

## ABSTRACT

### IDENTIFICATION OF THE SOURCE OF H<sub>2</sub>S AND CHARACTERIZATION OF VERTICAL GROUNDWATER-CHEMISTRY TRENDS IN THE SAN JOAQUIN VALLEY'S UNCONFINED AQUIFER

The San Joaquin Valley's (Valley) unconfined aquifer (Aquifer) is saturated with hydrogen sulfide (H<sub>2</sub>S) contaminated groundwater that has no verified source. H<sub>2</sub>S in the Aquifer was initially observed by Mendenhall et al. in 1916, but no thorough investigations into the source of H<sub>2</sub>S have been conducted. As a result, the surficial and vertical extent of H<sub>2</sub>S has not been estimated. To estimate surficial extent this study compiled H<sub>2</sub>S data from the water-quality databases of the National Water Quality Monitoring Council and the California State Water Resources Control Board. Based on the estimated H<sub>2</sub>S extent and the Aquifer's hydrogeologic characteristics this study hypothesized that H<sub>2</sub>S was generated as a byproduct of microbial mediated sulfate-reduction. Bacterial sulfate-reduction (BSR) is associated with the ecological succession of the terminal electron accepting processes (TEAP). This study classified the predominant TEAP in groundwater by measuring the concentration of redox related constituents and comparing results to the known evolution of microbial reduction. Results demonstrated the progressive depletion of dissolved oxygen, manganese, and iron from 50 to 200-feet (ft) below ground surface (bgs). From 200 to 240-ft bgs, these constituents, plus sulfate, were abruptly removed from the groundwater system due to the onset of BSR resulting in the initial detection of aqueous H<sub>2</sub>S. At 240-ft bgs, the depletion of sulfate, production of H<sub>2</sub>S, detection of sulfate-reducing bacteria (SRB), and the assigned sulfate-reducing TEAP were sufficient evidence to unambiguously conclude that the Aquifer's source of H<sub>2</sub>S is H<sub>2</sub>S generated as a byproduct of BSR mediated by SRB. In the future, the defined vertical groundwater-chemistry trends of redox related constituents can predict whether H<sub>2</sub>S is actively being produced within a portion of the Aquifer.

Benjamin Gooding  
August 2019



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OF VERTICAL GROUNDWATER-CHEMISTRY TRENDS IN THE  
SAN JOAQUIN VALLEY'S UNCONFINED AQUIFER

by  
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APPROVED

For the Department of Earth and Environmental Sciences:

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## 1. INTRODUCTION

The San Joaquin Valley (Valley) basin in California is virtually one large water-bearing sediment filled trough between the Coast Ranges to the west and the Sierra Nevada to the east (Faunt et al., 2010). The basin is separated by a broad confining unit creating a shallow unconfined aquifer, extending from ground surface to 400-feet (ft) below ground surface (bgs), and a deeper confined aquifer (Croft, 1972). Today we know that a portion of the Valley's unconfined aquifer (Aquifer) is saturated with hydrogen sulfide ( $H_2S$ ) contaminated groundwater (Davis and Poland, 1957), but the spatial extent and source of  $H_2S$  is not well understood (Fram, 2017). The presence of  $H_2S$  in the Aquifer has been noted in reports as early as 1916 (Mendenhall et al., 1916), and subsequently noted in other studies related to general Aquifer conditions or redox processes (Fram, 2017; Chapelle et al., 1995; McMahon and Chapelle, 2008). However, a single source or other possible sources of  $H_2S$  have yet to be verified, leaving open questions about the biogeochemical conditions and the extent to which these conditions exist in the Aquifer.

$H_2S$  is common in groundwater aquifers with varying hydrogeologic characteristics. It is thought that the presence of  $H_2S$  in a wide array of aquifers is due to the vast number of potential  $H_2S$  sources, which are commonly associated with bacterial or thermochemical sulfate-reduction (Machel et al., 1995; Machel, 2001; McMahon and Chapelle, 2008). However, previous studies have investigated the source of  $H_2S$ , in aquifers with hydrogeological characteristics comparable to the Valley's Aquifer and concluded that the primary source of  $H_2S$  was  $H_2S$  generated as a byproduct of bacterial sulfate-reduction (BSR) mediated by sulfate reducing bacteria (SRB) in groundwater. These aquifers included the Mahomet aquifer system in Illinois, composed of Pleistocene sediments deposited in an ancient river valley by continental glaciation, a glacial outwash

aquifer in Minnesota, and the Black Creek aquifer in South Carolina, composed of unconsolidated clastic sediments and carbonate shell material (Chapelle et al., 1995; Kirk et al., 2004; McMahon et al., 2011). Specific hydrogeological characteristics of each aquifer varied but each contained a well-defined groundwater path where groundwater age increased with distance along the flow path or with increased aquifer depth (Chapelle et al., 1995; Kirk et al., 2004; McMahon et al., 2011). Groundwater-chemistry trends along these paths varied between aquifers, depending on sediment composition, recharge source, and the evolution of redox processes (Chapelle et al., 1995; Kirk et al., 2004; McMahon et al., 2011). The evolution of redox processes followed the terminal electron accepting processes (TEAP) with H<sub>2</sub>S in each aquifer being generated as a byproduct of BSR, facilitated by microorganisms, which gains energy for growth through the reduction of sulfate (Chapelle et al., 1995; Jurgens et al., 2009; Kirk et al., 2004; McMahon et al., 2011). This study hypothesized that H<sub>2</sub>S in the Valley's Aquifer was a byproduct of similar sulfate-reducing processes and the primary purpose of this study was to confirm this hypothesis through methodology that included, among others, defining vertical groundwater-chemistry trends and redox process evolution.

## 2. BACKGROUND

Gaseous and aqueous H<sub>2</sub>S generation may occur under diverse environmental conditions resulting in several potential H<sub>2</sub>S sources. A majority of these sources within groundwater aquifers are related to bacterial, and to a lesser extent thermochemical, sulfate-reducing processes. The H<sub>2</sub>S source affecting groundwater aquifers is generally dependent on the biogeochemical and hydrogeological characteristics of the aquifer portion saturated with H<sub>2</sub>S. This study compiled available data and information to define the Aquifer's biogeochemical and hydrogeological characteristics. This was completed by approximating the spatial extent of H<sub>2</sub>S and subsequently defining the primary lithologic units, groundwater conditions, and the primary sources of sulfate within the approximated H<sub>2</sub>S extent. Through the review of previous studies concerning the source of H<sub>2</sub>S, in aquifers characteristically comparable to the Aquifer, the potential sources of H<sub>2</sub>S were narrowed to a single hypothesized source, bacterial sulfate-reduction, facilitated by microorganisms, to gain energy for growth (Chapelle et al., 1995; Kirk et al., 2004; McMahon et al., 2011). The primary purpose of this study was to confirm the hypothesized H<sub>2</sub>S source which initially required approximating the spatial extent of H<sub>2</sub>S within the Aquifer, characterizing the Aquifer's hydrogeological characteristics, knowledge of the general bacterial sulfate-reduction process, and defining a viable study area prior to the development of required methodology.

### 2.1 Approximate H<sub>2</sub>S Spatial Extent

To approximate the spatial extent of H<sub>2</sub>S groundwater-chemistry data was compiled from the National Water Quality Monitoring Council's (NWQMC) groundwater quality database (Survey et al., 2019). Data was compiled from the NWQMC's database due to the availability of total depth and perforation interval information for queried wells which other databases, such as the State Water Resources

Control Board's (SWRCB) Groundwater Ambient Monitoring and Assessment Program (GAMA) and Drinking Water Branch's databases, commonly lack. Compiled data included H<sub>2</sub>S sniff and concentration analysis results from wells within a 50-mile radius of the City of Mendota. Available H<sub>2</sub>S concentration data was minimal and these data points were converted to either extracting or not extracting, based on the detection or non-detection of H<sub>2</sub>S. Compiled H<sub>2</sub>S data and site information is included in Appendix A.

The location of groundwater wells extracting H<sub>2</sub>S contaminated groundwater and wells not extracting H<sub>2</sub>S contaminated groundwater, in addition to other boundaries, are included in Figure 1. As Figure 1 demonstrates, approximating the extent of H<sub>2</sub>S within the Aquifer is difficult due to the inconsistent patterning of wells extracting H<sub>2</sub>S contaminated groundwater. However, the general extent of H<sub>2</sub>S is within and along the Valley trough, which is the general low point of the Valley. The vertical extent of H<sub>2</sub>S was estimated based on well information (i.e. perforation interval) of wells near cross-section line A-A' illustrated in Figure 1. Nine wells with H<sub>2</sub>S data were present along this cross-section line. Figure 2 includes the location, total depth, and depth to top perforation, of each well, in reference to the primary lithologic units within the Valley trough. These wells illustrate that gaseous H<sub>2</sub>S is present within a majority of the Aquifer where the clay units are present, which is generally within the Valley trough. H<sub>2</sub>S was non-detect in shallow groundwater to the southwest outside of the A-Clay's extent and to the northeast in deeper groundwater. This indicates that the presence and generation of H<sub>2</sub>S is associated with the Aquifer's hydrogeological characteristics within the Valley trough.

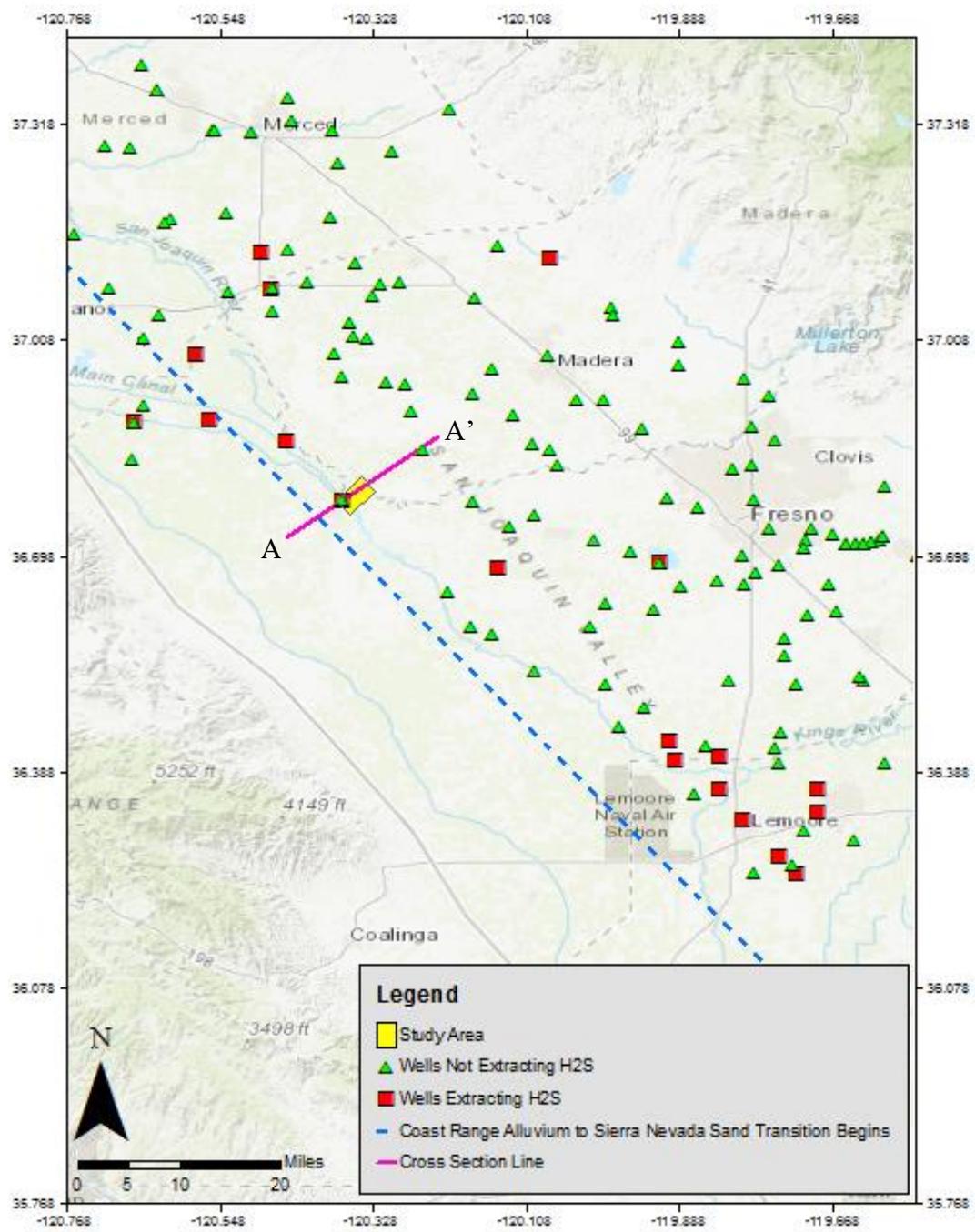


Figure 1 – Location of wells previously analyzed for H<sub>2</sub>S

*Note:* Figure 1 illustrates groundwater well locations in the central San Joaquin Valley that have previously undergone H<sub>2</sub>S analysis. Data was compiled from the NWQMC’s database (Survey et al., 2019). Analysis was conducted between 2005 and 2018 with a total of 178 wells measured with 19 wells extracting H<sub>2</sub>S contaminated groundwater. Total depth of these 19 wells ranged from 73 to 395-ft. The estimated transition boundary and cross-section line demonstrated within Figure 1 are illustrated in Figure 2.

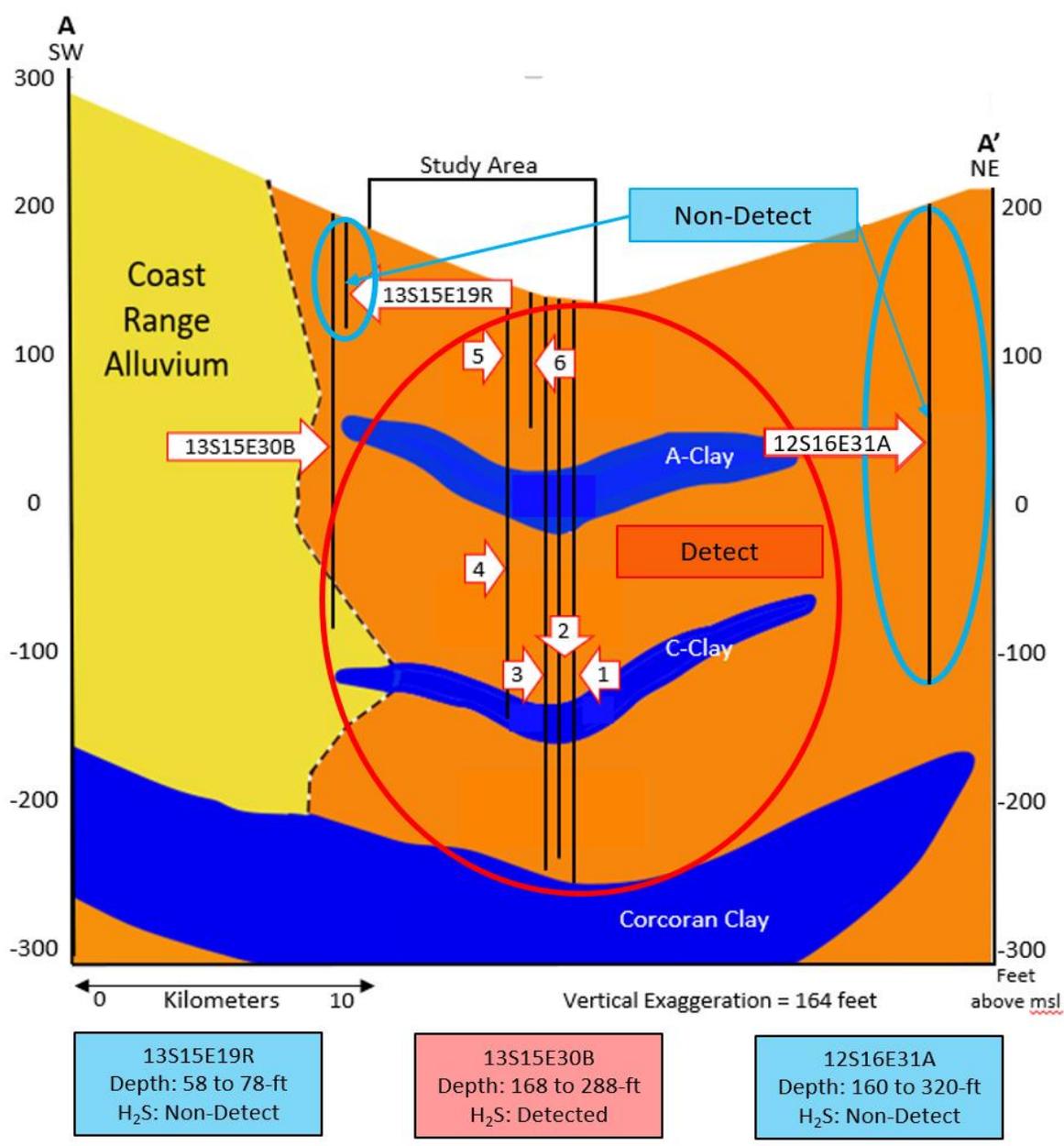


Figure 2 – Depth and extent of the aquifer’s primary lithologic units and approximated H<sub>2</sub>S extent

*Note:* Generalized cross-section in the southwest-northeast direction along the A-A’ line illustrated in Figure 1. The cross-section demonstrates the depth and extent of the semi-confining units which were approximated from United States Geological Survey (USGS) surficial mapping (Croft, 1972). The dashed boundary between the Coast Range alluvium and Sierra Nevada sands is representative of where Aquifer sediments begin to transition, estimated from Fram, 2017. Also depicted are the depths of Well 1 through Well 6 sampled during this study and three additional wells plotted in Figure 1. Arrows pointing at each well are the approximate depth to top perforation. The red boundary is the estimated gaseous H<sub>2</sub>S and the blue boundary is the estimated aqueous H<sub>2</sub>S extent.

## 2.2 General Lithologic Characteristics

The San Joaquin Valley basin contains two primary lithologic units, the Coast Range alluvium and the Sierra Nevada sands which are separated by several confining to semi-confining clay units (Croft and Gordon, 1968). Together these units create the Pleistocene to Pliocene aged, unconsolidated, and non-marine alluvial deposits of the Tulare Formation (Fram, 2017). The Sierra Nevada sands are composed of well-sorted micaceous and calcareous sediments, containing iron and manganese-bearing silicate and oxide minerals, that are chemically reduced, older, and more permeable than the Coast Range alluvium (Fram, 2017). The Coast Range alluvium is younger, chemically oxidized, and less permeable than the Sierra Nevada sands (Fram, 2017). The Coast Range alluvium extends from the Coast Range-Valley contact to approximately 20-kilometers east where it then transitions into the Sierra Nevada sands (Fram, 2017).

The confining to semi-confining units pertinent to this study include the Corcoran Clay, the overlying C-Clay, and the shallower A-Clay. These units were primarily deposited in lacustrine and marsh environments within the Valley trough, except for the Corcoran Clay which extends outside of the trough, and are generally characterized as containing organic-rich, reduced, and fine-grained sediments (Croft, 1972; Fram, 2017). The Corcoran Clay defines the base of the Aquifer and is approximately 400-ft bgs, within the Valley's trough (Davis and Poland, 1957). The A-Clay acts as an aquitard and previous studies have generally split the Aquifer into an unconfined sub-aquifer above the A-Clay and a semi-confined sub-aquifer below the A-Clay (Croft and Gordon, 1968). Beneath the A-Clay is the C-Clay, which does not have comparable impacts on the Aquifer, and previous studies generally have not characterized the C-Clay as further separating the Aquifer into three sub-aquifers (Croft and Gordon, 1968; Schmidt, 2011).

### 2.3 Groundwater Characteristics

The Coast Range alluvium and the Sierra Nevada sands have varied hydrogeologic and groundwater-chemistry characteristics. Coast Range alluvium was derived from the erosion of shales and marine deposits within the Coast Ranges and is composed of fine grained sediments with low hydraulic conductivity. Groundwater originating as surficial runoff from the Coast Ranges generally contains elevated sulfate, chloride, and total dissolved solid concentrations compared to runoff originating from the Sierra Nevada (Thiros et al., 2010). The Sierra Nevada sands were derived from the erosion of crystalline rocks that were deposited as alluvial fans, composed of coarser grained sediments with hydraulic conductivity values two to three times greater than the Coast Range alluvium (Fram, 2017; Thiros et al., 2010). Groundwater originating as surficial runoff from the Sierra Nevada sands contains total dissolved solid concentrations of generally less than 500 milligrams per liter (mg/l) (Fram, 2017; Thiros et al., 2010).

Groundwater is recharged from different sources above and below the A-Clay. Above the A-Clay, pumping of deeper groundwater has created vertically downward flow paths and groundwater is recharged primarily from irrigation return flows, the San Joaquin River, and other minor sources (Bertoldi et al., 1991; Davis and Poland, 1957; Schmidt, 2011). Beneath the A-Clay groundwater receives vertical recharge from similar sources in addition to horizontal recharge originating as seepage from west-side and east-side streams due to the northeastward or southwestward slope of the water table (Bertoldi et al., 1991; Davis and Poland, 1957; Schmidt, 2011). The differing recharge sources results in the Aquifer being saturated with groundwater above the A-Clay that was recharged after 1952, and below the A-Clay being saturated with groundwater that was either recharged prior to 1952 or a mix of groundwater recharged prior to and after 1952 (Fram, 2017). This results in the Aquifer's general trend of groundwater age increasing

with increased depth bgs. Groundwater age was classified as being recharged before or after 1952 due to analysis being based on tritium values (Fram, 2017). Above ground nuclear testing, which began in approximately 1952, resulted in a large increase in tritium concentrations in precipitation allowing tritium values to be used to differentiate between precipitation recharged prior to and after 1952 (Fram, 2017). A majority of potential H<sub>2</sub>S sources involve the reduction of sulfate, either bacterial or thermochemical, indicating that the availability of sulfate in groundwater is a pertinent characteristic required for the continued generation of H<sub>2</sub>S.

#### 2.4 Primary Source of Sulfate

The Aquifer's primary source of sulfate is the dissolution of sulfate salts into surface water runoff originating from the Coast Ranges and its secondary sources include the dissolution of gypsum, applied as a soil amendment, into runoff prior to recharging the Aquifer and the dissolution of gypsiferous Aquifer sediments (Croft, 1972; Fram, 2017; Presser et al., 1990). Exposed sedimentary rocks along the eastern edge of the Coast Ranges are composed of Cretaceous to Miocene aged sedimentary units composed of organic rich, pyrite-bearing, and siliceous marine shales (Fram, 2017). The subaerial exposure of these shales results in the oxidation of pyrite to sulfate which re-precipitates as calcium, magnesium, and sodium sulfate minerals into soils and sediments along the western portion of the Valley (Presser et al., 1990). These sulfate salts are dissolved by surficial runoff which subsequently enters the Aquifer as recharge near the Coast Range-Valley contact (Fram, 2017). Groundwater originating from this portion of the Valley has historically migrated vertically downward then horizontally toward the Valley trough (Fram, 2017). The presence of a continuous source of sulfate coupled with the Aquifer's hydrogeological characteristics narrowed the potential H<sub>2</sub>S sources and allowed a hypothesized source to be defined.

## 2.5 Hypothesized H<sub>2</sub>S Source

This study hypothesized that the source of H<sub>2</sub>S was bacterial sulfate reduction mediated by sulfate reducing bacteria resulting in the generation of H<sub>2</sub>S. The processes associated with BSR include those associated with the terminal electron accepting processes (TEAP). Understanding the TEAP, the aquifer conditions where sulfate is the predominate electron acceptor, and the BSR reaction products and byproducts assist with determining whether BSR is actively generating H<sub>2</sub>S within the Aquifer (Jurgens et al., 2009; McMahon et al., 2011).

### 2.5.1 TEAP Related Bacterial Reduction

Bacterial reduction in groundwater is associated with the availability of electron acceptors and donors (Jurgens et al., 2009). Redox conditions in groundwater are generally facilitated by microorganisms that gain energy for growth by transferring electrons from donors, commonly organic carbon, to acceptors, a group of inorganic species (Jurgens et al., 2009). These acceptors are characterized as terminal electron acceptors with the most common acceptors in groundwater being dissolved oxygen (O<sub>2</sub>), nitrate (NO<sup>3-</sup>), manganese (Mn<sup>4+</sup>), iron (Fe<sup>3+</sup>), sulfate (SO<sub>4</sub><sup>2-</sup>), and carbon dioxide (CO<sub>2(g)</sub>) (Jurgens et al., 2009).

Each electron acceptor provides differing amounts of energy to the microorganisms facilitating reduction (Jurgens et al., 2009). The electron acceptor species that yield the most energy are reduced first and the species that yield less are utilized in order of decreasing energy gain (Jurgens et al., 2009). Thus, in groundwater, the common ecological succession of electron acceptors is dissolved oxygen, nitrate, iron, sulfate, and carbon dioxide (Jurgens et al., 2009). This sequence is known as the TEAP where redox processes are defined based on the concentrations of the primary electron acceptors and the energy each species yields (Table 1) (Appelo and Postma, 2005; Jurgens et al., 2009).

Table 1 – Energy Gain from the Reduction of Electron Accepting Species

Redox Process	Released Energy (kJ/mol H <sub>2</sub> )
Dissolved Oxygen	-237
Nitrate	-224
Iron	-50
Sulfate	-38
Carbon Dioxide	-36

*Note:* Based on the reaction between H<sub>2</sub> and electron acceptors under standard conditions at pH 7.

The TEAP is controlled by the ability of differing microorganisms to thrive in groundwater depending on the availability of electron donors and electron acceptors (Bethke et al., 2008). Microbial communities are generally segmented into zones dependent on the predominate constituent being reduced (Bethke et al., 2008). This commonly results in aquifers having distinct redox zones that progressively becomes more reduced along groundwater flow paths (McMahon et al., 2011). These segmented zones vary between aquifers due to differing hydrogeochemical characteristics (McMahon and Chapelle, 2008). The availability of electron acceptors and donors affects the redox processes present in an aquifer (McMahon et al., 2011). The lack of available electron donors will prevent microorganisms from reducing available electron acceptors resulting in the preservation of electron acceptors across groundwater flow paths (McMahon et al., 2011). Additionally, the extent and presence of redox zones are dependent on the availability of electron acceptors (i.e. the absence of a specific electron acceptor results in the absence of that redox zone along an aquifer's groundwater flow path) (McMahon et al., 2011). The depositional environment and source of an aquifer's alluvial sediments affects the availability of electron donors and acceptors (Bethke et al., 2008; McMahon and Chapelle, 2008).

Electron donors and acceptors can originate from natural or anthropogenic sources. Electron donors vary but the most common constituent is organic carbon (McMahon et al., 2011). Organic carbon is generally deposited into sedimentary basins

simultaneously with other aquifer sediments or leached from plants and soils prior to percolating into the groundwater system as recharge (Shen et al., 2015). As previously discussed, an example of organic rich sediments present within the Aquifer are the A-Clay, C-Clay, and the Corcoran Clay. Aquifer's may have several wide-ranging electron acceptor sources including atmospheric, anthropogenic (i.e. nitrate based fertilizers or gypsum applied for soil amendments), sediment composition (i.e. manganese and iron-bearing oxyhydroxides, silicates, sulfides, or oxides), and as previously discussed, the oxidation of exposed pyrites (Fram, 2017; McMahon et al., 2011).

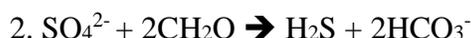
An aquifer's hydrologic characteristics influence groundwater residence times further affecting the evolution of redox processes and the extent of segmented microbial redox zones (Bethke et al., 2008; McMahon and Chapelle, 2008). Under predevelopment Aquifer conditions, prior to the installation of groundwater wells and the subsequent overdraft conditions resulting in groundwater level declines, groundwater discharged from the Aquifer system into rivers or from evapotranspiration within the Valley trough (Gronberg et al., 1998). The Aquifer's current rate of groundwater discharge has decreased significantly due to the lowered groundwater table, resulting in the stagnation of groundwater which increases residence times, and creates more reduced groundwater conditions (Gronberg et al., 1998). Based on the Aquifer's hydrogeological characteristics, redox processes were predicted to evolve vertically, becoming more reduced with depth bgs (Croft, 1972; Fram, 2017).

### 2.5.2 Bacterial Sulfate Reduction

Sulfate is the second to last species reduced within the TEAP (Miao et al., 2012). The general sulfate-reduction reaction is (Christensen et al., 2000; Miao et al., 2012):



Sulfate-reduction, within the TEAP sequence, is initiated from a group of prokaryotic bacteria which oxidize organic carbon or hydrogen (H<sub>2</sub>) and reduce sulfate. The general BSR reactions are (Canfield, 2001; Miao et al., 2012):



Organic carbon, or other organic matter donating electrons, undergoes a fermentation process producing H<sub>2</sub> prior to a respiration process which reduces electron acceptor constituents and consumes H<sub>2</sub> (McMahon, 2010). Thus, H<sub>2</sub> is an intermediate product in the redox processes and is present in concentrations which correlates to specific redox processes (McMahon, 2010). These BSR reactions illustrate how hydrogen ions are consumed, and bicarbonate is produced resulting in an overall decrease in H<sup>+</sup> within a groundwater system and a subsequent increase in pH (Miao et al., 2012). These prokaryotic bacteria include a wide array of SRB species in addition to iron-reducing bacteria and other reducing bacteria groups (Flynn et al., 2013). However, *Desulfovibrio* SRB are generally the primary species associated with BSR occurring in groundwater aquifers (Muyzer and Stams, 2008).

## 2.6 Study Area Characteristics

To test the hypothesized H<sub>2</sub>S source required the collection of groundwater-chemistry and bacterial data from a portion of the Aquifer saturated with H<sub>2</sub>S. The Study Area was defined based on the approximated extent of H<sub>2</sub>S, hydrogeological characteristics, and the ability to collect groundwater samples. The defined Study Area extends 1.5 miles northeast of Highway 180, located within the City of Mendota, to 3.4 miles northeast encompassing the San Joaquin River and Fresno Slough. The Study Area

boundaries were previously illustrated in Figures 1 and 2 but a larger scale map with increased surficial details is provided in Figure 3. The Study Area is located within the Valley trough, where groundwater flow paths are primarily vertical at the surface with increased horizontal influence and groundwater age with increased depth bgs (Fram, 2017; Bertoldi et al., 1991; Davis and Poland, 1957). Groundwater wells constructed to adequate depths, with sufficient spatial extent to define vertical groundwater-chemistry trends and the evolution of redox processes, were also present within the Study Area boundaries.

The general hydrogeological characteristics of the Study Area are the same as the Valley characteristics previously discussed. A previous groundwater-chemistry study conducted by the USGS determined that the sediments surrounding the perforations of wells near the Study Area were composed of Sierra Nevada sands indicating that the sediments surrounding wells within the Study Area are also composed of Sierra Nevada sands (Fram, 2017). Although the surrounding sediments are classified as Sierra Nevada sands groundwater within the Study Area, as previously discussed, partially originates as surficial runoff from the Coast Ranges which is saturated with elevated sulfate concentrations (Fram, 2017). Land use is approximately 58% agriculture, 41% natural, and 1% urban and groundwater levels vary between the sub-aquifers but are generally shallow, less than 40-ft bgs (Fram, 2017; Office, 2018).

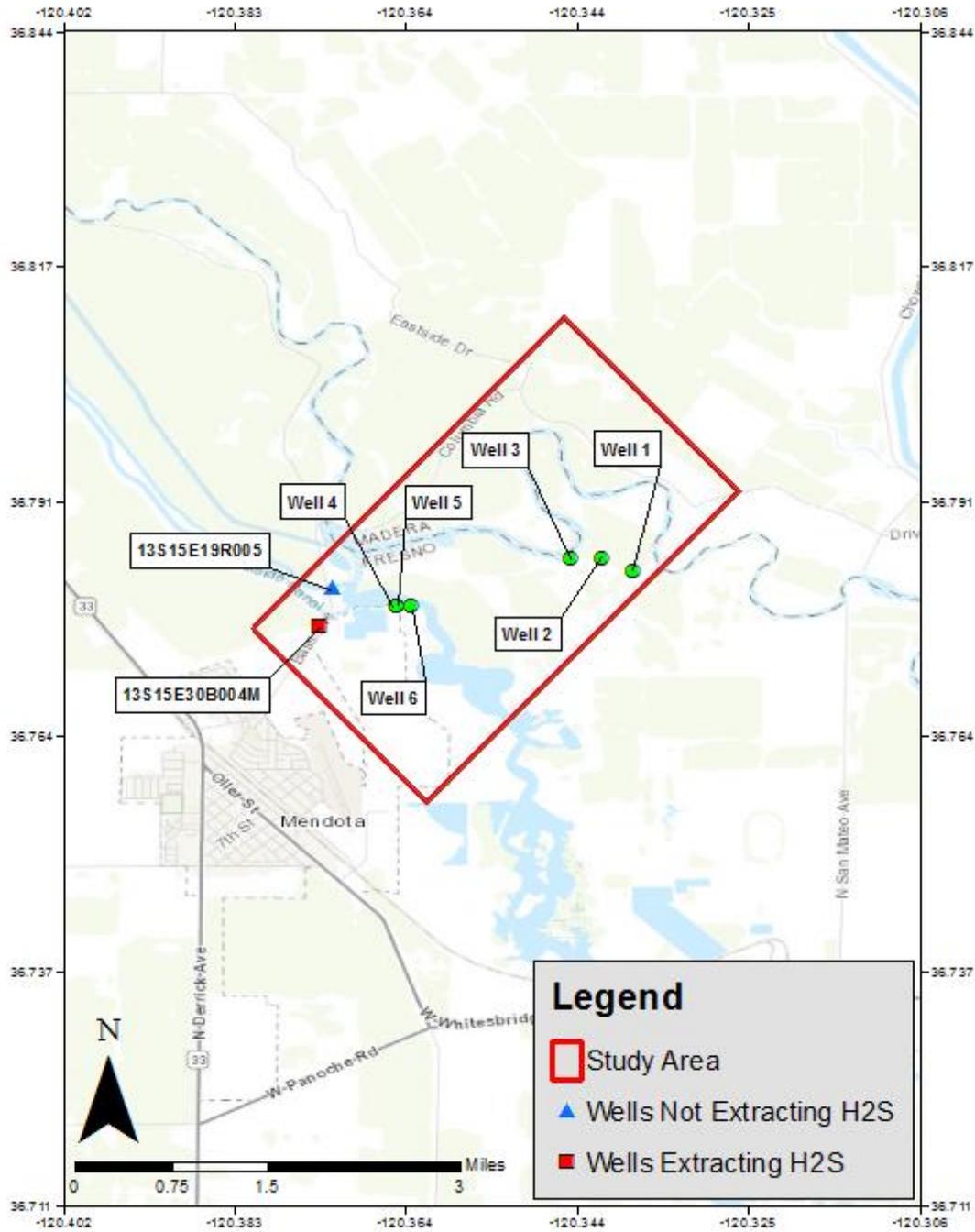


Figure 3 – Study area and well locations

*Note:* The Study Area begins adjacent to the City of Mendota and extends east across the San Joaquin River and Fresno Slough. The confluence of the San Joaquin River and the Fresno Slough is the general low point of the central San Joaquin Valley. This is a larger scale map of the Study Area initially outlined in yellow in Figure 1.

### 3. METHODOLOGY

The purpose of this study was to determine whether the Aquifer's source of H<sub>2</sub>S was H<sub>2</sub>S generated as a byproduct of BSR mediated by SRB by defining vertical groundwater-chemistry trends, the vertical evolution of redox processes, and analyzing for the presence of anaerobic SRB. This required the implementation of an extensive suite of methods including analytical testing of groundwater samples, assignment of redox processes using analytical groundwater-chemistry data, and the temporal and statistical analysis of historical and current groundwater-chemistry data. Individually some methods used during this study have data accuracy limitations. However, collectively this study's methodology, in addition to available data from previous studies, provided sufficient data to support the primary purposes of this study. Methodology data limitations are briefly discussed in the subsequent sections.

#### 3.1 Well Location and Characteristics

Six wells were used for sample collection based on their spatial distribution and extent, both vertical and horizontal, and the presence of H<sub>2</sub>S in extracted groundwater. The sampled wells are owned by the City of Mendota (City). Wells 1, 2, and 3 have always been owned by, and used for, the City's municipal groundwater source (Schmidt, 2018). Wells 4, 5, and 6 were owned and operated by Fordel, Inc. until 2004, when the City took control of the wells. These wells were used by Fordel, Inc. for management of the Mendota Pool area, are not municipal wells, and since transferring the wells to the City they have been used in a limited capacity (Luhdorff and Scalmanini and Associates, 2015).

The locations of Well 1 through Well 6 were illustrated in Figure 3 and well information is included in Table 2. Well location and depth were also displayed on Figure 2 to illustrate the primary sub-aquifer each well extracts groundwater from. Well 5 and

Well 6 are perforated within the unconfined sub-aquifer above the A-Clay and Wells 1, 2, 3, and 4 within the semi-confined sub-aquifer below the A-Clay.

Table 2 – Location, Depth, and Perforation Interval of Sampled Wells

Well #	Latitude	Longitude	Well Depth (ft bgs)	Perforations (ft bgs)
1	36.782573	-120.33839	405	260-395
2	36.784073	-120.341901	405	240-375
3	36.784083	-120.345344	405	260-395
4	36.778743	-120.364998	300	200-300
5	36.778699	-120.364917	100	50-100
6	36.778601	-120.363244	100	50-100

*Note:* Well depth used for analysis and discussion was the top perforation depth (50 to 260-ft bgs).

Analysis conducted during this study was based on each wells' depth to top perforation. Due to perforation intervals extending between 50 to 130-ft below the top perforation depth, extracted groundwater may contain groundwater which originated from depths greater than the top perforation depth. This may limit the precision of interpretations made from groundwater samples collected from Well 1 through Well 6.

### 3.2 Groundwater Sample Collection

A single sample collection event was conducted on March 6, 2018 between approximately 0800 and 1200. All wells were purged prior to sample collection and the collection of groundwater samples at each well followed the same procedure. The purpose of purging is to remove any stagnant water from a well immediately prior to sampling, allowing groundwater samples to originate from the adjacent formation which is representative of actual aquifer conditions (Vail, 2013). According to the Environmental Protection Agency (EPA), the required purging for wells with in-place pumps varies depending on how often the pumps are running. If a well is continuously pumped, then only opening the sample collection valve for a few minutes is required (Vail, 2013). For intermediately or infrequently pumped wells purging should consist of

running the well until groundwater-chemistry parameters stabilize (Vail, 2013). This study concluded that all wells should be pumped until pH and temperature values stabilize prior to the collection of groundwater samples. Wells sampled during this study were purged for approximately five to ten minutes each.

Although the purpose of purging is to ensure that collected groundwater samples are representative of a surrounding aquifer, the groundwater pumping required for purging may perturb an aquifer, resulting in the groundwater collected for analysis originating from varied depths. The mixing of groundwater from varied aquifer depths would decrease the precision of the analysis conducted during this study due to analysis being based on a well's depth to top perforation. However, it should be noted that the stagnant groundwater within a well's borehole is susceptible to anthropogenic contamination from, among others, surface waters entering the borehole, oils leaking from the groundwater pump, or metals leaching from the well casing. Additionally, for this study, groundwater levels measured at Well 1 through Well 6 have historically been above the top perforation depth and it would be difficult to assess where the groundwater above the top perforation depth originated from (Luhdorff and Scalmanini and Associates, 2015). As a result, despite the potential data limitations caused by purging, this method was chosen based on the EPA standard for groundwater sample collection from wells with pumps, the ability to explain the potential data limitations with purging, and the inability to thoroughly explain the potential data limitations in groundwater collected without purging.

Groundwater samples were collected from each well's primary discharge point or sample port. Groundwater samples from Wells 1, 2, and 3 were collected at similar sample ports (Figure 4). Wells 4 and 6 discharged groundwater into the San Joaquin River (Figure 5) and Well 5 discharged groundwater into a collection tank (Figure 6), groundwater samples were collected at these discharge points.



Figure 4 – General sample port for wells 1, 2, and 3

*Note:* Wells 1, 2, and 3 had the same construction design and groundwater samples were collected from similar sample ports. Groundwater extracted from these wells is directly transported to the City’s water treatment plant. *Credit:* Benjamin Gooding – 2018



Figure 5 – Well 4 and well 6 discharge point

*Note:* This picture illustrates the groundwater discharge location for Wells 4 and 6 where groundwater samples were collected, and field measurements conducted. Groundwater is being discharged into the San Joaquin River north of Wells 4 and 6. *Credit:* Benjamin Gooding – 2018



Figure 6 – Well 5 discharge point

*Note:* This picture illustrates the groundwater discharge location for Well 5 where groundwater samples were collected, and field measurements conducted. Groundwater is being discharged into a concrete collection tank south of Well 5. Groundwater samples were collected directly from the discharge not from the collection tank. *Credit:* Benjamin Gooding - 2018

### 3.3 Field Measurements

Field measurements determined the concentration or value for the following parameters: H<sub>2</sub>S, pH, temperature, and dissolved oxygen. The collection of groundwater samples for H<sub>2</sub>S analysis followed the USGS sniff and concentration testing standards. The USGS H<sub>2</sub>S concentration-testing standard required the use of a Hach H<sub>2</sub>S Test Kit, Model HS-C (Hach, 2017). Appendix B includes the Hach method manual. Table 3 provides general information about the meters used for field measurements. Prior to the use of each meter, the meter was decontaminated by washing the meter with Liquinox detergent and tap water, rinsing with tap water, and then rinsing with deionized water.

Table 3 – Field Meter Overview

Parameter	Meter	Range	Measurement Method
pH	Oakton Instruments - Waterproof pH/CON 10	0 - 14 pH	Rinse probe with deionized water, select desired parameter, insert probe into the groundwater sample ensuring the sensor tip is fully submerged, allow reading to stabilize, and take reading.
Temperature		0 - 100°C	
Dissolved Oxygen	YSI Pro 2030	0 - 50 mg/l	Turn on meter and wait 5 to 15 minutes, insert probe into the groundwater sample ensuring sensor is fully submerged, allow reading to stabilize, and take reading.

*Note:* All meters were calibrated prior to use. Calibration procedures followed the procedures provided by Oakton Instruments and YSI.

### 3.4 Lab Analysis

Laboratory analysis of constituents included nitrate as nitrogen ( $\text{NO}_3^-$ ), total manganese (Mn), total iron (Fe), sulfate ( $\text{SO}_4^{2-}$ ), total sulfide (sum of dihydrogen sulfide [aqueous  $\text{H}_2\text{S}$ ], hydrogen sulfide [ $\text{HS}^-$ ], and sulfide [ $\text{S}^{2-}$ ]), and arsenic (As).

Measuring  $\text{H}_2\text{S}$  concentrations in the field and in the laboratory allowed the estimation of whether laboratory analysis concentrations decrease due to the potential degassing of aqueous  $\text{H}_2\text{S}$  occurring between sample collection and sample analysis. Laboratory analysis was conducted by BSK Associates who forwarded the groundwater samples for total sulfide analysis to BC Laboratories and for total iron analysis to McCampbell Analytical. Samples were brought to BSK immediately following sample collection on March 6, 2018 and the analytical results were returned on March 21, 2018. Appendix C includes each laboratory's calibration and error information related to each analytical method used during this study.

The collection of groundwater samples followed the EPA or Standard Method (SM) requirements. Minimum detection concentrations associated with each constituent is the minimum concentration required by the laboratory to detect and calculate a

constituent's concentration. A non-detect result indicates that a constituent was below the minimum detection concentration of the given method. Table 4 lists the collection requirements and the minimum detection concentration for each constituent analyzed.

Table 4 – Analysis Methods, Sample Collection, Storage, and Preservation Requirements

Parameter	Method	Volume	Container Type	Required Preservation	Holding Time	Minimum Detection (mg/l)
Nitrate as Nitrogen	EPA 300.0	250 mL	HDPE Plastic	Refrigerate	2 Days	0.23
Manganese	EPA 200.7	500 mL	HDPE Plastic	HNO <sub>3</sub>	180 Days	0.01
Iron	EPA 200.7	500 mL	HDPE Plastic	HNO <sub>3</sub>	180 Days	0.02
Sulfate	EPA 300.0	250 mL	HDPE Plastic	Refrigerate	28 Days	1.0
Sulfide (Total)	SM-4500SD	500 mL	HDPE Plastic	ZnC <sub>4</sub> H <sub>6</sub> O <sub>4</sub> + NaOH	28 Days	0.05
Arsenic	EPA 200.8	500 mL	HDPE Plastic	HNO <sub>3</sub>	180 Days	0.002

*Note:* HNO<sub>3</sub> required preservation normally contains 3 ml of (1+1) acid per liter of sample. HNO<sub>3</sub> (1+1) consisting of adding 500 ml concentrated nitric acid to 400 ml of reagent grade water and diluting to 1l (Creed et al., 1994). ZnC<sub>4</sub>H<sub>6</sub>O<sub>4</sub> + NaOH required preservation contains 0.2 ml 2 molar ZnC<sub>4</sub>H<sub>6</sub>O<sub>4</sub> solution per 100 ml sample. Add NaOH until the pH is at least 9 (Edge Analytical, 2018).

### 3.5 Biological Analysis

A Biological Activity Reaction Test (BART) was used to determine whether anaerobic SRB were present in groundwater extracted from Well 1 through Well 6. The BART test was a visual, semi-quantitative test developed by Hach (Hach, 2016). Groundwater samples were collected using the BART method on March 6, 2018 along with the field measurement and laboratory analysis samples. The collected samples were examined over the following eight days as required by the Hach method. Appendix B includes the BART method manual. The BART results are an estimation of the number of anaerobic SRB colony forming units (cfu) present within groundwater collected from each well. However, the absence of historical SRB population data and the cfu result

units, which are estimated values, prevented estimating the accuracy of bacterial population values, thus, this study characterized the BART results as either detect or non-detect.

### 3.6 Assignment of Redox Conditions

This study used the USGS's excel workbook method to assign redox processes (Jurgens et al., 2009). Assignment of redox processes was based on the concentrations of dissolved oxygen ( $O_2$ ), nitrate as nitrogen ( $NO_3^-$ ), manganese ( $Mn^{4+}$ ), ferrous iron ( $Fe^{2+}$ ), sulfate ( $SO_4^{2-}$ ), and total sulfide (the sum of  $H_2S$ ,  $HS^-$ , and  $S^{2-}$ ) (Jurgens et al., 2009) (Table 5). This method assigns the predominate constituent being reduced within the TEAP. However, the precise determination of redox processes in groundwater can be difficult to define because aquifers are generally not in equilibrium and multiple redox processes may exist simultaneously (Jurgens et al., 2009). The USGS's defined thresholds were developed for broad applicability and may be variable depending on hydrogeological, microbiological, and other factors resulting in the potential for variable thresholds under specific conditions (McMahon and Chapelle, 2008). This study used the USGS's method to initially assign redox processes and subsequently interpreted conditions to determine whether secondary redox processes were occurring or if the assigned classification was not explicitly accurate.

Under the USGS's method the determination of a "Mixed (Oxic-Anoxic)" redox category indicates that secondary redox processes are occurring simultaneously (Jurgens et al., 2009). Suboxic redox conditions indicates low dissolved oxygen and nitrate and requires additional data to define the predominant redox process (Jurgens et al., 2009). This study did not collect manganese or iron speciation data. The analysis of total manganese and total iron, when coupled with other data collected during this study, was sufficient to determine whether sulfate-reduction was occurring. The collection of

speciation data is something that should be conducted in the future to better analyze the iron and manganese-reducing zones within the Aquifer.

Table 5 – Criteria and Threshold Concentrations for Redox Processes

Redox Category	Redox Process	O <sub>2</sub> >0.5 mg/l	NO <sub>3</sub> <sup>-</sup> >0.5 mg/l	Mn >0.05 mg/l	Fe >0.1 mg/l	SO <sub>4</sub> <sup>2-</sup> >0.5 mg/l	Fe/S Mass Ratio >0.3	Fe/S Mass Ratio >10
Oxic	O <sub>2</sub>	Yes	-	No	No	-	x	x
Suboxic	Suboxic	No	No	No	No	-	x	x
Anoxic	Mn(IV)	No	No	Yes	No	-	x	x
Anoxic	SO <sub>4</sub>	No	No	-	Yes	Yes	No	No
Anoxic	Fe(III)	No	No	-	Yes	Yes	Yes	Yes
Anoxic	Fe(III)/ SO <sub>4</sub>	No	No	-	Yes	Yes	No Data	No Data
Mixed (Anoxic)	Fe(III)- SO <sub>4</sub>	No	No	-	Yes	Yes	Yes	No
Mixed (Oxic- Anoxic)	O <sub>2</sub> -SO <sub>4</sub>	Yes	No	-	Yes	Yes	No	No

*Note:* Modified from (Jurgens et al., 2009). The “-“symbol indicates the constituent does not apply to the determination of the listed redox category and process. The minimum threshold values are representative of the concentration required for a redox process to be defined as the TEAP.

### 3.7 Compilation of Historical Groundwater-Chemistry Data

Historical groundwater-chemistry data was compiled to conduct temporal variability and statistical analysis. Data for Wells 1, 2, and 3 was compiled from the State Water Resources Control Board – Drinking Water Branch’s database (Branch, 2018). Data for Wells 4, 5, and 6, was compiled from the Mendota Pool Group Pumping and Monitoring Program’s 2014 Annual Report (Luhdorff and Scalmanini and Associates, 2015). The City is required to periodically conduct groundwater-chemistry monitoring on Wells 1, 2, and 3 due to drinking water well regulatory requirements. Wells 4, 5, and 6 are not municipal wells and the City is not required to conduct periodic monitoring and thus no historical data has been collected following the City taking ownership of the

wells. This resulted in significantly more historical groundwater-chemistry data being available for Wells 1, 2, and 3. The varied groundwater-chemistry data sources, data availability, and sample collection dates limited the precision of any interpretations made during this study concerning the temporal variability and statistical analysis results.

### 3.8 Statistical and Temporal Variability Analysis

To illustrate the Aquifer's general temporal variability consecutive monthly data, for a minimum of one year, was extracted from the compiled dataset. Consecutive monthly data for each constituent was only available for Wells 1, 2, and 3. Constituent concentrations of available consecutive monthly data were plotted against sample collection date and linear regression analysis was conducted within excel to illustrate and estimate temporal variability within the Study Area.

Statistical analysis was conducted on compiled data including the calculation of count, range, mean, median, standard deviation, and percent relative standard deviation (%RSD). If the result of a previously conducted sample collection event was below a labs minimum detection concentration, then the minimum detection concentration was used for analysis. This may potentially result in slightly greater mean and lower standard deviation calculation results but is more accurate than simply removing all these data points which would result in even greater means and likely greater standard deviation results. The %RSD was used to illustrate general variability in concentrations during the sample period of historical data (Dhar et al., 2008). Due to the limited availability of historical data for Wells 4, 5, and 6 analyses was conducted separately from Wells 1, 2, and 3.

The statistical analysis results were used to conduct comparative analysis to determine whether the analytical results, from this study's singular sample collection event, were comparable to historical data. Comparative analysis was conducted by

verifying whether sulfate, total iron, and total manganese analytical results were within the range of historical data or an acceptable number of standard deviations from the mean and median to be considered normal, commonly less than one to three. If data was not within the range of historical data further analysis was conducted to interpret the source of variability between historical and current groundwater-chemistry data.

## 4. RESULTS AND DISCUSSION

Results were analyzed to define groundwater-chemistry trends, assign redox processes, estimate the qualitative extent of anaerobic SRB, and demonstrate variability between historical and current data. Analysis of results collectively demonstrated whether H<sub>2</sub>S generated as a byproduct of BSR mediated by SRB was the Aquifer's source of H<sub>2</sub>S. These findings provided a better understanding of the extent of H<sub>2</sub>S and the groundwater conditions associated with the generation of H<sub>2</sub>S within the Valley's Aquifer. Additionally, these findings may assist domestic and municipal groundwater users aiming to mitigate the effects of H<sub>2</sub>S contaminated groundwater or future Aquifer studies related to the presence of H<sub>2</sub>S, or anaerobic SRB, and uranium immobility.

### 4.1 Analytical Results

Analytical results were available for eleven constituents collected from six sites within the Study Area, the laboratory results are included in Appendix C. Seven of these constituents were interpreted as having a pertinent impact on concluding whether H<sub>2</sub>S generated as a byproduct of BSR mediated by SRB was the Aquifer's source of H<sub>2</sub>S. The seven constituents were dissolved oxygen, total manganese, total iron, sulfate, total sulfide, pH, and arsenic. Analytical results and assigned redox processes demonstrated how Aquifer conditions become more reduced with depth bgs (Table 6 and Table 7).

Table 6 and Table 7 illustrate that the general vertical groundwater-chemistry trends included the depletion of the more energetically favorable constituents (dissolved oxygen, total manganese, and total iron) prior to the depletion of sulfate, and the saturation of aqueous H<sub>2</sub>S. Concentrations of the more energetically favorable constituents versus concentrations of the less energetically favorable constituents are inversed prior to and after the detection of H<sub>2</sub>S between 200 and 240-ft. This inverse relationship demonstrates how groundwater-chemistry and redox processes correlate due

redox processes being defined by groundwater-chemistry. To better illustrate the groundwater-chemistry trends within the Aquifer constituent concentrations were plotted versus depth to top perforation (Figure 7).

Table 6 – Analytical Results and Perforation Intervals

Well #	Top Perforation (ft bgs)	Perforation Interval Extent Between Semi-Confining Units
1	260	Between the A-Clay and the Corcoran Clay
3	260	Between the A-Clay and the Corcoran Clay
2	240	Between the A-Clay and the Corcoran Clay
4	200	Between the A-Clay and the C-Clay
5	50	Above the A-Clay
6	50	Above the A-Clay

Well #	pH	H <sub>2</sub> S Field (mg/l)	Temperature (C°)	Arsenic (µg/l)	Dissolved Oxygen (mg/l)	Sulfate (mg/l)
1	9.47	0.40	18.5	3.1	0.46	86
3	8.89	0.30	18.4	2.0	0.42	120
2	9.27	0.50	17.6	7.5	0.45	42
4	8.44	0.05	17.9	0.0	3.28	900
5	7.54	0.00	17.7	2.9	1.80	59
6	7.59	0.00	18.0	5.8	4.20	57

Well #	Total Manganese (mg/l)	Total Iron (mg/l)	Total Sulfide (mg/l)	Anaerobic SRB
1	0.023	0.08	0.45	Detected
3	0.031	0.046	0.11	Non-Detect
2	0.015	0.130	0.58	Detected
4	0.470	1.200	Non-Detect	Detected
5	0.690	8.800	Non-Detect	Non-Detect
6	0.950	8.200	Non-Detect	Non-Detect

Table 7 – Assigned Redox Processes

Well #	Redox Category	Redox Process
1	Suboxic	Suboxic
2	Anoxic	SO <sub>4</sub>
3	Suboxic	Suboxic
4	Mixed(oxic-anoxic)	O <sub>2</sub> -Fe(III)
5	Mixed(oxic-anoxic)	O <sub>2</sub> -Fe(III)
6	Mixed(oxic-anoxic)	O <sub>2</sub> -Fe(III)

All constituents have general increasing or decreasing concentration trends with increased Aquifer depth while also demonstrating smaller scale trends. The pertinent groundwater-chemistry trends were the progressive depletion of dissolved oxygen, total manganese, and total iron from 50 to 200-ft where the assigned redox process was mixed (oxic-anoxic) dissolved oxygen-total iron-reducing. Between 200 and 240-ft these constituents, plus sulfate, were abruptly removed from the groundwater system and H<sub>2</sub>S became initially detected as the predominant redox process evolved to anoxic sulfate-reduction. From 240 to 260-ft groundwater-chemistry trends varied slightly as the predominant redox process evolved to suboxic. However, these trends were minimal and concentration variances were minor compared to those between 200 and 240-ft.

The groundwater-chemistry trends between 200 and 240-ft coupled with the presence of anaerobic SRB, the initial detection of aqueous H<sub>2</sub>S, and the assigned anoxic sulfate-reduction TEAP collectively demonstrated comprehensive biogeochemical evidence for the Aquifer's source of H<sub>2</sub>S being the byproduct of BSR mediated by SRB. However, to thoroughly analyze groundwater-chemistry trends and to interpret the biogeochemical processes occurring within the Aquifer the Aquifer was subdivided into three zones (Zone 1, 50 to 200-ft; Zone 2, 200 to 240-ft; and Zone 3, 240 to 260-ft) which were analyzed individually. Figure 7 illustrates the vertical extent of each zone and the groundwater-chemistry trends within each zone.

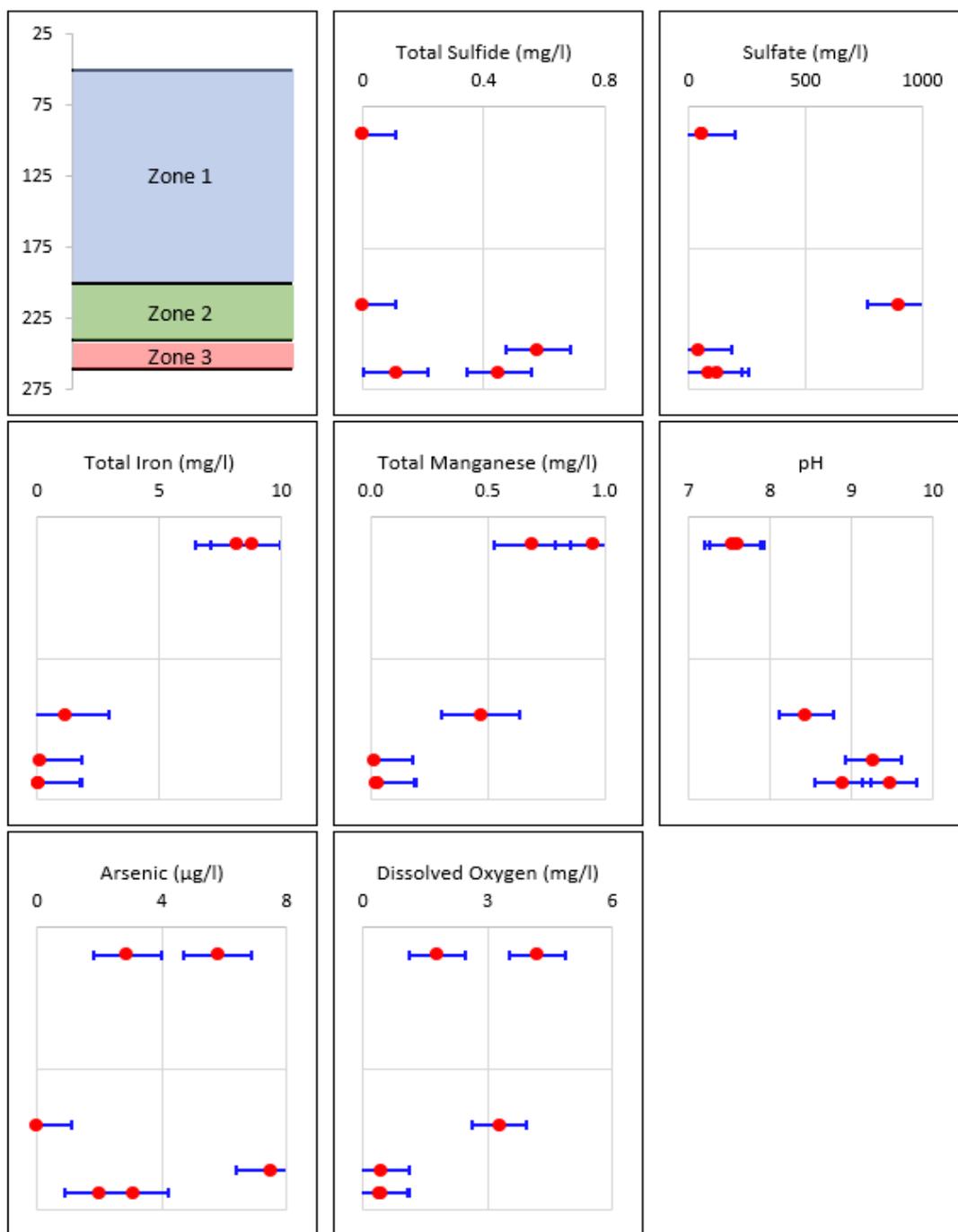


Figure 7 – Plotted analytical results versus depths with assigned redox processes

*Note:* The Zone figure in the top left illustrates the top perforation depth intervals where groundwater samples were collected, and redox processes assigned. Zone 1 is from 50 to 200-ft and includes Wells 4, 5, and 6; Zone 2 is from 200 to 240-ft and includes Well 2 and Well 4; and Zone 3 is from 240 to 260-ft and includes Wells 1, 2, and 3. The error bars were calculated as standard error in excel. The relative percent deviation values calculated by the laboratories used were less than 3% for all constituents.

#### 4.2 Zone 1: 50 to 200-ft

Redox processes did not evolve within Zone 1 indicating that the groundwater-chemistry patterns, previously illustrated in Figure 7, were a result of varied secondary redox processes and hydrogeologic conditions. Dissolved oxygen, total manganese, and total iron concentrations were elevated at 50-ft, relative to other sampled Aquifer depths. Previous studies demonstrated that elevated concentrations of the more energetically favorable constituents, such as dissolved oxygen, were common in shallow groundwater of unconfined aquifers (McMahon et al., 2011). The assigned redox process at 50-ft indicated the active reduction of ferric iron to ferrous iron, the more soluble form of iron, resulting in the dissolution of iron-bearing Aquifer sediments and the subsequent increase in total iron concentrations (Hem, 1985; Jurgens et al., 2009). A positive correlation between total iron and total manganese concentrations has been observed in several studies suggesting a natural overlap of iron and manganese-reducing zones (McMahon et al., 2018). Additionally, the simultaneous reduction of iron and manganese has previously been observed within the Aquifer (Fram, 2017; Hem, 1985; Jurgens et al., 2009). Thus, the elevated manganese concentrations at 50-ft were interpreted to be a result of secondary manganese-reduction. The detectable concentrations of arsenic at 50-ft were interpreted to be associated with the dissolution of arsenic-bearing aquifer sediments under these interpreted iron and manganese-reducing conditions (Fram, 2017).

At 200-ft total manganese and total iron concentrations decreased and sulfate concentrations increased, aqueous H<sub>2</sub>S was detected in low concentrations during field measurements, and anaerobic SRB were initially detected. Sulfate concentrations were greater than 1800 times the minimum concentration threshold required for sulfate-reduction to be the assigned TEAP, while total iron concentrations were approximately only 12 times greater (Jurgens et al., 2009). Collectively, the initial detection of H<sub>2</sub>S and anaerobic SRB coupled with the increased availability of sulfate electron acceptors

demonstrated the onset of secondary sulfate-reduction within a predominate iron-reducing zone.

Previous studies have confirmed the presence of mixed sulfate and iron-reducing zones where ferrous iron and H<sub>2</sub>S are produced simultaneously, subsequently reacting, and resulting in the precipitation of iron-sulfide minerals (Bethke et al., 2008; Chapelle et al., 2009). The rapid kinetics of this precipitating reaction creates the observed hyperbolic relationship between H<sub>2</sub>S and ferrous iron where concentrations of the predominant TEAP, iron at 200-ft, are elevated, while H<sub>2</sub>S is non-detect or in low concentrations (Bethke et al., 2008; Chapelle et al., 2009). The precipitation of iron-sulfides in these mixed sulfate and iron-reducing zones demonstrates the mutualistic behavior that has been observed between sulfate and iron-reducing microorganisms. The mutualistic behavior is a result of these microorganisms benefitting from the concurrent production of H<sub>2</sub>S and ferrous iron resulting in the precipitation of iron-sulfides which limits the saturation of each constituent maintaining the thermodynamic drive for each microorganism group's metabolism (Flynn et al., 2013).

The decrease in total iron and total manganese concentrations within Zone 1 were interpreted to partially be a result of the precipitation of iron and manganese-sulfides due to the onset of secondary sulfate-reduction. Other factors potentially affecting concentrations include the decreased dissolution of manganese and iron-bearing aquifer sediments due to the decreased availability of electron acceptors near 200-ft and the increased pH values resulting in increased adsorption rates (McMahon et al., 2018). Arsenic concentrations became non-detect at 200-ft. The non-detectable arsenic concentrations were interpreted to be caused by the precipitation of arsenic-sulfides which previous studies have observed occurring in environments containing relatively high-iron and low-sulfide concentrations, similar to those at 200-ft (O'Day et al., 2004).

#### 4.3 Zone 2: 200 to 240-ft

Within Zone 2 the predominate redox process evolved to anoxic sulfate-reducing which was observed with the varied groundwater-chemistry trends in Zone 2 compared to Zone 1, as illustrated in Figure 7. At 200-ft the interpretation of aquifer and groundwater conditions demonstrated the factors resulting in the non-detection of H<sub>2</sub>S. The evolution of redox processes to sulfate-reducing was due to the low concentrations of dissolved oxygen, total manganese, and total iron at 240-ft. These low concentrations demonstrate the consumption of the more energetically favorable constituents prior to the less energetically favorable sulfate which was predicted by the terminal electron accepting processes.

The assignment of anoxic sulfate-reduction, detection of aqueous H<sub>2</sub>S, and the presence of anaerobic SRB was evidence for the active generation of H<sub>2</sub>S at 240-ft. The inversed hyperbolic relationship between H<sub>2</sub>S and iron concentrations at 240-ft, compared to 200-ft, was representative of sulfate-reduction becoming the TEAP resulting in the rate of H<sub>2</sub>S generation being greater than the rate of ferrous iron generation. Additionally, the decline in sulfate concentrations from 900 to 42 mg/l within Zone 2 appeared to indicate a high rate of H<sub>2</sub>S generation. However, the low concentrations of H<sub>2</sub>S were interpreted to signify the continued precipitation of metal-sulfides resulting in the low H<sub>2</sub>S concentrations present within Zone 2.

Groundwater-chemistry trends for all constituents were similar to the expected trends, based on observations made in previous studies, except for arsenic. The increase in arsenic concentrations as redox processes evolved to sulfate-reduction was unanticipated. Arsenic concentrations are typically expected to decrease within sulfate-reducing zones due to the precipitation of arsenic-sulfides and the decreased solubility of arsenic in high pH environments, both conditions were present at 240-ft (Kirk et al., 2004; O'Day et al., 2004). However, within the Valley the desorption of arsenate has

been observed in alkaline environments which may explain the increased arsenic concentrations at 240-ft (Fram, 2017). The elevated arsenic concentrations while unexpected did not appear to influence the presence or production of H<sub>2</sub>S at 240-ft.

#### 4.4 Zone 3: 240 to 260-ft

Within Zone 3 the assigned redox process evolved to suboxic. Groundwater-chemistry trends within Zone 3 were inconsistent due to the variability in constituent concentrations at 260-ft, as illustrated in Figure 7. The assignment of suboxic conditions demonstrated that between 240 and 260-ft the concentration of one or more constituents, required to assign a predominate redox process, fell below the minimum concentration threshold (Jurgens et al., 2009). Total iron concentrations were below the minimum threshold of 0.1 mg/l in both Well 1 and Well 3 which resulted in redox conditions evolving to suboxic (Jurgens et al., 2009).

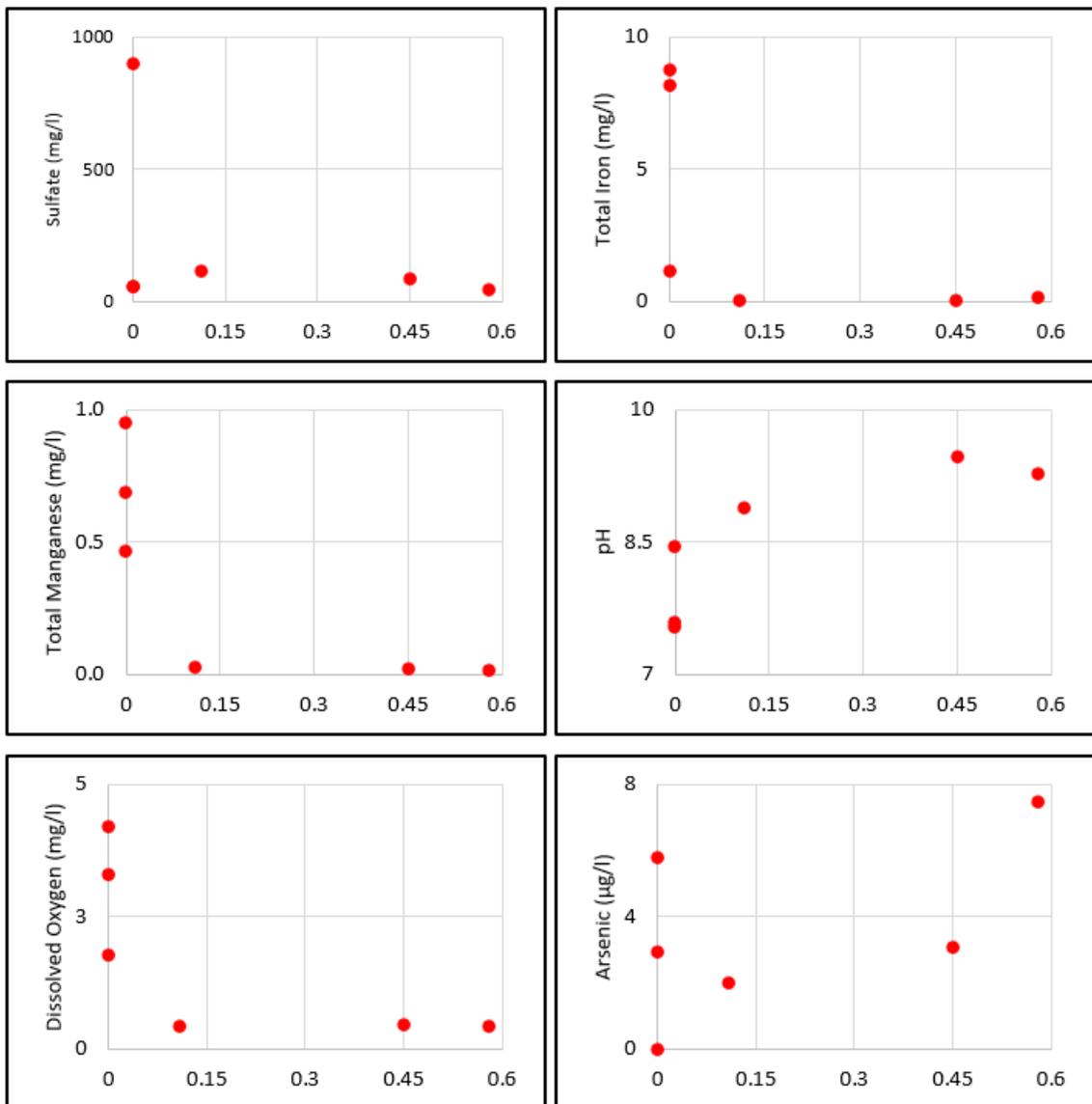
Data from Well 3 indicated that sulfate concentrations increased, pH decreased, and anaerobic SRB were non-detect at 260-ft. Data from Well 1 indicated that sulfate and pH concentrations increased and that anaerobic SRB were detected. Additionally, total sulfide concentrations decreased in both Well 1 and Well 3. The lab analytical results labeled Well 3's total sulfide concentrations as an estimated value due to potential matrix interference. Field H<sub>2</sub>S concentrations were 0.30 mg/l, slightly greater than the analytical result of 0.11 mg/l, indicating total sulfide concentrations in Well 3 are likely greater. Collectively the lower total sulfide concentrations, lower pH values, and the non-detection of anaerobic SRB in Well 3 indicated that redox conditions may have evolved from sulfate-reducing. However, the minimal decrease in total sulfide concentrations, increase in pH, and the detection of anaerobic SRB in Well 1 demonstrated that BSR mediated by SRB continued at 260-ft. Collectively the data available from Well 1 and Well 3 were interpreted as demonstrating the active generation of H<sub>2</sub>S in both wells.

Additionally, a majority of Well 2's perforation interval, used to interpret groundwater conditions at 240-ft, and of Well 1 and Well 3 perforation intervals, used to interpret groundwater conditions at 260-ft, overlap and the interpretations previously made concerning manganese and arsenic at 240-ft were the same interpretations made at 260-ft. The overlapping perforation intervals were interpreted as the primary reason groundwater conditions were similar between 240 and 260-ft.

#### 4.5 Relationship between H<sub>2</sub>S and Other Constituent Concentrations

The evolution of redox processes within an unconfined aquifer generally correlate with groundwater-chemistry trends. As an aquifer becomes more reduced the more energetically favorable electron acceptors are removed from solution and the less energetically favorable electron acceptors begin to have a bigger impact on groundwater-chemistry. This study aimed to determine where H<sub>2</sub>S was actively being generated as a byproduct of BSR, which was discussed in the previous sections. Previous studies have observed the significant impact sulfate-reduction has on aqueous geochemical conditions (Miao et al., 2012). These observations included the decreased concentrations of other redox related constituents within environments experiencing active BSR. These impacts were observed within the Aquifer and were illustrated in correlative plots between total sulfide and other redox related constituents (Figure 8).

Figure 8 illustrates the significant decline in total iron, total manganese, and dissolved oxygen concentrations within groundwater with detectable concentrations of aqueous H<sub>2</sub>S. Concentrations of pH increased with the detection and saturation of H<sub>2</sub>S, as projected based on the consumption of H<sup>+</sup> ions and the production of bicarbonate (Miao et al., 2012). Sulfate concentrations varied but were consistent within Aquifer zones with detectable H<sub>2</sub>S concentrations demonstrating the availability of a continuous source of sulfate. Concentration data for other redox related constituents is more widely available



X axis for all figures is equal to total sulfide (mg/l)

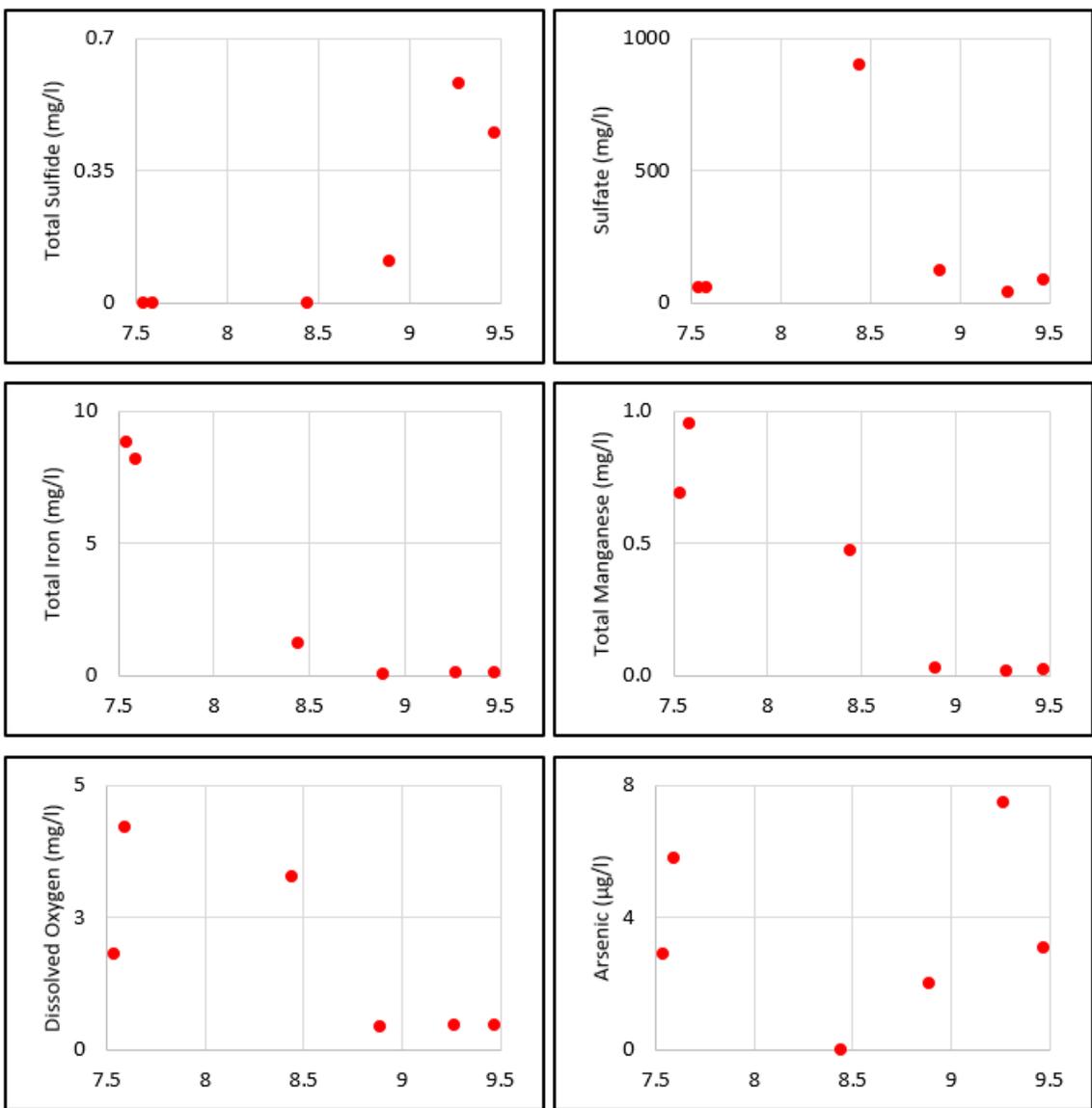
Figure 8 – Total sulfide versus other redox related constituent correlative plots

*Note:* Analysis of redox related constituent concentrations and total sulfide concentrations illustrates how concentrations of the more energetically favorable constituents decline significantly once total sulfide is detected. The lowest total sulfide concentrations within the Study Area was 0.11 mg/l at 260-ft and the greatest was 0.58 mg/l at 240-ft.

than H<sub>2</sub>S data. In the absence of available aqueous H<sub>2</sub>S concentration data the concentrations of these other redox related constituents can be used to estimate whether H<sub>2</sub>S is actively being produced, within the Aquifer portion a well is perforated within, based on the trends illustrated in Figure 8.

Correlative plots between the remaining redox related constituents demonstrated other potential geochemical factors affecting groundwater-chemistry trends within the Study Area. Figure 9 illustrates correlative plots between pH and other redox related constituents. The correlative plots illustrate similar trends between constituents as the total sulfide plots. These trends include total sulfide concentrations increasing and total manganese and total iron concentrations decreasing with increased pH. This represents the predicted trend of pH increasing with depth, which is the general trend in unconfined aquifers, which correlated with the reduction of the more energetically favorable constituents (i.e. total manganese and total iron) at shallower depths, prior to the reduction of sulfate. In addition to total sulfide and pH correlative plots, correlative plots between arsenic and other redox related constituents were developed (Figure 10).

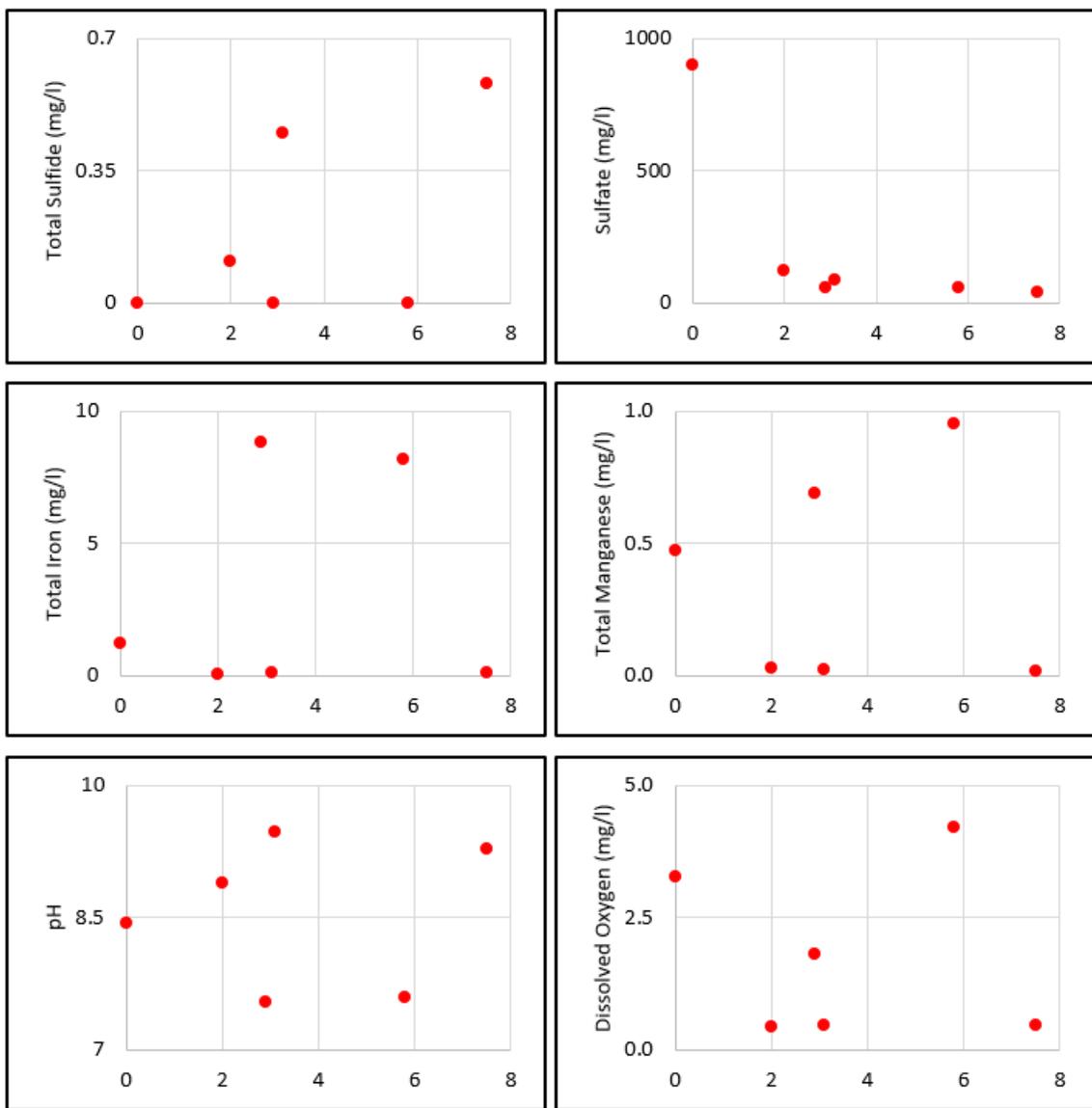
The arsenic correlative plots illustrate greater variability between all constituents, except sulfate, when compared to the total sulfide and pH plots. The non-detection of arsenic at 200-ft was interpreted in previous sections to be a result of the precipitation of arsenic-sulfides based on groundwater-chemistry and observations made in previous studies. However, the arsenic correlative plots demonstrate that sulfate concentrations may have a greater effect on arsenic concentrations than the precipitation of arsenic-sulfides. This would explain the unexpected elevated arsenic concentrations at 240 and 260-ft, where H<sub>2</sub>S was available in concentrations necessary for the continued precipitation of arsenic-sulfides, but sulfate concentrations were lower than concentrations at 200-ft. Additional data and analysis not conducted during this study is required to verify the affect sulfate and arsenic concentrations have on one another.



X axis is equal to pH (standard value)

Figure 9 – pH versus other redox related constituent correlative plots

*Note:* Correlative pH plots were comparable to the total sulfide plots demonstrating the correlation between total sulfide and pH concentrations with Aquifer depth.



X axis is equal to arsenic (µg/l)

Figure 10 – Arsenic versus other redox related constituent correlative plots

Note: Arsenic correlative plots demonstrate greater variability with other redox related constituents when compared to the total sulfide and pH plots. The sulfate correlative plots demonstrate a significant correlation between the two constituents.

#### 4.6 Extent of H<sub>2</sub>S Contamination

A purpose for determining the source of H<sub>2</sub>S was to gain a better understanding about the extent of H<sub>2</sub>S within the Aquifer. The interpretations made during this study confirmed that H<sub>2</sub>S generated as a byproduct of BSR mediated by SRB was the primary source of H<sub>2</sub>S. The extent of H<sub>2</sub>S is defined using two aspects – detectable concentrations of aqueous H<sub>2</sub>S and a positive sniff test result indicating detectable concentrations of gaseous H<sub>2</sub>S. Analytical testing detected aqueous H<sub>2</sub>S at 240 to 260-ft bgs. Zone 2 analysis demonstrated that H<sub>2</sub>S generation likely began prior to 240-ft bgs based on the rate in which sulfate concentrations declined and the Aquifer's maximum total sulfide concentrations at 240-ft bgs. Additionally, the perforation intervals of Well 1 and Well 3 extend below 260-ft bgs demonstrating that detectable concentrations of aqueous H<sub>2</sub>S are likely to be present at depths greater than 260-ft bgs. This study estimated that the extent of detectable concentrations of aqueous H<sub>2</sub>S was approximately 200 to 320-ft bgs, or greater. This demonstrates that detectable concentrations of aqueous H<sub>2</sub>S are present in the semi-confined sub-aquifer below the A-Clay, but not the unconfined sub-aquifer above the A-Clay, as illustrated in Figure 11.

A positive H<sub>2</sub>S sniff test indicated the presence of the “rotten egg” odor associated with gaseous H<sub>2</sub>S released from groundwater following extraction. The sniff test was conducted on Well 1 through Well 6 with each having a positive result. The California Air Resources Board states that the odor detection threshold is approximately 0.03 to 0.05 parts per million (ppm), which converts equally to mg/l (Board, 2019). The analytical minimum detection concentration for aqueous H<sub>2</sub>S is 0.05 mg/l. This demonstrates that the non-detection of H<sub>2</sub>S, in groundwater exhibiting the “rotten egg” odor, may have contained detectable concentrations of aqueous H<sub>2</sub>S prior to the release of H<sub>2</sub>S in the gaseous phase following groundwater extraction. This indicates that the extent of aqueous H<sub>2</sub>S may be greater than currently estimated. However, this study estimated

that the extent of gaseous H<sub>2</sub>S was from the groundwater table to approximately 320-ft bgs based on field observations and the estimated aqueous H<sub>2</sub>S extent as illustrated in Figure 11.

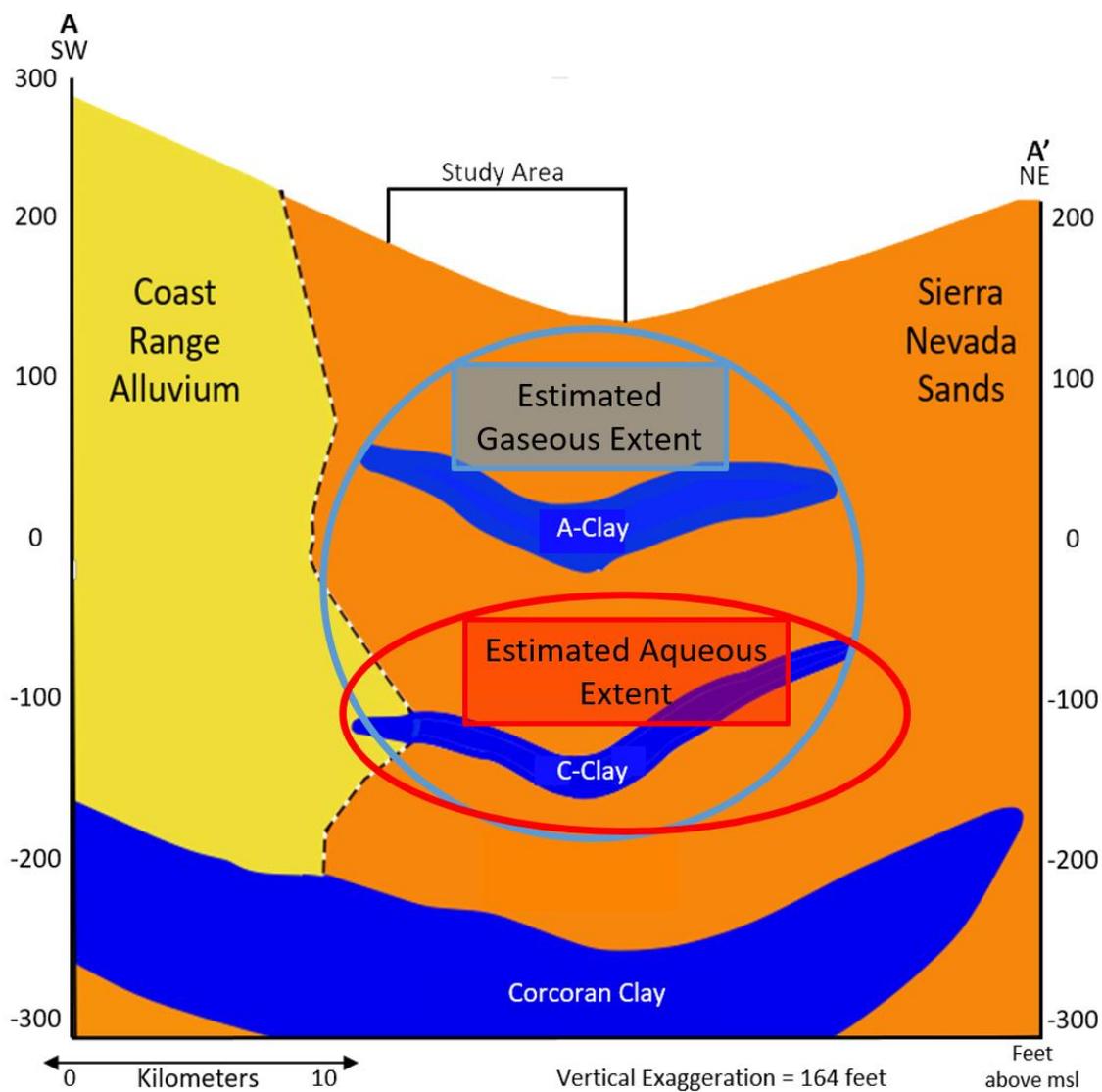


Figure 11 – Estimated gaseous and aqueous H<sub>2</sub>S extent

*Note:* The estimated gaseous and aqueous H<sub>2</sub>S extent was defined from interpretations made concerning field observations and vertical groundwater-chemistry trends.

#### 4.7 Temporal Variability Analysis

To illustrate temporal variability in the Aquifer, on a monthly to annual timescale, available consecutive monthly data was extracted from the compiled dataset and plotted against the sample collection date (Figure 12). Compiled historical data is provided in Appendix D. There was sufficient data to conduct temporal analysis on Wells 1, 2, and 3 but not Wells 4, 5, and 6.

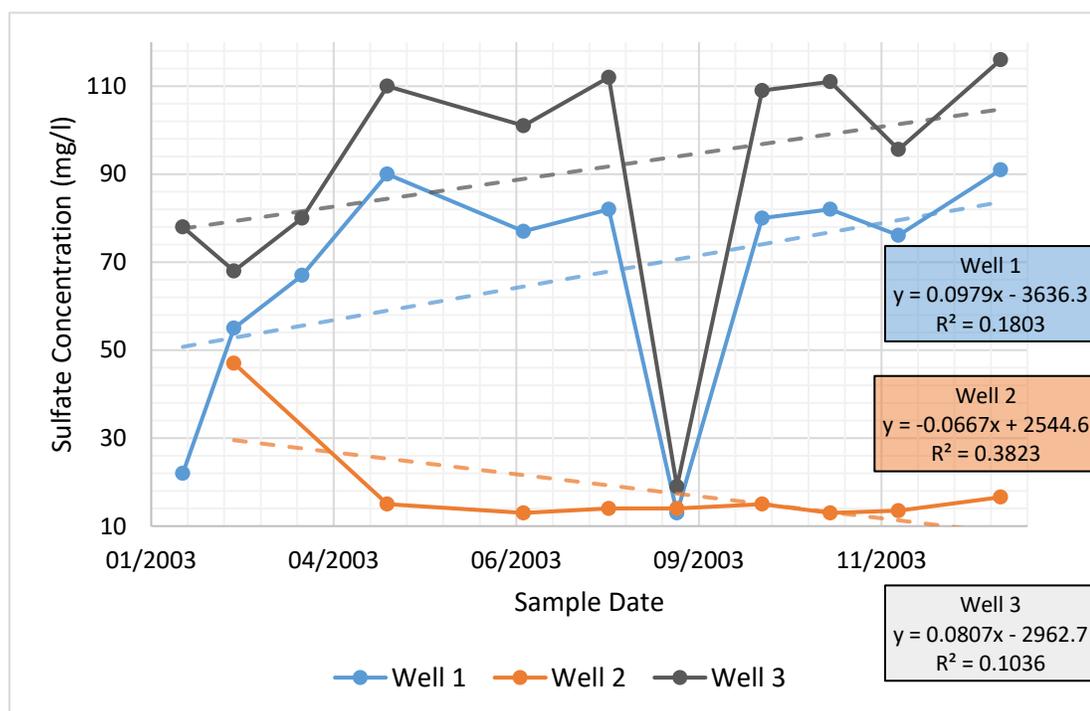


Figure 12 – Concentration of sulfate, total iron, and total manganese versus sample collection data profiles for wells 1, 2, and 3

*Note:* These profiles illustrate the variability of redox related constituents. Concentrations vary over minor timescales (months), but linear regression trend lines demonstrate the consistent average concentrations. The minimum detection limit for iron was 0.1 mg/l and for manganese was 0.02 mg/l.

Figure 12 continues next page.

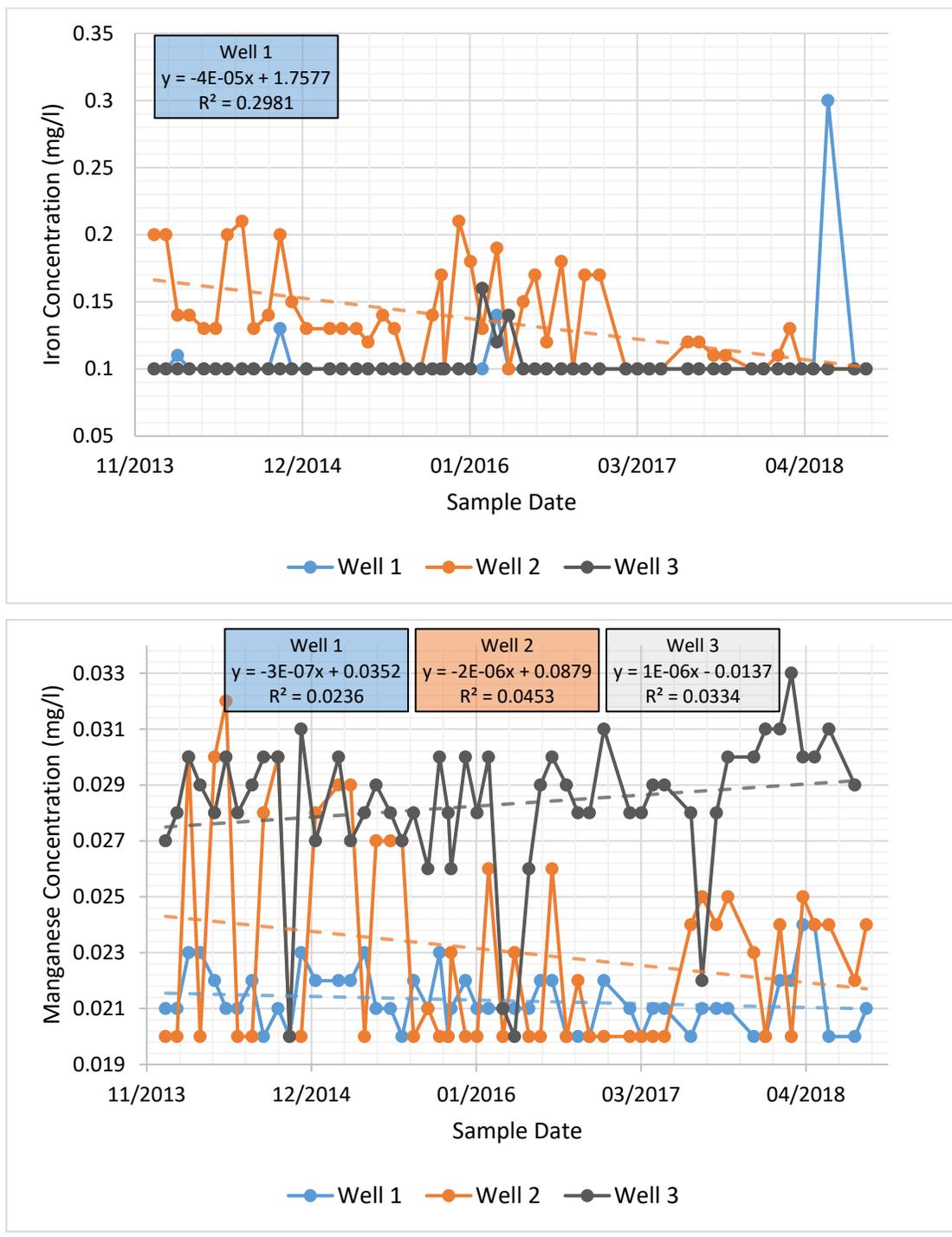


Figure 12 – (cont.)  
*Note:* These profiles illustrate the variability of redox related constituents. Concentrations vary over minor timescales (months), but linear regression trend lines demonstrate the consistent average concentrations. The minimum detection limit for iron was 0.1 mg/l and for manganese was 0.02 mg/l.

Sulfate concentrations in Well 1 and Well 3 were similar with concentrations in Well 2 being consistently lower. However, sulfate concentrations in all wells were significantly greater than the minimum concentration threshold required for sulfate-reduction. Total manganese concentrations varied monthly in all wells, with variability being the greatest in Well 2, but concentrations were always below the minimum concentration threshold for manganese-reduction, .05 mg/l, indicating it was unlikely manganese-reduction occurred during the plotted period. Total iron was below the minimum detection concentration for a majority of sample collection dates for Well 1 and Well 3. This indicates that the assigned redox process was consistently suboxic similar to the redox process assigned for Well 1 and Well 3 during this study. Total iron concentrations in Well 2 varied substantially increasing and decreasing over several months, such as June to September 2014, but trend downward over the entire plotted dataset. Additionally, concentrations during some sample collection dates were below the 0.1 mg/l minimum detection concentration which would result in an assigned suboxic redox process. This indicates that redox processes may occasionally vary in Well 2. The interpretations made concerning the temporal variability analysis results indicated that constituent concentration variances may result in varied assigned redox processes annually. However, sulfate concentrations were consistently above the minimal threshold concentration which was interpreted as indicating that sulfate-reduction is consistently occurring even as assigned redox processes change. This interpretation is similar to the previous interpretations made concerning secondary sulfate-reduction occurring within the assigned suboxic redox zone near Well 1 and Well 3.

#### 4.8 Statistical and Comparative Analysis - Wells 1, 2, and 3

The statistical analysis results are included in Table 8 with analytical results from this study and historical data included in Appendices C and D. Columns 2 through 9 in

Table 8 were calculated from historical data and column 10 includes the analytical results from this study.

Table 8 – Statistical and Comparative Analysis Results of Well 1, 2, and 3

Well #	Start Date	End Date	Count	Range	Mean	Median	Standard Deviation	% RSD	Study Results
Sulfate (mg/l)									
Well 1	2001	2015	17	13.0 – 91.0	72.45	80.00	22.82	31.5%	86
Well 2	2003	2015	14	13.0 – 47.0	19.14	15.80	8.94	46.7%	42
Well 3	2001	2015	17	19.0 – 116.0	95.51	106.00	24.27	25.4%	120
Iron (mg/l)									
Well 1	2001	2018	96	<0.100 – 0.506	0.120	0.100	59.06	49.0%	0.08
Well 2	2001	2018	89	<0.100 – 0.414	0.151	0.130	65.66	43.5%	0.13
Well 3	2001	2018	97	<0.100 – 0.403	0.120	0.100	54.93	45.8%	0.046
Manganese (mg/l)									
Well 1	2001	2018	92	< .020 – 0.041	0.022	0.021	3.73	17.0%	0.023
Well 2	2001	2018	92	< .020 – 0.042	0.023	0.020	4.57	19.9%	0.015
Well 3	2001	2018	93	< .020 – 0.052	0.028	0.028	5.15	18.4%	0.031

*Note:* Historical data was compiled from the State Water Resources Control Board – Drinking Water Branch’s groundwater-quality database.

Statistical analysis for Wells 1, 2, and 3 demonstrated that total iron experienced the greatest variability and total manganese the least. Comparative analysis demonstrated that constituent concentration results from this study, that are not within the concentration range of historical data, included sulfate in Well 3, total iron in Well 1 and Well 3, and total manganese in Well 2. However, calculated means for total iron in Well 1 and Well 3, and total manganese in Well 2, are near their minimum concentration values indicating

a majority of the historical data was near minimum concentrations. The minimum concentration of total iron and total manganese was equal to the minimum detection concentration of the previously used laboratory, 100 ( $\mu\text{g}/\text{l}$ ) for total iron and 20  $\mu\text{g}/\text{l}$  for total manganese. The laboratory used during this study had lower minimum detection concentrations and thus the results had the potential to be, and were, below the previous minimum concentrations. This was interpreted as evidence for this study's results demonstrating true minimum concentrations. Sulfate concentrations in Well 3 were slightly greater than the previous maximum concentration. However, this study's sulfate concentrations were approximately one standard deviation from the historical data's mean demonstrating that concentrations between the two sources are comparable.

Comparing the variability between this study's results and historical data in relation to redox concentration thresholds demonstrated that sulfate concentrations were always above the 0.5 mg/l threshold, total iron concentrations varied between above and below the 0.1 mg/l threshold, and total manganese concentrations were always below the 0.05 mg/l threshold, except for one data point from Well 3, the required thresholds over the entire sample period (Jurgens et al., 2009). This illustrates that sulfate was always available in concentrations required for sulfate-reduction to occur and that manganese-reduction rarely, if ever, takes place. The varied total iron concentrations demonstrate that redox conditions varied between sulfate-reduction, iron and sulfate-reduction, iron-reduction, and suboxic, based on the assignment of redox conditions without available total sulfide data. Total sulfide data was only collected in 2001 and was 0.94, 0.60, and 0.70 mg/l in Wells 1, 2, and 3, respectively (Branch, 2018). The assigned redox process during this sample event, based on the assumption that groundwater conditions in 2001 were anoxic since dissolved oxygen data was unavailable, was anoxic iron and sulfate-reducing. Previous studies have demonstrated evidence for the production of  $\text{H}_2\text{S}$  in aquifers experiencing each redox condition, except suboxic as it is commonly not further

defined (Appelo and Postma, 2005; Bethke et al., 2008; McMahon and Chapelle, 2008). This indicates that H<sub>2</sub>S generated as a byproduct of BSR mediated by SRB in groundwater has likely occurred continuously or nearly continuously within the Aquifer, near Wells 1, 2, and 3, since at least 2001, the earliest date sulfide data was available.

#### 4.9 Statistical and Comparative Analysis - Wells 4, 5, and 6

Historical data was compiled from the 2014 Annual Report for the Mendota Pool Group's Pumping and Monitoring Program (Luhdorff and Scalmanini and Associates, 2015). Data for these wells was minimal due to their limited use since 2004. The results of statistical analysis are included in Table 9 with analytical results from this study and historical data included in Appendices C and E. Columns 2 through 9 in Table 9 were calculated from historical data and column 10 includes analytical results from this study.

**Table 9 – Statistical and Comparative Analysis Results of Wells 4, 5, and 6**

Well #	Start Date	End Date	Count	Range	Mean	Median	Standard Deviation	% RSD	Study Results
Sulfate (mg/l)									
Well 4	1999	2004	6	97.0 – 180.0	138.67	136.50	36.33	26.2%	900
Well 5	1999	2003	6	42.0 – 201.0	129.33	138.50	67.73	52.4%	59
Well 6	1993	2003	3	150.0 – 305.0	224.33	218.00	77.69	34.6%	57
Iron (mg/l)									
Well 4	1999	2004	6	< 0.050 – 0.870	0.187	0.050	0.33	179.3%	1.2
Well 5	1999	2003	6	4.800 – 8.490	7.062	7.580	1.44	20.4%	8.8
Well 6	2001	2003	2	9.270 – 9.400	9.340	9.340	0.09	1.0%	8.2
Manganese (mg/l)									
Well 4	1999	2004	6	< 0.03 – 0.100	0.063	0.055	0.03	49.6%	0.47
Well 5	1999	2003	6	0.700 – 1.370	1.050	1.105	0.23	21.9%	0.69
Well 6	2001	2003	2	1.250 – 1.350	1.300	1.300	0.07	5.4%	0.95

*Note:* Historical data was compiled from the Mendota Pool Group's 2014 Pumping and Monitoring Program Annual Report.

Constituent concentrations were outside of the range of historical data for all constituents in Wells 4, 5, and 6, except for sulfate in Well 5. However, further analysis demonstrated that sulfate in Well 6, total iron in Well 5, and total manganese in Well 5 were a maximum of 2.25 standard deviations from the mean. This was interpreted as evidence for these analytical results being comparable to historical data. This study's total manganese and total iron concentrations from Well 6 were less than the minimum concentrations of historical data and more than three standard deviations from the mean. However, only two data points were available for statistical analysis which is insufficient for a thorough analysis of the historical range of constituent concentrations and resulted in the calculated standard deviation values be inaccurately low. As a result, it was interpreted that concentrations from Well 6 are comparable to historical concentrations.

This study's constituent concentrations from Well 4 were greater than the maximum concentration of historical data for sulfate, total iron, and total manganese. It is difficult to assess the source of variability between current and historical data due to the minimal amount of available data and the fifteen-year gap between sample collection dates. However, the elevated total iron and total manganese concentrations could be interpreted to be a result of the continued saturation of groundwater with total iron and total manganese due to the presence of iron-reducing redox conditions and the stagnation of groundwater within the Valley trough. Well 4's sulfate concentrations were four to five times greater than the maximum historical concentration. However, in reference to concentration threshold for sulfate-reduction to be the assigned TEAP all current and historical sulfate concentration data from Well 4 were significantly greater than the 0.5 mg/l threshold value. This was interpreted as indicating that the variability had minimal impact on the potential for sulfate-reduction to occur near Well 4.

## 5.0 CONCLUSION

This study confirmed that the source of H<sub>2</sub>S was the bacterial reduction of sulfate mediated by SRB resulting in the generation of H<sub>2</sub>S. This study determined that the Aquifer experienced an abrupt depletion of sulfate and simultaneous saturation of aqueous H<sub>2</sub>S over a portion of the Aquifer that contained anaerobic SRB and exhibited anoxic sulfate-reducing conditions which followed dissolved oxygen, manganese, and iron-reducing conditions as expected within the TEAP succession. Collectively these findings provided the necessary comprehensive biogeochemical evidence to confirm this study's hypothesized H<sub>2</sub>S source. These findings demonstrated the source of H<sub>2</sub>S given Aquifer conditions at the time of groundwater sample collection. As the results of the temporal variability and comparative analysis demonstrated constituent concentrations may vary temporally and previous studies have demonstrated how groundwater conditions have varied following the development of the Valley. This indicates future changes to Aquifer conditions could affect the presence and extent of H<sub>2</sub>S. However, this study interpreted historical and current data as evidence for the current source of H<sub>2</sub>S being the same as the historic source noted in previous studies.

Within the Study Area groundwater conditions have evolved with the development of the Valley resulting in groundwater level declines, the reduction of groundwater discharging to surface water bodies (i.e. San Joaquin River), increased vertical surficial recharge, and decreased sulfate saturated horizontal recharge originating from the Coast Ranges (Gronberg et al., 1998). This resulted in the varied Aquifer conditions above and below the A-Clay. Interpreting the potential for the continued generation of H<sub>2</sub>S, if the Aquifer experienced further groundwater level declines and decreased horizontal recharge, indicates that H<sub>2</sub>S generation is likely to proceed for the foreseeable future. Sulfate concentrations throughout the Aquifer are significantly greater than the minimum concentrations required for sulfate-reduction to proceed. Hydrologic

flow gradients may become more vertical with the continued overdraft of the Aquifer, reducing the impact of horizontal groundwater recharge originating from the Coast Range-Valley contact. However, as results from this study have demonstrated, the secondary sources of sulfate recharging the Aquifer above the A-Clay still result in sulfate concentrations significantly greater than the minimum concentration threshold required for sulfate-reduction to be the predominant TEAP.

Insights gained from this study concerning groundwater-chemistry trends are important to domestic and municipal groundwater users aiming to avoid or reduce current impacts from H<sub>2</sub>S contaminated groundwater or future impacts when placing and constructing groundwater wells. As previously discussed, the estimated extent of gaseous H<sub>2</sub>S within the Aquifer was from the water table to 320-ft bgs and the estimated extent of aqueous H<sub>2</sub>S was from 200 to 320-ft bgs. These estimations result in, as previously illustrated in Figure 11, gaseous H<sub>2</sub>S being present above and below both the A-Clay and C-Clay and aqueous H<sub>2</sub>S being present only below the A-Clay and above and below the C-Clay. This indicates that the placement of future wells could potentially avoid detectable aqueous H<sub>2</sub>S but will have difficulty constructing viable groundwater wells that do not extract groundwater containing gaseous H<sub>2</sub>S (i.e. the “rotten egg” odor). However, the assigned redox processes defined during this study demonstrated that the Aquifer experienced mixed redox processes and contained overlapping redox zones indicating that, based on the statistical and temporal variability analysis results, the extent of the redox zones, and the subsequent extent of aqueous H<sub>2</sub>S, may vary annually (Bethke et al., 2008). This could result in varied portions of the Aquifer being saturated with detectable concentrations of aqueous H<sub>2</sub>S hindering the ability to construct future groundwater wells outside of the extent of detectable aqueous H<sub>2</sub>S. This demonstrates the difficulty domestic and municipal groundwater users could have attempting to avoid aqueous H<sub>2</sub>S when placing future groundwater wells.

With the interpreted difficulty of placing wells that extract groundwater, without detectable concentrations of aqueous or gaseous H<sub>2</sub>S, then avoidance of hazardous concentrations of H<sub>2</sub>S is desirable. H<sub>2</sub>S is usually not a health hazard at concentrations present in groundwater, except when released into confined areas following extraction. Health hazards associated with gaseous H<sub>2</sub>S include nausea and headaches at 2 ppm to unconsciousness or death at 300 ppm (Board, 2019). Analytical results concluded that the Aquifer's maximum aqueous H<sub>2</sub>S concentrations were 0.58 mg/l at 240-ft bgs. The Aquifer's low aqueous H<sub>2</sub>S concentrations indicate that the potential for gaseous H<sub>2</sub>S concentrations reaching hazardous concentrations are minimal but the avoidance of aqueous H<sub>2</sub>S in a domestic or municipal water supply may still be a priority for some communities. The difficulties with avoiding aqueous H<sub>2</sub>S within the Aquifer demonstrates that treatment of H<sub>2</sub>S instead of avoidance is more realistic for these communities.

Methodology to treat or remove H<sub>2</sub>S in groundwater from within the Aquifer (i.e. prior to extraction) have not been developed. The oil and gas industry have injected nitrite-containing solution into wells to remove H<sub>2</sub>S in the aqueous and gaseous phases (Sturman et al., 1999). Observations from this method have resulted in aqueous H<sub>2</sub>S concentrations decreasing from 40 to 60 mg/l to less than 1 mg/l within individual wells (Sturman et al., 1999). This treatment method would not be suitable for domestic and municipal groundwater wells due to the nitrate within the solution. This demonstrates that the most viable H<sub>2</sub>S treatment strategies occur post-extraction.

Post-extraction treatment methods include active carbon filters, manganese greensand filters, aeration, and others. These three treatment methods can treat groundwater saturated with H<sub>2</sub>S concentrations of 0.05 to 0.03 mg/l, up to 10 mg/l, and less than 2 mg/l, respectively (L. McFarland and Provin, 1999). Active carbon filters are primarily suitable for individual faucets, manganese greensand filters for domestic wells,

and aeration for city water treatment systems (L. McFarland and Provin, 1999). The associated costs for these treatment methods vary and estimating treatment costs is outside the purposes of this study due to costs being highly variable depending on the quantity of groundwater. As stated treatment costs are generally associated with the quantity of groundwater (i.e. individual domestic use, municipal use, etc.) but costs of each treatment method may vary depending on the size of filters or aeration system required and all cost estimates should be made on a case by case basis.

This study hypothesized and confirmed the source of  $H_2S$ , characterized vertical groundwater-chemistry trends, and defined the evolution of redox processes within the Aquifer. However, there were known limitations with the data used during this study to confirm the source of  $H_2S$ , characterize groundwater-chemistry trends and the evolution of redox processes, and conduct statistical and temporal variability analysis. These data limitations included the: 1) long perforation intervals of the sampled wells, 2) lack of intermediary groundwater-chemistry data, 3) limited qualitative bacterial analysis, 4) limited geochemistry data for Aquifer sediments, and 5) the varied historical data sources and sample collection periods. The long perforation intervals of sampled wells and lack of intermediary groundwater-chemistry data prevented defining the vertical groundwater chemistry-trends more precisely. The groundwater-chemistry trends defined during this study are sufficient for general vertical trends but lack the precision necessary to characterize smaller scale trends. The limited bacterial analysis prevented the in-depth analysis of the bacterial communities present within the Aquifer. The qualitative analysis of anaerobic SRB was beneficial for the purposes of this study but further analysis may provide additional insights concerning the factors affecting groundwater-chemistry trends. The limited geochemistry data prohibited verifying the interpretations made concerning the precipitation of metal-sulfides throughout the Aquifer. Lastly, the varied historical data limited the inferences made concerning variability throughout the entire

Aquifer. The available data allowed general variability to be defined for Wells 1, 2, and 3 and Wells 4, 5, and 6 separately but not collectively. These data limitations demonstrate the potential for future studies concerning the effect bacterial reducing processes have on the Aquifer's biogeochemistry.

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## APPENDICES

APPENDIX A: H<sub>2</sub>S DATA COMPILED FROM THE NATIONAL  
WATER QUALITY MONITORING COUNCIL'S DATABASE

Sample Collection Date	State Well Number	Latitude	Longitude	Total Depth (Feet)	H2S Sniff Test Result	H2S Concentration (mg/l)
2015-08-05	006S012E21C001M	37.4032714	-120.6604757	121	Not Detected	0
2014-07-17	006S012E34G001M	37.3680861	-120.6396417	230	Not Detected	0
2006-03-27	006S012E34G002M	37.3683722	-120.6384972	148	Not Detected	0
2006-03-27	006S012E34G003M	37.3683722	-120.6384972	88	Not Detected	0
2006-04-03	007S011E36B001M	37.2876111	-120.713	268	Not Detected	0
2006-04-06	007S012E32B001M	37.2848889	-120.677861	380	Not Detected	0
2006-03-28	007S013E21M002M	37.3092722	-120.559236	168	Not Detected	0
2006-03-28	007S013E21M003M	37.3092722	-120.559236	56	Not Detected	0
2014-07-17	007S013E21M001M	37.3091722	-120.556111	180	Not Detected	0
2016-02-11	007S013E24M001M	37.3080833	-120.5035833	294	Not Detected	0
2006-05-02	007S014E05A001M	37.3577176	-120.451301	109	Not Detected	0
2006-04-10	007S014E16L002M	37.3245833	-120.4440833	266	Not Detected	0
2014-07-17	007S014E24K001M	37.30885	-120.3881139	230	Not Detected	0
2012-08-27	007S015E35F002M	37.2807752	-120.3001818	105	Not Detected	0
2006-05-02	007S016E09H001M	37.3393853	-120.2193465	130	Not Detected	0
2006-04-13	008S013E34L001M	37.1904444	-120.537861	355	Not Detected	0
2015-07-13	008S015E06M001M	37.2624056	-120.3787472	110	Not Detected	0
2015-09-15	009S009E07B001M	37.1734722	-121.0184444	280	Not Detected	0
2010-03-08	009S009E14N003M	37.1456389	-120.9574722	300	Not Detected	0
2010-06-30	009S011E10M001M	37.1608056	-120.7579444	230	Not Detected	0
2016-03-03	009S012E02A001M	37.1834722	-120.6195278	210	Not Detected	0
2006-04-13	009S012E02K002M	37.1764167	-120.6266389	368	Not Detected	0
2006-04-05	009S014E01B003M	37.1854444	-120.3901667	68	Not Detected	0
2008-04-28	009S014E19M001M	37.1331667	-120.4881389	300	Detected Not Quantified	0
2013-11-19	009S014E21C001M	37.1400278	-120.4500833	150	Not Detected	0
2014-03-20	009S015E29K001M	37.1191667	-120.3524722	300	Not Detected	0
2008-05-21	009S017E18J001M	37.1453611	-120.14825	200	Not Detected	0
2014-04-09	009S017E26A001M	37.12575	-120.0757778	340	Detected Not Quantified	0
2010-03-08	010S009E05C001M	37.1004986	-121.0074214	260	Not Detected	0
2010-03-02	010S010E23E002M	37.0527232	-120.8532483	310	Not Detected	0
2010-03-30	010S010E32L004M	37.0172806	-120.8999278	355	Not Detected	0
2010-03-30	010S010E32L005M	37.0172806	-120.8999278	160	Not Detected	0
2010-03-30	010S010E32L006M	37.0172806	-120.8999278	110	Not Detected	0
2010-06-16	010S011E01R001M	37.0843056	-120.7079167	150	Not Detected	0

2010-06-15	010S011E30G002M	37.0374444	-120.8080556	200	Not Detected	0
2010-03-02	010S012E22J002M	37.0454722	-120.63625	180	Not Detected	0
2010-04-12	010S012E33R001M	37.0113333	-120.6565278	150	Not Detected	0
2008-05-15	010S013E10G001M	37.0772222	-120.5366667	198	Not Detected	0
2013-12-12	010S014E03H001M	37.0915278	-120.4229722	300	Not Detected	0
2008-04-23	010S014E07A001M	37.0824444	-120.4736389	254	Not Detected	0
2008-05-08	010S014E07A002M	37.0803611	-120.47475	325	Detected Not Quantified	0
2013-11-20	010S014E20E001M	37.0493333	-120.4721944	260	Not Detected	0
2008-04-22	010S015E01M002M	37.0908333	-120.2899722	234	Not Detected	0
2013-11-18	010S015E03K001M	37.0897778	-120.3176667	300	Not Detected	0
2013-11-20	010S015E09J001M	37.0726111	-120.3293056	391	Not Detected	0
2011-03-16	010S015E29M001M	37.0323333	-120.3612222	216	Not Detected	0
2015-07-15	010S015E32P001M	37.0129806	-120.3561722	212	Not Detected	0
2011-03-16	010S015E33Q001M	37.0113889	-120.3361667	294	Not Detected	0
2013-11-18	010S016E13D001M	37.0687778	-120.18225	300	Not Detected	0
2011-03-15	010S018E15R001M	37.05575	-119.9849444	350	Not Detected	0
2013-12-10	010S018E22J001M	37.0441944	-119.9844722	369	Not Detected	0
2010-06-29	011S010E15B001M	36.9809444	-120.8643056	178	Not Detected	0
2010-06-16	011S013E07J001M	36.9855278	-120.5830556	150	Detected Not Quantified	0
2008-05-21	011S014E12J001M	36.9886111	-120.3844444	388	Not Detected	0
2014-04-10	011S015E19Q001M	36.9560833	-120.3730556	340	Not Detected	0
2008-05-13	011S015E25L002M	36.9446667	-120.2830278	200	Not Detected	0
2014-04-10	011S015E27H001M	36.9470278	-120.31025	200	Not Detected	0
2013-12-04	011S016E35J003M	36.9312222	-120.1842778	300	Not Detected	0
2013-12-04	011S017E11R001M	36.9854167	-120.0763056	280	Not Detected	0
2013-12-11	011S017E19C003M	36.9660833	-120.1562222	400	Not Detected	0
2008-05-06	011S018E32N001M	36.9241111	-120.0349722	330	Not Detected	0
2013-12-10	011S019E03F001M	37.0050833	-119.8881944	285	Not Detected	0
2014-03-19	011S019E15L001M	36.9728333	-119.8883889	310	Not Detected	0
2013-12-09	011S020E21P001M	36.9545556	-119.79575	320	Not Detected	0
2008-05-06	011S020E35L001M	36.9274167	-119.7603056	200	Not Detected	0
2010-04-12	012S012E04J001M	36.915	-120.6581667	218	Not Detected	0
2010-03-31	012S012E16E004M	36.8895944	-120.6701639	395	Detected Not Quantified	0
2010-03-31	012S012E16E005M	36.8895944	-120.6701639	215	Not Detected	0
2015-09-16	012S012E32R001M	36.8363889	-120.6739444	350	Not Detected	0
2010-06-15	012S013E17A001M	36.8925278	-120.56375	355	Detected Not Quantified	0

2010-03-03	012S014E28E003M	36.8611389	-120.4517222	230	Detected Not Quantified	0
2014-04-08	012S015E12A001M	36.9068889	-120.2741667	170	Not Detected	0
2008-05-20	012S016E31A001M	36.8506944	-120.2555833	340	Not Detected	0
2013-12-02	012S017E09M001M	36.9016667	-120.1263056	280	Not Detected	0
2008-04-30	012S017E25N001M	36.8520833	-120.0738333	388	Not Detected	0
2013-12-03	012S017E27G001M	36.8607222	-120.1004722	300	Not Detected	0
2013-12-03	012S018E03C002M	36.9229167	-119.9959444	190	Not Detected	0
2013-12-02	012S019E18P002M	36.8807222	-119.94125	212	Not Detected	0
2013-12-09	012S020E15N001M	36.8843056	-119.7837222	165	Not Detected	0
2014-01-08	012S020E26A001M	36.8655278	-119.7521944	231	Not Detected	0
2010-04-07	013S015E19R004M	36.7806806	-120.3722028	350	Not Detected	0
2010-04-06	013S015E19R005M	36.7806806	-120.3722028	78	Not Detected	0
2010-03-01	013S015E30B004M	36.7763194	-120.3736889	250	Detected Not Quantified	0
2014-03-19	013S016E25D003M	36.7766111	-120.1863056	123	Not Detected	0
2014-03-18	013S017E01J001M	36.8289722	-120.062861	253	Not Detected	0
2014-02-05	013S017E34H001M	36.7580278	-120.0974722	175	Not Detected	0
2014-01-29	013S019E21Q001M	36.7811111	-119.9063333	214	Not Detected	0
2014-01-09	013S019E25M001M	36.7683333	-119.8620556	166	Not Detected	0
2014-01-08	013S020E03F002M	36.8303333	-119.7838056	248	Not Detected	0
2008-11-04	013S020E05R001M	36.8245556	-119.8117778	270	Not Detected	0
2013-09-11	013S020E27C003M	36.7791667	-119.7822222	190	Not Detected	0
2005-11-03	013S022E17J001M	36.7995278	-119.5921667	390	Not Detected	0
2014-01-28	014S017E05J001M	36.7403611	-120.1328889	224	Not Detected	0
2014-02-23	014S017E29M001M	36.6811944	-120.1486944	258	Detected Not Quantified	0
2014-03-06	014S018E09Q001M	36.7223056	-120.0110556	185	Not Detected	0
2014-02-05	014S018E24B001M	36.7051667	-119.9592778	180	Not Detected	0
2005-11-16	014S019E29A002M	36.6885833	-119.9165556	208	Detected	1
2005-11-16	014S019E29A003M	36.6885833	-119.9165556	140	Not Detected	0
2013-09-11	014S020E02R002M	36.7371111	-119.7590278	160	Not Detected	0
2005-11-15	014S020E21K001M	36.6991389	-119.7979444	148	Not Detected	0
2013-09-24	014S020E25G001M	36.6854722	-119.744861	100	Not Detected	0
2013-08-22	014S020E31Q002M	36.6645556	-119.8334722	180	Not Detected	0
2010-08-25	014S020E34G001M	36.6732828	-119.7793089	124	Not Detected	0
2015-10-21	014S021E04N001M	36.73825	-119.6981944	236	Not Detected	0
2013-08-28	014S021E10H001M	36.7307778	-119.6682222	400	Not Detected	0
2013-08-19	014S021E13G001M	36.7165513	-119.6348638	77	Not Detected	0

2013-08-19	014S021E13G002M	36.7165513	-119.6348638	261	Not Detected	0
2013-08-20	014S021E13G003M	36.7165513	-119.6348638	184	Not Detected	0
2013-08-20	014S021E13G004M	36.7165513	-119.6348638	115	Not Detected	0
2013-07-23	014S021E14H002M	36.7166361	-119.64925	158	Not Detected	0
2013-07-23	014S021E14H003M	36.7166361	-119.6492583	80	Not Detected	0
2013-07-24	014S021E14H004M	36.7166146	-119.6491737	268	Not Detected	0
2013-07-22	014S021E14H005M	36.7162222	-119.6488889	132	Not Detected	0
2013-09-17	014S021E17B001M	36.7201667	-119.7078333	145	Not Detected	0
2018-07-17	014S021E17P001M	36.7097222	-119.7087222	320	Not Detected	0
2013-09-18	014S021E17Q002M	36.7096389	-119.709111	234	Not Detected	0
2013-08-12	014S022E08K001M	36.7273939	-119.5971432	268	Not Detected	0
2013-07-25	014S022E08K002M	36.7273939	-119.5971432	168	Not Detected	0
2013-07-25	014S022E08K003M	36.7273939	-119.5971432	81	Not Detected	0
2013-07-24	014S022E08K004M	36.7277222	-119.5974722	125	Not Detected	0
2013-09-10	014S022E17C001M	36.7210464	-119.6011514	81	Not Detected	0
2013-09-09	014S022E17C002M	36.7210464	-119.6011514	135	Not Detected	0
2013-09-09	014S022E17C003M	36.7210464	-119.6011514	89	Not Detected	0
2013-09-25	014S022E18A001M	36.7183803	-119.6131597	177	Not Detected	0
2013-09-25	014S022E18A002M	36.7183803	-119.6131597	140	Not Detected	0
2013-08-13	014S022E18E001M	36.7154911	-119.6242883	265	Not Detected	0
2013-08-13	014S022E18E002M	36.7154911	-119.6242883	172	Not Detected	0
2013-08-13	014S022E18E003M	36.7154911	-119.6242883	70	Not Detected	0
2013-08-14	014S022E18E005M	36.7154911	-119.6242883	113	Not Detected	0
2013-08-14	014S022E18E006M	36.7154911	-119.6242883	197	Not Detected	0
2005-10-26	014S022E23G001M	36.6996667	-119.5469444	370	Not Detected	0
2015-10-20	014S023E08D001M	36.7321944	-119.5010556	124	Not Detected	0
2014-02-24	014S023E20F003M	36.70125	-119.4977222	160	Not Detected	0
2014-04-08	015S016E03N001M	36.6466667	-120.2208056	300	Not Detected	0
2014-01-29	015S016E26H002M	36.5961667	-120.1885833	220	Not Detected	0
2014-01-30	015S017E31G001M	36.5858333	-120.1571944	260	Not Detected	0
2013-09-18	015S018E15B001M	36.6298889	-119.9943056	212	Not Detected	0
2013-09-12	015S018E28K001M	36.5963333	-120.0164722	300	Not Detected	0
2015-07-14	015S019E03G001M	36.6563611	-119.8854639	165	Not Detected	0
2013-08-29	015S019E17Q001M	36.6224167	-119.926	245	Not Detected	0
2013-09-19	015S020E04H001M	36.6572778	-119.794611	370.33	Not Detected	0
2014-02-26	015S020E36J001M	36.5808611	-119.737111	200	Not Detected	0

2012-07-10	015S021E03G001M	36.657728	-119.6723589	150	Not Detected	0
2014-04-07	015S021E14N002M	36.62035	-119.6634167	150	Not Detected	0
2010-07-14	015S021E20J001M	36.6124501	-119.7034704	120	Not Detected	0
2014-03-03	015S023E16E001M	36.6271111	-119.4794444	200	Not Detected	0
2014-02-25	015S023E32J001M	36.5808056	-119.4851667	125	Not Detected	0
2013-09-16	016S017E14N001M	36.5325278	-120.0970278	300	Not Detected	0
2014-01-28	016S018E27B001M	36.51475	-119.9955278	332	Not Detected	0
2014-02-04	016S020E20Q002M	36.5189722	-119.818361	209	Not Detected	0
2014-02-04	016S021E07E001M	36.5559444	-119.7362778	156	Not Detected	0
2014-03-04	016S021E24H001M	36.5261944	-119.62975	140	Not Detected	0
2014-02-03	016S021E30H001M	36.5138611	-119.71925	150	Not Detected	0
2014-02-27	016S022E01P001M	36.5619444	-119.5329722	280	Not Detected	0
2012-07-09	016S022E19P004M	36.5185617	-119.6237427	128	Not Detected	0
2014-02-06	016S023E20R001M	36.5201667	-119.4861944	180	Not Detected	0
2014-03-18	016S023E30G001M	36.5137222	-119.5117778	140	Not Detected	0
2014-01-06	017S018E13E001M	36.4533333	-119.9756667	235	Not Detected	0
2014-01-07	017S019E05M001M	36.4809722	-119.939861	400	Not Detected	0
2014-01-27	017S019E22N002M	36.4314444	-119.9016389	285	Detected Not Quantified	0
2015-07-15	017S019E34Q002M	36.4047556	-119.89445	200	Detected Not Quantified	0
2015-07-15	017S020E25K001M	36.4232778	-119.7523139	160	Not Detected	0
2005-10-17	017S020E30E001M	36.4267778	-119.8498889	380	Not Detected	0
2014-01-27	017S020E32E001M	36.4101111	-119.8300833	173	Detected Not Quantified	0
2014-02-03	017S021E18N001M	36.4457778	-119.7428333	200	Not Detected	0
2014-01-07	018S019E24D001M	36.3574167	-119.8679167	55	Not Detected	0
2015-02-23	018S020E01A001M	36.4000556	-119.7455833	300	Not Detected	0
2005-10-27	018S020E17N002M	36.3619722	-119.8318333	210	Detected	1
2002-08-14	018S020E34L001M	36.3169722	-119.7967778	232	Detected	1
2015-02-24	018S021E15M001M	36.3624167	-119.6898056	200	Detected Not Quantified	0
2015-07-16	018S021E27N004M	36.3297778	-119.6903056	200	Detected Not Quantified	0
2015-01-27	018S022E04C001M	36.4010833	-119.5929167	240	Not Detected	0
2015-03-17	019S020E24A001M	36.2665278	-119.7456389	180	Detected Not Quantified	0
2015-04-01	019S020E27R001M	36.2418056	-119.7820833	40	Not Detected	0
2015-02-23	019S021E05J001M	36.3045556	-119.7096389	240	Not Detected	0
2015-07-16	019S021E19R001M	36.2553056	-119.7272222	55	Not Detected	0
2015-08-17	019S021E32C001M	36.2394444	-119.72	73	Detected Not Quantified	0
2015-01-14	019S022E07M001M	36.2906389	-119.6364167	300	Not Detected	0

## APPENDIX B: FIELD MEASUREMENT MANUALS

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## Hydrogen Sulfide Test

0 to 5 mg/L H<sub>2</sub>S

For test kit 2537800 (Model HS-C)

DOC326.98.00022

Additional copies available on [www.hach.com](http://www.hach.com)

### Test preparation

- Rinse bottle with the sample water before testing. Rinse bottle with deionized water after testing.
- Wash all labware between tests. Contamination may alter test results. Clean with a non-abrasive detergent or a solvent such as isopropyl alcohol. Rinse with deionized water. Wipe and dry with a soft cloth.
- **Perform this test immediately after sampling.** Water that is aerated or allowed to stand will lose most of the hydrogen sulfide through aeration and oxidation.
- Test paper circles should be pale blue. Slight variations in the color of the test paper will not affect test results.
- Use only Alka-Seltzer tablets that do not contain aspirin. All other formulations of Alka-Seltzer will generate excess pressure and cause inaccurate test results.

**CAUTION: Handle chemical standards and reagents carefully. Review Material Safety Data Sheets for safe handling, storage and disposal information.**

### Replacement items

Description	Unit	Catalog no.
Alka-Seltzer® Tablets, without aspirin <sup>1</sup>	36	1453300
Hydrogen Sulfide Bottle, with cap	each	2532800
Hydrogen Sulfide Test Chart	each	2537900
Hydrogen Sulfide Test Papers	100/pkg	2537733

<sup>1</sup>Alka-Seltzer is a registered trademark of Miles Laboratories, Inc.

### Optional items

Description	Unit	Catalog no.
Deionized Water	500 mL	27249

### Test procedure



1. Fill the bottle to the 100-mL mark with sample.

2. Put a circle of Hydrogen Sulfide Test Paper inside the sample bottle cap. Do not get the paper wet.

3. Add two Alka-Seltzer tablets to the sample bottle. Cap the bottle immediately.

4. Wait two minutes for the tablets to dissolve and the effervescence to subside.

5. Remove the test paper from the cap. Compare the color of the test paper to the color on the color chart.

# Bacteria, Sulfate-reducing

DOC316.53.01326

## Visual determination

### Semi-quantitative

SRB-BART™<sup>1</sup>

**Scope and application:** For the determination of sulfate-reducing bacteria in brine solutions, produced waters and hydraulic fracturing waters.

<sup>1</sup> SRB-BART is a trademark of Droycon Bioconcepts Inc.



## Test preparation

### Before starting

Do not touch the inner surface of the tube or lid. Keep contamination out of the tube and lid. Use the aseptic technique.

Set the caps on a clean surface with the flat surface down.

Sulfate-reducing bacteria (SRB) grow primarily deep within biofilms and not directly in water. Make sure to get a representative sample.

Review the Safety Data Sheets (MSDS/SDS) for the chemicals that are used. Use the recommended personal protective equipment.

Dispose of reacted solutions according to local, state and federal regulations. Refer to the Safety Data Sheets for disposal information for unused reagents. Refer to the environmental, health and safety staff for your facility and/or local regulatory agencies for further disposal information.

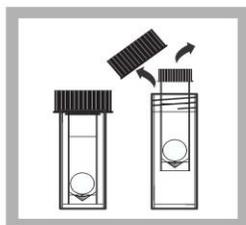
Sterilize the reacted sample before disposal. Refer to [Disposal](#) on page 3.

### Items to collect

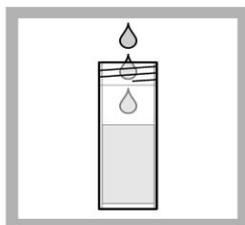
Description	Quantity
BART Test for sulfate-reducing bacteria (SRB)	1

Refer to [Consumables and replacement items](#) on page 4 for order information.

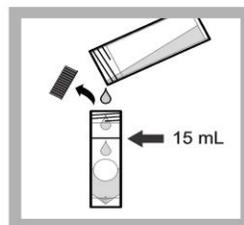
### Test procedure



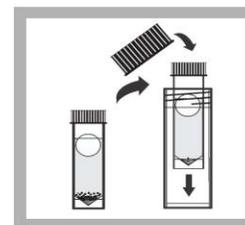
1. Remove the inner tube from the outer tube.



2. Pour at least 20 mL of sample in the outer tube.



3. Fill the inner tube to the fill line with the sample that is in the outer tube. Tighten the cap on the inner tube. Discard the unused sample in the outer tube.



4. Put the inner tube in the empty outer tube. Tighten the cap on the outer tube. Do not shake or swirl the tubes after the sample is added. Let the ball float to the top with no help.



5. Write the date and sample name on the outer tube.

6. Keep the tube at room temperature and away from direct sunlight for 8 days. Do not move the tube.

7. Examine the tube each day. Record the date when a reaction is first seen. Refer to [Test results](#) on page 2.

### Interferences

Interfering substance	Interference level
Hydrogen Sulfide (H <sub>2</sub> S)	More than 20 ppm can give a false positive. Remove hydrogen gas from the sample as follows: Add 30 mL of sample to the outer tube. Put the outer tube cap on the tube. Shake the tube for 10 seconds. Do not move the tube for 20 seconds. Use this sample in the test procedure.

### Test results

#### Presence/Absence

When sulfate-reducing bacteria are in the sample, a black slime forms in the tube. Refer to [Figure 1](#).

**Figure 1 Negative versus positive test results**



#### Negative (absent/non-aggressive)

The solution has no black slime.



#### Positive (present/aggressive)

A black slime ring forms around the ball and/or there is a black slime growth at the bottom of the tube.

#### Make an estimate of the bacteria population

If the test result is positive, make an estimate of the bacteria population and the aggressivity. Refer to [Table 1](#). A faster reaction occurs when the bacteria population is high.

**Table 1 Approximate bacteria population**

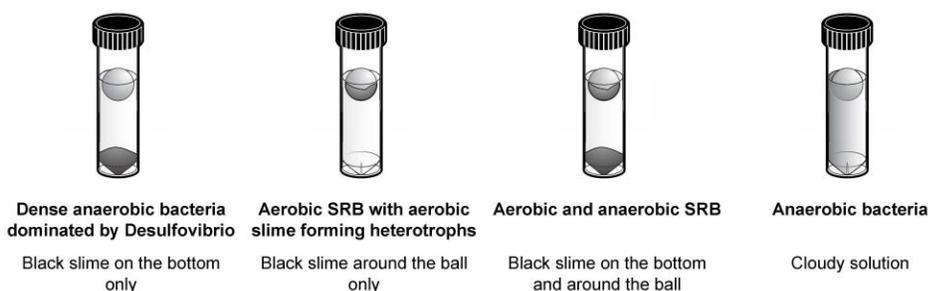
Days to reaction	Approximate SRB population (cfu/mL)	Aggressivity
1	2,200,000	Very high
2	500,000	High
3	115,000	High
4	27,000	High

**Table 1 Approximate bacteria population (continued)**

Days to reaction	Approximate SRB population (cfu/mL)	Aggressivity
5	6000	Moderate
6	1400	Moderate
7	325	Moderate
8	75	Low

**Advanced test information**

If the test result is positive, examine the tubes for dominant bacteria. Refer to [Figure 2](#).

**Figure 2 Dominant bacteria****Summary of method**

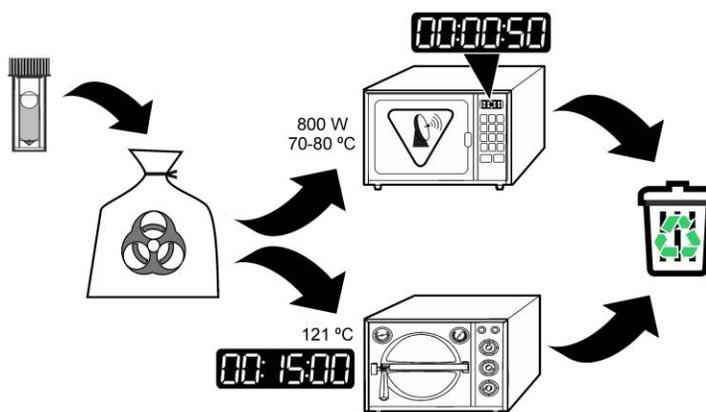
When sulfate-reducing bacteria (SRB) are in the sample, sulfate is reduced to hydrogen sulfide ( $H_2S$ ) in the SRB-BART tube during incubation. The  $H_2S$  reacts with the ferrous iron in the tube to form black iron sulfides. This sulfide commonly forms in the base as a black slime and/or around the ball as an irregular black ring.

Sulfate-reducing bacteria typically grow in anaerobic conditions deep within biofilms (slimes) as a part of a microbial community. Sulfate-reducing bacteria may not be in the free-flowing water over the site of the fouling. Sulfate-reducing bacteria can cause problems such as strong odors, blackening of equipment, slime formations and the start of corrosive processes.

**Disposal**

Sterilize the reacted sample before disposal. Refer to [Figure 3](#).

Figure 3 Disposal



### Consumables and replacement items

#### Required reagents

Description	Quantity/Test	Unit	Item no.
BART Test for sulfate-reducing bacteria (SRB)	1	9/pkg	2432409
BART Test for sulfate-reducing bacteria (SRB)	1	27/pkg	2432427



FOR TECHNICAL ASSISTANCE, PRICE INFORMATION AND ORDERING:  
 In the U.S.A. – Call toll-free 800-227-4224  
 Outside the U.S.A. – Contact the HACH office or distributor serving you.  
 On the Worldwide Web – [www.hach.com](http://www.hach.com); E-mail – [techhelp@hach.com](mailto:techhelp@hach.com)

HACH COMPANY  
 WORLD HEADQUARTERS  
 Telephone: (970) 669-3050  
 FAX: (970) 669-2932

## APPENDIX C: LABORATORY ANALYTICAL RESULTS



**A8C0579**  
**3/21/2018**  
Invoice: A806227

Ben Gooding

8658 N. Cedar Ave #104  
Fresno, CA 93720

**RE: Report for A8C0579 H25 Thesis - Ben Gooding**

Dear Ben Gooding,

Thank you for using BSK Associates for your analytical testing needs. In the following pages, you will find the test results for the samples submitted to our laboratory on 3/6/2018. The results have been approved for release by our Laboratory Director as indicated by the authorizing signature below.

The samples were analyzed for the test(s) indicated on the Chain of Custody (see attached) and the results relate only to the samples analyzed. BSK certifies that the testing was performed in accordance with the quality system requirements specified in the 2009 TNI Standard. Any deviations from this standard or from the method requirements for each test procedure performed will be annotated alongside the analytical result or noted in the Case Narrative. Unless otherwise noted, the sample results are reported on an "as received" basis.

If additional clarification of any information is required, please contact your Project Manager, Elaine M. Phillips, at 559-497-2888.

Thanks again for using BSK Associates. We value your business and appreciate your loyalty.

Sincerely,

Elaine M. Phillips, Project Coordinator



Accredited in Accordance with NELAP  
ORELAP #4021

**A8C0579***H25 Thesis - Ben Gooding***Case Narrative****Project and Report Details**

**Client:** Ben Gooding  
**Report To:** Ben Gooding  
**Project #:** Ben Gooding - H25 Thesis  
**Received:** 3/06/2018 - 14:10  
**Report Due:** 3/20/2018

**Invoice Details**

**Invoice Paid in Advance**  
**Payment type:** Charge  
**PIA #:** 051452  
**Sales Approval #:**

**Sample Receipt Conditions**

**Cooler:** Default Cooler  
**Temperature on Receipt °C:** 5.0

Containers Intact  
 COC/Labels Agree  
 Preservation Confirmed  
 Received On Wet Ice  
 Received On Blue Ice  
 Sample(s) arrived at lab on same day sampled.  
 Packing Material - Other  
 Sample(s) were received in temperature range.  
 Initial receipt at BSK-FAL

**Data Qualifiers**

The following qualifiers have been applied to one or more analytical results:

DL1.0 Sample required a dilution due to the matrix or high concentration of a non-target analyte.



**A8C0579**  
**H25 Thesis - Ben Gooding**  
Ben Gooding - H25 Thesis

**Certificate of Analysis**

Sample ID: A8C0579-01  
Sampled By: Ben Gooding  
Sample Description: 1

Sample Date - Time: 03/06/18 - 08:20  
Matrix: Ground Water  
Sample Type: Grab

**BSK Associates Laboratory Fresno**  
**General Chemistry**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Nitrate as N	EPA 300.0	ND	0.23	mg/L	1	A803057	03/07/18 03:57	03/07/18	
Sulfate as SO4	EPA 300.0	86	1.0	mg/L	1	A803057	03/07/18	03/07/18	

**Metals**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Arsenic	EPA 200.8	3.1	2.0	ug/L	1	A803180	03/08/18	03/15/18	
Manganese	EPA 200.7	0.023	0.010	mg/L	1	A803180	03/08/18	03/09/18	



**A8C0579**  
**H25 Thesis - Ben Gooding**  
Ben Gooding - H25 Thesis

**Certificate of Analysis**

Sample ID: A8C0579-02  
Sampled By: Ben Gooding  
Sample Description: 2

Sample Date - Time: 03/06/18 - 08:45  
Matrix: Ground Water  
Sample Type: Grab

**BSK Associates Laboratory Fresno**  
**General Chemistry**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Nitrate as N	EPA 300.0	ND	0.23	mg/L	1	A803057	03/07/18 04:07	03/07/18	
Sulfate as SO4	EPA 300.0	42	1.0	mg/L	1	A803057	03/07/18	03/07/18	

**Metals**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Arsenic	EPA 200.8	2.0	2.0	ug/L	1	A803180	03/08/18	03/15/18	
Manganese	EPA 200.7	0.015	0.010	mg/L	1	A803180	03/08/18	03/09/18	



**A8C0579**  
*H25 Thesis - Ben Gooding*  
Ben Gooding - H25 Thesis

**Certificate of Analysis**

Sample ID: A8C0579-03  
Sampled By: Ben Gooding  
Sample Description: 3

Sample Date - Time: 03/06/18 - 09:10  
Matrix: Ground Water  
Sample Type: Grab

**BSK Associates Laboratory Fresno**  
**General Chemistry**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Nitrate as N	EPA 300.0	ND	0.23	mg/L	1	A803057	03/07/18 04:57	03/07/18	
Sulfate as SO4	EPA 300.0	120	1.0	mg/L	1	A803057	03/07/18	03/07/18	

**Metals**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Arsenic	EPA 200.8	7.5	2.0	ug/L	1	A803180	03/08/18	03/15/18	
Manganese	EPA 200.7	0.031	0.010	mg/L	1	A803180	03/08/18	03/09/18	



**A8C0579**  
**H25 Thesis - Ben Gooding**  
Ben Gooding - H25 Thesis

**Certificate of Analysis**

Sample ID: A8C0579-04  
Sampled By: Ben Gooding  
Sample Description: 4

Sample Date - Time: 03/06/18 - 09:50  
Matrix: Ground Water  
Sample Type: Grab

**BSK Associates Laboratory Fresno**  
**General Chemistry**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Nitrate as N	EPA 300.0	ND	1.2	mg/L	5	A803057	03/07/18 05:06	03/07/18	DL1.0
Sulfate as SO4	EPA 300.0	900	5.0	mg/L	5	A803057	03/07/18	03/07/18	

**Metals**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Arsenic	EPA 200.8	ND	2.0	ug/L	1	A803180	03/08/18	03/15/18	
Manganese	EPA 200.7	0.47	0.010	mg/L	1	A803180	03/08/18	03/09/18	



**A8C0579**  
**H25 Thesis - Ben Gooding**  
Ben Gooding - H25 Thesis

**Certificate of Analysis**

Sample ID: A8C0579-05  
Sampled By: Ben Gooding  
Sample Description: 5

Sample Date - Time: 03/06/18 - 10:10  
Matrix: Ground Water  
Sample Type: Grab

**BSK Associates Laboratory Fresno**  
**General Chemistry**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Nitrate as N	EPA 300.0	ND	0.23	mg/L	1	A803057	03/07/18 05:16	03/07/18	
Sulfate as SO4	EPA 300.0	59	1.0	mg/L	1	A803057	03/07/18	03/07/18	

**Metals**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Arsenic	EPA 200.8	2.9	2.0	ug/L	1	A803180	03/08/18	03/15/18	
Manganese	EPA 200.7	0.69	0.010	mg/L	1	A803180	03/08/18	03/09/18	



**A8C0579**  
**H25 Thesis - Ben Gooding**  
Ben Gooding - H25 Thesis

**Certificate of Analysis**

Sample ID: A8C0579-06  
Sampled By: Ben Gooding  
Sample Description: 6

Sample Date - Time: 03/06/18 - 10:30  
Matrix: Ground Water  
Sample Type: Grab

**BSK Associates Laboratory Fresno**

**General Chemistry**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Nitrate as N	EPA 300.0	ND	0.23	mg/L	1	A803057	03/07/18 05:26	03/07/18	
Sulfate as SO4	EPA 300.0	57	1.0	mg/L	1	A803057	03/07/18	03/07/18	

**Metals**

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Arsenic	EPA 200.8	5.8	2.0	ug/L	1	A803180	03/08/18	03/15/18	
Manganese	EPA 200.7	0.95	0.010	mg/L	1	A803180	03/08/18	03/09/18	



**A8C0579**  
H25 Thesis - Ben Gooding

**BSK Associates Laboratory Fresno**  
**General Chemistry Quality Control Report**

Analyte	Result	RL	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Date Analyzed	Qual
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**EPA 300.0 - Quality Control**

Batch: A803057

Prepared: 3/7/2018

Prep Method: Method Specific Preparation

Analyst: BCB

**Blank (A803057-BLK1)**

Nitrate as N	ND	0.23	mg/L							03/07/18	
Sulfate as SO4	ND	1.0	mg/L							03/07/18	

**Blank Spike (A803057-BS1)**

Nitrate as N	23	0.23	mg/L	23		100	90-110			03/07/18	
Sulfate as SO4	100	1.0	mg/L	100		102	90-110			03/07/18	

**Matrix Spike (A803057-MS1), Source: A8C0579-02**

Nitrate as N	11	0.23	mg/L	11	ND	101	80-120			03/07/18	
Sulfate as SO4	93	1.0	mg/L	50	42	103	80-120			03/07/18	

**Matrix Spike (A803057-MS2), Source: A8C0583-01**

Nitrate as N	16	0.23	mg/L	11	4.0	105	80-120			03/07/18	
Sulfate as SO4	63	1.0	mg/L	50	9.7	106	80-120			03/07/18	

**Matrix Spike Dup (A803057-MSD1), Source: A8C0579-02**

Nitrate as N	12	0.23	mg/L	11	ND	102	80-120	2	20	03/07/18	
Sulfate as SO4	94	1.0	mg/L	50	42	104	80-120	1	20	03/07/18	

**Matrix Spike Dup (A803057-MSD2), Source: A8C0583-01**

Nitrate as N	16	0.23	mg/L	11	4.0	106	80-120	1	20	03/07/18	
Sulfate as SO4	63	1.0	mg/L	50	9.7	107	80-120	1	20	03/07/18	



**A8C0579**  
H25 Thesis - Ben Gooding

**BSK Associates Laboratory Fresno**  
**Metals Quality Control Report**

Analyte	Result	RL	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Date Analyzed	Qual
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**EPA 200.7 - Quality Control**

Batch: A803180

Prepared: 3/8/2018

Prep Method: EPA 200.2

Analyst: MDS

**Blank (A803180-BLK2)**

Manganese ND 0.010 mg/L 03/09/18

**Blank Spike (A803180-BS2)**

Manganese 0.21 0.010 mg/L 0.20 103 85-115 03/09/18

**Blank Spike Dup (A803180-BSD2)**

Manganese 0.21 0.010 mg/L 0.20 105 85-115 3 20 03/09/18

**Matrix Spike (A803180-MS3), Source: A8C0579-01**

Manganese 0.24 0.010 mg/L 0.20 0.023 107 70-130 03/09/18

**Matrix Spike (A803180-MS4), Source: A8C0597-05**

Manganese 0.21 0.010 mg/L 0.20 ND 103 70-130 03/09/18

**Matrix Spike Dup (A803180-MSD3), Source: A8C0579-01**

Manganese 0.24 0.010 mg/L 0.20 0.023 108 70-130 1 20 03/09/18

**Matrix Spike Dup (A803180-MSD4), Source: A8C0597-05**

Manganese 0.22 0.010 mg/L 0.20 ND 106 70-130 3 20 03/09/18

**EPA 200.8 - Quality Control**

Batch: A803180

Prepared: 3/8/2018

Prep Method: EPA 200.2

Analyst: MAS

**Blank (A803180-BLK1)**

Arsenic ND 2.0 ug/L 03/15/18

**Blank Spike (A803180-BS1)**

Arsenic 190 2.0 ug/L 200 95 85-115 03/15/18

**Blank Spike Dup (A803180-BSD1)**

Arsenic 190 2.0 ug/L 200 96 85-115 1 20 03/15/18

**Matrix Spike (A803180-MS1), Source: A8C0579-01**

Arsenic 190 2.0 ug/L 200 3.1 95 70-130 03/15/18

**Matrix Spike (A803180-MS2), Source: A8C0597-05**

Arsenic 170 2.0 ug/L 200 6.4 83 70-130 03/15/18

**Matrix Spike Dup (A803180-MSD1), Source: A8C0579-01**

Arsenic 200 2.0 ug/L 200 3.1 98 70-130 3 20 03/15/18

**Matrix Spike Dup (A803180-MSD2), Source: A8C0597-05**

Arsenic 170 2.0 ug/L 200 6.4 84 70-130 1 20 03/15/18

A8C0579 FINAL 03212018 1330

Printed: 3/21/2018

QA-RP-0001-10 Final.rpt

[www.BSKAssociates.com](http://www.BSKAssociates.com)

Page 10 of 43



A8C0579

H25 Thesis - Ben Gooding

## Certificate of Analysis

**Notes:**

- The Chain of Custody document and Sample Integrity Sheet are part of the analytical report.
- Any remaining sample(s) for testing will be disposed of according to BSK's sample retention policy unless other arrangements are made in advance.
- All positive results for EPA Methods 504.1 and 524.2 require the analysis of a Field Reagent Blank (FRB) to confirm that the results are not a contamination error from field sampling steps. If Field Reagent Blanks were not submitted with the samples, this method requirement has not been performed.
- Samples collected by BSK Analytical Laboratories were collected in accordance with the BSK Sampling and Collection Standard Operating Procedures.
- J-value is equivalent to DNQ (Detected, not quantified) which is a trace value. A trace value is an analyte detected between the MDL and the laboratory reporting limit. This result is of an unknown data quality and is only qualitative (estimated). Baseline noise, calibration curve extrapolation below the lowest calibrator, method blank detections, and integration artifacts can all produce apparent DNQ values, which contribute to the un-reliability of these values.
- (1) - Residual chlorine and pH analysis have a 15 minute holding time for both drinking and waste water samples as defined by the EPA and 40 CFR 136. Waste water and ground water (monitoring well) samples must be field filtered to meet the 15 minute holding time for dissolved metals.
- Summations of analytes (i.e. Total Trihalomethanes) may appear to add individual amounts incorrectly, due to rounding of analyte values occurring before or after the total value is calculated, as well as rounding of the total value.
- RL Multiplier is the factor used to adjust the reporting limit (RL) due to variations in sample preparation procedures and dilutions required for matrix interferences.
- Due to the subjective nature of the Threshold Odor Method, all characterizations of the detected odor are the opinion of the panel of analysts. The characterizations can be found in Standard Methods 2170B Figure 2170:1.
- The MCLs provided in this report (if applicable) represent the primary MCLs for that analyte.

**Definitions**

mg/L:	Milligrams/Liter (ppm)	MDL:	Method Detection Limit	MDA95:	Min. Detected Activity
mg/Kg:	Milligrams/Kilogram (ppm)	RL:	Reporting Limit: DL x Dilution	MPN:	Most Probable Number
µg/L:	Micrograms/Liter (ppb)	ND:	None Detected at RL	CFU:	Colony Forming Unit
µg/Kg:	Micrograms/Kilogram (ppb)	pCi/L:	Picocuries per Liter	Absent:	Less than 1 CFU/100mLs
%:	Percent Recovered (surrogates)	RL Mult:	RL Multiplier	Present:	1 or more CFU/100mLs
NR:	Non-Reportable	MCL:	Maximum Contaminant Limit		

Please see the individual Subcontract Lab's report for applicable certifications.

BSK is not accredited under the NELAP program for the following parameters:

**Certifications:** Please refer to our website for a copy of our Accredited Fields of Testing under each certification.

**Fresno**

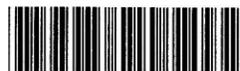
State of California - ELAP	1180	State of Hawaii	4021
State of Nevada	CA000792018-1	State of Oregon - NELAP	4021-009
EPA - UCMR4	CA00079	State of Washington	C997-17B
State of New York	12073		

**Sacramento**

State of California - ELAP	2435		
<b>San Bernardino</b>			
State of California - ELAP	2993	State of Oregon - NELAP	4119-002
<b>Vancouver</b>			
State of Oregon - NELAP	WA100008-010	State of Washington	C824-17



A8C0579



**03062018**

ANAFALPIA

Turnaround: Standard  
Due Date: 3/20/2018



PIA Client



Printed: 3/6/2018 5:00:51PM  
Page 1 of 1

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1414 Stenslieue St., Fresno-CA 93706  
 (559) 497-2888 · Fax (559) 497-2893  
 www.bs&kassociates.com

**Turnaround Time Request**

Standard - 10 business days  
 Rush (Surcharge may apply)  
 Date needed:

A8C0579  
 ANAFALPTL  
  
 10  
 03/06/2018

Company/Client Name: Benjamin Gooding  
 Address: 8658 N. Cedar Ave #104  
 Project: 425 Thesis  
 City: Fresno  
 State: CA  
 Zip: 93720  
 Report Attorney: Benjamin Gooding  
 Additional cc: PIA  
 Invoice To: PIA  
 PO#: CA  
 Phone: 916 539 6345  
 Fax: 916 539 6345  
 Email: benjamin.gooding@water.ca.gov

Reporting Options:  
 Trace (U-Frag)  Swamp  EDO Type  
 SWRCB (Drinking Water)  Fresno Co  
 Madera Co  Tulare Co  
 Other: \_\_\_\_\_  
 Matrix Type: SW-Surface Water BW-Boiled Water GW-Ground Water WW-Water Water STW-Storm Water DW-Drinking Water SO-Solid  
 Matrix: \_\_\_\_\_  
 Comments / Station Code / WTRAX: \_\_\_\_\_

#	Sample Description*	Date	Time	Matrix*	Arsenic, Manganese	Nitrate	Sulfate	EXT-Sulfide	EXT-Iron Speciation
1		5/1/18	8:20	420	X	X	X	X	X
2			9:10		X	X	X	X	X
3			9:50		X	X	X	X	X
4			10:10		X	X	X	X	X
5			10:50		X	X	X	X	X

Prepared By: Signature and Printed Name: Ben Farkas  
 Company: \_\_\_\_\_  
 Date: 5/1/18  
 Time: 10:10  
 Received By: Signature and Printed Name: \_\_\_\_\_  
 Company: \_\_\_\_\_  
 Date: 5/1/18  
 Time: 10:10

Requested by: Signature and Printed Name: Elaine Pichler  
 Company: WALK-IN  
 Date: 5/1/18  
 Time: 10:10  
 Payment Received at Delivery: \$1800.00  
 Amount: \$1800.00  
 PIA# 051450  
 Check # 101  
 Date: 5/1/18

BS&K ASSOCIATES is not responsible for the accuracy of the data received. If you do not, account balances are deemed delinquent. Delinquent balances are subject to monthly service charges and late fees as specified in BS&K's current Standard Terms and Conditions for Laboratory Services. The terms apply to the client and the client agrees to be responsible for payment of the services on the date of delivery. BS&K's current terms and conditions for laboratory services unless contractually stated otherwise. BS&K's current terms and conditions can be found at www.bs&kassociates.com/BS&K%20Terms%20and%20Conditions.pdf

BSK Associates SR-FL-0002-19

A8C0579 03/06/2018  
ANAFALPI 10

# Sample Integrity



BSK Bottles Yes No Page 1 of 1

COC Info		Yes	No	NA	Were correct containers and preservatives received for the tests requested?		Yes	No	NA
Was temperature within range? Chemistry $\leq 6^{\circ}\text{C}$ Micro $< 8^{\circ}\text{C}$							<input checked="" type="checkbox"/>		
If samples were taken today, is there evidence that chilling has begun?					Bubbles Present VOAs (524.2/TCP/TTHM)?		Yes	<input checked="" type="checkbox"/>	NA
Did all bottles arrive unbroken and intact?		<input checked="" type="checkbox"/>			TB Received? (Check Method Below)		Yes	<input checked="" type="checkbox"/>	NA
Did all bottle labels agree with COC?		Yes	No		Was a sufficient amount of sample received?		<input checked="" type="checkbox"/>		
Was sodium thiosulfate added to CN sample(s) until chlorine was no longer present?		Yes	<input checked="" type="checkbox"/>	NA	Do samples have a hold time <72 hours?		Yes	No	
					Was PM notified of discrepancies?		Yes	No	NA
					PM: _____ By/Time: _____				
250ml(A) 500ml(B) 1Liter(C) 40ml VOA(V)		Checks	Passed?						
Bacti $\text{Na}_2\text{S}_2\text{O}_3$									
None (P) White Cap									
Cr6 (P) Lt. Green Label/Blue Cap $\text{NH}_4\text{OH}(\text{NH}_4)_2\text{SO}_4$ DW		Cl, pH > 8	P	F					
Cr6 (P) Pink Label/Blue Cap $\text{NH}_4\text{OH}(\text{NH}_4)_2\text{SO}_4$ WW		pH 9.3-9.7	P	F					
Cr6 (P) Black Label/Blue Cap $\text{NH}_4\text{OH}(\text{NH}_4)_2\text{SO}_4$ 7199 ***24 HOUR HOLD TIME***		pH 9.0-9.5	P	F					
HNO <sub>3</sub> (P) Red Cap or HCl (P) Purple Cap/Lt. Blue Label									
H <sub>2</sub> SO <sub>4</sub> (P) or (AG) Yellow Cap/Label		pH < 2	P	F					
NaOH (P) Green Cap		Cl, pH > 10	P	F					
NaOH + ZnAc (P)		pH > 9	<input checked="" type="checkbox"/>	F					
Dissolved Oxygen 300ml (g)									
None (AG) 608/8081/8082, 625, 632/8321, 8151, 8270									
HCl (AG) Lt. Blue Label O&G, Diesel, TCP									
Ascorbic, EDTA, KH <sub>2</sub> Ct (AG) Pink Label 525									
Na <sub>2</sub> SO <sub>3</sub> 250mL (AG) Neon Green Label 515									
Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> 1 Liter (Brown P) 549									
Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> (AG) Blue Label 548, TTHM, 524									
Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> (CG) Blue Label 504, 505, 547									
Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> + MCAA (CG) Orange Label 531		pH < 3	P	F					
NH <sub>2</sub> Cl (AG) Purple Label 552									
EDA (AG) Brown Label DBPs									
HCL (CG) 524.2, BTEX, Gas, MTBE, 8260/624									
Buffer pH 4 (CG)									
H <sub>3</sub> PO <sub>4</sub> (CG) Salmon Label									
Other:									
Asbestos 1L (P) w/ Foil / LL Metals Bottle									
Bottled Water									
Clear Glass 250mL / 500mL / 1 Liter									
Solids: Brass / Steel / Plastic Bag									
Split	Container	Preservative	Date/Time/Initials		Container	Preservative	Date/Time/Initials		
	S P				S P				
	S P				S P				
Comments					<input checked="" type="checkbox"/> Indicates Blanks Received 504 ___ 524.2 ___ TCP ___ TTHM ___ 537 ___ 8260/624 ___				

Labeled by: PAW @ 15M Labels checked by: JND @ 16:29 RUSH Paged by: \_\_\_\_\_ @ \_\_\_\_\_



External



**A8C0579**





Date of Report: 03/13/2018

Elaine M. Phillips

BSK Analytical Labs  
1414 Stanislaus Street  
Fresno, CA 93706

Client Project: A8C0579  
BCL Project: Water Samples  
BCL Work Order: 1807624  
Invoice ID: B296756

Enclosed are the results of analyses for samples received by the laboratory on 3/8/2018. If you have any questions concerning this report, please feel free to contact me.

Sincerely,

Contact Person: Vanessa Sandoval  
Client Service Rep

Stuart Buttram  
Technical Director

Certifications: CA ELAP #1186; NV #CA00014; OR ELAP #4032-001; AK UST101

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Report ID: 1000717620

4100 Alias Court Bakersfield, CA 93308 (661) 327-4911 FAX (661) 327-1918 www.bclabs.com

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Chain of Custody and Cooler Receipt Form for 1807624 Page 1 of 2

**BSK ASSOCIATES** 1807624

**SUBCONTRACT ORDER**  
**A8C0579**

<b>SENDING LABORATORY:</b> BSK Associates Laboratory Fresno 1414 Stanislaus St Fresno, CA 93706 Phone: 559-497-2888 Fax: 559-485-6935 Project Manager: Elaine M. Phillips E-mail: ephillips@bskassociates.com	<b>RECEIVING LABORATORY:</b> BC Laboratories 4100 Atlas Court Bakersfield, CA 93308 Phone: (661) 327-4911 Fax: (661) 327-1918 Turnaround (Days): Standard QC Deliverables: I Std III IV
--	--

Sample ID	Samp Desc	Client Matrix	Ground Water	Sample Date
A8C0579-01	1 - 1 Lab Matrix: Water Analysis: 250 ml P NaOH + ZnAc <sub>2</sub> EXT-Sulfide	Client Matrix	Ground Water	03/06/2018 08:20
A8C0579-02	2 - 2 Lab Matrix: Water Analysis: _____ EXT-Sulfide	Client Matrix	Ground Water	03/06/2018 08:45
A8C0579-03	3 - 3 Lab Matrix: Water Analysis: _____ EXT-Sulfide	Client Matrix	Ground Water	03/06/2018 09:10
A8C0579-04	4 - 4 Lab Matrix: Water Analysis: _____ EXT-Sulfide	Client Matrix	Ground Water	03/06/2018 09:50
A8C0579-05	5 - 5 Lab Matrix: Water Analysis: _____ EXT-Sulfide	Client Matrix	Ground Water	03/06/2018 10:10
A8C0579-06	6 - 6 Lab Matrix: Water Analysis: _____ EXT-Sulfide	Client Matrix	Ground Water	03/06/2018 10:30

Released By: [Signature] Date: 3-7-18 Received By: [Signature] Date: 3-8-18 09:00

Released By: \_\_\_\_\_ Date: \_\_\_\_\_ Received By: \_\_\_\_\_ Date: \_\_\_\_\_

Page 1 of 2

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Chain of Custody and Cooler Receipt Form for 1807624 Page 2 of 2

SAMPLE CONTAINERS		SAMPLE NUMBERS									
		1	2	3	4	5	6	7	8	9	10
QT PE UNPRES											
4oz / Box / 16oz PE UNPRES											
2oz Cr <sup>6+</sup>											
QT INORGANIC CHEMICAL METALS											
INORGANIC CHEMICAL METALS 4oz / Box / 16oz											
PT CYANIDE											
PT NITROGEN FORMS											
PT TOTAL SULFIDE	802	A	A	A	A	A	A				
2oz NITRATE/NITRITE											
PT TOTAL ORGANIC CARBON											
PT CHEMICAL OXYGEN DEMAND											
PIA PHENOLICS											
40ml VOA VIAL TRAVEL BLANK											
40ml VOA VIAL											
QT EPA 1661											
PT ODOR											
RADIOLOGICAL											
BACTERIOLOGICAL											
49 ml VOA VIAL-504											
QT EPA 504/509/510											
QT EPA 515/1810											
QT EPA 525											
QT EPA 525 TRAVEL BLANK											
40ml EPA 547											
40ml EPA 531.1											
8oz EPA 548											
QT EPA 549											
QT EPA 801SM											
QT EPA 8270											
8oz / 16oz / 22oz AMBER											
8oz / 16oz / 22oz JAR											
SOIL SLURRY											
PCB VIAL											
PLASTIC BAG											
TEDLAR BAG											
FERRIC IRON											
ENCORE											
SMART KIT											
SUMMA CANSISTER											

Comments: \_\_\_\_\_ Date/Time: 3/8/18

Sample Numbering Completed By: GP

A = Actual / C = Corrected

Rev 21 06/23/2016  
(S:\WP\Doc\Work\Forms\LAB\DOC\FORMS\SAF\REC\ccr 20)

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BSK Analytical Labs  
1414 Stanislaus Street  
Fresno, CA 93706

Reported: 03/13/2018 10:24  
Project: Water Samples  
Project Number: A8C0579  
Project Manager: Elaine M. Phillips

### Laboratory / Client Sample Cross Reference

Laboratory	Client Sample Information			
1807624-01	COC Number:	---	Receive Date:	03/08/2018 09:00
	Project Number:	---	Sampling Date:	03/06/2018 08:20
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	A8C0579-01 1	Lab Matrix:	Water
	Sampled By:	---	Sample Type:	Groundwater
1807624-02	COC Number:	---	Receive Date:	03/08/2018 09:00
	Project Number:	---	Sampling Date:	03/06/2018 08:45
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	A8C0579-02 2	Lab Matrix:	Water
	Sampled By:	---	Sample Type:	Groundwater
1807624-03	COC Number:	---	Receive Date:	03/08/2018 09:00
	Project Number:	---	Sampling Date:	03/06/2018 09:10
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	A8C0579-03 3	Lab Matrix:	Water
	Sampled By:	---	Sample Type:	Groundwater
1807624-04	COC Number:	---	Receive Date:	03/08/2018 09:00
	Project Number:	---	Sampling Date:	03/06/2018 09:50
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	A8C0579-04 4	Lab Matrix:	Water
	Sampled By:	---	Sample Type:	Groundwater
1807624-05	COC Number:	---	Receive Date:	03/08/2018 09:00
	Project Number:	---	Sampling Date:	03/06/2018 10:10
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	A8C0579-05 5	Lab Matrix:	Water
	Sampled By:	---	Sample Type:	Groundwater
1807624-06	COC Number:	---	Receive Date:	03/08/2018 09:00
	Project Number:	---	Sampling Date:	03/06/2018 10:30
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	A8C0579-06 6	Lab Matrix:	Water
	Sampled By:	---	Sample Type:	Groundwater

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BSK Analytical Labs 1414 Stanislaus Street Fresno, CA 93706	<b>Reported:</b> 03/13/2018 10:24 <b>Project:</b> Water Samples <b>Project Number:</b> A8C0579 <b>Project Manager:</b> Elaine M. Phillips
---	--

**Water Analysis (General Chemistry)**

<b>BCL Sample ID:</b> 1807624-01	<b>Client Sample Name:</b> A8C0579-01 1, 3/6/2018 8:20:00AM
----------------------------------	---

Constituent	Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Total Sulfide	0.45	mg/L	0.10	0.050	SM-4500SD	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	SM-4500SD	03/12/18 11:00	03/12/18 11:00	DIW	SPEC06	1	6007366

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BSK Analytical Labs 1414 Stanislaus Street Fresno, CA 93706	<b>Reported:</b> 03/13/2018 10:24 <b>Project:</b> Water Samples <b>Project Number:</b> A8C0579 <b>Project Manager:</b> Elaine M. Phillips
---	--

**Water Analysis (General Chemistry)**

<b>BCL Sample ID:</b> 1807624-02	<b>Client Sample Name:</b> A8C0579-02 2, 3/6/2018 8:45:00AM
----------------------------------	---

Constituent	Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Total Sulfide	0.58	mg/L	0.10	0.050	SM-4500SD	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	SM-4500SD	03/12/18 11:00	03/12/18 11:00	DIW	SPEC06	1	B007366

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BSK Analytical Labs 1414 Stanislaus Street Fresno, CA 93706	Reported: 03/13/2018 10:24 Project: Water Samples Project Number: A8C0579 Project Manager: Elaine M. Phillips
---	--

**Water Analysis (General Chemistry)**

<b>BCL Sample ID:</b> 1807624-03	<b>Client Sample Name:</b> A8C0579-03 3, 3/6/2018 9:10:00AM
----------------------------------	---

Constituent	Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Total Sulfide	0.11	mg/L	0.20	0.10	SM-4500SD	ND	J,A07	1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	SM-4500SD	03/12/18 11:00	03/12/18 11:00	DIW	SPEC06	2	B007366

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BSK Analytical Labs 1414 Stanislaus Street Fresno, CA 93706	Reported: 03/13/2018 10:24 Project: Water Samples Project Number: A8C0579 Project Manager: Elaine M. Phillips
---	--

**Water Analysis (General Chemistry)**

<b>BCL Sample ID:</b> 1807624-04	<b>Client Sample Name:</b> A8C0579-04 4, 3/6/2018 9:50:00AM
----------------------------------	---

Constituent	Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Total Sulfide	ND	mg/L	0.10	0.050	SM-4500SD	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	SM-4500SD	03/12/18 11:00	03/12/18 11:00	DIW	SPEC06	1	B007366

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BSK Analytical Labs 1414 Stanislaus Street Fresno, CA 93706	<b>Reported:</b> 03/13/2018 10:24 Project: Water Samples Project Number: A8C0579 Project Manager: Elaine M. Phillips
---	---

**Water Analysis (General Chemistry)**

<b>BCL Sample ID:</b> 1807624-05	<b>Client Sample Name:</b> A8C0579-05 5, 3/6/2018 10:10:00AM
----------------------------------	--

Constituent	Result	Units	PQL	MDL	Method	MB Bias	Lab Quails	Run #
Total Sulfide	ND	mg/L	0.10	0.050	SM-4500SD	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	SM-4500SD	03/12/18 11:00	03/12/18 11:00	DIW	SPEC06	1	8007366

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BSK Analytical Labs 1414 Stanislaus Street Fresno, CA 93706	Reported: 03/13/2018 10:24 Project: Water Samples Project Number: A8C0579 Project Manager: Elaine M. Phillips
---	--

**Water Analysis (General Chemistry)**

<b>BCL Sample ID:</b> 1807624-06	<b>Client Sample Name:</b> A8C0579-06 6, 3/6/2018 10:30:00AM
----------------------------------	--

Constituent	Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Total Sulfide	ND	mg/L	0.10	0.050	SM-4500SD	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	SM-4500SD	03/12/18 11:00	03/12/18 11:00	DIW	SPEC06	1	B007366

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BSK Analytical Labs 1414 Stanislaus Street Fresno, CA 93706	<b>Reported:</b> 03/13/2018 10:24 <b>Project:</b> Water Samples <b>Project Number:</b> A8C0579 <b>Project Manager:</b> Elaine M. Phillips
---	--

### Water Analysis (General Chemistry)

#### Quality Control Report - Method Blank Analysis

Constituent	QC Sample ID	MB Result	Units	PQL	MDL	Lab Quals
<b>QC Batch ID: B007366</b>						
Total Sulfide	B007366-BLK1	ND	mg/L	0.10	0.050	

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BSK Analytical Labs  
1414 Stanislaus Street  
Fresno, CA 93706

Reported: 03/13/2018 10:24  
Project: Water Samples  
Project Number: A8C0579  
Project Manager: Elaine M. Phillips

### Water Analysis (General Chemistry)

#### Quality Control Report - Laboratory Control Sample

Constituent	QC Sample ID	Type	Result	Spike Level	Units	Percent Recovery	RPD	Control Limits		Lab
								Percent Recovery	RPD	
<b>QC Batch ID: B007366</b>										
Total Sulfide	B007366-BS1	LCS	0.49869	0.50000	mg/L	99.7		90 - 110		

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BSK Analytical Labs  
1414 Stanislaus Street  
Fresno, CA 93706

Reported: 03/13/2018 10:24  
Project: Water Samples  
Project Number: A8C0579  
Project Manager: Elaine M. Phillips

### Water Analysis (General Chemistry)

#### Quality Control Report - Precision & Accuracy

Constituent	Type	Source Sample ID	Source Result	Result	Spike Added	Units	RPD	Control Limits			
								Percent Recovery	RPD	Percent Recovery	Lab Quals
<b>QC Batch ID: B007366</b>		Used client sample: N									
Total Sulfide	DUP	1807667-02	ND	ND		mg/L				10	
	MS	1807667-02	ND	0.40395	0.50000	mg/L		80.8		80 - 120	
	MSD	1807667-02	ND	0.40570	0.50000	mg/L	0.4	81.1	10	80 - 120	

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Report ID: 1000717620

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BSK Analytical Labs  
1414 Stanislaus Street  
Fresno, CA 93706

**Reported:** 03/13/2018 10:24  
**Project:** Water Samples  
**Project Number:** A8C0579  
**Project Manager:** Elaine M. Phillips

#### Notes And Definitions

J	Estimated Value (CLP Flag)
MDL	Method Detection Limit
ND	Analyte Not Detected
PQL	Practical Quantitation Limit
A07	Detection and quantitation limits were raised due to sample dilution caused by high analyte concentration or matrix interference.

*The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety.*

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Report ID: 1000717620

4100 Alias Court Bakersfield, CA 93308 (661) 327-4911 FAX (661) 327-1918 www.bclabs.com

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McC Campbell Analytical, Inc.

"When Quality Counts"

## Analytical Report

**WorkOrder:** 1803593

**Report Created for:** BSK Engineers and Associates  
550 West Locust Avenue  
Fresno, CA 93650

**Project Contact:** Elaine M. Phillips  
**Project P.O.:**  
**Project:** A8C0579

**Project Received:** 03/09/2018

Analytical Report reviewed & approved for release on 03/16/2018 by:

Yen Cao  
Project Manager

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CA ELAP 1644 ♦ NELAP 4033 ORELAP



## Glossary of Terms & Qualifier Definitions

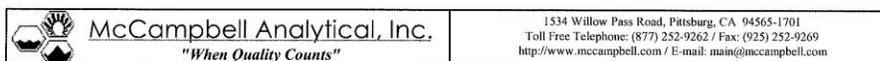
**Client:** BSK Engineers and Associates

**Project:** A8C0579

**WorkOrder:** 1803593

### Glossary Abbreviation

%D	Serial Dilution Percent Difference
95% Interval	95% Confident Interval
DF	Dilution Factor
DI WET	(DISTLC) Waste Extraction Test using DI water
DISS	Dissolved (direct analysis of 0.45 µm filtered and acidified water sample)
DLT	Dilution Test (Serial Dilution)
DUP	Duplicate
EDL	Estimated Detection Limit
ERS	External reference sample. Second source calibration verification.
ITEF	International Toxicity Equivalence Factor
LCS	Laboratory Control Sample
MB	Method Blank
MB % Rec	% Recovery of Surrogate in Method Blank, if applicable
MDL	Method Detection Limit
ML	Minimum Level of Quantitation
MS	Matrix Spike
MSD	Matrix Spike Duplicate
N/A	Not Applicable
ND	Not detected at or above the indicated MDL or RL
NR	Data Not Reported due to matrix interference or insufficient sample amount.
PDS	Post Digestion Spike
PDSD	Post Digestion Spike Duplicate
PF	Prep Factor
RD	Relative Difference
RL	Reporting Limit (The RL is the lowest calibration standard in a multipoint calibration.)
RPD	Relative Percent Deviation
RRT	Relative Retention Time
SPK Val	Spike Value
SPKRef Val	Spike Reference Value
SPLP	Synthetic Precipitation Leachate Procedure
ST	Sorbent Tube
TCLP	Toxicity Characteristic Leachate Procedure
TEQ	Toxicity Equivalents
WET (STLC)	Waste Extraction Test (Soluble Threshold Limit Concentration)



## Case Narrative

**Client:** BSK Engineers and Associates  
**Project:** A8C0579

**Work Order:** 1803593  
March 15, 2018

RE: Ferric Iron/ Iron (III) Result.

Please note that Iron (III) concentration is obtained by subtracting [Iron (II)] from [Total Iron].

The Iron (III) concentration for sample MAI Lab ID: 1803593- 001 is 80 ug/L.

The Iron (III) concentration for sample MAI Lab ID: 1803593- 002 is 130 ug/L.

The Iron (III) concentration for sample MAI Lab ID: 1803593- 003 is 46 ug/L.

The Iron (III) concentration for sample MAI Lab ID: 1803593- 004 is 1200 ug/L.

The Iron (III) concentration for sample MAI Lab ID: 1803593- 005 is 8800 ug/L.

The Iron (III) concentration for sample MAI Lab ID: 1803593- 006 is 8200 ug/L.

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## Analytical Report

**Client:** BSK Engineers and Associates  
**Date Received:** 3/9/18 11:26  
**Date Prepared:** 3/12/18  
**Project:** A8C0579

**WorkOrder:** 1803593  
**Extraction Method:** SM3500-Fe B4c  
**Analytical Method:** SM3500-Fe B4c  
**Unit:** µg/L

### Ferrous Iron

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-01	1803593-001A	Water	03/06/2018 08:20	SPECTROPHOTOMETER	154511

Analytes	Result	RL	DF	Date Analyzed
Ferrous Iron	ND	50	1	03/12/2018 07:00

Analyst(s): RB

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-02	1803593-002A	Water	03/06/2018 08:45	SPECTROPHOTOMETER	154511

Analytes	Result	RL	DF	Date Analyzed
Ferrous Iron	ND	50	1	03/12/2018 07:09

Analyst(s): RB

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-03	1803593-003A	Water	03/06/2018 09:10	SPECTROPHOTOMETER	154511

Analytes	Result	RL	DF	Date Analyzed
Ferrous Iron	ND	50	1	03/12/2018 07:12

Analyst(s): RB

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-04	1803593-004A	Water	03/06/2018 09:50	SPECTROPHOTOMETER	154511

Analytes	Result	RL	DF	Date Analyzed
Ferrous Iron	ND	50	1	03/12/2018 07:15

Analyst(s): RB

(Cont.)

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## Analytical Report

<b>Client:</b> BSK Engineers and Associates	<b>WorkOrder:</b> 1803593
<b>Date Received:</b> 3/9/18 11:26	<b>Extraction Method:</b> SM3500-Fe B4c
<b>Date Prepared:</b> 3/12/18	<b>Analytical Method:</b> SM3500-Fe B4c
<b>Project:</b> A8C0579	<b>Unit:</b> µg/L

### Ferrous Iron

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-05	1803593-005A	Water	03/06/2018 10:10	SPECTROPHOTOMETER	154511
<u>Analytes</u>	<u>Result</u>		<u>RL</u>	<u>DF</u>	<u>Date Analyzed</u>
Ferrous Iron	ND		50	1	03/12/2018 07:18

Analyst(s): RB

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-06	1803593-006A	Water	03/06/2018 10:30	SPECTROPHOTOMETER	154511
<u>Analytes</u>	<u>Result</u>		<u>RL</u>	<u>DF</u>	<u>Date Analyzed</u>
Ferrous Iron	ND		50	1	03/12/2018 07:21

Analyst(s): RB

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## Analytical Report

**Client:** BSK Engineers and Associates      **WorkOrder:** 1803593  
**Date Received:** 3/9/18 11:26      **Extraction Method:** E200.8  
**Date Prepared:** 3/9/18      **Analytical Method:** E200.8  
**Project:** A8C0579      **Unit:** µg/L

### Metals

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-01	1803593-001B	Water	03/06/2018 08:20	ICP-MS2 124SMPL.D	154498
<b>Analytes</b>	<b>Result</b>		<b>RL</b>	<b>DF</b>	<b>Date Analyzed</b>
Iron	80		20	1	03/13/2018 03:18
<b>Surrogates</b>	<b>REC (%)</b>		<b>Limits</b>		
Terbium	102		70-130		03/13/2018 03:18
<b>Analyst(s):</b> ND					
Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-02	1803593-002B	Water	03/06/2018 08:45	ICP-MS2 136SMPL.D	154498
<b>Analytes</b>	<b>Result</b>		<b>RL</b>	<b>DF</b>	<b>Date Analyzed</b>
Iron	130		20	1	03/13/2018 04:32
<b>Surrogates</b>	<b>REC (%)</b>		<b>Limits</b>		
Terbium	102		70-130		03/13/2018 04:32
<b>Analyst(s):</b> ND					
Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-03	1803593-003B	Water	03/06/2018 09:10	ICP-MS2 137SMPL.D	154498
<b>Analytes</b>	<b>Result</b>		<b>RL</b>	<b>DF</b>	<b>Date Analyzed</b>
Iron	46		20	1	03/13/2018 04:39
<b>Surrogates</b>	<b>REC (%)</b>		<b>Limits</b>		
Terbium	102		70-130		03/13/2018 04:39
<b>Analyst(s):</b> ND					
Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-04	1803593-004B	Water	03/06/2018 09:50	ICP-MS2 138SMPL.D	154498
<b>Analytes</b>	<b>Result</b>		<b>RL</b>	<b>DF</b>	<b>Date Analyzed</b>
Iron	1200		20	1	03/13/2018 04:45
<b>Surrogates</b>	<b>REC (%)</b>		<b>Limits</b>		
Terbium	104		70-130		03/13/2018 04:45
<b>Analyst(s):</b> ND					

(Cont.)

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## Analytical Report

<b>Client:</b>	BSK Engineers and Associates	<b>WorkOrder:</b>	1803593
<b>Date Received:</b>	3/9/18 11:26	<b>Extraction Method:</b>	E200.8
<b>Date Prepared:</b>	3/9/18	<b>Analytical Method:</b>	E200.8
<b>Project:</b>	A8C0579	<b>Unit:</b>	µg/L

### Metals

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-05	1803593-005B	Water	03/06/2018 10:10	ICP-MS2 139SMPL.D	154498

Analytes	Result	RL	DE	Date Analyzed
Iron	8800	20	1	03/13/2018 04:51

Surrogates	REC (%)	Limits	Date Analyzed
Terbium	101	70-130	03/13/2018 04:51

Analyst(s): ND

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
A8C0579-06	1803593-006B	Water	03/06/2018 10:30	ICP-MS2 140SMPL.D	154498

Analytes	Result	RL	DE	Date Analyzed
Iron	8200	20	1	03/13/2018 04:57

Surrogates	REC (%)	Limits	Date Analyzed
Terbium	102	70-130	03/13/2018 04:57

Analyst(s): ND

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## Quality Control Report

<b>Client:</b>	BSK Engineers and Associates	<b>WorkOrder:</b>	1803593
<b>Date Prepared:</b>	3/12/18	<b>BatchID:</b>	154511
<b>Date Analyzed:</b>	3/12/18	<b>Extraction Method:</b>	SM3500-Fe B4c
<b>Instrument:</b>	SPECTROPHOTOMETER	<b>Analytical Method:</b>	SM3500-Fe B4c
<b>Matrix:</b>	Water	<b>Unit:</b>	µg/L
<b>Project:</b>	A8C0579	<b>Sample ID:</b>	MB/LCS-154511 1803593-001AMS/MSD

### QC Summary Report for Ferrous Iron

Analyte	MB Result	LCS Result	RL	SPK Val	MB SS %REC	LCS %REC	LCS Limits
Ferrous Iron	ND	202	50	200	-	101	90-110

Analyte	MS Result	MSD Result	SPK Val	SPKRef Val	MS %REC	MSD %REC	MS/MSD Limits	RPD	RPD Limit
Ferrous Iron	191	188	200	ND	95	94	90-110	1.39	20

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### Quality Control Report

<b>Client:</b>	BSK Engineers and Associates	<b>WorkOrder:</b>	1803593
<b>Date Prepared:</b>	3/9/18	<b>BatchID:</b>	154498
<b>Date Analyzed:</b>	3/13/18	<b>Extraction Method:</b>	E200.8
<b>Instrument:</b>	ICP-MS2	<b>Analytical Method:</b>	E200.8
<b>Matrix:</b>	Water	<b>Unit:</b>	µg/L
<b>Project:</b>	A8C0579	<b>Sample ID:</b>	MB/LCS-154498 1803593-001BMS/MSD

#### QC Summary Report for Metals

Analyte	MB Result	LCS Result	RL	SPK Val	MB SS %REC	LCS %REC	LCS Limits
Iron	ND	5260	20	5000	-	105	85-115
<b>Surrogate Recovery</b>							
Terbium	765	764		750	102	102	70-130

Analyte	MS Result	MSD Result	SPK Val	SPKRef Val	MS %REC	MSD %REC	MS/MSD Limits	RPD	RPD Limit
Iron	5200	5170	5000	79.83	103	102	75-125	0.713	20
<b>Surrogate Recovery</b>									
Terbium	762	768	750		102	102	70-130	0	20

Analyte	DLT Result	DLTRef Val	%D	%D Limit
Iron	ND<100	79.83	-	-

%D Control Limit applied to analytes with concentrations greater than 25 times the reporting limits.





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**WORK ORDER SUMMARY**

**Client Name:** BSK ENGINEERS AND ASSOCIATES      **Project:** A8C0579;      **Work Order:** 1803593  
**Client Contact:** Elaine M. Phillips      **Comments:**      **QC Level:** LEVEL 2  
**Contact's Email:** ephillips@bskassociates.com      **Date Logged:** 3/9/2018

Lab ID	Client ID	Matrix	Test Name	Containers /Composites	Bottle & Preservative	De-chlorinated	Collection Date & Time	TAT	Sediment	Hold	SubOut
1803593-001A	A8C0579-01	Water	SM3500 Fe B4c (Ferrous Iron)	1	VOA w/ HCl	<input type="checkbox"/>	3/6/2018 8:20	5 days	None	<input type="checkbox"/>	None
1803593-001B	A8C0579-01	Water	E200.8 (Metals) <Iron>	1	125mL HDPE w/ HNO3	<input type="checkbox"/>	3/6/2018 8:20	5 days	None	<input type="checkbox"/>	None
1803593-002A	A8C0579-02	Water	SM3500 Fe B4c (Ferrous Iron)	1	VOA w/ HCl	<input type="checkbox"/>	3/6/2018 8:45	5 days	None	<input type="checkbox"/>	None
1803593-002B	A8C0579-02	Water	E200.8 (Metals) <Iron>	1	125mL HDPE w/ HNO3	<input type="checkbox"/>	3/6/2018 8:45	5 days	None	<input type="checkbox"/>	None
1803593-003A	A8C0579-03	Water	SM3500 Fe B4c (Ferrous Iron)	1	VOA w/ HCl	<input type="checkbox"/>	3/6/2018 9:10	5 days	None	<input type="checkbox"/>	None
1803593-003B	A8C0579-03	Water	E200.8 (Metals) <Iron>	1	125mL HDPE w/ HNO3	<input type="checkbox"/>	3/6/2018 9:10	5 days	None	<input type="checkbox"/>	None
1803593-004A	A8C0579-04	Water	SM3500 Fe B4c (Ferrous Iron)	1	VOA w/ HCl	<input type="checkbox"/>	3/6/2018 9:50	5 days	None	<input type="checkbox"/>	None
1803593-004B	A8C0579-04	Water	E200.8 (Metals) <Iron>	1	125mL HDPE w/ HNO3	<input type="checkbox"/>	3/6/2018 9:50	5 days	None	<input type="checkbox"/>	None
1803593-005A	A8C0579-05	Water	SM3500 Fe B4c (Ferrous Iron)	1	VOA w/ HCl	<input type="checkbox"/>	3/6/2018 10:10	5 days	None	<input type="checkbox"/>	None
1803593-005B	A8C0579-05	Water	E200.8 (Metals) <Iron>	1	125mL HDPE w/ HNO3	<input type="checkbox"/>	3/6/2018 10:10	5 days	None	<input type="checkbox"/>	None
1803593-006A	A8C0579-06	Water	SM3500 Fe B4c (Ferrous Iron)	1	VOA w/ HCl	<input type="checkbox"/>	3/6/2018 10:30	5 days	None	<input type="checkbox"/>	None
1803593-006B	A8C0579-06	Water	E200.8 (Metals) <Iron>	1	125mL HDPE w/ HNO3	<input type="checkbox"/>	3/6/2018 10:30	5 days	None	<input type="checkbox"/>	None

**NOTES:** - STLC and TCLP extractions require 2 days to complete; therefore, all TATs begin after the extraction is completed (i.e., One-day TAT yields results in 3 days from sample submission).  
 - MAI assumes that all material present in the provided sampling container is considered part of the sample - MAI does not exclude any material from the sample prior to sample preparation unless requested in writing by the client.



SUBCONTRACT ORDER  
A8C0579

1803593

SENDING LABORATORY:

BSK Associates Laboratory Fresno  
1414 Stanislaus St  
Fresno, CA 93706  
Phone: 559-497-2888  
Fax: 559-485-6935  
Project Manager: Elaine M. Phillips  
E-mail: ephillips@bskassociates.com

RECEIVING LABORATORY:

McC Campbell Analytical, Inc.  
1534 Willow Pass Road  
Pittsburg, CA 94565-1701  
Phone: (925) 252-9262  
Fax: (925) 252-9269  
Turnaround (Days): Standard  
QC Deliverables: I Std III IV

Sample ID	Samp Desc	Sample Date
A8C0579-01	1 Lab Matrix: Water Analysis: 250 mL P AND 40 mL VOA ACC EXT-Iron Speciation by SM 3500-Fe B4C/200.7, 200.8	Client Matrix Ground Water 03/06/2018 08:20
A8C0579-02	2 Lab Matrix: Water Analysis: _____ EXT-Iron Speciation by SM 3500-Fe B4C/200.7, 200.8	Client Matrix Ground Water 03/06/2018 08:45
A8C0579-03	3 Lab Matrix: Water Analysis: _____ EXT-Iron Speciation by SM 3500-Fe B4C/200.7, 200.8	Client Matrix Ground Water 03/06/2018 09:10
A8C0579-04	4 Lab Matrix: Water Analysis: _____ EXT-Iron Speciation by SM 3500-Fe B4C/200.7, 200.8	Client Matrix Ground Water 03/06/2018 09:50
A8C0579-05	5 Lab Matrix: Water Analysis: _____ EXT-Iron Speciation by SM 3500-Fe B4C/200.7, 200.8	Client Matrix Ground Water 03/06/2018 10:10
A8C0579-06	6 Lab Matrix: Water Analysis: _____ EXT-Iron Speciation by SM 3500-Fe B4C/200.7, 200.8	Client Matrix Ground Water 03/06/2018 10:30

Released By *[Signature]* Date 3/6/18  
 Received By ONTRAC Date  
 Released By ONTRAC Date  
 Received By *[Signature]* Date 3/9/18 1126

S.3

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### Sample Receipt Checklist

Client Name:	<b>BSK Engineers and Associates</b>	Date and Time Received	<b>3/9/2018 11:26</b>
Project:	<b>A8C0579;</b>	Date Logged:	<b>3/9/2018</b>
WorkOrder No:	<b>1803593</b>	Received by:	<b>Kena Ponce</b>
Carrier:	<b>OnTrac</b>	Logged by:	<b>Kena Ponce</b>
	Matrix: <b>Water</b>		

#### Chain of Custody (COC) Information

Chain of custody present?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Chain of custody signed when relinquished and received?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Chain of custody agrees with sample labels?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Sample IDs noted by Client on COC?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Date and Time of collection noted by Client on COC?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Sampler's name noted on COC?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
COC agrees with Quote?	Yes <input type="checkbox"/>	No <input type="checkbox"/>	NA <input checked="" type="checkbox"/>

#### Sample Receipt Information

Custody seals intact on shipping container/cooler?	Yes <input type="checkbox"/>	No <input type="checkbox"/>	NA <input checked="" type="checkbox"/>
Shipping container/cooler in good condition?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Samples in proper containers/bottles?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Sample containers intact?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
Sufficient sample volume for indicated test?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	

#### Sample Preservation and Hold Time (HT) Information

All samples received within holding time?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	NA <input type="checkbox"/>
Samples Received on Ice?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
	(Ice Type: BLUE ICE )		
Sample/Temp Blank temperature		Temp: 5.3°C	NA <input type="checkbox"/>
Water - VOA vials have zero headspace / no bubbles?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	NA <input type="checkbox"/>
Sample labels checked for correct preservation?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	
pH acceptable upon receipt (Metal: <2; 522: <4; 218.7: >8)?	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	NA <input type="checkbox"/>
<b>UCMR Samples:</b>			
pH tested and acceptable upon receipt (200.8: ≤2; 525.3: ≤4; 530: ≤7; 541: <3; 544: <6.5 & 7.5)?	Yes <input type="checkbox"/>	No <input type="checkbox"/>	NA <input checked="" type="checkbox"/>
Free Chlorine tested and acceptable upon receipt (<0.1mg/L)?	Yes <input type="checkbox"/>	No <input type="checkbox"/>	NA <input checked="" type="checkbox"/>

Comments:

APPENDIX D: HISTORICAL GROUNDWATER-CHEMISTRY DATA  
FOR WELLS 1, 2, AND 3

Sulfate					
Well 1		Well 2		Well 3	
Date	Concentration (mg/l)	Date	Concentration (mg/l)	Date	Concentration (mg/l)
08/2001	66.9	03/2003	47	06/2001	86
02/2003	22	05/2003	15	02/2003	78
03/2003	55	07/2003	13	03/2003	68
04/2003	67	08/2003	14	04/2003	80
05/2003	90	09/2003	14	05/2003	110
07/2003	77	10/2003	15	07/2003	101
08/2003	82	11/2003	13	08/2003	112
09/2003	13	12/2003	13.5	09/2003	19
10/2003	80	01/2004	16.6	10/2003	109
11/2003	82	10/2004	18	11/2003	111
12/2003	76.1	05/2007	22.3	12/2003	95.6
01/2004	91	10/2007	20.6	01/2004	116
10/2004	85	02/2012	20	10/2004	100
05/2007	90	11/2015	26	05/2007	106
10/2007	86.6			10/2007	112
02/2012	88			02/2012	110
11/2015	80			11/2015	110
Total Iron					
Well 1		Well 2		Well 3	
Date	Concentration (µg/l)	Date	Concentration (µg/l)	Date	Concentration (µg/l)
08/2001	315	10/2001	414	06/2001	277
02/2003	506	02/2003	271	02/2003	403
03/2003	232	03/2003	195	03/2003	211
04/2003	185	04/2003	183	04/2003	191
05/2003	175	09/2003	406	05/2003	184
07/2003	149	01/2004	240	07/2003	118
08/2003	134	04/2004	110	08/2003	164
09/2003	307	06/2004	170	09/2003	281
10/2003	152	09/2004	140	10/2003	152
11/2003	175	10/2004	390	11/2003	181
12/2003	160	12/2004	100	12/2003	390
01/2004	160	03/2005	200	01/2004	200
01/2004	160	08/2005	100	01/2004	200
04/2004	100	10/2005	120	04/2004	100
06/2004	100	01/2006	120	06/2004	100
09/2004	100	04/2006	140	09/2004	100
10/2004	100	07/2006	220	10/2004	100
12/2004	100	07/2006	110	12/2004	100
03/2005	100	10/2006	100	03/2005	100
08/2005	100	01/2007	100	08/2005	100
10/2005	100	04/2007	120	10/2005	100
01/2006	100	05/2007	100	01/2006	100
04/2006	100	07/2007	120	04/2006	120
07/2006	100	10/2007	120	07/2006	100
10/2006	100	01/2008	100	07/2006	100
01/2007	100	04/2008	140	10/2006	100
04/2007	100	09/2008	100	01/2007	100
05/2007	100	02/2009	241	04/2007	100
07/2007	100	04/2009	100	05/2007	100
10/2007	100	09/2009	250	07/2007	100
10/2007	100	11/2009	160	10/2007	100
01/2008	100	01/2010	100	10/2007	100
04/2008	100	07/2010	150	01/2008	100
09/2008	100	01/2011	100	04/2008	100
02/2009	246	02/2012	270	09/2008	100
04/2009	100	02/2013	260	02/2009	245
09/2009	100	01/2014	200	04/2009	100
11/2009	100	02/2014	200	09/2009	100
01/2010	100	03/2014	140	11/2009	100
07/2010	130	04/2014	140	01/2010	100
01/2011	100	05/2014	130	07/2010	100
02/2012	100	06/2014	130	01/2011	100
02/2013	100	07/2014	200	02/2012	100
01/2014	100	08/2014	210	02/2013	100

02/2014	100	09/2014	130	01/2014	100
03/2014	110	10/2014	140	02/2014	100
04/2014	100	11/2014	200	03/2014	100
05/2014	100	12/2014	150	04/2014	100
06/2014	100	01/2015	130	05/2014	100
07/2014	100	03/2015	130	06/2014	100
08/2014	100	04/2015	130	07/2014	100
09/2014	100	05/2015	130	08/2014	100
10/2014	100	06/2015	120	09/2014	100
11/2014	130	07/2015	140	10/2014	100
12/2014	100	08/2015	130	11/2014	100
01/2015	100	09/2015	100	12/2014	100
03/2015	100	10/2015	100	01/2015	100
04/2015	100	11/2015	140	03/2015	100
05/2015	100	11/2015	170	04/2015	100
06/2015	100	12/2015	100	05/2015	100
07/2015	100	01/2016	210	06/2015	100
08/2015	100	02/2016	180	07/2015	100
09/2015	100	03/2016	130	08/2015	100
10/2015	100	04/2016	190	09/2015	100
11/2015	100	05/2016	100	10/2015	100
11/2015	100	06/2016	150	11/2015	100
12/2015	100	07/2016	170	11/2015	100
01/2016	100	08/2016	120	12/2015	100
02/2016	100	09/2016	180	01/2016	100
03/2016	100	10/2016	100	02/2016	100
04/2016	140	11/2016	170	03/2016	160
05/2016	100	12/2016	170	04/2016	120
06/2016	100	02/2017	100	05/2016	140
07/2016	100	03/2017	100	06/2016	100
08/2016	100	04/2017	100	07/2016	100
09/2016	100	05/2017	100	08/2016	100
10/2016	100	07/2017	120	09/2016	100
11/2016	100	08/2017	120	10/2016	100
12/2016	100	09/2017	110	11/2016	100
02/2017	100	10/2017	110	12/2016	100
03/2017	100	12/2017	100	02/2017	100
04/2017	100	01/2018	100	03/2017	100
05/2017	100	02/2018	110	04/2017	100
07/2017	100	03/2018	130	05/2017	100
08/2017	100	04/2018	100	07/2017	100
09/2017	100	05/2018	100	08/2017	100
10/2017	100	06/2018	100	09/2017	100
12/2017	100	08/2018	100	10/2017	100
01/2018	100	09/2018	100	12/2017	100
02/2018	100			01/2018	100
03/2018	100			02/2018	100
04/2018	100			03/2018	100
05/2018	100			04/2018	100
06/2018	300			05/2018	100
08/2018	100			06/2018	100
09/2018	100			08/2018	100
				09/2018	100
<b>Total Manganese</b>					
Well 1		Well 2		Well 3	
Date	Concentration (µg/l)	Date	Concentration (µg/l)	Date	Concentration (µg/l)
08/2001	25.1	10/2001	29.8	06/2001	27.6
02/2003	20	02/2003	20	02/2003	20
03/2003	28	03/2003	25	03/2003	29
04/2003	20	04/2003	20	04/2003	20
05/2003	20	05/2003	20	05/2003	24
07/2003	20	07/2003	20	07/2003	21
08/2003	20	08/2003	20	08/2003	23
09/2003	20	09/2003	20	09/2003	20
10/2003	20	10/2003	20	10/2003	20
11/2003	20	11/2003	20	11/2003	20
12/2003	22	12/2003	22	12/2003	20

01/2004	20	01/2004	20	01/2004	25
01/2004	20	04/2004	20	01/2004	25
04/2004	20	06/2004	20	04/2004	30
06/2004	20	09/2004	20	06/2004	30
09/2004	20	10/2004	20	09/2004	30
10/2004	20	12/2004	20	10/2004	30
12/2004	20	03/2005	20	12/2004	30
03/2005	20	08/2005	30	03/2005	20
08/2005	20	10/2005	40	08/2005	20
10/2005	20	01/2006	20	10/2005	30
01/2006	20	04/2006	20	01/2006	25
04/2006	20	07/2006	20	04/2006	20
07/2006	20	07/2006	20	07/2006	26
10/2006	20	10/2006	20	07/2006	26
01/2007	20	01/2007	20	10/2006	23
04/2007	20	04/2007	20	01/2007	27
05/2007	20	05/2007	20	04/2007	27
10/2007	21.4	10/2007	20	05/2007	22
09/2008	27.3	09/2008	20	10/2007	30.3
02/2009	36.3	02/2009	36.6	09/2008	25.6
04/2009	25.8	04/2009	25.5	02/2009	38.4
09/2009	35.8	09/2009	25.7	04/2009	32.9
11/2009	33.6	11/2009	21.2	09/2009	45.6
01/2010	30.2	01/2010	30.4	11/2009	34.3
07/2010	25.9	07/2010	25.7	01/2010	36.4
01/2011	41.3	01/2011	41.5	07/2010	38.7
02/2012	20	02/2012	20	01/2011	52.3
02/2013	21	02/2013	20	02/2012	26
01/2014	21	01/2014	20	02/2013	28
02/2014	21	02/2014	20	01/2014	27
03/2014	23	03/2014	30	02/2014	28
04/2014	23	04/2014	20	03/2014	30
05/2014	22	05/2014	30	04/2014	29
06/2014	21	06/2014	32	05/2014	28
07/2014	21	07/2014	20	06/2014	30
08/2014	22	08/2014	20	07/2014	28
09/2014	20	09/2014	28	08/2014	29
10/2014	21	10/2014	30	09/2014	30
11/2014	20	11/2014	20	10/2014	30
12/2014	23	12/2014	20	11/2014	20
01/2015	22	01/2015	28	12/2014	31
03/2015	22	03/2015	29	01/2015	27
04/2015	22	04/2015	29	03/2015	30
05/2015	23	05/2015	20	04/2015	27
06/2015	21	06/2015	27	05/2015	28
07/2015	21	07/2015	27	06/2015	29
08/2015	20	08/2015	27	07/2015	28
09/2015	22	09/2015	20	08/2015	27
10/2015	21	10/2015	21	09/2015	28
11/2015	23	11/2015	20	10/2015	26
11/2015	20	11/2015	20	11/2015	30
12/2015	21	12/2015	23	11/2015	28
01/2016	22	01/2016	20	12/2015	26
02/2016	21	02/2016	20	01/2016	30
03/2016	21	03/2016	26	02/2016	28
04/2016	21	04/2016	20	03/2016	30
05/2016	21	05/2016	23	04/2016	21
06/2016	21	06/2016	20	05/2016	20
07/2016	22	07/2016	20	06/2016	26
08/2016	22	08/2016	26	07/2016	29
09/2016	20	09/2016	20	08/2016	30
10/2016	20	10/2016	22	09/2016	29
11/2016	20	11/2016	20	10/2016	28
12/2016	22	12/2016	20	11/2016	28
02/2017	21	02/2017	20	12/2016	31
03/2017	20	03/2017	20	02/2017	28
04/2017	21	04/2017	20	03/2017	28

05/2017	21	05/2017	20	04/2017	29
07/2017	20	07/2017	24	05/2017	29
08/2017	21	08/2017	25	07/2017	28
09/2017	21	09/2017	24	08/2017	22
10/2017	21	10/2017	25	09/2017	28
12/2017	20	12/2017	23	10/2017	30
01/2018	20	01/2018	20	12/2017	30
02/2018	22	02/2018	24	01/2018	31
03/2018	22	03/2018	20	02/2018	31
04/2018	24	04/2018	25	03/2018	33
05/2018	24	05/2018	24	04/2018	30
06/2018	20	06/2018	24	05/2018	30
08/2018	20	08/2018	22	06/2018	31
09/2018	22	09/2018	24	08/2018	29

APPENDIX E: HISTORICAL GROUNDWATER-CHEMISTRY DATA  
FOR WELLS 4, 5, AND 6

Well 4			
Sample Date	Sulfate	Iron	Manganese
08/1999	97.00	0.05	0.03
09/1999	118.00	0.05	0.04
08/2000	106.00	0.05	0.04
06/2001	155.00	0.05	0.07
07/2003	180.00	0.05	0.10
06/2004	176.00	0.87	0.10
Well 5			
Sample Date	Sulfate	Iron	Manganese
08/1999	42.00	5.80	0.70
09/1999	59.00	7.50	1.00
08/2000	201.00	8.12	1.21
06/2001	154.00	8.49	1.24
06/2002	197.00	7.66	1.27
07/2003	123.00	4.80	0.88
Well 6			
Sample Date	Sulfate	Iron	Manganese
04/1993	150.00	-	-
06/2001	218.00	9.27	1.35
07/2003	305.00	9.40	1.25