cd	213.2
Chloride	SM 4500 Cl D	Ca	200.7
Fluoride	340.2	Cr	218.2
Hardness	130.2	Cu	220.2
Nitrite-Nitrate Total N	353.2	Fe	200.7
Nitrite	353.2	K	258.1
Phosphorous	365.4	Hg	245.1
TKN	351.2	Mg	200.7
pH	150.1	Mn	200.7
Sulfate	375.2	Na	200.7
TDS	160.1	Pb	239.2
Turbidity	180.1	Se	200.9
Ag	272.2	Zn	200.7
As	200.9		