Arsenic in groundwater from Water Bank Well 30S/25E-23H01, San Joaquin Valley, California

A thesis by: Leslie A. Boockoff

Submitted to the Office of Graduate Programs,

California State University, Bakersfield,

in partial fulfillment of the requirements for the degree

Masters of Science, May 2005

Major Subject: Geology

To the Office of Graduate Programs:

The members of the committee approve the Thesis of Leslie A. Boockoff

presented on May 23, 2005

Approved By:

6/3/05

Dirk Baron, Ph.D., R.G., Chair
California State University, Bakersfield
Date

6/3/05

Rob Negrini, Ph.D.
California State University, Bakersfield
Date

6/3/05

Jonathan D. Parker, R.G., C.H.G.
Kern Water Bank Authority
Date

IN MEMORY OF KEN SMITH

You would never let me give up.

Abstract

A series of downhole measurements were evaluated on a well in the Kern Water Bank that contain anomalously high levels of dissolved arsenic (>20 ppb) in the groundwater. These measurements include (1) collecting depth-specific water samples under non-pumping conditions, (2) collecting water samples under pumping conditions, (3) measuring field parameters such as pH, conductivity, redox potential and dissolved oxygen and concentrations of major cations and anions from the collected water samples, (4) determining the speciation of the arsenic from the collected water samples in the field, and (4) measuring the direction and rate of groundwater flow under non-pumping conditions; and (5) evaluating groundwater quality data from wells throughout the KWB and Kern County and looking for trends in that data that may relate to the occurrence of arsenic.

The results from the analyses indicate that, under non-pumping conditions, concentrations of major cations and anions do not vary significantly throughout the wellbore. Well 23H is dominated by Na-HCO_3 type water. Concentrations of total arsenic measured from the depth-specific water samples collected under non-pumping conditions vary with depth. Arsenic concentrations were highest (15 ppb to 20 ppb) between 500 ft bgs to 600 ft bgs and 700 ft bgs to 800 ft bgs. This interval coincides with the high arsenic levels detected in a previous study by Negrini et al. (2005) on sediment grab samples from the well.

The average total arsenic concentration measured from the well while pumping was around 36 ppb, which is significantly higher than the highest levels observed when the well was

static. This suggests that, when pumped, the well receives water from zones that are not represented in the depth-specific samples that were collected under non-pumping conditions.

The average arsenic III concentration using the Clifford et al. (2004) speciation method used during pumping was 11 ppb with a calculated average arsenic V concentration of 25 ppb. Approximately, 30% of the arsenic is arsenic III, which is indicative of mixed redox conditions.

As with the depth-specific water samples, the water type under pumping conditions is Na-HCO_3 type water. The average pH of the water produced by the pumping well was 8.5. The average redox potential was 172 mV and the average dissolved oxygen was 4.6 ppm. The redox potential and dissolved oxygen suggest that redox conditions of the groundwater produced from Well 23H is intermediate, not strongly reducing, but also not completely oxidized.

The groundwater gradient measured under non-pumping conditions is downward from 160 feet below ground surface to the base of the well. The observed downward gradient may be reversed under pumping conditions.

Examination of water chemistry data collected from wells throughout the KWB and Kern County in general suggest that there is a correlation between arsenic concentrations greater than 5 ppb and Na-HCO_3 type water. In addition, wells with high arsenic concentrations typically had low sulfate and iron concentrations.

Coarsening-upward sequences have been identified and correlated across the KWB in a previous study. These sequences have been interpreted to represent a prograding delta ending in a terminal lake (Buena Vista Lake terminal basin). Arsenic concentrations greater than 5 ppb in the KWB correspond to the location of the terminal lake. Well 23H is located in the area of the hypothesized delta.

Sediment analyses of Well 23H and nearby Well 24K indicate that arsenic is more mobile in Well 23H. Arsenic was detected in water samples collected from 23H at concentrations greater than 10 ppb and less than 2ppb in Well 24K. Sediment analyses indicate that pyrite with several tenths of a percent of arsenic is present in Well 23H and not in Well 24K. The presence of pyrite is indicative of past reducing conditions.

Water chemistry analysis indicates mixed redox conditions. The mixed redox conditions suggest that oxygenated water may be mixing with reduced water. This mixing might cause dissolution of arsenic from pyrite, formation of iron oxyhydroxides, which bind some of the arsenic released from pyrite, and the mobilization of arsenic from the sediments.

The depths with the highest arsenic concentrations were at one time dominated by reducing conditions. Post-deposition of the deltaic sediments, oxygenated water mixed with the reduced deltaic sediments. This study suggests that this mixing was, and continues, to be an important factor in the mobilization of arsenic within the KWB in the immediate vicinity of Well 23H.

Acknowledgements

This research was funded in part by the Kern Water Bank Authority, the CSUB Department of Geology, and the State of California. Thanks to the Kern Water Bank Authority, the Kern County Water Agency, and West Kern Water District for providing water quality data. Special thanks to my thesis advisor Dr. Dirk Baron for standing out in the hot summer sun working tirelessly to pull samples from the water well and for your assistance, guidance, and encouragement. Thank you Jon Parker for your financial support and guidance. Thank you Dr. Robert Negrini for your open and candid discussions on all things Kern Water Bank. Thank you Dr. Robert Horton for finding the pyrite. Thank you Dr. Jan Gillespie and Dr. Kurt Burmeister for your words of encouragement. Thank you fellow graduate students John Huff and Anne Drauker for the 'insider' look at the Kern Water Bank. Thank you Tom Haslebacher for taking time out of your busy schedule and your infectious energy. Thank you Elizabeth Powers and Dr. Alvin Tanabe for all of your help. Thank you Douglas Derr for always asking, "Where are you and what are you standing in?"; thank you Dave Clark for pulling samples and Dave Palais for coming up with a much needed reference.

It was a long decade. Thank you to my family for not letting me forget what I started, and last, but certainly not least, thank you Scott for your uncompromising support, unyielding words of encouragement, and home cooked meals.

Table of Contents

List of Tables

List of Figures

Figure 7-2 WKWD Well 6-04 Zone Testing Water Quality and KWB Well 23H Depth-Specific Samples and Pumping Water Quality – Stiff Diagrams

1 Introduction

1.1 Background

The Kern Water Bank (KWB) is an aquifer storage and recovery project (Figure 1-1). Aquifer storage and recovery projects, such as a water bank, are used to supplement water supply by recharging permeable aquifers for later use. KWB is located southwest of the city of Bakersfield, Kern County, California, at the distal end of the Kern River alluvial fan (Swartz, 1995). The KWB covers a total area of approximately 78 km^2. There is very little vertical relief across the KWB. The Kern River cuts across the study area.

This study is supported and funded by California State University Bakersfield (CSUB) Department of Geology and the Kern Water Bank Authority (KWBA). This study is part of an ongoing KWB Project that is under the direction of Professors Dirk Baron, Rob Negrini, Jan Gillespie, and Robert Horton in collaboration with Jon Parker of the KWBA. The overall objective of the KWB Project is to create a geologic and geochemical model of the groundwater reservoir, combining information such as the stratigraphy of the region, the water quality, and the groundwater flow direction. A long-term goal of the project is to use this information to improve well yield and hopefully, the overall quality of the groundwater by understanding the origin and distribution of potential constituents of concern, such as arsenic (Negrini et al., 2005).

The portion of the KWB project that is addressed in the present study focused on collecting both pumped water samples and depth-specific water samples collected under non-pumping conditions from an active KWB groundwater extraction well (30S/25E-23H01) (Figure 1-2) and evaluating the overall water chemistry of the KWB with respect to the occurrence of arsenic in groundwater. Well 23H is located within Township 30S/Range 25E within the Mount Diablo Baseline and Meridian in the Southern San Joaquin Valley (Figure -1-1). It is in the south central region of the KWB and is in close proximity to the intersection of Interstate 5 and Highway 43.

Well 23H was selected as a good candidate for collecting depth-specific water samples due to anomalously high concentrations of arsenic (>60 ppb) that have been detected in water samples collected from the well (KWB, unpublished data). This high level of arsenic affords the opportunity to understand the origin of arsenic in the groundwater. Arsenic was also detected in sediment samples collected during the drilling of Well 23H (Negrini et al., 2005). In order to assist in understanding the occurrence and possible source of arsenic in the KWB, the larger KWB Project also proposed conducting a spinner log of Well 23H. A spinner log or similar logging tool can be utilized to determine the depth(s) and rate at which water either enters or exits the well and thus, the vertical direction and velocity of groundwater flow. Knowing the vertical direction and velocity of groundwater flow will add to the understanding of the possible source or sources for arsenic release.

1.2 Objectives and Scope of Work

In June 2000, the United States Environmental Protection Agency (USEPA) proposed to lower the National Primary Drinking Water Standard (DWS) for arsenic from 50 parts per billion (ppb) to 5 ppb (Federal Register, 2000). Following public comment, the final USEPA standard for arsenic was lowered to 10 ppb and goes into effect on January 1, 2006. This increases the need for water systems to better understand the sources and mobility of arsenic in groundwater. For the KWB, understanding sources and mobility of arsenic is complicated by observed variations in the concentration of arsenic. Water quality data provided by the Kern County Water Agency (KCWA) and the KWBA illustrate the variation in arsenic concentrations across the KWB (Figure 1-3). Similarly, arsenic concentrations in sediment samples collected during drilling from the subject well, 23H, and a nearby well, 30S/25E-24K01 (24K) with low arsenic in produced water, (Figure 1-3) illustrate variations in how strongly arsenic is bound to sediments in the two wells. The total concentrations of arsenic in the sediments (Figure 1-4) were very similar, however, the subject well has much higher concentrations of arsenic in groundwater (>50 ppb) than the neighboring well (2 ppb), suggesting that geochemical conditions in Well 23H are such that arsenic is more easily mobilized into the groundwater.

The overall objective of this study was to gain a better understanding of sources and distribution of arsenic at the KWB. To achieve this objective, the following goals were established for this study:

- Evaluating the water chemistry of depth-specific water samples collected under non-pumping conditions
- Evaluating the flow of water in the well under non-pumping conditions
- Evaluating the water chemistry from water samples collected under pumping conditions
- Evaluating the overall groundwater chemistry of the KWB

- Interpreting water chemistry results in the context of previous work on sediment samples from wells 23H and 24K

To accomplish the goals of the study, research focused on (1) collecting depth-specific water samples under non-pumping conditions, (2) collecting water samples under pumping conditions, (3) measuring field parameters such as pH, conductivity, redox potential and dissolved oxygen and concentrations of major cations and anions from the collected water samples, (4) determining the speciation of the arsenic from the collected water samples in the field, and (4) measuring the direction and rate of groundwater flow under non-pumping conditions; and (5) evaluating groundwater quality data from wells throughout the KWB and Kern County and looking for trends in that data that may relate to the occurrence of arsenic. Data was provided by the Kern Water Bank Authority and the Kern County Water Agency.

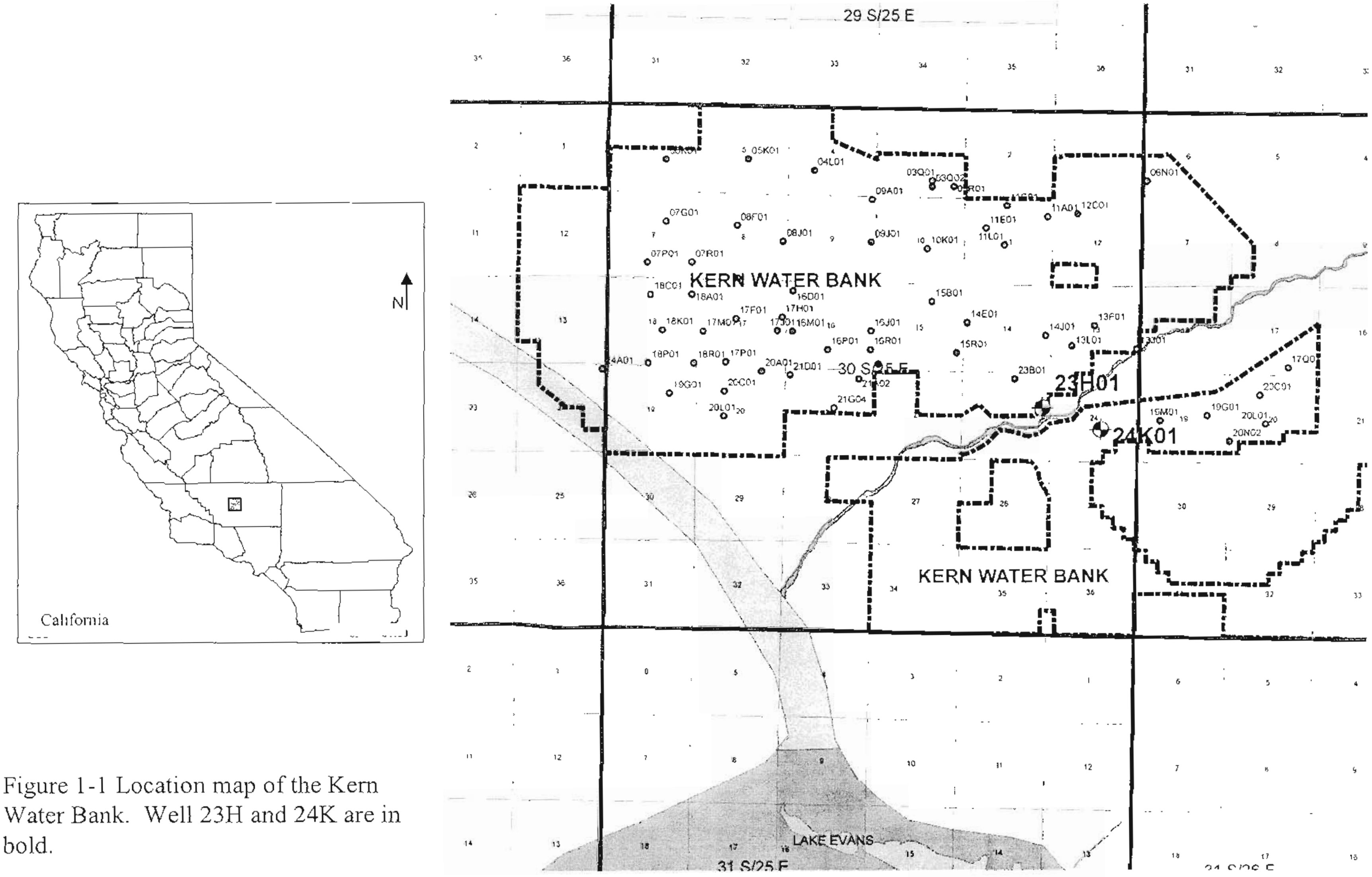


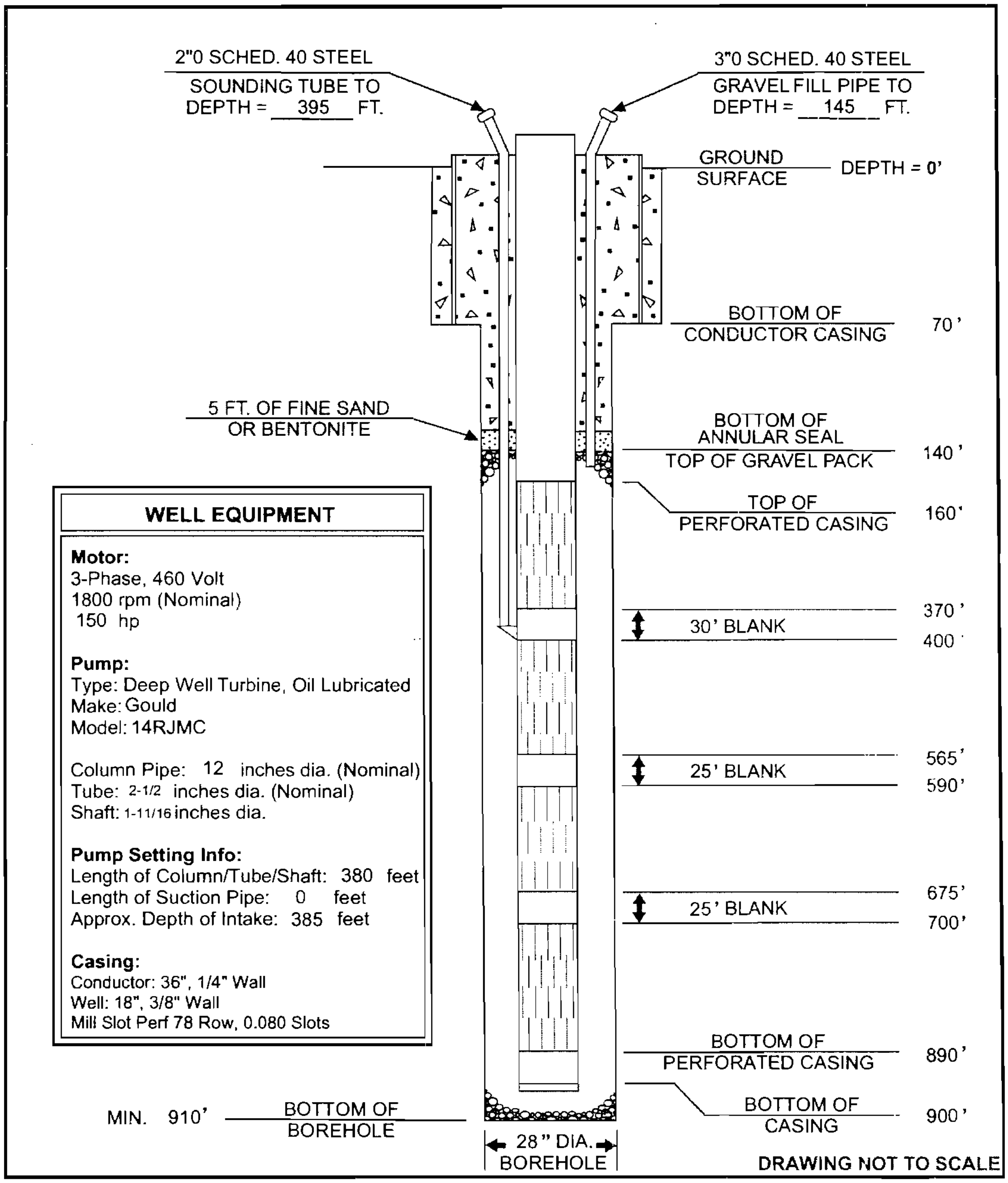
Figure 1-1 Location map of the Kern Water Bank. Well 23H and 24K are in bold.

KERN WATER BANK AUTHORITY

Well Construction Diagram

30S/25E-23H01

DATE: 08/07/00
JOB NO: 0033600
COMP. BY: SIMMONS
CHKD. BY:
SHEET: 1 OF 1



WELL EQUIPMENT

Motor:
3-Phase, 460 Volt
1800 rpm (Nominal)
150 hp

Pump:
Type: Deep Well Turbine, Oil Lubricated
Make: Gould
Model: 14RJMC

Column Pipe: 12 inches dia. (Nominal)
Tube: 2-1/2 inches dia. (Nominal)
Shaft: 1-11/16 inches dia.

Pump Setting Info:
Length of Column/Tube/Shaft: 380 feet
Length of Suction Pipe: 0 feet
Approx. Depth of Intake: 385 feet

Casing:
Conductor: 36", 1/4" Wall
Well: 18", 3/8" Wall
Mill Slot Perf 78 Row, 0.080 Slots

Figure 1-2: Well construction diagram of Well 23H from Kern Water Bank Authority

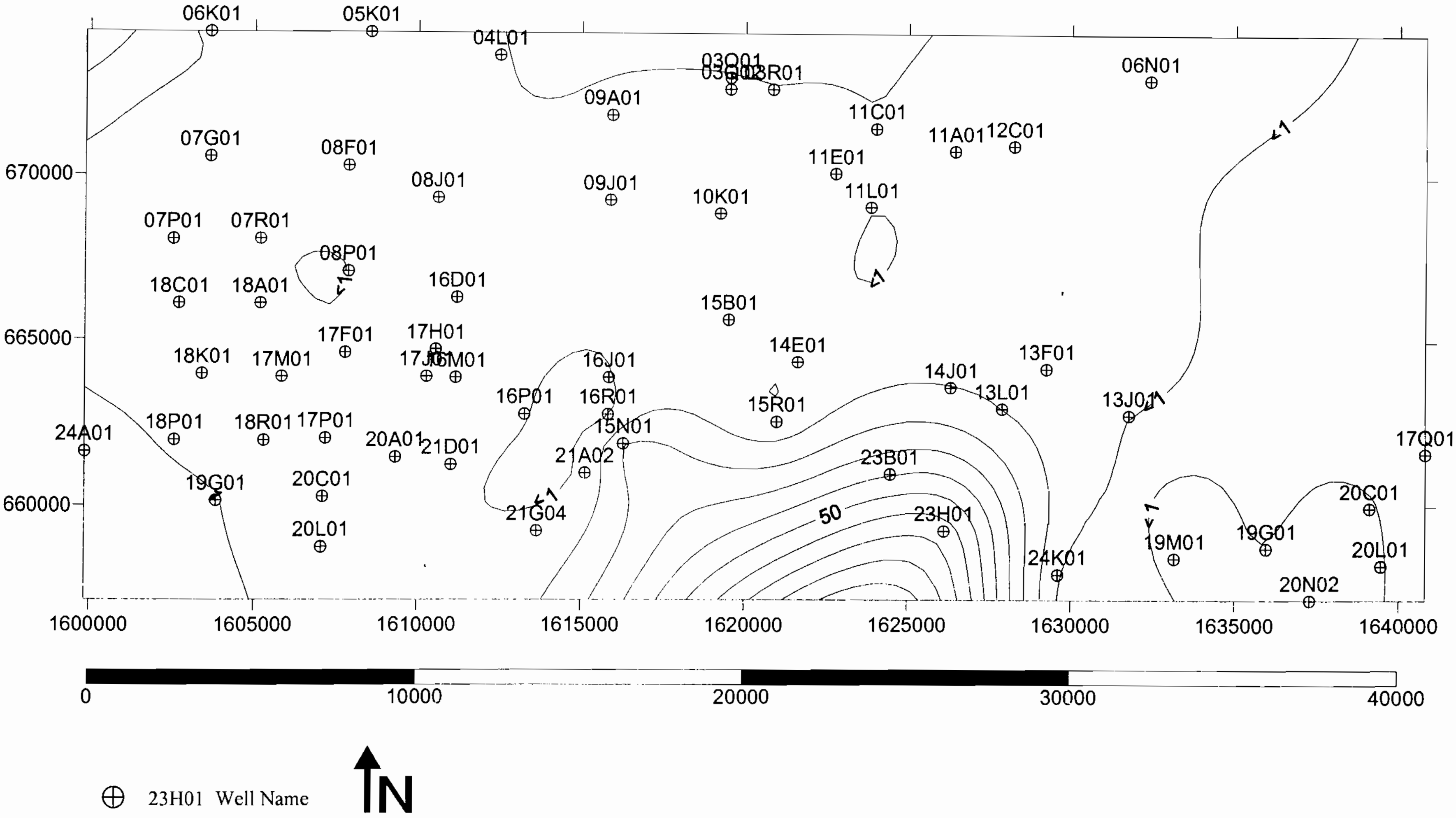


Figure 1-3: Distribution of arsenic concentrations in parts per billion across the Kern Water Bank. Contour interval is 10 ppb. Non-detect values are denoted as <1. Data was provided by the Kern Water Bank Authority.

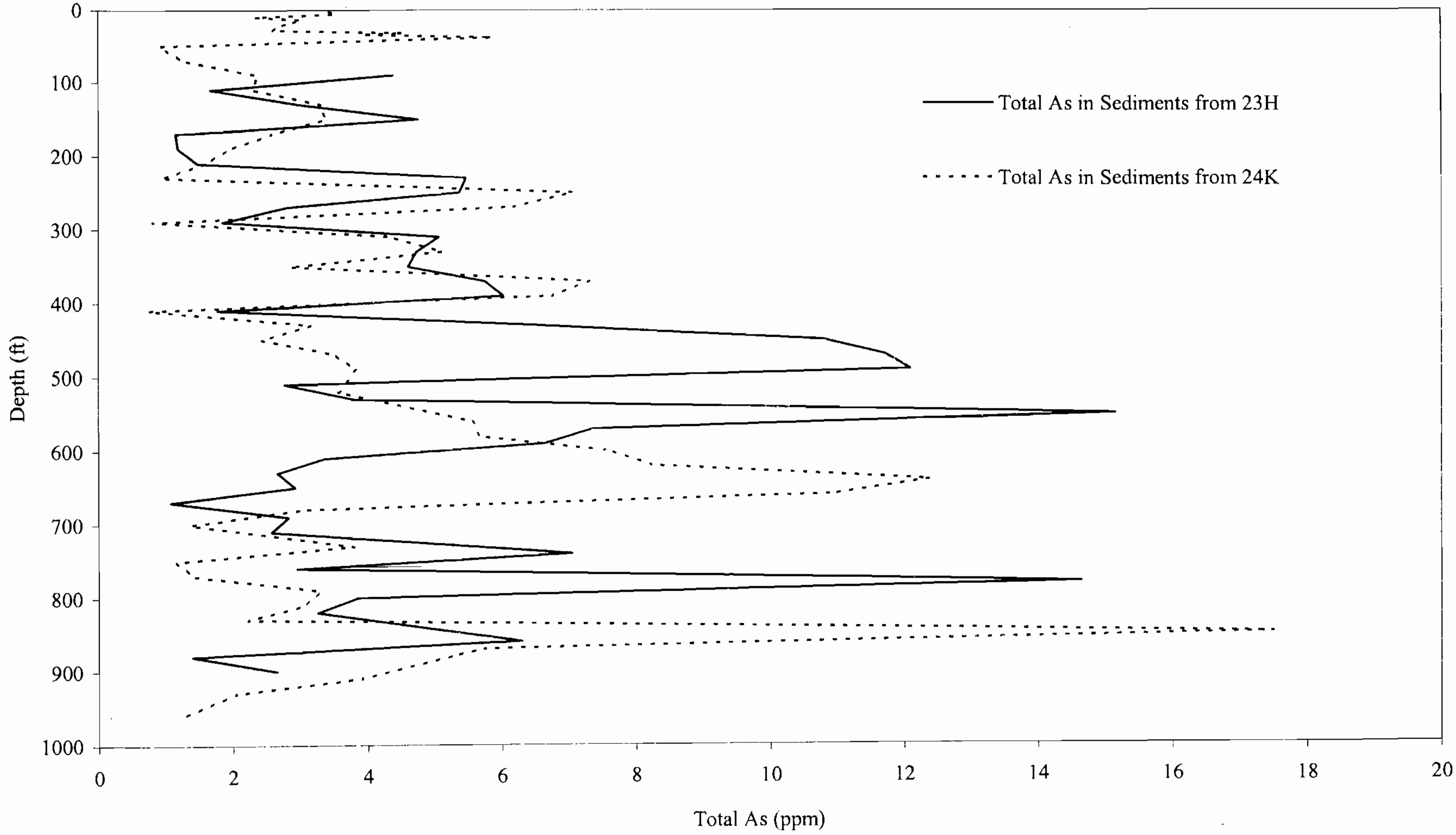


Figure 1-4: Comparison of arsenic concentrations in sediments from KWB Wells 23H and 24K

2 Regional Geology and Hydrogeology

2.1 Regional Geology

The KWB is located in the southern portion of the San Joaquin Valley (Figure 2-1). The San Joaquin Valley is both a topographic and structural basin. The valley is bounded by the Sierra Nevada to the east, the Temblor range to the west, and the San Emigdio mountains to the south (Davis, et al., 1959). Underlying the San Joaquin Valley basin are thick accumulations of sediments shed from the mountains that surround the valley (Davis et al., 1959). Davis et al. (1959) divided the San Joaquin Valley into four main geomorphic provinces. The KWB falls within the "low alluvial plains and fans" province (Davis et al., 1959).

Croft (1972) broadly groups the rocks of the Southern San Joaquin Valley into three assemblages, basement rocks of Mesozoic age, marine sediments of Mesozoic to Cenozoic age, and Cenozoic (including Recent) alluvium of continental origin. The formations that account for the uppermost 4000 feet beneath the study area are in order of increasing age, the Kern River Formation, the Tulare Formation, and the San Joaquin Formation (Croft, 1972).

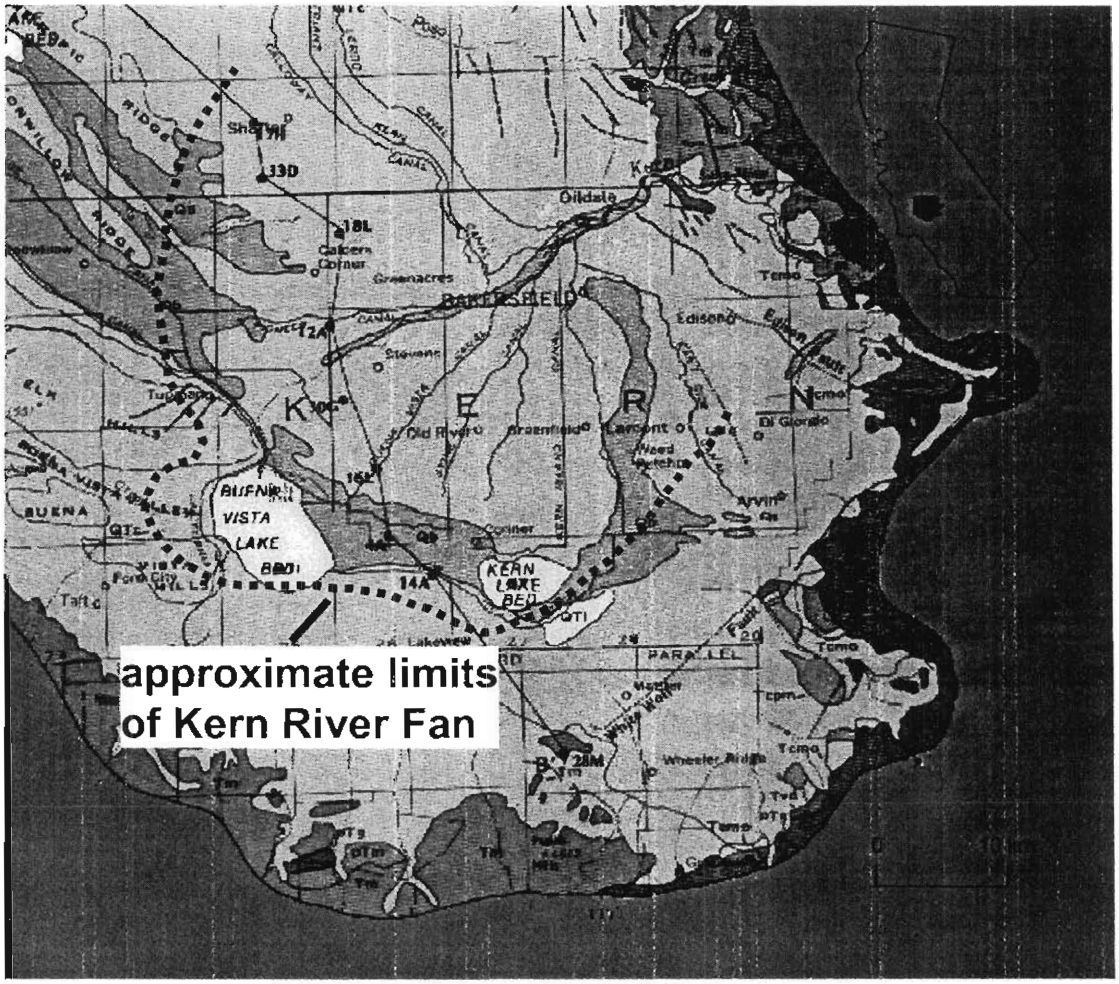
The KWB is part of the larger Quaternary-aged Kern River alluvial fan (Croft, 1972). The total surface area of the fan, as described by Hajas and Swanson (1979) is on the order of 1,100 square miles. Sediments that comprise the Kern River alluvial fan are derived from the Sierra Nevada and were transported via the Kern River. The KWB lies at the outer portion of the Kern River alluvial fan. On the western portion of the San Joaquin Valley Basin there are smaller alluvial fans that are derived from the marine sediments of the coast ranges (Croft, 1972).

2.2 Hydrogeology

The stratigraphy within the alluvial fan is complicated by large variations over small distances. However, some generalizations can be made. Groundwater reservoirs within the KWB are, in general, either unconfined or semi-confined (Croft, 1972). The upper, unconfined aquifer encompasses the upper 200 to 300 feet of the KWB. The upper unconfined aquifer is separated from the semi-confined aquifer by discontinuous clay layers.

The waters of the Kern River alluvial fan can be separated into water type based on geographic location (Dale, 1966). In addition, the waters have a distinctive chemistry based on the aquifer within these geographic divisions. Swartz (1995) describes that the eastside waters, which dominate the alluvial fan, have total dissolved solids (TDS) values that range from 100 mg/L to 300 mg/L and the upper aquifer is $Ca\text{-}HCO_3$ dominated water while the deeper aquifer is $Na\text{-}HCO_3$ dominated. The westside waters have higher TDS values and are $Na\text{-}Ca\text{-}SO_4$ dominated waters. A final water type within the Kern River alluvial fan that was observed by Swartz (1995) is a combination of east and west side water with possibly some mixing from surface infiltration.

Kern Water Bank Authority provided water quality data from wells within the KWB (appendix 11.3). Of the 56 wells sampled, six wells had arsenic levels that would exceed the newly established DWS of 10 ppb that takes affect January 1, 2006, and Well 23H had the highest arsenic concentration. In general, the water chemistry, as observed by Swartz (1995) varies across the KWB. Trends that were observed as part of this research will be discussed in more detail.



approximate limits of Kern River Fan

Figure 2-1: The approximate limits of the Kern River Fan are outlined with the dashed line (from Page, 1986).

3 Hydrogeochemistry of Arsenic

3.1 Arsenic

Arsenic is considered a hazardous substance based on its toxicity, high mobility, and wide distribution and occurrence (Keon, Grant Progress Report, 2000). In June 2000, the United States Environmental Protection Agency (USEPA) proposed to lower the National Primary Drinking Water Standard (DWS) for arsenic from 50 parts per billion (ppb) to 5 ppb (Federal Register, 2000). Following public comment, the final USEPA standard for arsenic was lowered to 10 ppb and goes into effect on January 1, 2006. Understanding the distribution of arsenate (arsenic V) versus arsenite (arsenic III) is important because arsenic III has a higher mobility, is more difficult to remove in water treatment plants, and is more toxic than arsenic V (Deutsch, 1997).

Arsenic can occur in the elemental form, As, but more often occurs as an inorganic or organic compound. The most common occurrence of arsenic in water is in the inorganic form of arsenic III or arsenic V (Federal Register, 2000). According to the Federal Register (2000), the occurrence of arsenic V over arsenic III in water is dependent on the pH and whether the system is oxidizing or reducing (Figure 3-1). Oxidizing conditions favor the presence of arsenic V, while more reducing conditions favor arsenic III (Figure3-1) (Deutsch, 1997). Arsenic V is anionic ($HAsO_4^{2-}$ and $H_2AsO_4^-$) throughout the pH range that is typical for groundwater (6.5 to 8.5) (Smedley and Kinniburgh, 2002), while arsenic III is neutral ($H_3AsO_3^0$) (Deutsch, 1997). This difference in the valence of arsenic V and arsenic III affects the mobility, treatment options, and toxicity.

According to the World Health Organization (Fact Sheet, 2002), long-term exposure to arsenic in drinking water causes cancer, typically of the skin, lungs, urinary bladder, and kidneys. The Federal Register of 1980 concluded that drinking water with arsenic increased the risk of developing cancer. Both arsenic III and arsenic V are toxic to humans and animals (Federal Register, 2000).

Arsenic mainly occurs naturally. It is introduced into groundwater through contact with minerals and rocks that contain arsenic (USGS, 2000). The average arsenic concentration in the Earth's crust ranges from 1.5 to 5 mg/kg (Federal Register, 2000). Arsenic has been found to occur naturally in more than 200 minerals (Smedley and Kinniburgh, 2002). Table 3-1 gives some of the most common arsenic containing minerals. Arsenic concentrations of up to 15 parts per million (ppm) have been reported for granitic rocks such as the source rocks for sediments in the KWB (Table 3-1). According to Smedley and Kinniburgh (2002), depositional environments with the highest concentrations of arsenic in groundwater were, in general, found in either arid/semi-arid, closed basins or reducing alluvial aquifers.

A secondary source of arsenic in groundwater is attributed to industrial use of products containing arsenic such as wood preservatives, pesticides, herbicides, and insecticides, to name a few. The use of arsenic for agricultural purposes was terminated by 1993 (Federal Register, 2000).

The United States Geological Survey (USGS Fact Sheet, 2000) discusses occurrence of arsenic in groundwater in the United States. As part of this investigation, the USGS detected arsenic in 18,850 potable water wells that serve a wide range of uses throughout the United States. The investigation concluded that arsenic concentrations were highest in the western United States. The USGS also investigated the frequency that small public water systems would exceed various maximum contaminant levels (50 ppb to 1 ppb) for arsenic. The investigation found that the likelihood of public water systems exceeding the maximum contaminant level increases with decreasing maximum contaminant levels. The study concluded that as the maximum contaminant levels for arsenic are lowered, small public water systems will either have to find new, arsenic-free sources for groundwater or treat their existing water (USGS, 2000).

3.2 Arsenic Treatment

It is easier to remediate arsenic V than arsenic III from water systems because arsenic V is present as an anionic species while arsenic III is a neutral species. Treating arsenic III is expensive and most treatment systems require an initial oxidation step in order to convert arsenic III to arsenic V (Washington State Department of Health, 2003). It is therefore important to determine the dominant species of arsenic that is present in groundwater. Arsenic removal techniques described by the USEPA include oxidation/filtration, ion exchange, activation alumina absorption, enhanced lime softening, reverse osmosis, and electrodialysis removal (Washington State Department of Health, 2003).

3.3 Speciation

As mentioned previously, it is important to understand the occurrence, source, and dominant species of arsenic in groundwater. The distribution of arsenic between arsenic V and arsenic III is important because arsenic III is more toxic, has a higher mobility, and is harder to treat than arsenic V. The oxidation state of arsenic can also provide clues to how arsenic is bound to sediments and what processes may have led to its release into the groundwater. Numerous investigations have been conducted on arsenic in groundwater. In many of these investigations, a determination was made as to the dominant species of arsenic present. Speciation of arsenic is complicated by the fact that arsenic III may quickly oxidize to arsenic V once in contact with the atmosphere and exposed to light. Different techniques were used to determine the speciation of the arsenic and were evaluated as part of this investigation. These techniques are summarized in this section.

Recent work by Wilkie and Hering (1998) and Clifford et al. (2004) suggests that arsenic speciation should be conducted in the field because arsenic speciation changes over time as water comes into contact with the atmosphere. Arsenic III is oxidized to arsenic V, thus, the amount of arsenic III can easily be underestimated. Clifford et al. (2004) explains that during transport of samples to the laboratory redox reactions a photochemical oxidation can cause changes in the arsenic speciation. Research conducted by McCleskey et al. (2004) found that the oxidation of arsenic III, in the presence of iron III, increased with increasing iron III/arsenic III ratios (at low pH or samples exposed to light). The addition of sulfate and iron II decreased the oxidation rate of arsenic III (both in the absence and presence of light).

Wilkie and Hering (1998) used anion-exchange columns to separate arsenic V from arsenic III in the field. Collected water samples were acidified in the field reducing the pH of the water to 3.5. At this pH, arsenic III is neutral and should pass through the column, while the resin retains anionic arsenic V (Figure 3-1). The acidified samples were poured through the anion-exchange columns. Total arsenic was measured from the influent to the anion-exchange columns and arsenic III concentrations were measured at the effluent of the columns. Wilkie and Hering (1998) validated this process by analyzing various concentrations of arsenic III/V mixtures in the laboratory (Wilkie and Hering, 1998). This method has been used by numerous other researchers.

Ryu et al. (2002) collected groundwater samples from the Owens Dry Lake area in order to study the spatial variation of arsenic concentrations. As part of this study, Ryu et al. (2002) determined the arsenic speciation at 30 well sites. The groundwater samples were filtered in the field through a 0.2 μm membrane and collected in polypropylene bottles. According to Ryu et al. (2002), the samples were not stored more than four days prior to arsenic speciation. While in the laboratory, Ryu et al. (1998) modified an arsenic speciation technique proposed by Glaubig and Goldberg (1988). The water in Owens Valley is high in alkalinity and was therefore reduced to a pH of 6 prior to determining the arsenic speciation (Ryu et al., 2002).

McCleskey et al. (2004) conducted an in-depth review and evaluation of procedures for preserving arsenic redox state. Their evaluation concluded that preserving the redox species of arsenic was dependent on proper sample handling. They recommended that water samples should be filtered to remove any microorganisms or colloids and they should be preserved using hydrochloric acid (HCl), sulfuric acid (H_2SO_4), or ethylenediametetraacetate (EDTA) in order to stabilize any iron present in the water. The biotic material, according to McClesky et al. (2004), could cause the reduction of arsenic V to arsenic III. Acidifying the water sample prevents oxidation of iron II and precipitation of iron hydroxides that can in turn absorb arsenic.

The AWWA Research Foundation, a nonprofit corporation, supports water supply focused research (Clifford et al, 2004). Recently, the AWWA in association with the USEPA and the Association of California Water Agencies jointly sponsored developing a field speciation method for inorganic arsenic (Clifford et al, 2004). Clifford et al. (2004) evaluated several arsenic field speciation techniques. The intent of this research project was to evaluate existing speciation methodologies and create a comprehensive and simple field speciation method that could separate the arsenic III from arsenic V, in the field without difficult sample handling such as flash-freezing, and allow for later laboratory analysis. Clifford et al. (2004) found that the 'acetate-form resin minicolumn' method used by Wilkie and Hering (1998) had reasonable results for pH values of around 3.0, acidified by HCl or H_2SO_4. However, it should be noted that Clifford et al. (2004) observed that the presence of iron II interfered with the speciation process. They described that the iron II would oxidize to iron III, which in the presence of water, formed ferric oxyhydroxides. According to Clifford et al (2004), these ferric oxyhydroxides with their large surface areas could absorb arsenic and prevent separation of the arsenic by the resin in the minicolumns. The presence of iron II in groundwater would thus lead to an underestimate of arsenic III.

Similar to the conclusions that were made in the McClesky et al. (2004) investigation, Clifford et al. (2004) also recognized that in order to successfully preserve the redox state of the arsenic in the presence of iron, it was necessary to use an iron chelating agent, such as EDTA, that would keep iron II in solution and prevent formation of ferric oxyhydroxides. Similar to other arsenic speciation techniques, Clifford et al. (2004) used an acid (specifically acetic acid) to lower the pH of the water sample. The Clifford et al. (2004) field speciation kit is described in more detail in this study.

3.4 Arsenic Mobilization

Previous studies of other aquifers and analysis of sediments from KWB indicate that all sediments contain several parts per million of arsenic (Swartz, 1995, Smedley and Kinniburgh, 2002, and Negrini et al, 2005). Fortunately, under most conditions, the arsenic remains bound to the sediments and does not dissolve into the groundwater. Understanding how arsenic is mobilized is important in selecting new well locations in order to potentially avoid areas where arsenic concentrations are high or could potentially increase over time.

One of the key factors controlling the release of arsenic is the redox state of the aquifer sediments and groundwater (Smedley and Kinniburgh, 2002). The mixing of oxygenated water with more reduced water over geologic time could alter the redox state of the groundwater (O'Day et al., 2004). The oxidation of arsenic-bearing sulfide minerals, such as pyrite, could cause the release of arsenic into the groundwater. Arsenic concentrations are often high in areas with mixed redox conditions (Arthur et al., 2002).

Other mechanisms for the release of arsenic that have been proposed are reductive dissolution of iron oxyhydroxides (Swartz, 2004) and oxidation of sulfides such as pyrite (Savage et al., 2000). Nickson et al. (2000) evaluated groundwater in Bangladesh and West Bengal and concluded that the mechanism for arsenic release into the groundwater was due to reductive dissolution of iron oxyhydroxides. The oxyhydroxides were present in the sediments as coating on the outside of the sediment particles. This reduction caused arsenic sorbed onto the oxyhydroxides to be released into the groundwater (Nickson et al, 2000). Nickson et al. (2000) also concluded that, in the investigated areas, the introduction of oxygenated water causing pyrite to oxidize and release arsenic was minor in comparison with the amount of arsenic released by the reduction of oxyhydroxides. Ahmed et al. (2004) also concluded that reductive dissolution of iron oxyhydroxides is the main mechanism for arsenic release in Bangladesh. Iron oxyhydroxides coat sand grains and biotite in the permeable aquifer (Ahmed et al., 2004). Guha (2001) also concluded that arsenic is released in Bangladesh groundwaters by the reductive dissolution of iron oxyhydroxides. Guha (2001) sites evidence for this mechanism as the observation that there is a correlation between iron and arsenic concentrations as well as arsenic and bicarbonate. The reduction of iron oxyhydroxides releases iron and any arsenic that may be coating the outside of sediments into the groundwater (Guha, 2001). The relationship between bicarbonate concentrations and arsenic concentrations is sited as evidence for the presence of a reducing environment, since, according to Guha (2001), bicarbonate is a by-product of the reduction of iron oxyhydroxides.

Wilkie and Hering (1998) found that in the stream waters of the Sierra Nevada, arsenic III oxidized to arsenic V downstream of a geothermal source very rapidly. This oxidation occurred within 1200 m of the geothermal inputs. Given the flow rate of the stream waters, this translates to an oxidation time of one hour (Wilkie and Hering, 1998). Wilkie and Hering (1998) conducted additional investigations of arsenic oxidation within the stream waters and found that a key component of the rapid oxidation below the geothermal source was the presence of bacteria.

Kirk et al. (2004) observed a disparity in arsenic concentrations in groundwater in central Illinois. The dominant arsenic species found in the groundwater was arsenic III. Kirk et al. (2004) observed that in samples with high arsenic concentrations, sulfate concentrations were low. Iron concentrations were also high in samples that had low sulfate concentrations. They concluded that groundwater with high arsenic and low sulfate lacked a sulfide sink. This lack of sulfide prevented a means for arsenic to precipitate under reducing conditions. Thus, arsenic levels in solution were higher in the absence of sulfate (Kirk et al., 2004). O'Day et al. (2004) made similar observations in groundwaters with changing redox conditions. They found that aquifers with low sulfate concentrations could potentially accumulate high levels of dissolved arsenic.

Wolthers et al. (2000) examined the relationship between pyrite formation and arsenic concentrations. They concluded that the absorption of arsenic III onto FeS prevents the formation of pyrite (FeS_2). However, arsenic could be absorbed onto already formed pyrite. Savage et al. (2000) studied arsenic speciation in pyrite near a mine and found that arsenic was replacing the sulfur in the pyrite (FeAsS instead of FeS_2). Savage et al. (2000) also evaluated secondary weathering of the pyrite-bearing sediments and found that pyrite with arsenic weathered more easily than without arsenic. Once the arsenic is removed, the absorption of the arsenic to other minerals is dependent, as mentioned previously, on pH and the redox conditions. Savage et al. (2000) summarized that arsenic is mobilized through a series of steps; 1) oxidation of arsenian pyrite, 2) weathering causing the formation of secondary minerals that incorporate arsenic through absorption (goethite) or substitution (jarosite), 3) these sediments are transported possibly to lake settings and 4) the release of arsenic is dependent on the pH and redox conditions that may change seasonally or over geologic time.

Table 3-1 a) Common Arsenic Minerals (from Smedley and Kinniburgh, 2002)

Mineral Name
Elemental arsenic
Niccolite
Realgar
Orpiment
Cobaltite
Arsenopyrite
Tennantite
Enargite
Arsenolite
Claudetite
Scorodite
Annabergite
Hoernesite
Conichalcite
Pharmacosiderite

b) Arsenic concentrations in rock-forming minerals (from Smedley and Kinniburgh, 2002)

Mineral Name	As Concentration (mg/kg)
Pyrite	100 to 77,000
Iron (III) oxyhydroxides	Up to 76,000
Iron oxide	Upt to 2,000
Hematite	Up to 160
Quartz	0.4 to 1.3
Feldspar	<0.1 to 2.1
Biotite	1.4
Amphibole	1.1 to 2.3
Pyroxene	0.05 to 0.8
Calcite	1 to 8
Gypsum	<1 to 6
Fluorite	<2

c) Arsenic concentrations by rock type (from Smedley and Kinniburgh, 2002)

Rock Type	Ranges of As Concentration (mg/kg)
Igneous rocks	
Gabbro	0.06 to 28
Basalt	0.18 to 113
Diorite, Granodiortie	0.09 to 13.4
Granite	0.2 to 15
Ryolite	3.2 to 5.4
Metamorphic rocks	
Quartzite	2.2 to 7.6
Phyllite	0.7 to 11
Schist. Gneiss	0.5 to 143
Amphibolite	0.4 to 45
Sedimentary rocks	
Marine shale, Mudstone	3 to 490
Non-marine shale	3 to 12
Sandstone	0.6 to 120
Limestone, Dolomite	0.1 to 20
Fe-rich sediments	1 to 2900
Evaporites	0.1 to 10
Lake sediments	0.5 to 44

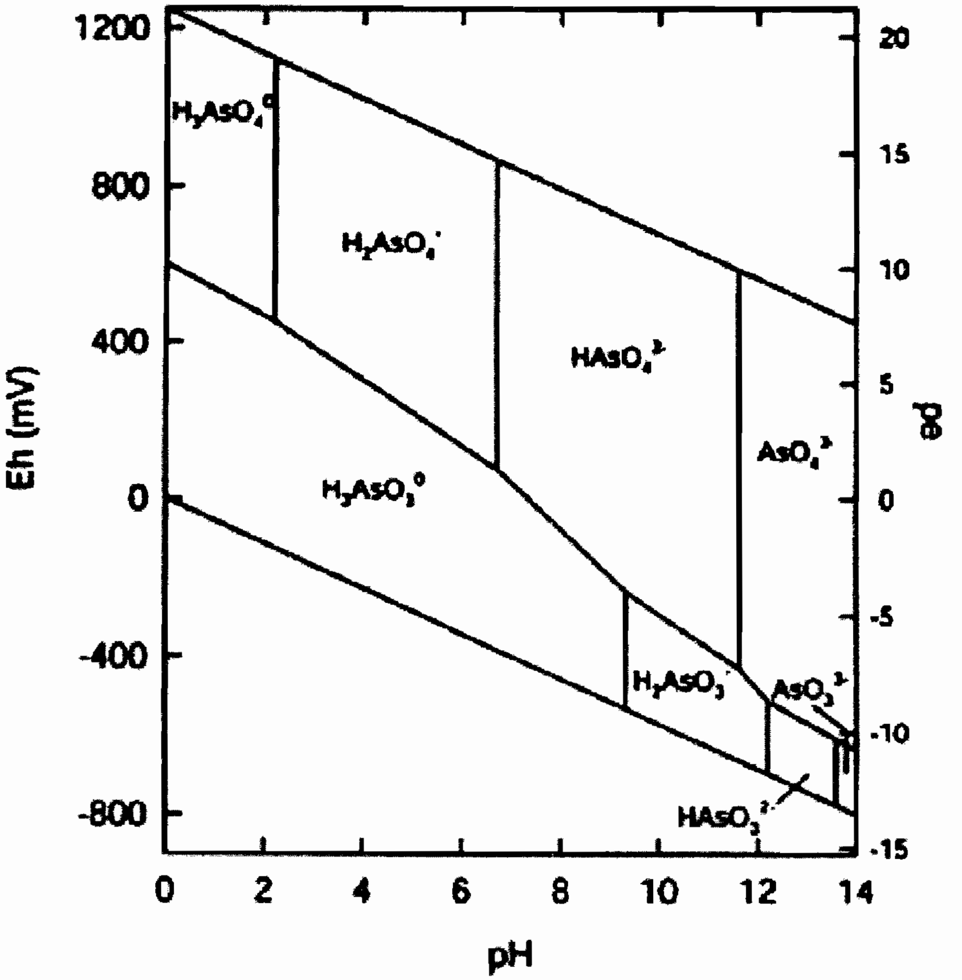


Figure 3-1: Eh-pH diagram of arsenic speciation. Arsenic V is anionic under pH conditions for natural waters, while arsenic III is neutral. (Modified from Deutsch, 1997).

4 Previous Work

4.1 Previous Work on Arsenic in the KWB and San Joaquin Valley

Swartz (1995) conducted an extensive investigation of the occurrence of arsenic on the Kern Fan Element within the KWB. Swartz (1995) assembled water quality data from monitoring wells and water production wells throughout the KWB. As mentioned previously, Swartz (1995) was able to group the quality of the water in the KWB into four distinct water types. The highest arsenic concentrations within the KWB were, in general, associated within the water type that Swartz (1995) labeled Na-HCO_3 type water. Swartz (1995) also evaluated concentrations of arsenic III versus arsenic V in three KWB wells and found that 95% to 98% of the arsenic was arsenic V. One of the conclusions of this study was that the increase in arsenic concentrations from the source waters (Sierra Nevada) was a function of dissolution along the long flow path from the Sierra Nevada to the KWB.

As part of the larger CSUB KWB Project, sequential extraction of arsenic from sediments retrieved from Well 23H and 24K were conducted (Table 4-1) (Negrini et al., 2005). According to Keon et. al (2001) the mobility of arsenic is dependent on the interaction of arsenic and the other solid phases within the sediment. Sequential extraction is a method that is used to differentiate sediment fractions that bind arsenic (Keon et. al, 2001, Tessier et. al, 1979, and Dhoum and Evans, 1998). These fractions include loosely and strongly absorbed arsenic, arsenic as a co-precipitate with metal oxides, arsenic as a co-precipitate with crystalline iron, arsenic with oxides, arsenic as a co-precipitate with pyrite, and arsenic with pyrite. In order to accurately predict the mobility of arsenic, it is necessary to quantify the arsenic that is bound to the sediments and evaluate which of the listed solid phases dominate (Keon et. al, 2001).

Sequential extraction methods have been developed by Tessier et al. (1979), and Huerta-Diaz and Morse (1990), and Keon, et al. (2001). These methods involve the sequential partitioning of arsenic through various reagents and analyzing the fraction of arsenic at each of the steps. Preliminary results from Negrini et al. (2005) (Figures 1-4 and 4-1, and Table 4-1) suggests that while overall arsenic concentrations in sediments in the two wells are similar, the arsenic bound to the minerals in the sediments collected from Well 23H has a higher mobility than the arsenic bound to minerals in Well 24K. Higher loosely bound arsenic concentrations are also related to higher total organic carbon and a lower magnetic susceptibility, as well as the tendency to occur with finer-grained sediments. High organic carbon and low magnetic susceptibility are indicators of reducing conditions (Figure 4-2), because oxidation of organic carbon uses up any available oxygen; magnetic iron oxides are often unstable under reducing conditions. Negrini et al. (2005) observed a correlation between elevated arsenic concentrations in groundwater to organic-rich, finer-grained sediments, possibly deltaic in origin. The results from the Negrini et al. (2005) sequential extraction study will be discussed more detail in Section 4.4. Similar observations have been made as to the correlation between finer-grained sediments and higher arsenic concentrations relative to their coarser counterparts (Goh and Lim, 2005).

4.2 Kern Water Bank Authority Water Analyses

The Kern Water Bank Authority and the Kern County Water Agency provided water quality data for 56 wells within the KWB. The water quality data provided was collected during the years 1994 thru 2004. Water quality information is collected by the Kern Water Bank Authority as part of their well monitoring program. The results from the water quality analyses are kept in a database at both the Kern Water Bank Authority and the Kern County Water Agency. The major cations and anions were evaluated as part of this study.

4.3 West Kern Water District Water Analyses

The West Kern Water District (WKWD) which operates in the area provided water quality results from a well that was drilled approximately one mile west of KWB Well 23H (Figure 1-1). WKWD drilled and sampled the well in 2003. The well report and water quality results were provided by Gary Hamilton of the WKWD for comparison of the water quality data measured during zone testing of the completed well. High arsenic levels were detected in this well and it was, therefore, never put into operation by the WKWD (personal communication with Gary Hamilton, WKWD, 2005). The well completion report for WKWD well 6-04 is included in appendix 11.4.

4.4 KWB Sediment Analyses

As mentioned previously, a sequential extraction study was conducted by Negrini et al. (2005) as part of the larger KWB project. Sediment samples collected from Well 23H and nearby KWB Well 24K were analyzed as part of the sequential extraction investigation.

Preliminary results from the sequential extractions suggests that the arsenic bound to the minerals in the sediments collected from Well 23H have a higher mobility than the arsenic bound to minerals in Well 24K (Table 4-1 and Figure 4-1). Easily exchangeable arsenic concentrations were higher in Well 23H than 24K. Conversely, arsenic in the residual fraction of the sediments was higher in Well 24K than 23H (Figure 4-1) (Negrini et al., 2005).

4.5 West Kern Water District Sediment Evaluation

A geologic log of drill cuttings for WKWD well 6-04 was provided by the WKWD (appendix 11.4). Well 6-04, according to the geologic log, is comprised of interbedded sands and clays. The geologic log begins at 80 ft bgs and is comprised of brown fine to medium sands with some coarse brown sands with brown clay. At 430 ft bgs the sands and clay change to a light brown color and the clay content, according to the log, increases. At 610 feet, there is another color change from light brown to blue-brown sand and clay.

4.6 Stratigraphic Interpretation

The sedimentary units of the KWB were delineated through the examination of numerous electric logs from water wells throughout the KWB (Negrini et al., 2005). Figure 4-3 is a type log from KWB well T30R25S35B1 (35B1). Coarsening-upward sediment sequences are distinguishable in well 35B1 and other wells throughout the KWB (Negrini et al., 2005). As shown in Figure 4-4, the LsCus2 has been defined by Negrini et al. (2005) as the "Large-Scale Coarsening upward sequence 2". This coarsening upward sequence has been correlated across the KWB and has been interpreted to represent a prograding delta projecting towards the Buena Vista terminal basin (Negrini et al., 2005). The location of the prograding delta corresponds to the only area within the KWB with arsenic concentrations greater than 5 ppb (Figure 4-5) (Negrini et al., 2005). Understanding the depositional environment is critical to understanding the source and mobility of arsenic because deltaic sediments are typically reduced as a result of deposition under the surface of a lake and high amounts of organic matter. As mentioned above, one of the key factors controlling the release of arsenic is the redox state of the aquifer sediments and groundwater (Smedley and Kinniburgh, 2002). Well 23H is within the deltaic lobe. It is possible that high arsenic in groundwater from this well is associated with these reduced sediments.

Table 4-1a. Concentration of arsenic in different fractions of sediment samples from well 23H (from Negrini et al., 2005)

Depth below Ground Surface (ft)	Arsenic in Exchangeable Fraction (ppm)	Arsenic in Carbonate Fraction (ppm)	Arsenic in Fe-Mn Oxide Fraction (ppm)	Arsenic in Organic Matter Fraction (ppm)	Arsenic in Residual Fraction (ppm)
90	1.83	0.08	1.74	0.12	0.62
110	0.36	0.05	1.13	0.04	0.09
110 Duplicate	0.33	0.08	1.37	0.06	Not measured
130	0.67	0.05	1.71	0.08	0.49
150	1.41	0.04	2.66	0.14	0.50
170	0.40	0.03	0.67	0.02	0.03
190	0.31	0.06	0.66	0.03	0.13
210	0.35	0.09	0.85	0.04	0.16
230	2.89	0.37	1.60	0.14	0.47
250	3.21	0.23	0.96	0.09	0.88
270	0.81	0.18	1.30	0.08	0.45
290	0.72	0.09	0.89	0.03	0.12
290 Duplicate	0.65	0.08	0.69	0.03	Not measured
310	2.99	0.14	1.08	0.10	0.75
330	2.66	0.23	0.96	0.11	0.77
350	2.21	0.29	1.33	0.07	0.70
370	3.36	0.36	1.70	0.11	0.22
390	3.87	0.25	1.29	0.08	0.54
390 Duplicate	3.52	0.28	1.56	0.29	Not measured
410	0.95	0.20	0.36	0.05	0.22
430	3.23	0.47	1.90	0.21	0.67
450	6.12	0.82	2.59	0.39	0.88
470	7.55	0.46	3.10	0.10	0.51
490	7.03	0.65	3.51	0.47	0.44
510	0.91	0.37	0.98	0.04	0.46
530	1.03	0.65	1.24	0.00	0.89
550	6.15	0.53	6.68	0.46	1.34
570	4.01	0.43	2.33	0.11	0.48
590	3.44	0.70	1.69	0.14	0.67
610	1.26	0.32	1.09	0.05	0.64
630	0.70	0.15	1.39	0.21	0.21
630 Duplicate	0.61	0.13	1.18	0.17	Not measured
650	0.65	0.33	1.81	0.05	0.09
670	0.37	0.05	0.90	0.14	0.00
690	0.51	0.29	1.53	0.09	0.40
710	0.75	0.26	1.26	0.04	0.27
720	0.44	0.10	0.43	0.05	Not measured
720 Duplicate	0.48	0.18	0.59	0.05	Not measured
740	3.67	0.32	1.61	0.26	1.19
740 Duplicate	3.41	0.35	1.87	0.18	Not measured
760	0.78	0.52	1.27	0.05	0.33
770	0.58	0.32	0.81	0.09	Not measured
780	6.09	0.65	5.46	1.58	0.87
800	1.35	0.32	1.59	0.10	0.50
820	1.47	0.22	1.22	0.09	0.25
840	1.98	0.21	1.82	0.06	0.68
860	3.09	0.44	1.88	0.02	0.88
880	0.45	0.20	0.70	0.02	0.03
900	1.12	0.25	0.92	0.04	0.32

Table 4-1b. Concentration of arsenic in different fractions of sediment samples from well 24K (from Negrini et al., 2005)

Depth below Ground Surface (ft)	Arsenic in Exchangeable Fraction (ppm)	Arsenic in Carbonate Fraction (ppm)	Arsenic in Fe-Mn Oxide Fraction (ppm)	Arsenic in Organic Matter Fraction (ppm)	Arsenic in Residual Fraction (ppm)
10	0.51	0.08	0.62	0.05	1.10
14	1.01	0.16	0.74	0.10	1.02
18	0.91	0.18	0.66	0.09	1.01
22	0.61	0.07	0.76	0.08	1.18
28	0.55	0.06	0.93	0.09	0.98
32	1.30	0.04	0.59	0.06	2.53
34	0.95	0.09	1.17	0.13	1.60
38	1.71	0.08	1.60	0.16	2.30
50	0.30	0.04	0.45	0.02	0.11
70	0.61	0.05	0.42	0.02	0.16
90	0.87	0.08	0.92	0.10	0.39
110	0.81	0.04	0.80	0.08	0.58
130	1.17	0.04	0.80	0.07	1.21
150	1.25	0.04	0.81	0.08	1.20
170	1.02	0.03	0.59	0.08	0.86
190	0.50	0.04	0.58	0.03	0.80
210	0.43	0.02	0.58	0.02	0.54
230	0.37	0.04	0.46	0.03	0.05
230 Duplicate	0.39	0.03	0.37	0.02	Not measured
250	1.73	0.54	1.49	0.07	3.25
270	2.22	0.36	1.40	0.05	2.15
270 Duplicate	2.41	0.43	1.14	0.06	Not measured
290	0.35	0.05	0.26	0.01	0.14
310	1.96	0.15	0.39	0.05	1.78
330	1.21	0.14	0.52	0.05	3.19
350	1.57	0.11	0.33	0.04	0.81
370	2.06	0.28	0.75	0.07	4.15
390	2.07	0.36	1.24	0.05	3.04
410	0.21	0.07	0.36	0.01	0.11
430	1.03	0.15	0.56	0.04	1.37
450	1.23	0.12	0.19	0.05	0.86
470	1.54	0.15	0.39	0.03	1.41
490	1.85	0.17	0.47	0.04	1.31
520	1.19	0.68	0.61	0.05	1.04
540	Not measured	0.41	0.69	0.05	Not measured
560	1.78	0.69	0.69	0.05	2.35
580	2.08	0.34	1.34	0.07	1.83
600	2.24	0.38	0.96	0.07	3.95
620	2.90	0.3	1.17	0.07	3.81
640	2.15	0.68	3.83	0.11	5.62
660	1.10	1.3	6.96	0.10	1.50
680	0.17	0.56	0.73	0.04	1.52
700	0.21	0.19	0.64	0.03	0.31
730	1.17	0.22	0.84	0.06	1.50
750	0.28	0.1	0.44	0.05	0.30
770	0.11	0.14	0.54	0.08	0.57
790	0.56	0.49	0.71	0.08	1.46
810	0.66	0.16	0.63	0.06	1.55
830	0.02	0.27	1.27	0.55	0.12
850	2.09	0.19	8.21	0.21	6.78
870	1.03	0.77	1.77	0.21	1.95
880	1.59	0.24	0.60	0.26	2.57
910	1.00	0.29	0.67	0.08	1.88
930	0.37	0.26	1.00	0.10	0.31
950	0.25	0.13	0.55	0.12	0.21

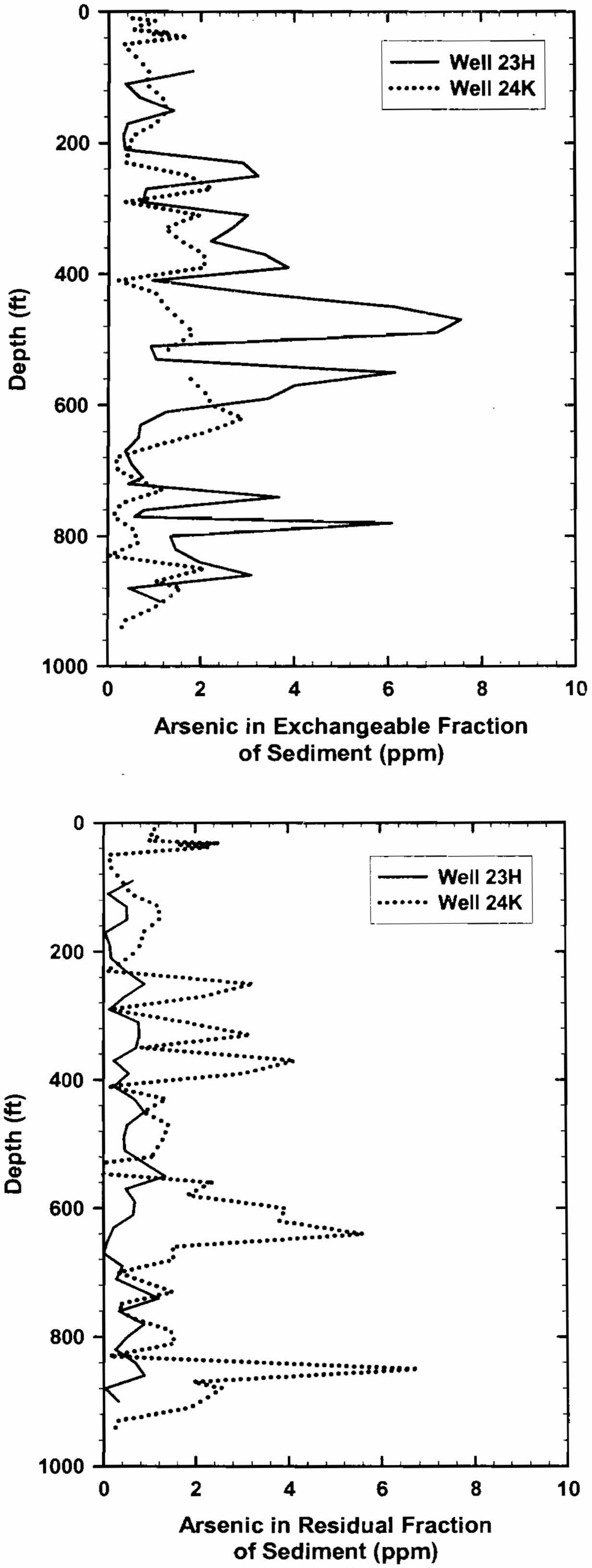


Figure 4-1 : Sequential extractions A) arsenic in the exchangeable fraction of sediments from wells 23H and 24K and B) arsenic in the residual fraction of sediments from wells 23H and 24K, this fraction includes primary silicate minerals and sulfide minerals (from Negrini et al, 2005).

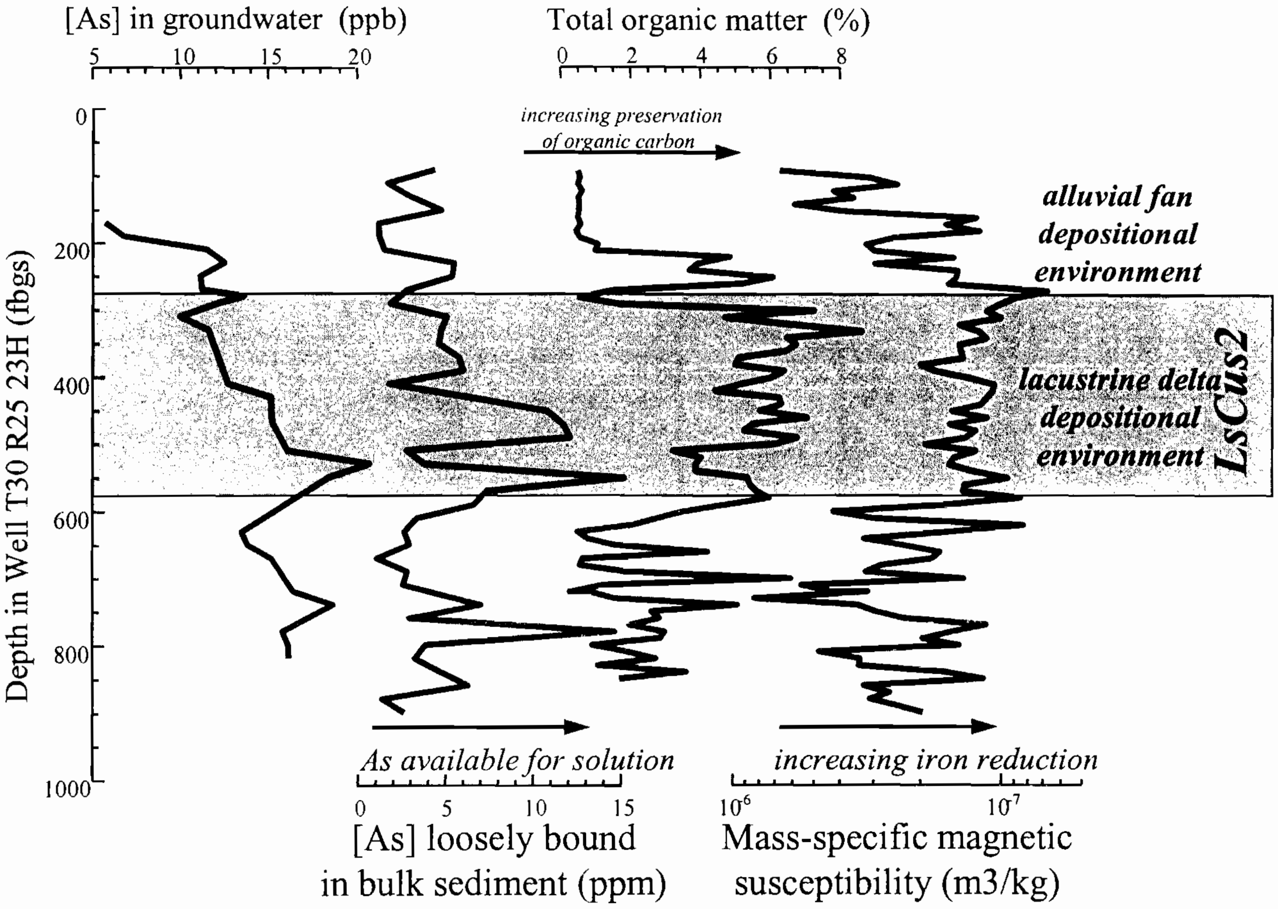


Figure 4-2: Well 23H, depth range of LsCus2 prograding delta unit is represented by shaded region, a) arsenic in gw, b) concentration of easily exchangeable arsenic in sediments, c) percentage of total organic carbon (TOC) in sediments, and d) mass-specific magnetic susceptibility (MS) from sediments. High TOC and low MS are indicators of reducing conditions (Negrini et al., 2005)

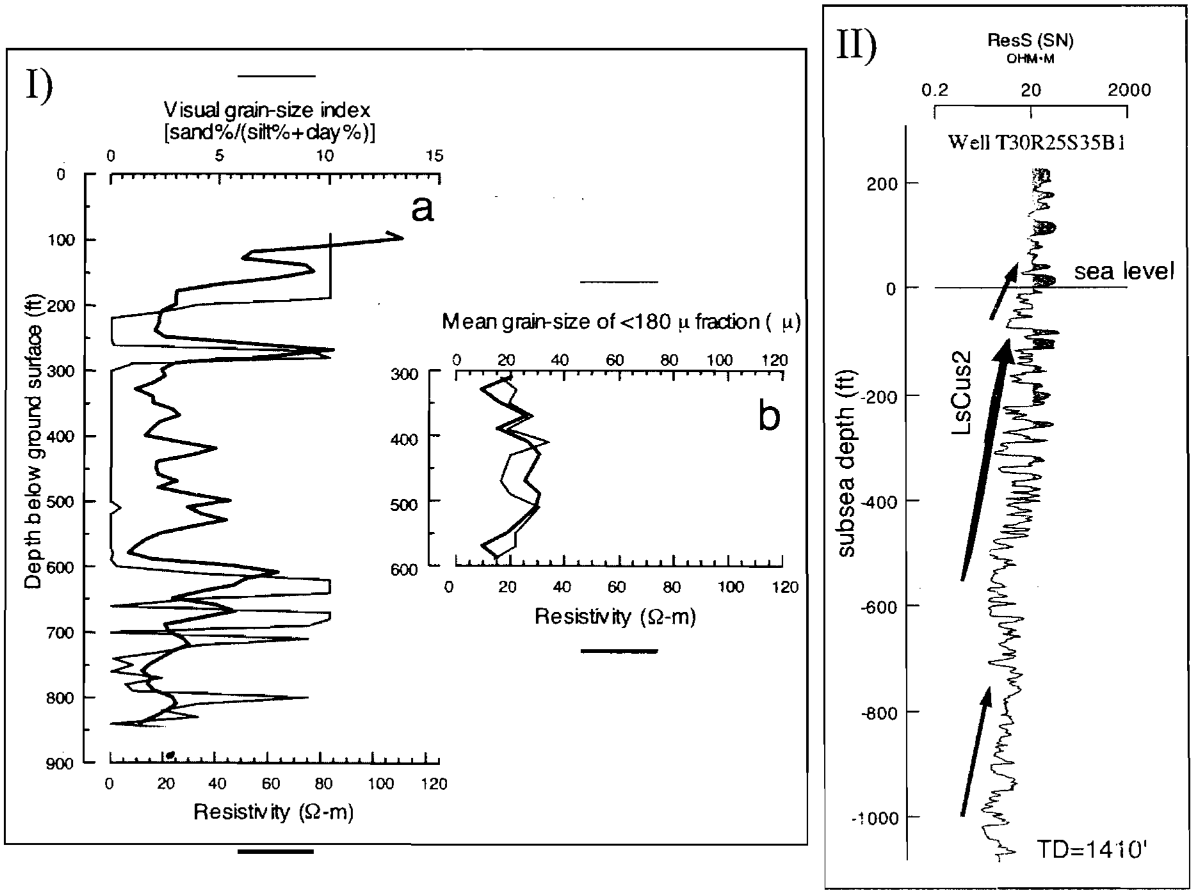


Figure 4-3: I) An electric log of resistivity is overlain by a visual grain size index. As shown in figure a), higher resistivity corresponds to coarser grain size. The inset on the right, b) is resistivity overlain by the mean grain size of the fine sediment fraction between the depth interval of 300 ft to 600 ft. II) Resistivity log from Kern Water Bank Well 35B1. The arrows indicate coarsening upward sequences. LsCus2, "Large-scale Coarsening upward sequence 2. This sequence has been correlated across the KWB and has been interpreted to represent a prograding delta (from Negrini et al., 2005)

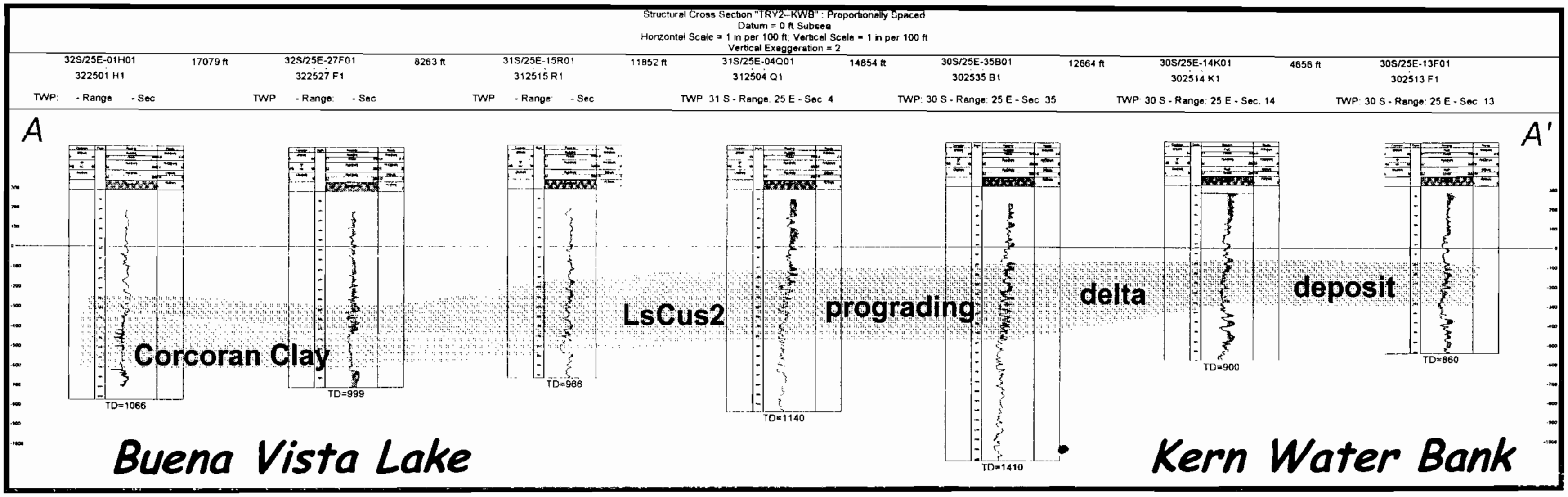


Figure 4-4: Cross-section of electric logs from several KWB wells showing the stratigraphic relationship between the LsCus2 deltaic deposit (darker gray) and “Corcoran Clay” (lighter gray). The “Corcoran Clay” is a unit that was deposited in a Central-valley wide lake hundreds of thousands of years ago (From Negrini et al, 2005).

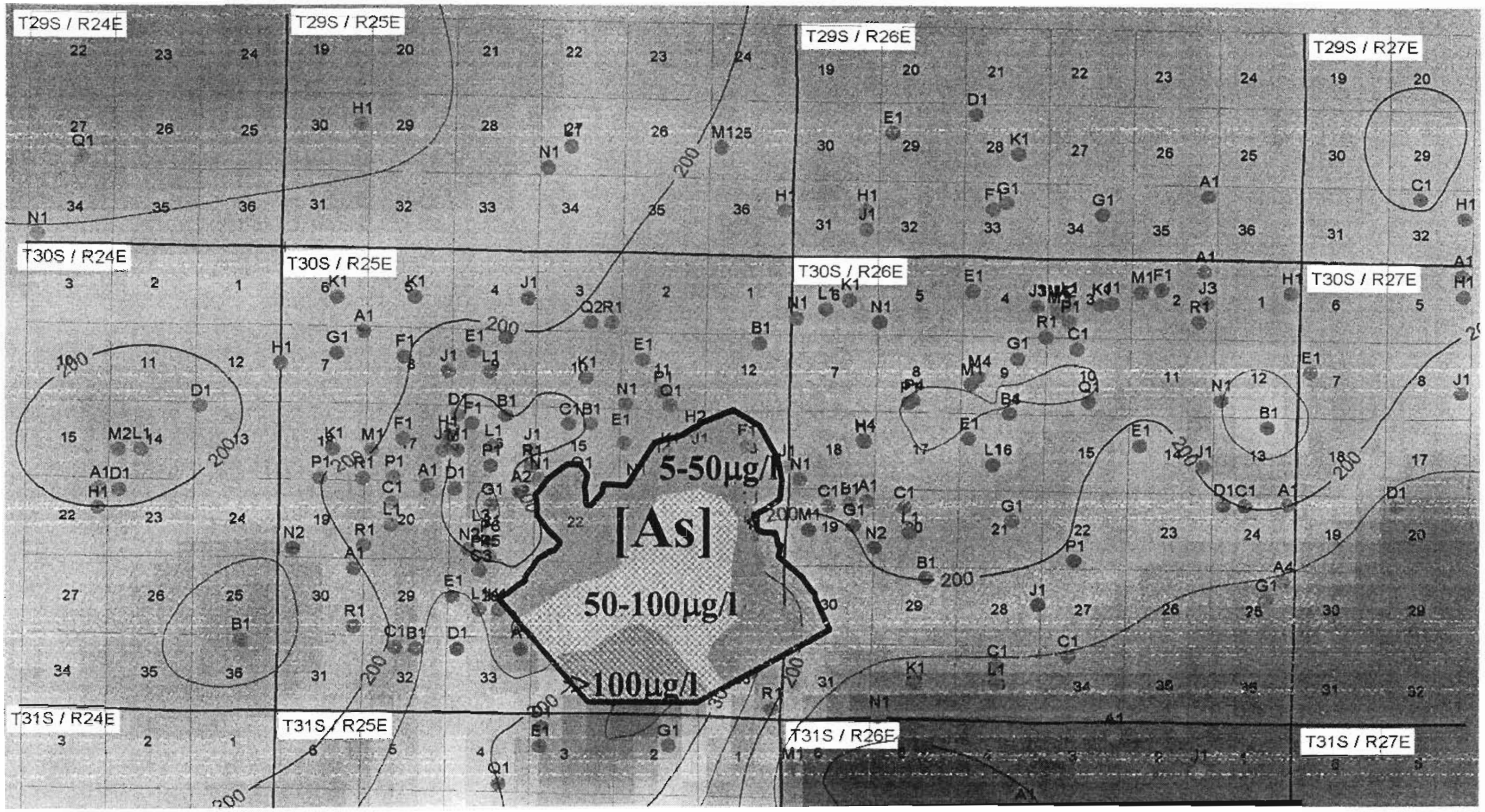


Figure 4-5: Contour plot showing thickness (isopach) of LsCus2 prograding delta deposit across the KWB. Township and range lines are subdivided by section. Each section is 1 square mile in distance. The heavy outlined region is the only area within the KWB with arsenic concentrations in the groundwater that are greater than 5 ppb (from Negrini et al, 2005).

5 Methodology

As part of this study, groundwater samples were collected from Well 23H under non-pumping and pumping conditions in August 2004 and February 2005, respectively. Depth-specific water samples collected under non-pumping conditions were analyzed for pH, conductivity, major cations and anions, total arsenic concentration, and the distribution of arsenic between arsenic III and arsenic V. Samples were also collected after pumping Well 23H for eight hours. The samples collected during pumping were analyzed for pH, conductivity, dissolved oxygen, redox potential, major cations and ions, total arsenic concentration, and the distribution of arsenic III and arsenic V. Flow measurements within the wellbore were evaluated under non-pumping conditions using Welenco's FloVision logging tool.

The separation of arsenic III and arsenic V should be performed in the field immediately after sample collection in order to avoid having the sample come into contact with the atmosphere or light, which could lead to oxidation of arsenic III to arsenic V (Clifford et al., 2005). Untreated samples that are shipped to a lab will show lower arsenic III concentrations than were actually present in the groundwater.

Two speciation methods described by Wilkie and Hering (1998) and Clifford et al. (2004) were used in the field in order to determine the dominant species of arsenic present in the groundwater. The speciation method adapted from Wilkie and Hering (1998) was used in both the August 2004 and February 2005 sampling events. The method after Clifford et al.

(2004) was published after the August 2004 sampling and was therefore only used during the February 2005 sampling event. Depth-specific water samples were collected during the August 2004, non-pumping sampling event in order to examine any vertical variation in arsenic concentration and determine the arsenic species. Samples collected during the February 2005 pumping sampling event were collected in order to evaluate the two different speciation methods and determine the arsenic species present in the groundwater.

5.1 Well Completion/Design (KWB Well 23H)

Well construction information for Well 23H is illustrated in Figure 1-2. The casing and borehole diameters of the well are 18 inches and 28 inches, respectively. The well is designed with four discrete perforated intervals (mill slot, 78 row, 0.080 inch slots) that begin at 140 feet below ground surface (ft bgs) and are 210 feet, 165 feet, 85 feet, and 190 feet in length from top to bottom. Although the well is designed with discrete perforated intervals, the annular space between the casing and the borehole from a depth of 140 ft bgs to total depth of the well, 900 ft bgs, is filled with gravel pack. The well is currently equipped with a Gould deep well turbine pump on column pipe that is 12 inches in diameter. The intake for the pump is at a depth of 385 feet below grade. Without disturbing the current well configuration, access to the well, below the pump, is restricted to a 2 inch schedule 40 steel sounding tube that runs along side of the casing and is open to the interior of the well at a depth of 395 ft bgs. This depth is below the first perforated zone (160 ft bgs to 370 ft bgs).

5.2 Collection of Depth-Specific Water Samples Under Non-Pumping Conditions

Well 23H is an active KWB pumping well. The pump intake and column pipe were removed prior to collecting any of the depth-specific water samples. The column pipe is made of steel and measures 12 inches in diameter. The KWB utilized the services of a local pump company, Farm Pump and Irrigation (FPI), with a rig capable of lifting 50 ton to remove the equipment from the wellbore. The well was equipped with a deep-set turbine pump. The pump motor is located at the surface and the bowls and intake are set at the desired pumping level within the wellbore. This type of motor requires lubrication with mineral oil as part of its general operation especially in agricultural and water system applications. This mineral oil leaves a film at the air-water interface within the wellbore. In order to avoid getting mineral oil on the sampling tools, logging tools, or sampling bags, PVC casing, measuring 4 inches in diameter, was temporarily installed within the wellbore. An end cap was attached to the bottom of the PVC and wire cable was fixed to the end cap for later retrieval. FPI assisted in setting bottom of the PVC 40 feet below the water level. As the PVC was lowered into the wellbore, the PVC was coated with liquid dish soap. This dish soap acts as a surfactant, dissipating the mineral oil, and preventing the oil from being carried below the water level. Once the PVC was landed at the surface, Welenco ran a weighted knock-out bar to dislodge the end cap from the bottom of the PVC. The end cap was hoisted up the wellbore and landed just below the top of the casing in order to keep it from interfering with any of the tools or sampling bags.

After the pump and column pipe were removed from Well 23H, the well sat idle for more than one week. A local geophysical logging company, Welenco, was contracted to collect water samples from KWB Well 23H using a depth-sampler attached to a wire line.

In August 2004, Welenco ran their wire line sampler into the well and sampled water from pre-determined sampling depths. KWB Well 23H, due to the unusually high arsenic concentrations, was the subject of a previous investigation, discussed above, involving the sequential extraction of arsenic from sediment grab samples collected during the drilling of 23H (Negrini et al., 2005). The selected depths for this investigation were based, in part, on the results from the sequential extraction study. The depths selected were also based on the construction of the well. Each depth corresponds to a portion of the wellbore that is opposite well screen as opposed to blank casing. The depths selected for Welenco's wire line sampler are summarized in Table 5-1.

The wire line sampler was lowered to the pre-determined water depth, the inlet was opened, water entered the sampler, the inlet was closed, and the sampler was returned to the surface. The sample was immediately poured from the wire line sampling tool into polypropylene sample containers. A portion of the sampled water from each depth was sent to a local commercial lab, Zalco Laboratories in Bakersfield, CA, for determination of concentrations of major cations and anions. The remaining water sample was used for determining the arsenic speciation (using the Wilkie and Hering, 1998 method), total arsenic, and pH and conductivity (in the field) of each sample.

Immediately following the wire line sampling, additional water samples were collected at various depths throughout the wellbore using HydraSleeve™ passive sampling bags (Table 5-1). These samples were intended as an inexpensive supplement to the wire-line samples. The HydraSleeve™ (Figure 5-1) is a double-bagged bailer that fills with water as the bag is raised up the water column. The bags are three feet in length, and thus sample a three-foot discrete zone within the water column. According to the manufacturer, several bags can be lowered on the same line, thus multiple, depth-discrete samples can be collected simultaneously. Unlike more typical passive sampling bags that rely on diffusion, HydraSleeve™ sampling bags can be used to measure most groundwater constituents, including arsenic (Eon Products). Ten HydraSleeve™ sampling bags were carefully attached to nylon rope with zip ties. The HydraSleeve™ sampling bags are three feet in length and as they are brought up the wellbore, the bags fill with water. Thus, the top of each bag was set three feet below the desired sampling depth. Both the top and bottom of the bag were attached to the nylon rope so that the bags would be lowered down and raised up the wellbore in a vertical position, avoiding catching on the temporary PVC. The bags were allowed to sit in the well for 24 hours prior to removal. This process was repeated for various depths until 25 samples were collected (Table 5-1).

One HydraSleeve™ sampling bag was removed from the wellbore at a time. Tubing was inserted into the sampling bag and the sample was poured into polypropylene sample containers for major ion analysis, field measurements of pH and conductivity, total arsenic analysis, as well as analysis for arsenic III and arsenic V. A total of 25 samples were collected with the HydraSleeve™ sampling bags in August 2004.

5.3 Collection of Water Samples from Pumping Well

In February 2005, water samples were collected from KWB 23H after eight hours of pumping and were preserved and speciated according to the methodologies described by Wilkie and Hering (1998) and Clifford et al. (2004) in February 2005 (detailed descriptions in appendix 11.1). Well 23H was pumped at a rate of approximately 2000 gallons per minute (gpm) and all flow lines and tubes were flushed prior to sampling. All water samples were collected from a side sampling port directly into polypropylene containers for major ion analysis, total arsenic analysis, and analysis for arsenic III and arsenic V. The samples collected represent the overall water quality of Well 23H.

5.4 Major Ion Analysis

The ten samples collected from the well under non-pumping conditions with the wire-line depth-specific sampling tool were placed in sample contains provided by a commercial analytical laboratory, placed on ice, and delivered to Zalco Laboratories in Bakersfield, CA for determination of major cations and anions. During the pumping sampling event, Kern Water Bank Authority personnel re-sampled Well 23H and the samples were sent to an analytical laboratory in Los Angeles, CA in order to measure the major cations and anions.

5.5 Field Measurements

All depth-specific samples collected during the non-pumping sampling event were analyzed in the field for pH and conductivity. During the pumping sampling event, a Horiba U-22 probe with a flow-through cell was used to measure pH, dissolved oxygen (DO), total dissolved solids (TDS), temperature, turbidity, and redox potential (ORP). Use of the flow-through cell prevents the pumped water from coming into contact with the atmosphere and any changes in water chemistry that are associated with this.

5.6 Total Arsenic Analysis

Samples for total arsenic analysis were filtered using a 0.1 μm cellulose nitrate filter in order to filter out possible fine particles and organic matter and then acidified using trace grade nitric acid to prevent precipitation of arsenic with ferric oxyhydroxides and then stored refrigerated. All samples were analyzed for total arsenic, plus iron, manganese, uranium, and aluminum by Inductively Coupled Plasma Mass Spectrometry (ICP/MS) using CSUB's Perkin Elmer Elan 6100 ICP/MS on the day after the samples were collected.

In order to compare various sample handling techniques, total arsenic concentrations from the depth-specific samples were also determined from samples that were either filtered, as described above, or unfiltered. Total arsenic concentrations were also determined from samples that were acidified using nitric acid or untreated. This methodology was repeated at each depth-specific sample. These water samples were also analyzed for concentrations of aluminum, arsenic, iron, manganese, and uranium.

During the February 2005 pumping sampling event, two of the collected water samples were filtered in the field using 0.1 μm cellulose nitrate membrane filter and a 25 mm filter holder with a 60 ml syringe (Wilkie, 2003).

5.7 Field Speciation of Arsenic III and Arsenic V

A speciation method adapted from Wilkie and Hering (1998) was used in both the August 2004 and February 2005 sampling events to separate arsenic III from arsenic V. This method is based on the fact that in natural waters, arsenic III is present as a neutral species while arsenic V is charged. The water sample is run through an ion-exchange column that will remove the charged arsenic V. The influent sample and the effluent sample both contain arsenic. The influent sample includes both arsenic III and arsenic V, while the effluent sample contains only arsenic III. Arsenic V is then calculated as the difference between total arsenic (influent sample) and arsenic III (effluent sample). The Wilkie and Hering (1998) arsenic speciation method and adaptations that were employed are described in detail in appendix 11.1.

In addition to the arsenic speciation method adapted from Wilkie and Hering (1998), a new method recently developed by Clifford et al. (2004) was used to determine the relative concentrations of arsenic III and arsenic V in the water from the pumped well. This method was published after the depth-specific samples were collected and could therefore not be used for these samples. The new method was developed in response to concerns that the presence of dissolved iron can lead to precipitation of ferric oxyhydroxides that remove arsenic from solution and are trapped in the ion –exchange column. This can lead to an underestimate of arsenic III (McClesky et al., 2004 and Clifford et al., 2004). Similar to the Wilkie and Hering (1998) speciation method, the Clifford et al. (2004), arsenic V is removed by running the sample through an ion-exchange column, but includes an additional pre-treatment step with EDTA. The EDTA will complex the dissolved iron and prevent it from precipitating as ferric oxyhydroxides. Prior to conducting fieldwork, ion-exchange resin and sample bottles were prepared according to the specifications described by Clifford et al. (2004). These specifications are included in appendix 11.1.

Five duplicate samples were collected from the pumped well in order to determine the distribution of arsenic III to arsenic V using the Clifford et al. (2004) speciation method. A blank sample with deionized water was used for quality control purposes. For comparison, an additional five samples were collected from the pumped well to determine the distribution of arsenic III to arsenic V using the Wilkie and Hering (1998) speciation method. Two of these samples were filtered as part of the pre-treatment process. The water samples were filtered using a 0.1 μm cellulose nitrate membrane filter and a 25 mm filter hold that was attached to a 60 cc luer-lock disposable syringe.

5.8 Downhole Flow Measurements

The direction of groundwater flow within KWB Well 23H was determined using Welenco's FloVision Flowmeter tool. FloVision is a video flowmeter used to determine vertical flow within the wellbore (Welenco web site). The flowmeter is sensitive to slight variations in groundwater flow rate and direction. The flowmeter was lowered into the wellbore and the operator carefully watched the flowmeter tool through the camera and recorded any noted deflection. As the tool was lowered, the operator sped up or slowed down the descent of the tool based on response of the flowmeter. For example, if the groundwater flow was downward, the tool deflected downward and the operator adjusted the speed of decent of the flowmeter tool until it matched the downward groundwater velocity and no deflection was visible. Once the decent rate of the tool was equivalent to the groundwater flow rate, the operator recorded the decent rate of the camera as the vertical groundwater flow rate.

5.9 KWB Water Quality

Seventy water sampling events (1994 thru 2004) were evaluated from 56 wells within the KWB. To assist in evaluating the variation in water quality, Stiff and Piper diagrams were created. Stiff and Piper diagrams are good visual tools for determining the water type and similarity or dissimilarity between water samples. Each water type produces a distinctively shaped Stiff diagram. The shape of the Stiff diagram lends insight into the water quality. Piper diagrams are trilinear plots that display multiple water quality parameters and relative concentrations of TDS. Cross-plots are also useful in evaluating the variability of arsenic in groundwater. Arsenic concentrations from KWB wells were plotted versus the concentrations of major cations and anions from water samples collected between 1994 thru 2004.

5.10 West Kern Water Quality

Water quality data from the five water samples collected from WKWD well 6-04 (appendix 11.4) were provided by the WKWD and evaluated as part of this study. The WKWD collected four water samples during zone testing and one water sample was collected after 24 hours of pumping the completed well. The water samples collected during the zone testing were collected from 720 ft bgs to 740 ft bgs (Zone 1), 620 ft bgs to 640 ft bgs (Zone 2), 515 ft bgs to 540 ft bgs (Zone 3), and from 360 ft bgs to 380 ft bgs (Zone 4) (appendix 11.4). WKWD had the zone test water samples analyzed for major cations and anions and arsenic by a commercial analytical laboratory. The sample collected after 24 hours of pumping was only analyzed for arsenic (by a commercial laboratory).

Table 5-1
August 2004 Non-Pumping Sampling Event
Depth-Specific Sample Depths and Sample Collection Method

Sample Depth	Method	Method
170	Hydrasleeve	▨
190	Hydrasleeve	Wire Line
210	Hydrasleeve	▨
230	Hydrasleeve	▨
250	Hydrasleeve	Wire Line
270	Hydrasleeve	▨
280	Hydrasleeve	Wire Line
290	Hydrasleeve	▨
310	Hydrasleeve	Wire Line
330	Hydrasleeve	▨
410	Hydrasleeve	Wire Line
430	Hydrasleeve	▨
450	Hydrasleeve	▨
470	Hydrasleeve	Wire Line
510	Hydrasleeve	▨
530	Hydrasleeve	▨
550	Hydrasleeve	Wire Line
630	Hydrasleeve	Wire Line
650	Hydrasleeve	▨
670	Hydrasleeve	▨
720	Hydrasleeve	▨
740	Hydrasleeve	Wire Line
780	Hydrasleeve	Wire Line
800	Hydrasleeve	▨
820	Hydrasleeve	▨

Samples were collected at various depths with HydraSleeve™ sampling bags and/or Welenco's Wire Line Sampler

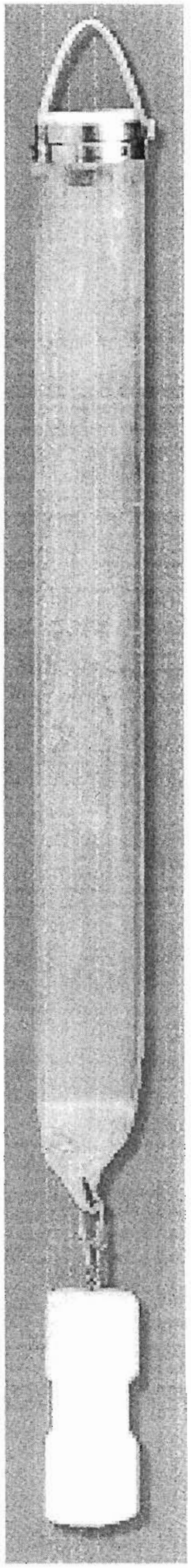


Figure 5-1: Hydrasleeve™ sampling bag from Eon Products

6 Results

6.1 Major Ion Analysis

The depth-specific water samples collected with the wire line tool were sent to Zalco for analysis of major ions. The initial analysis provided by Zalco had charge balance errors (Table 6-1) that were greater than 5%. Water is electrically neutral. That is, the sum of the cations should equal the sum of the anions (Kehew, 2001). The charge balance error is a measure of the quality of the laboratory analysis. There is often an error associated with measuring cations and anions and therefore, a zero charge error is very difficult to achieve. However, +/-5% charge balance error is the acceptable threshold according to Kehew (2001). Errors greater than 5% are typically attributed to laboratory measurement error, a transcription error, or the possibility that a cation or anion was not measured. The samples were re-run and the charge balance errors improved, however, the hold time for some of the parameters that were analyzed had been exceeded. These analyses should therefore be treated with caution.

Stiff diagrams were created for the ten water samples that were analyzed by Zalco in order to look for variations in water quality with depth (Figure 6-1). The original water quality results from Zalco were used to create the Stiff diagrams since the hold times were exceeded prior to the follow-up measurements. The depth-specific water samples collected in August 2004 exhibit very little variation in water quality with respect to the major cations and anions with depth (Figure 6-1). The Stiff diagrams are in descending order from 190 ft bgs to 780 ft bgs (Figure 6-1). Total arsenic concentration at each depth is included to the right of each Stiff diagram. There is little variation in the shape of the Stiff diagrams and therefore, the water quality with respect to major cations and anions are consistent throughout the wellbore. The shape of the Stiff diagram is indicative of the water type, which is a Na-HCO_3 type water.

The water sample that was collected by the Kern Water Bank Authority was sent to an analytical lab, which measured for major ions and total arsenic. The laboratory analytical results are summarized in Table 6-2. Similar to the depth-specific samples, the water produced from the pumping well is also Na-CO_3 type water (Figure 6-1).

6.2 Field Measurements

The pH of the depth-specific samples was difficult to measure in the field because the water warmed up rapidly when brought to the surface and also lost dissolved CO_2 gas. Measured pH values ranged from 5.66 to 8.7 (Table 6-3). Field measurements that were obtained with the Horiba U-22 with the flow through cell are considered more reliable as there is not contact with the atmosphere and the electrodes were constantly exposed to freshly produced water. The average pH of the water produced by the pumping well was 8.5. The average redox potential was 172 mV and the average dissolved oxygen was 4.6 ppm. The redox potential and dissolved oxygen suggest that redox conditions of the groundwater produced from Well 23H is intermediate, not strongly reducing, but also not completely oxidized. The results from the field measurements are summarized in Table 6-4.

6.3 Total Arsenic Analysis

Although no variation is observed in the general chemistry with depth, total arsenic concentration varies throughout the well under non-pumping conditions. Ten groundwater samples were collected using Welenco's wire line sampler, denoted with a 'W' in the sampling name (e.g. 190 W Total As) (Table 6-5). Twenty–five groundwater samples were collected with HydraSleeve™ sampling bags, denoted with an 'H' in the sampling name (170 H Total As). Total arsenic concentrations ranged from 6 ppb (170 ft bgs) to 19 ppb (530 ft bgs). Total arsenic concentrations were highest between 500 ft bgs to 600 ft bgs and from 700 ft bgs to 800 ft bgs (Figure 6-2). The analytical results from the wire line sampler and the HydraSleeve™ sampling bags are plotted on a graph of total arsenic concentration versus depth (Figures 6-2). Total arsenic concentrations varied less than 10% between the different sample treatments described above.

Total arsenic measured in samples collected during the February 2005 pumping sampling event was 35.71 ppb ± 2.5 ppb. This value is significantly higher than the highest arsenic levels observed when the well was not pumped. This suggests that, when pumped, the well receives water from zones that are not represented in the depth-specific samples collected under non-pumping conditions.

6.4 Field Speciation of Arsenic III and Arsenic V

Depth-specific samples collected during the non-pumping sampling event were speciated in the field in order to separate out arsenic V using the method adapted from Wilkie and Hering (1998). Arsenic III concentrations were all measured from the effluent water sample collected after passing through the anion-exchange column (Table 6-6). Arsenic III ranged in concentration from 0.16 ppb (800 ft bgs) to 1.14 ppb (270 ft bgs). As mentioned above, total arsenic concentrations ranged in concentration from 6 ppb to 19. Therefore, calculated arsenic V values ranged from 5.84 (170 ft bgs) to 17.86 (530 ft bgs). These results suggest that 87% to 99% of the arsenic in the depth-specific samples is arsenic V.

While sampling with the HydraSleeve™ sampling bags, the presence of iron was observed in many of the sampling bags. Iron was also observed collected on the magnetic stirrer used during the field titrations suggesting formation of iron III oxyhydroxides. A possible source for the iron is from the well casing and/or the pump discharge pipe. The discharge pipe, which was removed prior to sampling, had visible rust on the outside of the pipe. The high iron values detected in some of the water samples appear to be the result of the visible iron from the casing or the pipe rather than the aquifer, and is not representative of the overall water quality of the aquifer. Iron oxides may also be freshly precipitating as the water was exposed to oxygen and sunlight.

In February 2005, water samples collected from the pumping well were speciated using the recently published method from Clifford et al. (2004). This method includes an additional step designed to eliminate problems caused by water with high dissolved iron. The results are included with the depth-specific sample results in Table 6-5. For comparison, Table 6-6 is a summary table of the speciation results with arsenic concentrations only. Arsenic III concentrations from the Clifford et al. (2004) speciation method was 10.7 ppb ± 0.77 ppb. Total arsenic concentrations was 35.71 ppb ± 2.5 ppb. Therefore, the calculated arsenic V value is 25 ppb. These results suggest that 30% of the arsenic is present in the reduced form. The blank sample treated with the Clifford et al. (2004) speciation method had an arsenic III concentration of 0.91 ppb.

A sample from the pumping well was also speciated using the adapted Wilkie and Hering (1998) speciation method. The arsenic III concentration obtained with this method was less than 1 ppb, similar to the results from the depth-specific samples.

6.5 Flow Gradients

The direction of groundwater flow within Well 23H under static, non-pumping conditions was determined using Welenco's FloVision Flowmeter tool. Images were taken at various depths and the deflection of the flow measuring tool can been seen in Figure 6-3. Additional images from the flowmeter tool are included in appendix 11.5.

As mentioned previously, Well 23H is perforated from 160 ft bgs to 890 ft bgs with gravel pack from 130 ft bgs to 900 ft bgs (Figure 1-2). The static water level at the time of the August 2004 sampling event was at 133 ft bgs. Under static conditions groundwater flow is downward below 160 ft bgs, possibly due to water entering the borehole. The groundwater flow increases at 290 ft bgs and remains at this rate until 700 ft bgs. Groundwater appears to exit the borehole at depths greater than 700 ft bgs. Figure 6-4 is a graph of total arsenic concentration and velocity versus depth.

6.6 Overall KWB Water Chemistry and Correlations to Arsenic

Of the 56 wells evaluated, six wells had arsenic concentrations at or above the newly lowered DWS that goes into affect January 1, 2006 (10 ppb) (Table 6-7). Of these six wells, only one well (23H) had arsenic concentrations in excess of the previous DWS for arsenic (50 ppb). It should be noted that the Kern Water Bank Authority re-sampled Well 23H in February 2005 and the concentration of arsenic was 33 ppb.

Both Stiff and Piper diagrams were created to examine the variability in water quality across the KWB (Figures 6-5 thru 6-8). Measured arsenic concentrations for each well are included at the right of each Stiff diagram. After looking at the relationship of arsenic versus several cations and anions, graphs of arsenic versus iron and sulfate were included in the results for water samples collected between 1994 thru 2004 (Figure 6-9).

The results from water samples collected during the drilling and well construction of WKWD well 6-04 are included in this section due to its proximity to the KWB (Table 6-8). Concentrations of arsenic, major cations and anions are summarized in Table 6-8. The analytical report is included in the appendix 11.4 along with the well completion report and geologic log. Arsenic concentrations for Zones 1 thru 4 were 81 ppb, 92 ppb, 62 ppb, and 20 ppb, respectively. The arsenic concentration from the water sample collected after 24 hours of pumping was 12 ppb.

Concentrations of major cations and anions that were measured from the water samples collected from Well 23H during the February 2005 sampling event are also summarized in Table 6-8 along with the results from WKWD well 6-04 for comparison.

Table 6-1
August 2004 Non-Pumping Sampling Event
Major Cations and Anions

Sample ID	Units	Calcium	Iron	Potassium	Magnesium	Manganese	Sodium	Chloride	Carbonate	Bicarbonate	Sulfate	Charge Balance Error
23H 190'	mg/l	7.8	0.23	<1.0	0.09	ND	39	15	ND	90	12	1.18%
23H 250'	mg/l	5.3	1.4	<1.0	0.07	ND	37	12	ND	87	11	1.53%
23H 280'	mg/l	2.8	0.23	<1.0	ND	ND	34	9.2	ND	84	10	6.05%
23H 310'	mg/l	2.8	0.33	<1.0	ND	ND	35	9.3	ND	81	10	3.74%
23H 410'	mg/l	2.5	0.22	<1.0	ND	ND	31	9.1	ND	81	10	9.48%
23H 470'	mg/l	2.3	1.2	<1.0	ND	ND	32	9.1	ND	82	10	7.73%
23H 550'	mg/l	2.5	0.25	<1.0	ND	ND	33	9.1	ND	80	10	6.27%
23H 630'	mg/l	2.6	1.2	<1.0	ND	ND	33	9.1	ND	83	10	6.40%
23H 740'	mg/l	2.4	1.4	<1.0	ND	ND	32	9	ND	80	10	6.31%
23H 780'	mg/l	2.6	0.55	<1.0	ND	ND	34	9	28	43	10	12.60%

Amended report with silica removed 9/29/2004

Sample ID	Units	Calcium	Iron	Potassium	Magnesium	Manganese	Sodium	Chloride	Carbonate	Bicarbonate	Sulfate	Charge Balance Error
23H 280'	mg/l	2.1	<0.1	<0.5	<0.05	<0.03	34	8.4	ND	80	12	6.33%
23H 410'	mg/l	2.2	<0.1	<0.5	<0.05	<0.03	34	8.3	ND	81	11.8	6.44%
23H 470'	mg/l	2.2	0.35	<0.5	<0.05	<0.03	34	8.3	ND	79	11.8	5.13%
23H 550'	mg/l	1.8	<0.1	<0.5	<0.05	<0.03	33	8.6	ND	80	12.1	8.42%
23H 630'	mg/l	2.1	0.4	<0.5	<0.05	<0.03	33	8.4	ND	80	11.9	7.20%
23H 740'	mg/l	2	0.52	<0.5	<0.05	<0.03	34	8.4	ND	80	11.2	5.44%
23H 780'	mg/l	2	0.41	<0.5	<0.05	<0.03	34	8.4	ND	80	11.9	5.97%

Re-Analyzed and reported on 10/19/2004

ND - non-detect
All samples were collected using Welenco's depth specific sampler
Samples were analyzed by Zalco Laboratories, Inc., Bakersfield, CA

Table 6-2
February 2005 Pumping Sampling Event
Major Cations and Anions
(And Other Constituents)

CONSTITUENT	UNITS	VALUE	Detection Limit	DLR
Specific Conductance	UMHO	251	2.0	4.000
Lab pH	UNIT	9	0.00100	0.001
Carbon Dioxide,Free(25C)-Calc.	MGL	0.13	0.00100	0.001
Alkalinity in CaCO3 units	MGL	57	2.0	1.000
Bicarb.Alkalinity as HCO3,calc	MGL	67	0.00100	0.001
Carbonate as CO3, Calculated	MGL	4.3	0.00100	0.001
Total Hardness as CaCO3 by ICP	MGL	11	3.0	7.000
Calcium, Total, ICAP	MGL	4.3	1.0	1.000
Magnesium, Total, ICAP	MGL	ND	0.10	0.100
Sodium, Total, ICAP	MGL	48	1.0	1.000
Potassium, Total, ICAP	MGL	ND	1.0	1.000
Chloride	MGL	29	1.0	1.000
Sulfate	MGL	14	0.50	2.000
Fluoride	MGL	0.52	0.050	0.050
Arsenic, dissolved, ICAP/MS	UGL	33	1.0	1.000
Barium, dissolved, ICAP/MS	UGL	4	2.0	2.000
Beryllium, dissolved, ICAP/MS	UGL	ND	1.0	1.000
Cadmium, dissolved, ICAP/MS	UGL	ND	0.50	0.500
Chromium, dissolved, ICAP/MS	UGL	2.3	2.0	2.000
Copper, dissolved, ICAP/MS	UGL	ND	2.0	2.000
Iron, Dissolved, ICAP	MGL	ND	0.020	0.100
Lead, dissolved, ICAP/MS	UGL	1	0.50	0.500
Manganese, dissolved, ICAP/MS	UGL	ND	2.0	2.000
Thallium, dissolved, ICAP/MS	UGL	ND	1.0	1.000
Nickel, dissolved, ICAP/MS	UGL	ND	5.0	5.000
Silver, dissolved, ICAP/MS	UGL	ND	0.50	0.500
Zinc, dissolved, ICAP/MS	UGL	20	5.0	5.000
Antimony, dissolved, ICAP/MS	UGL	ND	1.0	1.000
Aluminum, dissolved, ICAP/MS	UGL	ND	25	25.000
Selenium, dissolved, ICAP/MS	UGL	ND	5.0	5.000
Total Dissolved Solid (TDS)	MGL	160	10	10.000
Mercury, dissolved	UGL	ND	0.20	0.200
Bromide	MGL	0.13	0.0050	0.005
Surfactants	MGL	ND	0.050	0.050
pH of CaCO3 saturation(60C)	UNIT	8.6	0.10	0.100
Langelier Index - 25 degree	NONE	0.01	0.0000000	-0.900
pH of CaCO3 saturation(25C)	UNIT	9	0.10	0.001

Results provided by commercial laboratory

Table 6-3
August 2004 Non-Pumping Sampling Event
Field Measurements

Sample Name	Depth (ft bgs)	Initial pH	Conductivity (mS/m)
23H 170' Hydrasleeve	170	8.52	205
23H 190' Hydrasleeve	190	8.48	219
23H 210' Hydrasleeve	210	6.4	180
23H 230' Hydrasleeve	230	6.73	180
23H 250' Hydrasleeve	250	6.7	180
23H 270' Hydrasleeve	270	6.45	198
23H 280' Hydrasleeve	280	6.71	190
23H 290' Hydrasleeve	290	6.52	219
23H 310' Hydrasleeve	310	6.61	219
23H 330' Hydrasleeve	330	6.39	220
23H 410' Hydrasleeve	410	7.33	180
23H 430' Hydrasleeve	430	6.58	178
23H 450' Hydrasleeve	450	6.53	175
23H 470' Hydrasleeve	470	6.87	170
23H 510' Hydrasleeve	510	8.68	200
23H 530' Hydrasleeve	530	6.83	178
23H 550' Hydrasleeve	550	8.77	180
23H 630' Hydrasleeve	630	6.46	198
23H 650' Hydrasleeve	650	5.66	196
23H 670' Hydrasleeve	670	8.63	192
23H 720' Hydrasleeve	720	8.53	180
23H 740' Hydrasleeve	740	8.64	178
23H 800' Hydrasleeve	800	8.49	180

Note: The pH measurements were challenging due to rapidly changing temperatures

Table 6-4
February 2005 Pumping Sampling Event
Field Water Quality Measurements

Time	pH	DO (ppm)	Conductivity (mS/m)	TDS	Temperature (°C)	Turbidity (ntu)	ORP (mV)
3:28 PM	8.20	5.2	26.0	0.17	22.5	46	178
3:33 PM	8.41	4.9	25.2	0.16	22.5	86	169
3:38 PM	8.37	4.8	25.0	0.16	22.5	120	178
3:43 PM	8.53	4.6	24.5	0.16	22.5	150	160
3:53 PM	9.15	4.2	23.7	0.15	22.0	140	138
4:03 PM	8.38	4.6	24.4	0.16	22.5	47	189
4:10 PM	8.47	4.4	23.0	0.15	22.5	58	178
4:16 PM	8.45	4.6	22.8	0.15	22.5	44	183
4:20 PM	8.45	4.4	22.5	0.15	22.5	42	179
Average ± stdev	8.49 ± 0.26	4.63 ± 0.30	24.12 ± 1.2	0.16 ± 0.01	22.44 ± 0.17	81.44 ± 44.14	172.44 ± 15.31

Measurements were taken using a Horiba U-22 with a flow-through cell

DO - Dissolved Oxygen

TDS - Total Dissolved Solids

ORP - Redox potential

stdev - standard deviaiton

Table 6-5
Summary of Groundwater Arsenic Analyses

Sample ID*	Sample Depth (ft)	Total As (ppb)	Stdev (Total As)	As (III) (ppb)**	Stdev(As 3)	Percent As (III)	As(V) (ppb)***	Percent As(V)
170 H	170	5.66	0.43	0.29		5	5.37	95
190 W	190	7.83	0.32	0.26		3	7.57	97
190 H	190	6.80	0.56	0.23		3	6.57	97
210 H	210	11.12	0.83	0.21		2	10.91	98
230 H	230	12.00	1.25	0.93		8	11.07	92
250 W	250	12.22	0.14	0.37		3	11.85	97
250 H	250	10.64	0.90	0.74		7	9.90	93
270 H	270	9.84	1.23	1.14		12	8.70	88
280 W	280	14.18	2.20	0.40		3	13.78	97
280 H	280	13.67	0.07	0.40		3	13.27	97
290 H	290	12.33	0.10	0.37		3	11.96	97
310 W	310	13.69	0.02	0.29		2	13.40	98
310 H	310	9.93	0.05	0.37		4	9.56	96
330 H	330	12.27	0.45	0.38		3	11.89	97
410 W	410	13.33	0.41	0.27		2	13.06	98
410 H	410	12.36	1.10	0.24		2	12.12	98
430 H	430	14.64	1.44	0.29		2	14.35	98
450 H	450	15.10	0.89	0.55		4	14.55	96
470 W	470	15.78	1.45	0.84		5	14.94	95
470 H	470	15.40	1.26	0.34		2	15.06	98
510 H	510	16.97	1.22	0.27		2	16.70	98
530 H	530	19.08	2.22	0.33		2	18.75	98
550 W	550	14.86	0.41	0.17		1	14.69	99
550 H	550	18.97	1.40	0.22		1	18.75	99
630 W	630	16.87	0.85	1.03		6	15.84	94
630 H	630	11.58	1.34	0.41		4	11.17	96
650 H	650	12.91	1.00	0.37		3	12.54	97
670 H	670	16.25	1.49	0.17		1	16.08	99
730 H	720	16.15	1.20	0.29		2	15.86	98
740 W	740	17.79	0.15	1.04		6	16.75	94
740 H	740	18.90	1.12	0.23		1	18.67	99
780 W	780	15.15	0.06	0.60		4	14.55	96
780 H	780	15.23	1.23	0.19		1	15.04	99
800 H	800	15.57	1.07	0.16		1	15.41	99
820 H	820	11.21	3.57	0.38		3	10.83	97
Pumping****	NA	35.71	2.50	10.70	0.77	30	25.01	70

* Samples designated H were collected with HydraSleeve sampler,
W with depth-specific sampler on a wire line

** Arsenic speciation using the method from Wilkie and Hering (1998)
except for pumping sample where method from Clifford (2004) was used

*** As(V) calculated by difference

**** Total As, pumping, average of 8 replicate samples; A(III), pumping, average of 5 replicate samples

Table 6-6
February 2005 Pumping Sampling Event
Arsenic Speciation Results

Sample ID*	Total As (ppb)**	As 3 (ppb)***	% As 3	As 5 (ppb)****	% As 5
As Speciation (W & H)	35.7 ±2.5	0.94 ± 0.32	2.6	34.8	97.4
As Speciation (Clifford)	35.7 ±2.5	10.7 ± 0.77	30.0	25.0	70.0

ppb - parts per billion
* W & H - Wilkie and Hering, 1998, speciation method;
Clifford - Clifford et al., 2004, speciation method
**Total As is the average of 8 measurements ± the standard deviation
***As 3 measurements are from 5 duplicate samples per speciaiton method ± standard deviation
****As 5 is calculated by subtracting As3 from Total As

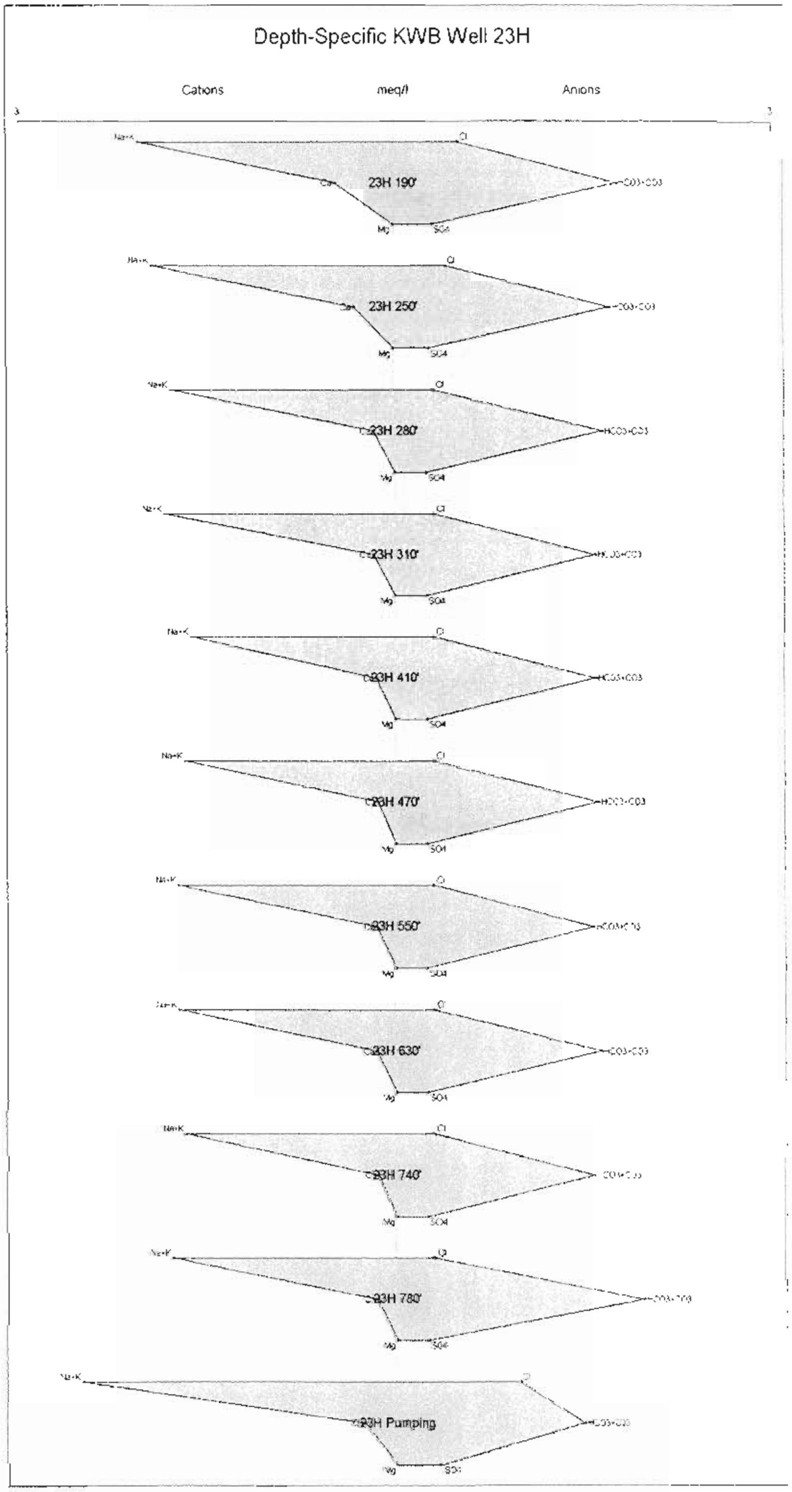
Table 6-7
Kern Water Bank Wells with Arsenic Concentrations Greater than 10 ppb

SamplingDate	WellNo	As (ppb)	Ca (ppm)	Cl (ppm)	CO3 (ppm)	Fe (ppb)	HCO3 (ppm)	K (ppm)	Mg (ppm)	Na (ppm)	SO4 (ppm)	NO3 (ppm)	Calc TDS (ppm)
04/24/03	30S/25E-14J01	10	11	24	3	0	64	0	0	41	25	nd	168
04/24/03	30S/25E-15N01	13	24	34	1	0	90	0	0	51	44	nd	244
06/22/94	30S/25E-05K01	17	8	12	38	0	22	0	0	38	24	2	142
04/28/03	30S/25E-16J01	22	15	39	6	0	73	0	0	43	20	nd	196
04/21/03	30S/25E-10K01	34	30	45	1	0	104	0	0	43	27	nd	250
9/5/2000	30S/25E-23H01	63	4	24	1	0	79	0	0	50	14	1	172

ppm - parts per million
ppb - parts per billion

Table 6-8
West Kern Water District
Well 6-04 Zone Testing and KWB Well 23H Pumping
Major Cations and Anions

		West Kern Water District Well 6-04					Well 23H Feb 10, 2005
Analyte	**units**	**(720' to 740')**	**(620' to 640')**	**(515' to 540')**	**(360' to 380')**	**Pumping 24 Hour**	**During Pumping**
As	mg/L	0.081	0.092	0.062	0.02	0.012	0.033
HCO3	mg/L	46.6	42.2	76.8	48.8		67
Ca	mg/L	30.2	2.2	4.8	1.7		4.3
CO3	mg/L	ND	15.9	ND	10.1		4.3
Cl	mg/L	490.8	45.1	16.2	6		29
F	mg/L	0.98	1.04	0.96	0.33		0.52
CaCO3	mg/L	81.3	5.5	16.1	5.5		11
OH	mg/L	ND	ND	ND	ND		
Fe	mg/L	ND	ND	ND	ND		ND
Mg	mg/L	1.4	ND	1	0.3		ND
Mn	mg/L	ND	ND	ND	ND		ND
NO3	mg/L	ND	ND	2.79	ND		
Na	mg/L	356	55.2	47.6	32.7		48
SO4	mg/L	162	15.2	31.1	12.2		14
Cr	mg/L	ND	ND	ND	ND		2.3
Conductivity	umhos/cm	1961	296	274	169		251
pH	pH units	7.64	9.41	7.46	9.33		9
TDS	mg/L	1078	142	186	104		160



Depth	Arsenic
190 ft bgs	7.34 ppb
250 ft bgs	11.44 ppb
280 ft bgs	11.93 ppb
310 ft bgs	11.81 ppb
410 ft bgs	12.93 ppb
470 ft bgs	15.54 ppb
550 ft bgs	16.03 ppb
630 ft bgs	15.29 ppb
740 ft bgs	18.13 ppb
780 ft bgs	14.73 ppb
Pumping	35.71 ppb

Figure 6-1: The Stiff diagrams are from water samples collected from KWB well 23H during the non-pumping and pumping sampling event. The non-pumping water samples were collected using Welenco's depth-specific sampling tool and are in descending order. The depths are feet below ground surface (ft bgs). The sample collected during pumping marked as 'Pumping' in the column on the right. The average total arsenic value for each sample is included to the left of each Stiff diagram.

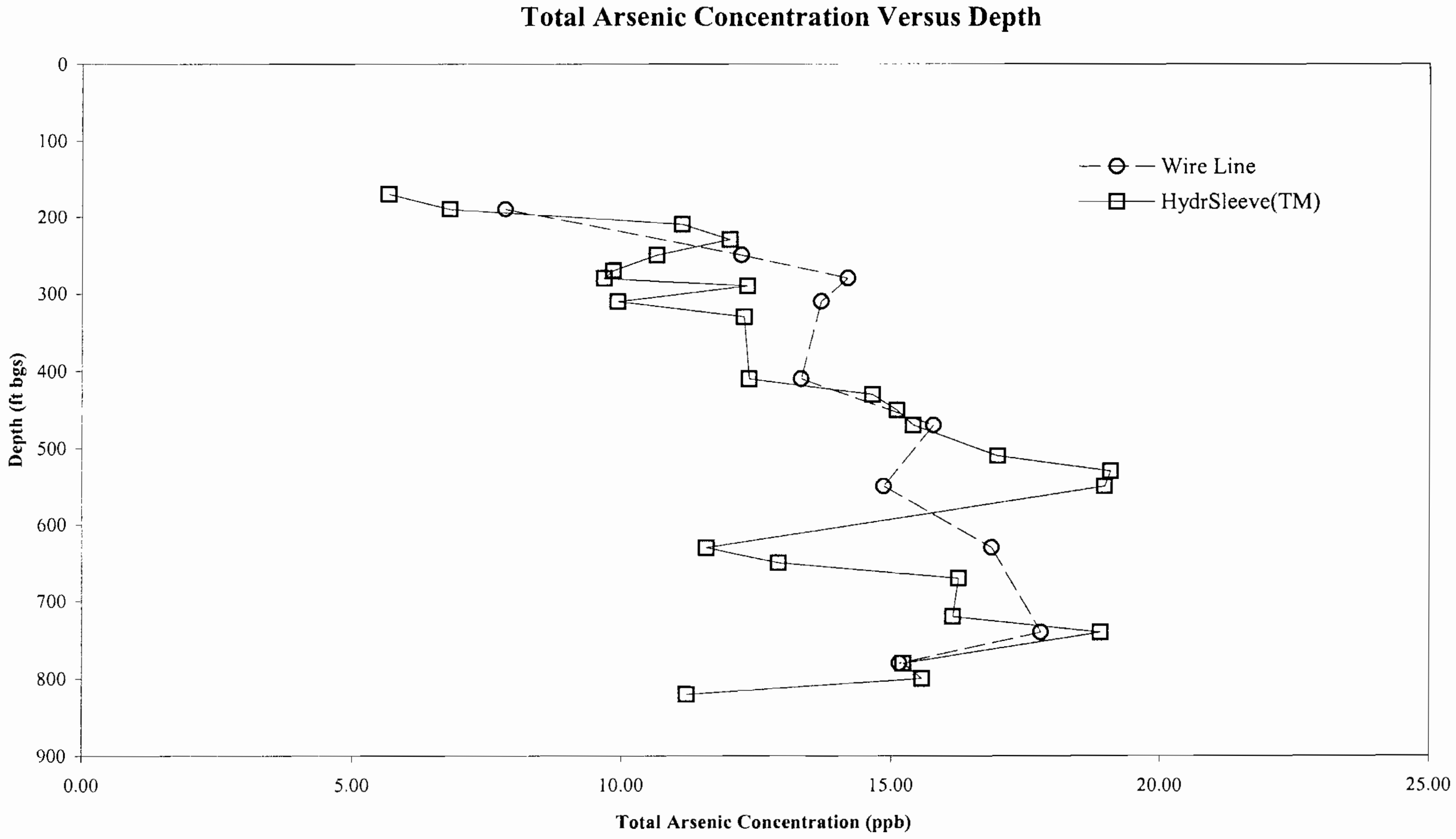


Figure 6-2: Total arsenic concentration (ppb) versus depth (ft bgs) for samples collected during the August 2004 Non-Pumping Sampling Event from the wire line sampler and HydraSleeve™ sampling bags.

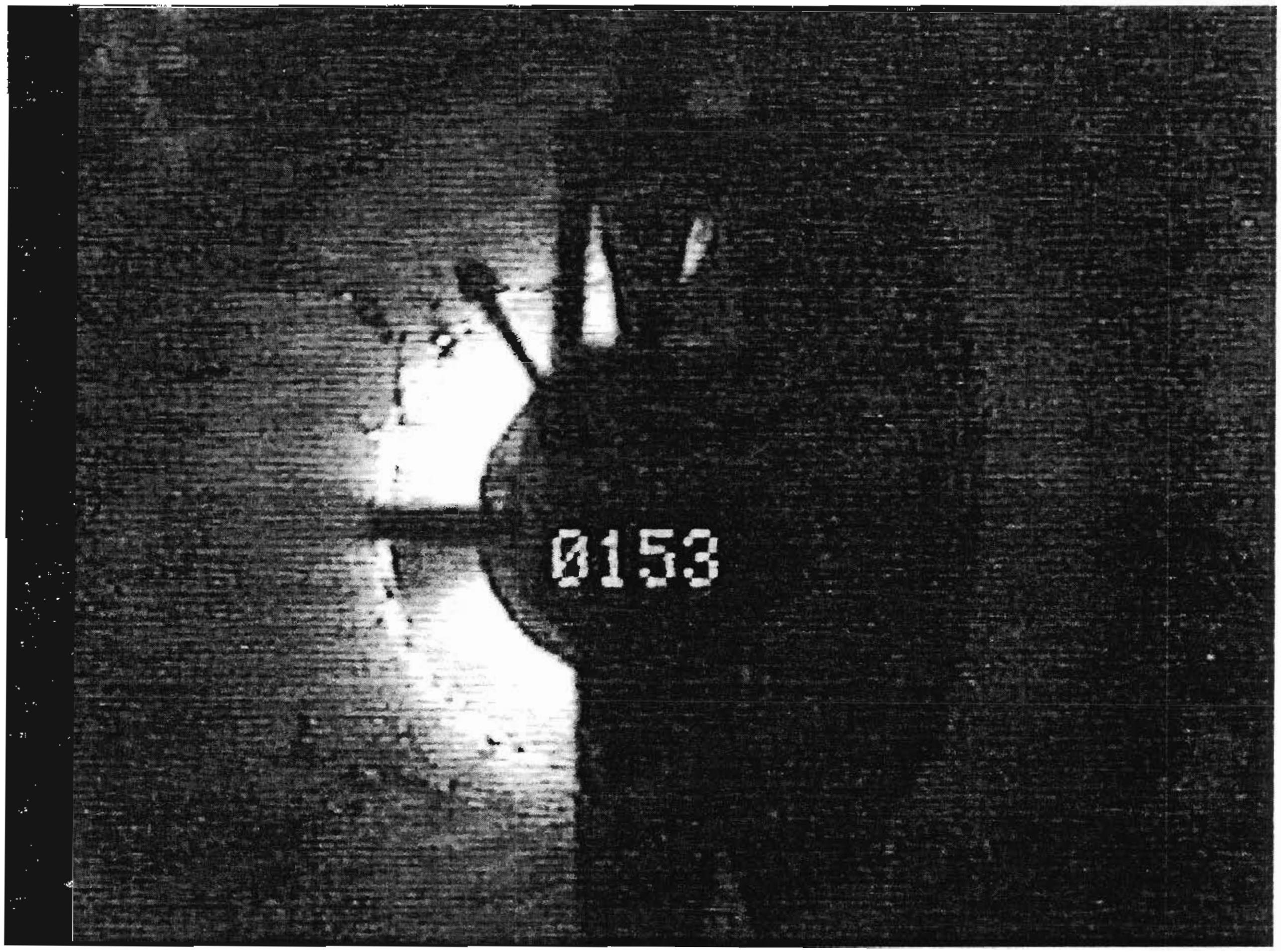


Figure 6-3: 153' - Upflow 1.8 inches / minute. In larger diameters wells the same water speed translates to more GPM flow. Casing over 17 inch in diameter allows to measure speeds that slow, with high level of repeatability. Flexible collar restricts water flow around the device, so almost two gallons of water is forced to flow through relatively small opening where the sensor is installed. No error is created by the fact, that water is forced into narrow passage because we will be following the water speed. So, when line speed is accurately matching water flow, camera with installed device become "invisible" to water flow, causing no restriction to free flow. Only errors, when FloVision speed differs from speed of water, will cause sensor deflections up or down.

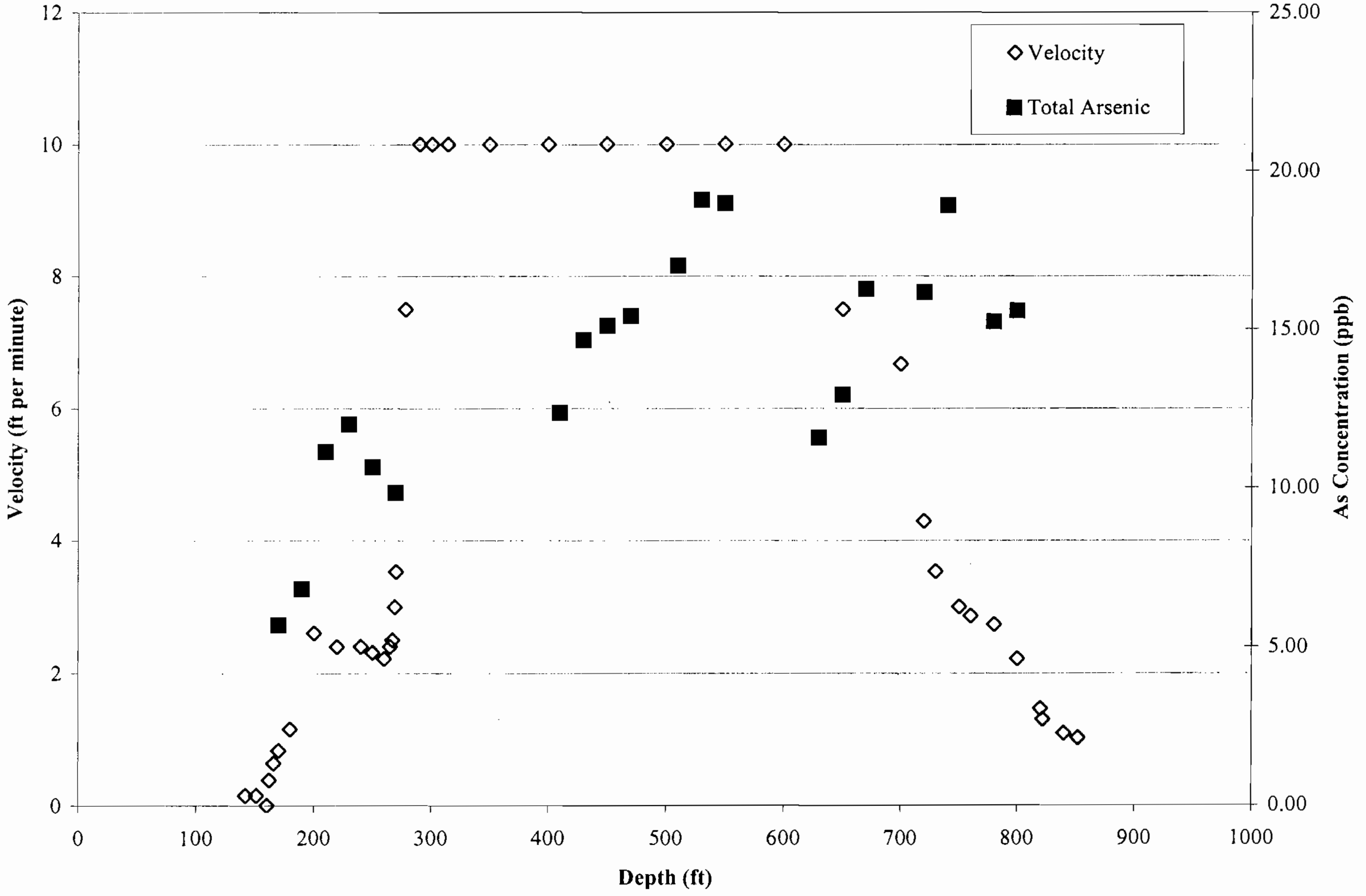


Figure 6-4: FloVision results with depth-specific total arsenic concentrations

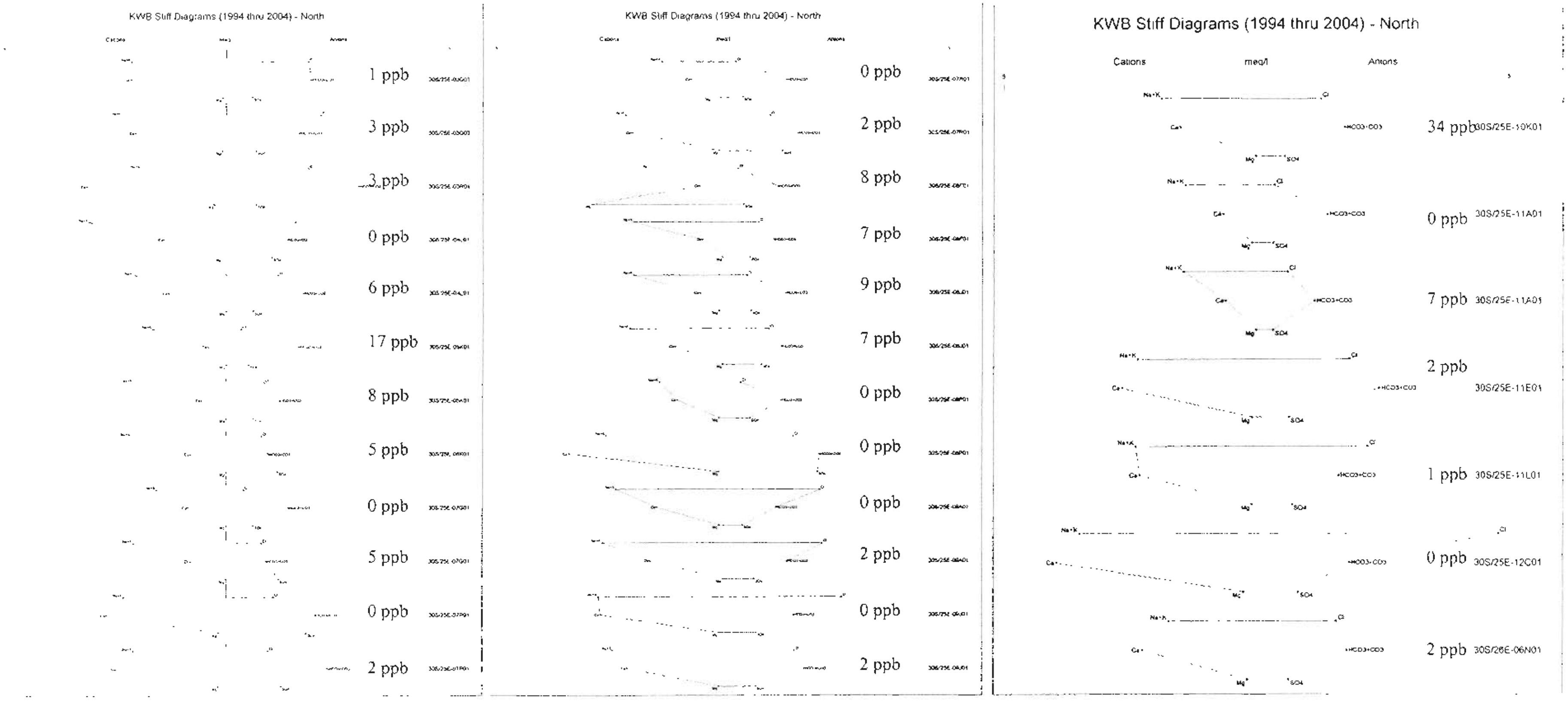


Figure 6-5: Stiff diagrams of major cations and anions from KWB wells in the northern portion of the water bank. In general, the northern waters are dominated by Na-HCO_3 type water, Ca-HCO_3 type water, or a combination of the two. Arsenic concentrations for each well are included to the right of each stiff diagram.

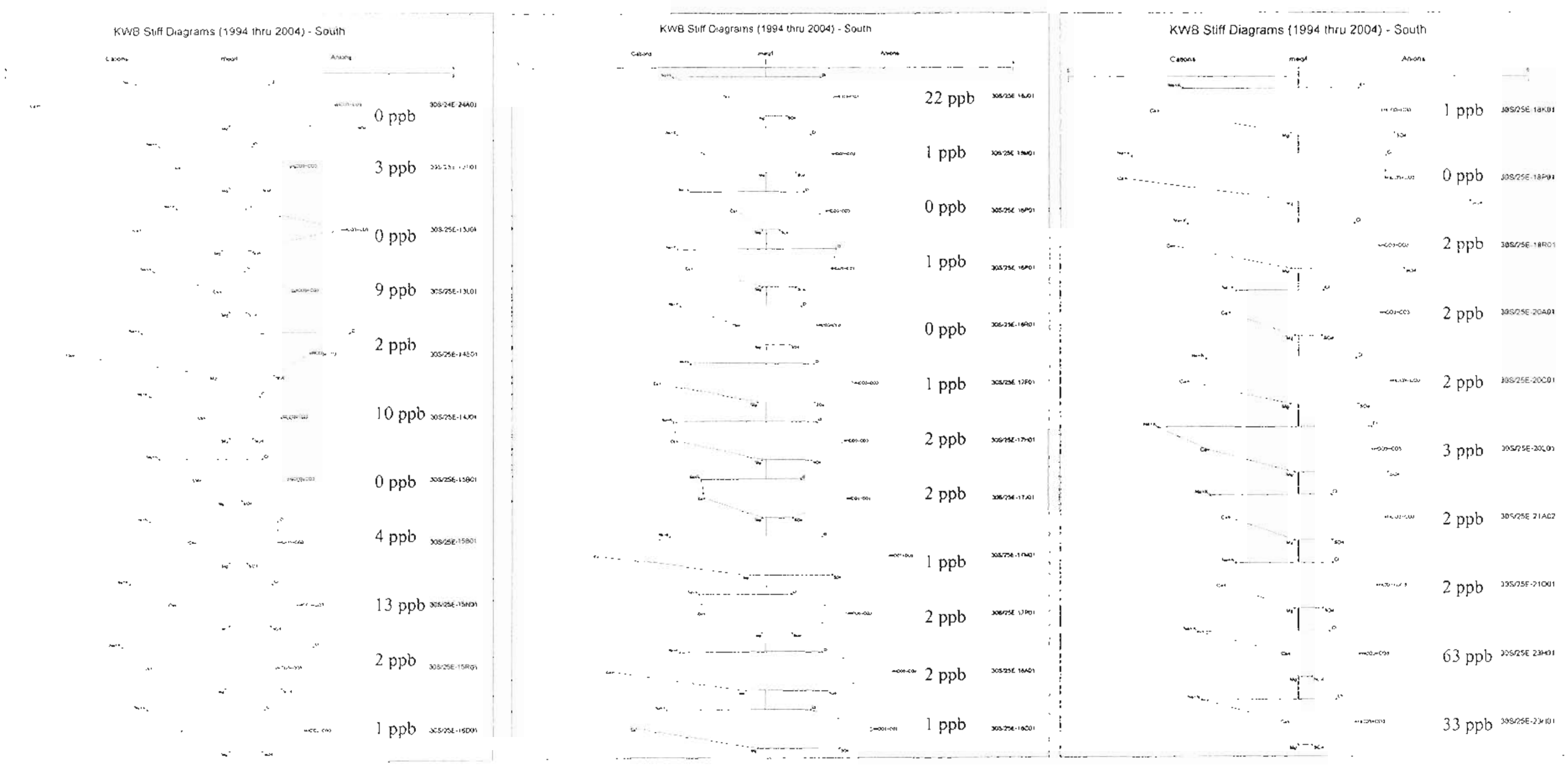


Figure 6-6: Stiff diagrams of major cations and anions from KWB wells in the southern portion of the water bank. In general, the southern waters are dominated by Na-HCO_3 type water, Ca-HCO_3 type water, or a combination of the two. Arsenic concentrations for each well are included to the right of each stiff diagram. The water quality of the subject well, 23H, is highlighted in the lower right of the figure.

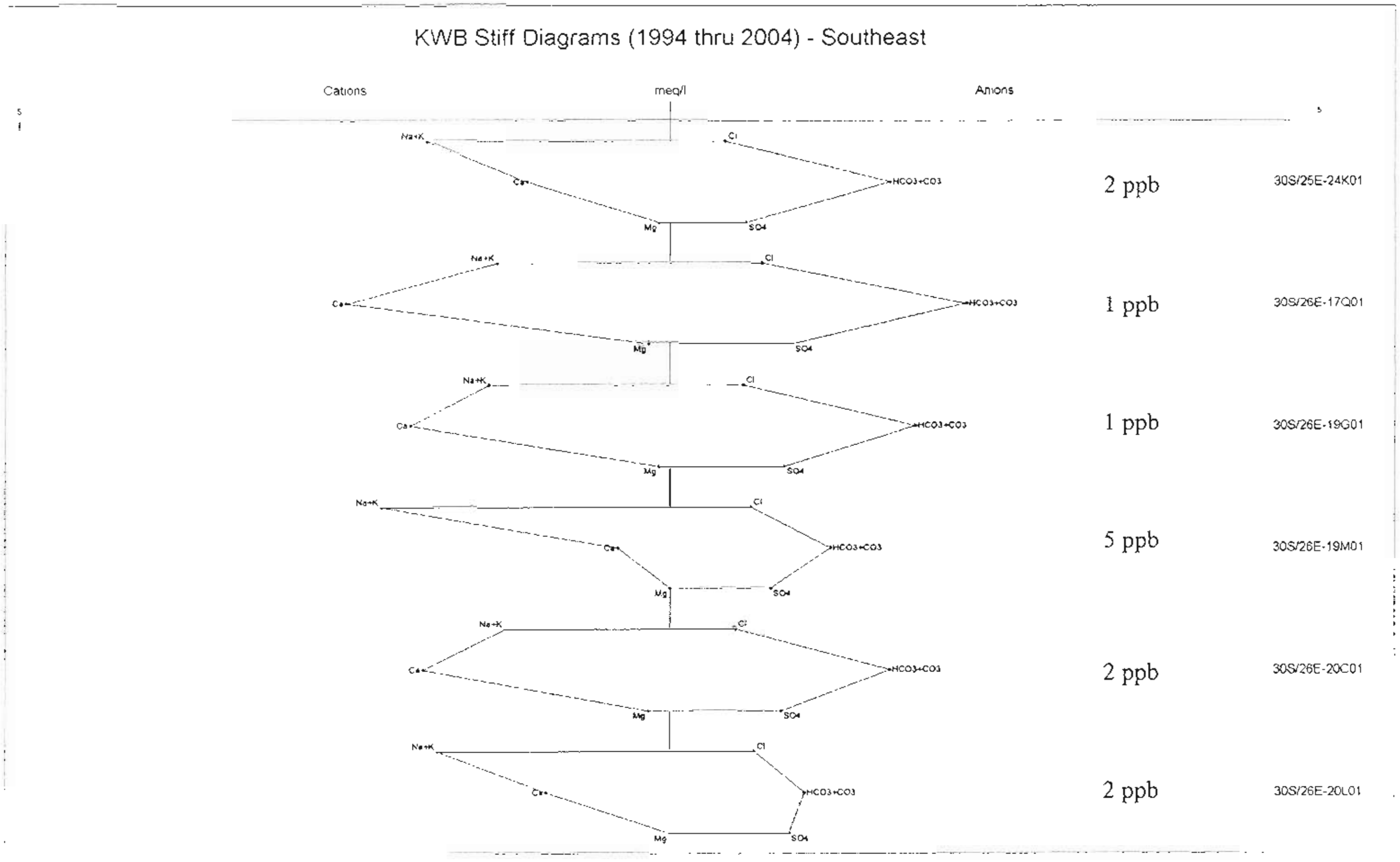


Figure 6-7: Stiff diagrams of major cations and anions from KWB wells in the southeast portion of the water bank. In general, the southeast waters are dominated by Na-HCO_3 type water, Ca-HCO_3 type water, or a combination of the two. Arsenic concentrations for each well are included to the right of each stiff diagram. As shown in the stiff diagrams, water quality varies over short distances within the KWB.

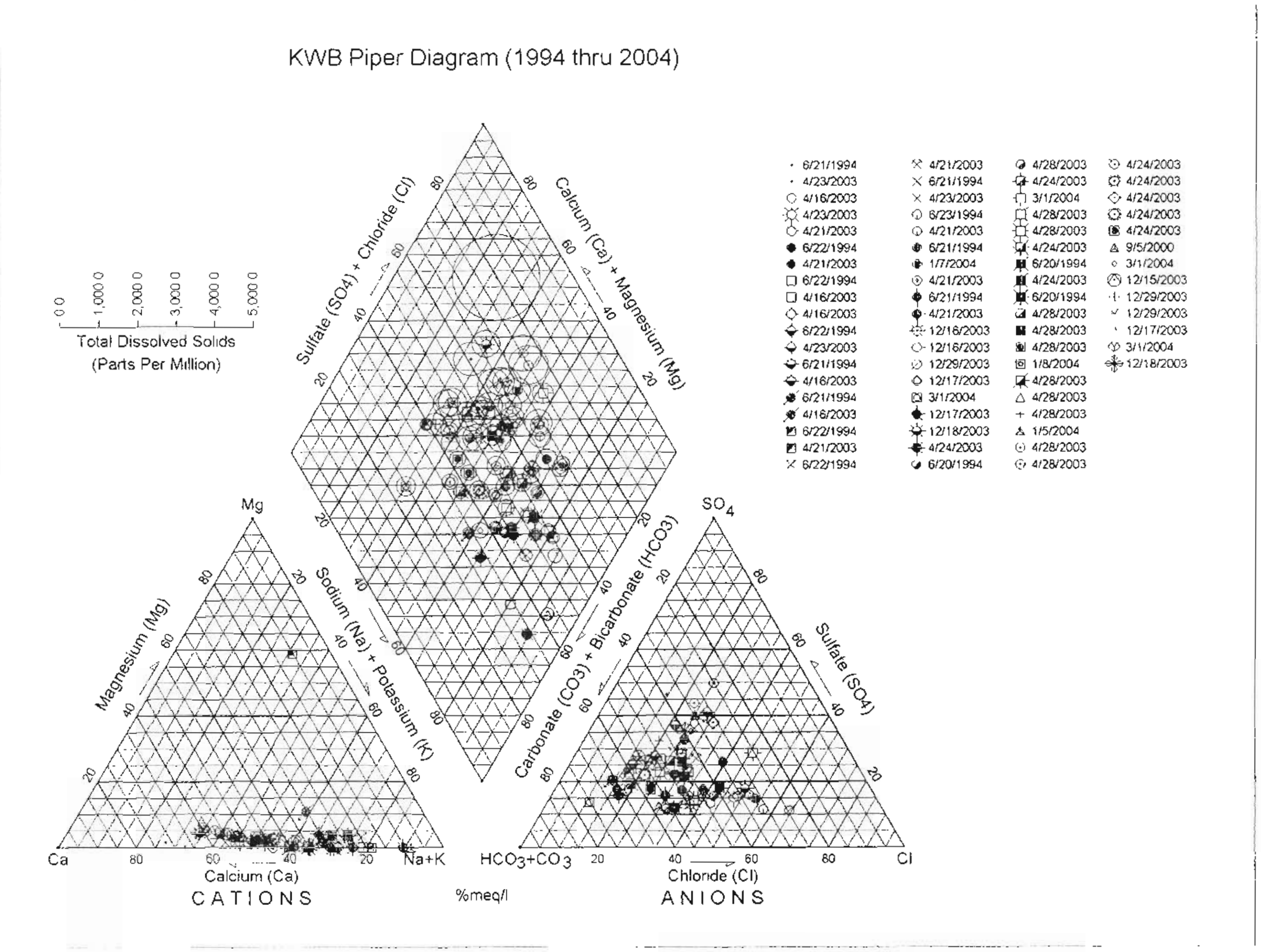


Figure 6-8: Piper Diagram from KWB wells sampled between 1994 and 2004. The water type of the KWB groundwater is, in general, Na-HCO_3 or Ca-HCO_3 or a combination of the two.

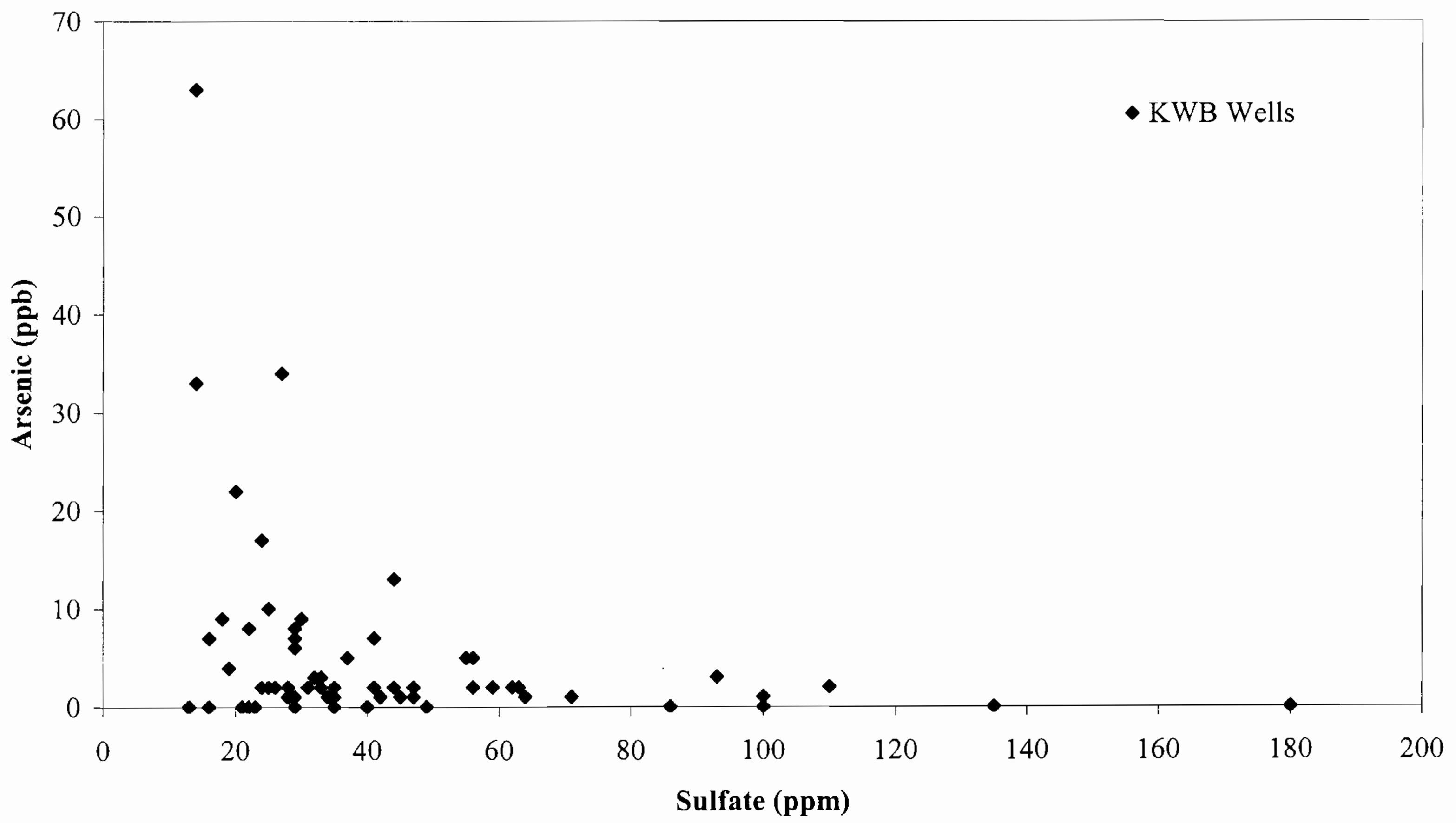


Figure 6-9: Arsenic concentration in parts per billion versus sulfate concentration in parts per million from KWB wells from 1994 thru 2005.

7 Discussion

The focus of this investigation was to gain a better understanding of the spatial variation and source of arsenic within the KWB, specifically in the immediate vicinity of KWB Well 23H. This research focused on collecting depth-specific water samples from Well 23H under static, non-pumping conditions and determining the speciation of the arsenic in the field (after Wilkie and Hering, 1998), collecting water samples from Well 23H while pumping (dynamic conditions) and determining the speciation of the arsenic in the field (after Wilkie and Hering, 1998 and Clifford et al, 2004), and looking for trends in the groundwater chemistry within KWB and Kern County in general. The overall objectives of this investigation were to understand the occurrence, spatial variation, and mobility of arsenic. Understanding the distribution of arsenic III to arsenic V, and factors that control this distribution are important due to the higher toxicity and mobility of arsenic III to arsenic V.

7.1 Comparison of Depth-Specific Sample Collection Methods

The depth-specific samples were collected using two sampling methods. Samples were collected using Welenco's wire line sampling tool and HydraSleeve™ sampling bags. The wire line sampler was much less labor intensive, but much more expensive than the HydraSleeve™ sampling bags. Up to ten HydraSleeve™ sampling bags could be lowered into the borehole at a time. The wire line sampler collected one sample, was raised up to the surface, emptied, and then lowered back into the wellbore to retrieve another sample. The HydraSleeve sampling bags could be re-used; however, the sampling bags knocked into the well casing and, upon occasion, sprang leaks and could not be re-used. Caution should be taken when lowering and raising the bags. The bags were reinforced with duct tape which helped in their durability and extending their longevity.

Groundwater collected from the HydraSleeve™ sampling bags and Welenco's depth-specific sampler had very similar concentrations of total arsenic, aluminum, iron, manganese, and uranium at each depth. Thus, the less expensive HydraSleeve™ sampling bags are a viable option when collecting depth-specific samples.

7.2 Overall Water Chemistry of KWB Well 23H

The water quality with respect to major cations and anions are consistent throughout the wellbore. The water type of KWB Well 23H at each sampled depth is Na-HCO_3 type water. The water sample from the well during pumping is also Na-HCO_3 type water. This is consistent with the results from previous work in the KWB (Swartz, 1995).

According to the Federal Register (2000), the occurrence of arsenic V over arsenic III in water is dependent on the pH and whether the system is oxidizing or reducing. In addition to pH, Eh can affect the dominant arsenic species (Figure 7-1). Oxidizing conditions favor the presence of arsenic V, while more reducing conditions favor arsenic III (Figure7-1) (Deutsch, 1997). The pH and redox potential measurements from the February 2005 pumping sampling event are plotted on the Eh-pH arsenic speciation diagram (Figure 7-1). The data plot near the boundary between arsenic III and arsenic V. Slight changes in pH and/or Eh from Well 23H could potentially affect the distribution of arsenic III to arsenic V. The redox potential and pH of the pumped water indicate an intermediate redox state. The dissolved oxygen concentrations are also indicative of intermediate redox conditions. The redox state of the groundwater could be intermediate due to the interaction of reduced water with more oxygenated water, which in turn could be mobilizing the arsenic. Arsenic concentrations are often high in areas with mixed redox conditions (Arthur et al., 2002).

7.3 Total Arsenic Analysis

Under non-pumping conditions, total arsenic concentrations vary with depth. In general, arsenic concentrations increase with depth. The highest arsenic concentrations, 15 ppb to 20 ppb, occur in the interval between 430 ft bgs and 630 ft bgs, and then below 630 ft bgs.

The total arsenic concentration measured from the well while pumping was around 36 ppb, which is significantly higher than the highest levels observed when the well was static. This suggests that, when pumped, the well receives water from zones that are not represented in the depth-specific samples that were collected under non-pumping conditions.

7.4 Field Speciation of Arsenic III and Arsenic V

The results from the August 2004 sampling event show that total arsenic concentrations vary with depth. However, concentrations of arsenic III were consistent throughout the well. This raises doubts whether the speciation method adapted from Wilkie and Hering (1998) successfully speciated arsenic. It would appear that the anion-exchange columns retained almost all of the arsenic and was unsuccessful at partitioning the arsenic III from arsenic V

(Table 6-6). The samples that were collected during the August 2004 sampling event had visible iron oxide and may have inhibited the separation of arsenic III from arsenic V (Clifford et al, 2004). As observed by McClesky et al. (2004) and Clifford et al. (2004), successful preservation of the redox state of arsenic in the presence of iron requires a chelating agent such as EDTA. This chelating agent was not used with the Wilkie and Hering (1998) method. However, Wilkie and Hering (1998) did not have visible iron oxides in the samples that they collected in the Sierra Nevada spring waters.

During the February 2005 pumping sampling event, water samples were collected and speciated using the Wilkie and Hering (1998) method and the Clifford et al. (2004) speciation method, for comparison. As mentioned previously, the Clifford et al. (2004) speciation method uses a chelating agent in addition to acetic acid (for reducing pH) as part of the pre-treatment process before the sample is poured through an ion-exchange resin filled column. Identical water samples were collected and speciated using the two different speciation methods. As with early results, the Wilkie and Hering (1998) method yielded very little arsenic III in the effluent. However, the Clifford et al. (2004) method successfully retained the redox state of the arsenic by chelating the iron oxides.

In light of the potential problems with the Wilkie and Hering (1998) speciation method and the different results from the two methods for the pumping sample, we consider our arsenic speciation results using the Wilkie and Hering (1998) method to be highly suspect. Based on the Clifford et al. (2004) method, it appears that about 30% of the arsenic from Well 23H under pumping conditions is present in the reduced form arsenic III, and 70% is present in the oxidized form arsenic V. This result is consistent with the dissolved oxygen and redox potential measurements and suggests that the redox conditions of the aquifer are intermediate.

7.5 Flow Gradients

Under static conditions shallow groundwater enters the wellbore at 160 ft bgs and the observable flow direction is downward. The flow rate increases significantly at 290 ft bgs and continues at the same rate to 700 ft bgs. The flow rate decreases from 700 ft bgs to the total depth of well. Groundwater appears to be exiting the borehole at depths greater 700 ft bgs. Under static conditions, shallow groundwater is mixing with deeper groundwater. The result is that oxygenated groundwater may be mixing with groundwater that is more reducing causing changes to the redox conditions in the immediate vicinity of the well. The observed downward gradient under static conditions may be reversed under pumping conditions, which would explain higher arsenic when pumped.

7.6 Overall KWB Water Chemistry and Correlations to Arsenic

The overall water quality within the KWB is very good. As previously discussed, of the 56 wells evaluated within the KWB, only six wells had arsenic concentrations at or above the newly lowered DWS that goes into affect January 1, 2006 (10 ppb) (Federal Register, 2000). The relationship of arsenic concentration versus the concentration of several major cations and anions were evaluated. The following key relationship that was distinguishable is that wells with the highest arsenic levels, including Well 23H, had sulfate concentrations greater than 14 ppm (Figures 6-9). Appreciable detections of sulfate in Well 23H is consistent with the hypothesis that arsenic mobilization may be due to the dissolution of pyrite, which in turn may be releasing arsenic and sulfur into the groundwater (Savage et al., 2000). However, the relationship of arsenic to sulfate across the KWB may be due to other processes. It is very feasible that in these other parts of the KWB there are different processes that control arsenic and sulfate. It is uncertain what these processes may be at this time.

In addition, arsenic concentrations greater than 5 ppb correspond to wells with Na-HCO_3 type water (Figures 6-5 thru 6-7). This relationship is consistent with observations made by Swartz (1995). However, it is unclear as to why this relationship is observable across the KWB at this time.

Examination of the Piper diagram created from the KWB water quality data reveals that the water quality varies significantly both spatially and temporally (Figure 6-8). The two dominant cations are sodium and calcium and across the KWB the two dominant anions are bicarbonate and sulfate, consistent with the results of Swartz (1995). Examination of the Stiff diagrams confirms that there is variability in water type across the KWB (Figures 6-5 thru 6-7).

The water quality of the WKWD well is similar from three of the zones that were measured. The lowermost zone has higher concentrations of total dissolved solids, sodium, calcium carbonate, chloride and sulfate. Based on the well log and the geologic log (appendix 11.4), which describes a blue-brown clay layer between zone 1 and zone 2, the sample from zone 1 appears to be from a different aquifer.

Water quality results from the water samples collected from Well 23H collected in February 2005 are summarized in Table 6-10 along with the results from WKWD well 6-04 for comparison. Stiff diagrams were created from the analytical results from the depth-specific samples from Well 23H, the samples collected during the pumping of Well 23H, and the samples collected from the WKWD well 6-04 (Figure 7-2). The water quality of the samples collected from Well 23H under non-pumping and pumping conditions are similar to the samples collected from the uppermost zones in WKWD well 6-04. Similar to KWB Well 23H, the groundwater in the vicinity of WKWD well 6-04 is Na-HCO_3 type water.

7.7 Hypothesis for High Arsenic in Groundwater

Total arsenic concentrations were evaluated from the depth-specific water samples and the sediment analysis that was part of a previous investigation (Negrini et al., 2005). The depth intervals containing the highest concentrations of arsenic in the depth-specific water samples collected from 23H (500 ft bgs to 600 ft bgs and 700 ft bgs to 800 ft bgs) correspond to those containing the highest total arsenic concentrations and highest concentrations of loosely bound arsenic in the sediments of the same well collected during drilling (400 ft bgs to 600 ft bgs and 700 ft bgs to 850 ft bgs) (Negrini et al., 2005). The highest total arsenic concentrations in sediments collected from 24K were found at depths between 600 ft bgs to 700 ft bgs and 800 ft bgs to 900 ft bgs (Negrini et al., 2005). However, less than 2 ppb arsenic was detected in the groundwater of Well 24K. Easily exchangeable arsenic concentrations were high in Well 23H compared to nearby KWB Well 24K (Negrini et al., 2005). That is arsenic bound to the minerals in the sediments collected from Well 23H appear to have a higher mobility than the arsenic bound to minerals in Well 24K. Much of the arsenic found in the sediments from Well 24K appears to be bound in the residual fraction of silicates and possibly sulfides. This arsenic is less likely to mobilize than arsenic that is loosely bound to the sediments. Thus, the high levels of exchangeable arsenic found in the sediments from Well 23H could explain the observed high arsenic concentrations that are found in the groundwater from Well 23H (Negrini et al., 2005).

The water quality data from this study were interpreted in the context of the stratigraphic interpretation of the sediments within the KWB from a previous investigation (Negrini et al., 2005). Coarsening-upward sequences have been identified and correlated across the KWB. These sequences have been interpreted to represent a prograding delta deposited in a terminal lake (Buena Vista Lake terminal basin). Notably, wells containing groundwater with arsenic concentrations greater than 5 ppb are located in a region that overlaps the location of the thickest deltaic deposit (Negrini et al., 2005). As argued by Negrini et al. (2005), this association may be due to the expected geochemical environments for deltaic sediments. Deltaic units are commonly deposited in a reducing geochemical environment relative to alluvial fan sediments.

The presence of pyrite is indicative of reducing conditions such as those found deltaic sediments (Deutsch, 1997). An investigation on the presence or absence of pyrite in sediments from the KWB is currently taking place as part of the larger KWB Project (personal communication with Dr. Robert Horton, 2005). Pyrite was found in the sediments from Well 23H and was absent (to date) from nearby Well 24K (Figure 1-1). The pyrite contains up to 0.4% arsenic (personal communication with Dr. Robert Horton, 2005). Pyrite, as long as it is stable under strongly reducing conditions, is a very good reservoir for arsenic and arsenic in groundwater in strongly reducing aquifers are generally low. The presence of arsenic V and arsenic III as well as dissolved oxygen and redox potential suggest that the introduction of oxygen, in the form of oxygenated water, is mixing with reduced sedimentary minerals, which could cause pyrite to become unstable and arsenic to be released into groundwater. Indeed, the pyrite that was found in the sediments from Well 23H appears to have undergone dissolution as evidenced by the observed SEM images (Negrini et al., 2005).

It appears that oxidative dissolution of pyrite is releasing arsenic and iron into the groundwater. As conditions become more oxidizing, some of the iron precipitates as iron oxides, binding arsenic again. However, in the intermediate redox conditions observed, arsenic concentrations in groundwater remain elevated.

Based on the results from this research project and the related work of Negrini et al. (2005), the mobility of the arsenic appears to be controlled by the pH and redox conditions of the aquifer. Reducing conditions in deltaic sediments led to pyrite formation that bound arsenic. The subsequent introduction of oxygenated water some time after the deposition of the deltaic sediments created mixed redox conditions, which in turn led to dissolution of pyrite and release of arsenic.

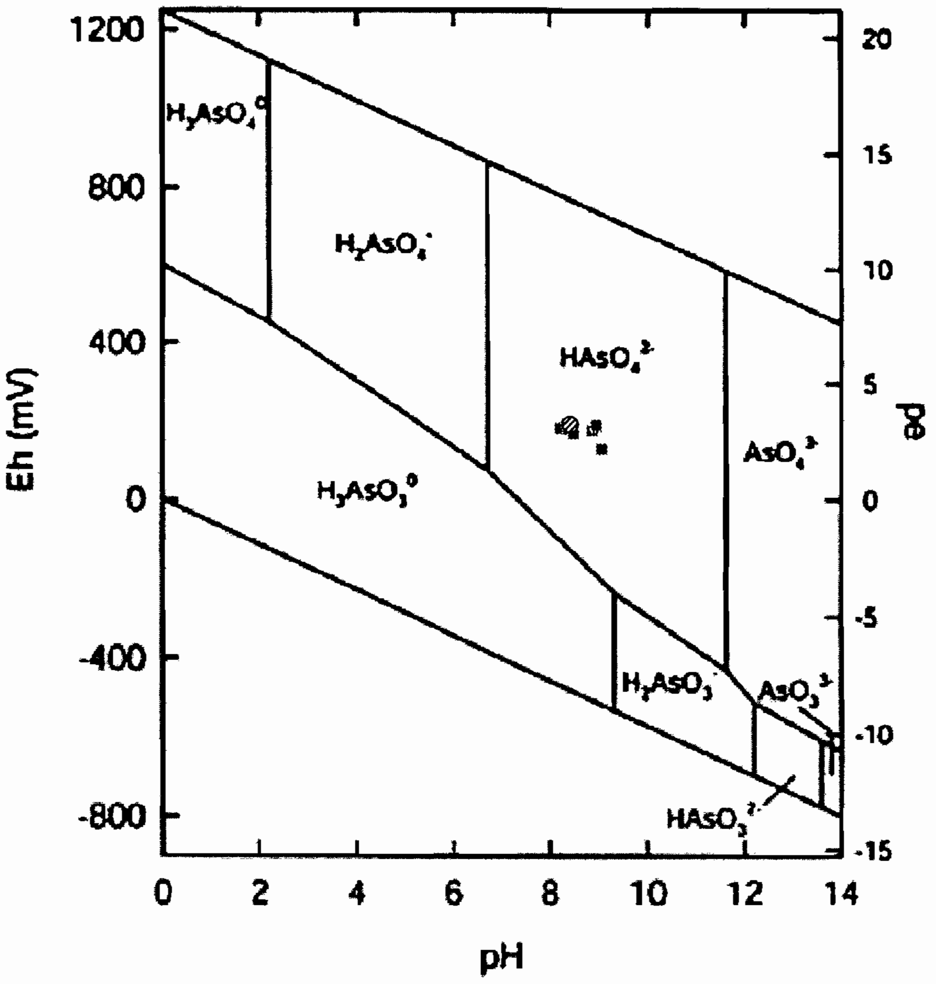


Figure 7-1: Eh-pH diagram of arsenic speciation. Arsenic V is anionic under pH conditions for natural waters, while arsenic III is neutral. The squares are the Eh-pH values measured during the February 2005 pumping sampling event, the circle is the average Eh-pH value (Modified from Deutsch, 1997).

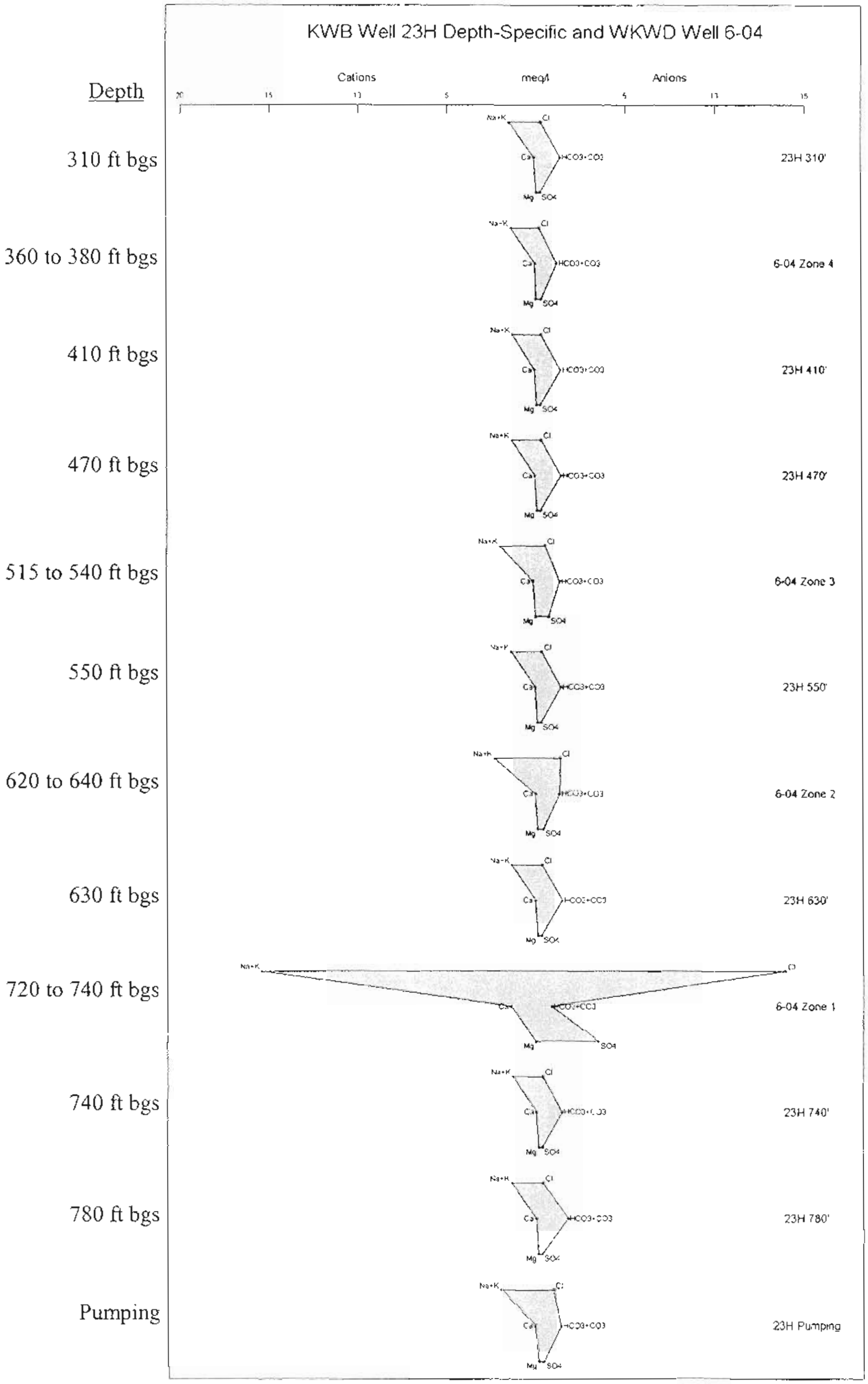


Figure 7-2: Stiff diagrams from depth-specific samples from KWB well 23H and samples collected during zone testing WKWD well 6-04. The depth that each sample was collected is included to the left of each Stiff diagram.

8 Conclusions

- HydraSleeve™ sampling bags are a less expensive, viable option when collecting depth-specific water samples. In their current state, the HydraSleeve™ sampling bags are not robust, and care is required when raising and lowering the bags.
- The overall water chemistry in KWB Well 23H is Na-HCO_3 type water. These results are consistent with previous studies and other high arsenic waters. The water type does not change regardless if the well is pumping or not pumping. The dissolved oxygen and redox potential indicate intermediate redox conditions.
- Total arsenic increases with depth, correlates with total and exchangeable arsenic in sediments, and is associated with fine grain size and total organic carbon. Total arsenic levels were much higher under pumping conditions than non-pumping suggesting that the well, when pumped, draws water from a zone that is relatively high in arsenic.
- The Clifford et al. (2004) speciation method works well, however, the Wilkie and Hering (1998) speciation method is not recommended for high iron waters such as these. Arsenic in Well 23H is 30% arsenic III indicative of intermediate redox conditions.
- Under non-pumping conditions there is a downward flow gradient. This gradient is perhaps reversed under pumping conditions, which may explain higher arsenic levels when pumped.
- Wells with the highest arsenic levels, including Well 23H, had sulfate concentrations greater than 14 ppm. Appreciable detections of sulfate in Well 23H is consistent with

the hypothesis that arsenic mobilization may be due to the dissolution of pyrite, which in turn may be releasing arsenic and sulfur into the groundwater.

- Reducing conditions in deltaic sediments lead to pyrite formation that binds arsenic. The introduction of oxygenated water some time after the deposition of the deltaic sediments creates mixed redox conditions, which in turn leads to dissolution of pyrite and release of arsenic bound to them.

9 Recommendations for Further Studies

The depth-specific samples collected with the HydraSleeve™ sampling bags and the depth sampler operated by Welenco successfully sampled discrete zones within Well 23H. However, the high amounts of visible iron clearly affected the speciation method (after Wilkie and Hering, 1998) employed during the depth-specific samples. The EDTA-HAc method used during the February 2005 sampling event (Clifford et al., 2004) successfully chelated the iron and speciated the arsenic. Thus, recommendations for further investigations would be to take depth-specific samples using HydraSleeve™ sample bags and speciate the arsenic with the EDTA-HAc method.

In areas where arsenic concentrations are of critical importance, the following steps are recommended to fully evaluate the distribution of this constituent:

- Drill a small diameter test hole using dual-wall air rotary drilling method. This drilling method does not require the use of drilling mud. Thus, depth-specific water samples could be collected during the drilling process. A portion of the water could be speciated in the field using the EDTA-HAc method (Clifford et al., 2004) and later analyzed for total arsenic and arsenic III. The remainder of the sample could be analyzed by a commercial laboratory for major cations and anions.
- Collect sediment samples at ten-foot intervals and/or when the lithology changes.
- Run an electric log of the test hole.
- Design a well (to be drilled 50 ft away from the test hole) based on the overall water quality results, the presence or absence of arsenic, the lithology, and the results from

the electric log of the test hole. If there are zones with high arsenic and/or clay-rich zones with low porosity and permeability, the final well design should have blank casing with cement adjacent to these zones. If there is little good quality sands and poor water quality, the test hole could be abandoned. There is less of a financial commitment in a small diameter test hole than in a pilot hole for a large diameter water well.

- The sediments that are collected from a dual-wall test hole better represent the actual lithology of the area in comparison to drilling mud or even reverse circulation. A better assessment could be made as to the grain size distribution.

A final recommendation for further studies is, if funding is not an issue, to collect depth-specific water samples using packers and a pump. The advantage to using packers with a pump rather than the sampling bags is that the discharge of the pump could be connected to a Horiba in a flow-through cell. It would be advantageous to collect Eh and dissolved oxygen values at various depths in order to determine if a definitive transition occurs between reducing and oxidizing conditions.

10 References

Ahmed, K.M., Bhattacharya, P., Hasan, M.A., Akhter, S.H., Alam, S.M.M., Bhuyian, M.A.H., Imam, M.B., Khan, A.A., Sracek, O., 2004, Arsenic enrichment in groundwater of the alluvial aquifers in Bangladesh: an overview, Applied Geochemistry, 19 (2004), pp. 181-200.

Arthur J.D., Dabous, A.A. and Cowart, J.B., 2002, Mobilization of arsenic and other trace elements during aquifer storage and recovery, southwest Florida, In George R. Aiken and Eve L. Kuniansky, editors, 2002, U.S. Geological Survey Artificial Recharge Workshop Proceedings, Sacramento, California, April 2-4, 2002: USGS Open-File Report 02-89.

Baron, D., Negrini, R.M., Gillespie, J., 2001. Long-term goal of CSUB Kern Water Bank Project.

California Groundwater Bulletin 118, 2004, San Joaquin Valley Groundwater Basin Kern County Subbasin, Update 2/27/2004.

Clifford, D.A., Karori, S., Ghurye, G., Samanta, G., 2004. Field Speciation Method for Arsenic Inorganic Species, AWWA Research Foundation, 88 pp.

Croft, M.G., 1972. Subsurface Geology of the Late Tertiary and Quaternary Water-Bearing Deposits of the Southern Part of the San Joaquin Valley, California, Contributions to the Hydrology of the United States, Geological Survey Water-Supply Paper 1999-H.

Dale R.H., French, J.J., Gordon, G.V., 1966. Ground-water geology and hydrology of the Kern River alluvial fan area, California, *U.S. Geol. Surv. Water Res. Div. Open-File Report.*

Davis, G. H., Green, J.H., Olmsted, F.H., and Brown, D.W., 1959. Ground-Water Conditions and Storage Capacity in the San Joaquin Valley California: U.S. Geol. Survey Water-Supply Paper 1469, 277 p.

Deutsch, W.J., 1997. Groundwater geochemistry, fundamentals and applications to contamination, Lewis Publishers, 221 pp.

Dhoum, R.T. and Evans, G.J., 1998. Evaluation of uranium and arsenic retention by soil from a low level radioactive waste management site using sequential extraction. *Applied Geochemistry*, v. 13, no. 4, pp. 415-420.

Driscoll, F.G., 1986. Groundwater and wells. St. Paul: Johnson Filtration Systems, Inc.

Federal Register, June 2000, v. 65, no. 121, pp. 38,888-38,983.

Fetter, C.W., 2001. Applied hydrogeology. Prentice Hall, fourth edition, 691pp.

Focazio, M.J., Welch, A.H., Watkins, S.A., Helsel, D.R., and Horn, M.A., A retrospective analysis on the occurrence of arsenic in ground-water resources if the United States and limitations in drinking-water-supply characterizations: *United States Geological Survey Water-Resources Investigation Report* 99-4279, 21 pp.

Goh, K., Lim, T., 2005. Arsenic fractionation in a fine soil fraction and influence of various anions on its mobility in the subsurface environment, *Applied Geochemistry*, v. 20, pp. 229-239.

Guha, S., 2001. A story of Arsenic in Drinking Water, Technology, July 2001, vol. 4, no. 2.

GRAC web site, 2004. Arsenic Conference.

Hajas, K.R. and Swanson, A.A., 1979. Preliminary evaluation of state water project groundwater storage program: Kern River fan area. CDWR study code No 1610-5-J-1

Hamilton, G., 2005. Personal communication with Gary Hamilton, West Kern Water District

Keon, N.E., 2000. 2000 progress report – controls on arsenic mobility in a metal-contaminated wetland, EPA website.

Keon, N.E., Swartz, C.H., Brabander, D.J., Harvey C., Hemond, H.F., 2001. Validation of an arsenic sequential extraction method for evaluating mobility in sediments. *Environ. Sci. Tech.*, v. 35, pp. 2778-2784.

Kern County Water Agency and California Department of Water Resources, 1994. Kern Water Bank monitoring report, 40 pp.

Kirk, M.F., Holm, T.R., Park, J., Jin, Q., Sanford, R.A., Fouke, B.W., Bethke, C.M., 2004, Bacterial sulfate reduction limits natural arsenic contamination in groundwater, *Geology*, November 2004, v. 32, no. 11, p. 953-956.

Klinchuch, L.A., Delfino, T., Jefferson, J., Waldron, J., 1998. Does biodegradation of petroleum hydrocarbons affect the occurrence or mobility of dissolved arsenic in groundwater. Results of Arsenic Study Mileposts 13 to 14 (Pioneer Property) Wait-Midway Pipeline, Kern County, California.

McCleskey, R.B., Nordstrom, D.K., Maest, A.S., 2004. Preservation of water samples for arsenic (III/V) determinations: an evaluation of the literature and new analytical results. *Applied Geochemistry*, v. 19, pp. 995-1009.

Negrini, R., Parker, J., Baron, D., Gillespie, J., Horton R., Boockoff, L., Philley, P., Draucker, A., Durham, N., 2005. 3-D characterization and monitoring of aquifer attributes in the Kern Water Bank: Final Grant Report, submitted by the Kern Water Bank Authority to the CA Department of Water Resources according to the guidelines of AB303, The Local Groundwater Management Assistance Act of 2000.

Nickson, R.T., McArthur, J.M., Ravenscroft, P., Burgess, W.G., Ahmed, K.M., 2000. Mechanism of arsenic release to groundwater, Bangladesh and West *Bengal, Applied Geochemistry*, 15 (2000), pp. 401-413.

O'Day, P.A., Vlassopoulos, D., Root, R., and Rivera, N., 2004. The influence of sulfur and iron on dissolved arsenic concentrations in the shallow subsurface under changing redox conditions, PNAS, September 2004, vol. 101, no. 38, pp. 13703-13708.

Page, R.W., 1986. Geology of the fresh ground-water basin of the central valley, California, with texture maps and sections. *U.S. Geological Survey Professional Paper*, 1401C, 54pp.

Ryker, S., 2001. Mapping arsenic in groundwater. *Geotimes* web feature.

Ryu, J., Gao, S., Dahlgren, R.A., Zierenberg, R.A., 2002. Arsenic distribution, speciation, and solubility in shallow groundwater of Owens Dry Lake, California. *Geochimica et Cosmochimica Acta*, v. 66, pp. 2981-2994.

Savage, K., Tingle, T., O'Day, P., Waychunas, G., Bird, D., 2000. Arsenic speciation in pyrite and secondary weathering phases, Mother Lode Gold District, Tuolumne County, California, *Applied Geochemistry*, v. 15, pp. 1219-1244.

Smedley, P.L., Kinniburgh, D.G., 2002. A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry*, v. 17, pp. 517-568.

Stone, D. B., Moomaw, C. L., and Davis, A., 2001. Estimating Recharge Distribution by Incorporating Runoff from Mountainous Areas in an Alluvial Basin in the Great Basin Region of the Southwestern United States. *Ground Water*, Vol. 39, No. 6, pp 807-818.

Swartz, C., Blute, N., Badruzzman, B., Ali, A., Brabander, D., Jay, J., Besancon, J., Islam, S., Hemond, H., Harvey, C., 2004. Mobility of arsenic in a Bangladesh aquifer: Inferences from geochemical profiles, leaching data, and mineralogical characterization. *Geochimica et Cosmochimica Acta*, Vol. 68, No. 22, pp. 4539-4557.

Swartz, R.J., 1995, A study of the occurrence of arsenic on the Kern Fan Element of the Kern Water Bank, southern San Joaquin Valley, California. Master's Thesis, CSUB, 138 pp.

Tessier, A., Campbell, P.G.C., Bisson, M., 1979. Sequential extraction procedure for the speciation of particulate trace metals. *Analytical Chemistry*, v. 51, no. 7, pp. 844-851.

United States Geological Survey (USGS), 2000. Arsenic in ground-water resources of the United States. *USGS Fact Sheet* 063-00.

Washington State Department of Health, 2003. Guidance document: Arsenic Treatment for small water systems, March 2003.

Welch, A.H., Helsel, D.R., Focazio, M.J., Watkins, S.A., 1999. Arsenic in ground water supplies of the United States, in: *Arsenic exposure and health effects*, W.R. Chappell, C.O. Abernathy, and R.L. Calderon, Eds., Elsevier Science, New York, pp. 9-17.

Welch, A.H., Lico, M.S., and Hughes, J.L., 1988. Arsenic in ground water of the United States: occurrence and geochemistry. *Ground Water*, v. 38, pp. 589-604.

Welch, A.H., Westjohn, D.B., Helsel D.R., Wanty, R.B., 2000. Arsenic in ground water of the United States: occurrence and geochemistry. Ground Water v. 38, no. 4, pp. 589-604.

Wenzel, W.W., Kirchbaumer, N., Prohaska, T., Stingeder, G., Lombi, E., Adriano, D., 2001. Arsenic fractionation in soils using an improved sequential extraction procedure. *Analytica Chimica Acta*, v. 436, pp. 309-323.

Wilkie, J., 1997. Processes controlling arsenic mobility in natural and engineered systems. Dissertation, University of California Los Angeles, 264 pp.

Wilkie, J. and Hering, J., 1998. Rapid oxidation of geothermal arsenic (III) in streamwaters of the Eastern Sierra Nevada, *Environ, Sci. Tech.*, v. 32, pp. 657-662.

Wolthers, M., Butler, I., Rickard, D., and van der Weijden, 2000, Arsenic Incorporation into Pyrite at low Temperature, Experimental Results, Goldschmidt 2000, Journal of Conference Abstracts, vol. 5(2), p. 1101.

World Health Organization (WHO), 2001. Arsenic in drinking water. *WHO Fact Sheet* no. 210.

Zhang, W., Yong, C., Tu, C., Mai, L.Q., 2002. Arsenic speciation and distribution in an arsenic hyperaccumulating plant. *The Science of the Total Environment*, v. 300, pp. 167-177.

11 Appendices

11.1 Arsenic Speciation

Wilkie and Hering (1998)

The following is a detailed description of the Wilkie and Hering (1998) anion-exchange method:

Anion-exchange columns were prepared using Dowex 1x 8 anion-exchange resin with a 50-100 mesh from Bio-Rad. The resin was in the chloride form and was converted to the acetate form with 1 M NaOH, distilled water rinse, then 1 M acetic acid. Approximately 2 ml of the resin and DI water (to keep the resin from drying out) were loaded into Bio-Rad Poly-Prep 0.8 x 4 cm chromatography columns. The columns were transferred to the field for use. Collected water samples were filtered then pre-treated with 100 µl of HCl, which reduced the pH of the sample to 3.5. The filtration step involved using a 0.1 µm cellulose nitrate membrane filter (from Satorius) with a 25 mm polycarbonate filter holder (Nuclepore) attached to a luer-lock disposable syringe. The filtered and treated sample was poured through the anion-exchange columns and the effluent was collected for arsenic III determinations.

The adapted Wilkie and Hering (1998) used in this study method is described as follows: Fifty anion-exchange columns were prepared in an analytical laboratory at CSUB, Department of Geology. The columns were prepared using Dowex 1x 8 anion-exchange resin with a 100-200 mesh from Bio-Rad. Unlike the method used by Wilkie and Hering

(1998), a 100-200 mesh was selected and the resin was purchased already in the acetate form. Poly prep 0.8 x 4cm chromatography columns (Bio-Rad) were filled with 2 ml of resin and de-ionized water to keep the resin from drying out . The anion-exchange columns were kept in a refrigerator in a CSUB laboratory prior to field sampling. The columns were transferred to the field in a closed cooler filled with ice.

Water samples were collected using a wire line sampling tool and HydraSleeve™ sampling bags. Each sample was treated with 100 μl of HCl, which reduced the pH of the sample to 3.5. Approximately 15 ml of the treated sample was poured into the prepared anion-exchange columns. The tip of the column was broken off and water was collected at the effluent end of the column in a polypropylene sample container. The containers were stored in a closed cooler for transport to the CSUB ICP/MS laboratory. Concentrations of arsenic III were measured from the effluent sample. Total arsenic concentrations were measured from the influent sample.

Clifford et al. (2004)

The Clifford et al. (2004) speciation method is described as follows:

Kontes economy columns were rinsed with deionized (DI) water. Dowex resin in chloride form was mixed into a slurry using 15 milliliters (ml) of resin and 15 ml of DI water. The resin slurry was poured into the columns and the water was allowed to drain out. The columns were filled to 1 cm over the neck of the column. The columns were set aside with the end plugs in place. A 0.1 M solution of EDTA was made by adding 3.72 grams (g) of disodium salt of EDTA to a small amount of DI water. The dissolved salt was diluted to 100 ml with DI water. This solution was set aside. A 2.0 M solution of acetic acid (HAc) was made by adding 11.5 ml of 17.4 M glacial acetic acid to 50 ml of DI water. This mixture was diluted to 100 ml with DI water. A portion of the 0.1 M EDTA (4.25 ml) and the 2.0 HAc (10.8 ml) were mixed together into several 250 ml reagent bottles. Water from Well 23H would be collected directly into the reagent bottles to make up a 250 ml sample (groundwater plus reagent).

A complete field speciation kit includes one column with 10 ml resin in chloride form, one 250 ml bottle containing EDTA-HAc solution, one 60 ml bottle for collecting effluent from column, one 60 ml syringe with Luer-lock tip, one 6" x 1/8" flexible tubing, and one 3-way Luer-lock valve.

As recommended by Clifford et al. (2004), the sampling lines and tubes were thoroughly flushed prior to sampling. The 250 ml reagent bottle with the EDTA-HAc solution was filled to the 250 ml mark on the bottle from a side sampling port from Well 23H. After collecting the sample, the bottle was inverted several times in order to mix the sample with the reagent and set aside for a few minutes. Tubing was placed on the end of the 60 ml syringe tip and the end caps were removed from the columns. Flexible tubing was placed into the 250 ml sample bottle and 60 ml of the sample was withdrawn. The tubing was removed from the sample bottle and inserted into the inlet of the column. Sixty milliliters of the sample was forced through the resin. The first 25 ml of the effluent sample was discarded the remainder was collected in the 60 ml effluent bottle (arsenic III concentration) (Clifford et al., 2004).

11.2 Non-Pumping and Pumping Water Sampling Results

Appendix
August 2004 Non-Pumping Sampling Results

Sample Number	Sample Depth	Al	As	Fe	Mn	U
170 H Total As	170	4.37	5.78	96.43	3.45	4.68
170 H Total As + HCl	170	4.50	5.55	85.95	3.13	4.63
170 H Total As 3	170	6.02	0.29	56.78	2.46	0.04
170 H Total As F	170	3.75	5.66	36.64	1.94	4.69
170 H Total As U	170	1.59	6.51	50.24	1.45	0.93
190 D Total As	190	10.56	8.29	590.94	11.88	4.52
190 D Total As + HCl	190	11.79	7.83	342.43	8.09	4.37
190 D Total As 3	190	11.29	0.26	113.91	3.80	0.05
190 H Total As	190	5.61	6.77	95.05	2.93	4.59
190 H Total As + HCl	190	5.76	6.85	77.34	2.86	4.55
190 H Total As 3	190	2.53	0.23	-0.91	1.78	0.01
190 H Total As F	190	4.61	6.80	32.83	1.62	4.77
190 H Total As U	190	2.28	7.92	39.28	1.24	0.81
210 H Total As	210	8.15	11.52	109.17	3.25	3.97
210 H Total As + HCl	210	6.38	11.28	78.65	2.05	3.99
210 H Total As 3	210	5.19	0.21	43.10	1.60	0.02
210 H Total As F	210	5.59	11.12	34.76	1.36	3.93
210 H Total As U	210	2.23	12.92	35.82	0.90	0.75
230 H Total As	230	5.89	12.56	841.11	8.06	3.98
230 H Total As + HCl	230	6.89	12.06	897.42	8.87	3.90
230 H Total As 3	230	5.51	0.93	156.16	5.40	0.03
230 H Total As F	230	5.73	12.00	62.86	2.45	3.91
230 H Total As U	230	2.07	14.65	276.59	2.57	0.69
250 D As 3	250	10.27	0.37	144.00	5.67	0.03
250 D Total As	250	8.14	12.41	1165.60	10.21	3.78
250 D Total As + HCl	250	11.97	12.22	1115.77	10.60	3.79
250 H As 3	250	5.48	0.74	116.54	4.58	0.07
250 H Total As	250	5.81	11.17	985.46	7.51	4.33
250 H Total As + HCl	250	6.50	10.65	992.92	7.48	4.22
250 H Total As F	250	4.88	10.64	69.39	2.90	3.98
250 H Total As U	250	1.69	12.55	188.89	2.31	0.67
270 H As 3	270	4.83	1.14	151.88	3.96	0.13
270 H Total As	270	6.52	11.27	981.92	7.29	4.18
270 H Total As + HCl	270	6.43	10.97	962.49	6.63	4.07
270 H Total As F	270	5.07	9.84	81.90	2.32	3.84
270 H Total As U	270	3.29	12.82	250.98	1.85	0.92
280 D As 3	280	18.08	0.40	149.05	5.09	0.04
280 D Total As	280	12.54	14.29	2034.88	11.25	3.06
280 D Total As + HCl	280	9.97	14.18	674.27	4.95	2.81
280 H As 3	280	6.57	0.40	134.03	4.62	0.02
280 H Total As	280	112.27	13.67	3640.87	1087.86	9.34
280 H Total As + HCl	280	16.58	9.67	874.46	13.32	4.51
290 H As 3	290	7.56	0.37	108.32	2.40	0.02
290 H Total As	290	9.47	12.19	616.13	7.62	3.66
290 H Total As + HCl	290	8.45	12.33	303.11	5.09	3.53
310 D As 3	310	10.51	0.29	146.16	2.60	0.03
310 D Total As	310	11.61	13.72	855.48	6.80	2.71
310 D Total As + HCl	310	9.63	13.69	487.32	3.50	2.65
310 H As 3	310	6.63	0.37	127.88	2.97	0.02
310 H Total As	310	11.16	10.00	386.42	5.10	3.98
310 H Total As + HCl	310	12.29	9.93	372.10	5.30	3.91

Appendix
August 2004 Non-Pumping Sampling Results

Sample Number	Sample Depth	Al	As	Fe	Mn	U
330 H As 3	330	8.65	0.38	132.35	1.78	0.03
330 H Total As	330	14.25	11.63	1337.30	5.45	3.42
330 H Total As + HCl	330	12.53	12.27	907.55	4.11	3.31
410 D As 3	410	7.37	0.27	130.90	2.66	0.03
410 D Total As	410	9.54	13.33	494.31	11.91	2.57
410 H As 3	410	3.32	0.24	49.80	1.67	0.02
410 H Total As	410	6.39	12.75	245.75	2.65	3.40
410 H Total As + HCl	410	7.69	12.93	225.08	3.26	3.35
410 H Total As F	410	5.41	12.36	30.38	1.17	3.43
410 H Total As U	410	3.62	14.48	54.81	0.65	0.69
430 H As 3	430	6.67	0.29	53.45	2.02	0.02
430 H Total As	430	7.27	15.23	98.37	2.60	3.46
430 H Total As + HCl	430	7.59	14.68	91.46	2.04	3.52
430 H Total As F	430	6.94	14.64	33.34	1.27	3.61
430 H Total As U	430	3.71	17.16	39.00	0.69	0.61
450 H As 3	450	7.38	0.55	83.56	2.08	0.03
450 H Total As	450	8.58	15.24	145.11	2.88	3.51
450 H Total As + HCl	450	8.67	15.66	179.59	3.18	3.49
450 H Total As F	450	7.86	15.10	37.38	1.70	3.52
450 H Total As U	450	4.07	17.04	54.94	1.03	0.62
470 D As 3	470	11.27	0.84	387.84	6.19	0.08
470 D Total As	470	32.93	17.82	2916.43	66.43	4.98
470 D Total As + HCl	470	18.52	15.78	1112.60	23.94	3.58
470 H As 3	470	6.64	0.34	55.15	1.45	0.03
470 H Total As	470	8.54	15.32	113.77	2.07	3.24
470 H Total As + HCl	470	8.35	15.30	113.94	1.89	3.33
470 H Total As F	470	7.35	15.40	27.42	1.42	3.33
470 H Total As U	470	5.40	17.85	46.88	0.66	0.66
510 H As 3	510	8.07	0.27	30.85	3.85	0.04
510 H Total As	510	50.93	16.15	204.55	7.56	4.22
510 H Total As + HCl	510	37.37	16.98	195.23	10.62	3.86
510 H Total As F	510	7.81	16.97	53.97	1.81	4.18
510 H Total As U	510	15.13	19.01	82.76	1.44	0.89
530 H As 3	530	6.32	0.33	70.69	1.67	0.05
530 H Total As	530	8.46	20.88	125.29	2.12	3.19
530 H Total As + HCl	530	8.54	20.16	110.13	1.97	3.20
530 H Total As F	530	8.20	19.08	32.01	0.96	3.19
530 H Total As U	530	5.48	24.22	46.74	0.61	0.73
550 D As 3	550	7.06	0.17	40.66	4.05	0.01
550 D Total As	550	12.60	15.44	407.74	11.10	2.83
550 D Total As + HCl	550	12.69	14.86	394.20	10.82	2.82
550 H As 3	550	7.66	0.22	35.68	2.07	0.03
550 H Total As	550	16.11	18.55	132.93	3.69	4.04
550 H Total As + HCl	550	14.24	17.21	100.32	2.52	4.03
550 H Total As F	550	8.97	18.97	45.93	1.65	4.19
550 H Total As U	550	10.48	20.61	61.35	0.82	0.99
630 D As 3	630	9.71	1.03	479.43	7.30	0.13
630 D Total As	630	24.14	18.07	2051.52	45.36	5.34
630 D Total As + HCl	630	19.69	16.87	1546.02	35.84	4.78
630 H As 3	630	8.57	0.41	103.73	3.69	0.05

Appendix
August 2004 Non-Pumping Sampling Results

Sample Number	Sample Depth	Al	As	Fe	Mn	U
630 H Total As	630	9.97	13.56	334.16	5.34	4.19
630 H Total As + HCl	630	10.47	13.71	342.74	5.35	4.19
630 H Total As F	630	7.28	11.58	78.34	1.86	4.18
630 H Total As U	630	5.17	14.79	107.17	1.60	0.79
650 H As 3	650	10.25	0.37	118.47	3.52	0.04
650 H Total As	650	13.61	13.90	1173.82	18.27	5.25
650 H Total As + HCl	650	10.12	13.50	439.73	6.87	4.36
650 H Total As F	650	6.20	12.91	42.99	1.74	4.08
650 H Total As U	650	4.92	15.27	212.52	1.71	0.86
670 H As 3	670	6.45	0.17	37.10	2.20	0.03
670 H Total As	670	20.85	15.26	173.01	5.46	4.41
670 H Total As + HCl	670	16.18	13.54	131.80	3.84	4.45
670 H Total As F	670	7.82	16.25	35.22	2.25	4.39
670 H Total As U	670	5.83	16.99	54.15	1.47	0.74
720 H As 3	720	9.14	0.29	35.16	2.73	0.02
720 H Total As	720	15.52	16.52	191.88	4.43	4.17
720 H Total As + HCl	720	25.12	15.49	202.31	6.24	4.34
720 H Total As F	720	7.69	16.15	37.43	1.66	4.28
720 H Total As U	720	7.11	18.29	84.40	1.51	0.72
740 D As 3	740	12.13	1.04	474.69	11.53	0.17
740 D Total As	740	17.38	17.58	1307.19	51.73	4.14
740 D Total As + HCl	740	17.10	17.79	1292.42	45.25	4.35
740 H As 3	740	10.05	0.23	50.04	2.91	0.03
740 H Total As	740	11.93	18.80	265.47	4.61	3.74
740 H Total As + HCl	740	13.37	18.48	280.01	6.64	3.71
740 H Total As F	740	8.52	18.90	38.76	1.81	3.74
740 H Total As U	740	6.09	20.93	163.74	1.84	0.66
780 D As 3	780	9.27	0.60	302.79	5.94	0.10
780 D Total As	780	13.04	15.23	703.95	19.87	3.36
780 D Total As + HCl	780	13.12	15.15	698.60	17.10	3.29
780 H As 3	780	7.45	0.19	67.39	7.84	0.03
780 H Total As	780	25.89	15.90	878.91	16.15	4.54
780 H Total As + HCl	780	27.96	14.32	1738.38	25.61	4.72
780 H Total As F	780	7.97	15.23	54.27	1.94	4.38
780 H Total As U	780	7.70	17.23	247.28	2.74	0.91
800 H As 3	800	7.66	0.16	53.95	2.67	0.02
800 H Total As	800	22.16	16.22	345.38	6.99	4.01
800 H Total As + HCl	800	13.04	15.53	271.46	4.29	3.90
800 H Total As F	800	7.92	15.57	42.96	1.90	4.02
800 H Total As U	800	7.87	17.81	139.81	2.11	0.70
820 H As 3	820	7.14	0.38	232.94	21.62	0.12
820 H Total As	820	29.79	16.26	3551.70	64.06	6.62
820 H Total As + HCl	820	27.15	11.21	2667.75	65.33	6.57

H- HydraSleeve™ Sampling bags
W - Wire Line Sampling tool

Appendix
February 2005 Pumping Sampling Event
Arsenic Speciation and Sample Descriptions

SampleID	Description	Al (ppb)	Fe (ppb)	Mn (ppb)	As (ppb)	U (ppb)
EDTA Blank (DI Water)	New method, EDTA-Hac with new columns, DI Water	9.35	1.31	0.95	0.91	0.00
EDTA 1 As 3	New method, EDTA-Hac with new columns, groundwater	8.47	3.06	0.50	9.96	0.41
EDTA 2 As 3	New method, EDTA-Hac with new columns, groundwater	5.05	9.29	1.44	11.75	0.42
EDTA 3 As 3	New method, EDTA-Hac with new columns, groundwater	1.90	4.63	0.45	10.67	0.36
EDTA 4 As 3	New method, EDTA-Hac with new columns, groundwater	4.55	2.75	0.42	9.99	0.39
EDTA 5 As 3	New method, EDTA-Hac with new columns, groundwater	3.49	2.37	0.27	11.14	0.27
Old Method 1 As 3	Old method, old columns	0.19	1.67	0.46	1.02	0.00
Old Method 2 As 3	Old method, old columns	0.12	1.77	0.48	0.64	0.00
Old Method 3 As 3	Old method, old columns	0.15	1.56	0.48	0.77	0.00
Total As Untreated	groundwater only	9.51	8.43	0.30	38.46	1.48
Total As HCl1	0.5 ml of Omni Trace HCl, groundwater (no column)	13.84	15.09	1.05	40.19	1.71
Total As HCl2	0.5 ml of Omni Trace HCl, groundwater (no column)	11.95	9.34	0.96	36.48	1.75
New Filter Old Method Total As	Filter, HCl	10.02	5.13	0.70	34.14	1.27
As 3 Filtered Old Method 1	Filter, HCl, old column	0.12	1.98	0.48	1.45	0.00
As 3 Filtered Old Method 2	Filter, HCl, old column	0.15	2.03	0.45	0.80	0.00
Old Speciation 1 Total As	Old method, HCl	12.67	7.74	0.92	35.17	1.61
Old Speciation 2 Total As	Old method, HCl	16.98	7.76	0.94	34.34	1.69
Old Speciation 3 Total As	Old method, HCl	16.42	8.56	0.99	33.94	1.72

11.3 Kern Water Bank Water Quality Data

Appendix
KWB Wells
Water Quality Data from 1994 thru 2004

SamplingDate	WellNo	As	Ca	Cl	CO3	Fe	HCO3	K	Mg	Na	SO4	NO3	Calc TDS
06/21/94	24A01	0	86	31	0	0	144	0	0	48	135	0	444
04/23/03	24A01	0	230	110	1	0	205	0	3	99	500	nd	1148
06/22/94	30S/25E-04L01	0	28	55	0	398	83	0	1	71	49	26	287
06/22/94	07G01	0	17	14	14	447	56	0	0	36	29	4	166
06/21/94	30S/25E-07P01	0	54	37	0	1391	122	2	2	52	86	14	355
06/21/94	07R01	0	14	10	7	152	71	0	3	31	21	4	157
06/21/94	30S/25E-08P01	0	20	14	0	0	78	0	1	32	29	7	174
04/23/03	30S/25E-08P01	0	68	55	1	0	128	0	1	59	100	nd	412
06/23/94	09A01	0	29	76	10	107	51	0	1	54	21	7	242
06/21/94	30S/25E-09J01	0	54	93	0	279	95	0	1	63	35	19	341
06/21/94	11A01	0	13	13	12	0	61	0	1	32	16	3	148
12/29/03	12C01	0	79	170	1	0	110	2	3	79	40	17	484
03/01/04	30S/25E-13J01	0	40	13	1	0	151	0	2	27	22	5	256
06/20/94	15B01	0	13	26	14	0	51	0	1	36	13	2	154
06/20/94	30S/25E-16P01	0	12	27	10	0	54	0	1	35	13	2	152
06/20/94	16R01	0	11	25	2	1715	59	0	1	40	23	3	161
04/28/03	30S/25E-18P01	0	75	67	1	0	113	0	1	83	180	nd	520
04/16/03	03Q01	1	43	65	1	0	114	0	1	49	28	nd	301
12/16/03	30S/25E-11L01	1	46	78	1	0	97	1	1	54	34	18	312
04/28/03	16D01	1	20	28	2	0	98	0	0	42	35	nd	225
04/24/03	16M01	1	24	32	1	0	79	0	0	41	29	nd	206
04/24/03	30S/25E-16P01	1	30	50	1	0	78	0	1	41	29	nd	230
04/28/03	30S/25E-17F01	1	43	34	1	0	107	0	2	35	47	nd	269
01/08/04	17M01	1	67	40	1	0	150	1	4	44	64	nd	371
04/28/03	18C01	1	52	32	1	0	131	0	2	46	71	nd	335
01/05/04	18K01	1	61	46	1	0	108	1	2	57	100	15	376
12/29/03	17Q01	1	50	25	1	0	137	1	2	30	45	nd	291
12/29/03	19G01	1	40	20	1	0	113	0	1	32	42	nd	249
04/16/03	30S/25E-07P01	2	49	33	0	0	139	0	2	48	59	nd	330
04/16/03	07R01	2	40	37	1	0	99	0	1	49	63	nd	290
04/21/03	09A01	2	32	78	1	0	84	0	0	61	33	nd	289
01/07/04	30S/25E-09J01	2	42	56	1	0	108	1	1	55	35	nd	299
12/16/03	11E01	2	53	65	1	0	146	1	1	53	31	11	351
12/18/03	14E01	2	70	95	1	0	107	0	3	45	47	11	368
03/01/04	15R01	2	35	66	1	0	61	0	1	55	56	11	275
04/28/03	17H01	2	36	36	1	0	95	0	1	43	44	nd	256
04/28/03	30S/25E-17J01	2	25	25	1	0	98	0	1	30	26	nd	206
04/28/03	30S/25E-17P01	2	25	18	2	0	97	0	1	31	25	nd	199
04/28/03	18A01	2	62	40	1	0	154	0	5	40	59	nd	361
04/28/03	18R01	2	54	43	1	0	104	0	2	55	110	nd	369
04/24/03	20A01	2	30	19	1	0	106	0	1	31	24	nd	212
04/24/03	20C01	2	48	44	1	0	120	0	2	46	62	nd	323
04/24/03	21A02	2	30	25	1	0	113	0	1	44	35	nd	249
04/24/03	21D01	2	32	26	1	0	102	0	1	31	25	nd	218
03/01/04	24K01	2	22	15	1	0	101	0	1	43	28	11	211
12/15/03	06N01	2	45	56	1	0	107	1	2	39	31	9	282
03/01/04	20C01	2	38	18	1	0	101	0	2	29	41	12	230
12/18/03	30S/26E-20L01	2	19	23	1	0	61	0	0	41	44	14	189
04/23/03	03Q02	3	41	75	1	0	98	0	1	54	32	nd	302
04/21/03	03R01	3	63	65	1	0	179	0	3	44	32	nd	387
12/17/03	30S/25E-13F01	3	21	18	2	0	79	0	0	36	33	10	189
04/24/03	30S/25E-20L01	3	39	56	1	0	95	0	1	70	93	nd	355
04/28/03	15B01	4	15	38	2	0	61	0	0	41	19	nd	176
04/16/03	06K01	5	16	28	3	0	51	0	0	49	55	nd	202
04/23/03	07G01	5	16	28	2	0	50	0	0	48	56	nd	200
12/17/03	19M01	5	8	22	4	0	67	0	0	51	37	8	189
04/21/03	30S/25E-04L01	6	26	41	1	0	103	0	0	47	29	nd	247
04/21/03	30S/25E-08F01	7	9	28	4	0	61	0	0	45	29	nd	176
04/21/03	30S/25E-08J01	7	21	36	2	0	75	0	0	47	41	nd	222
04/21/03	11A01	7	12	22	3	0	64	0	0	33	16	nd	150
04/16/03	05K01	8	11	30	4	0	64	0	0	48	29	nd	186
06/22/94	30S/25E-08F01	8	10	12	14	1161	46	0	35	35	22	1	174
06/22/94	30S/25E-08J01	9	10	19	19	168	46	0	1	45	30	7	170
12/17/03	30S/25E-13L01	9	4	12	9	0	67	0	0	39	18	4	149
04/24/03	30S/25E-14J01	10	11	24	3	0	64	0	0	41	25	nd	168
04/24/03	15N01	13	24	34	1	0	90	0	0	51	44	nd	244
06/22/94	05K01	17	8	12	38	0	22	0	0	38	24	2	142
04/28/03	30S/25E-16J01	22	15	39	6	0	73	0	0	43	20	nd	196
04/21/03	10K01	34	30	45	1	0	104	0	0	43	27	nd	250
9/5/2000	23H01	63	4	24	1	0	79	0	0	50	14	1	172

nd = no data

11.4 West Kern Water District Well 6-04 Completion Report and Water Quality Data

TRIPLICATE
Owner's Copy

STATE OF CALIFORNIA

WELL COMPLETION REPORT

Refer to Instruction Pamphlet

No. 804804

Page 1 of 1

Owner's Well No. 6-04

Date Work Began 10-9-02, Ended 5-1-03

Local Permit Agency ~~Kern County Environmental Health Services~~

Permit No EH-1412 Permit Date 10-4-02

DWR USE ONLY — DO NOT FILL IN

STATE WELL NO./STATION NO 118

LATITUDE LONGITUDE

APN/TRS/OTHER

GEOLOGIC LOG

ORIENTATION (✓) x VERTICAL ___ HORIZONTAL ___ ANGLE ___ (SPECIFY)

DRILLING METHOD ~~Reverse Circulation~~ FLUID ~~Poly Bore~~

DEPTH FROM SURFACE Ft.	to Ft.	DESCRIPTION *Describe material, grain size, color, etc.*
80	230	sand & gravel
230	240	sand, gravel, & little clay
240	280	~~sand, gravel, & clay~~
280	410	clay & sand
410	420	sand
420	470	clay & sand
470	480	sand
480	600	clay & sand
600	640	sand
640	740	clay & sand
740	760	sand

TOTAL DEPTH OF BORING 760 (Feet)

TOTAL DEPTH OF COMPLETED WELL 560 (Feet)

WELL OWNER

Name ~~West Kern Water District~~

Mailing Address 800 Kern Street

Taft, CA. 93268
CITY STATE ZIP

WELL LOCATION

Address HWY 119 & Tupman Rd

City Bakersfield

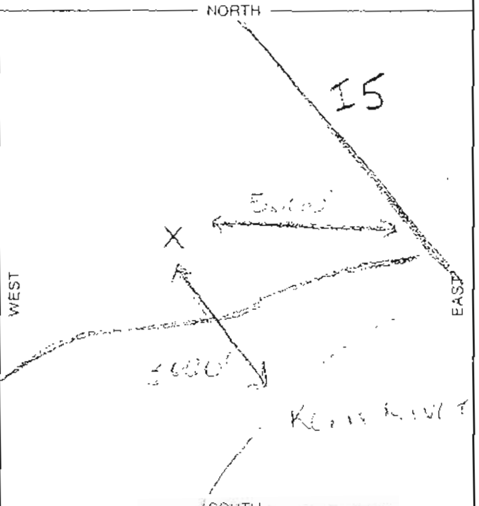
County Kern

APN Book 160 Page 110 Parcel 11

Township 30S Range 25E Section 22M

Latitude ___ NORTH (DEG MIN. SEC) Longitude ___ WEST (DEG MIN. SEC)

LOCATION SKETCH



Illustrate or Describe Distance of Well from Roads, Buildings, Fences, Rivers, etc. and attach a map. Use additional paper if necessary. PLEASE BE ACCURATE & COMPLETE.

ACTIVITY (✓)

x NEW WELL

MODIFICATION/REPAIR
- ___ Deepen
- ___ Other (Specify)

___ DESTROY (Describe Procedures and Materials Under "GEOLOGIC LOG")

PLANNED USES (✓)

WATER SUPPLY
- ___ Domestic x Public
- ___ Irrigation ___ Industrial

MONITORING ___

TEST WELL ___

CATHODIC PROTECTION ___

HEAT EXCHANGE ___

DIRECT PUSH ___

INJECTION ___

VAPOR EXTRACTION ___

SPARGING ___

REMEDIATION ___

OTHER (SPECIFY) ___

WATER LEVEL & YIELD OF COMPLETED WELL

DEPTH TO FIRST WATER 116 (Ft.) BELOW SURFACE

DEPTH OF STATIC WATER LEVEL 116 (Ft.) & DATE MEASURED 12-3-02

ESTIMATED YIELD * 2500 (GPM) & TEST TYPE Pump/Flowmeter

TEST LENGTH 1 (Hrs.) TOTAL DRAWDOWN 230 (Ft.)

* May not be representative of a well's long-term yield

CASING (S)

DEPTH FROM SURFACE Ft.	to Ft.	BORE-HOLE DIA (Inches)	TYPE (✓) BLANK	SCREEN	CON-DUCTOR	FILL PIPE	MATERIAL / GRADE	INTERNAL DIAMETER (Inches)	GAUGE OR WALL THICKNESS	SLOT SIZE IF ANY (Inches)
0	80	42			x		A53 Grade B	36	3/8	
+2	250	32	x				CB A139 B	20	5/16	
250	545	32		x			Louver	20	5/16	.080
545	560	32	x				CB A139 B	20	5/16	
+2	235	32				x	A53 Grade B	4	Sch.40	
+2	245	32					Sounding Tube	2	Sch.40	

ANNULAR MATERIAL

DEPTH FROM SURFACE Ft.	to Ft.	TYPE CE-MENT (✓)	BEN-TONITE (✓)	FILL (✓)	FILTER PACK (TYPE/SIZE)
0	220	x			
220	225		x		SRI
225	570				4x16 Silica
570	610	x			Resourc
610	760			x	

ATTACHMENTS (✓)

- ___ Geologic Log
- ___ Well Construction Diagram
- ___ Geophysical Log(s)
- ___ Soil/Water Chemical Analyses
- ___ Other

ATTACH ADDITIONAL INFORMATION, IF IT EXISTS.

CERTIFICATION STATEMENT

I, the undersigned, certify that this report is complete and accurate to the best of my knowledge and belief.

NAME Bakersfield Well & Pump Co.
(PERSON, FIRM, OR CORPORATION) (TYPED OR PRINTED)

7212 Fruitvale Ave., Bakersfield, CA. 93308
ADDRESS CITY STATE ZIP

Signed ___ 9-23-03 440537
WELL DRILLER/AUTHORIZED REPRESENTATIVE DATE SIGNED C-57 LICENSE NUMBER

DWR 188 REV. 11/97 IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

RECEIVED
JAN - 7 2003
WEST KERN WATER DISTRICT

GEOLOGIC LOG OF DRILL CUTTING FOR WEST KERN WATER DISTRICT WELL NO. 6-04

Depth (feet)	Description
80-95	Brown fine to medium sand
95-160	Brown medium sand
160-168	Brown clay
168-175	Brown medium to coarse sand
175-180	Brown clay
180-215	Brown medium to coarse sand
215-221	Brown clay
221-235	Brown medium sand
235-250	Brown clay
250-280	Brown fine to medium sand
280-287	Brown clay
287-293	Brown medium sand
293-304	Brown clay
304-312	Brown medium sand
312-325	Brown clay
325-335	Brown medium sand
335-364	Brown clay
364-370	Brown medium sand
370-423	Brown and gray clay
423-430	Brown medium sand
430-435	Light brown clay
435-459	Light brown fine to medium sand
459-465	Light brown clay
465-480	Light brown clayey medium sand
480-483	Light brown clay
483-504	Light brown medium sand
504-515	Light brown clay
515-524	Light brown medium sand
524-530	Light brown clay
530-545	Light brown medium sand
545-550	Light brown clay
550-560	Light brown fine to medium sand
560-610	Light brown clay
610-640	Blue-brown medium sand
640-674	Blue-brown clay
674-698	Blue-brown fine to medium sand
698-719	Blue-brown clay
719-738	Blue-brown fine to medium sand
738-750	Blue-brown clay

WEST KERN WATER DISTRICT
WELL # 6-04

DATE - 10-26-02
GPM - 40-50

TIME STARTED Pumping - 10:00pm
PERF - 380'
SEAL - 310'-325'

ZONE 4

TIME	TEMP(F°)	EC(umhos)	Ph	Color	ODOR
6:00Am	68°	141	7.35	CLEAR	N/D
6:20Am	70°	141	7.35	"	"
6:40 Am	70°	141	7.35	"	"
7:00Am	69°	139	7.35	"	"
7:20Am	70°	140	7.35	"	"
7:40Am	70°	140	8.94	"	"
8:00 Am	69°	138	8.91	"	"
8:20 Am	70°	138	8.85	"	"
8:40 Am	70°	138	8.91	"	"
9:00 Am	70°	138	8.89	"	"

SAmples Collected AT 9:00Am

Midway Laboratory Inc.
Petroleum-Industrial-Environmental
315 Main Street P.O. Box 1151
Taft California 93268

RECEIVED
JUN - 9 2003
WEST KERN WATER DISTRICT

State Certificate # 1396
Phone # (661) 765-2364
Fax # (661) 765-6920
E-Mail midlab@gte.net

XC: Gary
Troy

LABORATORY REPORT
ELAP STATE CERT.#1396

CUSTOMER: West Kern Water District
ATTENTION: Gary Hamilton

LOG NUMBER: 6643
DATE RECEIVED: 6/3/03
DATE COMPLETED: 6/4/03
REPORT DATE: 6/4/03

SAMPLE COLLECTION DATE: 6/3/03

SAMPLE DESCRIPTION: Water...as itemized below.

ANALYTICAL PARAMETER: Arsenic

SAMPLE TAKEN DURING FINAL 24 HR PUMPING

RESULTS

Chemical

Log Number	Sample Description	Constituent		Concentration (mg/L)	PQL (mg/L)	Method Number
6318	Well # 6-04	Arsenic	As	0.012	0.002	3113-As B

NOTES:

1) **PQL** = Practical Quantitation Limit is the lowest level that can be reliably achieved within specific limits of precision and accuracy. It also depends upon the size and digestion/analytical techniques employed.
2) **N.D.** = Not Detected

REFERENCES:

1) APHA-AWWA-WPCF, "**Standard Methods for the Examination of Water and Wastewater,**" 18th Edition, copyright 1992.
2) EPA, "**Methods for Chemical Analysis of Water and Wastes,**" 1983 United States Environmental Protection Agency, EPA 600/4-79-020, Revised March 1983

Michael E. Mayfield

Michael E. Mayfield
Laboratory Director
Midway Laboratory

Phone: 661-765-2364
Fax: 661-765-6920

Midway Laboratory Chain Of Custody

315 Main Street
Taft Ca. 93268
Cert # 1396

Project:

Log No: 6643

Company: West Kern Water District
Address: P.O. Box 1105
Taft Ca. 93268
Phone: (661) 763-3151 Fax: (661) 765-4271
Attention: Jerry Pearson
Special Instructions:
Sampler: Client

Analysis Requested:

Lab #	Sample Description	Date /Time		Arsenic								Containers #	Containers Type	Sample Matrix	Rush
	Well 6-04	6-3-03		X								1	P	W	

Reserved for Laboratory Use:

Relinquished by: Received by: Date: 6-3-03 Time: 3:20pm

Relinquished by: Received by: Date: Time:

Container types: G= Glass, M=Metal, P= Plastic, T=Tedlar

Sample Matrix: S= Soil, SL=Sludge, O= Oil, W= Water, G= Gas

LABORATORY REPORT
ELAP STATE CERT.#1396

CUSTOMER: West Kern Water District
ATTENTION: Jerry Pearson

LOG NUMBER: 5882
DATE RECEIVED: 10-23-02
DATE COMPLETED: 10-28-02
REPORT DATE: 10-28-02

SAMPLE DESCRIPTION: Well # 6-04 ZONE 1 720' to 740'

SAMPLE MATRIX: Water

ANALYTICAL PARAMETER: General Mineral Analysis

RESULTS:

Chemical:

Constituent		Concentration (mg/L)	PQL (mg/L)	Method Number
Bicarbonate	HCO_3	46.6	0.2	SM 2320 B
Calcium	Ca	30.2	0.015	SM 3500-Ca B
Carbonate	CO_3	N.D.	0.2	SM 2320 B
Chloride	Cl	490.8	2.0	SM 4500-Cl B
Copper	Cu	N.R.	0.05	SM 3500-Cu B
Fluoride	F^-	0.98	0.05	SM 4500-F^- D
Hardness	$CaCO_3$	81.3	0.1	SM 2340 B
Hydroxide	OH	N.D.	0.2	SM 2320 B
Iron	Fe	N.D.	0.1	SM 3500-Fe B
Magnesium	Mg	1.4	0.0025	SM 3500-Mg B
Manganese	Mn	N.D.	0.05	SM 3500-Mn B
Nitrate	NO_3	N.D.	0.10	SM 4500-NO_3E
Nitrite	NO_2	N.R.	0.01	SM 4500-NO_2B
Sodium	Na	356	0.01	SM 3500-Na B
Sulfate	SO_4	162	5.0	SM 4500-SO_4 E
Zinc	Zn	N.R.	0.025	SM 3500-Zn B

Chemical:

Constituent		Concentration (mg/L)	PQL (mg/L)	Method Number
Arsenic	As	0.081	0.002	SM 3113-As B
Chromium	Cr	N.D.	0.01	SM 3113-Cr B

Physical:

Characteristics	Results	Method Number
Conductivity (μmhos/cm)	1961	SM 2510 B
MBAS (mg/L as LAS, m.w. 316)	N.R.	SM 5540 C
pH	7.64	SM 4500-H^+ B
TDS (mg/L)	1078	SM 2540 C

NOTES:

1) **PQL** = Practical Quantitation Limit is the lowest level that can be reliably achieved within specific limits of precision and accuracy. It also depends upon the size and digestion/analytical techniques employed.
2) **N.D.** = Not Detected
3) **N.R.** = Not Requested

REFERENCES:

1) APHA-AWWA-WPCF, **Standard Methods for the Examination of Water and Wastewater"**, 18th Edition, copyright 1992.
2) EPA, "**Methods for Chemical Analysis of Water and Wastes,"** 1983 United States Environmental Protection Agency, EPA 600/4-79-020, Revised March 1983.

Michael E. Mayfield
Laboratory Director
Midway Laboratory

LABORATORY REPORT
ELAP STATE CERT.#1396

CUSTOMER: West Kern Water District
ATTENTION: Jerry Pearson

LOG NUMBER: 5888
DATE RECEIVED: 10-24-02
DATE COMPLETED: 10-28-02
REPORT DATE: 10-28-02

SAMPLE DESCRIPTION: Well # 6-04 ZONE 2 620' to 640'

SAMPLE MATRIX: Water

ANALYTICAL PARAMETER: General Mineral Analysis

RESULTS:

Chemical:

Constituent		Concentration (mg/L)	PQL (mg/L)	Method Number
Bicarbonate	HCO_3	42.2	0.2	SM 2320 B
Calcium	Ca	2.2	0.015	SM 3500-Ca B
Carbonate	CO_3	15.9	0.2	SM 2320 B
Chloride	Cl	45.1	2.0	SM 4500-Cl B
Copper	Cu	N.R.	0.05	SM 3500-Cu B
Fluoride	F^-	1.04	0.05	SM 4500-F^- D
Hardness	$CaCO_3$	5.5	0.1	SM 2340 B
Hydroxide	OH	N.D.	0.2	SM 2320 B
Iron	Fe	N.D.	0.1	SM 3500-Fe B
Magnesium	Mg	N.D.	0.0025	SM 3500-Mg B
Manganese	Mn	N.D.	0.05	SM 3500-Mn B
Nitrate	NO_3	N.D.	0.10	SM 4500-NO_3E
Nitrite	NO_2	N.R.	0.01	SM 4500-NO_2B
Sodium	Na	55.2	0.01	SM 3500-Na B
Sulfate	SO_4	15.2	5.0	SM 4500-SO_4 E
Zinc	Zn	N.R.	0.025	SM 3500-Zn B

Chemical:

Constituent		Concentration (mg/L)	PQL (mg/L)	Method Number
Arsenic	As	0.092	0.002	SM 3113-As B
Chromium	Cr	N.D.	0.01	SM 3113-Cr B

Physical:

Characteristics	Results	Method Number
Conductivity (µmhos/cm)	296	SM 2510 B
MBAS (mg/L as LAS, m.w. 316)	N.R.	SM 5540 C
pH	9.41	SM 4500-H^+ B
TDS (mg/L)	142	SM 2540 C

NOTES:

1) **PQL** = Practical Quantitation Limit is the lowest level that can be reliably achieved within specific limits of precision and accuracy. It also depends upon the size and digestion/analytical techniques employed.
2) **N.D.** = Not Detected
3) **N.R.** = Not Requested

REFERENCES:

1) APHA-AWWA-WPCF, Standard Methods for the Examination of Water and Wastewater", 18th Edition, copyright 1992.
2) EPA, "Methods for Chemical Analysis of Water and Wastes," 1983 United States Environmental Protection Agency, EPA 600/4-79-020, Revised March 1983.

Michael E. Mayfield
Laboratory Director
Midway Laboratory

LABORATORY REPORT
ELAP STATE CERT.#1396

CUSTOMER: West Kern Water District
ATTENTION: Jerry Pearson

LOG NUMBER: 5894
DATE RECEIVED: 10-24-02
DATE COMPLETED: 10-24-02
REPORT DATE: 10-30-02

SAMPLE DESCRIPTION: Well # 6-04 ZONE 3 515' to 540'

SAMPLE MATRIX: Water

ANALYTICAL PARAMETER: General Mineral Analysis

RESULTS:

Chemical:

Constituent		Concentration (mg/L)	PQL (mg/L)	Method Number
Bicarbonate	HCO_3	76.8	0.2	SM 2320 B
Calcium	Ca	4.8	0.015	SM 3500-Ca B
Carbonate	CO_3	N.D.	0.2	SM 2320 B
Chloride	Cl	16.2	2.0	SM 4500-Cl B
Copper	Cu	N.R.	0.05	SM 3500-Cu B
Fluoride	F	0.96	0.05	SM 4500-F D
Hardness	$CaCO_3$	16.1	0.1	SM 2340 B
Hydroxide	OH	N.D.	0.2	SM 2320 B
Iron	Fe	N.D.	0.1	SM 3500-Fe B
Magnesium	Mg	1.0	0.0025	SM 3500-Mg B
Manganese	Mn	N.D.	0.05	SM 3500-Mn B
Nitrate	NO_3	2.79	0.10	SM 4500-NO_3E
Nitrite	NO_2	N.R.	0.01	SM 4500-NO_2B
Sodium	Na	47.6	0.01	SM 3500-Na B
Sulfate	SO_4	31.1	5.0	SM 4500-SO_4 E
Zinc	Zn	N.R.	0.025	SM 3500-Zn B

Chemical:

Constituent		Concentration (mg/L)	PQL (mg/L)	Method Number
Arsenic	As	0.062	0.002	SM 3113-As B
Chromium	Cr	N.D.	0.01	SM 3113-Cr B

Physical:

Characteristics	Results	Method Number
Conductivity (μmhos/cm)	274	SM 2510 B
MBAS (mg/L as LAS, m.w. 316)	N.R.	SM 5540 C
pH	7.46	SM 4500-H^+ B
TDS (mg/L)	186	SM 2540 C

NOTES:

1) **PQL** = Practical Quantitation Limit is the lowest level that can be reliably achieved within specific limits of precision and accuracy. It also depends upon the size and digestion/analytical techniques employed.
2) **N.D.** = Not Detected
3) **N.R.** = Not Requested

REFERENCES:

1) APHA-AWWA-WPCF, Standard Methods for the Examination of Water and Wastewater", 18th Edition, copyright 1992.
2) EPA, "Methods for Chemical Analysis of Water and Wastes," 1983 United States Environmental Protection Agency, EPA 600/4-79-020, Revised March 1983.

Michael E. Mayfield
Laboratory Director
Midway Laboratory

LABORATORY REPORT
ELAP STATE CERT.#1396

CUSTOMER: West Kern Water District
ATTENTION: Jerry Pearson

LOG NUMBER: 5898
DATE RECEIVED: 10-26-02
DATE COMPLETED: 10-30-02
REPORT DATE: 10-30-02

SAMPLE DESCRIPTION: Well # 6-04 ZONE 4 360' to 380'

SAMPLE MATRIX: Water

ANALYTICAL PARAMETER: General Mineral Analysis

RESULTS:

Chemical:

Constituent		Concentration (mg/L)	PQL (mg/L)	Method Number
Bicarbonate	HCO_3	48.8	0.2	SM 2320 B
Calcium	Ca	1.7	0.015	SM 3500-Ca B
Carbonate	CO_3	10.1	0.2	SM 2320 B
Chloride	Cl	6.0	2.0	SM 4500-Cl B
Copper	Cu	N.R.	0.05	SM 3500-Cu B
Fluoride	F^-	0.33	0.05	SM 4500-F^- D
Hardness	$CaCO_3$	5.5	0.1	SM 2340 B
Hydroxide	OH	N.D.	0.2	SM 2320 B
Iron	Fe	N.D.	0.1	SM 3500-Fe B
Magnesium	Mg	0.3	0.0025	SM 3500-Mg B
Manganese	Mn	N.D.	0.05	SM 3500-Mn B
Nitrate	NO_3	N.D.	0.10	SM 4500-NO_3E
Nitrite	NO_2	N.R.	0.01	SM 4500-NO_2B
Sodium	Na	32.7	0.01	SM 3500-Na B
Sulfate	SO_4	12.2	5.0	SM 4500-SO_4 E
Zinc	Zn	N.R.	0.025	SM 3500-Zn B

Chemical:

Constituent		Concentration (mg/L)	PQL (mg/L)	Method Number
Arsenic	As	0.020	0.002	SM 3113-As B
Chromium	Cr	N.D.	0.01	SM 3113-Cr B

Physical:

Characteristics	Results	Method Number
Conductivity (μmhos/cm)	169	SM 2510 B
MBAS (mg/L as LAS, m.w. 316)	N.R.	SM 5540 C
pH	9.33	SM 4500-H^+ B
TDS (mg/L)	104	SM 2540 C

NOTES:

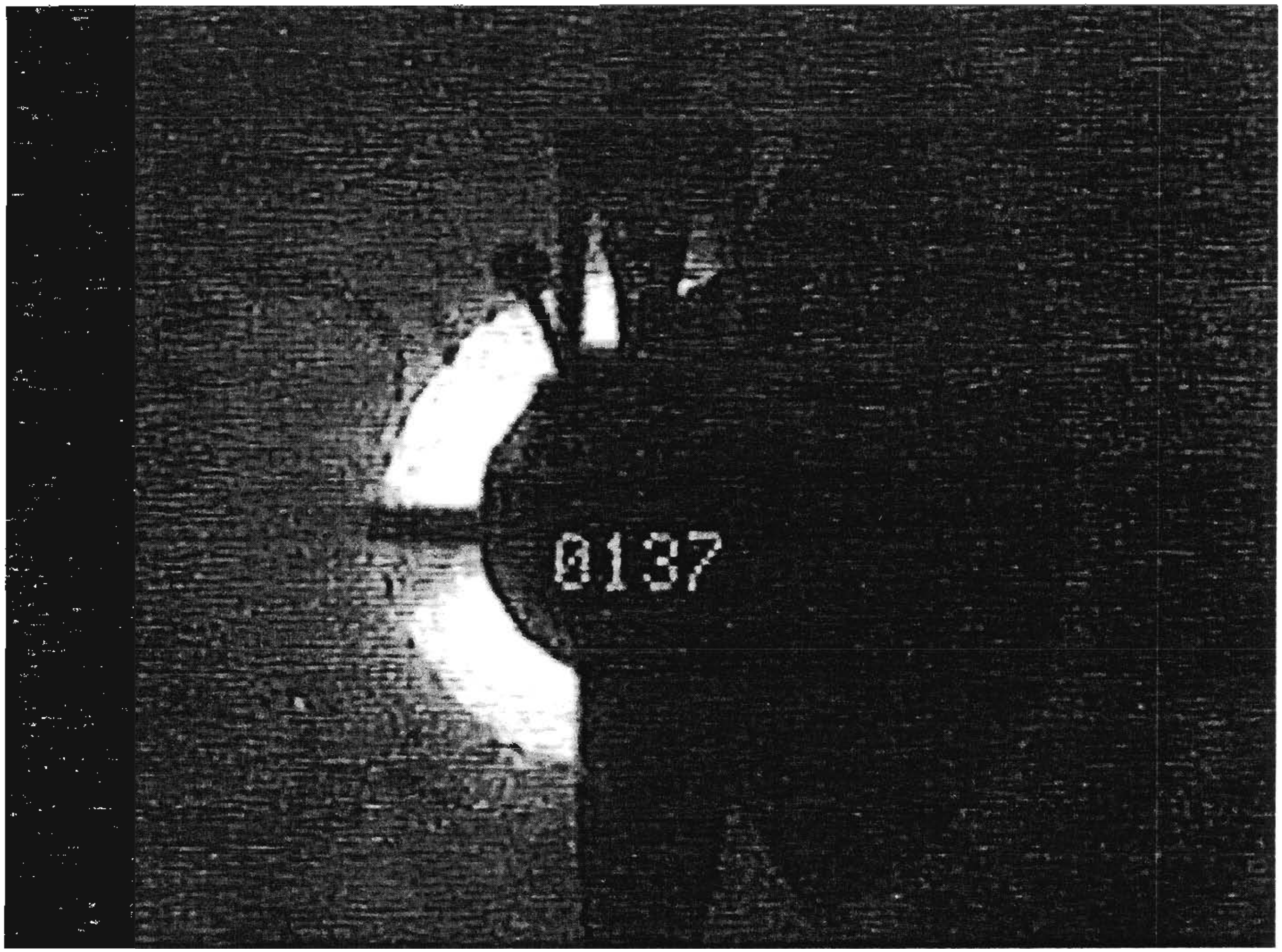
1) **PQL** = Practical Quantitation Limit is the lowest level that can be reliably achieved within specific limits of precision and accuracy. It also depends upon the size and digestion/analytical techniques employed.
2) **N.D.** = Not Detected
3) **N.R.** = Not Requested

REFERENCES:

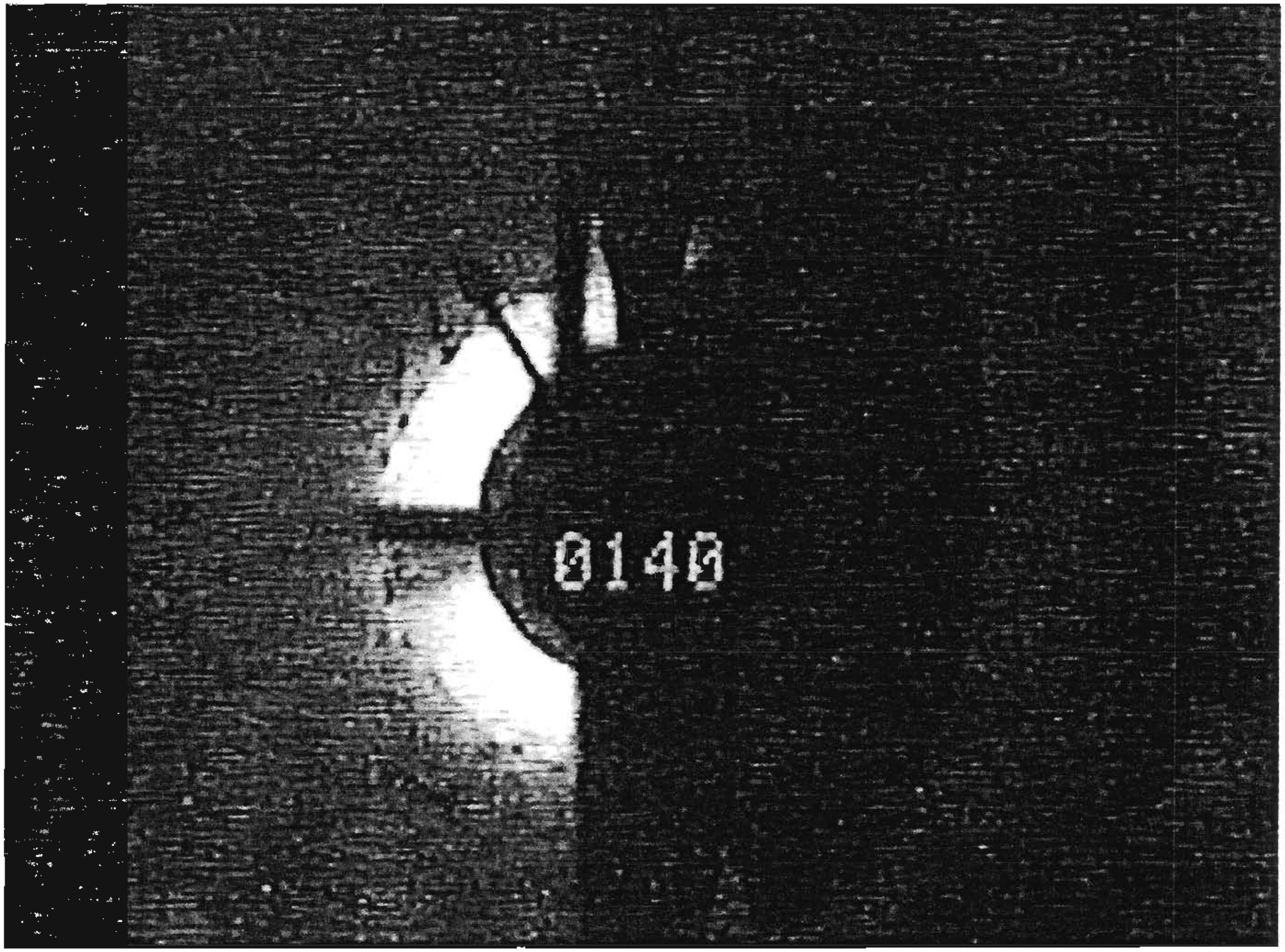
1) APHA-AWWA-WPCF, **Standard Methods for the Examination of Water and Wastewater"**, 18th Edition, copyright 1992.
2) EPA, "**Methods for Chemical Analysis of Water and Wastes,"** 1983 United States Environmental Protection Agency, EPA 600/4-79-020, Revised March 1983.

Michael E. Mayfield
Laboratory Director
Midway Laboratory

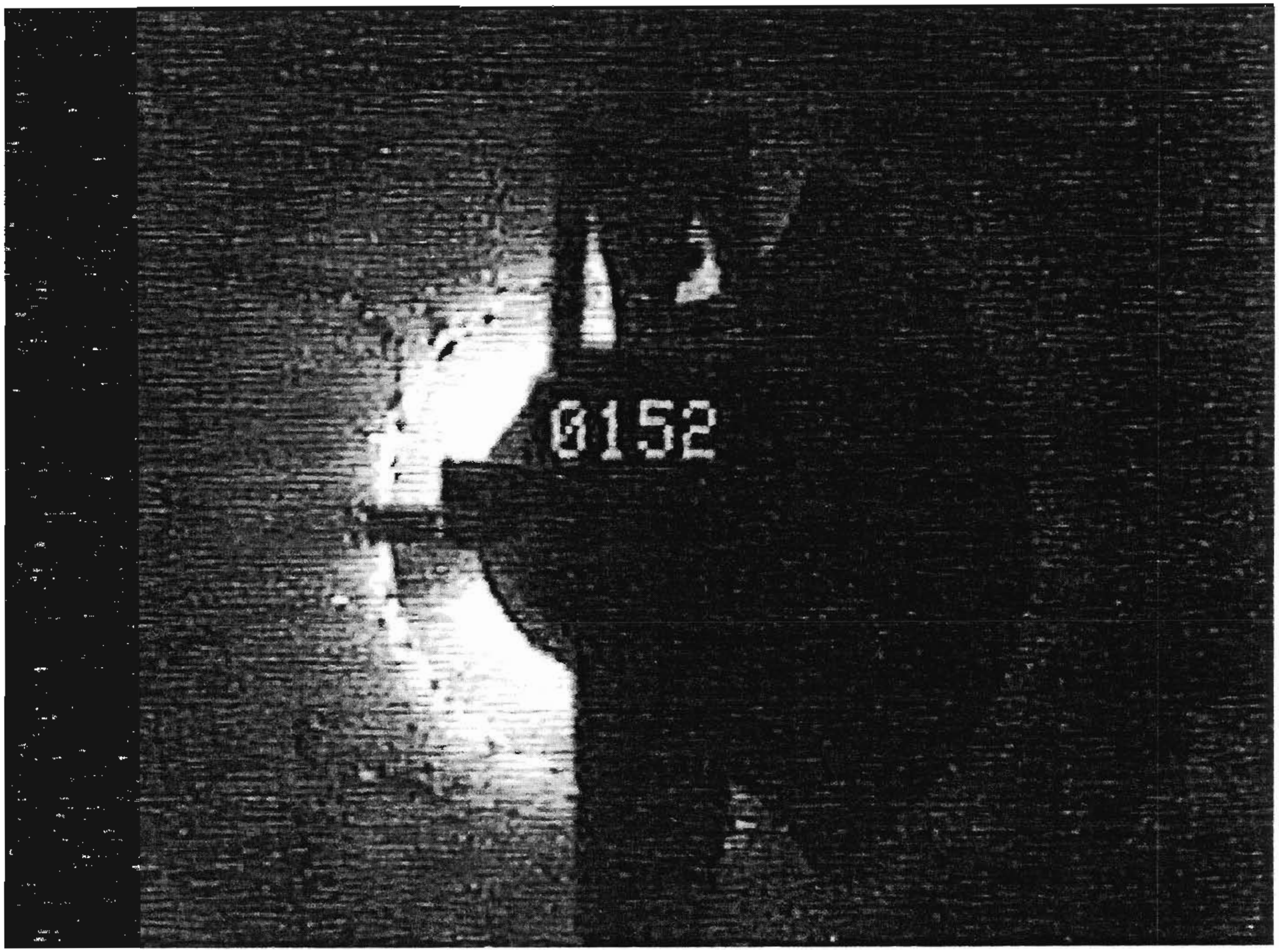
11.5 FloVision Flowmeter Images



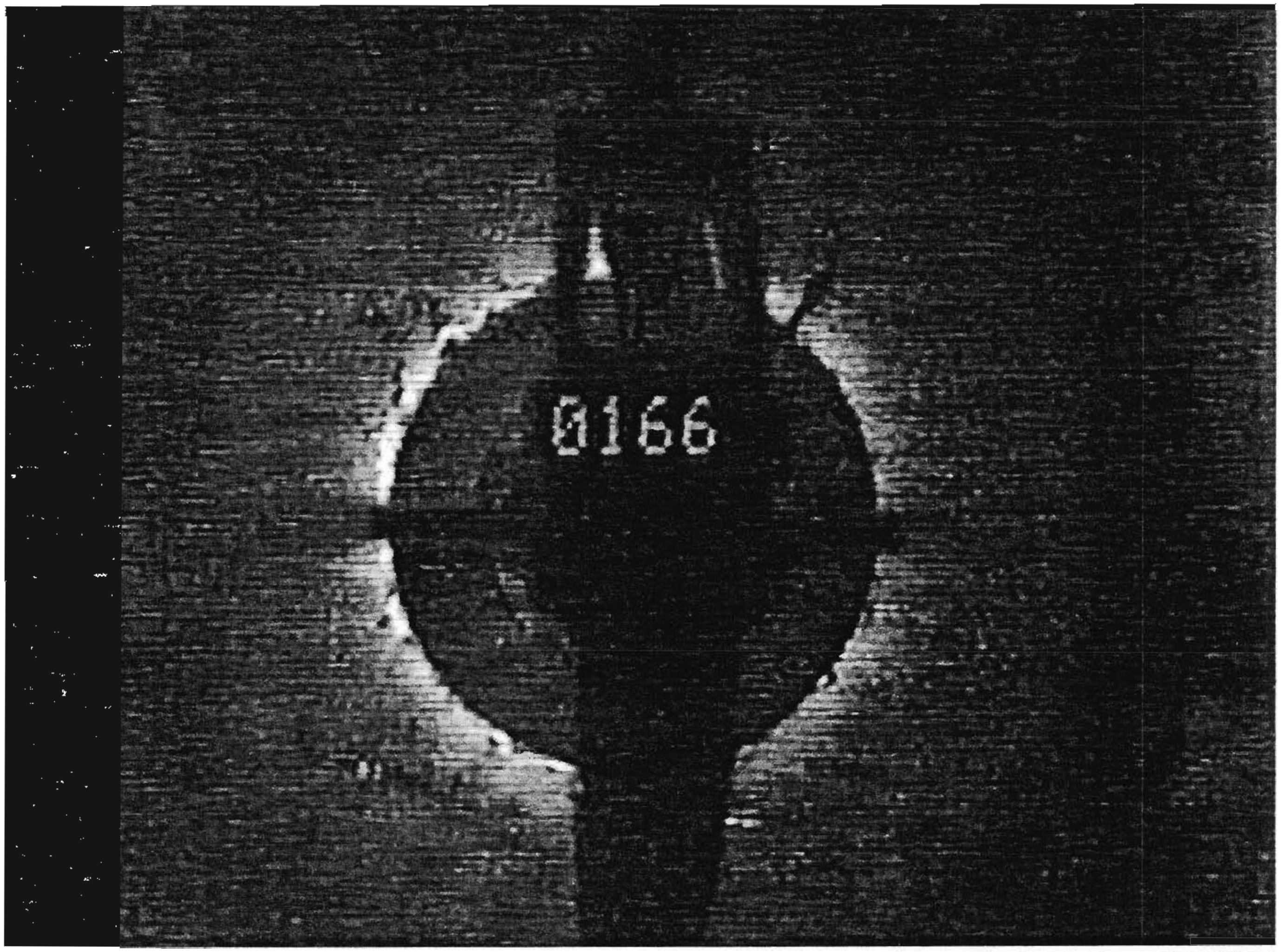
137' - 4 ft below static water level. Water still flowing up, but much slower as can be seen from lesser sensor plate deflection.



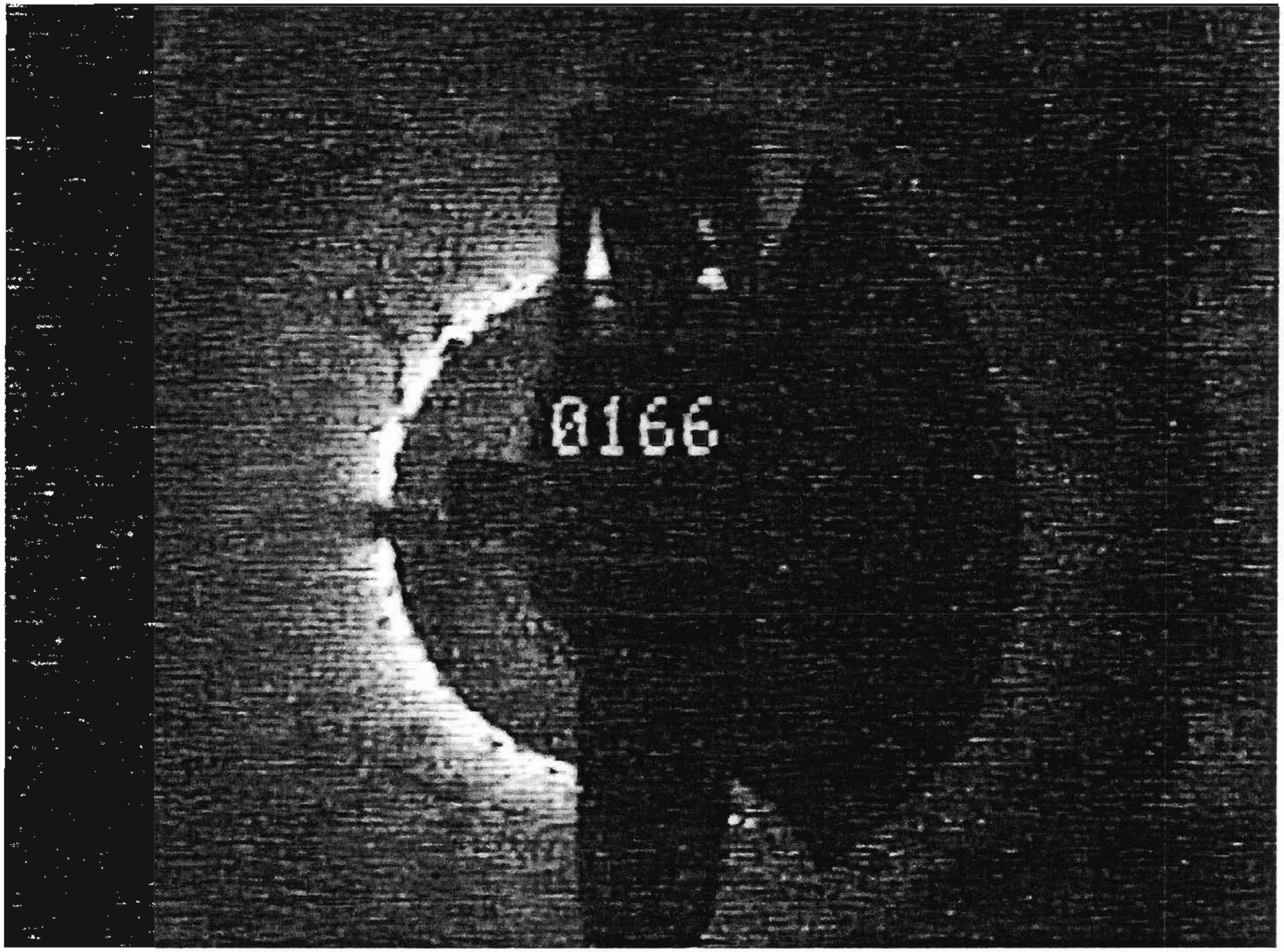
140' - By comparison with deflection at 153 ft depth, at this depth water is flowing with similar speed.



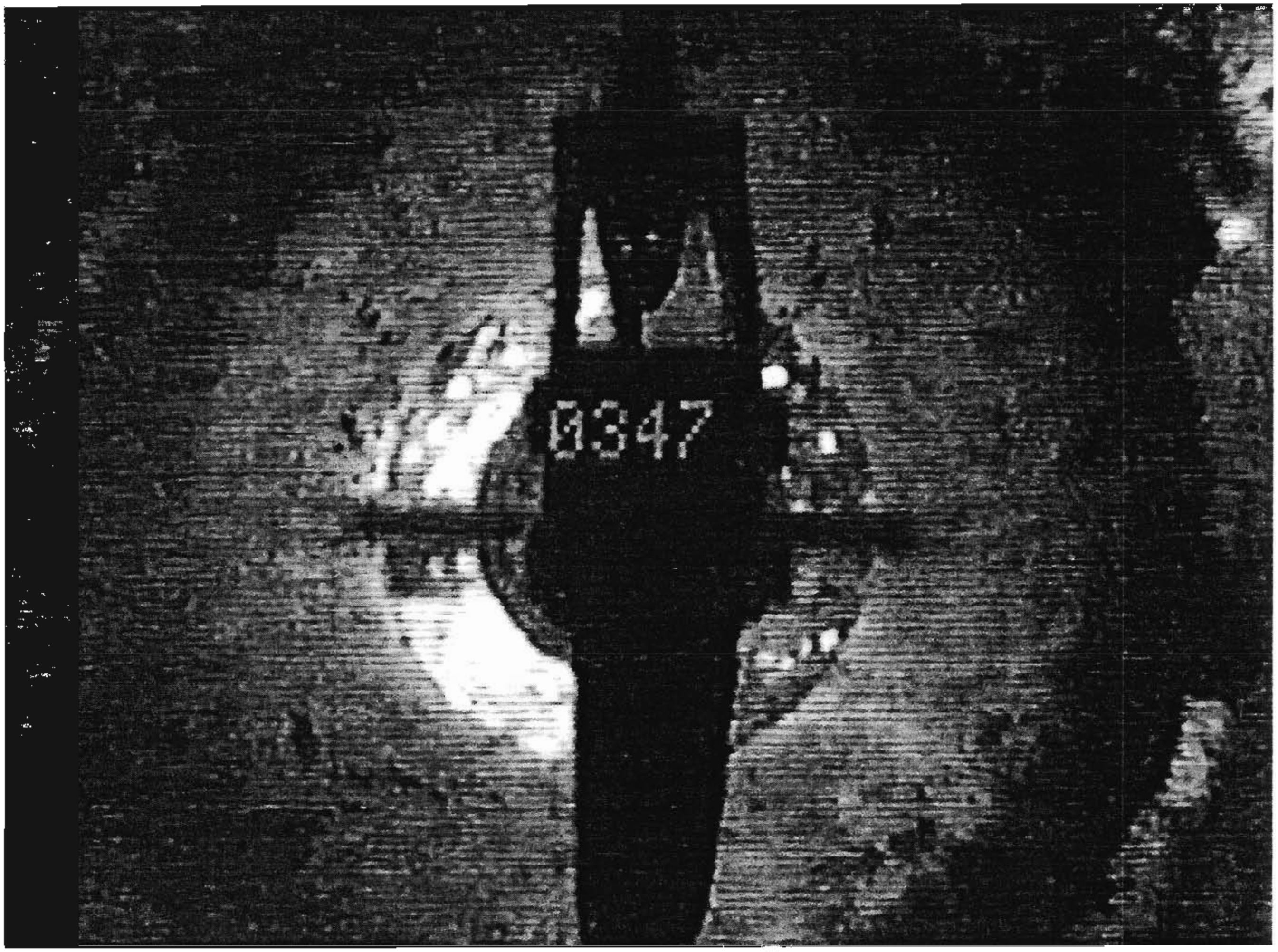
152' - FloVision following water speed during measurement run. Goal - keep pointer as close to center of the window as possible.



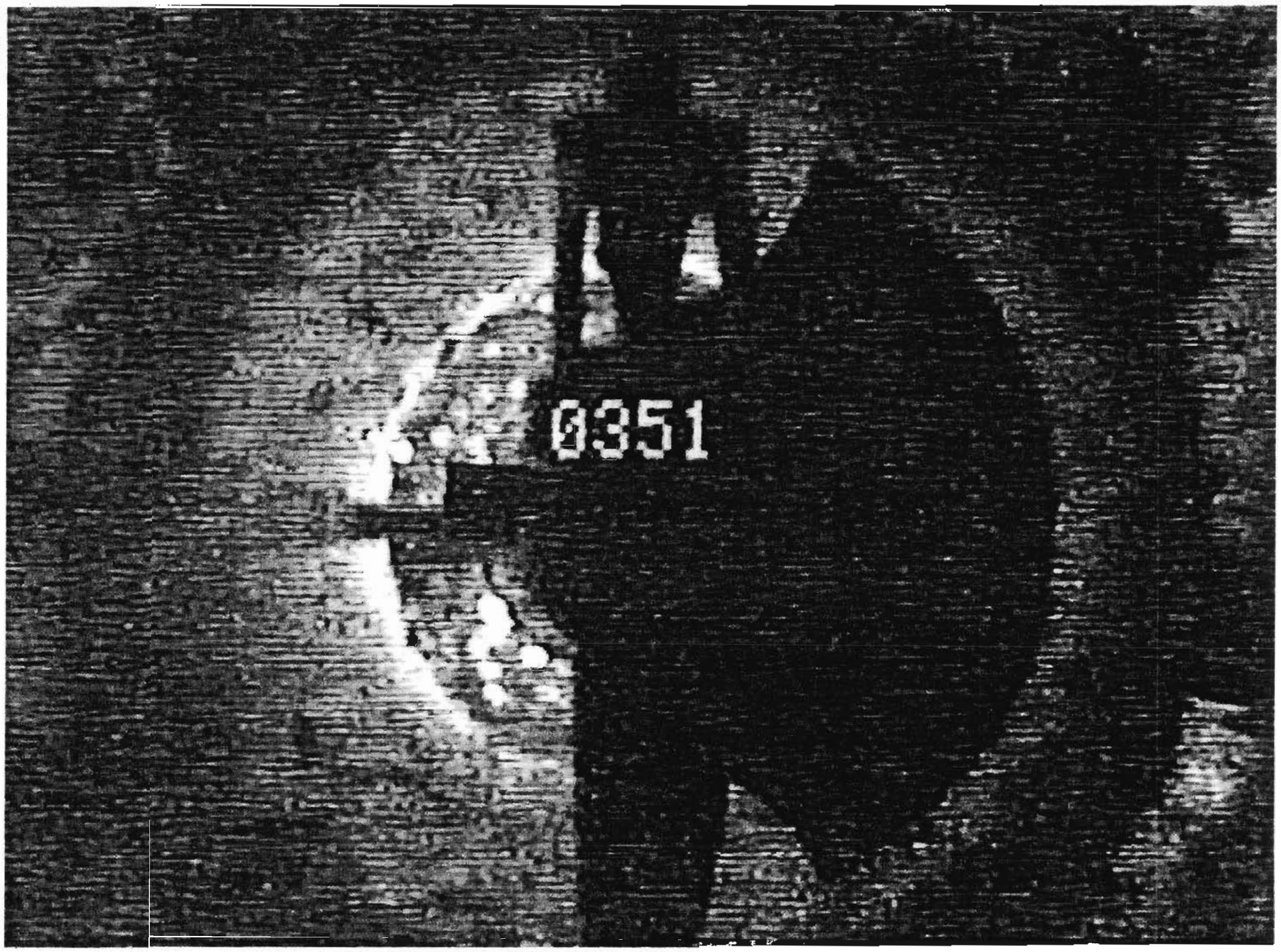
166' - Just before starting next measurement.



166A' - Following down water flow. Result: 0.64 fpm down flow.



347' – Down flow 10 fpm. FloVision stationary, preparing to start measurement. Sensor plate fully deflected. Pointer visible on right.



351' - Following 10 fpm down flow.