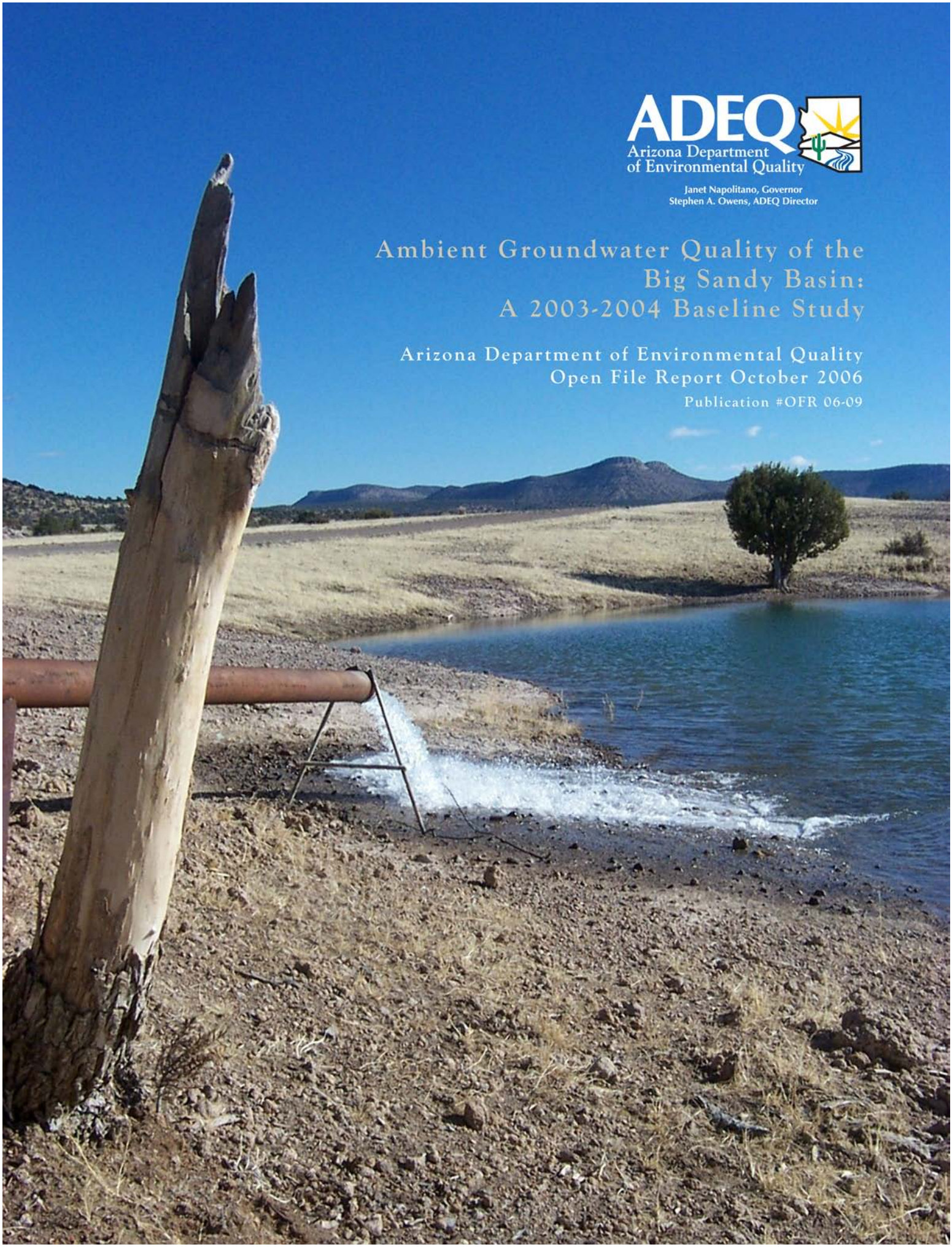

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Arizona Department of Environmental Quality

Janet Napolitano, Governor
Stephen A. Owens, ADEQ Director

Ambient Groundwater Quality of the Big Sandy Basin: A 2003-2004 Baseline Study

Arizona Department of Environmental Quality
Open File Report October 2006
Publication #OFR 06-09

Ambient Groundwater Quality of the Big Sandy Basin: A 2003-2004 Baseline Study

By Douglas C. Towne
Maps by Lisa Rowe

Arizona Department of Environmental Quality
Open File Report 06-09

ADEQ Water Quality Division
Surface Water Section
Monitoring Unit
1110 West Washington St.
Phoenix, Arizona 85007-2935

Thanks:

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Technical Assistance:	Nancy Caroli and Diana Marsh.
Photo Credits:	Douglas Towne

Report Cover: Groundwater pumped from a 225-foot well (BIS-68) pours into an unnamed reservoir to be used for irrigation just north of Fort Rock Ranch located a few miles south of Interstate 40 approximately 28 miles west of Seligman, Arizona. Water from this well was of calcium-bicarbonate chemistry and met all drinking water standards.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

ADEQ Ambient Groundwater Quality Open-File Reports (OFR):

Lake Mohave Basin	OFR 05-08, October 2005, 66 p.
Meadview Basin	OFR 05-01, January 2005, 29 p.
San Simon Sub-Basin	OFR 04-02, October 2004, 78 p.
Detrital Valley Basin	OFR 03-03, November 2003, 65 p.
San Rafael Basin	OFR 03-01, February 2003, 42 p.
Lower San Pedro Basin	OFR 02-01, July 2002, 74 p.
Willcox Basin	OFR 01-09, November 2001, 55 p.
Sacramento Valley Basin	OFR 01-04, June 2001, 77 p.
Upper Santa Cruz Basin	OFR 00-06, Sept. 2000, 55 p. (With the U.S. Geological Survey)
Prescott Active Management Area	OFR 00-01, May 2000, 77 p.
Upper San Pedro Basin	OFR 99-12, July 1999, 50 p. (With the U.S. Geological Survey)
Douglas Basin	OFR 99-11, June 1999, 155 p.
Virgin River Basin	OFR 99-04, March 1999, 98 p.
Yuma Basin	OFR 98-07, September, 1997, 121 p.

ADEQ Ambient Groundwater Quality Fact Sheets (FS):

Big Sandy Basin	FS 06-24, May 2006, 4 p.
Lake Mohave Basin	FS 05-21, October 2005, 4 p.
Meadview Basin	FS 05-01, January 2005, 4 p.
San Simon Sub-basin	FS 04-06, October 2004, 4 p.
Detrital Valley Basin	FS 03-07, November 2003, 4 p.
San Rafael Basin	FS 03-03, February 2003, 4 p.
Lower San Pedro Basin	FS 02-09, August 2002, 4 p.
Willcox Basin	FS 01-13, October 2001, 4 p.
Sacramento Valley Basin	FS 01-10, June 2001, 4 p.
Yuma Basin	FS 01-03, April 2001, 4 p.
Virgin River Basin	FS 01-02, March 2001 4 p.
Prescott Active Management Area	FS 00-13, December 2000, 4 p.
Douglas Basin	FS 00-08, September 2000, 4 p.
Upper San Pedro Basin	FS 97-08, August 1997, 2 p. (With the U.S. Geological Survey)

ADEQ Targeted Groundwater Quality Open-File Reports:

An Assessment of Methyl Tertiary-Butyl Ether (MTBE) Groundwater Occurrence in Maricopa County. ADEQ Open File Report 02-03, February 2003, 48 p.

The Impacts of Septic Systems on Water Quality of Shallow Perched Aquifers: A Case Study of Fort Valley, Arizona. ADEQ Open File Report 97-7, February 1997, 70 p.

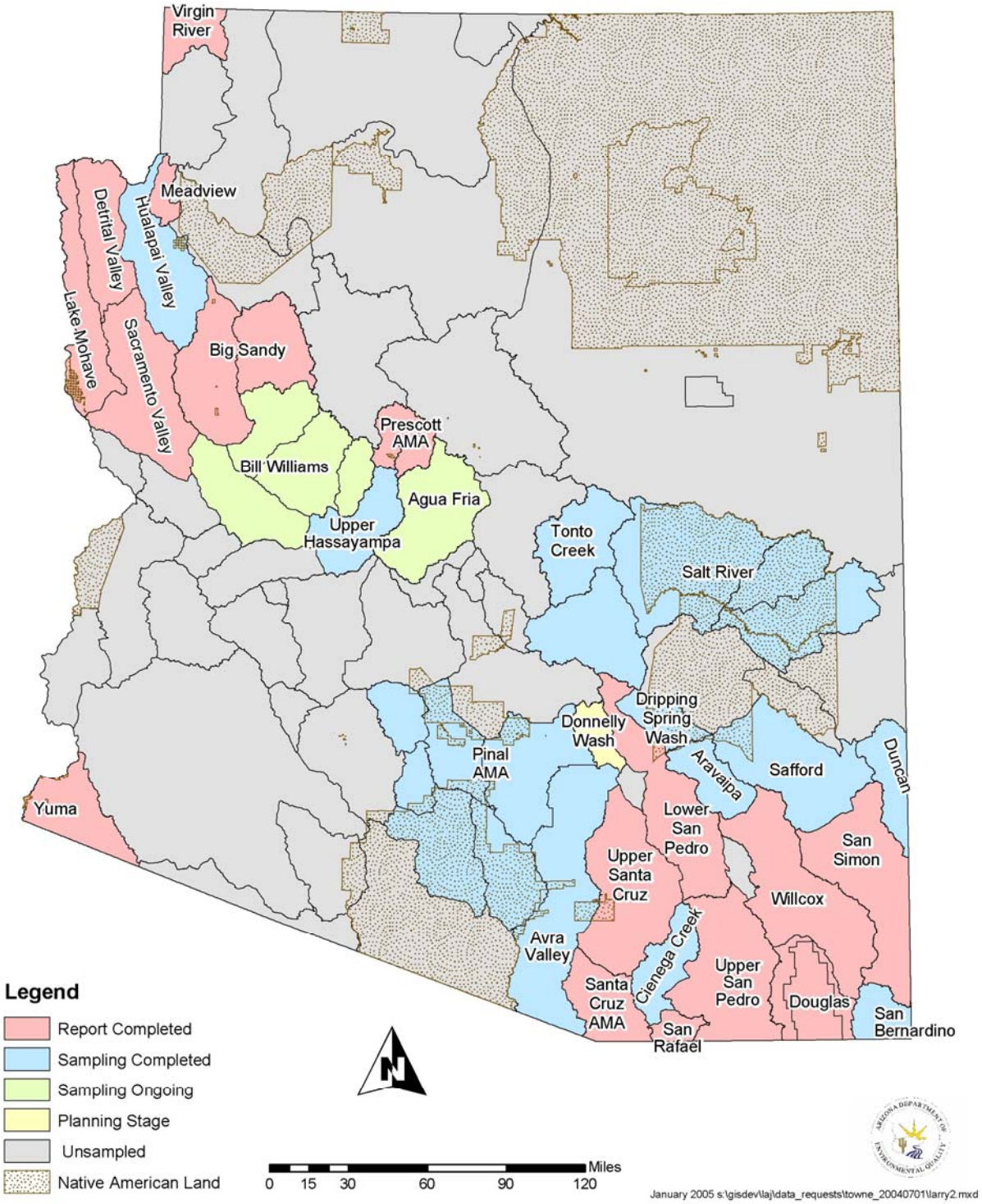
Most of these publications are available on-line.
Visit the ADEQ Ambient Groundwater Monitoring Program at:

http://www.azdeq.gov/environ/water/assessment/ambientst.html

http://www.azdeq.gov/environ/water/assessment/targeted.html

ADEQ Ambient Monitoring Program Studies

April 2006



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Abbreviations

amsl	above mean sea level
af	acre-feet
af/yr	acre-feet per year
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
ARRA	Arizona Radiation Regulatory Agency
AZGS	Arizona Geological Survey
As	arsenic
BIS	Big Sandy groundwater basin
bls	below land surface
BLM	U.S. Department of the Interior Bureau of Land Management
^{o}C	degrees Celsius
$CI_{0.95}$	95 percent Confidence Interval
Cl	chloride
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpm	gallons per minute
GWPL	Groundwater Protection List pesticide
HCl	hydrochloric acid
LLD	Lower Limit of Detection
Mn	manganese
MCL	Maximum Contaminant Level
ml	milliliter
msl	mean sea level
μg/L	micrograms per liter
μm	micron
μS/cm	microsiemens per centimeter at 25° Celsius
mg/L	milligrams per liter
MRL	Minimum Reporting Level
MTBE	Methyl tertiary-Butyl Ether
Ng/L	nanograms per liter
ns	not significant
ntu	nephelometric turbidity unit
pCi/L	picocuries per liter
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SAR	Sodium Adsorption Ratio
SDW	Safe Drinking Water
SC	Specific Conductivity
su	standard pH units
SO4	sulfate
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound
*	significant at $p \leq 0.05$
**	significant at $p \leq 0.01$
***	statistical test for this constituent invalid because detections fewer than 50 percent

"The stream runs through a sandy valley called Big Sandy Valley, naturally. In 1604 Juan Mateo de Onate called this stream Rio de San Andres, as he came to it on Saint Andrew's Day (November 30). In 1744 Jacobo Sedelmayr called it Rio Azul. In 1854 Lt. Amiel Whipple said that Capt. Joseph R. Walker descriptively named this stream. Whipple called it Williams River, proceeding along its juncture with the Santa Maria River (to form the Bill Williams River). The portion Whipple traveled is now called Little Sandy, and its lower section Big Sandy River."

Byrd Howell Granger
Arizona's Names: X Marks the Place [16]

Ambient Groundwater Quality of the Big Sandy Basin: A 2003-2004 Baseline Study

By Douglas Towne

Abstract - The Big Sandy groundwater basin (BIS) covers approximately 1,900 square miles of rugged terrain in northwestern Arizona stretching from north of Route 66 to south of the town of Wikieup along Highway 93.[9] Located in Mohave and Yavapai Counties, most lands are federally managed by the Bureau of Land Management with the remainder consisting chiefly of State trust and private lands.[5] Rangeland is the predominant land use with private land increasingly subdivided for dispersed housing. Knight Creek and Trout Creek drain the northern part of the BIS and converge 15 miles north of Wikieup to form the Big Sandy River. This waterway flows southward exiting the basin and eventually debouching into the Santa Maria River just upstream of Alamo Lake. Groundwater is the source of the vast majority of water uses in the BIS and occurs in at least five hydrologic settings: floodplain alluvium, unconfined basin-fill, confined basin-fill, sedimentary rock in the east-northeast portion of the basin, and the consolidated bedrock of the Hualapai, Peacock, Aquarius, and Mohon Mountains. [6, 9, 21]

To support an Arizona Department of Environment Quality (ADEQ) Total Maximum Daily Load study examining elevated mercury concentrations in fish tissue, sediment and water from Alamo Lake, in 2003-2004, ADEQ conducted a baseline groundwater quality study of the BIS.[36] Samples were collected for inorganic constituents (57 sites), isotopes of oxygen and hydrogen (57 sites), radon (37 sites), radiochemistry (30 sites), and ultra-clean mercury (21 sites) analyses. Samples were collected mainly from relatively shallow domestic or stock wells and springs. ADEQ was denied permission to sample deep wells owned either by the Phelps Dodge Corporation or Caithness Energy. Ninety-five (95) percent of groundwater pumped in the BIS is transported by Phelps Dodge to the Bill Williams basin for use at the company's Bagdad copper mine.[6] Caithness Energy wells were drilled for use at their proposed Big Sandy power plant which was denied a permit in 2001 by the Arizona Corporation Commission.[1]

Although 42 percent of the sites sampled contained one or more constituents that exceeded a health-based, federal or State water quality standard, most of these sites were located in the south-central portion of the basin; other areas—particularly in the northeast—had relatively few exceedances. Of the 57 sites sampled, 24 sites had concentrations of at least one constituent that exceeded a health-based, federal or State water-quality standard. These enforceable standards define the maximum concentrations of constituents allowed in water supplied to the public and are based on a lifetime daily consumption of two liters per person.[3, 29] Health-based exceedances included arsenic (11 sites), fluoride (11 sites), gross alpha (9 sites), lead (1 site), radium (1 site), and uranium (2 sites). At 29 sites, concentrations of at least one constituent exceeded an aesthetics-based, federal water-quality guideline. These are unenforceable guidelines that define the maximum concentration of a constituent that can be present in drinking water without an unpleasant taste, color, odor, or other effect.[29] Aesthetics-based exceedances included chloride (4 sites), fluoride (20 sites), iron (3 sites), manganese (4 sites), pH-field (2 sites), sulfate (2 sites), and total dissolved solids or TDS (22 sites).

Analytical results indicated that groundwater in the BIS is generally slightly alkaline, fresh, and moderately hard to very hard based on pH, TDS and hardness analyses. Most groundwater sample sites were either of mixed-bicarbonate or calcium-bicarbonate water chemistry. Nitrate concentrations were generally low with no samples exceeding health-based standards. Among trace elements, only arsenic, boron, copper, fluoride, and zinc were detected at more than 20 percent of sample sites. Mercury was not detected in any sample submitted to the Arizona State Health Department Laboratory which has a Minimum Report Level of 0.0005 milligrams per liter.

Patterns were found among groundwater sub-basins, aquifers, and recharge sources (ANOVA with Tukey test using log-transformed data, $p \leq 0.05$).[19] Temperature, TDS, sodium, chloride, sulfate, fluoride, boron, iron and gross beta were higher in the down-gradient Big Sandy sub-basin than in the up-gradient Trout Creek sub-basin. Temperature, TDS, sodium, chloride, sulfate, fluoride, boron, and radon were higher in basin-fill or artesian aquifers than in sedimentary rock. Temperature, pH-lab, sodium, sulfate, and fluoride are higher at depleted recharge sites than at enriched recharge sites; the opposite pattern occurs with calcium, magnesium, hardness, and nitrate.

These patterns suggest that groundwater in the basin generally follows a flow path evolving from calcium-bicarbonate chemistry, indicative of recently recharged groundwater, in sedimentary rock in the Trout Creek sub-basin to a more saline, mixed-bicarbonate chemistry with higher concentrations of constituents such as sodium, chloride, sulfate, fluoride and boron that are indicative of groundwater with a longer residence time.[23]

INTRODUCTION

Purpose and Scope

The Big Sandy groundwater basin (BIS) is located in northwestern Arizona within Mohave and Yavapai Counties and covers approximately 1,900 square miles (Map 1).[9] Groundwater is the primary source for domestic, public water supply, mining, irrigation, and stock water uses in the BIS. The basin was selected for study to support Arizona Department of Environmental Quality (ADEQ) Total Maximum Daily Load studies related to elevated mercury concentrations found in the fish tissue, sediment and water from Alamo Lake, which impounds the Big Sandy River which drains the BIS.[36]

The ADEQ Groundwater Monitoring Unit designed a study to characterize the current (2003-2004) groundwater quality conditions in the BIS. Sampling by ADEQ was completed as part of the Ambient Groundwater Monitoring Program, which is based on the legislative mandate in the Arizona Revised Statutes §49-225 that authorizes:

"*...ongoing monitoring of waters of the state, including...aquifers to detect the presence of new and existing pollutants, determine compliance with applicable water quality standards, determine the effectiveness of best management practices, evaluate the effects of pollutants on public health or the environment, and determine water quality trends*."[3]

An important resource in Arizona, groundwater provides a buffer against future water shortages, supplies base flow for rivers, and protects against land subsidence. The ADEQ ambient groundwater monitoring program examined the regional groundwater quality of BIS to:

- Provide a comprehensive baseline study that will provide help guide water quality issues affecting the Alamo Lake.
- Determine if there are areas where groundwater does not currently meet U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act (SDWA) water quality standards.[33]
- Examine water quality differences among different sub-basins, aquifers and recharge sources within the basin.
- Continue the assessment of the groundwater quality of the Upper Colorado River Planning Area that has culminated in ADEQ hydrology reports on the following basins: Sacramento Valley (2000),[24] Detrital Valley (2003),[25] Meadview (2004),[26] Lake Mohave (2005)[27] and Hualapai Valley (forthcoming)[28].

ADEQ collected samples from 57 sites for this groundwater quality assessment of the BIS. Types and numbers of samples collected and analyzed include inorganic constituents (physical parameters, major ions, nutrients, and trace elements) (57 sites), oxygen and hydrogen isotopes (57 sites), radon (37 sites), radiochemistry (30 sites), and ultra-clean mercury (21 sites). Six surface water hydrogen and oxygen isotope samples and one, ultra-clean mercury sample were also collected.

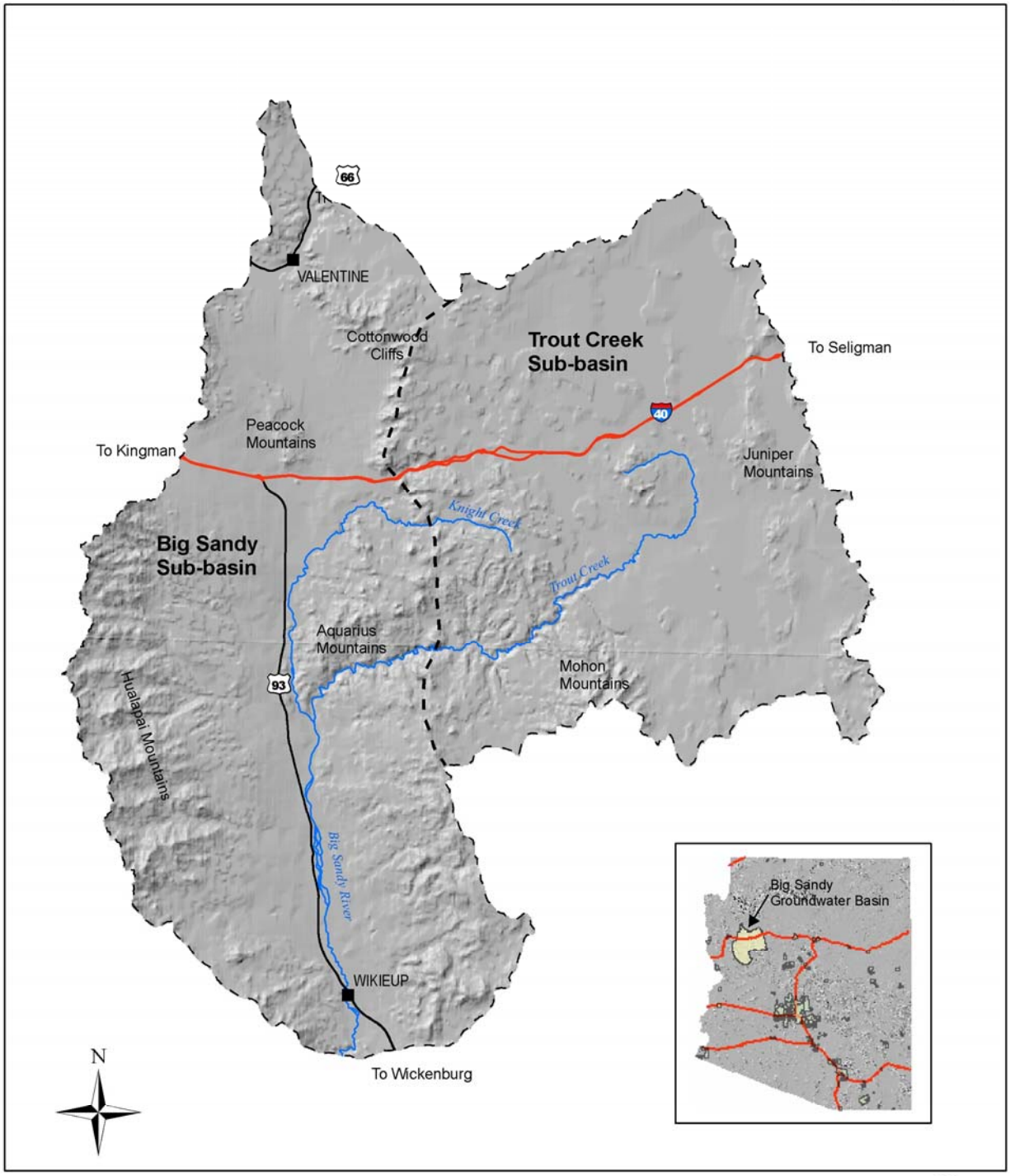
Benefits of Study – This study, which utilizes accepted sampling techniques and quantitative analyses, is designed to provide the following benefits:

- A general characterization of regional groundwater quality. Testing all private wells for a wide variety of groundwater quality concerns is prohibitively expensive. An affordable alternative is this type of statistically-based groundwater study which describes regional groundwater quality and identifies areas with impaired conditions.[19]
- A process for evaluating potential groundwater quality impacts arising from a variety of sources including mineralization, mining, agriculture, livestock, septic tanks, and poor well construction.
- Considerations for identifying future locations of public supply wells.

Physical and Cultural Characteristics

Geography – The BIS is located within the Basin and Range physiographic province which consists of northwest-trending alluvial basins separated by elongated fault-block mountain ranges.[6] The basin is traversed north to south by U.S. Highway 93 and the east to west by Interstate 40. The basin is bounded on the west by the Hualapai Mountains, on the south by the Mohon Mountains (Figure 1), on the east by the Juniper and Aquarius Mountains, and on the north by the Peacock Mountains and Cottonwood Cliffs (Map 1). The highest point in the basin is Hualapai Peak at 8,417 feet above mean sea level.

Map 1 Big Sandy Groundwater Basin



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Elevations descend southward to a low elevation of approximately 1,800 feet at the Big Sandy River where it exits the basin south of Wikieup.[6, 9] The BIS is located in Mohave and Yavapai Counties; most of the land in the basin is federally managed by the U.S. Bureau of Land Management (BLM). The remainder of the basin consists of private and State Trust lands along with small amounts of the Prescott National Forest, Mohave County Parks, and Hualapai Indian Reservation (Map 2).[5]

Climate - The climate of the BIS is semiarid, characterized by hot summers and mild winters. The Big Sandy Valley normally receives between 10 and 14 inches of precipitation annually. Precipitation increases with elevation with the upper reaches of the Hualapai Mountains receiving almost 20 inches of precipitation annually. Summer precipitation occurs in July and August with large amounts of water produced by high intensity thunderstorms; winter precipitation occurs from December to March and typically consists of long duration, low-intensity storms.[6]

Surface Water – The basin generally drains from north to south. Knight Creek, which drains the northwest part of the basin, and Trout Creek, which drains the northeast part of the basin, meet near the center of the basin to form the Big Sandy River. The Big Sandy River, Trout Creek, and Willow Creek—a tributary of Knight Creek—have reaches of perennial flow.[6] After exiting the basin, the Big Sandy River flows southward until merging with the Santa Maria River to form the Bill Williams River just above Alamo Lake. The BIS is within the Bill Williams Watershed. The ADEQ 303 (d) Listing Report describes Trout Creek as an "attaining all uses" stream while the Big Sandy River as an "attaining some uses" due to inconclusive data.[4]

Groundwater Development – Historically, the primary use of groundwater in the basin has been for irrigated agriculture in the Big Sandy Valley. However, since the early 1970s, most groundwater pumped in the BIS has been transported by pipeline to the Bill Williams Basin for use at the Phelps Dodge Bagdad Mine. In 1980, it was estimated that approximately 2,000 acre-feet of groundwater was pumped annually in the basin with 95 percent of that water used at the Bagdad Mine.[6]

In 2001, because of groundwater concerns, the proposed Caithness Energy Big Sandy power plant was denied a certificate of environmental compatibility in part because of the plant's reliance on groundwater for cooling.[1]

The BIS is lightly populated with Wikieup, a service and retirement town along U.S. Highway 93, the largest community. Recent residential development consists of scattered homes in the northern portion of the basin, an area that is predominantly a checkerboard of private and State Trust lands. Several ranches have sold most of their private lands for development, yet continue to graze the adjacent State Trust lands. Livestock grazing is the predominant land use in the basin but is a relatively minor user of groundwater.

HYDROLOGY

Groundwater occurs in five hydrologic settings in the Big Sandy basin: in unconsolidated deposits along the Big Sandy Valley consisting of either floodplain alluvium or upper basin-fill, in a confined, artesian aquifer near Wikieup, in the sedimentary rocks found in the extreme northeastern part of the basin, and in volcanic, metamorphic, and granite rock of the Hualapai, Peacock, Aquarius, and Mohon Mountains (Map 1, Map 3).[6, 9] The majority of groundwater development in the basin has been in southern portion along the Big Sandy Valley.

Floodplain - The alluvial floodplain in the Big Sandy River generally is 30 to 40 feet thick and consists of an unconsolidated deposit of gravel and sand underling the stream. Wells greater than 40 feet deep in this unit also tap the upper basin-fill and are capable of yielding up to 1,000 gallons per minute.[6]

Basin-Fill – These deposits vary from loosely-consolidated silty gravel to sandy silt and vary in thickness from 150 to 200 feet in the northern part of the basin to about 300 feet near Wikieup.[6] Like the floodplain unit, the basin fill receives recharge from stream flow during most of the year and from mountain front recharge.[13] The depth to groundwater varies from less than a foot in places along the Big Sandy River to approximately 750 feet in the northern part of the basin.[13]

Artesian – A confined, artesian aquifer appears to exist in the Wikieup area in field observations dating back to at least 1940.[35]

Sedimentary Rock – In the east-northeast portion of the basin, a sedimentary layer composed of the Redwall Limestone and the Martin Formation form a regional aquifer whose extent is difficult to determine because of the few wells in the area. Depths to water range from 32 feet below land surface (bls) in the east near Buck Dam to 950 feet bls in the northern part of the basin at Rubel Ranch.[6]

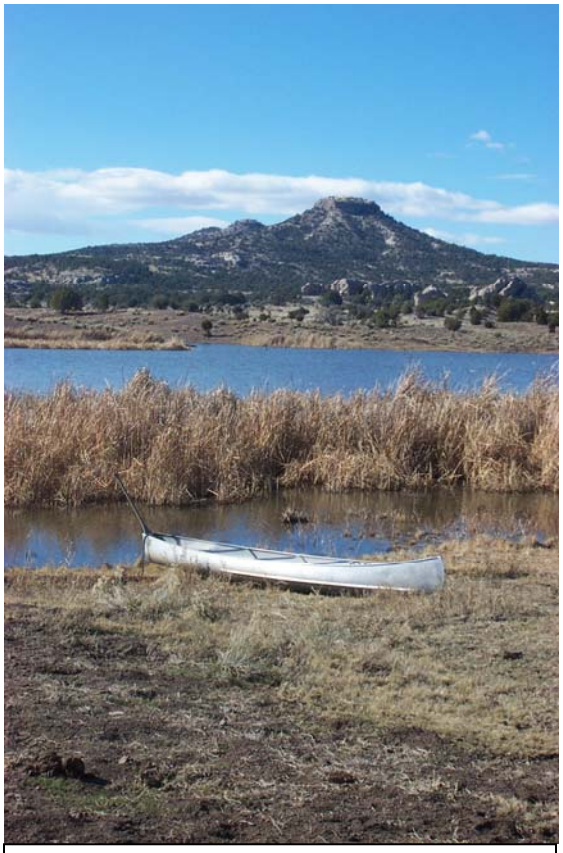


Figure 1. Meadow Lake, the headwaters of Fort Rock Creek, a tributary of Trout Creek, is pictured below the Three Sisters Buttes.

Figure 2. A perennial stretch of Trout Creek, a tributary of the Big Sandy River, flows on Fort Rock Ranch in the northwest part of the basin.

Figure 3. A pump jack is used to lift groundwater at Section 8 Well (BIS-61) on the extensive X-One Ranch located between Interstate 40 and Route 66. The windmill that formerly served the well lies abandoned nearby.

Figure 4. The remoteness of much of the Big Sandy is captured in this image of the snow-dusted Mohon Mountains southwest of the EL Well on the Anvil Rock Ranch.

Figure 5. Groundwater samples in remote parts of the Big Sandy basin are limited to springs, such as Black Jack Spring (BIS-45) located on the west flank of the Aquarius Mountains

Figure 6. Springs such as Casa Grande Spring (BIS-50) located north of Fort Rock Ranch, can expedite field work since they have a continuous flow of groundwater; thus, collecting samples from them can be immediate with no long wait to meet purging requirements.

Figure 7. Upper Tom Brown Well (BIS-32/33), located among granite rocks in the Aquarius Mountains, had both gross alpha and radium-226 health-based water quality exceedances.

Figure 8. Collecting samples from windmills, such as the Well #5 (BIS-74) located on the 74 Plains west of Seligman, requires not only proper meteorological conditions but access to fresh groundwater before it enters a water tank.

Figure 9. Cabin Spring flows from the west flank of the Aquarius Mountains near Trout Creek Road. The sample (BIS-23) collected from this spring met all water quality standards except the fluoride aesthetic guideline of 2.0 mg/L.

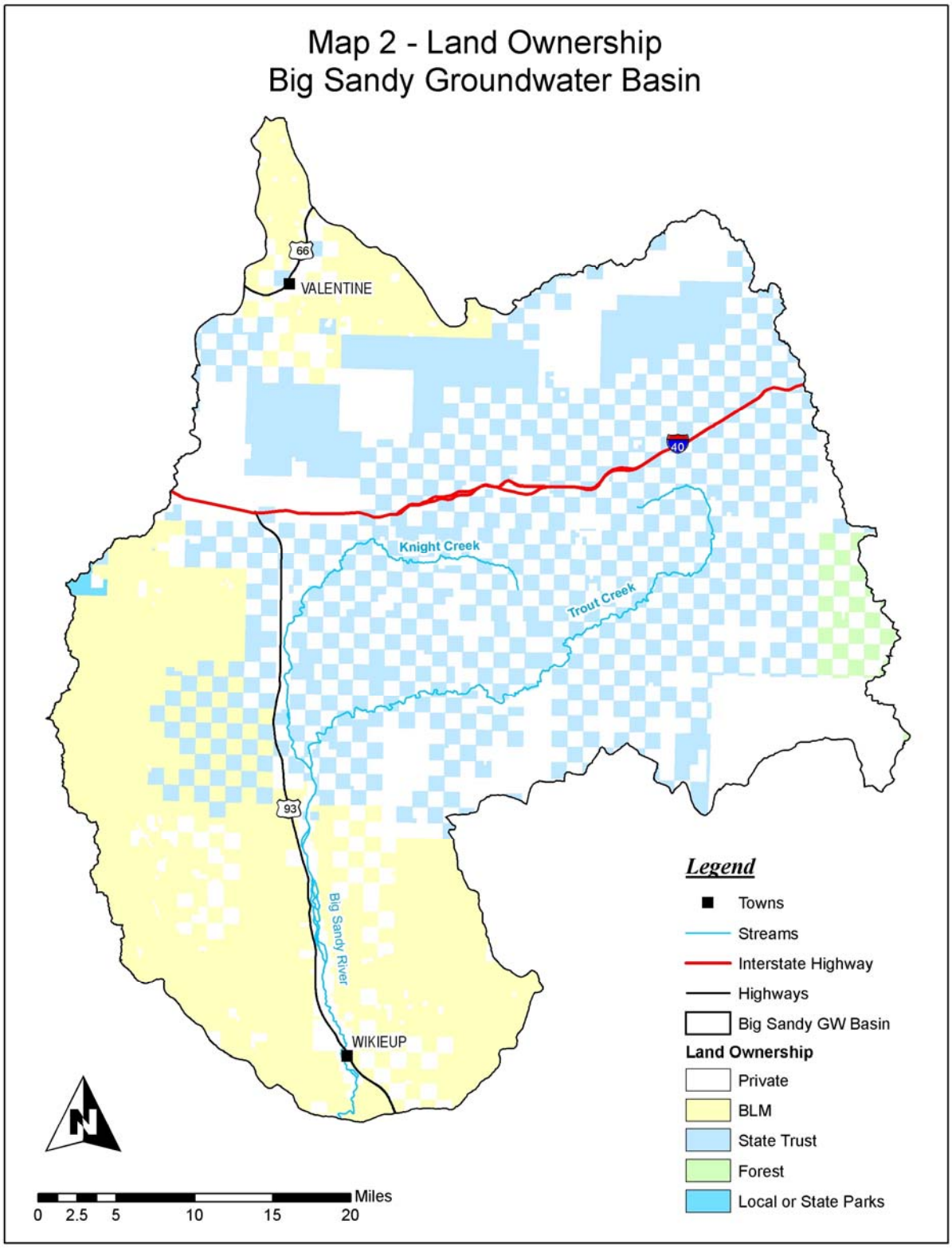
Figure 10. The basin varies from high grassland in the north to Sonoran Desert vegetation where the Big Sandy River is formed at the confluence of Trout Creek and Knight Creek.

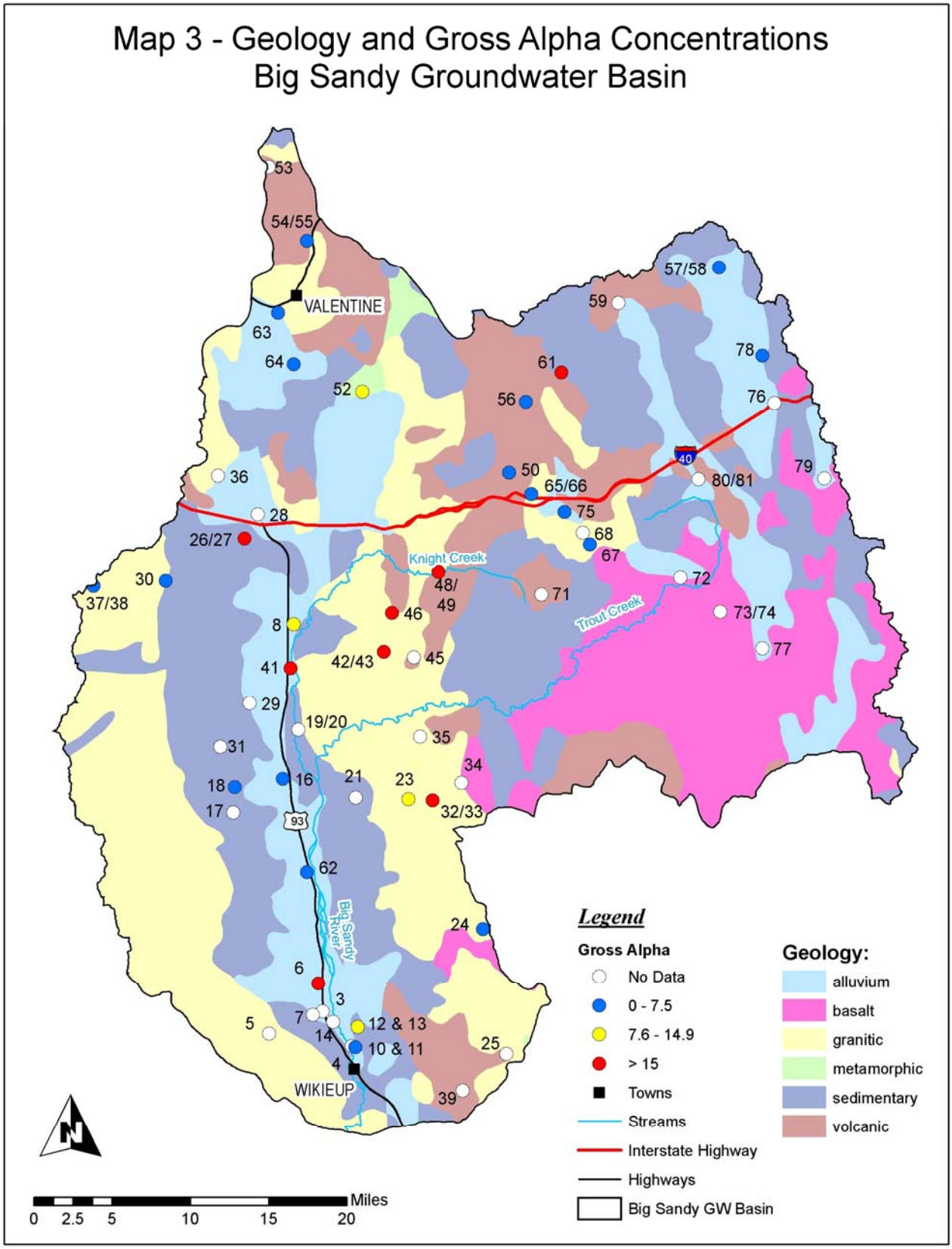
Figure 11. Private land in the basin is increasingly developed as remote home sites while the ranchers retain grazing rights on the interspersed federal (BLM) or state trust lands.

Figure 12. Phelps Dodge is the largest water user in the Big Sandy basin, using 95 percent of the basin's pumpage. Groundwater produced by their deep wells along the Big Sandy River is transported to the Bill Williams basin for use at the Bagdad Copper Mine in Bagdad.[6]

Figure 13. Groundwater data on the deep aquifer in the Big Sandy was difficult to obtain since both Phelps Dodge and the Caithness Energy did not allow permission to sample their wells. One of the few samples thought to come from the deep aquifer was collected from the Cofer Hot Springs (BIS-12/13) just east of Wikieup. The extensive riparian areas and palm trees attest to the prodigious flow from this spring. The Cofer Hot Spring had the highest arsenic concentration (0.125 mg/L) in the study.

Figure 14. Although residential development is occurring in the BIS, the only town within the basin is Wikieup, a service center for travelers on Highway 93. Perhaps the most eye catching landmark in Wikieup is this homespun folk art piece next to the highway. A major north-south arterial and the quickest route between Phoenix and Las Vegas, Highway 93 is currently being upgraded from two to four lanes.


Map 2 - Land Ownership
Big Sandy Groundwater Basin
66
VALENTINE
40
Knight Creek
Trout Creek
93
Big Sandy River
WIKIEUP
N
Legend
Towns
Streams
Interstate Highway
Highways
Big Sandy GW Basin
Land Ownership
Private
BLM
State Trust
Forest
Local or State Parks
Miles
0 2.5 5 10 15 20


Map 3 - Geology and Gross Alpha Concentrations
Big Sandy Groundwater Basin
VALENTINE
WIKIEUP
Knight Creek
Trout Creek
Big Sandy River
40
93
53
54/55
63
64
52
36
28
26/27
30
37/38
8
41
29
19/20
31
18
17
16
21
23
32/33
34
35
45
42/43
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48/
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71
72
73/74
77
79
76
78
57/58
59
61
56
50
65/66
75
68
67
80/81
62
24
6
3
7
5
14
12 & 13
10 & 11
4
25
39
Legend
Gross Alpha
No Data
0 - 7.5
7.6 - 14.9
> 15
Towns
Streams
Interstate Highway
Highways
Big Sandy GW Basin
Geology:
alluvium
basalt
granitic
metamorphic
sedimentary
volcanic
Miles
0 2.5 5 10 15 20

Bedrock – Limited amounts of groundwater are also produced from fractured or weathered zones or thin alluvium overlying the bedrock of the Hualapai, Peacock, Mohon, and Aquarius Mountains.[9]

INVESTIGATION METHODS

Various groundwater sites were sampled by the ADEQ Ambient Groundwater Monitoring Program to characterize regional groundwater quality in the BIS. Samples were collected at all sites for inorganic (physical parameters, major ions, nutrients, and trace elements) and hydrogen and oxygen isotope analyses. At select sites, samples were also collected for radiochemistry, radon, and special low-detection mercury analyses. No bacteria sampling was conducted because microbiological contamination problems in groundwater are often transient and subject to a variety of changing environmental conditions including soil moisture content and temperature.[16]

Sampling Strategy

This study focused on regional groundwater quality conditions that are large in scale and persistent in time. This research is designed to identify regional degradation of groundwater quality such as occurs from non-point sources of pollution or a high density of point sources. The quantitative estimation of regional groundwater quality conditions requires the selection of sampling locations that follow scientific principles for probability sampling.[18]

Sampling in the BIS conducted by ADEQ followed a systematic stratified random site-selection approach. This is an efficient method because it requires sampling relatively few sites to make valid statistical statements about the conditions of large areas. This systematic element requires that the selected wells be spatially distributed while the random element ensures that every well within a cell has an equal chance of being sampled. This strategy also reduces the possibility of biased well selection and assures adequate spatial coverage throughout the study area.[18] The main benefit of a statistically-designed sampling plan is that it allows for greater groundwater quality assumptions than would be allowable with a non-statistical approach.

Wells pumping groundwater for a variety of purposes - domestic, stock, and industrial - were sampled for this study, provided each individual well met ADEQ requirements. A well was considered suitable for sampling if the well owner gave permission to sample, if a sampling point existed near the wellhead, and if the well casing and surface seal appeared to be intact and undamaged.[7] Other factors such as casing access to determine groundwater depth and construction information were preferred but not essential.

If registered wells were unavailable for sampling, springs or unregistered wells were randomly selected for sampling. Springs were considered adequate for sampling if they had a constant flow through a clearly-defined point of egress, and if the sample point had minimal surface impacts. Well information compiled from the ADWR well registry and spring data are found in Appendix A.

Several factors were considered to determine sample size for this study. Aside from administrative limitations on funding and personnel, this decision was based on three factors related to the conditions in the area:

- Amount of groundwater quality data already available;
- Extent to which impacted groundwater is known or believed likely to occur; and
- Hydrologic complexity and variability of the basin.[18]

Sample Collection

The personnel who designed the BIS study were also responsible for the collection and interpretation of the data. This protocol helps ensure that consistently high quality data are collected, from which are drawn relevant and meaningful interpretations. The sample collection methods for this study conformed to the Quality Assurance Project Plan (QAPP)[2] and the Field Manual For Water Quality Sampling.[7] While these sources should be consulted as references to specific sampling questions, a brief synopsis of the procedures involved in collecting a groundwater sample is provided.

After obtaining permission from the owner to sample the well, the water level was measured with a sounder if the casing had access for a probe. The volume of water needed to purge the well three bore-hole volumes was calculated from well log and on-site information. Physical parameters - temperature, pH, and specific conductivity - were monitored at least every five minutes using a YSI multi-parameter instrument. To assure obtaining fresh water from the aquifer, typically after three bore volumes had been pumped and the physical parameters were stabilized within 10 percent, a sample representative of the aquifer was collected from a point as close to the wellhead as possible. In certain instances, it was not possible to purge three bore volumes. In these cases, at least one bore volume

was evacuated and the physical parameters had stabilized within 10 percent.

Sample bottles were filled in the following order:

1. Mercury
2. Radon
3. Inorganic
4. Radiochemistry
5. Isotope

Ultra-clean mercury samples were collected in a 1-liter glass bottles and were not preserved. The bottle was rinsed three times with sample water and then filled leaving a small headspace for subsequent acid preservation at the laboratory.[34]

Radon samples were collected in two unpreserved, 40-ml clear glass vials. Radon samples were carefully filled and sealed so that no headspace remained.[14]

The inorganic constituents were collected in three, 1-liter polyethylene bottles:

Samples to be analyzed for dissolved metals were filtered into bottles and preserved with 5 ml nitric acid (70 percent). An on-site positive pressure filtering apparatus with a 0.45 micron (µm) pore size groundwater capsule filter was used.

Samples to be analyzed for nutrients were collected in bottles and preserved with 2 ml sulfuric acid (95.5 percent).

Samples to be analyzed for other parameters were unpreserved.[22]

Radiochemistry samples were collected in two collapsible 4-liter plastic containers and preserved with 5 ml nitric acid to reduce the pH below 2.5 su.

Hydrogen and oxygen isotope samples were collected in a single 500 ml plastic bottle and were not preserved.

Samples were kept at 4^0C with ice in an insulated cooler, with the exception of the isotope and radiochemistry samples. Chain of custody procedures were followed in sample handling. Samples for this study were collected during eight field trips between August 2003 and February 2004.

Laboratory Methods

The inorganic analyses for this study were conducted by the Arizona Department of Health Services (ADHS) Laboratory in Phoenix, Arizona. Inorganic sample splits analyses were conducted by Del Mar Laboratory in Phoenix, Arizona. A complete listing of inorganic parameters, including laboratory method, EPA water method and Minimum Reporting Level (MRL) for each laboratory is provided in Table 1.

Ultra-clean mercury samples were analyzed by Frontier Geosciences Laboratory in Seattle, Washington.

Radon samples were analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, Arizona.

Radiochemistry samples were analyzed by either the Radiation Safety Engineering, Inc. Laboratory or the Arizona Radiation Agency Laboratory in Phoenix. The following EPA SDW protocols were used: Gross alpha was analyzed, and if levels exceeded 5 pCi/L, then radium-226 was measured. If radium-226 exceeded 3 pCi/L, radium-228 was measured. If gross alpha levels exceeded 15 pCi/L initially, then radium-226/228 and total uranium were measured.

Hydrogen and oxygen isotope samples were analyzed by the University of Arizona, Laboratory of Isotope Geochemistry in Tucson.

Sample Numbers

Fifty-seven (57) groundwater sites were sampled for the study. Six surface water sites were also sampled for isotope analyses and for an ultra-clean mercury sample on one occasion.

The various numbers and types of samples collected and analyzed were:

57 - inorganic
57 - hydrogen and oxygen isotopes
37 - radon
30 - radiochemistry
21 – ultra-clean mercury

Table 1. ADHS/Del Mar Laboratory Methods Used for the Big Sandy Basin Study

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
Physical Parameters and General Mineral Characteristics			
Alkalinity	Electrometric Titration	SM232OB	2 / 5
SC (uS/cm)	Electrometric	EPA 120.1/ SM2510B	-- / 1
Hardness	Titrimetric, EDTA	EPA 130.2 / SM2340B	10 / 1
Hardness	Calculation	Calculation	--
pH (su)	Electrometric	EPA 150.1	0.1
TDS	Gravimetric	EPA 160.1 / SM2540C	10 / 20
Turbidity (NTU)	Nephelometric	EPA 180.1	0.01 / 1
Major Ions			
Calcium	ICP-AES	EPA 200.7	1 / 2
Magnesium	ICP-AES	EPA 200.7	1 / 0.5
Sodium	ICP-AES	EPA 200.7 / EPA 273.1	1 / 5
Potassium	Flame AA	EPA 200.7 / EPA 258.1	0.5 / 1
Bicarbonate	Calculation	Calculation	2
Carbonate	Calculation	Calculation	2
Chloride	Potentiometric Titration	EPA 300.0	0.5 / 0.5
Sulfate	Colorimetric	EPA 300.0	1 / 0.5
Nutrients			
Nitrate as N	Colorimetric	EPA 353.2	0.02 / 0.1
Nitrite as N	Colorimetric	EPA 353.2	0.02 / 0.1
Ammonia	Colorimetric	EPA 350.1/ EPA 350.3	0.02 / 0.5
TKN	Colorimetric	EPA 351.2 / SM4500	0.05 / 0.5
Total Phosphorus	Colorimetric	EPA 365.4 / EPA 365.3	0.02 / 0.05

All units are mg/L except as noted
Source [14, 22]

Table 1. ADHS/Del Mar Laboratory Methods Used for the Big Sandy Basin Study--Continued

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
		Trace Elements	
Aluminum	ICP-AES	EPA 200.7	-- / 0.5
Antimony	Graphite Furnace AA	EPA 200.9	0.005 / 0.004
Arsenic	Graphite Furnace AA	EPA 200.9	0.01 / 0.003
Barium	ICP-AES	EPA 200.7	0.1 / 0.01
Beryllium	Graphite Furnace AA	EPA 200.9	0.0005
Boron	ICP-AES	EPA 200.7	0.1 / 0.5
Cadmium	Graphite Furnace AA	EPA 200.9	0.001 / 0.0005
Chromium	Graphite Furnace AA	EPA 200.9	0.01 / 0.004
Copper	Graphite Furnace AA	EPA 200.7 / EPA 200.9	0.01 / 0.004
Fluoride	Ion Selective Electrode	EPA 300.0	0.05 / 0.1
Iron	ICP-AES	EPA 200.7	0.1 / 0.2
Lead	Graphite Furnace AA	EPA 200.9	0.005 / 0.002
Manganese	ICP-AES	EPA 200.7	0.05 / 0.02
Mercury	Cold Vapor AA	SM 3112 B / EPA 245.1	0.0005 / 0.0002
Nickel	ICP-AES	EPA 200.7	0.1 / 0.05
Selenium	Graphite Furnace AA	EPA 200.9	0.005 / 0.004
Silver	Graphite Furnace AA	EPA 200.9 / EPA 200.7	0.001 / 0.005
Thallium	Graphite Furnace AA	EPA 200.9	0.002
Zinc	ICP-AES	EPA 200.7	0.05

All units are mg/L
Source [14, 22]

DATA EVALUATION

Quality Assurance

Quality-assurance (QA) procedures were followed and quality-control (QC) samples were collected to quantify data bias and variability for the BIS study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan* (*QAPP*)[2] and *the Field Manual For Water Quality Sampling*.[7] The types and numbers of QC samples collected for this study are as follows:

Inorganic: (5 duplicates, 8 splits, 6 blanks).

Isotope: (10 duplicates).

Radiochemical: (2 splits).

Radon: (1 duplicate).

Ultra-Clean Mercury: (2 duplicates).

Based on the QA/QC results, sampling procedures and laboratory equipment did not significantly affect the groundwater quality samples of this study.

Blanks - Equipment blanks for inorganic analyses were collected to ensure adequate decontamination of sampling equipment, and that the filter apparatus and/or de-ionized water were not impacting the groundwater quality sampling.[7]

Equipment blank samples for major ion and nutrient analyses were collected by filling unpreserved and sulfuric acid preserved bottles with de-ionized water. Equipment blank samples for trace element analyses were collected with de-ionized water that had been filtered into nitric acid preserved bottles.

Systematic contamination was judged to occur if more than 50 percent of the equipment blank samples contained measurable quantities of a particular groundwater quality constituent.[18] As such, SC-lab and turbidity were considered to be affected by systematic contamination; however, the extent of contamination was not considered significant.

SC was detected in all six equipment blanks while turbidity was detected four equipment blanks. For SC, equipment blanks had a mean (4.9 uS/cm) which was less than 1 percent of the SC mean concentration for the study. The SC detections may be explained in two ways: water passed through a de-ionizing exchange unit will normally have an SC value of at least 1 uS/cm, and carbon dioxide from the air can dissolve in de-ionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity.[22]

Similarly for turbidity, equipment blanks had a mean level (0.09 ntu) less than 1 percent of the turbidity median level for the study. Testing indicates turbidity is present at 0.01 ntu in the de-ionized water supplied by the ADHS laboratory, and levels increase with time due to storage in ADEQ carboys.[22]

Nitrate was detected in the two blanks (0.026 and 0.021 mg/L), and copper was detected in one blank (0.017 mg/L) but did not appear to significantly impact sampling results.

Duplicate Samples - Duplicate samples are identical sets of samples collected from the same source at the same time and submitted to the same laboratory. Data from duplicate samples provide a measure of variability from the combined effects of field and laboratory procedures.[7]

Duplicate samples were collected from sampling sites that were believed to have elevated constituent concentrations as judged by field SC values. Five duplicate samples were collected in this study.

Analytical results indicate that of the 21 constituents that had concentrations above the MRL, the maximum variation between duplicates was less than 6 percent (Table 2). The only exceptions were copper (46%), turbidity (33%), TKN (22%), and ammonia (15%). The median variation between duplicates was less than 1 percent except with copper (46%), TKN (13%) and turbidity (7%).

Analytical results for the 10 isotope duplicates conducted by the Laboratory of Isotope Geochemistry at the University of Arizona indicated the maximum variation between both oxygen and hydrogen duplicates was less than 1 percent.

Table 2. Summary Results of BIS Duplicate Samples from the ADHS Laboratory

Parameter	Number	Difference in Percent			Difference in Concentrations		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Physical Parameters and General Mineral Characteristics							
Alk., Total	5	0 %	6 %	0 %	0	40	0
SC (uS/cm)	5	0 %	1 %	0 %	0	10	0
Hardness	5	0 %	4 %	0 %	0	10	0
pH-field (su)	5	0 %	3 %	1 %	0	0.5	0.1
TDS	5	0 %	3 %	0 %	0	10	0
Turb. (ntu)	5	0 %	33 %	7 %	0	0.22	0.1
Major Ions							
Bicarbonate	5	0 %	6 %	0 %	0	50	0
Calcium	5	0 %	3 %	1 %	0	2	1
Magnesium	5	0 %	2 %	0 %	0	1	0
Sodium	5	0 %	6 %	0 %	0	30	0
Potassium	5	0 %	3 %	1 %	0	0.2	0.1
Chloride	5	0 %	3 %	0 %	0	10	0
Sulfate	5	0 %	2 %	0 %	0	10	0
Nutrients							
Nitrate (as N)	5	0 %	4 %	0 %	0	0.1	0
TKN*	3	11 %	22 %	13 %	0.03	0.046	0.023
Ammonia	2	11 %	15 %	-	0.017	0.019	-
Phos., Total*	-	-	-	-	-	-	-
Trace Elements							
Arsenic	2	4 %	4 %	-	0.001	0.01	-
Boron	3	0 %	0 %	0 %	0	0	0
Copper	1	46 %	46 %	46 %	0.017	0.017	0.017
Fluoride	5	0 %	1 %	0 %	0	0.1	0
Iron*	-	-	-	-	-	-	-
Zinc	3	0 %	0 %	0%	0	0	0

All units are mg/L except as noted with certain physical parameters
* - In one sample apiece, TKN, total phosphorus, and iron, were detected at near the MRL and not detected in the duplicate sample.

Split Samples - Split samples are identical sets of samples collected from the same source at the same time that are submitted to two different laboratories to check for laboratory differences.[7] Eight inorganic split samples were collected and analytical results were evaluated by examining the variability in constituent concentrations in terms of absolute levels and as the percent difference.

Analytical results indicate that of the 36 constituents examined, only 19 had concentrations above MRLs for both ADHS and Del Mar laboratories (Table 3). The maximum difference between split constituent only exceeded 20 percent for TDS (22%) and fluoride (36%). Analytical results of the two split samples radiochemistry results for the Arizona Radiation Agency laboratory and Del Mar laboratory revealed a maximum gross alpha difference of 10 percent.

Split samples were also evaluated using the non-parametric Sign test to determine if there were any significant (p. 0.05) differences between ADHS laboratory and Del Mar laboratory analytical results.[33] Results of the Sign test showed chloride (and almost sulfate, p. 0.07) concentrations reported by the ADHS laboratory were significantly higher than those reported by Del Mar laboratory; the opposite pattern occurred with potassium. Potassium concentrations determined by the ADHS laboratory were previously found to be higher than those determined by the U.S. Geological Survey in a previous study.[33] Both laboratories used the same test (EPA 200.7) for chloride and sulfate while different tests (EPA 200.7 and EPA 258.1) were used by each laboratory for potassium.

Split results reported by Del Mar laboratory detected iron, zinc, lead, antimony, cadmium (once each), and copper (twice), at concentrations above ADHS laboratory MRLs. Split results reported by ADHS laboratory detected zinc (once) at concentrations above Del Mar laboratory MRLs.

Based on the results of blanks, duplicates and the split sample collected for this study, no significant QA/QC problems were apparent with the groundwater quality collected for this study.

Data Validation

The analytical work for this study was subjected to the following five QA/QC correlations.

Cation/Anion Balances - In theory, water samples exhibit electrical neutrality. Therefore, the sum of milliequivalents per liter (meq/L) of cations must equal the sum of meq/L of anions. However, this neutrality rarely occurs due to unavoidable variation inherent in all water quality analyses. Still, if the cation/anion balance is found to be within acceptable limits, it can be assumed there are no gross errors in concentrations reported for major ions.[19]

Overall, cation/anion balances of BIS samples were significantly correlated (regression analysis, p. 0.01) and were within acceptable limits (90 - 110 percent).

SC/TDS - The SC and TDS concentrations measured by contract laboratories were significantly correlated as were field-SC and TDS concentrations (regression analysis, p. 0.01). Typically, the TDS concentration in mg/L should be from 0.55 to 0.75 times the SC in uS/cm for groundwater up to several thousand mg/L.[19] Groundwater in which the ions are mostly bicarbonate and chloride will have a multiplication factor near the lower end of this range and groundwater high in sulfate may reach or even exceed the higher number. The relationship of TDS to SC becomes undefined for groundwater either with very high and low concentrations of dissolved solids.[19]

Hardness - Concentrations of laboratory-measured and calculated values were significantly correlated (regression analysis, p. 0.01). Hardness concentrations were calculated using the following formula: [(Calcium x 2.497) + (Magnesium x 4.118)].

SC - The SC measured in the field using a YSI meter at the time of sampling was significantly correlated with the SC measured by contract laboratories (regression analysis, p. 0.01).

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.[19] Even so, the pH values measured in the field using a YSI meter at the time of sampling were significantly correlated with laboratory pH values (regression analysis, p. 0.01).

The analytical work conducted for this study was considered valid based on the quality control samples and the QA/QC correlations.

Table 3. Summary Results of BIS Split Samples From ADHS/Del Mar Laboratories

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	8	0 %	4 %	0	20	ns
SC (uS/cm)	8	1 %	20 %	0.4	500	ns
Hardness	8	0 %	5 %	0	20	ns
pH (su)	8	0 %	4 %	0.02	0.67	ns
TDS	8	0 %	22 %	0	190	ns
Turbidity (ntu)	3	12 %	14 %	0.8	1	ns
Major Ions						
Calcium	8	1 %	11 %	1	12	ns
Magnesium	8	0 %	9 %	0	5	ns
Sodium	8	1 %	11 %	0.4	50	ns
Potassium	8	0 %	16 %	0	3.5	*
Chloride	8	0 %	17 %	0	120	*
Sulfate	8	1 %	20 %	0.4	500	ns
Nutrients						
Nitrate (as N)	5	0 %	8 %	0	0.5	ns
Trace Elements						
Arsenic	4	0 %	4 %	0	0.003	ns
Boron	3	5 %	10 %	0.09	0.3	ns
Fluoride	8	0 %	36 %	0	0.64	ns
Iron#	1	11 %	11 %	0.05	0.05	ns
Manganese	1	1 %	1 %	0.001	0.001	ns
Zinc#	2	0 %	4 %	0	0.1	ns
Radiochemistry						
Gross alpha (pCi/L)	2	2 %	10 %	1	1.1	ns

All units are mg/L except as noted ns = No significant ($p \leq 0.05$) difference between labs
* = Significant ($p \leq 0.05$) difference between labs (ADHS > Del Mar with chloride; Del Mar > ADHS with potassium)
# = Split results reported by Del Mar laboratory had detections of iron, zinc, lead, copper (twice), antimony, and cadmium at concentrations above ADHS laboratory MRLs; split results reported by the ADHS laboratory had detections of zinc at concentrations above Del Mar laboratory MRLs.

Statistical Considerations

Various methods were used to complete the statistical analyses for the groundwater quality data of this study. All statistical tests were conducted on a personal computer using SYSTAT software.[32]

Data Normality: Data associated with 35 constituents were tested for non-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.[8] Results of this test revealed that 8 of the 35 constituents (oxygen-18, temperature, pH-field, hardness, hardness-calculated, calcium, total alkalinity, and bicarbonate) were normally distributed.

The results of log-transformed test revealed that 16 of the 35 constituents (oxygen-18, temperature, pH-field, SC-field, SC-lab, TDS, hardness, turbidity, sodium, total alkalinity, chloride, sulfate, fluoride, radon, gross alpha, and gross beta) were normally distributed. The log-transformed data were used for subsequent statistical analyses.

Spatial Relationships: The parametric analysis of variance (ANOVA) test in conjunction with the Tukey test using log-transformed data was applied to investigate the hypothesis that constituent concentrations from groundwater sites having different sources of water were the same. The ANOVA tests the equality of two or more means in experiments involving one continuous dependent variable and one categorical independent variable.[32] The null hypothesis of identical mean values for all data sets within each test was rejected if the probability of obtaining identical means by chance was less than or equal to 0.05. Comparisons conducted using the ANOVA test include aquifers (artesian, basin-fill, bedrock, floodplain, and sedimentary).

The ANOVA test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[18] However, the ANOVA test was applied to ammonia, arsenic, barium, chromium, copper, iron, manganese, and total phosphorus even though the results were not considered statistically valid in order to highlight possible significant differences. Highlights of these statistical tests are summarized in the groundwater quality section. The ANOVA test was not calculated for trace parameters or nutrients rarely detected such as antimony, beryllium, cadmium, lead, mercury, nickel, selenium, silver, thallium, phenolphthalein alkalinity, carbonate, nitrite, radium, and uranium.

Correlation Between Constituent Concentrations: In order to assess the strength of association between constituents, their concentrations were compared to each other using the Pearson Correlation Coefficient test.

The Pearson correlation coefficient varies between -1 and +1, with a value of +1 indicating that a variable can be predicted perfectly by a positive linear function of the other, and vice versa. A value of -1 indicates a perfect inverse or negative relationship. The results of the Pearson Correlation Coefficient test were then subjected to a probability test to determine which of the individual pair wise correlations were significant.[32] The Pearson test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[18] Consequently, Pearson Correlation Coefficients were not calculated for the same constituents as in spatial relationships.

GROUNDWATER SAMPLING RESULTS

To characterize the regional groundwater quality of the BIS basin, ADEQ personnel sampled 57 groundwater sites consisting of 43 wells and 14 springs. The water produced by the wells was used for stock (23), domestic (17), irrigation (2), industrial (1), and public water supply (1). The 14 springs were all used for stock watering.

Of the 43 wells, 1 had an artesian flow and the others were equipped with submersible pumps (23), windmills (18), and turbine pumps (1). Information on these groundwater sample sites is provided in Appendix A.

At the 57 sites, the following types of samples were collected: inorganic suites at 57 sites, hydrogen and oxygen isotopes at 57 sites, radon at 37 sites, radiochemistry samples (that are unstable elements, such as uranium, thorium, or radium that release radioactivity in the form of alpha, beta and gamma radiation) at 30 sites, and ultra-clean mercury at 21 sites. Six surface water sites were also sampled for hydrogen and oxygen isotopes and, on one occasion, for an ultra-clean mercury sample.

Water Quality Standards/Guidelines

The ADEQ ambient groundwater monitoring program characterizes regional groundwater quality. An important determination ADEQ makes concerning the collected samples is how the analytical results compare to various drinking water quality standards. Three sets of drinking water standards which reflect the best current scientific and

technical judgment available on the suitability of water for drinking purposes were used to evaluate the suitability of these groundwater sites for domestic purposes:

- Federal Safe Drinking Water (SDW) Primary Maximum Contaminant Levels (MCLs). These enforceable health-based standards establish the maximum concentration of a constituent allowed in water supplied by public systems.[29]

- State of Arizona Aquifer Water-Quality Standards. These apply to aquifers that are classified for drinking water protected use.[3] All aquifers within Arizona are currently regulated for drinking water use. These enforceable State standards are almost identical to the federal Primary MCLs.

- Federal SDW Secondary MCLs. These non-enforceable aesthetics-based guidelines define the maximum concentration of a constituent that can be present without imparting unpleasant taste, color, odor, or other aesthetic effect on the water.[29]

Health-based drinking water quality standards (such as Primary MCLs) are based on a lifetime consumption of two liters of water per day over a 70 year lifespan and, as such, are chronic not acute standards.[29]

BIS Sites - Of the 57 sites sampled for the BIS study, 24 (42 percent) met all SDW Primary and Secondary MCLs.

Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 24 of 57 sites (42 percent) (Map 4, Table 4). Constituents exceeding Primary MCLs include arsenic (11 sites), fluoride (11 sites), gross alpha (9 sites), lead (1 site), radium (1 site), and uranium (2 sites). Potential health effects of these chronic Primary MCL exceedances are provided in Table 1.[29, 31]

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 29 of 57 sites (51 percent) (Map 4, Table 5). Constituents above Secondary MCLs include chloride (4 sites), fluoride (20 sites), iron (3 sites), manganese (4 sites), pH (2 sites), sulfate (2 sites), and TDS (22 sites).

Radon is a naturally occurring, intermediate breakdown product from the radioactive decay of uranium-238 to lead-206.[11] Different opinions exist on the risk assessment of radon in drinking water, with proposed drinking water standards varying from 300 pCi/L to 4,000 piC/L.[11] Of the 36 sites sampled for radon, 16 exceeded the 300 pCi/L standard; none exceeded the 4,000 standard.

Suitability for Irrigation

The suitability of groundwater at each sample site was assessed as to its suitability for irrigation use based on salinity and sodium hazards. With increasing salinity, leaching, salt tolerant plants, and adequate drainage are necessary. Excessive levels of sodium are known to cause physical deterioration of the soil.[30] Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR) in conjunction with one another.[30]

Groundwater sites in the BIS basin display a wide range of irrigation water classifications with salinity hazards generally greater than sodium hazards (see Appendix B). The 57 sample sites are divided into the following salinity hazards: low or C1 (0), medium or C2 (40), high or C3 (15), and very high or C4 (2). The 57 sample sites are divided into the following sodium or alkali hazards: low or S1 (51), medium or S2 (4), high or S3 (0), and very high or S4 (2).

Analytical Results

Analytical inorganic and radiochemistry results of the 57 BIS sample sites are summarized (Table 6) using the following indices: minimum reporting levels (MRLs), number of sample sites over the MRL, upper and lower 95 percent confidence intervals ($CI_{95\%}$), and the median and mean. Confidence intervals are a statistical tool which indicates that 95 percent of a constituent's population lies within the stated confidence interval.[18] Specific constituent information for each groundwater site is found in Appendix B.

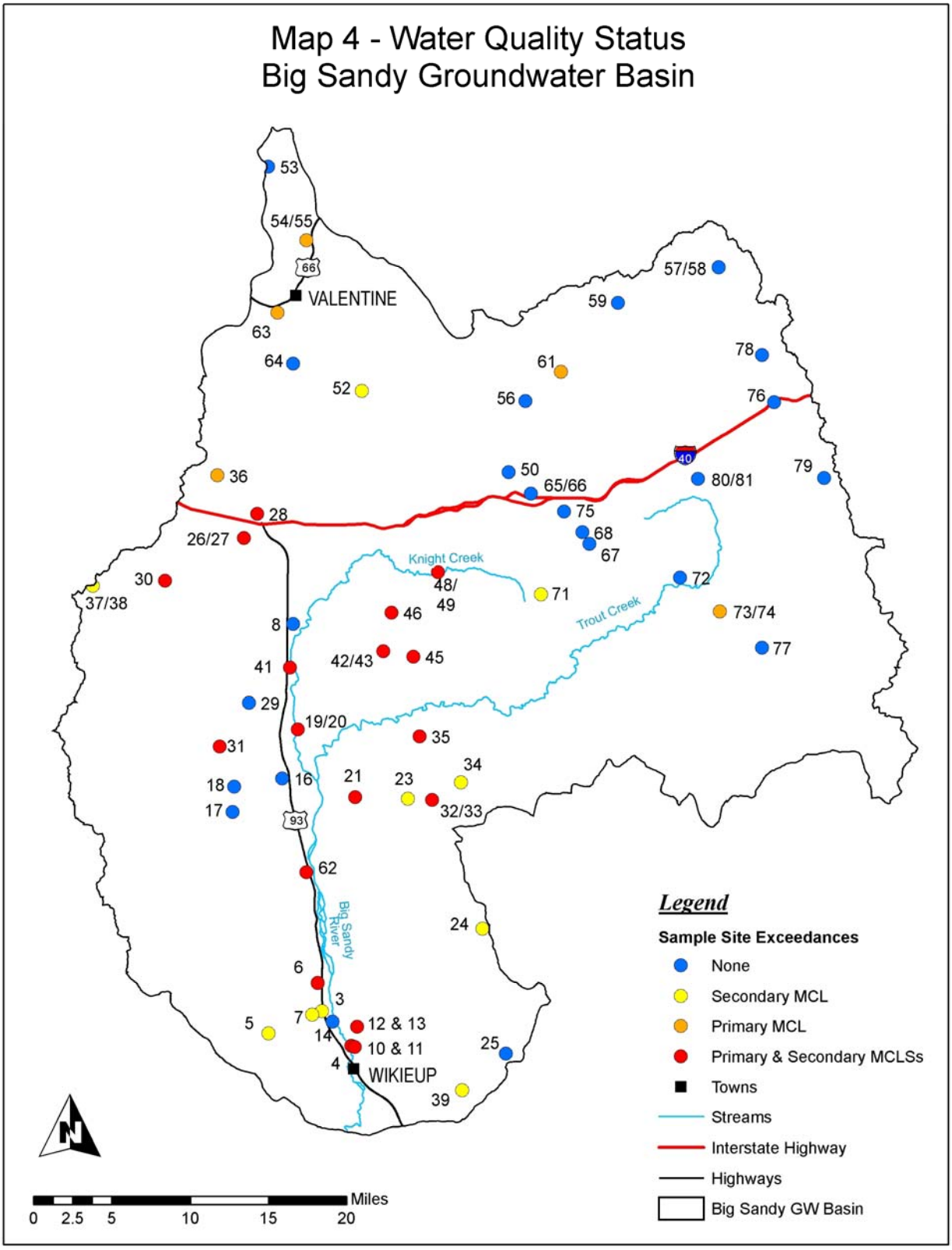
Map 4 - Water Quality Status
Big Sandy Groundwater Basin
VALENTINE
WIKIEUP
Knight Creek
Trout Creek
Big Sandy River
66
93
40
53
54/55
63
64
52
57/58
59
61
56
78
76
79
36
50
65/66
80/81
28
26/27
75
68
67
30
37/38
48/
49
71
72
73/74
77
8
46
42/43
45
41
29
19/20
35
31
34
18
16
21
23
32/33
17
62
24
6
3
7
5
14
12 & 13
10 & 11
4
25
39
Legend
Sample Site Exceedances
None
Secondary MCL
Primary MCL
Primary & Secondary MCLSs
Towns
Streams
Interstate Highway
Highways
Big Sandy GW Basin
Miles
0 2.5 5 10 15 20

Table 4. BIS Sites Exceeding Health-Based Water Quality Standards (Primary MCLs)

Constituent	Primary MCL	Sites Exceeding Primary MCL	Concentration Range of Exceedances	Potential Health Effects of MCL Exceedances *
Nutrients				
Nitrite (NO_2-N)	1.0	0	-	-
Nitrate (NO_3-N)	10.0	0	-	-
Trace Elements				
Antimony (Sb)	0.006	0	-	
Arsenic (As)	0.01	**13**	0.011 – 0.125	Dermal and nervous system toxicity
Barium (Ba)	2.0	0	-	-
Beryllium (Be)	0.004	0	-	-
Cadmium (Cd)	0.005	0	-	-
Chromium (Cr)	0.1	0	-	-
Copper (Cu)	1.3	0	-	-
Fluoride (F)	4.0	**11**	4.0 – 7.85	Skeletal damage
Lead (Pb)	0.015	**1**	0.016	Development difficulties
Mercury (Hg)	0.002	0	-	-
Nickel (Ni)	0.1	0	-	-
Selenium (Se)	0.05	0	-	-
Thallium (Tl)	0.002	0	-	-
Radiochemistry Constituents				
Gross Alpha	15	**9**	17 - 42	Cancer
Ra-226 + Ra-228	5	**1**	44	Bone cancer
Uranium	30	**2**	39 – 42	Cancer & kidney toxicity

All units in mg/L except gross alpha and radium-226+228 (pCi/L), and uranium (μg/L).Source: [29, 31]
* Health-based drinking water quality standards are based on a lifetime consumption of two liters of water per day.[31]

Table 5. BIS Sites Exceeding Aesthetics-Based Water Quality Standards (Secondary MCLs)

Constituents	Secondary MCL	Sites Exceeding Secondary MCLs	Concentration Range of Exceedances	Aesthetic Effects of MCL Exceedances
Physical Parameters				
pH - field	6.5 to 8.5	**2**	8.5 – 8.86	Corrosive Water
General Mineral Characteristics				
TDS	500	**22**	535 – 1,100	Unpleasant taste
Major Ions				
Chloride (Cl)	250	**4**	250 – 490	Salty taste
Sulfate (SO_4)	250	**2**	260 – 1,250	Rotten-egg odor, unpleasant taste and laxative effect
Trace Elements				
Fluoride (F)	2.0	**20**	2.0 – 7.85	Mottling of teeth enamel
Iron (Fe)	0.3	**3**	0.30 – 0.37	Rusty color, reddish stains and metallic tastes
Manganese (Mn)	0.05	**5**	0.07 – 0.1	Black stains and bitter taste
Silver (Ag)	0.1	0	-	-
Zinc (Zn)	5.0	0	-	-

All units mg/L except pH is in standard units (su). Source: [19, 29, 31]

Table 6. Summary Statistics for Big Sandy Basin Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Big Sandy River Mean (at Hwy 93)
Physical Parameters							
Temperature (C)	N/A	52	19.1	19.8	20.4	21.8	20.1
pH-field (su)	N/A	56	7.51	7.63	7.63	7.75	8.00
pH-lab (su)	0.01	57	7.61	7.70	7.68	7.76	8.01
Turbidity (ntu)	0.01	55	1.57	0.69	3.56	5.54	23
General Mineral Characteristics							
T. Alkalinity	2.0	57	218	240	247	276	310
Phenol. Alk.	2.0	0	> 50% of data below MRL				
SC-fld (uS/cm)	N/A	56	707	714	914	1121	1025
SC-lab (uS/cm)	N/A	57	688	710	869	1051	960
Hardness-lab	10.0	57	220	240	251	282	280
TDS	10.0	57	415	440	529	644	640
Major Ions							
Calcium	5.0	57	52	57	59	66	66
Magnesium	1.0	57	22	23	26	30	23
Sodium	5.0	57	51	41	91	131	120
Potassium	0.5	56	2.9	2.9	3.6	4.3	6.0
Bicarbonate	2.0	57	264	290	300	336	380
Carbonate	2.0	0	> 50% of data below MRL				
Chloride	1.0	57	48	38	71	95	79
Sulfate	10.0	57	39	40	85	131	110
Nutrients							
Nitrate (as N)	0.02	50	1.4	1.6	1.9	2.4	0.05
Nitrite (as N)	0.02	2	> 50% of data below MRL				
Ammonia	0.02	10	> 50% of data below MRL				
TKN	0.05	30	0.06	0.05	0.08	0.10	0.35
T. Phosphorus	0.02	18	> 50% of data below MRL				

Table 6. Summary Statistics for Big Sandy Basin Groundwater Quality Data—Continued

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Big Sandy River Mean (at Highway 93)
Trace Elements							
Antimony	0.005	0	> 50% of data below MRL				
Arsenic	0.01	11	> 50% of data below MRL				
Barium	0.1	6	> 50% of data below MRL				
Beryllium	0.0005	1	> 50% of data below MRL				
Boron	0.1	26	0.26	0.24	0.35	0.45	0.44
Cadmium	0.001	1	> 50% of data below MRL				
Chromium	0.01	5	> 50% of data below MRL				
Copper	0.01	14	> 50% of data below MRL				
Fluoride	0.20	57	1.3	0.8	1.9	2.6	1.90
Iron	0.1	10	> 50% of data below MRL				
Lead	0.005	1	> 50% of data below MRL				
Manganese	0.05	5	> 50% of data below MRL				
Mercury	0.0005	0	> 50% of data below MRL				
Mercury	.00000015	19	-0.000058	0.00000095	0.0000104	0.0000214	-
Nickel	0.1	0	> 50% of data below MRL				
Selenium	0.005	3	>50% of data below MRL				
Silver	0.001	0	> 50% of data below MRL				
Thallium	0.005	0	> 50% of data below MRL				
Zinc	0.05	30	0.15	0.05	0.35	0.55	-
Radiochemical and Isotopes							
Radon*	Varies	36	398	290	712	1026	-
Gross Alpha*	Varies	29	6.9	6.5	11.2	15.5	-
Gross Beta*	Varies	30	7.3	7.2	10.2	13.1	-
Ra-226*	Varies	6	> 50% of data below MRL				
Uranium**	Varies	9	> 50% of data below MRL				
Oxygen***	N/A	57	- 10.1	- 9.8	- 9.9	- 9.6	-
Hydrogen ***	N/A	57	- 75.4	- 74.0	- 73.9	-75.4	-

All units mg/L except where noted or * = pCi/L, ** = μg/L, *** = 0/00 and **** = ng/L

GROUNDWATER COMPOSITION

General Summary

Groundwater in the Big Sandy basin is *slightly alkaline*, *fresh*, and *moderately hard*-to-*very hard* as indicated by pH values and TDS and hardness concentrations. Levels of pH were *slightly alkaline* (above 7 su) at 56 sites and *slightly acidic* (below 7 su) at 1 site.[17] TDS concentrations were considered *fresh* (below 1,000 mg/L) at 54 sites, slightly saline (1,000 to 3,000 mg/L) 2 sites, and moderately saline (3,000 to 10,000 mg/L) at 1 site.[17] Hardness concentrations were divided into *soft* (below 75 mg/L) at 3 sites, *moderately hard* (75 – 150 mg/L) at 8 sites, *hard* (150 – 300 mg/L) at 31 sites, and *very hard* (above 300 mg/L) at 15 sites.[12]

Nitrate, TKN, and total phosphorus were detected at more than 20 percent of the sites. Nitrate (as nitrogen) concentrations were divided into natural background (12 sites < 0.2 mg/L), may or may not indicate human influence (31 sites between 0.2 - 3.0 mg/L), may result from human activities (14 sites between 3.0 - 10 mg/L), and probably result from human activities (0 sites > 10 mg/L).[20]

Most trace elements such as aluminum, antimony, barium, beryllium, cadmium, chromium, iron, lead, manganese, mercury, nickel, selenium, silver, and thallium were rarely–if ever--detected. Only arsenic, boron, copper, fluoride, and zinc were detected at more than 20 percent of the sites.

Groundwater in the 57 sites sampled in the Big Sandy basin (Map 5) is predominantly of either a mixed-bicarbonate (24 sites) or calcium-bicarbonate (16 sites) chemistry (Figure 15, the diamond triangle). Other water chemistry types found in the basin include sodium-mixed (8 sites), sodium-bicarbonate, sodium-sulfate, magnesium-bicarbonate, and mixed-mixed (each two sites) and calcium-sulfate (one site).

The dominant cations in the 57 sampled sites consist of calcium (17 sites), sodium (12 sites), and magnesium (2 sites). There was no dominant cation (or was mixed) at 26 of the sites (Figure 15, lower left triangle). The dominant anions in the 57 sites consist of bicarbonate (44 sites) and sulfate (3 sites). Chloride was never the dominant anion while at 10 sites, there was no dominant (or was mixed) anion (Figure 15, lower right triangle).

Constituent Covariation

The co-variation of constituent concentrations was determined to scrutinize the strength of the association. The results of each combination of constituents were examined for statistically-significant positive or negative correlations. A ***positive correlation*** occurs when, as the level of a constituent increases or decreases, the concentration of another constituent also correspondingly increases or decreases. A ***negative correlation*** occurs when, as the concentration of a constituent increases, the concentration of another constituent decreases, and vice-versa. A positive correlation indicates a direct relationship between constituent concentrations; a negative correlation indicates an inverse relationship.[32]

Many significant correlations (Table 7) occurred among the 57 Big Sandy basin sites (Pearson Correlation Coefficient test, $p \leq 0.05$). Two groups of correlations were identified:

- Positive correlations occurred among calcium, magnesium, hardness, total alkalinity, and bicarbonate; negative correlations occurred with pH-field.

- Positive correlations occurred among temperature, SC, TDS, sodium, potassium, chloride, sulfate, boron, and fluoride.

TDS concentrations are best predicted among major ions and cations by sodium concentrations while among anions, sulfate is the best predictor (multiple regression analysis, $p \leq 0.01$).

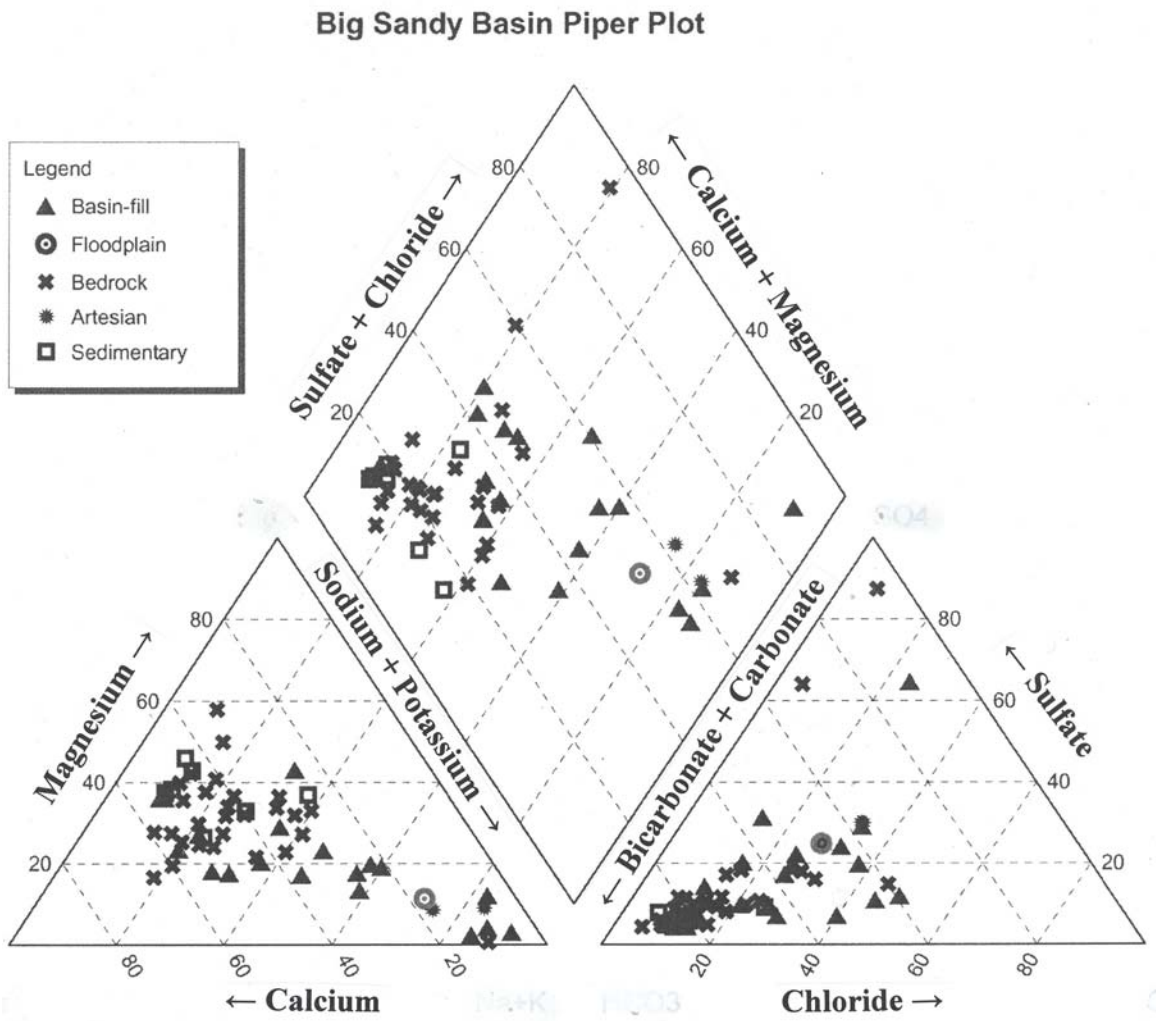

Figure 15. The piper trilinear diagram above shows sample sites in the Big Sandy basin are predominantly of calcium/magnesium-bicarbonate chemistry and reveal some patterns by water source. Water samples collected from bedrock and sedimentary water sources are predominantly of calcium/magnesium-bicarbonate chemistry, the basin-fill aquifer varies but tends towards a mixed-mixed chemistry and the artesian aqifer and floodplain aquifer tend towards a sodium/potassium-mixed chemistry.

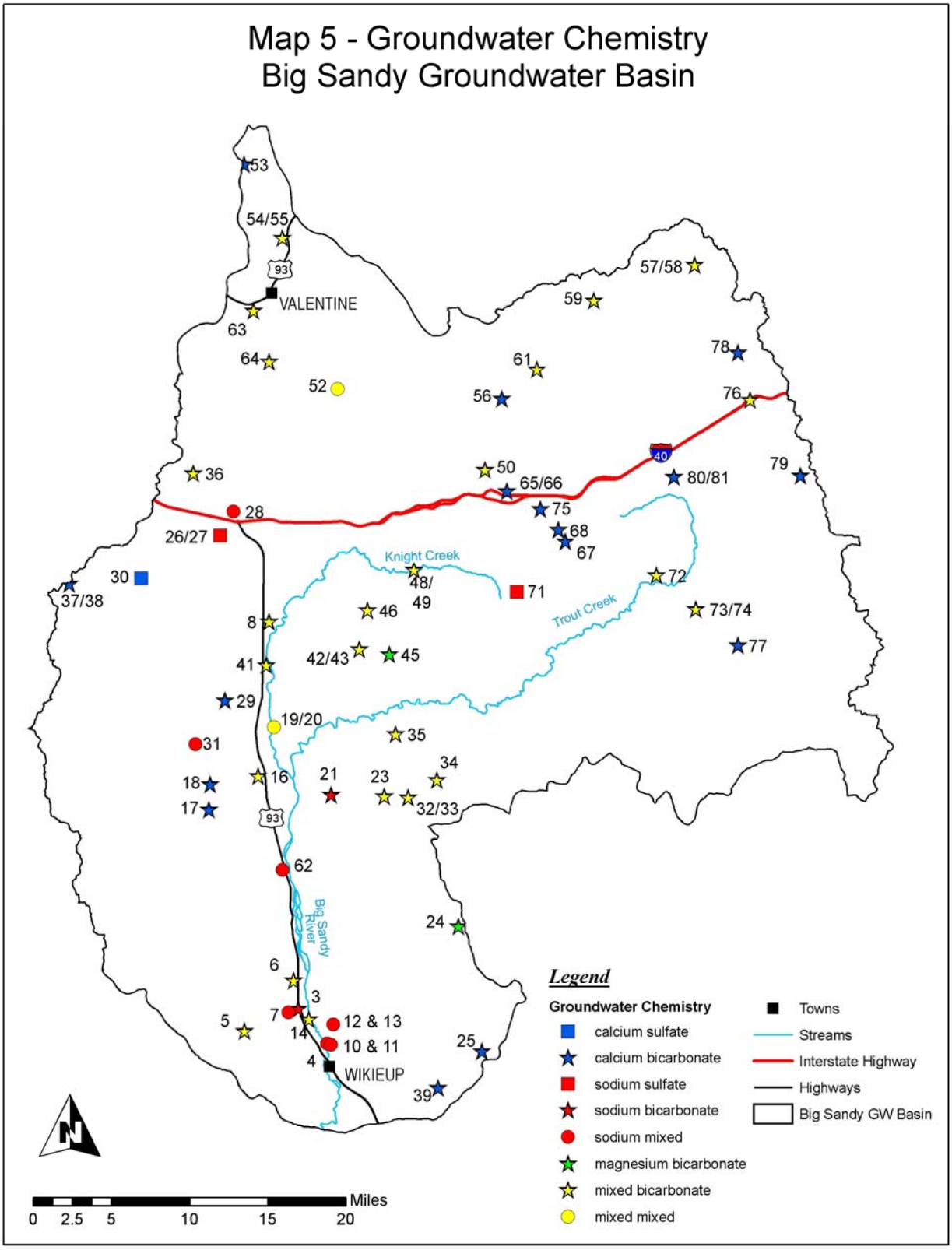
Map 5 - Groundwater Chemistry
Big Sandy Groundwater Basin
VALENTINE
WIKIEUP
Knight Creek
Trout Creek
Big Sandy River
93
40
53
54/55
63
64
52
57/58
59
61
56
78
76
79
36
50
65/66
80/81
28
26/27
75
68
67
30
37/38
48/
49
71
72
46
73/74
8
42/43
45
77
41
29
19/20
35
31
34
18
16
21
23
32/33
17
62
24
6
3
5
7
12 & 13
14
10 & 11
25
4
39
Legend
Groundwater Chemistry
calcium sulfate
calcium bicarbonate
sodium sulfate
sodium bicarbonate
sodium mixed
magnesium bicarbonate
mixed bicarbonate
mixed mixed
Towns
Streams
Interstate Highway
Highways
Big Sandy GW Basin
Miles
0 2.5 5 10 15 20

Table 7. Correlation Among BIS Groundwater Quality Constituent Concentrations Using Pearson Correlation Probabilities

Constituent	Positive Significant Correlations	Negative Significant Correlations
Oxygen-18	Deuterium & Nitrate	F
Deuterium	Oxygen-18 & Nitrate	Na, SO_4, B & F
Temperature – field (C)	SC-f, SC-lab, TDS, Na, K, Cl, SO_4, As, B & F	-
pH – field	TKN & P	Hard, Ca, Mg, & Bic
pH – lab	-	Hard & Ca
SC – field	Temp, SC-lab, TDS, Na, K, Cl, SO_4, B & F	-
SC – lab	Temp, SC-f, TDS, Na, K, Cl, SO_4, B & F	-
Turbidity	-	-
TDS	Temp, SC-f, SC-lab, Na, K, Cl, SO_4, B & F	-
Bicarbonate	Hard, Ca, Mg & Alpha	pH-f
Calcium	Hard, Mg & Bic	pH-f & pH-lab
Magnesium	Bic	pH-f
Hardness	Ca, Mg & Bic	pH-f & pH-lab
Sodium	Temp, SC-f, SC-lab, TDS, K, Cl, SO_4, B & F	Deuterium
Potassium	Temp, SC-f, SC-lab, TDS, Na, Cl, SO_4, B & F	–
Chloride	Temp, SC-f, SC-lab, TDS, Na, K, SO_4, B & F	-
Sulfate	Temp, SC-f, SC-lab, TDS, Na, K, Cl, B & F	Deuterium
Fluoride	Temp, SC-f, SC-lab, TDS, Na, K, Cl, SO_4 & B	Oxygen-18, Deuterium & Nitrate
Nitrate (as N)	Oxygen-18 & Deuterium	F
TKN	pH-f & P	–
Phosphorus, Total ***	pH-f & TKN	–
Arsenic ***	Temp	–
Boron***	Temp, SC-f, SC-lab, TDS, Na, K, Cl, SO_4, & F	Deuterium
Copper ***	-	–
Gross Alpha	Bic & Beta	–
Gross Beta	Beta	-
Radon	-	-

Significant difference level is $p \leq 0.05$
*** = Statistical test not valid because of the large number of non-detects

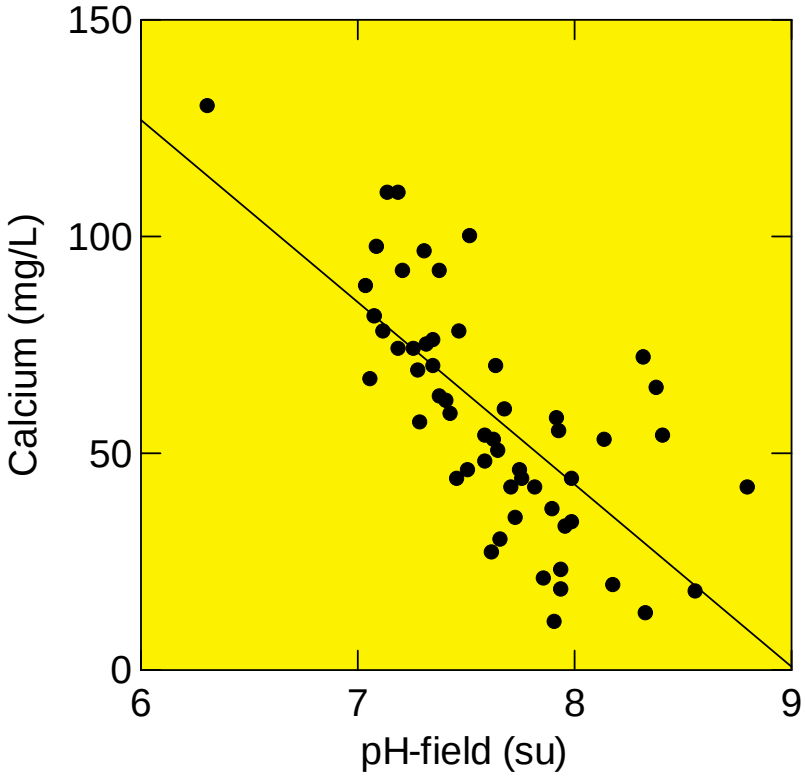

Figure 16. The graph to the left illustrates a negative correlation between two constituents: as pH-field values increase, calcium concentrations tend to decrease. This relationship is described by the regression equation: $y = -42x + 379$ ($r = 0.71$) which was found to be statistically significant ($p \leq 0.01$). The pH – calcium relationship has been found in other Arizona groundwater basins and is likely related to precipitation of calcite in response to increases in pH.[23]

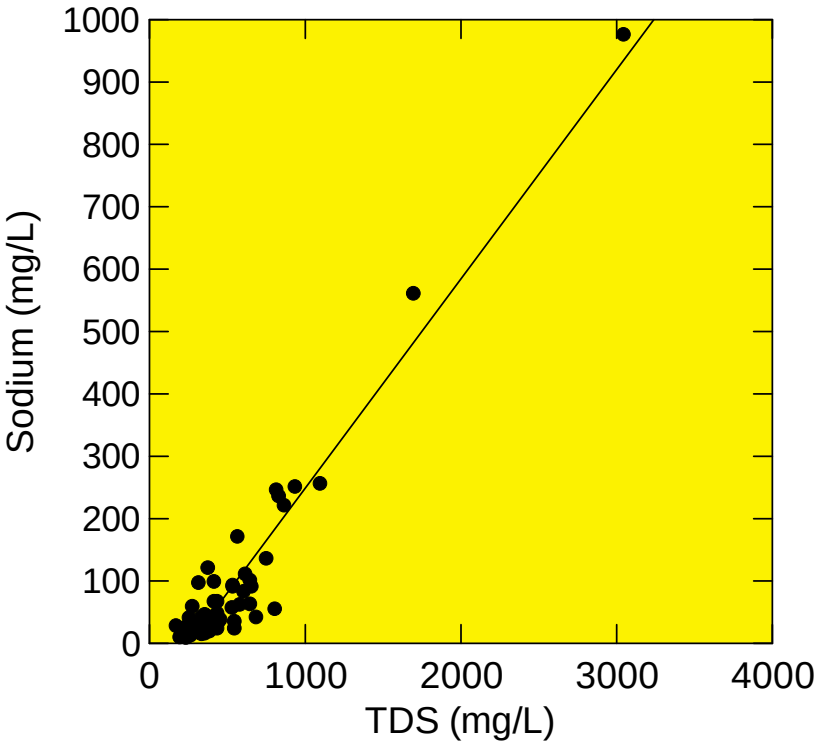

Figure 17. The graph to the left illustrates the positive relationship between two constituents: as TDS concentrations increase sodium concentrations also increase (regression analysis, $y = 0.34x – 86.9$, $n = 57$, $r = 0.96$). This relationship was found to be statistically significant ($p \leq 0.01$). Although recharge areas usually contain low concentrations of sodium, this constituent is frequently the dominant cation in down-gradient areas.[23]

Spatial Variation

The BIS basin was separated into spatial divisions by watershed, water source, and rock type.

Analytical results were compared between groundwater samples collected in the two sub-basins (Big Sandy and Trout Creek) as demarcated by ADWR to identify significant differences in concentrations of groundwater quality constituents.[6] Significant concentration differences were found with eleven constituents (Table 8): temperature-field, SC-field, SC-lab, TDS, sodium, chloride (Figure 18), sulfate, fluoride (Figure 19) (Map 6), boron, iron, and gross beta all of which were higher in the Big Sandy sub-basin (ANOVA test, $p \leq 0.05$ for iron and gross beta, $p \leq 0.01$ for other constituents). For constituents having significantly different concentrations between sub-basins, 95 percent confidence intervals are provided in Table 9.

Analytical results were compared between groundwater samples collected in five aquifers (artesian, basin-fill, bedrock, floodplain and sedimentary) to identify significant differences in concentrations of groundwater quality constituents.[9] Some of these demarcations (basin-fill, bedrock, and sedimentary) were used by ADWR in their 1981 report; some basin-fill samples were further divided into artesian or floodplain samples based on field observation. Significant concentration differences were found with eleven constituents (Table 10): temperature-field, SC-field, SC-lab, TDS, sodium, chloride (Figure 20), sulfate, fluoride, arsenic, boron, and radon (ANOVA with Tukey test, $p \leq 0.01$). For constituents having significantly different concentrations among aquifers, 95 percent confidence intervals are provided in Table 11.

Analytical results were compared between groundwater samples collected in six rock types (alluvium, basalt, granite, metamorphic, sedimentary, and volcanic) as demarcated in the Arizona State Geological Map to identify significant differences in concentrations of groundwater quality constituents.[21] Significant concentration differences were found with eight constituents (Table 12): SC-field, SC-lab, TDS, hardness, calcium, chloride, copper and radon (ANOVA with Tukey test, $p \leq 0.01$). For constituents having significantly different concentrations among aquifers, 95 percent confidence intervals are provided in Table 13.

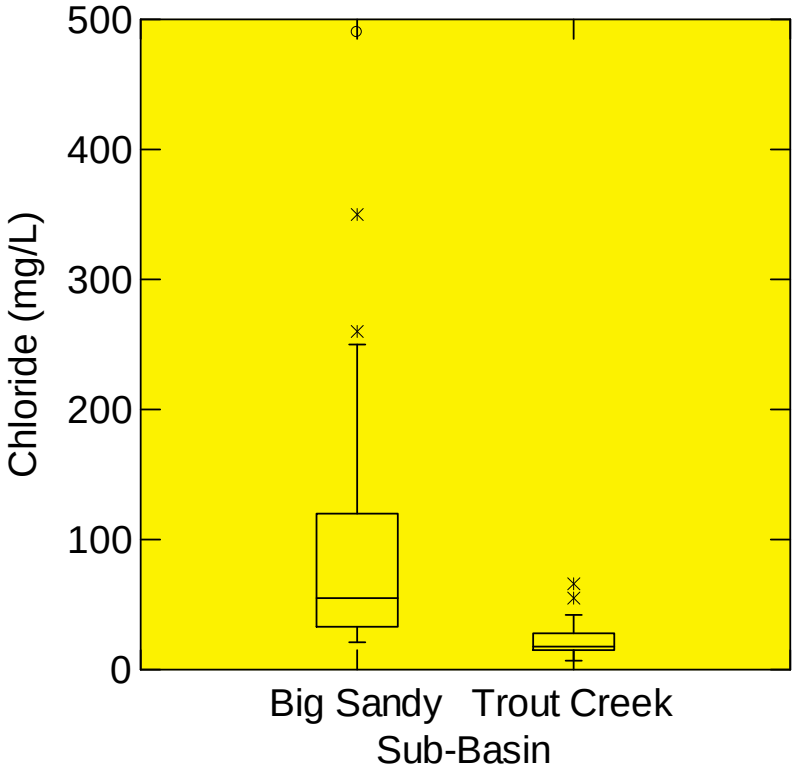

Figure 18. The box plot to the left illustrates that chloride concentrations in the Big Sandy sub-basin are higher than in the Trout Creek sub-basin. Chloride concentrations between these two sub-basins were shown to be statistically significantly different using an ANOVA test ($p \leq 0.01$). Water quality exceedances for chloride (Secondary MCL is 250 mg/L) occur infrequently in the Big Sandy sub-basin and did not occur in the Trout Creek sub-basin. Chloride concentrations typically are low in recharge areas and increase downgradient as TDS concentrations also increase.[23]

Table 8. Variation in Groundwater Quality Constituent Concentrations Between Two BIS Sub-basins Using Transformed Data with ANOVA Test.

Constituent	Significance	Differences Among Sub-Watersheds
Oxygen-18	ns	-
Deuterium	ns	-
Temperature – field (C)	**	Big Sandy > Trout Creek
pH – field	ns	-
pH – lab	ns	-
SC - field	**	Big Sandy > Trout Creek
SC - lab	**	Big Sandy > Trout Creek
Turbidity	ns	-
TDS	**	Big Sandy > Trout Creek
Bicarbonate	ns	-
Calcium	ns	-
Magnesium	ns	-
Hardness	ns	-
Sodium	**	Big Sandy > Trout Creek
Potassium	ns	-
Chloride	**	Big Sandy > Trout Creek
Sulfate	**	Big Sandy > Trout Creek
Fluoride	**	Big Sandy > Trout Creek
Nitrate (as N)	ns	-
TKN	ns	-
Phosphorus, Total ***	ns	-
Arsenic ***	ns	-
Boron***	**	Big Sandy > Trout Creek
Copper ***	ns	-
Iron ***	*	Big Sandy > Trout Creek
Gross Alpha	ns	-
Gross Beta	*	Big Sandy > Trout Creek
Radon	ns	-

ns = not significant * = significant at $p \leq 0.05$ ** = * = significant at $p \leq 0.01$ *** = Statistical test invalid because of few detections

Table 9. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Between Two BIS Sub-basins

Constituent	Significant Differences	Big Sandy	Trout Creek
Oxygen-18	ns	-	-
Deuterium	ns	-	-
Temperature – field (C)	**	20.9 to 24.0	15.3 to 17.9
pH – field	ns	-	-
pH – lab	ns	-	-
SC – field	**	818 to 1415	420 to 678
SC - lab	**	783 to 1303	437 to 659
Turbidity	ns	-	-
TDS	**	471 to 800	264 to 401
Bicarbonate	ns	-	-
Calcium	ns	-	-
Magnesium	ns	-	-
Hardness	ns	-	-
Sodium	**	63 to 182	14 to 51
Potassium	ns	-	-
Chloride	**	63 to 131	17 to 31
Sulfate	**	44 to 182	6 to 61
Fluoride	**	1.7 to 3.5	0.2 to 1.3
Nitrate (as N)	ns	-	-
TKN	ns	-	-
Phosphorus, T***	ns	-	-
Arsenic ***	ns	-	-
Boron ***	**	0.13 to 0.56	0.04 to 0.12
Copper ***	ns	-	-
Iron ***	*	0.07 to 0.13	0.05 to 0.06
Gross Alpha	ns	-	-
Gross Beta	*	8 to 15	1 to 12
Radon	ns	-	-

ns = not significant * = significant at $p \leq 0.05$ ** = * = significant at $p \leq 0.01$ *** = Statistical test invalid because of few detections

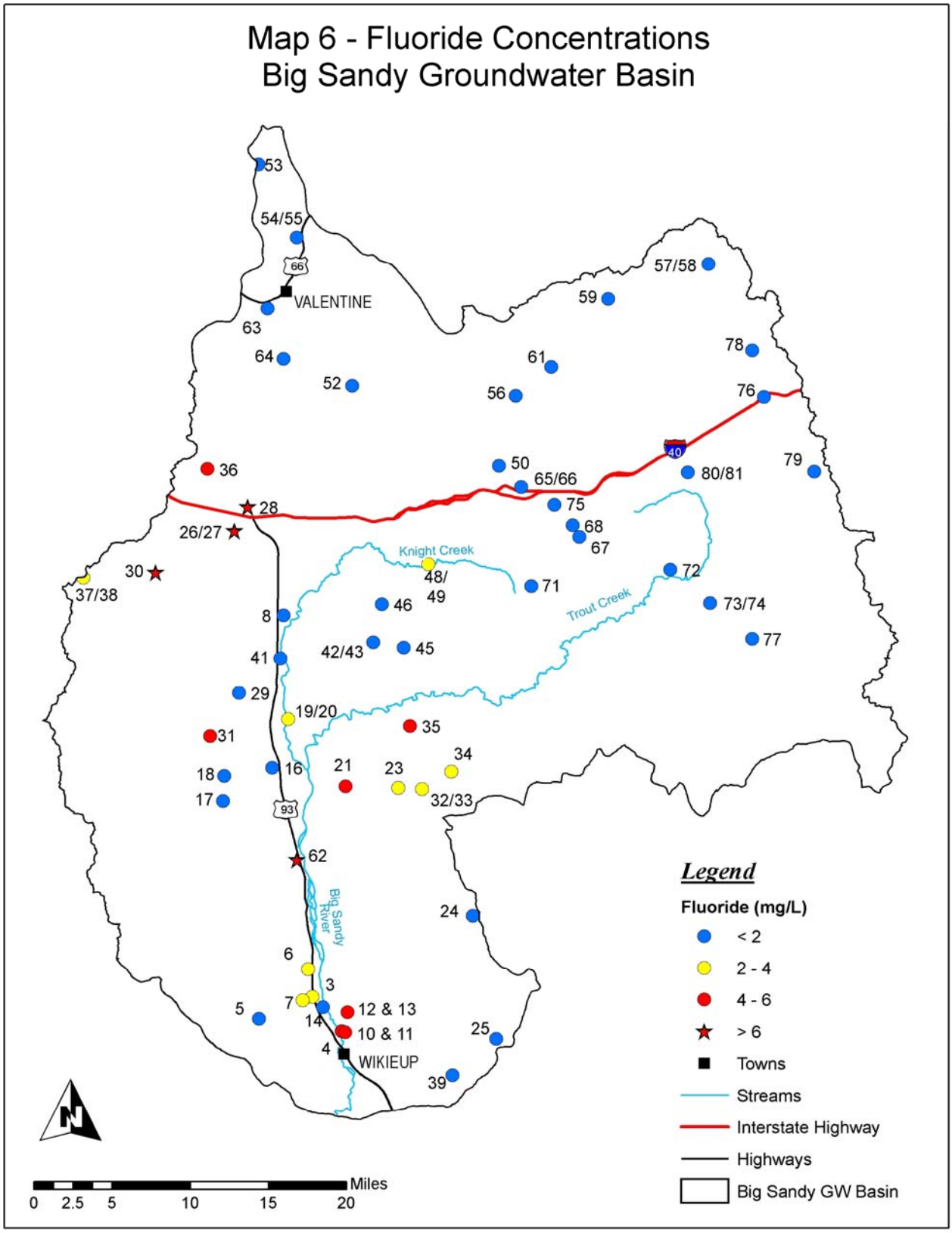
Map 6 - Fluoride Concentrations
Big Sandy Groundwater Basin
VALENTINE
WIKIEUP
Knight Creek
Trout Creek
Big Sandy River
66
93
40
53
54/55
63
64
52
57/58
59
61
56
78
76
79
36
50
65/66
80/81
28
26/27
75
68
67
30
37/38
48/
49
71
72
73/74
77
8
46
42/43
45
41
29
19/20
35
31
34
18
16
21
23
32/33
17
62
24
6
3
7
12 & 13
5
14
10 & 11
25
4
39
Legend
Fluoride (mg/L)
< 2
2 - 4
4 - 6
> 6
Towns
Streams
Interstate Highway
Highways
Big Sandy GW Basin
Miles
0 2.5 5 10 15 20

Table 10. Variation in Groundwater Quality Constituent Concentrations Among Five BIS Water Sources UsingTransformed Data with ANOVA and Tukey Tests.

Constituent	Significance	Differences Among Water Sources
Oxygen-18	ns	–
Deuterium	ns	-
Temperature – field (C)	**	Artesian & Basin-fill > Bedrock & Sedimentary
pH – field	ns	–
pH – lab	ns	–
SC – field	**	Artesian & Basin-fill > Sedimentary
SC – lab	**	Artesian & Basin-fill > Sedimentary
Turbidity	ns	–
TDS	**	Artesian & Basin-fill > Sedimentary
Bicarbonate	ns	–
Calcium	ns	–
Magnesium	ns	–
Hardness	ns	–
Sodium	**	Artesian & Basin-fill & Floodplain > Sedimentary; Artesian & Basin-fill > Bedrock
Potassium	ns	–
Chloride	**	Artesian & Basin-fill & Bedrock & Floodplain > Sedimentary; Artesian & Basin-fill > Bedrock
Sulfate	**	Artesian & Basin-fill & Floodplain > Sedimentary; Basin-fill > Bedrock
Fluoride	**	Artesian & Basin-fill & Bedrock & Floodplain > Sedimentary
Nitrate (as N)	ns	–
TKN	ns	–
Phosphorus, Total ***	ns	–
Arsenic ***	**	Artesian & Floodplain > Basin-fill & Bedrock & Sedimentary
Boron***	**	Artesian > Basin-fill & Bedrock & Sedimentary; Basin-fill & Floodplain > Bedrock & Sedimentary
Copper ***	ns	–
Iron ***	ns	–
Gross Alpha	ns	–
Gross Beta	ns	–
Radon	**	Basin-fill & Bedrock > Sedimentary

ns = not significant * = significant at $p \leq 0.05$ ** = * = significant at $p \leq 0.01$ *** = Statistical test invalid because of few detections

Table 11. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Among Five BIS Water Sources

Constituent	Significant Differences	Artesian	Basin-fill	Bedrock	Floodplain	Sedimentary
Oxygen-18	ns	–	–	–	–	_
Deuterium	ns	–	–	–	–	–
Temperature – field (C)	**	-18.5 to 79.3	22.0 to 25.9	17.4 to 19.8	–	13.4 to 18.9
pH – field	ns	–	–	–	–	–
pH – lab	ns	–	–	–	–	–
SC - field	**	1319 to 1471	645 to 1993	-	–	351 to 486
SC - lab	**	1224 to 1606	642 to 1764	-	–	369 to 504
Turbidity	ns	-	-	-	–	-
TDS	**	732 to 923	370 to 1088	-	–	221 to 289
Bicarbonate	ns	-	-	-	–	-
Calcium	ns	–	–	–	–	–
Magnesium	ns	–	–	–	–	–
Hardness	ns	–	–	–	–	–
Sodium	**	177 to 304	49 to 299	33 to 60	–	8 to 27
Potassium	ns	-	-	-	–	-
Chloride	**	97 to 224	58 to 192	27 to 64		15 to 22
Sulfate	**	102 to 293	- 3 to 294	28 to 89		9 to 15
Fluoride	**	3.4 to 5.3	1.4 to 4.2	0.7 to 2.6		0.15 to 0.33
Nitrate (as N)	ns	-	–	–	–	–
TKN	ns	-	–	–	–	–
Phosphorus, T***	ns	-	–	–	–	–
Arsenic ***	**	- 0.41 to 0.58	0.005 to 0.01	0.005 to 0.008	–	0.005
Boron ***	**	1.07 to 1.13	0.03 to 0.90	0.06 to 0.11	–	- 0.02 to 0.21
Copper ***	ns	–	–	–	–	–
Iron ***	ns	–	–	–	–	–
Gross Alpha	ns	–	–	–	–	–
Gross Beta	ns	–	–	–	–	–
Radon	**	–	190 to 597	577 to 1776	–	- 33 to 180

ns = not significant * = significant at $p \leq 0.05$ ** = * = significant at $p \leq 0.01$ *** = Statistical test invalid because of few detections

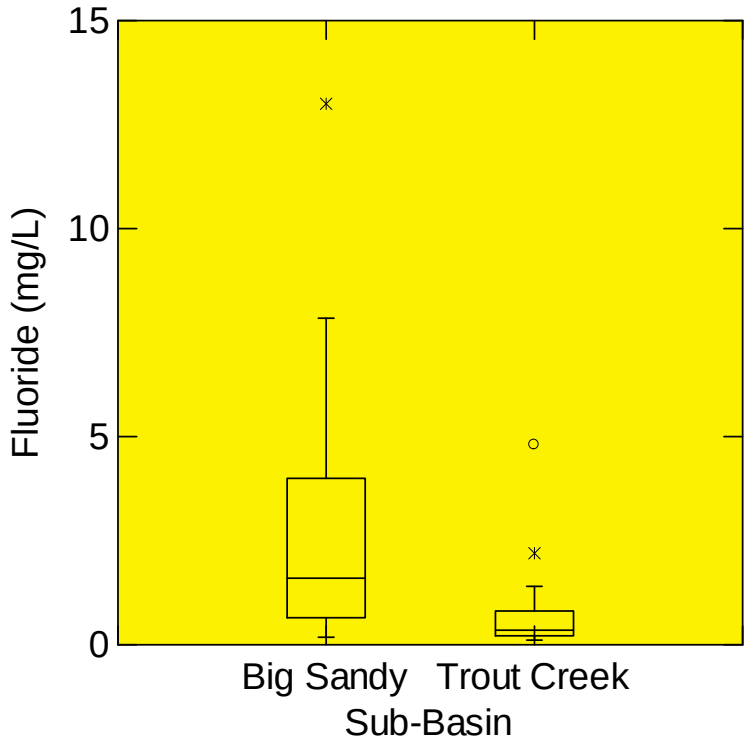

Figure 19. The boxplot to the left illustrates that fluoride concentrations in the Big Sandy sub-basin are generally higher than in the Trout Creek sub-basin. Fluoride concentrations between these two sub-basins were shown to be significantly ($p \leq 0.01$) different using an ANOVA statistical test. Water quality exceedances for fluoride (Secondary MCL is 2 mg/L, Primary MCL is 4 mg/L) also occur more frequently in the Big Sandy sub-basin. Fluoride concentrations are frequently low in recharge areas and increase with pH.[23]

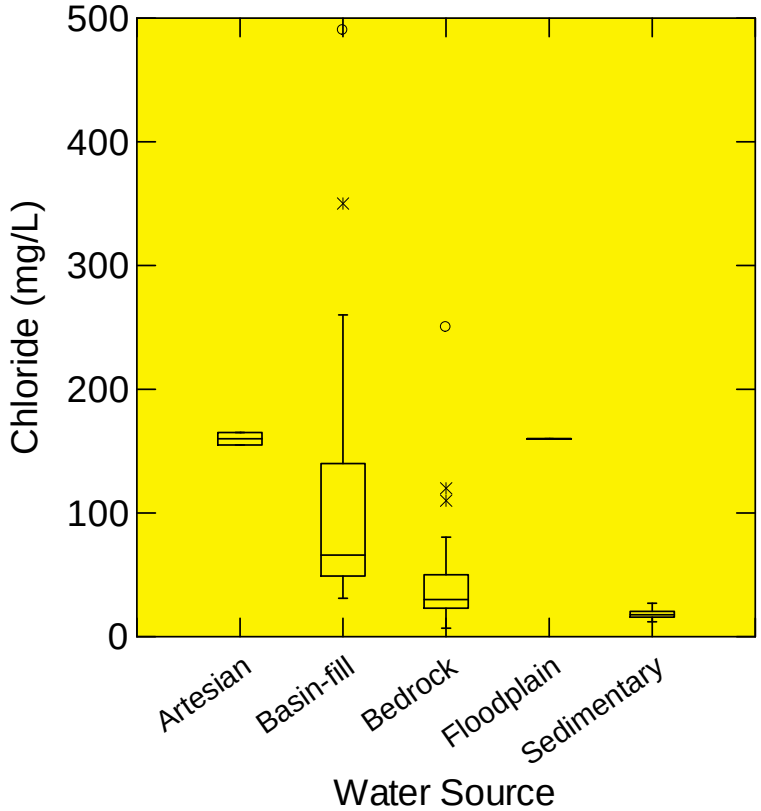

Figure 20. The box plot to the left graphically illustrates chloride concentrations among aquifers in the Big Sandy basin. Chloride concentrations were significantly higher in the artesian, basin-fill, bedrock, and floodplain than in sedimentary rock; and also significantly higher in the artesian and basin-fill than in bedrock (ANOVA test, $p \leq 0.01$). Other water quality constituents such as sodium, sulfate, fluoride, arsenic, and boron had similar aquifer patterns. These constituents typically increase in down-gradient areas or in old water such are found in artesian aquifers.[23]

Table 12. Variation in Groundwater Quality Constituent Concentrations Among Six BIS Rock Types UsingTransformed Data with ANOVA and Tukey Tests.

Constituent	Significance	Differences Among Water Sources
Oxygen-18	ns	-
Deuterium	ns	-
Temperature – field (C)	ns	-
pH – field	ns	-
pH – lab	ns	-
SC – field	*	Sedimentary > Basalt
SC – lab	*	Sedimentary > Basalt
Turbidity	ns	-
TDS	*	Sedimentary > Basalt
Bicarbonate	ns	-
Calcium	**	Granite > Alluvium & Basalt
Magnesium	ns	-
Hardness	**	Granite > Alluvium
Sodium	ns	-
Potassium	ns	-
Chloride	*	Sedimentary > Basalt & Granite
Sulfate	ns	-
Fluoride	ns	-
Nitrate (as N)	ns	-
TKN	ns	-
Phosphorus, Total ***	ns	-
Arsenic ***	ns	-
Boron***	ns	-
Copper ***	*	Granite > Alluvium
Iron ***	ns	-
Gross Alpha	ns	-
Gross Beta	ns	-
Radon	*	Sedimentary > Alluvium

ns = not significant * = significant at $p \leq 0.05$ ** = * = significant at $p \leq 0.01$ *** = Statistical test invalid because of few detections

Table 13. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Among Six BIS Rock Types

Constituent	Significant Differences	Alluvium	Basalt	Granite	Metamorphic	Sedimentary	Volcanic
Oxygen-18	ns	–	–	–	–	–	_
Deuterium	ns	–	–	–	–	–	–
Temperature – field (C)	ns	-	–	–	-	–	-
pH – field	ns	–	–	–	–	–	–
pH – lab	ns	–	–	–	–	–	–
SC – field	**	-	-90 to 724	–	-	165 to 3124	-
SC - lab	**	-	7 to 643	–	-	305 to 2535	-
Turbidity	ns	-	–	–	-	–	-
TDS	**	-	29 to 346	–	-	135 to 1639	-
Bicarbonate	ns	-	–	–	-	–	-
Calcium	**	34 to 52	-65 to 119	62 to 89	–	–	–
Magnesium	ns	–	–	–	–	–	–
Hardness	**	149 to 223	–	265 to 361	–	–	–
Sodium	ns	-	–	–	-	–	-
Potassium	ns	-	–	–	-	–	-
Chloride	*	-	-17 to 46	25 to 58	-	53 to 227	–
Sulfate	ns	-	–	–	-	–	-
Fluoride	ns	-	–	–	-	–	-
Nitrate (as N)	ns	-	–	–	–	–	–
TKN	ns	-	–	–	–	–	–
Phosphorus, T***	ns	-	–	–	–	–	–
Arsenic ***	ns	-	–	–	-	–	-
Boron ***	ns	-	–	–	-	–	-
Copper ***	*	0.005 to 0.008	–	0.007 to 0.019	–	–	–
Iron ***	ns	–	–	–	–	–	–
Gross Alpha	ns	–	–	–	–	–	–
Gross Beta	ns	–	–	–	–	–	–
Radon	*	94 to 549	–	–	-	78 to 814	-

ns = not significant * = significant at $p \leq 0.05$ ** = * = significant at $p \leq 0.01$ *** = Statistical test invalid because of few detections

Time Trend Comparison

For additional QA/QC measurements, two sites sampled as part of the 1958-69 Arizona Water Commission report on the Big Sandy area conducted by the U.S. Geological Survey were re-sampled in 2003.[15] The sites include Cofer Hot Spring (BIS-12/13) and the El Paso Natural Gas Well (BIS-28).[13] Only physical parameters, major ions, fluoride and nitrate were able to be compared between studies.

Analytical results of this data comparison indicate that of the 13 constituents examined, the minimum difference between sample constituents was typically 5 percent or less while the maximum difference was typically less than 15 percent except for fluoride (21 percent), magnesium (26 percent), nitrate (28 percent), and calcium (30 percent). However, some of these constituents had relatively small concentration differences such as nitrate (as N) with a 0.55 mg/L difference (Table 14).

Table 14. Summary Results of BIS Time Trend Sampling Comparison

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Temperature (C)	2	2 %	3 %	1	2	ns
SC (uS/cm)	2	1 %	5 %	30	300	ns
Hardness	2	7 %	14 %	28	82	ns
pH (su)	2	0 %	4 %	0.05	0.6	ns
TDS	2	2 %	6 %	40	200	ns
Major Ions						
Calcium	2	2 %	30 %	1.5	14	ns
Magnesium	2	12 %	26 %	4	30	ns
Sodium/Potassium	2	5 %	9 %	46	58	ns
Bicarbonate	2	2 %	7 %	15	118	ns
Chloride	2	4 %	4 %	14	40	ns
Sulfate	2	4 %	15 %	17	41	ns
Nutrients						
Nitrate (as N)	1	28 %	28 %	0.55	0.55	ns
Trace Elements						
Fluoride	2	1 %	21 %	0.05	2.3	ns

All units are mg/L except as noted
ns = No significant ($p \leq 0.05$) difference between studies

Isotope Comparison

Groundwater characterizations using oxygen and hydrogen isotope data may be made with respect to the climate and/or elevation where the water originated, residence within the aquifer, and whether or not the water was exposed to extensive evaporation prior to collection.[10]

This is accomplished by comparing oxygen-18 isotopes ($\delta^{18}O$) and deuterium (δD), an isotope of hydrogen, data to the Global Meteoric Water Line (GMWL). The GMWL is described by the linear equation:

$$\delta D = 8\delta^{18}O + 10$$

where δD is deuterium in parts per thousand (per mil, $^{0}/_{00}$), 8 is the slope of the line, $\delta^{18}O$ is oxygen-18 $^{0}/_{00}$, and 10 is the y-intercept.[10]

The GMWL is the standard by which water samples are compared and represents the best fit isotopic analysis of numerous worldwide water samples.

Isotopic data from a region may be plotted to create a Local Meteoric Water Line (LMWL) which is affected by varying climatic and geographic factors. When the LMWL is compared to the GMWL, inferences may be made about the origin or history of the local water.[11]

The LMWL created by $\delta^{18}O$ and δD values for samples collected at sites in the BIS were compared to the GMWL. The δD and $\delta^{18}O$ data lie to the right of the GMWL (Figure 21). Meteoric waters exposed to evaporation characteristically plot increasingly below and to the right of the GMWL. Evaporation tends to preferentially contain a higher percentage of lighter isotopes in the vapor phase and causes the water that remains behind to be isotopically heavier.[10]

Groundwater from arid environments is typically subject to evaporation, which enriches δD and $\delta^{18}O$, resulting in a lower slope value (usually between 3 and 6) as compared to the slope of 8 associated with the GMWL.[10]

The data for the arid BIS conform to this theory, having a slope of 6.07, with the LMWL described by the linear equation:

$$\delta D = 6.07^{18}O - 13.9$$

The BIS LMWL is similar to other nearby basin such as Detrital Valley (5.15) and Sacramento Valley (5.5).[24, 25]

There appears to be no geographic or hydrologic demarcation between sample sites having the most depleted or isotopically lighter waters in the BIS with those having the most enriched or isotopically higher waters. Using cluster analysis, the sample sites can be divided into two groups: a depleted group of 11 sites and an enriched group of 45 sites.

Analytical results were compared between groundwater samples collected in the two isotope groups (depleted and enriched) to identify significant differences in concentrations of groundwater quality constituents.

Significant concentration differences were found with eleven constituents (Map 7, Table 15): oxygen-18, deuterium, temperature-field, pH-lab, calcium, magnesium, hardness, sodium, sulfate, nitrate (Figure 22) and fluoride (ANOVA with Tukey test, $p \leq 0.01$). For constituents having significantly different concentrations between recharge sources, 95 percent confidence intervals are provided in Table 16.

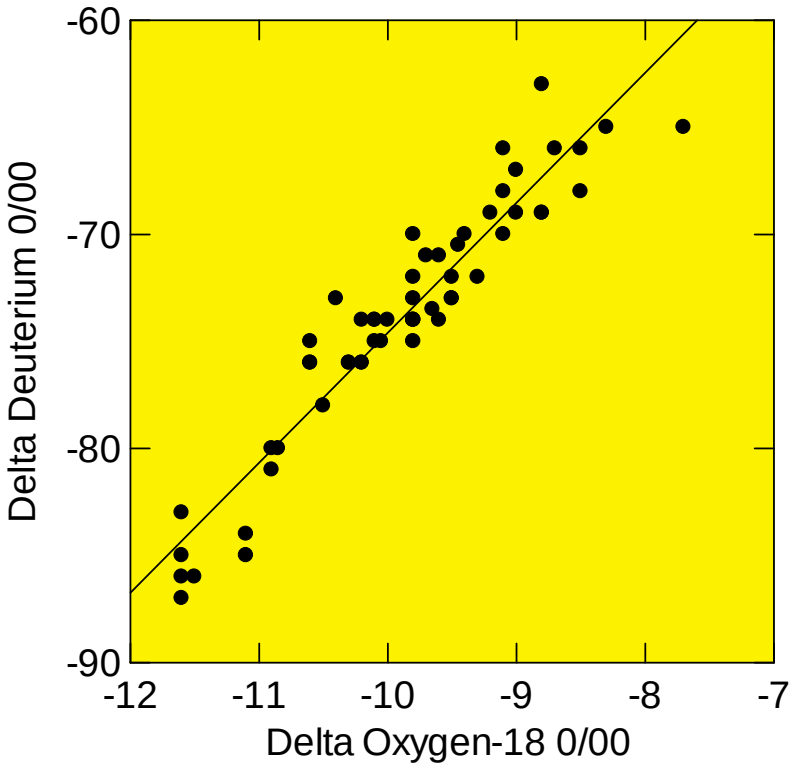

Figure 21. The 57 isotope sample sites were divided into two groups using Cluster analysis: 11depleted or isotopically lighter sites near the bottom left of the graph and 46 enriched or isotopically heavier sites near the upper right of the graph. Calcium, magnesium, hardness, and nitrate concentrations were found to be significantly higher in the enriched samples indicating these sites may have been more recently recharged than at the depleted sites. Three surface water isotope samples from the Big Sandy River averaged -9.75 and 72.3 while three samples from Trout Creek / Ft. Rock Creek were -8.6 and 65.3.

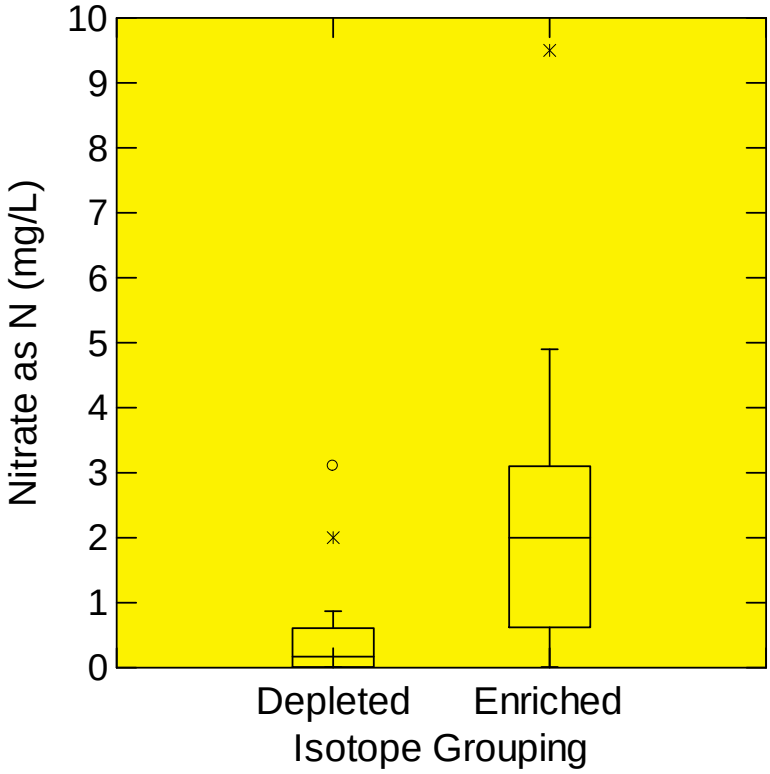

Figure 22. Cluster analysis was used to divide sample sites into two groups: depleted and enriched. Temperature, pH-lab, sodium, sulfate and fluoride concentrations were significantly higher in depleted samples than in enriched samples. This indicates water from the depleted sites may be older and more evolved than in the enriched samples. The enriched samples have significantly higher concentrations of constituents such as calcium, magnesium, hardness and nitrate (shown at the left) which are often indicative of recent recharge.[23]

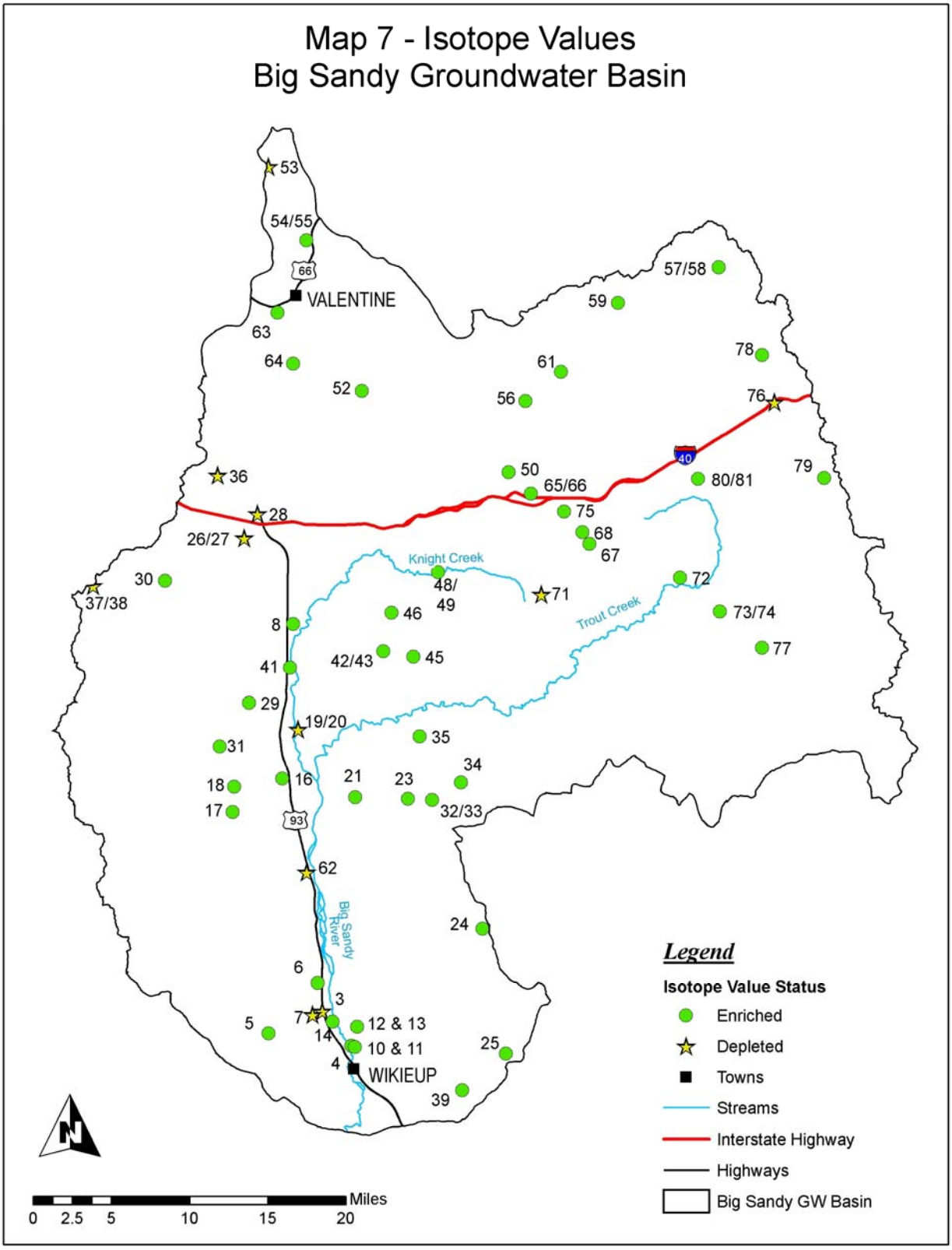
Map 7 - Isotope Values
Big Sandy Groundwater Basin
VALENTINE
WIKIEUP
Knight Creek
Trout Creek
Big Sandy River
66
40
93
53
54/55
63
64
52
57/58
59
61
56
78
76
79
36
50
65/66
80/81
28
26/27
75
68
67
30
37/38
48/
49
71
72
46
73/74
8
42/43
45
77
41
29
19/20
35
31
34
18
16
21
23
32/33
17
62
24
6
3
5
7
12 & 13
14
10 & 13
25
4
39
Legend
Isotope Value Status
Enriched
Depleted
Towns
Streams
Interstate Highway
Highways
Big Sandy GW Basin
Miles
0
2.5
5
10
15
20

Table 15. Variation in Groundwater Quality Constituent Concentrations Between Two BIS Recharge Sources Using Transformed Data with ANOVA.

Constituent	Significance	Differences Among Recharge Sources
Oxygen-18	**	Enriched > Depleted
Deuterium	**	Enriched > Depleted
Temperature – field (C)	*	Depleted > Enriched
pH – field	ns	-
pH – lab	**	Depleted > Enriched
SC - field	ns	-
SC - lab	ns	-
Turbidity	ns	-
TDS	ns	-
Bicarbonate	ns	-
Calcium	**	Enriched > Depleted
Magnesium	**	Enriched > Depleted
Hardness	**	Enriched > Depleted
Sodium	**	Depleted > Enriched
Potassium	ns	-
Chloride	ns	-
Sulfate	*	Depleted > Enriched
Fluoride	*	Depleted > Enriched
Nitrate (as N)	**	Enriched > Depleted
TKN	ns	-
Phosphorus, Total ***	ns	-
Arsenic ***	ns	-
Boron***	ns	-
Copper ***	ns	-
Iron ***	ns	-
Gross Alpha	ns	-
Gross Beta	ns	-
Radon	ns	-

ns = not significant * = significant at $p \leq 0.05$ ** = * = significant at $p \leq 0.01$ *** = Statistical test invalid because of few detections

Table 16. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Between Two BIS Recharge Sources

Constituent	Significant Differences	Depleted	Enriched
Oxygen-18	**	- 11.5 to - 10.9	- 9.8 to - 9.4
Deuterium	**	- 85.2 to - 81.2	- 72.7 to - 70.5
Temperature – field (C)	*	20.1 to 27.5	18.3 to 21.0
pH – field	ns	–	–
pH – lab	**	7.7 to 8.0	7.6 to 7.7
SC - field	ns	-	-
SC - lab	ns	-	-
Turbidity	ns	-	-
TDS	ns	-	-
Bicarbonate	ns	-	-
Calcium	**	23 to 65	54 to 69
Magnesium	**	10 to 28	23 to 32
Hardness	**	108 to 278	230 to 298
Sodium	**	5 to 404	43 to 85
Potassium	ns	-	-
Chloride	ns	-	-
Sulfate	*	-55 to 428	39 to 84
Fluoride	*	1.4 to 5.2	1.0 to 2.3
Nitrate (as N)	**	- 1.5 to 8.7	0.5 to 1.6
TKN	ns	-	–
Phosphorus, T***	ns	-	–
Arsenic ***	ns	–	-
Boron ***	ns	-	-
Copper ***	ns	–	–
Iron ***	ns	–	–
Gross Alpha	ns	–	–
Gross Beta	ns	–	–
Radon	ns	–	-

ns = not significant * = significant at $p \leq 0.05$ ** = * = significant at $p \leq 0.01$ *** = Statistical test invalid because of few detections

CONCLUSIONS

Study Design and Data Evaluation

The 57 groundwater sample sites were generally selected using a modified grid-based, random site-selection approach. This method allowed the spatial distribution of sample sites throughout the BIS although some mountainous areas were not sampled because of a combination of remote, rugged terrain and a corresponding lack of groundwater sample sites.

Quality assurance procedures were followed and quality control samples were collected to ensure the validity of groundwater quality data. Analysis of equipment blank samples indicated systematic contamination of SC-lab and turbidity; however, the extent of contamination by these parameters was not considered significant.

Analysis of the five duplicate inorganic samples, the ten isotope duplicate samples, and the one duplicate radon sample revealed excellent correlations of less than 6 percent except for ammonia (15 percent) , TKN (22 percent) turbidity (33 percent) and copper (46 percent). The eight inorganic split samples and two radiochemistry split samples generally had more variability but still only exceeded a maximum difference of 20 percent with TDS (22 percent) and fluoride (36 percent). Split samples were evaluated using the non-parametric Sign test to determine if there were any significant ($p \leq 0.05$) differences between laboratories. Chloride concentrations reported by the ADHS laboratory were significantly higher than those reported by Del Mar laboratory; the opposite pattern occurred with potassium.

Data validation was also examined in five QA/QC correlations that affirmed the acceptability of the groundwater quality data for further analysis.

Data analysis for this study was conducted using Systat software.[32] Spatial variations in constituent concentrations were investigated using the parametric Analysis of Variance (ANOVA) test with the Tukey test on log-transformed data. Correlations among constituent concentrations were analyzed using the Pearson Correlation Coefficient test.[32] Differences between analytical results from different laboratories were investigated using the Sign test. [32]

General Chemistry

Groundwater in the BIS is generally slightly alkaline, fresh, and moderately-to-very hard based on pH values, TDS concentrations, and hardness concentrations. The predominant water chemistries in the basin are mixed-bicarbonate or calcium-bicarbonate. Among trace elements, only arsenic, copper, fluoride, and zinc were detected at more than 20 percent of sample sites. Nutrient concentrations were generally low; no samples exceeded health-based standards for nitrate.

Groundwater appears to evolve in the BIS from a calcium or mixed-bicarbonate in the Trout Creek sub-basin to a sodium-mixed chemistry in the farthest down-gradient portions of the Big Sandy sub-basin near Wikieup. Constituents characteristic of evolved, down-gradient water such as TDS, sodium, chloride, sulfate, fluoride and boron were found to be significantly higher in the Big Sandy sub-basin than in the Trout Creek sub-basin.[19, 23]

Water Quality Standards

Of the 57 samples collected in the BIS, less than half (24 samples or 41 percent of samples) met all health and aesthetic water quality standards. Constituents most commonly exceeding health-based standards were arsenic, fluoride and gross alpha while TDS and fluoride most commonly exceeded aesthetics-based standards.

These water quality exceedances appear to be the result of naturally occurring geochemical processes because of the relatively remote and undeveloped nature of the basin as well as other nearby groundwater basins such as Sacramento Valley having similar constituent exceedances.[24]

Previous studies have suggested that calcium concentrations are an important control on fluoride concentrations over 5 mg/L through precipitation of the mineral fluorite.[23] This study appears to support this statement, with most samples having high fluoride concentrations also exhibiting low calcium concentrations. An exception occurred with the highest fluoride concentration found in the study at 13 mg/L. The sample (BIS-30), a windmill located in the Hualapai Mountains, was of calcium-sulfate chemistry. Although the sample met all QA/QC tests, there remains the possibility of some type of contamination of this unexpected result.

Arsenic concentrations in groundwater are influenced by oxidizing waters that allow many trace elements (including arsenic) to be converted to their more soluble oxyanion form.[23] Other potentially important factors include groundwater residence time, lithology, and clay mineralogy of the aquifer. The

highest concentrations of arsenic are typically associated with the central parts of basins whose chemistries evolve under closed conditions.[23]

Spatial Variation

Groundwater quality concerns are found in most parts of the BIS, particularly in the western portions of the basin within the Big Sandy sub-basin. Spatially examining groundwater quality found important differences between sub-basins. Of the 17 sites sampled in the Trout Creek sub-basin, only 2 (12 percent) exceeded health-based water quality standards and 14 sites (or 82 percent) met all health and aesthetic-based water quality standards. In contrast, of the 41 sites sampled in the Big Sandy sub-basin, 22 (54 percent) exceeded health-based water quality standards and 9 sites (22 percent) met all health and aesthetics-based water quality standards.

Statistically examining sub-basin patterns found similar patterns. Fluoride and TDS concentrations were found to be significantly higher in the Big Sandy sub-basin than in Trout Creek sub-basin; while not statistically significant, arsenic and gross alpha concentrations were also higher in the Big Sandy sub-basin compared with the Trout Creek sub-basin. Although radiochemistry samples were only collected at 30 of 57 sites, gross alpha exceedances were found throughout the basin though most exceedances (and the highest concentrations were located in granite portions of the Aquarius Mountains.

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Appendix A. Data for Sample Sites, Big Sandy Basin, 2003-04

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Aquifer
1st Field Trip, August 12, 2003 - Towne & Sutter									
BIS-1/2	B(14-13)13bad submersible	34°33'29.809" 113°34'23.793"	627863	20187	Rohr RanchWell	Inorganic, Radiochem Radon, Isotopes, Hg	250'	50'	Basin-fill
BIS-3	B(16-13)22cbd submersible	34°42'32.159" 113°36'47.871"	612053	20738	Wikieup MotelWell	Inorganic, Radon O, H isotopes, Hg	120'	61'	Basin-fill
BIS-4	B(16-13)36ccc submersible	34°40'38.540" 113°34'46.104"	-	20771	Noglaes RanchWell	Inorganic, Radon, O, H isotopes, Hg	15'	11'	Floodplain
2nd Field Trip, September 25-26, 2003 - Towne & Harmon (Equipment Blank, BIS-15)									
BIS-5	B(16-14)36cbb windmill	34°41'12.70" 113°40'25.88"	642259	20781	ChickenRd Windmill	Inorganic O, H isotopes	125'	100'	Bedrock
BIS-6	B(16-13)09ddc submersible	34°44'05.607" 113°37'08.306"	647897	62691	Van Bynen Well	Inorganic, Radiochem Radon, Isotopes, Hg	112'	57'	Basin-fill
BIS-7	B(16-13)21ddb submersible	34°42'19.611" 113°37'26.831"	610953	62692	Wikieup Bible Well	Inorganic, Radon O, H isotopes, Hg	110'	9'	Basin- fill
BIS-8	B(20-13)33ccd submersible	35°04'04.001" 113°39'26.566"	531750	62693	Nelssen Well	Inorganic, Radiochem O, H isotopes	119'	70'	Basin- fill
BIS-9	Big Sandy River at Highway 93	--	--	-	Big Sandy River	O, H isotopes	--	--	-
BIS-10/11	B(16-13)36ccc artesian	34°40'35.325" 113°34'31.430"	574699	62694	Peterson Well	Inorganic, Radiochem Radon, Isotopes, Hg	220'	3'	Artesian
BIS-12/13	B(16-13)25cad spring	34°41'43.555" 113°34'23.848"	--	20742	Cofer Hot Spring	Inorganic, Radiochem Radon, Isotopes, Hg	--	--	Artesian
BIS-14	B(16-13)27adc turbine	34°41'58.265" 113°36'04.000"	805824	20755	Links Well	Inorganic, Radon O, H isotopes, Hg	450'	--	Basin-fill
October 8-9, 2003 - Towne & Harmon (Equipment Blank, BIS-22)									
BIS-16	B(18-13)21cdd spring	34°55'25.688" 113°39'55.036"	--	21138	Cane Spring	Inorganic, Radiochem Radon, Isotopes, Hg	-	-	Basin fill
BIS-17	B(17-14)01bba windmill	34°53'29.131" 113°43'11.309"	611817	20951	Pilgrim Wash Well	Inorganic	140'	20'	Basin fill
BIS-18	B(18-14)25bca spring	34°54'54.627" 113°43'08.691"	--	62827	Higgins Spring	Inorganic, Radiochem Radon, Isotopes, Hg	-	-	Basin fill
BIS-19/20	B(18-13)03cba spring	34°58'12.281" 113°38'55.688"	--	62828	Hackberry Spring	Inorganic, Radon O, H isotopes, Hg	-	-	Basin fill
BIS-21	B(18-12)30dda spring	34°54'30.358" 113°34'56.388"	--	62829	Indian Grade Spr.	Inorganic, O, H isotopes, Hg	-	-	Basin fill
BIS-23	B(18-12)26cdb spring	34°54'29.097" 113°31'21.898"	--	21131	Cabin Spring	Inorganic, Radiochem Radon, Isotopes, Hg	-	-	Bedrock
BIS-24	B(16.5-11)29bdb spring	34°47'21.381" 113°26'07.273"	--	62830	Gordon Cyn Spr.	Inorganic, Radiochem O, H isotopes, Hg	-	-	Bedrock
BIS-25	B(15-11)03bbc spring	34°40'25.846" 113°24'20.440"	--	62831	Arrowhead Spring	Inorganic O, H isotopes	-	-	Bedrock
4th Field Trip, October 29-31, 2003 - Towne & Harmon (Equipment Blank, BIS-38)									
BIS-26/27	B(20-14)01bdd submersible	35°08'45.438" 113°42'55.671"	593594	62823	Ridge Well	Inorganic, Radiochem Radon, O, H isotopes	906'	763'	Basin fill
BIS-28	B(21-13)30dcb submersible	35°10'08.138" 113°42'04.371"	611599	21672	El Paso Gas Well	Inorganic, Radon O, H isotopes	820'	660'	Basin fill
BIS-29	B(19-14)25ddd windmill	34°59'36.125" 113°42'18.084"	611812	21382	Lwr Moss Wash Well	Inorganic, Radon O, H isotopes	350'	345'	Basin fill
BIS-30	B(20-14)19bd windmill	35°06'16.448" 113°48'11.241"	641256	21523	Section 19 Well	Inorganic, Radiochem O, H isotopes	160'	25'	Bedrock
BIS-31	B(18-14)11cca windmill	34°57'07.638" 113°44'10.948"	611815	21161	Lwr Blue Tank Well	Inorganic, Radon O, H isotopes	40'	17'	Basin fill
BIS-32/33	B(18-12)25ddb windmill	34°54'27.114" 113°29'44.732"	630660	21130	Upr Tom Brown Wl	Inorganic, Radiochem Radon, O, H isotopes	176'	58'	Bedrock

Appendix A. Data for Sample Sites, Big Sandy Basin, 2003-04–continued

Site #	Cadastral / Pump Type	Latitude – Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Aquifer
BIS-34	B(18-11)20bdb windmill	34°55'28.842" 113°27'48.945"	614834	21123	Simmons Up Well	Inorganic, Radon O, H isotopes	150'	47'	Bedrock
BIS-35	B(18-12)02dda windmill	34°57'59.154" 113°30'41.233"	614835	21126	Lwr Parson Well	Inorganic, Radon O, H isotopes	115'	35'	Bedrock
BIS-36	B(21-14)15aaa submersible	35°12'12.791" 113°44'51.778"	590918	62824	Malone Well	Inorganic, Radon O, H isotopes	960'	825'	Bedrock
BIS-37/38	B(20-15)20dca submersible	35°05'52.067" 113°53'04.059"	526884	62825	Hualapai Mtn Park	Inorganic, Radiochem Radon, Isotopes, Hg	280'	45'	Bedrock
BIS-39	B(15-11)18cb windmill	34°38'19.658" 113°27'13.668"	612826	62826	Rincon Well	Inorganic, Radon O, H isotopes	-	-	Bedrock
5th Field Trip, December 3-5, 2003 - Towne & Harmon (Equipment Blank, BIS-47)									
BIS-40	Big Sandy River at Banegas Crossing	--	--	--	Big Sandy River	O, H isotopes	-	-	-
BIS-41	B(19-13)16dbc submersible	35°01'36.766" 113°39'34.020"	637440	21374	Windmill Ranch HQ	Inorganic, Radiochem O, H isotopes, Hg	160’	60’	Basin fill
BIS-42/43	B(19-12)9dbb spring	35°02'39.422" 113°33'18.275"	--	62872	Bull Spring	Inorganic, Radiochem O, H isotopes, Hg	-	-	Bedrock
BIS-44	B(19-12)01dda spring	35°03'19.478" 113°29'45.233"	--	62876	N. Burns Spring	O, H isotopes	--'	--	Bedrock
BIS-45	B(19-12)11cad spring	35°02'24.829" 113°31’15.139"	--	62873	Blackjack Spring	Inorganic O, H isotopes	--	--	Bedrock
BIS-46	B(20-12)28ddd windmill	35°04'49.718" 113°32'47.991"	608174	21511	Cedar Basin Well	Inorganic, Radiochem O, H isotopes	120'	6'	Bedrock
BIS-48/49	B(20-12)13aba spring	35°07'09.013" 113°29'43.828"	--	62874	Unnamed Spring	Inorganic, Radiochem Radon, O, H Isotopes	--	--	Bedrock
BIS-50	B(21-11)11ccb spring	35°12'48.982" 113°25'05.443"	--	62875	Casa Grande Spr	Inorganic, Radiochem O, H isotopes	--	--	Bedrock
BIS-51	Trout Creek at mouth	--	--	--	Trout Creek	O, H isotopes	--	--	-
6th Field Trip, December 15-16, 2003 - Towne & Harmon (Equipment Blank, BIS-60)									
BIS-52	B(22-12)18dbd submersible	35°17'07.460" 113°35'12.352"	533392	62877	Love Well	Inorganic, Radiochem Radon, Isotopes, Hg	275’	170’	Bedrock
BIS-53	B(24-13)6dad spring	35°29'30.010" 113°41'58.911"	--	62878	Up. Grape-vine Spr.	Inorganic O, H isotopes	--	--	Bedrock
BIS-54/55	B(24-13)34acd submersible	35°25’26.275" 113°39'14.316"	592984	62879	Moore Well	Inorganic, Radiochem Radon, O, H Isotopes	155’	70’	Bedrock
BIS-56	B(22-11)23abd submersible	35°16’47.831" 113°24'04.294"	572641	62880	Bunny Well	Inorganic, Radiochem Radon, O, H Isotopes	730’	580’	Bedrock
BIS-57/58	B(23-9)1bcc submersible	35°24'30.038" 113°11'09.954"	623027	21939	Section 1 Well	Inorganic, Radiochem Radon, Isotopes, Hg	1020’	920’	Sedimentary
BIS-59	B(23-10)14ddc submersible	35°22'23.804" 113°17'56.820"	623026	21941	Rubel RanchWell	Inorganic O, H isotopes	1104’	970’	Sedimentary
BIS-61	B(22-10)8bbc submersible	35°18'28.879" 113°21’42.934"	614879	21832	Section 8 Well	Inorganic, Radiochem Radon, O, H Isotopes	900’	820’	Sedimentary
7th Field Trip, January 21-23, 2004 - Towne & Horsley (Equipment Blank, BIS-69)									
BIS-62	B(17-13)22daa submersible	34°50’14.653" 113°38'05.445"	637325	20928	Crampton Well	Inorganic, Radiochem Radon, O, H Isotopes	130’	70’	Basin fill
BIS-63	B(23-13)29aaa submersible	35°21'22.056" 113°41'05.158"	623028	21984	HQ Well	Inorganic, Radiochem Radon, O, H Isotopes	70’	37’	Bedrock
BIS-64	B(22-13)9abc submersible	35°18'32.714" 113°39'55.529"	623029	21834	Windmill Well	Inorganic, Radiochem Radon, O, H Isotopes	625’	-	Bedrock
BIS-65/66	B(21-11)24abd submersible	35°11'38.691" 113°23’33.790"	583575	63693	Dunton RanchWell	Inorganic, Radiochem Radon, O, H Isotopes	90’	20’	Bedrock

Appendix A. Data for Sample Sites, Big Sandy Basin, 2003-04–continued

Site #	Cadastral / Pump Type	Latitude – Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Aquifer
BIS-67	B(20-10)04ad submersible	35°08'55.660" 113°19'30.907"	620907	21505	Ft Rock RanchWell	Inorganic, Radiochem O, H isotopes	200'	40'	Bedrock
BIS-68	B(21-10)33dd submersible	35°09'33.715" 113°20'00.106"	620901	21665	Irrigation Well	Inorganic, Radon O, H isotopes, Hg	225'	12'	Bedrock
BIS-70	–	35°07'13.994" 113°19'26.036"	–	-	Ft Rock Creek	O, H isotopes, Hg	–	–	–
BIS-71	B(20-11)24dba windmill	35°06'03.922" 113°22'42.583"	614860	62926	Paso Robles	Inorganic, Radon O, H Isotopes	500'	25'	Bedrock
BIS-72	B(20-9)16aca windmill	35°07'10.862" 113°13'18.065"	614854	21498	Well #2	Inorganic, Radon O, H isotopes	375’	–	Bedrock
BIS-73/74	B(20-9)25bdc windmill	35°05'19.824" 113°10'33.561"	620910	21500	Well #3	Inorganic O, H isotopes, Hg	580’	-	Bedrock
BIS-75	B(21-10)29acb windmill	35°10'42.220" 113°21'16.042"	620906	21664	Carl F Well	Inorganic, Radiochem O, H isotopes	120’	-	Bedrock
BIS-76	B(22-8)21aba windmill	35°17'03.402" 113°07’11.964"	608306	21828	Markham Well	Inorganic O, H isotopes	650’	530’	Sedimentary
BIS-77	B(19-8)4cbc windmill	35°03'21.203" 113°07’39.019"	633381	21365	Anvil Rock RanchWell	Inorganic O, H isotopes	40'	30'	Sedimentary
8th Field Trip, February 5-6, 2004 - Towne & Horsley									
BIS-78	B(22-8)5aaa windmill	35°19'39.969" 113°08'04.761"	608307	21825	Well #5	Inorganic, Radiochem Radon, O, H Isotopes	726’	600’	Sedimentary
BIS-79	B(21-7)7ccc windmill	35°12'53.819" 113°03'40.725"	608302	21658	Red Lake Windmill	Inorganic O, H isotopes	870’	600’	Sedimentary
BIS-80/81	B(21-9)15aaa windmill	35°12’41.055" 113°12'15.307"	608301	21661	Well #2	Inorganic, Radon O, H Isotopes	700’	450’	Sedimentary
BIS-82	Trout Creek at mouth	--	--	--	Trout Creek	O, H Isotopes	-	-	–
BIS-83	Big Sandy River at Highway 93	--	--	--	Big Sandy River	O, H Isotopes	-	-	–

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04

Site #	MCL Exceedances	Temp (^{o}C)	pH-field (su)	pH-lab (su)	SC-field (uS/cm)	SC-lab (uS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
BS-1/2	TDS, Cl , Gross ά Pb	21.4	7.08	*7.83*	1832	2050	**1100**	385	390	*4.2*
BIS-3	F	25.1	7.86	*8.0*	462	470	280	93	98	*0.57*
BIS-4	TDS, As, **F**	23.9	7.63	*7.7*	1456	1400	**940**	210	220	*2.6*
BIS-5	TDS, Fe, Mn	21.9	7.52	7.5	1273	1100	**660**	360	370	8.5
BIS-6	F, TDS, Gross ά, Uranium	26.5	7.41	7.3	1075	1000	**620**	280	270	0.26
BIS-7	F	27.4	8.33	8.0	568	550	320	40	38	1.7
BIS-8	-	24.6	7.96	7.6	659	630	360	230	220	1.5
BIS-10/11	TDS, As*, **F**	26.5	7.94	*8.29*	1389	1430	**835**	105	99	*0.15*
BIS-12/13	TDS, As, **F**	34.2	7.65	7.35	1401	1400	**820**	180	190	0.06
BIS-14	-	21.0	7.64	7.8	718	700	440	230	260	0.16
BIS-16	-	20.1	7.29	7.6	569	550	340	190	190	2.5
BIS-17	-	-	-	7.9	-	740	440	290	300	1.6
BIS-18	-	22.6	7.12	7.5	744	720	460	290	300	0.16
BIS-19/20	TDS, As*, F	26.9	7.31	*7.7*	1265	1300	**755**	350	360	*0.33*
BIS-21	pH, As*, **F**	19.9	8.80	7.8	834	710	420	150	150	7.8
BIS-23	F	19.5	8.38	7.4	740	610	370	240	260	2.4
BIS-24	TDS	18.9	8.32	7.9	1029	860	**550**	420	440	4.0
BIS-25	-	25.0	8.14	7.3	544	470	280	180	190	0.15
BIS-26/27	TDS, Cl, SO_4, **F** As*, Mn, Gross ά	28.8	7.59	8.0	5150	4600	**3050**	190	190	3.0
BIS-28	TDS, Cl, As*, **F** Fe, Mn	29.6	7.66	7.8	3450	3000	**1700**	260	250	13
BIS-29	-	22.8	7.47	7.6	791	680	440	230	260	1.8
BIS-30	TDS, **F**	16.6	6.31	6.5	1070	900	**690**	380	410	12
BIS-31	TDS, **F**	26.2	7.21	7.4	1650	1400	**870**	360	380	0.24
BIS-32/33	TDS, F, Gross ά, Radium	17.2	7.04	7.55	1072	915	**535**	375	400	11
BIS-34	TDS, F	17.0	7.26	7.5	1159	1000	**610**	350	370	1.5
BIS-35	TDS, **F**	19.6	7.19	7.7	1237	1100	**650**	340	370	1.7

bold = constituent level exceeds Primary or Secondary MCL
italics = constituent exceeded holding time
* = concentration exceeds the revised arsenic SDW Primary MCL of 0.01 mg/l which becomes effective in 2006

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	T. Alk (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
BIS-1/2	81.5	44	255	11.25	425	510	ND	**260**	185
BIS-3	21	11	58	3.9	120	150	ND	40	41
BIS-4	53	21	250	7.0	380	460	ND	160	190
BIS-5	100	30	90	4.7	300	370	ND	110	96
BIS-6	62	29	110	2.0	270	330	ND	31	50
BIS-7	13	1.4	96	3.4	100	120	ND	62	73
BIS-8	33	34	45	4.0	210	260	ND	61	31
BIS-10/11	18.5	13.5	235	9.8	260	300	ND	155	190
BIS-12/13	50.5	15	245	8.3	265	325	ND	165	205
BIS-14	70	20	66	4.3	240	290	ND	42	72
BIS-16	57	12	41	1.6	150	180	ND	49	59
BIS-17	84	21	32	3.2	190	230	ND	100	24
BIS-18	78	25	37	2.5	210	260	ND	66	61
BIS-19/20	96.5	27	135	3.3	240	290	ND	210	69
BIS-21	42	12	98	3.4	230	280	ND	73	24
BIS-23	65	23	40	3.3	260	320	ND	23	36
BIS-24	72	62	34	1.8	425	520	ND	30	22
BIS-25	53	15	26	1.4	200	240	ND	23	15
BIS-26/27	48	17	975	15.5	220	270	ND	**350**	**1250**
BIS-28	30	43	560	7.1	680	830	ND	**490**	160
BIS-29	78	16	47	2.6	180	220	ND	33	99
BIS-30	130	20	41	3.5	27	32	ND	23	390
BIS-31	92	37	220	4	330	400	ND	140	170
BIS-32/33	88.5	43	56	1.85	370	450	ND	48	50
BIS-34	74	45	82	2.2	370	450	ND	55	88
BIS-35	74	46	100	2.9	370	450	ND	66	99
BIS-36	54	26	41	3	270	330	ND	21	27
BIS-37	92	26	23	1.1	310	380	ND	23	43

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Total Phosphorus (mg/L)	SAR (value)	Irrigation Quality
BIS-1/2	ND	ND	*ND*	ND	ND	ND	5.3	C3-S1
BIS-3	2.0	2.0	*ND*	ND	ND	ND	2.6	C2-S1
BIS-4	0.40	0.40	*ND*	0.052	ND	0.075	7.4	C3-S2
BIS-5	0.60	0.60	*ND*	0.051	0.029	ND	2.0	C3-S1
BIS-6	1.7	1.7	ND	0.12	ND	ND	2.9	C3-S1
BIS-7	0.87	0.87	ND	0.14	ND	ND	6.8	C2-S1
BIS-8	2.3	2.3	ND	0.12	ND	ND	1.3	C2-S1
BIS-10/11	1.2	1.2	*ND*	0.089	ND	ND	11.4	C3-S2
BIS-12/13	1.25	1.25	ND	0.107	ND	ND	8.2	C3-S2
BIS-14	0.39	0.39	ND	ND	ND	0.059	1.8	C2-S1
BIS-16	0.075	0.075	ND	0.088	ND	ND	1.3	C2-S1
BIS-17	5.2	5.2	ND	0.19	ND	ND	0.8	C2-S1
BIS-18	4.3	4.3	ND	0.069	ND	ND	0.9	C2-S1
BIS-19/20	3.1	3.1	ND	ND	ND	*ND*	3.3	C3-S1
BIS-21	ND	ND	ND	0.35	ND	0.029	3.4	C2-S1
BIS-23	0.46	0.46	ND	0.24	ND	0.066	1.1	C2-S1
BIS-24	ND	ND	ND	0.19	ND	0.051	0.7	C3-S1
BIS-25	0.89	0.89	ND	ND	ND	ND	0.9	C2-S1
BIS-26/27	0.025	0.025	ND	ND	ND	0.033	30.7	C4-S4
BIS-28	ND	ND	ND	0.11	0.10	ND	15.4	C4-S4
BIS-29	3.4	3.4	ND	0.080	ND	ND	1.3	C2-S1
BIS-30	0.73	0.73	ND	ND	0.098	ND	0.9	C3-S1
BIS-31	4.4	4.4	ND	0.12	ND	ND	4.9	C3-S1
BIS-32/33	2.55	2.55	ND	ND	0.082	ND	1.2	C3-S1
BIS-34	1.1	1.1	ND	0.080	ND	0.060	1.9	C3-S1
BIS-35	0.20	0.20	ND	0.068	0.026	ND	2.2	C3-S1
BIS-36	0.35	0.35	ND	ND	0.054	ND	1.1	C2-S1
BIS-37	ND	ND	ND	ND	ND	ND	0.5	C2-S1

bold = constituent level exceeds Primary or Secondary MCL
italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
BIS-1/2	ND	ND	ND	ND	0.845	ND	ND	ND	0.84
BIS-3	ND	ND	ND	ND	0.15	ND	0.022	ND	**2.1**
BIS-4	ND	**0.088**	ND	ND	1.1	ND	ND	ND	**4.4**
BIS-5	ND	ND	ND	ND	0.17	ND	ND	0.011	1.6
BIS-6	ND	ND	ND	ND	0.17	ND	ND	0.010	**2.4**
BIS-7	ND	ND	ND	ND	ND	ND	0.018	ND	**2.0**
BIS-8	ND	ND	ND	ND	0.16	ND	0.021	ND	1.1
BIS-10/11	ND	**0.0475**	ND	ND	1.095	ND	ND	ND	**4.4**
BIS-12/13	ND	**0.125***	ND	ND	1.1	ND	ND	ND	**4.25**
BIS-14	ND	ND	ND	ND	0.18	ND	ND	ND	0.18
BIS-16	ND	ND	ND	ND	ND	ND	ND	0.017	0.55
BIS-17	ND	ND	0.23	ND	ND	ND	ND	0.043	0.36
BIS-18	ND	ND	ND	ND	ND	ND	ND	ND	0.65
BIS-19/20	ND	**0.020***	ND	ND	0.18	ND	ND	0.011	**2.25**
BIS-21	ND	**0.013***	0.15	ND	0.13	ND	ND	ND	**5.5**
BIS-23	ND	ND	0.10	ND	ND	ND	ND	ND	**2.0**
BIS-24	ND	ND	ND	ND	ND	ND	ND	ND	0.80
BIS-25	ND	ND	ND	ND	ND	ND	ND	ND	0.45
BIS-26/27	ND	**0.0205***	ND	ND	3.05	ND	ND	ND	**7.85**
BIS-28	ND	**0.011***	ND	ND	2.2	ND	ND	ND	**6.7**
BIS-29	ND	ND	ND	ND	ND	ND	ND	0.016	0.61
BIS-30	ND	ND	ND	0.013	ND	0.0069	ND	0.028	**13**
BIS-31	ND	ND	ND	ND	0.15	ND	ND	0.016	**5.2**
BIS-32/33	ND	ND	ND	ND	ND	ND	ND	0.017	**2.0**
BIS-34	ND	ND	ND	ND	0.10	ND	ND	0.026	**2.2**
BIS-35	ND	ND	ND	ND	0.15	ND	ND	0.035	**4.8**
BIS-36	ND	ND	0.21	ND	ND	ND	ND	0.016	**4.0**
BIS-37	ND	ND	ND	ND	ND	ND	ND	0.016	**2.2**

bold = constituent level exceeds Primary or Secondary MCL
***** = concentration exceeds the revised arsenic SDW Primary MCL of 0.01 mg/l which becomes effective in 2006

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L - ng/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
BIS-1/2	0.28	**0.016**	ND	ND 15.1	ND	ND	ND	ND	ND
BIS-3	ND	ND	ND	ND 0.28	ND	ND	ND	ND	ND
BIS-4	ND	ND	ND	ND 1.08	ND	ND	ND	ND	0.14
BIS-5	**0.33**	ND	**0.086**	ND	ND	ND	ND	ND	0.14
BIS-6	ND	ND	ND	ND 0.25	ND	ND	ND	ND	ND
BIS-7	ND	ND	ND	ND 98.8	ND	ND	ND	ND	ND
BIS-8	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-10/11	ND	ND	ND	ND 39.0	ND	ND	ND	ND	ND
BIS-12/13	ND	ND	ND	ND 48.5	ND	ND	ND	ND	ND
BIS-14	ND	ND	ND	ND 0.39	ND	ND	ND	ND	ND
BIS-16	ND	ND	ND	ND 0.20	ND	ND	ND	ND	ND
BIS-17	0.20	ND	ND	ND	ND	0.0058	ND	ND	2.9
BIS-18	ND	ND	ND	ND 0.37	ND	ND	ND	ND	ND
BIS-19/20	0.235	ND	ND	ND 0.98	ND	ND	ND	ND	ND
BIS-21	ND	ND	ND	ND 4.11	ND	ND	ND	ND	ND
BIS-23	ND	ND	ND	ND 3.31	ND	ND	ND	ND	0.37
BIS-24	0.15	ND	**0.083**	ND 1.47	ND	ND	ND	ND	ND
BIS-25	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-26/27	ND	ND	**0.0705**	ND	ND	ND	ND	ND	1.35
BIS-28	**0.37**	ND	**0.086**	ND	ND	ND	ND	ND	0.083
BIS-29	ND	ND	ND	ND	ND	ND	ND	ND	1.3
BIS-30	0.25	ND	ND	ND	ND	ND	ND	ND	0.65
BIS-31	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-32/33	ND	ND	ND	ND	ND	ND	ND	ND	1.1
BIS-34	ND	ND	ND	ND	ND	ND	ND	ND	0.12
BIS-35	ND	ND	ND	ND	ND	ND	ND	ND	0.18
BIS-36	ND	ND	ND	ND	ND	ND	ND	ND	4.56
BIS-37	ND	ND	ND	ND 0.38	ND	ND	ND	ND	ND

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04–Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Radium 226/228 (pCi/L)	Uranium (µg/L)	δ^{18} O ($^0/_{00}$)	δ D ($^0/_{00}$)	Type of Chemistry
BIS-1/2	–	**20**	17	< LLD	23	- 9.2	- 69	sodium-mixed
BIS-3	559	-	-	-	-	- 10.9	- 81	sodium-bicarbonate
BIS-4	268	-	-	-	-	- 9.0	- 69	sodium-mixed
BIS-5	-	-	-	-	-	- 8.3	- 65	mixed-bicarbonate
BIS-6	230	**22**	26	< LLD	**48**	- 9.8	- 72	mixed-bicarbonate
BIS-7	133	-	-	-	-	- 10.5	- 78	sodium-mixed
BIS-8	–	8.0	7.3	< LLD	< LLD	- 10.1	- 75	mixed-bicarbonate
BIS-9	–	-	-	-	-	- 9.7	- 72	--
BIS-10/11	160	5.7	11	< LLD	< LLD	- 10.05	- 75	sodium-mixed
BIS-12/13	197	8.3	14	< LLD	< LLD	- 10.0	- 74	sodium-mixed
BIS-14	119	-	-	-	-	- 10.1	- 74	mixed-bicarbonate
BIS-16	76	1.3	2.6	-	-	- 10.1	- 74	mixed-bicarbonate
BIS-17	-	-	-	-	-	-	-	calcium-bicarbonate
BIS-18	349	3.4	3.0	-	-	- 9.4	- 70	calcium-bicarbonate
BIS-19/20	1076	-	-	-	-	- 10.85	- 80	mixed-mixed
BIS-21	-	-	-	-	-	- 7.7	- 65	sodium-bicarbonate
BIS-23	863	8.3	8.3	< LLD	< LLD	- 9.5	- 72	mixed-bicarbonate
BIS-24	-	3.3	2.3	-	-	- 9.1	- 68	magnesium-bicarbonate
BIS-25	-	-	-	-	-	- 10.4	- 73	calcium-bicarbonate
BIS-26/27	385	**25**	21	0.8	17	- 11.1	-85	sodium-sulfate
BIS-28	134	-	-	-	-	-11.5	-86	sodium-mixed
BIS-29	214	-	-	-	-	-9.8	-70	calcium-bicarbonate
BIS-30	-	< LLD	6.6	-	-	- 10.6	- 76	calcium-sulfate
BIS-31	578	-	-	-	-	- 9.8	- 73	sodium-mixed
BIS-32/33	2574	**31.5**	6.1	**43.8**	< LLD	- 10.6	- 76	mixed-bicarbonate
BIS-34	293	-	-	-	-	- 10.3	- 76	mixed-bicarbonate
BIS-35	1460	-	-	-	-	- 9.3	- 72	mixed-bicarbonate

bold = Primary MCL Exceedance
LLD = Lower Limit of Detection
italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (uS/cm)	SC-lab (uS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
BIS-36	**F**	24.3	8.41	7.7	695	610	390	240	240	18
BIS-37	F	19.58	7.38	7.7	710	720	440	350	340	0.69
BIS-39	TDS	-	7.19	7.2	1182	1100	**650**	400	410	1.8
BIS-41	Gross ά	16.4	7.92	8.0	704	710	420	250	260	0.19
BIS-42/43	TDS, Gross ά	13.6	7.09	7.46	983	965	**585**	420	430	ND
BIS-44	-	14.1	7.15	-	639	-	-	-	-	-
BIS-45	As*, TDS	16.9	7.35	7.8	896	910	**550**	520	490	0.02
BIS-46	TDS, Gross ά	17.8	7.93	8.1	866	870	**540**	310	300	0.28
BIS-48/49	F, TDS, Gross ά, U	21.1	7.35	7.6	902	905	**540**	300	305	0.51
BIS-50	-	-	7.68	7.8	609	620	390	290	290	0.69
BIS-52	TDS, Cl	19.9	7.14	7.3	1438	1480	**810**	630	550	0.13
BIS-53	-	-	7.32	7.5	728	760	450	350	300	4.4
BIS-54/55	As*	19.1	7.59	7.9	567	570	360	270	220	0.06
BIS-56	-	20.1	7.28	7.2	582	600	360	290	290	0.45
BIS-57/58	-	17.5	7.90	7.8	381	380	210	180	180	1.25
BIS-59	-	22.2	7.43	7.5	585	600	340	300	300	0.04
BIS-61	Gross ά	16.6	7.71	7.6	466	490	280	190	190	46
BIS-62	**F**, Fe, Mn	24.9	7.91	7.8	636	640	380	38	40	26
BIS-63	As*	18.5	7.38	7.9	700	720	440	290	300	0.04
BIS-64	-	22.0	7.94	7.8	352	360	240	110	120	2.8
BIS-65/66	-	16.0	7.06	7.51	553	565	340	245	240	ND
BIS-67	-	-	7.76	7.6	403	420	270	190	190	0.16
BIS-68	-	17.6	7.46	8.0	364	370	260	160	160	0.09
BIS-70	-	10.9	7.71	-	211	-	-	-	-	-
BIS-71	pH, TDS, SO_4	15.6	8.56	8.0	846	860	**570**	51	45	0.10
BIS-72	-	15.8	7.99	7.8	349	350	200	150	160	0.18

bold = constituent level exceeds Primary or Secondary MCL
italics = constituent exceeded holding time
* = concentration exceeds the revised arsenic SDW Primary MCL of 0.01 mg/l which becomes effective in 2006

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	T. Alk (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
BIS-39	110	32	62	6.4	290	350	ND	120	83
BIS-41	58	29	66	3.3	250	300	ND	52	33
BIS-42/43	97.5	42.5	61	2.25	365	440	ND	80.5	49
BIS-45	70	76	23	2.5	440	540	ND	29	29
BIS-46	55	40	90	1.9	310	380	ND	50	48
BIS-48/49	76	28	92	2.85	350	425	ND	55	41
BIS-50	60	34	18	3.0	230	280	ND	42	24
BIS-52	110	66	54	2.9	310	380	ND	**250**	110
BIS-53	75	27	34	2.1	330	400	ND	36	40
BIS-54/55	54	27.5	23.5	2.2	250	300	ND	30.5	20.5
BIS-56	69	29	15	1.9	280	340	ND	23	16
BIS-57/58	37	21.5	11	1.7	160	200	ND	17.5	9.6
BIS-59	59	37	14	1.5	290	350	ND	22	15
BIS-61	42	21	31	4.1	230	280	ND	18	13
BIS-62	11	3.0	120	1.8	130	160	ND	68	69
BIS-63	63	35	42	1.3	280	340	ND	38	33
BIS-64	23	16	25	2.7	130	110	ND	23	14
BIS-65/66	67	18.5	25.5	2.9	235	280	ND	35.5	13.5
BIS-67	44	19	12	4.8	170	210	ND	15	11
BIS-68	44	13	12	5	160	200	ND	6.9	7.4
BIS-71	18	ND	170	ND	130	160	ND	15	**260**
BIS-72	34	17	8.8	1.4	130	160	ND	17	8.8
BIS-73/74	19.5	10	27	2.8	110	130	ND	12	8.6
BIS-75	46	9.0	15	5.5	140	170	ND	13	13
BIS-76	27	23	40	6.5	220	270	ND	12	19
BIS-77	35	11	15	5.5	100	120	ND	27	13

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Total Phosphorus (mg/L)	SAR (value)	Irrigation Quality
BIS-39	2.0	2.0	ND	0.079	0.064	ND	1.3	C2-S1
BIS-41	3.9	3.9	ND	ND	ND	ND	1.8	C2-S1
BIS-42/43	1.6	1.6	ND	ND	ND	ND	1.3	C2-S1
BIS-45	0.62	0.62	*ND*	ND	ND	ND	0.5	C2-S1
BIS-46	9.5	9.5	ND	0.095	ND	ND	2.3	C2-S1
BIS-48/49	1.6	1.6	ND	0.089	ND	ND	2.3	C2-S1
BIS-50	2.2	2.2	ND	0.11	ND	ND	0.5	C2-S1
BIS-52	1.5	1.5	ND	0.062	ND	ND	1.0	C3-S1
BIS-53	0.35	0.35	ND	0.33	0.14	0.11	0.9	C2-S1
BIS-54/55	2.05	2.05	ND	ND	ND	0.032	0.6	C2-S1
BIS-56	2.2	2.2	ND	ND	ND	0.021	0.4	C2-S1
BIS-57/58	2.5	1.8	0.72	0.135	0.062	ND	0.4	C2-S1
BIS-59	2.3	2.3	ND	ND	ND	0.031	0.4	C2-S1
BIS-61	2.5	1.8	0.71	0.15	0.057	0.052	1.0	C2-S1
BIS-62	0.17	0.17	ND	ND	ND	ND	8.3	C2-S1
BIS-63	1.9	1.9	ND	ND	ND	0.035	1.1	C2-S1
BIS-64	4.9	4.9	ND	ND	ND	ND	1.0	C2-S1
BIS-65/66	0.025	0.025	ND	ND	ND	ND	0.7	C2-S1
BIS-67	3.8	3.8	ND	ND	ND	0.031	0.4	C2-S1
BIS-68	0.29	0.29	ND	ND	ND	0.095	0.4	C2-S1
BIS-71	ND	ND	ND	ND	ND	ND	11.0	C3-S2
BIS-72	2.6	2.6	ND	ND	ND	ND	0.3	C2-S1
BIS-73/74	2.9	2.9	ND	ND	ND	ND	1.2	C2-S1
BIS-75	4.1	4.1	ND	0.14	ND	0.031	0.5	C2-S1
BIS-76	ND	ND	ND	0.11	ND	ND	1.4	C2-S1
BIS-77	4.4	4.4	ND	0.23	ND	0.15	0.6	C2-S1

bold = constituent level exceeds Primary or Secondary MCL
italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
BIS-39	ND	ND	ND	ND	0.11	ND	ND	ND	1.5
BIS-41	ND	ND	ND	ND	0.19	ND	0.012	ND	1.4
BIS-42/43	ND	ND	ND	ND	ND	ND	ND	ND	0.815
BIS-45	ND	**0.017***	ND	ND	ND	ND	ND	ND	1.4
BIS-46	ND	ND	ND	ND	0.26	ND	ND	ND	1.4
BIS-48/49	ND	ND	ND	ND	0.26	ND	ND	ND	**2.1**
BIS-50	ND	ND	ND	ND	ND	ND	ND	ND	0.52
BIS-52	ND	ND	ND	ND	0.10	ND	ND	ND	0.47
BIS-53	ND	ND	ND	ND	ND	ND	ND	ND	0.47
BIS-54/55	ND	**0.0115***	ND	ND	ND	ND	ND	0.010	0.44
BIS-56	ND	ND	0.14	ND	ND	ND	ND	ND	0.30
BIS-57/58	ND	ND	ND	ND	ND	ND	ND	ND	0.23
BIS-59	ND	ND	ND	ND	ND	ND	ND	ND	0.21
BIS-61	ND	ND	ND	ND	ND	ND	ND	ND	0.39
BIS-62	ND	ND	ND	ND	0.27	ND	ND	ND	**7.8**
BIS-63	ND	**0.016***	ND	ND	0.15	ND	ND	ND	0.69
BIS-64	ND	ND	ND	ND	ND	ND	0.031	ND	0.53
BIS-65/66	ND	ND	ND	ND	ND	ND	ND	ND	1.1
BIS-67	ND	ND	ND	ND	ND	ND	ND	ND	0.39
BIS-68	ND	ND	ND	ND	ND	ND	ND	ND	0.24
BIS-71	ND	ND	ND	ND	ND	ND	ND	ND	0.40
BIS-72	ND	ND	ND	ND	ND	ND	ND	ND	0.22
BIS-73/74	ND	**0.0125***	ND	ND	0.13	ND	ND	ND	0.31
BIS-75	ND	ND	ND	ND	ND	ND	ND	ND	1.2
BIS-76	ND	ND	0.10	ND	0.43	ND	ND	ND	0.43
BIS-77	ND	ND	ND	ND	ND	ND	ND	ND	0.16

bold = constituent level exceeds Primary or Secondary MCL
***** = concentration exceeds the revised arsenic SDW Primary MCL of 0.01 mg/l which becomes effective in 2006

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L – ng/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
BIS-39	0.15	ND	ND	ND	ND	0.0082	ND	ND	0.58
BIS-41	ND	ND	ND	ND 2.67	ND	ND	ND	ND	0.080
BIS-42/43	ND	ND	ND	ND 0.26	ND	ND	ND	ND	ND
BIS-45	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-46	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-48/49	ND	ND	ND	ND	ND	0.0052	ND	ND	ND
BIS-50	ND	ND	ND	ND	ND	ND	ND	ND	0.073
BIS-52	ND	ND	ND	ND 0.95	ND	ND	ND	ND	ND
BIS-53	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-54/55	ND	ND	ND	ND	ND	ND	ND	ND	0.051
BIS-56	ND	ND	ND	ND	ND	ND	ND	ND	1.6
BIS-57/58	ND	ND	ND	ND 0.16	ND	ND	ND	ND	0.33
BIS-59	ND	ND	ND	ND	ND	ND	ND	ND	0.21
BIS-61	0.10	ND	ND	ND	ND	ND	ND	ND	0.47
BIS-62	**0.30**	ND	**0.10**	ND	ND	ND	ND	ND	0.055
BIS-63	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-64	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-65/66	ND	ND	ND	ND	ND	ND	ND	ND	0.052
BIS-67	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-68	ND	ND	ND	ND ND	ND	ND	ND	ND	ND
BIS-70	-	-	-	- 0.41	-	-	-	-	-
BIS-71	ND	ND	ND	ND	ND	ND	ND	ND	0.082
BIS-72	ND	ND	ND	ND	ND	ND	ND	ND	0.11
BIS-73/74	ND	ND	ND	ND ND	ND	ND	ND	ND	0.14
BIS-75	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS-76	ND	ND	ND	ND	ND	ND	ND	ND	0.33
BIS-77	ND	ND	ND	ND	ND	ND	ND	ND	1.1

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04–Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 (pCi/L)	Uranium (µg/L)	δ^{18} O ($^0/_{00}$)	δ D ($^0/_{00}$)	Type of Chemistry
BIS-36	295	-	-	-	-	- 11.1	- 84	mixed-bicarbonate
BIS-37/38	282	5.6	5.3	ND	5.7	- 11.6	- 83	calcium-bicarbonate
BIS-39	3686	-	-	-	-	- 8.7	- 66	calcium-bicarbonate
BIS-40	-	-	-	-	-	- 9.5	- 71	-
BIS-41	-	**17**	12	0.34	14	- 10.2	- 74	mixed-bicarbonate
BIS-42/43	-	**29**	24	< LLD	25	- 10.6	- 75	mixed-bicarbonate
BIS-44	-	-	-	-	-	- 9.8	- 74	-
BIS-45	-	-	-	-	-	- 9.1	- 70	magnesium-bicarbonate
BIS-46	-	**22**	16	< LLD	25	- 8.5	- 68	mixed-bicarbonate
BIS-48/49	2487	**42**	24	0.22	**39**	- 9.6	- 74	mixed-bicarbonate
BIS-50	-	1.3	3.2	-	-	- 8.8	- 69	mixed-bicarbonate
BIS-51	-	-	-	-	-	- 8.5	- 65	-
BIS-52	615	10	8.3	< LLD	-	- 9.6	- 71	mixed-mixed
BIS-53	-	-	-	-	-	- 10.9	- 80	calcium-bicarbonate
BIS-54/55	1376	3.0	7.1	-	-	- 9.5	- 73	mixed-bicarbonate
BIS-56	244	7.2	5.6	1.1	< LLD	- 10.3	- 76	calcium-bicarbonate
BIS-57/58	< 18	2.1	2.5	-	-	- 9.8	- 74	mixed-bicarbonate
BIS-59	-	-	-	-	-	- 9.8	-75	mixed-bicarbonate
BIS-61	92	**34**	21	0.85	22	- 9.8	- 74	mixed-bicarbonate
BIS-62	873	6.2	5.5	<LLD	-	- 11.6	- 87	sodium-mixed
BIS-63	286	6.7	23	< LLD	-	- 9.1	- 66	mixed-bicarbonate
BIS-64	1576	1.6	3.8	-	-	- 8.8	- 63	mixed-bicarbonate
BIS-65/66	3262	2.6	5.0	-	-	- 9.65	- 73.5	calcium-bicarbonate
BIS-67	-	4.4	6.5	-	-	- 8.8	- 69	calcium-bicarbonate
BIS-68	177	-	-	-	-	- 8.5	- 66	calcium-bicarbonate
BIS-70	-	-	-	-	-	- 8.7	- 68	-
BIS-71	390	-	-	-	-	- 11.6	- 85	sodium-sulfate
BIS-72	130	-	-	-	-	- 9.0	- 67	mixed-bicarbonate

bold = Primary MCL Exceedance
LLD = Lower Limit of Detection
italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (uS/cm)	SC-lab (uS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
BIS-73/74	As*	17.2	8.18	8.1	285	300	175	81.5	90	1.5
BIS-75	-	13.7	7.51	7.6	353	370	240	150	150	0.12
BIS-76	-	15.5	7.62	8.0	460	470	260	160	160	0.24
BIS-77	-	12.8	7.73	7.6	349	360	250	130	130	0.48
BIS-78	-	18.6	7.75	7.8	390	420	230	190	200	4.6
BIS-79	-	12.5	7.99	7.9	363	390	230	170	190	5.6
BIS-80/81	-	13.5	7.82	7.81	354	382	240	175	180	3.3
BIS-83	-	-	6.91	-	1151	-	-	-	-	-

bold = constituent level exceeds Primary or Secondary MCL
italics = constituent exceeded holding time
* = concentration exceeds the revised arsenic SDW Primary MCL of 0.01 mg/l which becomes effective in 2006

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	T. Alk (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
BIS-78	46	21	11	1.1	160	200	ND	19	11
BIS-79	44	19	9.2	1.1	160	200	ND	15	7.7
BIS-80/81	42	17.5	8.0	2.3	150	180	ND	16.5	8.3

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Total Phosphorus (mg/L)	SAR (value)	Irrigation Quality
BIS-78	4.8	4.8	ND	ND	ND	ND	0.3	C2-S1
BIS-79	3.1	3.1	ND	0.059	ND	ND	0.3	C2-S1
BIS-80/81	3.2	3.2	ND	ND	ND	0.025	0.3	C2-S1

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
BIS-78	ND	ND	ND	ND	ND	ND	ND	ND	0.17
BIS-79	ND	ND	ND	ND	ND	ND	ND	ND	0.21
BIS-80/81	ND	ND	ND	ND	ND	ND	ND	ND	0.11

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04--Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
BIS-78	ND	ND	ND	ND	ND	ND	ND	ND	0.40
BIS-79	ND	ND	ND	ND	ND	ND	ND	ND	0.52
BIS-80/81	ND	ND	ND	ND	ND	ND	ND	ND	0.28

Appendix B. Groundwater Quality Data, Big Sandy Basin, 2003-04–Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 (pCi/L)	Uranium (µg/L)	δ^{18} O ($^0/_{00}$)	δ D ($^0/_{00}$)	Type of Chemistry
BIS-73/74	-	-	-	-	-	- 10.2	- 76	mixed-bicarbonate
BIS-75	-	4.0	7.4	-	-	- 9.5	- 73	calcium-bicarbonate
BIS-76	-	-	-	-	-	- 11.6	- 86	mixed-bicarbonate
BIS-77	-	-	-	-	-	- 9.7	- 71	calcium-bicarbonate
BIS-78	33	0.59	0.70	-	-	- 10.2	- 76	calcium-bicarbonate
BIS-79	-	-	-	-	-	- 9.8	- 74	calcium-bicarbonate
BIS-80/81	159	-	-	-	-	- 9.45	- 70.5	calcium-bicarbonate
BIS-82	-	-	-	-	-	- 8.6	- 63	-
BIS-83	-	-	-	-	-	- 10.0	- 74	-