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The Effects of Fractures on the Occurrence and Distribution of Arsenic in the Upper Floridan Aquifer During Aquifer Storage and Recovery

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The Effects of Fractures on the Occurrence and Distribution of Arsenic in the Upper
Floridan Aquifer During Aquifer Storage and Recovery

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
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Keywords: Equivalent continuum, discontinuum, discrete fracture network, ASR, pyrite,
arsenopyrite

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DEDICATION

This dissertation is dedicated to my loving and thoughtful parents and family for providing continuous support and encouragement throughout this endeavor and my life. In the face of adversity, nothing rivals their warmth, confidence, and solace. I'd also like to dedicate this study to all those individuals that I've encountered through life that have etched their confidence in me, enabling me to pursue those goals that once were only mere dreams.

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I would like take this opportunity to extend my sincerest appreciation to Dr. Mark T. Stewart for his guidance, persistence, and resiliency throughout this study and for his relentless editing efforts to improve this dissertation over a countless number of revisions. I would also like to express my grateful appreciation to my entire committee for their constructive and critical recommendations of the study and reviews of the manuscript, which significantly improved the quality, meaningfulness, and potential scientific contribution of this study and final dissertation.

I also extend my sincere acknowledgement and appreciation to Dr. Henning Prommer of CSIRO, author of PHT3D, for his advice on the use of PHT3D and high-speed computing options, and to Ilka Wallis (CSIRO) for providing advice on PHT3D model modifications.

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ABSTRACT

Aquifer storage and recovery (ASR) is used world-wide to supplement available water supplies by storing surplus water in aquifers and recovering it during periods of drought and increased demand. The use of ASR as an option for increasing available municipal irrigation and fresh water supplies is threatened as a result of the mobilization of arsenic in some aquifers during ASR. Arsenic is liberated from arsenic-bearing sulfide minerals as a result of the mixing of oxidizing injected water with reducing insitu groundwater. Fracture networks can have significant influence on the migration and distribution of arsenic in the Upper Floridan Aquifer (UFA) during ASR operations through effects on fluid flow, chemical reactions, and transport characteristics. To characterize fracture flow and associated mass transport, numerical three-dimensional models constructed with MODFLOW and FracMan are used to represent fractures in equivalent continuum, discontinuum, and stochastic discontinuum or discrete fracture network (DFN) dual porosity or hybrid models. The geochemical reaction (PHREEQC-2) and transport (MT3DMS) models are coupled to the three dimensional numerical flow model (MODFLOW 2000) as PHT3D- 2003, and utilized to simulate the flow, transport, and inorganic reactions associated with the injection of oxidized water into the UFA of Southwest Florida during ASR cycles.

The discrete fractures, implicitly simulated in MODFLOW as high flow zones, are model layers of varying thicknesses with uniform hydraulic conductivity and storage parameters, and as stochastically-generated horizontal and vertical fractures with varying physical attributes including orientation, aperture widths, fracture intensity, and fracture distributions, distributed within a lower conductivity matrix. Discrete fracture networks are simulated with FracMan and the results imported into MODFLOW. Although each fracture zone layer is assigned a unique stochastic distribution of hydraulic conductivity, each model represents a single realization. The FracMan output of stochastic distributions of hydraulic conductance and storage parameters is "upscaled" for use in MODFLOW. The vertical migration of solute due to variations in the density of injectate and groundwater does not appear to be a significant characteristic of the modeled flow system.

The modeling results support the hypothesis that arsenopyrite, which is stable under reducing conditions, liberates arsenic during recharge cycles as a result of oxidation. The results also indicate that fracture flow significantly controls the distribution of all solutes affected by the ASR flow system due to the significantly higher transmissivity of the fractures compared to the matrix. The simulated distribution of arsenic in the matrix is significantly less than in the fractures as a result of the limited penetration of oxidized recharge waters into the inter-fracture matrix. Under the simulated aquifer and geochemical conditions, arsenic travels farther from the injection well via fractures than is observed in monitor wells, suggesting that the partially-penetrating monitoring well network does not intercept many of the fractures. The modeled increases in concentrations of arsenic in the ASR wells during the recovery

cycles are also consistent with observations. Explicit representation of fracture zones in numerical transport models provides an increased understanding of the flow system and the potential occurrence and distribution of arsenic in groundwater.

1.0 INTRODUCTION

Authigenic pyrite occurs in the Upper Floridan aquifer (UFA) and, during aquifer storage recovery (ASR) operations, arsenic released from pyrite occurs at low concentrations in the storage zone during cycle tests (Arthur et al., 2002; CH2MHill, 2007; Jones and Pichler, 2007; ASR Systems LLC, 2007). Several ASR studies have concluded that varying geochemical conditions during injection, storage, and recovery create conditions that result in the dissolution of arsenic-bearing pyrite and the increase of arsenic in solution (Arthur et al., 2002; Mirecki, 2006; CH2MHill, 2007; Jones and Pichler, 2007). Investigations of this problem have generally relied on the interpretation of observed data and the theoretical analysis of the geochemical environments through the use of various geochemical models including PHREEQC-2 (Mirecki, 2006) and Geochemist's Workbench (Jones and Pichler, 2007). Although numerous geochemical studies of ASR sites in Florida have been conducted to evaluate the potential causes of the occurrence and distribution of arsenic, as of the initiation of this study, mass and transport modeling of this scenario has not been conducted.

Another important aspect of the occurrence of arsenic in the UFA during ASR is its frequent anomalous spatial distributions, which have been attributed to dynamic geochemical reactions and preferential flow paths resulting from the presence of fractures. Specifically, arsenic has been observed at the closest monitor wells, located

approximately 250 ft from the ASR wells, at low concentrations ($<10\text{ }\mu\text{g/L}$) during recharge followed by significant increases between 20 and $30\text{ }\mu\text{g/L}$ during recovery cycles, representing an anomalous occurrence considering the typical geochemical model of arsenic generation under average flow conditions.

This study links a flow code, MODFLOW (Harbaugh et al., 2000), coupled with a geochemical model, PHREEQC-2 (Parkhurst and Appelo, 1999), and a code that simulates fracture flow, FracMan (Golder Associates, Inc., 2010). The basic objective of the study is to determine the potential effects of fracture flow during ASR operations on the occurrence and distribution of arsenic.

In undertaking this modeling effort, it should be emphasized that there are many inherent difficulties because the ASR operation was not designed with this study in mind. Some of the difficulties include the simulation of a well field consisting of 12 ASR wells and interference effects from two well fields, constraining model dimensions in order to achieve reasonable simulation run times, and a partially-penetrating monitor well network and a network of fully penetrating ASR wells.

The Manasota Peace River ASR facility located on the Peace River in Desoto County, Florida was selected for this investigation (**Figure 1**). This site has been in operation since approximately 1985, and extensive records of hydraulic, geochemical, and operating conditions are available. The facility includes ASR Well Field 1 and Well Field 2 (**Figure 2**). Details of Well Field 2 are presented on **Figure 3**.

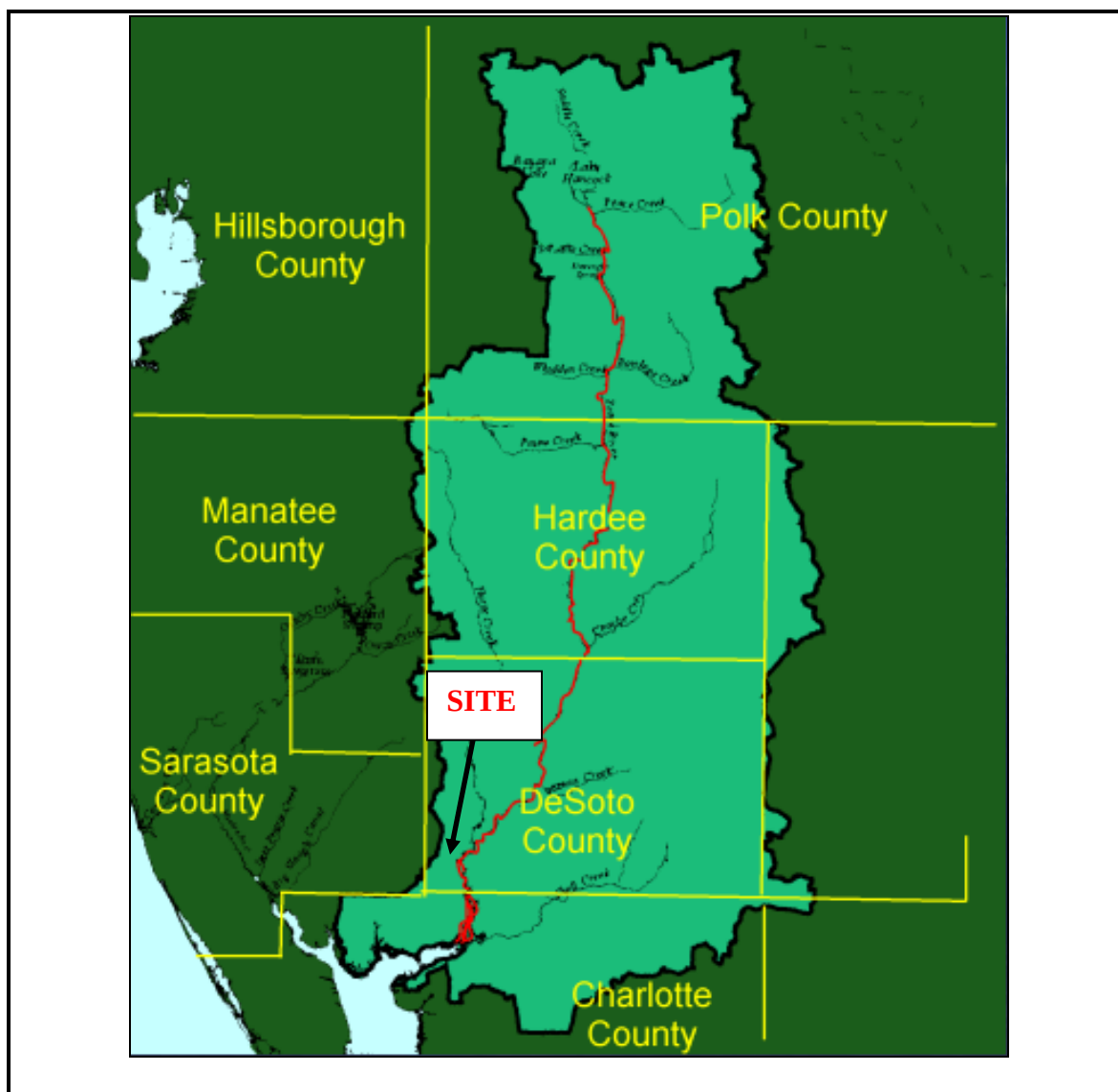


Figure 1. Site location map.

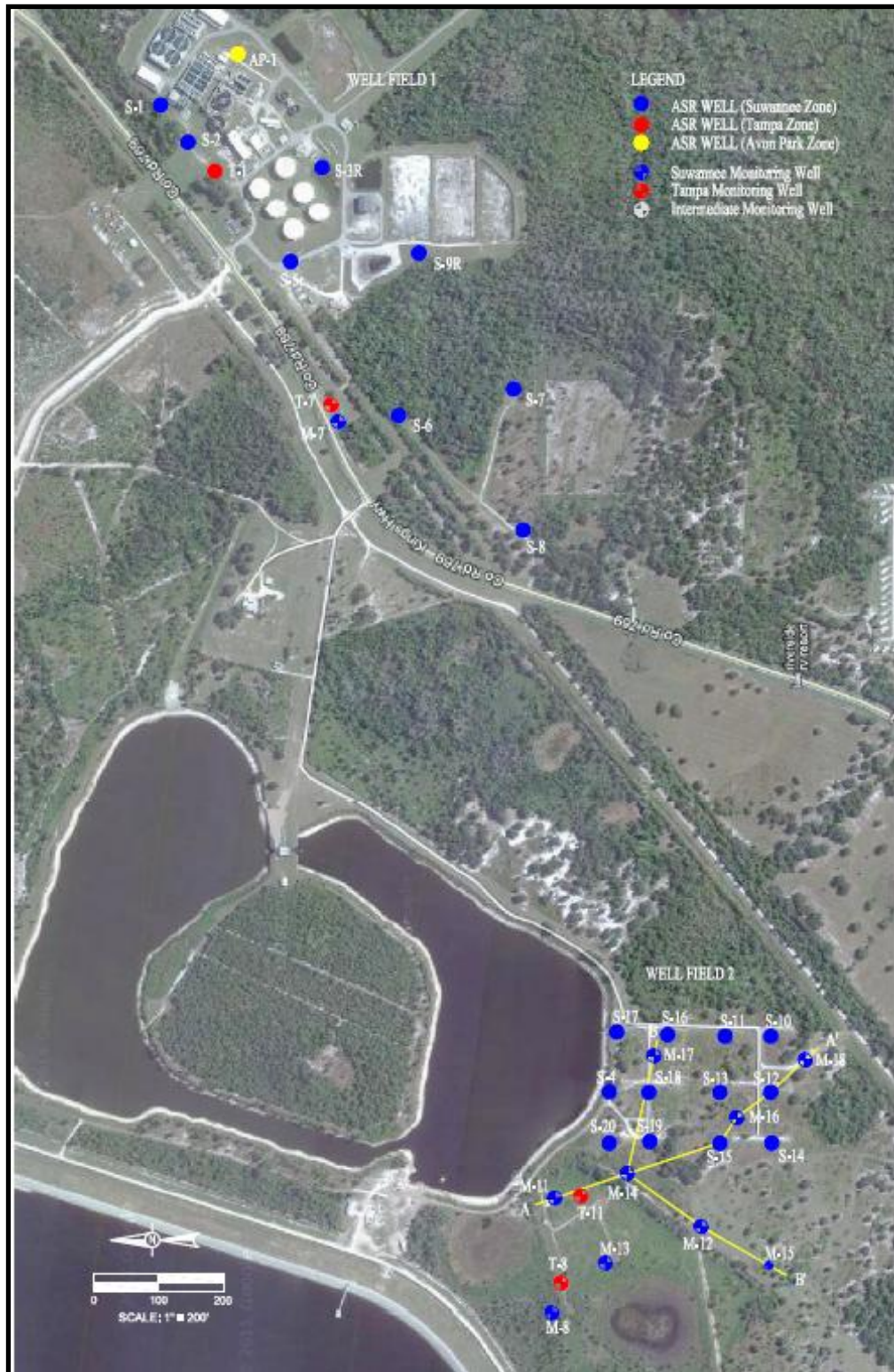


Figure 2. Manasota Peace River ASR facility Well Fields 1 and 2.



Figure 3. Manasota Peace River ASR facility Well Field 2.

Arsenic has been reported to occur in the UFA at concentrations ranging from 0.01 to 54.1 milligrams per kilogram (mg/Kg), with an average concentration of 3.5 mg/kg and exceeding 1000 mg/kg in framboidal pyrite that occurs in the UFA (Price and Pichler, 2005). The occurrence of arsenic, as detected in injection/recovery wells and monitoring wells in the UFA during ASR operations has been reported to vary with low concentrations, i.e., less than 3 micrograms per liter ($\mu\text{g/l}$), detected in the storage zone during cycle tests, but high concentrations groundwater (greater than 10 $\mu\text{g/l}$) in the recovered groundwater (Arthur, 2002; ASR Systems LLC, 2007; CH2MHill, 2007). Arsenic-free water is injected into the aquifer. The native groundwater initially exhibits reducing conditions resulting in pyrite stability and the immobility of arsenic.

With the injection of recharge water that is typically oxic, with dissolved oxygen concentrations greater than 2 mg/l, pyrite becomes unstable and arsenic is liberated and mobilized and, subsequently, detected in the monitor wells at low concentrations. However, upon recovery the extracted groundwater often contains moderate to high levels (10 to 130 µg/l) of arsenic (ASR Systems LLC, 2007; Jones and Pichler, 2007, CH2MHill, 2007) that exceed the Federal and State Maximum Contaminant Level (MCL) of 10 µg/L. With increasing number of cycles and constant recovery volumes, the arsenic concentrations detected in the ASR wells generally decrease; however with increasing recovery volumes arsenic concentrations are observed to increase (CH2MHill, 2007). Arsenic has also been detected in both siliciclastic and carbonate aquifer ASR systems operating in the Netherlands and Australia (Prommer and Stuyfzand, 2005; Pyne, 2005; Descourvieres, C. et al., 2010).

The conditions of varying oxygen concentrations and reduction-oxidation (redox) conditions are documented in several ASR systems that are in operation in the UFA (ASR Systems LLC, 2007). The Peace River/Manasota Regional Water Supply Authority operates an ASR system in the Suwannee Limestone aquifer between approximately 580 and 920 feet below land surface (ft bls). Previous interpretation of the well logs (CH2MHill, 2007) indicates that a major flow zone contributing between 60% and 80% of the groundwater from the production zone appears to occur below 820 ft bls. Another significant flow zone was previously and currently (from this study) inferred to occur near the top of the interval between 580 and 770 ft bls. From interpretation of caliper logs, additional fractures or high flow zones can be observed that should enhance groundwater flow.

1.1 Research Objectives

This modeling was performed to assess the effects of fractures and related features on the distribution of arsenic as a result of the conditions created during ASR operations. Since the oxidation of arsenopyrite and release of arsenic is a known reaction, confirming that reaction was not the purpose of this study. The purpose is to attempt to simulate the observed arsenic concentrations under the ASR conditions in order to determine if this reaction is potentially the cause of observed concentrations and distributions. The occurrence of fracture flow in the UFA is also a well known phenomena; therefore, the potential effects of fracture flow established by this study can be extended to other sites where observations similar to those that are described occur. In addition, although the arsenopyrite reaction is known, modeling this reaction and the consequent migration and distribution of arsenic has not been previously performed at an ASR site in Florida. The need for such modeling was first presented, discussed, and recommended in a collaborative report for the Southwest Florida Water Management District, "Evaluation of Arsenic Mobilization Processes Occurring During Aquifer Storage and Recovery Activities (H046)". The proposal to perform the present modeling effort was conceptually formalized independent of the SWFWMD report. This modeling effort with PHT3D is the first documented attempt to simulate this reaction-transport problem in the UFA and to-date it is only the second model ever constructed that addresses the arsenic-ASR issue in the UFA using PHT3D. Therefore, this modeling study and its results should be relevant in one or more respects to all ASR sites, both local and international.

In general, this research investigates the potential influence of fracture zones (high flow zones) on the occurrence, migration, and distribution of arsenic during ASR operations. The principal objective is to test the hypothesis that fracture flow is potentially responsible for the observed geochemical trends at monitoring well M-14 during ASR operations and; therefore, plays a critical role in the occurrence and distribution of arsenic during ASR operations in the Floridan aquifer. The specific trend that will be investigated is the occurrence of arsenic observed in monitoring wells closest to ASR wells that exhibit low arsenic concentrations during recharge cycles followed by higher concentrations during recovery cycles.

This hypothesis will be investigated with deterministic equivalent porous medium (EPM) and stochastically-generated dual porosity groundwater flow models coupled to reaction transport models. A simple single-layer equivalent continuum model will be used to determine the average groundwater flow patterns and arsenic distributions expected in a model that uses the concept of an equivalent porous medium. The results from the EPM, continuum, models will be used to determine whether representative flow patterns and arsenic distributions can be simulated with this method. Discrete fractures or fracture zones will be incorporated into multilayer discontinuum models to simulate fractures within a lower permeability matrix and the effects of fracture flow on arsenic migration. Stochastic discontinuum models incorporating stochastically-generated horizontal and vertical fracture zones will also be used to test the hypothesis of this research. The stochastic discontinuum models enable the characterization of discrete fracture networks (DFN). Although multiple realizations of this multilayer model could be used for a Monte Carlo analysis, it is the opinion of the author that a sufficient amount

of data does not exist to warrant the effort because a large number of parameter distributions appear to fit the observed data.

In testing the hypothesis, this research will consider fluid flow, chemical reactions, and transport characteristics of authigenic arsenic in the Upper Floridan aquifer (UFA) during ASR operations. Geochemical reaction and transport models are coupled to a numerical flow model to test the various scenarios. The effects of the varying geochemical conditions and transport in a fractured aquifer are investigated with the numerical reaction transport model PHT3D and fracture flow model FracMan. PHT3D is a chemical reaction and mass transport model coupled to the flow model MODFLOW in the processing environment of Visual MODFLOW (Schlumberger Water Services, 2009). The geochemical reaction and solute transport models utilize the background groundwater quality characteristics that have been measured, analyzed, and documented over the operation of the ASR system. In addition, the potential effects of variable-density conditions on the arsenic plume are evaluated to determine if density of the storage zone groundwater affects the distribution of arsenic. The project results describe the potential effects of fractures on the flow system, injected and recovered groundwater quality, alterations to background parameters and processes, arsenic distributions, and recovery efficiencies.

2.0 BACKGROUND

ASR was developed (circa 1970) in the U.S.A. to reduce groundwater-pumping stresses by injecting treated wastewater or surface water during periods of low demand into an aquifer followed by its recovery during periods of high demand.

2.1 Description of ASR Technology

ASR is defined as the storage of water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed (Pyne 1995, 2005). The injection phase usually takes place during the part of the year when water supplies are high and a surplus exists. During the injection phase, the injected water invades the aquifer and displaces native formation water. Due to advection and dispersion, mixing takes place during injection along the leading edge of the front forming the transition zone or buffer zone. The injected water that occurs between the well and the transition zone is referred to as the flushed or storage zone. Native groundwater occurs beyond the transition zone, known as the uninvaded zone. These characteristic zones associated with an ASR well are shown on **Figure 4a**. The storage period, which can either be omitted or range from days to months, depends on the available water needs and aquifer characteristics. In order for an ASR system to exhibit maximum recovery of injected water, repetitive cycles of injection, storage and

recovery need to be implemented. With increasing injection and recovery cycles, the mixing of injected water with native groundwater is reduced and mixing of injected water occurs primarily within the existing storage zone. With each cycle, the volume of the storage zone increases, thereby generally increasing the volume and quality of recoverable water. The entire volume of injected water is generally not recoverable after a single injection and it is only after repetitive cycles that the recovery of injected water may approach 100% (Pyne, 1995).

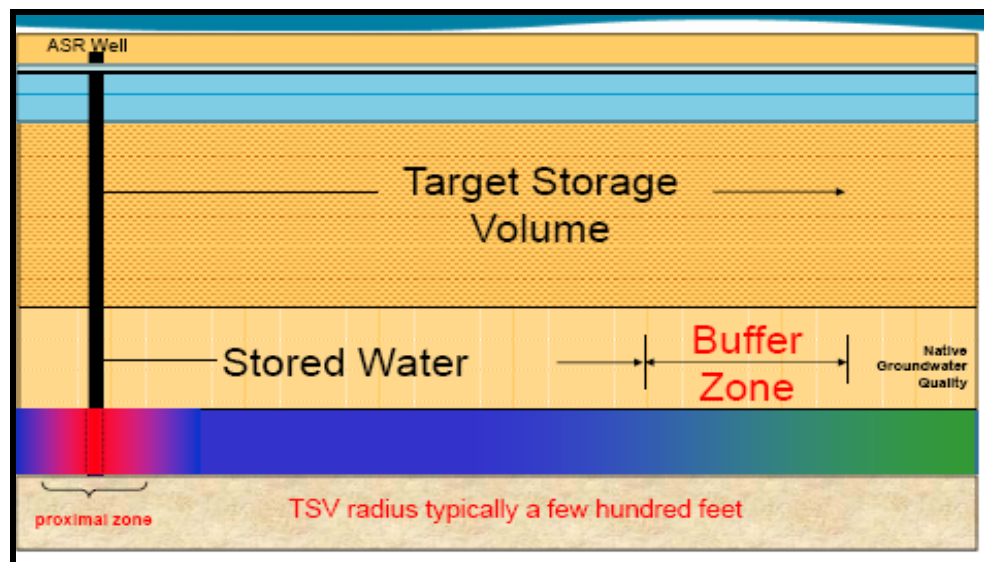


Figure 4a. Cross-section depicting typical ASR zones

This method has been successfully implemented in numerous locations across the U.S.A. and worldwide, mainly due to the cost savings provided by the use of a natural reservoir (aquifer) in which to store water compared to the costs to construct surface impoundments and the inherent problems with storing such water for extended periods of

time under evaporative atmospheric conditions (Pyne, 1995). The first integrated ASR project in Florida was implemented at Lake Manatee in 1983. Treated surface water from the Manatee County Water Treatment Plant was injected into the aquifer during the wet season and recovered during the dry season. The largest ASR project east of the Mississippi River, the Peace River ASR facility operated by the Manasota Regional Water Supply Authority, is also located in Florida. ASR activity in Florida has increased substantially during the past 10 to 15 years. Approximately 153 ASR wells are proposed or have been installed at approximately 50 FDEP-permitted sites according to the FDEP website (2011). The most recent FDEP map of ASR facilities is provided as **Figure 4b**. Most sites store surface water treated to drinking water standards in brackish aquifers exhibiting TDS concentrations ranging from 700 to 20,000 mg/L. The future of ASR in Florida is uncertain because of the occurrence of arsenic in stored and recovered water exceeding the Federal and State maximum contaminant level (MCL) of 10 micrograms per liter ($\mu\text{g/L}$).

2.2 Occurrence of Arsenic in the UFA During ASR

Flow in the UFA has been reported to occur within the matrix and fractures of the aquifer (Budd and Vacher, 2004; Vacher et al., 2006), with fractures generally exhibiting predominant control due to the lower permeability of the relatively unaltered matrix. Knowledge of the hydraulic characteristics of the fracture systems is necessary to accurately assess flow, reaction, and transport processes in the UFA. Characterization of the occurrence, orientation, and connectivity of fractures through the use of field techniques may not completely and accurately describe flow over small to large scales,

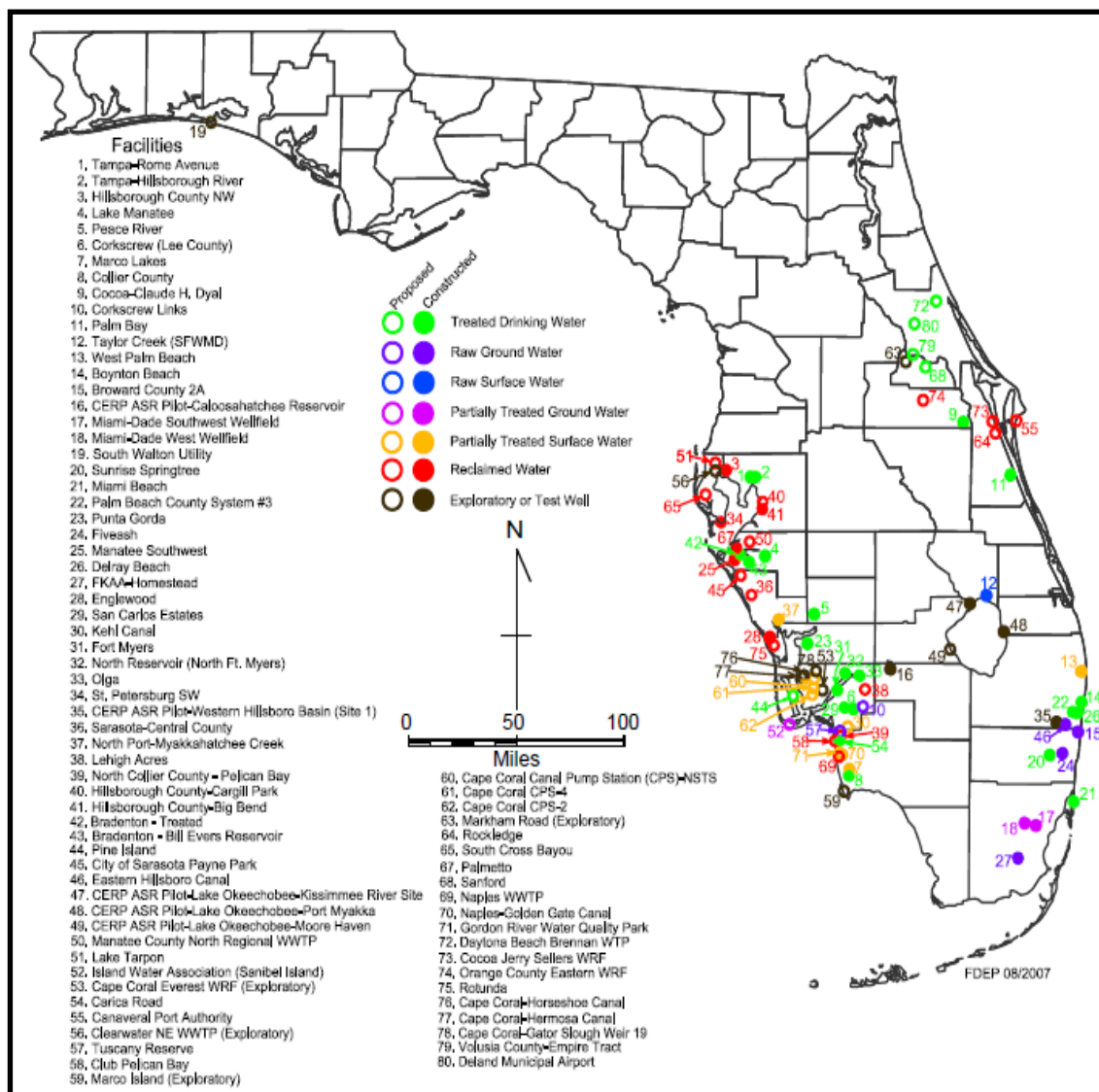


Figure 4b. FDEP Map of ASR facilities in Florida.

due to the complexity of fracture networks. Knowledge of the distribution of fractures in the UFA is critical to the understanding of flow and transport characteristics during ASR. Enhanced flow zones have been documented to result from karstic features including flow tubes, channels, caverns, and fractures in carbonate aquifers in Florida. Vertical and bedding plane fractures can promote the generation of karstic features by providing sites of preferential dissolution. A fracture flow model of the UFA was previously constructed with a continuum model incorporating stochastic generated vertical fractures (Langevin, 2003), based on the occurrence of fractures from photolineaments.

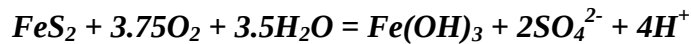
Arsenic has been reported to occur in the UFA at concentrations ranging from 0.01 to 54.1 milligrams per kilogram (mg/Kg), with an average concentration of 3.5 mg/kg and exceeding 1000 mg/kg in framboidal pyrite that occurs in the UFA (Price and Pichler; 2002). Arsenic in pyrite in the Floridan Aquifer System has been found to range from 100 to 11,000 mg/Kg (Pichler et al., 2011). The highest arsenic concentrations in pyrite may represent metastable solid solutions or arsenic incorporation by atomic substitution of arsenic for sulfur forming either AsS or As₂ dianion groups (Blanchard et al., 2007). Pyrite can incorporate up to approximately 10 weight % of arsenic.

Pyrite has been observed to occur as fine-grained minerals in the limestone matrix and as larger grains in highly permeable features. Pyrite grains attain larger sizes in larger pores and under relatively non-turbulent conditions (Brown and Cohen, 1995). Pyrite in the UFA occurs in intraparticle pores, interparticle space with cement, moldic porosity, and replacement mass filling pore spaces, and burrows (Fischler and Arthur, 2008). Assuming these characteristics, pyrite and arsenopyrite may occur in the matrix and associated zones of secondary permeability; however, higher flow fracture zones may

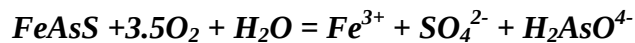
be ideal environments for the creation and propagation of pyrite in the UFA (Price and Pichler, 2002).

The occurrence of arsenic as detected in injection/recovery wells and monitoring wells in the UFA during ASR operations has been reported to vary with low background concentrations (less than 3 µg/l) detected in the storage zone prior to recharge cycle tests and high concentrations in the recovered groundwater significantly exceeding 10 µg/L (Arthur et al., 2005; Jones and Pichler, 2007). Arsenic-free water is injected into the aquifer, which initially exhibits reducing conditions resulting in pyrite stability and the immobility of arsenic. With the injection of recharge water that is typically oxidic, with dissolved oxygen concentrations as high as 7 mg/L, pyrite becomes unstable and arsenic is mobilized and detected in the monitor wells at low concentrations, in accordance with the following reaction(s):

Pyrite Oxidation



Arsenopyrite decomposition with Oxygen



Arsenopyrite decomposition without Oxygen



Upon recovery the extracted groundwater often contains moderate to high levels (10 to 130 µg/l) of arsenic (ASR Systems LLC, 2007; CH2MHill, 2007; Jones and Pichler, 2007) that exceed the Federal and State MCL of 10 µg/L. The above

occurrences of arsenic and concentrations are documented for the Tampa Rome Avenue Park (Hillsborough County), Punta Gorda (Charlotte County), and Peace River (Desoto County) ASR facilities (Arthur et al., 2005; CH2MHill, 2007). Additional studies conducted at the Eastern Hillsboro (Palm Beach County) and the Olga and North Reservoir ASR facilities (Lee County) exhibited similar trends at the ASR wells. The closest monitoring wells associated with all of the above ASR facilities occur between approximately 250 and 350 ft from the ASR wells. In general, it appears that arsenic concentrations are generally low ($<10 \mu\text{g/L}$) in these closest monitoring wells during recharge, storage, and recovery at the ASR sites, with the exception of the Peace River ASR facility, in which concentrations range from below detection limits to approximately $30 \mu\text{g/L}$. At the Peace River site, arsenic concentrations in the closest monitoring well (M-14) have ranged between less than the detection limit of $3 \mu\text{g/L}$ and approximately $20 \mu\text{g/L}$ during recharge. During the storage cycle, arsenic concentrations ranged between the detection limit and approximately $10 \mu\text{g/L}$. During the recovery cycles, arsenic concentrations have occasionally increased ranging between the detection limit and approximately $30 \mu\text{g/L}$ with most concentrations less than the MCL of $10 \mu\text{g/L}$. With increasing number of cycles and constant recovery volumes, the arsenic concentrations detected in all of the ASR wells significantly decrease.

Monitor wells at the Tampa Rome ASR (TRAP) facility have generally exhibited arsenic concentrations below the detection limit (0.003 mg/L) or the MCL throughout multiple cycle tests, with exceedances of the MCL at monitor well SZMW-1 located 190 ft south of ASR-1. In contrast, very few samples from monitor well SZMW-4 located only 150 ft from ASR-2 have exceeded the MCL. The exceedances detected at SZMW-

1 only occur during recharge and storage cycles and it is believed that preferential flow paths in the fractured Suwannee Limestone may control the distribution of recharge water and; consequently, arsenic mobility between ASR-1 and SZMW-1 (CH2MHill, 2007).

Although arsenic concentrations at the North Reservoir ASR facility were detected in both the ASR and closest monitoring well located 350 ft from the ASR well during recovery, the concentrations generally did not exceed 10 µg/L. During cycles 1 and 2, arsenic was not detected in the ASR and closest monitoring well; however, during cycle 3, the arsenic concentration in the monitor well increased to approximately 11 µg/L while the arsenic was not detected in the ASR well.

2.3 Additional Occurrences of Arsenic

Arsenic also occurs in ASR systems operating in the Netherlands and Australia (Prommer and Stuyfzand, 2005; Pyne, 2005; Descourvieres, et al., 2010) and is an especially significant health problem in West Bengal-India and Bangladesh (Stewart and Howell, 2003). In India and Bangladesh, the oxidation of arseniferous pyrite and arsenopyrite and the surface reactions associated with iron-oxyhydroxide due to varying redox conditions are similar to those that are proposed to occur under ASR conditions of this study. In these areas, aggressive groundwater withdrawal is believed to have led to aquifer aeration and consequent degradation of pyrite.

Because mobilized arsenic is detected in the extracted groundwater, it has been suggested that altered geochemical conditions in the presence of bacteria in the immediate vicinity of the extraction well and/or in the aquifer could potentially promote the solubility and mobility of arsenic, hence its occurrence in the recovery well and

recovered groundwater. This phenomenon is documented to occur in the vicinity of numerous potable water supply wells in the US. Studies of the arsenic distributions in aquifers from various locations including Maine (Weldon, 2005) and Illinois (Kirk et al., 2003) have documented the association of iron-reducing bacteria with the presence of arsenic in potable water supply wells. According to the study conducted in Maine, the dissolution of iron precipitates that adsorb arsenic is promoted by microbes of the genus *Geobacter* and the speciation of arsenic (arsenate and arsenite) is facilitated by NP4 bacterium from the genus *Sulfurospirillum*. According to the study of a glacial aquifer in Illinois, high arsenic concentrations have also been preferentially associated with highly reducing methanogenic zones. The underlying factor that results in the occurrence of dissolved arsenic in the above cases appears to be reducing conditions that promote the dissolution of iron to which arsenic is adsorbed by surface complexing.

2.4 Geochemical Conditions and Arsenic Trends

The distribution of arsenic species that could occur in groundwater under the conditions that exist at the Peace River ASR facility are depicted in Eh-pH diagrams (**Figure 5**, **Figure 6**, and **Figure 7**). Arsenate (As^{+5}) and arsenite (As^{+3}) species occur between 400 and -400 mV, within the pH range 6 and 8 SU. As pyrite is dissolved, the pH should decrease as a result of the production of the sulfate ion. Arsenate sorption is strongly dependent on pH, with sorption highest between approximately 3 and 7 SU. With increasing pH, greater than 7 to 8, arsenate sorption significantly decreases. Arsenite sorption is highest near neutral pH, and decreases at low and high pH (Pierce and Moore, 1982; Dixit and Hering, 2003).

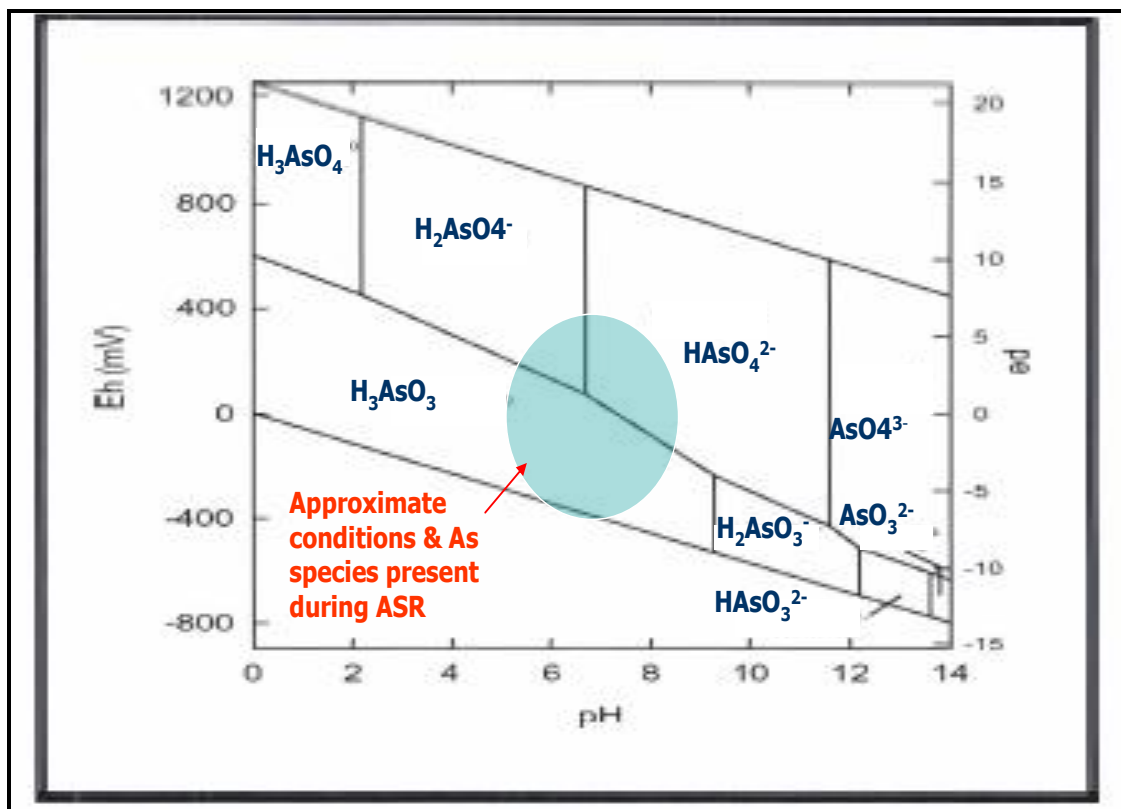


Figure 5. Eh-pH diagram of dissolved arsenic species in water at 25°C.

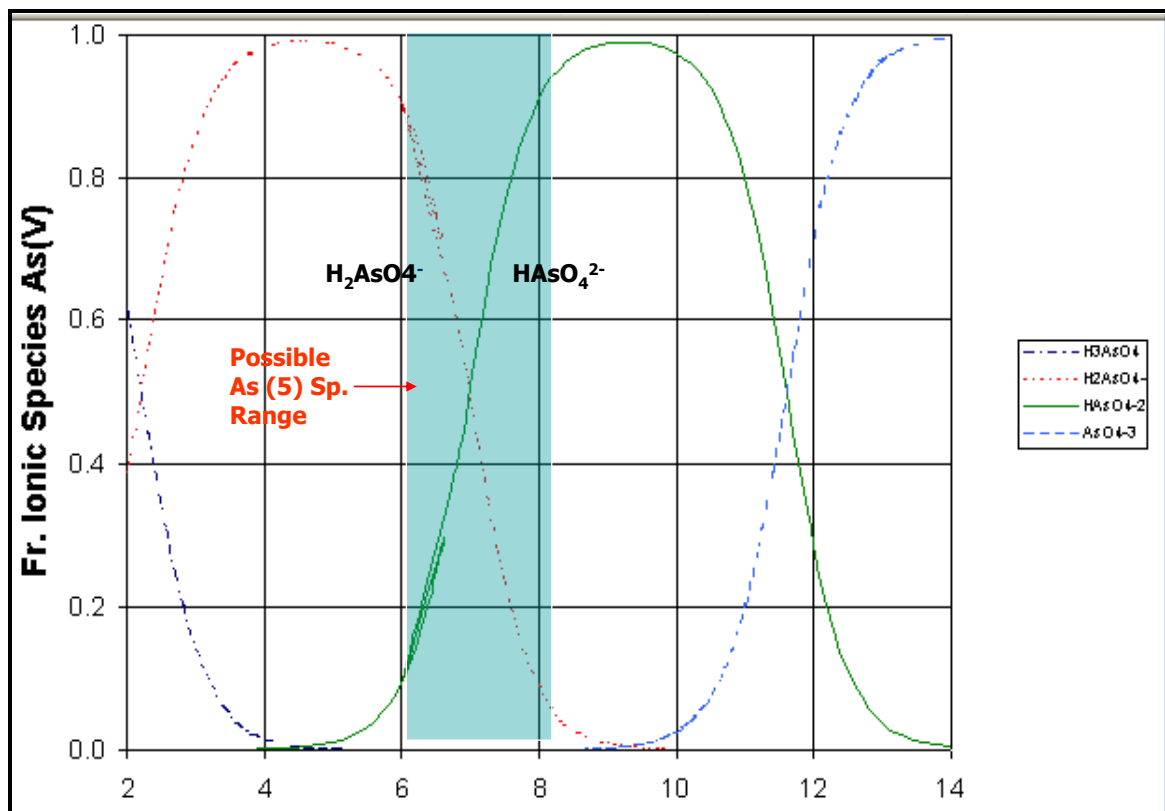


Figure 6. Fraction of arsenate species-pH diagram.

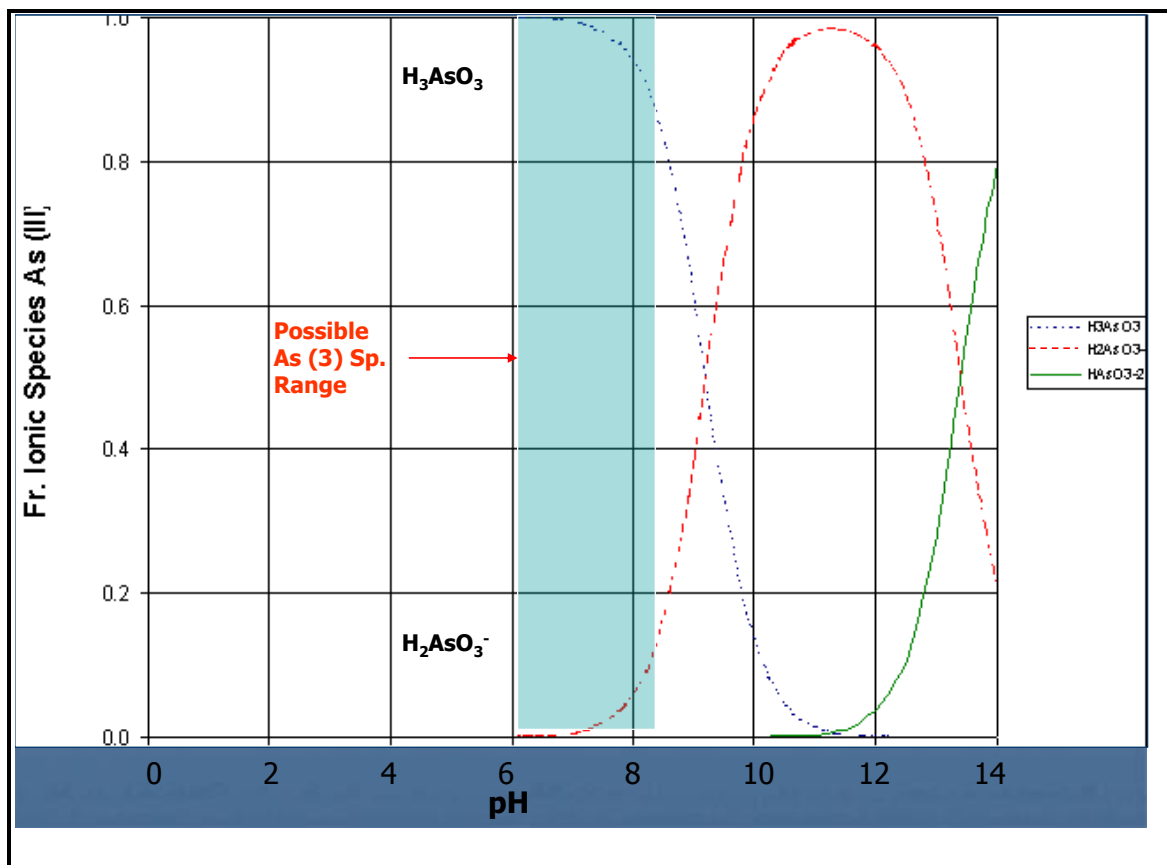


Figure 7. Fraction of arsenite species-pH diagram.

The high pH of groundwater in the vicinity of the ASR wells, due to the pH (>8 SU) of the recharge water, potentially decreases the sorptive capacity of the aquifer and enables increased migration of arsenic during the recharge cycles. With high ORP expected during recharge, arsenate should be the dominant species in the vicinity of the ASR well. As the arsenic migrates into the unaffected region of the aquifer exhibiting natural reducing conditions, arsenate may transform into the reduced arsenite species. This scenario consisting of varying oxygen concentrations and reduction-oxidation (redox) conditions is documented for several ASR systems that are in operation in the UFA (ASR Systems LLC, 2007; CH2MHill, 2007, Mirecki, 2006). The arsenic distributions in these systems are reported to occur in the following manner: 1) during recharge the storage zone becomes oxic and arsenic is released from pyrite. Iron oxy-hydroxide precipitates under these conditions and arsenic is consequently sorbed and removed from the aquifer; 2) during storage, the aquifer becomes more reducing as oxygen is consumed, in which case, iron oxy-hydroxide dissolves, liberating arsenic; and 3) during recovery, the reducing conditions persist leading to elevated arsenic concentrations at the recovery wells. In these cases the nearest observation wells are located approximately 200 to 350 ft from the recovery wells; therefore, the spatial distribution and radial extent of the reactions leading to high arsenic concentrations at the recovery wells is unknown, but is less than approximately 200 to 350 ft.

The partially penetrating monitor wells at the Peace River ASR facility are cased to approximately 575 ft bls with total depths of 675 ft bls and are open to approximately 30% of the injection zone. The six-inch diameter monitor wells (open boreholes) at Well

Field 2 are equipped with 4-inch diameter, 1-horsepower, submersible Grundfos pumps set at approximately 100 ft bls. Groundwater samples are collected in accordance with the Florida Department of Environmental Protection (FDEP) Standard Operating Procedures (DEP-SOP-001/01) per Chapter 62-160 of the Florida Administrative Code. Sample collection from this type well should generally be preceded by purging a minimum of three volumes of the pump tubing. This sampling technique is specified by the FDEP for wells in which the screened or open interval is located within the saturated part of the aquifer, thereby eliminating the need to purge one or more well volumes prior to sample collection. In this case, samples are collected from the interval of the well constantly occupied by flowing groundwater; therefore, the wells were not purged prior to the collection of water samples.

Given the large open sampling interval, large capacity pumps, and the mixing that takes place in the boreholes, the flow and geochemical data that are collected from these wells probably represent data averaged over the open interval, with more water contributed by higher conductivity zones. This sampling method is cost effective , however, details of the ASR system and effects of and on the aquifer can be masked if the system is heterogeneous, which is likely the case. Interpretations of the dynamics of the flow system in this case are limited to characteristics that represent the entire sampling interval. Factors that might exert more control than others could easily be dampened by such a sampling system. For example, the contrast in flow and transport in zones with different permeabilities, or as a result of fracture flow, cannot be resolved in such a system. A monitor well network consisting of clustered monitor wells with smaller

sampling intervals would provide an increased degree of horizontal and vertical resolution of the flow, transport, and geochemical characteristics of the ASR system.

The temporal trend of dissolved oxygen (DO) and arsenic observed in ASR wells S-14, S-15, and S-16 (**Figure 8**) between 2002 and 2009 indicates that DO increases during recharge cycles and is negligible during recovery cycles accompanied by an increase in arsenic. The exception to this trend occurred during the recovery cycle between March and June 2003 when all of the recovery wells exhibited DO concentrations ranging from approximately 1.5 to 4 mg/L. This trend occurred because the preceding recharge cycle lasted from August 2002 to March 2003, without a subsequent storage cycle. All other recovery cycles were preceded by storage cycles and the DO levels during recovery were generally less than approximately 0.5 mg/L.

When iron is plotted against DO and arsenic in these ASR wells, iron increases during both recharge and recovery; however, its occurrence at higher concentrations during recovery is more consistent (**Figure 9**). The addition of TDS to this trend (**Figure 10**) clearly shows an increase in TDS concentrations during the recovery cycles, which indicates that the recovery cycles are conducted for periods of time that may result in the pumping of groundwater from the transition boundary to formation water, at the edge of the storage zone. It should be noted that although the trends at all ASR wells are generally similar, the arsenic concentrations analyzed during recovery differ. The arsenic concentrations detected at S-14 and S-15 are approximately two to three times greater than those observed in the other ASR wells.

The temporal distributions of arsenic in all of the ASR wells during the period from 2002 to 2009 are shown on **Figure 11** (S-14, S-15, S-19, and S-20) and **Figure 12**

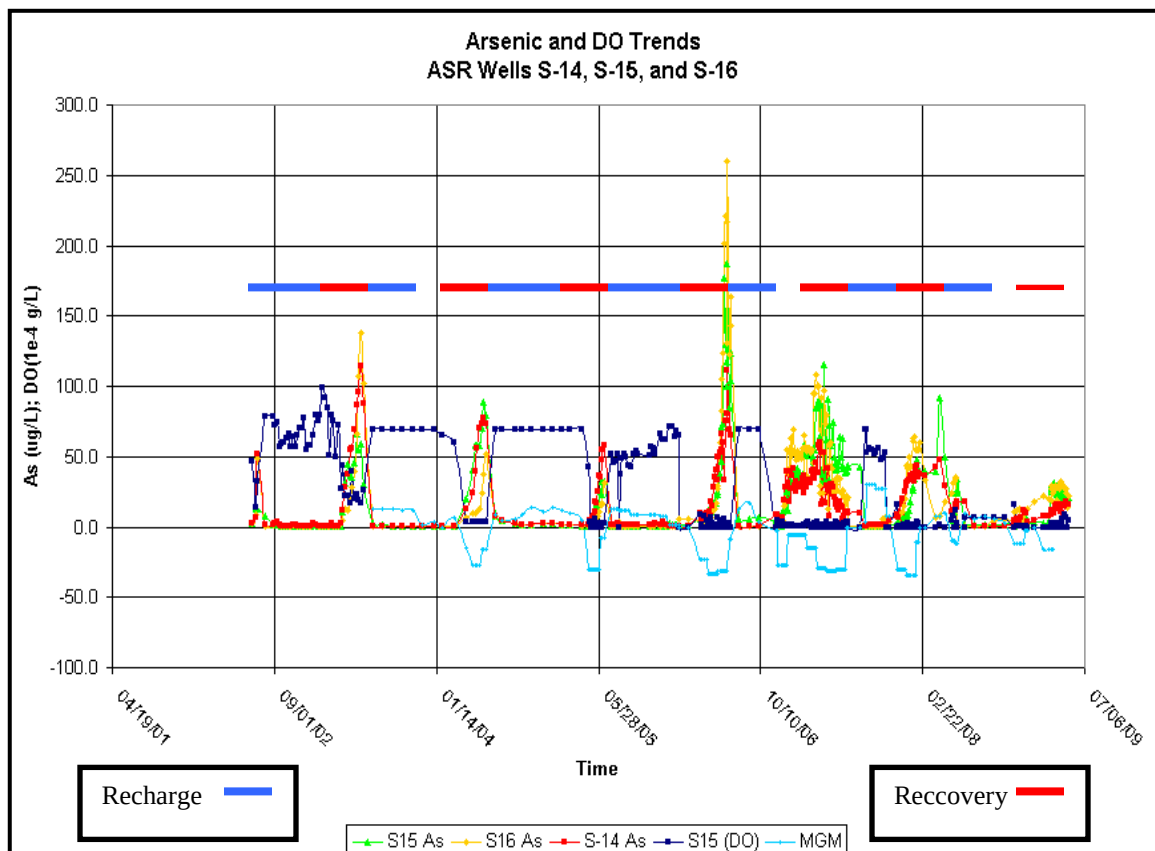


Figure 8. As and DO trends in ASR wells S-14, S-15, and S-16.

(S-12, S-13, S-18, and S-4). It is evident from these trends that the concentrations in S-19 and S-20 are generally less by a factor of 2 to 3 than the other ASR wells, especially S-14, and S-15. The number of recovery cycles ranged from six to nine with an average of seven each. The arsenic concentrations detected per recovery cycle typically exhibited a large range and the average concentrations per recovery cycle generally decreased over the seven year period from 2002 to 2009. The maximum concentrations detected during the recovery cycles ranged from 64 µg/l in S-20 to 187 µg/l in S-15. The average concentrations per recovery cycle in S-20 from 2002 to 2009 are 21 µg/l, 21 µg/l, 14 µg/l, 18 µg/l, 13 µg/l, 17 µg/l, and 7 µg/l. In contrast, the average concentrations in S-15 are generally 2 to 3 times higher at 38 µg/l, 60 µg/l, 14 µg/l, 47 µg/l, 43 µg/l, 18 µg/l, and 17 µg/l. This variation could potentially be the result of lower arsenopyrite concentrations in the vicinity of S-20.

The time-concentration trend of DO, iron, and arsenic from monitor well M-14 (**Figure 13**), located approximately 200 ft from the nearest ASR wells, is generally similar to the trends observed in the ASR wells. The DO generally increases during recharge cycles and decreases during recovery cycles. In contrast, the arsenic and iron concentrations generally appear to be below the method detection limit to low during the recovery cycles and increase during the recharge cycles. This well is close enough to the nearest ASR wells (S-19 and S-20) that it should normally exhibit increases in arsenic during the recharge cycles, if the dissolution of arsenic bearing iron sulfide minerals is responsible for the presence of arsenic. This is one of the questions concerning the occurrence and distribution of arsenic that this study proposes to address by evaluating the geochemical conditions, e.g. arsenopyrite distribution, that potentially occur in the

vicinity of the ASR wells and effects of fractures on this flow and transport system. The measured DO concentrations in monitor well M-14 are unusually high ranging between approximately 1.5 and 4.0 mg/L, which suggests highly transmissive zones may exist that enable the rapid delivery of oxic water to and beyond this monitor well. If the recharge water is highly oxygenated at this location, then pyrite oxidation should occur beyond M-14. In addition, if the arsenic in the aquifer is the result of biologically mediated reactions in the vicinity of the ASR wells, the trend observed in monitor well M-14 does not appear to support this explanation. Since the oxidation of pyrite and arsenopyrite has been documented in laboratories, and pyrite is ubiquitous in the UFA, it is reasonable to assume that this reaction may occur during ASR operations and explain many of the observed general trends in ASR systems in the UFA. This is also the reaction believed to be responsible for the occurrence of arsenic resulting from oxidation of aquifers in other siliciclastic and carbonate environments discussed previously, and associated with acid-mine drainage.

Although geochemical conditions control the sequestration and mobilization of arsenic, the fracture network controls groundwater flow, and therefore the transport and distribution of arsenic. If arsenic is dissolved during ASR injection, storage, and recovery cycles, migration along fractures may mask the detection in monitor wells that do not intersect fractures. This lack of detection in monitor wells could lead to the suggestion that the occurrence of arsenic is a localized occurrence in the immediate vicinity of the extraction well. If fracture flow significantly influences arsenic distribution, this suggestion is incorrect.

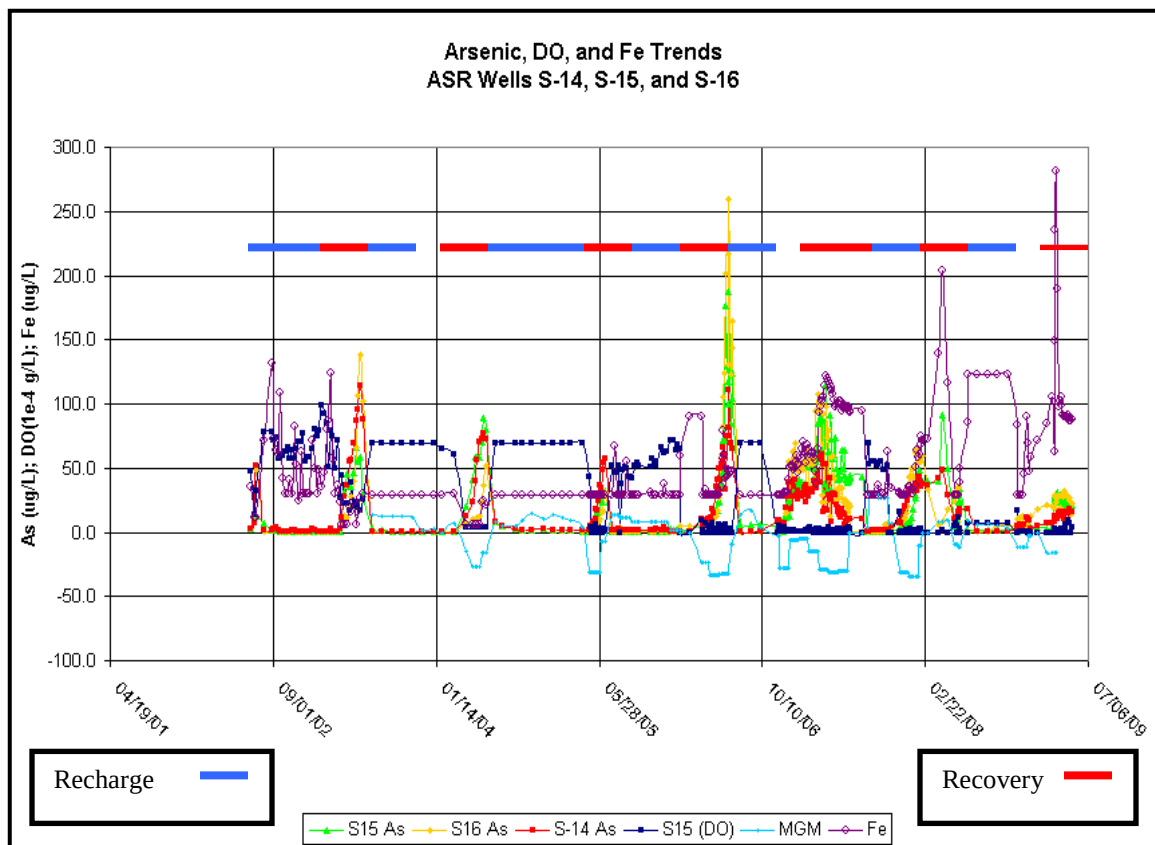


Figure 9. As, DO, and Fe trends in ASR wells S-14, S-15, and S-16.

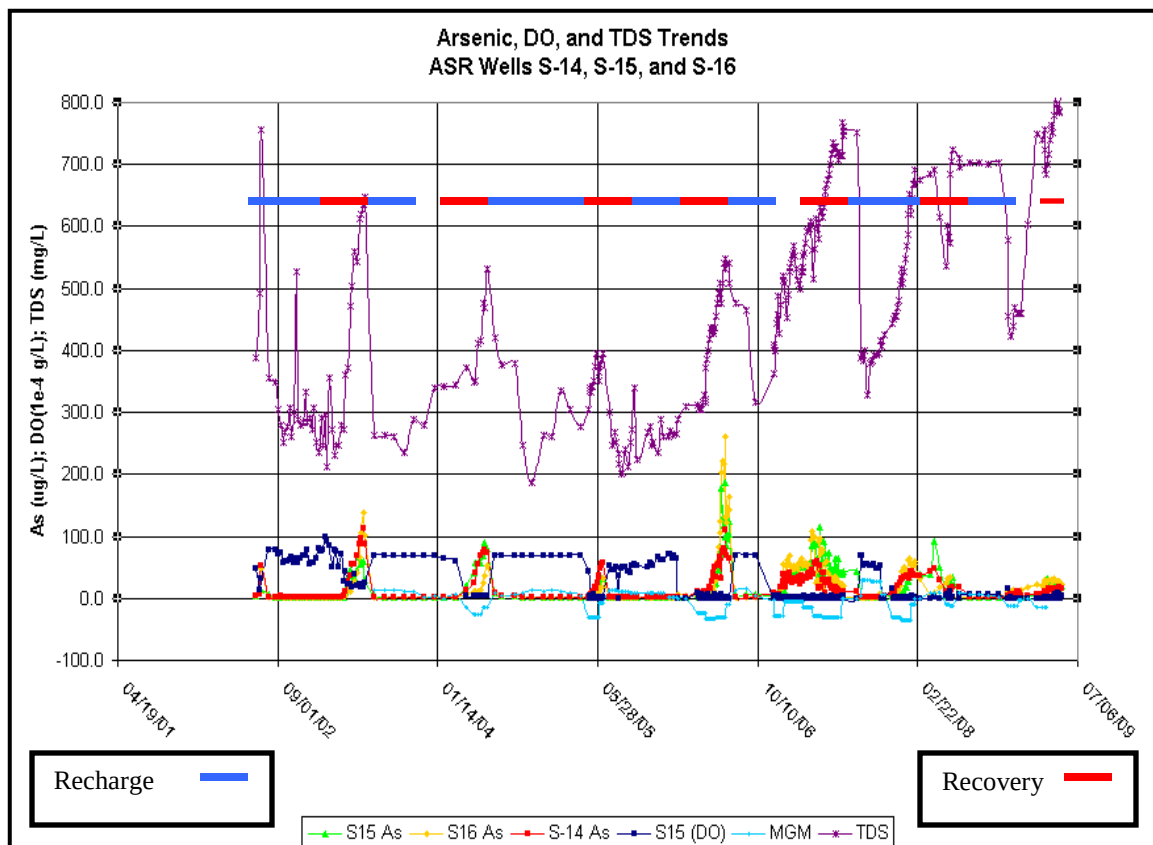


Figure 10. As, DO, and TDS trends in ASR wells S-14, S-15, and S-16.

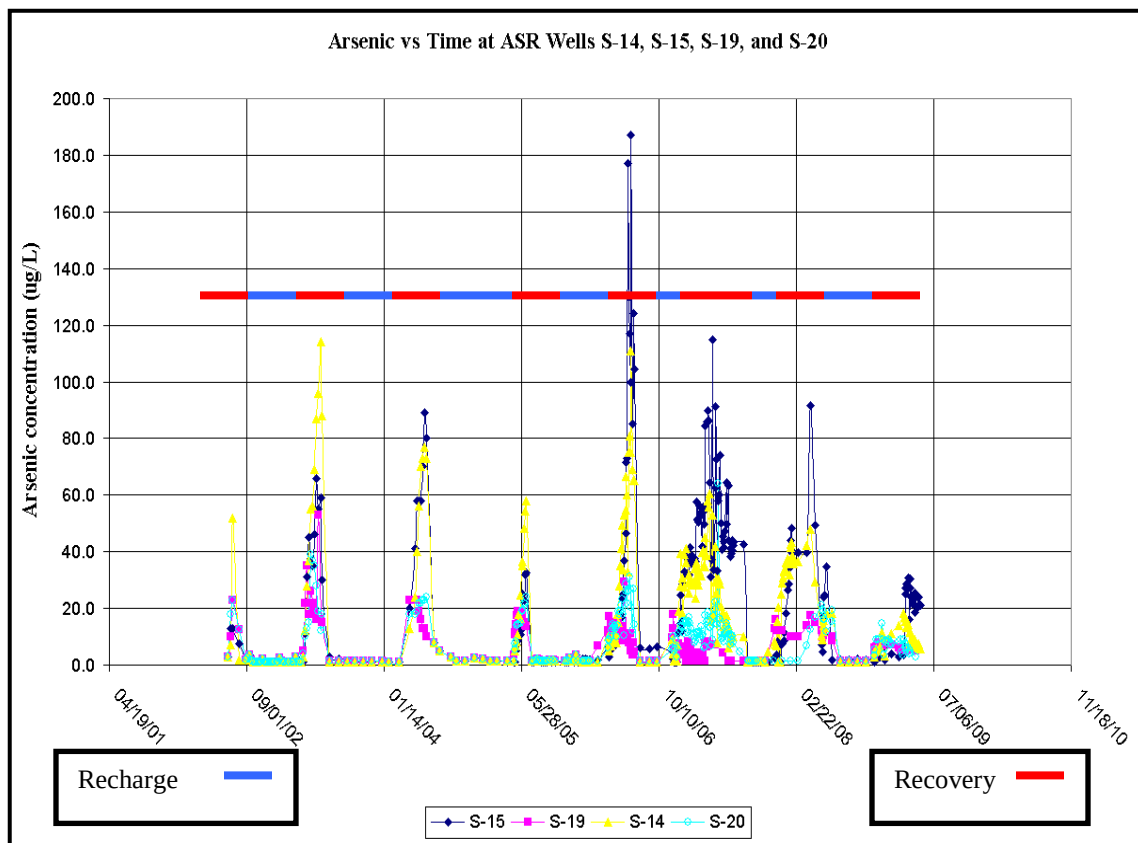


Figure 11. Arsenic-time trends in ASR wells S-14, S-15, S-19, and S-20.

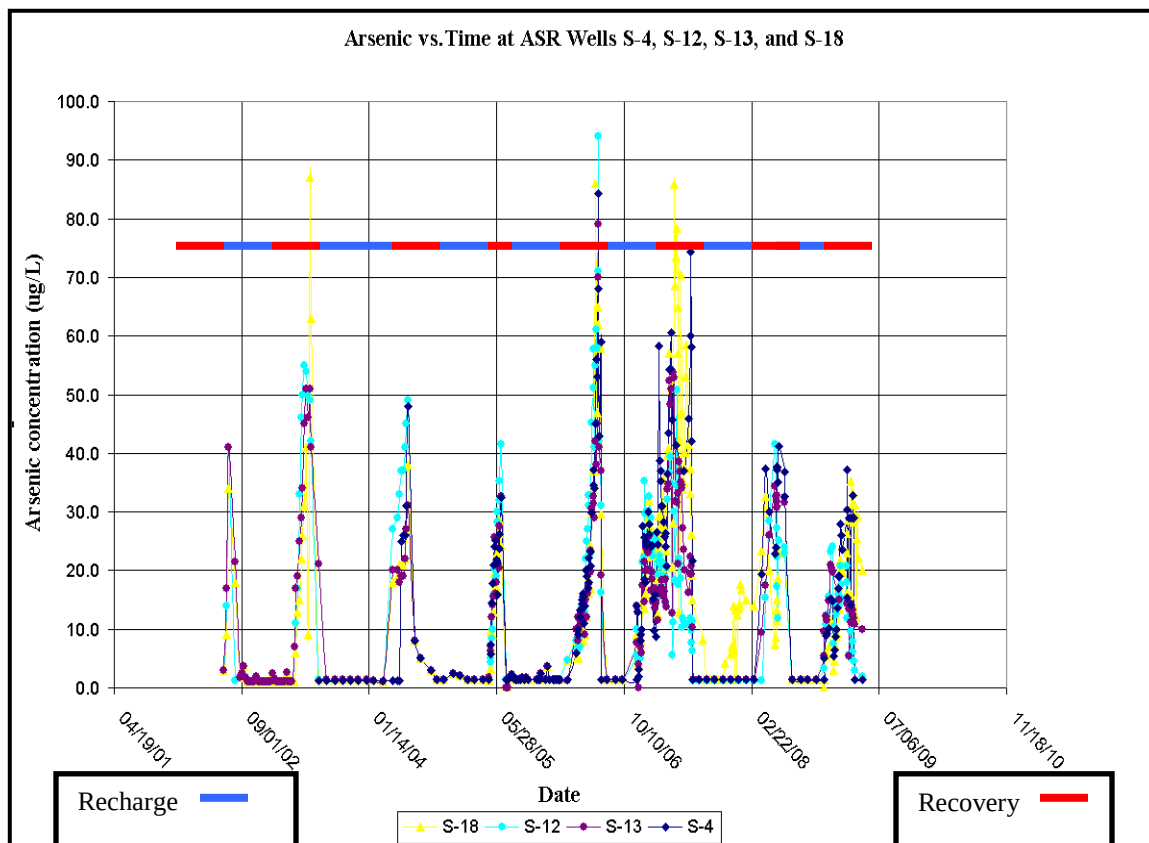


Figure 12. Arsenic-time trends in ASR wells S-4, S-12, S-13, and S-18.

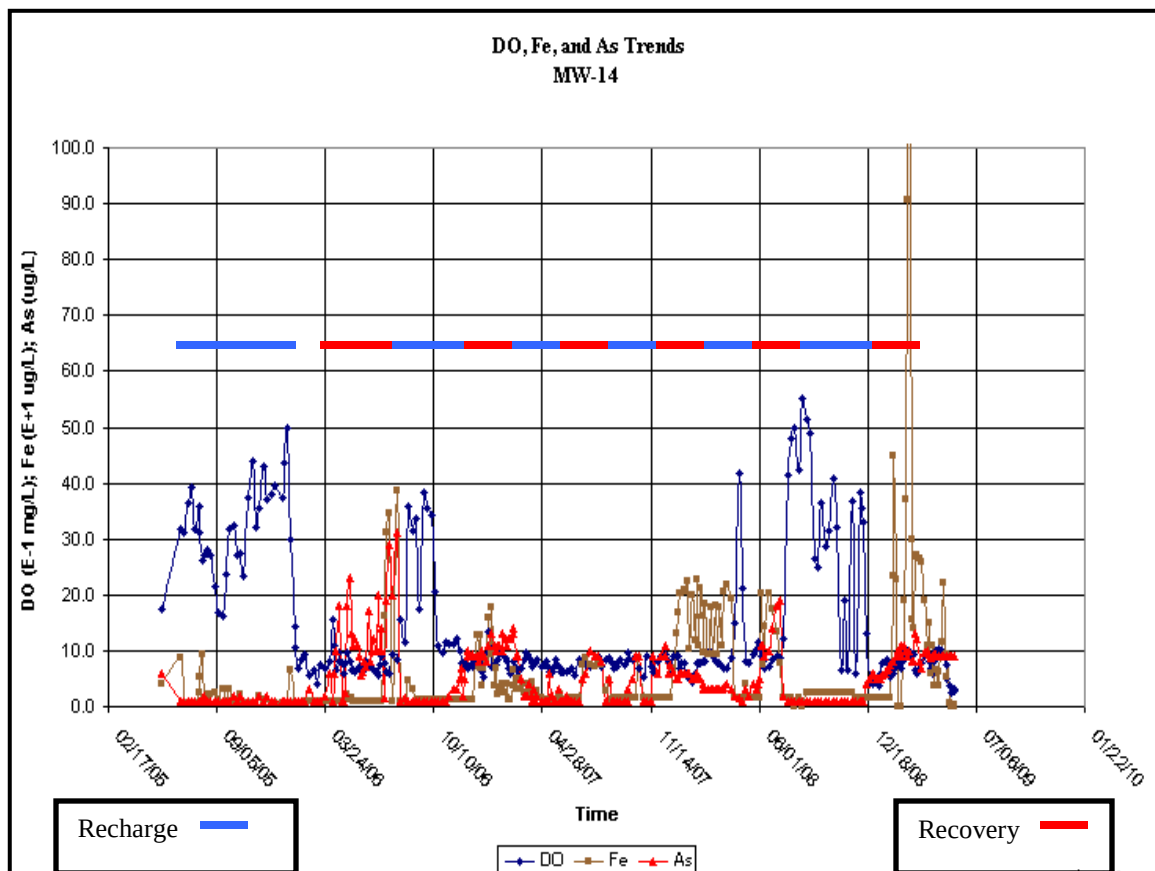


Figure 13. As, Do, and Fe-time trends in monitor well M-14 .

A preliminary analytical evaluation of the flow and transport to a hypothetical ASR well was performed with a three-dimensional, 200-layer (one foot each), discrete fracture model (Vacher et al., 2006) by assigning variable arsenic concentrations to the fractures only. Based on the distribution of hydraulic conductivities assigned to the matrix and fracture layers, the concentration of arsenic in the well was calculated and determined to be significantly greater than the concentration assigned to the matrix. If a monitor well does not intersect a fracture, then its concentration may be low; thereby, masking the occurrence of arsenic in the aquifer.

2.5 Geology and Hydrogeology

The Floridan aquifer is composed of a confined and highly permeable sequence of carbonate rocks of Tertiary age, which are divided into the Upper and Lower Floridan aquifers (Miller, 1987). In descending order, the Upper Floridan aquifer includes the Tampa Limestone, Suwannee Limestone, and Ocala Limestone of lower Miocene to upper Eocene age. The Lower Floridan aquifer includes the Avon Park Limestone, Lake City Limestone, Oldsmar Limestone, and the Cedar Keys Limestone ranging in age from middle Eocene to the middle Paleocene. The matrix of the Floridan aquifer primarily consists of calcite and dolomite with minor amounts of gypsum, apatite, glauconite, quartz, chert, clay minerals, and trace quantities of metal oxides and sulfides (Sprinkle, 1989; Sacks and Tihansky, 1996; Fischler and Arthur, 2008). The UFA is generally overlain by the low permeability sediments of the Miocene Hawthorn Group and the surficial aquifer. The contact between the Hawthorn Group sediments that form the

upper confining unit and the underlying UFA is an unconformity. Where the Hawthorn Group sediments are absent, the surficial aquifer directly overlies the UFA.

The geology underlying the site (**Figure 14 and Figure 15**) includes unconsolidated sands of Pleistocene to Holocene age to a depth of approximately 45 ft bls. Sandy phosphatic marls, limestones, and clays of the Miocene age Hawthorn Formation extend to a depth of approximately 380 ft bls. The sandy limestone of the Miocene age Tampa Formation underlies the Hawthorn Formation to a depth of approximately 510 ft bls. The Suwannee Limestone Formation of Eocene-Oligocene age is composed of tan, poor to moderately consolidated, fossiliferous limestones and extends to a depth of approximately 900 ft bls. The base of the Suwannee Limestone is composed of a bed of dolomite approximately 25 ft thick. Underlying the Suwannee Limestone is the Eocene age Ocala Limestone Formation composed of an upper unit of poor to moderately consolidated tan to grey granular limestone extending to approximately 1,010 feet and a lower unit of brown to cream dolomitic limestone. The range of transmissivities that are reported to occur in this general area for the Upper Floridan aquifer is 30,479 to 76,196 m²/day (Bush and Johnson, 1988).

The general background groundwater elevation and flow direction is indicated from the average potentiometric surface map for the UFA during 1999 (**Figure 16**). The hydraulic gradient across the site is approximately 0.0005 to the northwest, indicating that both the gradient and groundwater flow velocities are low. Groundwater flow maps constructed with Surfer (Version 9.0) using data during recharge (January 26, 2006) and recovery (June 29, 2006) cycles from the west half of the Well Field 2 demonstrate the variation in flow between static and dynamic conditions. During the recharge cycle

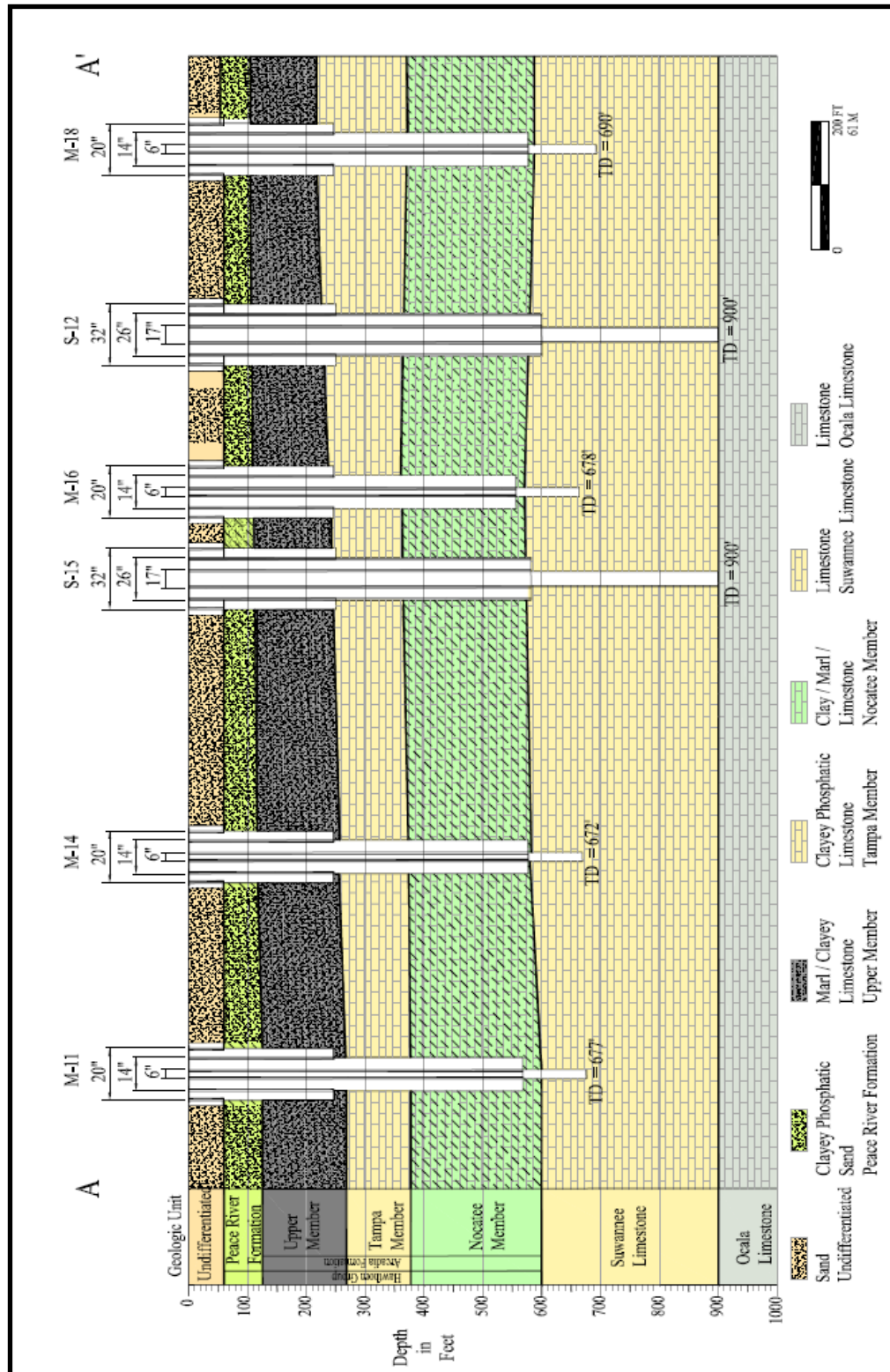


Figure 14. Geologic cross-section through ASR Well Field 2.



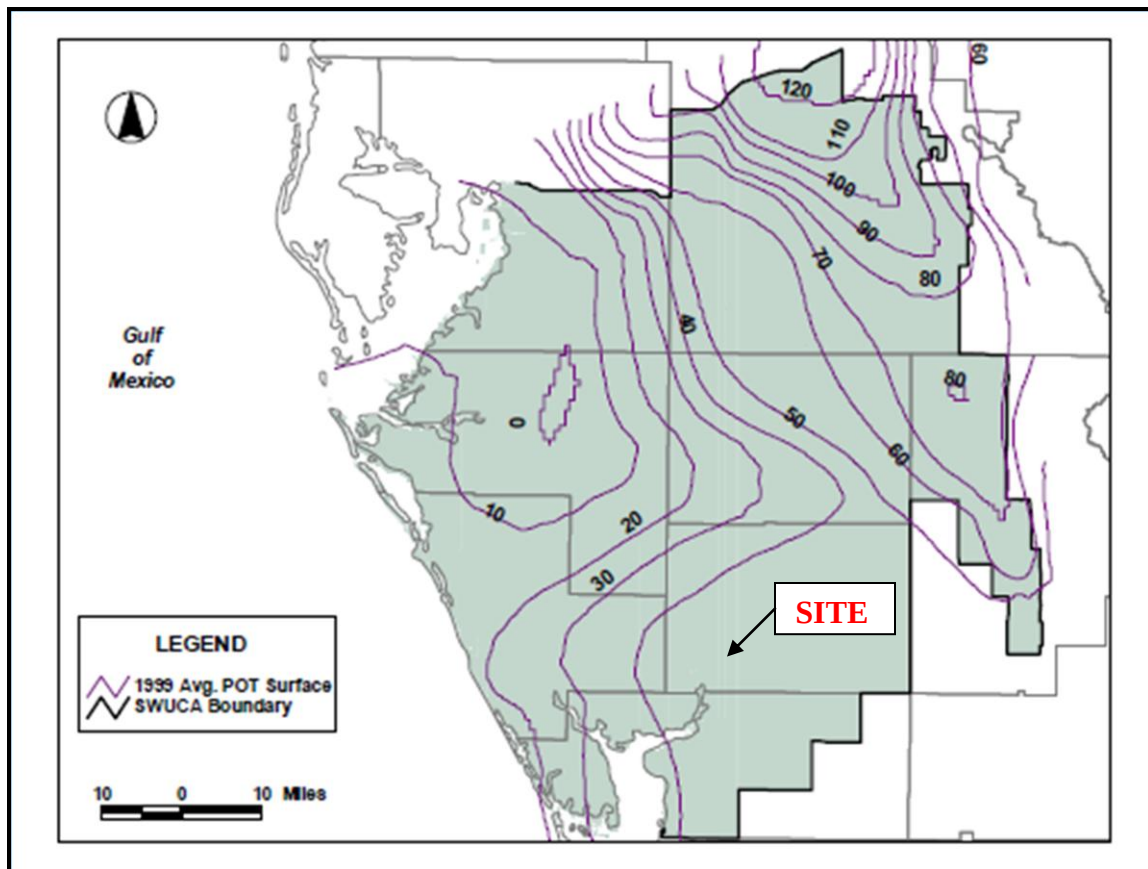


Figure 16. Average potentiometric surface map of 1999 for the UFA.

(Figure 17), groundwater with potentials between 12 and 18 meters flows approximately in radial flow paths from the ASR wells under horizontal hydraulic gradients from 0.002 to 0.04. During the recovery cycle (Figure 18), groundwater with potentials between -7

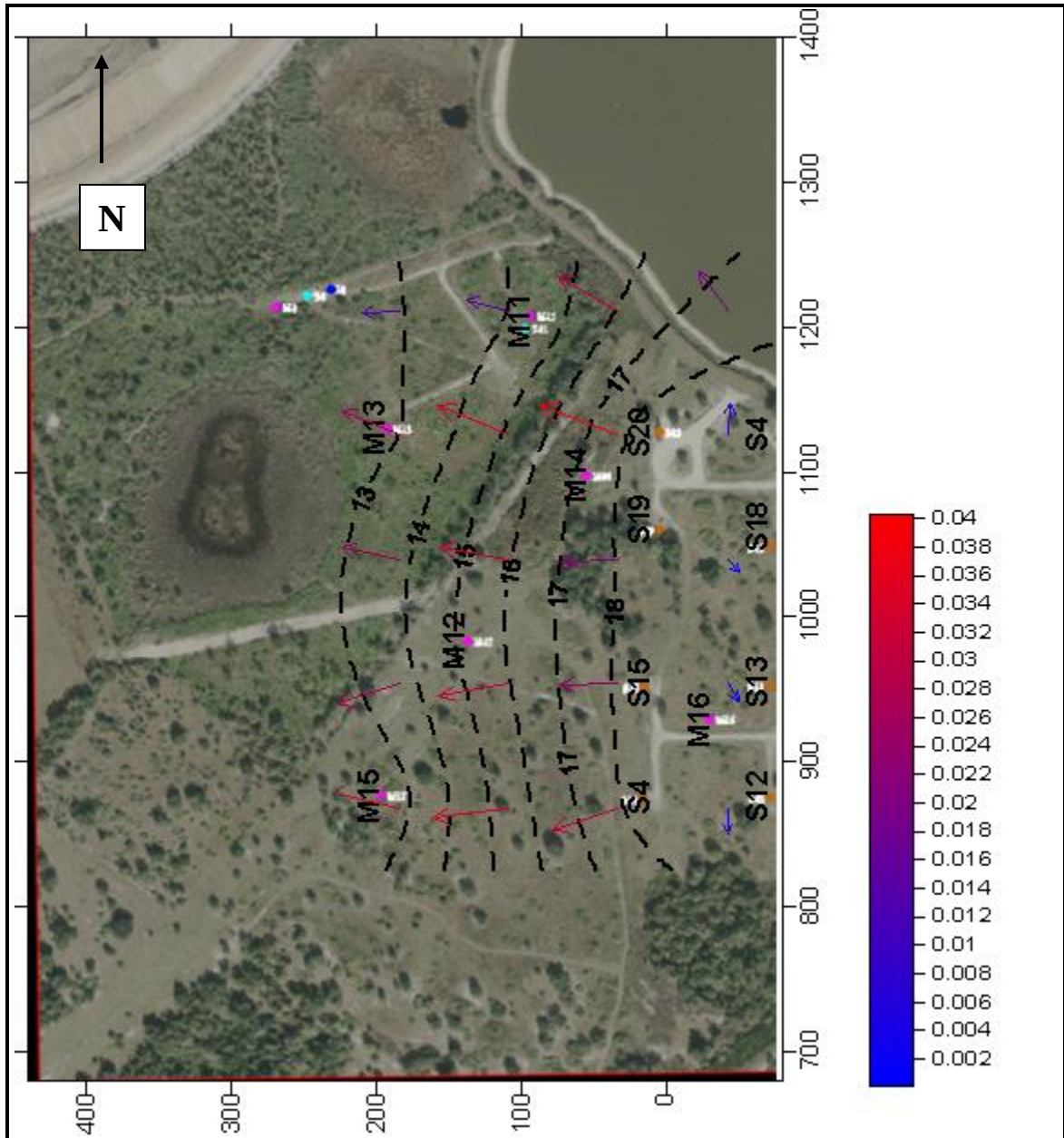


Figure 17. Flow map of site during recharge cycle (January 2006); 1,847 m³/d were injected at ASR wells.

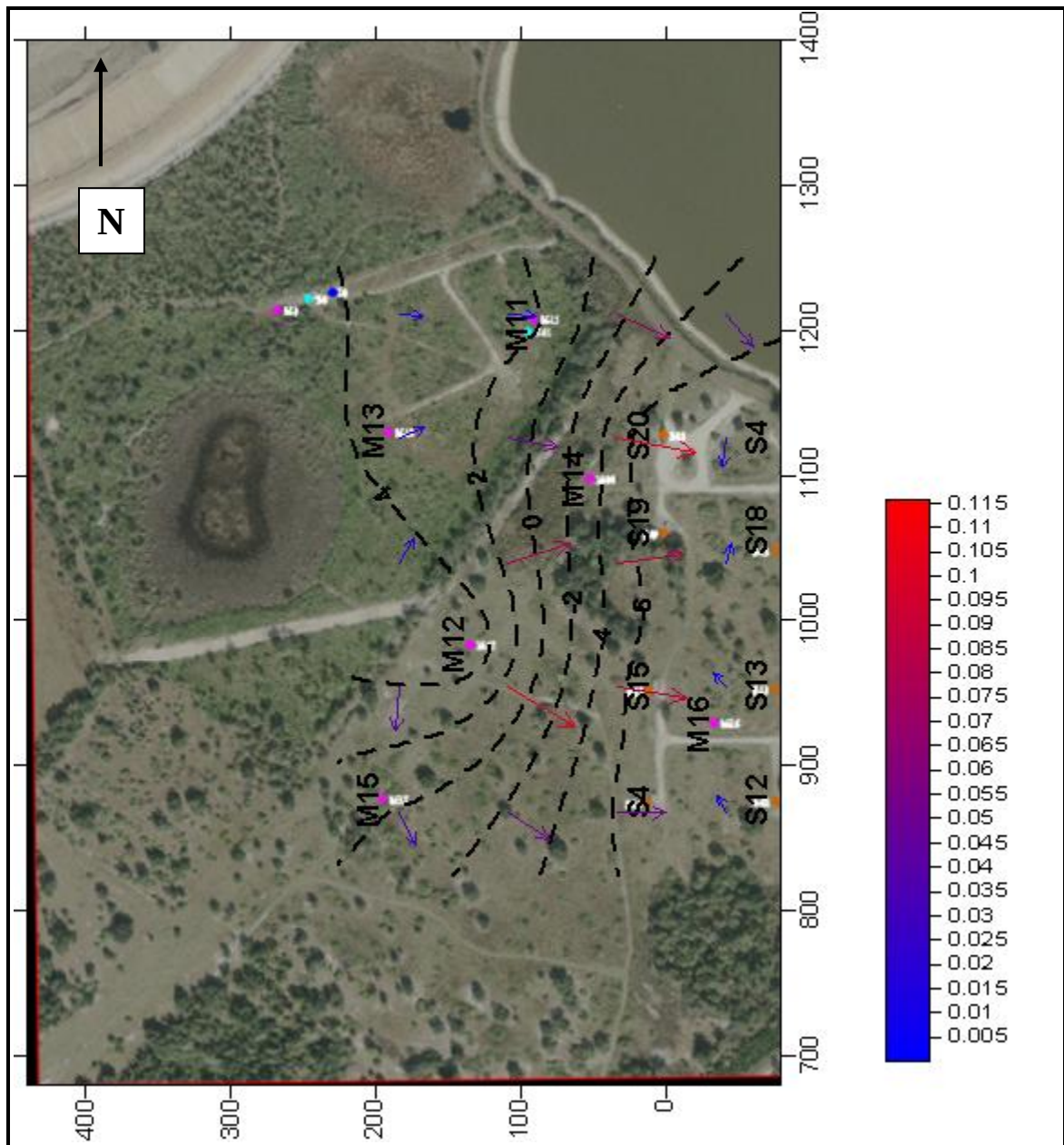


Figure 18. Flow map of site during recovery cycle (June 2006); 31,692 m³/d were extracted at ASR wells.

and 4 meters flows almost radial to the ASR wells under horizontal hydraulic gradients ranging from 0.005 to 0.11.

2.6 Geological Structural Features

Enhanced dissolution along bedding planes and horizontal fractures in limestone can be described as mechanical and is often characteristic of limestone formations. These depositional and structural features have previously been identified in the UFA and form a major component of the permeability of the aquifer (US Army Corp of Engineers, 2004; Vacher et al., 2006), especially when these features undergo further secondary dissolution. In addition, vertical fracture zones and faults are discernable at the surface as fracture traces and lineaments. These features are created by various stress fields and occur frequently in northwest-southeast and northeast-southwest trending sets. These features have propagated throughout the UFA and result in zones of enhanced porosity and permeability. The distribution of lineaments in South Florida is depicted on **Figure 19** (US Army Corp of Engineers, 2004). As shown on the figure, lineaments exist in the vicinity of the site suggesting that vertical fractures could exist in the UFA at the ASR facility. Lineaments have been described as fracture zones of increased fracture density as opposed to single fractures, and vertical fractures can occur outside of defined lineaments.

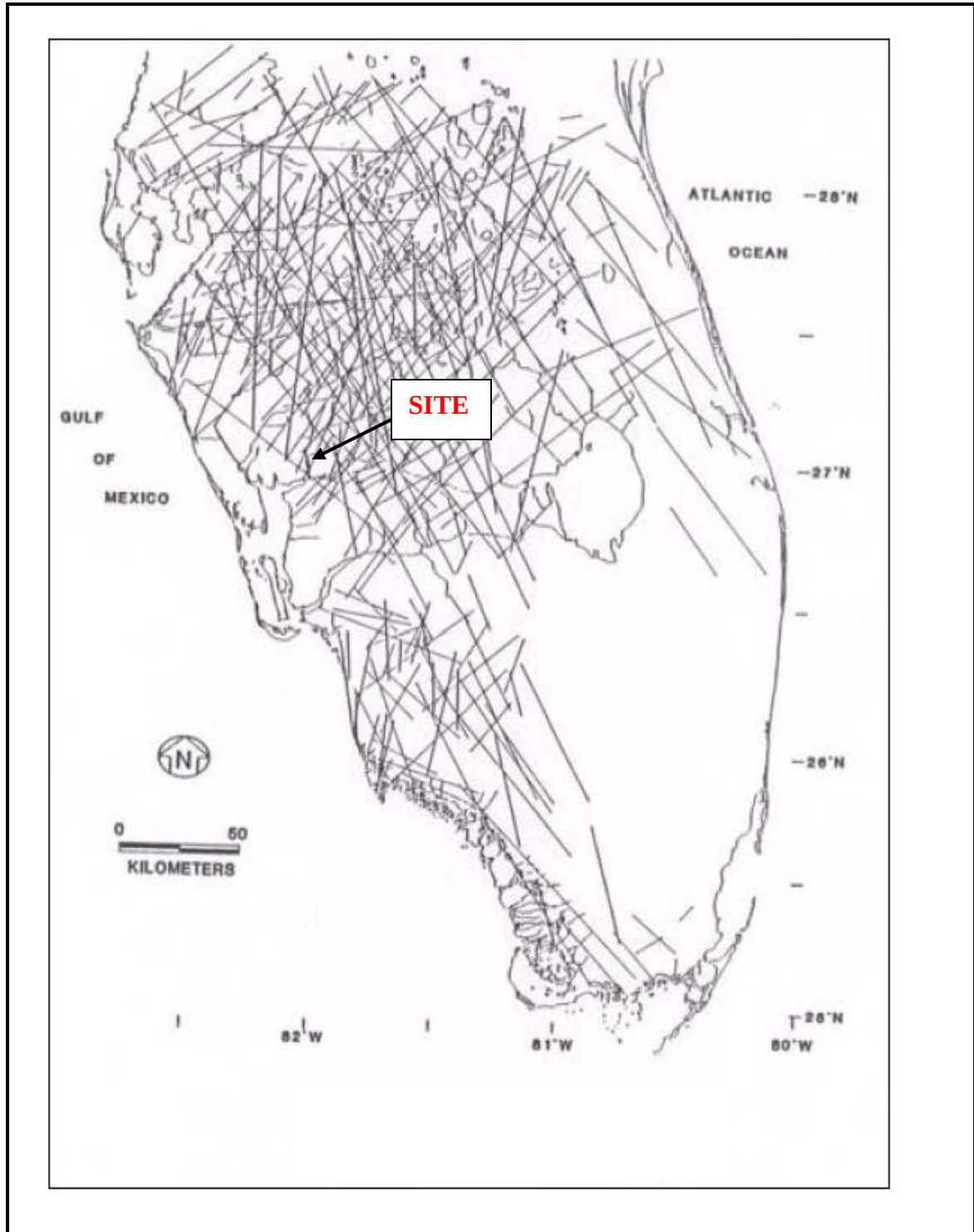


Figure 19. Distribution of photolineaments across South Florida.

3.0 DATA ANALYSIS

This section presents a discussion of the analysis of well logs and their interpretations used to identify potential fracture zones and associated zones of high flow and transmissivity. In addition, the geochemical conditions of the UFA that have been previously determined and those that have been inferred from existing data are presented and discussed in relation to this study.

3.1 Well Log Analysis and Interpretations for Fracture Flow

Geophysical well logging was conducted during the installation of the ASR and monitoring well network for Well Field 2, including electrical resistivity, spontaneous potential, caliper, gamma ray, sonic porosity, and fluid velocity-flow logs. Fractured zones in carbonate, igneous, and metamorphic rocks are indicated by the preceding logs (Rubin and Hubbard, 2005). These well logs were evaluated to determine if fractures are present that could indicate the presence of high permeability zones. Electrical resistivity or fluid conductivity are measures of the potential for the aquifer matrix and fluids to conduct an electrical current and indicate the presence of fluids with contrasting total dissolved solids concentrations. Fluids may exhibit intervals of high resistivity or low conductivity if the groundwater is relatively fresh. Spontaneous potential is a measure of the natural electrical properties of the aquifer matrix and fluids based on the contrast between a reference potential at the surface and the potential in the drilling mud and the

formation detected by the downhole tool. Fractures are indicated by deviations of the SP curve from the baseline position. A caliper log is a continuous measure of the diameter of the borehole and reflects borehole diameter in both x and y directions. Increasing borehole diameter is consistent with the presence of fractures or zones of contrasting matrix dissolution and enlargement. A gamma ray log is a measure of naturally occurring radioactive minerals and generally indicates the presence of clay minerals, although substitution of radioactive elements in the limestone matrix is also a possibility. Gamma ray and caliper logs are used concurrently to identify zones of enhanced permeability. A sonic porosity log is a measure of porosity based on the travel time between the sonde and the formation with increasing travel time directly correlated with increasing porosity. Fluid velocity and flow logs are conducted under static and pumping conditions and higher fluid velocity and flow are correlated with intervals of high porosity and fractures.

Although all of the above logs were used to determine the presence of fractures in the aquifer, the logs which exhibit the most significant evidence of the presence of fractures are the caliper, sonic porosity, and flow logs. The well logs used for the analysis of fractures and fracture zones are provided in **Appendix A**. In addition to the presence of fractures as indicated by the logs, many of the fractures are correlated across the well field, and it was these continuous zones that are used to construct the numerical flow and transport models. The drill bits used to install the ASR wells have a diameter of 14.5 inches (0.37 m) and the caliper logs indicate that the borehole is enlarged to a radius of approximately 10 inches (0.25 m) greater than the diameter of the borehole. The perceptible vertical fracture thickness inferred from the caliper logs ranges from

approximately two (0.6 m) to ten (3.05 m) feet, although smaller fractures likely exist which are not resolved at the scale of the caliper logs. The sonic porosity and differential travel time logs exhibit numerous oscillations indicating the presence of fractures or zones of secondary porosity in parts of the matrix making them potentially susceptible to dissolution. Many of these features on the sonic porosity logs are correlated across the well field. In addition, many of these same features are consistent with zones of increased flow and fluid velocity indicated by the flow logs.

The geophysical logs indicate the presence of two general zones of borehole enlargement occupying the upper part of the injection interval between approximately 610 (186 m) and 690 ft (210 m) bls and the mid-lower part of the interval between 710 (216 m) and 790 ft (241 m) bls (**Figure 20**). These intervals include several smaller inferred fractures that can be correlated between the ASR and monitoring wells.

Lithologic logs from ASR well S-19 indicate that these intervals are composed of moldic and fossiliferous limestone and the interval separating them from approximately 680 to 710 ft bls is composed of dolomite and marly limestone (Water Resources Solutions/Boyle Engineering Corporation, 2000) as follows:

S-19 585-592 ft bls, limestone, yellowish gray (5Y 8/1), calcarenite, moderately soft, moderate apparent intergranular porosity, moderate solution permeability.

592-595 ft bls, limestone, yellowish-grey (5Y 7/2), moderately well indurated, micrite, trace lime mud, trace fine phosphate, trace cement fragments, low to moderate apparent permeability and porosity.

The above interval occurs at the bottom of the casing and exhibits a large spike on the caliper log. This interval may represent solution enlargement of fractured limestone.

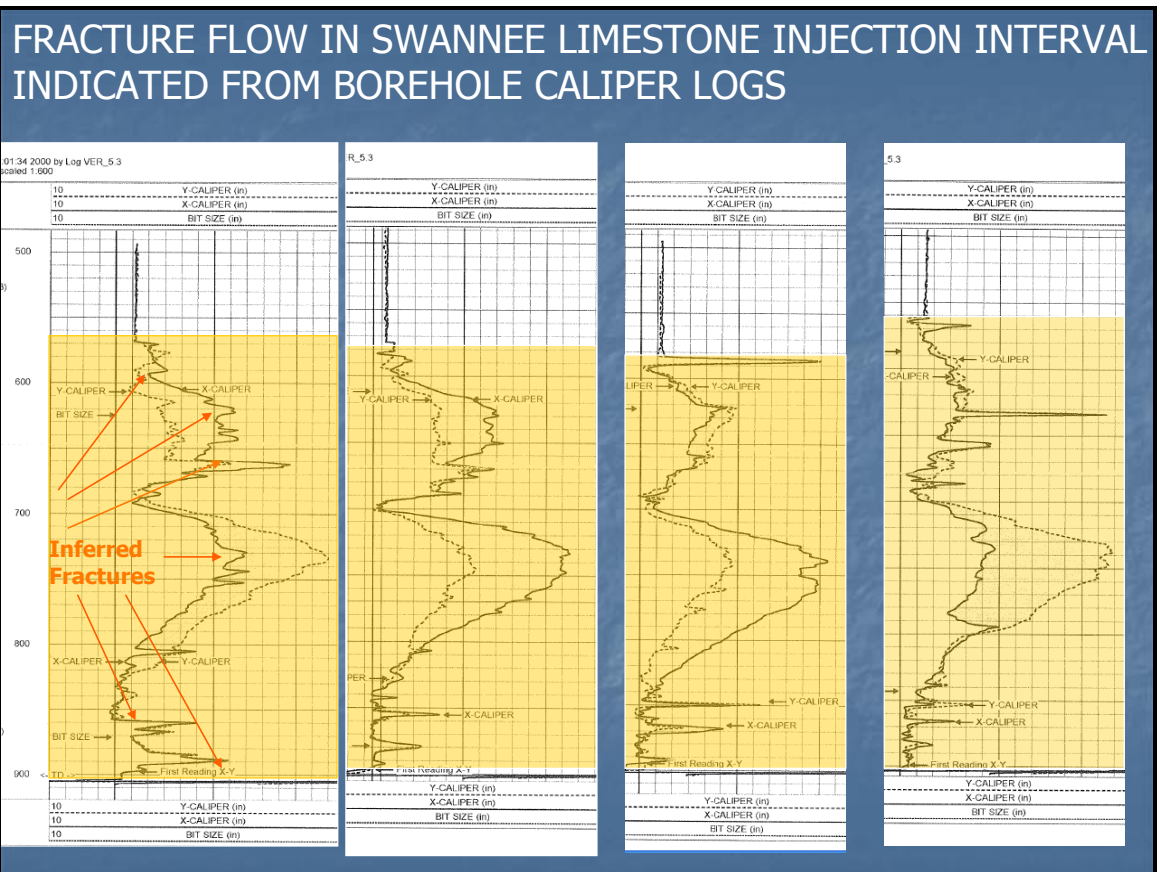


Figure 20. Representative geophysical logs depicting inferred fractures and fracture zones in the injection zone of the ASR wells.

S-19 610 - 620 ft bls, limestone, yellowish-grey (5Y 8/1) to very pale orange (10YR 8/2), moderately well indurated, biomicrite, slightly chalky, trace cement fragments, minor moldic porosity, moderate to good apparent permeability and porosity.

This interval exhibits varying amounts of molds, casts, and fossils indicating potential variations in permeability and porosity throughout the well field. The cement fragments may represent the site of historic fractured limestone.

S-19 750 - 760 ft bls, limestone, yellowish-grey (5Y 8/1), moderately well indurated, calcarenite, slightly chalky, moderately fossiliferous, moderate moldic porosity, good apparent permeability and porosity.

Another prominent fracture occurs in the lower part of the injection interval between approximately 875 (267 m) and 885 ft (270 m) bls. Due to the occurrence of numerous potential small fractures in the mid-lower zone, this zone was treated as a single fracture zone interval. Approximately 18 fractures or fracture zones appear to occur within the Suwannee Limestone injection interval.

High flow zones are identified to occur in the lower part of the Suwannee Limestone from flow-velocity logs run during 72-hour pumping tests. Fractures in high flow zones (600 to 821 gpm) have been observed in the samples collected from the bottom of the Suwannee Limestone during the installation of some ASR wells of Well Field 2 including S-11, S-15, S-17, and S-19 as follows:

S-11 830 - 840 ft bls, dolomite, pale yellowish brown (10YR 6/2), to yellowish gray (5Y 7/2), microcrystalline, very well indurated, low primary porosity/permeability, with

common interbedded biomicrite, yellowish gray (5Y 8/1), moderately well indurated, common fossil casts, good moldic porosity/apparent permeability. Note: dolomite has high secondary fracture porosity.

S-15 - 835-870 ft bls, dolomite, light olive gray (5Y 6/1) to moderate olive brown (5Y 4/4), very hard, microcrystalline, fractured, low apparent porosity/permeability, possible high permeability/porosity along fractures;

870-880 dolomitic limestone/dolomite, pale yellowish brown (10 YR 6/2), microcrystalline texture, moderately hard to hard, low apparent porosity/permeability, highly fractured causing high porosity permeability;

S-17 - 830-840 ft bls, dolomite, yellowish gray (5Y 8/1), microcrystalline, hard, trace marl, poor primary porosity, poor apparent permeability, good fracture porosity;

840-850 limestone, very pale orange (10YR 8/2), micrite, moderate induration, slightly arenitic, with common light grey (N7), interclasts, trace dolomite as above, good porosity, good apparent permeability;

850-860 limestone, very pale orange (10YR 8/2), micrite, soft to moderate induration, trace dolomite as above, good porosity, good apparent permeability;

860-870 limestone, as above, with common shell fragments, good porosity, good apparent permeability;

870-880 limestone, very pale orange (10YR 8/2), micrite, soft to moderate induration, minor fossil casts, good to excellent porosity, good apparent permeability.

S-19 – 860-870 ft bls, dolomite, pale yellowish brown (10YR 6/2), very well indurated, microcrystalline to sucrosic, trace arenitic limestone as above, low apparent permeability and porosity, probable fracture permeability;

870-880 dolomite, pale yellowish brown (10YR 6/2) to dark yellowish brown (10YR 4/2), very well indurated, microcrystalline to sucrosic, minor very pale orange (10 YR 8/2) dolomitic limestone, low apparent permeability and porosity; probable fracture permeability;

880-890 dolomite, pale yellowish brown (10YR 8/2) to dark yellowish brown (10YR 6/2), very well indurated, microcrystalline, trace very pale orange (10YR 8/2) arenitic limestone, low apparent permeability and porosity, probable fracture permeability;

890-900 limestone, very pale orange (10YR 8/2), well indurated, calcarenite, slightly chalky, common dark yellowish brown (10YR 4/2) sucrosic dolomite, moderate to good apparent permeability and porosity.

A fracture zone was previously identified to exist between approximately 630 and 640 ft bls according to interpretation of caliper, conductivity, and flow logs from monitor well M-14 (CH2MHill, 2005), which appears to persist across Well Field 2. The conductivity logs indicated that fresh water occurred at the bottom of the well that was overlain by more saline groundwater, suggesting downward vertical flow of recharge water during recovery as a result of preferential flow paths.

3.2 Previous Studies of Limestone Matrix Permeability

A previous detailed study of the permeability of the matrix of the UFA (Budd and Vacher, 2002) determined that the matrix exhibits an average permeability of approximately 0.5 m/day and that fractures present in the UFA account for a significant part of the transmissivity (Vacher et al., 2006). The matrix permeability does not account for the transmissivity of the aquifer determined from the aquifer performance test conducted at ROMP 20 (DeWitt and Thompson, 1997). The distribution of permeabilities per matrix rock type determined from the above study include: wackestone 1.97×10^{-7} meters per second (m/s), packstone 9.61×10^{-7} m/s, grainstone 3.82×10^{-6} m/s, and sucrosic dolostone 9.61×10^{-6} m/s. Studies conducted of the permeabilities of limestone aquifers in other locations (White and White, 2005) have also concluded that the matrix permeabilities are low. Examples include Silurian dolomite, Ontario, Canada 1×10^{-10} m/s (Worthington, 1999); English chalk 1×10^{-8} m/s (Worthington, 1999); Pliocene limestone, Yucatan, Mexico 7×10^{-5} m/s (Worthington, 1999); Edwards Aquifer, Texas, Cretaceous 1×10^{-8} m/s (Worthington et al., 2002); and Swabian Alb, Germany, Jurassic 8×10^{-9} m/s (Worthington et al., 2002).

Transmissivity of a fracture bound by planar top and bottom surfaces (parallel plate model) is related to the aperture according to the cubic law, $b = 0.24 T^{1/3}$, where b is the hydraulic aperture in millimeters and T is the transmissivity in square meters per day (m^2/day). Assuming the smallest fracture aperture that can be resolved on the logs is approximately 0.3 m, the transmissivity of the fracture is approximately $2.05 \times 10^9 \text{ m}^2/\text{day}$. From an aquifer performance test conducted on-site, the transmissivity of the UFA is approximately $2770 \text{ m}^2/\text{day}$, indicating that the assumptions of the cubic law do not apply

to the apparent scale of the fractures that occur on site and that the cubic law would significantly overestimate the transmissivity of the aquifer. According to a previous study of fracture flow in limestones (White and White, 2005), fractures occur in the size range of hundreds of micrometers. White and White also conclude that if fracture apertures are present in aquifers with very low matrix transmissivities and the fractures present are in the size range of millimeters and centimeters, the aquifer would likely be dominated by fracture flow. Given that the matrix hydraulic conductivity of the UFA ranges from approximately 1.97×10^{-7} to 9.61×10^{-6} m/s with an average of approximately 5.8×10^{-6} m/s or 0.5 meters/day, fracture flow likely does dominate flow in the injection interval of this study. If only the matrix is considered, the transmissivity of the UFA in the vicinity of the site should be about 50 m²/day; however, the results from aquifer performance tests indicate that the transmissivity is approximately 2770 m²/day. Dividing the aquifer transmissivity of 2770 m²/day by the aquifer thickness of 100 m, yields the average hydraulic conductivity of 27.7 m/day. The average hydraulic conductivity is significantly greater than the matrix hydraulic conductivity, suggesting the presence of more transmissive zones to account for the difference between the aquifer and matrix transmissivities.

The fractures that occur in the injection zone are likely small features that occur within the intervals identified by the geophysical logs. They are continuous across the well field as zones of variably interconnected and discontinuous fractures. Regardless of the structure of these flow zones, these fracture zones exhibit transmissivities significantly greater than the matrix. The matrix permeability therefore represents a relatively minor percentage of the aquifer permeability (approximately 2%) implying that

zones of higher permeability exist in the aquifer that account for most of the permeability. This difference could be accounted for in limestones by fractures, conduits, vuggy porosity, or high intergranular porosity. As discussed above, if ideal fractures are present, the difference could be represented by a minor thickness of the aquifer. However, given the evidence suggested by the various well logs of highly contrasting zones of borehole diameter, flow, velocity, and porosity, it is likely that a significant number of zones of contrasting permeability exist.

3.3 Geochemistry of the Upper Floridan Aquifer

The matrix of the UFA generally consists of calcite and dolomite; minor amounts of gypsum, apatite, glauconite, quartz (chert), clay minerals possibly including kaolinite and montmorillonite; and trace quantities of metals (Sprinkle, 1989). The major dissolved constituents include calcium, magnesium, carbonate, bicarbonate, chloride, and sulfate. The minor constituents include fluoride, silica, aluminum, nutrients, and trace metals (Sprinkle, 1989; Sacks and Tihansky, 1996).

The geochemical processes that occur in the UFA are correlated with the degree of confinement and chloride content of the aquifer, based on observed data and geochemical modeling (Sprinkle, 1989). If the aquifer is confined and chloride concentrations are less than 500 mg/L, the most important processes include the dissolution of calcite, dolomite, and gypsum, ion (calcium substitution for sodium) exchange with clays, and sulfate reduction by organic carbon oxidation.

The UFA is confined in the vicinity of the site and the average chloride concentration observed in background monitoring well M-6 is approximately 261 mg/L.

In coastal environments, where the chloride concentrations exceed 500 mg/L, mixing of seawater and freshwater also occurs which would tend to result in significant ion exchange associated with sodium, calcium, and magnesium. A study of the effects of the recharge of fresh water into a brackish shallow alluvial aquifer in Palo Alto, California with chromatography was conducted to evaluate the ion exchange characteristics on the surface of clays and confirmed the exchange of sodium, calcium, and magnesium. (Valocchi, 1980; Valocchi et al., 1981). The clays that occur in this study (Valocchi, 1980) are similar to those that have been encountered in the UFA, suggesting that the UFA has a cation exchange capacity similar to the Palo Alto, California field site aquifer. The cation exchange reactions identified above indicate that sodium, magnesium, and calcium in groundwater will potentially exchange sites with aquifer materials that have similarly charged surface-bonded species.

4.0 MODELING METHODS

This research uses the three-dimensional numerical model, PHT3D (Prommer, 2003), which is a MODFLOW-based program (Harbaugh et al., 2000) that couples PHREEQC-2 and MT3DMS (Zheng, 1996). It is capable of simulating pyrite-arsenic reactions under a variety of conditions, and mass transport to determine the factors and processes that control flow, transport, and distribution of arsenic in the UFA during ASR operations. PHREEQC Version 2 (Parkhurst and Appelo, 1999) is a U.S. Geological Survey geochemical reaction and speciation program that is capable of calculating reactions associated with a wide range of natural and environmental geochemical processes. PHREEQE (Parkhurst et al., 1980) preceded PHREEQC Version 1 (Parkhurst, 1995). PHT3D has been successfully used to simulate the effects of oxidation during deep well injections into a pyritic aquifer (Prommer and Stuyvezant, 2005) and was adapted to the site conditions documented for the UFA for background conditions and during ASR operations. The existing PHT3D reaction model (Prommer and Stuyfzand, 2005) was modified to characterize the natural geochemical processes and transport in the carbonate aquifer and those dynamic processes that occur during ASR operations. The modifications included the addition of major and minor equilibrium minerals and ion exchange reactions by modifying the Visual MODFLOW XML file and creating another variant of the model. Equilibrium sorption was simply simulated by

creating a variant of these models and importing all of the above processes and constituents.

The modifications to the XML file were performed by this author, upon the recommendations and guidance provided by H. Prommer and I. Wallis of the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. The use of PHT3D enables the simulation of the sequence of reactions and resulting chemical evolution of the storage zone during multiple ASR cycles. PHT3D was recently coupled with SEAWAT-2000 (Langevin and Guo, 2006) in the program PHWAT (Mao et al., 2006), which enables the simulation of the effects of variable density (Bauer-Gottwein et al., 2006) in those ASR systems that operate in brackish environments.

4.1 Modeling Considerations

4.1.1 Fluid Density

The potential density contrast of the formation and injectate waters in coastal environments is important to understanding the potential horizontal and vertical migration of dissolved arsenic during the ASR cycles in which arsenic is liberated from arsenopyrite. If the formation groundwater exceeds approximately 3,000 mg/L, then the recovery efficiency of the ASR system will decrease due to the bouyancy of the injected water. Simulated ASR systems under low variable-density conditions (less than approximately 2,500 mg/L) also indicate that recovery efficiency is not affected by heterogeneous (layered aquifer) or homogeneous aquifers (Vacher et al., 2006; Ward, et al., 2008). The TDS concentrations measured in the injection interval within the

Suwannee Limestone at the study site are less than 1,000 mg/L; therefore, the density contrast between the formation water and the injectate is not sufficient to cause the injectate to become bouyant and result in bouyancy stratification (Reese, 2002; Vacher et al., 2006).

The horizontal and vertical flow and transport system may be affected by the effects of density on hydraulic gradients. The effects of density on the horizontal and vertical hydraulic gradients that may exist on-site were evaluated by calculating the respective hydraulic gradients under a range of densities expected to be encountered on-site. Calculation of the horizontal hydraulic gradients takes into consideration the equivalent freshwater heads and densities (Langevin, C.D. and W. Guo, 2006) for each well as follows:

$$h = \rho_f / \rho * h_f + \rho - \rho_f / \rho / Z \quad \text{and} \quad h_f = \rho / \rho_f * h - \rho - \rho_f / \rho_f / Z$$

where: ρ = density of formation water (ML⁻³);

ρ_f = density of freshwater (ML⁻³); and

Z = elevation of measuring point (L)

Calculation of the vertical hydraulic gradients (Post et al., 2007) takes into consideration the equivalent freshwater heads and densities for each well as follows:

$$\nabla h = \Delta h_i / \Delta z + ((\rho_a - \rho_f) / \rho_f),$$

Where: ∇h = the vertical hydraulic gradient with respect to pressure or head distributions, and buoyancy;

h_i = equivalent freshwater head;

z = vertical separation between point measurements;

ρ_a = average density of groundwater between screened intervals; and

ρ_f = density of freshwater (Post et al., 2007)

Assuming an equivalent freshwater head difference of 10 ft, a vertical separation of 300 ft, and a TDS difference of 500 mg/L equivalent to a specific gravity of 0.0004, the difference in hydraulic gradient is approximately 0.00015 or 0.45%; which is insignificant. Therefore, simulating these ASR conditions with an assumption of constant density will not introduce significant errors associated with contrasting water densities.

4.1.2 Lithologic and Geochemical Data

Operational parameters and analytical data for background, treated recharge water, recovered groundwater, and aquifer geochemical field properties have been made available for this effort by the Manasota Regional Water Supply Authority and the Florida Department of Environmental Protection. Geologic, hydrogeologic, and geophysical data are obtained from historical publications and reviewed in order to accurately construct the representative models for this study. Lithologic well logs can be used to identify the lithologic and mineralogic characteristics, presence of potential flow features such as fractures, solution voids, tubes, and channels, and geochemical properties including the presence of pyrite and iron precipitates.

4.1.3 Aquifer Heterogeneity

Constraints on site characterization, whether they are due to budgets, accessibility, impracticality, or logistics, limit the degree of model refinement and, consequently, uncertainty is introduced into the simulation models. In order to overcome

these limitations, simplified equivalent porous medium or continuum models are often utilized, which neglect the small-scale heterogeneity of the aquifer (National Research Council, 1996). Alternatively, discontinuous models are utilized to attempt to represent the geometric and mechanical aspects of the fractures, but not the matrix. These equivalent porous medium and fracture flow approaches may also be combined as hybrid models, as is done in this study.

The heterogeneity of fractures in equivalent continuum models is generally not explicitly treated, except where they occur as large scale features. Aquifer hydraulic properties that represent the volume-averaged behavior of the fractures are used in continuum models. These average hydraulic properties can be those determined from aquifer pumping tests that average hydraulic parameters over large aquifer volumes. If the aquifer parameters are known with a significant degree of certainty, the model is considered to be deterministic. If the hydraulic parameters of the fractured rock are characterized by a spatially random field, their distributions may be characterized by a probability function with a stochastic model.

Equivalent continuum models are generally single or dual porosity models. In a single porosity model, all porosity is associated with fractures, while in a dual porosity model porosities from both fractures and matrix are included in the model. An equivalent continuum dual porosity model could be used where a large fracture occurs within a volume of aquifer otherwise occupied by the matrix, permitting the use of porosities characteristic of the fracture and matrix.

Another aspect of the hydrologic simulation model that can be significant between fractures and the matrix is matrix diffusion, which is usually simulated with a

dual porosity model. Diffusion can be important aspect of a transport model if advection is not the dominant process. The dynamic conditions of recharge and recovery are advection-dominated flow systems; however, during the storage period the advection component of flow significantly decreases and diffusion may become a significant component of the flow system.

In order to evaluate the effects of various fracture network configurations on the distribution of arsenic, stochastic hydraulic conductivity distributions are generated and used with the MODFLOW-based reactive-transport models. The model FracMan (Golder Associates, Inc.) is used to generate representative discrete fracture networks (DFN) with associated stochastic parameter distributions, which can subsequently be "upscaled" or converted to a format consistent with finite difference models, i.e., value entered into discrete cells, and imported into MODFLOW-based models such as PHT3D and SEAWAT-2000. It should be noted that volume averaging occurs when the FracMan fracture network is up-scaled; therefore, the FracMan fractures are not explicitly simulated in the MODFLOW-based models. If significant fractures and solution features are apparent from the data reviewed, the turbulent flow that may exist could be more accurately represented with the USGS model CFP (Shoemaker et al., 2007). Aquifer performance tests provide information on the hydraulic conductivities at the study site. Based on the inferred hydraulic conductivities that exist on-site and lithologic data reviewed, it is not likely that significant conduit (cavernous) flow occurs in the aquifer within the ASR well field, as discussed in Section 4.2.1.

4.2 Conceptual Models

The conceptual models used for this research can be formulated in terms of three principal processes groundwater flow, chemical reactions, and mass transport that affect water quality during ASR operations.

4.2.1 Conceptual Groundwater Flow Model

The conceptual groundwater flow model (**Figure 14** and **Figure 15**) consists of a stratified sequence of predominantly limestone and dolomite representing the UFA. The UFA is overlain by the low permeability Hawthorn Group sediments, which represent the upper confining unit of the UFA. The upper part of the UFA is represented by the Suwannee Limestone Formation, which is hydraulically isolated from the underlying Ocala Formation. The limestone matrix exhibits low primary porosity; however, secondary porosity has been created as a result of fractures, variations in fabric, sub-aerial exposure, and subsequent dissolution leading to horizontal and vertical permeability heterogeneities. The creation of fractures and zones of fractures due to lithostatic and compressional stresses on limestones creates preferential flow paths and subsequent limestone dissolution. The initial fracture zone sites are eventually transformed into zones of the aquifer that can exhibit very high hydraulic conductivity, which are referred to as high flow zones. Because of this relationship, fractures can be considered the progenitors of subsequent high flow zones. The karstic UFA can exhibit triple porosity including intergranular, fracture, and conduit (cavernous) porosity (Hill, 2008); however, the well logs from this site do not indicate the presence of cavernous porosity. Regardless, smaller scale conduit-like features could potentially exist which are not discernable with the investigative tools utilized. The other geologic characteristics of

the aquifer described above can also result in high flow zones; however, for this study it is inferred that most of the high flow zones are associated with initial horizontal and vertical fracture zones. Inferred fracture zones have been documented in the upper part of the Suwannee Limestone between approximately 630 and 640 ft bls. Lithologic logs indicate that these high flow zones are within hard fossiliferous limestone rocks. A clay and marl interval overlies the limestone in the vicinity of M-14 suggesting either localized diagenesis or a more widespread unconformity. An unconformity would represent an erosional surface on the limestone resulting in increased permeability that could contribute to the high flow associated with the inferred fracture zone. The natural potentiometric surface is near land surface; therefore the aquifer is confined, and the hydraulic gradient is negligible at approximately 0.0005 to the northwest across the site.

The ASR facility extracts surface water from the Peace River, treats it to drinking water standards, and injects it into a network of 12 ASR wells completely open to most of the Suwannee Limestone Formation. A reservoir in close proximity to the Peace River is used for the storage of diverted surface water from the Peace River. Typically, sufficient water is injected to create the design storage zone, prior to the subsequent cyclic injection and extraction cycles. The ASR operation consists of injection periods spanning several months or more at a time followed by equivalent or shorter recovery periods. The recovery of groundwater is terminated when the TDS concentration of groundwater is near the secondary drinking water standard of 500 mg/L.

4.2.2 Conceptual Chemical Reaction Model

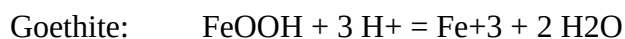
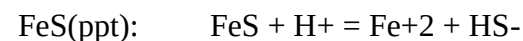
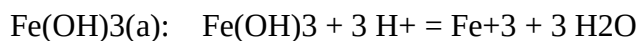
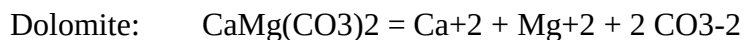
The Peace River ASR operation consists of the injection of surface water, pretreated to drinking water standards, into the nearly anoxic calcium-bicarbonate semi-

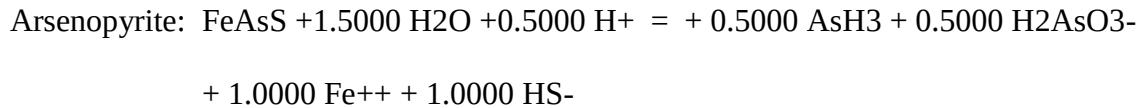
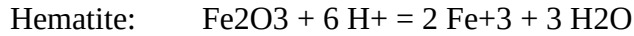
confined to confined Suwannee Limestone Formation of the UFA. The conceptual chemical reaction model for this study primarily concerns the chemical reaction of native pyrite (and arsenopyrite) and high dissolved oxygen in pre-treated recharge water that leads to the dissolution of pyrite and increased concentrations of iron and sulfur ions. The anoxic aquifer exhibits background dissolved arsenic concentrations that are generally less than the laboratory method detection limit of 1.3 µg/l. The concentrations of the native groundwater and recharge water of the conceptual model are summarized

Section 5.2 PHT3D Reaction Transport Model

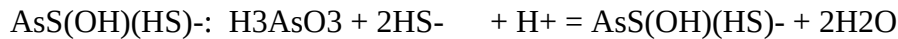
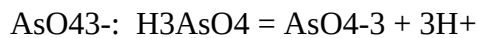
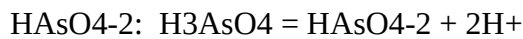
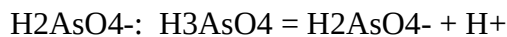
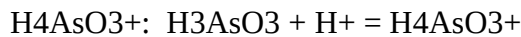
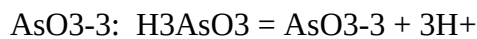
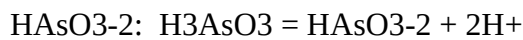
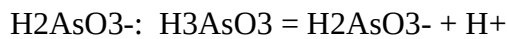
With the known occurrence of significant percentages of arsenic substitution in pyrite (Price and Pichler, 2005) analyzed from the UFA, it is proposed that the oxidation reaction with pyrite could also potentially release arsenic in significant concentrations that exceed the MCL of 10 ug/L. During the recharge cycles, the injected water has dissolved oxygen concentrations of approximately 8 mg/L, resulting in the rapid dissolution of pyrite upon contact with the oxidizing groundwater. The above reactions are simulated in the conceptual model using naturally occurring major and minor minerals and solid phases.

The conceptual reaction model utilizes the following solid phase reactions from the PHREEQC-2 database:





Arsenic species and reactions



The oxidizing conditions in the storage zone at this time create stable conditions for the occurrence of the oxidized pentavalent arsenate (As^{+5}) species. Iron that is released at this time is rapidly oxidized and subsequently precipitated as ferric oxyhydroxide or HFO. Arsenic immediately forms a strong surface complex with HFO retarding the migration of arsenic; thereby maintaining the majority of the arsenic mass in

close proximity to the ASR well and resulting in the detection of low concentrations of arsenic in the closest monitoring wells of most ASR sites.

During storage periods, the source of elevated DO in groundwater is terminated and oxygen receptors further reduce the DO concentrations to near static anoxic conditions across most of the storage zone. These conditions are proposed to persist during the recovery phase, during which time ferric iron becomes unstable and is reduced to ferrous iron with the concurrent release of sorbed arsenic. Arsenic subsequently migrates to the ASR well during the recovery cycle resulting in the highest detected concentrations of arsenic at the ASR site. During the storage and recovery cycles, it is anticipated that the reduced arsenic ion, arsenite (As^{+3}), is the predominant form of arsenic.

The preceding conceptual chemical reaction model describes the general occurrence and distribution of arsenic in the UFA during ASR operations; however, aquifer heterogeneities can potentially lead to chemical reaction and mass transport anomalies. Data collected during ASR recharge cycles from the monitoring well M-14, located approximately 200 ft from the nearest ASR well, exhibit DO concentrations of approximately 4 mg/L reflecting minor attenuation compared to concentrations in recharge water. This scenario implies that a high flow zone consistent with a fracture zone is likely present which facilitates the rapid migration of groundwater to the open borehole intercepted by M-14. The low arsenic concentrations detected in M-14 during recharge may also be due to a low background concentration of arsenopyrite in the vicinity of the ASR wells (S-19 and S-20) closest to M-14. The distribution of arsenopyrite in the aquifer is heterogeneous; therefore, the aquifer may contain

arsenopyrite at higher concentrations immediately downgradient from M-14 during recharge that makes contact with oxic groundwater and migrates past M-14 during recharge cycles. Arsenopyrite that is present in the aquifer beyond M-14 is oxidized with the release of arsenic, which is rapidly sorbed during the recharge cycle. During the recovery cycles, arsenic is subsequently detected in M-14 at high concentrations compared to recharge cycles. This scenario is likely complicated by zones of high vertical flow that have been previously documented.

4.2.3 Conceptual Mass Transport Model

The conceptual mass transport model for this study is described in terms of the effects of transport parameters on the solute migration. Mass transport parameters include dispersion, advection, sink/source, and reaction terms. Associated parameters include total and/or effective porosities, hydrodynamic dispersion, seepage or linear pore water velocity, and chemical species concentrations in the advection and sink/source terms. The conceptual transport model describes solute migration in the UFA with respect to average total and effective porosities for the matrix and high-flow zones. Porosity is not used by MODFLOW to calculate the flow field; however, it is used by MT3DMS to calculate the advection term.

Advection in the conceptual model can be described as $\partial/\partial x_i(\theta v_i C^k)$, where θ is the porosity of the aquifer medium, v_i is the linear or pore water velocity, and C^k is the concentration of the dissolved species k . The linear velocity is calculated from the Darcy flux using the average effective porosities for the aquifer. The solute transport distance is inversely correlated to effective porosity; therefore decreased effective porosity results in increased solute migration if hydraulic conductivity is constant. Although porosity is

highly variable within crystalline bedrock, the variability in the UFA is potentially less due to the relatively higher solubility of carbonate minerals. This difference would tend to support the use of an average effective porosity compared to a distributed porosity field for the UFA. The hydraulic conductivity for the UFA contrasts between the high and low flow zones. The high flow zones are associated with significantly greater hydraulic conductivities than the low flow zones (matrix), resulting in significantly greater transport paths even though effective porosity may be greater. Advection is likely the dominant mass transport process because of the high range of hydraulic conductivities and the high injection pressures resulting in large hydraulic gradients.

Hydrodynamic dispersion in the conceptual model is a combination of mechanical dispersion and molecular diffusion of the solute plume in UFA during ASR operations. Mechanical dispersion is the product of the dispersivity and the linear groundwater velocity. The longitudinal dispersivity for limestone is variable and has been documented to range between approximately 1 and 100 m; however, due to scale effects the local values likely range between 10^{-2} and 1.0 m (Gelhar et al., 1992; National Research Council, 1984). The longitudinal dispersivity for the aquifer is estimated to be 1.0 m and represents the localized area in the vicinity of the ASR wells. Molecular diffusion is only an important dispersive process at low flow velocities and can potentially create a significant mass flux between the matrix and fractures during long storage periods. Due to the short storage periods associated with this ASR operation, the site is dominated by advection and the effects of diffusion are considered to be negligible.

4.3 Model Descriptions

Fractures are often visualized and described conceptually as parallel plates separated by some distance (aperture), although under natural conditions this conceptualization is not accurate or meaningful. Generally, in the plane of a fracture there are regions in which the surfaces are in contact and regions, or voids, where the surfaces are not in contact. The voids of a fracture form an interconnected network through which fluid flows. The concept of a fracture as a planar network of interconnected voids leads to the analogy of fractured rock with porous media. The geometry of the void space is the consequence of the geological origin of the fracture, the subsequent changes in stress brought about by natural processes and the activities of humans, such as withdrawal or injection of fluids or construction of underground openings, and mineral precipitation and dissolution as fluids flow through a fracture.

An important difference between fracture void structure and pore structure that results in significant differences in hydrological behavior between fractures and porous media is the increased sensitivity of fractures to stress. Fracture voids tend to be more crack-like in shape compared to the equant shapes of voids in porous media and crack-like voids deform more easily under applied stress compared to more equi-dimensional voids. Because fractures represent discontinuities in material properties, shear stresses can also result in deformations, leading to large changes in hydrological properties. The difference in hydrologic characteristics between fractures and porous media creates the need to construct models that attempt to explicitly represent the physical properties that define fracture flow.

Mathematical (numerical) models can be classified into three categories including equivalent continuum models, discontinuum discrete network simulation models, and hybrid models. The models are classified by their representations of the fractured medium and are either deterministic or stochastic.

The models for this study (**Table 1**) can generally be described as equivalent continuum and equivalent discontinuum models, with the difference being the representation of inferred fracture zones (high flow zones) with averaged hydraulic properties. Using a similar averaging approach, the discontinuum model typically represents more of the aquifer discontinuities, i.e. fractures and fracture zones, than the equivalent continuum model. Since the FracMan results were up-scaled, the DFN aspects of the FracMan simulations are lost, so the models with stochastically generated hydraulic conductivity distributions become variants of the equivalent discontinuum model.

Table 1. Summary of Flow and Transport Models

Classification	Main Characteristics
Equivalent Continuum	Single layer Single permeability Single porosity
Discontinuum Discrete Fracture Network Network	Multi-layer dual porosity dual to multi-permeability
Stochastic Discontinuum Discrete Fracture Network	Multi-layer Stochastic geostastical hydraulic parameters parameters upscaled for geocellular model multi-permeability multiple storage parameters

4.3.1 Equivalent Continuum Models

Equivalent continuum models consist of a limited number of regions with volume-averaged properties representing a large volume of the aquifer, a representative elemental volume or REV (National Research Council, 1996). Volume-averaging includes matrix and fractures. Heterogeneities are represented on a large scale. A homogeneous and isotropic model would be an example of an equivalent continuum model; however, such models are not restricted to this model design. An equivalent continuum model could potentially include a limited number of layers to represent fracture zones within a matrix characterized by large scale horizontal or trending heterogeneities. In general, this modeling strategy implicitly represents the fractured aquifer by averaging the hydraulic parameters of the matrix and fractures over a large volume. Only major fracture zones would be simulated with an equivalent continuum model. The rationale behind the use of equivalent continuum models is that if the scale of the model is large compared to the REV, volume averaging should be sufficiently accurate to yield representative results. Representing the aquifer in this manner implies that fluid flux and solute transport are not significantly influenced at the model scale by individual fractures that form the fluid conducting network.

Equivalent continuum models with uniform flow properties are most beneficial with large scale models in which the aquifer contains many interconnected fractures and the interest is on volumetric flow, e.g., groundwater withdrawal for water supply. Aquifers composed of rocks with significant matrix permeabilities are suitable for continuum modeling. Fractures can be visualized as a distribution of voids and solid areas analogous to the pores and grains of porous media; therefore, the general equations

of flow, mass transport, and chemical reactions are applicable to both fractured and porous media when the model cell sizes are large compared to the fracture spacing.

In this study, the equivalent continuum model consists of a single layer model with one set of average hydraulic properties to represent the injection zone in the UFA. Previous modeling of this site for the purpose of obtaining a SWFWMD permit, treated the injection zone as a single layer, which is not an uncommon practice.

4.3.2 Discontinuum Discrete Fracture Network Models

Discontinuum models represent the discontinuities present in a fractured aquifer between the fractures and the lower permeability matrix. An equivalent discontinuum model represents the fracture network more explicitly than continuum models by volume averaging fracture zones (without the matrix) so that flow through the fractures is distinguishable from the matrix. A discontinuum discrete fracture network (DFN) model explicitly represents populations of individual fracture or equivalent fracture features. These models represent aquifer heterogeneities on a smaller scale than equivalent continuum or discontinuum models. Discrete fracture network models represent the fracture flow zones as permeable and treat the interfracture blocks as impermeable zones. This technique accurately represents some igneous rock aquifers; however, some fractured aquifers consisting of consolidated siliciclastic and carbonate rocks may contain significant secondary diagenetic porosity resulting in a permeable matrix. These aquifers can be more accurately simulated with hybrid models that attempt to represent flow through both fracture zones and the inter-fracture matrix.

An equivalent discontinuum model is a model that simulates flow in a fractured aquifer with a set of equivalent conductors to represent average fracture behavior, instead

of attempting to explicitly represent every fracture in the aquifer (National Research Council, 1996). For example, the major fracture zones could be assigned to model layers or, if inclined, the fracture zones could be simulated to cut across the model layers. This type of model is generally similar to the equivalent continuum model, except that there is a more deliberate intent to represent more of the fractures or fracture zones in the aquifer. The equivalent continuum model more of a generalization of the equivalent discontinuum model. The equivalent discontinuum is used to represent the discontinuous hydraulic behavior without modeling every fracture.

The discontinuum model used for this study simulates fractures and fracture zones that are apparent from geophysical and lithologic logs. Fracture resolution by these means is limited to the more obvious features; therefore, small scale features cannot be resolved. With this degree of resolution, it is likely that the inferred fracture zones are heterogeneous and average hydraulic properties are assigned to the fracture zones. Therefore, this 23-layer model consisting of 12 matrix and 11 fracture zone layers can be described as an equivalent discontinuum and hybrid model.

4.3.3 Stochastic Discontinuum Discrete Fracture Network Models

Stochastic models represent the heterogeneity of the fractured rock as a continuous or discontinuous random field. In cases where an equivalent continuum cannot be defined, a stochastic discrete network simulation may be a viable alternative. Discrete network models explicitly include large numbers of individual fractures that are implied to conduct fluid in the model structure. They reflect an attempt to represent heterogeneity on a scale smaller than normally considered in a continuum model. The stochastic approach is built on a geostatistical representation of the spatial variability in

the conductance properties of the rock mass. Stochastic theories provide equations for estimating larger-scale hydraulic and transport properties from the smaller-scale field measurements (Neuman and Depner, 1988). Discrete network models assume that fluid flow behavior can be predicted from knowledge of the fracture geometry and data on the transmissivity of individual fractures. The guiding principle is that one can measure spatial statistics associated with a fracture network, including fracture transmissivity, and use these statistics to generate a representation or realization of a fracture network with the same spatial properties. The fractures in these realizations become the conductive elements in a fracture network flow or transport model. Network geometry is characterized by statistical descriptions of fracture properties, e.g. fracture orientation, location, density, size, aperture width, areal extent, and transmissivity, for each of the fracture sets in the rock mass. From this statistical model it is possible to generate one or multiple realizations of a fracture network and to solve for fluid flow through each network.

Stochastic flow theory provides equations with which estimates of hydraulic conductivity can be used to estimate the effective conductivity ellipse for an anisotropic porous medium (e.g., Gelhar and Axness, 1983; Dagan, 1987). Stochastic equations permit estimates to be made of the magnitude of the uncertainties in flow and transport predictions. An alternative to estimating parameter values in the governing stochastic equations is to generate multiple realizations of the hydraulic properties of the rock mass in a Monte Carlo simulation to estimate probability distributions of output variables and improve model predictions. The number of realizations required for statistical evaluations of simulation results may range from one to four orders of magnitude.

The discrete network model approach appears most useful in problems of near-field simulation over length scales of 50 to 100 m. Simulations at larger scales require grouping fractures into single features or elimination of less transmissive fractures. Discrete network simulations are generally complex models because of the difficulty in obtaining the required statistical information, the intensive computational requirements for realistic fracture densities, and the lack of guarantee that a model reproducing the apparent geometric properties of a fracture network will capture its essential flow or transport features.

The stochastic discontinuum discrete fracture network models used in this study use the same 23-layer model consisting of 12 matrix and 11 fracture zone layers described for the previous equivalent discontinuum model in Section 4.3.2. However, in this case the hydraulic conductivity distribution assigned to each fracture zone layer is determined as a fracture network with FracMan. The stochastically generated fracture network for each layer is up-scaled to represent the distribution of hydraulic conductivity and storage parameters in the finite difference grid cells. Two PHT3D models were run with the FracMan results including a model with stochastically generated hydraulic conductivities values and average storage parameters, and a model incorporating stochastically generated hydraulic conductivities and storage parameters. As a result of the volume averaging performed by FracMan, the resulting model takes on characteristics of the equivalent discontinuum model. Comparison of these simulations should identify the effects and importance of variable storage parameters on transport properties within fracture networks.

4.3.4 Assumptions and Limitations

Based on previous studies of the UFA, fractures, conduits, and other hydraulic features of preferential high flow dominate the flow system in both the horizontal and vertical dimensions. Assuming the occurrence of these underlying complex characteristics of the aquifer, it should be stressed that accurate identification of these features and quantification of their hydraulic properties require inordinate expense and effort. In this study, the identification of fracture zones, which are characterized as high flow zones, is indirectly accomplished by the analysis of various borehole geophysical logs. Although these features are likely large-scale openings, compared to the average pore diameter, and represent high flow zones of varying permeabilities, the sources of these features are subject to interpretation of the lithology and geologic history of the site. The transmissivity of the Suwannee Limestone Formation of the UFA is assumed to be reasonably high determined from the results of aquifer performance tests conducted at the site.

The baseline positions of the various logs used are assumed to represent the matrix lithology of the aquifer that has undergone less alteration from its depositional state and, therefore, its permeability is inferred to be significantly less than those parts of the aquifer characterized by large-scale openings. Because of the difficulty in measuring the permeabilities of these low-flow zones, this study has assumed an average value based on extensive historical studies of the permeabilities of the Suwannee Limestone Formation of the UFA.

The aquifer is therefore assumed to be composed of horizontal intervals of low and high flow zones. Although the additional occurrence of vertical high flow zones are

inferred from the geophysical logs, their precise locations, orientations, sizes, permeabilities, etc. are unknown. Their approximate locations and orientations are estimated from previous studies. The remaining parameters are based on reasonable estimates that generate feasible results. Because of the uncertainty associated with these features, their simulated positions and values were determined using stochastic methods and model calibrations. This study assumes that the lognormal distribution of hydraulic parameters is an accurate representation for these parameters.

Additionally, it is assumed that the thermodynamic PHREEQC-2 database that PHT3D utilizes accurately represents the geochemical rock, mineral, and water reactions simulated by the designed models.

The most fundamental limitation of the discontinuum models used in this study is the inability to characterize many of the physical properties of the fractures and fracture networks that occur in the Suwannee Limestone Formation. However, it should be noted that the occurrence of fractures were observed in various samples that agree with the caliper, flow, and lithologic logs, which implies the potential occurrence of other fractures where these geophysical features are identified. This fundamental limitation is a result of the excessive cost required to adequately characterize fractures in the subsurface.

This study makes reference to flow within fracture zones and high flow zones, which is estimated with the equivalent continuum and discontinuum models. The use of these models to simulate fracture flow is a well-known approach to estimate this flow process and relies on the fact that volume averaging of fractures is synonymous with equivalent porous medium models; therefore, models based on Darcy's Law have and can

be used to estimate fracture flow. This study presents the results of both equivalent continuum and discontinuum models, which implicitly represent fracture and high flow zones. The model that incorporates stochastically-generated hydraulic conductivity distributions is just a variant of the equivalent discontinuum model. Regardless of the accuracy of these models, it can't be refuted that there are potentially more accurate modeling approaches that treat fracture flow explicitly.

The models used in this study have inherent predictive limitations because of the various and numerous assumptions associated with their design of the flow and transport systems. The apparent limitation that is generally present with most models is the non-uniqueness of simulated solutions, i.e., more than one solution of variables exists that can create the observed flow and geochemical conditions. This limitation may be more applicable in the case of models that simulate fracture flow and, reaction and mass transport in comparison to simple porous medium models.

An additional limitation of this study is due to the low number of monitor wells in close proximity to the ASR wells. A network of monitor wells closer to the ASR wells would provide confirmation of the dimensions, distribution, and reaction kinetics of the arsenic plume in the area where the concentrations are highest. In addition, the lack of monitor wells screened at various intervals through out the vertical extent of the storage zone would also provide increase details of the arsenic plume and the potential effects of heterogeneities.

In undertaking this modeling effort, it should be emphasized that there are many inherent difficulties because the ASR operation was not designed with this study in mind. Some of the difficulties include the simulation of a well field consisting of 12 ASR wells

and interference effects from two well fields, constraining model dimensions in order to achieve reasonable simulation run times, and a partially-penetrating monitor well network and a network of fully penetrating ASR wells.

5.0 MODEL DESIGN AND CONSTRUCTION

5.1 MODFLOW Groundwater Flow Models

Equivalent continuum and discontinuum groundwater flow models are constructed with different grid designs to represent the conceptual model. Two designs of equivalent continuum models were constructed for this study. The models include a preliminary one layer, isotropic, and homogeneous model (510 x 250 x 10 m) used to determine an adequate domain for large-scale models and to test various geochemical factors that control the solubility and distribution of arsenic. The three-dimensional, equivalent continuum (**Figure 21**) site model has dimensions of 2,000 by 1,000 m with a constant grid cell dimension of 10 m by 10 m (200 columns and 100 rows) and is also one layer, isotropic, and homogeneous.

Discontinuum models (2000 x 1000 x 100 m) representative of the entire aquifer are also constructed with an expanding grid (**Figure 22**) to reduce run times and memory requirements, while preserving the increased accuracy of closely spaced rows and columns in the vicinity of the ASR wells. The cells in the vicinity of the ASR wells have dimensions of 10 x 10 m to improve simulated hydraulic heads and gradients in the vicinity of the ASR wells. Beyond these cells, the dimensions increase to 130 meters in the x and y directions. Although the flow models run times are reasonable, regardless of the model used, the reaction and transport parts of the models require a maximum of approximately one week of computer time to run the 2,520-day simulation.

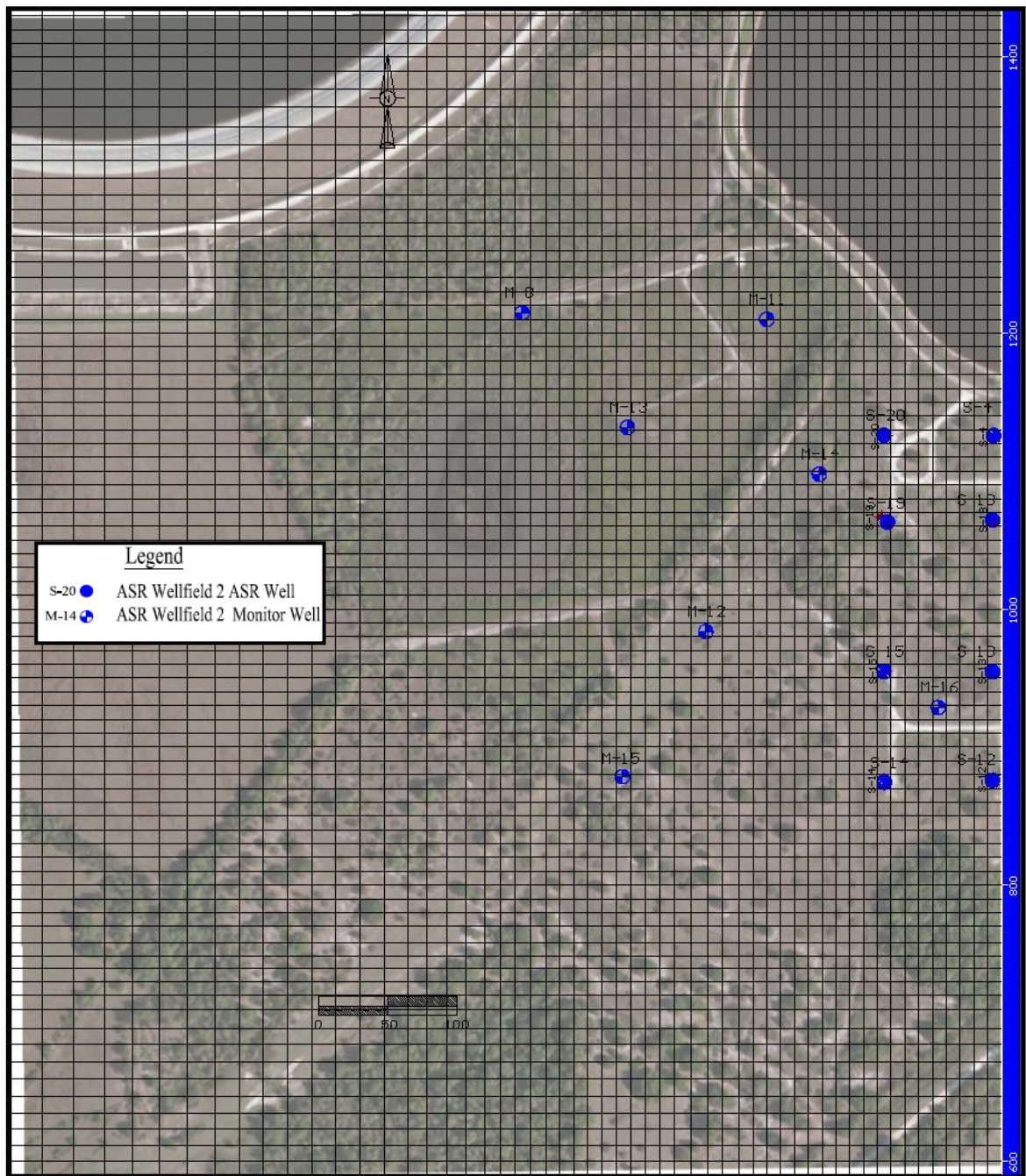


Figure 21. Constant model grid for equivalent continuum models.

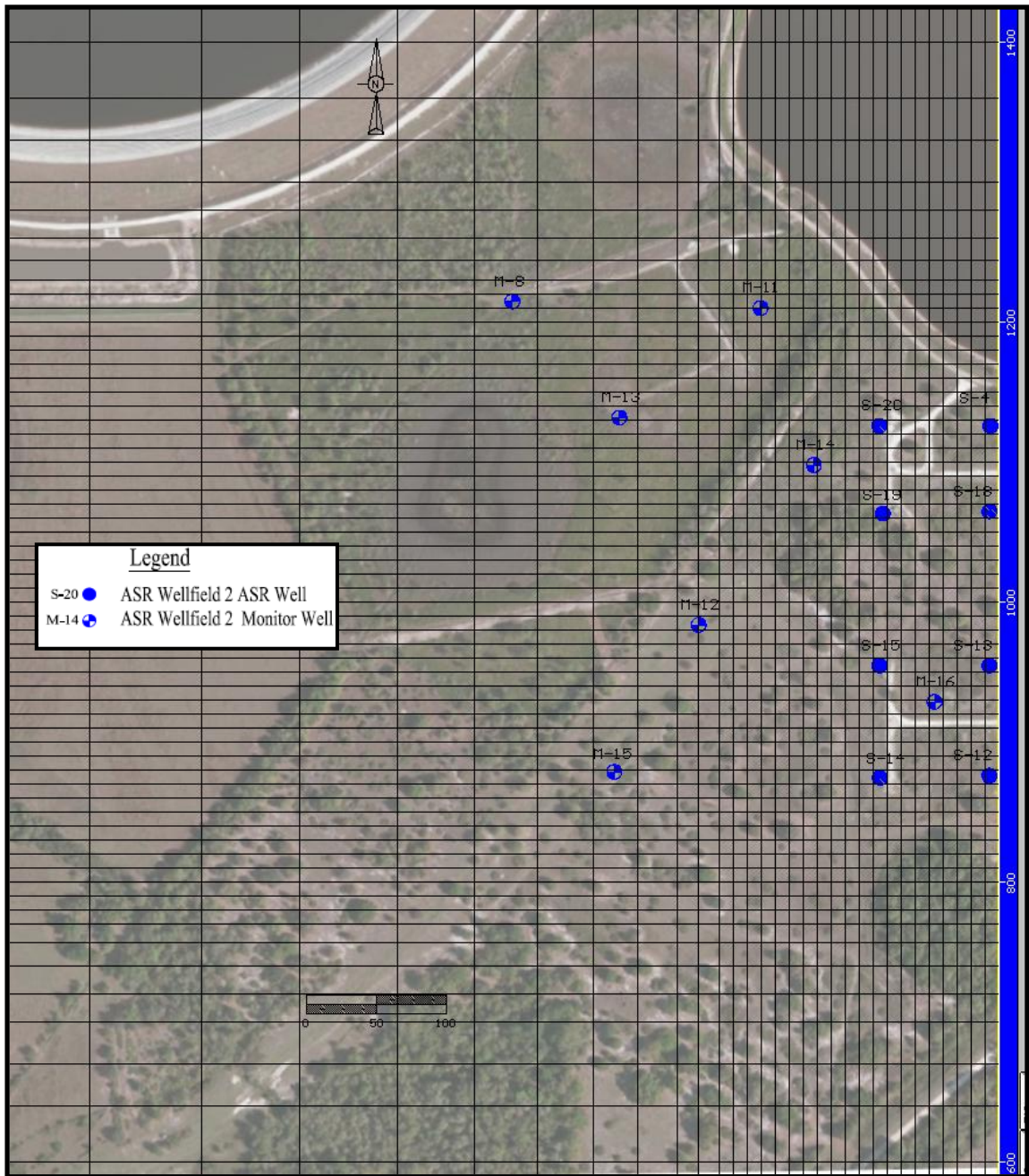


Figure 22. Expanding model grid for discontinuum and DFN models.

An additional three-layer preliminary model with an expanding grid was designed for the FracMan output that has dimensions of 1020 x 510 x 100 m. Layers one and three represent the matrix of a hypothetical aquifer and layer two represents a 10-meter thick fracture zone. The cells in the vicinity of the single ASR well used for this model have dimensions of 5 x 5 m and are expanded to a maximum of 10 x 10 m. These models consist of 133 columns and 69 rows. The reduced size of the model cells is to adequately represent the parameter heterogeneity generated by the stochastic simulations with FracMan. The preliminary MODFLOW grids were imported into FracMan in order to evaluate the effects on solute distributions of varying fracture intensity, aperture size, fracture transmissivity, and secondary vertical fracture sets. The simulations were run for 360 days represented by 270-day injection rates of 100 cubic meters per day followed by 90 days of recovery at 10 cubic meters per day.

Run times for the reaction and transport part of the models require a minimum of less than one day for the continuum models to approximately one week for the discontinuum models. All of the models were constructed to represent half of the horizontal flow system in order to reduce simulation times and modeling requirements. The ASR facility's Well Field 2 consists of 12 ASR wells; however, these models were set up with either one or eight ASR wells. In the case of single wells simulated along the model boundary, the injection and recovery rates were reduced to half rates because the wells were set up on the edge of the model in order to simulate half of the flow system. This design was successfully used by the author of PHT3D and other researchers, and is a theoretically accurate and representative manner in which to simulate the flow system near an ASR well. This design reduces run times and computer storage space. The axis

of symmetry trends north-south through ASR wells S-4, S-18, S-13, and S-12. The additional ASR wells included in the models are located west of the axis of symmetry and include from north to south ASR wells S-20, S-19, S-15, and S-14. The site continuum and discontinuum models include eight wells with the wells situated along the eastern model boundary assigned half rates and the wells west of these wells assigned full injection and extraction rates.

As the models are intended to simulate a confined aquifer, the top and bottom of the models are assigned “no flow” boundaries. The models are bound by general head boundaries on three sides. The general head boundaries are used to allow the boundaries to adjust to the model stresses and constrain the dimensions of the models, without significantly affecting the accuracy of the flow system. The actual flow system at the site has a very small horizontal hydraulic gradient. The external heads at the general-head boundaries have similar elevations to reflect the very small gradient. The continuum models have uniform 10 x 10 m cell sizes to reduce numerical dispersion associated with the dynamic flow field.

An average horizontal hydraulic conductivity of 27 m/day, determined from the results of previous on-site aquifer performance tests, is assigned to the single layer continuum model. The discontinuum or heterogeneous models are divided into 23 layers (**Figure 23, Figure 24, and Figure 25**) with the vertical boundaries of the layers determined from geophysical logs.

The flow data used for the models are obtained from reports prepared by Water Resources Solutions, Inc. and CH2MHill on behalf of the Manasota Regional Water Supply Authority, and submitted to the Southwest Florida Water Management District

(SWFWMD) and the Florida Department of Environmental Protection (FDEP, Southwest District). According to the available flow data associated with Well Field 2, between June 2, 2002 and May 9, 2009 (84 months) the ASR wells injected a combined total of 4,844.117 million gallons (MG) and recovered 5,539.799 MG, resulting in a net storage volume of -1066.851 MG. These monthly data are used to calculate the recharge, storage, and recovery cycles and are set up in the flow model as monthly stress periods. Recharge and recovery periods or cycles generally dominate the flow record for the well field and the recharge and recovery cycles are generally consistent in their temporal distribution among the ASR wells. The recharge and recovery volumes; however, are not consistent among the ASR wells. The recharge volumes for the ASR wells during this period range from 359.003 MG (S-12) to 499.658 MG (S-19). Using ASR well S-12 and a record of 47 months of recharge, the average monthly recharge amounts to 6.527 MG. Based on 51 months of recharge, the average monthly recharge for S-19 amounts to 9.797 MG.

Using the record for S-12, during the period from 2002 to 2009, storage cycles are represented by February 2004, February and March 2006, August 2007 to March 2008, and May 2009 for a total of 12 months or approximately 14% of the period.

The record for S-19 during the above period exhibits storage during February 2004, February and March 2006, May and July 2007, January to March and June 2008, and January, February, April, and May 2009 for a total of 13 months or approximately 15% of the period.

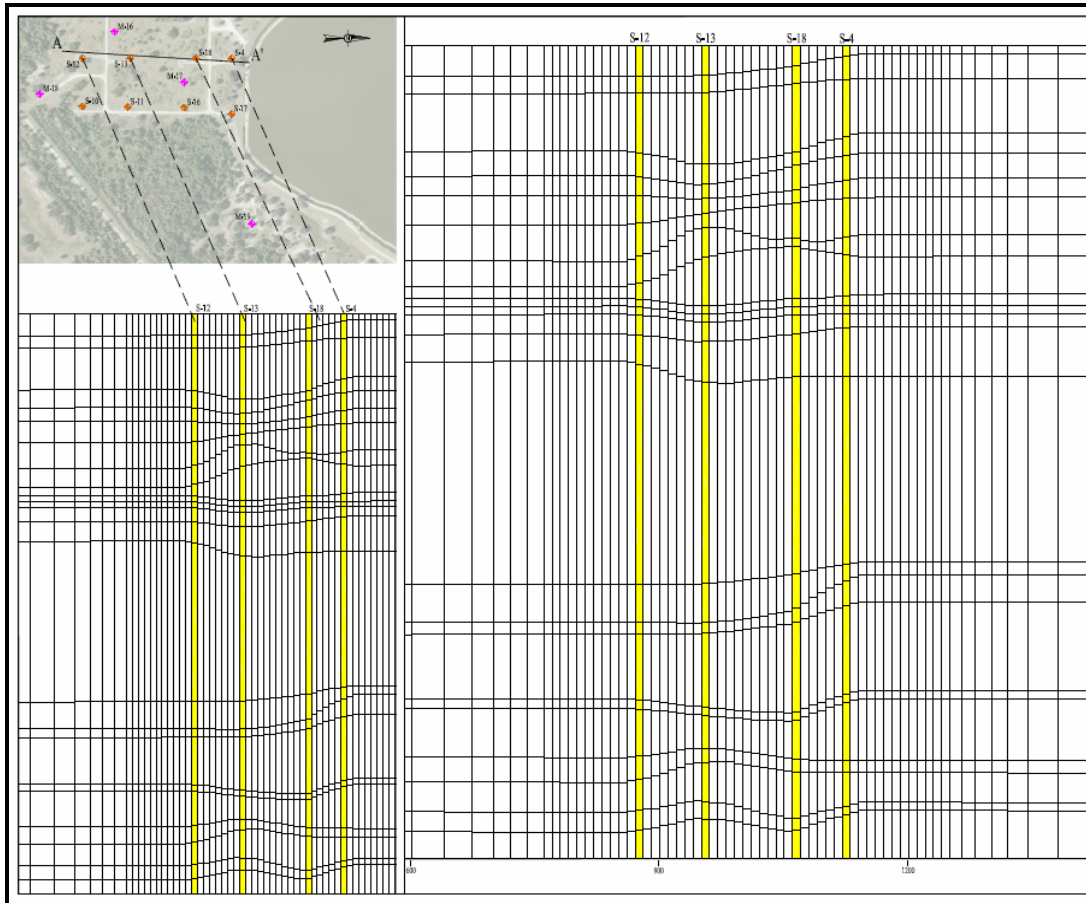


Figure 23. Cross-section through discontinuum model.

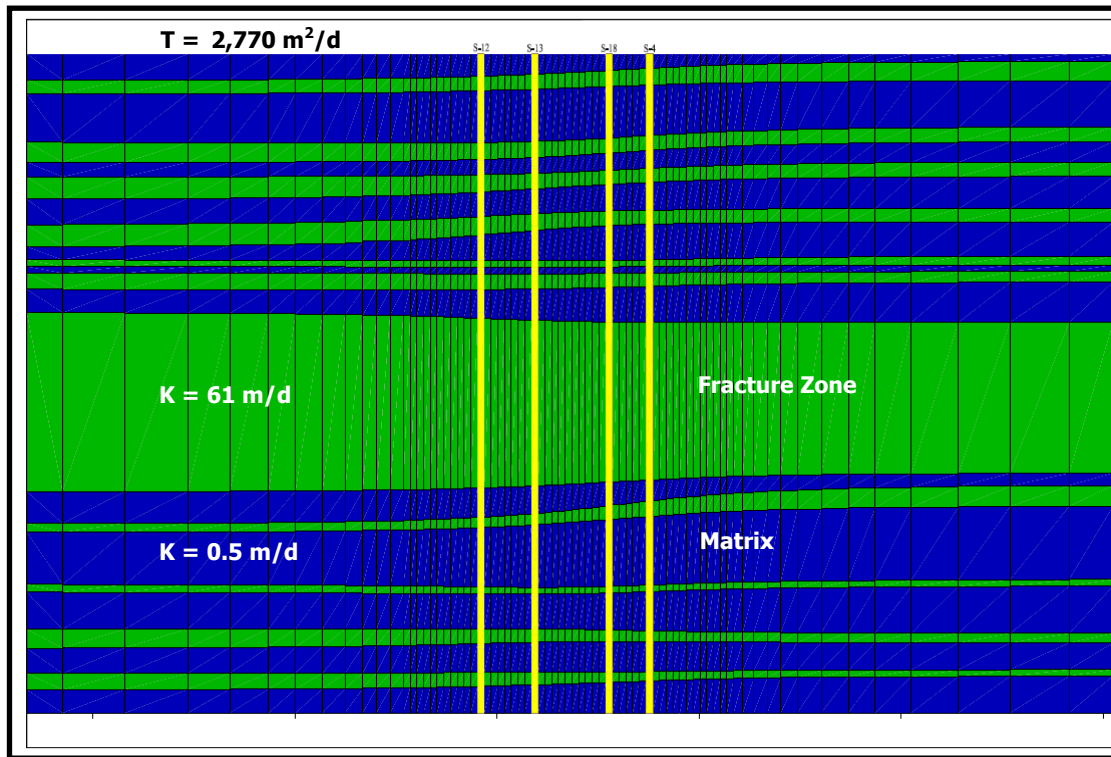


Figure 24. Identification of fracture zones on cross-section through discontinuum model.

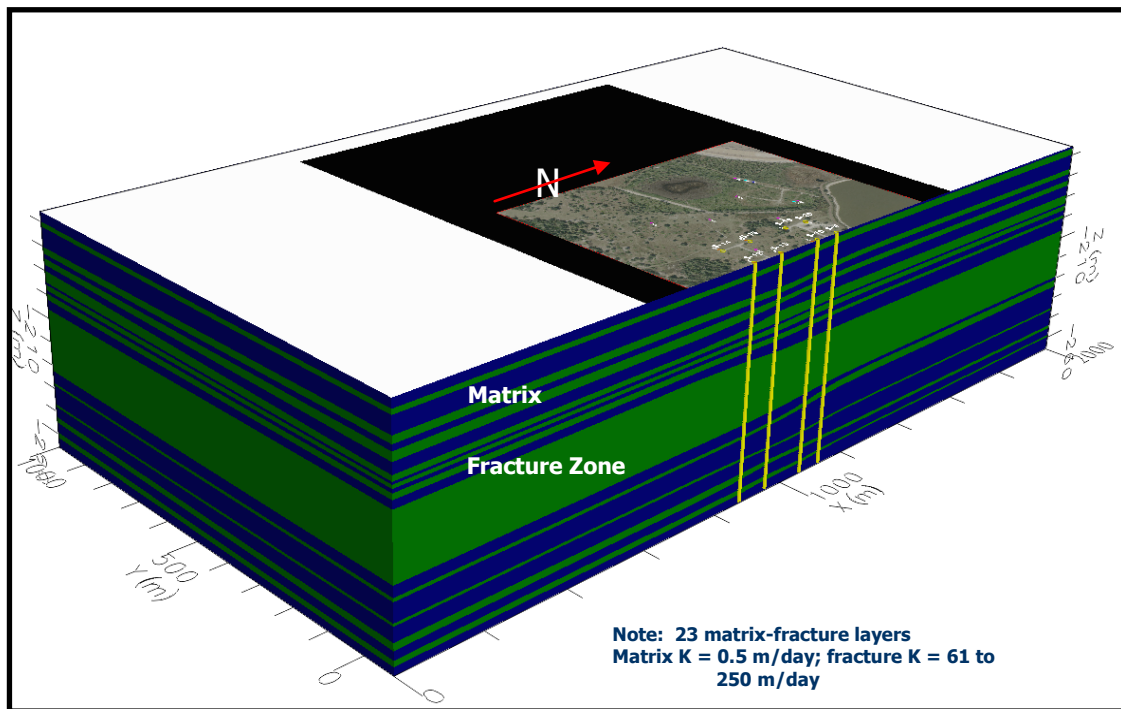


Figure 25. Depiction of fracture zones on three-dimensional discontinuum model.

The presence and continuity of the fractures and fracture zones among the boreholes were most evident from the caliper, sonic porosity, and flow logs. The fractures are assumed to exist throughout the model domain and their distributions throughout the model were determined by kriging with the contouring program Surfer (Golden Software, 2010). The contacts between the matrix and fractures were determined by inspection of the borehole logs and the elevation contacts and their coordinates were imported into Surfer. The data were kriged and imported into MODFLOW as grid files.

Four ASR wells, S-14, S-15, S-19, and S-20, were used to create the model layer top and bottom grid files. These wells provide the best representation and continuity of the hydrogeologic contacts inferred from the well logs. Due to the proximity and continuity of the relatively horizontal features and the significant extent of the model domain beyond the ASR wells, using all of the ASR wells would not be expected to improve the kriging analysis. Since only four ASR wells were used over the large grid geometry ($x = 2,000$ m and $y = 1,000$ m) and the features were assumed to be continuous and horizontal, four virtual control points were projected and located along the four sides of the grid, i.e. duplicate M-14 was located to a point south of actual M-14, duplicate M-15 to the west, duplicate M-19 to the west, and duplicate M-20 to the north. The point method of Kriging using the standard semi-variogram model was used to create the grid files for each of the 23 model layers.

The hydraulic conductivity distribution used for the discontinuum model was determined by assigning an average hydraulic conductivity to the matrix of the UFA, determined from a detailed study conducted from several continuous cores obtained from

Regional Observation Monitoring Program (ROMP) wells in the general vicinity of the site and others in various locations throughout Florida (Vacher and Budd, 2002). The average hydraulic conductivity of the matrix determined from this study is approximately 0.5 m/day (**Table 2**). With this value, the thickness of the aquifer not occupied by fractures, and the measured total aquifer transmissivity, the hydraulic conductivity of the fractures and fracture zones was estimated to be approximately 61 m/day. The calculated specific storage was determined to be 2.12×10^{-7} ; however, due to the excessive mounding that resulted using this value, the specific storage was increased to 0.001 m^{-1} . It should be clarified that 0.001 m^{-1} is only a preliminary estimate and that the calibrated values used in the models range from 5.0×10^{-4} for fracture zones $6.49175 \times 10^{-5} \text{ m}^{-1}$ for matrix layers, with an average of approximately 2.89312×10^{-4} . Adjustments to hydraulic conductivity to reduce the mounding required values inconsistent with aquifer performance tests. These rather high values are indicated in the case of a leaky aquifer with inflow from above or below the aquifer or when the aquifer is in connection with a source of water, e.g. surface water. The vertical hydraulic conductivity for the heterogeneous model is calculated as the weighted harmonic mean of the horizontal hydraulic conductivities to be approximately 1.0 m/day. This value is also initially used for the continuum model.

Previous studies conducted at the site have documented the existence of fractures (fracture zone) in the lower part of the injection interval that is believed to account for 60% to 80% of the flow from aquifer. Water Resources Solutions Inc. (2000) reports flows exceeding 600 gpm from the lower section of most of the ASR wells during testing immediately after installation. This scenario was evaluated by calculating the

distribution of hydraulic conductivities, assuming that 70% and 80% of the flow was from this lower interval and assigning the values to the heterogeneous models. The hydraulic conductivity of the matrix was held at 0.5 m/day and the remaining permeable zones were assigned the hydraulic conductivity that resulted in the aquifer transmissivity of 2770 m²/day. This approach resulted in hydraulic conductivities of approximately 388 and 20 m/day, with the higher value assigned to the fractures in the lower part of the model (layers 20 and 22) and the lower value to the remaining high flow zones of the model with 70% flow designated from the lower fracture zone. For the model set up with 80% of the flow from the lower fracture zone, the assignment of hydraulic conductivities was 443 m/day to lower fracture zone layers and 13 m/day to the remaining high flow zones. In both cases the matrix layers are assigned a hydraulic conductivity of 0.5 m/day.

In addition, the observed DO concentrations in the closest monitor well M-14 during recharge range between approximately 1.5 and 4.5 mg/L suggesting that a zone of very high hydraulic exists within the open interval of the well. This scenario was also simulated by assigning a hydraulic conductivity of 61 m/day to layers 2 and 4 in the above model that includes a high flow zone in the lower part of the injection interval. Another model included upper and lower major fracture zones with an average hydraulic conductivity of 256 m/day and intermediate flow zones set to 15 m/day. The hydraulic conductivity of the remaining fractures was determined by calculating the weighted percentage of the transmissivities of the model layers to the total transmissivity. The matrix hydraulic conductivity was constant at 0.5 m/day.

Table 2. Hydraulic Parameters Used in PHT3D Reaction-Transport Models

Peace River ASR Facility, Desoto County, Florida				
Parameter	Continuum model	Discontinuum model	FracMan DFN model	
			Horizontal fracture sets	Horiz & vert fracture sets
				0.001 - 10343 (133)
Kx (m/day)	27.7	0.5 - 443	0.001 - 857 (92)	0.001 - 10343 (133)
Ky (m/day)	27.7	0.5 - 443	0.001 - 857 (92)	0.001 - 10343 (133)
Kz (m/day)	2.77	0.5 - 443	0.001 - 857 (92)	0.001 - 10343 (133)
Ss (m ⁻¹)	2.12E-7 - 0.001	0.0005/variable	0.0005	6.49E-5 - 0.00055
nT	0.35	0.2 - 0.35	0.2 - 0.35	0.35
ne	0.25	0.15 - 0.25	0.15 - 0.25	0.25
Calibrated solutions				
Kx (m/day)	13	0.88 - 27	9.5 - 38	NA
Ky (m/day)	27.7	0.5 - 27	22 - 205	NA
Kz (m/day)	500	0.5 - 75	103 - 1514	NA
Ss (m ⁻¹)	0.0009	0.0005	6.86E-5 - 0.0005	NA
nT	0.35	0.2 - 0.35	0.35	NA
ne	0.25	0.15 - 0.25	0.25	NA
Kx - horizontal hydraulic conductivity, x direction Ky - horizontal hydraulic conductivity, y direction Kz - horizontal hydraulic conductivity, z direction NA - Not analyzed Ss - specific storage nT - total porosity ne - effective porosity () - Average value m/day - meters per day Calibrations performed with PEST				

5.2 PHT3D Reaction Transport Model

The dissolved or mobile geochemical parameters used in the models (**Table 3**) include carbon, calcium, chloride, ferrous and ferric iron, magnesium, sodium, sulfate, arsenite, arsenate, ammonia, and oxygen. Immobile phases included calcite, dolomite, gypsum, pyrite, arsenopyrite, iron hydroxide, and immobile parameters included pH, pe, and temperature. Ion exchange surface reactions have also been included in the models to represent reactions associated with sodium, calcium, and magnesium. A recent study of the ASR system in operation in Bradenton, Florida (Wallis et al., 2011) that included flow and transport modeling with PHT3D indicates that the trace mineral siderite (FeCO_3) potentially removes significant ferrous iron during recovery cycles. Although this mineral could potentially precipitate under these conditions, the occurrence of this mineral as a trace constituent in the UFA has not generally been reported (**see Geology and Hydrogeology**). A detailed mineralogical and geochemical study of three ASR sites in the UFA (Fischler and Arthur, 2008) did not identify the occurrence of siderite. However, trace amounts of strontium, sodium, iron, and manganese have been found in calcite and dolomite (Sprinkle, 1989). It is reported that sulfate is generally reduced in the UFA by bacterially mediated reduction resulting in the formation of pyrite and marcasite (Sprinkle, 1989) by sequestration of iron. Another trace mineral, gypsum, contains trace (usually less than 500 parts per million) amounts of strontium, magnesium, sodium, barium, aluminum, lithium, and iron.

Dissolved iron in groundwater of the UFA occurs in widely varying concentrations ranging from 0.000 to 46 mg/L (503 samples) with a median concentration of 0.030 mg/L (Sprinkle, 1989). This distribution can have a significant

effect on ASR site studies because the amount of iron typically generated from the dissolution of pyrite during ASR recharge cycles is minor and a high background concentration will significantly increase the HFO concentration and arsenic retardation.

The constant concentration boundaries include all geochemical parameters that are activated for the models, with the exception of pyrite and arsenopyrite. The background, initial, and injectate parameter concentrations used in the model are monthly data averaged over a multi-year period. Monthly temperature variations of the injected water are included in the models, as temperature has been shown to affect the solubility of pyrite (Prommer and Stuyfzand, 2005). The initial concentrations for the mobile species, in units of milligrams or micrograms per liter, were converted to the required model concentrations of moles per liter. The dissolved species and average concentrations that represent the background and initial concentration data (**Table 2**) were collected on June 4 and July 2, 2002 at background monitoring well M-6 located approximately 7,000 ft south of Well Field 2. The initial aqueous concentrations used in the model are charge charge-balanced with the geochemical analytical software AquaChem (Schlumberger Water Services, 2010). The data are charge-balanced with respect to sodium because it is a relatively conservative ion whose concentration does not significantly affect the majority of chemical reactions.

Pyrite and arsenopyrite concentrations are included as initial immobile phase constituents at concentrations ranging from of 0.0075 to 0.2 moles per liter (bulk concentration) to evaluate the required concentration to generate representative arsenic concentrations. The dissolution of arsenopyrite is linked to pyrite dissolution by setting

Table 3. Initial Parameter Concentrations Used in PHT3D Reaction-Transport Models

Peace River ASR Facility, Desoto County, Florida				
Aqueous parameters				
	Formation groundwater		Recharge water	
	Measured (mg/L)	Simulated (moles/L)	Measured (mg/L)	Simulated (moles/L)
pH	7.4	7.4	7.7 - 8.8 (8.1)	8.1
pe	NM	-3.36		5.82
C(4)	132	0.0022777	26 - 212 (46.6)	0.000934
C(-4)	NM	-		0
Ca	69	0.0017231	18.3 - 91.4 (50.8)	0.001268
Na	116	0.005052		0.001306
Cl	261	0.0050772	17 - 220 (78.3)	0.000949
Fe(2)	NM	3.17E-06		0
Fe(3)	NM	3.58E-14	<0.029 - 0.14	5.79E-07
Mg	NM	0.0020996		0.000988
O(0)	0.82	0	2.7 - 8.1 (5.7)	0.00036
S(6)	262	0.002729	64 - 301 (193.3)	0.00213
S(-2)	NM	-		-
As	<1.3	0	<1.3 - 6 (<1.3)	0
ORP	-201	-	-289 - 595 (345)	-
Temp	28	28	17 - 32 (25.6)	17 - 32
TDS	850	NA	200 - 860 (502)	-
Initial minerals				
Pyrite		0.0025 - 0.01 (0.01)		
Arsenopyrite		1e-6 - 0.1		
Calcite		16		
Dolomite		2		
Gypsum		0.2		
Ferrihydrite		0		
Initial exchanger compositions				
CaX2		0.0235		
MgX2		0.0164		
NaX		0.009		
mg/L - milligrams per liter				
moles/L - moles per liter				
Temp - temperature in degrees centigrade				
ORP - oxidation-reduction potential				
TDS - total dissolved solids				
() - average value				
pH - in standard units				

the dissolution parameter $P_{\text{arm}}(1)$ to 0.001 and 0.01, which results in the dissolution of 1 and 10 micromoles of arsenopyrite per each millimole of pyrite, respectively. The $P_{\text{arm}}(1)$ value used in the study of the Bradenton ASR site falls within this range (Wallis et al., 2011). The concentrations of pyrite and arsenopyrite estimated to occur in the aquifer were partly determined by using these minerals as calibration parameters. The distributions of pyrite and arsenopyrite minerals have been determined to be heterogeneously distributed in the UFA (Price and Pichler, 2005) and the distributions of dissolved metals in a large variety of aquifers, including arsenic, are lognormal (Amini et al., 2008; Newcomb and Rimstidt, 2001); therefore, it is concluded that the distribution of pyrite and arsenopyrite could potentially exhibit lognormal distributions. The potential effect of a lognormal distribution of the pyrite and arsenopyrite minerals on the distribution of the ASR plume is evaluated by assigning initial mineral concentrations with a lognormal distribution to the continuum model. The lognormal distributions are calculated using the FracMan porosity distributions scaled with respect to the average mineral concentrations. The stochastic porosity distribution calculated by FracMan was used to determine the mineral concentrations by assuming that the highest concentrations were associated with cells with the highest porosities. The ratio of the cell porosity to the maximum porosity was multiplied by the mineral concentration that results in the average concentration used in the model with a constant concentration. After rescaling, the average concentration is equal to the uniform values used in the models. This method assigns concentrations proportional to the cell porosities, which is consistent with observations that pyrite and arsenopyrite occur in parts of the aquifer with relatively high permeability (Price and Pichler, 2005).

Both average and lognormal mineral concentrations are assigned to the continuum and discontinuum models to evaluate these effects.

In addition, because the recovered arsenic concentrations in ASR wells S-19 and S-20 are approximately two to three times less than those from S-14 and S-15, the initial concentrations of initial arsenopyrite in the vicinity of S-19 and S-20 are reduced to $5\text{E-}6$ moles per liter (bulk), which is a significantly lower concentration than the value used in the vicinity of S-19 and S-20. This distribution of arsenopyrite was used in the continuum and discontinuum models to evaluate the effects on the dissolved arsenic distribution.

The geochemistry of the finished or recharge water is summarized in **Table 2**. These injectate or point source concentrations used in the model are also charge charge-balanced, similar to the initial concentrations. The major minerals and their bulk concentrations in the UFA that are simulated in the model are based on mineral descriptions included in the well logs constructed during the monitor well and ASR installations. Limestone is the predominant mineral in the aquifer occurring at a concentration of 16.6 moles/liter (bulk) followed by dolomite at 2.2 moles/liter, and gypsum at a trace concentration of 0.02 moles/liter.

The surface reactions involving clays and sodium, calcium, and magnesium are simulated in PHT3D by providing initial ion exchange concentrations that are determined from the cation exchange capacity of the aquifer. The CEC of the aquifer used in the study by Valocchi et al., 1981 of 10 millequivalents/100 grams (meq/100g) is assumed similar to the CEC of the UFA, based on the clay content. The CEC for the

injection interval was estimated using the empirical formula: $CEC \text{ (meq/100 g)} = 0.7 (\% \text{ clay}) + 3.5 (\% \text{ C})$. Lithologic logs for the Suwannee Limestone on-site indicate a clay content of approximately 10%, yielding a CEC of 7 meq/100g. The initial exchange concentrations used in the UFA model are significantly lower than those used in the Valocchi et al, 1981 study, based on the difference in TDS between the aquifers, and were also determined by model calibration. The initial exchange concentrations used in this model include 0.009 mole/liter for NaX, 0.0164 mole/liter for MgX₂, and 0.0235 mole/liter for CaX₂.

Sorption of arsenic to ferric hydroxide (Fe(OH)_{3(a)}) was simulated in the model as weak and strong sites, according to a PHREEQC-2 surface complexation model (Dzombak and Morel, 1990). The surface species is designated as an equilibrium phase with a density of 0.05 weak sites per mole and a specific area per mole of 5.34e-04. The kinetic forms of the surface species include weak sites with 0.06 and 0.2 sites in moles per mole (mol/mol) of ferrihydrite iron and a specific area per mole of 5.34e-04. The strong kinetic sites have densities of 0.0015 and 0.005 mol/mol. Due to the significant majority of weak sites compared to strong sites, the weak sites tend to exhibit more control over the sorption characteristics of the surface species.

Equilibrium sorption of arsenate and arsenite was simulated to compare the degree of retardation with the above kinetic form. Equilibrium sorption is represented in many transport analyses and models because it is represented with a proportionality constant or ratio describing the amount of arsenic partitioned onto the surface of the aquifer matrix to the amount in groundwater. Linear sorption is described by the equation: $K_d = C_s / C_w$, where C_s is concentration on solids in mass per mass (g/Kg)

and C_w (g/L) is concentration in groundwater in mass per volume or L/Kg. Kinetic sorption can be modeled using a K_d in the rate equation (Tebes-Steven and Valocchi, 1997): $R = -k_m (C_i - S_i / K_d)$ where k_m is the mass transfer coefficient (hr^{-1}); C_i is the aqueous concentration (moles/L); and S_i is the sorbed concentration (mol/g sediment), and K_d is the distribution coefficient (L/g). The mass transfer coefficients of arsenic onto HFO surfaces are relatively short (90% within 2 hours) compared to the model transport steps of one day and monthly recharge periods, therefore, a K_d value may be used to estimate the effects of linear equilibrium sorption. In addition, the oxidation of the sorbent HFO, which is the rate limiting reaction, occurs within approximately four minutes (Hussam et al., 2003).

If arsenic sorption is almost instantaneous, then the system should reach equilibrium within the time frame of each transport step. It should be noted; however, that K_d is a cumulative term that includes the effects of surface complexation, ion-exchange, and chemical precipitation and dissolution. All these processes are functions of pH, redox potential (pE), concentrations of constituents, cation-exchange capacity of the soil (CEC), specific surface area of the adsorbent mineral, and relative abundance of one constituent over the other (Ghosh et al., 2003). Therefore, the extent of sorption is spatially and temporally controlled by site mineralogy and geochemistry during ASR cycles. Under these conditions, a single K_d value likely will not completely represent the variation in sorption that could potentially occur.

The K_d for arsenic is reported by the U.S. Environmental Protection Agency's Office of Solid Waste to range from 0.005 to 20,412 L/Kg with a mean of 2,364 L/Kg and a median of 225 L/Kg ; however, when combined with additional literature results

the mean is reduced to 2,023 L/Kg and median to 120 L/Kg (Ghosh et al., 2003). The K_d values used in the continuum models are $1\text{E-}6$ L/mg (1.0 L/Kg) for arsenate and $5\text{E-}7$ L/mg (0.5 L/Kg) for arsenite (by calibration) which reflect the typically lower sorption potential of the arsenite species (Ghosh et al., 2003). For the discontinuum models the K_d values are $1\text{E-}6$ and $2\text{E-}6$ L/mg for arsenate and $1\text{E-}7$ and $2\text{E-}7$ L/mg for arsenite. The use of an equilibrium K_d likely overestimates the potential effects of sorption because the models simulate kinetic reactions; nonetheless, it should provide a possible estimate of the longer term average effect of sorption on the magnitude and distribution of arsenic.

The longitudinal (α_L), transverse (α_T), and vertical (α_V) dispersivities used in the models are $\alpha_L = 1$ m, $\alpha_T = 0.1$ m, and $\alpha_V = 0.01$ m. The longitudinal dispersivity is at the lower end of representative field-scale values for limestone aquifers (Fetter, 1999). This value produces a Peclet number ($Pe = \Delta x / \alpha_L$) of 10 in the vicinity of the well. Ideally, the Peclet number should be less than 4 (Anderson and Woessner, 1991; Zheng and Bennett, 2002). A longitudinal dispersivity of $\alpha_L = 1.0$ m was used to improve the results of PHT3D (calibration parameter) and may be required in similar dynamic advection-dominated problems where rapidly changing concentrations are expected to occur in response to the continuously changing geochemical conditions and reactions. Diffusion was not simulated in these models because the flow system is advection-dominated and diffusion during the storage period is not expected to significantly affect the plume. The continuum models were initially assigned a specific storage of $2.12\text{e-}7$ m^{-1} (subsequently increased to 0.001), a specific yield of 0.20, an effective porosity of 0.25, and a total porosity of 0.35. The discontinuum models were also assigned similar

values; however, simulations also included specific yield of 0.10, an effective porosity of 0.15, and a total porosity of 0.2 for the matrix. After model calibration with the automated parameter solver PEST, for Parameter ESTimation (Doherty, 2003; 2005), model parameters were updated as described in the following section.

The Geometric Multi-Grid (GMG) solver was used to solve the flow equation and the Modified Method of Characteristics was used to solve the transport equation. An initial time step of one day with a multiplier of one and a maximum time step size of one was generally used for the simulations. The simulations consisted of a maximum of 84 stress periods, each of which consisted of 30 days. The transport simulations generally simulate 750 to 1,500 days, with a maximum of 2,520 days. The 2,520 day simulation was performed with the equivalent continuum model and used a 0.5-day transport step, due to the rapidly changing flow system and chemical environments. The shorter transport time steps appear to improve the simulated accuracy of the model in the vicinity of the ASR wells where there the hydraulic gradients are greatest.

5.3 FracMan Discrete Fracture Network Model

FracMan 7 (Golder Associates, Inc., 2010) is a finite element discrete fracture network (DFN) simulator that represents fractures as stochastic distributions of permeability and storage parameters to simulate flow and transport paths. FracMan allows for the representation of various physical fracture characteristics in models including orientation, aperture widths, fracture intensity, fracture distributions, among others; thereby accounting for aquifer characteristics that are not generally represented in most finite difference and finite element numerical flow models. These characteristics of

FracMan are incorporated into this MODFLOW-based model in an attempt to more accurately represent fracture flow and mass transport. The occurrence and distribution of fractures are often difficult to characterize in numerical flow models because stochastic methods are required to estimate fracture characteristics. Each fracture set generated with FracMan is unique because of the random number generator employed. The only manner in which FracMan will generate an identical distribution is if the "seed" used to create the random set is consistently used in the creation of fractures for a model.

Fracture intensity is specified as the amount of fractures in a rock mass and is represented in FracMan as P10 or lineal fracture intensity (number of fractures per unit length), P32 or volumetric fracture density (fracture surface area per unit volume, L^2/L^3), or P-33 or fracture porosity (L^3/L^3). Fractures are described in FracMan with respect to the orientation or the fracture pole trend and plunge, where the pole is perpendicular to the fracture surface. The fracture orientation is also described by a distribution, e.g., Fisher, logarithmic, etc. and dispersion. Fractures are described by size and shape as equilateral polygons in which the number of sides can be identified. Fracture sizes and distribution can be specified along with the mean and standard deviation of the distribution. Shape includes a description of elongation that specifies an aspect ratio and a direction in which the fractures are to be stretched. FracMan also allows for the identification of the percentage of fractures that are terminated against other fractures. Fracture properties include aperture, permeability, and compressibility characteristics. The apertures are characterized by their size, distributions, truncation, and whether they are correlated to permeability. Aperture (b) and transmissivity (T) are assumed to be related as $T \propto b^a$, and assuming a parallel plate model and the cubic law, $a = 3$, and when

representing field data the alternative is the quadratic law, $a = 2$, which may provide a better fit (Doe, 1993). The equation relating fracture (equivalent fracture radius) size to transmissivity in FracMan is $A + Bx^C + De^{(Ex)}$ where A, B, C, D, and E are correlation coefficients, and can be used to define the empirical quadratic law, $b = 0.25T^{1/2}$ (Doe, 1993; Dershowitz et al., 1999), where b = aperture (m) and T = transmissivity (m^2/s). Lognormal distributions of apertures and transmissivities were generally used in the models for this study which are widely used in studies of transport in fractured rock (Painter, 2006).

FracMan allows for the definition of multiple fracture sets for a model. Following fracture definition, the fracture sets are generated and, subsequently, the various fracture parameters are "upscaled," or converted to the common parameters and distributions used in geocellular or finite difference grid models such as MODFLOW. Upscaling of the fracture permeability to the equivalent grid cell permeability is accomplished in FracMan using Oda's Method (Oda, 1985). Advective flow in three dimensions is described by Darcy's Law, $\mathbf{q} = -\rho/\nu \, k \nabla \mathbf{P}(x, y, z)$, where ρ is density, ν is viscosity, k is the isotropic permeability of the medium, $\mathbf{P}$ is the pressure gradient at the point (x,y,z) , and $\mathbf{q}$ is the resultant flux vector (mass per unit time per unit area) at that point. In terms of hydraulic head the groundwater flow equation becomes: $\mathbf{q} = -\rho g/\nu \, k \nabla \mathbf{h}(x, y, z)$, where g is the gravitational constant and h is hydraulic head.

FracMan computes the 3 x 3 symmetric permeability tensor of a fracture by projecting its isotropic permeability, k , onto its plane (Oda's method), and then scaling it by the ratio between the volume of the fracture and the volume of the grid cell.

The projected area of a fracture in the cell onto a plane parallel to the flow direction is the cross-product of the fracture pole and the direction of flow multiplied by the total area of the fracture. The projected area for each fracture in the box is then multiplied by the transmissivity of the fracture in that direction. These results are then summed and divided by the height of the grid being analyzed, along the axis parallel to the direction of flow. The calculation is repeated for both the positive and the negative direction along each of the x-, y-, and z-axes.

If the flux through each fracture within the cell is assumed to be additive, then these matrices can be summed together for a net permeability tensor $\mathbf{K}_{net}$. The principal permeabilities and flow directions within this cell are given by the eigenvalues and eigenvectors of $\mathbf{K}_{net}$. The upscaled model output is in the form of a layer property file (LPF) MODFLOW file or as individual parameter text files of permeabilities (K_{xx} , K_{yy} , and K_{zz}) and storage parameters (specific storage, specific yield, effective porosity and total porosity). In generating the stochastic distribution of parameters, the parameter values for each cell differ.

The moderate transmissivity of the aquifer and the high distribution of fractures and flow zones inferred from the well logs do not suggest that the flow occurs through a fracture system composed of roughly continuous planar surfaces that is characterized by the cubic law. The flow is believed to occur within laterally extensive zones exhibiting variable continuity and hydraulic conductivity. This type of flow system would result in the occurrence of relatively consistent geophysical signatures across the well field that can be correlated. FracMan provides options to simulate fracture zones similar to the above as sets of fractures characterized by a variety of structural features. The discrete

fractures are simulated with FracMan as stochastically-generated horizontal (**Figure 26**) and vertical fractures (**Figure 27**) with varying physical attributes including orientation, aperture widths, fracture intensity, and fracture distributions, distributed within a lower conductivity matrix. Since FracMan is based on the concept of stochastic distributions, each fracture set exhibits a unique distribution of hydraulic conductivity and storage parameters consistent with the structural features.

For this research project it is assumed that none of the fracture zones are identical, although they may exhibit similarities; therefore, each fracture set generated is unique. This aspect of the simulator is the result of the use of the random number generator or seed that was enabled with FracMan when defining fracture sets. Vertical fracture sets are also simulated in combination with horizontal sets in order to evaluate the potential effects of vertical flow on mass transport (**Figure 27**). In this case, each horizontal set of fractures is created per grid layer in which they are designed to occur, followed by the northwest-southeast trending and northeast-southwest trending vertical sets of fractures.

As described previously, after the fractures are generated, the results are upscaled to grid cell parameter values in a LPF file or as text files. Because the FracMan DFN models will be used to create hybrid MODFLOW models, the text files of the flow and storage parameters are imported to the MODFLOW models, instead of the LPF file. During this process, the cells within the matrix layer that contain fracture information are populated with values generated by FracMan. In summary, the finite difference model layers contain the fracture permeability distributions simulated with FracMan and the matrix layers are assigned constant permeabilities, thereby creating hybrid models. If

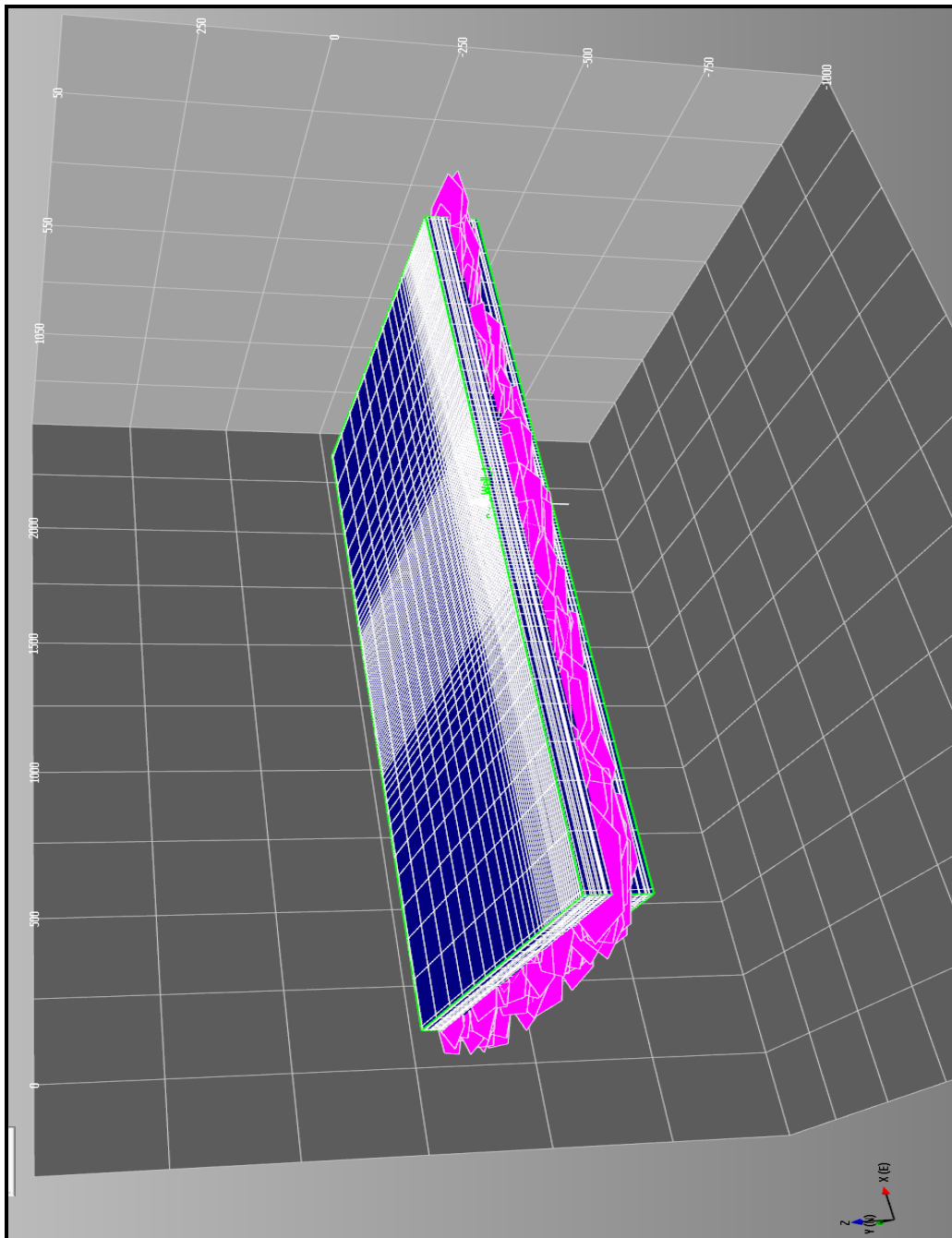


Figure 26. Simulation of typical horizontal set of fractures (represented by polygons) with FracMan.

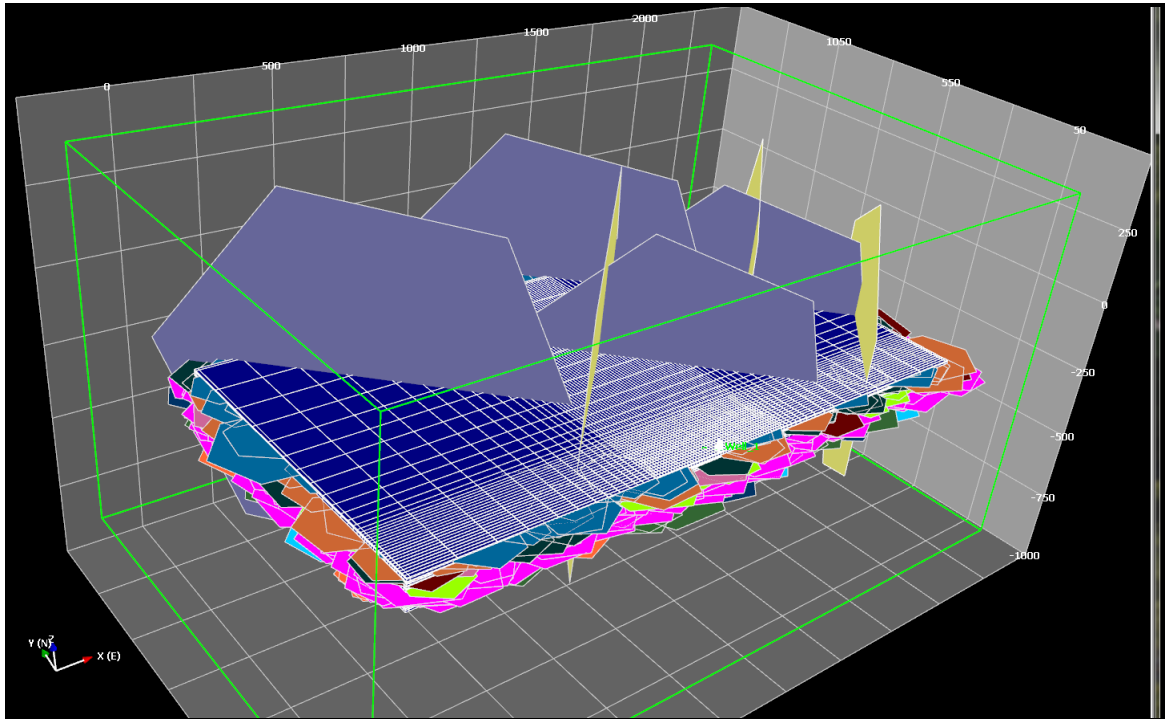


Figure 27. Simulation of all horizontal and vertical sets of fractures (represented by polygons) with FracMan.

vertical fractures are simulated, the FracMan permeabilities occupy only those cells that include the fractures. FracMan does not consider the matrix permeability (assumed impermeable) when calculating the model permeabilities. Prior to importing the results to the MODFLOW models, they were imported into an Excel file for review. The storage parameters that are created exhibit the same general distribution as the flow parameters exhibiting a wide range of values, resulting in significant increases to the computer run times. In order to reduce the run times, the average storage parameters were used in the models. By doing so, the run times were reduced to a maximum of one week compared to potential run times of weeks or more for the multilayer models. High speed computers with multiple processors and very large memory capacities are required to run the larger and more detailed models.

5.4 Summary of Flow Model Simulations and Parameters

Chemical reaction and mass transport model simulations were run with equivalent continuum, discontinuum discrete fracture network, and stochastic discrete fracture network flow models. These flow models were calibrated with PEST to improve the hydraulic parameter estimates using inverse modeling.

5.4.1 Equivalent Continuum Models

The model simulations for this study include a scaled-down preliminary equivalent continuum model (510 x 250 x 10 m) with a single ASR well to determine an appropriate grid size for larger domain models and to test the responses of several geochemical factors that control the solubility and distribution of arsenic. After the preliminary simulations were performed, equivalent continuum models with dimensions

of (1000 x 500 x 100 m) and (2000 m x 1000 m x 100 m) representative of the entire aquifer and a larger representative set of ASR wells were subsequently constructed to test the models' responses to the geochemical and aquifer characteristics used in the preliminary model. These single layer continuum models were assigned an average size of 10 x 10 m. An average horizontal hydraulic conductivity of 27.7 m/day, determined from the results of previous on-site aquifer performance tests, is assigned to the single layer continuum model resulting in a transmissivity of 2770 m²/day. The calculated specific storage was determined to be 2.12E-7 m; however, due to the excessive mounding that resulted using this value, the specific storage was increased to 0.001 m for some preliminary simulations. The model was assigned total and effective porosities of 0.35 and 0.25, respectively. The vertical hydraulic conductivity for the equivalent continuum model is calculated as the weighted harmonic mean of the horizontal hydraulic conductivities of the discontinuum model to be approximately 1.0 m/day. This value is also initially used for the continuum model, but was subsequently increased to 500 m/day according to the results of a model calibration with PEST. The vertical hydraulic conductivity predicted by the PEST analysis of the single-layer continuum model satisfies the solution criteria of the inverse model algorithm and the observed head distributions; however, it should be noted that a single layer model does not simulate nor create vertical flow. Therefore, the high vertical hydraulic conductivity predicted by PEST is merely coincidental with the expected vertical flow that occurs in karst aquifers such as the UFA.

5.4.2 Discontinuum Discrete Fracture Network Models

After the preliminary simulations were performed, equivalent continuum and discontinuum dual porosity models with dimensions of (1000 x 500 x 100 m) and (2000 m x 1000 m x 100 m) representative of the entire aquifer and a representative set of ASR wells were subsequently constructed to test the models' responses to the geochemical and aquifer characteristics used in the preliminary model. The implied fracture zones in these models are assigned as continuous features within model layers that span the model domain. The fractures are represented as homogeneous and isotropic features bounded vertically by the low permeability matrix layers; hence, the analogy to a DFN model. It should also be noted that the original fracture networks generated for these models are determined with FracMan as stochastic discrete fracture network models. It is only when the results are upscaled that volume averaging takes place and the final models exhibit characteristics of equivalent discontinuum models. Because the fractures were originally simulated with FracMan as DFN models, the final up-scaled model is referred to as a DFN model to avoid confusion with the equivalent discontinuum models that do not employ the discrete fracture simulator. The DFN models presented in this study were assigned a constant matrix of 0.5 m/day and fracture hydraulic conductivities 20, 61, or 388 m/day. The specific storage was set to 0.001 m for the simulations, based on manual and inverse modeling calibration with PEST. The matrix and fracture zones were assigned total and effective porosities of 0.35 and 0.25, respectively. To test the effects of porosity on the solutions, dual porosity simulations were also run with matrix total and effective porosities of 0.2 and 0.15. It should be noted that the initial DFN model used a value of 61 m/day for the fracture zones; however, subsequent models used various

combinations of the hydraulic conductivities in order to improve model calibration in the fracture zones with respect to observed values of several geochemical parameters.

Although the discontinuum models were assigned various values of hydraulic conductivity to the fracture zones or high flow zones, the injection zone transmissivity is maintained at $2770 \text{ m}^2/\text{day}$.

5.4.3 Stochastic Discontinuum Discrete Fracture Network Models

The above sequence was repeated with preliminary and full-scale models using FracMan to generate stochastic discrete fracture networks using various physical features that are commonly used to describe fractures. The preliminary three-layer models represent a 100-meter thick aquifer with a central horizontal fracture zone. The initial model is characterized with respect to the following parameters: fracture intensity with lognormal distribution (mean = 1); orientation with constant trend (0 degrees) and plunge (90 degrees); geometry with lognormal fracture size (mean = 90 m and standard deviation of 15 m); fracture shape consisting of six sides; aspect ratio with constant distribution of 1; elongation axis with constant distribution of 90; aperture correlated to size with $B=5e-5$; transmissivity correlated to size where $B=0.1$ and $C=2$; and storativity is constant at $1E-6$. Models are then designed with variations in fracture intensity (0.5, 1.0, and 10), aperture size (correlated to fracture size), and transmissivity (correlated to fracture size). Several models were run with varying parameter values to test the sensitivity of model flow and transport characteristics to these parameters. The average range of hydraulic conductivities calculated for the model layers designated as horizontal fracture zones is 0.007 to 509 m/day, with an average of 78 m/day. This average value of hydraulic

conductivity is moderately greater than the average calculated value of 61 m/day based on the transmissivity of 2770 m²/day; however, it is within a reasonable range of transmissivities for this general area. The model was assigned total and effective porosities of 0.35 and 0.25, respectively. Dual porosity simulations included an effective porosity of 0.15 and a total porosity of 0.2 for the matrix layers. Specific storage was assigned a value of approximately 0.001 m⁻¹.

5.4.4 Model Calibration

The flow models are calibrated with the model-independent nonlinear parameter estimation code PEST (Doherty, 2003; Schlumberger Water Services, 2009) to estimate the hydraulic conductivity distribution by minimizing the residuals between the simulated and observed heads. PEST uses the Gauss-Marquardt-Levenberg nonlinear parameter estimation technique to reduce residuals in an iterative process. Prior to an iteration, the relationship between model parameters and model-generated observations is made linear by formulating it as a Taylor expansion by calculating their derivatives. The linear model is then run under user-specified changing conditions during which PEST will compare parameter changes and objective function until optimization is achieved. The existing monitor wells for Well Field 2 were used as calibration points for the PEST analyses. The continuum model was assigned one constant value of hydraulic conductivity. The PEST model initially calculates the residuals between the simulated and observed heads and then proceeds to test the response of the model to a large number of changes to the horizontal, transverse, and vertical hydraulic conductivity, and specific storage until the residuals are reduced to lowest minimum values.

The stochastic DFN models contain a large distribution of hydraulic conductivities; therefore, the values were automatically grouped into zones by Visual MODFLOW. Each model layer with an assigned stochastic fracture network contained ten zones of hydraulic conductivity created by Visual MODFLOW. Calibration with PEST can not be performed with such a large number of values, within a reasonable period of time, which was confirmed during this study. In order to facilitate efficient analysis with PEST, the hydraulic conductivity distribution created for model layer 12 was used for each model layer. Since each FracMan fracture network was created with the same parameters, the average hydraulic conductivity per layer should be similar; therefore, layer 12 was used as the surrogate for all other fracture zone layers for the calibration of this model.

Although Well Field 2 is the only well field simulated with these models, Well Field 1 is operating simultaneously. As a result of superposition, the drawdown created by Well Field 1 is superimposed on the drawdown from Well Field 2. The magnitude and shape of the cone of depression from Well Field 1 was determined by extending the model domain and boundaries and simulating the dynamic conditions of the well field over a recharge cycle. The head distribution in the vicinity of Well Field 2 resulting from pumping Well Field 1 is approximately a concentric set of hydraulic head contours, which can be approximated by the operation of Well Field 2. The additional drawdown created by Well Field 1 is approximately one meter over the Well Field 2 monitoring well network. The existing Well Field 2 monitor wells west of the ASR wells were used to evaluate the superposition created by pumping from Well Field 1, e.g. M-12, M-13, M-14, and M-15. In order to compensate for this effect on the observed heads, the pumping

rates from Well Field 2 ASR wells are incrementally increased and the model is analyzed with PEST until the residuals are reduced. The best fit results from the PEST analysis are assumed to represent the aquifer parameters.

The PEST calibration using adjusted fluxes to compensate for superposition did not exhibit a significant difference on the results, i.e., the residuals were not significantly improved compared to the model calibrations that did not compensate for superposition. This could be due to the limited resolution of the calibration solution based on the observed head difference of approximately 1 meter across Well Field 2. The flow models used for this study are only sensitive to hydraulic conductivity, specific storage, and injection/extraction rates that create the hydraulic gradients that occur over the well field. Estimates of hydraulic conductivity and specific storage remain generally similar to the model that does not include variations in flux. Porosity is not used by MODFLOW in the calculations of the flow-velocity field provided for mass transport modeling.

6.0 MODEL SIMULATION RESULTS

Simulation results for equivalent continuum, discrete fracture network, and stochastic discrete fracture network models are presented in the following sections.

6.1 Equivalent Continuum Model Simulation Results

Simulation results are presented for preliminary and full-scale equivalent continuum models. Simulation results for models with variations in chemical and reaction parameters, stochastic initial pyrite and arsenopyrite concentrations, variable initial arsenopyrite concentrations, and sorption characteristics are presented to evaluate their potential effects on arsenic distribution during ASR cycles.

6.1.1 Preliminary Equivalent Continuum Model Simulations

The modeled hydraulic heads from the preliminary continuum and discontinuum models were initially brought into reasonable agreement with observed data by adjusting the specific storage; however, this calibrated value (0.001) is significantly greater than the theoretical value ($1\text{E-}7$) for the limestone aquifer. The results from the reaction-transport model are also in general agreement with the observed distribution of arsenic after calibrating the concentrations of pyrite in the aquifer and sulfate in the injected water. The simulated oxygen concentrations are highest during recharge periods at the ASR wells (**Figure 28**). In contrast, arsenic concentrations at the ASR wells are

negligible during recharge and increase to maximum concentrations within a small radius (approximately less than 250 ft) of the ASR well. During the recovery cycles, dissolved oxygen concentrations decrease (although not to background values) and arsenic concentrations increase in the ASR wells (**Figure 29**). Arsenate is the dominant form of arsenic observed in the aquifer during recharge and recovery periods in the vicinity of the ASR wells. The average sulfate concentration of 0.00201 moles per liter (193 mg/L) in recharge water was reduced to 0.00175 moles per liter to reduce the concentration of oxygen in the immediate vicinity of the injection well to that of the injected water. The total dissolved arsenic concentrations represented by arsenite and arsenate concentrations generally range from 1×10^{-7} to 1.3×10^{-6} moles per liter in the simulations. The models with maximum arsenic concentration of approximately 1×10^{-6} moles per liter are generally unaffected by pyrite concentrations greater than 0.01 moles per liter, when the rate of arsenopyrite to pyrite dissolution is set at 0.001. When the pyrite to arsenopyrite dissolution rate is set to 0.01 to 0.1, the simulated arsenic concentrations in the aquifer increase and are generally in general agreement with the observed concentrations.

It should also be noted that the concentrations and areal distributions of arsenic increase with time and that, after the second to third recharge cycle, the concentrations and distributions have generally stabilized, after which arsenic concentrations decreased slightly. The arsenate species persist in the vicinity of the ASR wells during recovery, although the DO concentrations have decreased to near background levels.

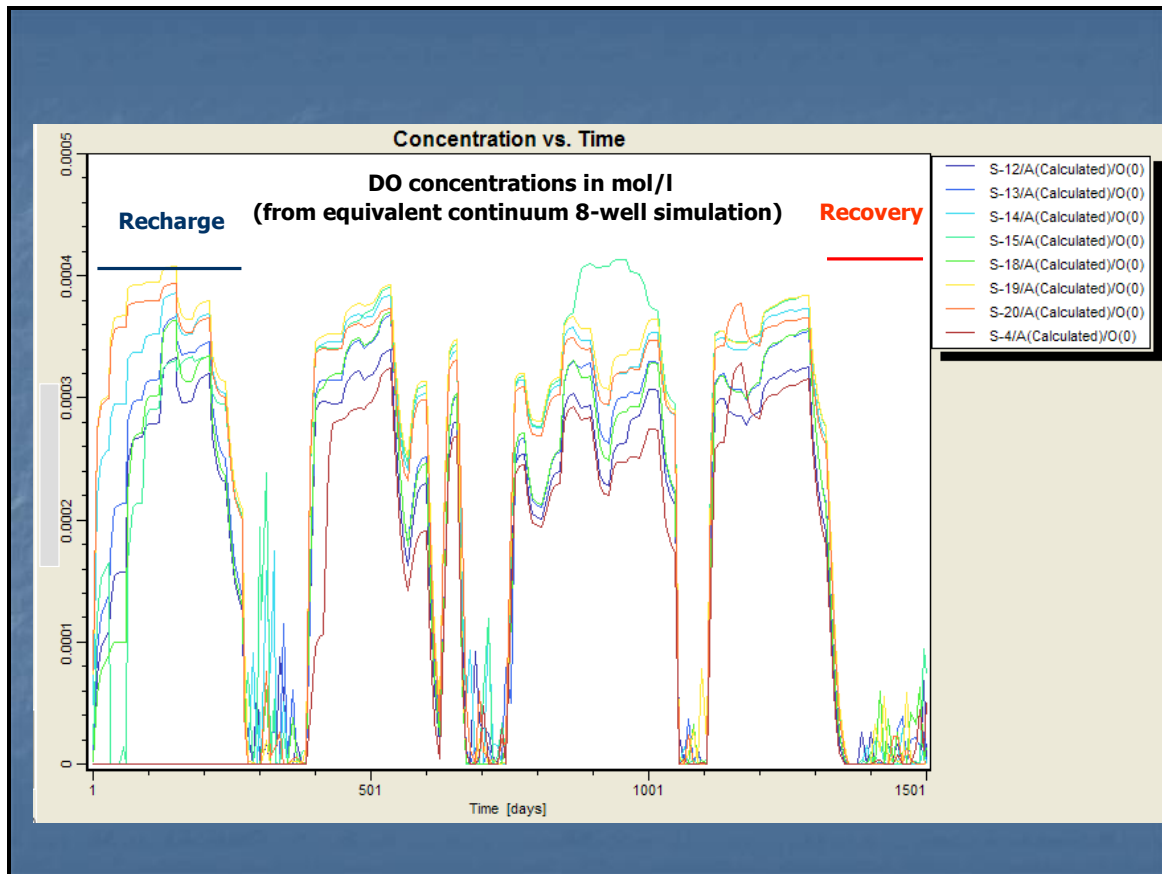


Figure 28. Simulated DO in equivalent continuum model after multiple cycles (1500 days).

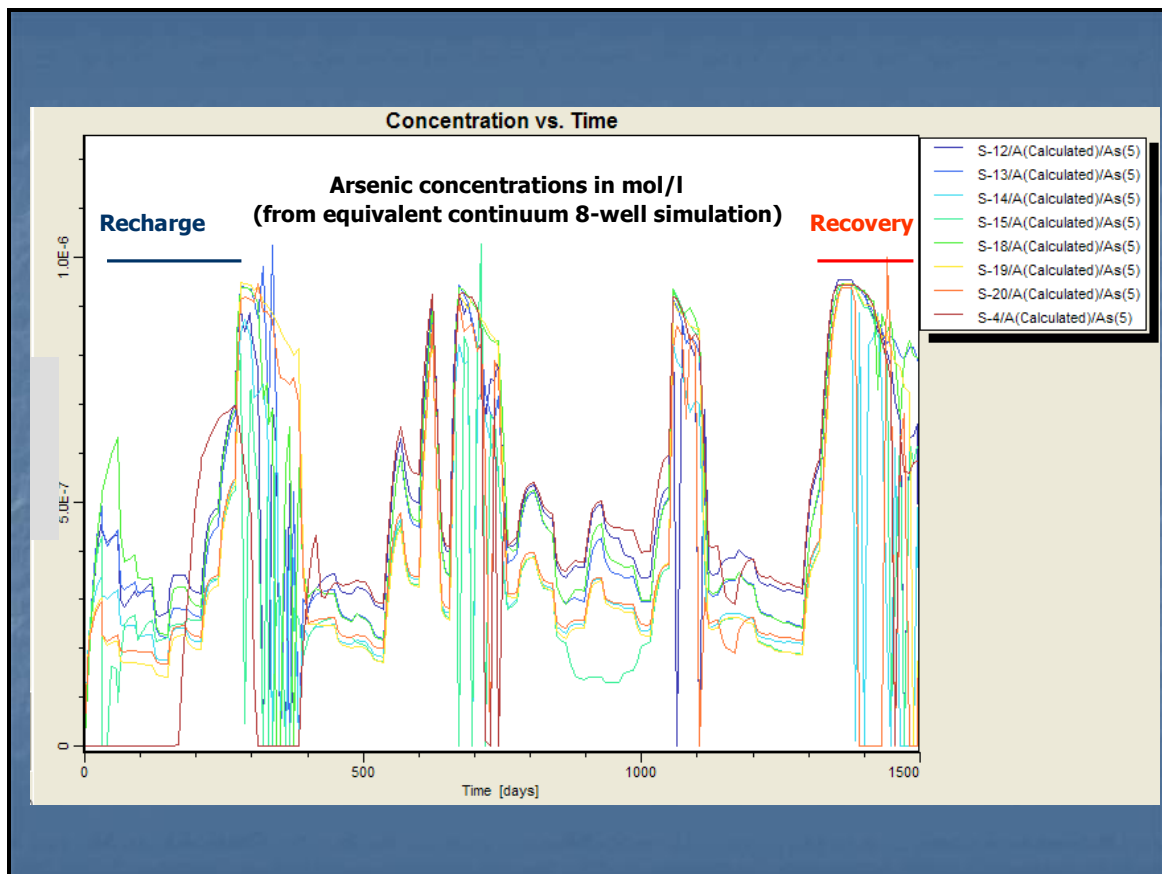


Figure 29. Simulated arsenic in equivalent continuum model after multiple cycles (1500 days).

6.1.2 Equivalent Continuum Model Simulations

The site model constructed with MODFLOW using average hydraulic parameters was run with the above conditions and the arsenic distributions after two recharge cycles (660 days) are depicted on **Figure 30** and **Figure 31**. Lower arsenic concentrations are generated using the Parm(1) of 0.005 compared to Parm(1) of 0.01, and the areal distribution of arsenic is slightly less and closer to the observed distribution with Parm(1) of 0.005. In contrast, the maximum concentrations simulated for S-14 and S-15 are closer to the observed values with Parm(1) of 0.01. The results after two recovery cycles (750 days) are depicted on **Figure 32** (Parm(1) 0.01) and **Figure 33** (Parm(1) 0.005). The distribution of solutes shown occurs throughout the thickness of the model due to the use of average flow and transport parameters. The plume depicts several dissolved parameters including arsenate, arsenite, sodium, chloride, ferrous and ferric iron, and pH to evaluate the distribution of species with varying responses to the chemical reactions that take place. Arsenic is distributed in the aquifer with the more oxidized arsenate species occurring in the vicinity of the ASR well and the reduced arsenite species occurring at greater distances from the ASR well. These distributions represent an environment with redox zones ranging from oxidizing to reducing and stability fields for various arsenic species. The results indicate that the maximum arsenate concentration slightly exceeds the maximum arsenite concentration, with each exhibiting decreasing concentrations away from the ASR wells. The maximum arsenite concentration is observed at the location at which the arsenate concentration has decreased to near its lowest concentration from the ASR well, i.e, the arsenite plume partially overlies the arsenate plume. Under static conditions in which the aquifer is normally reducing with

low Eh and pe (redox), arsenic is typically present at concentrations less than approximately 5×10^{-8} moles/liter. The DO is distributed in rather close proximity to each ASR well with maximum concentrations close to the values of the recharge water compared to the simulated DO concentration at the closest monitoring well M-14, which remains relatively low. The pH distribution ranges from approximately 8.1 SU in the vicinity of the ASR well to 7.3 SU at greater distances from the ASR well, during the recharge cycle, representing the recharge water and native groundwater pH, respectively. The chloride concentrations increase with increasing distances from the ASR wells and indicate the horizontal extent of the storage zone, as the highest chloride concentration represents the native formation groundwater.

6.1.3 Stochastic Lognormal Initial Concentration Simulation

The lognormal fracture distributions from layer 8 (**Figure 34**) and layer 14 (**Figure 36**) were used in the continuum model, with an expanding grid, to evaluate the potential effects of non-uniform initial concentrations of the minerals pyrite and arsenopyrite over the operational period of 2,520 days. Since arsenic is heterogeneously distributed in the aquifer and arsenopyrite solubility is variable dependent on grain size, the potential effect of its distribution was tested with the model. The grids for these simulations were further discretized with cells in the vicinity of the ASR wells assigned x and y dimensions equal to 5 m, instead of the 10 m used in the models. Using an expanding grid significantly reduces the run times and running the models to 2,520 days provides enough time for chemical reactions to propagate to their maximum extent across the model.

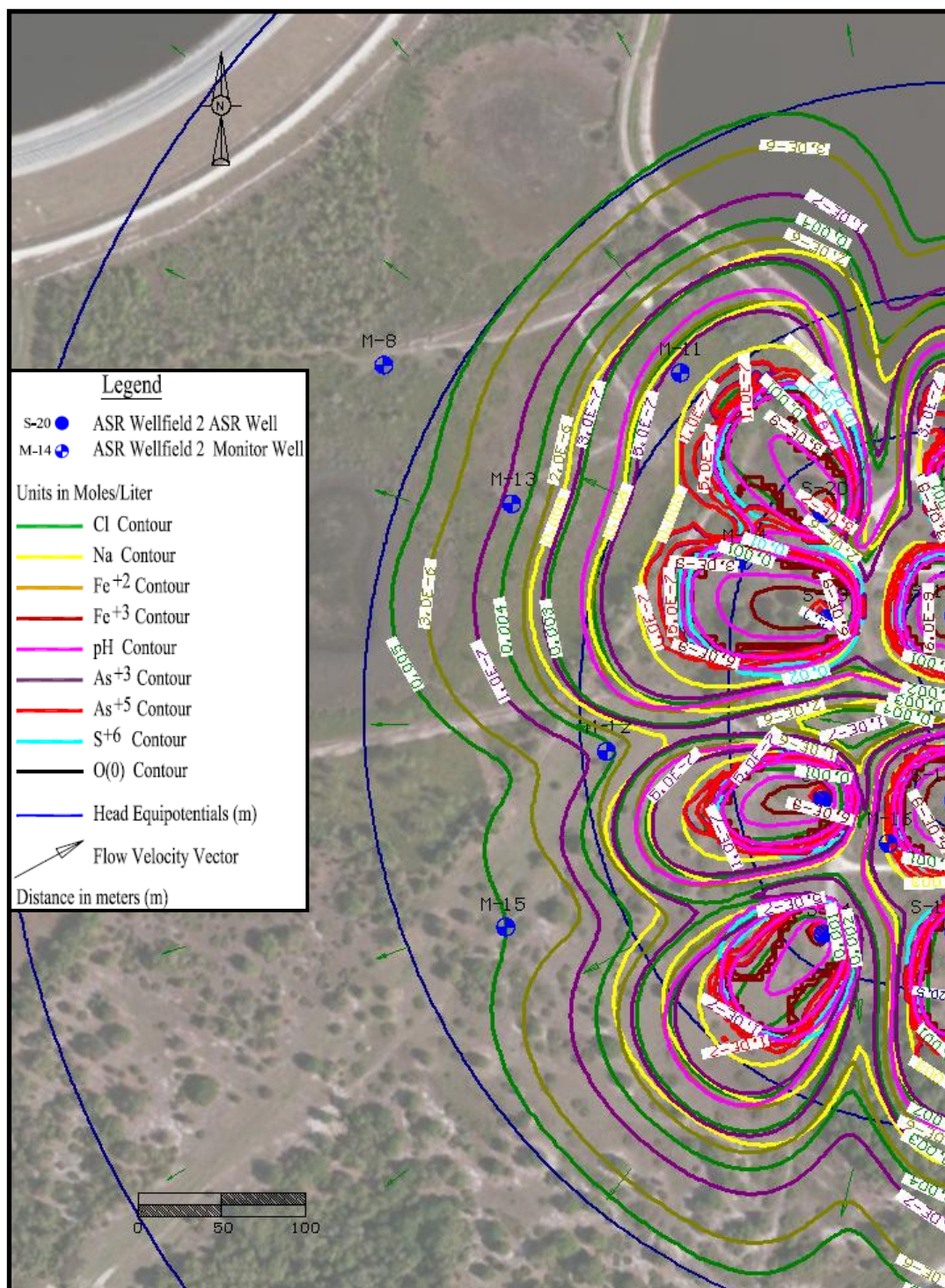


Figure 30. Simulation results of solutes after recharge cycle 2 in continuum model with Parm(1) = 0.01

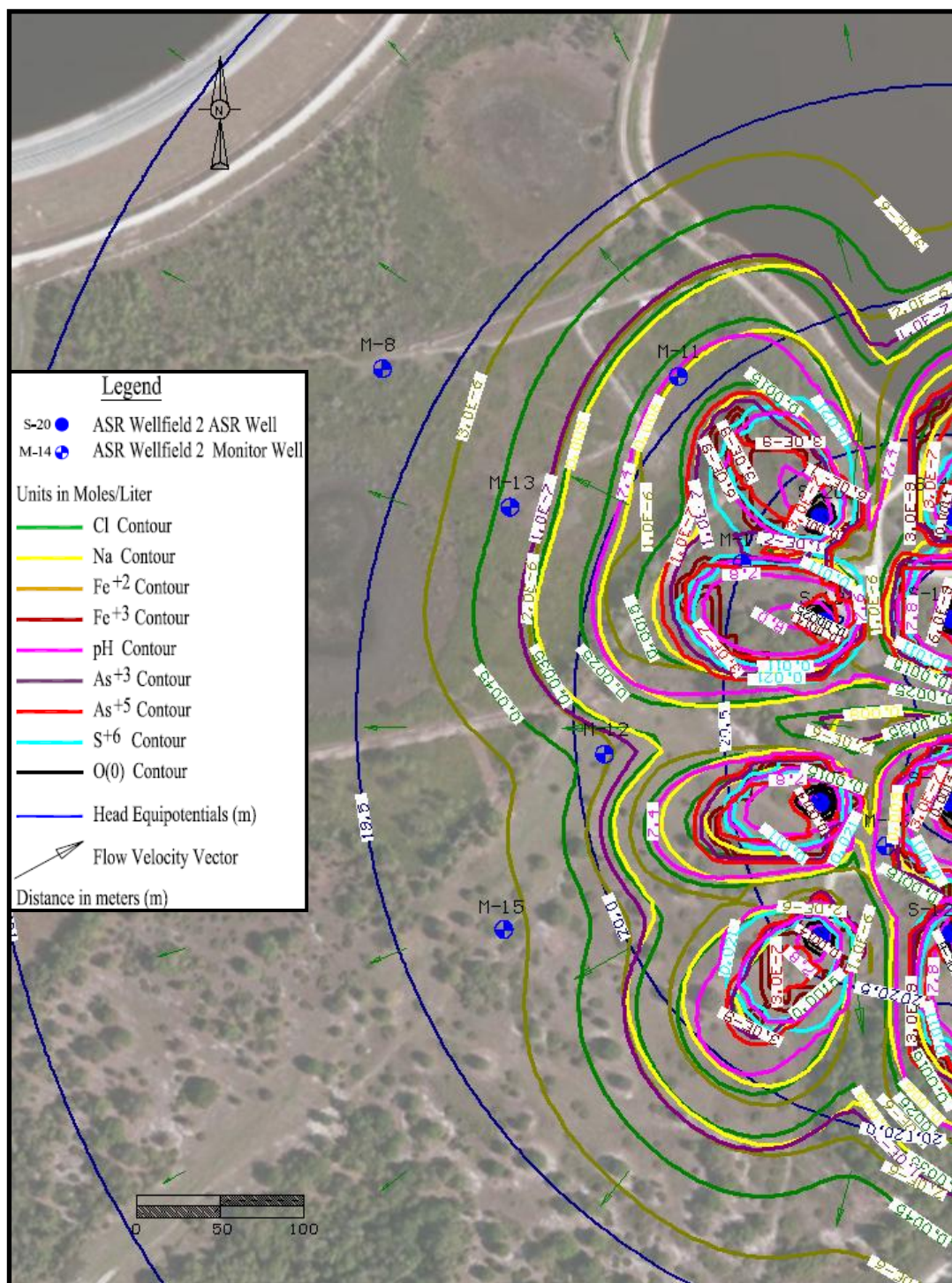


Figure 31. Simulation results after recharge cycle 2 in continuum model with Parm(1) = 0.005.

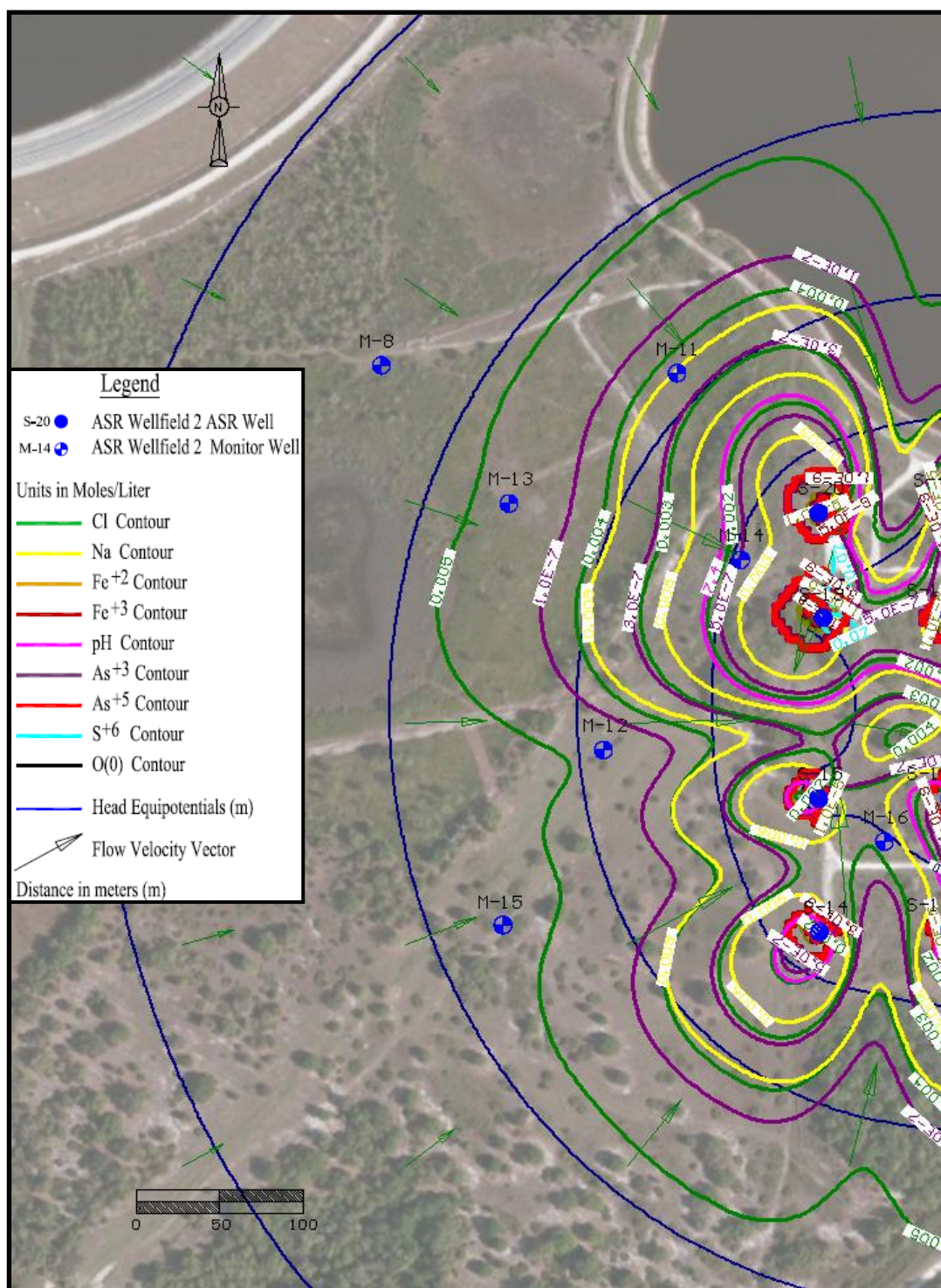


Figure 32. Simulation of solutes after cycle 2 recovery in continuum model with Parm(1) = 0.01.

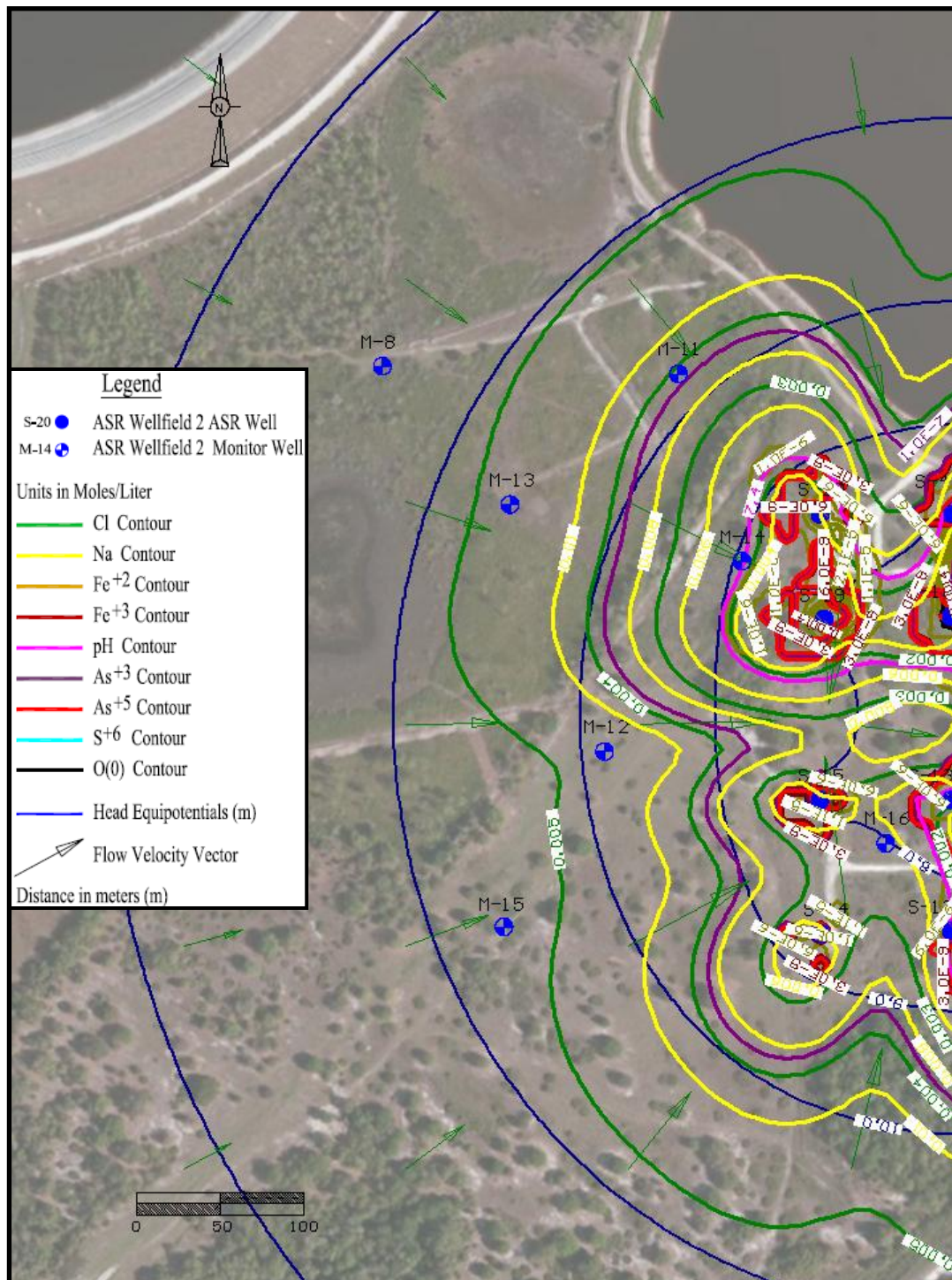


Figure 33. Simulation of solutes after cycle 2 recovery in continuum model with Parm(1) = 0.005.

Inspection of the solute plumes, using the varying initial concentrations from layer 8 (**Figure 35**) and layer 14 (**Figure 37**), at the end of the second recharge cycle (660 days) indicates that small variations occur in the position of the iron and arsenic concentration contours in the vicinity of the ASR wells compared to more distant locations. These variations are noted in the general vicinity of the ASR wells where the oxidation reactions are significant compared to more distant locations that are not affected by the oxidizing recharge water. If the initial distribution of arsenopyrite has an effect on the distribution of solutes of iron and arsenic, then these distributions will differ because the average concentration of arsenic in each model is identical, although the distributions differ. The results demonstrate that position of the arsenate and ferrous iron contours appear to exhibit minor variations of approximately 3 to 10 meters, respectively, compared to the model using average arsenopyrite concentrations. The degree of variation between the models is not significant in this case.

6.1.4 Variable Arsenopyrite Concentrations in Source Areas

The simulation results of the continuum model with low arsenopyrite concentrations ($1\text{E-}6$ moles/L) in the vicinity of the northern ASR wells (S-19, S-20, S-18, and S-4) are presented in **Figure 38** and **Figure 39** after cycle 2 (660 days) and cycle 4 (1320 days), respectively. These simulation results reasonably agree with the observed variations in spatial and temporal arsenic distributions. The simulated arsenate concentrations in the southern ASR wells S-14 and S-15 are approximately two to three times the concentrations in the adjacent ASR wells, S-19 and S-20, to the north during both recharge cycles. After recharge cycle 4 (**Figure 39**), the arsenic concentrations in

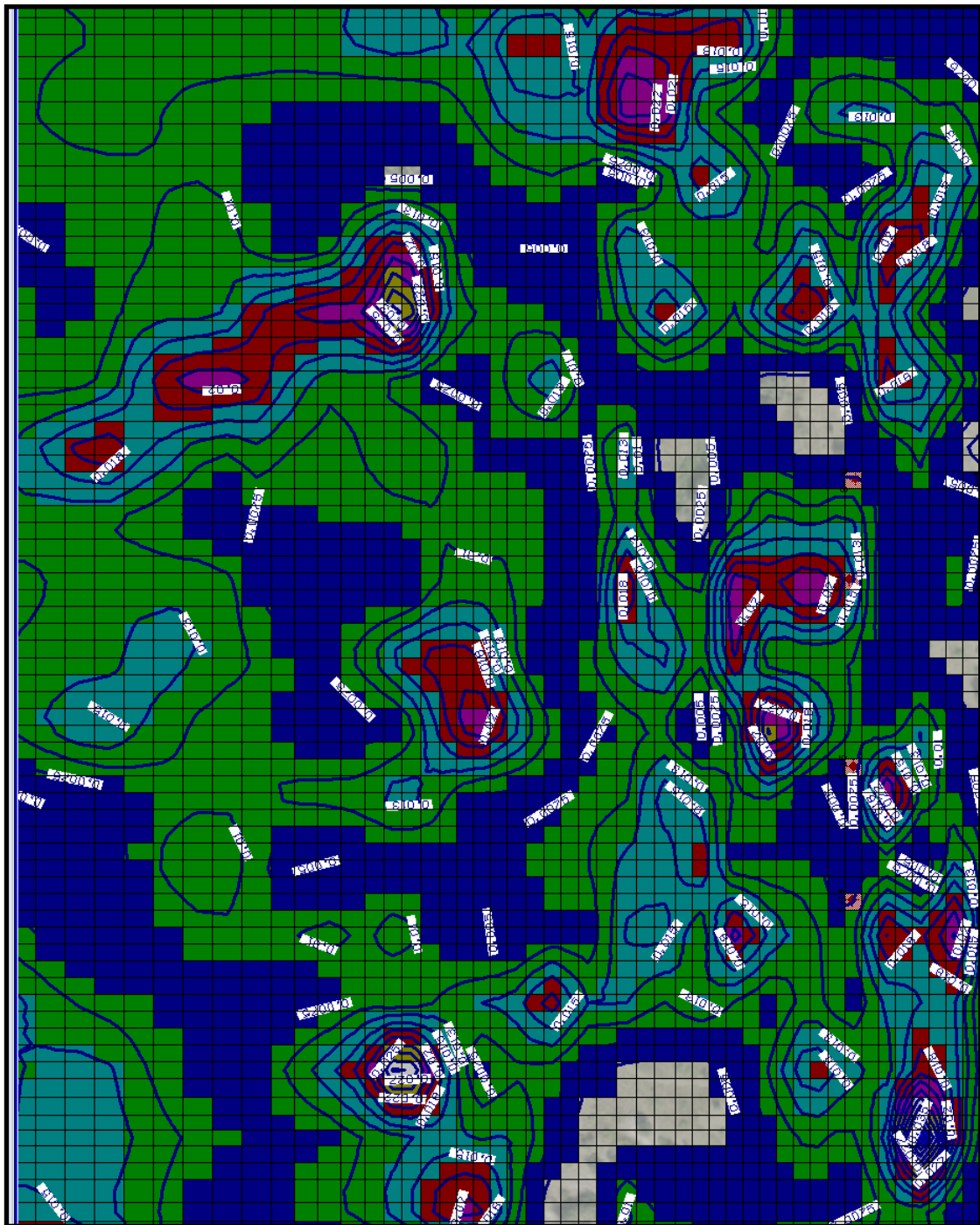


Figure 34. Lognormal distribution of initial concentrations of pyrite and arsenopyrite in layer 8.

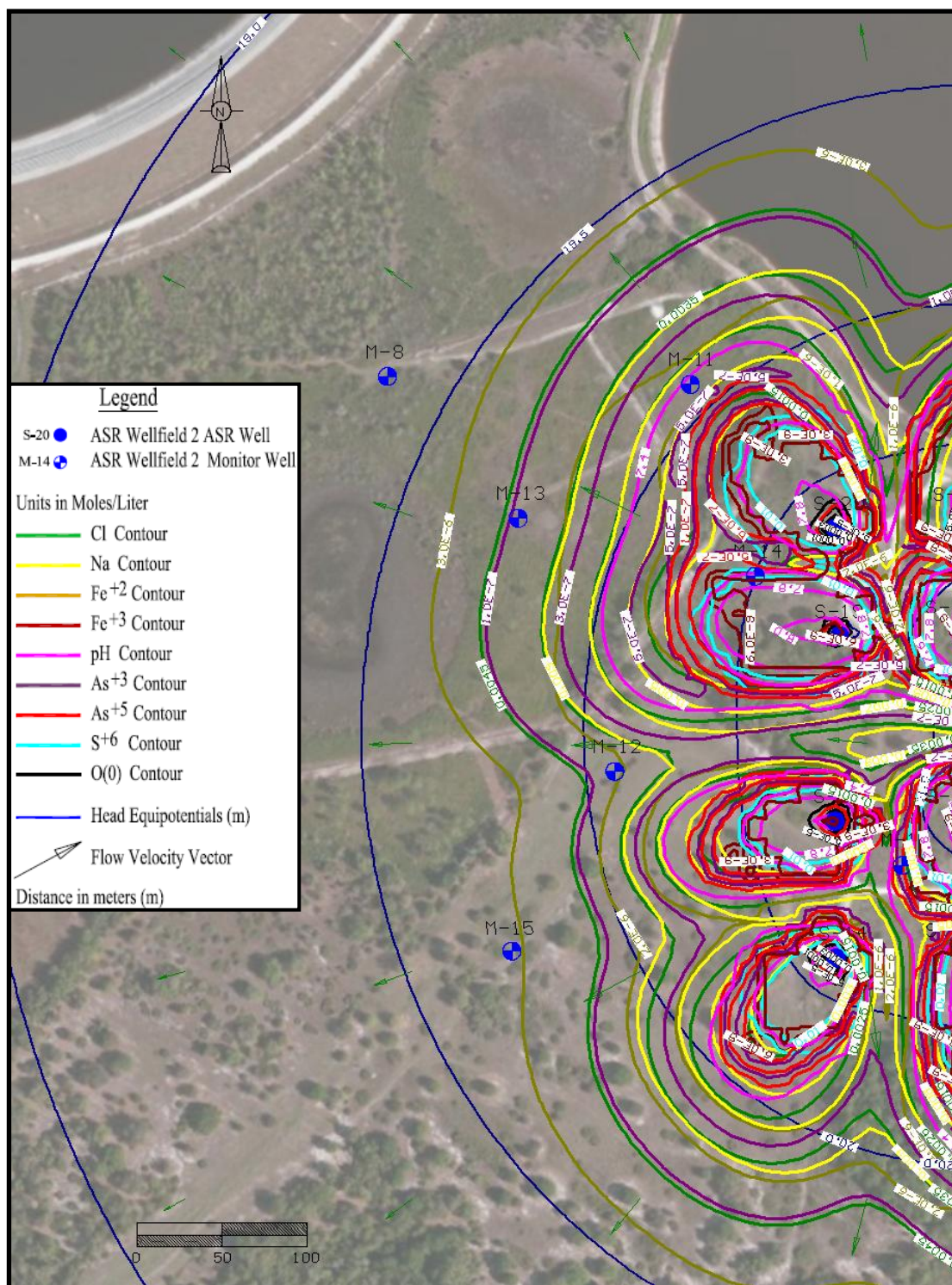


Figure 35. Solute distribution after recharge cycle 2 using lognormal distribution of initial concentrations of pyrite and arsenopyrite in layer 8.

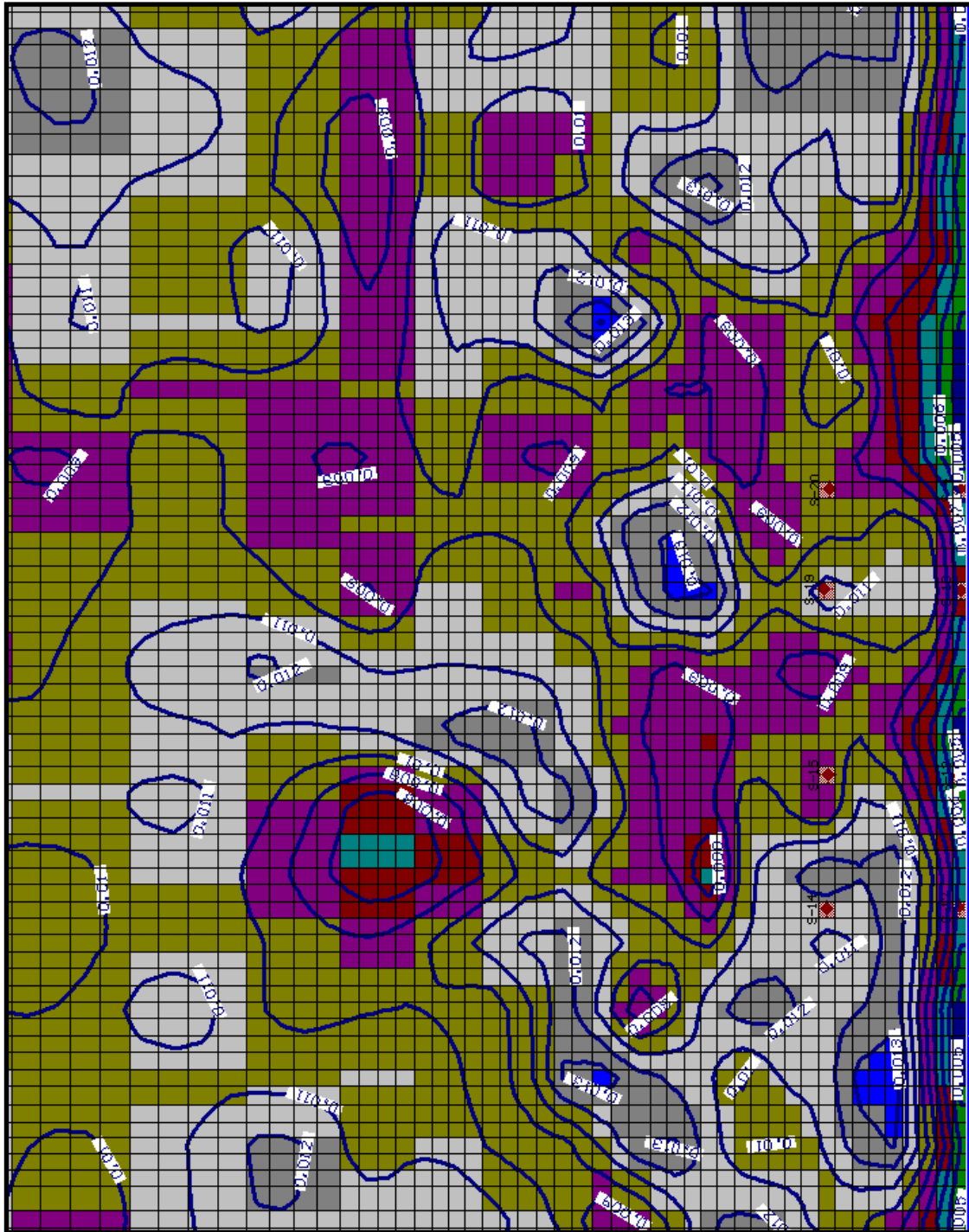


Figure 36. Lognormal distribution of initial concentrations of pyrite and arsenopyrite in layer 14.

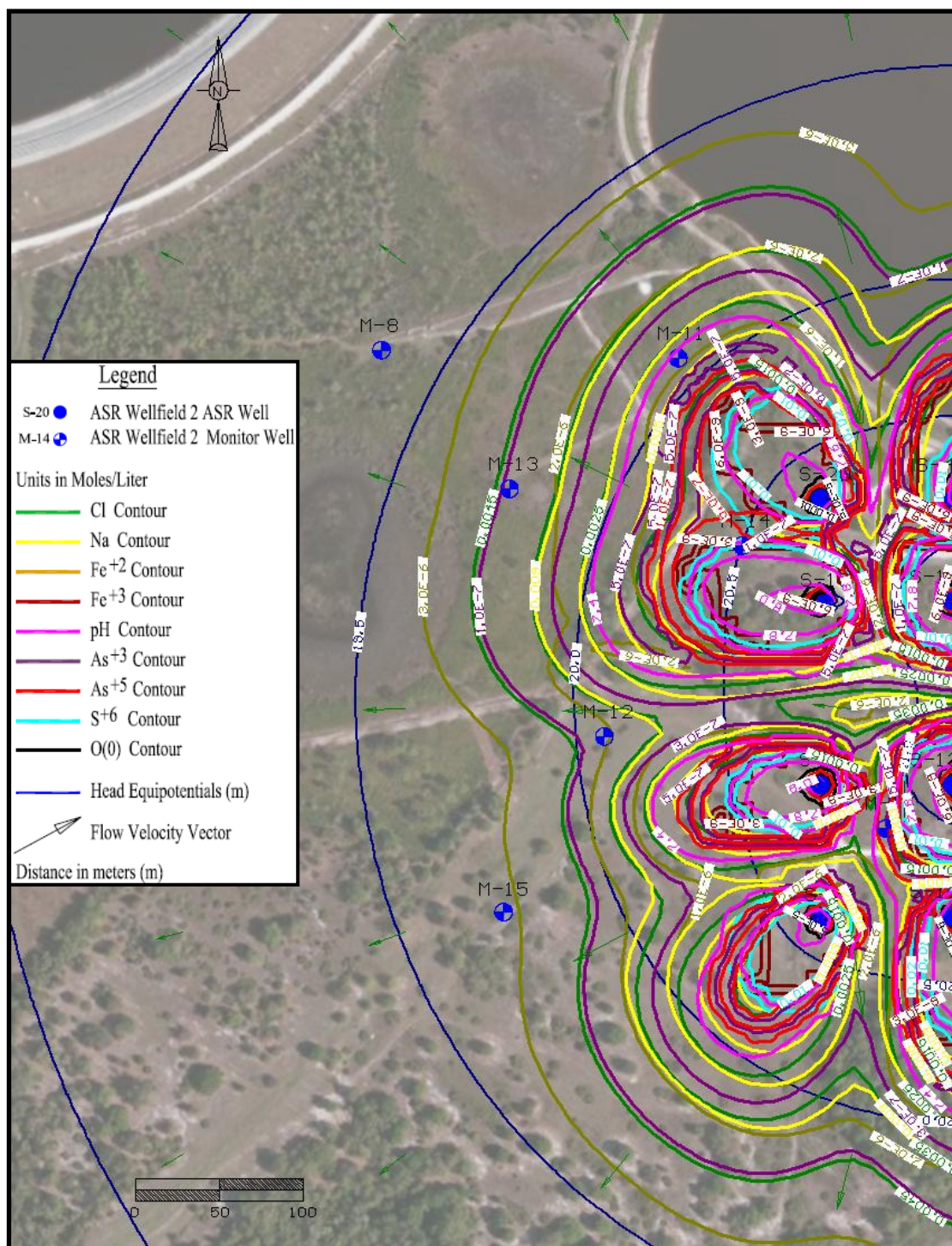


Figure 37. Solute distribution after recharge cycle 2 using lognormal distribution of initial concentrations of pyrite and arsenopyrite in layer 14.

S-19 and S-20 exhibit lower concentrations compared to the end of cycle 2, which is also consistent with observed trends. Low concentrations of arsenite ($<3.0\text{E-}7$ moles/liter) occur beyond 250 feet from the ASR wells that may slightly exceed the observed arsenic concentrations in the vicinity of M-14. Without a monitor well within close proximity to ASR wells S-14 and S-15, it is not possible to accurately characterize and delineate the arsenic distribution in this area. However, with respect to the existing monitor wells in the general vicinity of S-14 and S-15, the simulated arsenic concentrations and distributions could be reasonably representative of observed data. The simulated pH at the closest monitoring well (7.7 SU), M-14, is slightly less than observed values at this well, approximately 8 SU during recharge cycles. The simulated magnitude of DO in this simulation approaches the magnitude observed in monitor well M-14; however, the horizontal extent of DO appears to decrease to near background values at a distance of less than approximately 200 ft.

6.1.5 Simulation with Equilibrium-Controlled Linear Sorption

The results for the simulations of the equivalent continuum (**Figure 40**) model with linear equilibrium sorption exhibit distributions of arsenic that do not extend significantly beyond monitor well M-14. The initial concentrations of arsenopyrite are not decreased as in some previous simulations; therefore, the arsenic concentrations reach approximately the same maximum concentrations of approximately $7\text{E-}7$ moles/liter in the immediate vicinity of each ASR well. Arsenate is the only species that occurs at significant concentrations and the K_d used has decreased the distributions to within approximately 200 ft of the ASR wells. Arsenite concentrations persist beyond the arsenate at concentrations less than $1\text{E-}7$ moles/Liter or slightly less than the arsenic

MCL of 10 $\mu\text{g/L}$. The horizontal extent of the arsenic distribution in all of the model results presented is generally quite consistent with observed data.

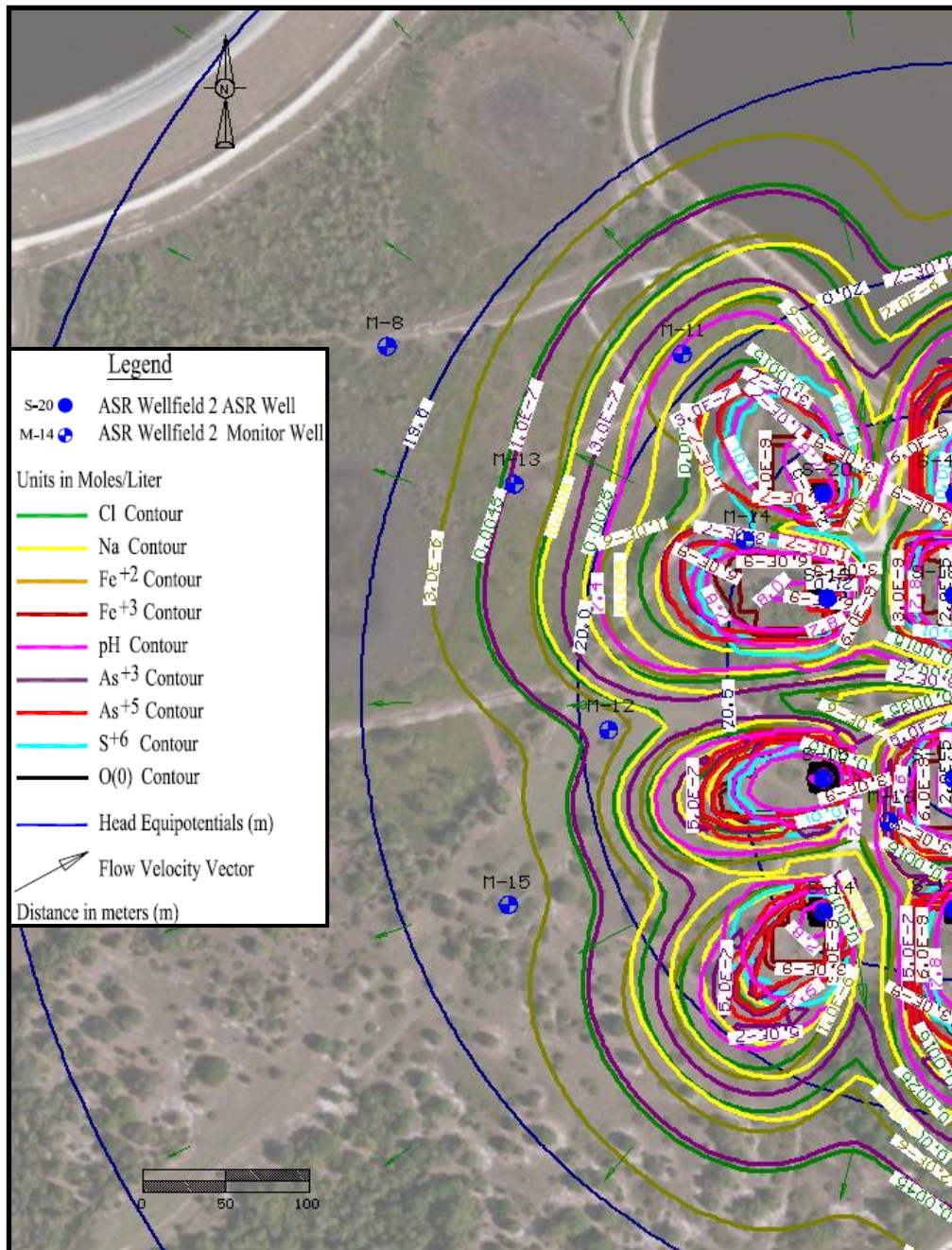


Figure 38. Solute distribution in continuum model after recharge cycle 2 using variable distribution of initial arsenopyrite concentrations in the vicinity of ASR wells.

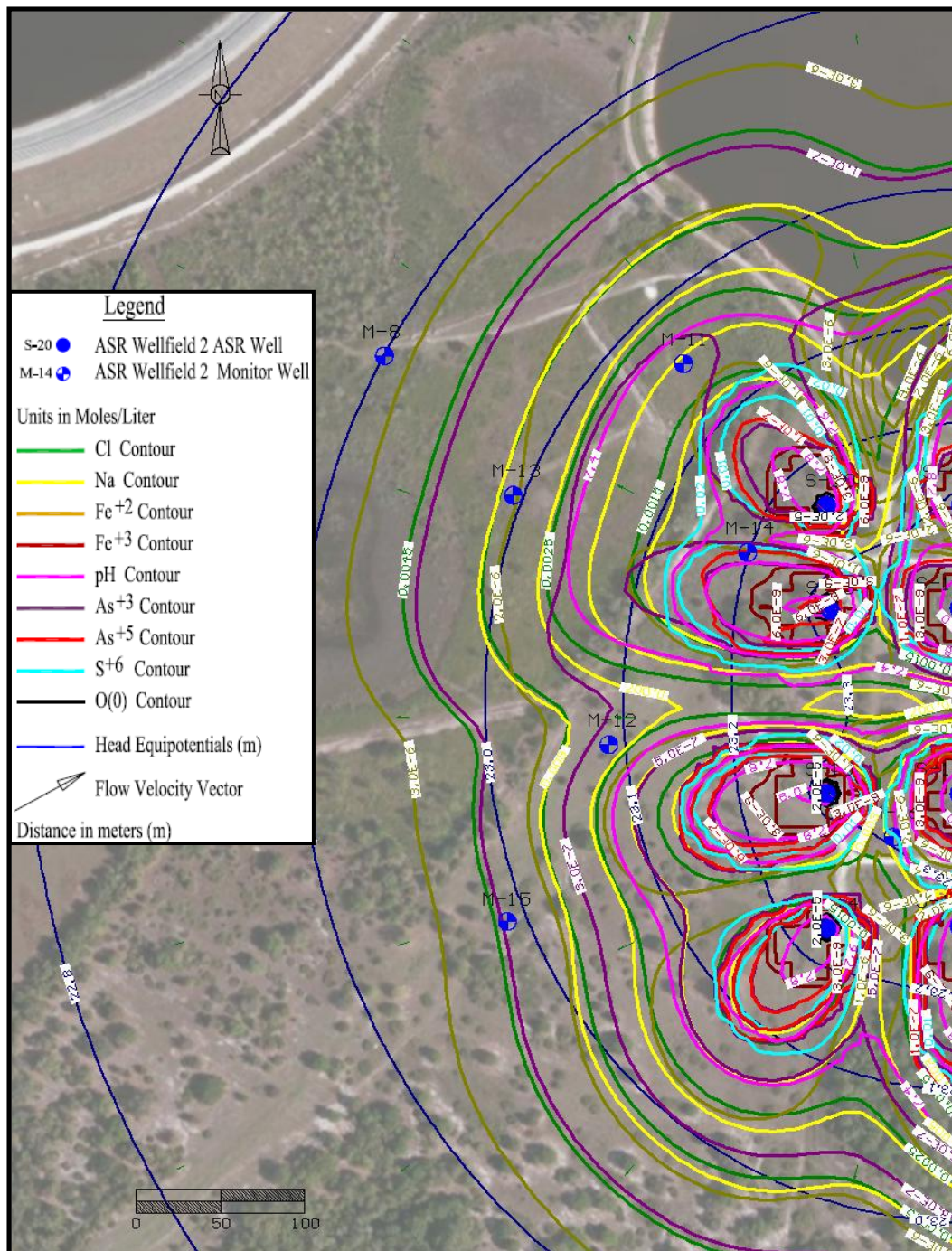


Figure 39. Solute distribution in continuum after recharge cycle 4 using variable distribution of initial arsenopyrite concentrations in the vicinity of ASR wells.

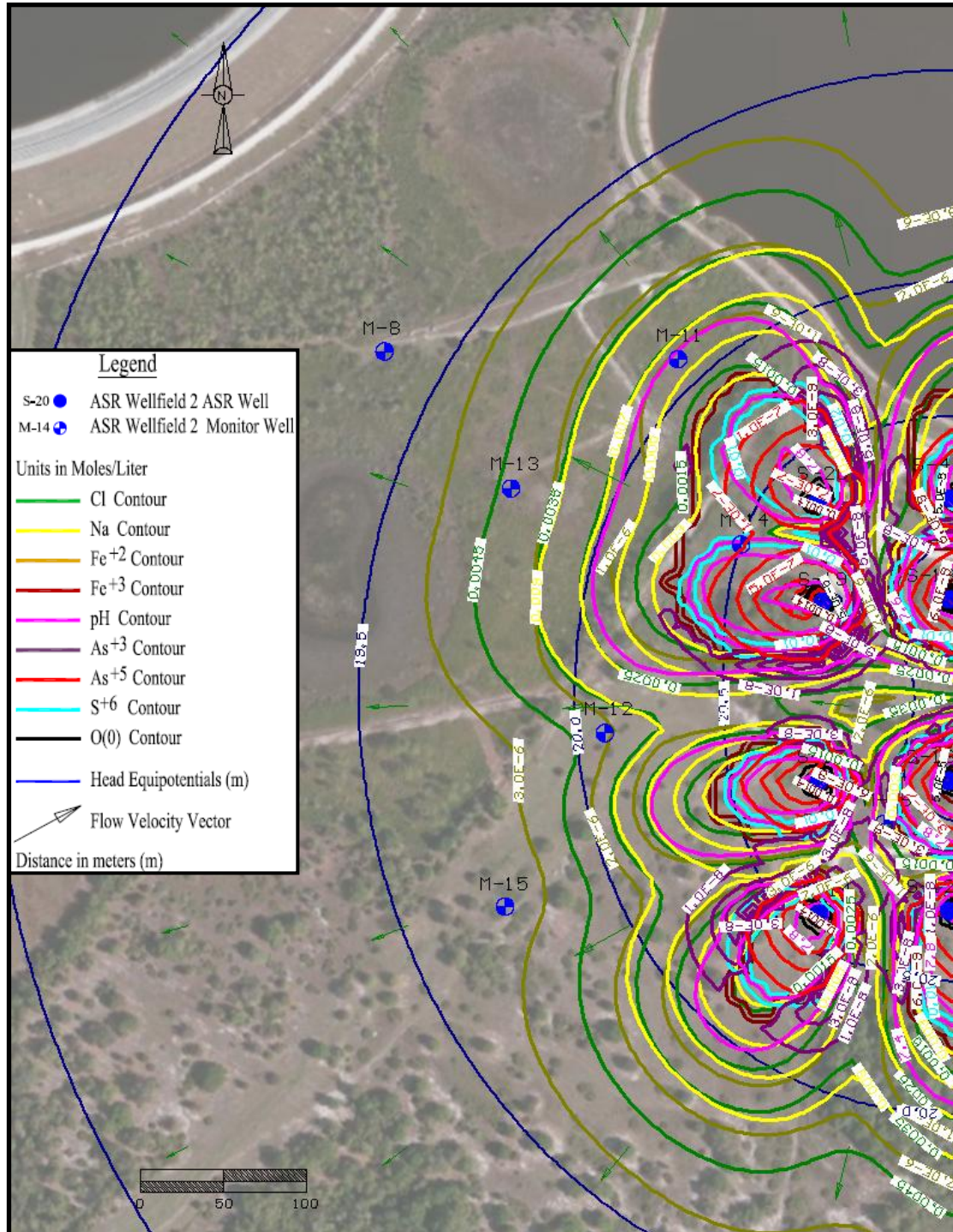


Figure 40. Solute distribution in continuum model after recharge cycle (660 days) with equilibrium sorption.

6.2 Discontinuum Model Simulation Results

Simulation results are presented for preliminary and full-scale equivalent discontinuum models. Simulation results for models with variations in chemical and reaction parameters, stochastic initial pyrite and arsenopyrite concentrations, variable initial arsenopyrite concentrations, and sorption characteristics are presented to evaluate their potential effects on arsenic distribution during ASR cycles. Simulation results for models that include variations in hydraulic conductivity associated with fracture zones are also presented to test their effects on dissolved arsenic heterogeneities.

6.2.1 Discontinuum Model Simulations

The heterogeneous dual porosity model simulation results (**Figure 41** and **Figure 42**) exhibit contrasting arsenic distributions in matrix and fracture zones, with the higher transmissivity zones, e.g. layer 8 fracture zone, resulting in more laterally extensive dissolved species distributions during recharge cycles compared to the low transmissivity matrix layers. The simulation results shown on **Figure 41** and **Figure 42** represent model simulations with contrasting magnitudes of arsenic concentrations because Parm(1) is 0.005 and 0.01, which controls the arsenic generation rate due to the oxidation of arsenopyrite. In the vicinity of the ASR wells, the arsenate concentrations increase from low concentrations at the ASR wells to maximum concentrations of approximately $7.0\text{E-}7$ moles/liter (in the fracture zone) within 200 ft or less of the ASR well using Parm(1) of 0.01. The pH of the recharge water remains significantly above the background (approximately 7.5 to 8 SU) within greater than 200 ft of the ASR wells.

The simulation results using the model with Parm(1) of 0.005 exhibit maximum arsenate concentrations of approximately $4\text{E-}7$ moles/Liter and slightly lower arsenite

concentrations. The maximum arsenic concentrations using this Parm(1) value are in reasonably close agreement with the average arsenic concentrations per recharge cycle for each ASR well. In comparison, the simulation results using the model with Parm(1) of 0.01 exhibit maximum arsenate concentrations of approximately $7\text{E-}7$ moles/Liter and slightly lower arsenite concentrations. These maximum concentrations are in closer agreement to the maximum concentrations observed in many of the ASR wells. The simulations with higher maximum concentrations exhibit larger horizontal distributions of arsenic. The DO concentrations and areal distributions are greater in the simulations results for the model with Parm(1) of 0.005 compared to the model with Parm(1) of 0.01 because less arsenopyrite is available to consume the DO. The observed DO from monitoring well S-14 exhibits very high concentrations, which is more consistent with the lower Parm(1). Ferric iron distribution is similar to that of arsenate because of the similar redox stability fields and dissolution of pyrite releasing iron into the groundwater in the vicinity of the ASR wells. The pH of the recharge water remains above the background in the general vicinity of the ASR well and the increased pH extends beyond 200 ft of the ASR wells, which is characteristic of the observed values in monitor well M-14.

The simulation results for the matrix layer (layer 13; **Figure 43 and Figure 44**) exhibit lower concentrations and smaller spatial distributions of arsenic, compared to the fracture zone (layer 8) as a result of decreased penetration of recharge water and consequent decreased oxidation of available arsenopyrite. As stated above, the lower Parm(1) is associated with higher DO because the degree of arsenopyrite oxidation is less. The significantly lower hydraulic conductivity of the matrix reduces the migration

of arsenic released into the aquifer after pyrite oxidation. The pH of the recharge water remains above the background in the immediate vicinity of the ASR well and decreases rapidly within less than 200 ft of the ASR wells, which is not observed in monitor well M-14. The chloride and sodium contour distributions representative of formation water are generally closer to the ASR wells in the matrix. The position of the chloride contour between the matrix and fracture zones exhibits similarities because of the conservative nature of chloride that minimizes reactions and the vertical hydraulic continuity between the matrix and intermatrix layers.

In general, the radial extent of arsenic species following recovery in fractures (**Figure 45**) remains greater compared to the matrix (**Figure 46**). The radial extent or migration of all dissolved species during the recharge and recovery cycles are significantly greater in the fracture zone layers, compared to the matrix layers. In both fractures and matrix layers, the highest arsenic concentrations occur in the vicinity of the ASR wells and consist of the arsenate species. The arsenite species occurs farther from the ASR wells where reducing conditions prevail. In the fracture zone and matrix layers, low concentrations of arsenic persist in the aquifer in the immediate vicinity of the ASR wells following the recovery cycle. In reviewing the simulated results of recovery periods during all of the cycles, the arsenate species are predominant in the immediate vicinity of the ASR wells during the recovery periods with the arsenite species persisting at greater distances from the ASR wells. The persistence of the arsenate species in the vicinity of the ASR wells during recovery suggests that conditions for arsenate stability persist during the recovery cycles. This distribution could potentially be expected when

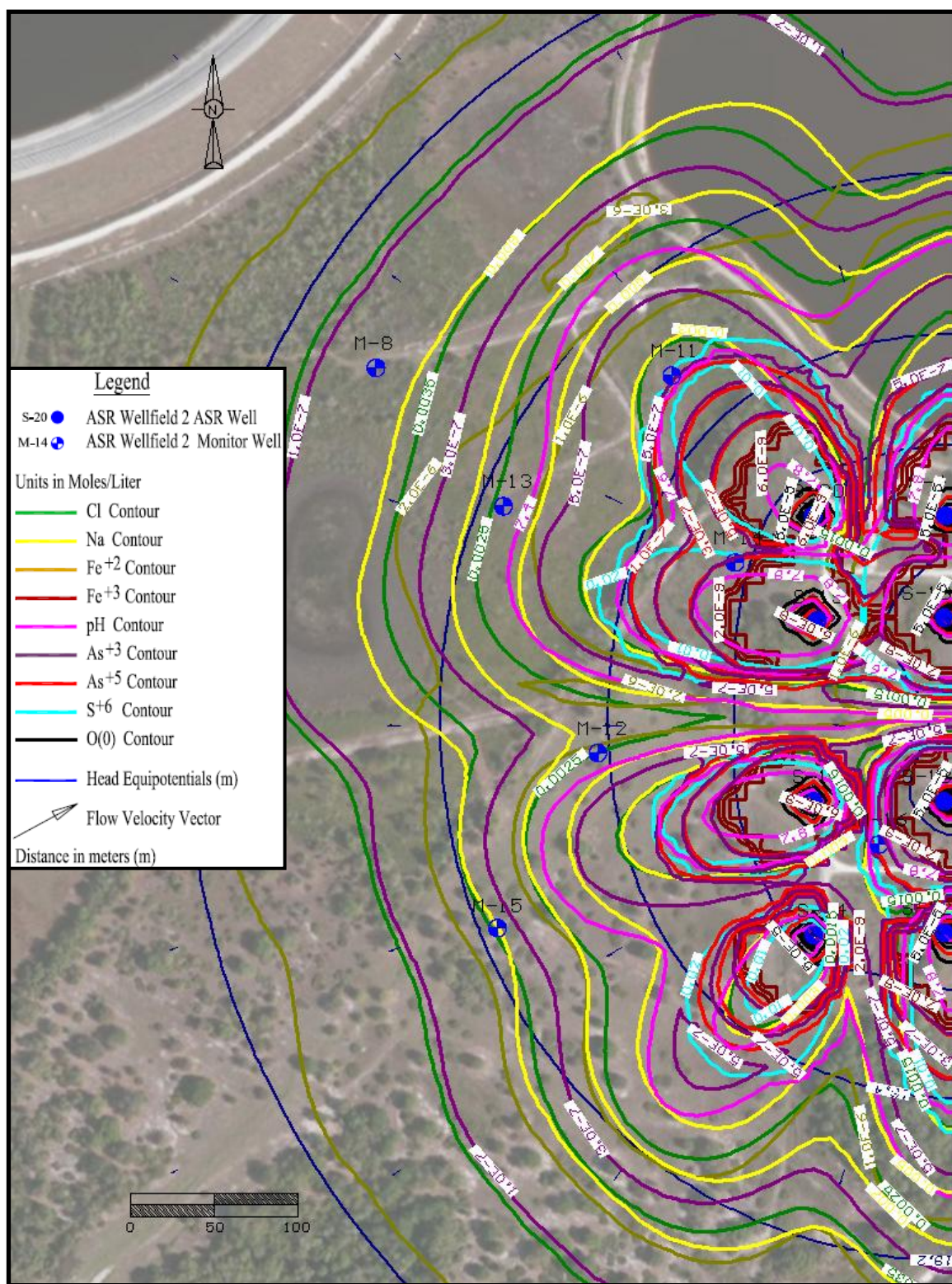


Figure 41. Simulation results of solutes after cycle 2 recharge in fracture zone (layer 8) of heterogeneous model with Parm(1) = 0.01.

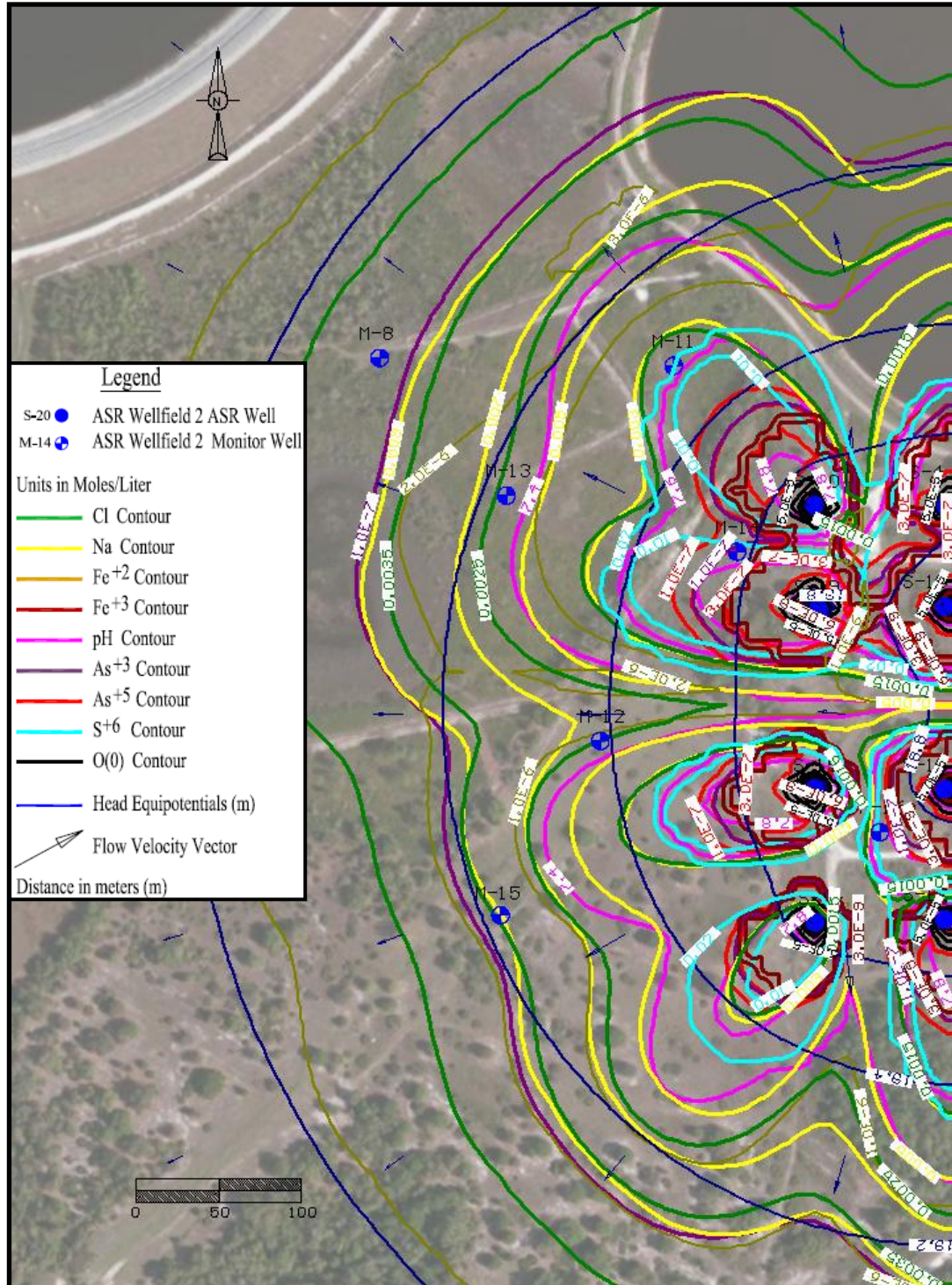


Figure 42. Simulation results of solutes after cycle 2 recharge in fracture zone (layer 8) of heterogeneous model with decreased source concentration with Parm(1) = 0.005.

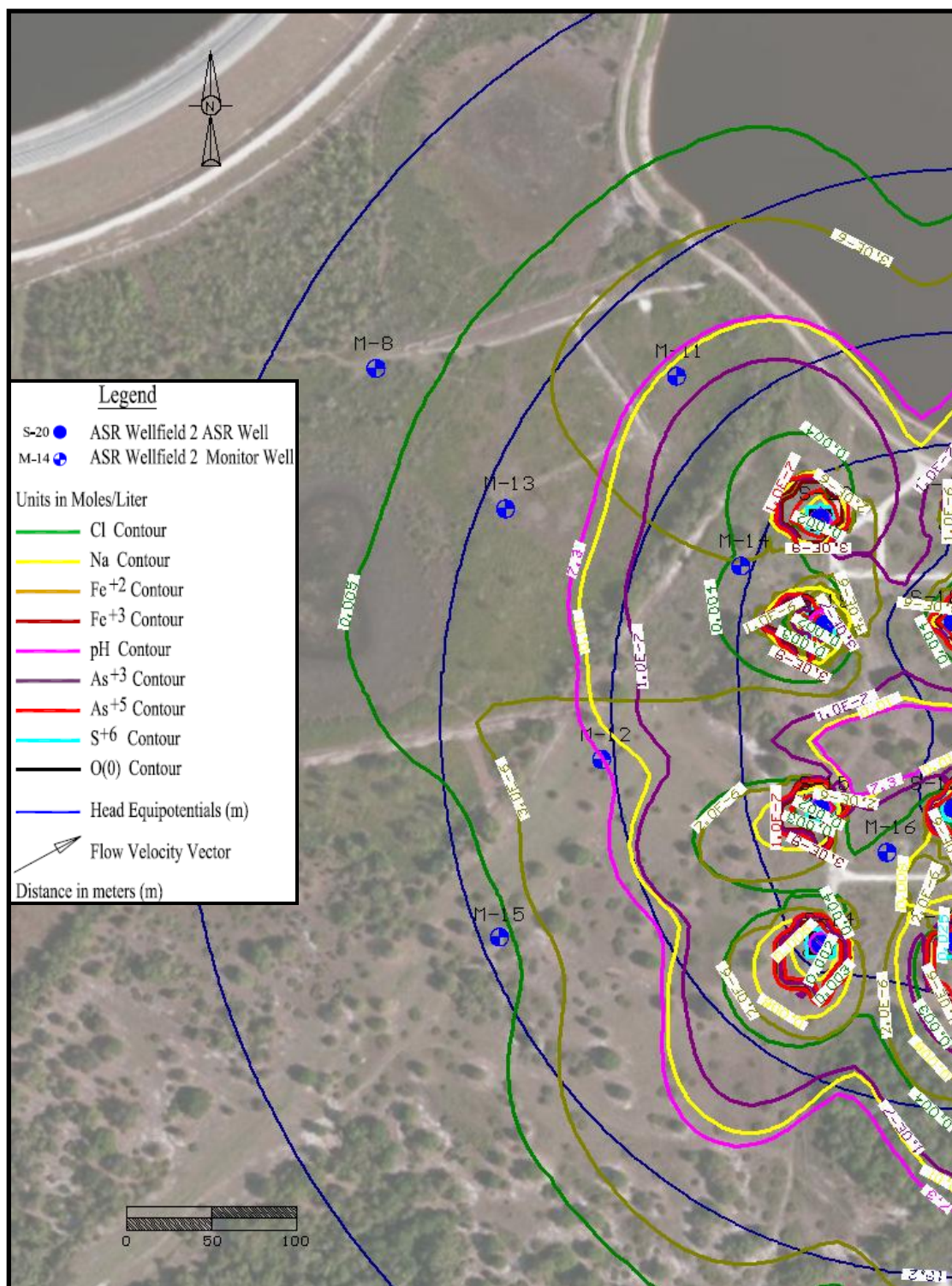
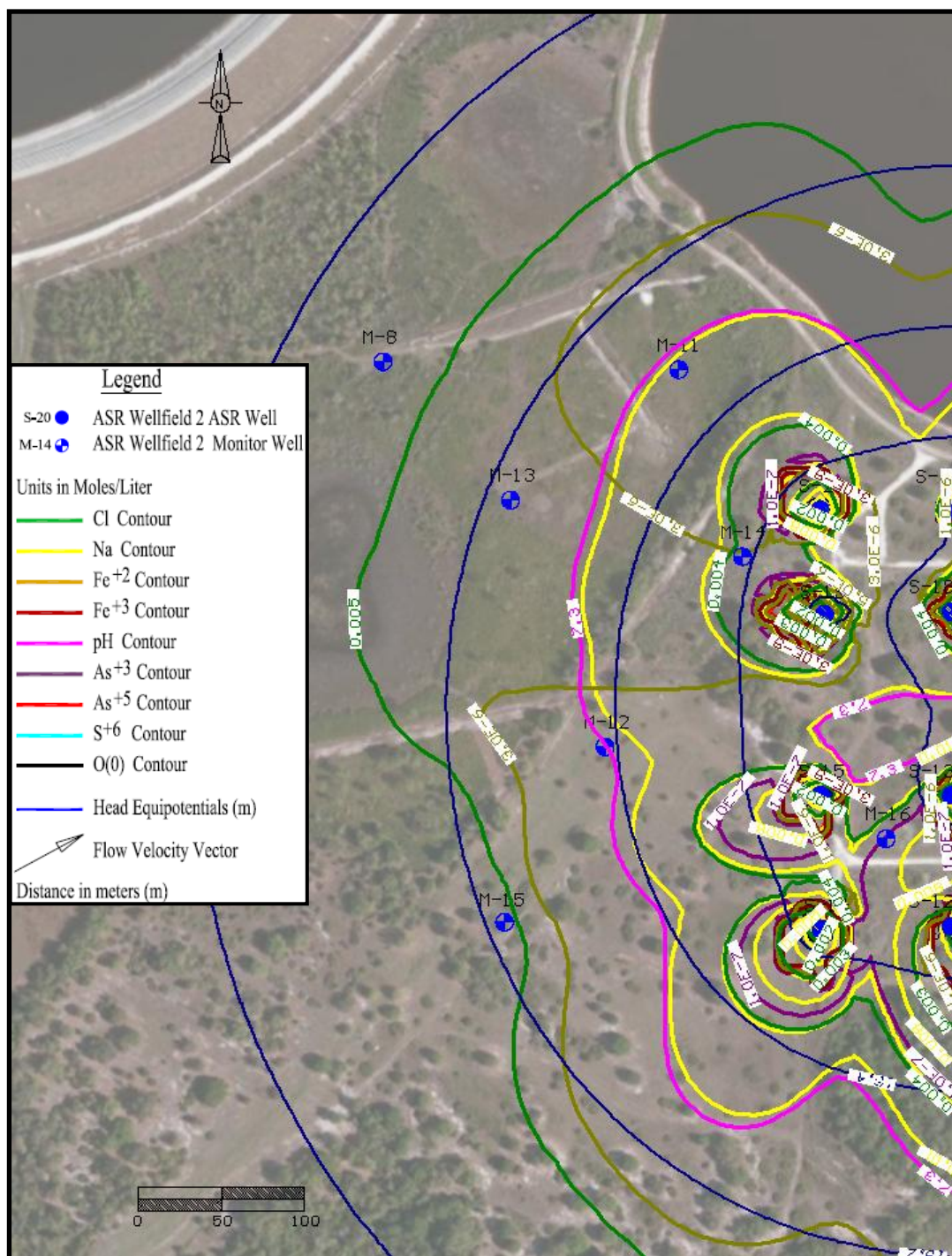


Figure 43. Simulation results of solutes after cycle 2 recharge in matrix (layer 13) of heterogeneous model with Parm(1) = 0.01



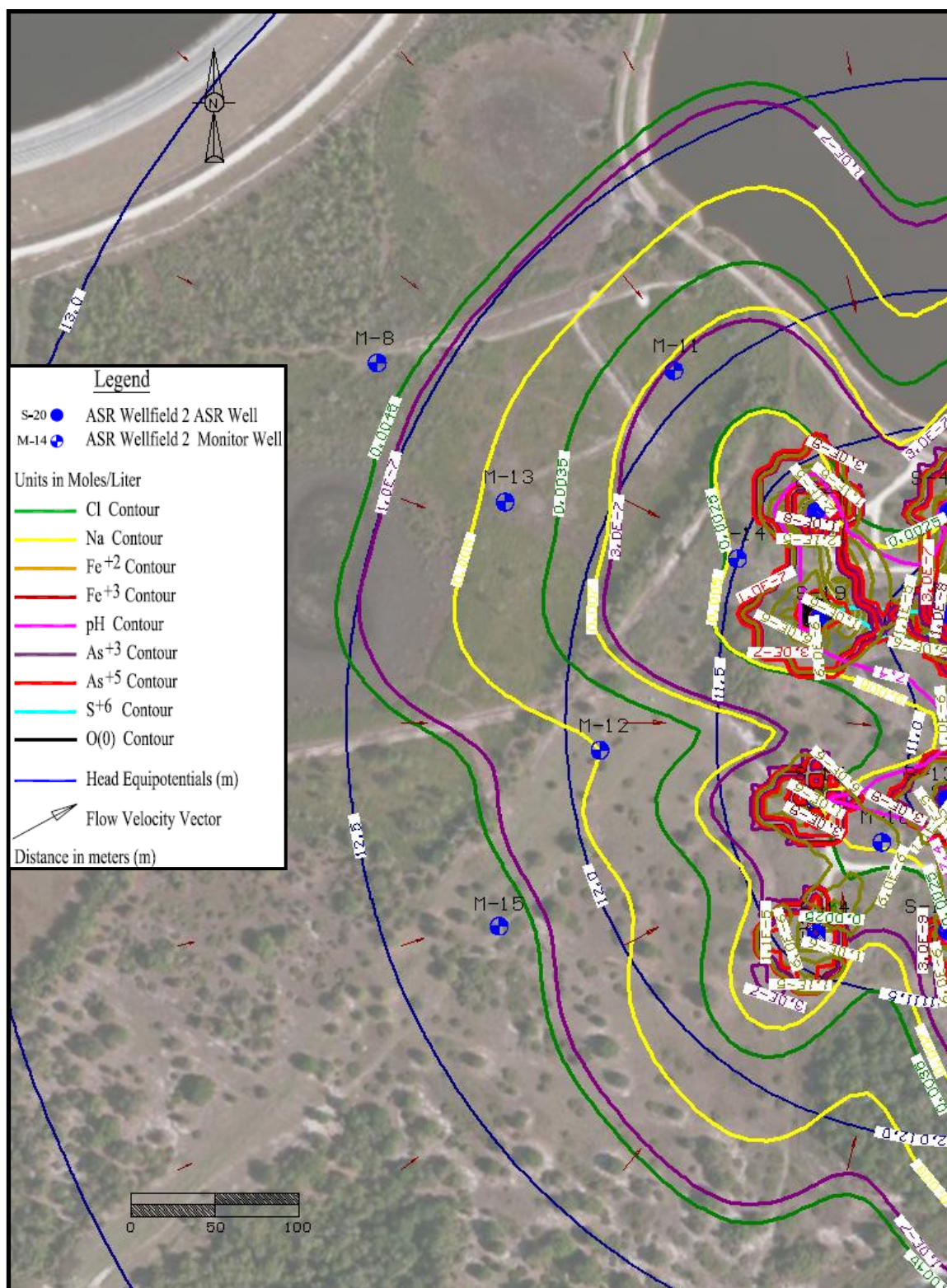


Figure 45. Simulation results of solutes after cycle 2 recovery in fracture zone (layer 8) of heterogeneous model.

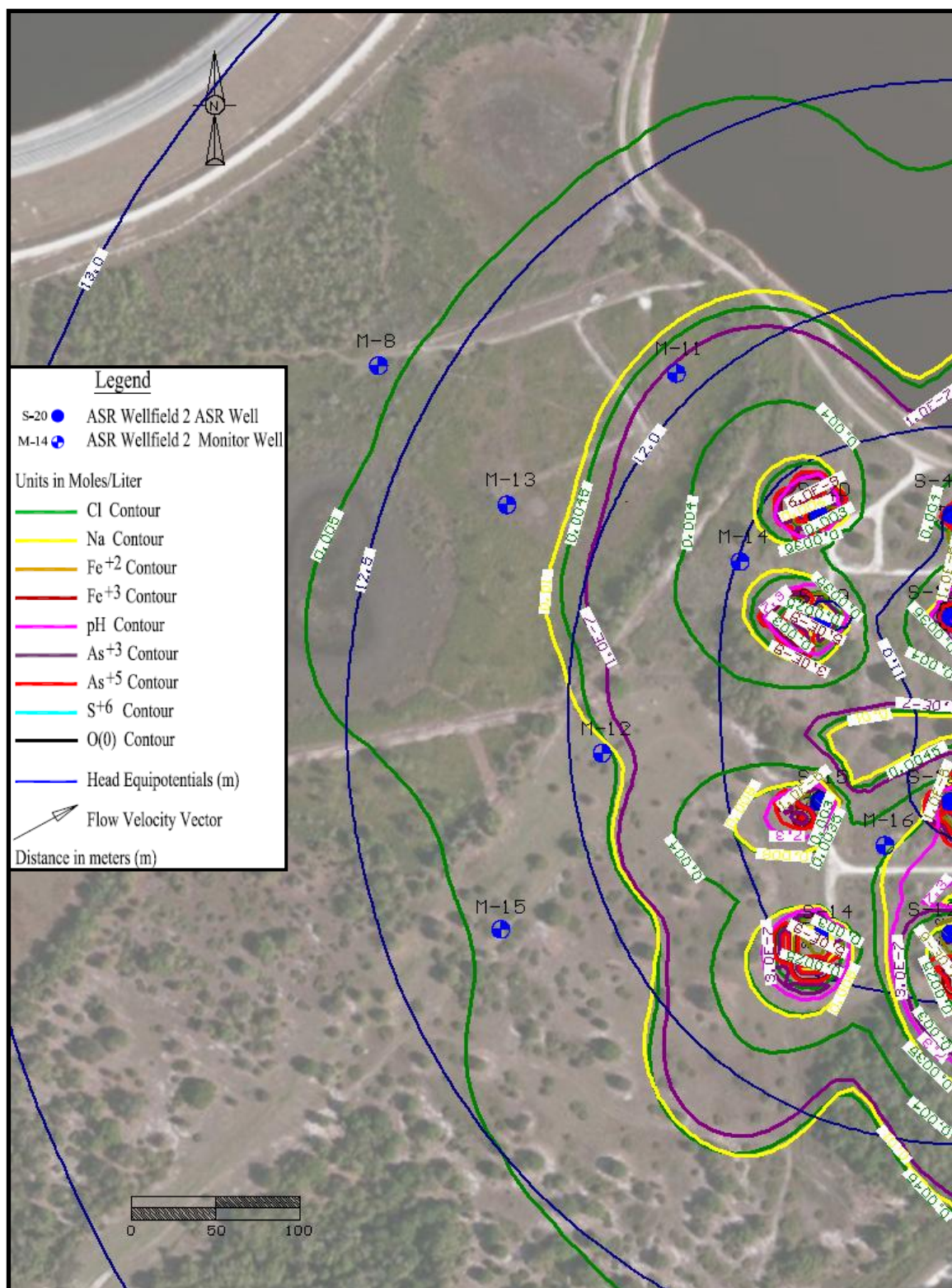


Figure 46. Simulation results of solutes after cycle 2 recovery in matrix (layer 13) of heterogeneous model.

the length of the recovery cycles are significantly less than the length of the recharge cycles.

6.2.2 Variable Arsenopyrite in Source Areas and High Flow Zones in

Discontinuum Models

The simulation results of the discontinuum model with low ($1\text{E-}6$ moles/liter) and vertically varying arsenopyrite concentrations in the vicinity of the northern ASR wells, and fracture zones with highly varying transmissivities are presented in **Figure 47** through **Figure 52** after cycle 2 (660 days). The arsenopyrite concentrations were vertically varied with higher concentrations assigned to most fracture zones, with exception of the high flow zones in the upper and lower parts of the aquifer. The fracture zones in the upper and lower parts of the aquifer were assigned low arsenopyrite concentrations in order to produce high DO and pH concentrations that extend beyond the closest monitoring well, M-14, and relatively low arsenic concentrations. These characteristics are observed at M-14. The simulation results for the typical matrix (layer 5) are presented in **Figure 47** after cycle 2 (660 days) and depict distributions of arsenate well within 200 ft of the ASR wells with arsenite concentrations generally less than $1\text{E-}7$ moles/liter more distant than M-14. The simulation results for the typical intermediate transmissivity flow zones (layer 8 and layer 14) presented in **Figure 48** and **Figure 49** depict distributions of arsenate that extend to M-14 with arsenite concentrations generally less than $1\text{E-}7$ moles/liter more distant than M-14. The simulated arsenic concentrations and distributions across the well field in the matrix and intermediate flow zones agree well with the observed data from the monitor well network. The simulated arsenic distributions in the upper high flow zones of layer 2 (**Figure 50**) and layer 4 (**Figure 51**)

show the occurrence of arsenate in the vicinity of S-14 and S-15; however, arsenate is essentially absent from the northern ASR wells S-19 and S-20. The highest flow zone in the model (layers 20 and 22) exhibits negligible concentrations of arsenate and arsenite (on the order of 10^{-8}); however, the concentrations of DO and pH values remain at high levels at significantly greater distances from the ASR wells than observed in any other layers. The contribution of these flow zones to observed concentrations in both ASR and monitoring wells could reduce arsenic concentrations and increase DO and pH levels, consistent with observed concentrations.

The simulated results of the fracture zone(s) in the lower part of the aquifer are presented on **Figure 52** and depict very high DO and pH within approximately 250 ft of the ASR wells, which is close agreement with observations at monitoring well M-14.

The simulated arsenic distribution across the well field ranges within the E-8 moles/Liter order of magnitude, indicating that all of the concentrations are less than the MCL for arsenic of 10 µg/l. The low initial source concentrations assigned to this layer in comparison to the other fracture zones significantly reduces the arsenic concentrations; however, this approach minimizes the attenuation of DO and pH, which is an observed characteristic of the data observed at M-14.

6.2.3 Simulation with Equilibrium-Controlled Linear Sorption

The results for the simulations of the discontinuum (**Figure 53**) models with linear equilibrium sorption exhibit distributions of arsenic that do not extend significantly beyond monitor well M-14. The initial concentrations of arsenopyrite are not decreased as in some previous simulations; therefore, the arsenic concentrations reach

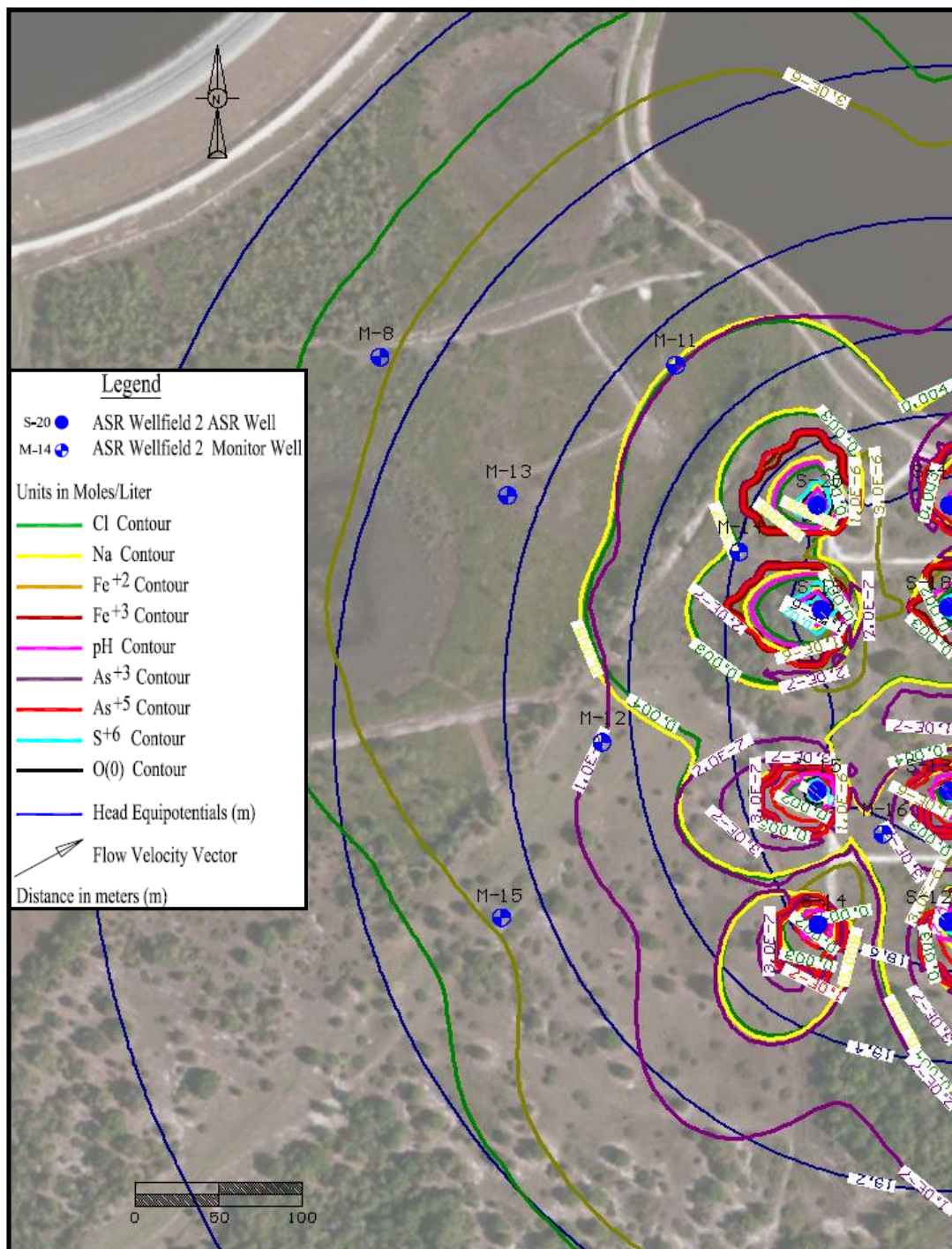


Figure 47. Solute distribution in matrix after recharge cycle 2 using high flow zones in upper and lower parts of aquifer, and variable distribution of initial arsenopyrite concentrations in the vicinity of ASR wells.

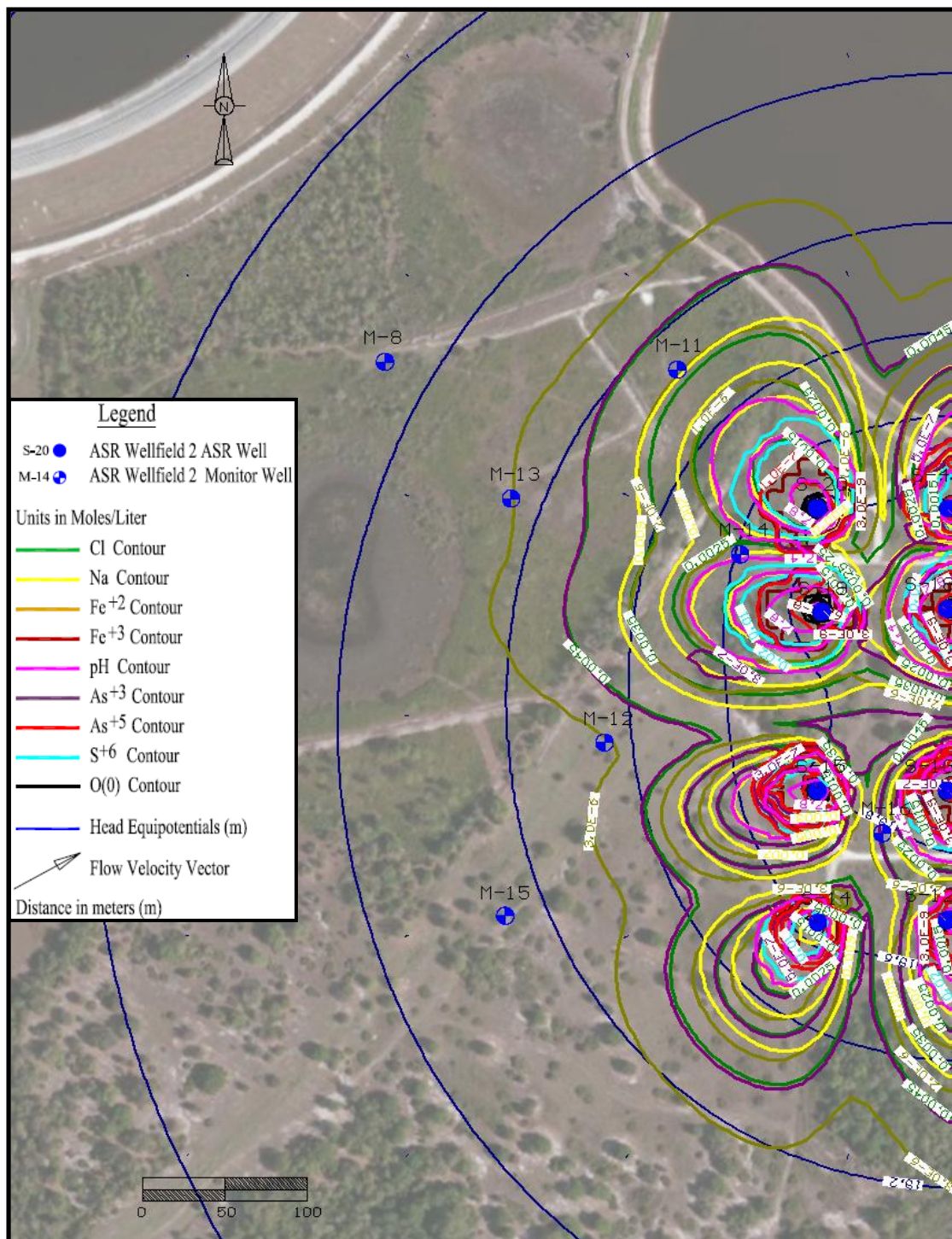


Figure 48. Solute distribution in intermediate flow zone (layer 8) after recharge cycle 2 using high flow zones in upper and lower parts of aquifer, and variable distribution of initial arsenopyrite concentrations in the vicinity of ASR wells.

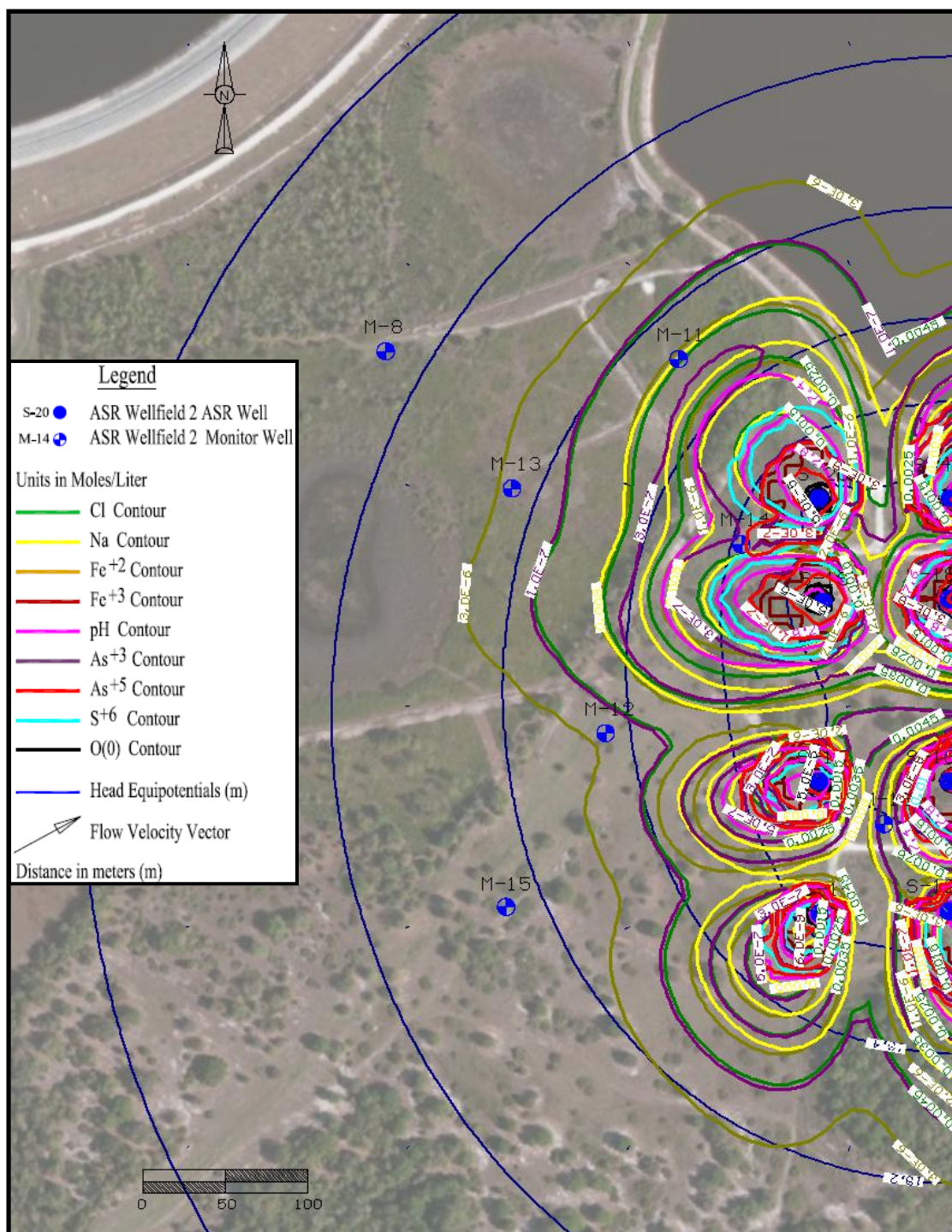


Figure 49. Solute distribution in intermediate flow zone (layer 14) after recharge cycle 2 using high flow zones in upper and lower parts of aquifer, and variable distribution of initial arsenopyrite concentrations in the vicinity of ASR wells with decreased source concentrations.

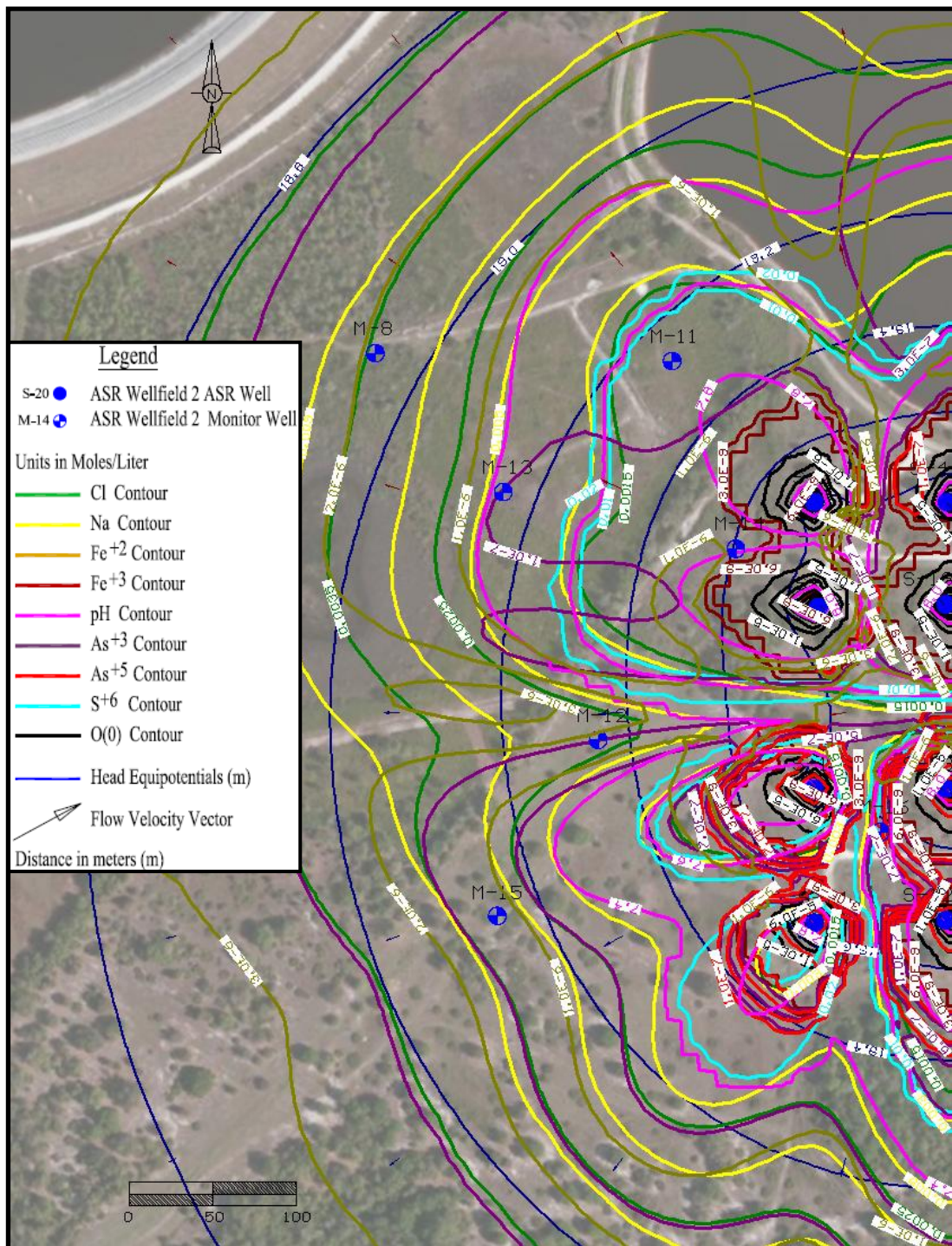


Figure 50. Solute distribution in high flow zone (layer 2; $K=61$ m/day) after recharge cycle 2 using high flow zones in upper and lower parts of aquifer, and variable distribution of initial arsenopyrite concentrations in the vicinity of ASR wells with decreased source concentrations.

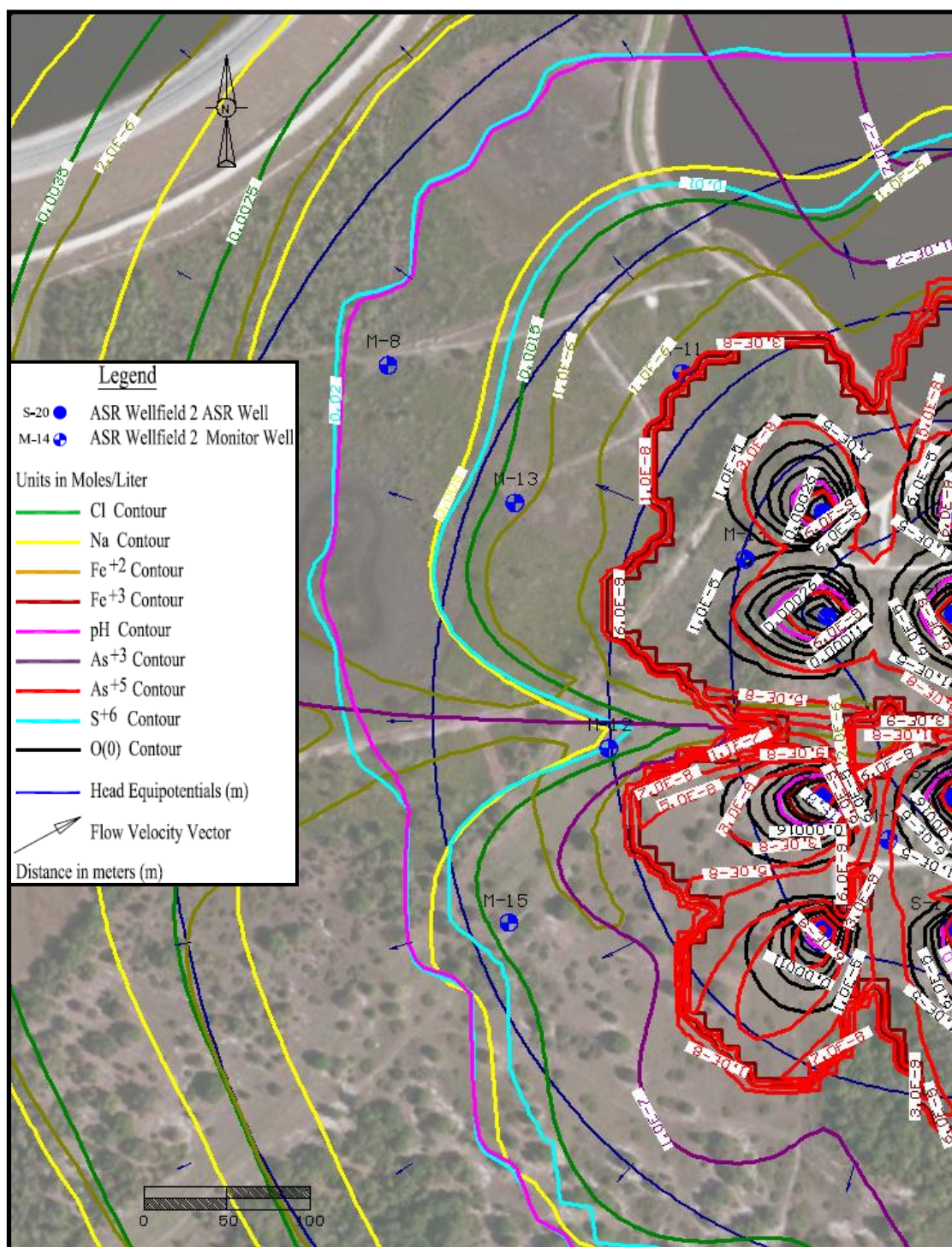


Figure 51. Solute distribution in high flow zone (layer 4; K=256) after recharge cycle 2 using high flow zones in upper and lower parts of aquifer, and variable distribution of initial arsenopyrite concentrations in the vicinity of ASR wells with decreased source concentrations.

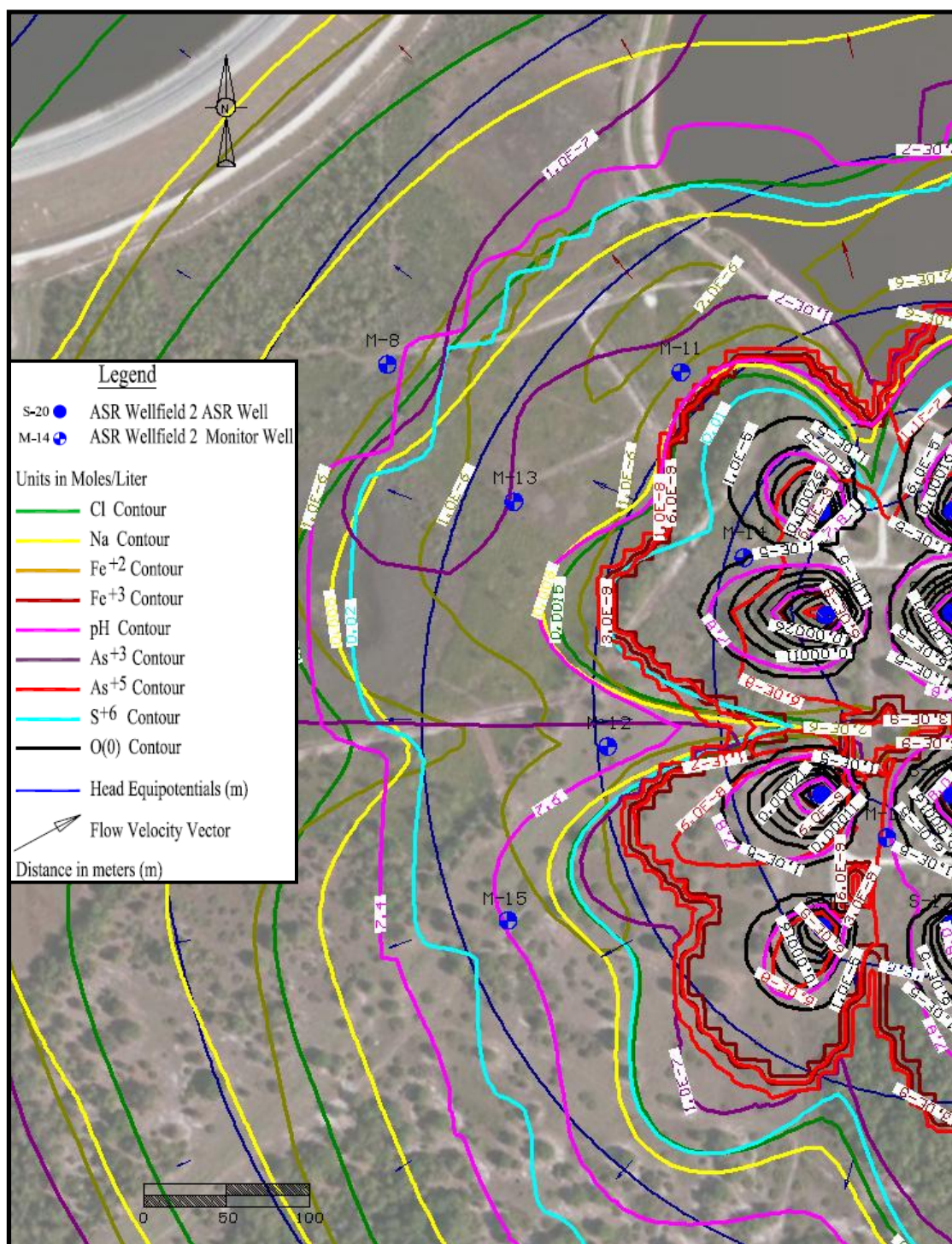


Figure 52. Solute distribution in high flow zone (layer 22) after recharge cycle 2 using high flow zones in upper and lower parts of aquifer, and variable distribution of initial arsenopyrite concentrations in the vicinity of ASR wells with decreased source concentrations.

approximately the same maximum concentrations of approximately $7\text{E-}7$ moles/liter in the immediate vicinity of each ASR well. Arsenate is the only species that occurs at significant concentrations and the K_d used has decreased the distributions to within approximately 200 ft of the ASR wells. Arsenite concentrations persist beyond the arsenate at concentrations less than $1\text{E-}7$ moles/Liter or slightly less than the arsenic MCL of $10\text{ }\mu\text{g/L}$. Arsenite has been sorbed to the extent that it has effectively been removed from the simulated interval (layer 8) of the aquifer, with the exception of minor concentrations beyond the arsenate plume. The horizontal extent of the arsenic distribution in all of the model results presented is generally quite consistent with observed data.

6.3 Stochastic Discontinuum Model Simulation Results

Simulation results are presented for preliminary and full-scale stochastic discontinuum models using FracMan. The preliminary models are set up to test the effects of fracture intensity, aperture size, fracture transmissivity, and secondary vertical fracture sets on groundwater and solute migration. Full-scale models are constructed with horizontal and vertical fracture networks simulated with FracMan. Simulation results for full-scale models include variations in chemical and reaction parameters, stochastic initial pyrite and arsenopyrite concentrations, variable initial arsenopyrite concentrations, and sorption characteristics are presented to evaluate their potential effects on arsenic distribution during ASR cycles.

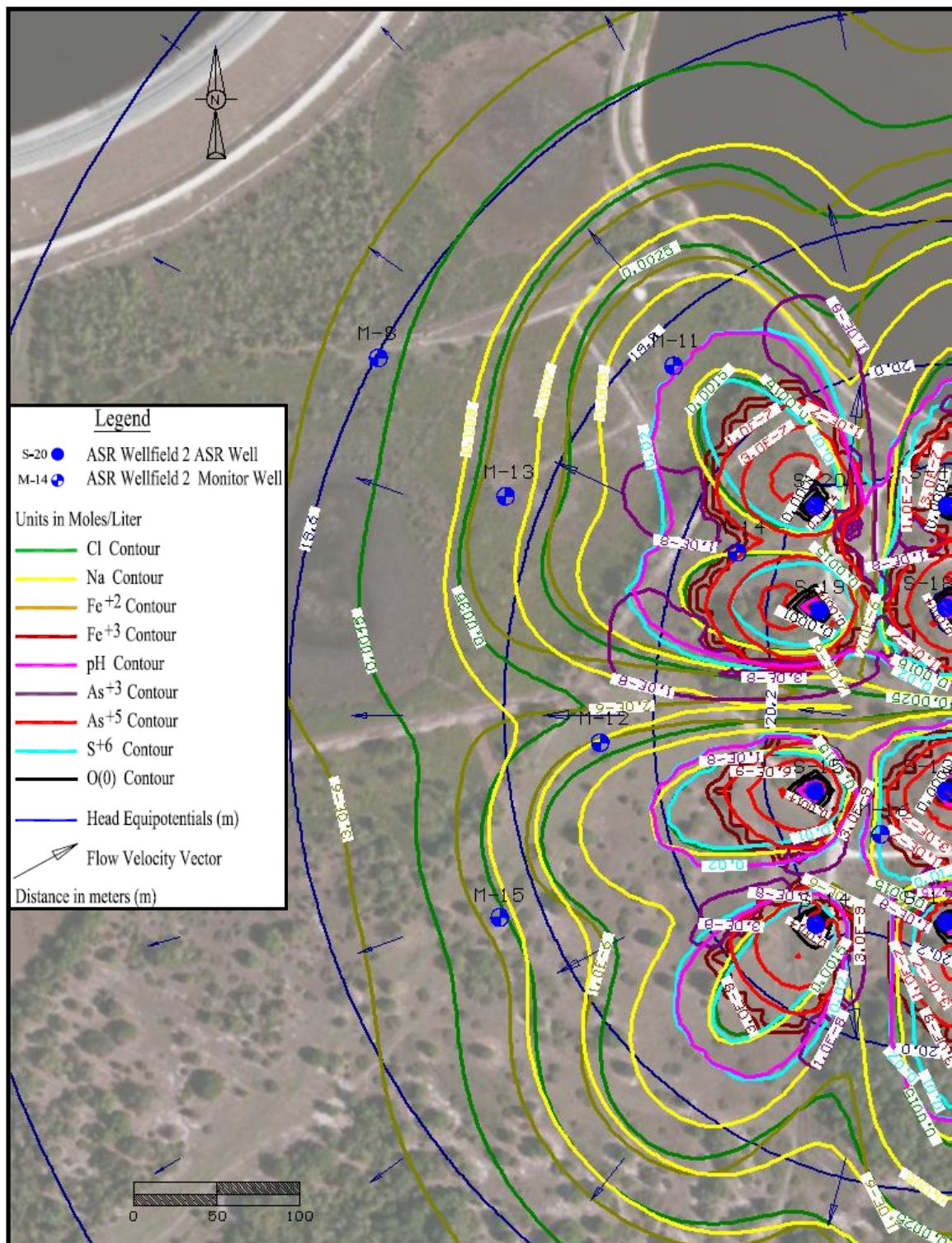


Figure 53. Solute distribution in discontinuum model (layer 8) after recharge cycle (660 days) with equilibrium sorption.

6.3.1 Stochastic Preliminary Discontinuum Model Simulations

Prior to running simulations with FracMan using grids from the previous dual porosity models, a preliminary three-layer model was constructed with a single fracture zone in order to evaluate the effects that fracture parameters have on the distribution of solutes during the simulation of a hypothetical ASR system. It should be noted that each set of fractures within the model layers is generated by the use of a different random number seed; therefore, although they may have many common fracture parameter values, the fracture, permeability, and storage parameter distributions are spatially unique. By using this approach, the effect on the system of varying one parameter can easily be determined and the variation in hydraulic parameter distributions that results from random lognormal distributions is also demonstrated.

The preliminary MODFLOW grids were imported into FracMan to evaluate the effects on solute distributions of varying fracture intensity, aperture size, fracture transmissivity, and secondary vertical fracture sets. In order to improve the convergence of the models, the storage terms were held constant with specific storage of 0.001 m^{-1} , total porosity of 0.35, effective porosity of 0.25, and specific yield of 0.20. The models simulated 360 days represented by 270 days of injection at 100 cubic meters per day followed by 90 days of recovery at 10 cubic meters per day. The models that compare the effects of fracture intensity, total fracture area per regional volume, included fracture intensity values of 0.5, 1.0, and $10 \text{ m}^2/\text{m}^3$. The transmissivity was calculated from the equation relating fracture size to transmissivity in FracMan is $A + Bx^C + De^{(Ex)}$, where A, B, C, D, and E are correlation coefficients where x = fracture size (equivalent fracture radius), $B = 0.1$, and $C = 2$. Aperture was also correlated to size where $B = 5\text{E-}5$. The

FracMan model results were imported into a PHT3D model that simulated the same chemical reactions used in the full scale models. Although a variety of solute parameters can be evaluated, only the conservative ion chloride was used for this analysis and comparisons. Due to the significant variation in transport distances of the chloride ion in some of these models after 270 days of recharge, the transport distances after 90 or 270 days are compared.

The location of the chloride concentration contour of 0.005 mole/liter after 90 days was used as the criterion to compare the simulation results. The models with fracture intensities of 0.5, 1.0, and 10 exhibit transport distances of >500 m, 434 m, and 144 m after 90 days, respectively, implying that groundwater velocity increases with decreasing fracture target intensities.

Models with fracture intensity of 1.0 were used to test the effects of apertures scaled to fracture size with B equal to 0.001, 0.01, and 0.1 in the above FracMan equation. In this case, the transmissivity was similar in the models and correlated to fracture size with $B = 0.01$ and $C = 2$. The models with B equal to 0.001, 0.01, and 0.1 exhibit chloride transport distances of 185 m, 75 m, and 60 m after 270 days, respectively. These results indicate that groundwater velocity and transport decreases with increased aperture width.

Variations in transmissivity of the fracture zone are tested with fracture intensity of 1.0 and transmissivities correlated to fracture size calculated using B and C in the FracMan equation, with values of B including 0.01, 0.1, and 1.0, and $C = 2.0$. The aperture width was maintained in all simulations at 0.01 m. The models with varying transmissivities correlated to fracture size using B equal to 0.01, 0.1, and 1.0 exhibit

chloride transport distances of 66 m, 75 m, and 60 m after 270 days, respectively.

Although the transport distances are generally similar, the intermediate transmissivity appears to result in a moderately greater chloride travel distance. The mean hydraulic conductivities calculated by FracMan using B equal to 0.01, 0.1, and 1.0 and C=2 are 82, 786, and 9177 m/day, respectively; therefore, the hydraulic gradient likely varies among these simulations. The storage terms are identical, so variations in these terms do not explain the variation in transport distances.

Three models were also compared each of which had horizontal and vertical sets of fractures. The horizontal fractures were assigned similar parameters consisting of target intensities of $1.0 \text{ m}^2/\text{m}^3$ and transmissivity correlated to fracture size with $B = 0.1$ and $C = 2$. The vertical fractures were assigned target intensities of 0.2, 0.5, and $0.9 \text{ m}^2/\text{m}^3$ and a similar transmissivity correlated to fracture size with $B = 2.5$ and $C = 2$. Unlike the previous models, the storage terms calculated by FracMan with lognormal distributions were used in these models. After 270 days, the chloride contour in the model with the vertical set of fractures characterized by the smallest fracture intensity of $0.2 \text{ m}^2/\text{m}^3$ occurred at 243 m from the recharge well compared to the models with target intensities of $0.5 \text{ m}^2/\text{m}^3$ (207 m) and $0.9 \text{ m}^2/\text{m}^3$ (123 m). These results are consistent with the former models indicating that mass transport distance is inversely proportional to intensity.

It should be noted that in addition to the lognormal distribution of hydraulic conductivities generated by FracMan, all of the specific storage values exhibit the same distributions; therefore, the results for porosity and specific storage vary widely. The use of widely varying storage parameters in the typical numerical model is an uncommon

feature. With the above models, the large spatial variation in porosity and specific storage within the fracture zones does not appear to affect the stability or convergence of the flow and transport models; however, the use of such widely varying values appears to have a significant effect on the run times of the full-scale models, resulting in run times on the order of weeks with the 3.2 GigaHertz (GHz) desktop personal computer with 6 Gigabytes (GB) of random access memory (RAM) used for this study.

6.3.2 Stochastic Discontinuum Model Simulations

The MODFLOW models constructed with fracture zones generated with FracMan are generally characterized by fractures with 0-degree trend, 90-degree plunge, target intensities using P32 or estimates of fracture intensity of square meter per cubic meter less than one, lognormal fracture size distribution with mean of 100 meters and standard deviation of 20 meters, and aperture, transmissivity, and storage correlated to fracture size. Although the models typically simulate horizontal fracture zones, known vertical sets of northeast-southwest and northwest-southeast fault zones are also simulated in order to understand the potential vertical flow and transport that could occur if such features intersected the site.

The results of the model constructed with horizontal fracture zones after two recharge cycles or 660 days are depicted on **Figure 54** for layer 8 (fracture zone) and **Figure 55** for layer 12 (fracture zone). The maximum arsenate concentrations at the ASR wells are approximately $7\text{E-}7$ moles/Liter and the distributions to $1\text{E-}7$ moles/Liter extend slightly beyond M-14, located approximately 200 ft from ASR wells S-19 and S-20. The ferric iron distribution is approximately similar. The arsenate distributions associated with ASR wells S-14 and S-15 represent smaller areas and the extent of

arsenate appears to be approximately 250 ft from the ASR wells in these areas. The arsenate plumes are very consistent with observed distributions of arsenic. Arsenite extends approximately 700 ft beyond the arsenate distribution to a concentration of $1\text{E-}7$ moles/Liter. This extent of arsenic is not observed at this distance from the ASR wells; however, this distribution is not identical among the fracture zones. Although the arsenic characteristics in both of these fractures are generally similar, it should be noted that all of the other parameters exhibit significantly variable distribution patterns reflecting the random nature of the stochastic process. The maximum DO concentrations of approximately 0.0004 moles/Liter are observed essentially at the ASR wells and rapidly decrease with distance from the ASR wells. The range of DO concentrations is similar to observed values; however, the radial extent of the DO from the ASR wells is not consistent with the observations at M-14, which range from approximately 0.0001 to 0.0002 moles/Liter. In contrast, relatively high pH values extend to significant distances from the ASR wells consistent with observations from M-14. Although similar trends are apparent between these results and the preceding heterogeneous models, these results depict significantly more variability in the spatial distribution of all solutes. The difference in the solute distributions between the discontinuum dual porosity model and these DFN stochastic models results from the strong variation in the hydraulic conductivities assigned to the cells and the resultant variation of flow velocities and preferred transport paths. These factors create more variability in the solute concentrations that occur at each location throughout the horizontal and vertical extent of the model than would occur in the discontinuum model; resulting in increased heterogeneities and apparent anomalies within the plume.

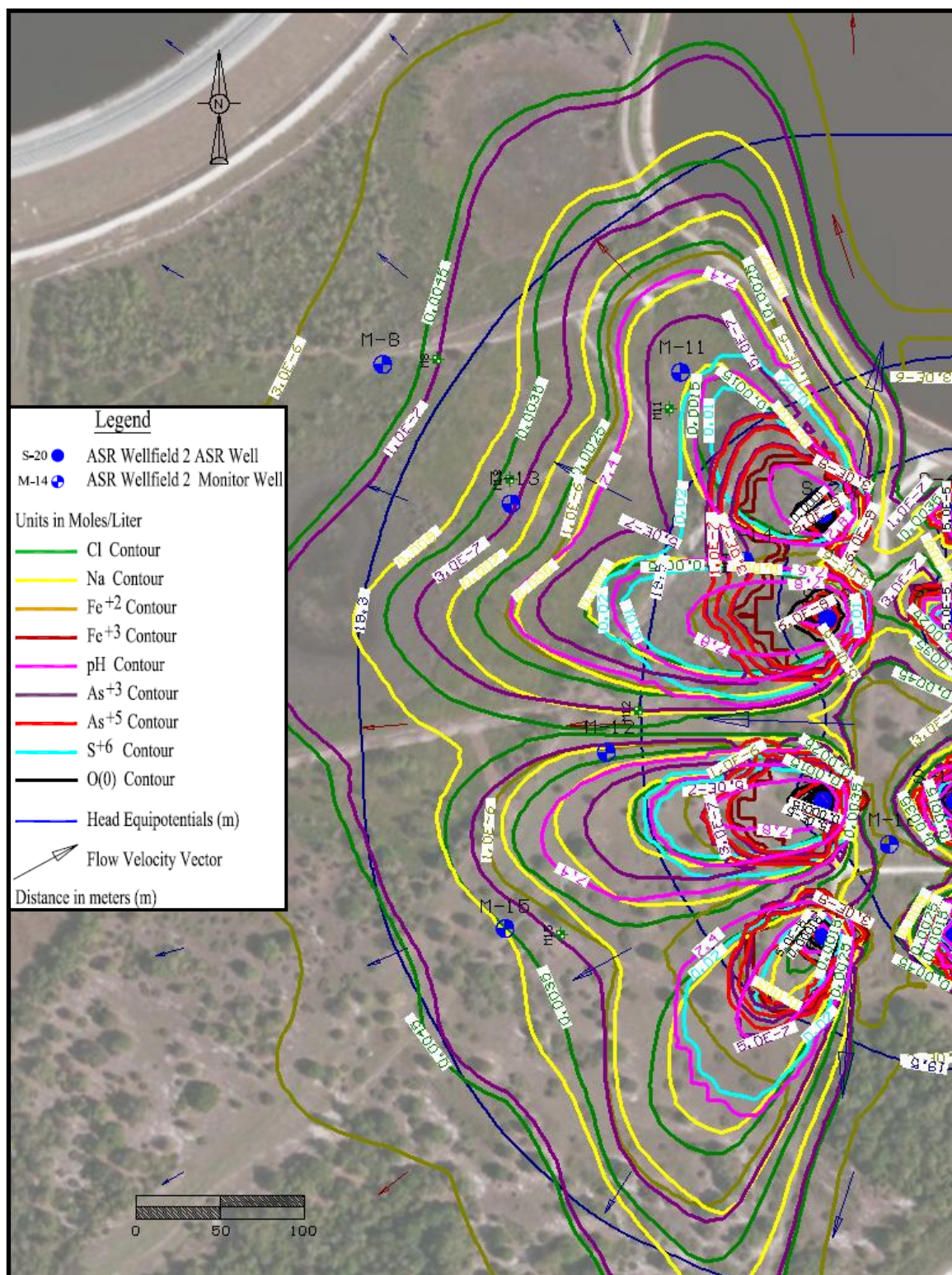


Figure 54. Simulation results of solutes after cycle 2 recharge in fracture (layer 8) of FracMan DFN model with horizontal fractures.

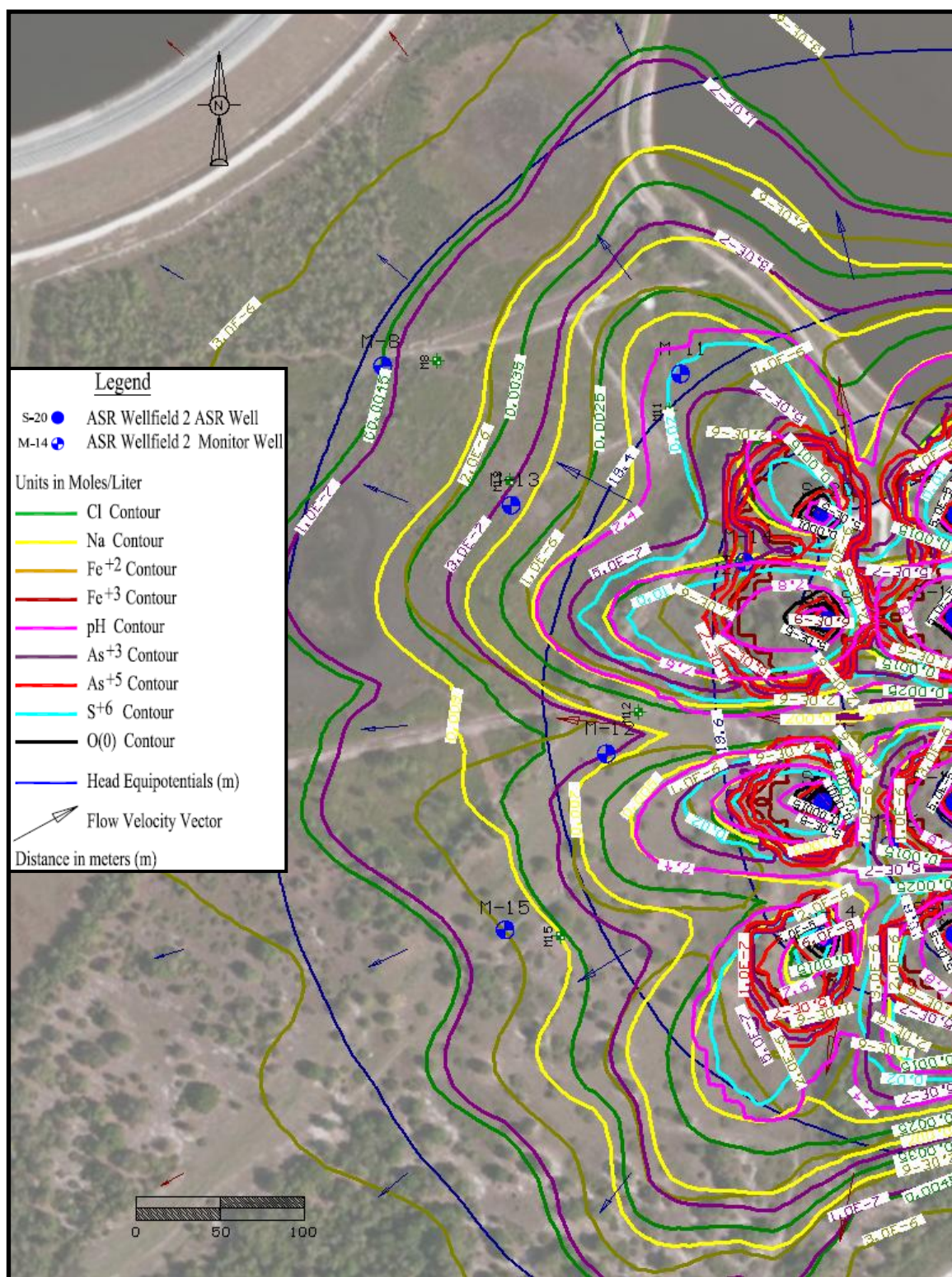


Figure 55. Simulation results of solutes after cycle 2 recharge in fracture (layer 12) of FracMan DFN model with horizontal fractures.

The results of the model constructed with both horizontal and vertical fracture zones shown on **Figure 56, Figure 57, and Figure 58** for a fracture zone and on **Figure 59** for a matrix zone are generally similar to the results for the preceding DFN model that only simulates horizontal fractures (**Figure 54 and Figure 55**). A distinctive difference exists between the anisotropy of the arsenic distributions of layer 8 from each model. The arsenic distributions of ASR wells S-19 and S-20 shown on **Figure 51** are preferentially elongated indicating the influence of the vertical fractures by the creation of preferential flow and transport pathways. These distributions result in low arsenic concentrations in the immediate vicinity of monitor well M-14, although the plumes from S-19 and S-20 extend significantly beyond M-14. In contrast, in layer 16 of the model (**Figure 58**), the arsenic in the fracture zone is distributed more evenly about and in closer proximity to ASR wells S-19 and S-20 attesting to the variability of the stochastic lognormal permeability field within each set of fractures. The arsenate and arsenite distributions in the vicinity of monitoring well M-14 are in close agreement with the observed data. The low permeability matrix layer 13 (**Figure 59**) exhibits a relatively small area of arsenate around each ASR well as a result of the limited oxidation of pyrite and migration of arsenic. The arsenite distribution extends farther from the ASR wells in this matrix layer, which is inconsistent with the low permeability of this interval and; consequently could be influenced by the intersecting vertical fracture facilitating vertical transport along variable pathways.

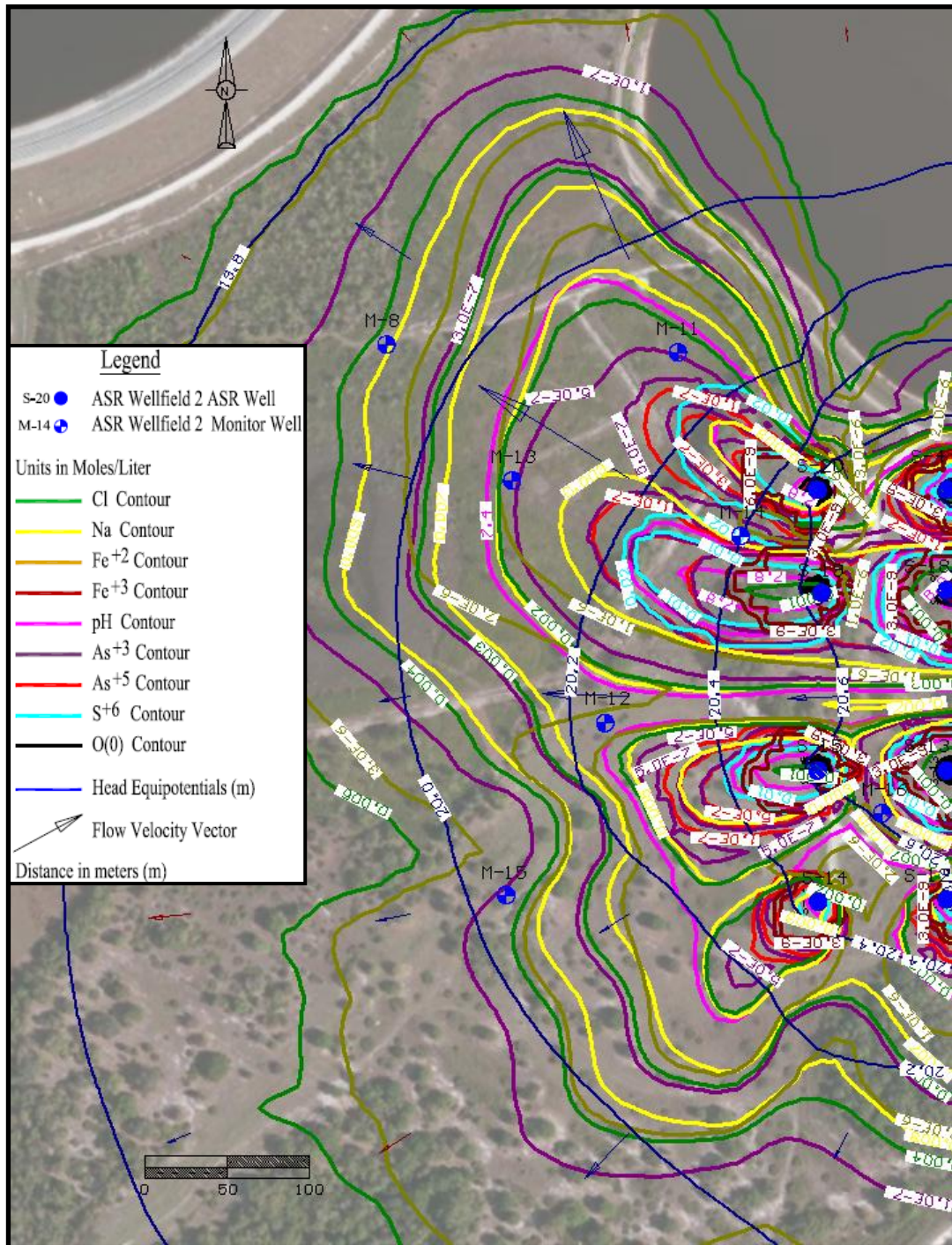


Figure 56. Simulation results of solutes in DFN FracMan model with horizontal, NE, and NW fractures after recharge cycle 2; layer 8, 660 days

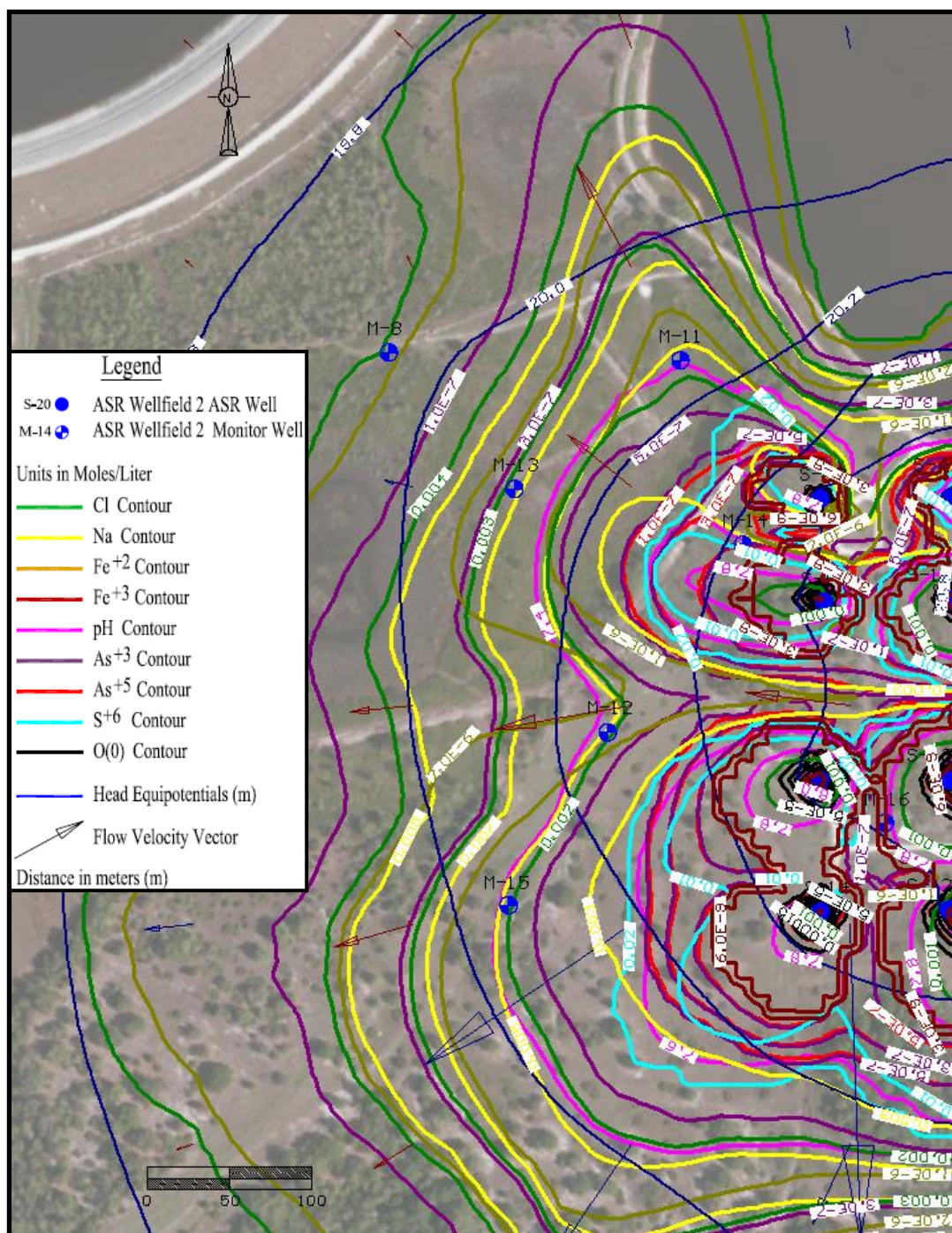


Figure 57. Simulation results of solutes in DFN FracMan model with horizontal, NE, and NW fractures after recharge cycle 2; layer 12, 660 days

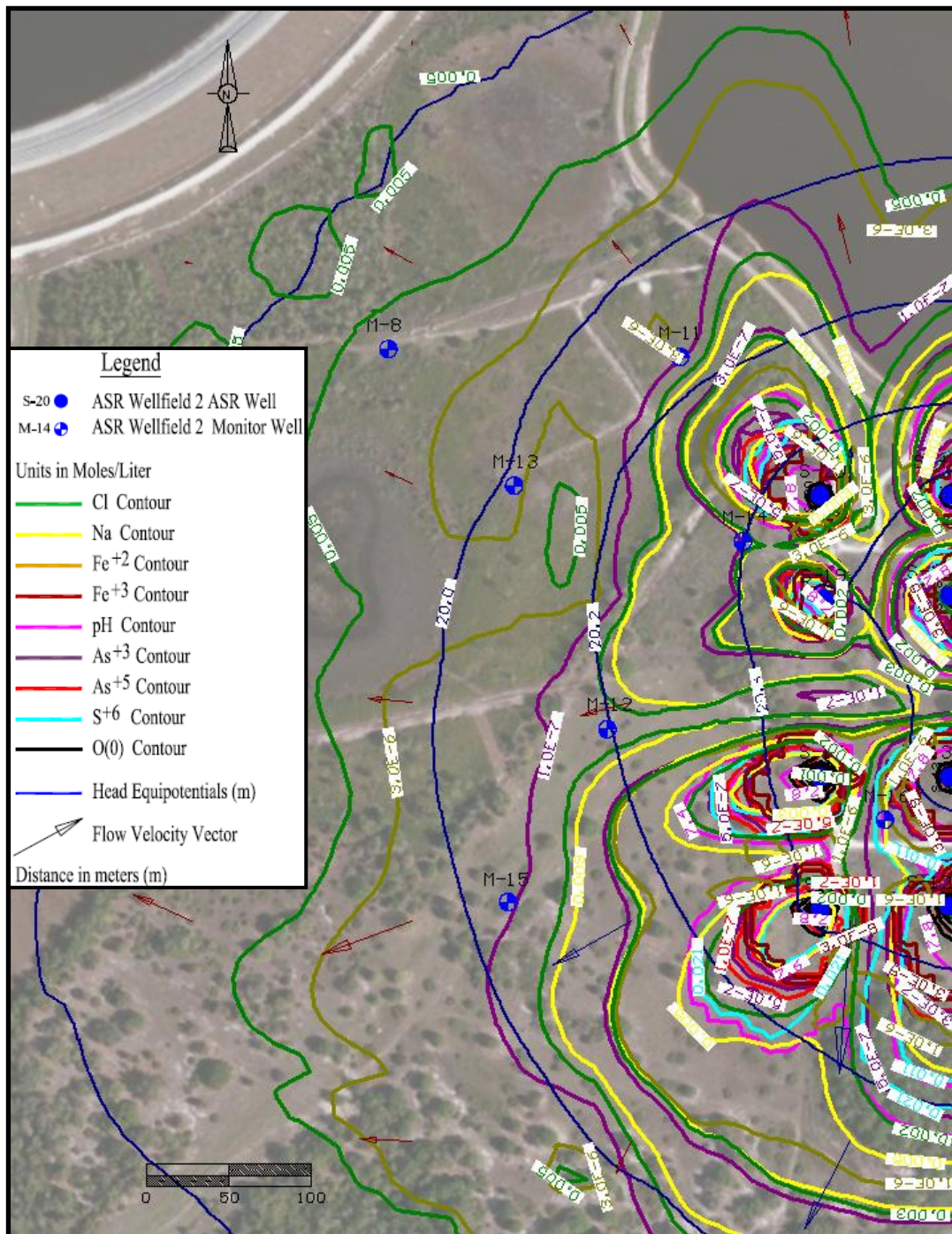


Figure 58. Simulation results of solutes in DFN FracMan model with horizontal, NE, and NW fractures after recharge cycle 2; layer 16, 660 days.

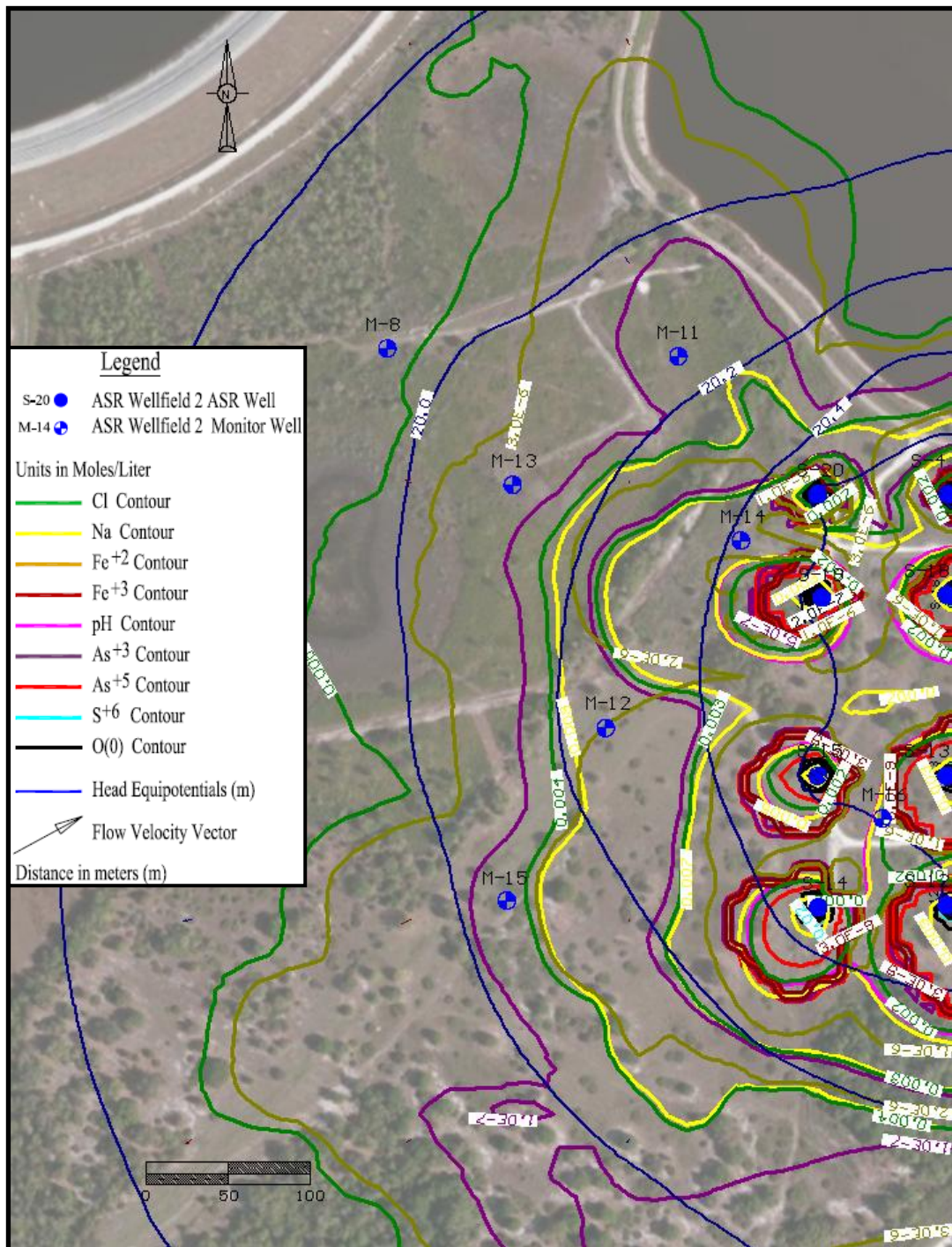


Figure 59. Simulation results of solutes in DFN FracMan model with horizontal, NE, and, NW fractures after recharge cycle 2; layer 13 (matrix), 660 days.

6.3.3 Simulation with Equilibrium-Controlled Sorption in the Stochastic Model

The results for the simulations of the stochastic discontinuum DFN (**Figure 60**) models with linear equilibrium sorption exhibit distributions of arsenic that do not extend significantly beyond monitor well M-14. The initial concentrations of arsenopyrite are not decreased as in some previous simulations; therefore, the arsenic concentrations reach approximately the same maximum concentrations of approximately $7\text{E-}7$ moles/liter in the immediate vicinity of each ASR well. Arsenate is the only species that occurs at significant concentrations and the K_d used has decreased the distributions to within approximately 200 ft of the ASR wells. Arsenite concentrations persist beyond the arsenate at concentrations less than $1\text{E-}7$ moles/Liter or slightly less than the arsenic MCL of $10\text{ }\mu\text{g/L}$. Arsenite has been sorbed to the extent that it has effectively been removed from the simulated interval (layer 8) of the aquifer, with the exception of minor concentrations beyond the arsenate plume. The horizontal extent of the arsenic distribution in all of the model results presented is generally quite consistent with observed data.

6.3.4 Stochastic Discontinuum Model Simulations - Variable Storage Parameters

Simulation results of the model containing stochastically generated hydraulic conductivity and storage parameters are presented for fracture layers 8 and 12 on **Figure 61** and **Figure 62**, respectively. All dissolved inorganic species including arsenic have migrated farther from the ASR wells in both implied fracture zones compared to the models using constant average specific storage and porosities (**Figure 54** and **Figure 55**). In addition, **Figure 61** depicts apparently isolated distributions of arsenic that appear anomalous compared to previous model results. In layer 8 (**Figure 61**), arsenate is

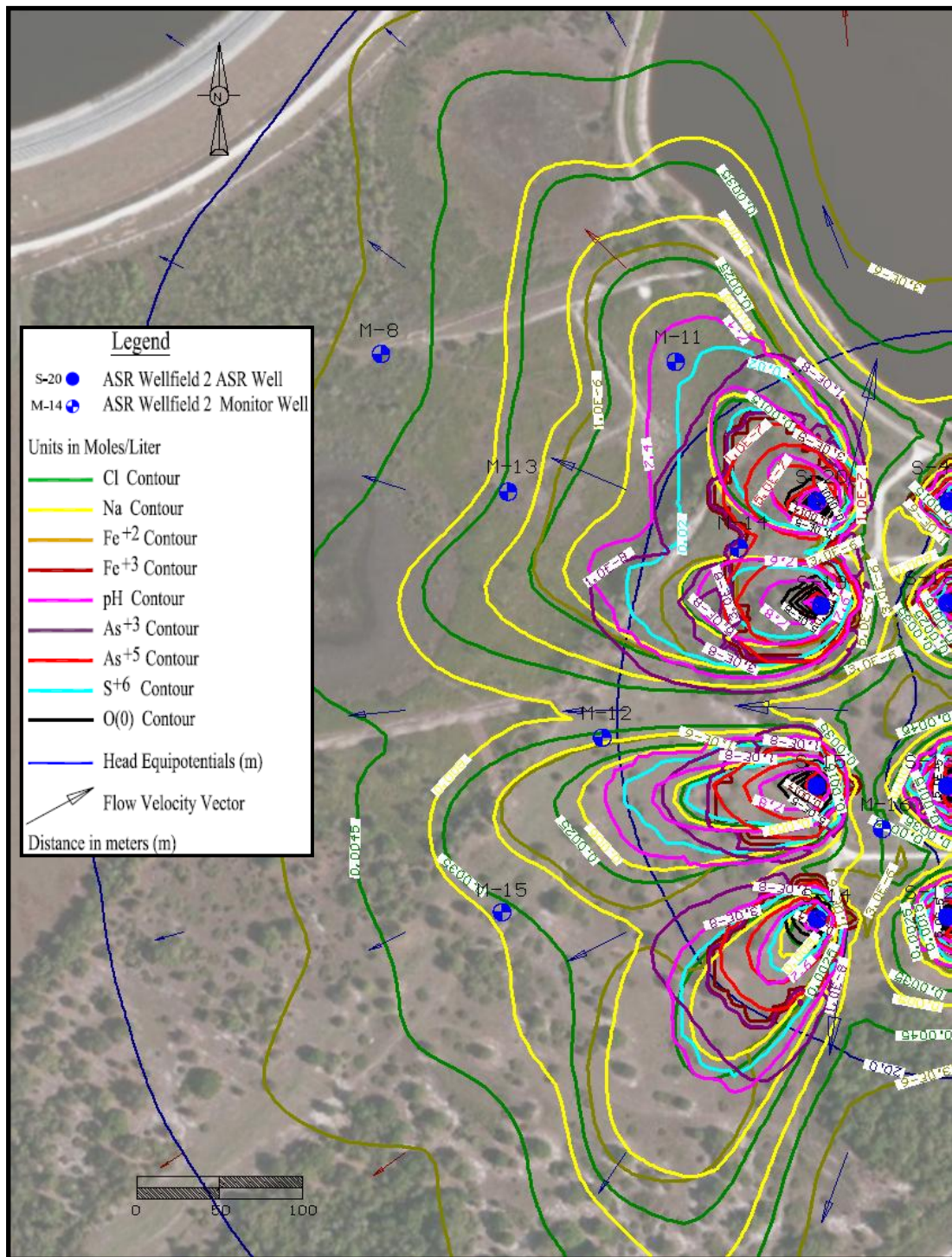


Figure 60. Solute distribution in stochastic DFN model (layer 8) after recharge cycle (660 days) with equilibrium sorption.

simulated as occurring at approximately 200 m from the ASR wells at the MCL concentration and in layer 12 (**Figure 62**) arsenate is simulated as occurring at approximately 300 meters from the ASR wells. The hydraulic heads from this model are approximately four meters less than the heads for the model using average storage parameters.

The specific storage values were reduced by an order of magnitude for layers 8 and 12 to make them more consistent with the average calibrated value and the simulations are presented on **Figure 63** and **Figure 64**, respectively. The solute distributions extend slightly farther from the ASR wells compared to the model with average storage parameters; however, this model with variable storage parameters is generally more similar to models with average storage parameters and the arsenate plume only extends approximately 75 meters from the ASR wells. With the reduction in specific storage, the hydraulic heads are approximately 2.5 meters less than models with average storage parameters. Specific storage was further reduced by a factor of 30, which resulted in significant improvement of similarity of heads (approximately one meter) to previous models with average values of specific storage.

Fracture layer 4 was also assigned the variable storage parameters calculated with FracMan and specific storage was further reduced by a factor of 30, which significantly improved the hydraulic head elevations in comparison to calibrated values. In addition, the stochastically generated hydraulic conductivity distribution was increased by a factor of 3.25 in order to make the average value approximately 250 m/day. This simulation includes the same background arsenopyrite concentration as the preceding models in this

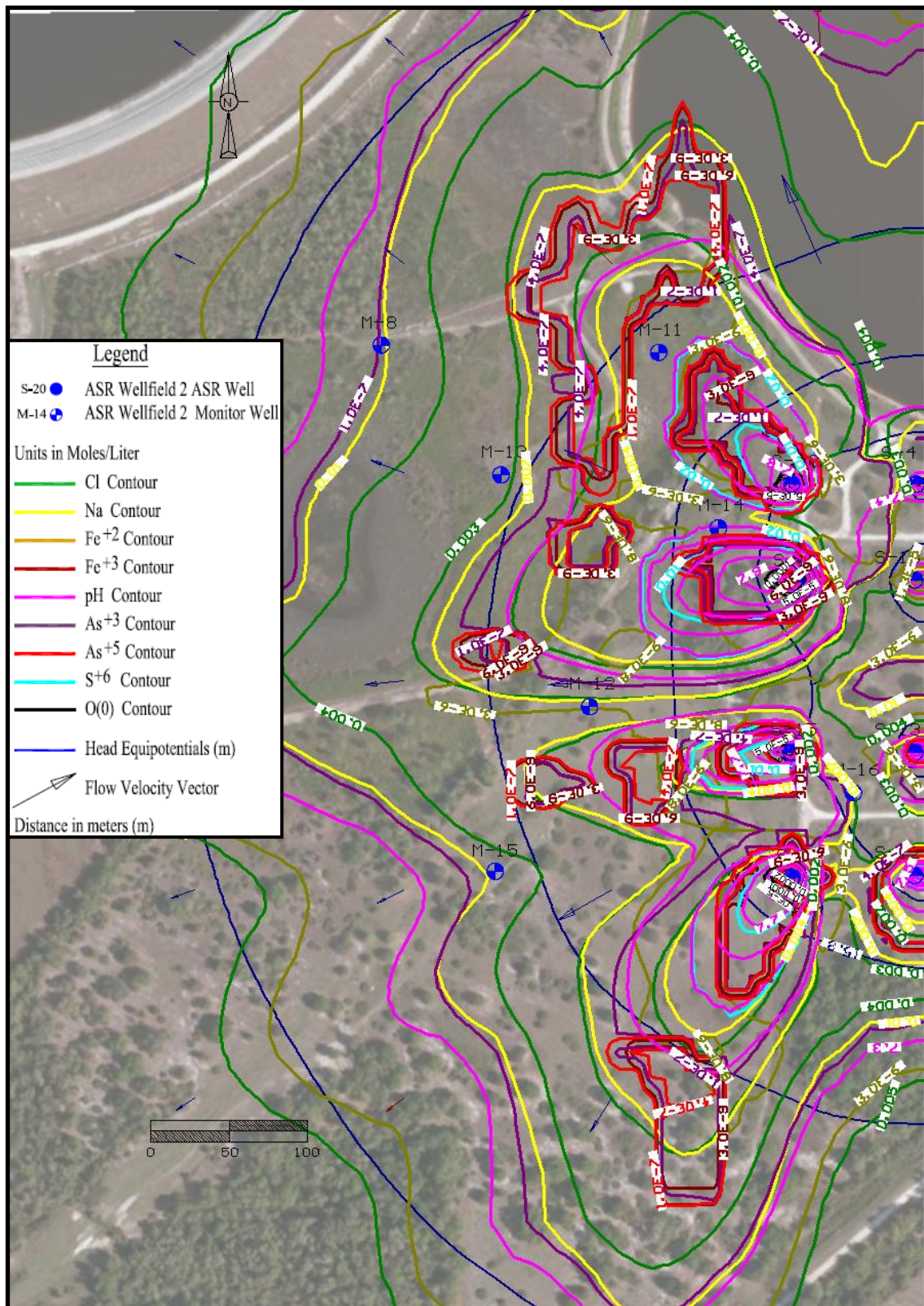


Figure 61. Simulation results of solutes after cycle 2 recharge in fracture (layer 8) of FracMan DFN model with horizontal fractures, including stochastically generated storage parameters.

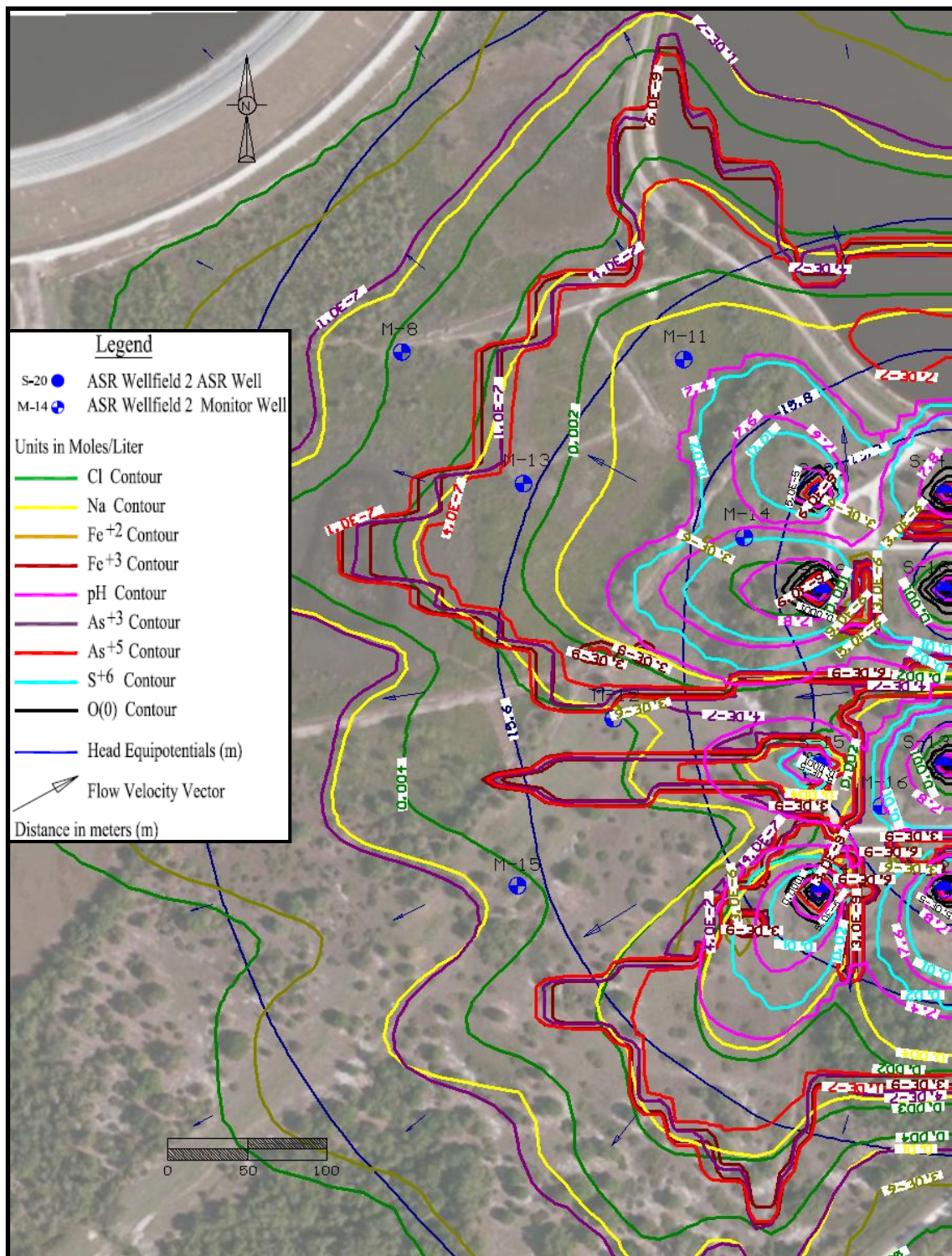


Figure 62. Simulation results of solutes after cycle 2 recharge in fracture (layer 12) of FracMan DFN model with horizontal fractures, including stochastically generated storage parameters.

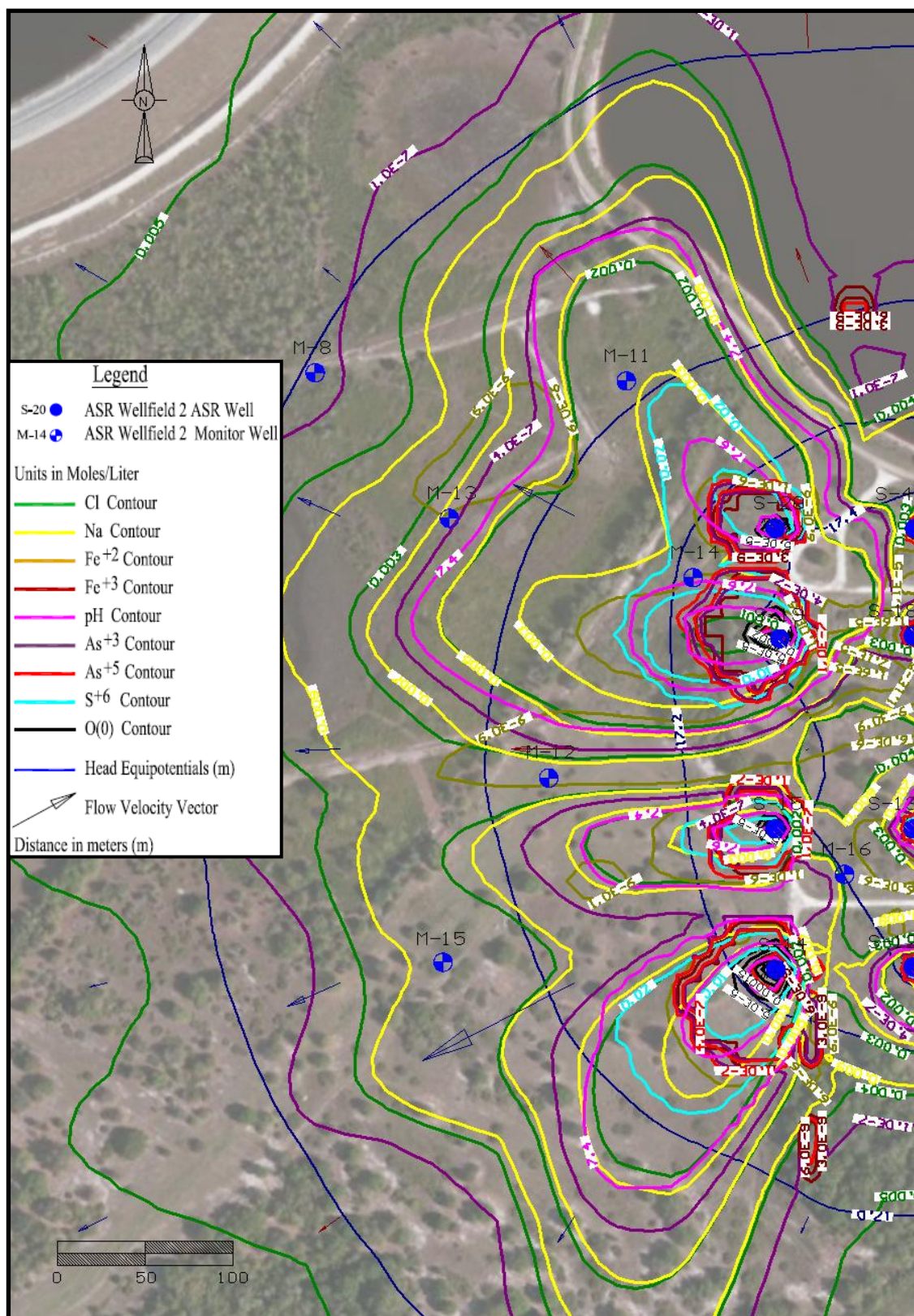


Figure 63. Simulation results of solutes after cycle 2 recharge in fracture (layer 8) of FracMan DFN model with horizontal fractures, including stochastically generated storage parameters reduced by 10x.

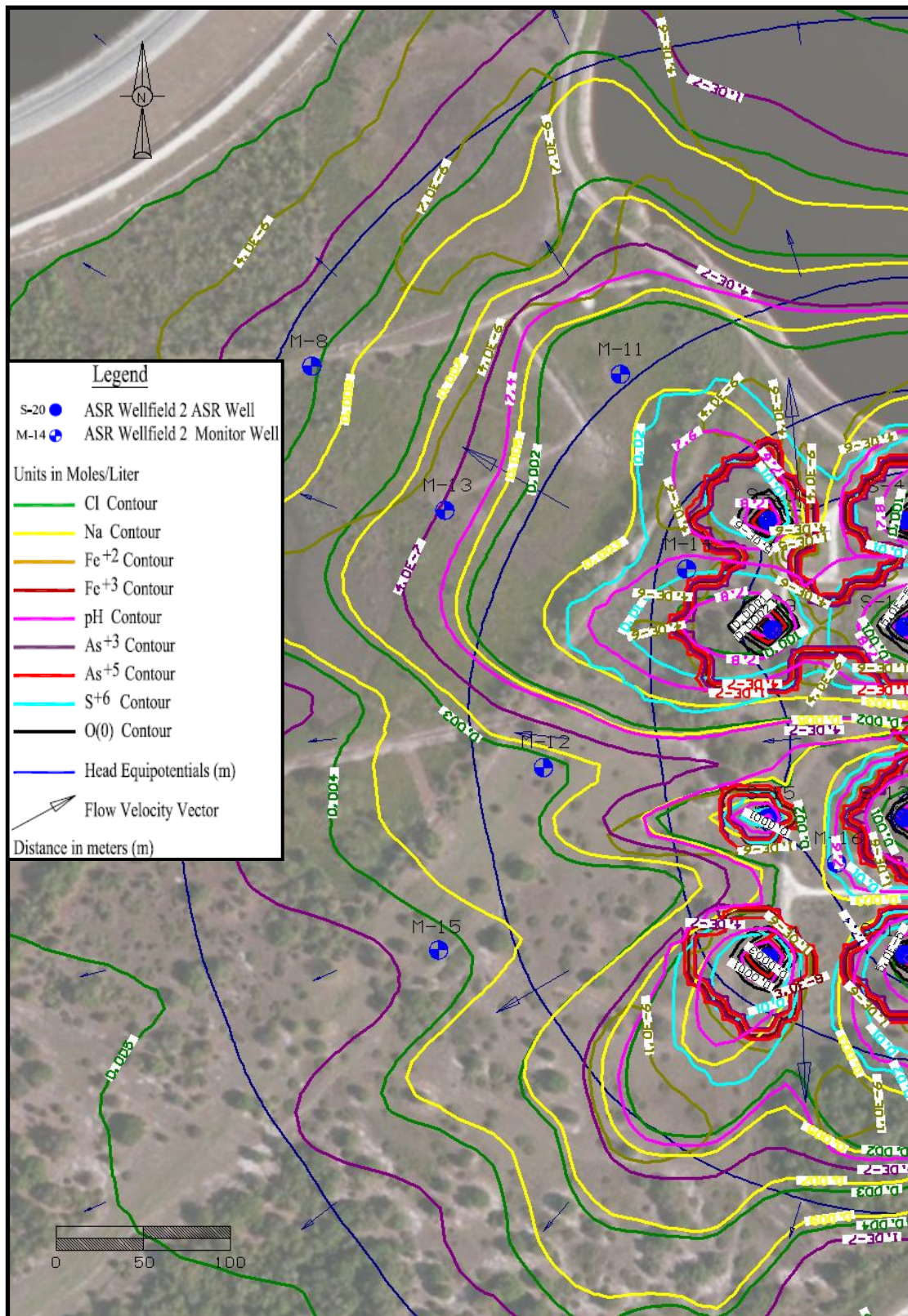


Figure 64. Simulation results of solutes after cycle 2 recharge in fracture (layer 12) of FracMan DFN model with horizontal fractures, including stochastically generated storage parameters reduced by 10x.

section. The results of this simulation are presented on **Figure 65** and **Figure 66** after simulation periods of 120 and 270 days, respectively, within the first recharge cycle. This model was subsequently revised by decreasing the background arsenopyrite concentration in the vicinity of the ASR wells from 0.1 to $1\text{e-}6$ mol/liter, with the results presented on **Figure 67** and **Figure 68**, after simulation periods of 120 and 270 days, respectively, within the first recharge cycle.

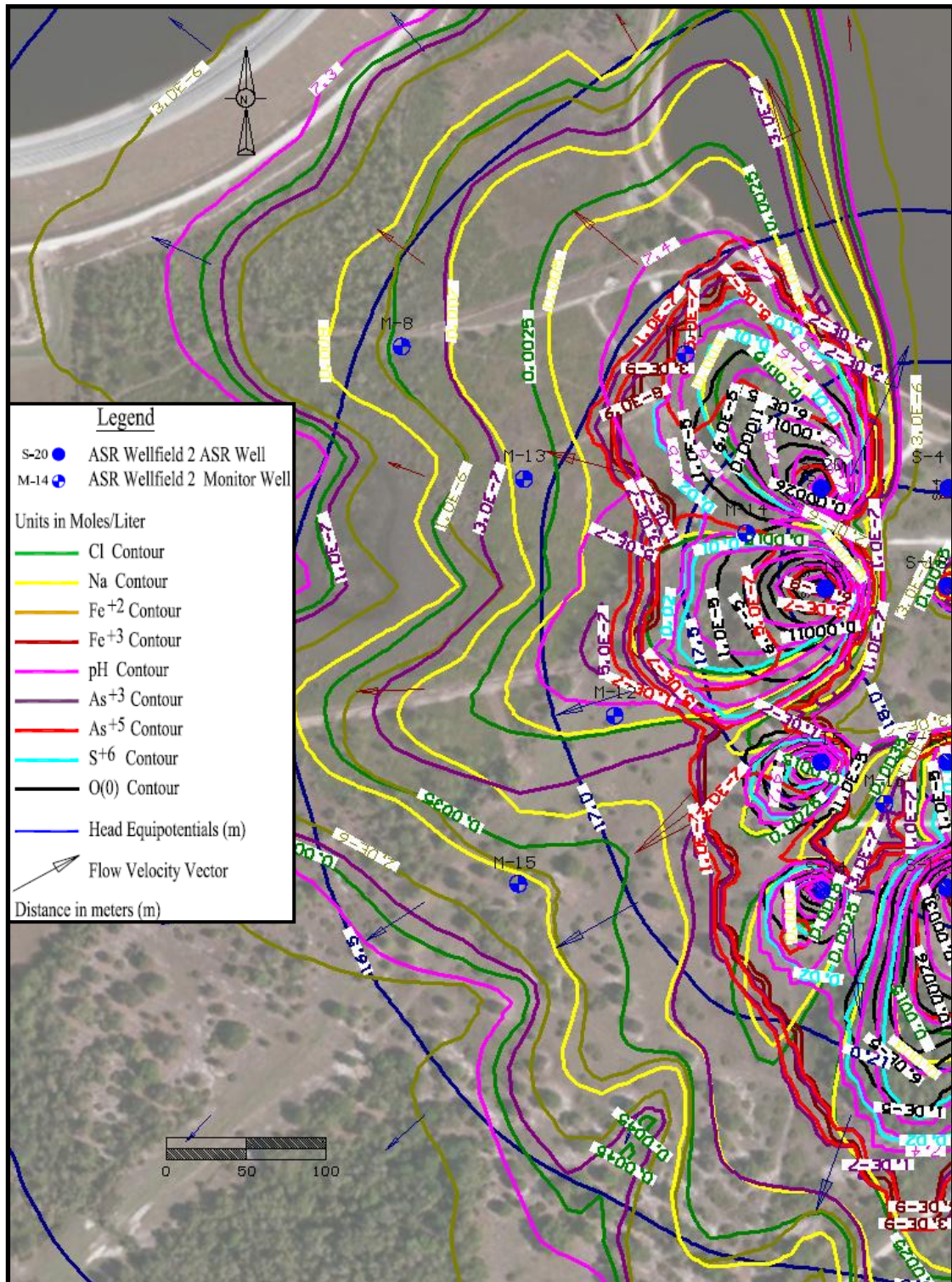


Figure 65. Simulation results of solutes after 120 days of cycle 1 recharge in fracture (layer 4) of FracMan DFN model with horizontal fractures, including stochastically generated K(x3.25) and specific storage reduced by 30x.

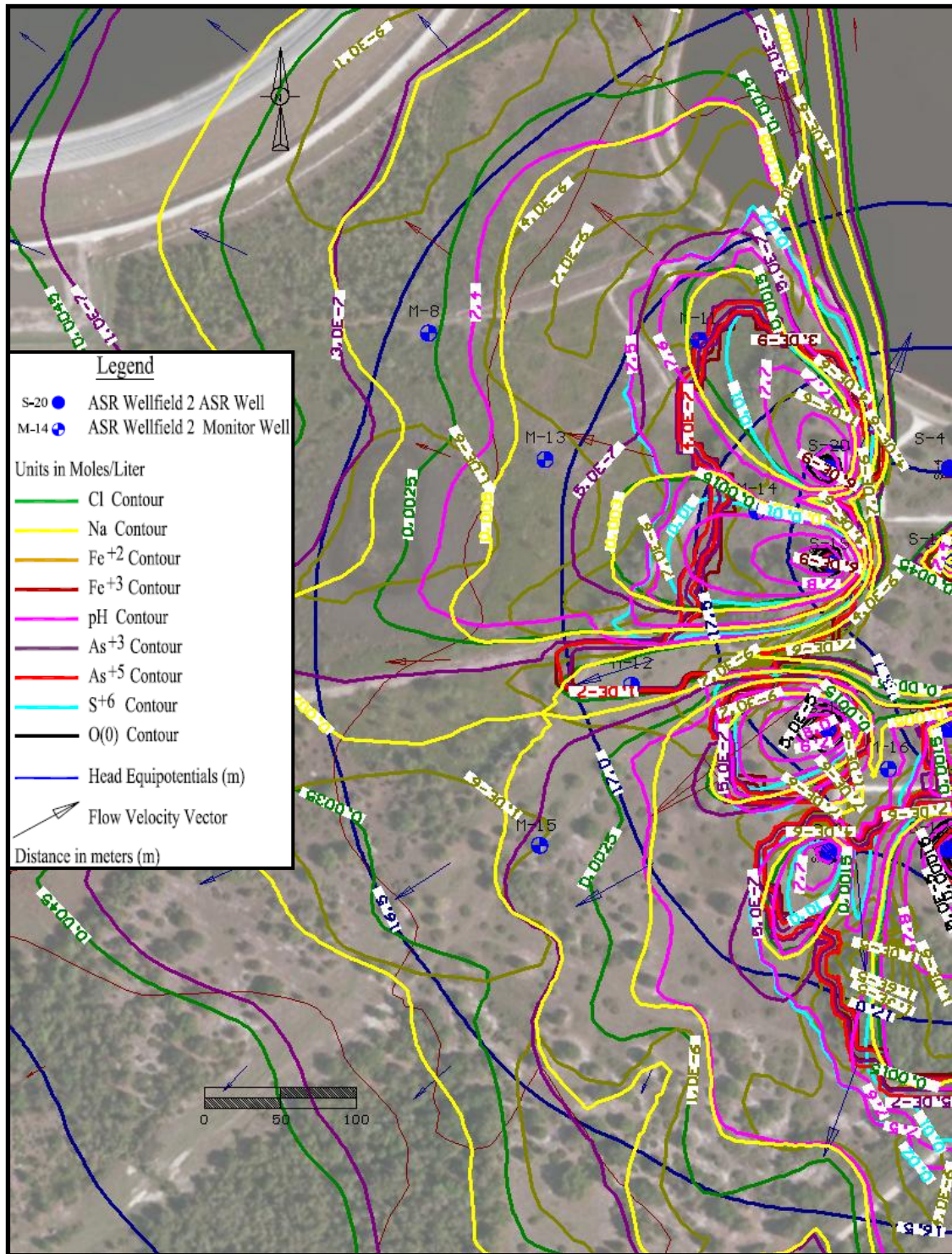


Figure 66. Simulation results of solutes after cycle 1 (270 days) recharge in fracture (layer 4) of FracMan DFN model with horizontal fractures, including stochastically generated $K(x3.25)$ and specific storage reduced by 30x.

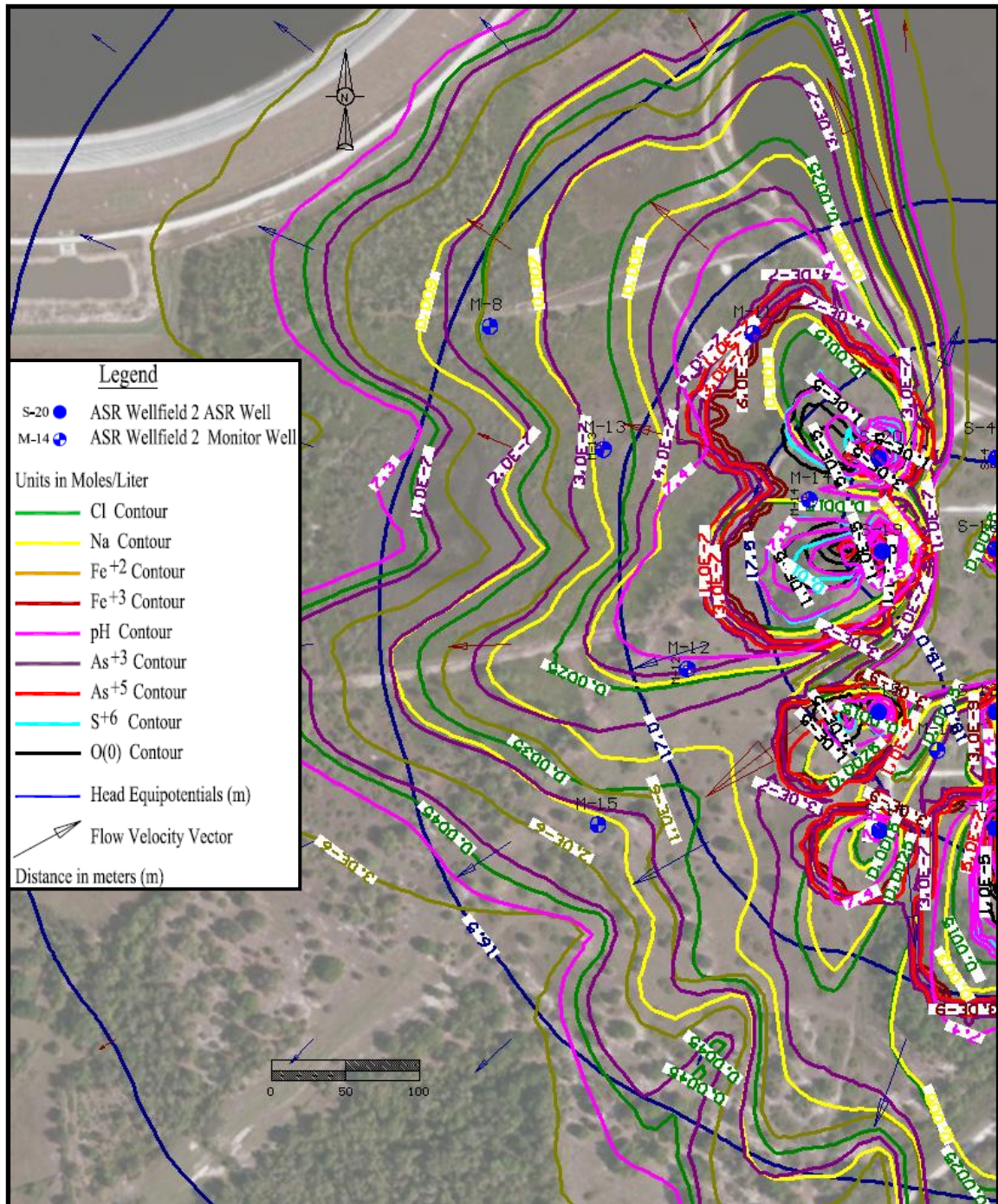


Figure 67. Simulation results of solutes after 120 days of cycle 1 recharge in fracture (layer 4) of FracMan DFN model with horizontal fractures, including stochastically generated K(x3.25); specific storage reduced by 30x; ASR wells source area arsenopyrite 1e-6 moles/liter.

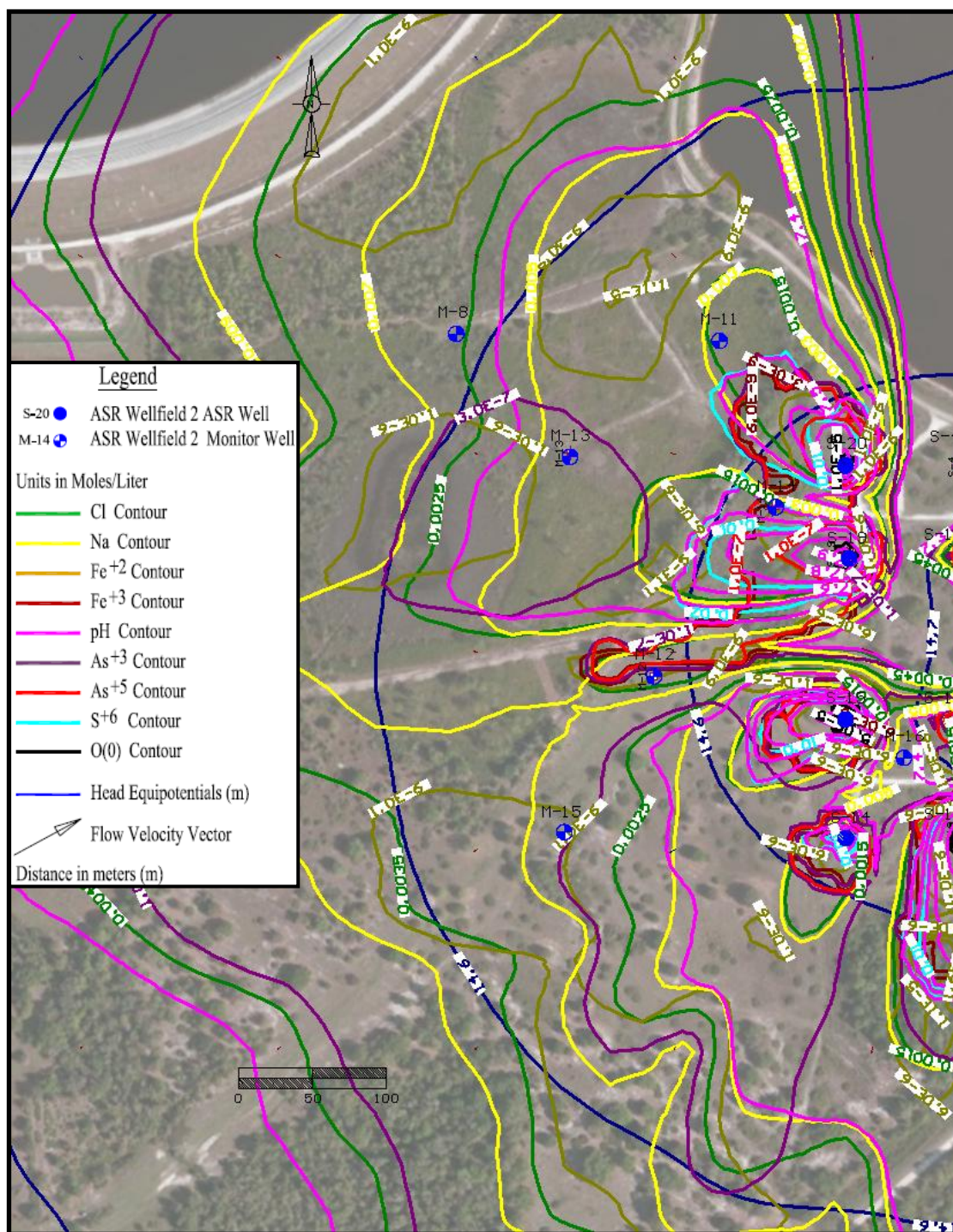


Figure 68. Simulation results of solutes after cycle 1 (270 days) recharge in fracture (layer 4) of FracMan DFN model with horizontal fractures, including stochastically generated $K(x3.25)$; specific storage reduced by 30x; ASR wells source area arsenopyrite $1e-6$ moles/liter.

7.0 DISCUSSION

7.1 Equivalent Continuum Models

The simulations using the equivalent continuum models are representations of the general flow system for the aquifer under dynamic conditions. This method was previously used for the site to obtain a water use permit and for practical purposes is sufficiently accurate because the effects of heterogeneities were not of primary concern. In addition, the transport system of this model provides sufficient detail of the general characteristics of solute migration to enable reasonably accurate interpretations of the dynamics of arsenic reactions and migration in this system. From these simulations, the general effects of arsenopyrite dissolution in response to mixing with oxygenated recharge water, release and migration of arsenic during recharge, and the increased arsenic concentrations at the ASR wells during recovery are evident. The calibrated hydraulic heads during recharge and recovery cycles provide sufficient evidence that the simulated flow system is a reasonable representative solution of the aquifer, when the aquifer is represented with average hydraulic parameters. The horizontal extent or migration of the arsenic plume, dictated by the 10 ug/L MCL, is generally exceeded by these models. The continuum models used in this study that exhibit distributions of arsenic in better agreement with observed values are those that include $P_{\text{arm}}(1)$ of 0.005, assignment of reduced arsenopyrite in the source areas in ASR wells near M-14, and equilibrium-controlled linear sorption. The degree of sorption in the equilibrium model

may overestimate the iron concentrations in the aquifer. Although these modeling results generally agree with observed arsenic distributions, these models do not simulate the observed behavior of arsenic in the upper part of the storage zone characterized by monitor well M-14 during recharge and recovery cycles, which supports the hypothesis that the aquifer is sufficiently heterogeneous that it could contain high flow zones. These results provide evidence suggesting that more complicated heterogeneities, such as high flow zones, need to be included in models to simulate more representative details of the flow and transport characteristics.

7.2 Discontinuum Models

The simulations using the discontinuum models present improved representations of the heterogeneous flow system of the aquifer under dynamic conditions. Simulation of the heterogeneous flow system includes discrete representations of the matrix and high flow zones. As explained in the discussion of the conceptual models, the presence of fractures are inferred to represent areas of variable and increased permeability in the aquifer.

The simulated transport system of these models also provides an increased amount of detail of the arsenic reactions, migration, and the arsenic distributions in the system during recharge and recovery cycles. The simulated horizontal extent of the arsenic plume, dictated by the 10 ug/L MCL, in the upper part of the UFA monitored by M-14 is variable and partly dependent on the vertical distribution of hydraulic conductivities, distribution of initial arsenopyrite, and $P_{\text{arm}}(1)$ value used in the discontinuum models. Once again, improved results are obtained using equilibrium sorption; however, reasonable results are also obtained using kinetic-based sorption.

These modeling results reasonably agree with observed distributions and enable simulation of the observed behavior of arsenic in the upper part of the storage zone characterized by monitor well M-14 during recharge and recovery cycles. The improved fit of the heterogeneous aquifer model to the observed concentration data support the hypothesis that the aquifer is heterogeneous and the high flow zones influence the range of arsenic concentrations and distributions in the UFA. These results provide evidence that simulations that include permeability heterogeneities, such as low and high flow zones, in discontinuum models can better simulate the more complex occurrences and distributions of arsenic observed in field data.

7.3 Stochastic Discontinuum Models

The simulations using stochastic discontinuum models present a unique set of representations of the heterogeneous flow system of the aquifer under dynamic conditions using variable hydraulic conductivity and average storage parameters. The simulations of the heterogeneous flow system include implied discrete representations of the horizontal distributions of low flow matrix and high flow zones, in addition to vertical fracture (high flow zone) networks. It should be emphasized that the presence of fractures are inferred to represent areas of variable and increased permeability in the aquifer.

The simulated transport system of these models provides an increased amount of detail of the arsenic reactions, migration, and the arsenic distributions in the system during recharge and recovery cycles. The simulated horizontal extent of the arsenic plume, defined by the 10 ug/L MCL, in the upper part of the UFA monitored by M-14 is

variable and partly dependent on the vertical distribution of hydraulic conductivities, distribution of initial arsenopyrite, and Parm(1) value used in the discontinuum models.

7.3.1 Stochastic Discontinuum Models with Variable Storage Parameters

The discontinuum models with stochastically generated distributions of hydraulic conductivity and storage parameters (specific storage and porosities) present the opportunity to compare the use of average and variable hydraulic parameters. Since the distributions of hydraulic parameters of an aquifer are often unknown, their average values are generally used in numerical models. The FracMan DFN simulator provides stochastic distributions of hydraulic parameters for use in MODFLOW and PHT3D. The distributions of solutes and arsenic in simulated fracture or high flow zones are generally similar, although subtle differences are apparent. In order to compare these numerical models, the average hydraulic parameters must be equivalent; therefore, the initial stochastic results must be adjusted. Comparison of these modeling methods tends to suggest that models with average storage parameters can be used to evaluate the general flow and transport characteristics of the system. However, due to the upscaling method that relies on the volume of the aquifer or fracture system, the detail of the DFN model may become obscure or generalized when model layers are thicker than the fractures or fracture zones.

The simulation results of the implied fracture zone in layer 4 after 120 and 270 days of cycle 1 recharge reveal the importance of the recharge volume of oxygenated water on the distribution and extent of arsenic migration from the ASR well. Between 90 and 120 days, a larger volume of water was injected than between 240 and 270 days, and the extent of arsenic migration into the aquifer is correlated with this change in recharge

volume. Due to the decreased recharge between 240 and 270 days, the arsenic distribution receded reflecting a potentially significant change in concentrations at monitoring points. For example, monitor well M-11 exhibits an arsenic concentration significantly exceeding the MCL after 120 days; however, at the end of the recharge cycle the concentration appears to decrease to significantly less than the MCL. This relationship indicates that the analysis of arsenic data at ASR facilities should take into consideration the recharge rate in order to determine when to sample the monitor well network, in order to ensure the plume is accurately monitored for environmental purposes. Another aspect of this model that is likely characteristic of the random hydraulic parameters, is the variable shape of the plume between the two recharge periods of cycle 1.

The initial arsenopyrite concentration affects the distribution of arsenic during the early part of the recharge cycle 1. With a homogeneous concentration of arsenopyrite of 0.1 moles/liter, the arsenic plume extends a maximum of approximately 145 m from the ASR wells, with higher concentrations in the vicinity of the ASR wells, compared to the model with an initial arsenopyrite concentration of $1\text{e-}6$ moles/liter in the vicinity of the ASR wells. This suggests that oxidation and dissolution of arsenopyrite is occurring across the low and higher background concentration areas, because DO is not being consumed by the arsenopyrite in the closer vicinity of the ASR wells.

The initial arsenopyrite distribution also appears to effect the distribution of dissolved arsenic during the latter part of the recharge cycle. During this part of the cycle when the recharge rate is comparatively lower, recharge water mainly reacts with the part

of the aquifer with lower arsenopyrite in the vicinity of the ASR wells yielding lower arsenic concentrations.

7.4 General Discussion

The results of this research provide insights into the potential occurrence, origin, and distribution of dissolved arsenic during ASR. The transport models used in this research include pyrite and arsenopyrite in concentrations that have been confirmed to occur in the UFA. The oxidation of pyrite and arsenopyrite under conditions similar to those of ASR operations in the UFA has been documented in laboratory studies.

The reactions used in these numerical models are well known and represent the general suite of reactions that are known to occur in the UFA under these conditions. These modeling results support the conceptual model that the arsenic in UFA water during ASR operations is the result of the natural occurrence of pyrite and arsenopyrite in the aquifer that has reacted with an oxidizing injectate. The oxidation of pyrite and arsenopyrite results in the dissolution of these minerals and the generation of the oxidized and reduced arsenic species arsenate and arsenite in solution, respectively. As a result of the oxidation reaction, the dissolved oxygen concentration decreases with a concurrent decrease of pH associated with the formation of iron and sulfate by $\text{FeS}_2 + 3.75\text{O}_2 + 3.5\text{H}_2\text{O} \rightarrow \text{Fe}(\text{OH})_3 + 2\text{SO}_4^{2-} + 4\text{H}^+$ and subsequent production of sulfuric acid. This study also supports the hypothesis that the effects of fracture flow exert a significant effect on the migration of arsenic and can account for the observed behavior of arsenic in UFA ASR operations.

The results of the simulations completed in this study indicate that the simulated dissolved arsenic concentrations reproduce the observed data documented during ASR operations. The simulation results are further improved by model calibration with respect to flow and transport parameters, suggesting that arsenic detected in the UFA during ASR likely results from pyrite oxidation, as opposed to bacteria-mediated reactions.

This study site exhibits an apparent anomaly in that arsenic is detected at low to negligible concentrations in the monitor well closest to ASR wells S-19 and S-20, M-14, during the recharge cycles; however, during recovery the arsenic concentrations increase, exceeding the MCL of 10 µg/l. Arsenic concentrations between 10 to 15 µg/l that exceed the background values of less than 3 µg/L are detected during the recharge cycles in monitoring wells M-16 located within the ASR well network and M-14 located approximately 200 ft from ASR wells S-19 and S-20. Since arsenic is not present in native fluids at concentrations significantly exceeding the method detection limit, the observed arsenic trend during the recharge cycle and the significant increase in arsenic at M-14 during recovery suggests that arsenic is being mobilized. The results of this study also conclude that the presence and effects of fracture flow are a significant control on the migration of arsenic and the observed behavior of arsenic species during ASR operations.

The arsenic concentrations from ASR wells S-19 and S-20 during recovery are generally less than at other ASR wells. During recharge arsenic is only detected in M-14 at low concentrations, with a maximum of approximately 20 µg/l and generally less. These data suggest that the arsenic source in the vicinity of these ASR wells has lower

concentrations than in the vicinity of the neighboring ASR wells. The operational data also indicate that DO increases in this closest monitor well, M-14, during recharge cycles to highly oxidic concentrations ranging from approximately 1.5 to 4.0 mg/L, suggesting minor attenuation of DO between the ASR (S-19 and S-20) and monitoring (M-14) wells. The presence of a highly conductive interval(s) can explain why arsenic is detected approximately 200 ft from the ASR well, although the source area is relatively low in arsenic. Additionally, the migration of groundwater with high DO levels past M-14 promotes the oxidation of available pyrite and release of arsenic during the recharge cycles in the area beyond M-14. During the recovery cycles, low concentrations of arsenic are subsequently detected at M-14. Due to this process, both arsenate and arsenite could be generated in the area between M-14 and the more distant monitor wells that do not exhibit arsenic during recharge cycles. These hydraulic and transport characteristics indicate that the effects of pyrite oxidation likely extend beyond the distance to M-14, approximately 200 ft (Mirecki, 2011).

An objective of this study was to identify the factors that influence mobilization and transport of arsenic and to explain by reproducing the observed data using model simulations that include the proposed structural and geochemical controls on arsenic distribution. There are several factors that control the concentrations and distributions of arsenic in the UFA examined in this study that can explain the variations and similarities between the simulated results and observed data, for example, the absence of significant arsenic concentrations during recharge at the closest monitoring well, M-14, and the occurrence of significant arsenic detections during recovery. This relationship appears to

eliminate the possibility that the source of arsenic in the ASR wells is due solely to bacterial activity in the vicinity of the ASR wells.

Given the available geochemical and hydrostratigraphic data, simulating an accurate and detailed representation of the magnitude and distribution of arsenic during ASR operations may not be feasible. However, simulation of arsenic generation at the approximate observed concentrations and distributions is achieved by these simulations of arsenopyrite oxidation. Model calibration could be significantly improved if field data for a single ASR well, such as the Bradenton ASR study, were used in contrast to this study in which eight ASR wells are used resulting in significantly more complex flow and transport characteristics. For example, monitor well M-14 is the only monitoring well within 200 ft of the network of eight ASR wells; therefore, the trend observed at this well cannot be confirmed to occur at all locations of equal distance from the other ASR wells. It should be noted that during recharge cycles, arsenic concentrations do increase in this monitor well to concentrations slightly exceeding 10 $\mu\text{g/l}$. This trend is an indication of the oxidation process resulting in the dissolution of arsenic that likely increases at greater distances from M-14. Because of the heterogeneous distribution and potentially large variation of arsenic concentrations in pyrite, a source of arsenic may occur beyond M-14 which may be oxidized during recharge cycles to generate dissolved arsenic. The observed DO (approximately 2 to 4 mg/L) and ORP (approximately 200 to 300 mV) in M-14 during recharge cycles are indicative of oxidizing conditions that are capable of dissolving pyrite and are within the stability field of arsenate. The pH measured at M-14 is also similar to the pH of the recharge water, which supports the hypothesis that fracture flow facilitates the high flow

transport of recharge water beyond M-14. The moderately high pH at this distance could also decrease sorption of arsenic and facilitate its transport beyond M-14. The presence of these conditions at this significant distance from the ASR well suggests the presence of a fracture zone.

The reaction of organic matter in the aquifer with oxygen-saturated water follows the reaction, $\text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$, resulting in the formation of carbonic acid. Dissolved organic matter does occur in the UFA at an average concentration of approximately 10-15 mg/L. In limestone aquifers the pH is buffered by the presence of CaCO_3 , therefore, this mineral was included in the models. Laboratory tests of rock-water geochemical reactions to identify those reactions that occur during ASR have confirmed the buffering effects of limestone (Descourvieres, C. et al., 2010, Descourvieres, C. et al., 2010). Since there is an ample supply of CaCO_3 in the aquifer, the potential oxidation of organic matter should not affect the modeling results if this reaction was omitted. In addition, it appears that the effects of this parameter are more apparent where the injectate contains high concentrations of DOC, which potentially is the case when reclaimed water is injected. Models run without limestone exhibit greater decreases in pH than those that include CaCO_3 as an equilibrium phase mineral. The pH measurements collected during ASR operations at the site indicate variations in pH consistent with the introduction of recharge water with pH of approximately 8.1 SU into the aquifer with background pH of approximately 7.4 SU. During recharge, the pH in the vicinity of the ASR wells is the highest and during the recovery period, the maximum and range are less. The increase in pH in the vicinity of the ASR wells is generally due to the recharge water and the dissolution of limestone with a high buffering capacity against the

oxidation of pyrite. The pH-buffering by CaCO_3 tends to decrease the effects on other minerals and species by variations in pH, e.g. mineral dissolution and adsorption which is generally highest under conditions of low pH. The simulated pH of groundwater ranges between approximately 7.3 and 8.1 SU, which is consistent with observed measurements.

The iron that is liberated occurs in both the ferric (Fe^{+3}) and ferrous (Fe^{+2}) iron oxidation states with ferric iron forming in the proximity of the ASR well and the ferrous iron forming at greater distances from the ASR well where the DO is close to that of the background formation groundwater. FeOOH or HFO is formed and precipitated near the ASR well under recharge conditions. During the recharge periods, arsenate occurs in the vicinity of the ASR well with arsenite occurring at greater distances from the ASR well. Background concentrations of arsenic in the UFA are typically low and expected to be in the reduced form of arsenite. The modeling results exhibit the presence of arsenite at concentrations greater than those that occur as background, therefore, it appears that arsenic from the dissolution of pyrite and arsenopyrite undergoes changes in oxidation states during its migration through the flow field, resulting in the occurrence of both arsenate and arsenite.

The background iron concentration at this site is very low and likely affects the degree of arsenic sorption because the background iron fails to contribute a significant quantity of HFO by oxidation during recharge. Therefore, it appears at this site that most of the iron that contributes to sorption is generated by the oxidation of pyrite. Native iron concentrations in the aquifer exhibit a wide range and are heterogeneously distributed; therefore, sorption at ASR sites operating in the UFA likely varies and, at some sites, dissolved iron concentrations could be significant.

During the operation of the ASR system between 2002 and 2009, the arsenic concentrations have varied during the recovery cycles; however, the data indicate general trends at the ASR wells of decreasing concentrations during the latter part of the period. The simulated arsenic concentration-time graphs for the ASR wells exhibit a series of peaks with variations in maximum concentrations, which are coincident with recovery cycles. During the period simulated, if average source arsenopyrite concentrations are assigned in the models the arsenic concentrations do not decrease over time indicating that the source of pyrite and arsenopyrite simulated has not been significantly depleted in most of the ASR wells. However, arsenopyrite in the vicinity of S-19 and S-20 was assigned a very low concentration in order to calibrate the model to the observed temporal distribution of arsenic. The dissolved arsenic concentrations at these wells exhibit a general decreasing trend. The simulations indicate that over time the dissolved arsenic associated with these ASR wells is decreasing as a result of the depletion of arsenopyrite. These results suggests that the pyrite and arsenopyrite in the vicinity of most of the ASR wells will not quickly be dissolved under the conditions at the site, unless the source area concentrations are very low. Although the pyrite and arsenopyrite concentrations exhibit decreasing trends, the difference between the initial and final concentrations eight simulated ASR cycles is only approximately 0.1% in the vicinity of most of the ASR wells.

The low permeability of the matrix of the UFA suggests that this characteristic must be considered when modeling these aquifers, whether equivalent continuum or discontinuum models are employed. Although the measured hydraulic conductivities for the matrices may be very low for limestone aquifers, aquifer performance tests indicate

that the aquifer transmissivities are significantly greater than the sum of the matrix hydraulic conductivities, indicating the presence of high permeability intervals of post-depositional origin. The equivalent continuum model results provide a much more general interpretation of the solute plume distribution that exhibits a solute plume with constant vertical concentration contours throughout the thickness of the aquifer. In addition, the horizontal extent of dissolved arsenic is overestimated. The simulations support the presence of continuous fractures, fracture zones, and zones of high secondary permeability in the UFA. These features need to be represented in models used to simulate mass transport in the UFA. The modeling results demonstrate that the horizontal boundaries (leading edge) of the solute plumes are not similar in the matrix and intermatrix flow zones. The horizontal extent of these boundaries vary significantly throughout the vertical extent of the aquifer. One of the best fitting models for this site include very high transmissivity flow zones in the upper and lower parts of the model with matrix and moderate transmissivity zones dispersed throughout the remainder of the model.

With the use of numerical models, this study represents the occurrence of these enhanced flow zones in order to determine if some observed anomalies are the result of or are affected by fracture flow in the UFA at ASR facilities. The presence of nearly horizontal layers of high and low permeability does result in the creation of vertical flow due to flow line refraction at these boundaries. In addition, the results of calibrating the equivalent continuum and discrete fracture network models indicate that the vertical hydraulic conductivity is higher than the horizontal conductivity. This suggests that preferential zones of vertical hydraulic conductivity exist that could increase the potential

for vertical flow. The existence of preferred vertical flow under ASR conditions could produce solute distributions that would not be apparent under conditions of more uniform distributions of permeability and under conditions of typical vertical heterogeneity.

Although the heterogeneous PEST-calibrated models exhibit higher vertical hydraulic conductivity, the models calibrated to the concentration data in the upper and lower parts of the aquifer exhibit higher horizontal hydraulic conductivity in these fracture zones. These models suggest that the highest hydraulic conductivities are in the horizontal direction; however, high vertical hydraulic conductivity also occur, which is not uncommon in parts of the UFA. Although horizontal high flow zones are associated with many known geologic features in the UFA, vertical fracture zones and high flow zones have been documented in the UFA consistent with photolineaments and geologic field evidence, e.g. faults (Sproul et al., 1972).

The results from the equivalent continuum models are reasonably representative of the observed concentrations and concentrations; however, the arsenic distributions extend beyond the observed distribution indicated by M-14. In addition, due to the implied existence of fracture zones in the lower part of the storage zone, it is highly unlikely that a homogeneous model can adequately simulate the obvious heterogeneous character of the aquifer. Nonetheless, the preliminary results appear promising, if heterogeneity is adapted to the model. This study further indicates that the heterogeneous models are likely better representations of the aquifer. The use of high-K layers in the upper part of the aquifer potentially explains the low concentrations detected at M-14. The observed high DO and pH in M-14 are duplicated by varying the arsenopyrite and hydraulic conductivity of the potential high flow zones. The variable arsenopyrite and

hydraulic conductivity could not have been simulated with the equivalent continuum model.

In this particular hydrogeologic setting, other factors that limit the availability of data to accurately assess the implications of the mixing of highly oxidizing injectate with groundwater and the aquifer matrix are the horizontal spacing and depths of screened intervals of the monitor wells. The current well specifications are satisfactory for the intended purpose of monitoring geochemical and hydraulic conditions if the aquifer is homogeneous and isotropic. At this site, the monitoring wells are located 200 to 500 feet from the ASR wells. Because most of the reactions of injectate with pyrite and arsenopyrite at ASR sites typically occur within close proximity (approximately <250 ft) of the ASR wells and the highest concentrations occur within this radius, the current network of monitor wells is likely inadequate to evaluate the characteristics of the plumes generated by the oxidation of pyrite in the proximity of the ASR wells. Due to the expense of installing monitoring wells at these depths, it is understood how cost becomes an issue and dictates the monitoring strategy. In addition, the monitoring wells are screened across the upper half of the aquifer (partially penetrating) and the ASR wells are open across the entire aquifer (fully penetrating).

If the distributions of matrix and fracture flow zones were similar within the upper and lower parts of the aquifer, the current depths of monitoring well screened intervals would enable satisfactory interpretation of flow and transport characteristics, as depicted on **Figure 69**. However, because of the apparent dissimilarity between the distribution of matrix and fracture zones, clusters of monitoring wells with screened

intervals effectively spanning the entire aquifer are required to assess the dynamic flow and chemical characteristics that occur across the aquifer (**Figure 70**).

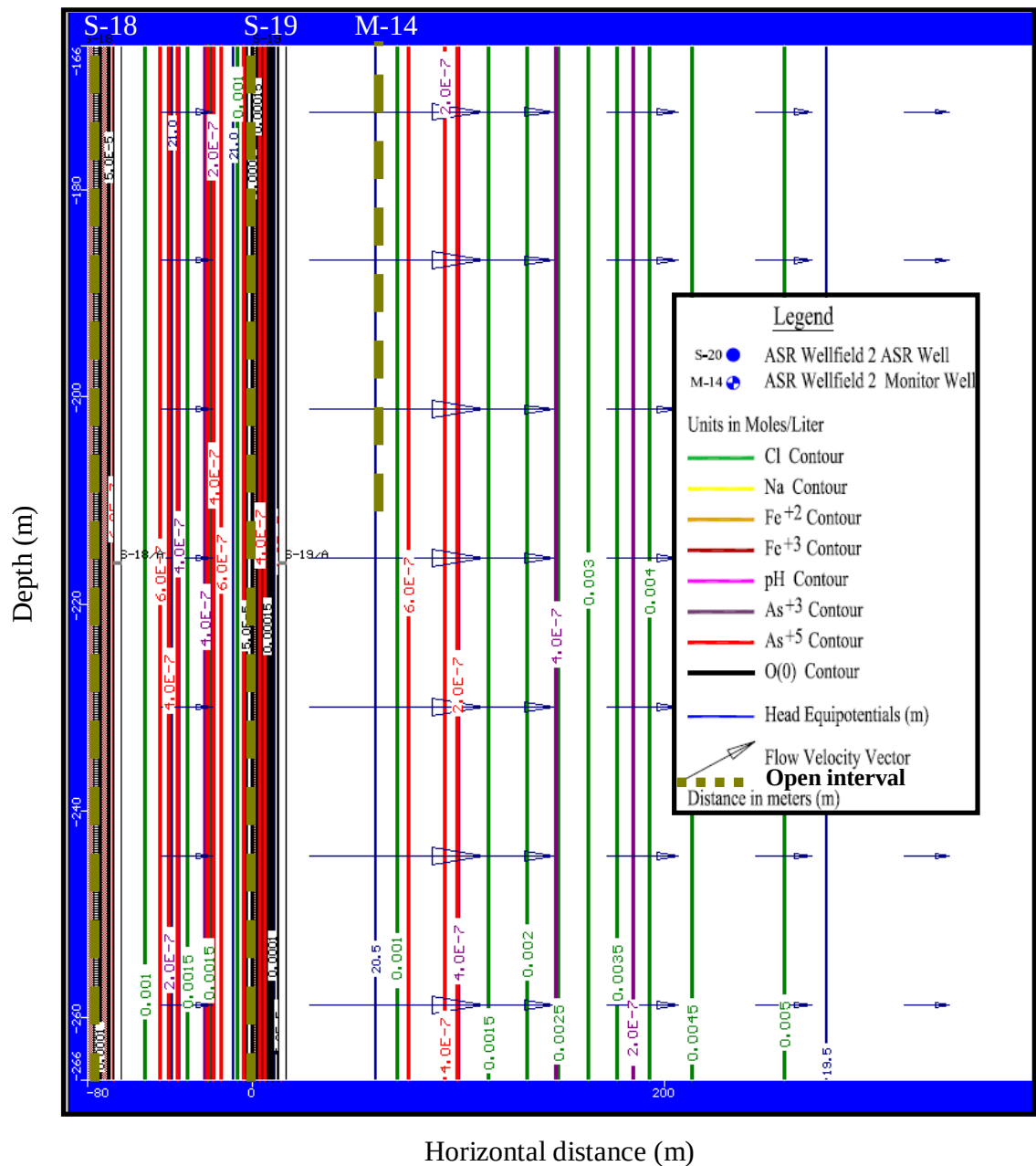


Figure 69. Simulated E-W Cross-section through S-18, S-19, and M-14 using homogeneous model illustrating lack of vertical variations in solute migration with depth through storage zone.

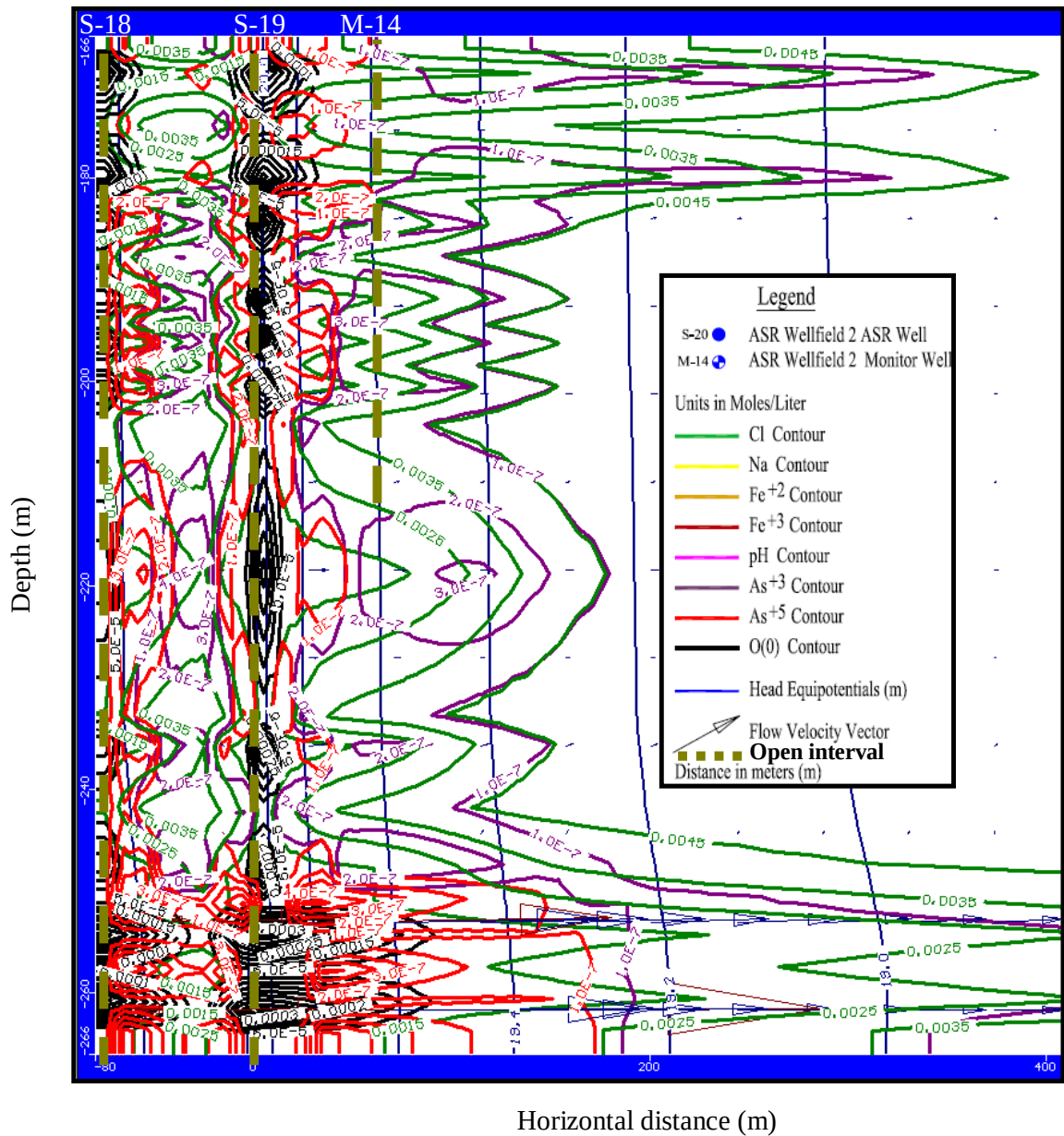


Figure 70. Simulated E-W Cross-section through S-18, S-19, and M-14 through heterogeneous model illustrating vertical variations in solute migration with depth through storage zone.

The presence of multiple open or screened intervals provide more valuable data that improves the assessment and interpretation of flow and geochemical data. These same data provide multiple flow and geochemical calibration points that enable the construction of higher accuracy numerical models. Without the ability to monitor the variability and permeable zones in the aquifer, the distribution of the arsenic plume may not be accurately known.

8.0 SUMMARY

Numerical flow and mass transport modeling was performed to evaluate the effects of fracture flow on the occurrence and distribution of arsenic released in the UFA during ASR operations at the Peace River ASR facility in Desoto County, Florida. Fracture flow and reaction-mass transport were performed using numerical three-dimensional models constructed with MODFLOW and FracMan to represent fractures in equivalent continuum, discontinuum, and stochastic discontinuum dual porosity hybrid models. The geochemical reaction (PHREEQC-2) and transport (MT3DMS) models coupled to the three dimensional numerical flow model (MODFLOW 2000) as PHT3D-2003, were utilized to simulate inorganic reactions and mass transport associated with the injection of oxidized water into the UFA of Southwest Florida during ASR cycles.

The fracture zones, implicitly simulated in MODFLOW as high flow zones, were modeled as layers of varying thicknesses with uniform hydraulic conductivity and storage parameters, and as stochastically-generated horizontal and vertical fracture zones with varying physical attributes including orientation, aperture widths, fracture intensity, and fracture distributions, distributed within a lower conductivity matrix. Discrete fracture networks simulated with FracMan were up-scaled and imported into MODFLOW. Each fracture zone layer was assigned a unique stochastic distribution of hydraulic conductivity; therefore, each model represents a single realization.

The geochemical conditions of the UFA injection zone were simulated with respect to the naturally occurring major and minor minerals, ion-exchange, iron surface complexing or sorption, and major and minor dissolved constituents using PHT3D. The chemistry of the recharge water, and records of injection and recovery were obtained from historic records of ASR operation from 2002 to 2009.

As expected, the equivalent continuum models provided general representations of the flow and potential migration characteristics of arsenic, after the oxidation of arsenopyrite. The equivalent discontinuum models more accurately simulate the expected contrasting migration characteristics in low and high flow zones, as the generation of arsenic is controlled by the penetration of oxic recharge water. The discontinuum models that incorporated up-scaled FracMan DFN models also provided the required flexibility to accurately simulate the observed migration characteristics in low and high flow zones.

The modeling results support the hypothesis that arsenopyrite, which is stable under reducing conditions, liberates arsenic during recharge cycles as a result of oxidation. The simulated distribution of arsenic in the matrix is significantly less than in the fractures as a result of the limited penetration of oxidized recharge waters into the inter-fracture matrix. Under the simulated aquifer and geochemical conditions, arsenic travels farther from the injection well via fractures than is observed in monitor wells, suggesting that the partially-penetrating monitoring well network does not intercept many of the fractures. The modeled increases in concentrations of arsenic in the ASR wells during the recovery cycles are also consistent with observations. Explicit representation

of fracture zones in numerical transport models provides an increased understanding of the flow system and the potential occurrence and distribution of arsenic in groundwater.

9.0 CONCLUSIONS

These modeling results support the conceptual model that the dissolution of pyrite and arsenopyrite in the UFA by the introduction of oxygenated water through recharge wells is a viable explanation of the observed elevated arsenic concentrations at this ASR site and other ASR systems operating under similar aquifer conditions. The general trend that most of the ASR sites cited in this study appear to exhibit is the presence of low levels of arsenic in the closest monitor wells followed by the occurrence of elevated arsenic only in the ASR wells during the recovery phases. The simulated arsenic concentrations and distributions associated with ASR wells S-14 and S-15 exhibit the same general behavior as the field data from most of the ASR sites.

The results of this research support the hypothesis that the behavior of arsenic in the vicinity of M-14 can be attributed to the presence of fractures represented as high flow zones. The anomaly described to exist at the closest monitoring well, M-14, represented by the occurrence of negligible to low arsenic during recharge and higher concentrations during recovery can be explained as a consequence of the presence of a high flow zone(s) in the upper part of the storage zone intercepted by the partially penetrating monitor well. The observation of low arsenic concentrations at M-14 during recharge cycles, approximately 200 ft from the nearest ASR well, followed by increased concentrations during recovery appears to be the result of the oxidation of pyrite between

the ASR well and MW-14 and followed by the oxidation of pyrite beyond MW-14 during recharge.

This oxidation of pyrite at distances of and greater than approximately 200 ft is facilitated by oxic injectate delivered to these distant locations by preferential flow paths, e.g. fracture zone. During the recovery phase, arsenic that was released and sorbed to iron oxyhydroxides during the recharge phase is subsequently released due to the dissolution of iron and is detected at M-14. This occurrence is also potentially the result of the heterogeneous distribution of arsenopyrite in the UFA. The observations of arsenic at M-14 are the result of the heterogeneous distribution of fracture(s) in the upper part of the UFA that intersect the monitoring well. This explanation supports the hypothesis that fracture flow affects the occurrence of arsenic at M-14 and is supported by numerical modeling results of this study.

The use of continuum and discontinuum models to simulate the dissolution of pyrite and arsenopyrite results in similar simulated concentrations as those observed at this ASR site; however, some significant differences exist between the distributions of all solutes with the two modeling approaches. These results indicate that if the aquifer's hydraulic parameters are lognormally distributed throughout the vertical extent of the aquifer as typically assumed, without fractures or preferential flow paths present, then the set of average hydraulic parameters in a continuum model can be used to simulate flow and mass transport processes with reasonable accuracy.

These modeling results indicate that fracture zones appear to exert significant control over distribution of flow and mass in the UFA under the ASR operating conditions. The pyrite oxidant in this case is oxygen dissolved in the recharge water;

therefore, the available flow paths that exist in the aquifer will control the distribution of available oxygen that will subsequently react with pyrite and arsenopyrite.

Monitor well M-14, located approximately 200 ft from the nearest ASR well, exhibits DO concentrations exceeding 2.0 mg/L during recharge cycles, which suggests minor attenuation of the DO level over the 200 feet and the occurrence of a preferential high flow zone in the vicinity of this well. The DO measured in this monitor well is also significantly greater than the concentrations measured in the nearest monitor well at the Bradenton site which is located approximately 223 ft from the ASR well. In addition, other groundwater parameters including redox and pH also exhibit minor attenuation at M-14.

The fractures and/or fracture zones that transport the greatest mass of dissolved arsenic tend to exhibit the greatest control on the water quality measured and analyzed at the intercepting monitor wells. Although the plumes simulated in the matrix appear to be consistent with the observed arsenic concentrations between the ASR and closest monitoring wells, the ASR and monitoring wells intercept both low and high flow zones; therefore, the concentrations in these wells represent an average concentration of contributions from all flow zones.

Pyrite has been observed to occur as fine-grained minerals in the limestone matrix and as larger grains in larger pores and high permeability flow zones. The models for this study represented the occurrence of arsenic in arsenopyrite as the source of arsenic to the aquifer. Arsenopyrite was assigned as both similar average concentrations to all layers of the model and as a horizontally and vertically heterogeneous parameter. The best simulated results were obtained with the heterogeneously distributed arsenopyrite

source concentrations. In order to accurately simulate the distribution of arsenic associated with ASR, accurate field data on the distribution of initial pyrite and arsenopyrite in the matrix and fracture are required. The assignment of the characteristic initial pyrite and arsenopyrite concentrations to cells and layers with matrix and intermatrix fractures affects the dissolved arsenic concentrations and distributions.

The distribution of solutes and arsenic in this aquifer appears to be most affected by the variability of hydraulic conductivity associated with the distribution of matrix and flow zones within fractured intervals, and the relative distribution of initial arsenopyrite in the modeled matrix and fracture zones. Contrasting lognormal distributions of pyrite and arsenopyrite in the aquifer with the same average concentrations only exhibit minor differences in the simulated solute concentrations and distributions. However, if the source concentrations in parts of the aquifer differ by several orders of magnitude, significant variations are demonstrated by the models. In addition, the modeling results are sensitive to source concentrations because the range of arsenopyrite required to simulate the magnitude of dissolved concentrations is rather large. However, if decreasing arsenic trends are observed over time, then low source concentrations likely exist that will be consumed over time by oxidation. Therefore, it appears that initial source area and aquifer arsenopyrite concentrations should be calibrated to reproduce the observed dissolved arsenic concentrations.

The use of FracMan (Golder, 2010) to generate fracture zones is an effective method to simulate fracture flow that enables increased definition of the physical characteristics of fractures and consequent flow and transport in these complex features. The results are generally comparable to the discontinuum models created with

MODFLOW; however, more variability appears to be introduced in the solute distributions. These variabilities in the plume characteristics could explain potential anomalies that are observed and can not be simulated with traditional discontinuum models that don't possess the ability to simulate stochastic parameter distributions. The calibrated FracMan model simulations produced results that are consistent with the observed data and allow for greater definition of fracture zone properties than conventional models.

Arsenic compounds related to the oxidation of arsenopyrite are toxic and represent serious health concerns for the international community due to their pervasive occurrence in a variety of geologic environments utilizing ASR. This study represents one of the earliest attempts to evaluate the reaction of recharge water on native arsenopyrite in the ASR setting and the consequent distribution of arsenic in response to this unique flow system. This study provides insight into the potential origin and migration characteristics of arsenic in the UFA during ASR and, as such, should be helpful in evaluating the feasibility of the use of ASR in Florida. The use of ASR in Florida faces environmental and legal challenges as a result of the arsenic created during injection and, the availability of this modeling tool to study the problem, may assist regulators in evaluating potential solutions. The injection of recharge water with drinking water characteristics into the UFA appears to be detrimental to groundwater quality and may require the evaluation of potential treatments to reduce the high DO in recharge water in order to permit the continued use of ASR in Florida as a means of augmenting drinking water supplies.

As to this specific site, this issue is sensitive and complex and requires the consideration of various environmental and economic factors before passing judgement or making recommendations on the operation and arsenic problem. Arsenic concentrations appear to be decreasing and there are several options at present to consider including pre-treatment to reduce DO, running several cycles until attenuation occurs to acceptable levels, and treatment following recovery. In addition, if ASR in general is an economical and technically sound means of supplementing water supplies, the prospective site should be bounded by monitoring wells to ensure the extent of the temporary arsenic plume is known and monitored through time, and that institutional and engineering controls be set up to preclude the use of water within a safety zone surrounding the site, until concentrations have decreased to acceptable levels. This approach would eliminate the need for costly and lengthy pre-permitting studies and impacts to the surrounding population.

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11.0 APPENDICES

Appendix A: Geophysical Logs

Geophysical		FLOWMETER INTERPRETATION	
MV Geophysical		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-4 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA	
Location ASR WELL FIELD EXPANSION		Other Services X-Y CALIPER FLOW VIDEO	
Permanent Datum Log Measured From Drilling Measured From		Ground Level Ground Level Ground Level	
Date Run Number Depth Driller Depth Logger Bottom Logged Interval Top Log Interval Open Hole Size Type Fluid Density / Viscosity Max. Recorded Temp Estimated Cement Top Time Well Ready Equipment Number		5-MAY-2003 ONE 903' 903' 903' 525' 11.875" WATER M/M/A NA NA 08:30 5-MAY-00 11:00 5-MAY-00 M/VGS-1	
Location Reported By Witnessed By		MILLERVINCENT G. SUSORF (WRS)	
Run Number ONE		Boreside Record Bit From To Size Weight Turning Record From To	
11.875' 560' 903'		12" SURFACE 560'	
Casing Record Surface String Prod. String Production String Liner		Size Weight Top Bottom 12" SURFACE 560'	
Invoice No. 2000093		P.O. # 6248	
* FINAL PRINT *			
All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule.			
Comments			
Q, %Q & Fluid Velocity presentations include a regular Line Speed and Caliper corrected only format, and an interpretative "LOGICAL" format. "LOGICAL" Q, %Q & Fluid Velocity passes assume no thief zones (Q & %Q can only increase). STATIC & DYNAMIC data was collected logging DOWN @ 40 & 80 fpm. Est'd Qmax=175 gpm			

Figure A1. ASR Well S-4.

Appendix A: Geophysical Logs (Continued)

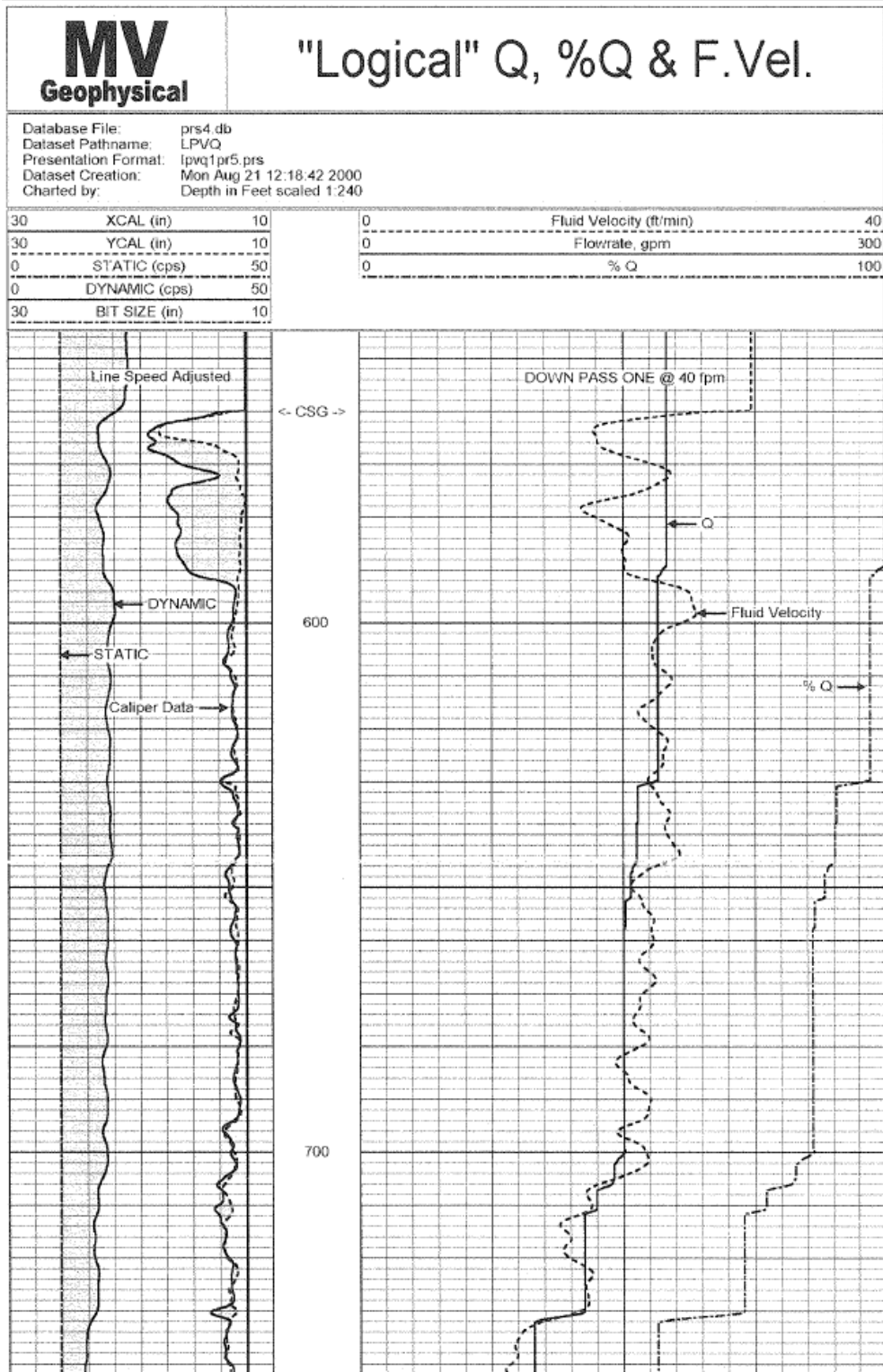


Figure A1. ASR Well S-4 (Continued).

Appendix A: Geophysical Logs (Continued)

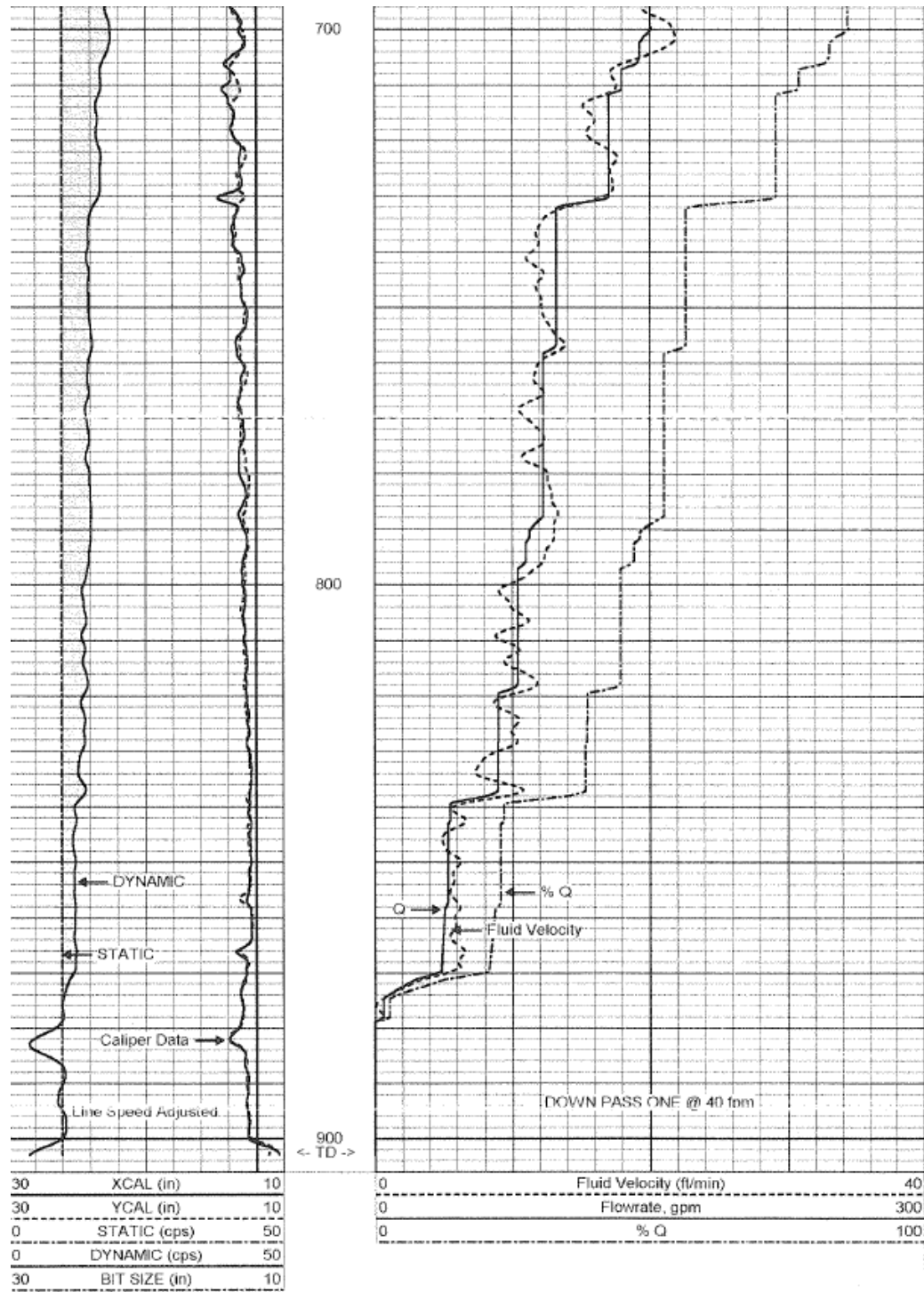


Figure A1. ASR Well S-4 (Continued).

Appendix A: Geophysical Logs (Continued)

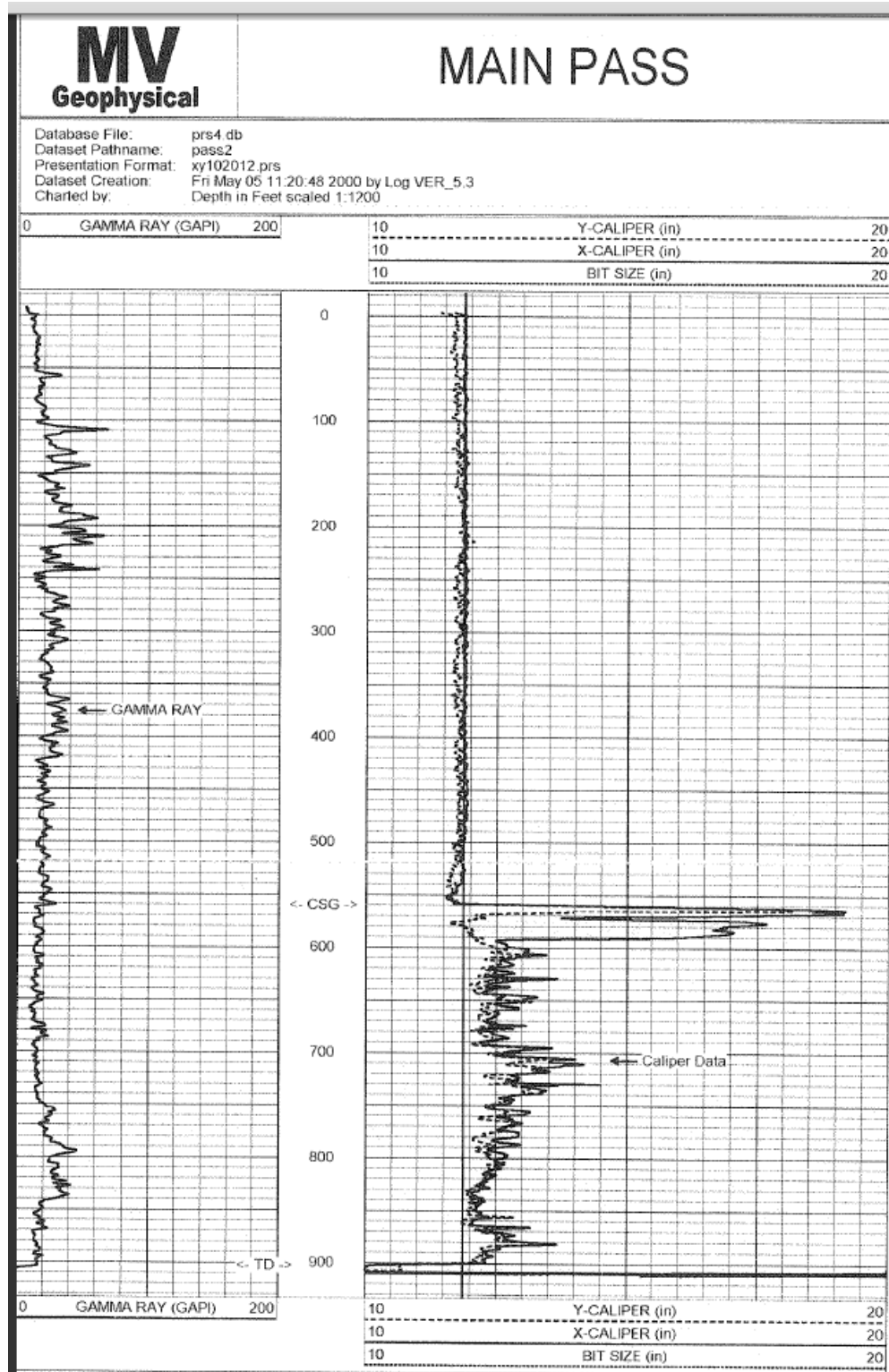


Figure A1. ASR Well S-4 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical Geophysical FLOWMETER INTERPRETATION																																									
Company DIVERSIFIED DRILLING Well ASR WELL S-10 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-10 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA																																									
Location PRMRWSA ASR WELL FIELD EXPANSION																																									
Permanent Datum Log Measured From Drilling Measured From	Ground Level Ground Level Ground Level																																								
Elevation na K.B. na D.F. na G.L. na																																									
Other Services DIL, XYGR BHC FLOW FRT, VIDEO																																									
Date 4-MAY-2000 Run Number FIVE																																									
Depth Diller 905 Depth Logger 905 Bottom Logged Interval 898' Top Log Interval 620' Open Hole Size 14"																																									
Type Fluid WATER Density / Viscosity N/A/N/A Max Recorded Temp na Estimated Cement Top NA Time Well Ready 08:30 4-MAY-00 Time Logger on Bottom 12:30 4-MAY-00 Equipment Number MAVCS-1 Location FT. MYERS Recorded By MILLER/VINCENT Witnessed By C. TARCISKA (WRS)																																									
Borehole Record <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>Run Number</th> <th>Bit</th> <th>From</th> <th>To</th> <th>Size</th> <th>Weight</th> <th>From</th> <th>To</th> </tr> </thead> <tbody> <tr> <td>ONE</td> <td>12.25"</td> <td>60'</td> <td>265'</td> <td>FIVE</td> <td>14"</td> <td>620'</td> <td></td> </tr> <tr> <td>TWO</td> <td>30"</td> <td>60'</td> <td>265'</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>THREE</td> <td>12.25"</td> <td>250'</td> <td>620'</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>FOUR</td> <td>25"</td> <td>250'</td> <td>620'</td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>		Run Number	Bit	From	To	Size	Weight	From	To	ONE	12.25"	60'	265'	FIVE	14"	620'		TWO	30"	60'	265'					THREE	12.25"	250'	620'					FOUR	25"	250'	620'				
Run Number	Bit	From	To	Size	Weight	From	To																																		
ONE	12.25"	60'	265'	FIVE	14"	620'																																			
TWO	30"	60'	265'																																						
THREE	12.25"	250'	620'																																						
FOUR	25"	250'	620'																																						
Casing Record <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>Size</th> <th>WT</th> <th>Top</th> <th>Bottom</th> </tr> </thead> <tbody> <tr> <td>32"</td> <td>375' WT</td> <td>SURFACE</td> <td>60'</td> </tr> <tr> <td>26"</td> <td>375' WT</td> <td>SURFACE</td> <td>250'</td> </tr> <tr> <td>17.25" PVC</td> <td>1" WT</td> <td>SURFACE</td> <td>620'</td> </tr> </tbody> </table>		Size	WT	Top	Bottom	32"	375' WT	SURFACE	60'	26"	375' WT	SURFACE	250'	17.25" PVC	1" WT	SURFACE	620'																								
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Production String 17.25" PVC Line 2000092 Invoice No. 2000092 P.O. # 6247 * FINAL PRINT *																																									

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Comments

Q, %Q & Fluid Velocity presentations include a regular Line Speed and Caliper corrected only format, and an interpretative "LOGICAL" format. "LOGICAL" Q, %Q & Fluid Velocity passes assume no thief zones (Q & %Q can only increase).

STATIC & DYNAMIC data was collected logging DOWN @ 40 & 80 fpm.

Est'd Qmax=350 gpm

Figure A2. ASR Well S-10.

Appendix A: Geophysical Logs (Continued)

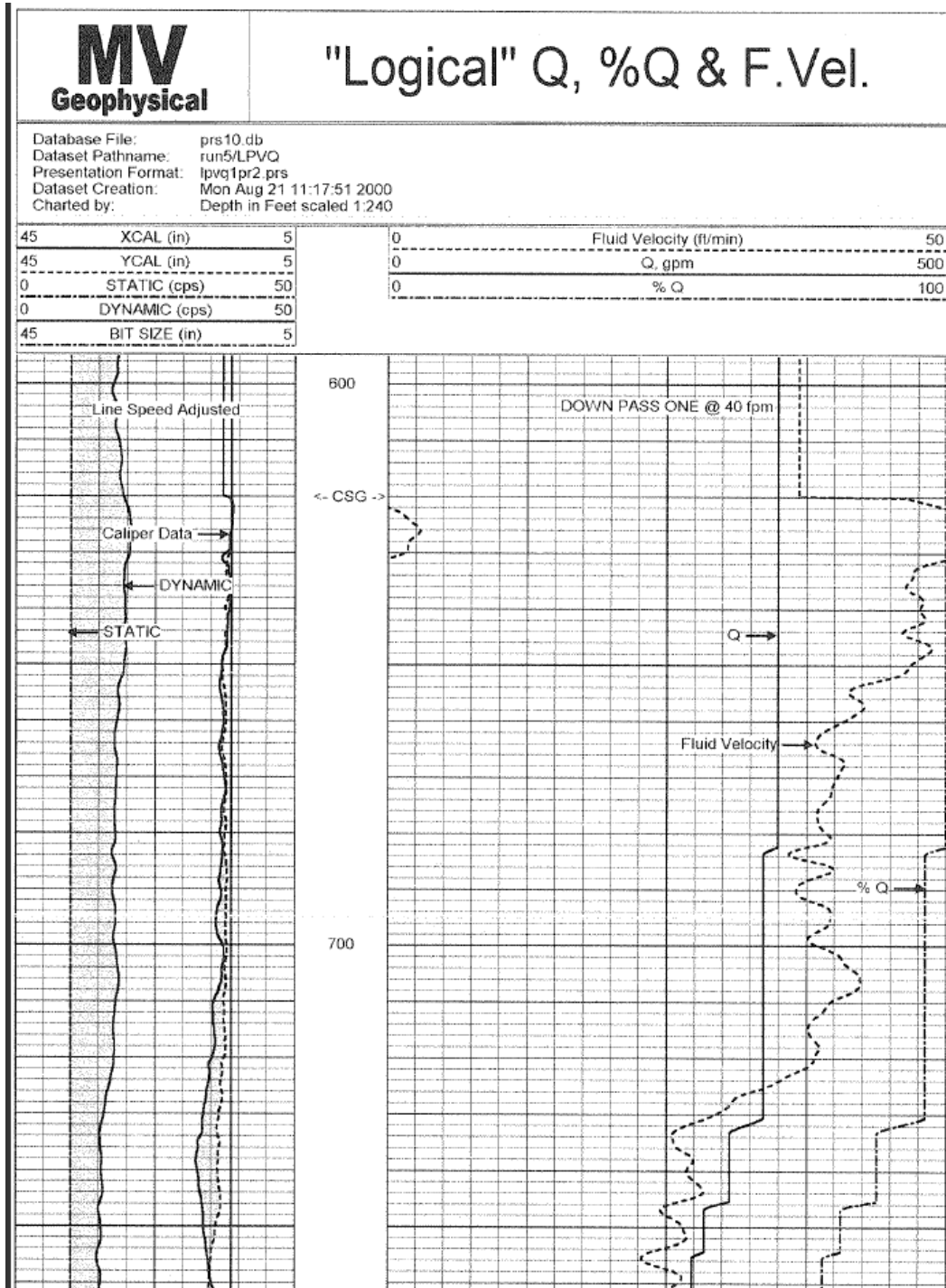


Figure A2. ASR Well S-10 (Continued).

Appendix A: Geophysical Logs (Continued)

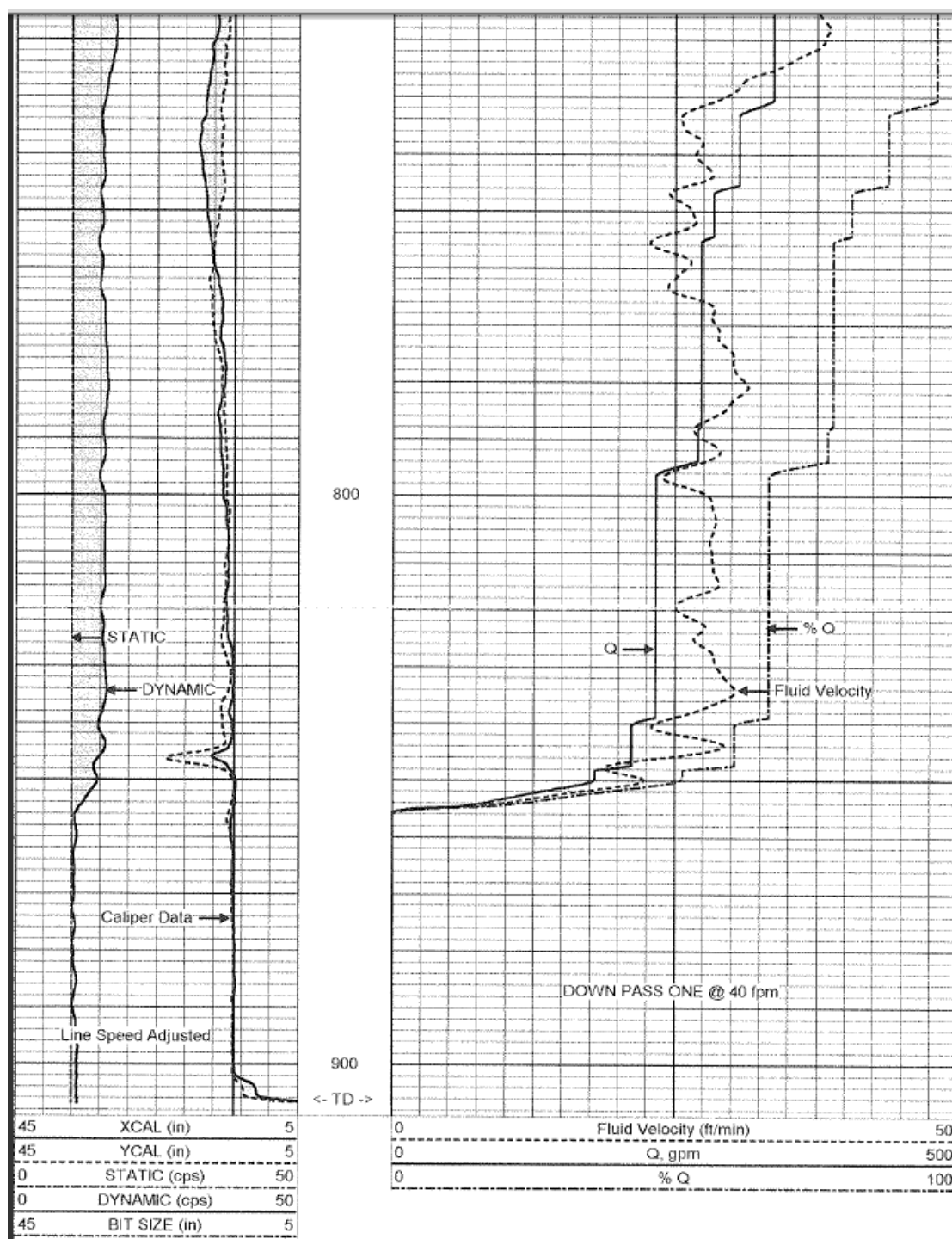


Figure A2. ASR Well S-10 (Continued).

Appendix A: Geophysical Logs (Continued)

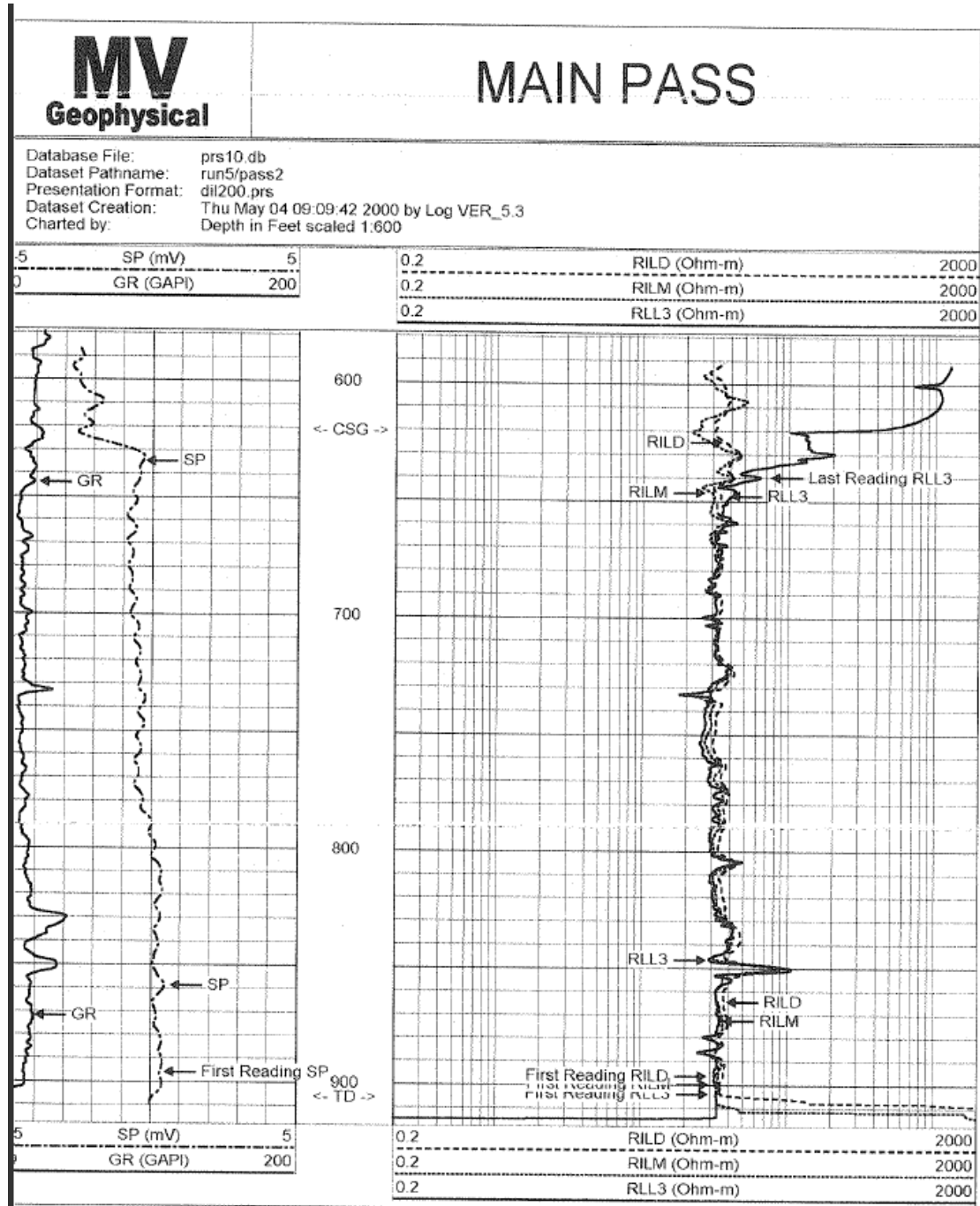


Figure A2. ASR Well S-10 (Continued).

Appendix A: Geophysical Logs (Continued)

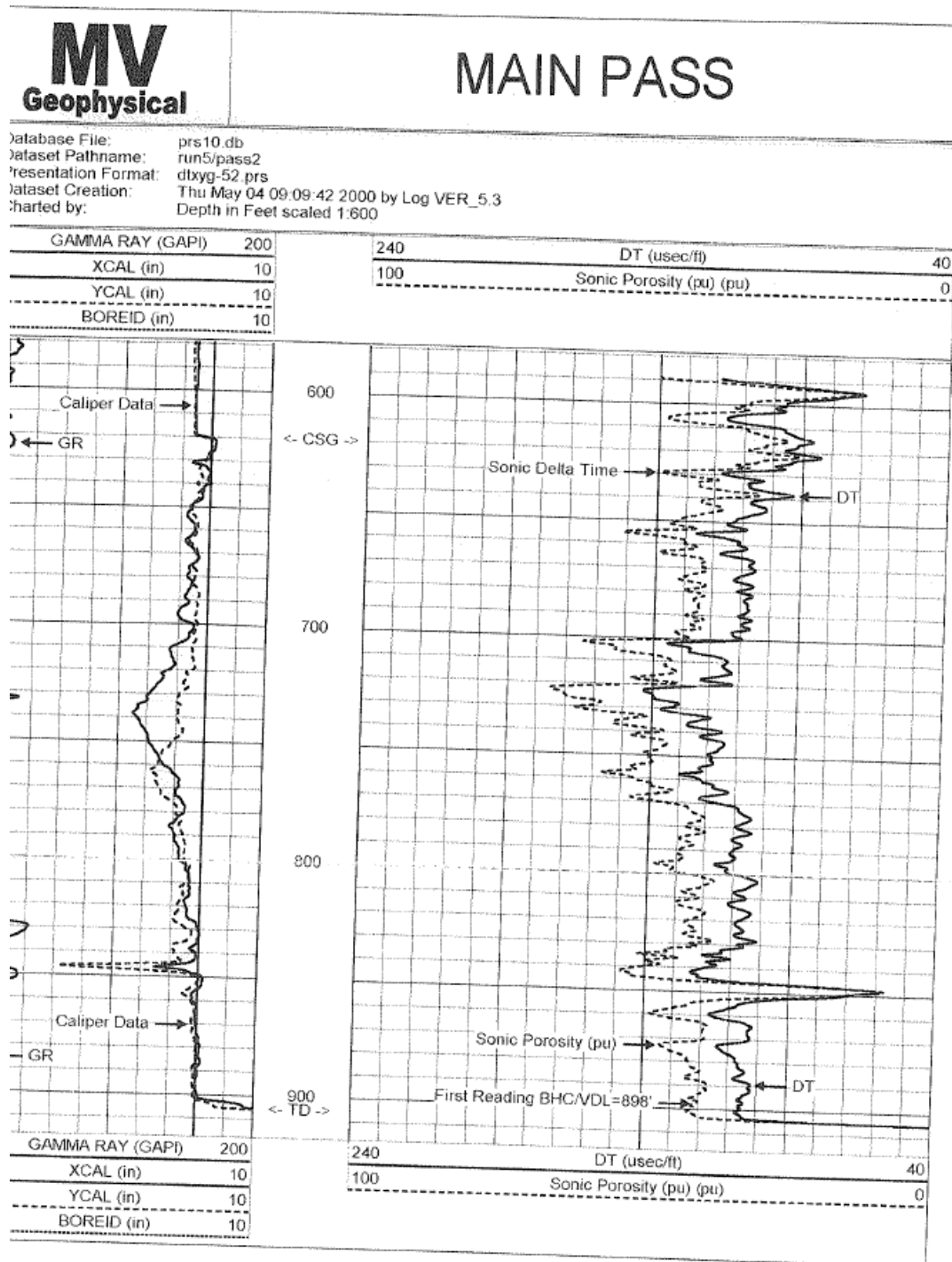


Figure A2. ASR Well S-10 (Continued).

Appendix A: Geophysical Logs (Continued)

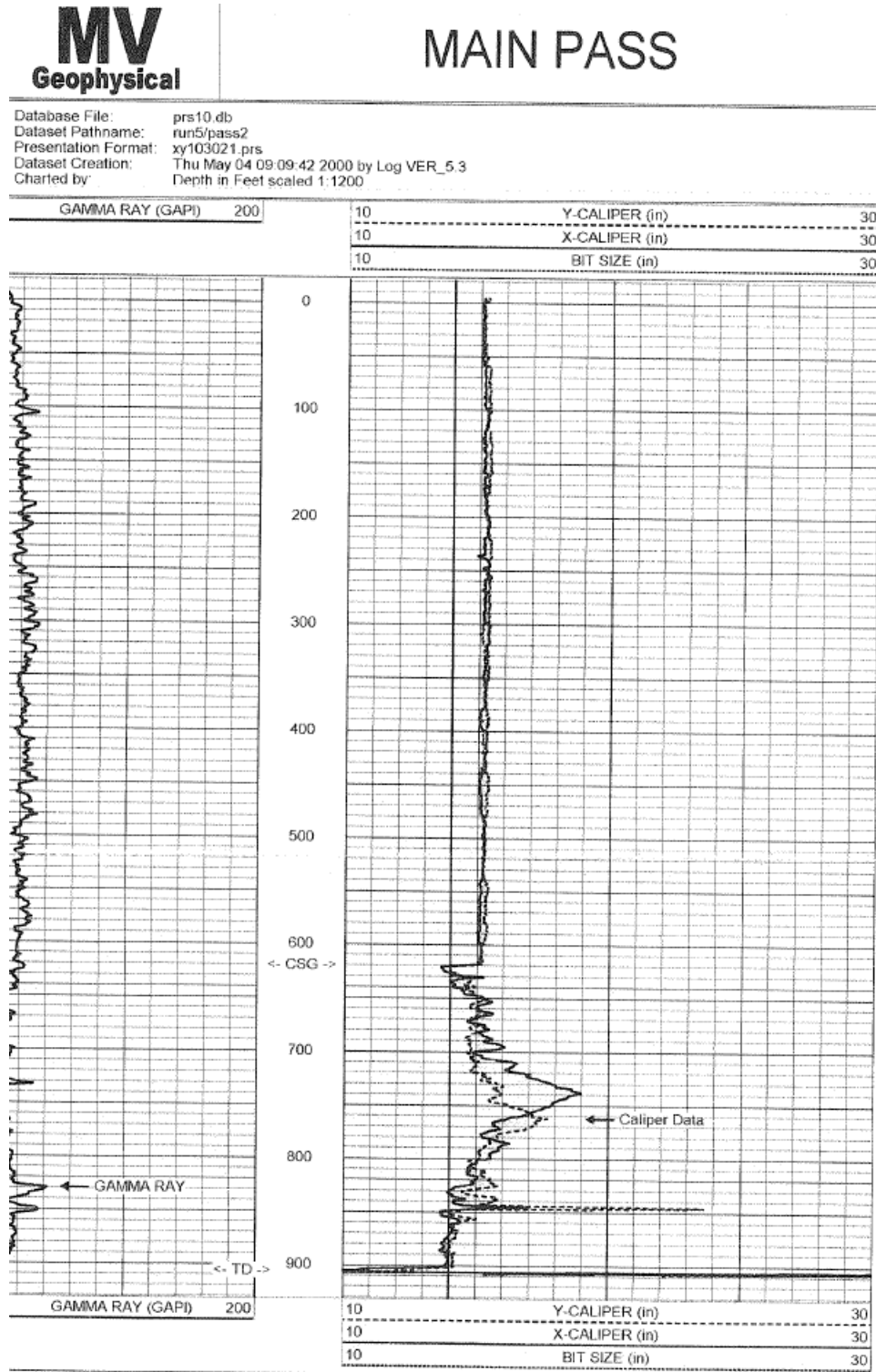


Figure A2. ASR Well S-10 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		FLOWMETER LOG	
Company DIVERSIFIED DRILLING Well ASR WELL S-11 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-11 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA	
Location ASR WELL FIELD EXPANSION		Other Services XY/GR DIL BHC/FRT VIDEO	
Permanent Datum Log Measured From Drilling Measured From	Ground Level Ground Level	Elevation na	Elevation K.B. na D.F. na G.L. na
Date 18-FEB-2000			
Run Number Depth Driller Depth Logger Bottom Logged Interval Top Log Interval Open Hole Size Type Fluid Density / Viscosity Max. Recorded Temp. Estimated Current Top Time Well Ready Time Logger on Bottom Equipment Number	FIVE 903' 905' 585' 14" WATER NANA NA 12:30 16-FEB-00 16:30 16-FEB-00 MVGS-1 FT MYERS		
Recorded By Witnessed By	C TARCISKA (WRS) M PEARCE (WRS)		
Borehole Record			
Run Number ONE TWO THREE FOUR	BT 12.25' 30" 12.25' 25"	From 60' 80' 245' 245'	To 280' 252' 592' 592'
Tubing Record			
Size 32" 26" 17.25" PVC	Weight 375 WT 375 WT 1 WT	Top SURFACE SURFACE SURFACE	Bottom 60' 245' 585'
Invoice No. 2000042	P.O. #	* FINAL PRINT *	

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Comments
 STATIC & DYNAMIC data was collected logging DOWN @ 40 & 80 fpm.
 Qmax~~600 gpm

Figure A3. ASR Well S-11.

Appendix A: Geophysical Logs (Continued)

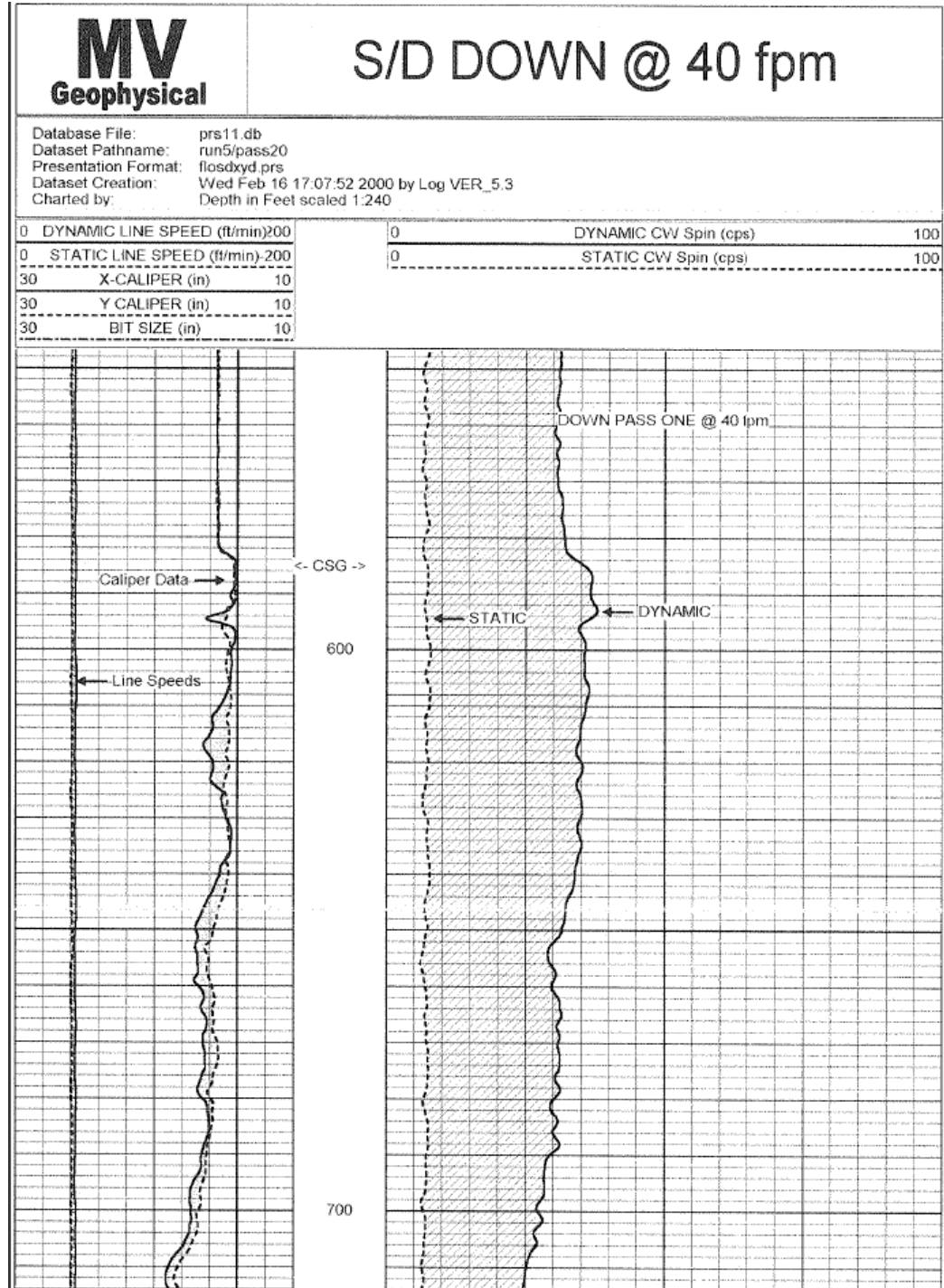


Figure A3. ASR Well S-11 (Continued).

Appendix A: Geophysical Logs (Continued)

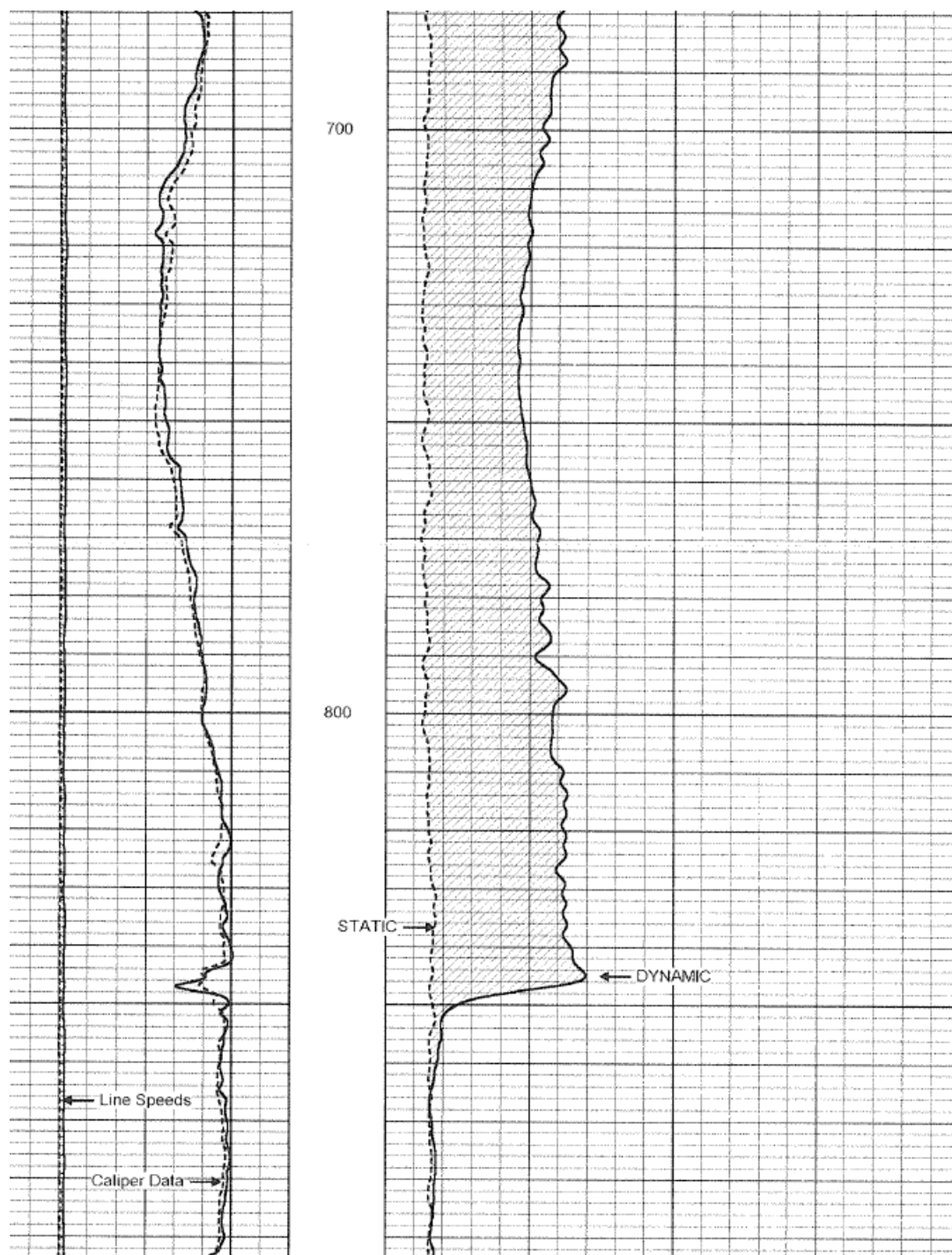
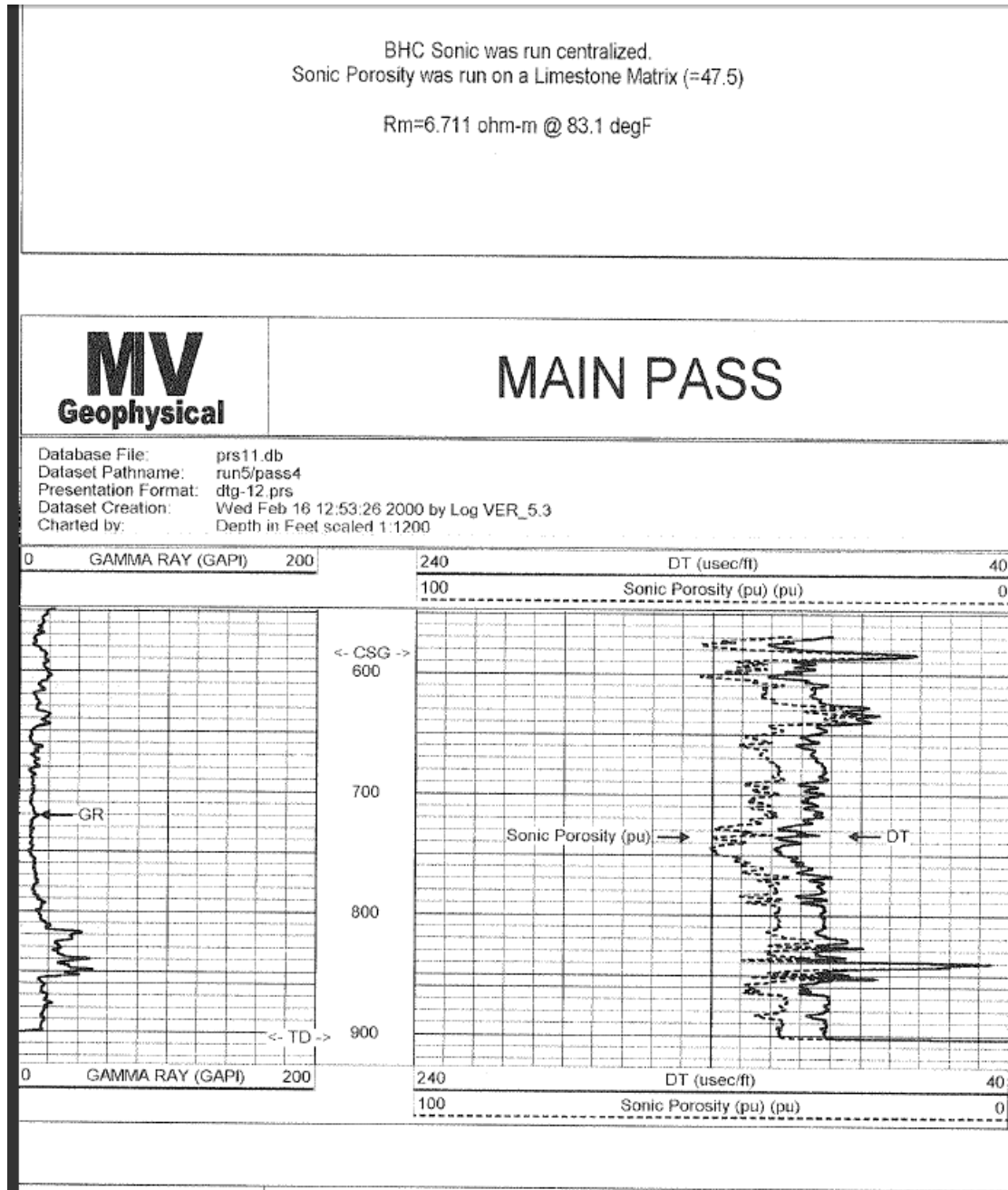


Figure A3. ASR Well S-11 (Continued).

Appendix A: Geophysical Logs (Continued)



Appendix A: Geophysical Logs (Continued)

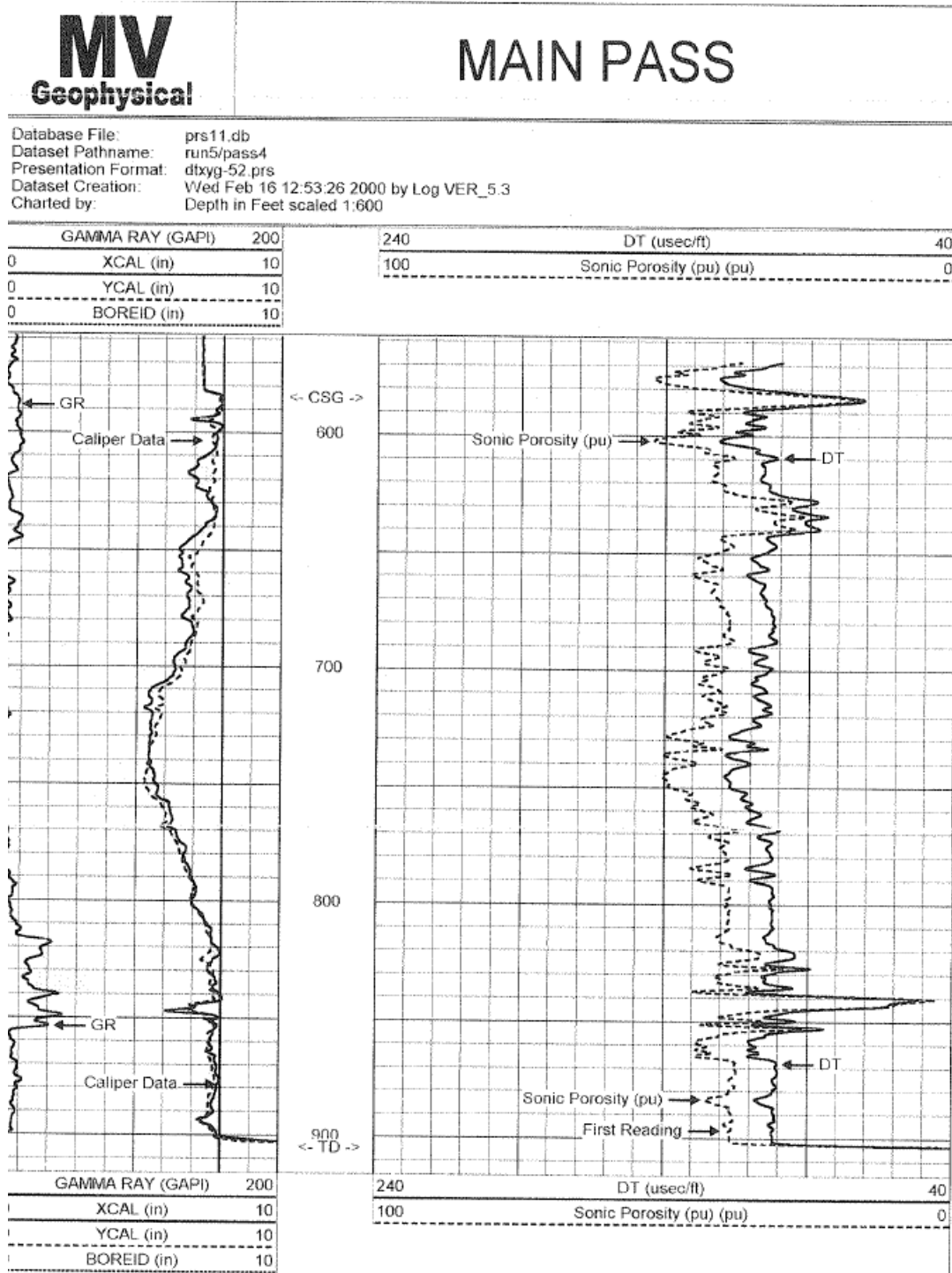


Figure A3. ASR Well S-11 (Continued).

Appendix A: Geophysical Logs (Continued)

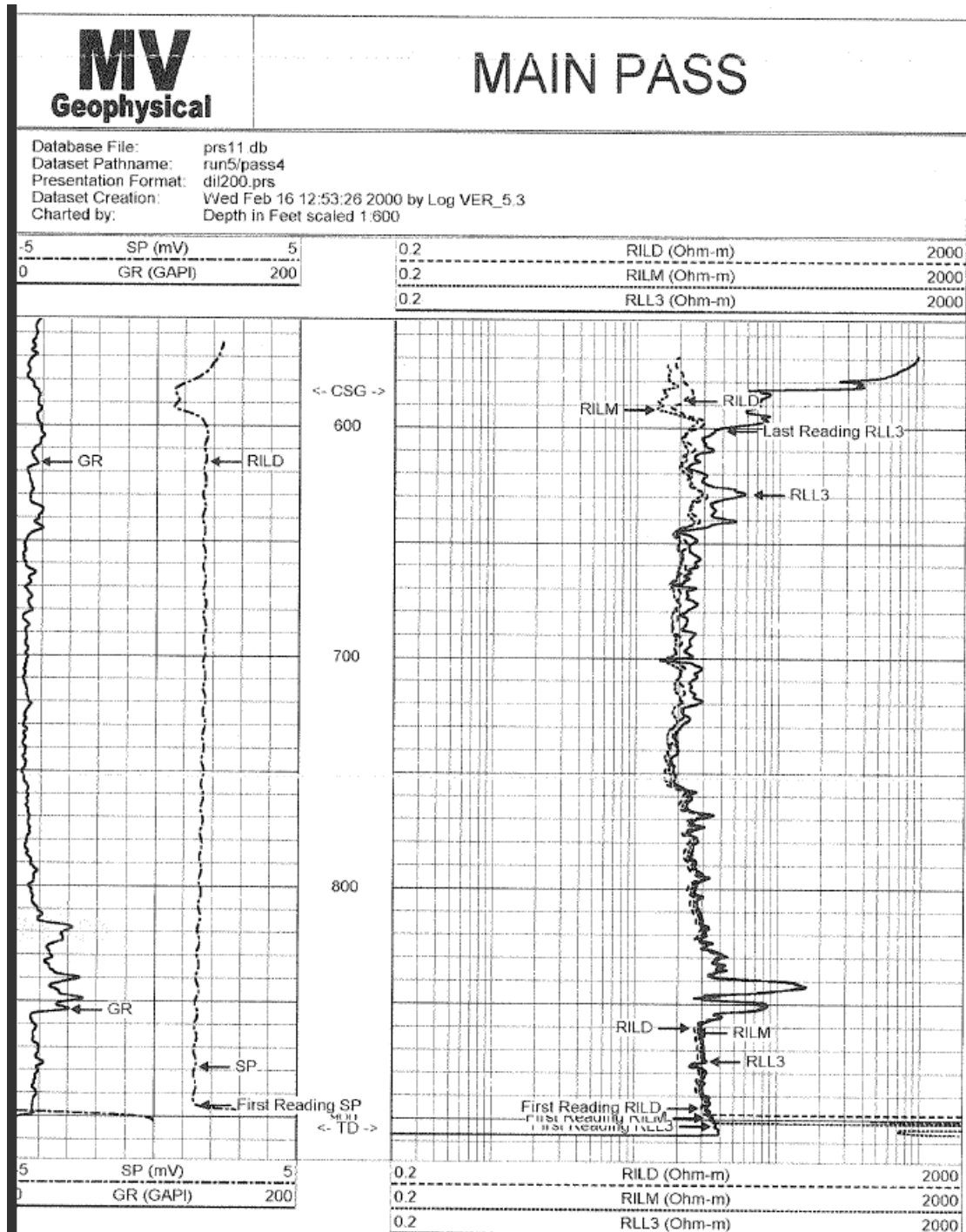


Figure A3. ASR Well S-11 (Continued).

Appendix A: Geophysical Logs (Continued)

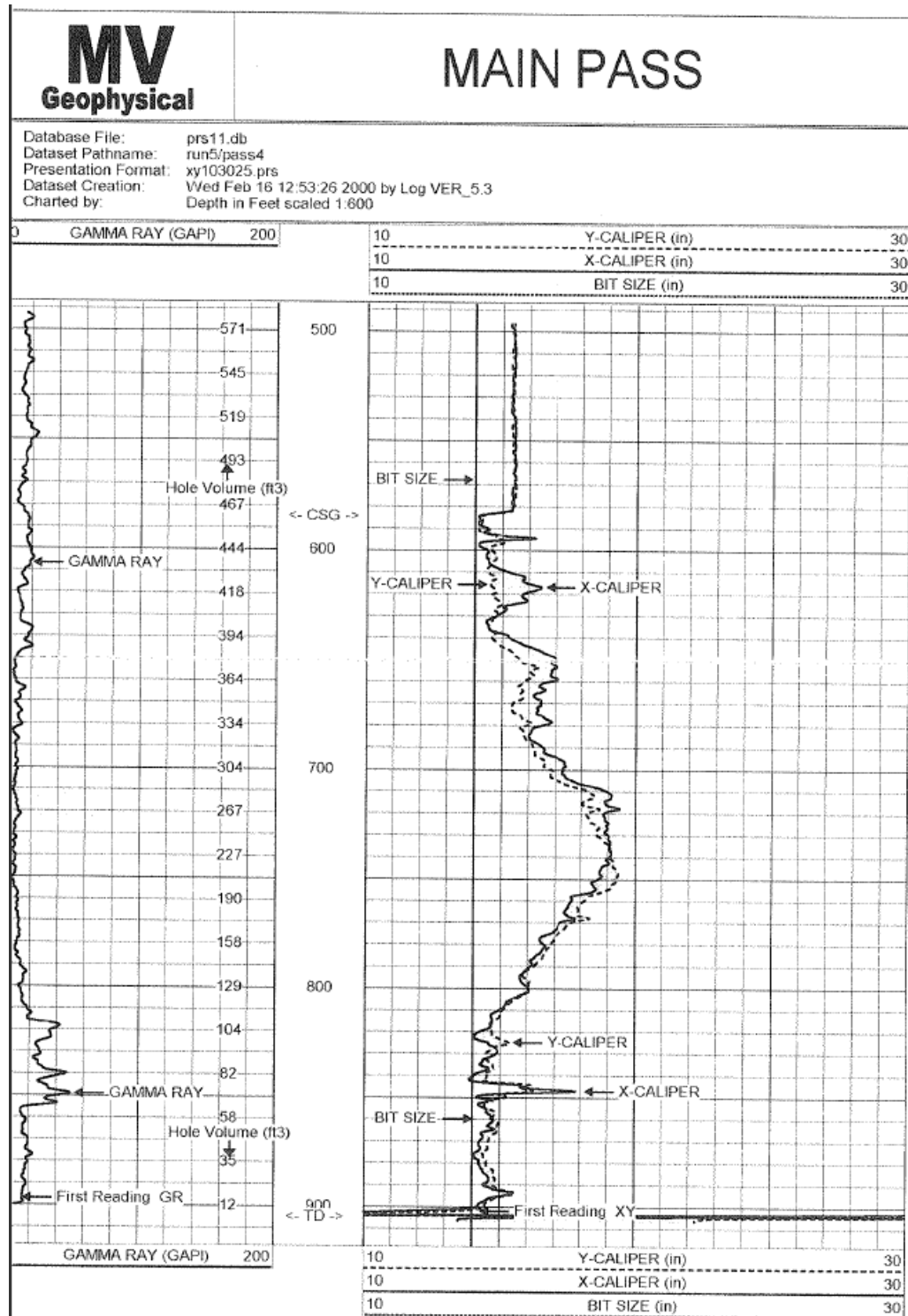


Figure A3. ASR Well S-11 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		FLOWMETER INTERPRETATION	
Company DIVERSIFIED DRILLING Well ASR WELL S-12 Field PEACE RIVER Country DeSOTO State/Pv FLORIDA		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-12 Field PEACE RIVER Country DeSOTO State/Pv FLORIDA	
Location ASR WELL FIELD EXPANSION		Other Services XY/GP DIL BHC FLOW FRT VIDEO	
Permanent Datum Log Measured From Drilling Measured From	Ground Level Ground Level Ground Level	Elevation na na na	K/B na na na
Date 24-MAR-2000			
Run Number Depth Driller Depth Logger Bottom Logged Interval Top Log Interval Open Hole Size Type Fluid Density / Viscosity Max. Recorded Temp. Estimated Cement Top Time Well Ready Time Logger on Bottom Equipment Number	24-MAR-2000 FIVE 905' 907' 907' 550' 14" WATER N/A N/A 07:00 24-MAR-00 11:30 24-MAR-00 MWGS-1 FT MYERS		
Location Recorded By Witnessed By	MILLERVINCENT C. TARRICKA (WRS)		
Borehole Record			
Run Number ONE TWO THREE FOUR	Bit 12.25" 30" 12.25" 23"	From 60' 255' 246' 246'	To 260' 255' 815' 815'
Tubing Record			
Casing Record Surface String Prod. String Production String Log	Size 32" 28" 17.25" PVC	WT 375 WT 375 WT 1" WT	Top SURFACE SURFACE SURFACE SURFACE
Bottom 607' 246' 607'			
Invoice No. 2000071 P.O. # 5867 * FINAL PRINT *			

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Comments

Q, %Q & Fluid Velocity presentations include a regular Line Speed and Caliper corrected only format, and an interpretative "LOGICAL" format. "LOGICAL" Q, %Q & Fluid Velocity passes assume no thief zones (Q & %Q can only increase).

STATIC & DYNAMIC data was collected logging DOWN @ 40 & 80 fpm.

Qmax=150 gpm

"Logical" Q, %Q & F.Vel.

Figure A4. ASR Well S-12.

Appendix A: Geophysical Logs (Continued)

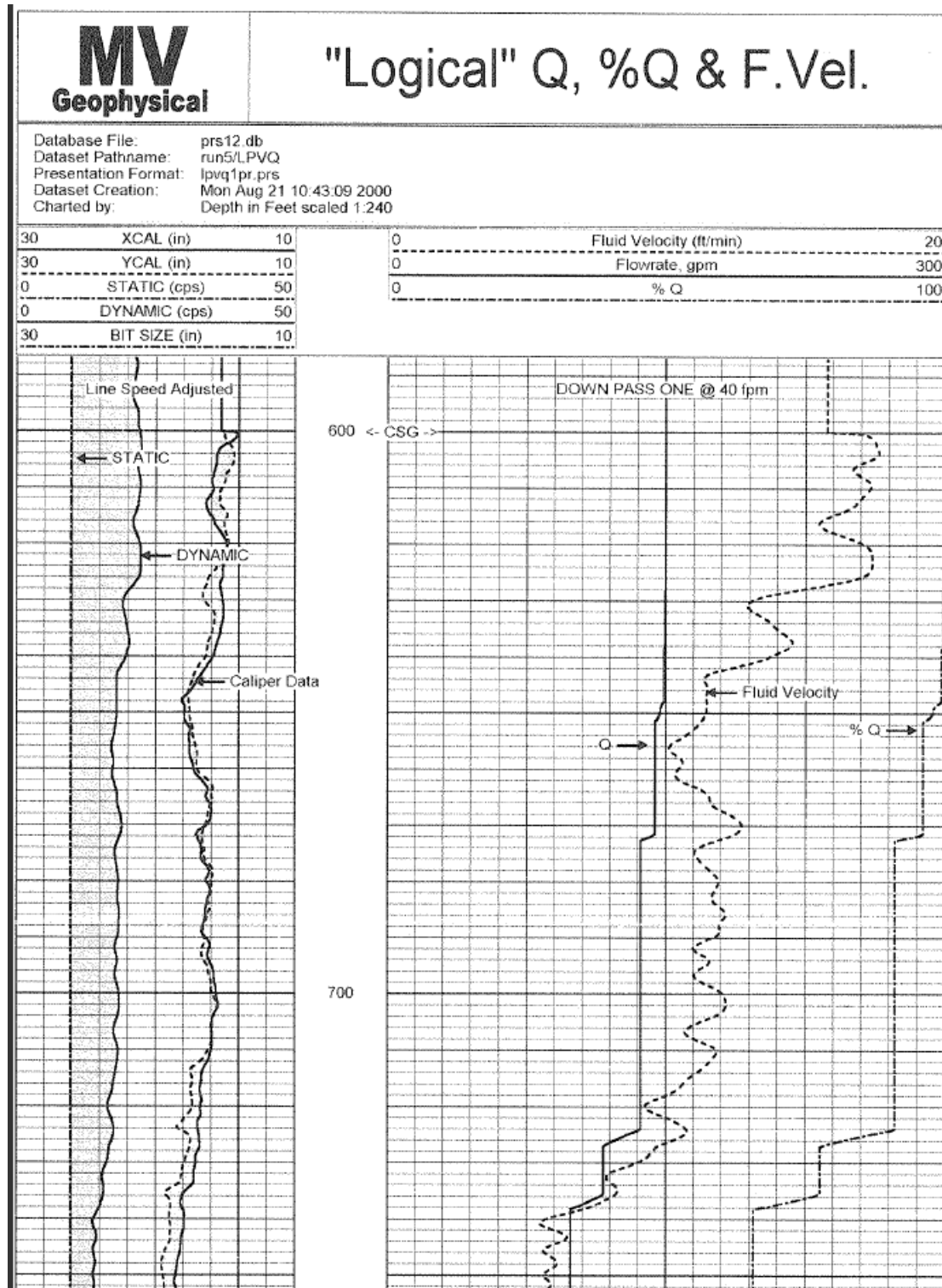


Figure A4. ASR Well S-12 (Continued).

Appendix A: Geophysical Logs (Continued)



Figure A4. ASR Well S-12 (Continued).

Appendix A: Geophysical Logs (Continued)

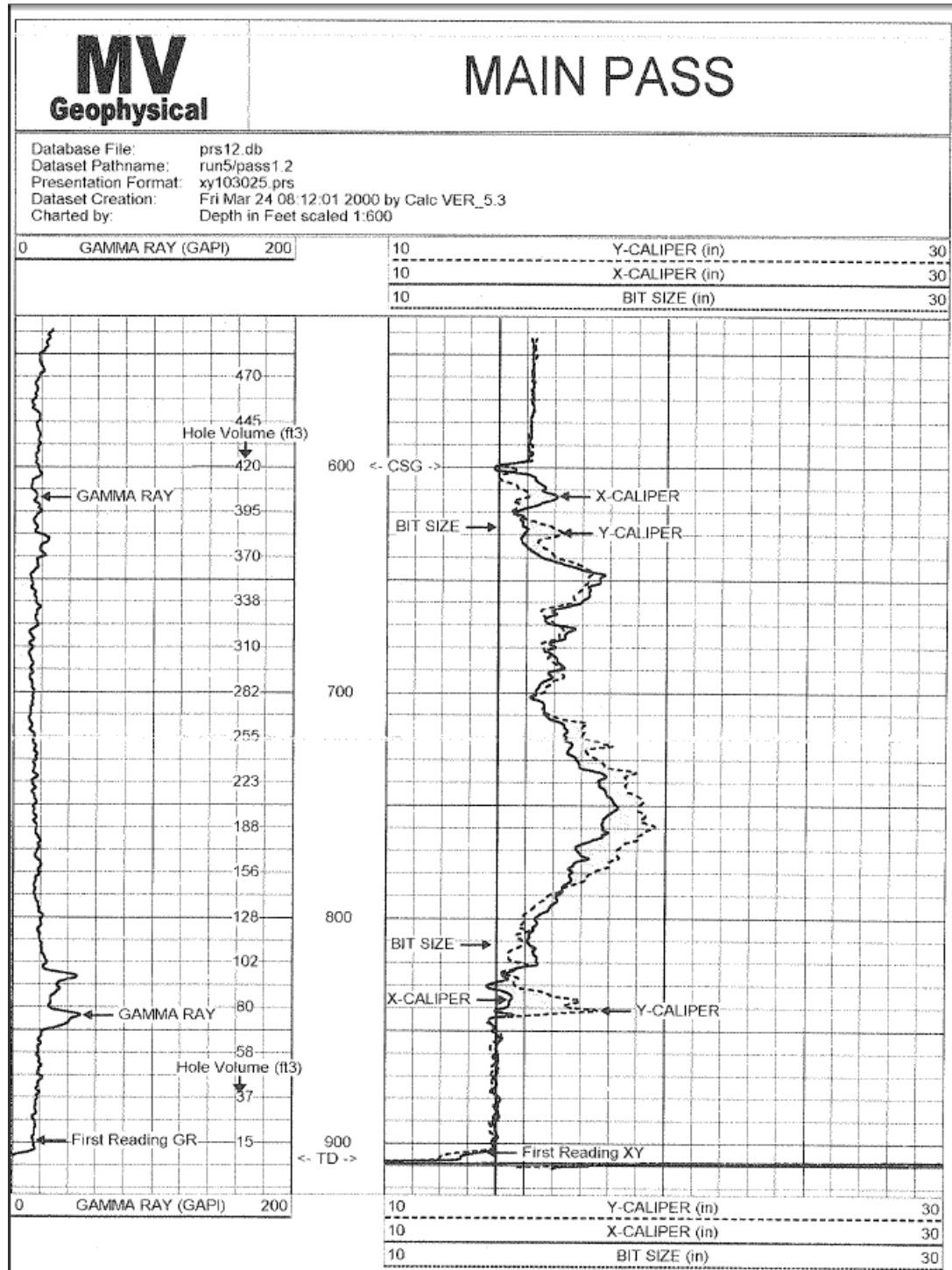


Figure A4. ASR Well S-12 (Continued).

Appendix A: Geophysical Logs (Continued)

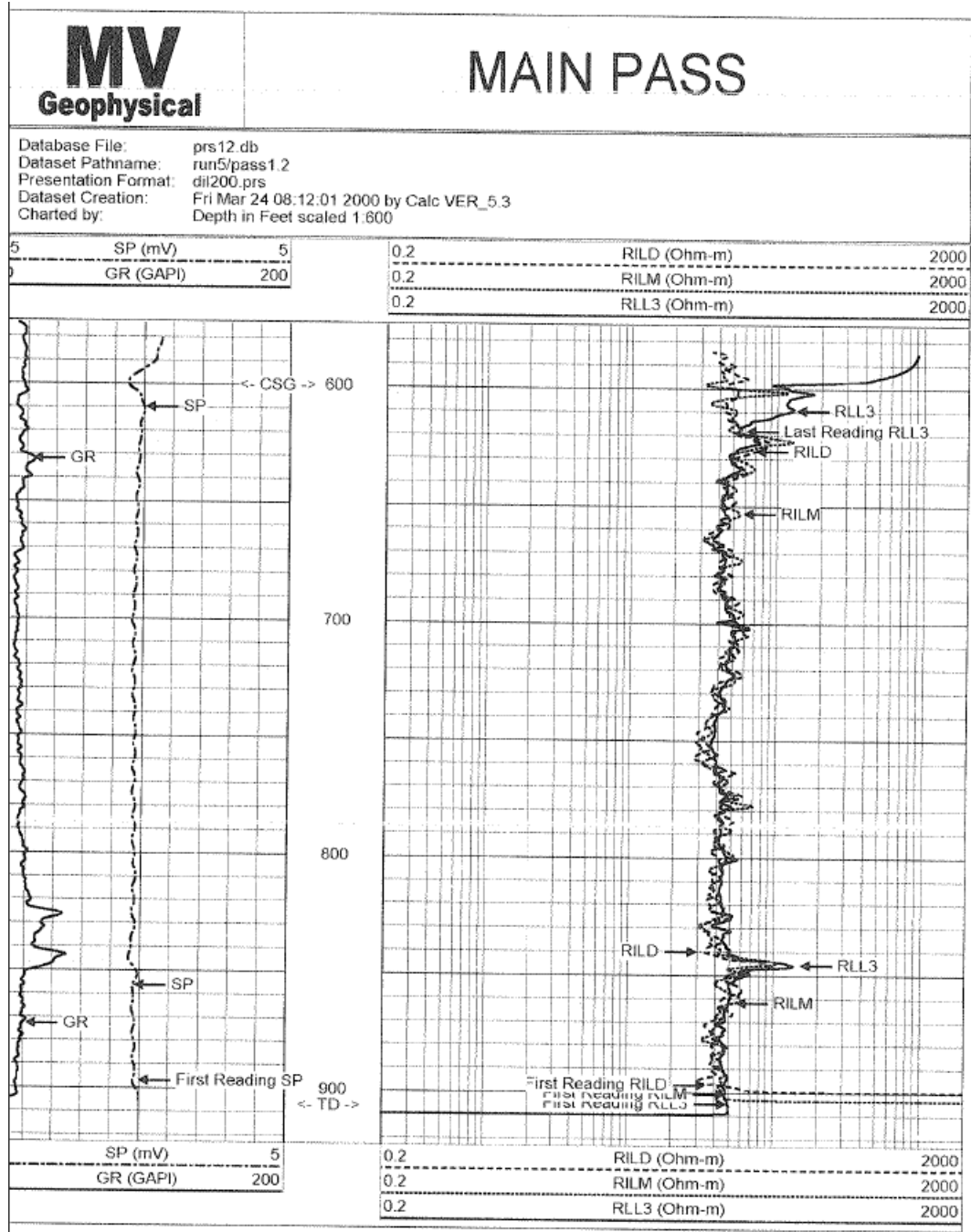


Figure A4. ASR Well S-12 (Continued).

Appendix A: Geophysical Logs (Continued)

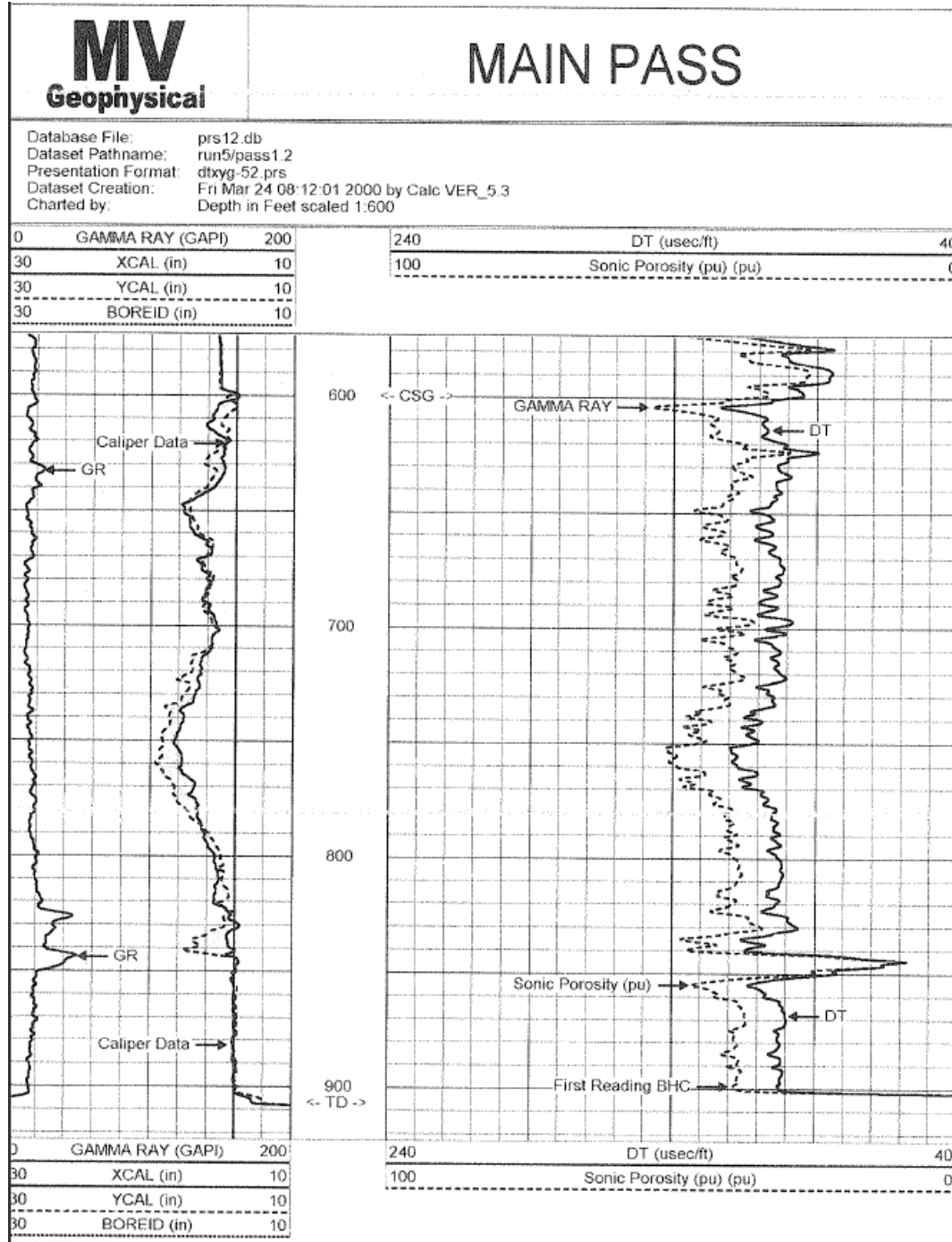


Figure A4. ASR Well S-12 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		FLOWMETER INTERPRETATION LOG																																									
Company DIVERSIFIED DRILLING Well ASR WELL S-13 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-13 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA																																									
Location ASR WELL FIELD EXPANSION		Other Services XY/GR DIL BHC/FRT FLOW VIDEO																																									
Permanent Datum Log Measured From Drilling Measured From	Ground Level Ground Level Ground Level	Elevation na na na	Elevation na na na																																								
Date 28-OCT-88 Run Number SIX Depth Under 903 Depth Logger 902 Bottom Logged Interval 902 Top Log Interval 595 Open Hole Size 14"																																											
Type Fluid WATER Density / Viscosity N/A Max. Recorded Temp. N/A Estimated Cement Top N/A Time Well Ready 08:00 10/26/88 Time Logger on Bottom 12:00 10/26/88 Equipment Number MWGS-1 Location FT. MYERS Recorded By MILLER/VINCENT Witnessed By P. BREDEN (WRS)																																											
Borehole Record <table border="1"> <thead> <tr> <th>Run Number</th> <th>Bit</th> <th>From</th> <th>To</th> <th>Size</th> <th>Weight</th> <th>From</th> <th>To</th> </tr> </thead> <tbody> <tr> <td>ONE</td> <td>12.25"</td> <td>57"</td> <td>249"</td> <td>FIVE</td> <td>14"</td> <td>SURFACE</td> <td>903</td> </tr> <tr> <td>TWO</td> <td>31"</td> <td>57"</td> <td>249"</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>THREE</td> <td>12.25"</td> <td>249"</td> <td>750"</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>FOUR</td> <td>25"</td> <td>623"</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>				Run Number	Bit	From	To	Size	Weight	From	To	ONE	12.25"	57"	249"	FIVE	14"	SURFACE	903	TWO	31"	57"	249"					THREE	12.25"	249"	750"					FOUR	25"	623"					
Run Number	Bit	From	To	Size	Weight	From	To																																				
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Invoice No. 99002 P.O. # 4866 * FINAL PRINT *																																											

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Comments

DYNAMIC Flowmeter passes were made down @30, 60, & 90 fpm.
 Qmax=238 gpm

A DYNAMIC UP pass was made @ 30 fpm (FILE 17) to identify a possible DOWN flow zone (TD-855").
 Down flow confirmed by the DOWHOLE VIDEO SURVEY.

Figure A5. ASR Well S-13.

Appendix A: Geophysical Logs (Continued)

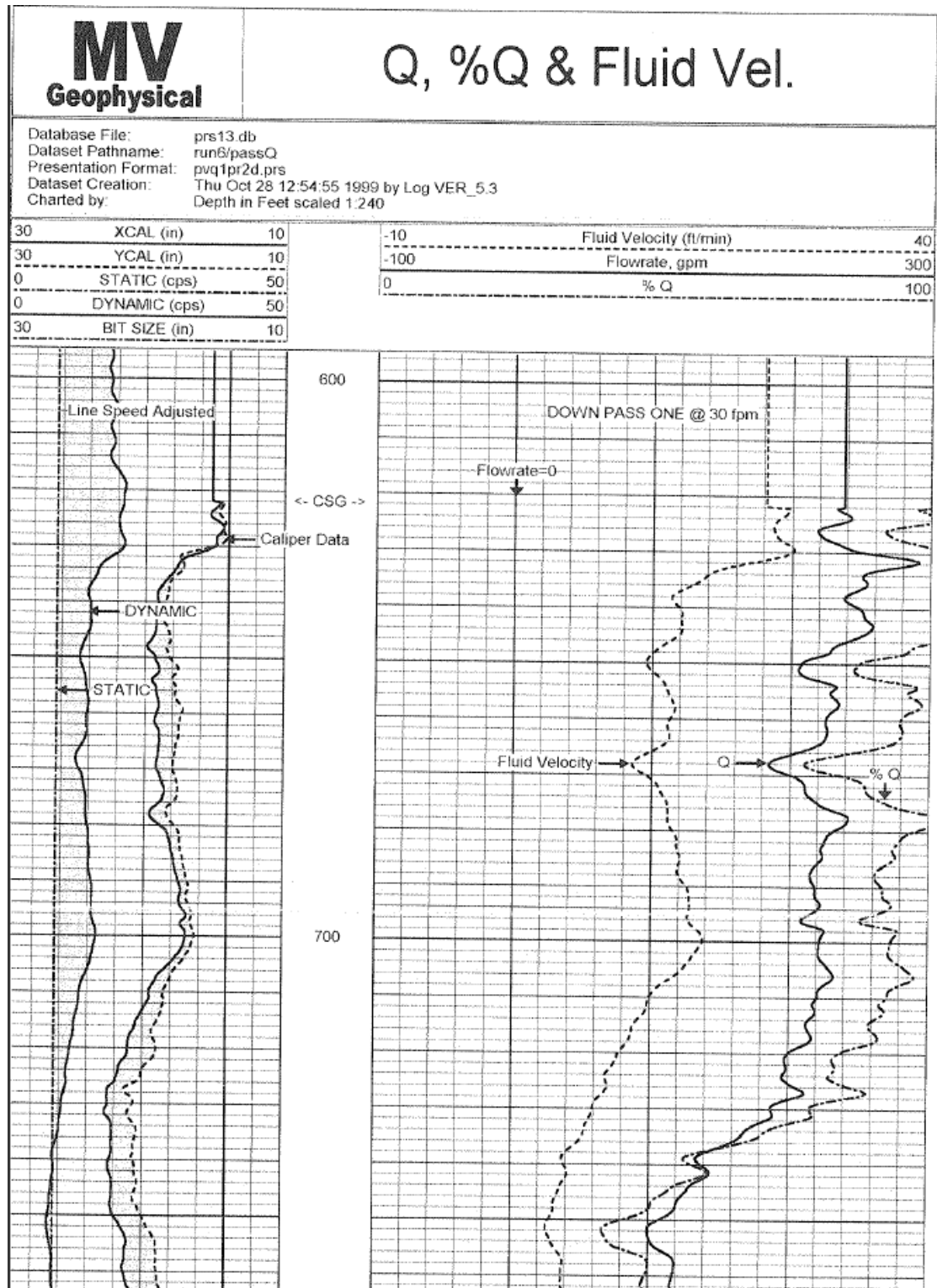


Figure A5. ASR Well S-13 (Continued).

Appendix A: Geophysical Logs (Continued)

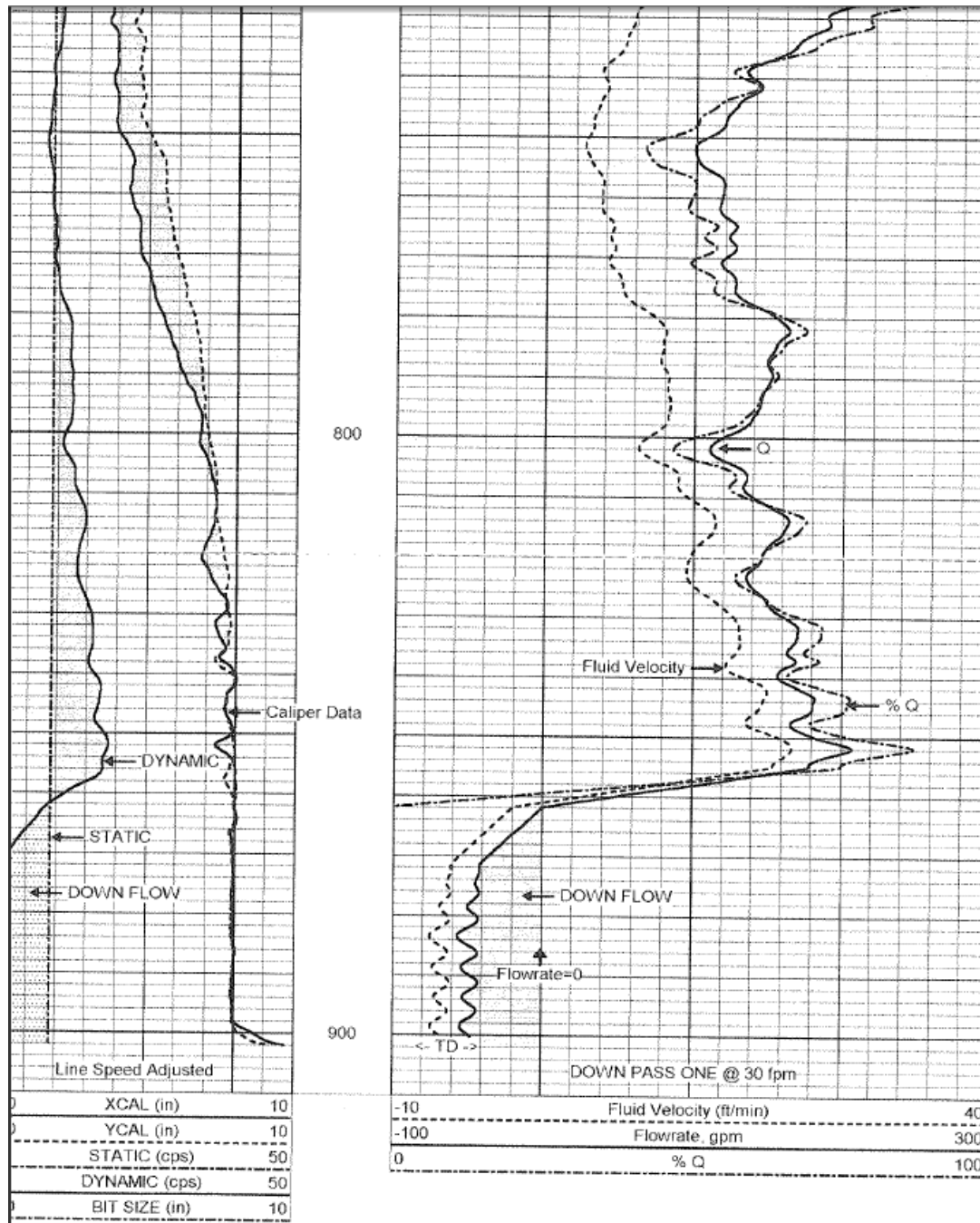


Figure A5. ASR Well S-13 (Continued).

Appendix A: Geophysical Logs (Continued)

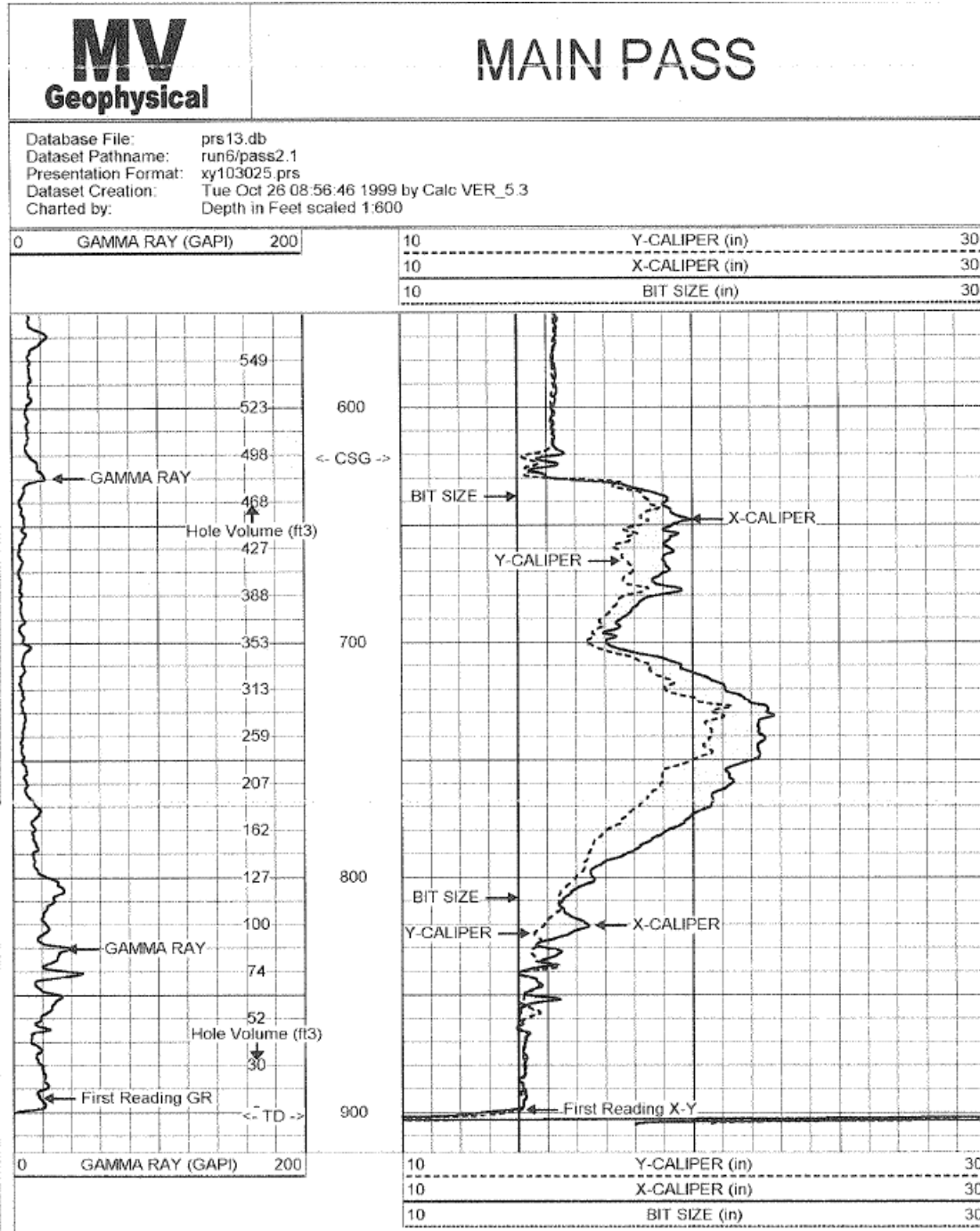


Figure A5. ASR Well S-13 (Continued).

Appendix A: Geophysical Logs (Continued)

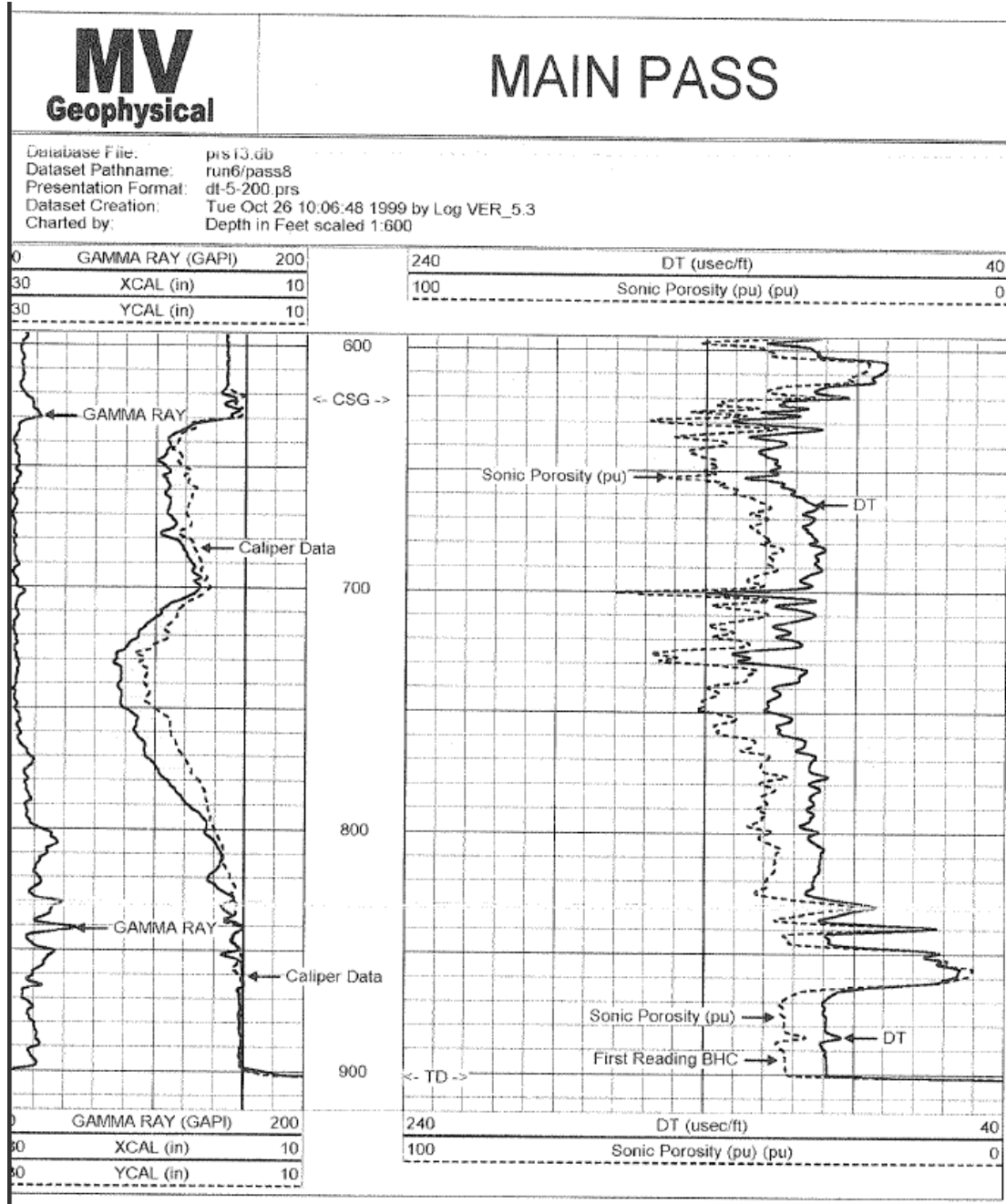


Figure A5. ASR Well S-13 (Continued).

Appendix A: Geophysical Logs (Continued)

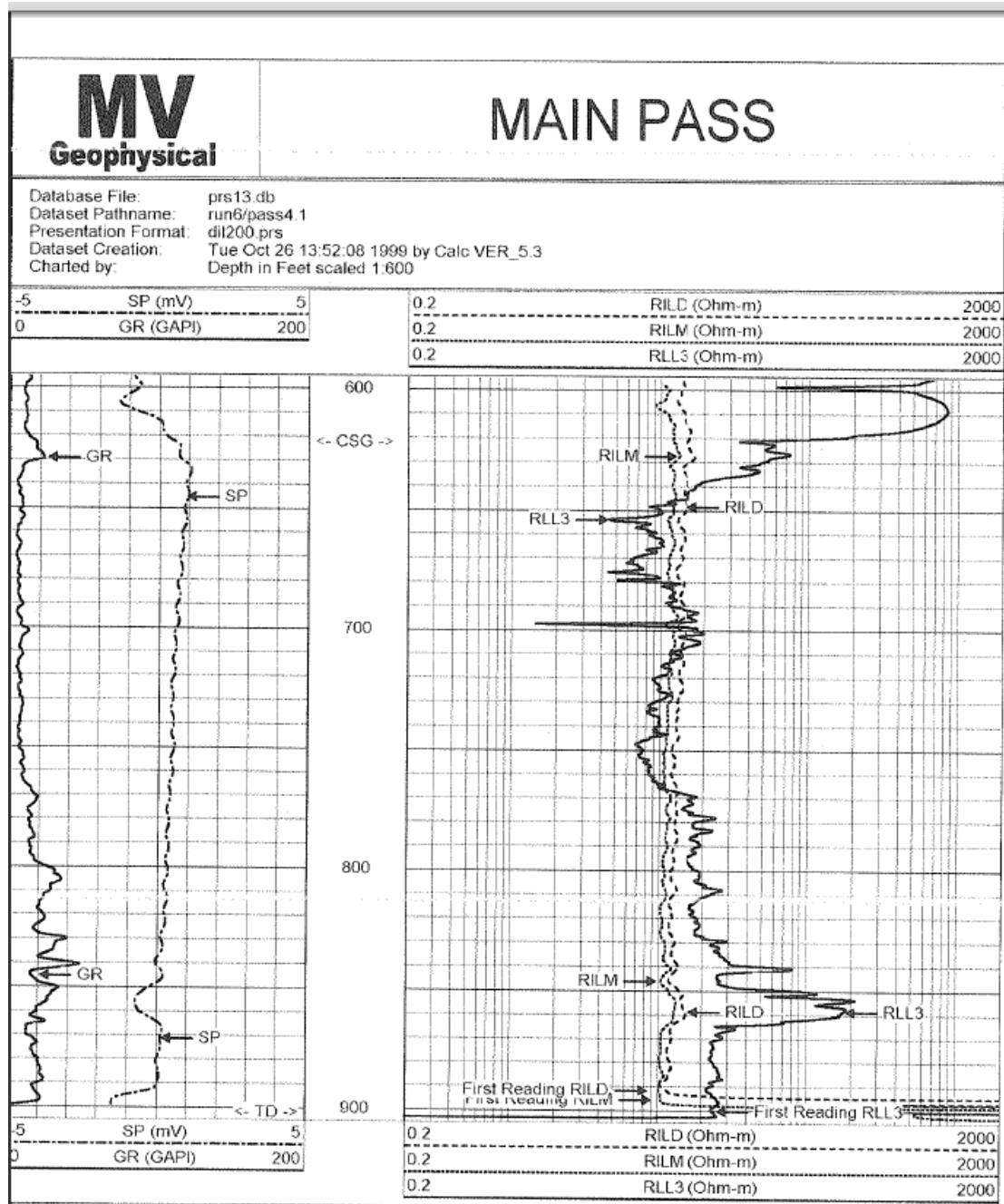


Figure A5. ASR Well S-13 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		Borehole Compensated SONIC w/ Variable Density Log	
MV Company: DIVERSIFIED DRILLING CORP. Well: ASR WELL S-14 Field: PEACE RIVER Country: DESOTO State/Prov: FLORIDA		Location: PRIMRWSA ASR WELL FIELD EXPANSION	
Company: DIVERSIFIED DRILLING CORP. Well: ASR WELL S-14 Field: PEACE RIVER Country: DESOTO State/Prov: FLORIDA		Location: PRIMRWSA ASR WELL FIELD EXPANSION	
Date: 7-MAR-2000 Run Number: FIVE Depth Driller: 900' Depth Logger: 900' Bottom Logged Interval: 893' Top Log Interval: 550' Open Hole Size: 14" Type Fluid: WATER Density / Viscosity: NANA Max. Recorded Temp: NA Estimated Cement Top: 07:00 3/7/00 Time Well Ready: 10:00 3/7/00 Time Logger on Bottom: 10:00 3/7/00 Equipment Number: MAVS-1 Location: FT MYERS Recorded By: MILLER/MINCENT Witnessed By: G.SUSENDORF (MRS)		Permanent Datum: Ground Level Log Measured From: Ground Level Drilling Measured From: Ground Level Elevation: na K.B. na D.F. na C.L. na	
Run Number: ONE Size: 12.25" From: 40' To: 280' Weight: 565' From: 900' To: 900'		Run Number: TWO Size: 30" From: 40' To: 255' Weight: 14" From: 565' To: 900'	
Run Number: THREE Size: 12.25" From: 255' To: 565' Weight: 565' From: 900' To: 900'		Run Number: FOUR Size: 23" From: 255' To: 565' Weight: 565' From: 900' To: 900'	
Casing Record Surface String: 32" Prof. String: 28" Production String: 17.25" PVC		Taking Record Surface: 40' Surface: 255' Surface: 565'	
Invoice No.: 2000058 P.O. #: 5784		* FINAL PRINT *	

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Comments

BHC Sonic was run centralized.
 Sonic Porosity was run on a Limestone Matrix (=47.5)

Well Status: STATIC

Rm=6.920 ohm-m @ 84.7 degF

Figure A6. ASR Well S-14.

Appendix A: Geophysical Logs (Continued)

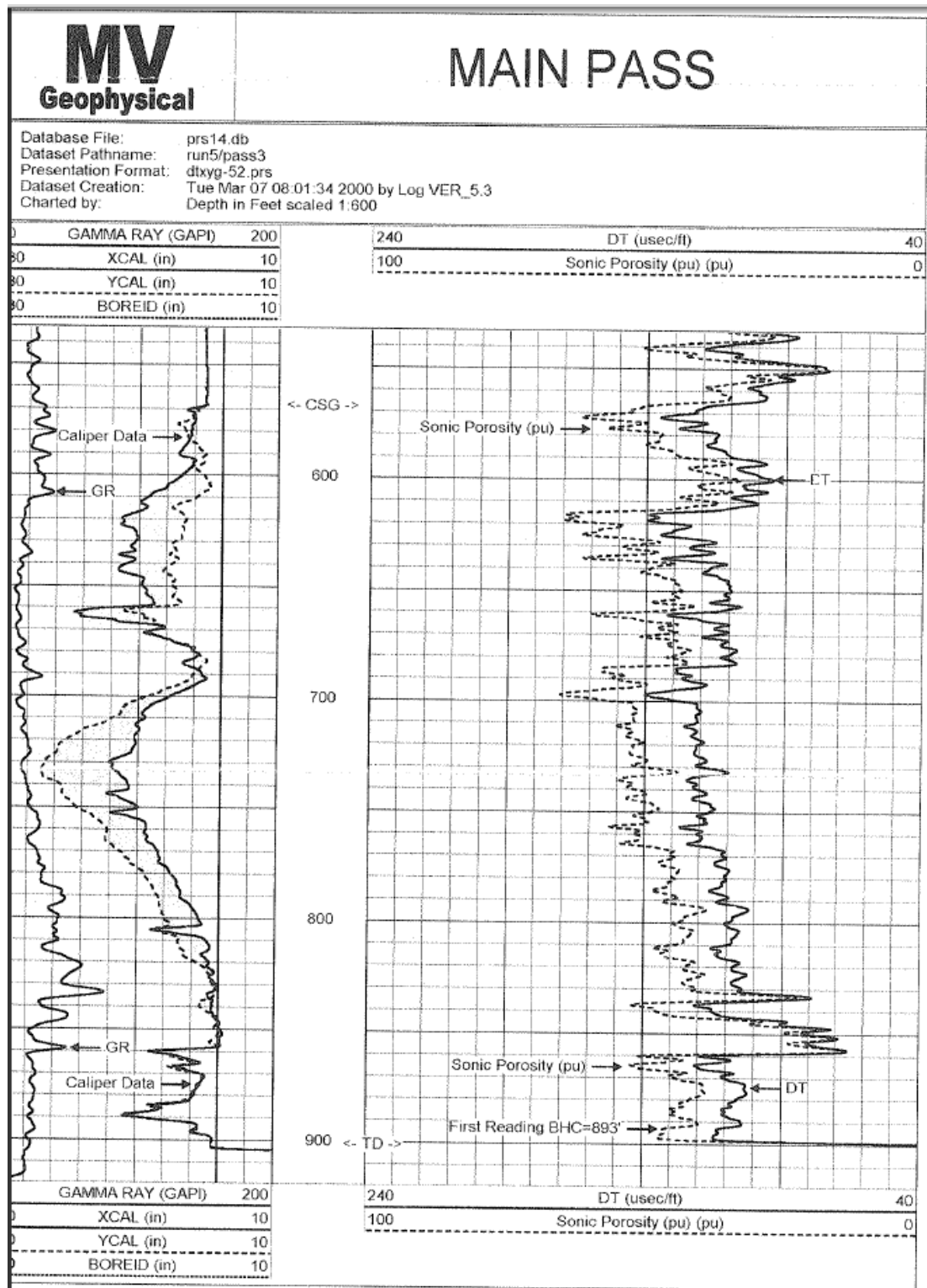


Figure A6. ASR Well S-14 (Continued).

MV Geophysical DUAL INDUCTION LL3 / SP LOG		Company DIVERSIFIED DRILLING CORP.			
		Well ASR WELL S-14			
Field PEACE RIVER		Country DeSOTO		State/Prv FLORIDA	
Location ASR WELL FIELD EXPANSION		Other Services XYGR BHC FRT FLOW VIDEO		Elevation K.B. na O.F. na G.L. na	
Permanent Datum Log Measured From Drilling Measured From		Ground Level Ground Level Ground Level		Elevation na na na	
Run Number ONE TWO THREE FOUR		From 40' 37' 12.25' 23'		To 260' 255' 363' 372'	
Size 32" 26" 12.25" PVC		Weight 14" 566'		Bottom 40' 253' 566'	
Water 3.75" WT 1" WT		Surface SURFACE SURFACE		Bottom SURFACE SURFACE	
Production String 12.25" PVC		Log 12.25" PVC		Production String 12.25" PVC	
Invoice No. 2000058		P.O. # 5764		* FINAL PRINT *	

Run Number: ONE, TWO, THREE, FOUR
 From: 40', 37', 12.25', 23'
 To: 260', 255', 363', 372'
 Size: 32", 26", 12.25" PVC
 Weight: 14", 566'
 Bottom: 40', 253', 566'
 Water: 3.75" WT, 1" WT
 Surface: SURFACE, SURFACE
 Production String: 12.25" PVC

Date: 7-MAR-2000
 Company: DIVERSIFIED DRILLING
 Well: ASR WELL S-14
 Field: PEACE RIVER
 Country: DeSOTO
 State/Prv: FLORIDA

Location: ASR WELL FIELD EXPANSION
 Other Services: XYGR BHC, FRT FLOW, VIDEO
 Elevation: K.B. na, O.F. na, G.L. na

Permanent Datum: Log Measured From, Drilling Measured From
 Ground Level: Ground Level, Ground Level
 Elevation: na, na, na

Run Number: ONE, TWO, THREE, FOUR
 From: 40', 37', 12.25', 23'
 To: 260', 255', 363', 372'
 Size: 32", 26", 12.25" PVC
 Weight: 14", 566'
 Bottom: 40', 253', 566'
 Water: 3.75" WT, 1" WT
 Surface: SURFACE, SURFACE
 Production String: 12.25" PVC

Invoice No.: 2000058
 P.O. #: 5764
 * FINAL PRINT *

All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule.

Comments:

Rm=6.920 ohm-m @ 84.7 degF

239

Appendix A: Geophysical Logs (Continued)

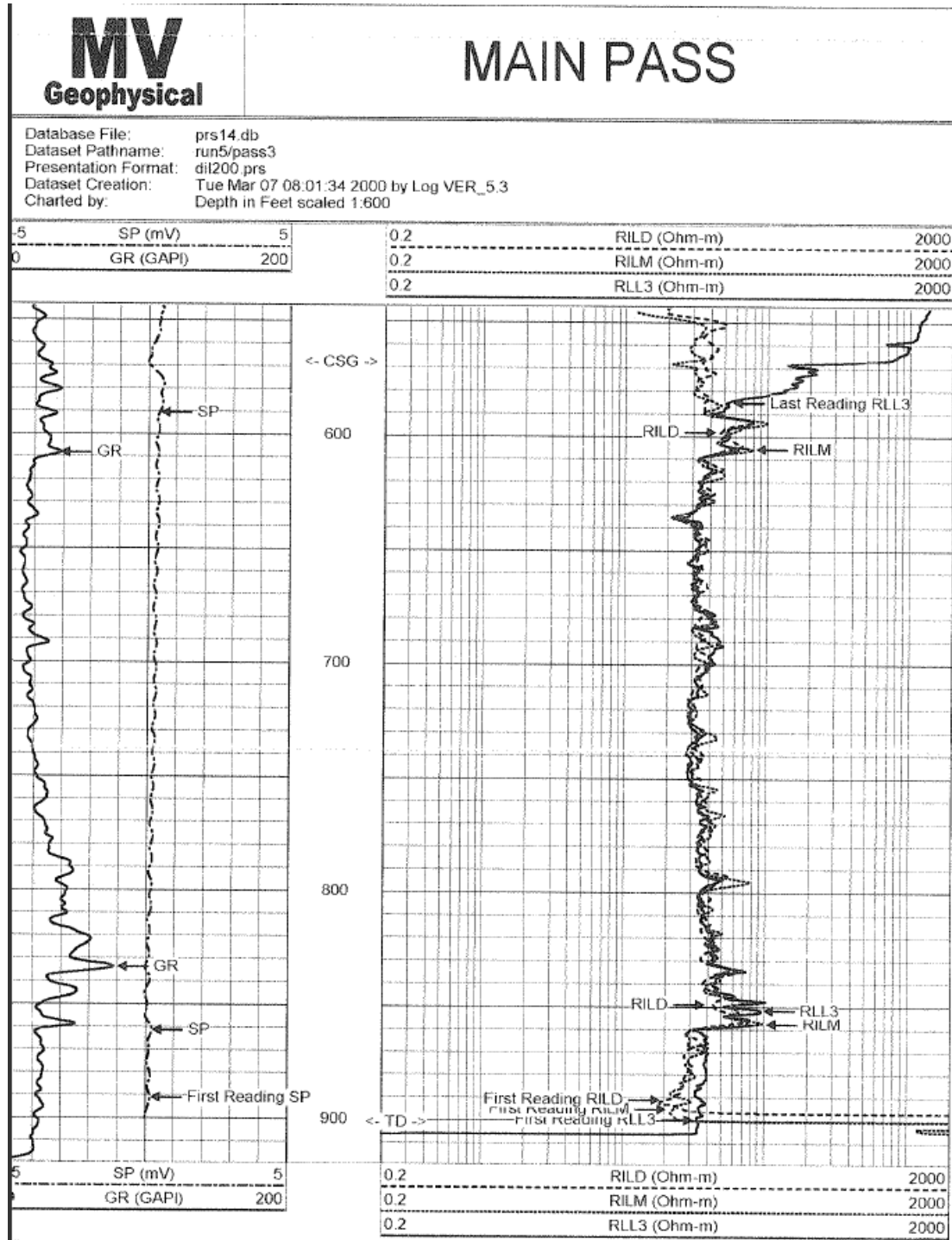


Figure A6. ASR Well S-14 (Continued).

Appendix A: Geophysical Logs (Continued)

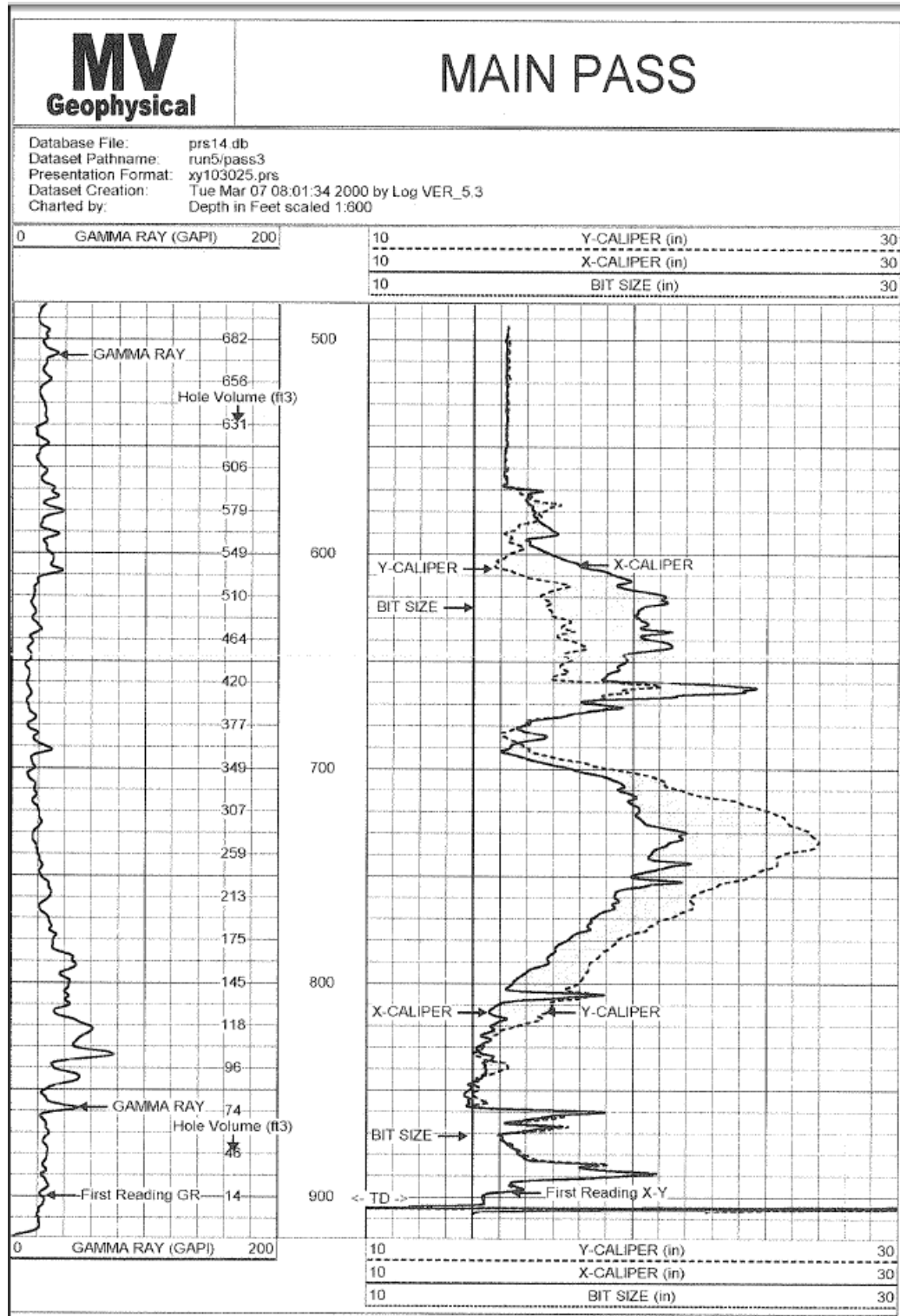


Figure A6. ASR Well S-14 (Continued).

Appendix A: Geophysical Logs (Continued)

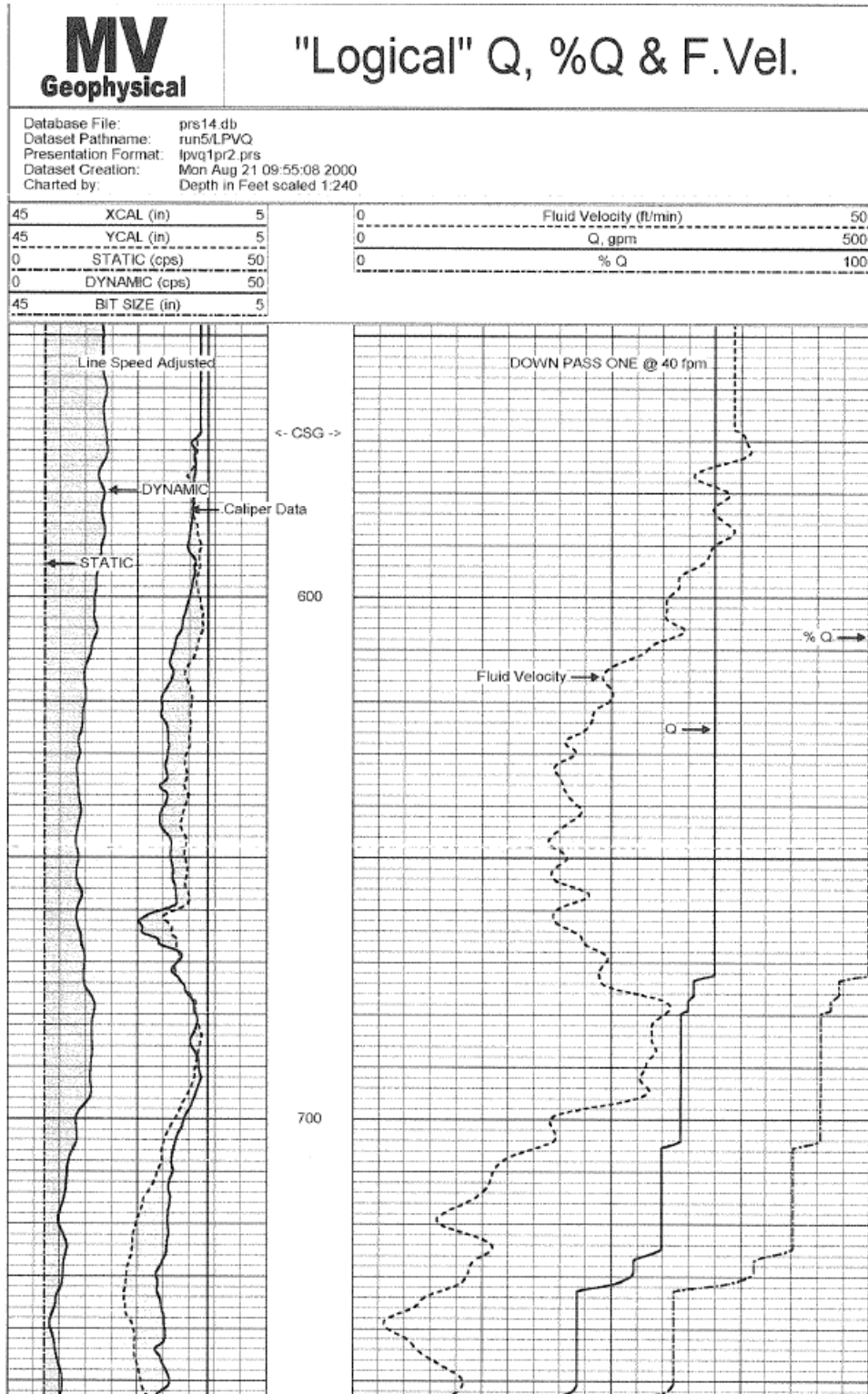


Figure A6. ASR Well S-14 (Continued).

Appendix A: Geophysical Logs (Continued)

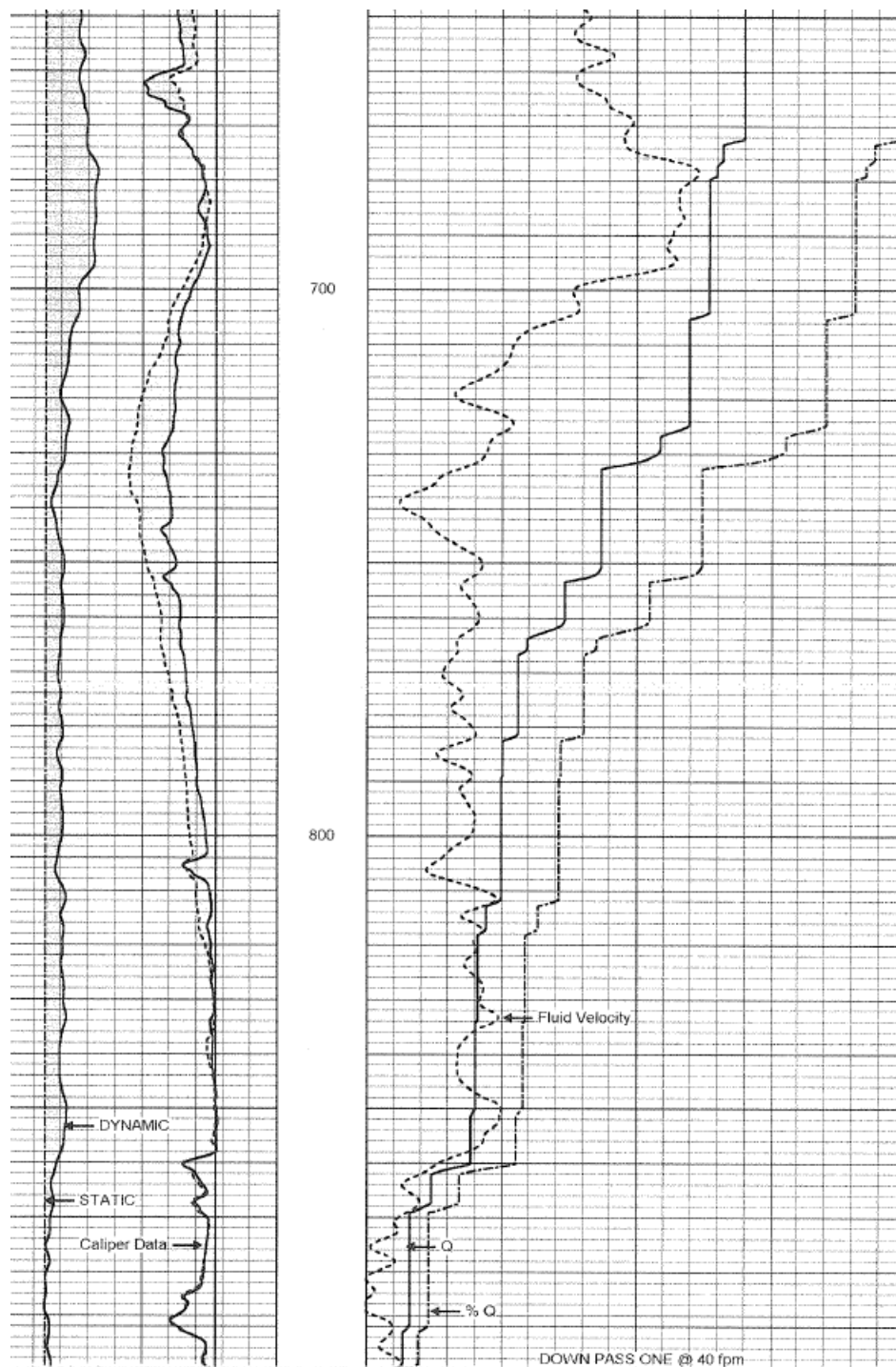


Figure A6. ASR Well S-14 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		FLOWMETER INTERPRETATION	
Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-15 Field PEACE RIVER Country DESOTO State/Pvt FLORIDA		Location PRMRWSA ASR WELL FIELD EXPANSION	
Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-15 Field PEACE RIVER Country DESOTO State/Pvt FLORIDA		Other Services D/L BHC/FRT XY/GR FLOW VIDEO	
Date 8-DEC-99 Run Number FIVE Depth Diller 600' Depth Logger 600' Bottom Logged Interval 600' Top Log Interval 583' Open Hole Size 25" Type Fluid WATER Density / Viscosity N/A Max. Recorded Temp NA Estimated Cement Top 07-30 1256/99 Time Well Ready 11-15 1256/99 Time Logger on Bottom 11-15 1256/99 Equipment Number MVCS-1 Location FT. MYERS Recorded By MILLER/MINCENT Witnessed By P. BREDEN (WRS) C. TARGISA (WRS)		Permanent Datum Ground Level Log Measured From Ground Level Drilling Measured From Ground Level Elevation na K.B. na D.F. na GL. na	
Run Number ONE Bit 12.25" From 60' To 256' Size FIVE Weight 14.5" From 583' To 900'		Run Number TWO Bit 12.25" From 60' To 256' Size FIVE Weight 14.5" From 583' To 900'	
Run Number THREE Bit 12.25" From 60' To 256' Size FIVE Weight 14.5" From 583' To 900'		Run Number FOUR Bit 12.25" From 60' To 256' Size FIVE Weight 14.5" From 583' To 900'	
Casing Record Surface String 32" Pilot String 26" Production String 17.25" PVC Liner 17.25" PVC		Top SURFACE Bottom SURFACE Bottom SURFACE Bottom SURFACE	
Invoice No. 99121 P.O. # 5128		* FINAL PRINT *	

All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or wilful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule.

Comments

Q, %Q & Fluid Velocity presentations include a regular Line Speed and Caliper corrected only format, and an interpretative "LOGICAL" format. "LOGICAL" Q, %Q & Fluid Velocity passes assume no thief zones (Q & %Q can only increase).

STATIC & DYNAMIC data was collected logging DOWN @ 40 & 80 fpm.

Qmax=933 gpm

Figure A7. ASR Well S-15.

Appendix A: Geophysical Logs (Continued)

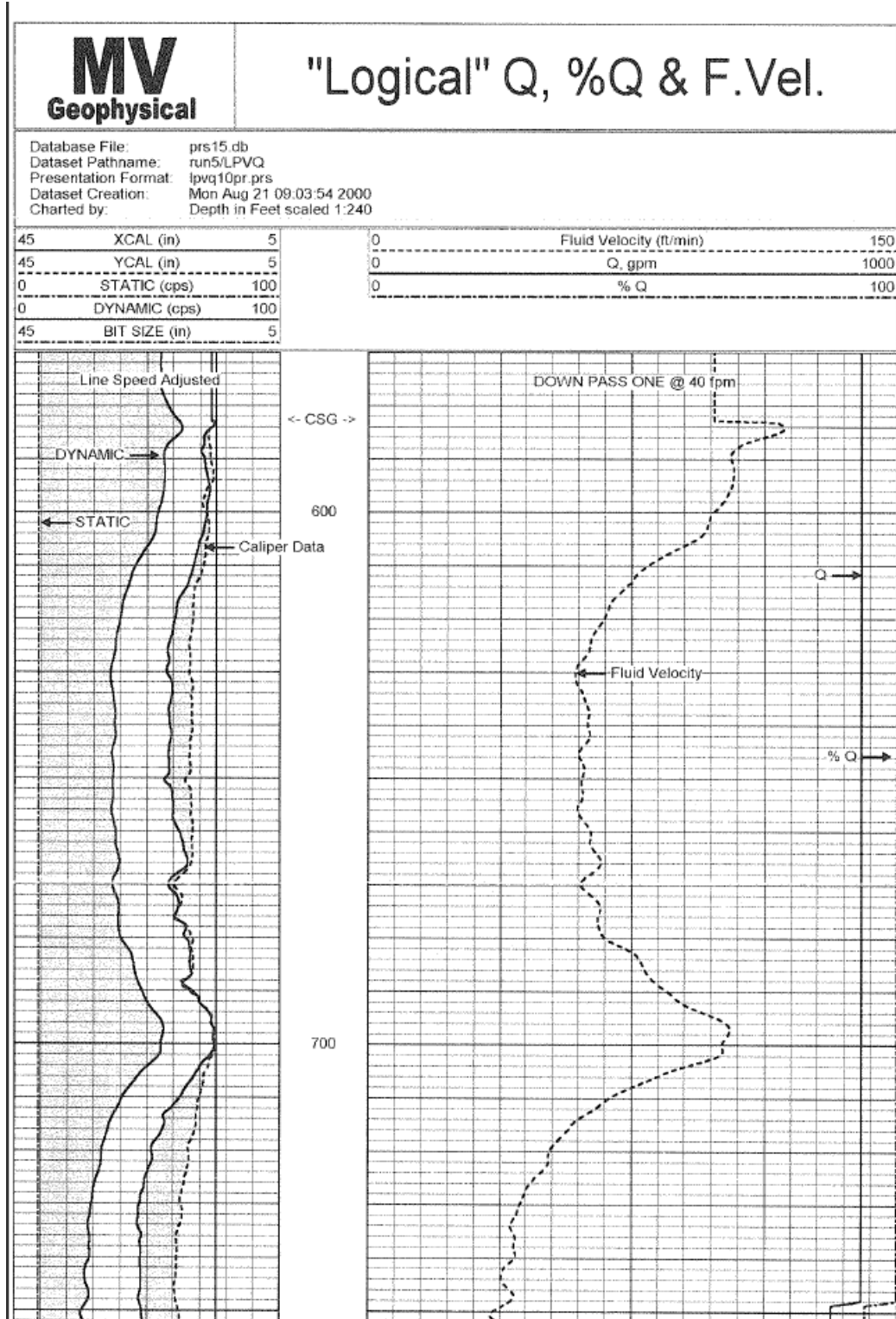


Figure A7. ASR Well S-15 (Continued).

Appendix A: Geophysical Logs (Continued)

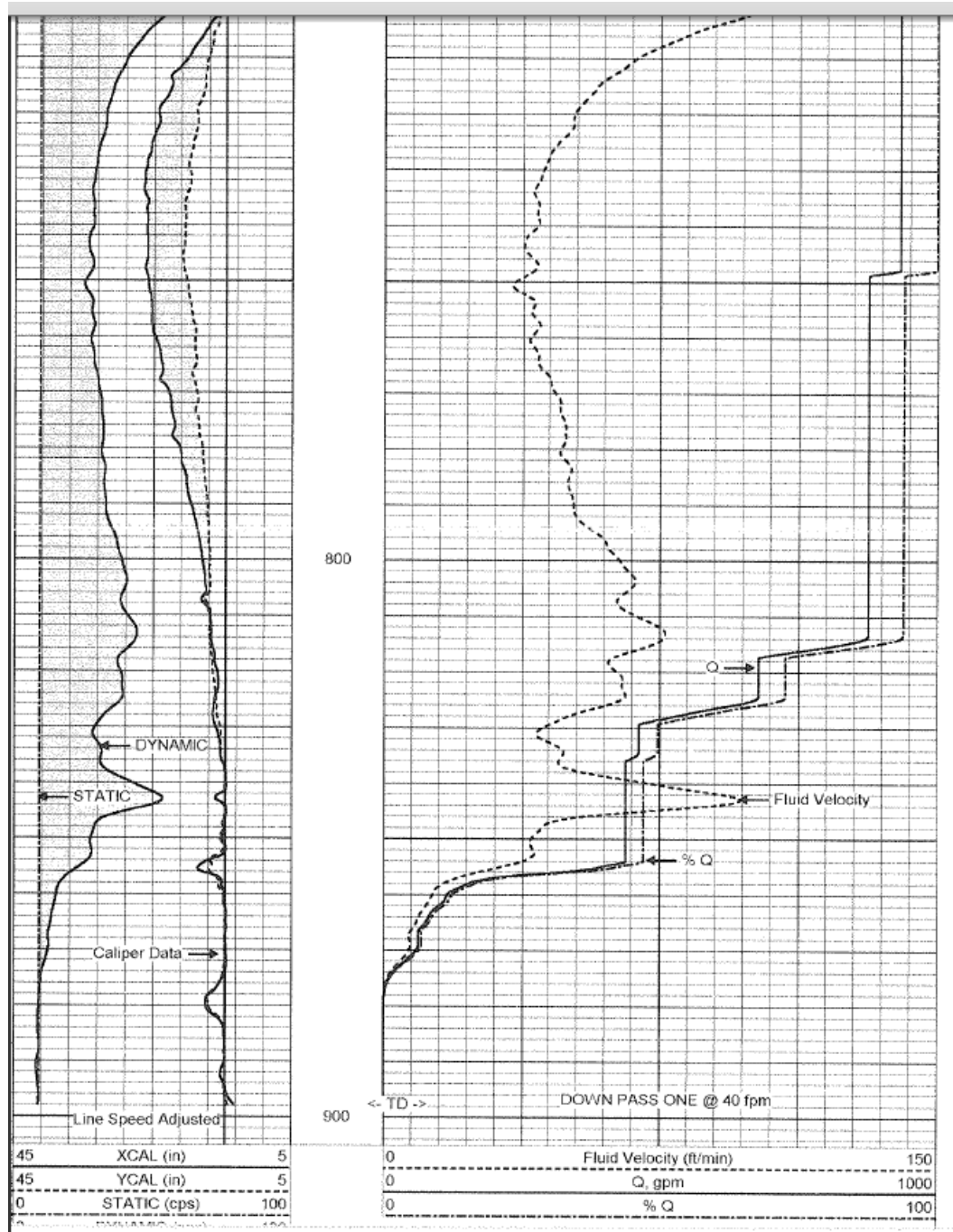


Figure A7. ASR Well S-15 (Continued).

Appendix A: Geophysical Logs (Continued)

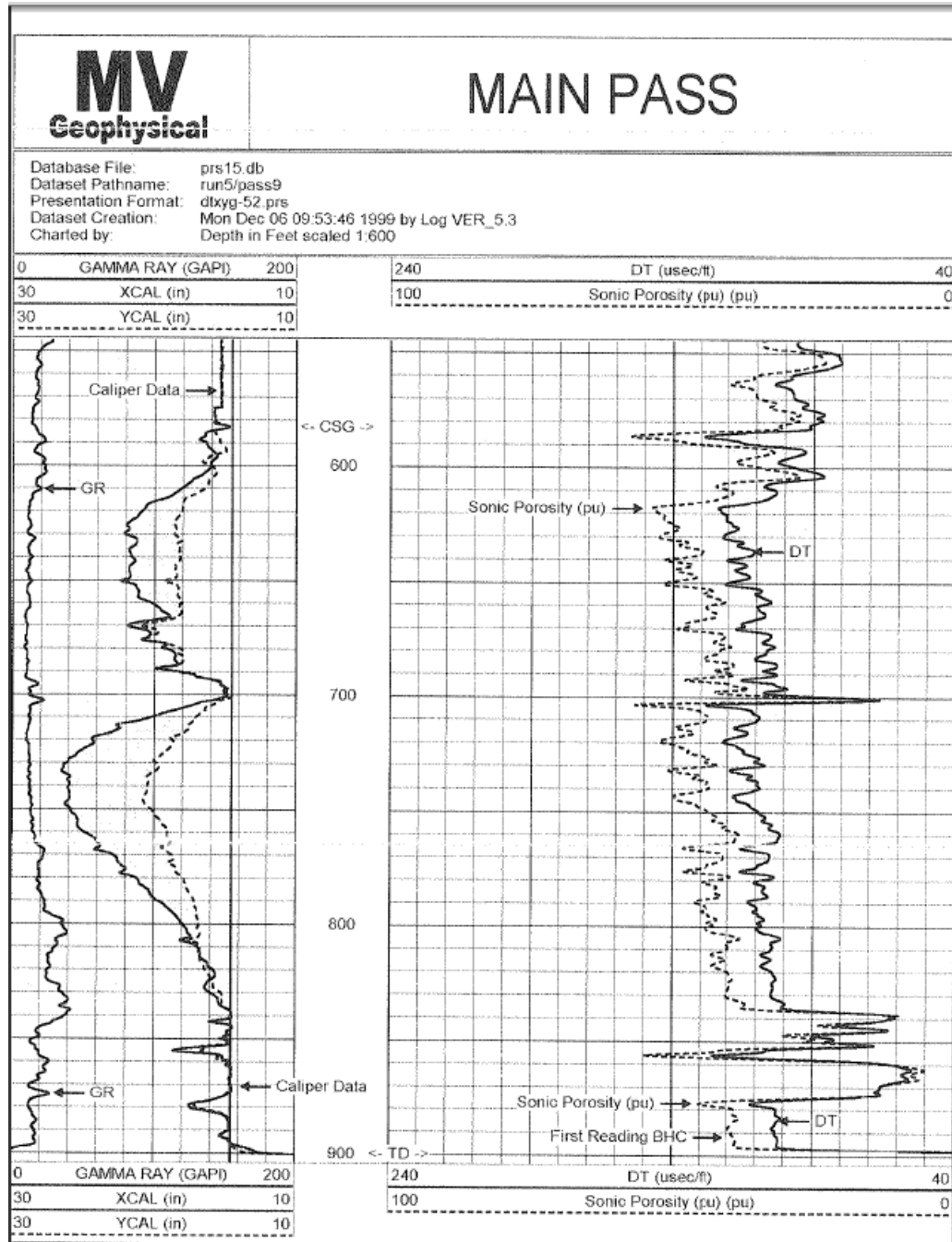


Figure A7. ASR Well S-15 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical DUAL INDUCTION LL3 / SP LOG																																				
Company DIVERSIFIED DRILLING Well ASR WELL S-15 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-15 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA																																				
Location ASR WELL FIELD EXPANSION Other Services DILV/GR FRT FLOW VIDEO																																				
Permanent Datum Log Measured From Disting Measured From Ground Level Ground Level Ground Level																																				
Elevation na Elevation K.B. na D.F. na G.L. na																																				
Date 6-DEC-98																																				
Run Number FIVE																																				
Depth Driller 900'																																				
Depth Logger 900'																																				
Bottom Logged Interval 898'																																				
Top Log Interval 553'																																				
Open Hole Size 25"																																				
Type Fluid WATER																																				
Density / Viscosity N/A																																				
Max Recorded Temp. N/A																																				
Estimated Cement Top N/A																																				
Time Well Ready 07:30 12/6/98																																				
Time Logger on Bottom 00:45 12/6/98																																				
Equipment Number MWGS-1																																				
Location FT. MYERS																																				
Recorded By MILLER/MINCENT																																				
Witnessed By P. BEDEN (MRS) C. TARCISKA (MRS)																																				
Borehole Record																																				
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>Run Number</th> <th>From</th> <th>To</th> <th>Size</th> <th>Weight</th> <th>From</th> <th>To</th> </tr> </thead> <tbody> <tr> <td>ONE</td> <td>12.25'</td> <td>60'</td> <td>250</td> <td>FIVE</td> <td>14.5'</td> <td>800'</td> </tr> <tr> <td>TWO</td> <td>31'</td> <td>60'</td> <td>250</td> <td></td> <td></td> <td></td> </tr> <tr> <td>THREE</td> <td>12.25'</td> <td>200'</td> <td>152</td> <td></td> <td></td> <td></td> </tr> <tr> <td>FOUR</td> <td>25'</td> <td>200'</td> <td>580</td> <td></td> <td></td> <td></td> </tr> </tbody> </table>		Run Number	From	To	Size	Weight	From	To	ONE	12.25'	60'	250	FIVE	14.5'	800'	TWO	31'	60'	250				THREE	12.25'	200'	152				FOUR	25'	200'	580			
Run Number	From	To	Size	Weight	From	To																														
ONE	12.25'	60'	250	FIVE	14.5'	800'																														
TWO	31'	60'	250																																	
THREE	12.25'	200'	152																																	
FOUR	25'	200'	580																																	
Casing Record																																				
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>Size</th> <th>Weight</th> <th>Top</th> <th>Bottom</th> </tr> </thead> <tbody> <tr> <td>32"</td> <td>315' WT</td> <td>SURFACE</td> <td>60'</td> </tr> <tr> <td>28"</td> <td>315' WT</td> <td>SURFACE</td> <td>200'</td> </tr> <tr> <td>17.25" PVC</td> <td>1" WT</td> <td>SURFACE</td> <td>523'</td> </tr> </tbody> </table>		Size	Weight	Top	Bottom	32"	315' WT	SURFACE	60'	28"	315' WT	SURFACE	200'	17.25" PVC	1" WT	SURFACE	523'																			
Size	Weight	Top	Bottom																																	
32"	315' WT	SURFACE	60'																																	
28"	315' WT	SURFACE	200'																																	
17.25" PVC	1" WT	SURFACE	523'																																	
Production String 17.25" PVC																																				
Invoice No. 98121 P.O. # 5128 * FINAL PRINT *																																				

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Comments

Rm=6.15 @ 79.5 degF

Figure A7. ASR Well S-15 (Continued).

Appendix A: Geophysical Logs (Continued)

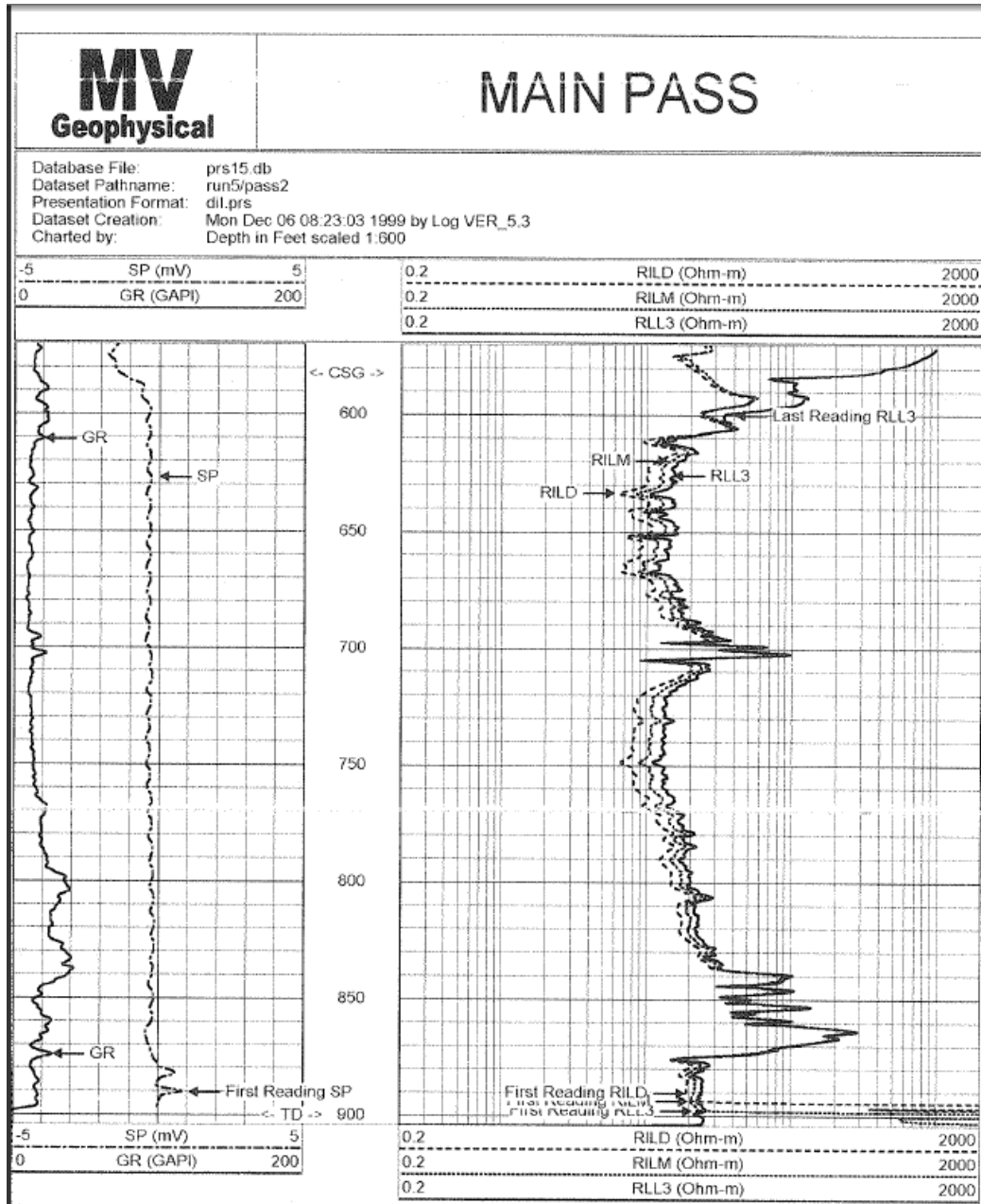


Figure A7. ASR Well S-15 (Continued).

Appendix A: Geophysical Logs (Continued)

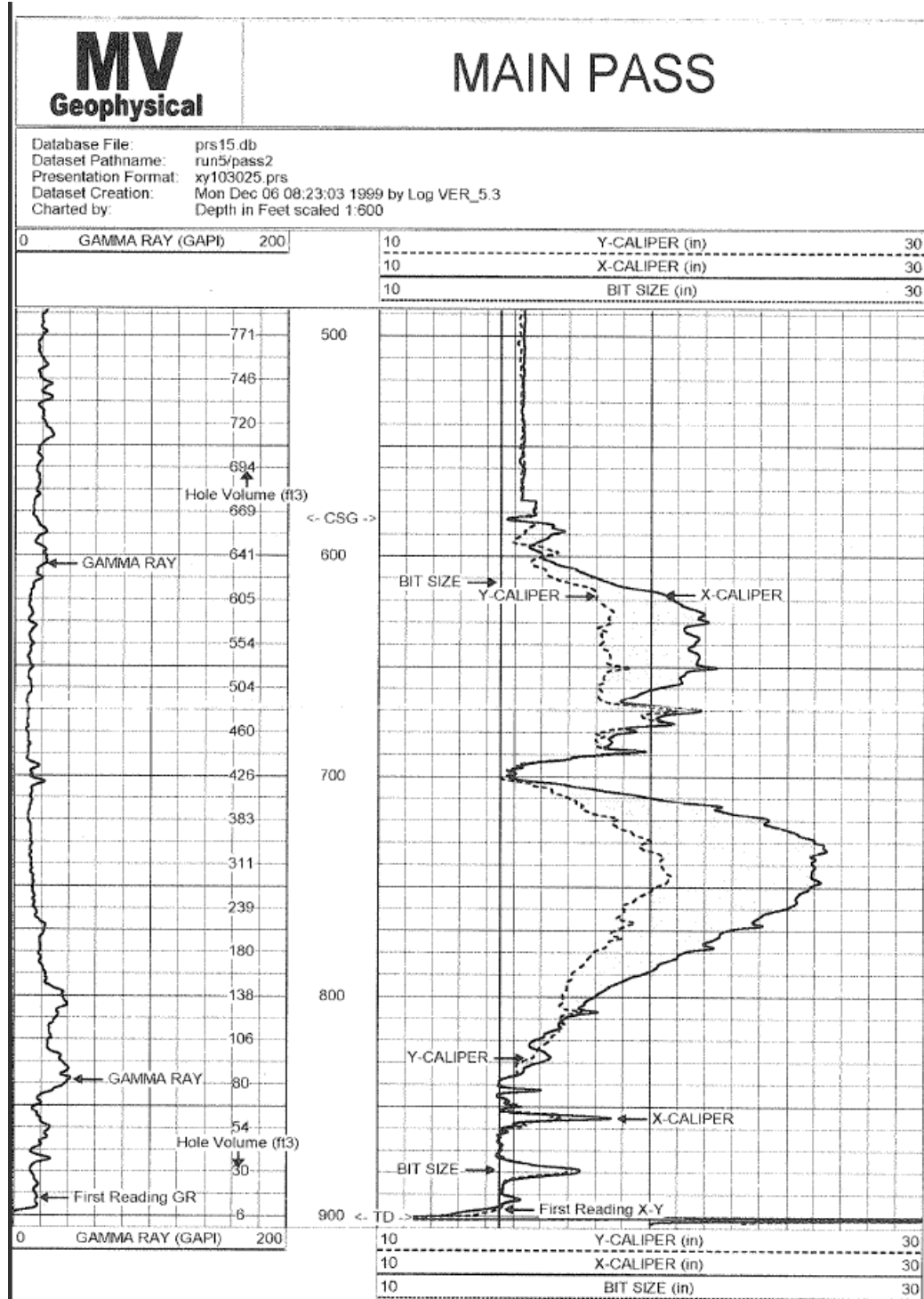


Figure A7. ASR Well S-15 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		FLOWMETER INTERPRETATION																																									
MV Geophysical		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-16 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA																																									
Location ASR WELL FIELD EXPANSION		PRMRWSA Other Services XY/GR FLOW BHC/PRT/DIL VIDEO																																									
Permanent Datum Log Measured From Drilling Measured From		Ground Level Ground Level Ground Level																																									
Elevation na Elevation na Elevation na		KB na D.F. na GL na																																									
Date 13-JAN-2000 Run Number FIVE Depth Driller 900 Depth Logger 905 Bottom Logged Interval 905 Top Log Interval 860 Open Hole Size 14" Type Fluid WATER Density / Viscosity N/A Max Recorded Temp. NA Estimated Current Top NA Time Well Ready 14:00 1/12/00 Time Logger on Bottom 11:30 1/12/00 Equipment Number MNGS-1 Location FT. MYERS Recorded By MILLER VINCENT Witnessed By C. TARCISKA (MRS)		Borehole Record <table border="1"> <thead> <tr> <th>Run Number</th> <th>Bl</th> <th>From</th> <th>To</th> <th>Size</th> <th>Weight</th> <th>From</th> <th>To</th> </tr> </thead> <tbody> <tr> <td>ONE</td> <td>12.25"</td> <td>60'</td> <td>252'</td> <td>FIVE</td> <td>14"</td> <td>585'</td> <td>800'</td> </tr> <tr> <td>TWO</td> <td>29"</td> <td>60'</td> <td>252'</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>THREE</td> <td>12.25"</td> <td>251'</td> <td>610'</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>FOUR</td> <td>24"</td> <td>251'</td> <td>591'</td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>		Run Number	Bl	From	To	Size	Weight	From	To	ONE	12.25"	60'	252'	FIVE	14"	585'	800'	TWO	29"	60'	252'					THREE	12.25"	251'	610'					FOUR	24"	251'	591'				
Run Number	Bl	From	To	Size	Weight	From	To																																				
ONE	12.25"	60'	252'	FIVE	14"	585'	800'																																				
TWO	29"	60'	252'																																								
THREE	12.25"	251'	610'																																								
FOUR	24"	251'	591'																																								
Casing Record Surface String 32" Pd. String 28" Production String 17.25" PVC Line 2000013 Invoice No. 2000013 P.O. # 5393		Top Bottom Bottom 60' Bottom 251' Bottom 585' * FINAL PRINT *																																									
All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule.																																											
Comments Q, %Q & Fluid Velocity presentations include a regular Line Speed and Caliper corrected only format, and an interpretative "LOGICAL" format. "LOGICAL" Q, %Q & Fluid Velocity passes assume no thief zones (Q & %Q can only increase). STATIC & DYNAMIC data was collected logging DOWN @ 40 & 80 fpm. Qmax=225 gpm																																											

Figure A8. ASR Well S-16.

Appendix A: Geophysical Logs (Continued)

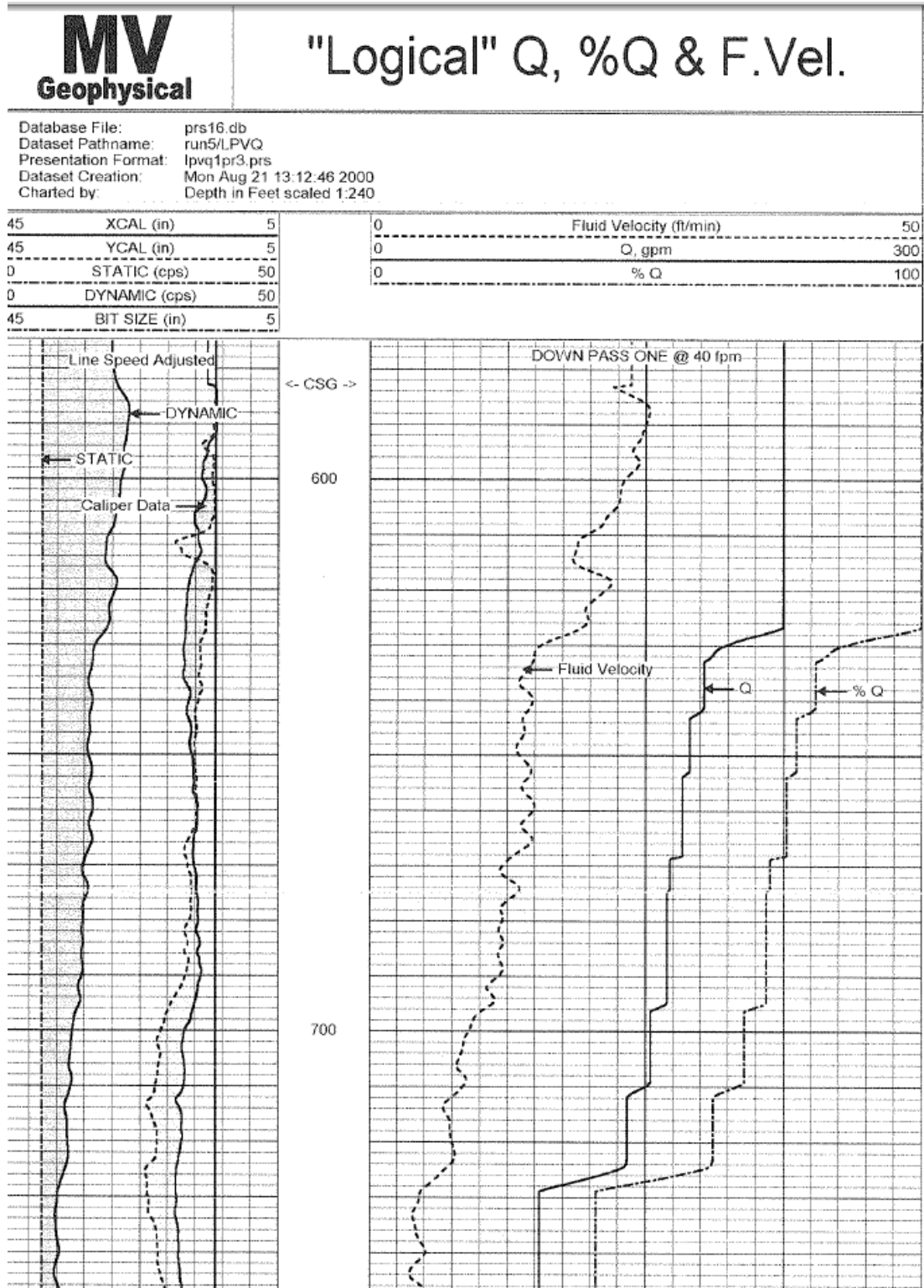


Figure A8. ASR Well S-16 (Continued).

Appendix A: Geophysical Logs (Continued)

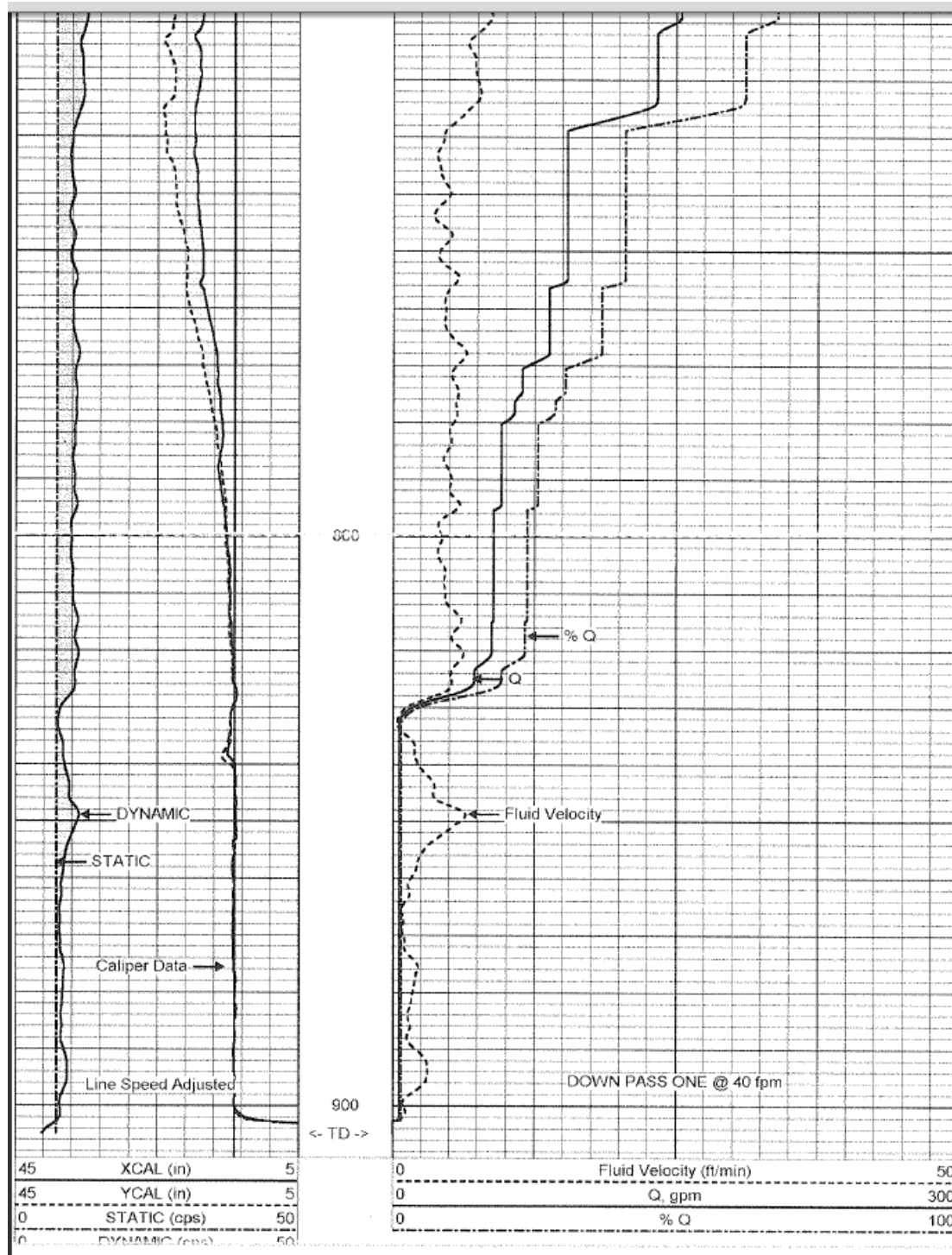


Figure A8. ASR Well S-16 (Continued).

Appendix A: Geophysical Logs (Continued)

<b style="font-size: 2em;">MV Geophysical BOREHOLE COMPENSATED SONIC w/ VARIABLE DENSITY LOG	
Company DIVERSIFIED DRILLING Well ASR WELL S-16 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-16 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA	
Location ASR WELL FIELD EXPANSION Other Services XY/GR DIL FRT/FLOW VIDEO	
Permanent Datum Log Measured From Drilling Measured From Ground Level Ground Level Ground Level	
Date Run Number Depth Driller Depth Logger Bottom Logged Interval Top Log Interval Open Hole Size Type Fluid Density / Viscosity Box Recorded Temp. Estimated Current Top Time Logger on Bottom Time Well Ready Equipment Number Location Recorded By Witnessed By 13 JAN 2000 FIVE 900' 905' 897' 533' 14" WATER N/A N/A 14.00 1/1/2000 10.30 1/13/00 M/VGS-1 FT. LAYERS MILLER/VINCENT C. PARCISHA (WMS)	
Boothole Record Run Number ONE TWO THREE FOUR Casing Record Surface String Prod. String Production String Liner Invoice No. BA 12.25' 28' 12.25' 24' 32' 28' 17.25" PVC 2000013	
From 60' 60' 25' 25' 32' 28' 17.25" PVC 2000013 To 252' 252' 610' 591' 375' WT 375' WT 1" WT P.O. # 5393	
Size FIVE FIVE FIVE 591' 375' WT 375' WT 1" WT P.O. # 5393 Weight 14" 563' 563' 563' 563' 563' 563' 563'	
From 563' 563' 563' 563' 563' 563' 563' 563' To 900' 900' 900' 900' 900' 900' 900' 900'	
Top SURFACE SURFACE SURFACE SURFACE SURFACE SURFACE SURFACE SURFACE Bottom 60' 251' 563' 563' 563' 563' 563' 563'	
Final Print * FINAL PRINT *	
All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule. Comments BHC Sonic was run centralized. Sonic Porosity was run on a Limestone Matrix (=47.5) Rm=6.757 ohm-m @ 73.9 degF	

Figure A8. ASR Well S-16 (Continued).

Appendix A: Geophysical Logs (Continued)

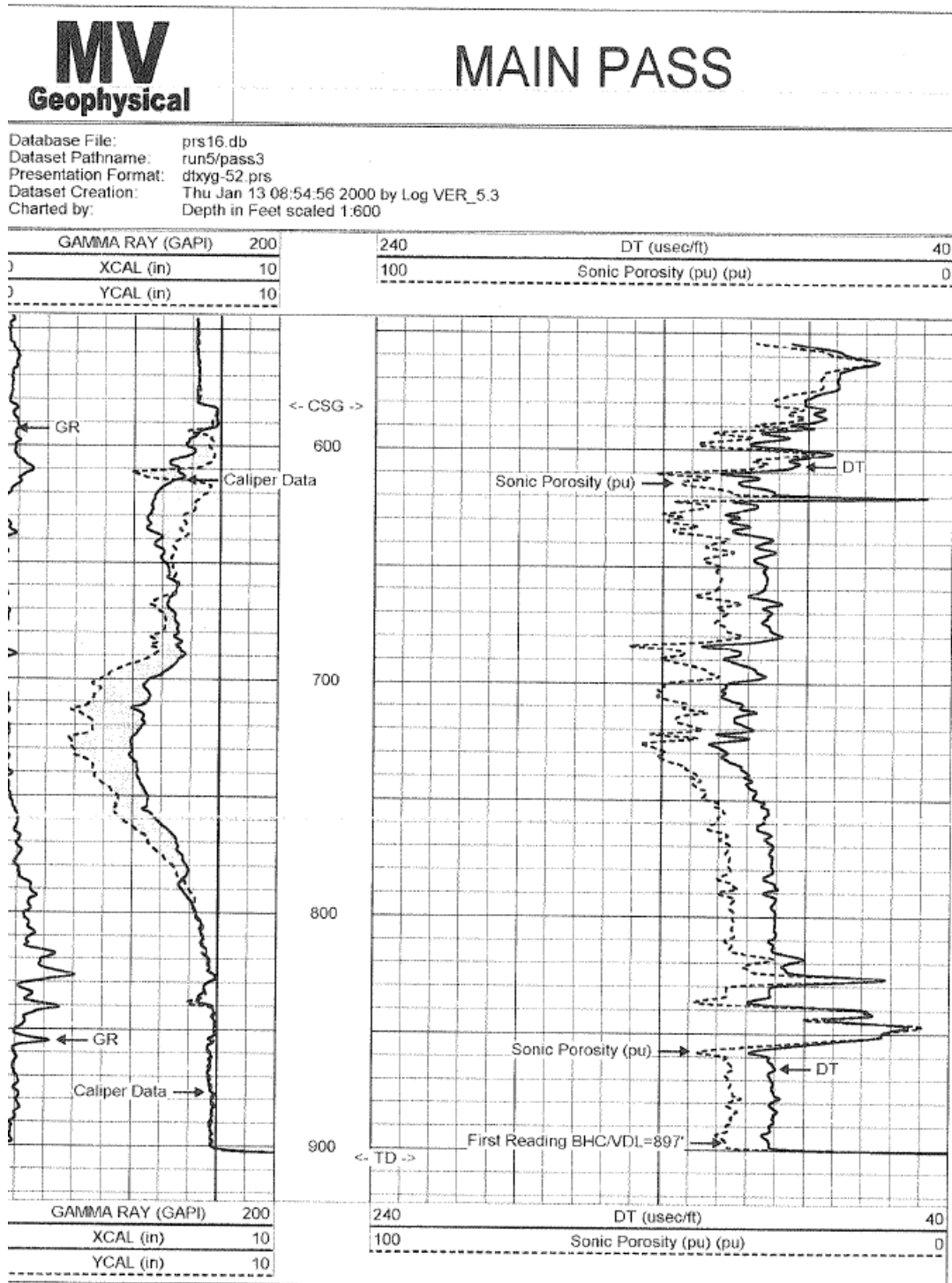


Figure A8. ASR Well S-16 (Continued).

Appendix A: Geophysical Logs (Continued)

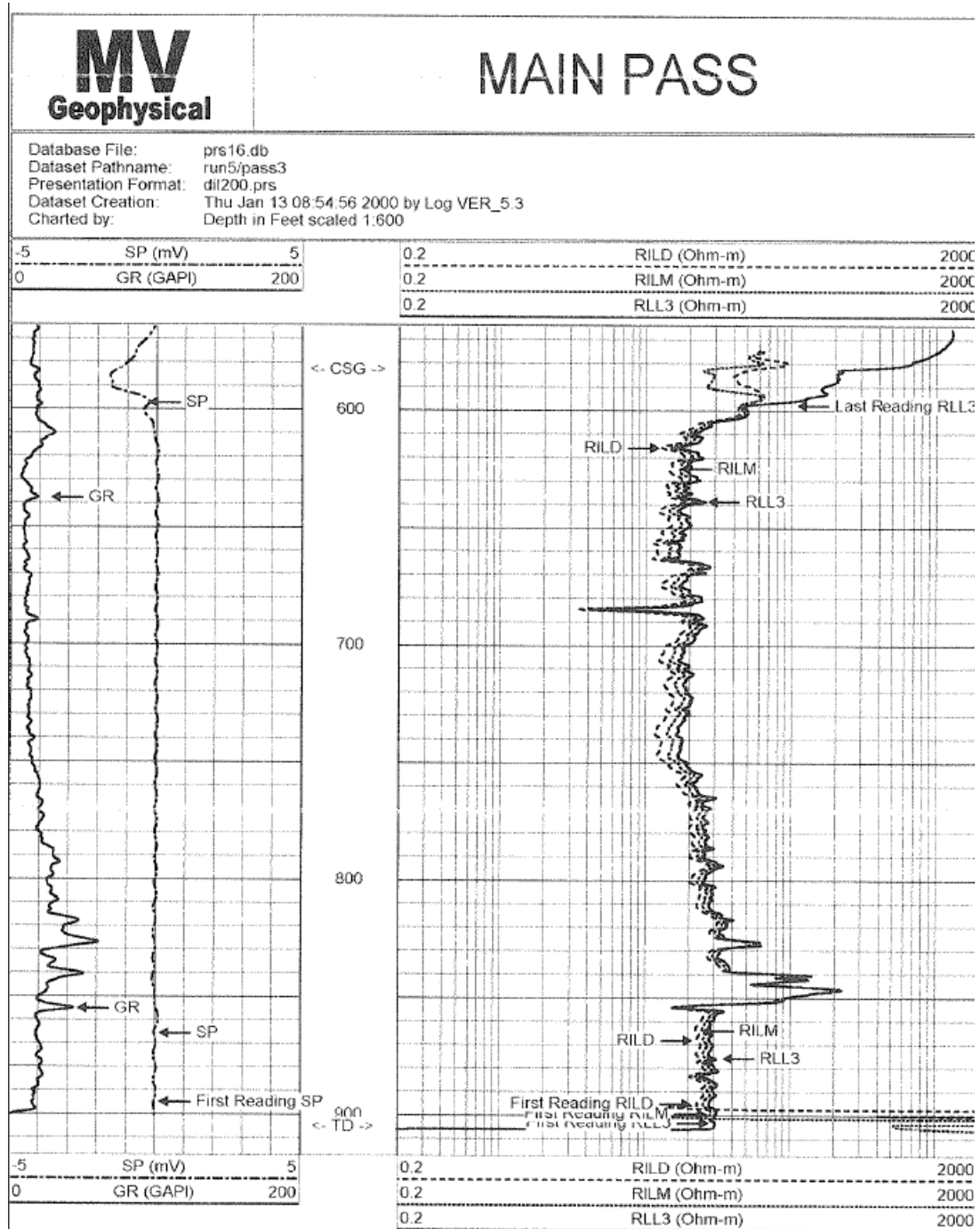


Figure A8. ASR Well S-16 (Continued).

Appendix A: Geophysical Logs (Continued)

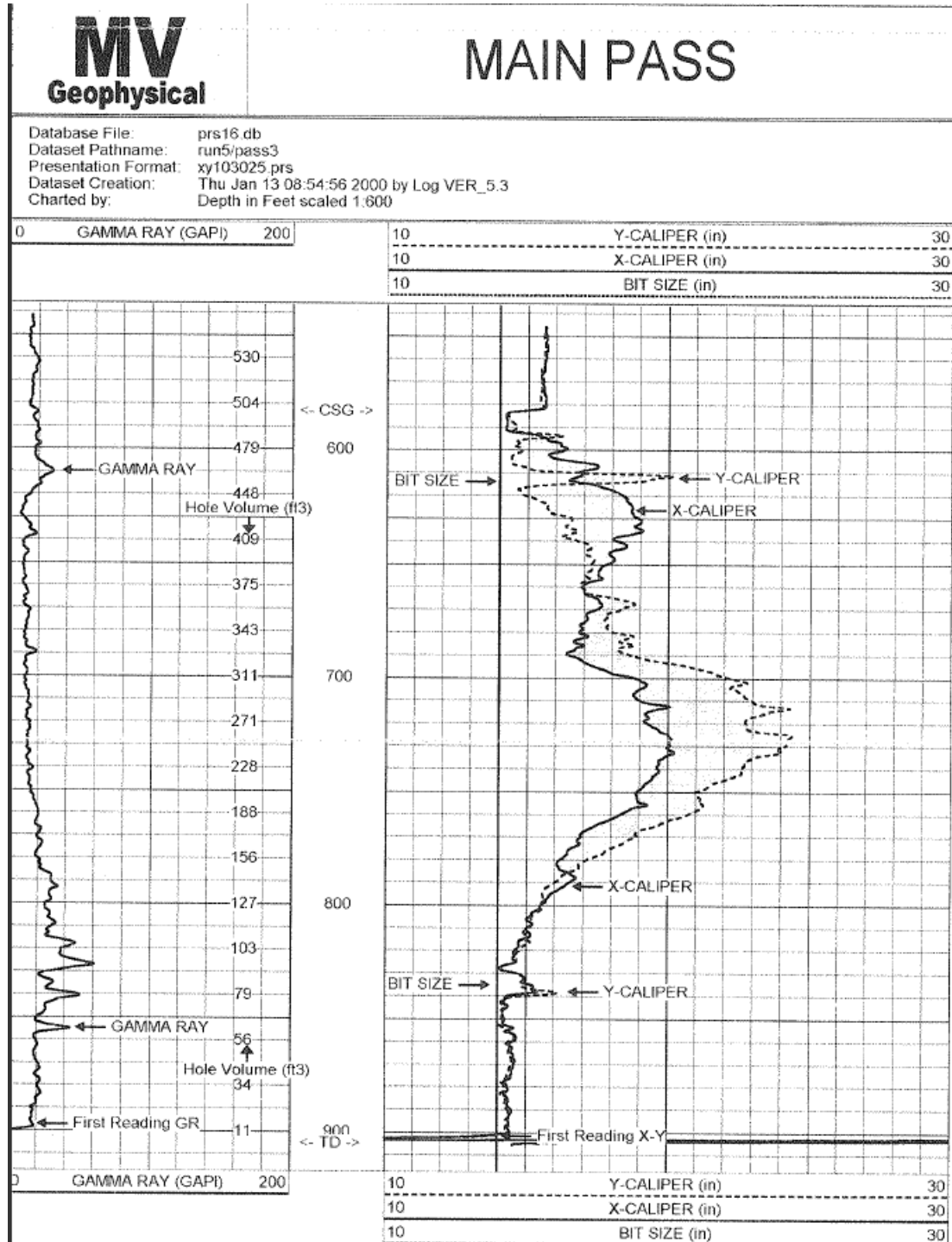


Figure A8. ASR Well S-16 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical DUAL INDUCTION LL3 / SP LOG		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-17 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA	
Location PRMRWSA ASR WELL FIELD EXPANSION		Other Services BHC, XY/GP FRT FLOW VIDEO	
Permanent Datum Log Measured From Drilling Measured From		Elevation K.B. na D.F. na G.L. na	
Date Run Number Depth Driller Depth Logger Bottom Logged Interval Top Log Interval Open Hole Size Type Fluid Density / Viscosity Max. Recorded Temp. Estimated Cement Top Time Well Ready Time Logger on Bottom Equipment Number Location Recorded By Witnessed By		Ground Level Ground Level Ground Level 5.4 MAY 2000 FIVE 863' 890' 876' 576' 14" WATER NA/NA NA 07.00 9.4 MAY 00 09.30 9.4 MAY 00 MWGS-1 FT. LAYERS MILLER/INCENT C. TARCISKA (WRS)	
Borehole Record Run Number ONE TWO THREE FOUR Casing Record Surface String Prot. String Production String Liner Invoice No.		Tubing Record Bit 12.25" 30" 12.25" 23" From 60' 80' 260' 260' To 254' 263' 584' 583' Size FIVE 14" Weight 5800' 8800' Top SURFACE SURFACE SURFACE SURFACE Bottom 60' 250' 580' 578' Logger	
<<< Fold Here >>>			
All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule.			
Comments Rm=6.59 ohm-m @ 68.7 degF			

Figure A9. ASR Well S-17.

Appendix A: Geophysical Logs (Continued)

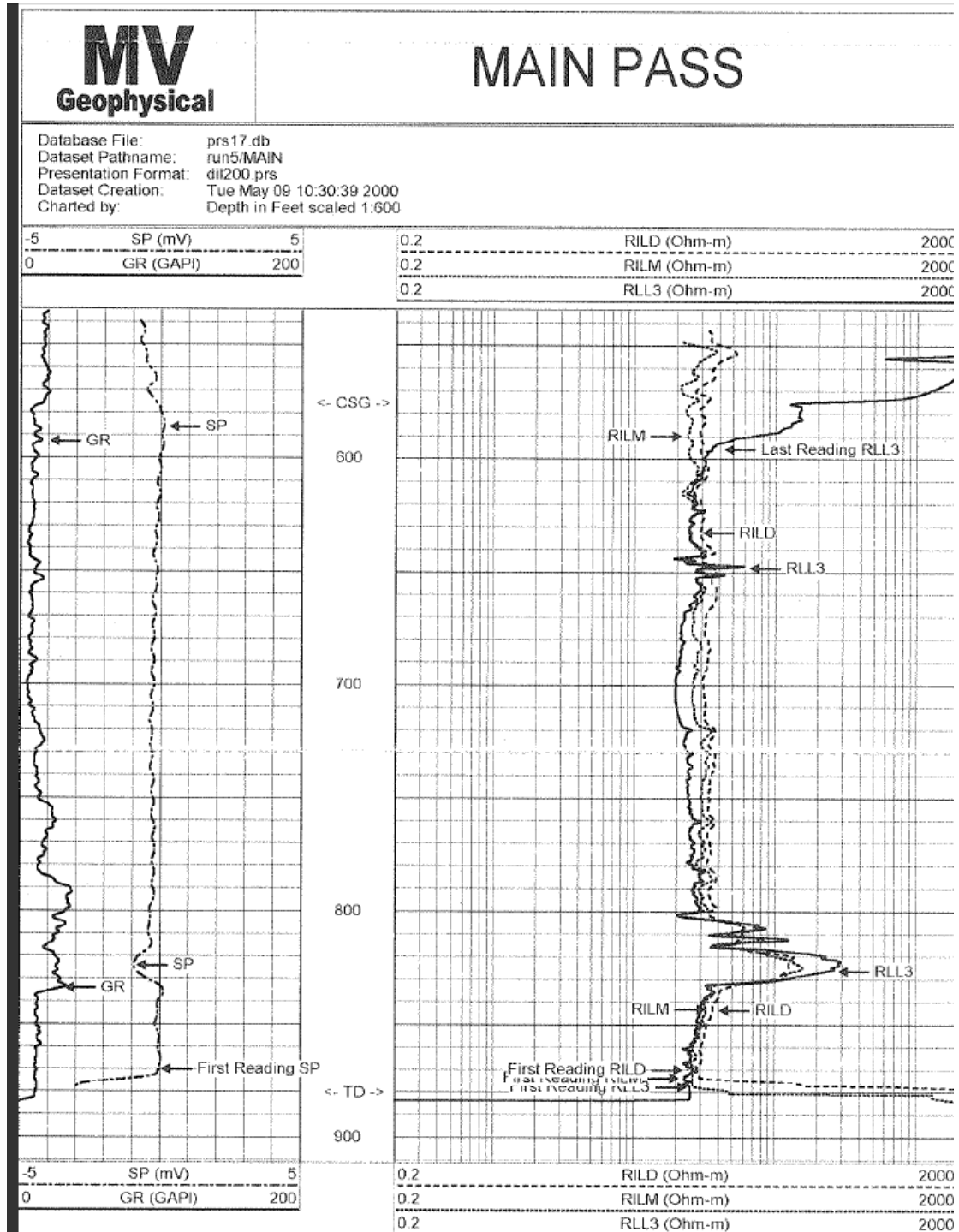


Figure A9. ASR Well S-17 (Continued).

Appendix A: Geophysical Logs (Continued)

		FLOWMETER INTERPRETATION	
Company DIVERSIFIED DRILLING Well ASR WELL S-17 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-17 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA	
Location ASR WELL FIELD EXPANSION Other Services DIL BHC FRT XY/GP FLOW VIDEO		Permanent Datum Log Measured From Drilling Measured From	
Ground Level Ground Level Ground Level		Elevation na na na	
Date 9-MAY-2000 Run Number FIVE Depth Driller 883' Depth Logger 883' Bottom Logged Interval 883' Top Log Interval 500' Open Hole Size 14" Type Fluid WATER Density / Viscosity N/A Max. Recorded Temp. NA Estimated Cement Top NA Time Well Ready 07:00 9-MAY-00 Time Logger on Bottom 11:30 9-MAY-00 Equipment Number LVGS-1 Location FT MYERS Recorded By MILLER/INCENT Witnessed By C TARIOS/SA (WRSJ)		Borehole Record Run Number B1 ONE 12.25' 80' 254' FIVE 14' 580' 883' TWO 30' 80' 254' FIVE 14' 580' 883' THREE 12.25' 280' 584' FOUR 23' 280' 583' Casing Record Surface String 3 1/2" WT 375' WT SURFACE 60' Pick String 28' 375' WT SURFACE 250' Production String 17.25' 1" WT SURFACE 580' Liner LOGGER 576'	
Invoice No. 2000055 P.O. # 0248 * FINAL PRINT *			

All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule.

Comments

Q, %Q & Fluid Velocity presentations include a regular Line Speed and Caliper corrected only format, and an interpretative "LOGICAL" format. "LOGICAL" Q, %Q & Fluid Velocity passes assume no thief zones (Q & %Q can only increase).

STATIC & DYNAMIC data was collected logging DOWN @ 40 & 80 fpm.

Est'd Qmax=600 gpm

Figure A9. ASR Well S-17 (Continued).

Appendix A: Geophysical Logs (Continued)

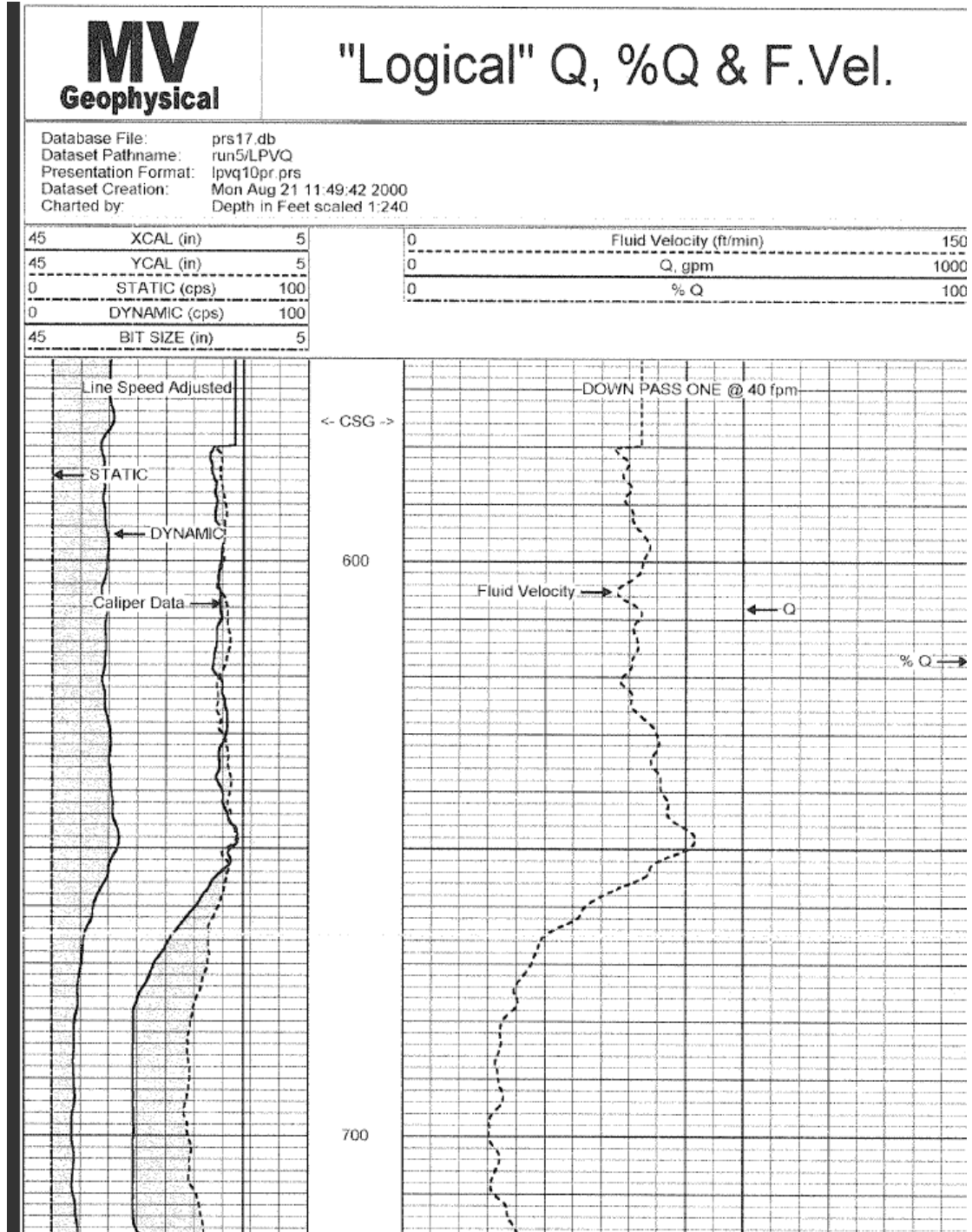


Figure A9. ASR Well S-17 (Continued).

Appendix A: Geophysical Logs (Continued)

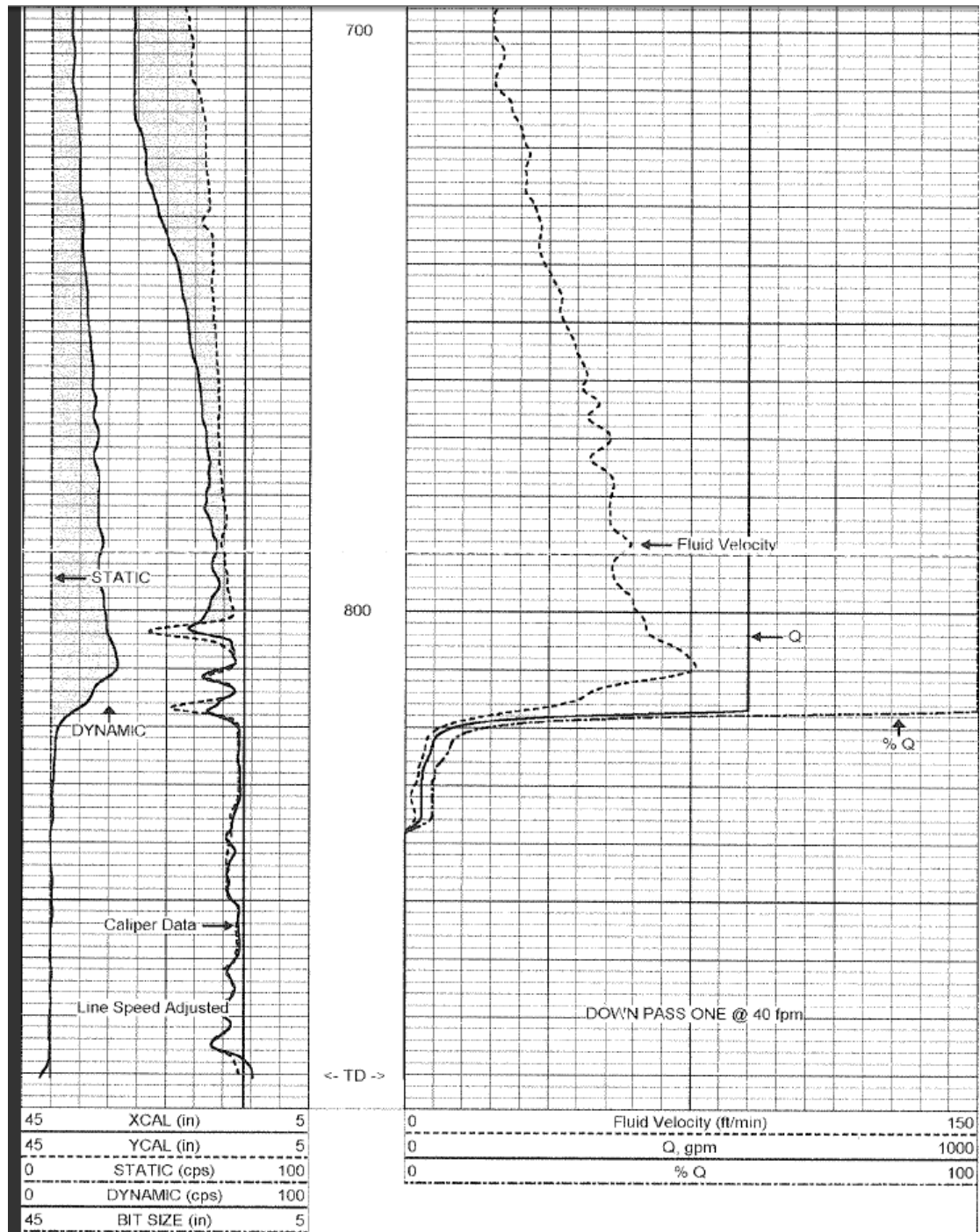


Figure A9. ASR Well S-17 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		BOREHOLE COMPENSATED SONIC w/ VARIABLE DENSITY LOG	
Company DIVERSIFIED DRILLING		Company DIVERSIFIED DRILLING CORP.	
Well ASR WELL S-17		Well ASR WELL S-17	
Field PEACE RIVER		Field PEACE RIVER	
Country DeSOTO		Country DeSOTO	
State/Prv FLORIDA		State/Prv FLORIDA	
Location		PRMRWSA ASR WELL FIELD EXPANSION	
Permanent Datum		Ground Level	Elevation na
Log Measured From		Ground Level	
Dating Measured From		Ground Level	
Date 9 MAY 2000		Elevation	K B na D F na GL na
Run Number	FIVE		
Depth Driller	883'		
Depth Logger	880'		
Bottom Logged Interval	872'		
Top Log Interval	876'		
Open Hole Size	14"		
Type Fluid	WATER		
Density / Viscosity	NA/NA		
Max. Recorded Temp.	NA		
Estimated Cement Top	NA		
Time Well Ready	07:00 9-MAY-00		
Time Logger on Bottom	10:30 9-MAY-00		
Equipment Number	MVCS-1		
Location	FT. MYERS		
Recorded By	MILLERVINCENT		
Witnessed By	C. TARCISKA (MRS)		
Borehole Record		Logging Record	
Run Number	ONE	Bit	From
	TWO	12.25"	80'
	THREE	30"	254'
	FOUR	12.25"	250'
		25"	583'
Casing Record	32"	WT	580'
Surface String	37.5"	WT	580'
Pilot String	20"	WT	580'
Production String	17.25"	WT	580'
Line			
Invoice No.	20000065	P.O. #	6246
* FINAL PRINT *			

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Comments

BHC Sonic was run centralized.

Sonic Porosity was run on a Limestone Matrix (=47.5 usec)

Rm=6.59 ohm-m @ 68.7 degF

Figure A9. ASR Well S-17 (Continued).

Appendix A: Geophysical Logs (Continued)

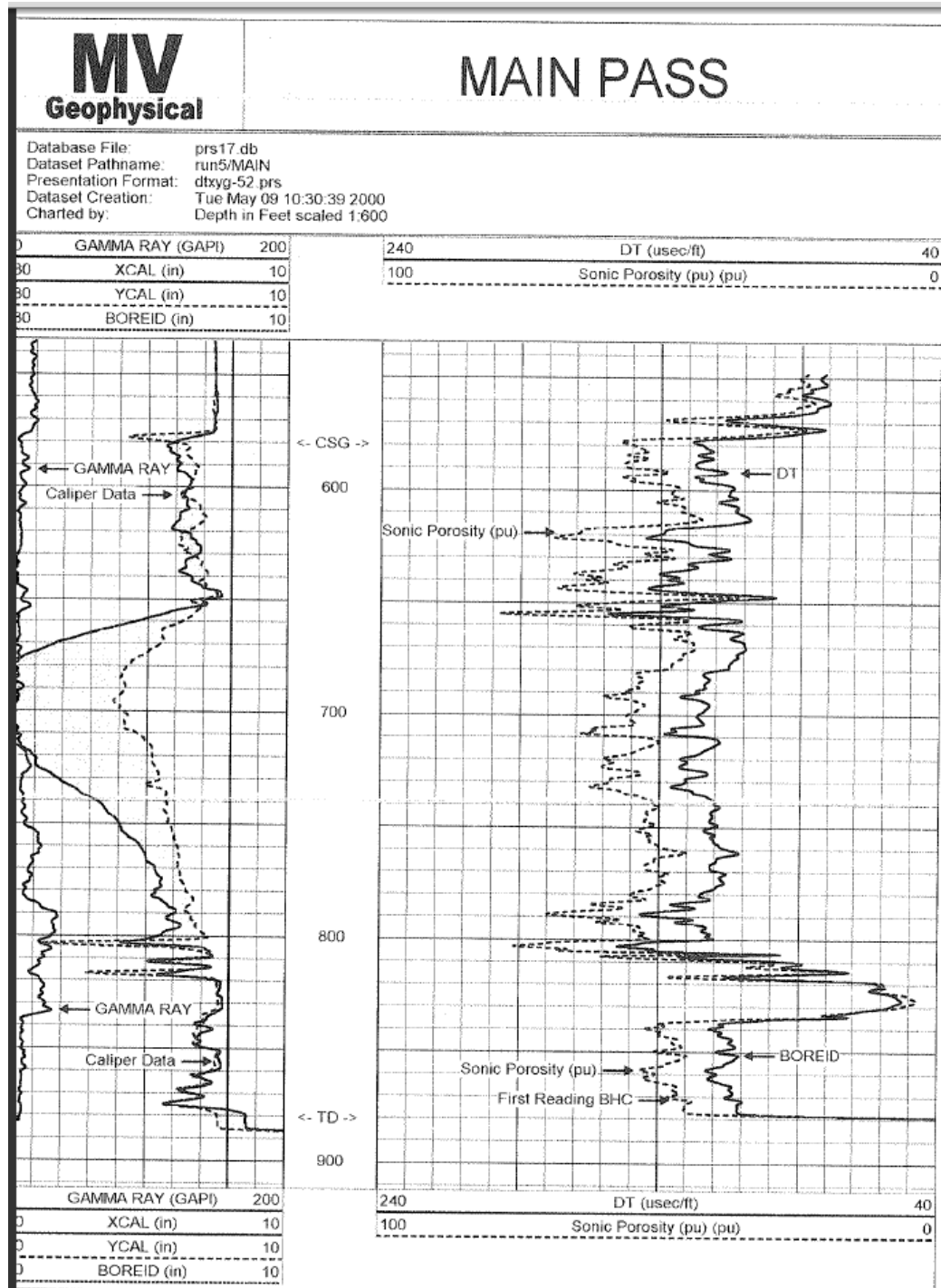


Figure A9. ASR Well S-17 (Continued).

Appendix A: Geophysical Logs (Continued)

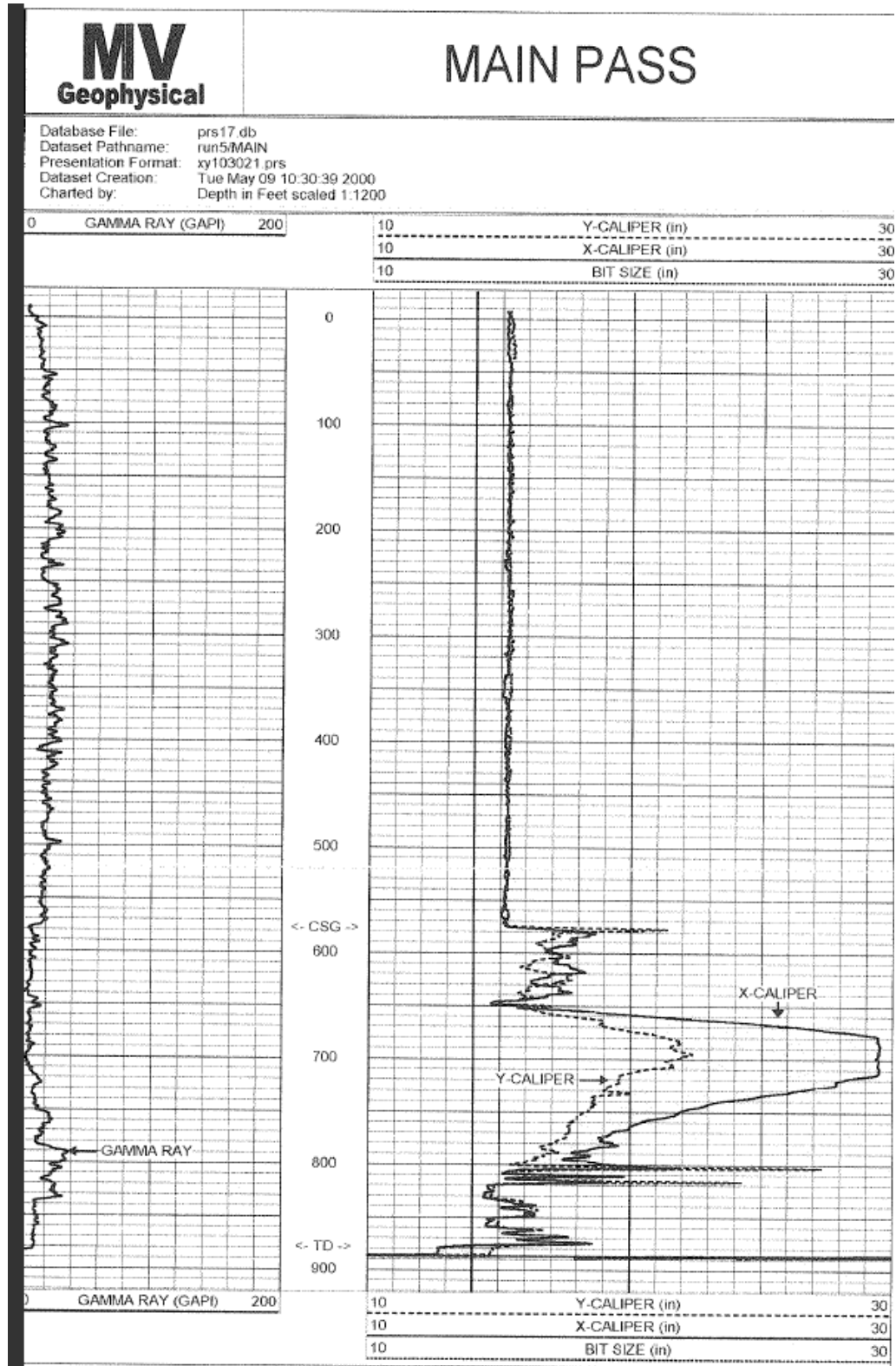


Figure A9. ASR Well S-17 (Continued).

Appendix A: Geophysical Logs (Continued)

<b style="font-size: 2em;">MV Geophysical BOREHOLE COMPENSATED SONIC W/ VARIABLE DENSITY LOG	
Company DIVERSIFIED DRILLING Well ASR WELL S-18 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-18 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA	
Location ASR WELL FIELD EXPANSION Other Services DIL XYGR FRT. FLOW VIDEO	
Permanent Datum Log Measured From Drilling Measured From Ground Level Ground Level Ground Level	
Elevation na na na	
Date 3-DEC-99	
Run Number FIVE	
Depth Driller 900	
Depth Logger 904	
Bottom Logged Interval 880	
Top Log Interval 560	
Open Hole Size 14"	
Type Fluid WATER	
Density / Viscosity NA	
Max Recorded Temp NA	
Estimated Cement Top 07.30 12/3/99	
Time Well Ready 09.30 12/3/99	
Time Logger on Bottom NA	
Equipment Number MVG5-1	
Location FT. MYERS	
Recorded By MILLER/VINCENT	
Witnessed By P. BEDEN (WRS)	
C. GODWIN (DDC)	
Borehole Record	
Run Number ONE	Bit 12.25"
ONE 31"	From 80'
TWO 12.25"	To 250'
THREE 25"	Size FIVE
FOUR 25"	Weight 14"
Weight 593	From 900'
Surface String 32"	Top 375" WT
Pick String 26"	Bottom 60'
Production String 17.25" PVC	Surface 375" WT
Line 16" ID	Surface 592'
Invoice No. 99118	P.O. # 5127
* FINAL PRINT *	

All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule.

Comments

BHC Sonic was run centralized.
Sonic Porosity was run on a Limestone Matrix (=47.5)

Rm=6.54 ohm-m @ 79.4 degF

Figure A10. ASR Well S-18.

Appendix A: Geophysical Logs (Continued)

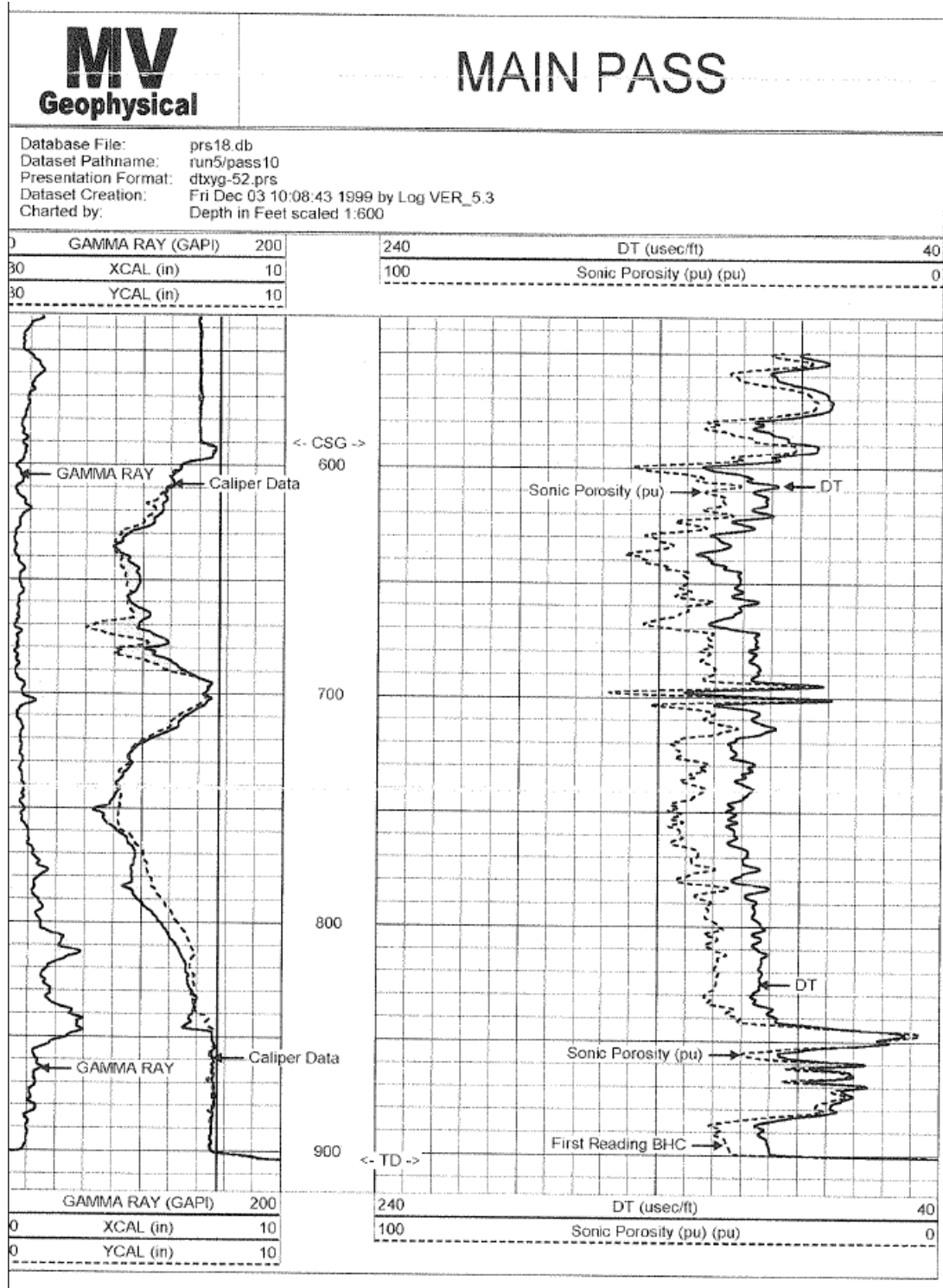


Figure A10. ASR Well S-18 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		DUAL INDUCTION LL3 / SP LOG	
MV Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-18 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA		Location PRMRWSA ASR WELL FIELD EXPANSION	
Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-18 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA		Other Services XY/GP, BHC FRT FLOW VIDEO	
Date 3-DEC-99 Run Number FIVE Depth Entry 9007 Depth Logger 9004 Bottom Logged Interval 9007 Top Log Interval 5907 Open Hole Size 14" Type Fluid WATER Density / Viscosity N/A Max Recorded Temp N/A Estimated Cement Top N/A Time Well Ready 07:30 12/31/99 Time Logger on Bottom 08:30 12/31/99 Equipment Number MIVGS-1 Location FT. MYERS Recorded By MILLER/VINCENZI Witnessed By P. BEDEN (WRS)		Permanent Datum na Log Measured From Ground Level Drilling Measured From Ground Level Elevation na K/B na D/F na G/L na	
Run Number ONE ONE 12.25" TWO 31.75" THREE 42.25" FOUR 25" Size 32" Surface String 28" Pick String 17.25" PVC Production String 17.25" PVC Lineer 99116 Invoice No. P.O. # 5127		Bottom Record From 00 To 2507 Size FIVE Weight 14" Tubing Record From 00 To 9007 Bottom 807 5907 LOGGER FINAL PRINT	

All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule.

Comments

Rm=6.54 ohm-m @ 79.4 degF

Figure A10. ASR Well S-18 (Continued).

Appendix A: Geophysical Logs (Continued)

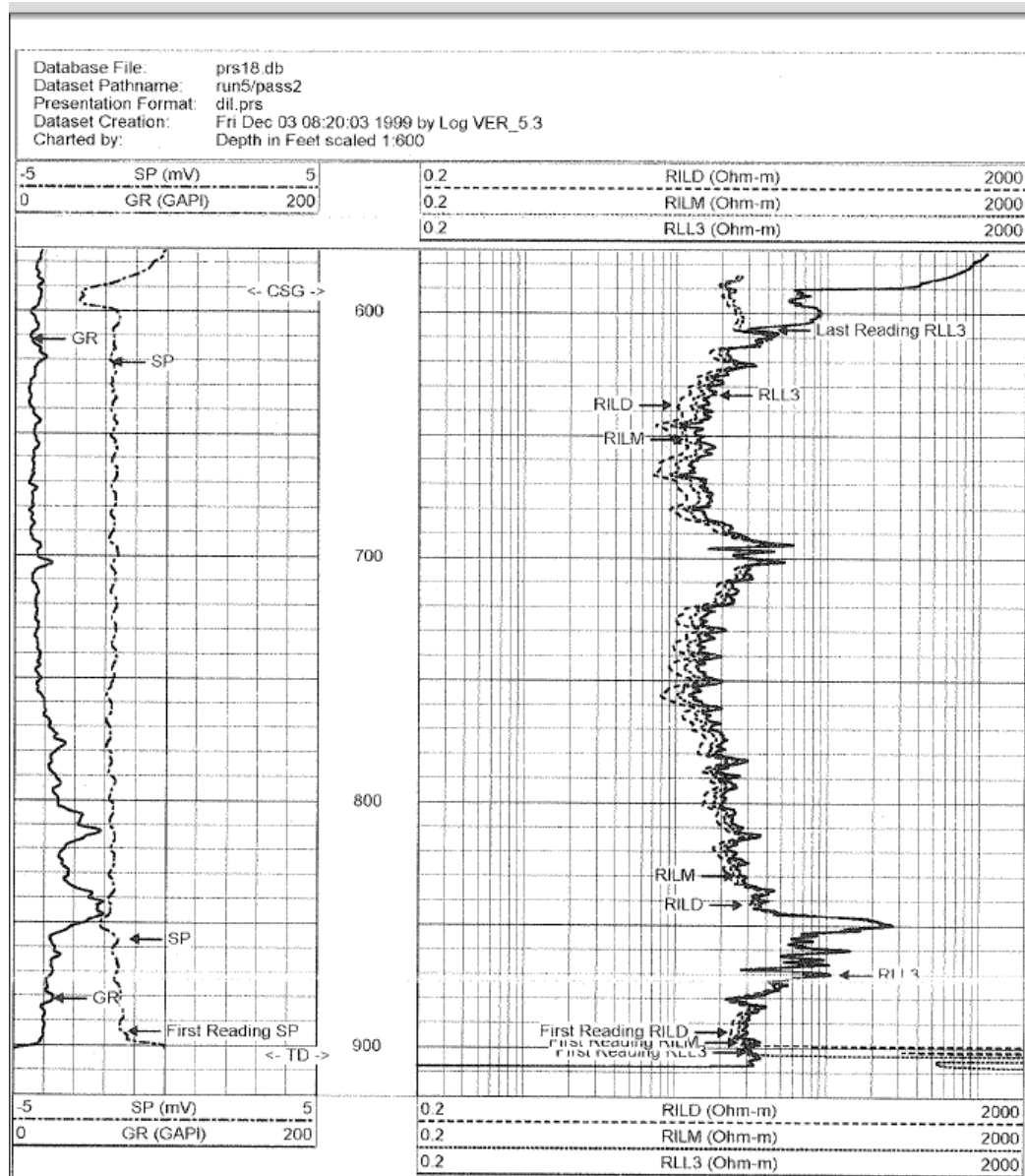


Figure A10. ASR Well S-18 (Continued).

Appendix A: Geophysical Logs (Continued)

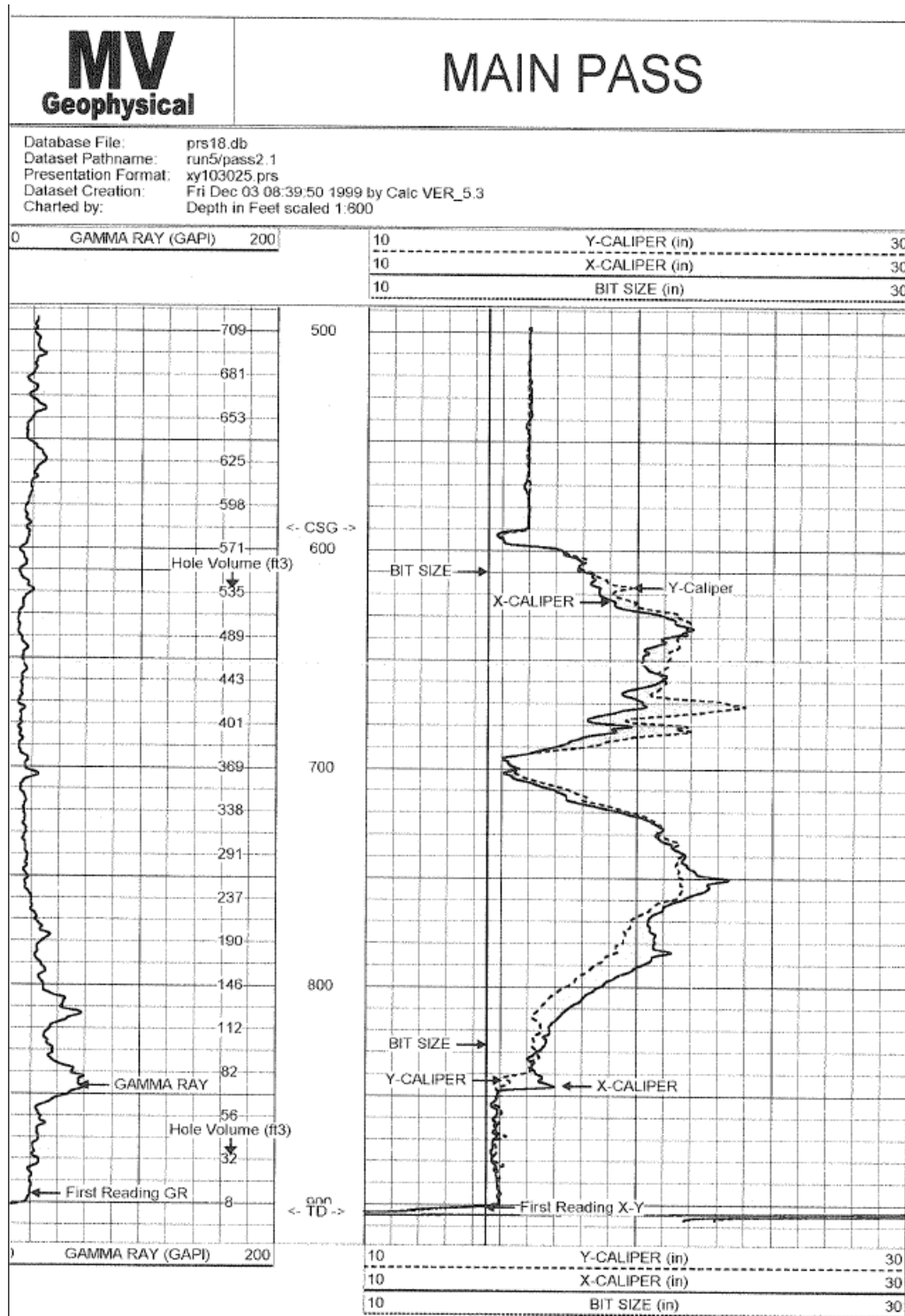


Figure A10. ASR Well S-18 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		FLOWMETER INTERPRETATION	
Company DIVERSIFIED DRILLING Well ASR WELL S-18 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-18 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA	
Location ASR WELL FIELD EXPANSION		PRMRWSA PRMRWSA	
Permanent Datum Log Measured From Drilling Measured From		Ground Level Ground Level Ground Level	
Date Run Number Depth (Feet) Bottom Logged Interval Top Log Interval Open Hole Size Type Fluid Density / Viscosity Max. Recorded Temp. Estimated Circulation Top Time Well Ready Time Logged on Bottom Equipment Number Location Recorded By Witnessed By		3 DEC 88 FIVE 600' 500' 500' 14" WATER N/A N/A 07:30 12/29/88 14:00 12/29/88 8VGS-1 FT MYERS MILLERWINGENT P. BERTEN (NRS)	
Barrel Record Run Number DATE TIME FOUR Casing Record Surface String Plot String Production String Line		Size From To 25' 25' 25' 32" 28" 17 25" PVC 99116	
Weight From To 250 250 250 375 WT 375 WT 16" ID 500' LOGGER		Weight From To 14 14 14 14 14 14 14	
Top Bottom 500' LOGGER		Top Bottom 500' LOGGER	
Invoice No. 99116 P.O. # 5127 * FINAL PRINT *			

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Comments

Q, %Q & Fluid Velocity presentations include a regular Line Speed and Caliper corrected only format, and an interpretative "LOGICAL" format. "LOGICAL" Q, %Q & Fluid Velocity passes assume no thief zones (Q & %Q can only increase).

STATIC & DYNAMIC data was collected logging DOWN @ 40 & 80 fpm.

Qmax=225 gpm

Figure A10. ASR Well S-18 (Continued).

Appendix A: Geophysical Logs (Continued)

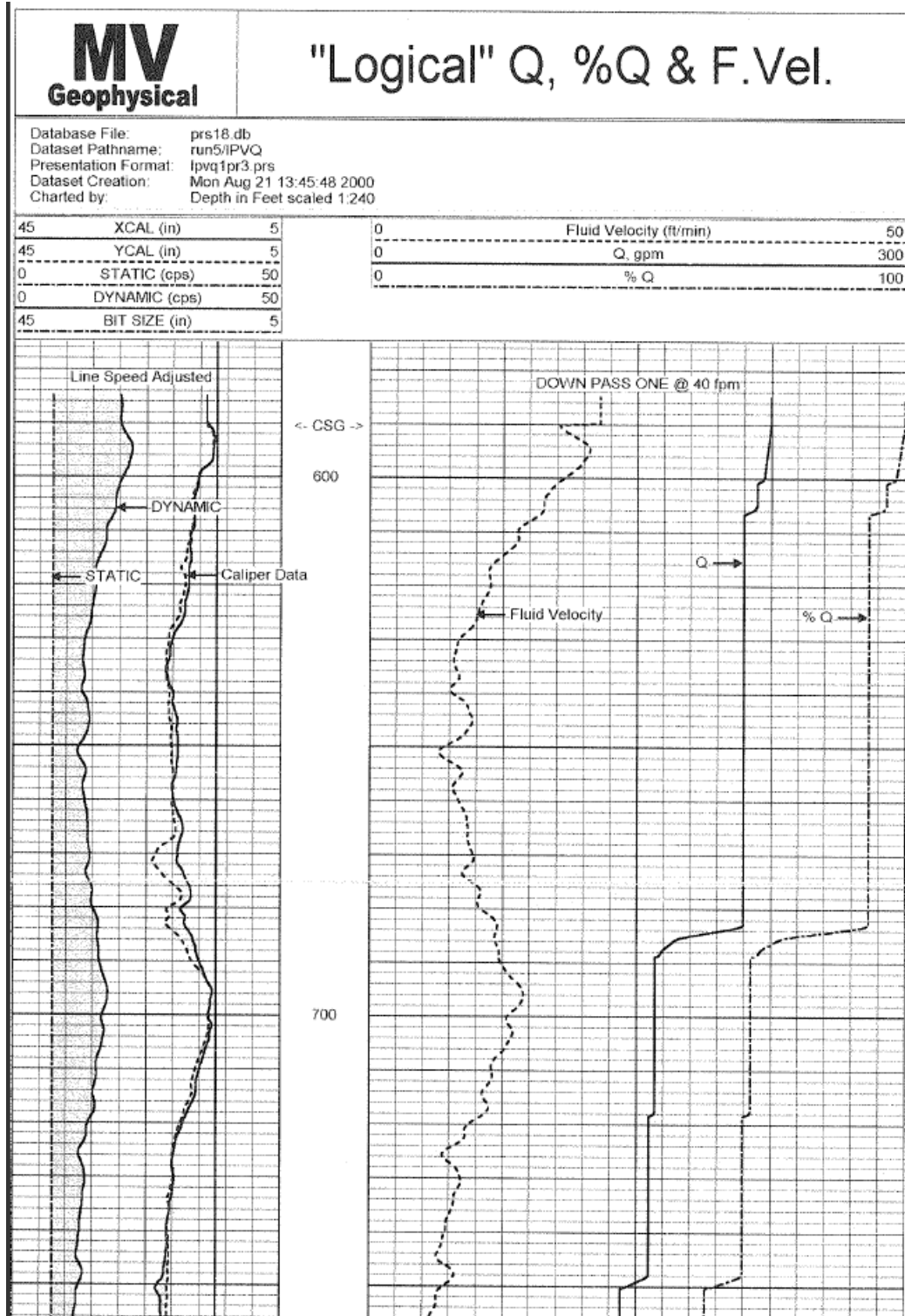


Figure A10. ASR Well S-18 (Continued).

Appendix A: Geophysical Logs (Continued)

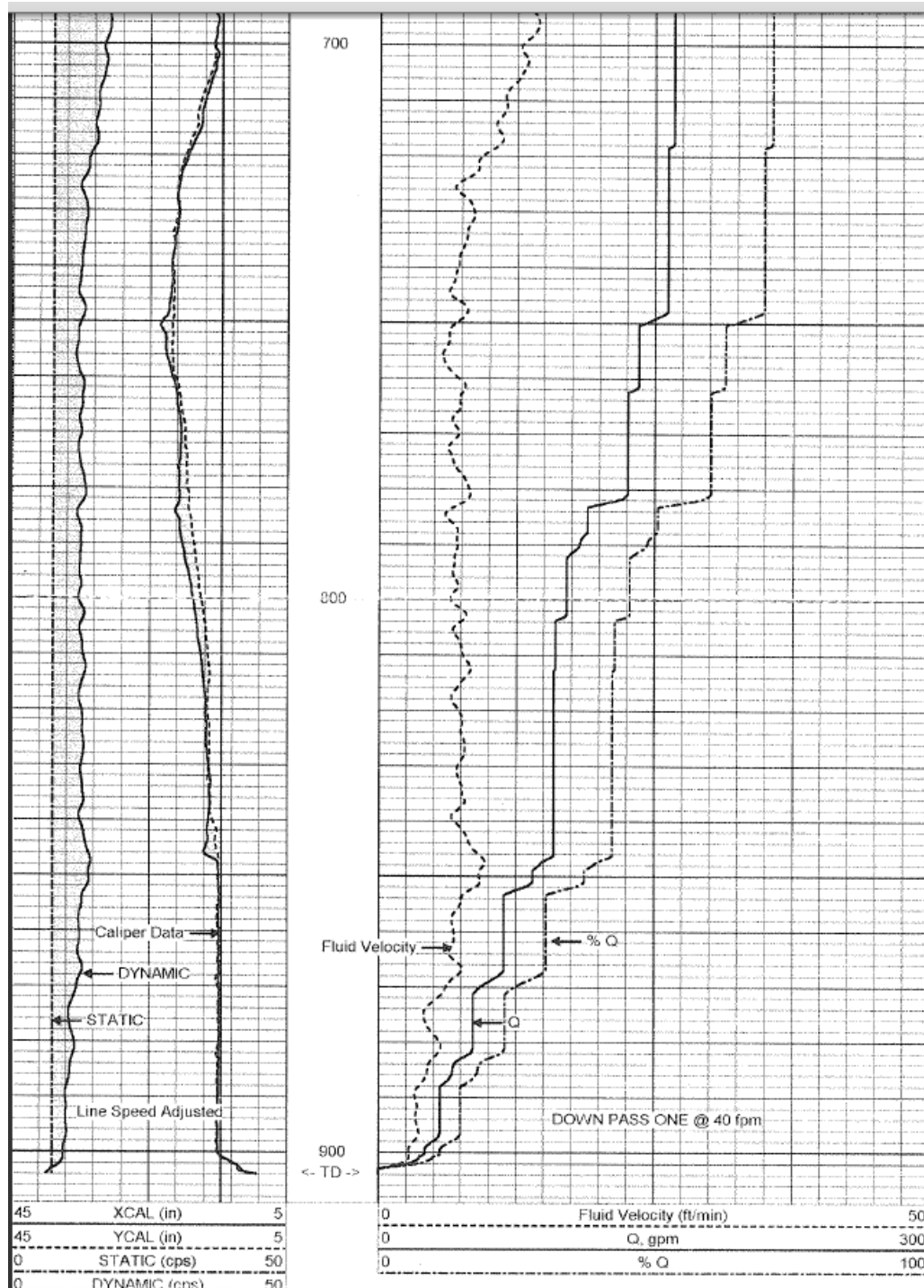


Figure A10. ASR Well S-18 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical DUAL INDUCTION LL3 / SP LOG																																									
Company DIVERSIFIED DRILLING Well ASR WELL S-19 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-19 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA																																									
Location ASR WELL FIELD EXPANSION Other Services BHC, XY/GR FRT, FLOW VIDEO																																									
Permanent Datum Log Measured From Drilling Measured From Ground Level Ground Level Ground Level																																									
Elevation na Elevation K.R. na D.F. na G.L. na																																									
Date 25-JAN-2000																																									
Run Number FIVE																																									
Depth Diller 903																																									
Depth Logger 898																																									
Bottom Logged Interval 898																																									
Top Log Interval 583																																									
Open Hole Size 14"																																									
Type Fluid WATER																																									
Density / Viscosity N/A																																									
Max. Recorded Temp. N/A																																									
Estimated Cement Top N/A																																									
Time Well Ready 10:00 1/25/00																																									
Time Logger on Bottom 10:45 1/25/00																																									
Equipment Number MWGS-1																																									
Location FT. MYERS																																									
Recorded By MILLER/MINCENT																																									
Witnessed By C. TARKISKA (WRS)																																									
Borehole Record																																									
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>Run Number</th> <th>Bit</th> <th>From</th> <th>To</th> <th>Size</th> <th>Weight</th> <th>From</th> <th>To</th> </tr> </thead> <tbody> <tr> <td>ONE</td> <td>12.25"</td> <td>80'</td> <td>260'</td> <td>FIVE</td> <td>14"</td> <td>583'</td> <td>903'</td> </tr> <tr> <td>TWO</td> <td>30"</td> <td>80'</td> <td>260'</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>THREE</td> <td>11.875"</td> <td>280'</td> <td>589'</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>FOUR</td> <td>24"</td> <td>280'</td> <td>388'</td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>		Run Number	Bit	From	To	Size	Weight	From	To	ONE	12.25"	80'	260'	FIVE	14"	583'	903'	TWO	30"	80'	260'					THREE	11.875"	280'	589'					FOUR	24"	280'	388'				
Run Number	Bit	From	To	Size	Weight	From	To																																		
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TWO	30"	80'	260'																																						
THREE	11.875"	280'	589'																																						
FOUR	24"	280'	388'																																						
Casing Record																																									
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17.25" PUC	1" WT	SURFACE	583'																																						
Production String																																									
Log																																									
Remarks																																									

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Comments

Rm=6.192 ohm-m @ 68.7 degF

Figure A11. ASR Well S-19.

Appendix A: Geophysical Logs (Continued)

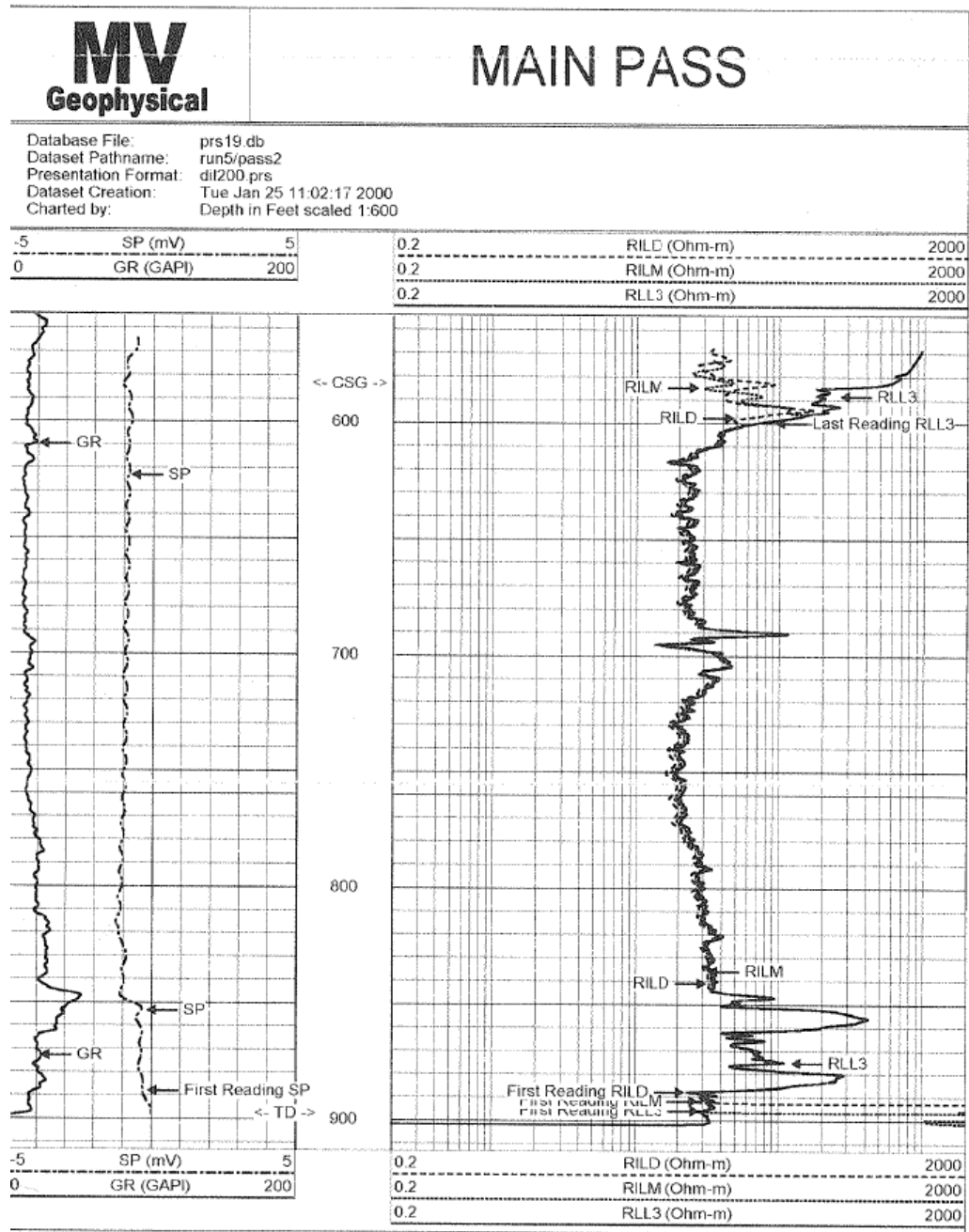


Figure A11. ASR Well S-19 (Continued).

Appendix A: Geophysical Logs (Continued)

MV Geophysical X-Y CALIPER GAMMA RAY LOG																																																									
Company DIVERSIFIED DRILLING Well ASR WELL S-19 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-19 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA																																																									
Location ASR WELL FIELD EXPANSION Other Services BHC DIL FRT FLOW VIDEO																																																									
Permanant Datum Log Measured From Drilling Measured From Ground Level Ground Level Ground Level																																																									
Elevation NA NA NA																																																									
Date 25 JAN 2000																																																									
Run Number FIVE																																																									
Depth Dater 600'																																																									
Depth Logger 888'																																																									
Bottom Logged Interval 888'																																																									
Top Log Interval 900'																																																									
Open Hole Size 14"																																																									
Type Fluid WATER																																																									
Density / Viscosity NANA																																																									
Max. Recorded Temp. NA																																																									
Estimated Cement Top NA																																																									
Time Well Ready 10:00 1/25/00																																																									
Time Logger on Bottom 10:00 1/25/00																																																									
Equipment Number HAWGS-1																																																									
Location FT. WATERS																																																									
Recorded By MILLER/VINCENZI																																																									
Witnessed By C. TARIKSKA (WRS)																																																									
Borehole Record <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>Run Number</th> <th>BA</th> <th>From</th> <th>To</th> <th>Size</th> <th>Weight</th> <th>From</th> <th>To</th> </tr> </thead> <tbody> <tr> <td>ONE</td> <td>12.25"</td> <td>60'</td> <td>260'</td> <td>FIVE</td> <td>14"</td> <td>583'</td> <td>903'</td> </tr> <tr> <td>TWO</td> <td>30'</td> <td>260'</td> <td>360'</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>THREE</td> <td>11.875"</td> <td>260'</td> <td>560'</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>FOUR</td> <td>24"</td> <td>560'</td> <td>585'</td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table> Tubing Record <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>Size</th> <th>Weight</th> <th>From</th> <th>To</th> </tr> </thead> <tbody> <tr> <td>32"</td> <td>315 WT</td> <td>SURFACE</td> <td>90'</td> </tr> <tr> <td>26"</td> <td>375 WT</td> <td>SURFACE</td> <td>255'</td> </tr> <tr> <td>17.25" PVC</td> <td>4" WT</td> <td>SURFACE</td> <td>585'</td> </tr> </tbody> </table>		Run Number	BA	From	To	Size	Weight	From	To	ONE	12.25"	60'	260'	FIVE	14"	583'	903'	TWO	30'	260'	360'					THREE	11.875"	260'	560'					FOUR	24"	560'	585'					Size	Weight	From	To	32"	315 WT	SURFACE	90'	26"	375 WT	SURFACE	255'	17.25" PVC	4" WT	SURFACE	585'
Run Number	BA	From	To	Size	Weight	From	To																																																		
ONE	12.25"	60'	260'	FIVE	14"	583'	903'																																																		
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Invoice No. 2000024 P.O. # 5464 * FINAL PRINT *																																																									

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Comments

Figure A11. ASR Well S-19 (Continued).

Appendix A: Geophysical Logs (Continued)

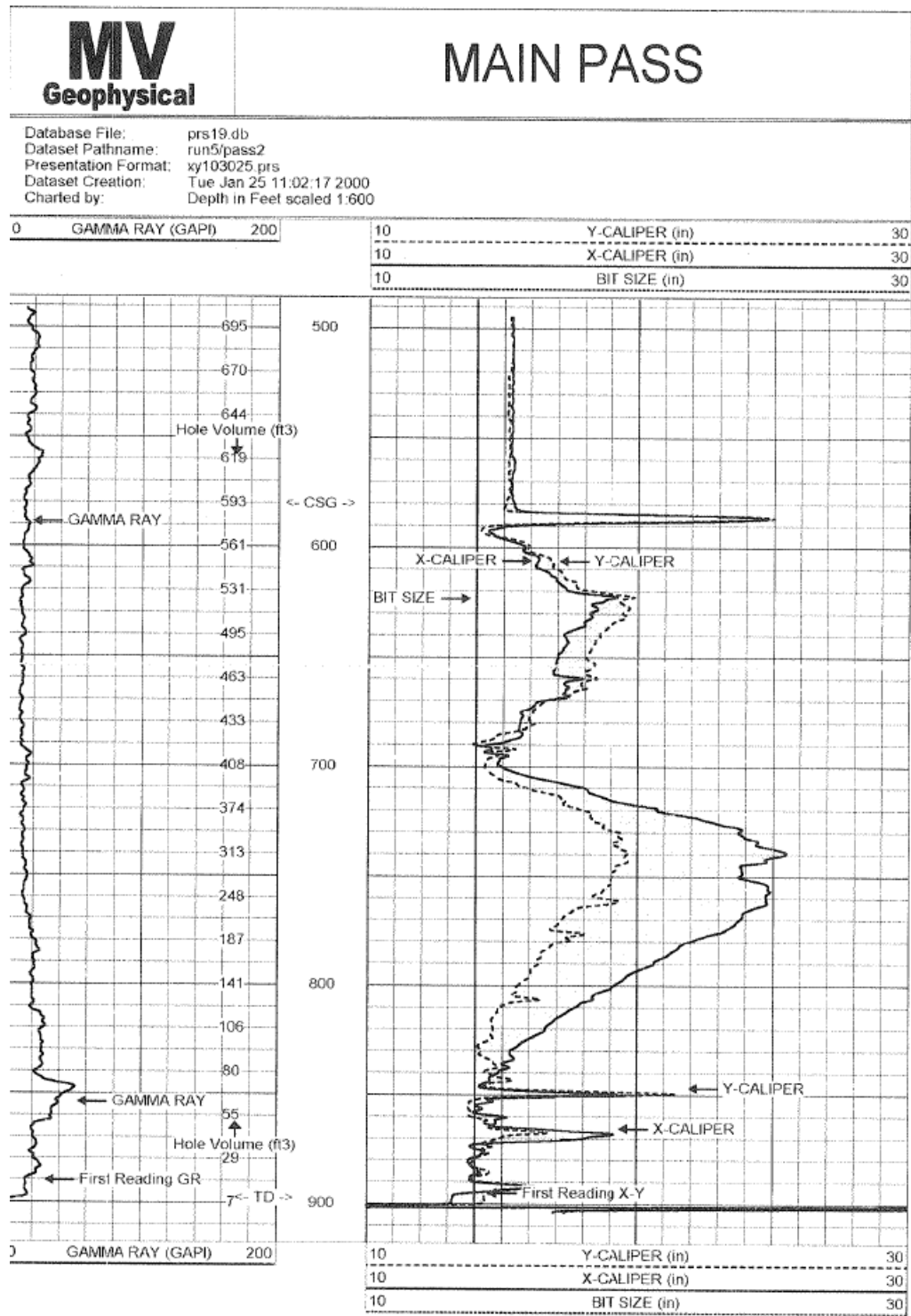


Figure A11. ASR Well S-19 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		FLOWMETER INTERPRETATION	
Company DIVERSIFIED DRILLING Well ASR WELL S-19 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-19 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA	
Location ASR WELL FIELD EXPANSION		Other Services BHC DL FRT XYGR FLOW VIDEO	
Permanent Datum Log Measured From Drilling Measured From	Ground Level Ground Level	Elevation na na	Elevation na na
Date 26-JAN-2000			
Ran Number Depth Driller Depth Logger Bottom Logged Interval Top Log Interval Open Hole Size Type Fluid Density / Viscosity Max. Recorded Temp. Estimated Current Top Time Logger on Bottom Equipment Number Location Recorded By Witnessed By	FIVE 803 896 845 547 14" WATER NA NA 10:00 1125:00 15:00 1125:00 MWGS-1 FT. MYERS MILLERMAN/CEMENT G. SUSCONE (MWS)		
Borehole Record			
Rat Number ONE TWO THREE FOUR	From 12.75' 30" 11.875' 24"	To 60" 280' 200' 585'	Size FIVE FIVE FIVE 585'
Casing Record Surface String Prod. String Production String Line	32" 28" 17.25" PVC 2000024	Weight 375 WT 375 WT 1 WT P.O. # 5484	Top SURFACE SURFACE SURFACE * FINAL PRINT *
All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule. Comments Q, %Q & Fluid Velocity presentations include a regular Line Speed and Caliper corrected only format, and an interpretative "LOGICAL" format. "LOGICAL" Q, %Q & Fluid Velocity passes assume no thief zones (Q & %Q can only increase). STATIC & DYNAMIC data was collected logging DOWN @ 40 & 80 fpm. Qmax ~ 700 gpm			

Figure A11. ASR Well S-19 (Continued).

Appendix A: Geophysical Logs (Continued)

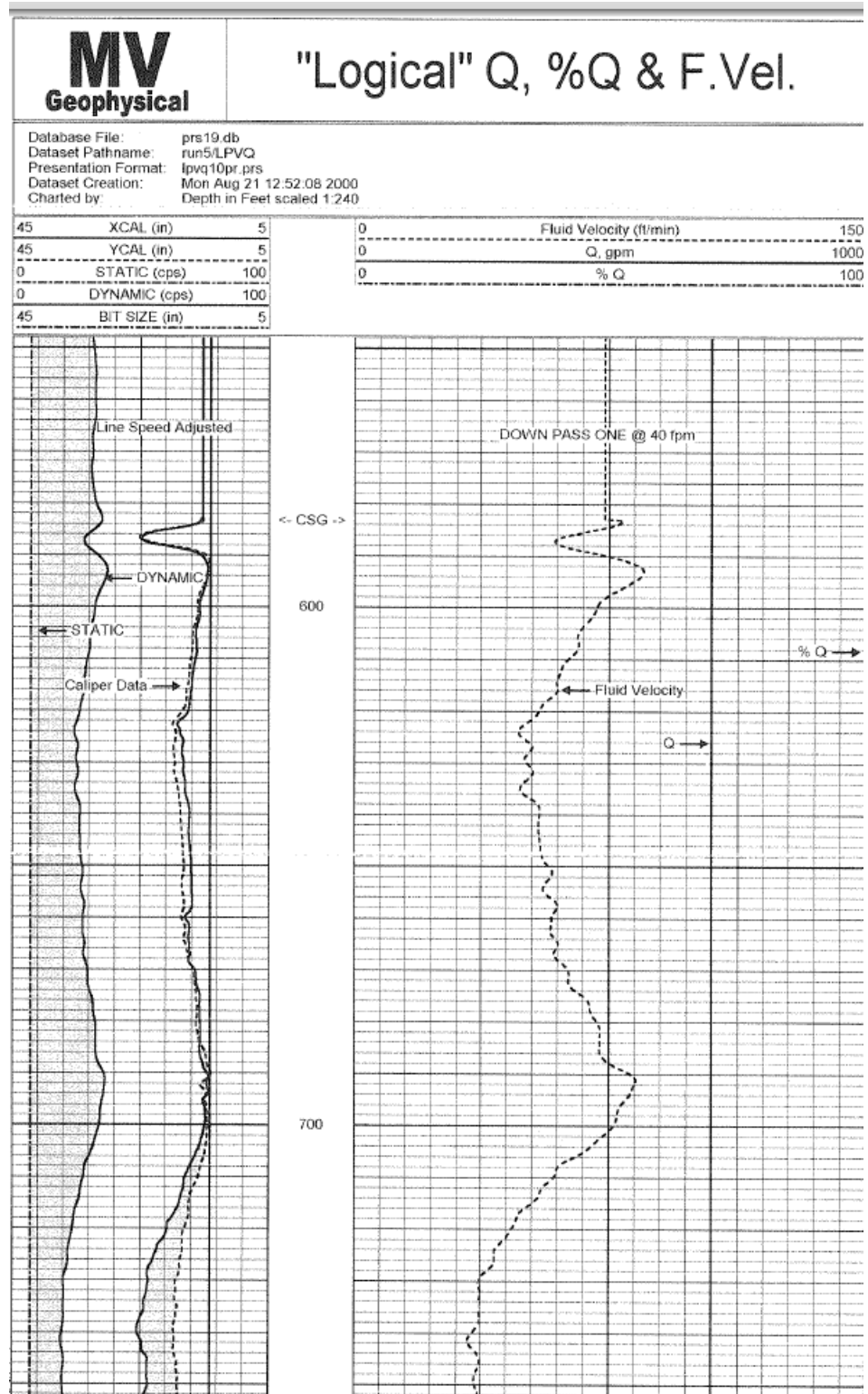


Figure A11. ASR Well S-19 (Continued).

Appendix A: Geophysical Logs (Continued)

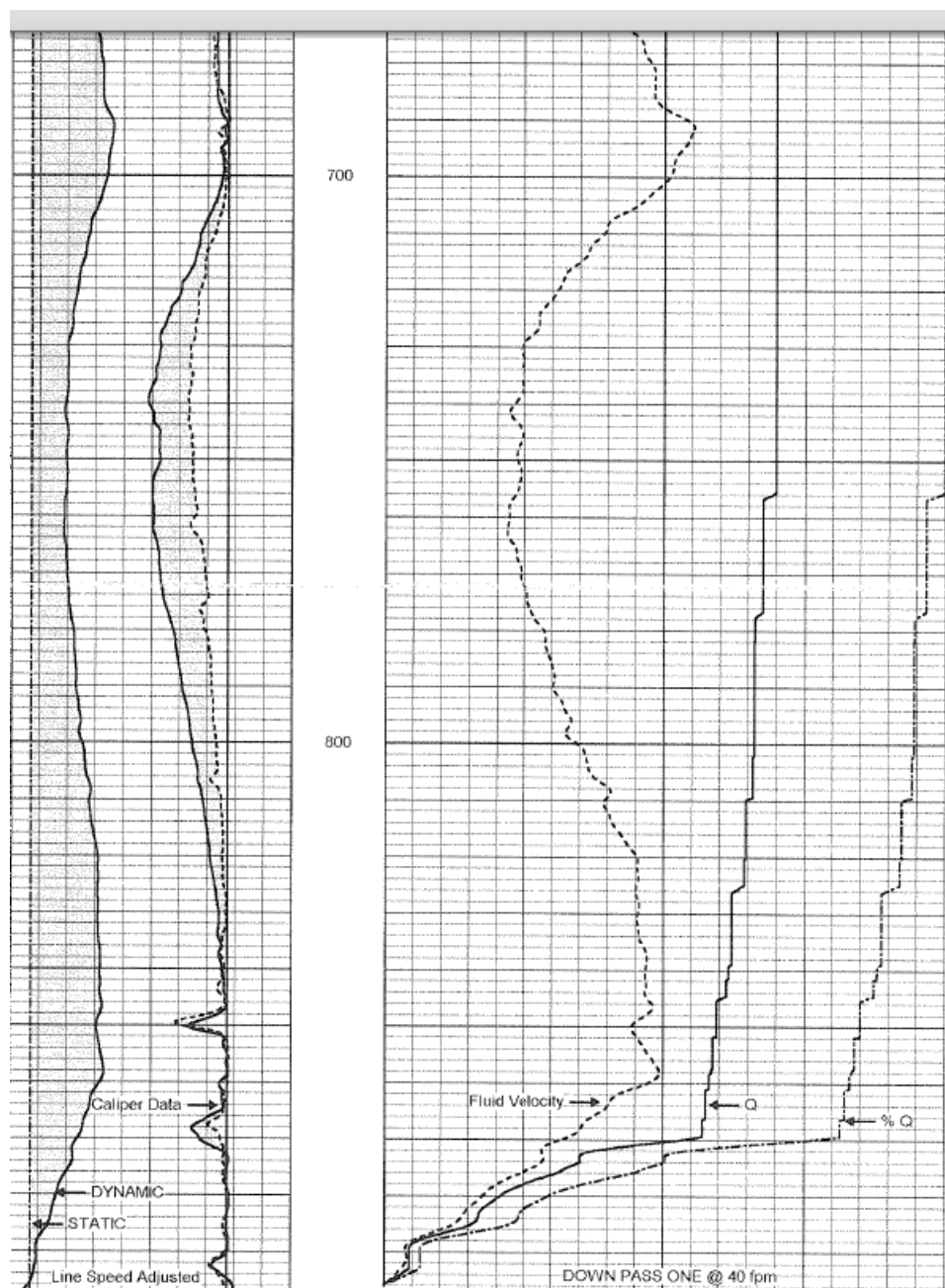


Figure A11. ASR Well S-19 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		BOREHOLE COMPENSATED SONIC w/ VARIABLE DENSITY LOG	
MV Geophysical		Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-19 Field PEACE RIVER Country DESOTO State/Prv FLORIDA	
Location ASR WELL FIELD EXPANSION		Other Services DILV/GR FRT FLOW VIDEO	
Permanent Datum Log Measured From Drilling Measured From		Ground Level Ground Level Ground Level	
Date 25-JAN-2008		Elevation K.B. no O.F. no G.L. no	
Run Number FIVE		Time 11:30:00	
Depth Driller 500		Depth Logger 500	
Bottom Logged 500		Bottom Logged Interval 500	
Top Log Interval 500		Open Hole Size 14"	
Type Fluid WATER		Density / Viscosity N/A	
Max. Recorded Temp. N/A		Estimated Cement Top N/A	
Time Well Ready 10:00 12:00		Time Logger on Bottom 11:30 12:00	
Equipment Number MVSS-1		Location FT MYERS	
Recorded By MILLER/VINCENT		Witnessed By C. TARCISIA W/RSI	
Run Number ONE		Boreside Record	
ONE 12.25'		From 0'	
TWO 30'		To 250'	
THREE 11.05'		Size FIVE	
FOUR 24'		Weight 14"	
Casing Record		Turnup Record	
Surface String 30'		From 0'	
Prod. String 28'		To 500'	
Production String 17.25' PVC		Weight 14"	
Log 2300024		P.O. # 5464	
Invoice No. 2300024			

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Comments

BHC Sonic was run centralized.
Sonic Porosity was run on a Limestone Matrix (=47.5)
Rm=6.192 ohm-m @ 68.7 degF

Figure A11. ASR Well S-19 (Continued).

Appendix A: Geophysical Logs (Continued)

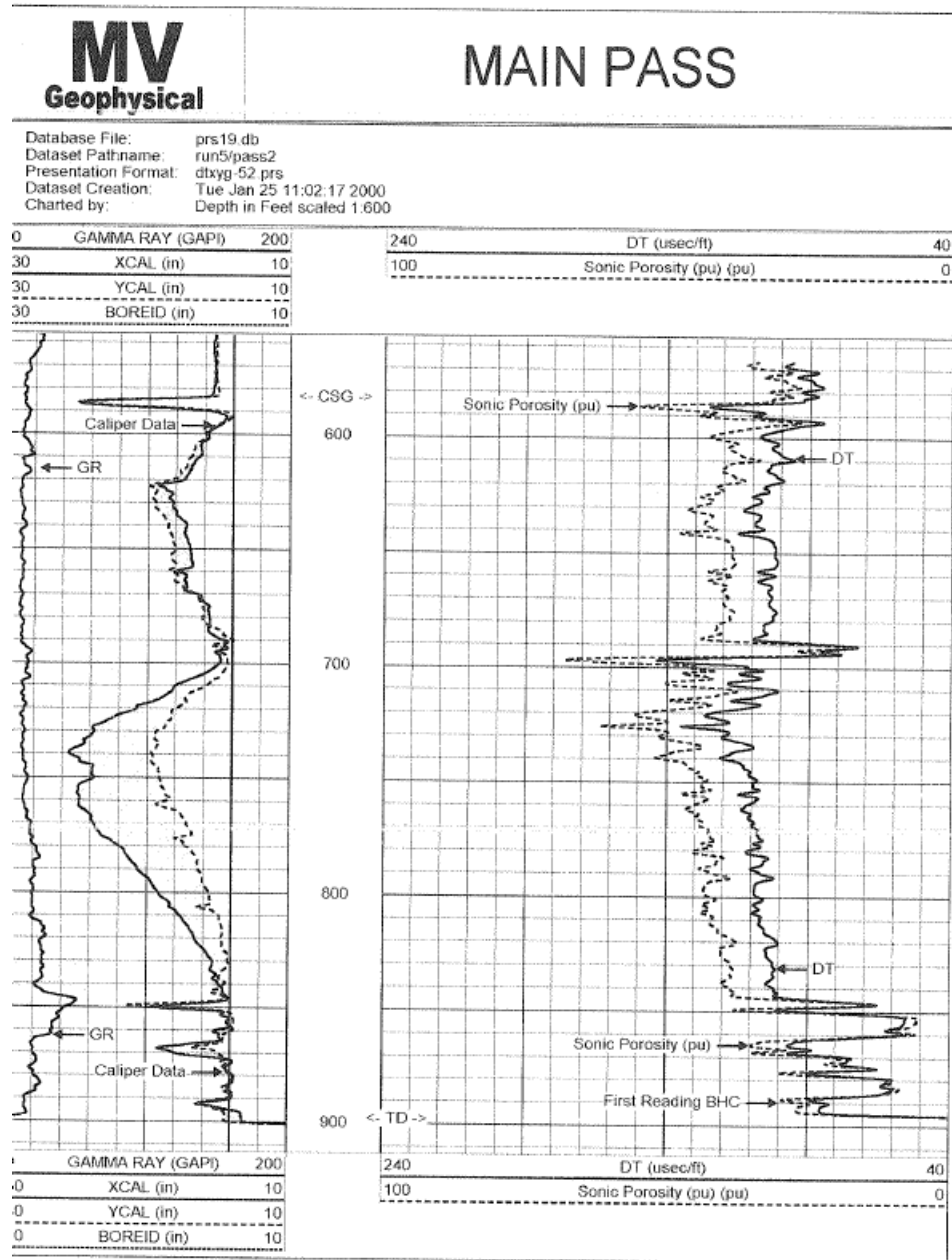


Figure A11. ASR Well S-19 (Continued).

Appendix A: Geophysical Logs (Continued)

 Geophysical FLOWMETER INTERPRETATION																																									
Company DIVERSIFIED DRILLING Well ASR WELL S-20 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-20 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA																																									
Location ASR WELL FIELD EXPANSION Log Measured From Permanent Datum Drilling Measured From Ground Level																																									
Ground Level na Elevation na Elevation D.L. 564' B.H.C. FRT FLOW/VIDEO																																									
Date 22 OCT 98																																									
Run Number FIVE																																									
Depth Dater 669'																																									
Depth Logger 502'																																									
Bottom Logged Interval 501'																																									
Top Log Interval 564'																																									
Open Hole Size 14"																																									
Type Fluid WATER																																									
Density / Viscosity N/A																																									
Max. Recorded Temp. NA																																									
Estimated Cement Top NA																																									
Time Well Ready 09:00 10/22/98																																									
Time Logger on Bottom 14:30 10/22/98																																									
Equipment Number IMVGS-1																																									
Location FT MYERS																																									
Recorded By MILLER/MINCENT																																									
Witnessed By G. SUSENDORF (WRS)																																									
Recorded By P. BEDEN (WRS)																																									
Witnessed By J. SCHMIDT (DDC)																																									
Borehole Record																																									
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Prod. String																																									
Production String																																									
Invoice No. 98091																																									
P.O. #.																																									
* FIELD PRINT *																																									

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Comments

Well Status: FLOWING/DYNAMIC

Est'd Qmax=375 GPM

DYNAMIC Flowmeter passes were made down @30, 60, & 90 fpm.

Figure A12. ASR Well S-20.

Appendix A: Geophysical Logs (Continued)

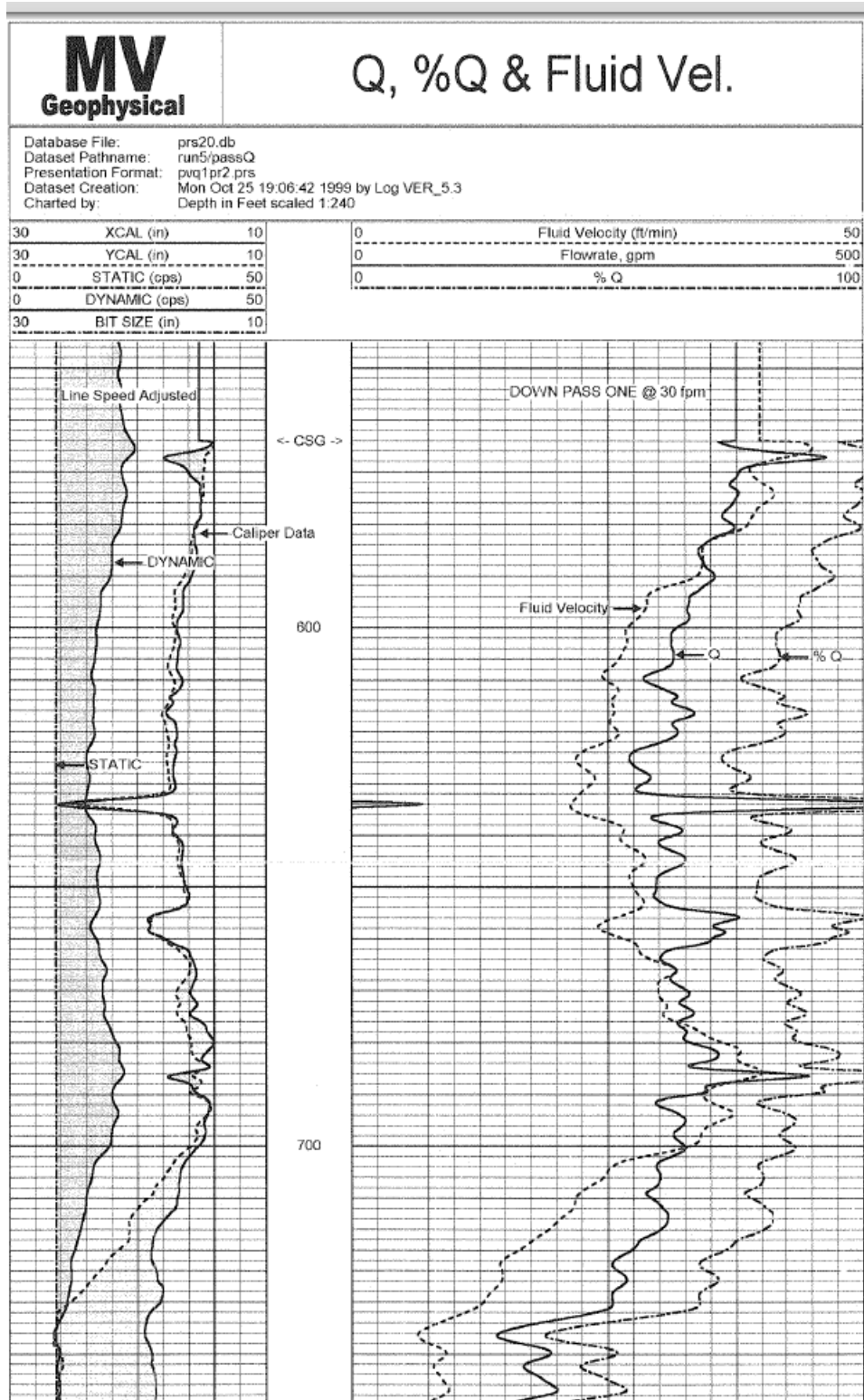


Figure A12. ASR Well S-20 (Continued).

Appendix A: Geophysical Logs (Continued)

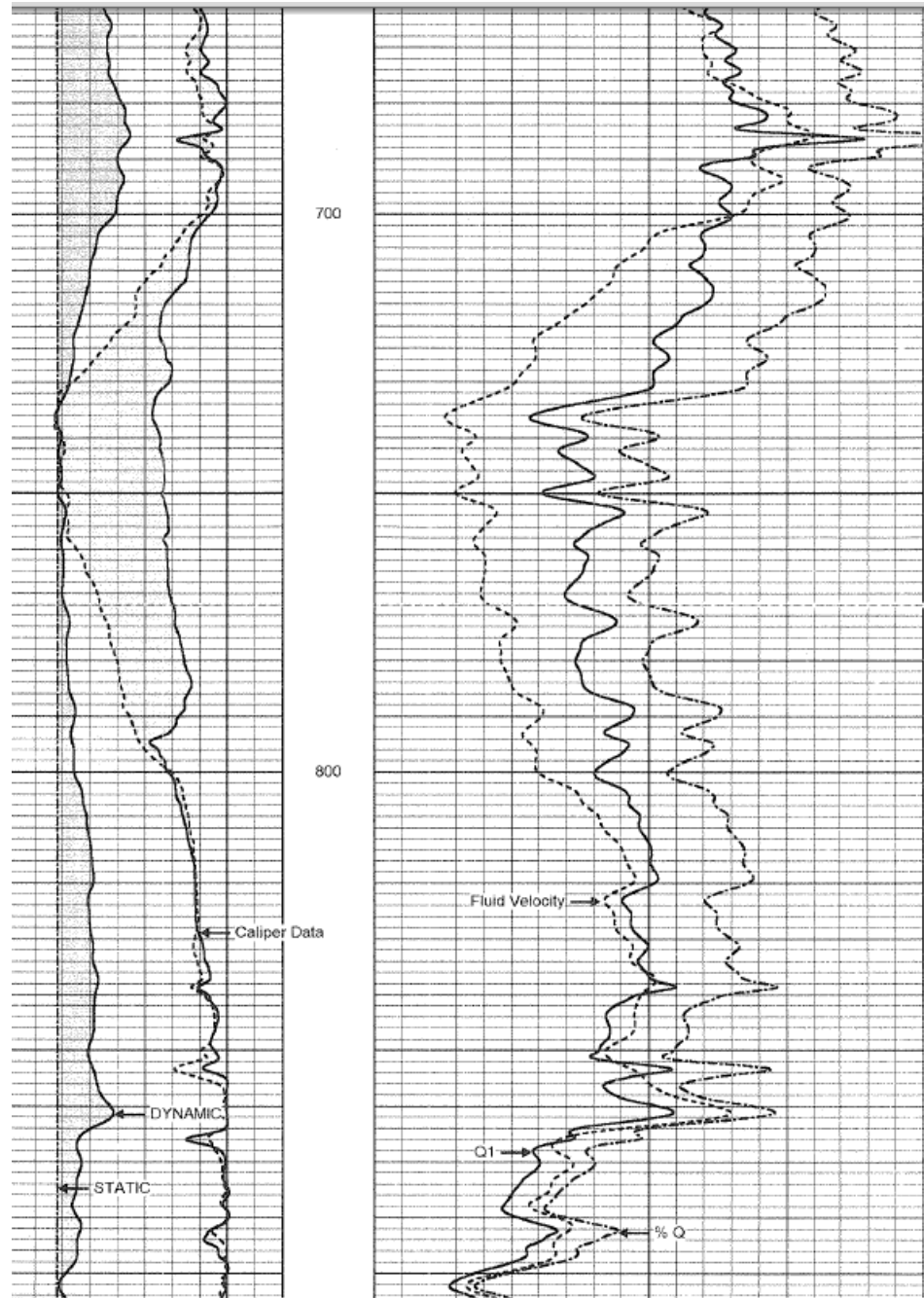


Figure A12. ASR Well S-20 (Continued).

Appendix A: Geophysical Logs (Continued)

<b style="font-size: 2em;">MV <b style="font-size: 1.2em;">Geophysical <b style="font-size: 1.2em;">DUAL INDUCTION <b style="font-size: 1.1em;">LL3 / SP <b style="font-size: 1.1em;">LOG																																									
Company DIVERSIFIED DRILLING Well ASR WELL S-20 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-20 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA																																									
Location PRMRWSA ASR WELL FIELD EXPANSION Other Services XYGR, BHC FRT, FLOW VIDEO																																									
Permanent Datum Log Measured From Datum Measured From Ground Level Ground Level Ground Level																																									
Date Run Number Depth Order Depth Logger Bottom Logged Interval Top Log Interval Open Hole Size Type Fluid Density / Viscosity Max. Recorded Temp. Estimated Cement Top Time Well Ready Time Logger on Bottom Equipment Number 22-OCT-89 FIVE 889 502 500 564 14" WATER NANA NA NA 09:00 10/22/89 11:30 10/22/89 NWGS-1 FT. MYERS																																									
Recorded By MILLER/MINCENT Witnessed By G. SUSDORF (WRS)																																									
Booth/Reel P. BEDEEN (WRS) J. SCHMIDT (DDCI)																																									
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>Run Number</th> <th>Reel</th> <th>From</th> <th>To</th> <th>Size</th> <th>Weight</th> <th>Tubing Record</th> <th>To</th> </tr> </thead> <tbody> <tr> <td>ONE</td> <td>12.25</td> <td>56</td> <td>249</td> <td>14"</td> <td>NA</td> <td>564</td> <td>856</td> </tr> <tr> <td>TWO</td> <td>32</td> <td>56</td> <td>255</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>THREE</td> <td>12.25</td> <td>255</td> <td>750</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>FOUR</td> <td>25</td> <td>255</td> <td>566</td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>		Run Number	Reel	From	To	Size	Weight	Tubing Record	To	ONE	12.25	56	249	14"	NA	564	856	TWO	32	56	255					THREE	12.25	255	750					FOUR	25	255	566				
Run Number	Reel	From	To	Size	Weight	Tubing Record	To																																		
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Invoice No. 98501 P.O. # 4885 * FINAL PRINT *																																									

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Comments

Rm=6.00 @ 84.4 degF

Figure A12. ASR Well S-20 (Continued).

Appendix A: Geophysical Logs (Continued)

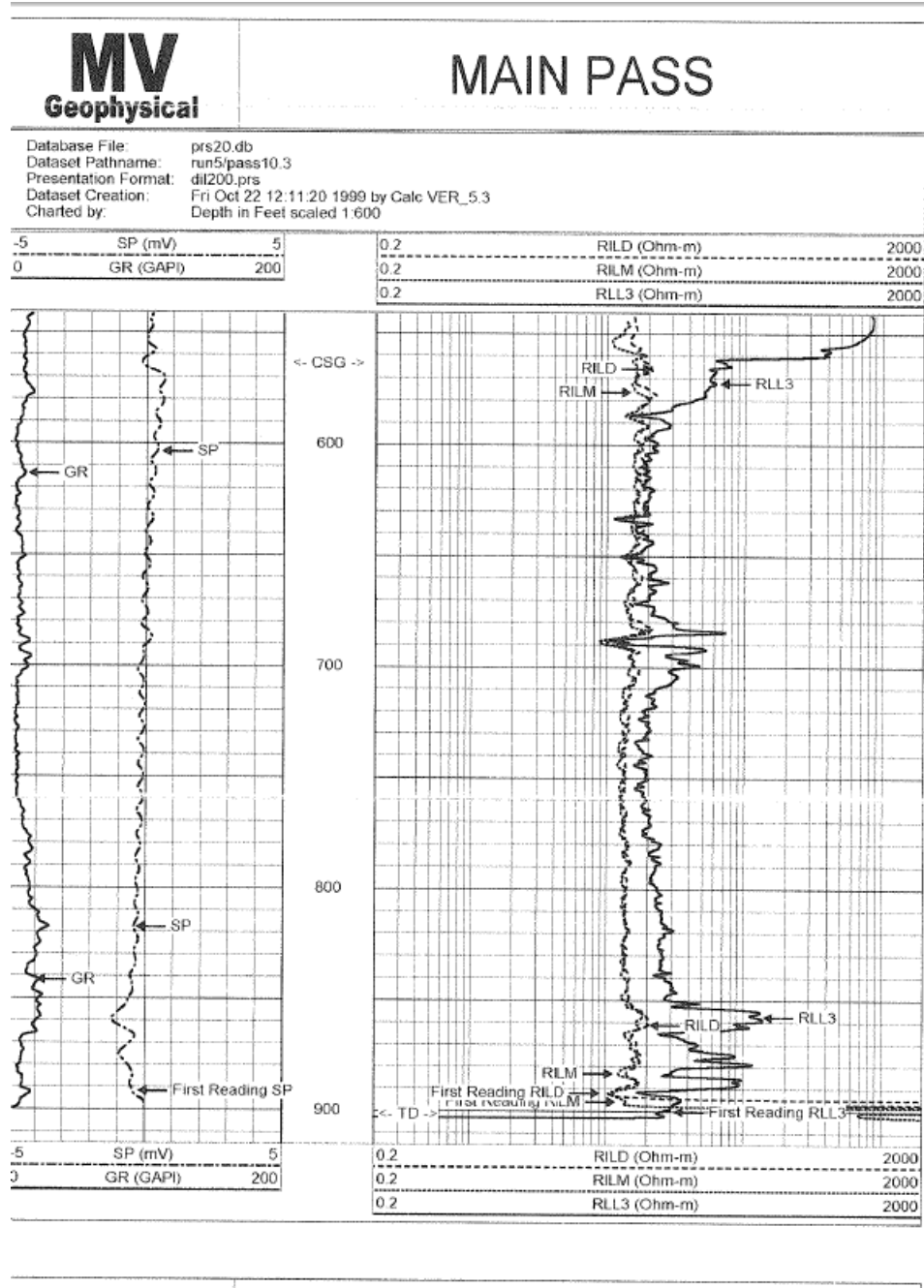


Figure A12. ASR Well S-20 (Continued).

Appendix A: Geophysical Logs (Continued)

Geophysical		FLOWMETER INTERPRETATION	
MV Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-20 Field PEACE RIVER Country DESOTO State/Pv FLORIDA		Location PRMRWSA ASR WELL FIELD EXPANSION	
Date 22 OCT 99 Run Number 889 Depth 889 Depth Logger 889 Bottom Logged Interval 889 Top Log Interval 889 Open Hole Size 14" Type Fluid WATER Density / Viscosity N/A Max Recorded Temp N/A Estimated Cement Top N/A Time Well Ready 08:00 10/22/99 Time Logger on Bottom 14:30 10/22/99 Equipment Number MAVSS-1 Location FT. MYERS Recorded By MILLER/VINCENT Witnessed By G. SUSKOFF (WRS)		Permanent Datum Ground Level Log Measured From Ground Level Drilling Measured From Ground Level Elevation n/a Other Services DIL, XYGR, BHC FLOW, FRT, VIDEO K.B. no D.F. no G.L. no	
Run Number 889 ONE 12.25" TWO 32" THREE 12.25" FOUR 25" Casey Record 32" Surface String 26" Prod. String 17.4" PVC Invoice No. 99091		From 50' To 249' Size 14" Weight 544' From 544' To 889' Top 50' Bottom 255' Surface 584' Surface 584' P.O. # 4695	
*** Fold Here *** All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule. Comments Well Status: FLOWING/DYNAMIC Est'd Qmax=375 GPM DYNAMIC Flowmeter passes were made down @30, 60, & 90 fpm.			

Figure A12. ASR Well S-20 (Continued).

Appendix A: Geophysical Logs (Continued)

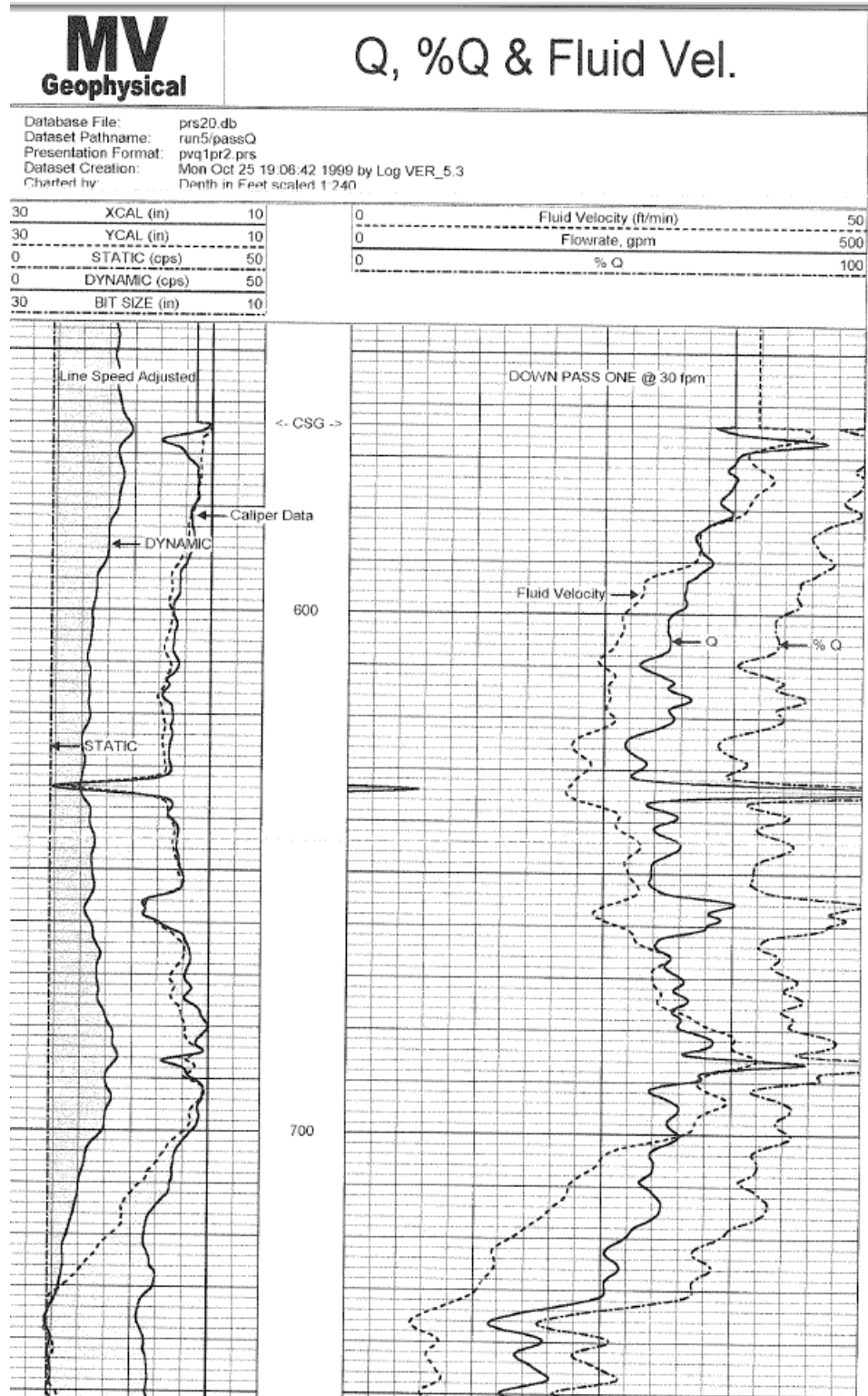


Figure A12. ASR Well S-20 (Continued).

Appendix A: Geophysical Logs (Continued)

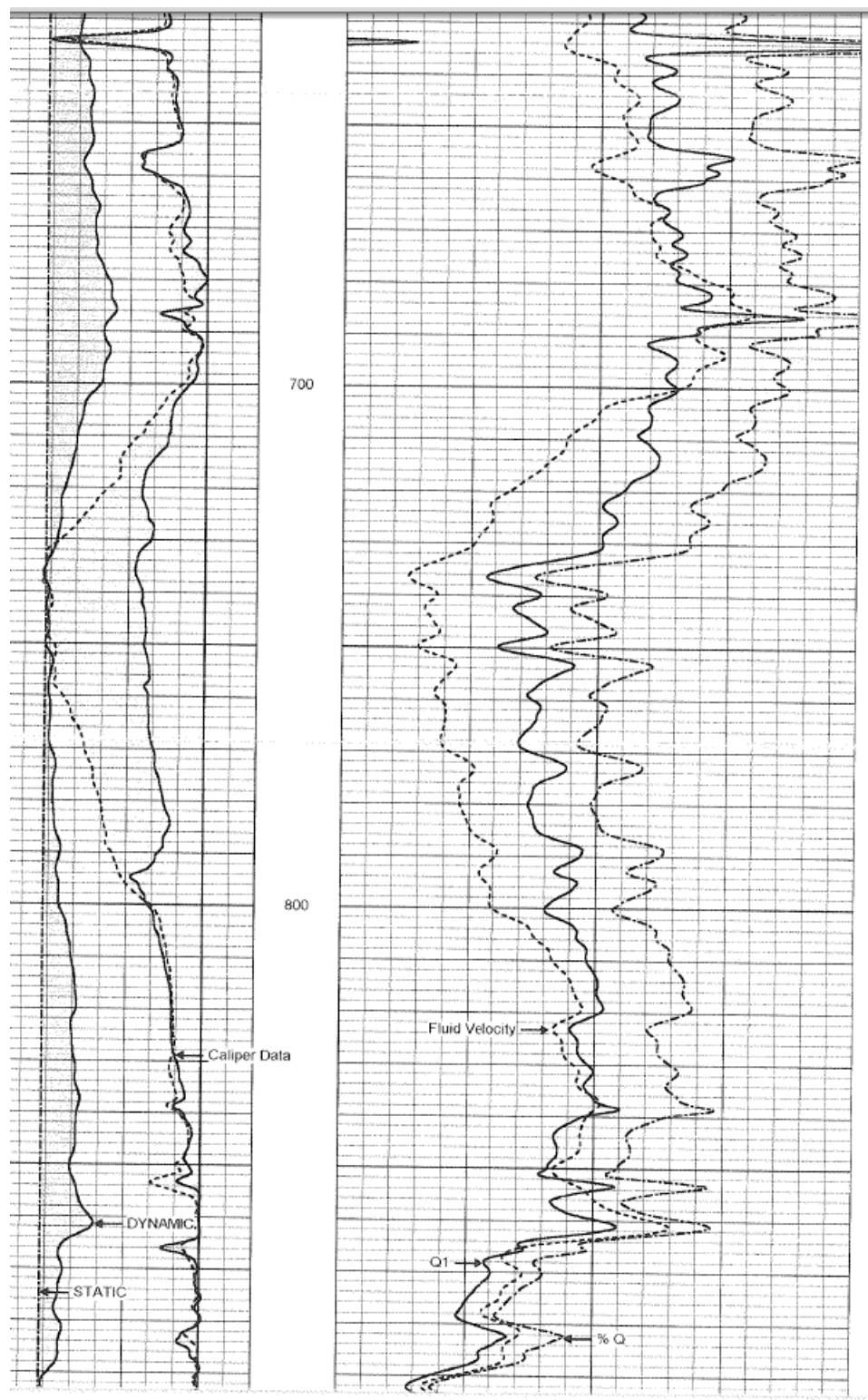


Figure A12. ASR Well S-20 (Continued).

Appendix A: Geophysical Logs (Continued)

		X-Y CALIPER GAMMA RAY LOG			
Company DIVERSIFIED DRILLING CORP. Well ASR WELL S-20 Field PEACE RIVER Country DeSOTO State/Prv FLORIDA		Location PRMRWSA ASR WELL FIELD EXPANSION		Other Services DIL. B+C FRT. FLOW VIDEO	
Date 22 OCT 89 Run Number FIVE Depth Other 899 Bottom Logger 907 Bottom Logged Interval 899 Top Log Interval 507 Open Hole Size 14" Type Fluid WATER Density / Viscosity NANA Max. Recorded Temp. NA Estimated Cement Top 09:00 10/22/89 Time Well Ready 09:30 10/22/89 Equipment Number MWGS-1 Location FT. MYERS Recorded By MILLER/VINCENT Witnessed By GUSISCOFF (WRS)		Permanent Datum Log Measured From Drilling Measured From		Ground Level Ground Level Ground Level	
Run Number ONE Depth 12.25' Bottom 56' Top 246' Size 14" Weight NA From 564' To 899'		Run Number TWO Depth 32' Bottom 256' Top 756' Size 14" Weight NA From 564' To 899'		Run Number THREE Depth 12.25' Bottom 256' Top 756' Size 14" Weight NA From 564' To 899'	
Run Number FOUR Depth 25' Bottom 256' Top 566' Size 14" Weight NA From 564' To 899'		Run Number FIVE Depth 12.25' Bottom 256' Top 756' Size 14" Weight NA From 564' To 899'		Run Number SIX Depth 12.25' Bottom 256' Top 756' Size 14" Weight NA From 564' To 899'	
Casing String 32" Production String 17.4" PVC Line 99091		Top SURFACE Bottom SURFACE From 564' To 899'		Final Print *	

All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages, or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current Price Schedule.

Comments

Figure A12. ASR Well S-20 (Continued).

Appendix A: Geophysical Logs (Continued)

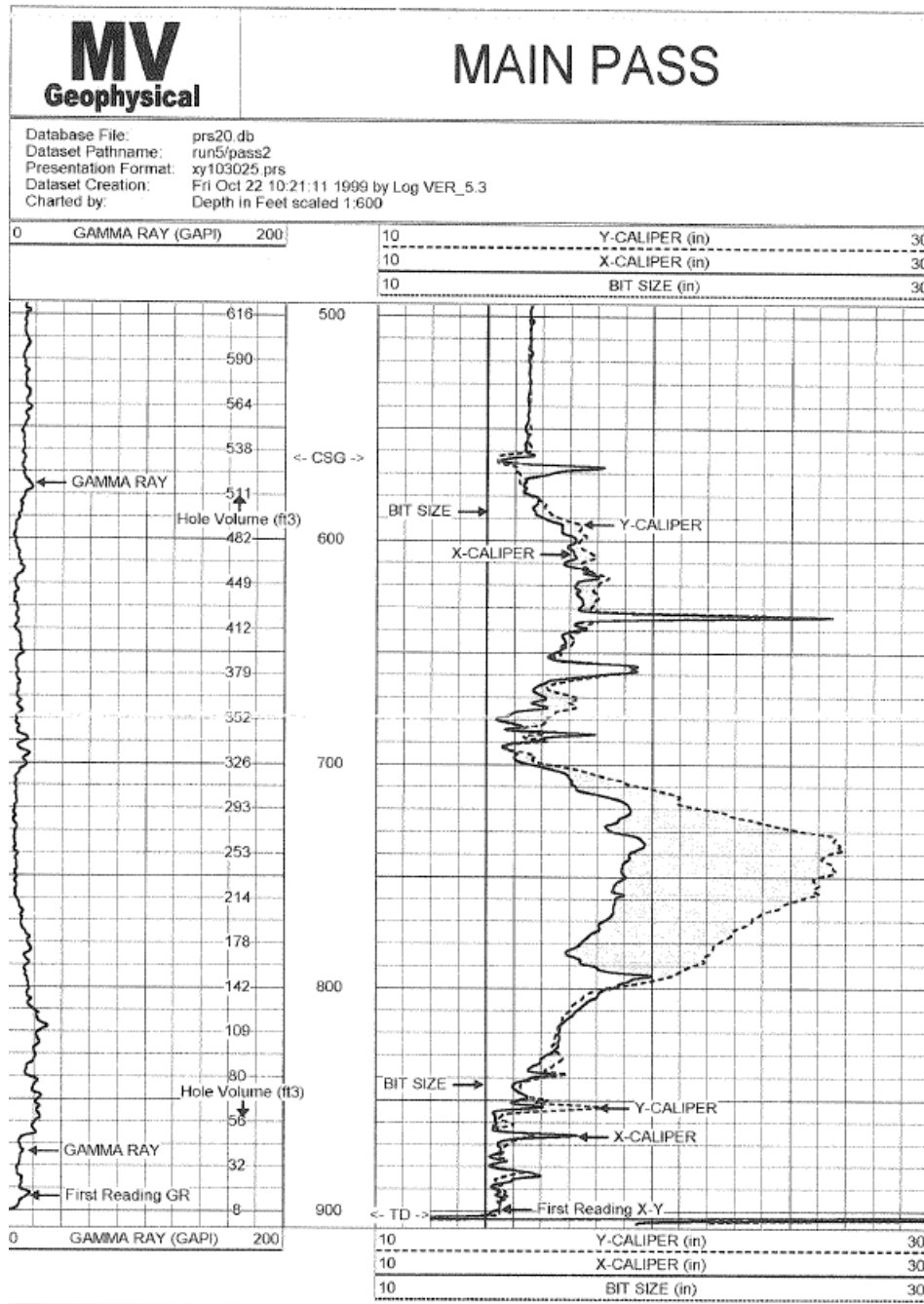


Figure A12. ASR Well S-20 (Continued).

Appendix A: Geophysical Logs (Continued)

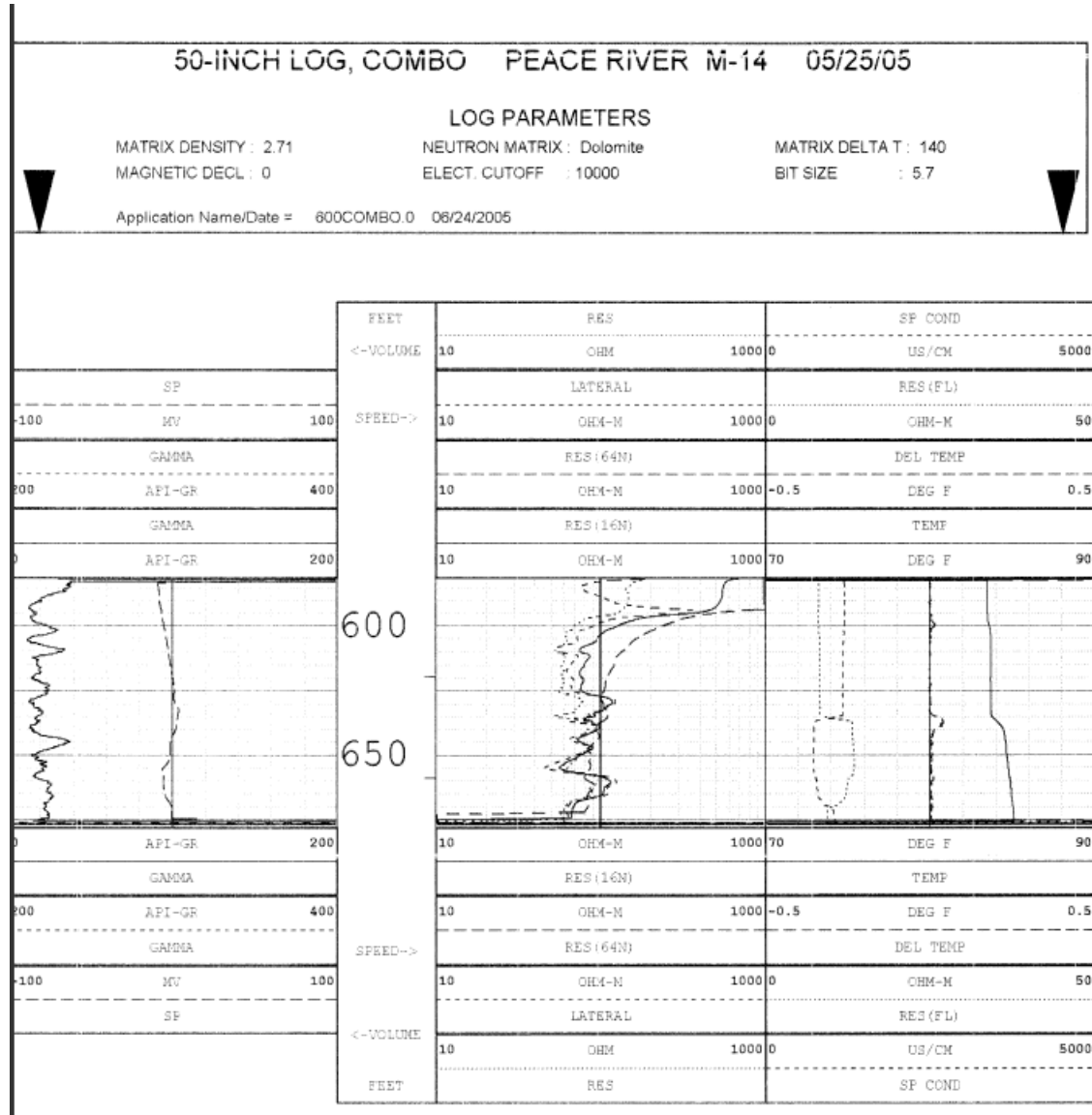


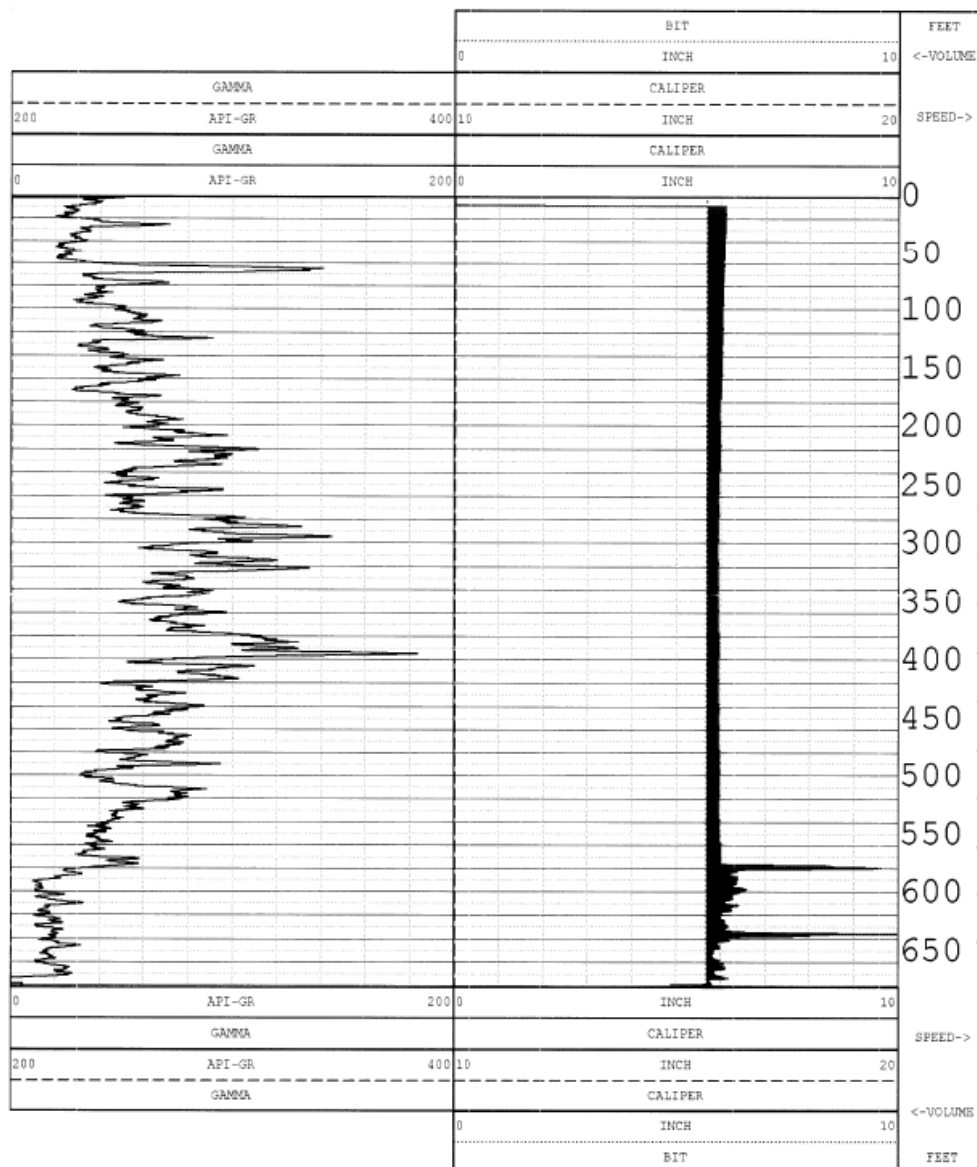
Figure A13. Monitoring Well M-14.

100-INCH LOG, CALIPER/GRAY PEACE RIVER M-14 05/25/05

LOG PARAMETERS

MATRIX DENSITY : 2.71 NEUTRON MATRIX : Dolomite MATRIX DELTA T : 140
 MAGNETIC DECL : 0 ELECT. CUTOFF : 10000 BIT SIZE : 5.7

Application Name/Date = 1200CAL.0 06/17/2005



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Appendix A: Geophysical Logs (Continued)

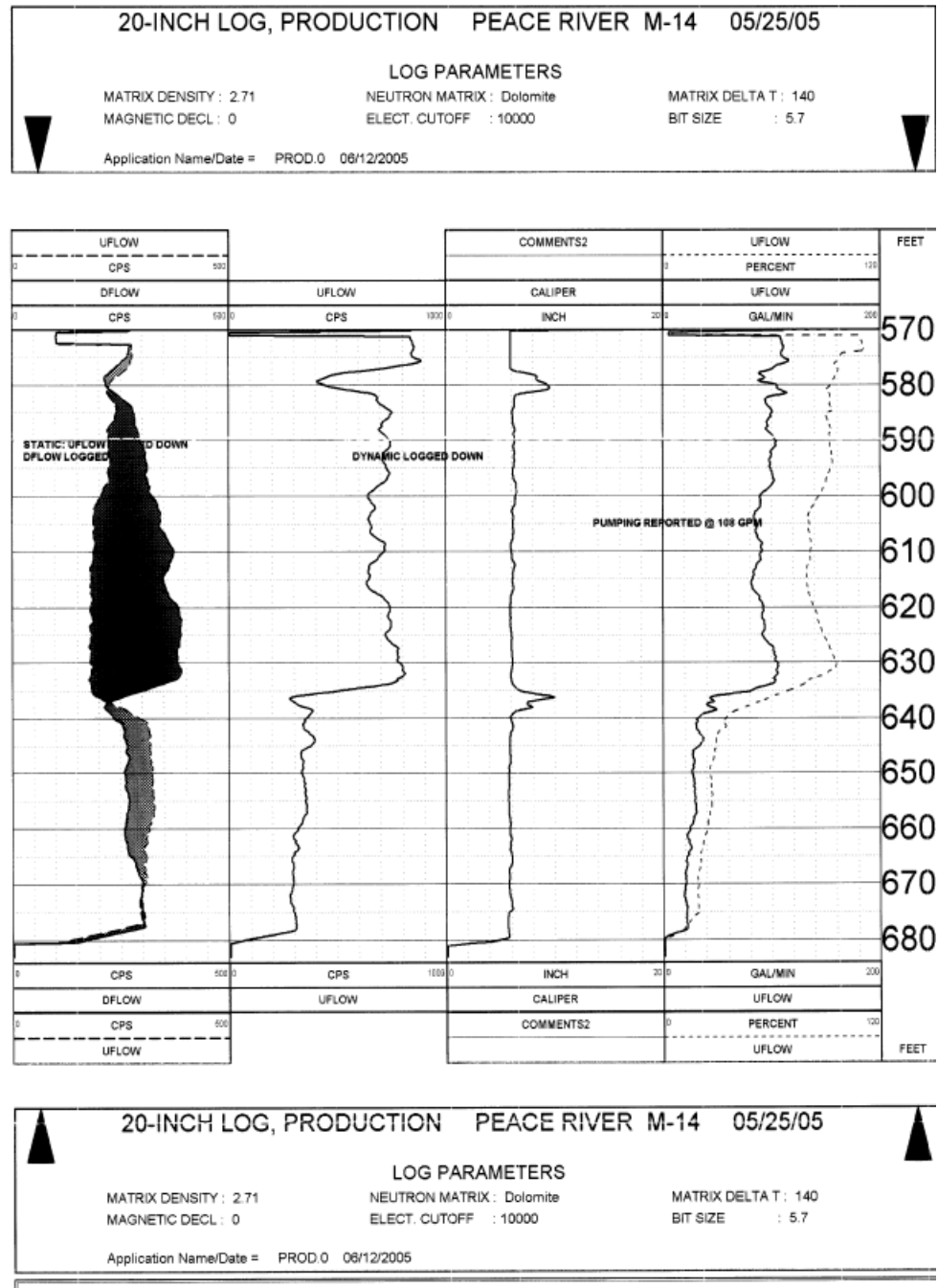


Figure A13. Monitoring Well M-14 (Continued).

Appendix A: Geophysical Logs (Continued)

100-INCH LOG, CALIPER/GRAY PEACE RIVER M-15 04/27/05		
LOG PARAMETERS		
MATRIX DENSITY : 2.71 MAGNETIC DECL : 0	NEUTRON MATRIX : Dolomite ELECT. CUTOFF : 10000	MATRIX DELTA T : 140 BIT SIZE : 5.7
Application Name/Date = 1200CAL.0 08/17/2005		

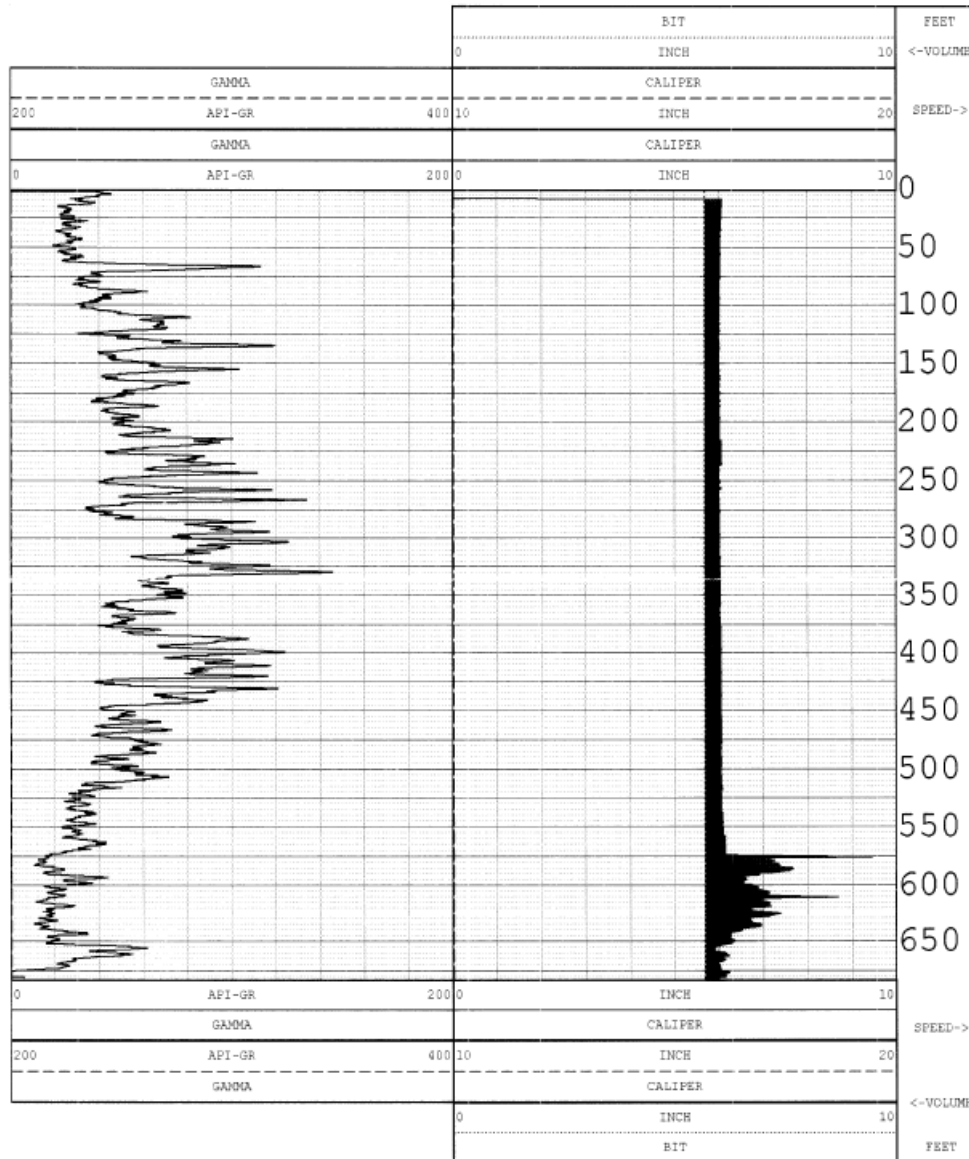


Figure A14. Monitoring Well M-15.

Appendix A: Geophysical Logs (Continued)

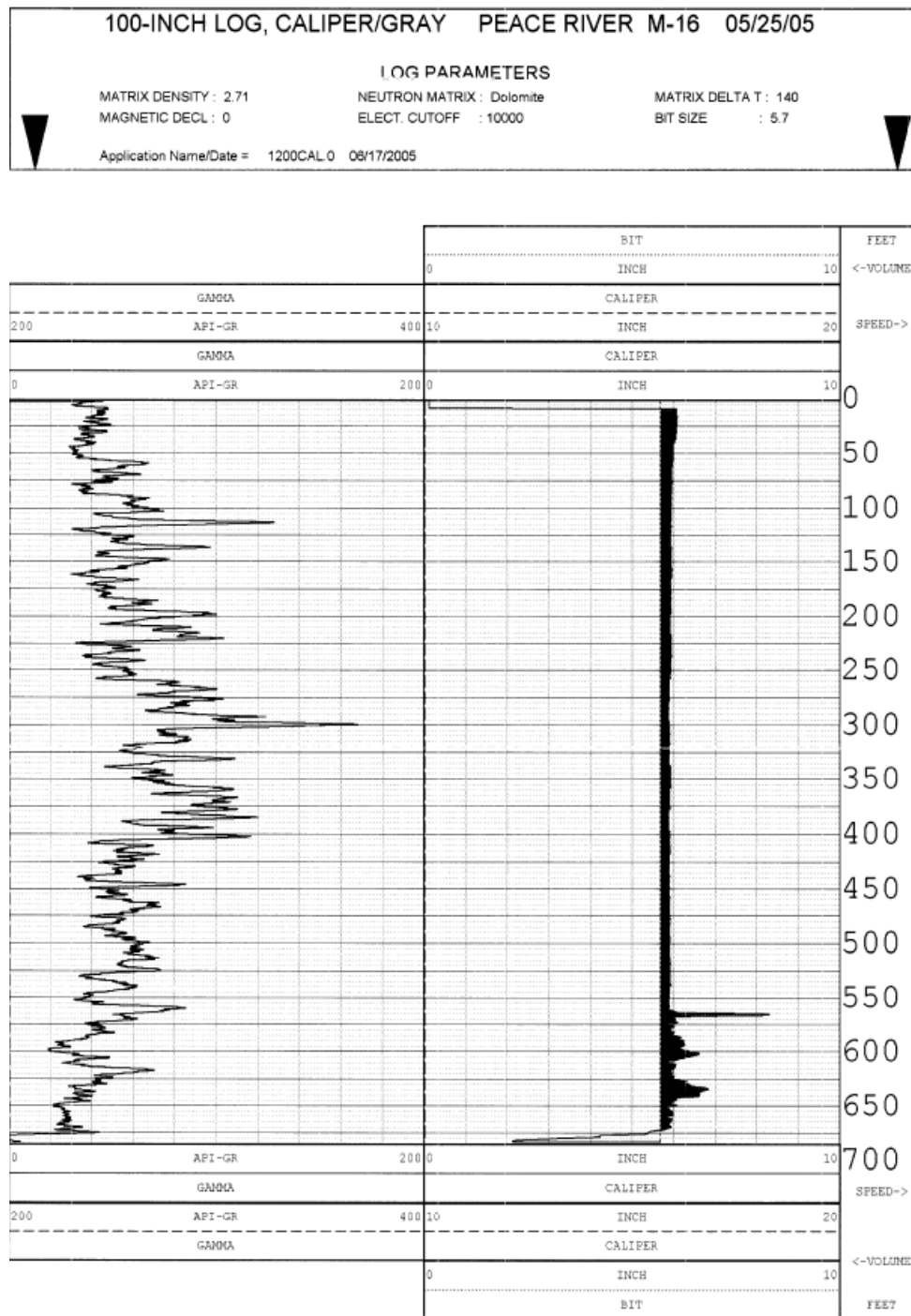


Figure A15. Monitoring Well M-16.

Appendix A: Geophysical Logs (Continued)

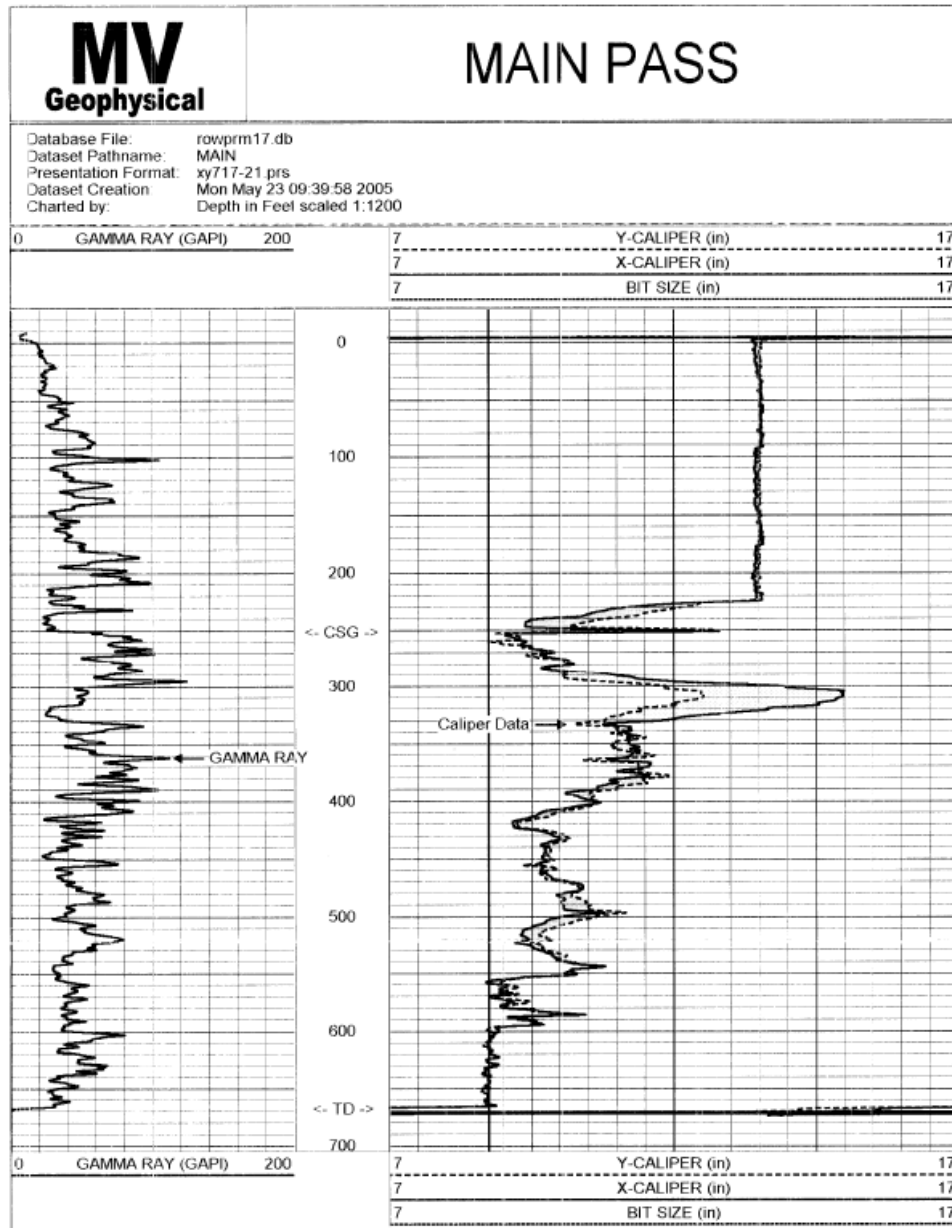


Figure A16. Monitoring Well M-17

Appendix A: Geophysical Logs (Continued)

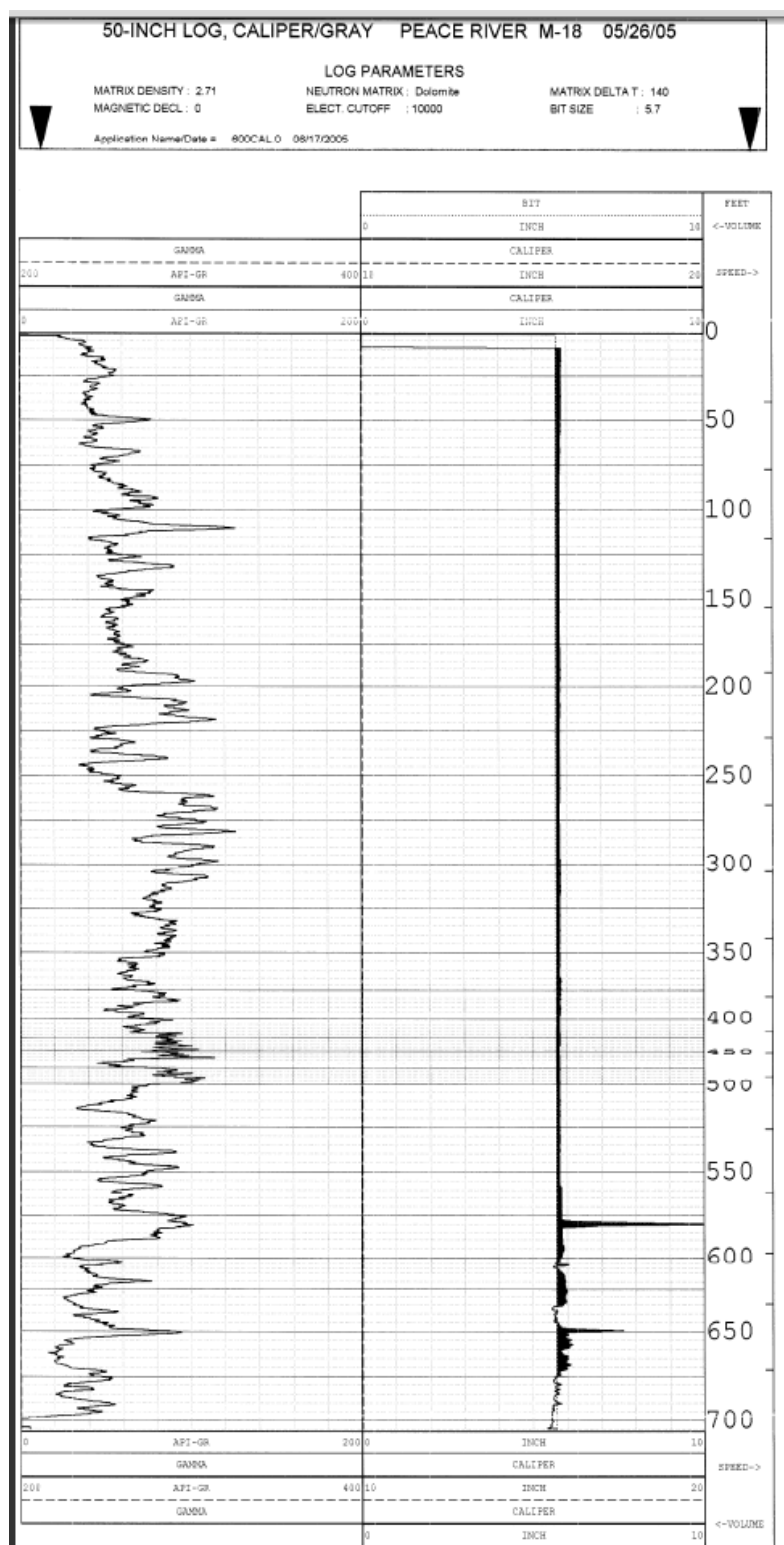


Figure A17. Monitoring Well M-18

Appendix A: Geophysical Logs (Continued)

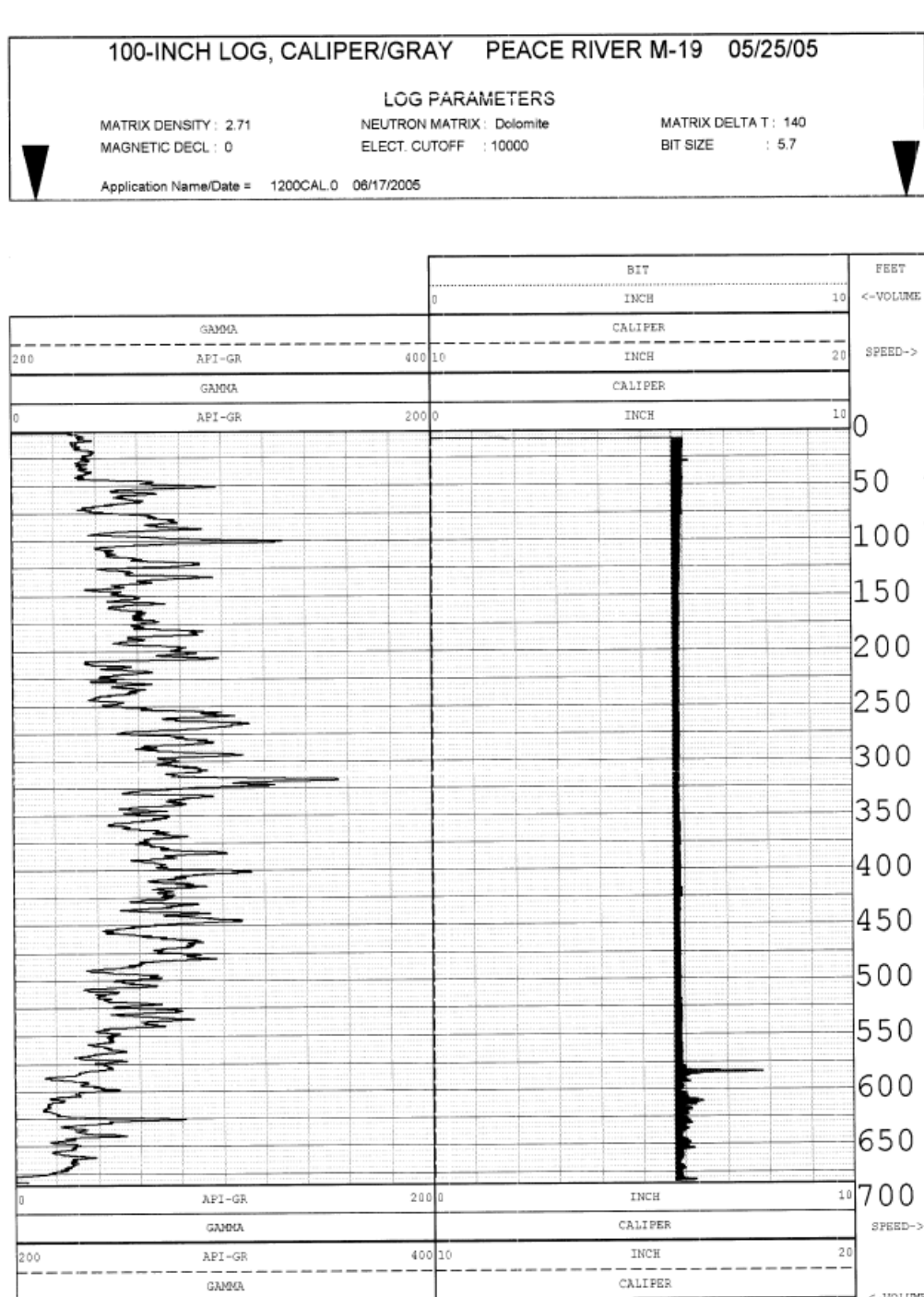


Figure A18. Monitoring Well M-19

100-INCH LOG, CALIPER/GRAY PEACE RIVER M-20 04/05/05

LOG PARAMETERS

MATRIX DENSITY : 2.71

NEUTRON MATRIX : Dolomite

MATRIX DELTA T : 140

MAGNETIC DECL : 0

ELECT CUTOFF : 10000

BIT SIZE : 5.7

Application Name/Date = 1200CAL 0 06/17/2005

		BIT		FEET	
		INCH		<-VOLUME	
GAMMA		CALIPER		SPEED->	
200	API-GR	400	10	20	
GAMMA		CALIPER		SPEED->	
0	API-GR	200	0	10	
		INCH		0	
				50	
				100	
				150	
				200	
				250	
				300	
				350	
				400	
				450	
				500	
				550	
				600	
				650	
				700	
0	API-GR	200	0	10	
GAMMA		CALIPER		SPEED->	
200	API-GR	400	10	20	
GAMMA		CALIPER		SPEED->	
		INCH		0	
				50	
				100	
				150	
				200	
				250	
				300	
				350	
				400	
				450	
				500	
				550	
				600	
				650	
				700	
		BIT		FEET	

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Appendix B: Field Data for ASR and Monitor Wells

Table B1. Finish Water Concentrations

Test Date (Finish Water)	DO mg/L	ORP mV	pH std. units	T °C	As µg/L	Ca mg/L	Cl mg/L	Total Fe ug/L	SO ₄ mg/L	Alk mg/L	TDS mg/L
06/02/05	5.2		8.4	27.5	<1.3		48		163	36	364
06/07/05	4.2		8.3	28.0	<1.3		53		166	40	376
06/16/05	3.6		8.3	28.0	1.5		62		169	40	420
06/24/05	3.1	325	8.3	28.0	1.3		60	102	166	36	328
06/29/05	2.7	399	8.3	29.0	<1.3		53	<29.0	155	36	300
07/06/05	5.2	458	8.2	29.0	<1.3	29	43	<29.0	129	32	300
07/13/05	4.6	384	8.3	29.0	<1.3		37	67	116		248
07/21/05	4.7	450	8.0	30.0	1.8		31	<29.0	113		268
07/25/05	5.2	513	8.2	31.0	2.3		29	<29.0	108		252
07/28/05			8.2		<6.0		30	<29.0	104		284
08/02/05	3.8	430	8.1	30.5	1.6		27	<29.0	104	33	216
08/09/05	4.9	476	8.2	30.0	<1.3		26	<29.0	100		200
08/16/05	5.1	465	8.3	30.0	<1.3		25	<29.0	100		204
08/22/05	5.0	478	8.2	31.0	<1.3	18	25	55	100	26	240
08/29/05	4.4	420	8.2	30.0	<1.3		25	<29.0	99		212
09/07/05	4.2	412	8.2	32.0	1.7	20	25	<29.0	99	26	252
09/13/05	5.2	331	8.7	30.0	<1.3		22	<29.0	100		272
09/20/05	5.4	472	8.1	30.0	1.7		26	<29.0	106		340
09/27/05	5.2	442	8.2	29.0	<1.3		23	<29.0	99		224
10/03/05			8.2				22		106		248
11/01/05	5.1	524	8.1	23.0			26		109	32	268
12/05/05			8.2				28		112		236
01/04/06	7.2	418	8.3	20.0	<1.3	28	31	<29	119	43	300
01/09/06	7.1	424	8.3	19.0	<1.3		36	<29	132	44	320
01/17/06	6.4	396	8.4	19.0	<1.3		21	<29	87	50	300
01/23/06	6.8	571	8.4	19.5	<1.3		33	<29	143	55	288
01/30/06	6.5	459	8.2	20.0	<1.3		30	<29	132	57	300
02/01/06											
03/01/06											
04/03/06	6.1	424	8.2	23.0	<1.3	37	35	<29	143	46	336
04/10/06	5.0	498	8.2	25.0	3.0		38	41	160	44	424
04/17/06	5.3	511	8.2	24.0	<1.3		48	<29	156	42	416
04/24/06	5.9	471	8.2	27.0	<1.3		55	<29	174	43	396
05/01/06	6.5	366	8.1	26.0	<1.3		44	<29	193	40	420
05/09/06	6.3	305	8.2	28.0	<1.3		68	5	203	44	476
05/17/06	5.8	300	8.3	28.0	1.5		59	<29	169	46	524

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B1. Finish Water Concentrations (Continued)

Test Date (Finish Water)	DO mg/L	ORP mV	pH std. units	Tem P °C	As µg/L	Ca mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	Alk mg/L	TDS mg/ L
05/31/06	5.8	315	8.2	28.0	3.7		104	<29	249	54	584
06/06/06	5.9	331	8.3	29.0	<1.3	58	106	<29	229	48	496
06/14/06	5.4	293	8.4	28.0	1.3		56	<29	230	48	636
06/20/06	5.5	330	8.4	29.0	1.6		130	<29	215	50	660
06/27/06	5.5	289	8.3	30.0	<1.3		110	<29	237	51	664
07/05/06		237	8.2	30.0	<1.3	62	140	32	277	55	720
07/10/06	5.8	335	8.1	30.0	2.0		130	<29	247	52	752
07/19/06	6.0	505	8.1	30.0	4.1		81	<29	208	33	552
07/25/06	5.8	409	7.9	29.0	2.4		85	74	201	37	548
08/01/06	5.8	477	8.2	30.0	1.9	49	64	30	210	38	476
08/09/06	5.7	551	8.2	29.0	<1.3 <6.0		60	<29	183	42	440
08/16/06	5.7	321	8.2	31.0	2		52	<29	184	37	480
08/22/06	5.9	410	8.2	30.0	<1.3		60	<29	151	39	412
08/29/06	6.0	318	8.2	29.5	6.0		51	<29	148	34	420
09/06/06	3.6	385	8.2	29.0	2.4	40	54	<29	162	34	464
09/13/06	5.8	351	8.2	30.0	<1.3		50	140	153	36	372
09/19/06	5.6	432	8.1	29.0	1.6		48	<29	149	34	352
09/26/06	5.6	428	8.2	29.0				<29	133	33	328
10/03/06	6.2	377	8.1	29.0	<1.3	31	38	<29	131	32	316
10/10/06	6.0	378	8.2	28.0	<6.0		34	90	121	33	300
10/17/06	6.0	497	8.0	27.0	<1.3		17	<29	64	33	308
10/25/06	6.5	177	8.1	26.0	<1.3		36	<29	139	36	372
10/31/06	6.1	269	8.1	25.0			38	<29	145	30	320
11/07/06	6.8	355	8.1	24.0	<1.3	35	38	<29	149	38	340
11/15/06	6.6	479	8.1	24.0	2.0		43	<29	158	39	340
11/21/06	5.9	473	8.1	22.0	<1.3		50	37	175	40	364
11/28/06	5.8	422	8.2	21.0	<1.3		54	<29	178	43	416
12/04/06	5.3	468	8.0	24.0	<1.3	49	65	<29	196	43	448
12/12/06	5.6	387	8.1	22.0	<1.3		80	<29	217	46	456
12/19/06	6.0	431	8.1	23.0	<1.3		89	<29	223	48	480
12/27/06	5.9	303	8.0	23.0	<1.3		100	<29	234	49	572
01/02/07	6.2	294	8.3	22.0	4.0	57	92	<29	226	53	540
01/09/07	5.9	365	8.3	23.0	2.8		87	<29	221	52	432
01/16/07	3.2	247	8.2	21.0	2.0		85	<29	232	48	408
01/23/07	6.4	425	8.1	22.0	<1.3		84	51	244	50	488
01/30/07	6.0	431	8.2	20.0	2.0		83	<29	243	49	516
02/06/07	7.2	354	8.3	19.0	<1.3	54	80	<29	244	52	512
02/13/07	6.5	458	8.3	19.0	<1.3		73	135	240	54	532

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B1. Finish Water Concentrations (Continued)

Test Date (Finish Water)	DO mg/L	ORP mV	pH std. units	Tem P °C	As µg/L	Ca mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	Alk mg/L	TDS mg/L
03/06/07	6.1	425	8.3	22.0	<1.3		69	<29	235	51	500
03/13/07	5.5	378	8.3	22.5	<1.3		69	<29	237	55	544
03/20/07	5.7	402	8.1	22.0	<1.3		94	<29	254	55	600
03/27/07	5.2	285	7.9	23.2	<1.3		100	<29	264	58	576
04/03/07	5.5	414	8.2	24.0	4.5	60	119	<29	279	50	628
04/10/07	5.2	174	8.2	23.7	<1.3	70	139	<29	286	60	732
04/17/07	5.5	412	8.2	24.0	<1.3	69	149	<29	292	60	712
04/24/07	5.6	377	8.1	25.0	<1.3		151	<29	301	55	764
05/01/07	4.9	307	8.2	26.0	<1.3		159	<29	300	56	720
05/08/07	8.1	284	8.4	27.0	<1.3	74	153	<29	290	50	760
05/15/07	6.5	303	8.3	27.0	<1.3		163	<29	208	56	776
05/22/07	5.8	314	8.4	27.0	<1.3		168	<29	290	55	768
05/29/07	5.6	286	8.2	25.0	<1.3		161	<29	237	58	792
06/05/07	5.4	316	8.4	27.0	<1.3	78	185	<29	288	60	788
06/12/07	6.9	350	8.5	29.0	<1.3		191	30	280	61	828
06/19/07	6.1	353	8.3	29.0	<1.3		184	43	290	63	796
06/26/07	6.0	400	8.0	29.0	1.6		212	<29	288	63	824
07/03/07	5.8	378	8.3	29.0	<1.3	91	220	38	295	68	840
07/10/07	5.3	375	7.9	30.0	<1.3		150	29	234	52	756
07/17/07	6.7	459	7.9	31.0	2.6		137	<29	269	44	672
07/24/07	6.0	430	8.3	29.5	1.6		117	<29	259	45	640
07/31/07	5.8	407	8.2	30.5	<1.3		98	<29	225	43	572
08/07/07	6.2	384	8.2	30.0	2.0	52	93	116	238	43	496
08/14/07	4.1	452	7.9	31.0	<1.3		69	29	212	36	456
08/21/07	5.0	449	8.0	31.0	<1.3		59		196	41	440
08/28/07	5.4	449	8.1	30.0	<1.3		55	41	167		416
09/04/07	5.3	470	8.0	30.0	<1.3	38	48	<29	178	40	384
09/11/07	5.6	403	7.9	29.0	<1.3		43	<29	173		400
09/18/07	5.5	457	8.0	31.0	<1.3		43	<29	170		328
09/25/07	5.2	489	8.1	29.0	<1.3		43	<29	185		380
10/02/07	5.4	390	8.1	27.0	<1.3		40	37	175	40	384
10/09/07	5.5	387	8.1	29.0	<1.3		39	29	168		392
10/16/07	4.8	595	8.3	28.0	<1.3		37	30	169		392
10/23/07	4.8	323	8.0	28.0	<1.3		42	29	183		396
10/30/07	5.2	465	8.1	26.0	<1.3		38	63	180		416
11/06/07	6.2	412	7.9	24.0	<1.3		39	41	177	46	404
11/13/07	5.9	204	8.2	23.5	<1.3		41	<29	193		456
11/20/07	6.7	423	7.9	22.0	<1.3		50	<29	209		448

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B1. Finish Water Concentrations (Continued)

Test Date (Finish Water)	DO mg/L	ORP mV	pH std. units	Tem P °C	As µg/L	Ca mg/L	Cl mg/L	Total Fe ug/L	SO ₄ mg/L	Alk mg/L	TDS mg/ L
12/11/07	5.6	475	7.9	23.0	<1.3		59	<29	240		512
12/18/07	6.0	164	8.1	22.5	<1.3		68	<29	245		516
12/27/07	6.1	164	8.0	23.0	<1.3		76	72	247		532
01/03/08	6.4	176	8.2	17.0	<1.3		81	0.05	247	36	564
01/08/08	6.1	145	8.1	20.0	<1.3		83	<29	262		588
01/15/08	6.1	125	8.0	23.0	1.8		85	<29	262		568
01/22/08	6.5	-50	7.9	21.5	1.4		85	<29	255		560
01/29/08	6.6	-62	8.0	21.6	4.0		86	<29	249		552
02/05/08	6.3	81	7.9	22.5	<1.3	54	90	<29	248	38	560
02/12/08	6.0	-134	7.9	21.3	<1.3		94	41	256		556
02/19/08	6.8	-289	8.3	22.0	2.0		97	46	269		596
02/26/08	6.4	-283	8.3	23.2	<1.3		94	<29	275		604
03/04/08	6.8	-177	7.8	23.0	<1.3	58	91	<29	295	41	588
03/11/08	6.8	-112	8.2	22.0	<1.3		86	<29	267		608
03/18/08	6.6	-36	7.8	22.5	<1.3		91	<29	254		612
03/25/08	6.2	-25	8.0	22.0	<1.3		82	<29	257		580
04/01/08	6.2	-108	8.1	23.0	<1.3	59	83	<29	266	40	588
04/08/08	5.9	35	8.0	23.7	<1.3		81	<29	257		572
04/15/08	6.7	82	8.2	24.0	<1.3		73	<29	228		500
04/22/08	6.4	197	7.9	24.0	<1.3		69	<29	236		532
04/29/08	6.1	288	8.1	25.0	<1.3		72	<29	257		548
05/06/08	5.7	296	8.0	26.0	<1.3	56	65	<29	248	41	540
05/13/08		353	8.0	26.0	<1.3		60	<29	192		548
05/20/08	6.9	331	8.0	25.4	<1.3		70	<29	226		552
05/27/08	6.6	298	8.2	27.0	<1.3		76	<29	229		564
06/03/08	6.3	311	8.3	29.0	<1.3	55	101	<29	246	48	648
06/10/08	6.1	328	8.1	29.0	<1.3		114	<29	261		648
06/17/08	3.4	362	8.1	29.5	<1.3		117	<29	251		660
06/24/08	3.5	396	7.8	29.0	<1.3		113	<29	255		576
07/01/08	6.4	330	8.1	29.0	<1.3	57	97	<29	271	37	608
07/08/08	5.7	301	8.4	29.0	<1.3		77	<29	269		564
07/15/08	4.9	380	8.1	29.0	<1.3		67	<29	245		532
07/22/08	5.0	320	8.3	29.0	<1.3		59	<29	221		500
07/30/08	5.1	365	8.2	29.0	<1.3		53	<29	199		428
08/05/08	5.1	370	7.9	29.0	<1.3	36	50	<29	184	33	376
08/12/08	6.0	373	7.8	29.5	<1.3		48	<29	170		352
08/20/08	6.3	410	8.0	28.0	<1.3		42	<29	158		356
08/26/08	4.3	366	8.1	29.0	<1.3		37	<29	134		324

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B1. Finish Water Concentrations (Continued)

Test Date (Finish Water)	DO mg/L	ORP mV	pH std. units	Tem P °C	As µg/L	Ca mg/L	Cl mg/L	Total Fe ug/L	SO ₄ mg/L	Alk mg/L	TDS mg/ L
09/16/08	4.2	438	8.2	30.0	<1.3		39	80	159		352
09/23/08	4.4	417	7.9	28.0	<1.3		35	<29	140		332
09/30/08	5.9	48	7.9	27.0	<1.3		35	<29	147		352
10/07/08	5.1	444	7.9	27.0	<1.3	27	39	<29	152	29	336
10/14/08	4.7	397	8.2	27.5	<1.3		36	<29	155		348
10/21/08	4.8	324	8.2	27.5	<1.3		40	<29	163		404
10/28/08	4.7	415	8.3	24.0	<1.3		43	<29	174		376
11/04/08	6.0	398	8.3	23.0	<1.3	37	42	<29	188	34	412
11/10/08	5.0	318	8.3	23.0	<1.3		46	<29	201		432
11/18/08	6.2	397	8.0	21.0	<1.3		47	<29	184		368
11/24/08	7.0	456	8.1	19.5	<1.3		50	<29	197		384
12/01/08	7.6	349	8.0	19.5	<1.3	39	57	<29	204	38	432
12/09/08	6.4	420	8.0	19.0	<1.3		67	<29	221		496
12/16/08	5.6	385	7.9	20.0	<1.3		76	<29	229		532
12/22/08	6.2	291	8.2	22.3	<1.3		80	<29	242		548
12/30/08	6.2	400	8.2	21.0	<1.3		81	<29	238		540
01/06/09	6.5	342	8.0	22.0	<1.3	54	86	<29	252	51	580
01/13/09	5.7	427	8.0	20.0	<1.3		93	<29	259		604
01/20/09	6.3	415	8.1	20.0	<1.3		105	<29	270		644
01/27/09	5.5	435	8.1	20.0	<1.3		98	<29	250		652
02/02/09	6.4	344	8.0	20.0	<1.3	66	113	<29	115	60	668
02/10/09	7.9	289	8.0	21.2	<1.3		133	<29	111		688
02/17/09	4.9	451	8.0	20.0	<1.3		108	<29	116		668
02/24/09	6.5	385	8.1	19.5	<1.3		104	40	111		700
03/03/09	6.5	484	8.2	20.0	<1.3	63	101	<29	108	62	672
03/10/09	6.4	467	8.3	24.5	<1.3		116	<29	111		704
03/17/09	5.6	451	8.0	24.0	<1.3		141	<29	119		732
03/24/09	5.8	531	7.7	23.0	<1.3		154	<29	117		792
03/31/09	6.0	439	8.0	24.0	<1.3		163	<29	124		860
04/07/09	5.3	300	8.1	24.5	<1.3	72	177	<29	114	72	808
04/14/09	5.9	362	8.0	25.0	<1.3		183	<29	114		816
04/21/09	6.2	345	8.1	25.0	<1.3		184	<29	118		800
04/28/09	5.3	415	8.2	25.0	<1.3		178	<29	114		800
05/05/09	6.0	237	8.0	25.6	<1.3	71	180	<29	109	71	824
05/12/09	5.2	301	8.1	27.0	<1.3		177	<29	118		820
05/19/09	6.1	235	8.1	27.0	<1.3		177	<29	113		812
05/26/09	5.8	315	8.2	27.0	<1.3		168	<29	104		784
06/01/09	4.9	345	8.3	28.0	<1.3	79	155	<29	270	57	736

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B1. Finish Water Concentrations (Continued)

Test Date (Finish Water)	DO mg/L	ORP mV	pH std. units	Temp °C	As µg/L	Ca mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	Alk mg/L	TDS mg/L
06/23/09	5.1	475	8.0	30.0	<1.3		86	<29	208		568
06/30/09	4.7	348	8.2	30.0	<1.3		74	<29	196		536
07/07/09	5.0	452	8.1	29.0	<1.3	48	71	<29	196	37	484
07/14/09	5.4	448	8.1	29.0	<1.3		58	<29	172		428
07/21/09	5.2	406	7.8	30.0	<1.3		50	<29	156		396
07/28/09	5.1	487	8.0	30.0	<1.3		43	<29	145		392

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B2. Background Monitor Well Concentrations

Test Date (M-6)	DO mg/L	ORP mv	pH std.units	Temp °C	Cl mg/L	Na mg/L	SO ₄ mg/L	Total Alk mg/L	TDS mg/L	As µg/L
Initial Quality			7.6		169		225		900	
01/01/00										
02/01/00			7.5	25.0	219		294		1000	
03/01/00			7.4	28.1	228		310		907	
04/01/00			7.6	28.5	224		314		930	
05/01/00			7.6	28.5	240		302		930	
06/01/00			7.7	28.7	253		272		1010	
07/01/00			7.7	28.5	268		280		968	
08/01/00			7.8	28.4	248		267		965	
09/01/00			6.9	29.2	285		311		942	
10/01/00			7.1	28.5	212		319		868	
11/01/00			7.5	27.8	213		307		892	
12/01/00			7.1	28.5	218		271		919	
01/01/01			7.7	25.6	221		284		832	
02/01/01			7.5	27.5	225		259		901	
03/01/01			7.5	27.1	230		280		879	
04/01/01			7.4	26.3	229		259		930	
05/01/01			7.4	27.6	242		280		880	
06/01/01			7.8	28.8	220		251		932	
07/01/01			8.2	28.9	215		249		879	
08/01/01			7.3	28.8	229		265		892	
09/05/01			7.4	29.9	227		274	144	880	
10/02/01			7.8	27.1	228		262	144	899	
11/06/01			8.0	26.7	214		290	143	860	
12/01/01			7.6	27.9	222		295	138	947	
01/02/02			7.8	27.0	211		266	137	870	
02/04/02			7.2	25.2	216		256	141	933	
03/04/02			8.0	26.9	230		251	148	877	
04/02/02			7.9	28.4	232		266	145	981	
05/07/02			7.5	27.1	277		268	135	884	
06/04/02			7.5	28.2	244		251	138	852	
07/02/02			7.5	28.4	278		272	125	848	
08/06/02			7.7	25.4	269		284	137	876	
09/03/02			7.6	29.5	258		281	138	944	
10/01/02			7.8	27.8	256		273	140	920	
11/05/02			7.6	29.1	219		244	141	888	
12/03/02			7.6	29.3	208		280	139	892	
01/07/03			7.8	26.4	213		275	139	896	
02/04/03			7.9	25.9	217		237	139	916	
03/04/03			7.5	29.2	227		227	140	900	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B2. Background Monitor Well Concentrations (Continued)

Test Date (M-6)	DO mg/L	ORP mv	pH std.units	Temp °C	Cl mg/L	Na mg/L	SO ₄ mg/L	Total Alk mg/L	TDS mg/L	As µg/L
Initial Quality			7.6		169		225		900	
06/03/03			7.4	28.4	236		253	142	940	
07/01/03			7.4	29.5	233		230	147	856	
08/04/03			7.4	28.8	226		248	142	864	
09/02/03			7.4	27.2	229		256	142	936	
10/01/03			7.4	27.7	195		261	141	944	
11/03/03			7.4	27.3	223		248	147	952	
12/01/03			7.4	27.5	235		258	146	904	
01/05/04			7.3	27.2	230		250	143	880	
02/02/04			7.4	27.0	244		244	145	872	
03/01/04			7.4	26.8	235		249	139	884	
06/01/04			7.5	27.9	222		238	142	980	
07/02/04			7.4	27.8	219		276	141	872	
08/02/04			7.5	26.1	220		257	140	928	
09/01/04			7.5	26.8	231		281	141	876	
10/01/04			7.5	28.2	253		247	143	908	
11/01/04			7.4	28.2	223		235	144	836	
12/08/04			7.4	27.3	245		269	142	916	
01/03/05			7.4	27.7	279		297	138	912	
02/01/05			7.3	28.1	220		251	143	852	
03/01/05			7.3	27.0	233		253	141	832	
04/04/05			7.3	25.9	227		246	140	880	
05/02/05			7.4	27.8	228		249	142	896	<1.3
05/06/05										2.0
05/11/05	1.30	-110	7.4	26.6	220		240	142	884	<1.3
05/13/05										<1.3
05/18/05	1.73	-202	7.3	26.2	227		250	140	904	<1.3
05/20/05										<1.3
05/25/05	1.12	-11	7.3	28.3	220		245	141	896	<1.3
05/27/05										<1.3
06/01/05	2.44	-198	7.4	26.8	221		248	142	924	<1.3
06/03/05										1.7
06/08/05	1.22	-207	7.4	28.7	224		251	143	948	1.6
06/10/05										1.4
06/16/05	0.58	-173	7.4	27.6	226		250	144	868	
06/22/05	0.97	-209	7.4	25.5						<1.3
06/28/05	0.52	-215	7.2	30.5	217		257	141	892	<1.3
07/05/05	0.48	-257	7.3	28.7	224		259	142	948	<1.3
07/13/05	0.96	-230	7.2	27.5	214		250	140	940	<1.3
07/20/05	0.88	-212	7.3	28.3	216		257	140	948	1.9
07/25/05	0.58	-197	7.3	28.2	216		259	144	936	1.3
08/02/05	1.17	-226	7.3	29.3	215		256	140	880	<1.3

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B2. Background Monitor Well Concentrations (Continued)

Test Date (M-6)	DO mg/L	ORP mv	pH std.units	Temp °C	Cl mg/L	Na mg/L	SO ₄ mg/L	Total Alk mg/L	TDS mg/L	As µg/L
Initial Quality			7.6		169		225		900	
08/17/05	0.73	-216	7.4	28.7	218		254	143	856	<1.3
08/24/05	0.63	-196	7.4	27.8	219		257	141	888	<1.3
08/31/05	0.73	-165	7.5	28.3	213		259	142	908	<1.3
09/06/05	0.56	205	7.4	28.2	215		255	142	920	<1.3
09/14/05	0.67	209	7.4	28.0	218		263	143	808	<1.3
09/20/05	0.93	221	7.5	27.9	190		224	144	912	<1.3
10/03/05	0.95	222	7.4	26.4	229		250	140	944	<1.3
10/25/05	0.42	208	7.6	27.6	212		249	143	932	<1.3
11/02/05	0.88	205	7.5	27.6	232		262	141	936	<1.3
11/07/05	0.90	211	7.5	27.6	219		247	144	920	<1.3
11/16/05	0.64	201	7.5	27.9	223		258	141	872	2.9
11/21/05	0.73	-202	7.5	25.5	223		264	140	884	<1.3
11/30/05	0.44	-192	7.5	27.0	214		256	142	952	<1.3
12/05/05	0.75	-190	7.5	27.4	222		254	145	844	1.4
12/14/05	0.53	-187	7.5	26.3	204		242	144	792	<1.3
12/19/05	0.68	-191	7.4	25.8	217		250	142	836	<1.3
01/04/06	0.88	-181	7.6	26.4	214		251	143	876	<1.3
01/11/06	0.95	-213	7.5	27.3	204		251	144	880	<1.3
01/18/06	0.65	-119	7.5	25.8	209		241	146	836	<1.3
01/25/06	0.68	-240	7.4	26.4	186		220	145	872	1.9
02/01/06	0.89	-221	7.6	26.8	162		201	144	860	
02/02/06										1.8
02/07/06	0.69	-293	7.4	24.0	206		257	144	920	3.7
02/15/06	0.80	-233	7.4	26.9	208		264	145	848	<1.3
02/22/06	0.69	-252	7.3	28.2	214		316	146	840	
02/23/06										<1.3
03/01/06	0.97	-239	7.3	27.7	232		250	143	880	<1.3
03/08/06	0.87	-229	7.4	26.7	231		262	146	872	
03/09/06										<1.3
03/13/06	0.68	-264	7.4	28.0	199		232	144	948	
03/14/06										<1.3
03/22/06	0.88	-264	7.4	28.2	201		236	152	908	<1.3
03/29/06	0.80	-330	7.4	27.9	217		249	144	916	<1.3
04/05/06	0.78	-294	7.4	27.9	239		259	143	928	<1.3
04/12/06	0.78	-291	7.4	28.0	231		247	144	876	<1.3
04/19/06	0.83	-280	7.5	27.4	217		254	143	872	<1.3
04/24/06										<1.3
04/26/06	0.63	-330	7.5	28.7	200		258	145	948	2.0
05/01/06										<1.3
05/03/06	0.60	-275	7.7	27.4	221		260	143	956	<1.3
05/08/06										<1.3

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B2. Background Monitor Well Concentrations (Continued)

Test Date (M-6)	DO mg/L	ORP mv	pH std.units	Temp °C	Cl mg/L	Na mg/L	SO ₄ mg/L	Total Alk mg/L	TDS mg/L	As µg/L
Initial Quality			7.6		169		225		900	
05/17/06	0.89	-319	7.5	28.7	209		215	147	960	<1.3
05/22/06										<1.3
05/24/06	0.76	-302	7.5	29.2	195		211	141	936	6.0
06/07/06	0.76	-309	7.6	29.3	217		257	143	1032	
06/13/06										<1.3
06/14/06	0.90	-289	7.7	29.7	230		226	146	956	
06/19/06										<1.3
06/21/06	0.88	-242	7.5	29.4	210		247	140	896	
06/26/06										3.0
06/28/06	0.98	-283	7.7	30.3	230		228	143	892	<1.3
07/03/06	1.45	-278	7.5	26.8	160		238	144	908	<1.3
07/07/06										<1.3
07/10/06										<1.3
07/12/06	1.30	-225	7.6	29.7	211		224	143	932	2.8
07/19/06	0.95	-248	7.5	28.8	209		230	145	908	4.8
07/26/06	0.96	-283	7.5	28.3	192		216	147	920	<1.3
08/02/06	0.90	-371	7.4	28.6	195		223	145	940	
08/03/06										<1.3
08/09/06	0.97	-308	7.4	27.8	207		234	142	1004	<1.3
08/16/06	0.98	-327	7.4	28.0	222		233	144	940	<1.3
08/23/06	1.02	-259	7.4	28.2	221		257	143	848	<1.3
08/29/06	0.99	-304	7.4	27.5	221		251	143	912	3.7
09/05/06	1.10	-344	7.4	28.7	217		251	141	932	
09/06/06										2.2
09/13/06	0.87	-267	7.6	28.1	227		257	142	912	<1.3
09/20/06	0.96	-232	7.4	26.7	225		257	146	912	1.4
09/27/06	1.12	-285	7.3	27.0	229		267	144	444	<1.3
10/04/06	1.28	-233	7.4	26.5	199		263	151	940	<1.3
10/11/06	1.12	-211	7.5	26.4	216		256	140	904	<1.3
10/18/06	1.17	-206	7.6	27.1	230		266	144	872	1.6
10/25/06	0.99	-300	7.5	26.6	230		263	146	904	<1.3
11/01/06	1.12		7.4	27.9	240		257	144	948	2.0
11/06/06	0.94		7.4	28.2	218		265	141	860	
11/08/06										<1.3
11/13/06	0.57	-240	7.5	27.5	220		275	134	856	<1.3
11/20/06	0.80	-175	7.5	26.5	230		267	142	880	<1.3
11/27/06	0.68	-166	7.5	25.6	237		255	145	856	1.6
12/04/06										<1.3
12/06/06	0.73	-214	7.5	27.3	229		252	142	896	<1.3
12/11/06										<1.3
12/13/06	0.81	-272	7.4	25.1	233		261	144	888	<1.3

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B2. Background Monitor Well Concentrations (Continued)

Test Date (M-6)	DO mg/L	ORP mv	pH std.units	Temp °C	Cl mg/L	Na mg/L	SO ₄ mg/L	Total Alk mg/L	TDS mg/L	As µg/L
Initial Quality			7.6		169		225		900	
01/02/07	0.90	-256	7.5	27.3	234	102	259	147	880	<1.3
01/04/07										<1.3
01/08/07										<1.3
01/10/07	0.75	-256	7.6	26.9	227	106	258	142	872	<1.3
01/15/07										<1.3
01/17/07	0.92	-325	7.3	24.1	224	56	259	143	868	<1.3
01/23/07										<1.3
01/25/07	0.54	-244	7.5	26.0	235	254	254	146	892	3.7
01/29/07										3.4
01/31/07	0.91	-248	7.5	26.8	233	111	261	143	928	<1.3
02/05/07										<1.3
02/07/07	0.82	-178	7.6	26.7	249	112	251	144	856	1.5
02/12/07										<1.3
02/14/07	0.79	-219	7.7	27.0	227	106	266	145	836	<1.3
02/19/07										<1.3
02/21/07	0.98	-278	7.5	25.6	236	114	253	145	880	<1.3
02/26/07										<1.3
02/28/07	0.57	-281	7.6	27.8	219	105	265	140	884	<1.3
03/05/07										<1.3
03/07/07	1.16	-277	7.4	27.9	225	98	267	150	892	<1.3
03/12/07										<1.3
03/14/07	0.54	-278	7.4	28.2	226	116	263	150	908	<1.3
03/19/07										<1.3
03/21/07	0.70	-294	7.5	28.0	234	116	260	145	872	<1.3
03/26/07	0.92	-263	7.4	28.1	226	124	261	145	944	<1.3
03/28/07										<1.3
04/02/07										<1.3
04/04/07	0.91	-300	7.4	28.6	235	109	256	147	908	2.5
04/09/07										2.8
04/11/07	0.78	-295	7.4	28.5	234	112	250	147	852	<1.3
04/16/07										<1.3
04/18/07	1.13	-276	7.4	28.5	237	123	252	147	876	<1.3
04/23/07										<1.3
04/25/07	0.62	-293	7.5	28.7	227	113	263	145	880	3.5
05/02/07	1.28	-253	7.5	29.6	240	126	251	145	856	1.9
05/04/07										<1.3
05/07/07										<1.3
05/09/07	2.31	-262	7.5	26.6	236	117	253	140	888	<1.3
05/23/07	0.97	-302	7.4	28.7	218	110	238	142	856	3.6
05/29/07	0.79	-267	7.4	28.7	234	118	248	139	900	
05/31/07										<1.3

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B2. Background Monitor Well Concentrations (Continued)

Test Date (M-6)	DO mg/L	ORP mv	pH std.units	Temp °C	Cl mg/L	Na mg/L	SO ₄ mg/L	Total Alk mg/L	TDS mg/L	As µg/L
Initial Quality			7.6		169		225		900	
06/11/07										<1.3
06/13/07	1.03	-292	7.4	27.2	230	114	254	141	880	
06/14/07										<1.3
06/18/07										<1.3
06/21/07										4.2
06/20/07	0.81	259	7.4	29.8	234	115	252	142	908	
06/25/07										4.8
06/27/07	0.95	-345	7.4	30.1	231	114	259	144	876	<1.3
07/01/07										
07/03/07										1.7
07/05/07	0.75	-261	7.4	29.4	236	114	246	144	888	<1.3
07/11/07	1.06	-287	7.5	29.7	228	121	224	139	868	
07/13/07										<1.3
07/18/07	0.88	-204	7.4	30.5	230	117	263	139	896	<1.3
07/25/07	0.96	-266	7.4	30.2	238	118	276	139	880	<1.3
08/01/07	0.94	-316	7.4	28.3	239	118	251	142	864	<1.3
08/08/07	0.52	-242	7.6	28.2	233	108	256	141	856	<1.3
08/15/07	0.64	-278	7.6	28.1	240	112	260	138	900	<1.3
09/05/07	1.06	-282	7.6	28.8	239	109	252	141	908	<1.3
10/03/07	0.92	-278	7.6	29.6	237	105	249	137	908	<1.3
11/05/07	0.86	-251	7.5	27.0	230	112	244	140	892	<1.3
12/03/07	0.58	-290	7.4	28.5	244	114	243	141	924	<1.3
01/03/08	0.91	-346	7.5	25.6	242	113	246	143	952	<1.3
02/01/08										
02/04/08	0.91	-358	7.3	28.6	243	112	231	140	868	<1.3
03/01/08	0.68	-383	7.3	26.5	251	118	241	141	932	
03/05/08										<1.3
04/01/08										
04/02/08	0.75	-225	7.3	27.5	247	111	240	147	944	1.5
05/05/08	0.90	-321	7.3	28.7	225	110	225	143	848	<1.3
06/04/08	0.81	-288	7.5	29.5	227	119	213	142	912	<1.3
07/07/08	0.63	-260	7.2	29.1	236	117	231	1.5	892	<1.3
08/04/08	0.80	-274	7.3	28.8	238	114	236	143	892	<1.3
09/03/08	0.91	-287	7.3	28.6	231	119	228	143	892	<1.3
12/01/08	1.27	-219	7.6	26.5	234	116	230	148	860	<1.3
01/05/09	0.54	-172	7.5	25.8	236	116	228	143	920	2.0
02/02/09	0.84	-256	7.6	25.6	228	130	223	142	880	<1.3
03/02/09	0.65	-189	7.6	25.5	230	114	216	145	868	<1.3
04/01/09	0.89	-245	7.6	28.8	235	117	234	144	948	<1.3
05/06/09	0.99	-253	7.6	27.7	240	123	234	145	908	<1.3

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B2. Background Monitor Well Concentrations (Continued)

	DO mg/L	ORP mv	pH std.units	Temp °C	Cl mg/L	Na mg/L	SO ₄ mg/L	Total Alk mg/L	TDS mg/L	As µg/L
Model Bkgrd	0.82	-201.0	7.5	28	261	116	262	132	850	1.24E-03
From M-13	Ca									
	69.00									

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates

Date	S-10 (+) mgd	S-10 (-) mgd	S-11 (+) mgd	S-11 (-) mgd	S-12 (+) mgd	S-12 (-) mgd
Jun-02	3.725	0.000	6.936	0.000	2.545	0.000
Jul-02	12.806	-5.939	24.684	-5.869	10.017	-5.802
Aug-02	16.714	0.000	33.496	0.000	12.531	0.000
Sep-02	18.801	0.000	33.537	0.000	14.369	0.000
Oct-02	21.657	0.000	27.744	0.000	18.310	0.000
Nov-02	8.204	0.000	8.428	0.000	8.216	0.000
Dec-02	8.683	0.000	8.803	0.000	8.600	0.000
Jan-03	2.825	0.000	3.104	0.000	2.955	0.000
Feb-03	1.282	0.000	1.176	0.000	1.200	0.000
Mar-03	1.019	-4.439	1.267	-4.315	1.090	-4.481
Apr-03	0.000	-29.285	0.000	-28.914	0.000	-29.777
May-03	0.000	-25.920	0.000	-30.028	0.000	-26.457
Jun-03	2.023	-9.273	1.868	-8.525	2.015	-9.358
Jul-03	14.518	0.000	14.909	0.000	14.681	0.000
Aug-03	14.632	0.000	14.631	0.000	14.505	0.000
Sep-03	14.449	0.000	14.459	0.000	14.179	0.000
Oct-03	10.596	0.000	10.637	0.000	10.527	0.000
Nov-03	11.650	0.000	11.720	0.000	11.638	0.000
Dec-03	1.516	-0.024	1.538	-0.024	1.489	-0.027
Jan-04	3.189	0.000	3.289	0.000	3.163	0.000
Feb-04	0.000	0.000	0.000	0.000	0.000	0.000
Mar-04	6.963	-0.037	7.089	-0.078	6.905	-0.034
Apr-04	0.000	-14.468	0.000	-14.550	0.000	-14.621
May-04	0.000	-26.491	0.000	-26.471	0.000	-26.574
Jun-04	0.000	-15.516	0.000	-15.391	0.000	-15.564
Jul-04	8.446	0.000	8.440	0.000	8.429	0.000
Aug-04	5.089	0.000	5.001	0.000	5.061	0.000
Sep-04	5.430	-0.010	5.541	-0.009	5.383	-0.019
Oct-04	8.653	0.000	8.799	0.000	8.558	0.000
Nov-04	6.858	0.000	6.853	0.000	6.840	0.000
Dec-04	3.098	0.000	3.214	0.000	3.079	0.000
Jan-05	4.730	0.000	4.879	0.000	4.840	0.000
Feb-05	5.252	0.000	5.323	0.000	5.962	0.000
Mar-05	8.794	0.000	8.832	0.000	8.876	0.000
Apr-05	5.597	-1.685	5.542	-1.670	5.621	-1.665
May-05	0.000	-30.765	0.000	-30.664	0.000	-29.405
Jun-05	6.482	-13.726	6.404	-13.825	6.443	-13.449
Jul-05	13.337	0.000	13.230	0.000	13.275	0.000
Aug-05	11.437	0.000	11.473	0.000	11.290	0.000
Sep-05	8.400	0.000	8.457	0.000	8.368	0.000
Oct-05	9.438	0.000	9.309	0.000	9.336	0.000
Nov-05	8.550	0.000	8.438	0.000	8.402	0.000
Dec-05	7.653	0.000	7.617	0.000	7.563	0.000

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-10 (+) mgd	S-10 (-) mgd	S-11 (+) mgd	S-11 (-) mgd	S-12 (+) mgd	S-12 (-) mgd
Jan-06	1.769	0.000	1.779	0.000	1.794	0.000
Feb-06	0.000	0.000	0.000	0.000	0.000	0.000
Mar-06	0.000	0.000	0.000	0.000	0.000	0.000
Apr-06	0.000	-23.334	0.000	-23.287	0.000	-23.397
May-06	0.000	-33.384	0.000	-33.469	0.000	-33.570
Jun-06	0.000	-31.458	0.000	-31.586	0.000	-31.614
Jul-06	0.000	-8.971	0.000	-9.005	0.000	-9.101
Aug-06	13.179	0.000	13.168	0.000	13.071	0.000
Sep-06	16.537	0.000	16.529	0.000	16.322	0.000
Oct-06	4.025	0.000	4.028	0.000	4.013	0.000
Nov-06	0.000	-2.527	0.000	-2.561	0.000	-2.530
Dec-06	0.000	-27.395	0.000	-20.463	0.000	-27.419
Jan-07	0.000	-6.323	0.000	0.000	0.000	-5.755
Feb-07	0.000	-5.235	0.000	0.000	0.000	-5.296
Mar-07	0.000	-15.405	0.000	0.000	0.000	-14.937
Apr-07	0.000	-18.176	0.000	0.000	0.000	-29.770
May-07	0.000	0.000	0.000	0.000	0.000	-30.942
Jun-07	0.000	-10.276	0.000	-1.980	0.000	-21.854
Jul-07	0.000	-2.413	0.000	0.000	0.000	-4.594
Aug-07	0.000	0.000	0.000	0.000	0.000	0.000
Sep-07	0.000	0.000	0.000	0.000	0.000	0.000
Oct-07	0.000	0.000	0.000	0.000	0.000	0.000
Nov-07	0.000	0.000	0.000	0.000	0.000	0.000
Dec-07	0.000	0.000	0.000	0.000	0.000	0.000
Jan-08	0.000	0.000	0.000	0.000	0.000	0.000
Feb-08	0.000	0.000	0.000	0.000	0.000	0.000
Mar-08	0.000	0.000	0.000	0.000	0.000	0.000
Apr-08	8.454	-0.119	4.448	-0.100	7.186	-0.119
May-08	0.000	-9.511	0.000	-5.927	0.000	-9.657
Jun-08	0.000	-7.966	0.000	-7.090	0.000	-11.436
Jul-08	9.234	-0.071	7.678	-0.072	9.129	-0.072
Aug-08	6.450	0.000	4.581	0.000	6.032	0.000
Sep-08	5.679	0.000	6.093	0.000	7.279	0.000
Oct-08	4.543	0.000	4.575	0.000	5.122	0.000
Nov-08	2.703	0.000	2.254	0.000	2.659	0.000
Dec-08	0.159	-11.897	0.114	-10.911	0.135	-12.141
Jan-09	0.000	-19.560	0.000	-15.424	0.000	-19.628
Feb-09	0.000	-2.151	0.000	-5.670	0.000	-5.960
Mar-09	0.000	-21.168	0.000	-19.001	0.000	-31.714
Apr-09	0.000	0.000	0.000	-23.324	0.000	-5.608
May-09	0.000	0.000	0.000	-14.180	0.000	0.000

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

	S-10 (+) mg	S-10 (-) mg	S-11 (+) mg	S-11 (-) mg	S-12 (+) mg	S-12 (-) mg
Total Recharge (mg)	375.228	-434.918	421.914	-404.383	359.003	-514.347
Start Storage Volume (mg)	0.000		0.000		0.000	
End Storage Volume (mg)	-59.690		17.531		-155.344	
Total Recharge (mg)	4844.117					
Total Recovery (mg)	-5539.799					
Net Storage Volume (mg)	-1066.851		PR bal:	15.407± :	-803.583	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-13 (+) mgd	S-13 (-) mgd	S-14 (+) mgd	S-14 (-) mgd	S-15 (+) mgd	S-15 (-) mgd	S-16 (+) mgd	S-16 (-) mgd
Jun-02	3.057	0.000	3.997	0.000	1.982	0.000	2.222	0.000
Jul-02	11.977	-5.754	12.929	-5.996	5.286	-5.854	8.493	-5.890
Aug-02	14.523	0.000	14.206	0.000	4.583	0.000	9.437	0.000
Sep-02	16.849	0.000	17.865	0.000	9.265	0.000	13.284	0.000
Oct-02	20.282	0.000	21.044	0.000	10.582	0.000	19.058	0.000
Nov-02	9.490	0.000	8.238	0.000	6.420	0.000	8.171	0.000
Dec-02	8.671	0.000	8.607	0.000	5.531	0.000	8.360	-8.873
Jan-03	2.945	0.000	2.953	0.000	2.657	0.000	2.850	0.000
Feb-03	1.189	0.000	1.161	0.000	1.177	0.000	1.197	0.000
Mar-03	1.269	-4.450	1.209	-4.442	1.195	-4.498	1.267	-4.463
Apr-03	0.000	-29.051	0.000	-29.577	0.000	-29.546	0.000	-29.754
May-03	0.000	-26.520	0.000	-26.104	0.000	-24.690	0.000	-26.186
Jun-03	2.018	-9.287	1.644	-9.324	1.886	-9.282	1.867	-9.339
Jul-03	14.322	0.000	14.150	0.000	13.189	0.000	14.463	0.000
Aug-03	14.471	0.000	14.705	0.000	13.098	0.000	14.591	0.000
Sep-03	14.374	0.000	14.445	0.000	12.573	0.000	14.306	0.000
Oct-03	10.595	0.000	10.551	0.000	10.412	0.000	10.530	0.000
Nov-03	11.607	0.000	12.053	0.000	11.744	0.000	11.681	0.000
Dec-03	1.489	-0.027	1.500	-0.061	1.501	-0.061	1.471	0.000
Jan-04	3.301	0.000	3.204	0.000	3.238	0.000	3.183	0.000
Feb-04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar-04	7.038	-0.045	7.009	-0.036	7.020	-0.049	6.972	-0.036
Apr-04	0.000	-14.589	0.000	-14.558	0.000	-14.628	0.000	-14.107
May-04	0.000	-26.809	0.000	-26.909	0.000	-26.845	0.000	-26.999
Jun-04	0.000	-15.559	0.000	-15.545	0.000	-15.458	0.000	-14.017
Jul-04	8.438	0.000	8.420	0.000	8.423	0.000	8.480	0.000
Aug-04	5.075	0.000	5.056	0.000	5.012	0.000	5.056	0.000
Sep-04	5.378	-0.009	5.403	-0.009	5.423	-0.009	5.437	-0.008
Oct-04	8.586	0.000	8.587	0.000	9.229	0.000	8.592	0.000
Nov-04	6.822	0.000	6.800	0.000	14.315	0.000	6.615	0.000
Dec-04	3.092	0.000	3.042	0.000	10.345	0.000	4.613	0.000
Jan-05	4.889	0.000	4.783	0.000	13.950	0.000	5.226	0.000
Feb-05	5.281	0.000	5.172	0.000	11.717	0.000	5.303	0.000
Mar-05	8.800	0.000	8.748	0.000	9.541	0.000	8.852	0.000
Apr-05	5.504	-1.675	5.712	-1.663	5.708	-1.538	5.661	-1.673
May-05	0.000	-30.630	0.000	-30.701	0.000	-30.753	0.000	-29.885
Jun-05	6.486	-13.664	6.386	-13.817	6.444	-13.758	6.448	-13.743
Jul-05	13.347	0.000	13.309	0.000	13.308	0.000	13.298	0.000
Aug-05	11.575	0.000	11.239	0.000	11.491	0.000	11.399	0.000
Sep-05	8.471	0.000	8.422	0.000	8.500	0.000	8.409	0.000
Oct-05	9.398	0.000	9.424	0.000	9.398	0.000	9.272	0.000
Nov-05	8.517	0.000	8.435	0.000	8.604	0.000	8.396	0.000
Dec-05	7.667	0.000	7.524	0.000	7.757	0.000	7.477	0.000

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-13 (+) mgd	S-13 (-) mgd	S-14 (+) mgd	S-14 (-) mgd	S-15 (+) mgd	S-15 (-) mgd	S-16 (+) mgd	S-16 (-) mgd
Jan-06	1.880	0.000	1.820	0.000	1.839	0.000	1.836	0.000
Feb-06	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar-06	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr-06	0.000	-23.217	0.000	-23.396	0.000	-23.299	0.000	-22.722
May-06	0.000	-33.455	0.000	-33.498	0.000	-33.388	0.000	-33.414
Jun-06	0.000	-31.599	0.000	-31.590	0.000	-31.690	0.000	-31.600
Jul-06	0.000	-9.026	0.000	-9.115	0.000	-8.964	0.000	-9.130
Aug-06	13.199	0.000	13.216	0.000	13.216	0.000	13.136	0.000
Sep-06	16.520	0.000	16.548	0.000	16.623	0.000	16.480	0.000
Oct-06	4.011	0.000	4.028	0.000	4.051	0.000	4.011	0.000
Nov-06	0.000	-2.503	0.000	-2.517	0.000	-2.529	0.000	-2.541
Dec-06	0.000	-27.284	0.000	-27.320	0.000	-27.640	0.000	-27.817
Jan-07	0.000	-6.306	0.000	-6.568	0.000	-6.111	0.000	-8.775
Feb-07	0.000	-5.680	0.000	-5.323	0.000	5.193	0.000	-7.219
Mar-07	0.000	-15.364	0.000	-15.070	0.000	-15.263	0.000	-14.580
Apr-07	0.000	-29.677	0.000	-29.694	0.000	-29.439	0.000	-30.003
May-07	0.000	-31.077	0.000	-30.820	0.000	-30.889	0.000	-30.960
Jun-07	0.000	-15.809	0.000	-29.763	0.000	-29.960	0.000	-29.982
Jul-07	0.000	-2.453	0.000	-4.596	0.000	-4.582	0.000	-4.635
Aug-07	0.000	0.000	3.580	-0.007	3.580	-0.007	3.597	-0.011
Sep-07	0.000	0.000	30.294	0.000	30.162	0.000	30.156	0.000
Oct-07	0.000	0.000	28.008	0.000	26.921	0.000	28.004	0.000
Nov-07	0.000	0.000	7.681	0.000	7.301	0.000	7.661	0.000
Dec-07	0.000	0.000	0.000	-30.435	0.000	-30.663	0.000	-30.563
Jan-08	0.000	0.000	0.000	-31.932	0.000	-34.150	0.000	-33.925
Feb-08	0.000	0.000	0.000	-10.732	0.000	-10.649	0.000	-10.697
Mar-08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr-08	7.921	-0.117	8.732	-0.119	8.161	-0.118	8.462	-0.119
May-08	0.000	-9.600	0.000	-9.537	0.000	-9.603	0.000	-9.665
Jun-08	0.000	-2.524	0.000	-11.425	0.000	-11.475	0.000	-9.658
Jul-08	9.233	-0.072	9.270	-0.072	9.252	-0.071	9.419	-0.074
Aug-08	6.275	0.000	6.663	0.000	6.120	0.000	6.375	0.000
Sep-08	7.453	0.000	7.575	0.000	7.386	0.000	7.462	0.000
Oct-08	5.048	0.000	5.166	0.000	5.199	0.000	5.149	0.000
Nov-08	2.672	0.000	2.666	0.000	2.664	0.000	2.670	0.000
Dec-08	0.164	-12.129	0.162	-12.396	0.161	-11.669	0.160	-13.426
Jan-09	0.000	-1.132	0.000	-19.858	0.000	-2.820	0.000	-20.529
Feb-09	0.000	0.000	0.000	-5.932	0.000	0.000	0.000	-5.571
Mar-09	0.000	-27.594	0.000	-33.529	0.000	-15.372	0.000	-33.440
Apr-09	0.000	-5.530	0.000	-34.774	0.000	-30.346	0.000	-33.333
May-09	0.000	0.000	0.000	-19.580	0.000	-17.082	0.000	-19.593

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-13 (+) mg	S-13 (-) mg	S-14 (+) mg	S-14 (-) mg	S-15 (+) mg	S-15 (-) mg	S-16 (+) mg	S-16 (-) mg
Total Recharge (mg)	371.169	-470.217	443.341	-648.340	425.140	-589.555	426.515	-658.955
Start Storage Volume (mg)	0.000		0.000		0.000		0.000	
End Storage Volume (mg)	-99.048		-204.999		-164.415		-232.440	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-17 (+) mgd	S-17 (-) mgd	S-18 (+) mgd	S-18 (-) mgd	S-19 (+) mgd	S-19 (-) mgd	S-20 (+) mgd	S-20 (-) mgd
Jun-02	6.724	0.000	2.070	0.000	5.892	0.000	6.174	0.000
Jul-02	24.327	-5.690	8.186	-5.862	23.380	-5.806	22.127	-5.888
Aug-02	35.142	0.000	9.513	0.000	33.718	0.000	28.407	0.000
Sep-02	35.812	0.000	13.241	0.000	34.788	0.000	30.125	0.000
Oct-02	28.301	0.000	19.739	0.000	27.568	0.000	26.534	0.000
Nov-02	8.664	0.000	8.226	0.000	8.438	0.000	8.746	0.000
Dec-02	0.000	0.000	8.553	0.000	8.837	0.000	8.809	0.000
Jan-03	3.092	0.000	2.851	0.000	2.973	0.000	2.973	0.000
Feb-03	1.192	0.000	1.190	0.000	1.164	0.000	1.168	0.000
Mar-03	1.179	-4.677	1.272	-4.487	1.263	-4.443	1.276	-4.499
Apr-03	0.000	-29.917	0.000	-28.662	0.000	-29.331	0.000	-29.808
May-03	0.000	-26.907	0.000	-24.264	0.000	-26.120	0.000	-26.331
Jun-03	1.878	-9.344	1.980	-6.666	1.880	-9.279	1.945	-9.344
Jul-03	15.006	0.000	14.271	0.000	14.130	0.000	14.392	0.000
Aug-03	14.704	0.000	14.777	0.000	14.693	0.000	14.879	0.000
Sep-03	14.397	0.000	14.401	0.000	14.473	0.000	14.432	0.000
Oct-03	10.476	0.000	10.464	0.000	10.677	0.000	10.684	0.000
Nov-03	11.644	0.000	11.599	0.000	11.685	0.000	11.633	0.000
Dec-03	1.500	-0.049	1.466	-0.028	1.499	-0.028	1.475	-0.055
Jan-04	3.332	0.000	3.162	0.000	3.262	0.000	3.255	0.000
Feb-04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar-04	6.980	-0.027	7.010	-0.038	7.086	-0.017	7.004	-0.013
Apr-04	0.000	-14.538	0.000	-14.604	0.000	-14.483	0.000	-14.051
May-04	0.000	-26.907	0.000	-26.638	0.000	-26.725	0.000	-26.686
Jun-04	0.000	-15.672	0.000	-14.817	0.000	-15.394	0.000	-15.496
Jul-04	8.432	0.000	8.412	0.000	8.406	0.000	8.425	0.000
Aug-04	5.043	0.000	5.074	0.000	5.112	0.000	5.008	0.000
Sep-04	5.396	-0.009	5.366	-0.018	5.450	-0.025	5.354	-0.012
Oct-04	8.504	0.000	8.494	0.000	8.687	0.000	8.558	0.000
Nov-04	6.688	0.000	6.530	0.000	6.624	0.000	6.583	0.000
Dec-04	2.981	0.000	3.058	0.000	3.046	0.000	3.063	0.000
Jan-05	4.850	0.000	4.872	0.000	4.879	0.000	4.860	0.000
Feb-05	5.207	0.000	5.196	0.000	5.234	0.000	5.201	0.000
Mar-05	8.796	0.000	8.783	0.000	8.825	0.000	8.767	0.000
Apr-05	5.594	-1.195	5.616	-1.667	5.589	-1.668	5.702	-1.434
May-05	0.000	-30.430	0.000	-30.809	0.000	-29.649	0.000	-30.632
Jun-05	6.432	-13.788	6.433	-12.361	6.409	-13.686	6.429	-13.668
Jul-05	13.290	0.000	13.235	0.000	13.240	0.000	13.281	0.000
Aug-05	11.184	0.000	11.190	0.000	11.269	0.000	11.309	0.000
Sep-05	8.653	0.000	8.408	0.000	8.350	0.000	8.455	0.000
Oct-05	9.257	0.000	9.365	0.000	9.378	0.000	9.271	0.000
Nov-05	8.517	0.000	8.295	0.000	8.460	0.000	8.360	0.000

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-17 (+) mgd	S-17 (-) mgd	S-18 (+) mgd	S-18 (-) mgd	S-19 (+) mgd	S-19 (-) mgd	S-20 (+) mgd	S-20 (-) mgd
Dec-05	7.701	0.000	7.603	0.000	7.572	0.000	7.571	0.000
Jan-06	1.854	0.000	1.819	0.000	1.837	0.000	1.835	0.000
Feb-06	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar-06	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr-06	0.000	-23.498	0.000	-23.321	0.000	-23.347	0.000	-23.449
May-06	0.000	-33.403	0.000	-33.360	0.000	-33.094	0.000	-33.432
Jun-06	0.000	-30.961	0.000	-31.283	0.000	-31.261	0.000	-31.507
Jul-06	0.000	-9.034	0.000	-9.005	0.000	-8.878	0.000	-9.044
Aug-06	13.201	0.000	13.143	0.000	13.208	0.000	13.188	0.000
Sep-06	16.545	0.000	16.469	0.000	16.554	0.000	16.518	0.000
Oct-06	4.010	0.000	3.991	0.000	4.011	0.000	3.994	0.000
Nov-06	0.000	-2.528	0.000	-2.517	0.000	-2.482	0.000	-2.546
Dec-06	0.000	-20.477	0.000	-27.542	0.000	-21.346	0.000	-27.461
Jan-07	0.000	0.000	0.000	-6.474	0.000	-6.776	0.000	-6.077
Feb-07	0.000	0.000	0.000	-5.867	0.000	-5.712	0.000	-5.251
Mar-07	0.000	0.000	0.000	-14.385	0.000	-15.256	0.000	-15.238
Apr-07	0.000	0.000	0.000	-29.834	0.000	-8.696	0.000	-29.883
May-07	0.000	0.000	0.000	-30.928	0.000	0.000	0.000	-31.040
Jun-07	0.000	-1.806	0.000	-21.715	0.000	-1.973	0.000	-29.945
Jul-07	0.000	0.000	0.000	-2.430	0.000	0.000	0.000	-4.608
Aug-07	0.000	0.000	3.621	-0.007	3.614	-0.008	0.000	0.000
Sep-07	0.000	0.000	30.352	0.000	30.704	0.000	0.002	0.000
Oct-07	0.000	0.000	27.992	0.000	27.565	0.000	0.000	0.000
Nov-07	0.000	0.000	7.651	0.000	7.483	0.000	0.000	0.000
Dec-07	0.000	0.000	0.000	-30.182	0.000	-7.098	0.000	0.000
Jan-08	0.000	0.000	0.000	-17.089	0.000	-0.001	0.000	0.000
Feb-08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar-08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr-08	8.610	-0.122	8.703	-0.112	9.117	-0.120	8.906	-0.120
May-08	0.000	-9.734	0.000	-9.531	0.000	-5.923	0.000	-9.597
Jun-08	0.000	-11.492	0.000	-9.622	0.000	0.000	0.000	-8.150
Jul-08	9.262	-0.071	9.218	-0.073	9.312	-0.074	9.190	-0.071
Aug-08	6.233	0.000	6.582	0.000	6.687	0.000	5.924	0.000
Sep-08	7.498	0.000	7.518	0.000	7.607	0.000	5.726	0.000
Oct-08	5.103	0.000	5.053	0.000	5.152	0.000	5.154	0.000
Nov-08	2.668	0.000	2.677	0.000	2.711	0.000	2.699	0.000
Dec-08	0.161	-13.846	0.158	-11.515	0.160	-9.957	0.161	-12.339
Jan-09	0.000	-21.106	0.000	-19.395	0.000	0.000	0.000	-19.938
Feb-09	0.000	-6.081	0.000	-5.432	0.000	0.000	0.000	-2.025
Mar-09	0.000	-29.097	0.000	-30.036	0.000	-4.827	0.000	-27.647
Apr-09	0.000	-17.339	0.000	-14.641	0.000	0.000	0.000	-12.531
May-09	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-17 (+) mg	S-17 (-) mg	S-18 (+) mg	S-18 (-) mg	S-19 (+) mg	S-19 (-) mg	S-20 (+) mg	S-20 (-) mg
Total Recharge (mg)	426.020	-409.745	424.848	-557.217	499.658	-363.483	415.532	-519.816
Start Storage Volume (mg)	0.000		0.000		0.000		0.000	
End Storage Volume (mg)	16.275		-132.369		136.175		-104.284	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-4 (+) mgd	S-4 (-) mgd
Jun-02		
Jul-02		
Aug-02		
Sep-02		
Oct-02		
Nov-02		
Dec-02		
Jan-03		
Feb-03		
Mar-03		
Apr-03		
May-03		
Jun-03		
Jul-03	3.461	0.000
Aug-03	14.547	0.000
Sep-03	12.412	0.000
Oct-03	9.839	0.000
Nov-03	11.573	0.000
Dec-03	1.499	-0.123
Jan-04	2.606	0.000
Feb-04	0.000	0.000
Mar-04	7.000	-0.097
Apr-04	0.000	-1.942
May-04	0.000	-14.983
Jun-04	0.000	-15.517
Jul-04	8.523	0.000
Aug-04	5.191	0.000
Sep-04	5.476	-0.074
Oct-04	8.565	0.000
Nov-04	6.809	0.000
Dec-04	3.112	0.000
Jan-05	4.595	0.000
Feb-05	4.902	0.000
Mar-05	7.503	0.000
Apr-05	4.828	-1.665
May-05	0.000	-30.709
Jun-05	4.770	-13.796
Jul-05	10.526	0.000
Aug-05	11.054	0.000
Sep-05	8.326	0.000
Oct-05	8.958	0.000
Nov-05	8.257	0.000

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-4 (+) mgd	S-4 (-) mgd
Dec-05	7.637	0.000
Jan-06	1.803	0.000
Feb-06	0.000	0.000
Mar-06	0.000	0.000
Apr-06	0.000	-23.375
May-06	0.000	-32.170
Jun-06	0.000	-30.690
Jul-06	0.000	-8.882
Aug-06	13.182	0.000
Sep-06	16.463	0.000
Oct-06	4.011	0.000
Nov-06	0.000	-2.515
Dec-06	0.000	-27.372
Jan-07	0.000	-6.988
Feb-07	0.000	-7.198
Mar-07	0.000	-15.064
Apr-07	0.000	-13.068
May-07	0.000	0.000
Jun-07	0.000	-10.256
Jul-07	0.000	-2.405
Aug-07	0.000	0.000
Sep-07	0.000	0.000
Oct-07	0.000	0.000
Nov-07	0.000	0.000
Dec-07	0.000	0.000
Jan-08	0.000	0.000
Feb-08	0.000	0.000
Mar-08	0.000	0.000
Apr-08	7.280	-0.120
May-08	0.000	-9.554
Jun-08	0.000	-10.172
Jul-08	9.244	-0.060
Aug-08	6.374	0.000
Sep-08	7.474	0.000
Oct-08	5.138	0.000
Nov-08	2.649	0.000
Dec-08	0.162	-11.408
Jan-09	0.000	-19.396
Feb-09	0.000	-5.417
Mar-09	0.000	-24.976
Apr-09	0.000	0.000
May-09	0.000	0.000

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B3. ASR Wells Flow Rates (Continued)

Date	S-4 (+) mgd	S-4 (-) mgd
Total Recharge (mg)	255.749	-339.992
Start Storage Volume (mg)	0.000	
End Storage Volume (mg)	-84.243	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality

Test Date (S-4)	Recharge	Storage	Recovery	Total Mo. Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
07/01/03	x			3.461					
08/01/03	x			14.547			8.2	461	
09/01/03	x			12.412			8.4	387	
10/01/03									
11/01/03	x			11.573			8.2	412	
12/01/03	x						8.3	496	
01/06/04	x			2.606			8.5	541	
02/01/04		x							
03/09/04	x			10.583			8.3	542	
04/14/04			x	-1.942			7.6	592	
05/05/04			x	-14.983					
05/12/04			x						
05/19/04			x				7.5	815	27.1
05/26/04			x				7.6	852	27.9
06/03/04			x	-15.517			7.6	914	27.8
06/09/04			x				7.7	963	28.6
06/16/04			x				7.5	1010	29.0
07/13/04	x			8.523			8.4	684	30.0
08/02/04	x			5.191			8.2	580	30.0
09/13/04	x			5.402			8.5	502	29.0
10/05/04	x			8.565			8.3	388	28.0
11/02/04	x			6.809			8.5	348	26.0
12/09/04	x			3.112			8.2	431	22.5
01/06/05	x			4.595			8.4	480	19.0
02/03/05	x			4.902			8.2	489	19.0
03/01/05	x			7.503			8.2	523	21.5
04/06/05	x			3.163			8.5	449	24.0
04/29/05			x		2.45		8.2	908	24.1
05/03/05			x	-30.709	0.45		8.0	654	24.6
05/05/05			x						
05/09/05			x		0.43		7.9	717	24.9
05/12/05			x						
05/16/05			x		0.33	51	7.8	749	25.4
05/19/05			x						
05/23/05			x		0.27	223	7.8	807	25.7
05/26/05			x						
05/31/05			x			336	7.8	834	24.0
06/02/05			x	-9.026					
06/06/05			x		0.31	-11	7.7	909	27.7

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Recharge	Storage	Recovery	Total Mo. Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
06/14/05			x		0.49	-70	7.7	979	28.0
07/06/05	x			10.526	5.20	458	8.2	491	29.0
07/13/05	x				4.60	384	8.3	458	29.0
07/21/05	x				4.69	450	8.0	423	30.0
07/25/05	x				5.15	513	8.2	405	31.0
08/01/05	x			11.054					
08/02/05	x				3.75	430	8.1	384	30.5
08/09/05	x				4.90	476	8.2	377	30.0
08/16/05	x				5.13	465	8.3	367	30.0
08/22/05	x				4.99	478	8.2	375	31.0
08/29/05	x				4.36	420	8.2	366	30.0
09/07/05	x			8.326	4.22	412	8.2	364	32.0
09/13/05	x				5.20	331	8.7	355	30.0
09/20/05	x				5.41	472	8.1	371	30.0
09/27/05	x				5.19	442	8.2	375	29.0
11/01/05	x			8.257	5.10	524	8.1	395	23.0
11/08/05	x				5.73	513	8.2	388	24.0
11/14/05	x				5.54	449	8.4	373	24.0
11/18/05	x				5.20	453	8.3	372	
12/05/05	x			7.637	6.61	459	8.2	380	24.0
12/12/05	x				6.18	521	8.2	384	20.0
12/20/05	x				6.25	516	8.2	390	20.0
01/04/06	x			1.803	7.17	418	8.3	421	20.0
01/09/06	x				7.14	424	8.3	423	19.0
01/17/06	x				6.39	396	8.4	438	19.0
01/23/06	x				6.82	571	8.4	447	19.5
01/30/06	x				6.53	459	8.2	472	20.0
02/01/06		x							
03/01/06		x							
04/07/06			x	-23.375	0.97	-33	8.0	501	23.2
04/11/06			x		0.35	150	8.0	598	23.5
04/13/06			x						
04/19/06			x		0.81	-84	8.4	579	27.9
04/21/06			x						
04/26/06			x		0.46	-25	7.8	734	27.9
04/28/06			x						
05/01/06			x	-32.170					
05/02/06			x		0.44	-60	8.0	822	28.2
05/04/06			x						
05/09/06			x		0.51	123	7.7	721	26.7
05/11/06			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Recharge	Storage	Recovery	Total Mo. Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
05/19/06			x						
05/23/06			x		0.19	108	7.9	846	27.2
05/25/06			x						
05/30/06			x		0.45	104	7.8	940	30.8
06/01/06			x	-30.690					
06/06/06			x		0.41	-140	7.7	928	30.6
06/12/06			x						
06/13/06			x		0.19	-142	7.8	1065	28.2
06/15/06			x						
06/20/06			x		0.50	-79	7.9	1060	30.2
06/23/06			x						
06/27/06			x		0.36	-187	7.7	1244	29.4
06/29/06			x						
06/30/06			x						
07/05/06			x	-8.882	0.28	-165	7.7	1435	29.3
07/11/06			x						
07/12/06		x							
08/04/06	x			13.182			8.2	720	
09/06/06	x			16.463			8.2	569	
10/03/06	x			4.011			8.1	452	
11/28/06			x	-2.515					
11/29/06			x		0.18	4	7.9	653	27.9
12/01/06			x	-27.372					
12/05/06			x		0.18	82	7.9	776	27.7
12/07/06			x						
12/12/06			x		0.29	157	7.8	875	26.7
12/14/06			x						
12/18/06			x		0.34	83	7.8	936	29.0
12/21/06									
12/27/06			x		0.11	-52	7.9	1053	26.2
12/29/06		x							
01/02/07			x	-6.988	0.16	-104	7.8	1131	28.7
01/05/07			x						
01/09/07			x		0.03	-50	7.8	1085	27.5
01/12/07			x						
01/16/07			x		0.19	-94	7.6	1148	28.3
01/18/07			x						
01/24/00			x		0.11	-137	7.9	1117	28.1
01/26/07			x						
01/29/07			x		0.08	-28	7.8	1169	27.2
02/01/07			x	-7.198					
02/05/07			x		0.02	64	7.7	1368	18.6

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Recharge	Storage	Recovery	Total Mo. Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
02/12/07			x		0.11	82	7.9	1380	22.5
02/17/07			x						
02/20/07			x		0.47	44	7.6	1364	30.3
02/23/07			x						
02/27/07			x		0.25	-69	7.7	1217	29.2
03/01/07			x	-15.064					
03/02/07			x						
03/05/07			x		0.29	104	7.6	1256	28.3
03/08/07			x						
03/13/07			x		0.19	-123	7.8	1250	27.8
03/16/07			x						
03/20/07			x		0.07	-154	7.9	1332	26.3
03/23/07			x						
03/26/07			x		0.28	-175	7.7	1346	28.9
03/28/07			x						
04/02/07			x	-13.068	0.28	-193	7.7	1393	29.1
04/06/07			x						
04/10/07			x		0.13	-226	7.6	1495	28.0
04/13/07			x						
04/17/07			x		0.14	-131	7.6	1856	28.9
05/01/07		x							
06/01/07			x	-10.256					
06/21/08			x						
06/26/07			x		0.27	-185	7.5	2050	29.3
06/28/07			x						
07/01/07			x	-2.405					
07/03/07			x		0.21	-184	7.6	2620	29.2
07/05/07			x						
07/06/07		x							
08/01/07		x							
09/01/07		x							
10/01/07		x							
11/01/07		x							
12/01/07		x							
01/01/08		x							
02/01/08		x							
03/01/08		x							
04/01/08	x			7.280					
04/15/08	x				0.12	48	7.6	1513	25.6
05/01/08	x			9.554					
05/23/08			x		0.37	-96	7.7	968	26.7

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Recharge	Storage	Recovery	Total Mo. Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
05/30/08			x						
06/01/08			x	10.172					
06/02/08			x		1.06	-204	7.4	1204	30.7
06/05/08			x						
06/09/05			x		0.30	-245	7.5	1238	30.4
07/01/08	x			9.244					
07/02/08	x				0.38	-161	7.7	1353	29.8
08/01/08	x			6.374					
09/01/08	x			7.474					
10/01/08	x			5.138					
11/01/08	x			2.649					
12/01/08			x	11.408					
12/02/08			x		0.59	111	8.0	800	22.0
12/08/08			x		0.04	115	8.1	918	24.0
12/15/08			x		0.05	101	8.0	981	26.6
12/22/08			x		0.05	86		1054	25.6
12/29/08			x		0.04	57	8.0	1144	27.2
01/01/09			x	19.369					
01/05/09			x		0.06	-56	7.8	1156	29.8
01/09/09			x						
01/12/09			x		0.10	-14	7.9	1208	26.7
01/16/09			x						
01/21/09			x		0.09	-32	7.8	973	26.9
01/23/09			x						
01/26/09			x		0.66	-100	7.8	1247	27.6
01/29/09			x						
02/01/09			x	5.417					
02/02/09			x		0.62	48	7.8	1323	26.0
02/05/09			x						
02/09/09			x		0.34	-322	7.7	1366	29.0
02/13/09			x						
03/01/09			x	24.976					
03/02/09			x		0.06	-46	7.8	1318	26.5
03/04/09			x						
03/09/09			x		0.33	-156	7.8	1359	25.6
03/16/09			x						
03/19/09			x		0.31	-134	7.7	1478	27.7
03/25/09			x						
03/26/09			x		0.13	-162	7.7	1613	25.9
03/27/09			x						
03/30/09			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L
2/01 Initial Quality		182	BDL	251	952	BDL
07/01/03						
08/01/03		39		109	264	
09/01/03		31		100	260	
10/01/03						
11/01/03		27		106	288	
12/01/03		35		134	280	
01/06/04		37		143	340	
02/01/04						
03/09/04		157		159	344	
04/14/04		46		147	376	
05/05/04						
05/12/04						
05/19/04	82	97	172	196	508	25.0
05/26/04	80	97	200	191	508	26.0
06/03/04	84	120	163	214	556	26.0
06/09/04	86	132	162	200	600	31.0
06/16/04	90	142	226	188	660	48.0
07/13/04	46	66	29	203	420	8.0
08/02/04	42	46	29	157	376	5.1
09/13/04	35	38	29	131	380	3.0
10/05/04	30	28	29	99	248	1.3
11/02/04	30	22	29	85	188	1.3
12/09/04	37	29	29	122	264	2.5
01/06/05	37	31	29	128	260	2.1
02/03/05	34	30	29	122	336	1.3
03/01/05	40	32	29	148	304	1.3
04/06/05	31	27	<29.0	124	276	<1.3
04/29/05	48	28	475	130	340	<1.3
05/03/05		45	44	151	404	5.7
05/05/05						7.4
05/09/05		58	33	165	496	14.4
05/12/05						17.8
05/16/05		65	89	165	484	21.0
05/19/05						24.0
05/23/05	74	77	119	177	512	25.2
05/26/05						21.9
05/31/05		93	166	187	548	21.3
06/02/05						15.8

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L
2/01 Initial Quality		182	BDL	251	952	BDL
06/14/05	89	119	205	200	600	32.4
07/06/05	32	43	<29.0	129	300	<1.3
07/13/05		37	67	116	248	<1.3
07/21/05		31	<29.0	113	268	1.8
07/25/05		29	<29.0	108	252	2.3
08/01/05						
08/02/05	33	27	<29.0	104	216	1.6
08/09/05		26	<29.0	100	200	<1.3
08/16/05		25	<29.0	100	204	<1.3
08/22/05	26	25	55	100	240	<1.3
08/29/05		25	<29.0	99	212	<1.3
09/07/05	26	25	<29.0	99	252	1.7
09/13/05		22	<29.0	100	272	<1.3
09/20/05		26	<29.0	106	340	1.7
09/27/05		23	<29.0	99	224	<1.3
11/01/05		26	31	109	268	<1.3
11/08/05		24	<29.0	107	276	<1.3
11/14/05		23	<29.0	101	248	<1.3
11/18/05		26	<29.0	115	252	2.4
12/05/05		28	<29.0	112	236	<1.3
12/12/05		28	38	120	288	3.6
12/20/05		26	<29.0	111	260	<1.3
01/04/06						
01/09/06						
01/17/06						
01/23/06						
01/30/06						
02/01/06						
03/01/06						
04/07/06		35	574	137	336	6.0
04/11/06		45	73	153	372	10.0
04/13/06						9.0
04/19/06		46	90	157	400	12.0
04/21/06						13.2
04/26/06	67	65	103	159	460	14.3
04/28/06						15.0
05/01/06						
05/02/06		67	105	156	468	16.0
05/04/06						11.0
05/09/06		75	463	180	532	14.0

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L
2/01 Initial Quality		182	BDL	251	952	BDL
05/15/06		74	121	138	568	19.0
05/19/06						17.0
05/23/06		82	169	154	540	18.0
05/25/06						22.1
05/30/06		105	173	182	556	23.2
06/01/06						20.8
06/06/06		117	216	184	660	29.8
06/12/06						34.5
06/13/06	93	123	455	174	708	37.2
06/15/06						34.0
06/20/06		155	199	200	728	45.0
06/23/06						56.0
06/27/06		140	231	272	696	53.0
06/29/06		190	154	223	744	84.3
06/30/06						68.0
07/05/06						43.0
07/11/06						59.0
07/12/06						
08/04/06		64		210	476	
09/06/06		54		162	464	
10/03/06		38		131	316	
11/28/06						
11/29/06	60.5	64	188	159	432	14.0
12/01/06						13.0
12/05/06		86	97	183	460	2.0
12/07/06						3.1
12/12/06		102	111	191	520	9.0
12/14/06						8.0
12/18/06		114	112	200	536	10.0
12/21/06						27.6
12/27/06		140	144	210	616	18.5
12/29/06						25.6
01/02/07		160	367	219	672	18.0
01/05/07						24.3
01/09/07		165	321	220	620	24.7
01/12/07						30.0
01/16/07		167	349	221	676	28.0
01/18/07						26.1
01/24/00		170	332	228	704	24.0
01/26/07						24.2

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L
2/01 Initial Quality		182	BDL	251	952	BDL
01/29/07		174	340	174	748	24.3
02/01/07						15.1
02/05/07		216	353	243	888	9.8
02/08/07						15.8
02/12/07		219	406	250	800	8.7
02/17/07						26.6
02/20/07		212	721	244	872	24.5
02/23/07						58.3
02/27/07		191	356	237	716	38.8
03/01/07						
03/02/07						35.3
03/05/07		191	379	236	692	30.9
03/08/07						31.1
03/13/07		190	263	232	792	28.3
03/16/07						25.9
03/20/07		208	264	237	812	26.3
03/23/07						24.0
03/26/07		215	242	240	820	20.7
03/28/07						36.5
04/02/07		225	284	240	800	43.5
04/06/07						54.2
04/10/07		250	251	235	1072	54.4
04/13/07						60.6
04/17/07		358	365	273	1092	45.7
05/01/07						
06/01/07						
06/21/08						45.9
06/26/07						
06/28/07						74.3
07/01/07						
07/03/07	124	411	300	283	1220	42.0
07/05/07						
07/06/07						
08/01/07						
09/01/07						
10/01/07						
11/01/07						
12/01/07						
01/01/08						
02/01/08						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L
2/01 Initial Quality		182	BDL	251	952	BDL
04/01/08						
04/15/08	106	240	552	221	892	37.3
05/01/08						
05/23/08	72	101	138	225	632	22.9
05/27/08		147	168	251	756	23.9
05/30/08						37.7
06/01/08						
06/02/08	72	202	185	264	820	37.2
06/05/08						35.1
06/09/08	97	223	185	268	876	41.1
07/01/08						
07/02/08	99.5	245	614	260	936	32.6
08/01/08						
09/01/08						
10/01/08						
11/01/08						
12/01/08						
12/02/08	55.5	72	<29	202	484	5.0
12/08/08		90	251	200	532	8.9
12/15/08		102	67	204	540	9.2
12/22/08		116	228	209	658	10.2
12/29/08		126	163	214	612	15.2
01/01/09						
01/05/09	77.5	131	165	92.3	660	14.8
01/09/09						5.5
01/12/09		127	122		612	6.5
01/16/09						8.7
01/21/09		159	273		748	9.9
01/23/09						13.6
01/26/09		168	266		788	16.9
01/29/09						19.0
02/01/09						
02/02/09	94	177	241	227	776	19.0
02/05/09						28.0
02/09/09		197	216	244	756	26.0
02/13/09						23.5
03/01/09						
03/02/09	95.5	189	264	236	772	37.2
03/04/09						15.4

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-4)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L
2/01 Initial Quality		182	BDL	251	952	BDL
03/16/09						14.2
03/19/09		230	208	254	852	29.0
03/25/09						32.8
03/26/09		273	217	248	976	29.0
03/27/09						
03/30/09						
04/01/09						
05/01/09						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. μS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.8		
06/24/02	x				4.70		7.8	708	27.5
07/05/02			x		1.30		7.8	923	27.0
07/11/02			x		3.10		7.5	1190	26.0
08/05/02	x						8.5	565	
08/27/02	x				7.80		8.2	485	30.0
09/03/02	x				7.20		8.0	565	35.0
09/10/02	x				7.40		8.1	446	26.7
09/17/02	x				5.70		8.1	432	25.8
09/24/02	x				5.90		8.2	444	27.6
10/01/02	x				6.00		8.3	423	28.2
10/08/02	x				6.30		8.1	423	27.0
10/15/02	x				6.60		8.0	426	27.6
10/22/02	x				5.70		8.3	462	27.5
10/29/02	x				6.40		8.3	470	28.0
11/05/02	x				5.70		8.1	447	26.5
11/12/02	x				6.50		8.1	471	26.0
11/19/02	x				7.00		8.1	464	23.1
11/26/02	x				7.00		8.4	470	22.3
12/03/02	x				7.70		8.0	464	23.0
12/10/02	x				5.50		8.1	465	20.0
12/18/02	x				5.80		8.3	469	20.0
12/23/02	x				5.80		8.4	451	19.0
12/31/02	x				6.50		8.4	430	19.0
01/07/03	x				8.00		8.5	420	18.5
01/14/03	x				7.50		8.2	410	18.5
01/21/03	x				7.90		8.5	407	17.0
01/28/03	x				9.90		8.2	399	16.0
02/03/03	x				9.20		7.8	394	17.0
02/11/03	x				8.50		8.2	428	18.5
02/18/03	x				5.10		8.2	435	20.0
02/25/03	x				7.90		8.1	447	21.2
03/03/03	x				7.50		8.3	455	22.4
03/11/03	x				5.00		8.3	472	24.1
03/18/03	x				7.20		8.3	474	24.1
03/27/03			x		2.50		8.1	507	24.0
04/01/03			x		2.80		8.0	636	25.0
04/08/03			x		1.50		7.9	653	25.7

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.8		
04/29/03			x		2.10		7.8	864	27.4
05/05/03			x		2.00		7.7	900	29.8
05/14/03			x		2.80		7.7	1023	27.8
05/20/03			x		1.80		7.6	1059	28.5
05/28/03			x		2.00		7.7	1144	27.2
06/02/03			x		2.20		7.5	1196	27.9
07/01/03	x			14.518					
08/01/03	x			14.632			8.2	461	
09/01/03	x			14.449			8.4	387	
10/01/03	x			10.596			8.3	355	
11/01/03	x			11.650			8.2	412	
12/01/03	x			1.492			8.3	496	
01/06/04	x			3.189			8.5	541	
02/01/04		x							
03/09/04	x			6.926	6.05		8.3	542	21.5
04/14/04			x	-14.468			7.8	653	26.8
05/05/04			x	-26.491			7.8	657	27.2
05/12/04			x				7.8	672	27.4
05/19/04			x				7.7	747	27.8
05/26/04			x				7.7	803	28.1
06/03/04			x	-15.516			7.6	864	28.3
06/09/04			x				7.7	936	28.3
06/16/04			x				7.6	987	28.4
07/13/04	x			8.446			8.4	684	30.0
08/02/04	x			5.089			8.2	580	30.0
09/13/04	x			5.420			8.5	502	29.0
10/05/04	x			8.653			8.3	388	28.0
11/02/04	x			6.858			8.5	348	26.0
12/09/04	x			3.098			8.2	431	22.5
01/06/05	x			4.730			8.4	480	19.0
02/03/05	x			5.252			8.2	489	19.0
03/01/05	x			8.794			8.2	523	21.5
04/06/05	x			3.912			8.5	449	24.0
04/29/05			x		3.26		8.1	527	24.2
05/03/05			x	-30.765	0.23		8.0	620	24.0
05/05/05			x						
05/09/05			x		0.26		7.8	674	24.3
05/12/05			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.8		
05/23/05			x		0.26	513	7.9	725	25.5
05/26/05			x						
05/31/05			x			267	7.9	808	25.0
06/02/05			x	-7.244					
06/06/05			x		0.16	52	7.6	862	26.8
06/09/05			x						
06/14/05			x		0.14	58	7.6	963	26.8
07/06/05	x			13.337	5.20	458	8.2	491	29.0
07/13/05	x				4.60	384	8.3	458	29.0
07/21/05	x				4.69	450	8.0	423	30.0
07/25/05	x				5.15	513	8.2	405	31.0
08/01/05	x			11.437					
08/02/05	x				3.75	430	8.1	384	30.5
08/09/05	x				4.90	476	8.2	377	30.0
08/16/05	x				5.13	465	8.3	367	30.0
08/22/05	x				4.99	478	8.2	375	31.0
08/29/05	x				4.36	420	8.2	366	30.0
09/07/05	x			8.400	4.22	412	8.2	364	32.0
09/13/05	x				5.20	331	8.7	355	30.0
09/20/05	x				5.41	472	8.1	371	30.0
09/27/05	x				5.19	442	8.2	375	29.0
11/01/05	x			8.550	5.10	524	8.1	395	23.0
11/08/05	x				5.73	513	8.2	388	24.0
11/14/05	x				5.54	449	8.4	373	24.0
11/18/05	x				5.20	453	8.3	372	
12/05/05	x			7.653	6.61	459	8.2	380	24.0
12/12/05	x				6.18	521	8.2	384	20.0
12/20/05	x				6.25	516	8.2	390	20.0
01/04/06	x			1.769	7.17	418	8.3	421	20.0
01/09/06	x				7.14	424	8.3	423	19.0
01/17/06	x				6.39	396	8.4	438	19.0
01/23/06	x				6.82	571	8.4	447	19.5
01/30/06	x				6.53	459	8.2	472	20.0
02/01/06		x							
03/01/06		x							
04/07/06			x	-23.334	0.73	62	7.9	464	23.1
04/11/06			x		0.08	156	7.9	548	23.9
04/13/06			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.8		
04/26/06			x		0.37	39	7.9	684	28.8
04/28/06			x						
05/01/06			x	-33.384					
05/02/06			x		0.36	-94	8.0	758	29.0
05/04/06			x						
05/09/06			x		0.34	250	7.7	694	26.4
05/11/06			x						
05/15/06			x		0.26	-92	7.8	866	28.6
05/19/06			x						
05/23/06			x		0.15	191	7.7	865	27.1
05/25/06			x						
05/30/06			x		0.28	165	7.6	1009	28.1
06/01/06			x	-31.458					
06/06/06			x		0.32	-152	7.6	1003	29.6
06/12/06			x						
06/13/06			x		0.19	-26	7.5	1113	29.0
06/15/06			x						
06/20/06			x		0.27	101	7.6	1151	28.7
06/23/06			x						
06/27/06			x		0.29	34	7.5	1309	27.6
06/29/06			x						
06/30/06			x						
07/05/06			x	-8.971	0.21	197	7.6	1480	29.2
07/11/06			x						
07/12/06		x							
08/04/06	x			13.179			8.2	720	
09/06/06	x			16.537			8.2	569	
10/03/06	x			4.025			8.1	452	
11/28/06			x	-2.527					
11/29/06			x		0.18	139	7.9	620	26.7
12/01/06			x	-27.395					
12/05/06			x				8.0	729	27.4
12/07/06			x						
12/12/06			x				7.7	829	27.3
12/14/06			x						
12/18/06			x				7.7	952	28.6
12/21/06			x						
12/27/06			x				7.8	1140	27.2

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.8		
12/29/06		x							
01/02/07			x	-6.323	0.17	-67	7.8	1260	27.8
01/05/07			x						
01/09/07			x		0.02	101	7.7	1191	26.9
01/12/07			x						
01/16/07			x		0.18	237	7.7	1258	27.9
01/18/07			x						
01/24/07			x		0.06	38	7.8	1211	28.7
01/26/07			x						
01/29/07			x		0.02	149	7.6	1272	27.1
02/01/07			x	-5.235					
02/05/07			x		0.06	232	7.7	1280	27.0
02/08/07			x						
02/12/07			x		0.10	213	7.7	1316	27.1
02/17/07			x						
02/20/07			x		0.06	219	7.6	1297	28.2
02/23/07			x						
02/27/07			x		0.21	178	7.6	1301	29.1
03/01/07			x	-15.405					
03/02/07			x						
03/05/07			x		0.26	274	7.5	1389	28.7
03/08/07			x						
03/13/07			x		0.03	-132	7.7	1390	27.7
03/16/07			x						
03/20/07			x		0.10	99	7.7	1458	27.6
03/23/07			x						
03/26/07			x		0.23	-164	7.6	1479	29.0
03/28/07			x						
04/02/07			x	-18.176	0.13	-49	7.6	1527	28.4
04/06/07			x						
04/10/07			x		0.06	-92	7.5	1687	27.0
04/13/07			x						
04/17/07			x		0.04	-157	7.5	1711	27.2
05/01/07		x							
06/01/07			x	-10.276					
06/21/07			x						
06/26/07			x		0.10	-83	7.5	2020	28.5
06/28/07			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.8		
07/04/07		x							
08/01/07		x							
09/01/07		x							
10/01/07		x							
11/01/07		x							
12/01/07		x							
01/01/08		x							
02/01/08		x							
03/01/08		x							
04/01/08	x			8.454					
04/15/08	x				0.17	50	7.4	1520	25.0
05/01/08	x			9.511					
05/23/08			x		0.37	228	7.6	993	25.4
05/27/08			x		0.52	59	7.5	1129	29.3
05/30/08			x						
06/01/08			x	7.966					
06/02/08			x		0.87	126	7.5	1275	28.1
06/05/08			x						
06/09/08			x		0.22	182	7.5	1323	28.1
07/01/08	x			9.234					
07/02/08	x				0.26	-31	7.3	1314	28.1
08/01/08	x			6.450					
09/01/08	x			5.679					
10/01/08	x			4.543					
11/01/08	x			2.703					
12/01/08			x	11.897					
12/02/08			x		1.08	87	7.7	793	22.1
12/08/08			x		0.10	44	7.6	902	25.3
12/15/08			x		0.05	235	7.6	988	26.2
12/22/08			x		<0.05	149	7.6	1045	25.9
12/29/08			x		0.03	189	7.5	1141	26.2
01/01/09				19.566					
01/05/09			x		0.03	14	7.8	1162	28.5
01/09/09			x						
01/12/09			x		0.01	153	7.5	1206	27.0
01/16/09			x						
01/21/09			x		0.03	73	7.8	1221	26.7
01/23/09			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. μS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.8		
02/01/09			x	2.151					
02/02/09			x		0.57	-71	7.7	1380	27.0
03/01/09			x	21.168					
03/09/09			x		0.38	-106	7.7	1396	24.4
03/12/09			x						
03/16/09			x		0.53	-140	7.6	1546	26.8
03/19/09			x						
03/25/09			x		0.02	-189	7.5	1773	24.6
03/26/09			x						
04/01/09		x							
05/01/09		x							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		200	35	300	948	BDL	
06/24/02	38	53	35	135	388	<3.0	07/01/03
07/05/02	64	100	37	211	540	11.0	08/01/03
07/11/02	110	162	51	243	828	89.0	09/01/03
08/05/02	34	55		154	356		10/01/03
08/27/02	35	38	132	132	348	1.8	11/01/03
09/03/02	34	38	73	140	304	2.5	12/01/03
09/10/02	31	35	64	124	280	3.7	01/06/04
09/17/02	35	30	61	147	252	1.7	02/01/04
09/24/02	37	34	109	124	268	<1.0	03/09/04
10/01/02	28	33	42	121	276	<1.0	04/14/04
10/08/02	35	27	<30.0	107	308	<1.0	05/05/04
10/15/02	33	26	<30.0	88	260	<1.0	05/12/04
10/22/02	39	29	41	121	300	<1.0	05/19/04
10/29/02	41	33	<30.0	101	528	2.0	05/26/04
11/05/02	40	31	82	106	288	1.1	06/03/04
11/12/02	42	31	53	124	280	<1.0	06/09/04
11/19/02	43	29	25	123	284	<1.0	06/16/04
11/26/02	40	31	63	127	332	<1.0	07/13/04
12/03/02	35	33	<30.0	143	284	<1.0	08/02/04
12/10/02	35	34	<30.0	114	292	<1.0	09/13/04
12/18/02	34	32	<30.0	124	272	<1.0	10/05/04
12/23/02	34	31	<30.0	120	308	<1.0	11/02/04
12/31/02	32	34	72	124	252	2.4	12/09/04
01/07/03	30	28	50	112	236	1.6	01/06/05
01/14/03	28	30	<30.0	104	292	<1.0	02/03/05
01/21/03	32	28	49	98	248	<1.0	03/01/05
01/28/03	34	26	36	99	296	<1.0	04/06/05
02/03/03	29	27	46	94	212	<1.0	04/29/05
02/11/03	32	26	80	100	356	<1.0	05/03/05
02/18/03	36	32	87	103	272	<1.0	05/05/05
02/25/03	32	27	124	92	232	2.7	05/09/05
03/03/03	32	35	57	111	248	<1.0	05/12/05
03/11/03	37	25	<30.0	113	248	<1.0	05/16/05
03/18/03	39	31	37	106	280	<1.0	05/19/05
03/27/03	52	48	38	109	280	5.0	05/23/05
04/01/03	54	58	<6.0	135	364	12.0	05/26/05
04/08/03	64	61	<6.0	142	364	13.0	05/31/05

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		200	35	300	948	BDL	
04/29/03	82	97	40	164	560	36.0	06/09/05
05/05/03	86	105	35	144	564	48.0	06/14/05
05/14/03	92	130	104	157	632	66.0	07/06/05
05/20/03	98	152	89	160	620	76.0	07/13/05
05/28/03	104	157	98	180	676	96.0	07/21/05
06/02/03	106	38	118	167	744	89.0	07/25/05
07/01/03							08/01/05
08/01/03		39		109	264		08/02/05
09/01/03		31		100	260		08/09/05
10/01/03		17		85	236		08/16/05
11/01/03		27		106	288		08/22/05
12/01/03		35		134	280		08/29/05
01/06/04		37		143	340		09/07/05
02/01/04							09/13/05
03/09/04	43	157	30	159	344	1.0	09/20/05
04/14/04	70	66	6	158	420	15.0	09/27/05
05/05/04	62	75	6	140	372	19.0	11/01/05
05/12/04	68	80	22	157	388	25.0	11/08/05
05/19/04	74	85	32	165	456	29.0	11/14/05
05/26/04	70	102	54	168	472	44.0	11/18/05
06/03/04	78	117	87	180	548	54.0	12/05/05
06/09/04	88	130	89	179	612	62.0	12/12/05
06/16/04	92	142	160	188	656	81.0	12/20/05
07/13/04	46	66	29	203	420	8.0	01/04/06
08/02/04	42	46	29	157	376	5.1	01/09/06
09/13/04	35	38	29	131	380	3.0	01/17/06
10/05/04	30	28	29	99	248	1.3	01/23/06
11/02/04	30	22	29	85	188	1.3	01/30/06
12/09/04	37	29	29	122	264	2.5	02/01/06
01/06/05	37	31	29	128	260	2.1	03/01/06
02/03/05	34	30	29	122	336	1.3	04/07/06
03/01/05	40	32	29	148	304	1.3	04/11/06
04/06/05	31	27	<29.0	124	276	<1.3	04/13/06
04/29/05	47	27	<29.0	124	320	1.5	04/19/06
05/03/05		41	<29.0	143	384	4.8	04/21/06
05/05/05						7.2	04/26/06
05/09/05		51	<29.0	152	392	6.9	04/28/06
05/12/05						9.8	05/01/06

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		200	35	300	948	BDL	
05/16/05		56	<29.0	147	412	13.1	05/02/06
05/19/05						15.0	05/04/06
05/23/05	70	69	<29.0	160	468	15.6	05/09/06
05/26/05						19.6	05/11/06
05/31/05		85	53	170	480	24.9	05/15/06
06/02/05						33.3	05/19/06
06/06/05		97	65	178	512	41.5	05/23/06
06/09/05						45.1	05/25/06
06/14/05	90	122	104	191	584	61.0	05/30/06
07/06/05	32	43	<29.0	129	300	<1.3	06/01/06
07/13/05		37	67	116	248	<1.3	06/06/06
07/21/05		31	<29.0	113	268	1.8	06/12/06
07/25/05		29	<29.0	108	252	2.3	06/13/06
08/01/05							06/15/06
08/02/05	33	27	<29.0	104	216	1.6	06/20/06
08/09/05		26	<29.0	100	200	<1.3	06/23/06
08/16/05		25	<29.0	100	204	<1.3	06/27/06
08/22/05	26	25	55	100	240	<1.3	06/29/06
08/29/05		25	<29.0	99	212	<1.3	06/30/06
09/07/05	26	25	<29.0	99	252	1.7	07/05/06
09/13/05		22	<29.0	100	272	<1.3	07/11/06
09/20/05		26	<29.0	106	340	1.7	07/12/06
09/27/05		23	<29.0	99	224	<1.3	08/04/06
11/01/05		26	31	109	268	<1.3	09/06/06
11/08/05		24	<29.0	107	276	<1.3	10/03/06
11/14/05		23	<29.0	101	248	<1.3	11/28/06
11/18/05		26	<29.0	115	252	2.4	11/29/06
12/05/05		28	<29.0	112	236	<1.3	12/01/06
12/12/05		28	38	120	288	3.6	12/05/06
12/20/05		26	<29.0	111	260	<1.3	12/07/06
01/04/06							12/12/06
01/09/06							12/14/06
01/17/06							12/18/06
01/23/06							12/21/06
01/30/06							12/27/06
02/01/06							12/29/06
03/01/06							01/02/07

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		200	35	300	948	BDL	
04/13/06						8.0	01/12/07
04/19/06		41	<29.0	131	356	9.6	01/16/07
04/21/06						10.2	01/18/07
04/26/06	61	58	38	146	400	14.4	01/24/07
04/28/06						13.0	01/26/07
05/01/06							01/29/07
05/02/06		63	50	154	436	13.0	02/01/07
05/04/06						16.0	02/05/07
05/09/06		77	62	169	488	13.0	02/08/07
05/11/06						18.0	02/12/07
05/15/06		77	57	141	536	26.0	02/17/07
05/19/06						33.0	02/20/07
05/23/06		89	125	155	540	41.0	02/23/07
05/25/06						43.2	02/27/07
05/30/06		120	170	192	632	55.2	03/01/07
06/01/06						49.0	03/02/07
06/06/06		168	232	245	708	95.8	03/05/07
06/12/06						89.2	03/08/07
06/13/06	130	132	178	170	740	96.5	03/13/07
06/15/06						79.0	03/16/07
06/20/06		172	185	210	760	84.0	03/20/07
06/23/06						107.0	03/23/07
06/27/06		170	216	213	748	94.0	03/26/07
06/29/06		170		213	788	162.0	03/28/07
06/30/06						77.0	04/02/07
07/05/06						73.0	04/06/07
07/11/06						61.0	04/10/07
07/12/06							04/13/07
08/04/06		64		210	476		04/17/07
09/06/06		54		162	464		05/01/07
10/03/06		38		131	316		06/01/07
11/28/06							06/21/07
11/29/06	56.5	54	67	150	396	12.0	06/26/07
12/01/06						5.0	06/28/07
12/05/06		77		175	476	3.0	07/01/07
12/07/06						<1.3	07/03/07
12/12/06		95		191	524	11.0	07/05/07
12/14/06						10.0	07/06/07

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		200	35	300	948	BDL	
12/27/06		163		216	664	33.4	10/01/07
12/29/06						33.7	11/01/07
01/02/07		194	239	232	748	33.6	12/01/07
01/05/07						34.4	01/01/08
01/09/07		193	233	234	680	33.5	02/01/08
01/12/07						36.0	03/01/08
01/16/07		193	232	233	698	<1.3	04/01/08
01/18/07						43.2	04/15/08
01/24/07		195	240	238	728	31.2	05/01/08
01/26/07						28.5	05/23/08
01/29/07		202	235	239	796	33.6	05/27/08
02/01/07						30.0	05/30/08
02/05/07		200	250	235	808	29.2	06/01/08
02/08/07						22.5	06/02/08
02/12/07		204	277	236	728	25.6	06/05/08
02/17/07						31.6	06/09/08
02/20/07		205	273	240	804	23.6	07/01/08
02/23/07						28.6	07/02/08
02/27/07		211	318	240	768	29.6	08/01/08
03/01/07							09/01/08
03/02/07						28.2	10/01/08
03/05/07		212	307	241	796	20.9	11/01/08
03/08/07						27.5	12/01/08
03/13/07		223	237	235	828	30.4	12/02/08
03/16/07						25.3	12/08/08
03/20/07		240	241	241	872	27.7	12/15/08
03/23/07						23.4	12/22/08
03/26/07		246	236	239	900	22.1	12/29/08
03/28/07						43.6	01/01/09
04/02/07		261	230	243	886	45.3	01/05/09
04/06/07						56.0	01/09/09
04/10/07		294	268	256	1008	43.8	01/12/09
04/13/07						34.5	01/16/09
04/17/07		315	256	266	984	41.7	01/21/09
05/01/07							01/23/09
06/01/07							01/26/09
06/21/07						33.7	01/29/09
06/26/07							02/01/09

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		200	35	300	948	BDL	
07/03/07	123	413	220	273	1212	26.6	02/09/09
07/04/07							02/13/09
08/01/07							03/01/09
09/01/07							03/02/09
10/01/07							03/04/09
11/01/07							03/09/09
12/01/07							03/16/09
01/01/08							03/19/09
02/01/08							03/25/09
03/01/08							03/26/09
04/01/08							03/27/09
04/15/08	115	239	329	216	904	51.4	03/30/09
05/01/08							04/01/09
05/23/08	73	112	68	258	640	37.0	05/01/09
05/27/08		146	133	234	772	31.8	
05/30/08						30.1	
06/01/08							
06/02/08	73	195	157	242	808	27.2	
06/05/08						23.0	
06/09/08		234	184	266	908	26.4	
07/01/08							
07/02/08	109	230	293	254	872	34.6	
08/01/08							
09/01/08							
10/01/08							
11/01/08							
12/01/08							
12/02/08	56	72	<29	203	508	5.8	
12/08/08		90	<29	197	532	13.0	
12/15/08		103	<29	203	548	13.6	
12/22/08		118	72	210	596	16.5	
12/29/08		120	88	205	628	24.3	
01/01/09							
01/05/09	76.5	129	106	218	640	23.7	
01/09/09						7.0	
01/12/09		124	121	217	604	9.3	
01/16/09						12.9	
01/21/09		166	196	236	752	12.3	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-10)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		200	35	300	948	BDL	
01/29/09						18.0	
02/01/09							
02/02/09	102	199	229	244	788	15.9	
03/01/09							
03/09/09		209	169	242	824	16.9	
03/12/09						8.0	
03/16/09		251	177	256	904	16.0	
03/19/09						18.0	
03/25/09		306	161	248	1048		
03/26/09						14.4	
04/01/09							
05/01/09							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.9		
06/24/02	x				4.70		7.8	708	27.5
07/05/02			x		1.10		7.8	875	28.0
07/11/02			x		3.10		7.6	1180	27.5
08/05/02	x						8.5	565	
08/27/02	x				7.80		8.2	485	30.0
09/03/02	x				7.20		8.0	565	35.0
09/10/02	x				7.40		8.1	446	26.7
09/17/02	x				5.70		8.1	432	25.8
09/24/02	x				5.90		8.2	444	27.6
10/01/02	x				6.00		8.3	423	28.2
10/08/02	x				6.30		8.1	423	27.0
10/15/02	x				6.60		8.0	426	27.6
10/22/02	x				5.70		8.3	462	27.5
10/29/02	x				6.40		8.3	470	28.0
11/05/02	x				5.70		8.1	447	26.5
11/12/02	x				6.50		8.1	471	26.0
11/19/02	x				7.00		8.1	464	23.1
11/26/02	x				7.00		8.4	470	22.3
12/03/02	x				7.70		8.0	464	23.0
12/10/02	x				5.50		8.1	465	20.0
12/18/02	x				5.80		8.3	469	20.0
12/23/02	x				5.80		8.4	451	19.0
12/31/02	x				6.50		8.4	430	19.0
01/07/03	x				8.00		8.5	420	18.5
01/14/03	x				7.50		8.2	410	18.5
01/21/03	x				7.90		8.5	407	17.0
01/28/03	x				9.90		8.2	399	16.0
02/03/03	x				9.20		7.8	394	17.0
02/11/03	x				8.50		8.2	428	18.5
02/18/03	x				5.10		8.2	435	20.0
02/25/03	x				7.90		8.1	447	21.2
03/03/03	x				7.50		8.3	455	22.4
03/11/03	x				5.00		8.3	472	24.1
03/18/03	x				7.20		8.3	474	24.1
03/27/03			x		2.40		8.0	582	24.2
04/01/03			x		2.50		7.9	778	6.1
04/08/03			x		1.90		7.7	859	26.9

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.9		
04/29/03			x		2.50		7.8	1061	28.2
05/05/03			x		2.00		7.7	1128	29.9
05/14/03			x		2.20		7.7	1273	28.6
05/20/03			x		2.00		7.7	1336	29.5
05/28/03			x		1.20		7.7	1470	28.4
06/02/03			x		2.30		7.6	1557	28.5
07/01/03	x			14.909					
08/01/03	x			14.631			8.2	461	
09/01/03	x			14.459			8.4	387	
10/01/03	x			10.637			8.3	355	
11/01/03	x			11.720			8.2	412	
12/01/03	x			1.514			8.3	496	
01/06/04	x			3.289			8.5	541	
02/01/04		x							
03/09/04	x			7.011	6.05		8.3	542	21.5
04/14/04			x	-14.550			7.8	805	27.9
05/05/04			x	-26.471			7.8	809	28.1
05/12/04			x				7.7	845	28.0
05/19/04			x				7.7	959	28.5
05/26/04			x				7.6	1050	28.5
06/03/04			x	-15.391			7.6	1190	28.8
06/09/04			x				7.6	1260	28.8
06/16/04			x				7.6	1360	29.0
07/13/04	x			8.440			8.4	684	30.0
08/02/04	x			5.001			8.2	580	30.0
09/13/04	x			5.532			8.5	502	29.0
10/05/04	x			8.799			8.3	388	28.0
11/02/04	x			6.853			8.5	348	26.0
12/09/04	x			3.214			8.2	431	22.5
01/06/05	x			4.879			8.4	480	19.0
02/03/05	x			5.323			8.2	489	19.0
03/01/05	x			8.832			8.2	523	21.5
04/06/05	x			3.872			8.5	449	24.0
04/29/05			x		0.49		8.0	552	24.7
05/03/05			x	-30.664	0.27		7.9	722	25.1
05/05/05			x						
05/09/05			x		0.18		7.8	810	25.7
05/12/05			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.9		
05/23/05			x		0.13	280	7.8	899	26.7
05/26/05			x						
05/31/05			x			253	7.8	988	25.1
06/02/05			x						
06/06/05			x	-7.421	0.12	-28	7.7	1083	27.4
06/09/05			x						
06/14/05			x		0.12	-44	7.7	1206	27.9
07/06/05	x			13.230	5.20	458	8.2	491	29.0
07/13/05	x				4.60	384	8.3	458	29.0
07/21/05	x				4.69	450	8.0	423	30.0
07/25/05	x				5.15	513	8.2	405	31.0
08/01/05	x			11.473					
08/02/05	x				3.75	430	8.1	384	30.5
08/09/05	x				4.90	476	8.2	377	30.0
08/16/05	x				5.13	465	8.3	367	30.0
08/22/05	x				4.99	478	8.2	375	31.0
08/29/05	x				4.36	420	8.2	366	30.0
09/07/05	x			8.457	4.22	412	8.2	364	32.0
09/13/05	x				5.20	331	8.7	355	30.0
09/20/05	x				5.41	472	8.1	371	30.0
09/27/05	x				5.19	442	8.2	375	29.0
11/01/05	x			8.438	5.10	524	8.1	395	23.0
11/08/05	x				5.73	513	8.2	388	24.0
11/14/05	x				5.54	449	8.4	373	24.0
11/18/05	x				5.20	453	8.3	372	
12/05/05	x			7.617	6.61	459	8.2	380	24.0
12/12/05	x				6.18	521	8.2	384	20.0
12/20/05	x				6.25	516	8.2	390	20.0
01/04/06	x			1.779	7.17	418	8.3	421	20.0
01/09/06	x				7.14	424	8.3	423	19.0
01/17/06	x				6.39	396	8.4	438	19.0
01/23/06	x				6.82	571	8.4	447	19.5
01/30/06	x				6.53	459	8.2	472	20.0
02/01/06		x							
03/01/06		x							
04/07/06			x	-23.287	0.61	-10	7.9	486	25.1
04/11/06			x		0.05	76	8.0	647	23.9
04/13/06			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.9		
04/26/06			x		0.37	-64	7.8	822	29.0
04/28/06			x						
05/01/06			x	-33.469					
05/02/06			x		0.39	-134	8.0	981	28.8
05/04/06			x						
05/09/02			x		0.41	110	7.8	918	26.9
05/11/06			x						
05/15/06			x		0.33	-207	7.7	1172	28.8
05/19/06			x						
05/23/06			x		0.15	38	7.8	1198	27.3
05/25/06			x						
05/30/06			x		0.40	93	7.6	1450	29.9
06/01/06			x	-31.586					
06/06/06			x		0.36	-204	7.6	1487	29.7
06/12/06			x						
06/13/06			x		0.25	-110	7.7	1765	28.2
06/15/06			x						
06/20/06			x		0.32	-31	7.6	1759	29.5
06/23/06			x						
06/27/06			x		0.16	-228	7.6	1790	28.9
06/29/06			x						
06/30/06			x						
07/05/06			x	-9.005	0.18	-228	7.6	2420	29.3
07/11/06			x						
07/12/06		x							
08/04/06	x			13.168			8.2	720	
09/06/06	x			16.529			8.2	569	
10/03/06	x			4.028			8.1	452	
11/28/06			x	-2.561					
11/29/06			x		0.12	94	7.9	748	27.3
12/01/06			x	-20.463					
12/05/06			x		0.17	117	7.8	871	27.8
12/07/06			x						
12/12/06			x		0.04	76	7.7	991	27.2
12/14/06			x						
12/18/06			x		0.24	-73	7.7	1145	29.1
12/21/06			x						
12/27/06			x		0.05	-97	7.8	1428	27.1

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.9		
01/05/07		x							
01/09/07		x							
01/12/07		x							
01/16/07		x							
1/018/07		x							
01/24/07		x							
01/26/07		x							
01/29/07		x							
02/01/07		x							
03/01/07		x							
04/01/07		x							
05/01/07		x							
06/01/07			x	-1.980					
06/21/07			x						
07/01/07		x							
08/01/07		x							
09/01/07		x							
10/01/07		x							
11/01/07		x							
12/01/07		x							
01/01/08		x							
02/01/08		x							
03/01/08		x							
04/01/08	x			4.448					
04/15/08	x				0.19	40	7.5	1453	25.1
05/01/08	x			5.927					
05/23/08			x		0.42	257	7.8	862	25.1
05/27/08			x		0.50	27	7.5	1033	29.6
05/30/08			x						
06/01/08			x	7.060					
06/02/08			x		0.98	92	7.4	1262	28.5
06/05/08			x						
06/09/08			x		0.22	-267	7.5	1266	29.1
07/01/08	x			7.678					
07/02/08	x				0.21		7.6	1197	28.6
08/01/08	x			4.581					
09/01/08	x			6.093					
10/01/08	x			4.575					

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.9		
12/02/08			x		1.55	186.1	7.9	727	18.8
12/08/08			x		0.08	55.4	7.9	725	23.0
12/15/08			x		0.03	181.3	7.8	765	26.3
12/22/08			x		<0.05	213.4	7.9	824	25.4
12/29/08			x		0.02	197.3	7.9	911	26.4
01/01/09				15.424					
01/05/09			x		0.03	38.1	8.0	960	28.1
01/09/09			x						
01/12/09			x		0.07	283.2	7.7	1109	26.9
01/16/09			x						
01/21/09			x		0.08	96.4	7.8	1137	26.1
01/23/09			x						
01/26/09			x		0.24	-16.5	7.7	1168	26.0
01/29/09			x						
02/01/09			x	5.670					
02/02/09			x		0.32	-49.5	7.7	1220	26.3
02/05/09			x						
02/09/09			x		0.28	-340.9	7.7	1237	29.0
02/13/09			x						
03/01/09			x	19.001					
03/02/09			x		0.60	-71	7.8	1230	27.6
03/04/09			x						
03/09/09			x		0.39	-151.6	7.6	1257	25.0
03/12/09									
03/16/09			x		0.20	-151.2	7.6	1288	25.2
03/19/09			x						
03/25/09			x		0.14	-93.6	7.6	1254	25.7
03/26/09			x						
03/27/09			x						
03/30/09			x		0.12	-210.5	7.5	1330	24.2
04/03/09			x						
04/08/09			x		0.06	-195.3	7.6	1389	22.6
04/10/09			x						
04/13/09			x		0.35	-209.7	7.6	1347	25.3
04/15/09			x						
04/20/09			x		0.46	-176.2	7.6	1346	26.0
04/23/09			x						
04/27/09			x		0.03	-198.8	7.6	1344	25.9

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. μS/cm	Temp. °C
2/01 Initial Quality					Field	Field	Field	Field	Field
							7.9		
05/08/09			x						
05/11/09			x		0.63	-252.4	7.5	1278	28.1
05/13/09			x						
05/18/09			x		0.47	-302.1	7.7	1279	27.8

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		328	0.1	412	936	BDL	
06/24/02	38	53	35.0	135	388	<3.0	
07/05/02	62	85	<12.0	207	524	6.7	
07/11/02	102	204	244.0	333	740	130.0	
08/05/02	34	55		154	356		
08/27/02	35	38	132.0	132	348	1.8	
09/03/02	34	38	73.0	140	304	2.5	
09/10/02	31	35	64.0	124	280	3.7	
09/17/02	35	30	61.0	147	252	1.7	
09/24/02	37	34	109.0	124	268	<1.0	
10/01/02	28	33	42.0	121	276	<1.0	
10/08/02	35	27	<30.0	107	308	<1.0	
10/15/02	33	26	<30.0	88	260	<1.0	
10/22/02	39	29	41.0	121	300	<1.0	
10/29/02	41	33	<30.0	101	528	2.0	
11/05/02	40	31	82.0	106	288	1.1	
11/12/02	42	31	53.0	124	280	<1.0	
11/19/02	43	29	25.0	123	284	<1.0	
11/26/02	40	31	63.0	127	332	<1.0	
12/03/02	35	33	<30.0	143	284	<1.0	
12/10/02	35	34	<30.0	114	292	<1.0	
12/18/02	34	32	<30.0	124	272	<1.0	
12/23/02	34	31	<30.0	120	308	<1.0	
12/31/02	32	34	72.0	124	252	2.4	
01/07/03	30	28	50.0	112	236	1.6	
01/14/03	28	30	<30.0	104	292	<1.0	
01/21/03	32	28	49.0	98	248	<1.0	
01/28/03	34	26	36.0	99	296	<1.0	
02/03/03	29	27	46.0	94	212	<1.0	
02/11/03	32	26	80.0	100	356	<1.0	
02/18/03	36	32	87.0	103	272	<1.0	
02/25/03	32	27	124.0	92	232	2.7	
03/03/03	32	35	57.0	111	248	<1.0	
03/11/03	37	25	<30.0	113	248	<1.0	
03/18/03	39	31	37.0	106	280	<1.0	
03/27/03	64	40	47.0	128	328	16.0	
04/01/03	76	88	<6.0	150	452	28.0	
04/08/03	80	100	<6.0	165	464	28.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		328	0.1	412	936	BDL	
04/29/03	94	137	215.0	178	652	52.0	
05/05/03	96	157	276.0	178	704	53.0	
05/14/03	104	197	290.0	178	752	57.0	
05/20/03	106	222	242.0	195	780	50.0	
05/28/03	108	265	286.0	185	824	59.0	
06/02/03	112	265	213.0	188	960	40.0	
07/01/03							
08/01/03		39		109	264		
09/01/03		31		100	260		
10/01/03		17		85	236		
11/01/03		27		106	288		
12/01/03		35		134	280		
01/06/04		37		143	340		
02/01/04							
03/09/04	43	157	30.0	159	344	1.0	
04/14/04	80	98	6.0	158	484	32.0	
05/05/04	80	110	99.0	158	496	31.0	
05/12/04	84	110	167.0	183	504	36.0	
05/19/04	88	137	237.0	191	632	37.0	
05/26/04	84	100	291.0	197	620	34.0	
06/03/04	98	197	307.0	236	820	33.0	
06/09/04	96	202	278.0	198	756	34.0	
06/16/04	100	240	323.0	245	836	31.0	
07/13/04	46	66	29.0	203	420	8.0	
08/02/04	42	46	29.0	157	376	5.1	
09/13/04	35	38	29.0	131	380	3.0	
10/05/04	30	28	29.0	99	248	1.3	
11/02/04	30	22	29.0	85	188	1.3	
12/09/04	37	29	29.0	122	264	2.5	
01/06/05	37	31	29.0	128	260	2.1	
02/03/05	34	30	29.0	122	336	1.3	
03/01/05	40	32	29.0	148	304	1.3	
04/06/05	31	27	<29.0	124	276	<1.3	
04/29/05	57	30	<29.0	128	332	5.0	
05/03/05		66	<29.0	161	460	8.0	
05/05/05						10.9	
05/09/05		80	<29.0	169	512	14.5	
05/12/05						19.6	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		328	0.1	412	936	BDL	
05/23/05	79	108	134.0	184	588	25.8	
05/26/05						28.1	
05/31/05		133	220.0	193	604	27.7	
06/02/05						39.5	
06/06/05		150	255.0	202	632	35.3	
06/09/05						37.7	
06/14/05	88	199	327.0	215	764	29.8	
07/06/05	32	43	<29.0	129	300	<1.3	
07/13/05		37	67.0	116	248	<1.3	
07/21/05		31	<29.0	113	268	1.8	
07/25/05		29	<29.0	108	252	2.3	
08/01/05							
08/02/05	33	27	<29.0	104	216	1.6	
08/09/05		26	<29.0	100	200	<1.3	
08/16/05		25	<29.0	100	204	<1.3	
08/22/05	26	25	55.0	100	240	<1.3	
08/29/05		25	<29.0	99	212	<1.3	
09/07/05	26	25	<29.0	99	252	1.7	
09/13/05		22	<29.0	100	272	<1.3	
09/20/05		26	<29.0	106	340	1.7	
09/27/05		23	<29.0	99	224	<1.3	
11/01/05		26	31.0	109	268	<1.3	
11/08/05		24	<29.0	107	276	<1.3	
11/14/05		23	<29.0	101	248	<1.3	
11/18/05		26	<29.0	115	252	2.4	
12/05/05		28	<29.0	112	236	<1.3	
12/12/05		28	38.0	120	288	3.6	
12/20/05		26	<29.0	111	260	<1.3	
01/04/06							
01/09/06							
01/17/06							
01/23/06							
01/30/06							
02/01/06							
03/01/06							
04/07/06		32	<29.0	133	340	16.0	
04/11/06		47	41	135	424	14.7	
04/13/06						14.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		328	0.1	412	936	BDL	
04/26/06	72.5	86	108	172	508	17.4	
04/28/06						21.0	
05/01/06							
05/02/06		96	173	177	552	22.0	
05/04/06						20.0	
05/09/02		134	178	203	640	17.0	
05/11/06						26.0	
05/15/06		145	220	208	740	27.0	
05/19/06						27.0	
05/23/06		169	334	183	776	27.0	
05/25/06						27.9	
05/30/06		223	305	216	852	30.8	
06/01/06						20.8	
06/06/06		270	323	235	1004	30.5	
06/12/06						30.6	
06/13/06	107	275	353	204	1032	24.8	
06/15/06						24.0	
06/20/06		359	312	247	1116	25.0	
06/23/06						26.0	
06/27/06		420	312	297	1220	24.0	
06/29/06		370	245	252	1236	35.0	
06/30/06						30.0	
07/05/06						20.0	
07/11/06						18.0	
07/12/06							
08/04/06		64		210	476		
09/06/06		54		162	464		
10/03/06		38		131	316		
11/28/06							
11/29/06	63.5	89	103	172	484	9.0	
12/01/06						6.0	
12/05/06		112	<29	193	540	6.0	
12/07/06						5.1	
12/12/06		134	141	209	624	16.0	
12/14/06						18.0	
12/18/06		169	285	217	672	19.0	
12/21/06						28.3	
12/27/06		239	355	317	792	17.7	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		328	0.1	412	936	BDL	
01/02/07							
01/05/07							
01/09/07							
01/12/07							
01/16/07							
1/018/07							
01/24/07							
01/26/07							
01/29/07							
02/01/07							
03/01/07							
04/01/07							
05/01/07							
06/01/07							
06/21/07						13.0	
07/01/07							
08/01/07							
09/01/07							
10/01/07							
11/01/07							
12/01/07							
01/01/08							
02/01/08							
03/01/08							
04/01/08							
04/15/08	130	217	130	214	876	6.1	
05/01/08							
05/23/08	61.5	70	<29	236	548	40.6	
05/27/08		123	<29	231	684	57.8	
05/30/08						80.9	
06/01/08							
06/02/08	61.5	243	77	243	836	45.0	
06/05/08						17.6	
06/09/08	115	219	97.3	260	900	13.6	
07/01/08							
07/02/08	123	190	170	242	828	18.6	
08/01/08							
09/01/08							
10/01/08							
11/01/08							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		328	0.1	412	936	BDL	
12/08/08		50	<29	180	412	3.5	
12/15/08		58	<29	181	424	10.3	
12/22/08		71	37.4	188	472	16.3	
12/29/08		78	34	192	476	24.3	
01/01/09							
01/05/09	64.5	85	29.3	196	516	77.7	
01/09/09						27.2	
01/12/09		105	<29	211	552	50.5	
01/16/09						76.8	
01/21/09		137	33.9	225	668	67.2	
01/23/09						80.2	
01/26/09		144	56	228	720	75.6	
01/29/09						80.5	
02/01/09							
02/02/09	99	153	90.9	230	712	62.5	
02/05/09						65.2	
02/09/09		161	97.1	234	688	55.1	
02/13/09						40.6	
03/01/09							
03/02/09	108	164	156	233	736	42.9	
03/04/09						29.8	
03/09/09		165	123	234	760	27.0	
03/12/09						9.8	
03/16/09		171	114	240	752	16.4	
03/19/09						16.9	
03/25/09		172	99.44	240	796		
03/26/09						11.0	
03/27/09						10.0	
03/30/09		176	97.2	238	784	6.8	
04/03/09						3.72	
04/08/09	126	188	81.5	248	820	3.59	
04/10/09						3.8	
04/13/09		188	77.7	236	864	3.8	
04/15/09						2.5	
04/20/09		193	71.9	239	852	1.8	
04/23/09						<1.3	
04/27/09		194	65.6	245	868	2.7	
04/30/09						2.3	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-11)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		328	0.1	412	936	BDL	
05/11/09	128	198	62	234	832	2.3	
05/13/09						1.7	
05/18/09		207	65.1	238	884	1.8	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. μS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							8.1		
06/24/02	x				4.70		7.8	708	27.5
07/05/02			x		1.40		7.9	845	28.0
07/11/02			x		3.10		7.6	1330	27.5
08/05/02	x						8.5	565	
08/27/02	x				7.80		8.2	485	30.0
09/03/02	x				7.20		8.0	565	35.0
09/10/02	x				7.40		8.1	446	26.7
09/17/02	x				5.70		8.1	432	25.8
09/24/02	x				5.90		8.2	444	27.6
10/01/02	x				6.00		8.3	423	28.2
10/08/02	x				6.30		8.1	423	27.0
10/15/02	x				6.60		8.0	426	27.6
10/22/02	x				5.70		8.3	462	27.5
10/29/02	x				6.40		8.3	470	28.0
11/05/02	x				5.70		8.1	447	26.5
11/12/02	x				6.50		8.1	471	26.0
11/19/02	x				7.00		8.1	464	23.1
11/26/02	x				7.00		8.4	470	22.3
12/03/02	x				7.70		8.0	464	23.0
12/10/02	x				5.50		8.1	465	20.0
12/18/02	x				5.80		8.3	469	20.0
12/23/02	x				5.80		8.4	451	19.0
12/31/02	x				6.50		8.4	430	19.0
01/07/03	x				8.00		8.5	420	18.5
01/14/03	x				7.50		8.2	410	18.5
01/21/03	x				7.90		8.5	407	17.0
01/28/03	x				9.90		8.2	399	16.0
02/03/03	x				9.20		7.8	394	17.0
02/11/03	x				8.50		8.2	428	18.5
02/18/03	x				5.10		8.2	435	20.0
02/25/03	x				7.90		8.1	447	21.2
03/03/03	x				7.50		8.3	455	22.4
03/11/03	x				5.00		8.3	472	24.1
03/18/03	x				7.20		8.3	474	24.1
03/27/03			x		2.30		8.3	516	23.8
04/01/03			x		3.70		8.1	651	25.8
04/08/03			x		1.30		7.9	724	26.1
04/15/03			x		2.50		7.8	794	27.0

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							8.1		
05/05/03			x		1.90		7.7	982	29.8
05/14/03			x		2.60		7.7	1056	28.4
05/20/03			x		2.20		7.6	1102	29.6
05/28/03			x		1.60		7.7	1192	28.3
06/02/03			x		2.10		7.6	1190	28.5
07/01/03	x			14.681					
08/01/03	x			14.505			8.2	461	
09/01/03	x			14.179			8.4	387	
10/01/03	x			10.527			8.3	355	
11/01/03	x			11.638			8.2	412	
12/01/03	x			1.462			8.3	496	
01/06/04	x			3.163			8.5	541	
02/01/04		x							
03/09/04	x			6.871	6.05		8.3	542	21.5
04/14/04			x	-14.621			7.9	676	27.2
05/05/04			x	-26.574			7.9	697	27.3
05/12/04			x				7.8	729	27.6
05/19/04			x				7.8	778	28.1
05/26/04			x				7.7	823	28.3
06/03/04			x	-15.564			7.7	870	28.6
06/09/04			x				7.7	925	28.4
06/16/04			x				7.6	956	28.7
07/13/04	x			8.429			8.4	684	30.0
08/02/04	x			5.061			8.2	580	30.0
09/13/04	x			5.364			8.5	502	29.0
10/05/04	x			8.558			8.3	388	28.0
11/02/04	x			6.840			8.5	348	26.0
12/09/04	x			3.079			8.2	431	22.5
01/06/05	x			4.840			8.4	480	19.0
02/03/05	x			5.962			8.2	489	19.0
03/01/05	x			8.876			8.2	523	21.5
04/06/05	x			3.956			8.5	449	24.0
04/29/05			x		3.09		8.2	529	24.5
05/03/05			x	-29.405	0.34		8.0	637	24.3
05/05/05			x						
05/09/05			x		0.14		7.9	707	24.4
05/12/05			x						
05/16/05			x		0.51	191	7.8	701	25.1

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. μS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							8.1		
05/26/05			x						
05/31/05			x			266	7.9	819	25.2
06/02/05			x						
06/06/05			x	-7.006	0.21	143	7.7	844	26.8
06/09/05			x						
06/14/05			x		0.30	-15	7.8	913	27.5
07/06/05	x			13.275	5.20	458	8.2	491	29.0
07/13/05	x				4.60	384	8.3	458	29.0
07/21/05	x				4.69	450	8.0	423	30.0
07/25/05	x				5.15	513	8.2	405	31.0
08/01/05	x			11.290					
08/02/05	x				3.75	430	8.1	384	30.5
08/09/05	x				4.90	476	8.2	377	30.0
08/16/05	x				5.13	465	8.3	367	30.0
08/22/05	x				4.99	478	8.2	375	31.0
08/29/05	x				4.36	420	8.2	366	30.0
09/07/05	x			8.368	4.22	412	8.2	364	32.0
09/13/05	x				5.20	331	8.7	355	30.0
09/20/05	x				5.41	472	8.1	371	30.0
09/27/05	x				5.19	442	8.2	375	29.0
11/01/05	x			8.402	5.10	524	8.1	395	23.0
11/08/05	x				5.73	513	8.2	388	24.0
11/14/05	x				5.54	449	8.4	373	24.0
11/18/05	x				5.20	453	8.3	372	
12/05/05	x			7.563	6.61	459	8.2	380	24.0
12/12/05	x				6.18	521	8.2	384	20.0
12/20/05	x				6.25	516	8.2	390	20.0
01/04/06	x			1.794	7.17	418	8.3	421	20.0
01/09/06	x				7.14	424	8.3	423	19.0
01/17/06	x				6.39	396	8.4	438	19.0
01/23/06	x				6.82	571	8.4	447	19.5
01/30/06	x				6.53	459	8.2	472	20.0
02/01/06		x							
03/01/06		x							
04/07/06			x	-23.397	0.89	49	8.0	474	23.3
04/11/06			x		0.03	234	8.1	564	23.5
04/13/06			x						
04/19/06			x		0.61	-12	8.3	556	27.7
04/21/06			x						
04/26/06			x		0.51	-6	7.8	710	28.5

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. μS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							8.1		
05/02/06			x		0.37	-76	8.0	789	28.7
05/04/06			x						
05/09/06			x		0.43	134	7.9	695	26.5
05/11/06			x						
05/15/06			x		0.34	-104	7.9	833	28.5
05/19/06			x						
05/23/06			x		0.12	193	7.9	807	26.8
05/25/06			x						
05/30/06			x		0.39	180	7.7	910	30.2
06/01/06			x	-31.614					
06/06/06			x		0.36	-164	7.7	890	29.8
06/12/06			x						
06/13/06			x		0.17	-55	7.8	1037	28.2
06/15/06			x						
06/20/06			x		0.40	39	7.7	981	29.3
06/23/06			x						
06/27/06			x		0.18	-194	7.6	1130	29.0
06/29/06			x						
06/30/06			x						
07/05/06			x	-9.101	0.18	-186	7.7	1212	28.6
07/11/06			x						
07/12/06		x							
08/04/06	x			13.071			8.2	720	
09/06/06	x			16.322			8.2	569	
10/03/06	x			4.013			8.1	452	
11/28/06			x	-2.530					
11/29/06			x		0.17	99	8.0	635	27.2
12/01/06			x	-27.419					
12/05/06			x		0.34	97	7.9	742	27.5
12/07/06			x						
12/12/06			x		0.05	112	7.8	832	27.2
12/14/06			x						
12/18/06			x		0.26	-60	7.8	907	28.4
12/21/06			x						
12/27/06			x		0.04	-34	7.8	1027	26.8
12/29/06		x							
01/02/07			x	-5.755	0.09	-95	7.8	1160	28.8
01/05/07			x						
01/09/07			x		0.02	12	7.7	1106	26.8
01/12/07			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. μS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							8.1		
01/24/07			x		0.10	11	7.8	1119	29.0
01/26/07			x						
01/29/07			x		0.03	118	7.8	1168	27.6
02/01/07			x	-5.296					
02/05/07			x		0.02	210	7.7	1209	26.5
02/08/07			x						
02/12/07			x		0.08	216	7.8	1219	27.4
02/17/07			x						
02/20/07			x		0.03	223	7.7	1235	27.2
02/23/07			x						
02/27/07			x		0.18	126	7.6	1202	29.1
03/01/07			x	-14.937					
03/02/07			x						
03/05/07			x		0.24	271	7.6	1253	28.6
03/08/07			x						
03/13/07			x		0.04	-173	7.7	1239	27.2
03/16/07			x						
03/20/07			x		0.03	93	7.7	1280	27.2
03/23/07			x						
03/26/07			x		0.21	-170	7.6	1295	28.5
03/28/07			x						
04/02/07			x	-29.770	0.16	-142	7.7	1290	28.5
04/06/07			x						
04/10/07			x		0.06	-168	7.6	1369	27.4
04/13/07			x						
04/17/07			x		0.05	-225	7.6	1387	27.0
04/20/07			x						
04/23/07			x		0.13	-234	7.6	1476	28.7
04/27/07			x						
05/02/07			x	-30.942	0.28	-200	7.6	1488	28.9
05/04/07			x						
05/08/07			x		0.17	97	7.6	1484	25.8
05/11/07			x						
05/15/07			x		0.20	-228	7.6	1562	28.4
05/18/07			x						
05/22/07			x		0.10	-251	7.4	1591	27.9
05/25/07			x						
05/29/07			x		0.72	-247	7.5	1620	29.0
06/01/07			x	-21.854					
06/04/07			x				7.4	1657	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							8.1		
06/26/07			x		0.18	-272	7.5	1637	28.3
06/28/07			x						
07/01/07			x	-4.594					
07/03/06			x		0.22	-225	7.5	1624	28.8
07/05/07			x		0.24	-265	7.5	1775	29.1
07/06/07			x						
07/07/07		x							
08/01/07		x							
09/01/07		x							
10/01/07		x							
11/01/07		x							
12/01/07		x							
01/01/08		x							
02/01/08		x							
03/01/08		x							
04/01/08	x			7.186					
04/15/08	x				0.14	39	7.5	1568	25.3
05/01/08	x			9.567					
05/23/08			x		0.34	210	7.8	941	25.6
05/27/08			x		0.64	-55	7.5	1104	29.1
05/30/08			x						
06/01/08			x	11.436					
06/02/08			x		0.96	-17	7.4	1227	29.1
06/05/08			x						
06/09/08			x		0.31	-232	7.5	1144	30.2
07/01/08	x			9.129					
07/02/08	x				0.17	-119.5	7.7	1218	29.2
08/01/08	x			6.032					
09/01/08	x			7.279					
10/01/08	x			5.122					
11/01/08	x			2.659					
12/01/08			x	12.141					
12/02/08			x		1.05	28.8	7.9	763	20.0
12/08/08			x		0.07	110.2	7.8	883	23.7
12/15/08			x		0.06	152.1	7.9	943	26.2
12/22/08			x		0.07	147.1	7.8	1018	25.9
12/29/08			x		0.05	180.4	7.8	1140	26.3
01/01/09				19.628					
01/05/09			x		0.04	-12.5	7.8	1152	28.8
01/09/09			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. μS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							8.1		
01/21/09			x		0.12	41.7	7.8	950	25.2
01/23/09			x						
01/26/09			x		0.52	-80.5	7.8	1233	26.3
01/29/09			x						
02/01/09			x	5.960					
02/02/09			x		0.48	55.1	7.8	1282	25.9
02/05/09			x						
02/09/09			x		0.27	-320.9	7.8	1311	29.1
02/13/09			x						
03/01/09			x	31.714					
03/02/09			x		0.04	-38.4	7.8	1222	27.2
03/04/09			x						
03/09/09			x		0.48	-170.4	7.6	1286	25.1
03/12/09									
03/16/09			x		0.37	-136.5	7.7	134	27.4
03/19/09			x						
03/25/09			x		0.23	-206.6	7.6	1488	24.5
03/26/09			x						
03/27/09			x						
03/30/09			x		0.21	-210.4	7.6	1648	24.3
04/01/09		x							
05/01/09		x							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		181	193	226	1070	BDL	
06/24/02	38	53	35	135	388	<3.0	
07/05/02	58	83	<12.0	195	464	14.0	
07/11/02	112	191	<12.0	257	864	41.0	
08/05/02	34	55		154	356		
08/27/02	35	38	132	132	348	1.8	
09/03/02	34	38	73	140	304	2.5	
09/10/02	31	35	64	124	280	3.7	
09/17/02	35	30	61	147	252	1.7	
09/24/02	37	34	109	124	268	<1.0	
10/01/02	28	33	42	121	276	<1.0	
10/08/02	35	27	<30.0	107	308	<1.0	
10/15/02	33	26	<30.0	88	260	<1.0	
10/22/02	39	29	41	121	300	<1.0	
10/29/02	41	33	<30.0	101	528	2.0	
11/05/02	40	31	82	106	288	1.1	
11/12/02	42	31	53	124	280	<1.0	
11/19/02	43	29	25	123	284	<1.0	
11/26/02	40	31	63	127	332	<1.0	
12/03/02	35	33	<30.0	143	284	<1.0	
12/10/02	35	34	<30.0	114	292	<1.0	
12/18/02	34	32	<30.0	124	272	<1.0	
12/23/02	34	31	<30.0	120	308	<1.0	
12/31/02	32	34	72	124	252	2.4	
01/07/03	30	28	50	112	236	1.6	
01/14/03	28	30	<30.0	104	292	<1.0	
01/21/03	32	28	49	98	248	<1.0	
01/28/03	34	26	36	99	296	<1.0	
02/03/03	29	27	46	94	212	<1.0	
02/11/03	32	26	80	100	356	<1.0	
02/18/03	36	32	87	103	272	<1.0	
02/25/03	32	27	124	92	232	2.7	
03/03/03	32	35	57	111	248	<1.0	
03/11/03	37	25	<30.0	113	248	<1.0	
03/18/03	39	31	37	106	280	<1.0	
03/27/03	52	38	27	104	284	7.0	
04/01/03	66	60	<6	145	396	11.0	
04/08/03	74	67	<6	137	380	17.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		181	193	226	1070	BDL	
04/29/03	92	102	95	144	560	50.0	
05/05/03	98	117	98	150	624	55.0	
05/14/03	104	137	77	159	668	54.0	
05/20/03	110	147	82	157	644	50.0	
05/28/03	114	157	66	169	748	49.0	
06/02/03	118	162	55	186	744	42.0	
07/01/03							
08/01/03		39		109	264		
09/01/03		31		100	260		
10/01/03		17		85	236		
11/01/03		27		106	288		
12/01/03		35		134	280		
01/06/04		37		143	340		
02/01/04							
03/09/04	43	157	30	159	344	1.0	
04/14/04	70	70	45	155	428	27.0	
05/05/04	68	90	26	154	400	29.0	
05/12/04	80	82	62	150	424	33.0	
05/19/04	80	92	74	183	488	37.0	
05/26/04	72	122	91	176	456	37.0	
06/03/04	88	110	119	184	560	41.0	
06/09/04	92	135	105	182	612	45.0	
06/16/04	98	135	95	183	612	49.0	
07/13/04	46	66	29	203	420	8.0	
08/02/04	42	46	29	157	376	5.1	
09/13/04	35	38	29	131	380	3.0	
10/05/04	30	28	29	99	248	1.3	
11/02/04	30	22	29	85	188	1.3	
12/09/04	37	29	29	122	264	2.5	
01/06/05	37	31	29	128	260	2.1	
02/03/05	34	30	29	122	336	1.3	
03/01/05	40	32	29	148	304	1.3	
04/06/05	31	27	<29.0	124	276	<1.3	
04/29/05	46	29	70	125	332	1.7	
05/03/05		42	<29.0	142	388	5.0	
05/05/05						4.3	
05/09/05		53	<29.0	154	408	8.4	
05/12/05						10.0	
05/16/05		63	<29.0	162	428	15.9	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		181	193	226	1070	BDL	
05/19/05						20.2	
05/23/05	74	70	52	164	448	23.9	
05/26/05						19.0	
05/31/05		81	88	173	480	30.0	
06/02/05						28.3	
06/06/05		88	94	177	488	31.9	
06/09/05						35.2	
06/14/05	86.0	102	129	187	544	41.6	
07/06/05	31.5	43	<29.0	129	300	<1.3	
07/13/05		37	67	116	248	<1.3	
07/21/05		31	<29.0	113	268	1.8	
07/25/05		29	<29.0	108	252	2.3	
08/01/05							
08/02/05	32.5	27	<29.0	104	216	1.6	
08/09/05		26	<29.0	100	200	<1.3	
08/16/05		25	<29.0	100	204	<1.3	
08/22/05	25.5	25	55	100	240	<1.3	
08/29/05		25	<29.0	99	212	<1.3	
09/07/05	26.0	25	<29.0	99	252	1.7	
09/13/05		22	<29.0	100	272	<1.3	
09/20/05		26	<29.0	106	340	1.7	
09/27/05		23	<29.0	99	224	<1.3	
11/01/05		26	31	109	268	<1.3	
11/08/05		24	<29.0	107	276	<1.3	
11/14/05		23	<29.0	101	248	<1.3	
11/18/05		26	<29.0	115	252	2.4	
12/05/05		28	<29.0	112	236	<1.3	
12/12/05		28	38	120	288	3.6	
12/20/05		26	<29.0	111	260	<1.3	
01/04/06							
01/09/06							
01/17/06							
01/23/06							
01/30/06							
02/01/06							
03/01/06							
04/07/06		32	<29.0	135	312	8.0	
04/11/06		39	<29.0	132	360	6.5	
04/13/06						7.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		181	193	226	1070	BDL	
04/26/06	65	65	56	154	420	13.7	
04/28/06						13.0	
05/01/06							
05/02/06		65	73	151	440	15.0	
05/04/06						13.0	
05/09/06		77	77	175	484	13.0	
05/11/06						22.0	
05/15/06		72	56	143	516	25.0	
05/19/06						27.0	
05/23/06		75	121	152	532	31.0	
05/25/06						32.8	
05/30/06		94	144	183	556	32.8	
06/01/06						22.8	
06/06/06		100	147	188	628	45.2	
06/12/06						51.2	
06/13/06	100	120	167	223	676	57.8	
06/15/06						41.0	
06/20/06		123	137	198	660	55.0	
06/23/06						61.0	
06/27/06		140	131	208	724	58.0	
06/29/06		140	118	203	652	94.0	
06/30/06						71.0	
07/05/06						42.0	
07/11/06						31.0	
07/12/06							
08/04/06		64		210	476		
09/06/06		54		162	464		
10/03/06		38		131	316		
11/28/06							
11/29/06	58	55	61	147	460	10.0	
12/01/06						5.0	
12/05/06		78	66	177	444	5.0	
12/07/06						<1.3	
12/12/06		93	87	191	512	5.0	
12/14/06						7.0	
12/18/06		106	102	198	544	9.0	
12/21/06						21.4	
12/27/06		129	126	207	608	22.4	
12/29/06						35.2	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		181	193	226	1070	BDL	
01/09/07		168	208	229	644	23.4	
01/12/07						30.0	
01/16/07		168	202	227	688	30.0	
01/18/07						32.7	
01/24/07		172	206	230	676	28.9	
01/26/07						23.7	
01/29/07		172	177	229	712	25.8	
02/01/07						22.5	
02/05/07		177	208	231	748	25.2	
02/08/07						16.4	
02/12/07		178	211	231	656	19.4	
02/17/07						25.1	
02/20/07		183	271	233	720	15.6	
02/23/07						21.5	
02/27/07		184	558	232	688	22.5	
03/01/07							
03/02/07						20.9	
03/05/07		181	241	232	716	19.2	
03/08/07						21.4	
03/13/07		179	174	232	732	15.6	
03/16/07						20.8	
03/20/07		186	168	231	780	18.8	
03/23/07						14.5	
03/26/07		193	160	237	820	20.5	
03/28/07						32.1	
04/02/07		192	167	230	760	34.8	
04/06/07						36.6	
04/10/07		208	184	239	804	39.4	
04/13/07						34.9	
04/17/07		221	193	245	772	5.6	
04/20/07						11.2	
04/23/07		244	230	245	836	30.0	
04/27/07						18.3	
05/02/07		258	212	253	828		
05/04/07						50.7	
05/08/07		263	208	253	940	17.7	
05/11/07						17.9	
05/15/07		273	190	258	916	22.0	
05/18/07						21.1	
05/22/07		282	202	259	912	18.7	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		181	193	226	1070	BDL	
06/01/07							
06/04/07		297	188	265	952		
06/12/07			191				
06/21/07						10.6	
06/26/07							
06/28/07						11.8	
07/01/07							
07/03/06	124	285	137	251	996	7.7	
07/05/07		303	154	216	1056	11.4	
07/06/07							
07/07/07							
08/01/07							
09/01/07							
10/01/07							
11/01/07							
12/01/07							
01/01/08							
02/01/08							
03/01/08							
04/01/08							
04/15/08	116	250	214	226	940	15.3	
05/01/08							
05/23/08	70	98	83	260	612	41.5	
05/27/08		145	107	230	758	32.7	
05/30/08						27.3	
06/01/08							
06/02/08	70	199	174	253	804	17.3	
06/05/08						11.9	
06/09/08	109	211	173	343	876	25.1	
07/01/08							
07/02/08	117	201	239	243	820	22.8	
08/01/08							
09/01/08							
10/01/08							
11/01/08							
12/01/08							
12/02/08	54.5	65	<29	200	464	5.4	
12/08/08		82	<29	192	500	10.9	
12/15/08		94	39	197	516	12.4	
12/22/08		112	96	206	572	15.6	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-12)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		181	193	226	1070	BDL	
01/05/09	78	125	121	215	628	24.1	
01/09/09						7.5	
01/12/09		116	88	214	592	10.5	
01/16/09						14.7	
01/21/09		153	165	231	720	12.5	
01/23/09						14.1	
01/26/09		160	171	234	760	15.8	
01/29/09						17.0	
02/01/09							
02/02/09	99	169	184	236	724	14.0	
02/05/09						20.7	
02/09/09		183	187	239	768	17.7	
02/13/09						15.2	
03/01/09							
03/02/09	104	162	183	229	704	20.7	
03/04/09						11.8	
03/09/09		175	141	233	732	13.5	
03/12/09						5.6	
03/16/09		200	135	244	812	5.1	
03/19/09						9.6	
03/25/09		231	128	248	900		
03/26/09						6.2	
03/27/09						6.2	
03/30/09		257	126	239	948	4.5	
04/01/09							
05/01/09							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. µS/cm	Cond. µS/cm	Temp. °C
					Field	Field	Field		Field	Field
2/01 Initial Quality							7.5			
06/24/02	x				4.70		7.8	708		27.5
07/05/02			x		1.30		7.9	835		28.0
07/11/02			x		3.20		7.6	1330		27.5
08/05/02	x						8.5	565		
08/27/02	x				7.80		8.2	485		30.0
09/03/02	x				7.20		8.0	565		35.0
09/10/02	x				7.40		8.1	446		26.7
09/17/02	x				5.70		8.1	432		25.8
09/24/02	x				5.90		8.2	444		27.6
10/01/02	x				6.00		8.3	423		28.2
10/08/02	x				6.30		8.1	423		27.0
10/15/02	x				6.60		8.0	426		27.6
10/22/02	x				5.70		8.3	462		27.5
10/29/02	x				6.40		8.3	470		28.0
11/05/02	x				5.70		8.1	447		26.5
11/12/02	x				6.50		8.1	471		26.0
11/19/02	x				7.00		8.1	464		23.1
11/26/02	x				7.00		8.4	470		22.3
12/03/02	x				7.70		8.0	464		23.0
12/10/02	x				5.50		8.1	465		20.0
12/18/02	x				5.80		8.3	469		20.0
12/23/02	x				5.80		8.4	451		19.0
12/31/02	x				6.50		8.4	430		19.0
01/07/03	x				8.00		8.5	420		18.5
01/14/03	x				7.50		8.2	410		18.5
01/21/03	x				7.90		8.5	407		17.0
01/28/03	x				9.90		8.2	399		16.0
02/03/03	x				9.20		7.8	394		17.0
02/11/03	x				8.50		8.2	428		18.5
02/18/03	x				5.10		8.2	435		20.0
02/25/03	x				7.90		8.1	447		21.2
03/03/03	x				7.50		8.3	455		22.4
03/11/03	x				5.00		8.3	472		24.1
03/18/03	x				7.20		8.3	474		24.1
03/27/03			x		2.50		8.3	526		23.5
04/01/03			x		2.40		8.0	695		25.4
04/08/03			x		1.90		7.8	767		26.3
04/15/03			x		2.30		7.8	814		26.9

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. µS/cm	Cond. µS/cm	Temp. °C
					Field	Field	Field		Field	Field
2/01 Initial Quality							7.5			
05/05/03			x		2.40		7.8	987		31.2
05/14/03			x		2.70		7.7	1080		28.6
05/20/03			x		1.60		7.6	1138		29.5
05/28/03			x		1.80		7.7	1225		28.5
06/02/03			x		2.00		7.6	1223		28.4
07/01/03	x			14.322						
08/01/03	x			14.471			8.2	461		
09/01/03	x			14.374			8.4	387		
10/01/03	x						8.3	355		
11/01/03	x			11.607			8.2	412		
12/01/03	x			1.462			8.3	496		
01/06/04	x			3.301			8.5	541		
02/01/04		x								
03/09/04	x			6.993	6.05		8.3	542		22
04/14/04			x	-14.589			7.9	727		27
05/05/04			x	-26.809			7.9	738		28
05/12/04			x				7.8	762		28
05/19/04			x				7.8	807		28
05/26/04			x				7.7	864		29
06/03/04			x	-15.559			7.7	932		29
06/09/04			x				7.7	970		29
06/16/04			x				7.7	1010		29
07/13/04	x			8.438			8.4	684		30.0
08/02/04	x			5.075			8.2	580		30.0
09/13/04	x			5.369			8.5	502		29.0
10/05/04	x			8.586			8.3	388		28.0
11/02/04	x			6.822			8.5	348		26.0
12/09/04	x			3.092			8.2	431		22.5
01/06/05	x			4.889			8.4	480		19.0
02/03/05	x			5.281			8.2	489		19.0
03/01/05	x			8.800			8.2	523		21.5
04/06/05	x			3.829			8.5	449		24.0
04/29/05			x		2.61		8.2	535		24.3
05/03/05			x	-30.630	0.57		8.0	637		24.3
05/05/05			x							
05/09/05			x		0.12		7.7	742		24.5
05/12/05			x							
05/16/05			x		0.15	125	7.8	754		25.4

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. μS/cm	Cond. μS/cm	Temp. °C
					Field	Field	Field		Field	Field
2/01 Initial Quality							7.5			
05/26/05			x							
05/31/05			x			267	7.9	850		25.1
06/02/05			x							
06/06/05			x	-7.178	0.14	219	7.7	878		27.5
06/09/05			x							
06/14/05			x		0.44	-397	7.8	954		27.7
07/06/05	x			13.347	5.20	458	8.2	491		29.0
07/13/05	x				4.60	384	8.3	458		29.0
07/21/05	x				4.69	450	8.0	423		30.0
07/25/05	x				5.15	513	8.2	405		31.0
08/01/05	x			11.575						
08/02/05	x				3.75	430	8.1	384		30.5
08/09/05	x				4.90	476	8.2	377		30.0
08/16/05	x				5.13	465	8.3	367		30.0
08/22/05	x				4.99	478	8.2	375		31.0
08/29/05	x				4.36	420	8.2	366		30.0
09/07/05	x			8.471	4.22	412	8.2	364		32.0
09/13/05	x				5.20	331	8.7	355		30.0
09/20/05	x				5.41	472	8.1	371		30.0
09/27/05	x				5.19	442	8.2	375		29.0
11/01/05	x			8.517	5.10	524	8.1	395		23.0
11/08/05	x				5.73	513	8.2	388		24.0
11/14/05	x				5.54	449	8.4	373		24.0
11/18/05	x				5.20	453	8.3	372		
12/05/05	x			7.667	6.61	459	8.2	380		24.0
12/12/05	x				6.18	521	8.2	384		20.0
12/20/05	x				6.25	516	8.2	390		20.0
01/04/06	x			1.880	7.17	418	8.3	421		20.0
01/09/06	x				7.14	424	8.3	423		19.0
01/17/06	x				6.39	396	8.4	438		19.0
01/23/06	x				6.82	571	8.4	447		19.5
01/30/06	x				6.53	459	8.2	472		20.0
02/01/06		x								
03/01/06		x								
04/07/06			x	-23.217	0.65	59	8.0	481		23.1
04/11/06			x		0.10	205	8.0	618		23.4
04/13/06			x							
04/19/06			x		0.60	-35	8.3	612		27.7

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. μS/cm	Cond.	Temp. °C
					Field	Field	Field		Field	Field
2/01 Initial Quality							7.5			
04/26/06			x		0.43	-28	7.7	770		28.6
04/28/06			x							
05/01/06			x	-33.455						
05/02/06			x		0.49	-99	7.9	846		29.3
05/04/06			x							
05/09/06			x		0.50	134	7.9	737		27.2
05/11/06			x							
05/15/06			x		0.32	-139	7.7	920		28.7
05/19/06			x							
05/23/06			x		0.11	183	8.0	854		27.1
05/25/06			x							
05/30/06			x		0.41	144	7.8	946		30.3
06/01/06			x	-31.599						
06/06/06			x		0.41	-176	7.7	943		29.7
06/12/06			x							
06/13/06			x		0.17	-100	7.8	1056		28.3
06/15/06			x							
06/20/06			x		0.35	-87	7.8	1030		29.6
06/23/06			x							
06/27/06			x		0.17	-233	7.8	1052		28.9
06/29/06			x							
06/30/06			x							
07/05/06			x	-9.026	0.19	-184	7.7	1294		28.8
07/11/06			x							
07/12/06		x								
08/04/06	x			13.199			8.2	720		
09/06/06	x			16.520			8.2	569		
10/03/06	x			4.011			8.1	452		
11/28/06			x	-2.503						
11/29/06			x		0.22	44	8.0	642		27.8
12/01/06			x	-27.284						
12/05/06			x		0.24	77	7.9	804		28.0
12/07/06			x							
12/12/06			x		0.05	92	7.8	892		26.9
12/14/06			x							
12/18/06			x		0.23	-74	7.9	963		28.7
12/21/06			x							
12/27/06			x		0.04	-30	7.8	1073		26.7

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. µS/cm	Cond.	Temp. °C
					Field	Field	Field		Field	Field
2/01 Initial Quality							7.5			
01/05/07			x							
01/09/07			x		0.03	-33	7.7	1177		27.4
01/12/07			x							
01/16/07			x		0.11	137	7.6	1244		28.9
01/18/07			x							
01/24/07			x		0.10	-70	7.8	1199		29.2
01/26/07			x							
01/29/07			x		0.08	112	7.8	1265		26.7
02/01/07			x	-5.680						
02/05/07			x		0.01	147	7.8	1258		26.3
02/08/07			x							
02/12/07			x		0.06	181	7.7	1303		27.8
02/17/07			x							
02/20/07			x		0.02	148	7.7	1324		26.4
02/23/07			x							
02/27/07			x		0.19	18	7.7	1313		29.3
03/01/07			x	-15.364						
03/02/07			x							
03/05/07			x		0.28	202	7.6	1325		28.9
03/08/07			x							
03/13/07			x		0.06	-222	7.7	1295		27.3
03/16/07			x							
03/20/07			x		0.04	34	7.8	1330		27.0
03/23/07			x							
03/26/07			x		0.21	-196	7.6	1339		28.9
03/28/07			x							
04/02/07			x	-29.677	0.18	-202	7.7	1314		28.7
04/06/07			x							
04/10/07			x		0.08	-205	7.6	1356		28.4
04/13/07			x							
04/17/07			x		0.03	-281	7.6	1398		27.6
04/20/07			x							
04/23/07			x		0.13	-258	7.6	1500		28.8
04/27/07			x							
05/02/07			x	-31.077	0.24	-217	7.7	1534		29.0
05/04/07			x							
05/08/07			x		0.17	96	7.6	1542		27.2
05/11/07			x							
05/15/07			x		0.17	-229	7.6	1607		28.7

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. µS/cm	Cond. µS/cm	Temp. °C
					Field	Field	Field		Field	Field
2/01 Initial Quality							7.5			
05/23/07			x		0.06	-288	7.5	1655		27.9
05/25/07			x							
05/29/07			x		0.18	-258	7.6	1676		29.2
06/01/07			x	-15.809						
06/04/07			x				7.4	1720		
06/21/07			x							
06/26/07			x		0.19	-280	7.5	1880		28.0
06/28/07			x							
07/01/07			x	-0.020						
07/03/07			x		0.35	-219	7.5	1712		30.4
07/06/07			x							
07/07/07		x								
08/01/07		x								
09/01/07		x								
10/01/07		x								
11/01/07		x								
12/01/07		x								
01/01/08		x								
02/01/08		x								
03/01/08		x								
04/01/08	x			7.921						
04/15/08	x				0.16	44	7.5	1546		25.3
05/01/08	x			9.600						
05/23/08			x		0.38	122	7.7	998		25.5
05/27/08			x		0.56	-126	7.5	1163		29.2
05/30/08			x							
06/01/08			x	2.524						
06/02/08			x		1.01	-98	7.4	1319		28.8
07/01/08	x			9.233						
07/02/08	x				0.21	-132.6	7.7	1474		28.9
08/01/08	x			6.275						
09/01/08	x			7.453						
10/01/08	x			5.048						
11/01/08	x			2.672						
12/01/08			x	12.129						
12/02/08			x		0.98	92.6	7.96	802		20.8
12/08/08			x		0.03	98.1	7.81	986		22.9
12/15/08			x		0.73	99.6	7.83	1053		26.3
12/22/08			x		0.10	120.3	7.85	1157		25.6

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. µS/cm	Cond.	Temp. °C
					Field	Field	Field		Field	Field
2/01 Initial Quality							7.5			
01/05/09			x		0.05	-39	7.8	1306		28.7
02/01/09		x								
03/01/09			x	27.594						
03/09/09			x		0.36	-161.4	7.7	1466		25.8
03/12/09			x							
03/16/09			x		0.37	-137.7	7.7	1474		27.6
03/19/09			x							
03/25/09			x		0.08	-198.2	7.6	1600		24.6
03/26/09			x							
03/27/09			x							
03/30/09			x		0.16	-204.2	7.6	17200		24.2
04/01/09		x								
05/01/09		x								

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		167	BDL			255	950	BDL	
06/24/02	38	53	35			135	388	<3.0	
07/05/02	58	82	<12.0			193	476	17.0	
07/11/02	112	191	<12.0			257	864	41.0	
08/05/02	34	55				154	356		
08/27/02	35	38	132			132	348	1.8	
09/03/02	34	38	73			140	304	2.5	
09/10/02	31	35	64			124	280	3.7	
09/17/02	35	30	61			147	252	1.7	
09/24/02	37	34	109			124	268	<1.0	
10/01/02	28	33	42			121	276	<1.0	
10/08/02	35	27	<30.0			107	308	<1.0	
10/15/02	33	26	<30.0			88	260	<1.0	
10/22/02	39	29	41			121	300	<1.0	
10/29/02	41	33	<30.0			101	528	2.0	
11/05/02	40	31	82			106	288	1.1	
11/12/02	42	31	53			124	280	<1.0	
11/19/02	43	29	25			123	284	<1.0	
11/26/02	40	31	63			127	332	<1.0	
12/03/02	35	33	<30.0			143	284	<1.0	
12/10/02	35	34	<30.0			114	292	<1.0	
12/18/02	34	32	<30.0			124	272	<1.0	
12/23/02	34	31	<30.0			120	308	<1.0	
12/31/02	32	34	72			124	252	2.4	
01/07/03	30	28	50			112	236	1.6	
01/14/03	28	30	<30.0			104	292	<1.0	
01/21/03	32	28	49			98	248	<1.0	
01/28/03	34	26	36			99	296	<1.0	
02/03/03	29	27	46			94	212	<1.0	
02/11/03	32	26	80			100	356	<1.0	
02/18/03	36	32	87			103	272	<1.0	
02/25/03	32	27	124			92	232	2.7	
03/03/03	32	35	57			111	248	<1.0	
03/11/03	37	25	<30.0			113	248	<1.0	
03/18/03	39	31	37			106	280	<1.0	
03/27/03	54	40	31			118	292	7.0	
04/01/03	70	72	<6.0			140	400	17.0	
04/08/03	74	75	<6.0			145	428	19.0	
04/15/03	78	90	68			163	520	25.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		167	BDL			255	950	BDL	
05/05/03	92	120	108			172	600	45.0	
05/14/03	102	135	107			162	676	51.0	
05/20/03	106	157	89			174	660	46.0	
05/28/03	110	170	102			194	732	51.0	
06/02/03	114	162	61			194	804	41.0	
07/01/03									
08/01/03		39				109	264		
09/01/03		31				100	260		
10/01/03		17				85	236		
11/01/03		27				106	288		
12/01/03		35				134	280		
01/06/04		37				143	340		
02/01/04									
03/09/04	43	157	30			159	344	1.0	
04/14/04	76	76	28			160	460	20.0	
05/05/04	76	82	71			159	444	20.0	
05/12/04	76	87	77			157	456	18.0	
05/19/04	80	100	102			184	484	19.0	
05/26/04	78	87	119			185	520	19.0	
06/03/04	88	130	128			189	584	22.0	
06/09/04	90	135	124			186	612	27.0	
06/16/04	96	145	117			224	676	31.0	
07/13/04	46	66	29			203	420	8.0	
08/02/04	42	46	29			157	376	5.1	
09/13/04	35	38	29			131	380	3.0	
10/05/04	30	28	29			99	248	1.3	
11/02/04	30	22	29			85	188	1.3	
12/09/04	37	29	29			122	264	2.5	
01/06/05	37	31	29			128	260	2.1	
02/03/05	34	30	29			122	336	1.3	
03/01/05	40	32	29			148	304	1.3	
04/06/05	31	27	<29.0			124	276	<1.3	
04/29/05	49	29	<29.0			129	336	1.8	
05/03/05		49	<29.0			149	424	6.2	
05/05/05								7.1	
05/09/05		62	<29.0			161	428	12.0	
05/12/05								14.1	
05/16/05		70	53			164	472	15.5	
05/19/05								25.7	
05/23/05	74	78	73			172	504	16.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		167	BDL			255	950	BDL	
06/02/05								21.5	
06/06/05		94	114			184	548	27.6	
06/09/05								20.4	
06/14/05	90	119	170			202	592	32.7	
07/06/05	31.5	43	<29.0			129	300	<1.3	
07/13/05		37	67			116	248	<1.3	
07/21/05		31	<29.0			113	268	1.8	
07/25/05		29	<29.0			108	252	2.3	
08/01/05									
08/02/05	32.5	27	<29.0			104	216	1.6	
08/09/05		26	<29.0			100	200	<1.3	
08/16/05		25	<29.0			100	204	<1.3	
08/22/05	25.5	25	55			100	240	<1.3	
08/29/05		25	<29.0			99	212	<1.3	
09/07/05	26.0	25	<29.0			99	252	1.7	
09/13/05		22	<29.0			100	272	<1.3	
09/20/05		26	<29.0			106	340	1.7	
09/27/05		23	<29.0			99	224	<1.3	
11/01/05		26	31			109	268	<1.3	
11/08/05		24	<29.0			107	276	<1.3	
11/14/05		23	<29.0			101	248	<1.3	
11/18/05		26	<29.0			115	252	2.4	
12/05/05		28	<29.0			112	236	<1.3	
12/12/05		28	38			120	288	3.6	
12/20/05		26	<29.0			111	260	<1.3	
01/04/06									
01/09/06									
01/17/06									
01/23/06									
01/30/06									
02/01/06									
03/01/06									
04/07/06		34	47			136	316	10.0	
04/11/06		43	67			128	376	8.0	
04/13/06								12.0	
04/19/06		57	70			152	416	10.6	
04/20/06	30		74						
04/21/06								12.4	
04/26/06		68	74			162	452	13.0	
04/28/06								13.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		167	BDL			255	950	BDL	
05/04/06								11.0	
05/09/06		85	91			177	524	9.0	
05/11/06								15.0	
05/15/06		76	92			150	568	12.0	
05/19/06								16.0	
05/23/06		82	154			158	548	17.0	
05/25/06								17.6	
05/30/06		120	168			221	600	23.4	
06/01/06								19.7	
06/06/06		114	152			194	672	30.5	
06/12/06								31.4	
06/13/06	97	120	186			194	648	32.6	
06/15/06								29.0	
06/20/06		137	139			210	700	42.0	
06/23/06								38.0	
06/27/06		120	146			208	704	45.0	
06/29/06		130	95			183	732	79.0	
06/30/06								70.0	
07/05/06								41.0	
07/11/06								37.0	
07/12/06									
08/04/06		64				210	476		
09/06/06		54				162	464		
10/03/06		38				131	316		
11/28/06									
11/29/06	62	64	99			159	452	14.0	
12/01/06								13.0	
12/05/06		93	106			185	492	4.0	
12/07/06								<1.3	
12/12/06		107	126			199	560	8.0	
12/14/06								7.0	
12/18/06		119	129			201	552	6.0	
12/21/06								17.4	
12/27/06		143	147			220	620	14.6	
12/29/06								21.4	
01/02/07		181	337			236	724	19.9	
01/05/07								23.8	
01/09/07		186	252			238	712	20.0	
01/12/07								23.0	
01/16/07		188	218			238	716	20.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		167	BDL			255	950	BDL	
01/26/07								18.5	
01/29/07		196	199			242	792	19.8	
02/01/07								14.7	
02/05/07		197	207			242	780	17.0	
02/08/07								13.6	
02/12/07		200	209			243	724	14.6	
02/17/07								16.5	
02/20/07		203	228			244	836	11.6	
02/23/07								16.0	
02/27/07		209	565			245	816	16.8	
03/01/07									
03/02/07								16.9	
03/05/07		203	214			240	760	17.1	
03/08/07								18.4	
03/13/07		194	157			240	788	15.5	
03/16/07								16.4	
03/20/07		203	138			243	768	18.5	
03/23/07								14.6	
03/26/07		208	130			245	872	13.8	
03/28/07								33.8	
04/02/07		204	137			246	788	34.7	
04/06/07								52.3	
04/10/07		209	154			238	808	48.4	
04/13/07								51.0	
04/17/07		226	181			251	804	12.7	
04/20/07								53.8	
04/23/07		252	183			254	844	52.9	
04/27/07								31.8	
05/02/07		267	176			261	888		
05/04/07								31.6	
05/08/07		275	174			262	876	33.2	
05/11/07								21.1	
05/15/07		285	158			266	940	38.6	
05/18/07								36.9	
05/22/07								35.1	
05/23/07		296	170			270	944		
05/25/07								34.1	
05/29/07		307	150			272	1048	27.2	
06/01/07									
06/04/07		316	169			275	1004		

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		167	BDL			255	950	BDL	
06/28/07								22.3	
07/01/07									
07/03/07	120	317	141	60	162	264	1044	19.4	
07/06/07									
07/07/07									
08/01/07									
09/01/07									
10/01/07									
11/01/07									
12/01/07									
01/01/08									
02/01/08									
03/01/08									
04/01/08									
04/15/08	119	249	210	45	123	229	956	17.5	
05/01/08									
05/23/08	75	105	142	32	91	230	608	34.4	
05/27/08		168	144			267	756	32.7	
05/30/08								32.8	
06/01/08									
06/02/08	104	219	156	45	116	254	880	30.7	
07/01/08									
07/02/08	114	274	291	57	145	268	1012	32.4	
08/01/08									
09/01/08									
10/01/08									
11/01/08									
12/01/08									
12/02/08	57.5	71	<29	16	77	203	472	9.5	
12/08/08		103	<29			205	544	12.3	
12/15/08		117	59			208	584	11.6	
12/22/08		141	157			219	660	14.8	
12/29/08		145	147			221	680	20.9	
01/01/09									
01/05/09	87	158	203	37	101	229	708	19.8	
02/01/09									
03/01/09									
03/09/09		224	199			249	840	13.5	
03/12/09								5.5	
03/16/09		233	158			254	848	11.1	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-13)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		167	BDL			255	950	BDL	
03/26/09								12.3	
03/27/09								12.6	
03/30/09		285	141			248	976	11.8	
04/01/09									
05/01/09									

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.7		
06/24/02	x				4.70		7.8	708	27.5
07/05/02			x		1.30		8.0	818	28.0
07/11/02			x		2.70		7.6	1130	28.0
08/05/02	x						8.5	565	
08/27/02	x				7.80		8.2	485	30.0
09/03/02	x				7.20		8.0	565	35.0
09/10/02	x				7.40		8.1	446	26.7
09/17/02	x				5.70		8.1	432	25.8
09/24/02	x				5.90		8.2	444	27.6
10/01/02	x				6.00		8.3	423	28.2
10/08/02	x				6.30		8.1	423	27.0
10/15/02	x				6.60		8.0	426	27.6
10/22/02	x				5.70		8.3	462	27.5
10/29/02	x				6.40		8.3	470	28.0
11/05/02	x				5.70		8.1	447	26.5
11/12/02	x				6.50		8.1	471	26.0
11/19/02	x				7.00		8.1	464	23.1
11/26/02	x				7.00		8.4	470	22.3
12/03/02	x				7.70		8.0	464	23.0
12/10/02	x				5.50		8.1	465	20.0
12/18/02	x				5.80		8.3	469	20.0
12/23/02	x				5.80		8.4	451	19.0
12/31/02	x				6.50		8.4	430	19.0
01/07/03	x				8.00		8.5	420	18.5
01/14/03	x				7.50		8.2	410	18.5
01/21/03	x				7.90		8.5	407	17.0
01/28/03	x				9.90		8.2	399	16.0
02/03/03	x				9.20		7.8	394	17.0
02/11/03	x				8.50		8.2	428	18.5
02/18/03	x				5.10		8.2	435	20.0
02/25/03	x				7.90		8.1	447	21.2
03/03/03	x				7.50		8.3	455	22.4
03/11/03	x				5.00		8.3	472	24.1
03/18/03	x				7.20		8.3	474	24.1
03/27/03			x		2.90		8.3	512	23.5
04/01/03			x		3.70		8.1	614	25.1
04/08/03			x		2.10		7.9	674	26.2

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.7		
04/29/03			x		3.60		7.9	827	27.7
05/05/03			x		2.40		7.9	846	29.8
05/14/03			x		2.30		7.8	912	28.4
05/20/03			x		1.80		7.7	949	29.2
05/28/03			x		2.10		7.7	1019	28.1
06/02/03			x		2.90		7.7	1027	28.4
07/01/03	x			14.150					
08/01/03	x			14.705			8.2	461	
09/01/03	x			14.445			8.4	387	
10/01/03	x						8.3	355	
11/01/03	x			12.053			8.2	412	
12/01/03	x			1.439			8.3	496	
01/06/04	x			3.204			8.5	541	
02/01/04		x							
03/09/04	x			6.973	6.05		8.3	542	21.5
04/14/04			x	-14.558			7.9	651	27.0
05/05/04			x	-26.909			8.0	658	27.3
05/12/04			x				7.9	681	27.5
05/19/04			x				7.8	726	28.2
05/26/04			x				7.8	751	28.3
06/03/04			x	-15.545			7.8	785	28.4
06/09/04			x				7.8	803	28.6
06/16/04			x				7.8	859	28.7
07/13/04	x			8.420			8.4	684	30.0
08/02/04	x			5.056			8.2	580	30.0
09/13/04	x			5.394			8.5	502	29.0
10/05/04	x			8.587			8.3	388	28.0
11/02/04	x			6.800			8.5	348	26.0
12/09/04	x			3.042			8.2	431	22.5
01/06/05	x			4.783			8.4	480	19.0
02/03/05	x			5.172			8.2	489	19.0
03/01/05	x			8.748			8.2	523	21.5
04/06/05	x			4.049			8.5	449	24.0
04/29/05			x		3.22		8.2	523	24.7
05/03/05			x	-30.701	0.35		7.8	617	24.4
05/05/05			x						
05/09/05			x		0.20		7.9	676	24.2
05/12/05			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.7		
05/23/05			x		0.19	309	7.8	716	25.7
05/26/05			x						
05/31/05			x			260	7.9	757	24.9
06/02/05			x						
06/06/05			x	-7.431	0.16	491	7.7	790	26.9
06/09/05			x						
06/14/05			x		0.15	-27	7.7	829	27.6
07/06/05	x			13.309	5.20	458	8.2	491	29.0
07/13/05	x				4.60	384	8.3	458	29.0
07/21/05	x				4.69	450	8.0	423	30.0
07/25/05	x				5.15	513	8.2	405	31.0
08/01/05	x			11.239					
08/02/05	x				3.75	430	8.1	384	30.5
08/09/05	x				4.90	476	8.2	377	30.0
08/16/05	x				5.13	465	8.3	367	30.0
08/22/05	x				4.99	478	8.2	375	31.0
08/29/05	x				4.36	420	8.2	366	30.0
09/07/05	x			8.422	4.22	412	8.2	364	32.0
09/13/05	x				5.20	331	8.7	355	30.0
09/20/05	x				5.41	472	8.1	371	30.0
09/27/05	x				5.19	442	8.2	375	29.0
11/01/05	x			8.435	5.10	524	8.1	395	23.0
11/08/05	x				5.73	513	8.2	388	24.0
11/14/05	x				5.54	449	8.4	373	24.0
11/18/05	x				5.20	453	8.3	372	
12/05/05	x			7.524	6.61	459	8.2	380	24.0
12/12/05	x				6.18	521	8.2	384	20.0
12/20/05	x				6.25	516	8.2	390	20.0
01/04/06	x			1.820	7.17	418	8.3	421	20.0
01/09/06	x				7.14	424	8.3	423	19.0
01/17/06	x				6.39	396	8.4	438	19.0
01/23/06	x				6.82	571	8.4	447	19.5
01/30/06	x				6.53	459	8.2	472	20.0
02/01/06		x							
03/01/06		x							
04/07/06			x	-23.396	0.77	69	8.0	463	23.1
04/11/06			x		0.17	188	8.1	591	23.5
04/13/06			x						
04/19/06			x		0.81	-7	8.3	532	28.1

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.7		
04/28/06			x						
05/01/06			x	-33.498					
05/02/06			x		0.42	-84	8.0	755	
05/04/06			x						
05/09/06			x		0.47	143	7.7	664	
05/11/06			x						
05/15/06			x		0.28	-111	7.8	789	
05/19/06			x						
05/23/06			x		0.16	208	8.0	736	
05/25/06			x						
05/30/06			x		0.46	165	7.8	827	
06/01/06			x	-31.590					
06/06/06			x		0.45	-192	7.7	810	29.7
06/12/06			x						
06/13/06			x		0.18	-124	7.9	910	28.2
06/15/06			x						
06/20/06			x		0.37	-106	7.8	881	29.5
06/23/06			x						
06/27/06			x		0.24	-220	7.9	995	28.7
06/29/06			x						
06/30/06			x						
07/05/06			x	-9.115	0.19	-179	7.7	1106	28.6
07/11/06			x						
07/12/06		x							
08/04/06	x			13.216			8.2	720	
09/06/06	x			16.548			8.2	569	
10/03/06	x			4.028			8.1	452	
11/28/06			x	-2.517					
11/29/06			x		0.15	97	8.1	614	28.1
12/01/06			x	-27.320					
12/05/06			x		0.22	55	7.8	713	28.1
12/07/06			x						
12/12/06			x		0.03	72	7.8	811	26.5
12/14/06			x						
12/18/06			x		0.31	-58	7.8	864	29.0
12/21/06			x						
12/27/06			x		0.07	-95	7.8	950	27.8
12/29/06		x							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.7		
01/09/07			x		0.02	-48	7.8	987	27.9
01/12/07			x						
01/16/07			x		0.19	60	7.7	1041	27.9
01/18/07			x						
01/24/07			x		0.08	-89	7.8	1009	28.4
01/26/07			x						
01/29/07			x		0.07	30	7.8	1080	26.4
02/01/07			x	-5.323					
02/05/07			x		0.01	110	7.8	1096	26.0
02/08/07			x						
02/12/07			x		0.08	150	7.8	1108	27.7
02/17/07			x						
02/20/07			x		0.02	89	7.7	1097	27.5
02/23/07			x						
02/27/07			x		0.21	-7	7.7	1090	29.1
03/01/07			x	-15.070					
03/02/07			x						
03/05/07			x		0.34	154	7.6	1137	28.5
03/08/07			x						
03/13/07			x		0.05	-225	7.7	1113	27.2
03/16/07			x						
03/20/07			x		0.05	-12	7.8	1118	27.8
03/23/07			x						
03/26/07			x		0.24	-182	7.6	1127	28.9
03/28/07			x						
04/02/07			x	-29.694	0.26	-235	7.6	1289	29.3
04/06/07			x						
04/10/07			x		0.11	-226	7.6	1148	28.2
04/13/07			x						
04/17/07			x		0.02	-251	7.6	1166	27.4
04/20/07			x						
04/23/07			x		0.14	-261	7.6	1195	28.0
04/27/07			x						
05/02/07			x	-30.820	0.31	-227	7.6	1202	29.5
05/04/07			x						
05/08/07			x		0.15	76	7.6	1155	26.3
05/11/07			x						
05/15/07			x		0.14	-235	7.8	1238	28.0

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.7		
05/25/07			x						
05/29/07			x		0.26	-264	7.6	1248	29.0
06/01/07			x	-29.763					
06/04/07			x		0.27	-253	7.4	1266	29.3
06/05/07			x						
06/08/07			x						
06/12/07			x		0.16	-276	7.4	1290	28.3
06/15/07			x						
06/19/07			x		0.15	-244	7.5	1276	28.7
06/21/07			x						
06/26/07			x		0.21	-269	7.5	1319	28.1
06/28/07			x						
07/01/07			x	-0.005					
07/03/07			x		0.49	-220	7.5	1288	30.4
07/05/07			x		0.28	-286	7.5	1317	28.9
07/06/07			x						
07/07/07		x							
08/14/07		x							
08/27/07	x			3.580					
09/01/07	x			30.294					
09/04/07	x				5.25	470	8.0	630	30.0
09/11/07	x				5.57	403	7.9	605	29.0
09/18/07	x				5.51	457	8.0	591	31.0
09/25/07	x				5.22	489	8.1	617	29.0
10/01/07	x			28.008					
10/02/07	x				5.36	390	8.1	617	27.0
10/09/07	x				5.54	387	8.1	628	29.0
10/16/07	x				4.81	595	8.3	620	28.0
10/23/07	x				4.84	325	8.0	640	28.0
10/30/07	x				5.24	465	8.1	649	26.0
11/01/07	x			7.681					
11/10/07		x							
12/05/07			x	-30.435	0.68	171	7.6	770	25.2
12/07/07			x						
12/11/07			x		0.12	149	7.7	842	26.5
12/14/07			x						
12/18/07			x		0.04	-94	7.7	892	24.6
12/20/07			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.7		
01/02/08			x	-31.932	0.45	124	7.7	1034	25.6
01/04/08			x						
01/07/08			x		0.21	-258	7.8	1041	29.0
01/10/08			x						
01/15/08			x		0.10	-185	7.8	1031	24.7
01/17/08			x						
01/23/08			x		0.15	-258	7.9	1036	27.8
01/24/08			x						
01/29/08			x		0.08	-167	7.7	1100	24.7
01/31/08			x						
02/01/08			x	-10.732					
02/04/08			x		0.31	-271	7.7	1107	30.4
02/09/08			x						
02/11/08			x		0.23	-330	7.6	1160	28.5
02/12/08		x							
03/01/08		x							
04/01/08	x			8.732					
04/15/08	x				0.11	64	7.7	1152	24.7
05/01/08	x			9.537					
05/23/08			x		0.42	118	7.9	923	25.5
05/27/08			x		0.54	-128	7.5	989	29.5
05/30/08			x						
06/01/08			x	11.425					
06/02/08			x		1.08	-199	7.5	1061	28.6
06/05/08			x						
06/09/08			x		0.26	-338	7.5	1069	29.6
07/01/08	x			9.720					
07/02/08	x				0.50	-122	7.8	1101	28.7
08/01/08	x			6.663					
09/01/08	x			7.575					
10/01/08	x			5.166					
11/01/08	x			2.666					
12/01/08			x	12.396					
12/02/08			x		1.43	107	8.1	771	21.3
12/08/08			x		0.02	103	8.0	873	23.2
12/15/08			x		0.03	117	7.9	917	26.8
12/22/08			x		<0.05	137	7.9	993	25.7
12/29/08			x		0.04	117	8.0	1077	26.6

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.7		
01/09/09			x						
01/12/09			x		0.03	54	7.8	1149	27.0
01/16/09			x						
01/21/09			x		0.04	27	7.9	906	26.0
01/23/09			x						
01/26/09			x		0.53	-116	7.8	1159	26.7
01/29/09			x						
02/01/09			x	5.932					
02/02/09			x		0.51	18	7.8	1194	26.7
02/05/09			x						
02/09/09			x		0.43	-298	7.7	1217	28.8
02/13/09			x						
03/01/09			x	33.529					
03/02/09			x		0.15	-69	7.8	1129	27.5
03/04/09			x						
03/09/09			x		0.12	-181	7.7	1177	26.1
03/12/09			x						
03/16/09			x		0.17	-139	7.7	1250	27.2
03/19/09			x						
03/25/09			x		0.15	-186	7.7	1299	24.6
03/26/09			x						
03/27/09			x						
03/30/09			x		0.13	-201	7.6	1340	24.3
04/03/09			x						
04/08/09			x		0.19	-162	7.6	1407	22.3
04/10/09			x						
04/13/09			x		0.13	-199	7.7	1326	26.1
04/15/09			x						
04/20/09			x		0.30	-168	7.7	1376	25.9
04/23/09			x						
04/27/09			x		0.02	-186	7.6	1352	26.0
04/30/09			x						
05/05/09			x		0.73	-293	7.6	1223	30.0
05/08/09			x						
05/11/09			x		0.54	-258	7.5	1284	29.0
05/13/09			x						
05/18/09			x		0.53	-289	7.6	1284	28.5

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	As µg/L	Verified
2/01 Initial Quality		162	1	231	876	BDL		
06/24/02	38	53	35	135	388	<3.0	3.0	
07/05/02	56	79	<12.0	188	448	7.0	7.0	
07/11/02	112	139	13	239	752	52.0	52.0	
08/05/02	34	55		154	356		1.8	
08/27/02	35	38	132	132	348	1.8	1.8	
09/03/02	34	38	73	140	304	2.5	2.5	
09/10/02	31	35	64	124	280	3.7	3.7	
09/17/02	35	30	61	147	252	1.7	1.7	
09/24/02	37	34	109	124	268	<1.0	1.0	
10/01/02	28	33	42	121	276	<1.0	1.0	
10/08/02	35	27	<30.0	107	308	<1.0	1.0	
10/15/02	33	26	<30.0	88	260	<1.0	1.0	
10/22/02	39	29	41	121	300	<1.0	1.0	
10/29/02	41	33	<30.0	101	528	2.0	2.0	
11/05/02	40	31	82	106	288	1.1	1.1	
11/12/02	42	31	53	124	280	<1.0	1.0	
11/19/02	43	29	25	123	284	<1.0	1.0	
11/26/02	40	31	63	127	332	<1.0	1.0	
12/03/02	35	33	<30.0	143	284	<1.0	1.0	
12/10/02	35	34	<30.0	114	292	<1.0	1.0	
12/18/02	34	32	<30.0	124	272	<1.0	1.0	
12/23/02	34	31	<30.0	120	308	<1.0	1.0	
12/31/02	32	34	72	124	252	2.4	2.4	
01/07/03	30	28	50	112	236	1.6	1.6	
01/14/03	28	30	<30.0	104	292	<1.0	1.0	
01/21/03	32	28	49	98	248	<1.0	1.0	
01/28/03	34	26	36	99	296	<1.0	1.0	
02/03/03	29	27	46	94	212	<1.0	1.0	
02/11/03	32	26	80	100	356	<1.0	1.0	
02/18/03	36	32	87	103	272	<1.0	1.0	
02/25/03	32	27	124	92	232	2.7	2.7	
03/03/03	32	35	57	111	248	<1.0	1.0	
03/11/03	37	25	<30.0	113	248	<1.0	1.0	
03/18/03	39	31	37	106	280	<1.0	1.0	
03/27/03	54	35	<6.0	119	272	3.0	3.0	
04/01/03	62	52	<6.0	126	356	12.0	12.0	
04/08/03	68	57	31	131	364	28.0	28.0	
04/15/03	74	75	38	154	448	37.0	37.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	As µg/L	Verified
2/01 Initial Quality		162	1	231	876	BDL		
05/05/03	88	90	21	152	504	69.0	69.0	
05/14/03	94	102	119	146	568	87.0	87.0	
05/20/03	102	112	47	157	576	96.0	96.0	
05/28/03	106	117	73	158	624	114.0	114.0	
06/02/03	110	127	47	155	664	88.0	88.0	
07/01/03							1.0	
08/01/03		39		109	264		1.0	
09/01/03		31		100	260		1.0	
10/01/03		17		85	236		1.0	
11/01/03		27		106	288		1.0	
12/01/03		35		134	280		1.0	
01/06/04		37		143	340		1.0	
02/01/04							1.0	
03/09/04	43	157	30	159	344	1.0	1.0	
04/14/04	68	62	18	140	408	13.0	13.0	
05/05/04	70	75	6	156	380	24.0	24.0	
05/12/04	72	72	28	114	352	40.0	40.0	
05/19/04	80	77	28	149	420	56.0	56.0	
05/26/04	72	67	25	174	436	70.0	70.0	
06/03/04	82	92	41	196	492	73.0	73.0	
06/09/04	84	105	45	171	532	77.0	77.0	
06/16/04	98	107	35	183	580	73.0	73.0	
07/13/04	46	66	29	203	420	8.0	8.0	
08/02/04	42	46	29	157	376	5.1	5.1	
09/13/04	35	38	29	131	380	3.0	3.0	
10/05/04	30	28	29	99	248	1.3	1.3	
11/02/04	30	22	29	85	188	1.3	1.3	
12/09/04	37	29	29	122	264	2.5	2.5	
01/06/05	37	31	29	128	260	2.1	2.1	
02/03/05	34	30	29	122	336	1.3	1.3	
03/01/05	40	32	29	148	304	1.3	1.3	
04/06/05	31	27	<29.0	124	276	<1.3	1.3	
04/29/05	49	27	<29.0	121	312	<1.3	1.3	
05/03/05		41	<29.0	144	392	5.0	5.0	
05/05/05						5.0	5.0	
05/09/05		49	<29.0	151	392	6.8	6.8	
05/12/05						8.1	8.1	
05/16/05		57	44	155	412	10.9	10.9	
05/19/05						17.9	17.9	
05/23/05	71	62	43	159	440	16.5	16.5	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	As µg/L	Verified
2/01 Initial Quality		162	1	231	876	BDL		
06/02/05						34.9	34.9	
06/06/05		76	52	169	488	48.2	48.2	
06/09/05						54.5	54.5	
06/14/05	85	86	62	182	536	57.9	57.9	
07/06/05	32	43	<29.0	129	300	<1.3	1.3	
07/13/05		37	67	116	248	<1.3	1.3	
07/21/05		31	<29.0	113	268	1.8	1.8	
07/25/05		29	<29.0	108	252	2.3	2.3	
08/01/05							2.0	
08/02/05	33	27	<29.0	104	216	1.6	1.6	
08/09/05		26	<29.0	100	200	<1.3	1.3	
08/16/05		25	<29.0	100	204	<1.3	1.3	
08/22/05	26	25	55	100	240	<1.3	1.3	
08/29/05		25	<29.0	99	212	<1.3	1.3	
09/07/05	26	25	<29.0	99	252	1.7	1.7	
09/13/05		22	<29.0	100	272	<1.3	1.3	
09/20/05		26	<29.0	106	340	1.7	1.7	
09/27/05		23	<29.0	99	224	<1.3	1.3	
11/01/05		26	31	109	268	<1.3	1.3	
11/08/05		24	<29.0	107	276	<1.3	1.3	
11/14/05		23	<29.0	101	248	<1.3	1.3	
11/18/05		26	<29.0	115	252	2.4	2.4	
12/05/05		28	<29.0	112	236	<1.3	1.3	
12/12/05		28	38	120	288	3.6	3.6	
12/20/05		26	<29.0	111	260	<1.3	1.3	
01/04/06							1.0	
01/09/06							1.0	
01/17/06							1.0	
01/23/06							1.0	
01/30/06							1.0	
02/01/06							1.0	
03/01/06							1.0	
04/07/06		31	45	130	312	10.0	10.0	
04/11/06		37	<29.0	133	352	7.1	7.1	
04/13/06						5.0	5.0	
04/19/06		43	57	134	364	6.8	6.8	
04/21/06						8.8	8.8	
04/26/06	65	54	41	149	404	10.2	10.2	
04/28/06						8.0	8.0	
05/01/06							9.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	As µg/L	Verified
2/01 Initial Quality		162	1	231	876	BDL		
05/09/06		69	54	164	436	8.0	8.0	
05/11/06						18.0	18.0	
05/15/06		70	<29.0	159	488	15.0	15.0	
05/19/06						28.0	28.0	
05/23/06		62	66	140	444	35.0	35.0	
05/25/06						41.0	41.0	
05/30/06		89	70	194	532	49.4	49.4	
06/01/06						33.6	33.6	
06/06/06		90	62	187	588	52.9	52.9	
06/12/06						54.9	54.9	
06/13/06	94	76	109	150	588	66.6	66.6	
06/15/06						60.0	60.0	
06/20/06		104	80	185	576	33.0	33.0	
06/23/06						75.0	75.0	
06/27/06		100	101	208	596	81.0	81.0	
06/29/06		100	84	163	644	75.0	75.0	
06/30/06						111.0	111.0	
07/05/06						69.0	69.0	
07/11/06						65.0	65.0	
07/12/06							65.0	
08/04/06		64		210	476		1.0	
09/06/06		54		162	464		1.0	
10/03/06		38		131	316		1.0	
11/28/06							9.0	
11/29/06	59	53	164	149	448	9.0	9.0	
12/01/06						4.0	4.0	
12/05/06		74	56	174	460	<1.3	1.3	
12/07/06						<1.3	1.3	
12/12/06		88	58	188	512	4.0	4.0	
12/14/06						<1.3	1.3	
12/18/06		97	320	496	193	7.0	7.0	
12/21/06						18.8	18.8	
12/27/06		113	71	200	544	28.0	28.0	
12/29/06						39.3	39.3	
01/02/07		131	117	214	608	30.8	30.8	
01/05/07						18.1	18.1	
01/09/07		134	95	207	552	27.4	27.4	
01/12/07						39.0	39.0	
01/16/07		134	101	209	620	36.0	36.0	
01/18/07						41.2	41.2	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	As µg/L	Verified
2/01 Initial Quality		162	1	231	876	BDL		
01/29/07		141	92	218	700	32.0	32.0	
02/01/07						29.9	29.9	
02/05/07		144	102	219	680	30.0	30.0	
02/08/07						28.2	28.2	
02/12/07		147	111	220	608	28.5	28.5	
02/17/07						34.0	34.0	
02/20/07		145	107	217	840	23.7	23.7	
02/23/07						36.3	36.3	
02/27/07		147	193	214	684	31.5	31.5	
03/01/07							30.0	
03/02/07						28.2	28.2	
03/05/07		147	128	219	644	33.2	33.2	
03/08/07						31.5	31.5	
03/13/07		145	128	221	676	31.4	31.4	
03/16/07						39.7	39.7	
03/20/07		145	124	223	696	40.3	40.3	
03/23/07						35.0	35.0	
03/26/07		148	118	218	728	34.6	34.6	
03/28/07						45.2	45.2	
04/02/07		175	169	229	724	38.7	38.7	
04/06/07						58.0	58.0	
04/10/07		154	224	227	704	55.9	55.9	
04/13/07						60.5	60.5	
04/17/07		157	237	228	680	15.4	15.4	
04/20/07						17.5	17.5	
04/23/07		163	262	232	680	53.1	53.1	
04/27/07						17.2	17.2	
05/02/07		169	250	235	732		29.5	
05/04/07						41.7	41.7	
05/08/07		168	226	233	740	25.4	25.4	
05/11/07						8.0	8.0	
05/15/07		174	208	236	764	30.3	30.3	
05/18/07						30.2	30.2	
05/22/07		179	162	239	696	28.6	28.6	
05/25/07						20.8	20.8	
05/29/07		182	134	240	796	16.3	16.3	
06/01/07							18.6	
06/04/07		184	127	241	800		17.5	
06/05/07						13.6	13.6	
06/08/07						11.8	11.8	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	As µg/L	Verified
2/01 Initial Quality		162	1	231	876	BDL		
06/19/07		186	105	241	780	14.0	14.0	
06/21/07						2.5	6.1	
06/26/07							7.9	
06/28/07						9.6	9.6	
07/01/07							10.0	
07/03/07	124	186	1011	229	984	10.4	10.4	
07/05/07		169	87	188	776	10.3	10.3	
07/06/07							10.0	
07/07/07							10.0	
08/14/07							10.0	
08/27/07							1.0	
09/01/07							1.0	
09/04/07	40	48	<29.0	178	384	<1.3	1.3	
09/11/07		43	<29.0	173	400	<1.3	1.3	
09/18/07		43	<29.0	170	328	<1.3	1.3	
09/25/07		43	<29.0	185	380	<1.3	1.3	
10/01/07							1.3	
10/02/07	175	40	37	175	384	<1.3	1.3	
10/09/07	168	39	29	168	392	<1.3	1.3	
10/16/07	169	37	30	169	392	<1.3	1.3	
10/23/07	183	42	29	183	396	<1.3	1.3	
10/30/07	180	38	63	180	416	<1.3	1.3	
11/01/07							1.0	
11/10/07							4.6	
12/05/07	68	68	66	208	488	8.2	8.2	
12/07/07						7.2	7.2	
12/11/07		79	75	208	508	6.8	6.8	
12/14/07						15.4	15.4	
12/18/07		88	<29.0	213	516	<1.3	1.0	
12.20/07						20.4	20.4	
12/27/07		100	<29.0	210	496	<1.3	1.0	
12/28/07						25.1	25.1	
01/02/08	76	108	82	217	560	29.0	29.0	
01/04/08						30.8	30.8	
01/07/08		114	87	220	556	32.8	32.8	
01/10/08						33.4	33.4	
01/15/08		123	85	221	592	33.1	33.1	
01/17/08						36.0	36.0	
01/23/08		130	99	223	620	37.5	37.5	
01/24/08						35.9	35.9	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	As µg/L	Verified
2/01 Initial Quality		162	1	231	876	BDL		
02/01/08							42.4	
02/04/08	97	143	147	221	672	43.2	43.2	
02/09/08						38.8	38.8	
02/11/08		154	161	228	748	35.6	35.6	
02/12/08							37.2	
03/01/08							36.4	
04/01/08							42.3	
04/15/08	110	142	310	192	716	48.1	48.1	
05/01/08							29.3	
05/23/08	73	90	46	224	588	10.4	10.4	
05/27/08		111	35	223	676	9.1	9.1	
05/30/08						11.7	11.7	
06/01/08							13.8	
06/02/08	73	139	41	227	728	15.8	15.8	
06/05/08						13.4	13.4	
06/09/08	102	152	68	224	756	18.3	18.3	
07/01/08							18.3	
07/02/08	113	168	189	231	752	18.4	18.4	
08/01/08							1.0	
09/01/08							1.0	
10/01/08							1.0	
11/01/08							1.0	
12/01/08							2.8	
12/02/08	56	65	<29	199	444	4.6	4.6	
12/08/08		80	<29	191	496	5.6	5.6	
12/15/08		89	53	194	508	4.9	4.9	
12/22/08		105	94	201	584	6.4	6.4	
12/29/08		109	92	204	568	11.6	11.6	
01/01/09							10.5	
01/05/09	78	116	90	210	576	9.3	9.3	
01/09/09						3.2	3.2	
01/12/09		112	46	213	588	4.4	4.4	
01/16/09						7.5	7.5	
01/21/09		138	66	225	708	7.3	7.3	
01/23/09						9.4	9.4	
01/26/09		142	69	226	704	8.6	8.6	
01/29/09						12.1	12.1	
02/01/09							11.2	
02/02/09	99	149	74	227	692	10.2	10.2	
02/05/09						15.1	15.1	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-14)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	As µg/L	Verified
2/01 Initial Quality		162	1	231	876	BDL		
03/01/09							14.0	
03/02/09	100	141	122	220	668	15.6	15.6	
03/04/09						10.4	10.4	
03/09/09		152	135	223	692	15.5	15.5	
03/12/09						8.6	8.6	
03/16/09		167	191	230	748	15.1	15.1	
03/19/09						18.1	18.1	
03/25/09		179	195	231	832		16.8	
03/26/09						15.4	15.4	
03/27/09						16.0	16.0	
03/30/09		185	176	235	788	13.2	13.2	
04/03/09						14.2	14.2	
04/08/09	121	191	129	237	816	6.9	6.9	
04/10/09						11.7	11.7	
04/13/09		193	109	229	824	11.4	11.4	
04/15/09						8.8	8.8	
04/20/09		195	77	228	864	8.2	8.2	
04/23/09						6.4	6.4	
04/27/09		200	73	240	876	8.9	8.9	
04/30/09						6.9	6.9	
05/05/09		207	73	235	864	7.3	7.3	
05/08/09						7.1	7.1	
05/11/09	122	209	68	235	820	6.2	6.2	
05/13/09						7.6	7.6	
05/18/09		209	64	233	900	5.8	5.8	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
06/24/02	x				4.70		7.8	708	27.5
07/05/02			x		1.40		7.9	815	28.0
07/11/02			x		3.20		7.6	1140	28.0
08/05/02	x						8.5	565	
08/27/02	x				7.80		8.2	485	30.0
09/03/02	x				7.20		8.0	565	35.0
09/10/02	x				7.40		8.1	446	26.7
09/17/02	x				5.70		8.1	432	25.8
09/24/02	x				5.90		8.2	444	27.6
10/01/02	x				6.00		8.3	423	28.2
10/08/02	x				6.30		8.1	423	27.0
10/15/02	x				6.60		8.0	426	27.6
10/22/02	x				5.70		8.3	462	27.5
10/29/02	x				6.40		8.3	470	28.0
11/05/02	x				5.70		8.1	447	26.5
11/12/02	x				6.50		8.1	471	26.0
11/19/02	x				7.00		8.1	464	23.1
11/26/02	x				7.00		8.4	470	22.3
12/03/02	x				7.70		8.0	464	23.0
12/10/02	x				5.50		8.1	465	20.0
12/18/02	x				5.80		8.3	469	20.0
12/23/02	x				5.80		8.4	451	19.0
12/31/02	x				6.50		8.4	430	19.0
01/07/03	x				8.00		8.5	420	18.5
01/14/03	x				7.50		8.2	410	18.5
01/21/03	x				7.90		8.5	407	17.0
01/28/03	x				9.90		8.2	399	16.0
02/03/03	x				9.20		7.8	394	17.0
02/11/03	x				8.50		8.2	428	18.5
02/18/03	x				5.10		8.2	435	20.0
02/25/03	x				7.90		8.1	447	21.2
03/03/03	x				7.50		8.3	455	22.4
03/11/03	x				5.00		8.3	472	24.1
03/18/03	x				7.20		8.3	474	24.1
03/27/03			x		2.70		8.3	498	23.7
04/01/03			x		4.40		8.0	491	25.3
04/08/03			x		2.20		7.9	698	26.2
04/15/03			x		2.20		7.7	760	26.9

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH	std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field		Field	Field
2/01 Initial Quality								7.5		
05/05/03			x		2.00			7.8	903	29.7
05/14/03			x		2.30			7.7	976	28.7
05/20/03			x		1.90			7.6	1008	29.6
05/28/03			x		1.70			7.7	1071	28.0
06/02/03			x		2.60			7.6	1090	28.7
07/01/03	x			13.189						
08/01/03	x			13.098				8.2	461	
09/01/03	x			12.573				8.4	387	
10/01/03	x							8.3	355	
11/01/03	x			11.744				8.2	412	
12/01/03	x			1.440				8.3	496	
01/06/04	x			3.238				8.5	541	
02/01/04		x								
03/09/04	x			6.971	6.05			8.3	542	21.5
04/14/04			x	-14.628				7.9	586	26.4
05/05/04			x	-26.845				8.0	601	26.9
05/12/04			x					7.9	618	27.1
05/19/04			x					7.9	651	27.9
05/26/04			x					7.9	684	28.0
06/03/04			x	-15.458				7.8	709	28.3
06/09/04			x					7.8	757	28.4
06/16/04			x					7.8	781	28.6
07/13/04	x			8.423				8.4	684	30.0
08/02/04	x			5.012				8.2	580	30.0
09/13/04	x			5.414				8.5	502	29.0
10/05/04	x			9.229				8.3	388	28.0
11/02/04	x			14.315				8.5	348	26.0
12/09/04	x			10.345				8.2	431	22.5
01/06/05	x			13.950				8.4	480	19.0
02/03/05	x			11.717				8.2	489	19.0
03/01/05	x			9.541				8.2	523	21.5
04/06/05	x			4.170				8.5	449	24.0
04/29/05			x		4.28			8.2	507	24.7
05/03/05			x	-30.753	0.39			8.0	556	23.5
05/05/05			x							
05/09/05			x		0.25			8.0	609	23.2
05/12/05			x							
05/16/05			x		0.57	145		7.9	613	23.8
05/19/05			x							
05/23/05			x		0.21	351		7.9	633	23.8

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
06/02/05			x						
06/06/05			x	-7.314	0.25	94	7.8	661	25.5
06/09/05			x						
06/14/05			x		0.21	40	7.9	675	26.0
07/06/05	x			13.308	5.20	458	8.2	491	29.0
07/13/05	x				4.60	384	8.3	458	29.0
07/21/05	x				4.69	450	8.0	423	30.0
07/25/05	x				5.15	513	8.2	405	31.0
08/01/05	x			11.491					
08/02/05	x				3.75	430	8.1	384	30.5
08/09/05	x				4.90	476	8.2	377	30.0
08/16/05	x				5.13	465	8.3	367	30.0
08/22/05	x				4.99	478	8.2	375	31.0
08/29/05	x				4.36	420	8.2	366	30.0
09/07/05	x			8.500	4.22	412	8.2	364	32.0
09/13/05	x				5.20	331	8.7	355	30.0
09/20/05	x				5.41	472	8.1	371	30.0
09/27/05	x				5.19	442	8.2	375	29.0
11/01/05	x			8.604	5.10	524	8.1	395	23.0
11/08/05	x				5.73	513	8.2	388	24.0
11/14/05	x				5.54	449	8.4	373	24.0
11/18/05	x				5.20	453	8.3	372	
12/05/05	x			7.757	6.61	459	8.2	380	24.0
12/12/05	x				6.18	521	8.2	384	20.0
12/20/05	x				6.25	516	8.2	390	20.0
01/04/06	x			1.839	7.17	418	8.3	421	20.0
01/09/06	x				7.14	424	8.3	423	19.0
01/17/06	x				6.39	396	8.4	438	19.0
01/23/06	x				6.82	571	8.4	447	19.5
01/30/06	x				6.53	459	8.2	472	20.0
02/01/06		x							
03/01/06		x							
04/07/06			x	-23.299	0.89	52	8.0	448	22.4
04/11/06			x		0.19	208	8.1	490	23.1
04/13/06			x						
04/19/06			x		0.73	41	8.4	485	27.3
04/21/06			x						
04/26/06			x		0.47	83	7.9	587	28.1
04/28/06			x						
05/01/06			x	-33.388					

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
05/09/06			x		0.70	163	7.8	566	26.6
05/11/06			x						
05/15/06			x		0.26	-49	7.8	657	27.8
05/19/06			x						
05/23/06			x		0.15	213	8.1	628	26.5
05/25/06			x						
05/30/06			x		0.64	197	7.9	676	30.1
06/01/06			x	-31.690					
06/06/06			x		0.44	-63	7.9	672	29.5
06/12/06			x						
06/13/06			x		0.19	-19	8.0	748	27.8
06/15/06			x						
06/20/06			x		0.56	82	7.9	743	29.0
06/23/06			x						
06/27/06			x		0.23	-159	8.0	971	28.4
06/29/06			x						
06/30/06			x						
07/05/06			x	-8.964	0.25	-132	7.8	957	28.7
07/11/06			x						
07/12/06		x							
08/04/06	x			13.216			8.2	720	
09/06/06	x			16.623			8.2	569	
10/03/06	x			4.051			8.1	452	
11/28/06			x	-2.529					
11/29/06			x		0.32	85	8.1	561	27.5
12/01/06			x	-27.640					
12/05/06			x		0.19	126	8.0	663	27.7
12/07/06			x						
12/12/06			x		0.06	141	7.9	721	26.9
12/14/06			x						
12/18/06			x		0.34	0	7.9	762	28.9
12/21/06			x						
12/27/06			x		0.04	18	7.9	8	26.5
12/29/06		x							
01/02/07			x	-6.111	0.12	-56	7.9	853	28.4
01/05/07			x						
01/09/07			x		0.02	42	7.9	824	26.7
01/12/07			x						
01/16/07			x		0.12	70	7.8	860	27.4
01/18/07			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
01/29/07			x		0.10	31	7.9	873	26.4
02/01/07			x	-5.193					
02/05/07			x		0.02	141	7.9	883	26.5
02/08/07			x						
02/12/07			x		0.08	196	7.9	909	26.9
02/17/07			x						
02/20/07			x		0.02	137	7.9	922	26.3
02/23/07			x						
02/27/07			x		0.20	22	7.8	883	28.7
03/01/07			x	-15.263					
03/02/07			x						
03/05/07			x		0.33	2200	7.7	915	28.1
03/08/07			x						
03/13/07			x		0.04	-122	7.8	929	27.9
03/16/07			x						
03/20/07			x		0.05	-62	7.9	958	26.2
03/23/07			x						
03/26/07			x		0.28	-152	7.8	953	28.3
03/28/07			x						
04/02/07			x	-29.439	0.31	-188	7.7	987	28.7
04/06/07			x						
04/10/07			x		0.10	-206	7.7	1006	27.8
04/13/07			x						
04/17/07			x		0.14	-214	7.7	1027	27.2
04/20/07			x						
04/23/07			x		0.19	-226	7.7	1052	28.2
04/27/07			x						
05/02/07			x	-30.889	0.34	-202	7.7	1068	29.3
05/04/07			x						
05/08/07			x		0.17	-91	7.6	1033	26.5
05/11/07			x						
05/15/07			x		0.14	-162	7.7	1112	28.1
05/18/07			x						
05/22/07			x		0.18	-272	7.6	1133	27.4
05/25/07			x						
05/29/07			x		0.31	-243	7.7	1145	28.7
06/01/07			x	-29.960					
06/04/07			x		0.28	-219	7.6	1168	29.0
06/05/07			x						
06/08/07			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
06/19/07			x		0.17	-208	7.6	1206	27.7
06/21/07			x						
06/26/07			x		0.24	-282	7.6	1244	28.3
06/28/07			x						
07/01/07			x	-0.005					
07/03/07			x		0.38	-206	7.5	1222	30.6
07/05/07			x		0.26	-268	7.5	1250	28.7
07/06/07			x						
07/07/07		x							
08/14/07		x							
08/27/07	x			3.580					
09/01/07	x			30.162					
09/04/07	x				5.25	470	8.0	630	30.0
09/11/07	x				5.57	403	7.9	605	29.0
09/18/07	x				5.51	457	8.0	591	31.0
09/25/07	x				5.22	489	8.1	617	29.0
10/01/07	x			26.921					
10/02/07	x				5.36	390	8.1	617	27.0
10/09/07	x				5.54	387	8.1	628	29.0
10/16/07	x				4.81	595	8.3	620	28.0
10/23/07	x				4.84	325	8.0	640	28.0
10/30/07	x				5.24	465	8.1	649	26.0
11/01/07	x			7.301					
11/10/07		x							
12/05/07			x	-30.663	1.57	161	7.8	726	25.0
12/07/07			x						
12/11/07			x		0.08	207	8.1	767	25.0
12/14/07			x						
12/18/07			x		0.05	-21	7.9	786	24.7
12/20/07			x						
12/27/07			x		0.12	-69	7.8	859	24.7
12/28/07			x						
01/02/08			x	-34.150	0.08	130	7.9	944	24.9
01/04/08			x						
01/07/08			x		0.22	-203	7.9	979	28.6
01/10/08			x						
01/15/08			x		0.09	-184	7.9	943	24.8
01/17/08			x						
01/23/08			x		0.20	-214	8.0	960	28.1
01/24/08			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH	std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field		Field	Field
2/01 Initial Quality								7.5		
02/01/08			x	-10.649						
02/04/08			x		0.31	-248	7.9		1042	30.1
02/09/08			x							
02/11/08			x		0.28	-296	7.6		1113	29.3
02/12/08		x								
03/01/08		x								
04/01/08	x			8.161						
04/15/08	x				0.12	43	7.6		1084	25.5
05/01/08	x			9.603						
05/23/08			x		0.44	134	7.9		845	25.6
05/27/08			x		0.74	2	7.6		923	29.4
05/30/08			x							
06/01/08			x	11.475						
06/02/08			x		1.13	-111	7.5		990	29.9
06/05/08			x							
06/09/08			x		0.27	-209	7.5		1009	29.7
07/01/08	x			9.252						
07/02/08	x				0.68	-99	7.8		1038	28.6
08/01/08	x			6.120						
09/01/08	x			7.386						
10/01/08	x			5.199						
11/01/08	x			2.664						
12/01/08			x	11.669						
12/02/08			x		1.64	109	8.1		722	20.6
12/08/08			x		0.09	107	8.0		752	23.1
12/15/08			x		0.05	141	8.1		779	26.0
12/22/08			x		0.06	152	8.1		800	26.0
12/29/08			x		0.04	126	7.9		876	26.3
01/01/09			x	2.820						
01/05/09			x		0.04	285	7.9		886	29.0
01/09/09			x							
02/01/09		x								
03/01/09			x	15.372						
03/19/09			x							
03/25/09			x		0.25	-114	7.7		1146	24.8
03/26/09			x							
03/27/09			x							
03/30/09			x		0.20	-162	7.7		1201	23.7
04/03/09			x							
04/08/09			x		0.21	-120	7.8		1200	25.9

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
04/15/09			x						
04/20/09			x		0.23	-125	7.7	1244	26.4
04/23/09			x						
04/27/09			x		0.55	-156	7.7	1264	25.7
04/30/09			x						
05/05/09			x		0.90	-269	7.7	1159	28.8
05/08/09			x						
05/11/09			x		0.70	-232	7.6	1211	29.0
05/13/09			x						
05/18/09			x		0.43	-244	7.7	1213	28.6

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		161	BDL	241	894	BDL	
06/24/02	38	53	35.0	135	388	<3.0	
07/05/02	58	81	<12.0	191	492	13.0	
07/11/02	128	150	<12.0	250	756	13.0	
08/05/02	34	55		154	356		
08/27/02	35	38	132.0	132	348	1.8	
09/03/02	34	38	73.0	140	304	2.5	
09/10/02	31	35	64.0	124	280	3.7	
09/17/02	35	30	61.0	147	252	1.7	
09/24/02	37	34	109.0	124	268	<1.0	
10/01/02	28	33	42.0	121	276	<1.0	
10/08/02	35	27	<30.0	107	308	<1.0	
10/15/02	33	26	<30.0	88	260	<1.0	
10/22/02	39	29	41.0	121	300	<1.0	
10/29/02	41	33	<30.0	101	528	2.0	
11/05/02	40	31	82.0	106	288	1.1	
11/12/02	42	31	53.0	124	280	<1.0	
11/19/02	43	29	25.0	123	284	<1.0	
11/26/02	40	31	63.0	127	332	<1.0	
12/03/02	35	33	<30.0	143	284	<1.0	
12/10/02	35	34	<30.0	114	292	<1.0	
12/18/02	34	32	<30.0	124	272	<1.0	
12/23/02	34	31	<30.0	120	308	<1.0	
12/31/02	32	34	72.0	124	252	2.4	
01/07/03	30	28	50.0	112	236	1.6	
01/14/03	28	30	<30.0	104	292	<1.0	
01/21/03	32	28	49.0	98	248	<1.0	
01/28/03	34	26	36.0	99	296	<1.0	
02/03/03	29	27	46.0	94	212	<1.0	
02/11/03	32	26	80.0	100	356	<1.0	
02/18/03	36	32	87.0	103	272	<1.0	
02/25/03	32	27	124.0	92	232	2.7	
03/03/03	32	35	57.0	111	248	<1.0	
03/11/03	37	25	<30.0	113	248	<1.0	
03/18/03	39	31	37.0	106	280	<1.0	
03/27/03	50	35	23.0	113	272	<1.0	
04/01/03	62	48	<6.0	120	360	11.0	
04/08/03	72	60	<6.0	162	372	31.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		161	BDL	241	894	BDL	
04/29/03	90	85	16.0	166	560	35.0	
05/05/03	94	95	24.0	165	544	46.0	
05/14/03	106	112	<6.0	167	612	66.0	
05/20/03	110	120	16.0	174	620	55.0	
05/28/03	112	132	27.0	164	636	59.0	
06/02/03	116	140	30.0	171	648	30.0	
07/01/03							
08/01/03		39		109	264		
09/01/03		31		100	260		
10/01/03		17		85	236		
11/01/03		27		106	288		
12/01/03		35		134	280		
01/06/04		37		143	340		
02/01/04							
03/09/04	43	157	30.0	159	344	1.0	
04/14/04	68	54	6.0	129	372	20.0	
05/05/04	66	52	6.0	134	348	41.0	
05/12/04	66	55	6.0	132	352	58.0	
05/19/04	70	62	6.0	166	412	58.0	
05/26/04	66	82	6.0	144	416	58.0	
06/03/04	78	77	23.0	147	476	70.0	
06/09/04	80	87	25.0	157	468	89.0	
06/16/04	84	95	21.0	217	532	80.0	
07/13/04	46	66	29.0	203	420	8.0	
08/02/04	42	46	29.0	157	376	5.1	
09/13/04	35	38	29.0	131	380	3.0	
10/05/04	30	28	29.0	99	248	1.3	
11/02/04	30	22	29.0	85	188	1.3	
12/09/04	37	29	29.0	122	264	2.5	
01/06/05	37	31	29.0	128	260	2.1	
02/03/05	34	30	29.0	122	336	1.3	
03/01/05	40	32	29.0	148	304	1.3	
04/06/05	31	27	<29.0	124	276	<1.3	
04/29/05	44	27	<29.0	123	304	<1.3	
05/03/05		31	<29.0	134	340	<1.3	
05/05/05						<1.3	
05/09/05		35	<29.0	142	332	5.1	
05/12/05						7.3	
05/16/05		39	<29.0	145	352	8.5	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
05/23/05		42	<29.0	147	396	10.9	
05/26/05						12.2	
05/31/05	59	48	<29.0	150	352	16.2	
06/02/05						24.9	
06/06/05		52	<29.0	153	376	23.0	
06/09/05						31.8	
06/14/05	64	54	<29.0	154	396	32.6	
07/06/05	32	43	<29.0	129	300	<1.3	
07/13/05		37	67.0	116	248	<1.3	
07/21/05		31	<29.0	113	268	1.8	
07/25/05		29	<29.0	108	252	2.3	
08/01/05							
08/02/05	33	27	<29.0	104	216	1.6	
08/09/05		26	<29.0	100	200	<1.3	
08/16/05		25	<29.0	100	204	<1.3	
08/22/05	26	25	55.0	100	240	<1.3	
08/29/05		25	<29.0	99	212	<1.3	
09/07/05	26	25	<29.0	99	252	1.7	
09/13/05		22	<29.0	100	272	<1.3	
09/20/05		26	<29.0	106	340	1.7	
09/27/05		23	<29.0	99	224	<1.3	
11/01/05		26	31.0	109	268	<1.3	
11/08/05		24	<29.0	107	276	<1.3	
11/14/05		23	<29.0	101	248	<1.3	
11/18/05		26	<29.0	115	252	2.4	
12/05/05		28	<29.0	112	236	<1.3	
12/12/05		28	38.0	120	288	3.6	
12/20/05		26	<29.0	111	260	<1.3	
01/04/06							
01/09/06							
01/17/06							
01/23/06							
01/30/06							
02/01/06							
03/01/06							
04/07/06		30	90	125	312	6.0	
04/11/06		27	<29.0	123	308	2.9	
04/13/06						3.0	
04/19/06		38	33	131	304	5.4	
04/21/06						7.5	
04/26/06	54	38	<29.0	136	328	7.2	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
05/01/06							
05/02/06		43	<29.0	138	372	9.0	
05/04/06						7.0	
05/09/06		50	<29.0	146	400	11.0	
05/11/06						15.0	
05/15/06		50	<29.0	142	436	17.0	
05/19/06						16.0	
05/23/06		46	<29.0	126	428	18.0	
05/25/06						16.9	
05/30/06		61	<29.0	161	436	23.1	
06/01/06						25.0	
06/06/06		64	35	158	476	37.0	
06/12/06						46.6	
06/13/06	76	57	79	134	508	71.7	
06/15/06						73.0	
06/20/06		80	42	163	476	177.0	
06/23/06						130.0	
06/27/06		100	44	198	540	117.0	
06/29/06		110	49	193	548	100.0	
06/30/06						187.0	
07/05/06						85.0	
07/11/06						124.0	
07/12/06							
08/04/06		64		210	476		
09/06/06		54		162	464		
10/03/06		38		131	316		
11/28/06							
11/29/06	54	41	<29.0	140	408	8.0	
12/01/06						2.0	
12/05/06		58	<29.0	160	400	<1.3	
12/07/06						<1.3	
12/12/06		68	<29.0	170	488	<1.3	
12/14/06						<1.3	
12/18/06		77	31	178	428	<1.3	
12/21/06						11.9	
12/27/06		89	31	190	520	14.5	
12/29/06						24.7	
01/02/07		93	51	192	508	12.3	
01/05/07						28.5	
01/09/07		94	52	192	452	28.5	
01/12/07						33.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
01/18/07						38.4	
01/24/07		98	60	191	540	31.3	
01/26/07						31.8	
01/29/07		99	46	194	568	36.9	
02/01/07						41.4	
02/05/07		101	60	196	552	35.8	
02/08/07						38.6	
02/12/07		102	70	196	512	36.7	
02/17/07						37.4	
02/20/07		104	54	197	500	36.5	
02/23/07						57.7	
02/27/07		100	72	193	552	51.6	
03/01/07							
03/02/07						50.6	
03/05/07		102	61	193	556	56.0	
03/08/07						53.6	
03/13/07		105	62	200	592	53.1	
03/16/07						41.9	
03/20/07		108	56	202	596	55.7	
03/23/07						49.7	
03/26/07		109	38	202	608	54.9	
03/28/07						84.3	
04/02/07		116	93	200	516	85.9	
04/06/07						89.8	
04/10/07		122	102	207	612	86.4	
04/13/07						64.4	
04/17/07		130	106	211	580	31.3	
04/20/07						37.2	
04/23/07		136	122	216	632	115.0	
04/27/07						33.7	
05/02/07		142	117	219	616		
05/04/07						91.2	
05/08/07		146	113	219	644	72.7	
05/11/07						33.3	
05/15/07		152	108	221	668	57.8	
05/18/07						60.2	
05/22/07		157	98	223	684	74.2	
05/25/07						50.0	
05/29/07		159	100	223	716	40.8	
06/01/07							
06/04/07		163	102	223	736		

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
06/08/07						47.1	
06/12/07	108	168	94	225	728	64.4	
06/15/07						49.7	
06/19/07		173	99	227	708	63.4	
06/21/07						44.0	
06/26/07							
06/28/07						38.3	
07/01/07							
07/03/07	114	183	97	219	768	40.6	
07/05/07		180	93	215	760	44.0	
07/06/07							
07/07/07							
08/14/07							
08/27/07							
09/01/07							
09/04/07	40	48	<29.0	178	384	<1.3	
09/11/07		43	<29.0	173	400	<1.3	
09/18/07		43	<29.0	170	328	<1.3	
09/25/07		43	<29.0	185	380	<1.3	
10/01/07							
10/02/07	40	40	37	175	384	<1.3	
10/09/07		39	29	168	392	<1.3	
10/16/07		37	30	169	392	<1.3	
10/23/07		42	29	183	396	<1.3	
10/30/07		38	63	180	416	<1.3	
11/01/07							
11/10/07							
12/05/07	61	61	31	199	444	3.0	
12/07/07						2.0	
12/11/07		57	<29.0	197	456	3.4	
12/14/07						8.2	
12/18/07		65	<29.0	203	456	<1.3	
12/20/07						7.9	
12/27/07		77	<29.0	201	480	<1.3	
12/28/07						7.1	
01/02/08	69	87	35	207	532	7.5	
01/04/08						8.3	
01/07/08		94	36	208	508	8.6	
01/10/08						11.3	
01/15/08		104	30	208	548	18.3	
01/17/08						18.3	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
01/24/08						28.7	
01/29/08		128	64	215	652	34.4	
01/31/08						40.0	
02/01/08							
02/04/08	86	135	61	213	644	48.2	
02/09/08						40.1	
02/11/08		149	75	218	692	39.6	
02/12/08							
03/01/08							
04/01/08							
04/15/08	101	133	204	183	692	91.6	
05/01/08							
05/23/08	66	73	<29	244	536	7.1	
05/27/08		95	<29	218	600	4.8	
05/30/08						10.8	
06/01/08							
06/02/08	91	132	<29	220	684	23.9	
06/05/08						24.8	
06/09/08		140	49	198	724	34.8	
07/01/08							
07/02/08	101	157	123	218	696	45.7	
08/01/08							
09/01/08							
10/01/08							
11/01/08							
12/01/08							
12/02/08	49	54	<29	193	456	<1.3	
12/08/08		55	<29	181	424	3.7	
12/15/08		60	<29	178	440	2.7	
12/22/08		67	45	182	468	3.0	
12/29/08		69	91	182	460	7.8	
01/01/09							
01/05/09	68	73	48	188	460	6.5	
01/09/09						1.6	
02/01/09							
03/01/09							
03/19/09							
03/25/09		149	63	216	756	25.1	
03/26/09						27.2	
03/27/09						28.8	
03/30/09		156	281	217	684	27.1	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-15)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
04/08/09	102	171	97	223	716	16.2	
04/10/09						27.3	
04/13/09		174	106	226	764	30.3	
04/15/09						24.0	
04/20/09		177	91	227	752	23.0	
04/23/09						21.5	
04/27/09		183	90	229	808	25.5	
04/30/09						18.6	
05/05/09	106	190	91	222	788	24.6	
05/08/09						20.4	
05/11/09		198	87	226	784	21.0	
05/13/09						24.0	
05/18/09		199	88	222	836	21.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-9.344			7.3		
06/24/02	x				4.70		7.8	708	27.5
07/05/02			x		1.30		8.0	849	29.0
07/11/02			x		2.90		7.6	1130	28.5
08/05/02	x						8.5	565	
08/27/02	x				7.80		8.2	485	30.0
09/03/02	x				7.20		8.0	565	35.0
09/10/02	x				7.40		8.1	446	26.7
09/17/02	x				5.70		8.1	432	25.8
09/24/02	x				5.90		8.2	444	27.6
10/01/02	x				6.00		8.3	423	28.2
10/08/02	x				6.30		8.1	423	27.0
10/15/02	x				6.60		8.0	426	27.6
10/22/02	x				5.70		8.3	462	27.5
10/29/02	x				6.40		8.3	470	28.0
11/05/02	x				5.70		8.1	447	26.5
11/12/02	x				6.50		8.1	471	26.0
11/19/02	x				7.00		8.1	464	23.1
11/26/02	x				7.00		8.4	470	22.3
12/03/02	x				7.70		8.0	464	23.0
12/10/02	x				5.50		8.1	465	20.0
12/18/02	x				5.80		8.3	469	20.0
12/23/02	x				5.80		8.4	451	19.0
12/31/02	x				6.50		8.4	430	19.0
01/07/03	x				8.00		8.5	420	18.5
01/14/03	x				7.50		8.2	410	18.5
01/21/03	x				7.90		8.5	407	17.0
01/28/03	x				9.90		8.2	399	16.0
02/03/03	x				9.20		7.8	394	17.0
02/11/03	x				8.50		8.2	428	18.5
02/18/03	x				5.10		8.2	435	20.0
02/25/03	x				7.90		8.1	447	21.2
03/03/03	x				7.50		8.3	455	22.4
03/11/03	x				5.00		8.3	472	24.1
03/18/03	x				7.20		8.3	474	24.1
03/27/03			x		2.30		8.3	522	23.4
04/01/03			x		3.40		8.0	631	25.3
04/08/03			x		1.30		7.9	714	26.3

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-9.344			7.3		
04/29/03			x		2.80		7.9	909	27.5
05/05/03			x		1.70		7.9	931	32.1
05/14/03			x		2.00		7.7	999	28.5
05/20/03			x		2.20		7.6	1045	30.6
05/28/03			x		2.40		7.8	1120	28.4
06/02/03			x		2.40		7.6	1155	28.8
07/01/03	x			14.271					
08/01/03	x			14.777			8.2	461	
09/01/03	x						8.4	387	
10/01/03	x						8.3	355	
11/01/03	x			11.599			8.2	412	
12/01/03	x			1.438			8.3	496	
01/06/04	x			3.162			8.5	541	
02/01/04		x							
03/09/04	x			6.972	6.05		8.3	542	21.5
04/14/04			x	-14.604			7.9	667	26.9
05/05/04			x	-26.638			8.0	698	27.1
05/12/04			x				7.9	723	27.3
05/19/04			x				7.9	773	28.0
05/26/04			x				7.8	822	28.0
06/03/04			x	-14.817			7.8	856	28.2
06/09/04			x				7.8	895	28.3
06/16/04			x					1140	28.9
07/13/04	x			8.412			8.4	684	30.0
08/02/04	x			5.074			8.2	580	30.0
09/13/04	x			5.348			8.5	502	29.0
10/05/04	x			8.494			8.3	388	28.0
11/02/04	x			6.530			8.5	348	26.0
12/09/04	x			3.058			8.2	431	22.5
01/06/05	x			4.872			8.4	480	19.0
02/03/05	x			5.196			8.2	489	19.0
03/01/05	x			8.783			8.2	523	21.5
04/06/05	x			3.949			8.5	449	24.0
04/29/05			x		2.21		8.2	530	25.5
05/03/05			x	-30.809	0.40		8.0	614	24.3
05/05/05			x						
05/09/05			x		0.41		8.0	687	25.4
05/12/05			x						
05/16/05			x		0.31	94	7.9	685	25.9

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-9.344			7.3		
05/26/05			x						
05/31/05			x			247	7.9	843	24.0
06/02/05			x						
06/06/05			x	-5.928	0.33	4	7.7	947	27.3
06/09/05			x						
06/14/05			x		0.37	-4	7.7	886	29.3
07/06/05	x			13.235	5.20	458	8.2	491	29.0
07/13/05	x				4.60	384	8.3	458	29.0
07/21/05	x				4.69	450	8.0	423	30.0
07/25/05	x				5.15	513	8.2	405	31.0
08/01/05	x			11.190					
08/02/05	x				3.75	430	8.1	384	30.5
08/09/05	x				4.90	476	8.2	377	30.0
08/16/05	x				5.13	465	8.3	367	30.0
08/22/05	x				4.99	478	8.2	375	31.0
08/29/05	x				4.36	420	8.2	366	30.0
09/07/05	x			8.408	4.22	412	8.2	364	32.0
09/13/05	x				5.20	331	8.7	355	30.0
09/20/05	x				5.41	472	8.1	371	30.0
09/27/05	x				5.19	442	8.2	375	29.0
11/01/05	x			8.295	5.10	524	8.1	395	23.0
11/08/05	x				5.73	513	8.2	388	24.0
11/14/05	x				5.54	449	8.4	373	24.0
11/18/05	x				5.20	453	8.3	372	
12/05/05	x			7.603	6.61	459	8.2	380	24.0
12/12/05	x				6.18	521	8.2	384	20.0
12/20/05	x				6.25	516	8.2	390	20.0
01/04/06	x			1.819	7.17	418	8.3	421	20.0
01/09/06	x				7.14	424	8.3	423	19.0
01/17/06	x				6.39	396	8.4	438	19.0
01/23/06	x				6.82	571	8.4	447	19.5
01/30/06	x				6.53	459	8.2	472	20.0
02/01/06		x							
03/01/06		x							
04/07/06			x	-23.321	0.88	37	8.0	468	23.3
04/11/06			x		0.28	195	8.1	541	24.8
04/13/06			x						
04/19/06			x		0.78	-17	8.4	536	28.8
04/21/06			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-9.344			7.3		
05/01/06			x	-33.360					
05/02/06			x			-22	8.0	777	28.6
05/04/06			x						
05/09/06			x			125	7.6	679	27.0
05/11/06			x						
05/15/06			x			-128	7.6	840	28.4
05/19/06			x						
05/23/06			x			99	8.0	815	26.5
05/25/06			x						
05/30/06			x			137	7.7	914	30.5
06/01/06			x	-31.283					
06/06/06			x		0.43	-140	7.7	906	30.3
06/12/06			x						
06/13/06			x		0.20	-133	7.7	1033	27.9
06/15/06			x						
06/20/06			x		0.53	-82	7.8	1019	29.9
06/23/06			x						
06/27/06			x		0.32	-172	8.0	1038	28.7
06/29/06			x						
06/30/06			x						
07/05/06			x	-9.005	0.25	-159	7.7	1325	28.9
07/11/06			x						
07/12/06		x							
08/04/06	x			13.143			8.2	720	
09/06/06	x			16.469			8.2	569	
10/03/06	x			3.991			8.1	452	
11/28/06			x	-2.517					
11/29/06			x		0.19	21	8.0	634	27.8
12/01/06			x	-27.542					
12/05/06			x		0.23	110	7.9	783	27.6
12/07/06			x						
12/12/06			x		0.06	156	7.8	832	26.4
12/14/06			x						
12/18/06			x		0.33	-67	7.9	899	28.7
12/21/06			x						
12/27/06			x		0.02	-28	7.8	1006	27.5
12/29/06		x							
01/02/07			x	-6.474	0.16	-126	7.8	1057	28.3
01/05/07			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-9.344			7.3		
01/16/07			x		0.21	-33	7.6	1080	28.2
01/18/07			x						
01/24/07			x		0.10	-92	7.9	1034	28.0
01/26/07			x						
01/29/07			x		0.05	-2	7.8	1097	25.9
02/01/07			x	-5.867					
02/05/07			x		0.02	106	7.9	1105	25.4
02/08/07			x						
02/12/07			x		0.08	161	7.9	1124	27.4
02/17/07			x						
02/20/07			x		0.12	61	7.9	1137	26.4
02/23/07			x						
02/27/07			x		0.31	-190	7.6	1104	29.2
03/01/07			x	-14.385					
03/02/07			x						
03/05/07			x		0.29	107	7.6	1156	28.4
03/08/07			x						
03/13/07			x		0.10	16	7.6	1177	27.5
03/16/07			x						
03/20/07			x		0.06	-183	7.8	1199	26.2
03/23/07			x						
03/26/07			x		0.27	-184	7.6	1209	28.5
03/28/07			x						
04/02/07			x	-29.834	0.21	-211	7.7	1246	28.4
04/06/07			x						
04/10/07			x		0.11	-239	7.6	1305	28.1
04/13/07			x						
04/17/07			x		0.09	-246	7.6	1350	27.0
04/20/07			x						
04/23/07			x		0.15	-210	7.6	1382	28.2
04/27/07			x						
05/02/07			x	-30.928	0.28	-218	7.7	1427	28.7
05/04/07			x						
05/08/07			x		0.22	-272	7.6	1378	26.6
05/11/07			x						
05/15/07			x		0.12	-175	7.6	1512	27.9
05/18/07			x						
05/22/07			x		0.12	-266	7.5	1543	28.0
05/25/07			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-9.344			7.3		
06/04/07			x		0.31	-214	7.4	1633	28.8
06/05/07			x						
06/08/07			x						
06/12/07			x		0.19	-231	7.4	1640	28.7
06/21/07			x						
06/26/07			x		0.28	-259	7.5	1734	28.6
06/28/07			x						
07/01/07			x	-2.430					
07/03/07			x		0.28	-194	7.5	1704	30.1
07/04/07		x							
08/14/07		x							
08/27/07	x			3.621					
09/01/07	x			30.352					
09/04/07	x				5.25	470	8.0	630	30.0
09/11/07	x				5.57	403	7.9	605	29.0
09/18/07	x				5.51	457	8.0	591	31.0
09/25/07	x				5.22	489	8.1	617	29.0
10/01/07	x			27.992					
10/02/07	x				5.36	390	8.1	617	27.0
10/09/07	x				5.54	387	8.1	628	29.0
10/16/07	x				4.81	595	8.3	620	28.0
10/23/07	x				4.84	325	8.0	640	28.0
10/30/07	x				5.24	465	8.1	649	26.0
11/01/07	x			7.651					
11/10/07			x						
12/05/07			x	-30.182	0.81	170	7.8	757	24.8
12/07/07			x						
12/11/07			x		0.12	193	8.0	868	25.9
12/14/07			x						
12/18/07			x		0.03	18	7.9	745	23.5
12/20/07			x						
12/27/07			x		0.07	-72	7.6	1018	25.2
12/28/07			x						
01/02/08			x	17.089	0.10	132	7.8	1116	24.0
01/04/08			x						
01/07/08			x		0.25	-204	7.9	925	28.1
01/10/08			x						
01/15/08			x		0.08	-130	7.8	1143	25.0
02/01/08		x							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-9.344			7.3		
04/15/08	x				0.10	54	7.6	1319	25.8
05/01/08	x			9.531					
05/23/08			x		0.42	112	7.7	904	26.3
05/27/08			x		0.64	-65	7.5	997	28.8
05/30/08			x						
06/01/08			x	9.622					
06/02/08			x		1.13	-195	7.5	1095	29.9
06/05/08			x						
06/09/08			x		0.31	-235	7.6	1120	29.9
07/01/08	x			9.218					
07/02/08	x				0.38	-139	7.8	1150	29.2
08/01/08	x			6.582					
09/01/08	x			7.518					
10/01/08	x			5.035					
11/01/08	x			2.677					
12/01/08			x	11.515					
12/02/08			x		0.52	97	7.7	762	21.4
12/08/08			x		0.04	119	8.0	850	24.3
12/15/08			x		0.02	118	8.0	916	26.7
12/22/08			x		<0.05	127	8.0	986	
12/29/08			x		0.03	87	8.0	1076	26.7
01/01/09				19.395					
01/05/09			x		0.08	5	7.8	1095	28.9
01/09/09			x						
01/12/09			x		0.14	13	7.8	1151	26.6
01/16/09			x						
01/21/09			x		0.13	40	7.9	927	25.8
01/23/09			x						
01/26/09			x		0.49	-97	7.8	1175	26.4
01/29/09			x						
02/01/09			x	5.432					
02/02/09			x		0.47	71	7.8	1284	26.0
02/05/09			x						
02/09/09			x		0.29	-296	7.8	1238	28.9
02/13/09			x						
03/01/09			x	30.036					
03/02/09			x		0.23	-35	7.9	1195	26.9
03/04/09			x						
03/09/09			x		0.24	-142	7.7	1259	25.5

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-9.344			7.3		
03/19/09			x						
03/25/09			x		0.10	-158	7.6	1480	24.6
03/26/09			x						
03/27/09			x						
03/30/09			x		0.09	-174	7.7	1549	23.7
04/03/09			x						
04/08/09			x		0.10	-152	7.8	1657	22.7
04/10/09			x						
04/13/09			x		0.47	-165	7.7	1604	26.2
04/15/09			x						
05/01/09		x							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		169	BDL			264	844	BDL	
06/24/02	38	53	35			135	388	<3.0	
07/05/02	60	83	<12.0			194	480	9.0	
07/11/02	126	190	<12.0			263	828	34.0	
08/05/02	34	55				154	356		
08/27/02	35	38	132			132	348	1.8	
09/03/02	34	38	73			140	304	2.5	
09/10/02	31	35	64			124	280	3.7	
09/17/02	35	30	61			147	252	1.7	
09/24/02	37	34	109			124	268	<1.0	
10/01/02	28	33	42			121	276	<1.0	
10/08/02	35	27	<30.0			107	308	<1.0	
10/15/02	33	26	<30.0			88	260	<1.0	
10/22/02	39	29	41			121	300	<1.0	
10/29/02	41	33	<30.0			101	528	2.0	
11/05/02	40	31	82			106	288	1.1	
11/12/02	42	31	53			124	280	<1.0	
11/19/02	43	29	25			123	284	<1.0	
11/26/02	40	31	63			127	332	<1.0	
12/03/02	35	33	<30.0			143	284	<1.0	
12/10/02	35	34	<30.0			114	292	<1.0	
12/18/02	34	32	<30.0			124	272	<1.0	
12/23/02	34	31	<30.0			120	308	<1.0	
12/31/02	32	34	72			124	252	2.4	
01/07/03	30	28	50			112	236	1.6	
01/14/03	28	30	<30.0			104	292	<1.0	
01/21/03	32	28	49			98	248	<1.0	
01/28/03	34	26	36			99	296	<1.0	
02/03/03	29	27	46			94	212	<1.0	
02/11/03	32	26	80			100	356	<1.0	
02/18/03	36	32	87			103	272	<1.0	
02/25/03	32	27	124			92	232	2.7	
03/03/03	32	35	57			111	248	<1.0	
03/11/03	37	25	<30.0			113	248	<1.0	
03/18/03	39	31	37			106	280	<1.0	
03/27/03	52	35	11			106	284	<1.0	
04/01/03	64	52	<6.0			123	376	6.0	
04/08/03	70	72	<6.0			152	412	13.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		169	BDL			264	844	BDL	
04/29/03	88	97	59			156	600	26.0	
05/05/03	92	102	22			155	576	31.0	
05/14/03	98	125	54			162	596	41.0	
05/20/03	114	202	217			194	752	9.0	
05/28/03	106	142	16			179	664	87.0	
06/02/03	106	150	<6.0			166	672	63.0	
07/01/03									
08/01/03		39				109	264		
09/01/03		31				100	260		
10/01/03		17				85	236		
11/01/03		27				106	288		
12/01/03		35				134	280		
01/06/04		37				143	340		
02/01/04									
03/09/04	43	157	30			159	344	1.0	
04/14/04	72	64	6			158	412	18.0	
05/05/04	70	77	6			156	432	19.0	
05/12/04	76	82	25			155	420	21.0	
05/19/04	76	87	28			192	0	21.0	
05/26/04	76	160	223			170	496	21.0	
06/03/04	82	112	67			200	552	22.0	
06/09/04	88	125	84			180	580	27.0	
06/16/04	106	170	206			224	720	38.0	
07/13/04	46	66	29			203	420	8.0	
08/02/04	42	46	29			157	376	5.1	
09/13/04	35	38	29			131	380	3.0	
10/05/04	30	28	29			99	248	1.3	
11/02/04	30	22	29			85	188	1.3	
12/09/04	37	29	29			122	264	2.5	
01/06/05	37	31	29			128	260	2.1	
02/03/05	34	30	29			122	336	1.3	
03/01/05	40	32	29			148	304	1.3	
04/06/05	31	27	<29.0			124	276	<1.3	
04/29/05	49	29	<29.0			128	320	1.3	
05/03/05		42	<29.0			144	364	3.3	
05/05/05								9.6	
05/09/05		49	<29.0			150	380	6.5	
05/12/05								9.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		169	BDL			264	844	BDL	
05/23/05		68	34			164	452	17.2	
05/26/05								18.5	
05/31/05		81	45			173	500	16.7	
06/02/05								23.0	
06/06/05		115	94			195	564	26.3	
06/09/05								28.6	
06/14/05		106	85			189	552	24.3	
07/06/05	31.5	43	<29.0			129	300	<1.3	
07/13/05		37	67			116	248	<1.3	
07/21/05		31	<29.0			113	268	1.8	
07/25/05		29	<29.0			108	252	2.3	
08/01/05									
08/02/05	32.5	27	<29.0			104	216	1.6	
08/09/05		26	<29.0			100	200	<1.3	
08/16/05		25	<29.0			100	204	<1.3	
08/22/05	25.5	25	55			100	240	<1.3	
08/29/05		25	<29.0			99	212	<1.3	
09/07/05	26.0	25	<29.0			99	252	1.7	
09/13/05		22	<29.0			100	272	<1.3	
09/20/05		26	<29.0			106	340	1.7	
09/27/05		23	<29.0			99	224	<1.3	
11/01/05		26	31			109	268	<1.3	
11/08/05		24	<29.0			107	276	<1.3	
11/14/05		23	<29.0			101	248	<1.3	
11/18/05		26	<29.0			115	252	2.4	
12/05/05		28	<29.0			112	236	<1.3	
12/12/05		28	38			120	288	3.6	
12/20/05		26	<29.0			111	260	<1.3	
01/04/06									
01/09/06									
01/17/06									
01/23/06									
01/30/06									
02/01/06									
03/01/06									
04/07/06		33	69			137	328	8.0	
04/11/06		37	32			134	328	5.2	
04/13/06								5.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		169	BDL			264	844	BDL	
04/26/06	64	56	36			149	436	9.2	
04/28/06								9.0	
05/01/06									
05/02/06		63	43			156	452	10.0	
05/04/06								8.0	
05/09/06		76	50			169	476	9.0	
05/11/06								13.0	
05/15/06		82	33			170	508	12.0	
05/19/06								16.0	
05/23/06		79	89			151	488	16.0	
05/25/06								18.8	
05/30/06		129	110			230	556	24.3	
06/01/06								17.0	
06/06/06		112	137			184	624	29.8	
06/12/06								33.8	
06/13/06	90	105	199			158	736	37.1	
06/15/06								37.0	
06/20/06		145	153			200	660	86.0	
06/23/06								58.0	
06/27/06		150	151			247	740	47.0	
06/29/06		150	119			178	752	62.0	
06/30/06								65.0	
07/05/06								42.0	
07/11/06								58.0	
07/12/06									
08/04/06		64				210	476		
09/06/06		54				162	464		
10/03/06		38				131	316		
11/28/06									
11/29/06	57	56	136			153	468	9.0	
12/01/06								4.0	
12/05/06		75	46			172	444	4.0	
12/07/06								4.5	
12/12/06		93	55			181	516	7.0	
12/14/06								7.0	
12/18/06		106	78			193	516	8.0	
12/21/06								14.5	
12/27/06		131	96			209	596	13.6	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		169	BDL			264	844	BDL	
01/05/07								16.1	
01/09/07		148	197			218	628	22.4	
01/12/07								29.0	
01/16/07		149	165			218	612	28.0	
01/18/07								31.9	
01/24/07		152	167			220	600	24.1	
01/26/07								23.5	
01/29/07		154	163			222	700	23.1	
02/01/07								26.5	
02/05/07		153	170			220	636	26.0	
02/08/07								23.8	
02/12/07		158	191			222	624	22.6	
02/17/07								18.5	
02/20/07		157	195			221	712	12.5	
02/23/07								29.3	
02/27/07		156	187			219	656	29.5	
03/01/07									
03/02/07								25.9	
03/05/07		159	196			225	652	22.1	
03/08/07								26.3	
03/13/07		164	163			218	740	35.6	
03/16/07								27.0	
03/20/07		169	146			223	692	27.0	
03/23/07								20.5	
03/26/07		177	132			225	756	23.4	
03/28/07								39.7	
04/02/07		185	163			222	656	40.9	
04/06/07								57.1	
04/10/07		200	169			231	756	52.7	
04/13/07								51.5	
04/17/07		220	163			238	776	20.6	
04/20/07								28.1	
04/23/07		225	178			240	796	85.9	
04/27/07								68.5	
05/02/07		237	175			237	832		
05/04/07								78.4	
05/08/07		245	168			244	896	65.0	
05/11/07								57.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		169	BDL			264	844	BDL	
05/22/07		272	166			253	852	70.5	
05/25/07								46.7	
05/29/07		279	168			255	896	33.8	
06/01/07									
06/04/07		289	179			259	936		
06/05/07								40.1	
06/08/07								53.0	
06/12/07	112	274	169	55	148	248	956	58.4	
06/21/07								41.5	
06/26/07		326	194			256	1048		
06/28/07								33.2	
07/01/07									
07/03/07	114	326	194	60	175	256	984	19.2	
07/04/07									
08/14/07									
08/27/07									
09/01/07									
09/04/07	39.5	48	<29.0	15	54	178	384	<1.3	
09/11/07		43	<29.0	15	52	173	400	<1.3	
09/18/07		43	<29.0	15	52	179	328	<1.3	
09/25/07		43	<29.0	15	55	185	380	<1.3	
10/01/07									
10/02/07	40	40	37	16	53	175	384	<1.3	
10/09/07		39	29	15	55	168	392	<1.3	
10/16/07		37	30	16	57	169	392	<1.3	
10/23/07		42	29	16	59	183	396	<1.3	
10/30/07		38	63	16	58	180	416	<1.3	
11/01/07									
11/10/07									
12/05/07	67	69	59	22	65	203	464	6.9	
12/07/07								5.8	
12/11/07		86	49			208	528	6.4	
12/14/07								14.0	
12/18/07		98	<29.0			215	524	<1.3	
12/20/07								13.2	
12/27/07		119	<29.0			216	548	<1.3	
12/28/07								12.4	
01/02/08	78.5	133	75	29	83	223	636	13.4	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		169	BDL			264	844	BDL	
01/10/08								17.6	
01/15/08		153	95			226	652	16.8	
02/01/08									
03/01/08									
04/01/08									
04/15/08	104	195	347	37	99	208	788	32.6	
05/01/08									
05/23/08	71	88	<29	28	83	225	612	7.4	
05/27/08		121	37			238	700	8.5	
05/30/08								11.6	
06/01/08									
06/02/08	90	169	80	37	100	248	776	15.0	
06/05/08								18.7	
06/09/08		188	110			247	836	23.0	
07/01/08									
07/02/08	108	189	202	46	111	241	796	23.9	
08/01/08									
09/01/08									
10/01/08									
11/01/08									
12/01/08									
12/02/08	54.5	63	<29	16	76	198	476	1..82	
12/08/08		76	<29			194	496	5.4	
12/15/08		88	<29			198	524	5.8	
12/22/08		104	72			206	548	6.9	
12/29/08		110	64			207	568	11.6	
01/01/09									
01/05/09	77	116	69	30	87	213	596	10.8	
01/09/09								3.0	
01/12/09		115	49			213	576	4.5	
01/16/09								7.2	
01/21/09		145	105			226	716	8.7	
01/23/09								9.3	
01/26/09		151	106			228	736	13.9	
01/29/09								17.2	
02/01/09									
02/02/09	82.8	160	113	40	108	229	688	13.5	
02/05/09								21.9	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-18)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	Mg mg/L	Na mg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		169	BDL			264	844	BDL	
03/01/09									
03/02/09	93.5	161	119	34	93	225	704	26.4	
03/04/09								16.0	
03/09/09		176	91			230	744	28.6	
03/12/09								14.7	
03/16/09		203	107			240	784	15.8	
03/19/09								35.3	
03/25/09		235	138			245	912		
03/26/09								31.5	
03/27/09								31.2	
03/30/09		241	129			234	904	28.2	
04/03/09								31.2	
04/08/09	108	262	137	52	143	255	960	12.1	
04/10/09								25.5	
04/13/09		275	141			247	972	29.3	
04/15/09								22.1	
05/01/09									

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
06/24/02	x				4.70		7.8	708	27.5
07/05/02			x		1.10		7.8	1040	28.0
07/11/02			x		2.60		7.6	1460	28.5
08/05/02	x						8.5	565	
08/27/02	x				7.80		8.2	485	30.0
09/03/02	x				7.20		8.0	565	35.0
09/10/02	x				7.40		8.1	446	26.7
09/17/02	x				5.70		8.1	432	25.8
09/24/02	x				5.90		8.2	444	27.6
10/01/02	x				6.00		8.3	423	28.2
10/08/02	x				6.30		8.1	423	27.0
10/15/02	x				6.60		8.0	426	27.6
10/22/02	x				5.70		8.3	462	27.5
10/29/02	x				6.40		8.3	470	28.0
11/05/02	x				5.70		8.1	447	26.5
11/12/02	x				6.50		8.1	471	26.0
11/19/02	x				7.00		8.1	464	23.1
11/26/02	x				7.00		8.4	470	22.3
12/03/02	x				7.70		8.0	464	23.0
12/10/02	x				5.50		8.1	465	20.0
12/18/02	x				5.80		8.3	469	20.0
12/23/02	x				5.80		8.4	451	19.0
12/31/02	x				6.50		8.4	430	19.0
01/07/03	x				8.00		8.5	420	18.5
01/14/03	x				7.50		8.2	410	18.5
01/21/03	x				7.90		8.5	407	17.0
01/28/03	x				9.90		8.2	399	16.0
02/03/03	x				9.20		7.8	394	17.0
02/11/03	x				8.50		8.2	428	18.5
02/18/03	x				5.10		8.2	435	20.0
02/25/03	x				7.90		8.1	447	21.2
03/03/03	x				7.50		8.3	455	22.4
03/11/03	x				5.00		8.3	472	24.1
03/18/03	x				7.20		8.3	474	24.1
03/27/03			x		1.20		8.1	658	24.0
04/01/03			x		4.00		7.9	896	25.3
04/08/03			x		2.00		7.7	986	27.4

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
04/29/03			x		2.70		7.8	1165	28.2
05/05/03			x		2.10		7.7	1174	31.9
05/14/03			x		2.10		7.7	1250	29.4
05/20/03			x		1.70		7.7	1295	30.8
05/28/03			x		2.50		7.7	1387	29.6
06/02/03			x		1.70		7.6	1406	29.8
07/01/03	x			14.130					
08/01/03	x			14.693			8.2	461	
09/01/03	x			14.473			8.4	387	
10/01/03	x						8.3	355	
11/01/03	x			11.685			8.2	412	
12/01/03	x						8.3	496	
01/06/04	x			3.262			8.5	541	
02/01/04		x							
03/09/04	x			7.069	6.05		8.3	542	21.5
04/14/04			x	-14.483			7.8	914	27.5
05/05/04			x	-26.725			7.8	938	28.0
05/12/04			x				7.7	942	27.3
05/19/04			x				7.7	1017	29.1
05/26/04			x				7.7	1080	29.2
06/03/04			x	-15.394			7.7	1160	29.7
06/09/04			x				7.7	1220	29.6
06/16/04			x				7.7	1220	29.9
07/13/04	x			8.406			8.4	684	30.0
08/02/04	x			5.112			8.2	580	30.0
09/13/04	x			5.425			8.5	502	29.0
10/05/04	x			8.687			8.3	388	28.0
11/02/04	x			6.624			8.5	348	26.0
12/09/04	x			3.046			8.2	431	22.5
01/06/05	x			4.879			8.4	480	19.0
02/03/05	x			5.234			8.2	489	19.0
03/01/05	x			8.825			8.2	523	21.5
04/06/05	x			3.921			8.5	449	24.0
04/29/05			x		0.37		8.0	641	25.4
05/03/05			x	-29.649	0.46		7.8	793	25.6
05/05/05			x						
05/09/05			x		0.41		7.8	892	26.5
05/12/05			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
05/23/05			x		0.72	179	7.8	975	27.3
05/26/05			x						
05/31/05			x			231	7.8	1000	23.2
06/02/05			x						
06/06/05			x	-7.277	0.60	-94	7.7	1084	28.8
06/09/05			x						
06/14/05			x		0.33	-105	7.7	1173	29.5
07/06/05	x			13.24	5.20	458	8.2	491	29.0
07/13/05	x				4.60	384	8.3	458	29.0
07/21/05	x				4.69	450	8.0	423	30.0
07/25/05	x				5.15	513	8.2	405	31.0
08/01/05	x			11.269					
08/02/05	x				3.75	430	8.1	384	30.5
08/09/05	x				4.90	476	8.2	377	30.0
08/16/05	x				5.13	465	8.3	367	30.0
08/22/05	x				4.99	478	8.2	375	31.0
08/29/05	x				4.36	420	8.2	366	30.0
09/07/05	x			8.350	4.22	412	8.2	364	32.0
09/13/05	x				5.20	331	8.7	355	30.0
09/20/05	x				5.41	472	8.1	371	30.0
09/27/05	x				5.19	442	8.2	375	29.0
11/01/05	x			8.460	5.10	524	8.1	395	23.0
11/08/05	x				5.73	513	8.2	388	24.0
11/14/05	x				5.54	449	8.4	373	24.0
11/18/05	x				5.20	453	8.3	372	
12/05/05	x			7.572	6.61	459	8.2	380	24.0
12/12/05	x				6.18	521	8.2	384	20.0
12/20/05	x				6.25	516	8.2	390	20.0
01/04/06	x			1.837	7.17	418	8.3	421	20.0
01/09/06	x				7.14	424	8.3	423	19.0
01/17/06	x				6.39	396	8.4	438	19.0
01/23/06	x				6.82	571	8.4	447	19.5
01/30/06	x				6.53	459	8.2	472	20.0
02/01/06		x							
03/01/06		x							
04/07/06			x	-23.347	1.00	-104	7.8	607	24.2
04/11/06			x		0.32	89	8.0	738	25.1
04/13/06			x						
04/19/06			x		0.78	-104	8.4	756	29.0

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
04/28/06			x						
05/01/06			x	-33.094					
05/02/06			x		0.42	-150	8.0	1089	29.3
05/04/06			x						
05/09/06			x		0.51	36	7.6	943	27.0
05/11/06			x						
05/15/06			x		0.27	-210	7.6	1131	29.1
05/19/05			x						
05/23/06			x		0.14	-55	7.8	1100	27.9
05/25/06			x						
05/30/06			x		0.44	-85	7.6	1254	31.2
06/01/06			x	-31.261					
06/06/06			x		0.44	-85	7.7	1233	30.4
06/12/06			x						
06/13/06			x		0.43	-217	7.8	1390	28.7
06/15/06			x						
06/20/06			x		0.18	-232	7.7	1372	30.7
06/23/06			x						
06/27/06			x		0.49	-187	7.7	1530	31.3
06/29/06			x		0.21	-206			
06/30/06			x						
07/05/06			x	-8.878	0.31	-189	7.8	1379	30.2
07/11/06			x						
07/12/06		x							
08/04/06	x			13.208			8.2	720	
09/06/06	x			16.554			8.2	569	
10/03/06	x			4.011			8.1	452	
11/28/06			x	-2.482					
11/29/06			x		0.22	-64	7.8	849	28.3
12/01/06			x	-21.346					
12/05/06			x		0.18	-44	7.7	1046	28.0
12/07/06			x						
12/12/06			x		0.08	-70	7.7	1156	27.6
12/14/06			x						
12/18/06			x		0.25	-114	7.7	1204	29.5
12/21/06			x						
12/27/06			x		0.04	-119	7.7	1352	27.3
12/29/06		x							
01/02/07			x	-6.776	0.15	-142	7.7	1390	29.1

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
01/12/07			x						
01/16/07			x		0.15	-186	7.6	1414	28.9
01/18/07			x						
01/24/07			x		0.09	-158	7.7	1363	28.7
01/26/07			x						
01/29/07			x		0.04	-105	7.7	1430	26.4
02/01/07			x	-5.712					
02/05/07			x		0.01	-6	7.7	1471	26.8
02/08/07			x						
02/12/07			x		0.10	75	7.9	1505	28.3
02/17/07			x						
02/20/07			x		0.10	-68	7.7	1509	27.8
02/23/07			x						
02/27/07			x		0.27	-211	7.5	1466	30.1
03/01/07			x	-15.256					
03/02/07			x						
03/05/07			x		0.27	67	7.6	1536	29.0
03/08/07			x						
03/13/07			x		0.04	-231	7.6	1561	28.7
03/16/07			x						
03/20/07			x		0.05	-307	7.8	1619	28.0
03/23/07			x						
03/26/07			x		0.31	-227	7.6	1628	29.8
03/28/07			x						
04/02/07			x	-8.696	0.15	-249	7.6	1710	29.5
04/06/07			x						
05/01/07		x							
06/01/07			x	-1.973					
06/21/07			x						
07/01/07		x							
08/14/07		x							
08/27/07	x			3.614					
09/01/07	x			30.704					
09/04/07	x				5.25	470	8.0	630	30.0
09/11/07	x				5.57	403	7.9	605	29.0
09/18/07	x				5.51	457	8.0	591	31.0
09/25/07	x				5.22	489	8.1	617	29.0
10/01/07	x			27.565					27.0
10/02/07	x				5.36	390	8.1	617	29.0

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality							7.5		
10/23/07	x				4.84	325	8.0	640	26.0
10/30/07	x				5.24	465	8.1	649	
11/01/07	x			7.483			7.7	938	
12/05/07			x	-7.098	0.24	65	7.8	1278	25.3
12/07/07			x						
12/11/07			x		0.07	89			26.1
01/01/08		x							
02/01/08		x							
03/01/08		x							
04/01/08	x			9.117					
04/15/08	x				0.09	44	7.6	1530	25.4
05/01/08	x			5.923					
05/23/08			x		0.34	90	7.6	1133	26.7
05/27/08			x		0.65	-157	7.4	1289	29.9
05/30/08			x						
06/01/08		x							
07/01/08	x			9.312					
07/02/08	x				0.36	-167	7.6	1457	30.1
08/01/08	x			6.687					
09/01/08	x			7.607					
10/01/08	x			5.152					
11/01/08	x			2.711					
12/01/08			x	9.957					
12/02/08			x		0.15				
12/08/08			x		0.02	116	7.9	928	22.4
12/15/08			x		0.02	103	7.8	1158	23.4
12/22/08			x		<0.05	-76	7.9	1258	27.2
12/29/08		x				81	7.9	1280	25.9
01/01/09		x							
02/01/09		x							
03/01/09			x	4.827					
03/09/09			x		0.05	-193	7.7	1680	26.4
04/01/09		x							
05/01/09		x							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		222	BDL	263	1054	BDL	
06/24/02	38	53	35	135	388	<3.0	
07/05/02	72	118	<12.0	218	576	10.0	
07/11/02	120	230	110	263	936	23.0	
08/05/02	34	55		154	356		
08/27/02	35	38	132	132	348	1.8	
09/03/02	34	38	73	140	304	2.5	
09/10/02	31	35	64	124	280	3.7	
09/17/02	35	30	61	147	252	1.7	
09/24/02	37	34	109	124	268	<1.0	
10/01/02	28	33	42	121	276	<1.0	
10/08/02	35	27	<30.0	107	308	<1.0	
10/15/02	33	26	<30.0	88	260	<1.0	
10/22/02	39	29	41	121	300	<1.0	
10/29/02	41	33	<30.0	101	528	2.0	
11/05/02	40	31	82	106	288	1.1	
11/12/02	42	31	53	124	280	<1.0	
11/19/02	43	29	25	123	284	<1.0	
11/26/02	40	31	63	127	332	<1.0	
12/03/02	35	33	<30.0	143	284	<1.0	
12/10/02	35	34	<30.0	114	292	<1.0	
12/18/02	34	32	<30.0	124	272	<1.0	
12/23/02	34	31	<30.0	120	308	<1.0	
12/31/02	32	34	72	124	252	2.4	
01/07/03	30	28	50	112	236	1.6	
01/14/03	28	30	<30.0	104	292	<1.0	
01/21/03	32	28	49	98	248	<1.0	
01/28/03	34	26	36	99	296	<1.0	
02/03/03	29	27	46	94	212	<1.0	
02/11/03	32	26	80	100	356	<1.0	
02/18/03	36	32	87	103	272	<1.0	
02/25/03	32	27	124	92	232	2.7	
03/03/03	32	35	57	111	248	<1.0	
03/11/03	37	25	<30.0	113	248	<1.0	
03/18/03	39	31	37	106	280	<1.0	
03/27/03	70	55	<6.0	128	348	5.0	
04/01/03	90	110	<6.0	178	512	22.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		222	BDL	263	1054	BDL	
04/22/03	100	150	290	183	648	26.0	
04/29/03	104	147	287	195	716	22.0	
05/05/03	108	165	315	195	792	19.0	
05/14/03	110	177	280	178	832	16.0	
05/20/03	100	140	49	155	608	53.0	
05/28/03	118	207	251	195	828	16.0	
06/02/03	120	225	142	194	828	15.0	
07/01/03							
08/01/03		39		109	264		
09/01/03		31		100	260		
10/01/03		17		85	236		
11/01/03		27		106	288		
12/01/03		35		134	280		
01/06/04		37		143	340		
02/01/04							
03/09/04	43	157	30	159	344	1.0	
04/14/04	90	120	124	141	568	23.0	
05/05/04	94	122	200	197	568	23.0	
05/12/04	96	130	230	211	636	23.0	
05/19/04	102	142	290	207	604	19.0	
05/26/04	98	130	270	221	688	16.0	
06/03/04	108	187	280	232	736	13.0	
06/09/04	108	195	250	197	796	13.0	
06/16/04	112	220	210	254	904	10.0	
07/13/04	46	66	29	203	420	8.0	
08/02/04	42	46	29	157	376	5.1	
09/13/04	35	38	29	131	380	3.0	
10/05/04	30	28	29	99	248	1.3	
11/02/04	30	22	29	85	188	1.3	
12/09/04	37	29	29	122	264	2.5	
01/06/05	37	31	29	128	260	2.1	
02/03/05	34	30	29	122	336	1.3	
03/01/05	40	32	29	148	304	1.3	
04/06/05	31	27	<29.0	124	276	<1.3	
04/29/05	63	41	39	151	408	3.4	
05/03/05		75	<29.0	180	520	11.6	
05/05/05						10.7	
05/09/05		93	66	188	512	14.3	
05/12/05						17.4	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		222	BDL	263	1054	BDL	
05/23/05		115	230	196	620	17.8	
05/26/05						17.7	
05/31/05		131	319	205	628	18.7	
06/02/05						17.9	
06/06/05		146	298	213	636	14.9	
06/09/05						14.1	
06/14/05		131	343	215	644	13.6	
07/06/05	32	43	<29.0	129	300	<1.3	
07/13/05		37	67	116	248	<1.3	
07/21/05		31	<29.0	113	268	1.8	
07/25/05		29	<29.0	108	252	2.3	
08/01/05							
08/02/05	33	27	<29.0	104	216	1.6	
08/09/05		26	<29.0	100	200	<1.3	
08/16/05		25	<29.0	100	204	<1.3	
08/22/05	26	25	55	100	240	<1.3	
08/29/05		25	<29.0	99	212	<1.3	
09/07/05	26	25	<29.0	99	252	1.7	
09/13/05		22	<29.0	100	272	<1.3	
09/20/05		26	<29.0	106	340	1.7	
09/27/05		23	<29.0	99	224	<1.3	
11/01/05		26	31	109	268	<1.3	
11/08/05		24	<29.0	107	276	<1.3	
11/14/05		23	<29.0	101	248	<1.3	
11/18/05		26	<29.0	115	252	2.4	
12/05/05		28	<29.0	112	236	<1.3	
12/12/05		28	38	120	288	3.6	
12/20/05		26	<29.0	111	260	<1.3	
01/04/06							
01/09/06							
01/17/06							
01/23/06							
01/30/06							
02/01/06							
03/01/06							
04/07/06		57	341	176	424	12.0	
04/11/06		68	133	171	500	9.8	
04/13/06						17.0	
04/19/06		73	165	187	548	14.9	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		222	BDL	263	1054	BDL	
04/28/06						14.0	
05/01/06							
05/02/06		112	218	193	632	13.0	
05/04/06						9.0	
05/09/06		130	254	206	676	9.0	
05/11/06						10.0	
05/15/06		116	220	173	716	16.0	
05/19/05						11.0	
05/23/06		151	344	218	696	9.0	
05/25/06						10.9	
05/30/06		199	302	265	784	13.5	
06/01/06						8.6	
06/06/06		175	286	222	896	29.2	
06/12/06						11.2	
06/13/06	109	173	269	192	876	8.8	
06/15/06						9.0	
06/20/06		226	242	230	900	10.0	
06/23/06						8.0	
06/27/06		220	239	272	936	8.0	
06/29/06		240	176	178	964	5.0	
06/30/06						11.0	
07/05/06		240	195	213		3.5	
07/11/06						8.0	
07/12/06							
08/04/06		64		210	476		
09/06/06		54		162	464		
10/03/06		38		131	316		
11/28/06							
11/29/06	74	108	317	195	596	18.0	
12/01/06						13.0	
12/05/06		148	277	219	636	6.0	
12/07/06						5.8	
12/12/06		168	269	230	720	5.0	
12/14/06						2.0	
12/18/06		178	304	228	700	4.0	
12/21/06						7.6	
12/27/06		210	270	250	788	6.5	
12/29/06						5.4	
01/02/07		222	352	253	800	4.3	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		222	BDL	263	1054	BDL	
01/12/07						6.0	
01/16/07		232	311	255	792	<1.3	
01/18/07						4.2	
01/24/07		237	286	256	800	8.2	
01/26/07						5.7	
01/29/07		241	311	259	864	7.8	
02/01/07						3.5	
02/05/07		246	265	260	920	5.6	
02/08/07						2.7	
02/12/07		248	287	259	840	1.6	
02/17/07						<1.3	
02/20/07		251	268	263	916	<1.3	
02/23/07						1.5	
02/27/07		250	252	260	864	4.2	
03/01/07							
03/02/07						3.6	
03/05/07		251	263	261	860	3.5	
03/08/07						3.3	
03/13/07		260	207	258	936	4.4	
03/16/07						3.6	
03/20/07		268	177	266	896	3.8	
03/23/07						<1.3	
03/26/07		276	206	267	1004	<1.3	
03/28/07						7.9	
04/02/07		294	210	265	940	6.3	
04/06/07						8.3	
05/01/07							
06/01/07							
06/21/07						1.4	
07/01/07							
08/14/07							
08/27/07							
09/01/07							
09/04/07	40	48	<29.0	178	384	<1.3	
09/11/07		43	<29.0	173	400	<1.3	
09/18/07		43	<29.0	170	328	<1.3	
09/25/07		43	<29.0	185	380	<1.3	
10/01/07							
10/02/07	40	40	37	175	384	<1.3	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-19)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		222	BDL	263	1054	BDL	
10/23/07		42	29	183	396	<1.3	
10/30/07		38	63	180	416	<1.3	
11/01/07		124		226	544		
12/05/07	77	187	315	246	768	12.9	
12/07/07						16.2	
12/11/07			247			12.2	
01/01/08							
02/01/08							
03/01/08							
04/01/08							
04/15/08	113	243	534	228	908	17.6	
05/01/08							
05/23/08		158	70	254	760	12.1	
05/27/08		197	213	235	844	9.7	
05/30/08							
06/01/08							
07/01/08							
07/02/08	110	275	416	272	1008	8.5	
08/01/08							
09/01/08							
10/01/08							
11/01/08							
12/01/08							
12/02/08							
12/08/08	69	101	<29	217	580	6.5	
12/15/08		146	<29	226	696	7.9	
12/22/08		161	139	231	724	6.4	
12/29/08		172	291	234	756	6.8	
01/01/09							
02/01/09							
03/01/09							
03/09/09		277	166	267	972	5.2	
04/01/09							
05/01/09							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-11.090			7.6		
06/24/02	x				4.70		7.8	708	27.5
07/05/02			x		1.20		7.9	815	28.0
07/11/02			x		2.60		7.7	1260	29.0
08/05/02	x						8.5	565	
08/27/02	x				7.80		8.2	485	30.0
09/03/02	x				7.20		8.0	565	35.0
09/10/02	x				7.40		8.1	446	26.7
09/17/02	x				5.70		8.1	432	25.8
09/24/02	x				5.90		8.2	444	27.6
10/01/02	x				6.00		8.3	423	28.2
10/08/02	x				6.30		8.1	423	27.0
10/15/02	x				6.60		8.0	426	27.6
10/22/02	x				5.70		8.3	462	27.5
10/29/02	x				6.40		8.3	470	28.0
11/05/02	x				5.70		8.1	447	26.5
11/12/02	x				6.50		8.1	471	26.0
11/19/02	x				7.00		8.1	464	23.1
11/26/02	x				7.00		8.4	470	22.3
12/03/02	x				7.70		8.0	464	23.0
12/10/02	x				5.50		8.1	465	20.0
12/18/02	x				5.80		8.3	469	20.0
12/23/02	x				5.80		8.4	451	19.0
12/31/02	x				6.50		8.4	430	19.0
01/07/03	x				8.00		8.5	420	18.5
01/14/03	x				7.50		8.2	410	18.5
01/21/03	x				7.90		8.5	407	17.0
01/28/03	x				9.90		8.2	399	16.0
02/03/03	x				9.20		7.8	394	17.0
02/11/03	x				8.50		8.2	428	18.5
02/18/03	x				5.10		8.2	435	20.0
02/25/03	x				7.90		8.1	447	21.2
03/03/03	x				7.50		8.3	455	22.4
03/11/03	x				5.00		8.3	472	24.1
03/18/03	x				7.20		8.3	474	24.1
03/27/03			x		2.70		8.2	557	23.6
04/01/03			x		2.70		8.0	708	25.9
04/08/03			x		1.60		7.8	827	27.3
04/15/03			x		3.00		7.7	898	28.3

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-11.090			7.6		
05/05/03			x		1.20		7.7	1041	31.5
05/14/03			x		2.30		7.7	1101	29.1
05/20/03			x		1.90		7.6	1127	30.2
05/28/03			x		1.80		7.7	1185	29.3
06/02/03			x		2.10		7.7	1186	29.2
07/01/03	x			14.392					
08/01/03	x			14.879			8.2	461	
09/01/03	x			14.432			8.4	387	
10/01/03	x						8.3	355	
11/01/03	x			11.633			8.2	412	
12/01/03	x						8.3	496	
01/06/04	x			3.255			8.5	541	
02/01/04		x							
03/09/04	x			6.991	6.05		8.3	542	21.5
04/14/04			x	-14.051			7.9	761	27.2
05/05/04			x	-26.686			7.9	815	27.6
05/12/04			x				7.8	847	28.0
05/19/04			x				7.8	904	28.4
05/26/04			x				7.8	948	28.6
06/03/04			x	-15.496			7.7	990	28.9
06/09/04			x				7.7	1020	28.9
06/16/04			x				7.7	1080	29.2
07/13/04	x			8.425			8.4	684	30.0
08/02/04	x			5.008			8.2	580	30.0
09/13/04	x			5.342			8.5	502	29.0
10/05/04	x			8.558			8.3	388	28.0
11/02/04	x			6.583			8.5	348	26.0
12/09/04	x			3.063			8.2	431	22.5
01/06/05	x			4.860			8.4	480	19.0
02/03/05	x			5.201			8.2	489	19.0
03/01/05	x			8.767			8.2	523	21.5
04/06/05	x			4.268			8.5	449	24.0
04/29/05			x		0.98		8.1	562	25.6
05/03/05			x	-30.632	0.47		7.9	684	24.8
05/05/05			x						
05/09/05			x		0.43		7.9	738	26.2
05/12/05			x						
05/16/05			x		0.37	6	7.8	785	26.7
05/19/05			x						

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-11.090			7.6		
05/31/05			x			215	7.9	935	24.1
06/02/05			x						
06/06/05			x	-7.239	0.28	-107	7.7	962	28.4
06/09/05			x						
06/14/05			x		0.30	-90	7.7	1017	28.7
07/06/05	x			13.281	5.20	458	8.2	491	29.0
07/13/05	x				4.60	384	8.3	458	29.0
07/21/05	x				4.69	450	8.0	423	30.0
07/25/05	x				5.15	513	8.2	405	31.0
08/01/05	x			11.309					
08/02/05	x				3.75	430	8.1	384	30.5
08/09/05	x				4.90	476	8.2	377	30.0
08/16/05	x				5.13	465	8.3	367	30.0
08/22/05	x				4.99	478	8.2	375	31.0
08/29/05	x				4.36	420	8.2	366	30.0
09/07/05	x			8.455	4.22	412	8.2	364	32.0
09/13/05	x				5.20	331	8.7	355	30.0
09/20/05	x				5.41	472	8.1	371	30.0
09/27/05	x				5.19	442	8.2	375	29.0
11/01/05	x			8.360	5.10	524	8.1	395	23.0
11/08/05	x				5.73	513	8.2	388	24.0
11/14/05	x				5.54	449	8.4	373	24.0
11/18/05	x				5.20	453	8.3	372	
12/05/05	x			7.571	6.61	459	8.2	380	24.0
12/12/05	x				6.18	521	8.2	384	20.0
12/20/05	x				6.25	516	8.2	390	20.0
01/04/06	x			1.835	7.17	418	8.3	421	20.0
01/09/06	x				7.14	424	8.3	423	19.0
01/17/06	x				6.39	396	8.4	438	19.0
01/23/06	x				6.82	571	8.4	447	19.5
01/30/06	x				6.53	459	8.2	472	20.0
02/01/06		x							
03/01/06		x							
04/07/06			x	-23.449	0.83	38	7.9	483	24.1
04/11/06			x		0.41	143	8.0	598	24.8
04/13/06			x						
04/19/06			x		0.72	-57	8.5	645	29.0
04/21/06			x						
04/26/06			x		0.63	-25	7.7	820	28.6

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-11.090			7.6		
05/02/06			x		0.41	-122	7.9	941	29.1
05/04/06			x						
05/09/06			x		0.84	44	7.6	836	27.3
05/11/06			x						
05/15/06			x		0.29	-195	7.6	984	28.5
05/19/06			x						
05/23/06			x		0.17	-96	8.0	942	27.1
05/25/06			x						
05/30/06			x		0.47	-104	7.7	1053	30.6
06/01/06			x	-31.507					
06/06/06			x		0.46	-210	7.7	1013	30.8
06/12/06			x						
06/13/06			x		0.23	-214	7.7	1137	28.7
06/15/06			x						
06/20/06			x		0.62	-151	7.7	1095	30.5
06/23/06			x						
06/27/06			x		0.32	-193	7.9	1266	30.0
06/29/06			x						
06/30/06			x						
07/05/06			x	-9.044	0.31	-189	7.8	1379	30.2
07/11/06			x						
07/12/06		x							
08/04/06	x			13.188			8.2	720	
09/06/06	x			16.518			8.2	569	
10/03/06	x			3.994			8.1	452	
11/28/06			x	-2.546					
11/29/06			x		0.24	-35	7.9	660	28.7
12/01/06			x	-27.461					
12/05/06			x		0.27	55	7.9	839	28.1
12/07/06			x						
12/12/06			x		0.18	-56	7.8	960	27.5
12/14/06			x						
12/18/06			x		0.34	-101	7.8	1038	29.1
12/21/06			x						
12/27/06			x		0.08	-101	7.8	1142	27.3
12/29/06		x							
01/02/07			x	-6.077	0.14	-130	7.8	1220	29.1
01/05/07			x						
01/09/07			x		0.18	-84	7.8	1160	27.9

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-11.090			7.6		
01/18/07			x						
01/24/07			x		0.08	-139	7.8	1190	28.3
01/26/07			x						
01/29/07			x		0.03	-106	7.7	1238	28.0
02/01/07			x	-5.251					
02/05/07			x		0.02	-4	7.8	1252	27.5
02/08/07			x						
02/12/07			x		0.10	88	7.9	1288	28.3
02/17/07			x						
02/20/07			x		0.17	-80	7.8	1274	28.4
02/23/07			x						
02/27/07			x		0.27	-178	7.6	1243	29.6
03/01/07			x	-15.238					
03/02/07			x						
03/05/07			x		0.34	24	7.6	1286	28.6
03/08/07			x						
03/13/07			x		0.05	-197	7.7	1279	27.3
03/16/07			x						
03/20/07			x		0.08	-294	7.9	1307	28.0
03/23/07			x						
03/26/07			x		0.35	-209	7.7	1317	29.2
03/28/07			x						
04/02/07			x	-29.883	0.15	-227	7.7	1311	28.4
04/06/07			x						
04/10/07			x		0.13	-271	7.6	1350	28.8
04/13/07			x						
04/17/07			x		0.10	-289	7.6	1403	28.4
04/20/07			x						
04/23/07			x		0.10	-222	7.5	1453	28.2
04/27/07			x						
05/02/07			x	-31.040	0.26	-226	7.6	1493	29.6
05/04/07			x						
05/08/07			x		0.30	-392	7.6	1432	27.4
05/11/07			x						
05/15/07			x		0.12	-184	7.5	1564	27.8
05/18/07			x						
05/22/07			x		0.14	-292	7.5	1570	28.5
05/25/07			x						
05/29/07			x		0.28	-243	7.5	1577	29.1

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. μS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-11.090			7.6		
06/05/07			x						
06/08/07			x						
06/12/07			x		0.22	-272	7.8	1640	29.3
06/15/07			x						
06/19/07			x		25.00	-224	7.4	1689	28.6
06/21/07			x						
06/26/07			x		0.34	-293	7.5	1656	29.4
06/28/07			x						
07/01/07			x	-0.575					
07/03/07			x		0.29	-239	7.6	1638	30.4
07/05/07			x		0.27	-283	7.5	1643	29.3
07/06/07		x							
08/01/07		x							
09/01/07	x			0.002					
09/04/07	x				5.25	470	8.0	630	30.0
09/11/07	x				5.57	403	7.9	605	29.0
09/18/07	x				5.51	457	8.0	591	31.0
09/25/07	x				5.22	489	8.1	617	29.0
10/01/07		x							
11/01/07		x							
12/01/07		x							
01/01/08		x							
02/01/08		x							
03/01/08		x							
04/01/08	x			8.906					
04/15/08	x				0.11	43	7.6	1351	26.6
05/01/08	x			9.597					
05/23/08			x		0.42	94	7.7	965	26.9
05/27/08			x		0.57	-149	7.5	1100	29.5
05/30/08			x						
06/01/08			x	8.150					
06/02/08			x		2.23	-224	7.4	1223	31.2
06/05/08			x						
06/09/08			x		0.32	-257	7.5	1288	30.2
07/01/08	x			9.190					
07/02/08	x				0.38	-159.1	7.7	1284	30.1
08/01/08	x			5.924					
09/01/08	x			5.726					
10/01/08	x			5.154					

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Recharge	Storage	Recovery	Total Monthly Volume MG	DO mg/L	ORP mV	pH std. units	Spec. Cond. µS/cm	Temp. °C
					Field	Field	Field	Field	Field
2/01 Initial Quality				-11.090			7.6		
12/02/08			x		0.10	105.1	8.1	793	22.8
12/08/08			x		0.02	127.5	8.0	966	24.3
12/15/08			x		0.03	-50.9	8.0	1056	26.7
12/22/08			x		0.05	105.3	8.0	1127	26.1
12/29/08			x		0.02	80.5	7.9	1252	26.8
01/01/09			x	19.938					
01/05/09			x		0.06	-74.2	7.8	1289	29.3
01/09/09			x						
01/12/09			x		0.10	7.3	7.8	1372	27.2
01/16/09			x						
01/21/09			x		0.09	64.1	7.7	1095	25.8
01/23/09			x						
01/26/09			x		0.64	-115.4	7.8	1386	27.3
01/29/09			x						
02/01/09			x	2.025					
02/02/09			x		0.59	15.3	7.7	1457	26.1
03/01/09			x	27.647					
01/00/00			x		0.57	-180.1	7.7	1395	27.1
03/12/09			x						
01/00/00			x		0.53	-144.7	7.7	1491	28.0
03/19/09			x						
03/25/09			x		0.04	-196.4	7.7	1580	24.9
03/26/09			x						
03/27/09			x						
03/30/09			x		0.25	-206.4	7.7	1647	24.2
04/03/09			x						
04/08/09			x		0.08	-174.4	7.7	1708	24.0
04/10/09			x						
04/13/09			x		0.41	-199.8	7.7	1680	26.8
05/01/09		x							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		206	BDL	252	916	BDL	
06/24/02	38	53	35.0	135	388	<3.0	
07/05/02	56	80	15.0	193	500	18.0	
07/11/02	106	179	31.0	250	780	23.0	
08/05/02	34	55		154	356		
08/27/02	35	38	132.0	132	348	1.8	
09/03/02	34	38	73.0	140	304	2.5	
09/10/02	31	35	64.0	124	280	3.7	
09/17/02	35	30	61.0	147	252	1.7	
09/24/02	37	34	109.0	124	268	<1.0	
10/01/02	28	33	42.0	121	276	<1.0	
10/08/02	35	27	<30.0	107	308	<1.0	
10/15/02	33	26	<30.0	88	260	<1.0	
10/22/02	39	29	41.0	121	300	<1.0	
10/29/02	41	33	<30.0	101	528	2.0	
11/05/02	40	31	82.0	106	288	1.1	
11/12/02	42	31	53.0	124	280	<1.0	
11/19/02	43	29	25.0	123	284	<1.0	
11/26/02	40	31	63.0	127	332	<1.0	
12/03/02	35	33	<30.0	143	284	<1.0	
12/10/02	35	34	<30.0	114	292	<1.0	
12/18/02	34	32	<30.0	124	272	<1.0	
12/23/02	34	31	<30.0	120	308	<1.0	
12/31/02	32	34	72.0	124	252	2.4	
01/07/03	30	28	50.0	112	236	1.6	
01/14/03	28	30	<30.0	104	292	<1.0	
01/21/03	32	28	49.0	98	248	<1.0	
01/28/03	34	26	36.0	99	296	<1.0	
02/03/03	29	27	46.0	94	212	<1.0	
02/11/03	32	26	80.0	100	356	<1.0	
02/18/03	36	32	87.0	103	272	<1.0	
02/25/03	32	27	124.0	92	232	2.7	
03/03/03	32	35	57.0	111	248	<1.0	
03/11/03	37	25	<30.0	113	248	<1.0	
03/18/03	39	31	37.0	106	280	<1.0	
03/27/03	56	40	20.0	132	304	4.0	
04/01/03	70	70	<6.0	150	444	10.0	
04/08/03	62	60	30.0	128	376	13.0	
04/15/03	84	107	15.0	200	552	15.0	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		206	BDL	252	916	BDL	
05/05/03	98	125	91.0	184	680	35.0	
05/14/03	106	145	119.0	167	712	28.0	
05/20/03	106	150	131.0	193	692	19.0	
05/28/03	110	160	103.0	195	768	12.0	
06/02/03	110	157	72.0	191	856	18.0	
07/01/03							
08/01/03		39		109	264		
09/01/03		31		100	260		
10/01/03		17		85	236		
11/01/03		27		106	288		
12/01/03		35		134	280		
01/06/04		37		143	340		
02/01/04							
03/09/04	43	157	30.0	159	344	1.0	
04/14/04	74	84	6.0	166	453	18.0	
05/05/04	82	100	38.0	166	480	18.0	
05/12/04	84	107	86.0	188	504	19.0	
05/19/04	86	107	97.0	213	576	22.0	
05/26/04	86	102	123.0	198	456	22.0	
06/03/04	96	127	164.0	221	624	23.0	
06/09/04	98	132	164.0	197	636	23.0	
06/16/04	104	155	177.0	184	660	24.0	
07/13/04	46	66	29.0	203	420	8.0	
08/02/04	42	46	29.0	157	376	5.1	
09/13/04	35	38	29.0	131	380	3.0	
10/05/04	30	28	29.0	99	248	1.3	
11/02/04	30	22	29.0	85	188	1.3	
12/09/04	37	29	29.0	122	264	2.5	
01/06/05	37	31	29.0	128	260	2.1	
02/03/05	34	30	29.0	122	336	1.3	
03/01/05	40	32	29.0	148	304	1.3	
04/06/05	31	27	<29.0	124	276	<1.3	
04/29/05	53	30	<29.0	133	340	<1.3	
05/03/05		38	<29.0	120	428	5.5	
05/05/05						7.4	
05/09/05		60	<29.0	163	452	8.3	
05/12/05						14.0	
05/16/05		76	51.0	178	500	14.2	
05/19/05						14.3	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		206	BDL	252	916	BDL	
05/31/05		103	108.0	195	576	19.0	
06/02/05						19.4	
06/06/05		112	128.0	205	584	21.8	
06/09/05						21.3	
06/14/05		181	174.0	224	732	24.0	
07/06/05	31.5	43	<29.0	129	300	<1.3	
07/13/05		37	67.0	116	248	<1.3	
07/21/05		31	<29.0	113	268	1.8	
07/25/05		29	<29.0	108	252	2.3	
08/01/05							
08/02/05	32.5	27	<29.0	104	216	1.6	
08/09/05		26	<29.0	100	200	<1.3	
08/16/05		25	<29.0	100	204	<1.3	
08/22/05	25.5	25	55.0	100	240	<1.3	
08/29/05		25	<29.0	99	212	<1.3	
09/07/05	26.0	25	<29.0	99	252	1.7	
09/13/05		22	<29.0	100	272	<1.3	
09/20/05		26	<29.0	106	340	1.7	
09/27/05		23	<29.0	99	224	<1.3	
11/01/05		26	31.0	109	268	<1.3	
11/08/05		24	<29.0	107	276	<1.3	
11/14/05		23	<29.0	101	248	<1.3	
11/18/05		26	<29.0	115	252	2.4	
12/05/05		28	<29.0	112	236	<1.3	
12/12/05		28	38.0	120	288	3.6	
12/20/05		26	<29.0	111	260	<1.3	
01/04/06							
01/09/06							
01/17/06							
01/23/06							
01/30/06							
02/01/06							
03/01/06							
04/07/06		34	68	139	336	6.0	
04/11/06		43	48	145	384	8.6	
04/13/06						9.0	
04/19/06		43	62	164	452	10.1	
04/21/06						12.0	
04/26/06	74.5	75	82	172	520	14.3	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		206	BDL	252	916	BDL	
05/02/06		83	115	185	528	14.0	
05/04/06						13.0	
05/09/06		100	116	195	604	10.0	
05/11/06						14.0	
05/15/06		92	105	166	640	19.0	
05/19/06						18.0	
05/23/06		93	210	173	612	19.0	
05/25/06						21.0	
05/30/06		119	169	211	656	23.1	
06/01/06						18.0	
06/06/06		127	193	216	728	10.2	
06/12/06						28.7	
06/13/06	102	114	238	176	772	26.0	
06/15/06						22.0	
06/20/06		149	203	220	752	26.0	
06/23/06						26.0	
06/27/06		180	218	267	780	31.0	
06/29/06		180	224	218	840	20.4	
06/30/06						27.0	
07/05/06						12.0	
07/11/06						27.0	
07/12/06							
08/04/06		64		210	476		
09/06/06		54		162	464		
10/03/06		38		131	316		
11/28/06							
11/29/06	61.5	33	98	83	504	10.0	
12/01/06						6.0	
12/05/06		99	110	209	512	5.0	
12/07/06						5.6	
12/12/06		120	138	210	604	9.0	
12/14/06						3.0	
12/18/06		136	165	211	588	6.0	
12/21/06						11.5	
12/27/06		159	172	233	660	13.5	
12/29/06						12.3	
01/02/07		176	314	233	728	13.6	
01/05/07						15.4	
01/09/07		175	684	228	684	11.2	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		206	BDL	252	916	BDL	
01/18/07						15.6	
01/24/07		185	270	243	712	11.6	
01/26/07						15.3	
01/29/07		187	269	242	780	16.9	
02/01/07						14.7	
02/05/07		190	275	243	776	13.0	
02/08/07						10.3	
02/12/07		192	297	245	724	10.7	
02/17/07						7.9	
02/20/07		190	301	242	746	8.5	
02/23/07						11.6	
02/27/07		187	343	244	748	11.5	
03/01/07							
03/02/07						10.6	
03/05/07		187	309	240	692	11.7	
03/08/07						9.1	
03/13/07		188	243	244	600	13.5	
03/16/07						10.5	
03/20/07		194	220	247	768	10.9	
03/23/07						6.1	
03/26/07		195	186	249	840	6.6	
03/28/07						17.5	
04/02/07		188	222	241	744	15.5	
04/06/07						18.7	
04/10/07		200	169	231	756	15.8	
04/13/07						13.2	
04/17/07		222	190	254	812	13.4	
04/20/07						6.9	
04/23/07		231	203	258	848	9.1	
04/27/07						17.2	
05/02/07		249	206	264	836		
05/04/07						22.3	
05/08/07		251	198	268	884	14.7	
05/11/07						14.3	
05/15/07		263	172	251	908	64.1	
05/18/07						16.4	
05/22/07		271	190	272	924	16.2	
05/25/07						11.4	
05/29/07		276	181	273	936	9.4	

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		206	BDL	252	916	BDL	
06/05/07						8.2	
06/08/07						10.6	
06/12/07	117	290	185	274	984	14.5	
06/15/07						13.7	
06/19/07		294	192	277	964	12.0	
06/21/07						10.7	
06/26/07						10.6	
06/28/07						7.1	
07/01/07							
07/03/07	119	284	177	254	1028	10.5	
07/05/07							
07/06/07							
08/01/07							
09/01/07							
09/04/07	39.5	48	<29.0	178	384	<1.3	
09/11/07		43	<29.0	173	400	<1.3	
09/18/07		43	<29.0	170	328	<1.3	
09/25/07		43	<29.0	185	380	<1.3	
10/01/07							
11/01/07							
12/01/07							
01/01/08							
02/01/08							
03/01/08							
04/01/08							
04/15/08	110	204	344	216	824	12.6	
05/01/08							
05/23/08	75.5	116	160	268	640	21.1	
05/27/08		141	188	230	700	19.3	
05/30/08						19.0	
06/01/08							
06/02/08	101	187	231	228	828	16.1	
06/05/08						16.2	
06/09/08		212	223	236	920	11.9	
07/01/08							
07/02/08	103	225	414	258	848	19.2	
08/01/08							
09/01/08							
10/01/08							

Appendix B: Field Data for ASR and Monitor Wells (Continued)

Table B4. Summary ASR Well Flow Rates and Water Quality (Continued)

Test Date (S-20)	Total Alk mg/L	Cl mg/L	Total Fe µg/L	SO ₄ mg/L	TDS mg/L	As µg/L	Verified
2/01 Initial Quality		206	BDL	252	916	BDL	
12/02/08	59	70	<29	204	480	5.3	
12/08/08		101	<29	208	580	9.0	
12/15/08		118	56	215	596	9.0	
12/22/08		136	170	221	656	9.4	
12/29/08		149	172	226	712	14.6	
01/01/09							
01/05/09	84	158	192	231	704	3.4	
01/09/09							
01/12/09		156	145	233	736	8.1	
01/16/09							
01/21/09		194	192	247	860	8.8	
01/23/09							
01/26/09		203	201	249	840	8.8	
01/29/09							
02/01/09							
02/02/09	102	213	222	253	836	7.5	
03/01/09							
01/00/00		206	166	251	784	9.1	
03/12/09						4.5	
01/00/00		230	154	260	868	3.6	
03/19/09						9.1	
03/25/09		254	142	266	972		
03/26/09						6.3	
03/27/09						6.0	
03/30/09		262	135	264	964	5.3	
04/03/09						6.2	
04/08/09	118	283	128	166	1020	4.0	
04/10/09						4.4	
04/13/09		291	128	265	1044	5.0	
05/01/09							

Appendix C: PEST Calibration Statistics

Equivalent Continuum Model

EST RUN RECORD: CASE C:\ASRHO7X8W(DAS)-PESTOPT-2\ASRHO7X8W(DAS)-PESTOPT-2

PEST run mode:-

Parameter estimation mode

Case dimensions:-

Number of parameters	:	5
Number of adjustable parameters	:	5
Number of parameter groups	:	3
Number of observations	:	63
Number of prior estimates	:	0

Model command line(s):-

"C:\vmodnt\dosmess.exe" 591284 1101

Jacobian command line:-

na

Model interface files:-

Templates:

ASRHO7X8W(DAS)-PESTOPT-2.MF.TPL

for model input files:

ASRHO7X8W(DAS)-PESTOPT-2.MF.PL

(Parameter values written using single precision protocol.)

(Decimal point always included.)

Instruction files:

ASRHO7X8W(DAS)-PESTOPT-2.INH

for reading model output files:

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

ASRHO7X8W(DAS)-PESTOPT-2.HOB

PEST-to-model message file:-

na

Derivatives calculation:-

Param group	Increment type	Increment low bound	Increment central	Forward or (central)	Multiplier (central)	Method
cndct	relative	2.0000E-02	none	switch	2.000	parabolic
ss	relative	2.0000E-02	none	switch	2.000	parabolic
sy	relative	2.0000E-02	none	switch	2.000	parabolic

Parameter definitions:-

Name	Transformation	Change limit	Initial value	Lower bound	Upper bound
kx__1	log	factor	6.65000	1.000000E-15	1.000000E+29
ky__1	log	factor	27.7000	1.000000E-15	1.000000E+29
kz__1	log	factor	500.000	1.000000E-15	1.000000E+29
ss__1	log	factor	1.000000E-03	1.000000E-15	1.000000E+29
sy__1	log	factor	0.200000	1.000000E-15	0.500000

Name	Group	Scale	Offset	Model command number
kx__1	cndct	1.00000	0.00000	1
ky__1	cndct	1.00000	0.00000	1
kz__1	cndct	1.00000	0.00000	1
ss__1	ss	1.00000	0.00000	1
sy__1	sy	1.00000	0.00000	1

Prior information:-

No prior information supplied

Observations:-

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

Observation name	Observation	Weight	Group
of000007	19.9600	1.000	hds.a
of000008	18.5500	1.000	hds.a
of000009	19.9600	1.000	hds.a
of000010	19.9600	1.000	hds.a
of000011	17.8500	1.000	hds.a
of000012	18.5500	1.000	hds.a
of000013	17.1400	1.000	hds.a
of000014	13.6200	1.000	hds.a
of000015	13.6200	1.000	hds.a
of000016	3.60000	1.000	hds.a
of000017	2.62000	1.000	hds.a
of000018	19.1600	1.000	hds.a
of000019	21.7100	1.000	hds.a
of000020	20.1000	1.000	hds.a
of000021	19.6000	1.000	hds.a
of000022	17.7000	1.000	hds.a
of000023	15.3700	1.000	hds.a
of000024	13.9700	1.000	hds.a
of000025	-0.300000	1.000	hds.a
of000026	18.1100	1.000	hds.a
of000027	17.0600	1.000	hds.a
of000028	17.7600	1.000	hds.a
of000029	17.0600	1.000	hds.a
of000030	17.0600	1.000	hds.a
of000031	18.4600	1.000	hds.a
of000032	15.6500	1.000	hds.a
of000033	12.8300	1.000	hds.a
of000034	12.8300	1.000	hds.a
of000035	5.68000	1.000	hds.a
of000036	3.85000	1.000	hds.a
of000037	23.1400	1.000	hds.a
of000038	19.9800	1.000	hds.a
of000039	19.9800	1.000	hds.a
of000040	20.3300	1.000	hds.a
of000041	19.6200	1.000	hds.a
of000042	13.9900	1.000	hds.a
of000043	13.9900	1.000	hds.a
of000044	-3.12000	1.000	hds.a
of000045	-3.04000	1.000	hds.a
of000046	20.8300	1.000	hds.a
of000047	18.0100	1.000	hds.a

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

of000048	19.4200	1.000	hds.a
of000049	18.0100	1.000	hds.a
of000050	15.9000	1.000	hds.a
of000051	18.0100	1.000	hds.a
of000052	13.7900	1.000	hds.a
of000053	12.3800	1.000	hds.a
of000054	12.3800	1.000	hds.a
of000055	12.3800	1.000	hds.a
of000056	1.78000	1.000	hds.a
of000057	0.640000	1.000	hds.a
of000058	15.7200	1.000	hds.a
of000059	15.2100	1.000	hds.a
of000060	14.6700	1.000	hds.a
of000061	14.9100	1.000	hds.a
of000062	14.7600	1.000	hds.a
of000063	14.4800	1.000	hds.a
of000064	12.9700	1.000	hds.a
of000065	12.5500	1.000	hds.a
of000066	12.2500	1.000	hds.a
of000067	8.50000	1.000	hds.a
of000068	4.73000	1.000	hds.a
of000069	5.04000	1.000	hds.a

Control settings:-

Initial lambda	: 10.000
Lambda adjustment factor	: 2.0000
Sufficient new/old phi ratio per optimisation iteration	: 0.30000
Limiting relative phi reduction between lambdas	: 2.00000E-02
Maximum trial lambdas per iteration	: 20

Maximum factor parameter change (factor-limited changes)	: 10.000
Maximum relative parameter change (relative-limited changes)	: na
Fraction of initial parameter values used in computing change limit for near-zero parameters	: 1.00000E-03

Relative phi reduction below which to begin use of central derivatives	: 0.10000
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Relative phi reduction indicating convergence	: 0.10000E-01
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Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

Number of phi values required within this range : 3
Maximum number of consecutive failures to lower phi : 3
Minimal relative parameter change indicating convergence : 0.10000E-01
Number of consecutive iterations with minimal param change : 3
Maximum number of optimisation iterations : 50

OPTIMISATION RECORD

INITIAL CONDITIONS:

Sum of squared weighted residuals (ie phi) = 424.81

Current parameter values

kx__1	6.65000
ky__1	27.7000
kz__1	500.000
ss__1	1.000000E-03
sy__1	0.200000

OPTIMISATION ITERATION NO. : 1

Model calls so far : 1

Starting phi for this iteration: 424.81

Parameter "ky__1" has no effect on observations.

Parameter "kz__1" has no effect on observations.

Parameter "sy__1" has no effect on observations.

Lambda = 10.000 ----->

Phi = 198.71 (0.468 of starting phi)

Lambda = 5.0000 ----->

Phi = 197.90 (0.466 of starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0200

Lowest phi this iteration: 197.90

Current parameter values		Previous parameter values	
kx__1	9.30423	kx__1	6.65000
ky__1	27.7000	ky__1	27.7000

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

kz__1	500.000	kz__1	500.000
ss__1	1.057894E-03	ss__1	1.000000E-03
sy__1	0.200000	sy__1	0.200000
Maximum factor change: 1.399 ["kx__1"]			
Maximum relative change: 0.3991 ["kx__1"]			

OPTIMISATION ITERATION NO. : 2

Model calls so far : 8

Starting phi for this iteration: 197.90

Parameter "ky__1" has no effect on observations.

Parameter "kz__1" has no effect on observations.

Parameter "sy__1" has no effect on observations.

Lambda = 2.5000 ----->

Phi = 189.77 (0.959 of starting phi)

Lambda = 1.2500 ----->

Phi = 188.27 (0.951 of starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0200

Lowest phi this iteration: 188.27

Relative phi reduction between optimisation iterations less than 0.1000

Switch to central derivatives calculation

Current parameter values		Previous parameter values	
kx__1	10.4215	kx__1	9.30423
ky__1	27.7000	ky__1	27.7000
kz__1	500.000	kz__1	500.000
ss__1	8.767374E-04	ss__1	1.057894E-03
sy__1	0.200000	sy__1	0.200000
Maximum factor change: 1.207 ["ss__1"]			
Maximum relative change: 0.1712 ["ss__1"]			

OPTIMISATION ITERATION NO. : 3

Model calls so far : 15

Starting phi for this iteration: 188.27

Parameter "ky__1" has no effect on observations.

Parameter "kz__1" has no effect on observations.

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

Lambda = 0.62500 ----->
Phi = 188.27 (1.000 times starting phi)

Lambda = 0.31250 ----->
Phi = 188.27 (1.000 times starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0200
Lowest phi this iteration: 188.27

Current parameter values		Previous parameter values	
kx__1	10.4215	kx__1	10.4215
ky__1	27.7000	ky__1	27.7000
kz__1	500.000	kz__1	500.000
ss__1	8.767374E-04	ss__1	8.767374E-04
sy__1	2.000000E-02	sy__1	0.200000
Maximum factor change: 10.00 ["sy__1"]			
Maximum relative change: 0.9000 ["sy__1"]			

OPTIMISATION ITERATION NO. : 4
Model calls so far : 27
Starting phi for this iteration: 188.27

Parameter "ky__1" has no effect on observations.
Parameter "kz__1" has no effect on observations.

Lambda = 0.31250 ----->
Phi = 188.27 (1.000 times starting phi)

Lambda = 0.15625 ----->
Phi = 188.27 (1.000 times starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0200
Lowest phi this iteration: 188.27

Current parameter values		Previous parameter values	
kx__1	10.4215	kx__1	10.4215
ky__1	27.7000	ky__1	27.7000
kz__1	500.000	kz__1	500.000
ss__1	8.767374E-04	ss__1	8.767374E-04
sy__1	2.000000E-03	sy__1	2.000000E-02
Maximum factor change: 10.00 ["sy__1"]			

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

Maximum relative change: 0.9000 ["sy__1"]

Optimisation complete: the 3 lowest phi's are within a relative distance
of eachother of 1.000E-02

Total model calls: 39

OPTIMISATION RESULTS

Covariance matrix and parameter confidence intervals cannot be determined:-
Normal matrix nearly singular; cannot be inverted.

Parameters ----->

Parameter	Estimated value
kx__1	10.4215
ky__1	27.7000
kz__1	500.000
ss__1	8.767374E-04
sy__1	0.200000

See file C:\ASRHO7X8W(DAS)-PESTOPT-2\ASRHO7X8W(DAS)-PESTOPT-2.SEN
for parameter sensitivities.

Observations ----->

Observation	Measured value	Calculated	Residual	Weight	Group
of000007	19.9600	19.9752	-1.521000E-02	1.000	hds.a
of000008	18.5500	19.3072	-0.757220	1.000	hds.a
of000009	19.9600	18.2533	1.70668	1.000	hds.a
of000010	19.9600	18.2174	1.74264	1.000	hds.a
of000011	17.8500	17.8959	-4.595000E-02	1.000	hds.a
of000012	18.5500	17.5666	0.983440	1.000	hds.a
of000013	17.1400	15.7736	1.36645	1.000	hds.a
of000014	13.6200	14.7694	-1.14940	1.000	hds.a
of000015	13.6200	14.4394	-0.819380	1.000	hds.a
of000016	3.60000	2.77354	0.826458	1.000	hds.a
of000017	2.62000	1.83836	0.781642	1.000	hds.a
of000018	19.1600	19.8685	-0.708540	1.000	hds.a

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

of000019	21.7100	18.6739	3.03612	1.000	hds.a
of000020	20.1000	18.6781	1.42187	1.000	hds.a
of000021	19.6000	18.3135	1.28647	1.000	hds.a
of000022	17.7000	15.8787	1.82126	1.000	hds.a
of000023	15.3700	14.7808	0.589220	1.000	hds.a
of000024	13.9700	14.4442	-0.474160	1.000	hds.a
of000025	-0.300000	1.19668	-1.49668	1.000	hds.a
of000026	18.1100	19.4144	-1.30442	1.000	hds.a
of000027	17.0600	18.8108	-1.75077	1.000	hds.a
of000028	17.7600	17.8785	-0.118500	1.000	hds.a
of000029	17.0600	17.8121	-0.752150	1.000	hds.a
of000030	17.0600	17.5283	-0.468330	1.000	hds.a
of000031	18.4600	17.2328	1.22716	1.000	hds.a
of000032	15.6500	15.6798	-2.984000E-02	1.000	hds.a
of000033	12.8300	14.7597	-1.92968	1.000	hds.a
of000034	12.8300	14.4354	-1.60539	1.000	hds.a
of000035	5.68000	4.17257	1.50743	1.000	hds.a
of000036	3.85000	3.18754	0.662463	1.000	hds.a
of000037	23.1400	21.3043	1.83572	1.000	hds.a
of000038	19.9800	20.4596	-0.479550	1.000	hds.a
of000039	19.9800	19.1631	0.816930	1.000	hds.a
of000040	20.3300	18.7521	1.57789	1.000	hds.a
of000041	19.6200	15.9805	3.63946	1.000	hds.a
of000042	13.9900	14.7848	-0.794770	1.000	hds.a
of000043	13.9900	14.4458	-0.455780	1.000	hds.a
of000044	-3.12000	-0.517883	-2.60212	1.000	hds.a
of000045	-3.04000	-1.31344	-1.72656	1.000	hds.a
of000046	20.8300	19.7707	1.05932	1.000	hds.a
of000047	18.0100	19.1092	-1.09922	1.000	hds.a
of000048	19.4200	18.1026	1.31744	1.000	hds.a
of000049	18.0100	18.0575	-4.749000E-02	1.000	hds.a
of000050	15.9000	17.7503	-1.85034	1.000	hds.a
of000051	18.0100	17.4306	0.579420	1.000	hds.a
of000052	13.7900	15.7378	-1.94779	1.000	hds.a
of000053	12.3800	14.7676	-2.38757	1.000	hds.a
of000054	12.3800	14.4387	-2.05872	1.000	hds.a
of000055	12.3800	7.86021	4.51979	1.000	hds.a
of000056	1.78000	3.34299	-1.56299	1.000	hds.a
of000057	0.640000	2.38228	-1.74228	1.000	hds.a
of000058	15.7200	18.7844	-3.06440	1.000	hds.a
of000059	15.2100	18.2597	-3.04968	1.000	hds.a
of000060	14.6700	17.4603	-2.79033	1.000	hds.a

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

of000061	14.9100	17.3639	-2.45392	1.000	hds.a
of000062	14.7600	17.1211	-2.36106	1.000	hds.a
of000063	14.4800	16.8644	-2.38443	1.000	hds.a
of000064	12.9700	15.5664	-2.59644	1.000	hds.a
of000065	12.5500	14.7415	-2.19147	1.000	hds.a
of000066	12.2500	14.4278	-2.17782	1.000	hds.a
of000067	8.50000	9.42904	-0.929036	1.000	hds.a
of000068	4.73000	5.67789	-0.947888	1.000	hds.a
of000069	5.04000	4.66047	0.379530	1.000	hds.a

See file C:\ASRHO7X8W(DAS)-PESTOPT-2\ASRHO7X8W(DAS)-PESTOPT-2.RES for more details of residuals in graph-ready format.

See file C:\ASRHO7X8W(DAS)-PESTOPT-2\ASRHO7X8W(DAS)-PESTOPT-2.SEO for composite observation sensitivities.

Objective function ----->

Sum of squared weighted residuals (ie phi) = 188.3

Correlation Coefficient ----->

Correlation coefficient = 0.9638

Analysis of residuals ----->

All residuals:-

Number of residuals with non-zero weight	= 63
Mean value of non-zero weighted residuals	= -0.3562
Maximum weighted residual [observation "of000055"]	= 4.520
Minimum weighted residual [observation "of000058"]	= -3.064
Standard variance of weighted residuals	= 3.246
Standard error of weighted residuals	= 1.802

Note: the above variance was obtained by dividing the objective function by the number of system degrees of freedom (ie. number of observations with non-zero weight plus number of prior information articles with non-zero weight minus the number of adjustable parameters.)
If the degrees of freedom is negative the divisor becomes

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Continuum Model

the number of observations with non-zero weight plus the number of prior information items with non-zero weight.

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

EST RUN RECORD: CASE C:\ASRHE10X8W(DK)-PESTOPT-1(SHORT)\ASRHE10X8W(DK)-PESTOPT-1(SHORT)

PEST run mode:-

Parameter estimation mode

Case dimensions:-

Number of parameters	: 10
Number of adjustable parameters	: 10
Number of parameter groups	: 3
Number of observations	: 63
Number of prior estimates	: 0

Model command line(s):-

"C:\vmodnt\dosmess.exe" 4720228 1101

Jacobian command line:-

na

Model interface files:-

Templates:

ASRHE10X8W(DK)-PESTOPT-1(SHORT).MF.TPL

for model input files:

ASRHE10X8W(DK)-PESTOPT-1(SHORT).MF.PL

(Parameter values written using single precision protocol.)

(Decimal point always included.)

Instruction files:

ASRHE10X8W(DK)-PESTOPT-1(SHORT).INH

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

for reading model output files:

ASRHE10X8W(DK)-PESTOPT-1(SHORT).HOB

PEST-to-model message file:-

na

Derivatives calculation:-

Param group	Increment type	Increment low bound	Increment central	Forward or (central)	Multiplier (central)	Method
cndct	relative	2.0000E-02	none	switch	2.000	parabolic
ss	relative	2.0000E-02	none	switch	2.000	parabolic
sy	relative	2.0000E-02	none	switch	2.000	parabolic

Parameter definitions:-

Name	Transformation	Change limit	Initial value	Lower bound	Upper bound
kx__2	log	factor	0.880000	1.000000E-15	1.000000E+29
ky__2	log	factor	0.500000	1.000000E-15	1.000000E+29
kz__2	log	factor	0.500000	1.000000E-15	1.000000E+29
kx__9	log	factor	27.0000	1.000000E-15	1.000000E+29
ky__9	log	factor	27.0000	1.000000E-15	1.000000E+29
kz__9	log	factor	75.0000	1.000000E-15	1.000000E+29
ss__1	log	factor	8.010450E-05	1.000000E-15	1.000000E+29
ss__2	log	factor	5.000000E-04	1.000000E-15	1.000000E+29
sy__1	log	factor	0.150000	1.000000E-15	0.500000
sy__2	log	factor	0.200000	1.000000E-15	0.500000

Name	Group	Scale	Offset	Model command number
kx__2	cndct	1.00000	0.00000	1
ky__2	cndct	1.00000	0.00000	1
kz__2	cndct	1.00000	0.00000	1
kx__9	cndct	1.00000	0.00000	1
ky__9	cndct	1.00000	0.00000	1
kz__9	cndct	1.00000	0.00000	1
ss__1	ss	1.00000	0.00000	1
ss__2	ss	1.00000	0.00000	1

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

sy__1	sy	1.00000	0.00000	1
sy__2	sy	1.00000	0.00000	1

Prior information:-

No prior information supplied

Observations:-

Observation name	Observation	Weight	Group
of000007	19.9600	1.000	hds.a
of000008	18.5500	1.000	hds.a
of000009	19.9600	1.000	hds.a
of000010	19.9600	1.000	hds.a
of000011	17.8500	1.000	hds.a
of000012	18.5500	1.000	hds.a
of000013	17.1400	1.000	hds.a
of000014	13.6200	1.000	hds.a
of000015	13.6200	1.000	hds.a
of000016	3.60000	1.000	hds.a
of000017	2.62000	1.000	hds.a
of000018	19.1600	1.000	hds.a
of000019	21.7100	1.000	hds.a
of000020	20.1000	1.000	hds.a
of000021	19.6000	1.000	hds.a
of000022	17.7000	1.000	hds.a
of000023	15.3700	1.000	hds.a
of000024	13.9700	1.000	hds.a
of000025	-0.300000	1.000	hds.a
of000026	18.1100	1.000	hds.a
of000027	17.0600	1.000	hds.a
of000028	17.7600	1.000	hds.a
of000029	17.0600	1.000	hds.a
of000030	17.0600	1.000	hds.a
of000031	18.4600	1.000	hds.a
of000032	15.6500	1.000	hds.a
of000033	12.8300	1.000	hds.a
of000034	12.8300	1.000	hds.a
of000035	5.68000	1.000	hds.a
of000036	3.85000	1.000	hds.a

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

of000037	23.1400	1.000	hds.a
of000038	19.9800	1.000	hds.a
of000039	19.9800	1.000	hds.a
of000040	20.3300	1.000	hds.a
of000041	19.6200	1.000	hds.a
of000042	13.9900	1.000	hds.a
of000043	13.9900	1.000	hds.a
of000044	-3.12000	1.000	hds.a
of000045	-3.04000	1.000	hds.a
of000046	20.8300	1.000	hds.a
of000047	18.0100	1.000	hds.a
of000048	19.4200	1.000	hds.a
of000049	18.0100	1.000	hds.a
of000050	15.9000	1.000	hds.a
of000051	18.0100	1.000	hds.a
of000052	13.7900	1.000	hds.a
of000053	12.3800	1.000	hds.a
of000054	12.3800	1.000	hds.a
of000055	12.3800	1.000	hds.a
of000056	1.78000	1.000	hds.a
of000057	0.640000	1.000	hds.a
of000058	15.7200	1.000	hds.a
of000059	15.2100	1.000	hds.a
of000060	14.6700	1.000	hds.a
of000061	14.9100	1.000	hds.a
of000062	14.7600	1.000	hds.a
of000063	14.4800	1.000	hds.a
of000064	12.9700	1.000	hds.a
of000065	12.5500	1.000	hds.a
of000066	12.2500	1.000	hds.a
of000067	8.50000	1.000	hds.a
of000068	4.73000	1.000	hds.a
of000069	5.04000	1.000	hds.a

Control settings:-

Initial lambda	: 10.000
Lambda adjustment factor	: 2.0000
Sufficient new/old phi ratio per optimisation iteration	: 0.30000
Limiting relative phi reduction between lambdas	: 2.00000E-02
Maximum trial lambdas per iteration	: 20

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

Maximum factor parameter change (factor-limited changes) : 10.000
Maximum relative parameter change (relative-limited changes) : na
Fraction of initial parameter values used in computing
change limit for near-zero parameters : 1.00000E-03

Relative phi reduction below which to begin use of
central derivatives : 0.10000

Relative phi reduction indicating convergence : 0.10000E-01
Number of phi values required within this range : 3
Maximum number of consecutive failures to lower phi : 3
Minimal relative parameter change indicating convergence : 0.10000E-01
Number of consecutive iterations with minimal param change : 3
Maximum number of optimisation iterations : 50

OPTIMISATION RECORD

INITIAL CONDITIONS:

Sum of squared weighted residuals (ie phi) = 223.45

Current parameter values

kx__2	0.880000
ky__2	0.500000
kz__2	0.500000
kx__9	27.0000
ky__9	27.0000
kz__9	75.0000
ss__1	8.010450E-05
ss__2	5.000000E-04
sy__1	0.150000
sy__2	0.200000

OPTIMISATION ITERATION NO. : 1

Model calls so far : 1

Starting phi for this iteration: 223.45

Parameter "ky__2" has no effect on observations.

Parameter "ky__9" has no effect on observations.

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

Parameter "sy__1" has no effect on observations.
Parameter "sy__2" has no effect on observations.

Lambda = 10.000 ----->
Phi = 305.13 (1.366 times starting phi)

Lambda = 5.0000 ----->
Phi = 305.32 (1.366 times starting phi)

Lambda = 20.000 ----->
Phi = 302.92 (1.356 times starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0200
Lowest phi this iteration: 302.92
Relative phi reduction between optimisation iterations less than 0.1000
Switch to central derivatives calculation
(restart from best parameters so far - these achieved at iteration 0)

Current parameter values
kx__2 0.880000
ky__2 0.500000
kz__2 0.500000
kx__9 27.0000
ky__9 27.0000
kz__9 75.0000
ss__1 8.010450E-05
ss__2 5.000000E-04
sy__1 0.150000
sy__2 0.200000

OPTIMISATION ITERATION NO. : 2
Model calls so far : 14
Starting phi for this iteration: 223.45

Parameter "ky__2" has no effect on observations.
Parameter "ky__9" has no effect on observations.
Parameter "sy__1" has no effect on observations.

Lambda = 10.000 ----->
Phi = 223.45 (1.000 times starting phi)

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

Lambda = 5.0000 ----->
Phi = 223.45 (1.000 times starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0200
Lowest phi this iteration: 223.45

Current parameter values		Previous parameter values	
kx__2	0.880000	kx__2	0.880000
ky__2	0.500000	ky__2	0.500000
kz__2	0.500000	kz__2	0.500000
kx__9	27.0000	kx__9	27.0000
ky__9	27.0000	ky__9	27.0000
kz__9	75.0000	kz__9	75.0000
ss__1	8.010450E-05	ss__1	8.010450E-05
ss__2	5.000000E-04	ss__2	5.000000E-04
sy__1	0.150000	sy__1	0.150000
sy__2	2.000000E-02	sy__2	0.200000
Maximum factor change: 10.00 ["sy__2"]			
Maximum relative change: 0.9000 ["sy__2"]			

OPTIMISATION ITERATION NO. : 3

Model calls so far : 36

Starting phi for this iteration: 223.45

Parameter "ky__2" has no effect on observations.

Parameter "ky__9" has no effect on observations.

Parameter "sy__1" has no effect on observations.

Lambda = 5.0000 ----->
Phi = 223.45 (1.000 times starting phi)

Lambda = 2.5000 ----->
Phi = 223.45 (1.000 times starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0200
Lowest phi this iteration: 223.45

Current parameter values		Previous parameter values	
kx__2	0.880000	kx__2	0.880000
ky__2	0.500000	ky__2	0.500000
kz__2	0.500000	kz__2	0.500000

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

kx__9	27.0000	kx__9	27.0000
ky__9	27.0000	ky__9	27.0000
kz__9	75.0000	kz__9	75.0000
ss__1	8.010450E-05	ss__1	8.010450E-05
ss__2	5.000000E-04	ss__2	5.000000E-04
sy__1	0.150000	sy__1	0.150000
sy__2	2.000000E-03	sy__2	2.000000E-02
Maximum factor change: 10.00 ["sy__2"]			
Maximum relative change: 0.9000 ["sy__2"]			

Optimisation complete: the 3 lowest phi's are within a relative distance
of each other of 1.000E-02

Total model calls: 58

OPTIMISATION RESULTS

Covariance matrix and parameter confidence intervals cannot be determined:-
Normal matrix nearly singular; cannot be inverted.

Parameters ----->

Parameter	Estimated value
kx__2	0.880000
ky__2	0.500000
kz__2	0.500000
kx__9	27.0000
ky__9	27.0000
kz__9	75.0000
ss__1	8.010450E-05
ss__2	5.000000E-04
sy__1	0.150000
sy__2	0.200000

See file C:\ASRHE10X8W(DK)-PESTOPT-1(SHORT)\ASRHE10X8W(DK)-
PESTOPT-1(SHORT).SEN for parameter sensitivities.

Observations ----->

Observation	Measured	Calculated	Residual	Weight	Group
-------------	----------	------------	----------	--------	-------

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

value	value				
of000007	19.9600	19.5961	0.363890	1.000	hds.a
of000008	18.5500	18.5203	2.968000E-02	1.000	hds.a
of000009	19.9600	17.4247	2.53529	1.000	hds.a
of000010	19.9600	17.6990	2.26101	1.000	hds.a
of000011	17.8500	17.3878	0.462200	1.000	hds.a
of000012	18.5500	17.0813	1.46866	1.000	hds.a
of000013	17.1400	14.9908	2.14919	1.000	hds.a
of000014	13.6200	14.2385	-0.618500	1.000	hds.a
of000015	13.6200	14.2025	-0.582530	1.000	hds.a
of000016	3.60000	1.87390	1.72611	1.000	hds.a
of000017	2.62000	2.34829	0.271715	1.000	hds.a
of000018	19.1600	18.9259	0.234080	1.000	hds.a
of000019	21.7100	17.7248	3.98518	1.000	hds.a
of000020	20.1000	18.0343	2.06571	1.000	hds.a
of000021	19.6000	17.6910	1.90897	1.000	hds.a
of000022	17.7000	15.0575	2.64252	1.000	hds.a
of000023	15.3700	14.2392	1.13083	1.000	hds.a
of000024	13.9700	14.2026	-0.232580	1.000	hds.a
of000025	-0.300000	0.688461	-0.988461	1.000	hds.a
of000026	18.1100	19.1100	-0.999950	1.000	hds.a
of000027	17.0600	18.0977	-1.03774	1.000	hds.a
of000028	17.7600	17.1093	0.650740	1.000	hds.a
of000029	17.0600	17.3521	-0.292100	1.000	hds.a
of000030	17.0600	17.0738	-1.382000E-02	1.000	hds.a
of000031	18.4600	16.7966	1.66342	1.000	hds.a
of000032	15.6500	14.9210	0.729020	1.000	hds.a
of000033	12.8300	14.2380	-1.40799	1.000	hds.a
of000034	12.8300	14.2025	-1.37250	1.000	hds.a
of000035	5.68000	3.11196	2.56804	1.000	hds.a
of000036	3.85000	3.52073	0.329268	1.000	hds.a
of000037	23.1400	20.6620	2.47803	1.000	hds.a
of000038	19.9800	19.4324	0.547640	1.000	hds.a
of000039	19.9800	18.4505	1.52955	1.000	hds.a
of000040	20.3300	18.0671	2.26291	1.000	hds.a
of000041	19.6200	15.1405	4.47953	1.000	hds.a
of000042	13.9900	14.2393	-0.249340	1.000	hds.a
of000043	13.9900	14.2026	-0.212590	1.000	hds.a
of000044	-3.12000	-0.800524	-2.31948	1.000	hds.a
of000045	-3.04000	-0.182228	-2.85777	1.000	hds.a
of000046	20.8300	19.3678	1.46224	1.000	hds.a
of000047	18.0100	18.3046	-0.294630	1.000	hds.a

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

of000048	19.4200	17.2621	2.15786	1.000	hds.a
of000049	18.0100	17.5239	0.486100	1.000	hds.a
of000050	15.9000	17.2288	-1.32883	1.000	hds.a
of000051	18.0100	16.9338	1.07621	1.000	hds.a
of000052	13.7900	14.9551	-1.16513	1.000	hds.a
of000053	12.3800	14.2385	-1.85850	1.000	hds.a
of000054	12.3800	14.2025	-1.82253	1.000	hds.a
of000055	12.3800	6.26415	6.11585	1.000	hds.a
of000056	1.78000	2.50599	-0.725990	1.000	hds.a
of000057	0.640000	2.94585	-2.30585	1.000	hds.a
of000058	15.7200	18.5930	-2.87303	1.000	hds.a
of000059	15.2100	17.6601	-2.45011	1.000	hds.a
of000060	14.6700	16.7834	-2.11339	1.000	hds.a
of000061	14.9100	16.9927	-2.08266	1.000	hds.a
of000062	14.7600	16.7484	-1.98838	1.000	hds.a
of000063	14.4800	16.5029	-2.02289	1.000	hds.a
of000064	12.9700	14.8478	-1.87776	1.000	hds.a
of000065	12.5500	14.2370	-1.68697	1.000	hds.a
of000066	12.2500	14.2024	-1.95243	1.000	hds.a
of000067	8.50000	7.56624	0.933763	1.000	hds.a
of000068	4.73000	4.38922	0.340783	1.000	hds.a
of000069	5.04000	4.73277	0.307227	1.000	hds.a

See file C:\ASRHE10X8W(DK)-PESTOPT-1(SHORT)\ASRHE10X8W(DK)-PESTOPT-1(SHORT).RES for more details of residuals in graph-ready format.

See file C:\ASRHE10X8W(DK)-PESTOPT-1(SHORT)\ASRHE10X8W(DK)-PESTOPT-1(SHORT).SEO for composite observation sensitivities.

Objective function ----->

Sum of squared weighted residuals (ie phi) = 223.4

Correlation Coefficient ----->

Correlation coefficient = 0.9557

Analysis of residuals ----->

Appendix C: PEST Calibration Statistics (Continued)

Equivalent Discontinuum Model

All residuals:-

Number of residuals with non-zero weight	= 63
Mean value of non-zero weighted residuals	= 0.1844
Maximum weighted residual [observation "of000055"]	= 6.116
Minimum weighted residual [observation "of000058"]	= -2.873
Standard variance of weighted residuals	= 4.216
Standard error of weighted residuals	= 2.053

Note: the above variance was obtained by dividing the objective function by the number of system degrees of freedom (ie. number of observations with non-zero weight plus number of prior information articles with non-zero weight minus the number of adjustable parameters.)
If the degrees of freedom is negative the divisor becomes the number of observations with non-zero weight plus the number of prior information items with non-zero weight.

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

EST RUN RECORD: CASE C:\ASRHE11X8W(DK)FRAC3K1-
PESTOPT3\ASRHE11X8W(DK)FRAC3K1-PESTOPT3

PEST run mode:-

Parameter estimation mode

Case dimensions:-

Number of parameters	:	34
Number of adjustable parameters	:	34
Number of parameter groups	:	3
Number of observations	:	63
Number of prior estimates	:	0

Model command line(s):-

"C:\vmodnt\dosmess.exe" 6488890 1101

Jacobian command line:-

na

Model interface files:-

Templates:

ASRHE11X8W(DK)FRAC3K1-PESTOPT3.MF.TPL
for model input files:
ASRHE11X8W(DK)FRAC3K1-PESTOPT3.MF.PL

(Parameter values written using single precision protocol.)
(Decimal point always included.)

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

Instruction files:

ASRHE11X8W(DK)FRAC3K1-PESTOPT3.INH

for reading model output files:

ASRHE11X8W(DK)FRAC3K1-PESTOPT3.HOB

PEST-to-model message file:-

na

Derivatives calculation:-

Param group	Increment type	Increment low bound	Increment central	Forward or (central)	Multiplier (central)	Method
cndct	relative	2.0000E-02	none	switch	2.000	parabolic
ss	relative	2.0000E-02	none	switch	2.000	parabolic
sy	relative	2.0000E-02	none	switch	2.000	parabolic

Parameter definitions:-

Name	Trans-formation	Change limit	Initial value	Lower bound	Upper bound
kx_57	log	factor	9.33694	1.000000E-15	1.000000E+29
ky_57	log	factor	22.0000	1.000000E-15	1.000000E+29
kz_57	log	factor	69.0414	1.000000E-15	1.000000E+29
kx_58	log	factor	24.8129	1.000000E-15	1.000000E+29
ky_58	log	factor	40.0000	1.000000E-15	1.000000E+29
kz_58	log	factor	249.716	1.000000E-15	1.000000E+29
kx_59	log	factor	25.8660	1.000000E-15	1.000000E+29
ky_59	log	factor	61.0000	1.000000E-15	1.000000E+29
kz_59	log	factor	24.2684	1.000000E-15	1.000000E+29
kx_60	log	factor	29.3387	1.000000E-15	1.000000E+29
ky_60	log	factor	90.0000	1.000000E-15	1.000000E+29
kz_60	log	factor	28.4908	1.000000E-15	1.000000E+29
kx_61	log	factor	26.4775	1.000000E-15	1.000000E+29
ky_61	log	factor	100.000	1.000000E-15	1.000000E+29
kz_61	log	factor	48.8612	1.000000E-15	1.000000E+29
kx_62	log	factor	25.8808	1.000000E-15	1.000000E+29
ky_62	log	factor	119.000	1.000000E-15	1.000000E+29
kz_62	log	factor	109.967	1.000000E-15	1.000000E+29

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

kx_63	log	factor	38.4961	1.000000E-15	1.000000E+29
ky_63	log	factor	144.000	1.000000E-15	1.000000E+29
kz_63	log	factor	153.558	1.000000E-15	1.000000E+29
kx_64	log	factor	12.8743	1.000000E-15	1.000000E+29
ky_64	log	factor	161.000	1.000000E-15	1.000000E+29
kz_64	log	factor	262.360	1.000000E-15	1.000000E+29
kx_65	log	factor	16.4494	1.000000E-15	1.000000E+29
ky_65	log	factor	191.000	1.000000E-15	1.000000E+29
kz_65	log	factor	206.331	1.000000E-15	1.000000E+29
kx_66	log	factor	60.6356	1.000000E-15	1.000000E+29
ky_66	log	factor	205.000	1.000000E-15	1.000000E+29
kz_66	log	factor	151.417	1.000000E-15	1.000000E+29
ss__1	log	factor	6.862530E-05	1.000000E-15	1.000000E+29
ss__2	log	factor	5.479440E-04	1.000000E-15	1.000000E+29
sy__1	log	factor	0.150000	1.000000E-15	0.500000
sy__2	log	factor	0.300000	1.000000E-15	0.500000

Name	Group	Scale	Offset	Model command number
kx_57	cndct	1.00000	0.00000	1
ky_57	cndct	1.00000	0.00000	1
kz_57	cndct	1.00000	0.00000	1
kx_58	cndct	1.00000	0.00000	1
ky_58	cndct	1.00000	0.00000	1
kz_58	cndct	1.00000	0.00000	1
kx_59	cndct	1.00000	0.00000	1
ky_59	cndct	1.00000	0.00000	1
kz_59	cndct	1.00000	0.00000	1
kx_60	cndct	1.00000	0.00000	1
ky_60	cndct	1.00000	0.00000	1
kz_60	cndct	1.00000	0.00000	1
kx_61	cndct	1.00000	0.00000	1
ky_61	cndct	1.00000	0.00000	1
kz_61	cndct	1.00000	0.00000	1
kx_62	cndct	1.00000	0.00000	1
ky_62	cndct	1.00000	0.00000	1
kz_62	cndct	1.00000	0.00000	1
kx_63	cndct	1.00000	0.00000	1
ky_63	cndct	1.00000	0.00000	1
kz_63	cndct	1.00000	0.00000	1
kx_64	cndct	1.00000	0.00000	1
ky_64	cndct	1.00000	0.00000	1
kz_64	cndct	1.00000	0.00000	1

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

kx_65	cndct	1.00000	0.00000	1
ky_65	cndct	1.00000	0.00000	1
kz_65	cndct	1.00000	0.00000	1
kx_66	cndct	1.00000	0.00000	1
ky_66	cndct	1.00000	0.00000	1
kz_66	cndct	1.00000	0.00000	1
ss__1	ss	1.00000	0.00000	1
ss__2	ss	1.00000	0.00000	1
sy__1	sy	1.00000	0.00000	1
sy__2	sy	1.00000	0.00000	1

Prior information:-

No prior information supplied

Observations:-

Observation name	Observation	Weight	Group
of000007	19.9600	1.000	hds.a
of000008	18.0000	1.000	hds.a
of000009	19.9600	1.000	hds.a
of000010	19.9600	1.000	hds.a
of000011	18.3000	1.000	hds.a
of000012	18.5500	1.000	hds.a
of000013	17.1400	1.000	hds.a
of000014	13.6200	1.000	hds.a
of000015	13.6200	1.000	hds.a
of000016	4.00000	1.000	hds.a
of000017	2.62000	1.000	hds.a
of000018	19.6000	1.000	hds.a
of000019	21.7100	1.000	hds.a
of000020	20.1000	1.000	hds.a
of000021	19.6000	1.000	hds.a
of000022	17.7000	1.000	hds.a
of000023	15.3700	1.000	hds.a
of000024	13.9700	1.000	hds.a
of000025	-4.000000E-02	1.000	hds.a
of000026	18.1100	1.000	hds.a
of000027	16.9000	1.000	hds.a
of000028	17.7600	1.000	hds.a

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

of000029	17.0600	1.000	hds.a
of000030	17.0600	1.000	hds.a
of000031	18.4600	1.000	hds.a
of000032	15.1000	1.000	hds.a
of000033	12.8300	1.000	hds.a
of000034	12.8300	1.000	hds.a
of000035	5.68000	1.000	hds.a
of000036	3.85000	1.000	hds.a
of000037	23.1400	1.000	hds.a
of000038	19.3000	1.000	hds.a
of000039	19.9800	1.000	hds.a
of000040	21.4000	1.000	hds.a
of000041	19.1000	1.000	hds.a
of000042	13.9900	1.000	hds.a
of000043	13.9900	1.000	hds.a
of000044	-3.12000	1.000	hds.a
of000045	-3.04000	1.000	hds.a
of000046	20.8300	1.000	hds.a
of000047	18.0400	1.000	hds.a
of000048	19.4200	1.000	hds.a
of000049	18.0100	1.000	hds.a
of000050	15.9000	1.000	hds.a
of000051	18.0100	1.000	hds.a
of000052	13.5000	1.000	hds.a
of000053	12.3800	1.000	hds.a
of000054	12.3800	1.000	hds.a
of000055	12.3800	1.000	hds.a
of000056	1.78000	1.000	hds.a
of000057	0.640000	1.000	hds.a
of000058	15.7200	1.000	hds.a
of000059	15.2100	1.000	hds.a
of000060	14.6700	1.000	hds.a
of000061	14.9100	1.000	hds.a
of000062	14.7600	1.000	hds.a
of000063	14.4800	1.000	hds.a
of000064	12.9700	1.000	hds.a
of000065	12.5500	1.000	hds.a
of000066	12.2500	1.000	hds.a
of000067	8.50000	1.000	hds.a
of000068	4.73000	1.000	hds.a
of000069	5.04000	1.000	hds.a

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

Control settings:-

Initial lambda	: 10.000
Lambda adjustment factor	: 2.0000
Sufficient new/old phi ratio per optimisation iteration	: 0.10000
Limiting relative phi reduction between lambdas	: 2.00000E-02
Maximum trial lambdas per iteration	: 10
Maximum factor parameter change (factor-limited changes)	: 10.000
Maximum relative parameter change (relative-limited changes)	: na
Fraction of initial parameter values used in computing	
change limit for near-zero parameters	: 1.00000E-03
Relative phi reduction below which to begin use of	
central derivatives	: 0.10000
Relative phi reduction indicating convergence	: 0.10000E-01
Number of phi values required within this range	: 3
Maximum number of consecutive failures to lower phi	: 3
Minimal relative parameter change indicating convergence	: 0.10000E-01
Number of consecutive iterations with minimal param change	: 3
Maximum number of optimisation iterations	: 50

OPTIMISATION RECORD

INITIAL CONDITIONS:

Sum of squared weighted residuals (ie phi) = 245.74

Current parameter values

kx_57	9.33694
ky_57	22.0000
kz_57	69.0414
kx_58	24.8129
ky_58	40.0000
kz_58	249.716
kx_59	25.8660
ky_59	61.0000
kz_59	24.2684

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

kx_60	29.3387
ky_60	90.0000
kz_60	28.4908
kx_61	26.4775
ky_61	100.000
kz_61	48.8612
kx_62	25.8808
ky_62	119.000
kz_62	109.967
kx_63	38.4961
ky_63	144.000
kz_63	153.558
kx_64	12.8743
ky_64	161.000
kz_64	262.360
kx_65	16.4494
ky_65	191.000
kz_65	206.331
kx_66	60.6356
ky_66	205.000
kz_66	151.417
ss__1	6.862530E-05
ss__2	5.479440E-04
sy__1	0.150000
sy__2	0.300000

OPTIMISATION ITERATION NO. : 1

Model calls so far : 1

Starting phi for this iteration: 245.74

Parameter "ky_57" has no effect on observations.

Parameter "ky_58" has no effect on observations.

Parameter "ky_59" has no effect on observations.

Parameter "ky_60" has no effect on observations.

Parameter "ky_61" has no effect on observations.

Parameter "ky_62" has no effect on observations.

Parameter "ky_63" has no effect on observations.

Parameter "ky_64" has no effect on observations.

Parameter "kz_64" has no effect on observations.

Parameter "ky_65" has no effect on observations.

Parameter "kz_65" has no effect on observations.

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

Parameter "ky_66" has no effect on observations.

Parameter "kz_66" has no effect on observations.

Parameter "sy__1" has no effect on observations.

Parameter "sy__2" has no effect on observations.

Lambda = 10.000 ----->

Phi = 245.84 (1.000 times starting phi)

Lambda = 5.0000 ----->

Phi = 245.87 (1.001 times starting phi)

Lambda = 20.000 ----->

Phi = 245.84 (1.000 times starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0200

Lowest phi this iteration: 245.84

Relative phi reduction between optimisation iterations less than 0.1000

Switch to central derivatives calculation

(restart from best parameters so far - these achieved at iteration 0)

Current parameter values

kx_57	9.33694
ky_57	22.0000
kz_57	69.0414
kx_58	24.8129
ky_58	40.0000
kz_58	249.716
kx_59	25.8660
ky_59	61.0000
kz_59	24.2684
kx_60	29.3387
ky_60	90.0000
kz_60	28.4908
kx_61	26.4775
ky_61	100.000
kz_61	48.8612
kx_62	25.8808
ky_62	119.000
kz_62	109.967
kx_63	38.4961
ky_63	144.000
kz_63	153.558

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

kx_64	12.8743
ky_64	161.000
kz_64	262.360
kx_65	16.4494
ky_65	191.000
kz_65	206.331
kx_66	60.6356
ky_66	205.000
kz_66	151.417
ss__1	6.862530E-05
ss__2	5.479440E-04
sy__1	0.150000
sy__2	0.300000

OPTIMISATION ITERATION NO. : 2

Model calls so far : 38

Starting phi for this iteration: 245.74

Parameter "ky_57" has no effect on observations.

Parameter "ky_58" has no effect on observations.

Parameter "ky_59" has no effect on observations.

Parameter "ky_60" has no effect on observations.

Parameter "ky_61" has no effect on observations.

Parameter "ky_62" has no effect on observations.

Parameter "ky_63" has no effect on observations.

Parameter "ky_64" has no effect on observations.

Parameter "ky_65" has no effect on observations.

Parameter "ky_66" has no effect on observations.

Parameter "sy__1" has no effect on observations.

Parameter "sy__2" has no effect on observations.

Lambda = 10.000 ----->

Phi = 245.74 (1.000 of starting phi)

Lambda = 5.0000 ----->

Phi = 245.74 (1.000 of starting phi)

Lambda = 20.000 ----->

Phi = 245.74 (1.000 of starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0200

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

Lowest phi this iteration: 245.74

Current parameter values		Previous parameter values	
kx_57	9.50701	kx_57	9.33694
ky_57	22.0000	ky_57	22.0000
kz_57	103.534	kz_57	69.0414
kx_58	24.9213	kx_58	24.8129
ky_58	40.0000	ky_58	40.0000
kz_58	236.342	kz_58	249.716
kx_59	25.7014	kx_59	25.8660
ky_59	61.0000	ky_59	61.0000
kz_59	18.6661	kz_59	24.2684
kx_60	29.3795	kx_60	29.3387
ky_60	90.0000	ky_60	90.0000
kz_60	29.9392	kz_60	28.4908
kx_61	26.5497	kx_61	26.4775
ky_61	100.000	ky_61	100.000
kz_61	63.1614	kz_61	48.8612
kx_62	25.7382	kx_62	25.8808
ky_62	119.000	ky_62	119.000
kz_62	65.1020	kz_62	109.967
kx_63	37.9714	kx_63	38.4961
ky_63	144.000	ky_63	144.000
kz_63	223.169	kz_63	153.558
kx_64	12.9402	kx_64	12.8743
ky_64	161.000	ky_64	161.000
kz_64	624.891	kz_64	262.360
kx_65	17.5983	kx_65	16.4494
ky_65	191.000	ky_65	191.000
kz_65	29.5376	kz_65	206.331
kx_66	67.2802	kx_66	60.6356
ky_66	205.000	ky_66	205.000
kz_66	1514.17	kz_66	151.417
ss__1	6.491755E-05	ss__1	6.862530E-05
ss__2	5.527317E-04	ss__2	5.479440E-04
sy__1	0.150000	sy__1	0.150000
sy__2	0.300000	sy__2	0.300000

Maximum factor change: 10.00 ["kz_66"]

Maximum relative change: 9.000 ["kz_66"]

Optimisation complete: the 3 lowest phi's are within a relative distance of eachother of 1.000E-02

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

Total model calls: 109

OPTIMISATION RESULTS

Covariance matrix and parameter confidence intervals cannot be determined:-
Normal matrix nearly singular; cannot be inverted.

Parameters ----->

Parameter	Estimated value
kx_57	9.50701
ky_57	22.0000
kz_57	103.534
kx_58	24.9213
ky_58	40.0000
kz_58	236.342
kx_59	25.7014
ky_59	61.0000
kz_59	18.6661
kx_60	29.3795
ky_60	90.0000
kz_60	29.9392
kx_61	26.5497
ky_61	100.000
kz_61	63.1614
kx_62	25.7382
ky_62	119.000
kz_62	65.1020
kx_63	37.9714
ky_63	144.000
kz_63	223.169
kx_64	12.9402
ky_64	161.000
kz_64	624.891
kx_65	17.5983
ky_65	191.000
kz_65	29.5376
kx_66	67.2802
ky_66	205.000
kz_66	1514.17

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

ss__1 6.491755E-05
 ss__2 5.527317E-04
 sy__1 0.150000
 sy__2 0.300000

See file C:\ASRHE11X8W(DK)FRAC3K1-PESTOPT3\ASRHE11X8W(DK)FRAC3K1-PESTOPT3.SEN for parameter sensitivities.

Observations ----->

Observation	Measured value	Calculated value	Residual	Weight	Group
of000007	19.9600	18.9894	0.970640	1.000	hds.a
of000008	18.0000	18.5991	-0.599070	1.000	hds.a
of000009	19.9600	17.5263	2.43371	1.000	hds.a
of000010	19.9600	17.7996	2.16041	1.000	hds.a
of000011	18.3000	17.4839	0.816080	1.000	hds.a
of000012	18.5500	17.1690	1.38101	1.000	hds.a
of000013	17.1400	15.0345	2.10546	1.000	hds.a
of000014	13.6200	14.2491	-0.629050	1.000	hds.a
of000015	13.6200	14.2039	-0.583900	1.000	hds.a
of000016	4.00000	1.55960	2.44040	1.000	hds.a
of000017	2.62000	2.00140	0.618599	1.000	hds.a
of000018	19.6000	18.9573	0.642720	1.000	hds.a
of000019	21.7100	17.7918	3.91820	1.000	hds.a
of000020	20.1000	18.0964	2.00358	1.000	hds.a
of000021	19.6000	17.7525	1.84749	1.000	hds.a
of000022	17.7000	15.0940	2.60603	1.000	hds.a
of000023	15.3700	14.2499	1.12014	1.000	hds.a
of000024	13.9700	14.2040	-0.233970	1.000	hds.a
of000025	-4.000000E-02	4.92248	-4.96249	1.000	hds.a
of000026	18.1100	18.4597	-0.349710	1.000	hds.a
of000027	16.9000	18.1306	-1.23063	1.000	hds.a
of000028	17.7600	17.1761	0.583920	1.000	hds.a
of000029	17.0600	17.4144	-0.354420	1.000	hds.a
of000030	17.0600	17.1353	-7.528000E-02	1.000	hds.a
of000031	18.4600	16.8529	1.60708	1.000	hds.a
of000032	15.1000	14.9567	0.143250	1.000	hds.a
of000033	12.8300	14.2484	-1.41835	1.000	hds.a
of000034	12.8300	14.2038	-1.37384	1.000	hds.a
of000035	5.68000	6.60669	-0.926688	1.000	hds.a

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

of000036	3.85000	3.30296	0.547044	1.000	hds.a
of000037	23.1400	19.9980	3.14198	1.000	hds.a
of000038	19.3000	19.4748	-0.174820	1.000	hds.a
of000039	19.9800	18.5219	1.45812	1.000	hds.a
of000040	21.4000	18.1370	3.26302	1.000	hds.a
of000041	19.1000	15.1789	3.92113	1.000	hds.a
of000042	13.9900	14.2501	-0.260060	1.000	hds.a
of000043	13.9900	14.2040	-0.213980	1.000	hds.a
of000044	-3.12000	-1.01012	-2.10988	1.000	hds.a
of000045	-3.04000	-0.431059	-2.60894	1.000	hds.a
of000046	20.8300	18.6994	2.13060	1.000	hds.a
of000047	18.0400	18.3296	-0.289590	1.000	hds.a
of000048	19.4200	17.3236	2.09637	1.000	hds.a
of000049	18.0100	17.5802	0.429780	1.000	hds.a
of000050	15.9000	17.2849	-1.38495	1.000	hds.a
of000051	18.0100	16.9852	1.02484	1.000	hds.a
of000052	13.5000	14.9902	-1.49018	1.000	hds.a
of000053	12.3800	14.2491	-1.86908	1.000	hds.a
of000054	12.3800	14.2039	-1.82390	1.000	hds.a
of000055	12.3800	6.21158	6.16842	1.000	hds.a
of000056	1.78000	2.34997	-0.569973	1.000	hds.a
of000057	0.640000	2.74831	-2.10831	1.000	hds.a
of000058	15.7200	17.9497	-2.22973	1.000	hds.a
of000059	15.2100	17.6829	-2.47293	1.000	hds.a
of000060	14.6700	16.8416	-2.17155	1.000	hds.a
of000061	14.9100	17.0458	-2.13576	1.000	hds.a
of000062	14.7600	16.8013	-2.04135	1.000	hds.a
of000063	14.4800	16.5515	-2.07152	1.000	hds.a
of000064	12.9700	14.8810	-1.91104	1.000	hds.a
of000065	12.5500	14.2470	-1.69703	1.000	hds.a
of000066	12.2500	14.2037	-1.95374	1.000	hds.a
of000067	8.50000	7.51666	0.983335	1.000	hds.a
of000068	4.73000	4.24237	0.487630	1.000	hds.a
of000069	5.04000	4.54636	0.493635	1.000	hds.a

See file C:\ASRHE11X8W(DK)FRAC3K1-PESTOPT3\ASRHE11X8W(DK)FRAC3K1-PESTOPT3.RES for more details of residuals in graph-ready format.

See file C:\ASRHE11X8W(DK)FRAC3K1-PESTOPT3\ASRHE11X8W(DK)FRAC3K1-PESTOPT3.SEO for composite observation sensitivities.

Appendix C: PEST Calibration Statistics (Continued)

Discontinuum FracMan Model

Objective function ----->

Sum of squared weighted residuals (ie phi) = 245.7

Correlation Coefficient ----->

Correlation coefficient = 0.9515

Analysis of residuals ----->

All residuals:-

Number of residuals with non-zero weight	= 63
Mean value of non-zero weighted residuals	= 0.1146
Maximum weighted residual [observation "of000055"]	= 6.168
Minimum weighted residual [observation "of000025"]	= -4.962
Standard variance of weighted residuals	= 8.474
Standard error of weighted residuals	= 2.911

Note: the above variance was obtained by dividing the objective function by the number of system degrees of freedom (ie. number of observations with non-zero weight plus number of prior information articles with non-zero weight minus the number of adjustable parameters.) If the degrees of freedom is negative the divisor becomes the number of observations with non-zero weight plus the number of prior information items with non-zero weight.

Appendix D: Model Input/Output for Continuum Model

PHT3D (Input)

SOLUTION 1 # [K,I,J] = 1,1,1

units mol/kgw

water 1.0

temp 1.500000e+001

pH 7.500000e+000 # comp 24

pe -3.360000e+000 # comp 25

C(4) 2.277700e-003 # comp 1

C(-4) 0.000000e+000 # comp 2

Ca 1.723100e-003 # comp 3

Cl 5.077200e-003 # comp 4

Fe(2) 3.172200e-006 # comp 5

Fe(3) 3.580000e-014 # comp 6

K 0.000000e+000 # comp 7

Mg 2.099600e-003 # comp 8

N(5) 0.000000e+000 # comp 9

N(3) 0.000000e+000 # comp 10

N(0) 0.000000e+000 # comp 11

Amm 0.000000e+000 # comp 12

Na 5.052000e-003 # comp 13

O(0) 0.000000e+000 # comp 14

S(-2) 0.000000e+000 # comp 15

S(6) 2.729000e-003 # comp 16

As(3) 0.000000e+000 # comp 17

As(5) 0.000000e+000 # comp 18

Si 0.000000e+000 # comp 19

Tmp 2.800000e-002 # comp 20

END

EQUILIBRIUM_PHASES 1

Calcite 0.000000e+000 6.400000e+001 # comp 26

Dolomite 0.000000e+000 8.000000e+000 # comp 27

Gypsum 0.000000e+000 8.000000e-002 # comp 28

Fe(OH)3(a) 0.000000e+000 4.000000e-014 # comp 29

END

KINETICS 1

Pyrite # 34

-parms 1.600000e+001 6.700000e-001 5.000000e-001 -1.100000e-001

1.150000e+002

-m0 2.091160e-002

Arsenopyrite # 35

-parms 1.000000e-002

-m0 2.091160e-002

Appendix D: Model Input/Output for Continuum Model (Continued)

PHT3D (Input)

```
Fe(OH)3(a) # 36
    -parms 2.000000e-013
    -m0 4.000000e-014
END
EXCHANGE 1
    X 0.000000e+000
    NaX 9.000000e-003
    MgX2 1.640000e-002
    CaX2 2.350000e-002
END
SOLUTION 2 # [K,I,J] = 1,1,2
    units mol/kgw
    water 1.0
    temp 1.500000e+001
    pH 7.500000e+000 # comp 24
    pe -3.360000e+000 # comp 25
    C(4) 2.277700e-003 # comp 1
    C(-4) 0.000000e+000 # comp 2
    Ca 1.723100e-003 # comp 3
    Cl 5.077200e-003 # comp 4
    Fe(2) 3.172200e-006 # comp 5
    Fe(3) 3.580000e-014 # comp 6
    K 0.000000e+000 # comp 7
    Mg 2.099600e-003 # comp 8
    N(5) 0.000000e+000 # comp 9
    N(3) 0.000000e+000 # comp 10
    N(0) 0.000000e+000 # comp 11
    Amm 0.000000e+000 # comp 12
    Na 5.052000e-003 # comp 13
    O(0) 0.000000e+000 # comp 14
    S(-2) 0.000000e+000 # comp 15
    S(6) 2.729000e-003 # comp 16
    As(3) 0.000000e+000 # comp 17
    As(5) 0.000000e+000 # comp 18
    Si 0.000000e+000 # comp 19
    Tmp 2.800000e-002 # comp 20
END
EQUILIBRIUM_PHASES 2
    Calcite 0.000000e+000 6.400000e+001 # comp 26
    Dolomite 0.000000e+000 8.000000e+000 # comp 27
    Gypsum 0.000000e+000 8.000000e-002 # comp 28
    Fe(OH)3(a) 0.000000e+000 4.000000e-014 # comp 29
```

Appendix D: Model Input/Output for Continuum Model (Continued)

PHT3D (Input)

END

KINETICS 2

Pyrite # 34

-parms 1.600000e+001 6.700000e-001 5.000000e-001 -1.100000e-001

1.150000e+002

-m0 8.000000e-002

Arsenopyrite # 35

-parms 1.000000e-002

-m0 2.290680e-002

Fe(OH)3(a) # 36

-parms 2.000000e-013

-m0 4.000000e-014

END

EXCHANGE 2

X 0.000000e+000

NaX 9.000000e-003

MgX2 1.640000e-002

CaX2 2.350000e-002

END

Appendix D: Model Input/Output for Continuum Model (Continued)

PHT3D (Output)

Input file: phinp.dat
Output file: phout.dat
Database file: pht3d_datab.dat

Reading data base.

SOLUTION_MASTER_SPECIES
SOLUTION_SPECIES
PHASES
EXCHANGE_MASTER_SPECIES
EXCHANGE_SPECIES
RATES
RATES
SURFACE_MASTER_SPECIES
SURFACE_SPECIES
END

Reading input data for simulation 1.

SOLUTION 1 # [K,I,J] = 1,1,1
units mol/kgw
water 1.0
temp 1.500000e+001
pH 7.500000e+000 # comp 24
pe -3.360000e+000 # comp 25
C(4) 2.277700e-003 # comp 1
C(-4) 0.000000e+000 # comp 2
Ca 1.723100e-003 # comp 3
Cl 5.077200e-003 # comp 4
Fe(2) 3.172200e-006 # comp 5
Fe(3) 3.580000e-014 # comp 6
K 0.000000e+000 # comp 7
Mg 2.099600e-003 # comp 8
N(5) 0.000000e+000 # comp 9
N(3) 0.000000e+000 # comp 10
N(0) 0.000000e+000 # comp 11
Amm 0.000000e+000 # comp 12
Na 5.052000e-003 # comp 13

Appendix D: Model Input/Output for Continuum Model (Continued)

PHT3D (Output)

O(0) 0.000000e+000 # comp 14
S(-2) 0.000000e+000 # comp 15
S(6) 2.729000e-003 # comp 16
As(3) 0.000000e+000 # comp 17
As(5) 0.000000e+000 # comp 18
Si 0.000000e+000 # comp 19
Tmp 2.800000e-002 # comp 20

END

Beginning of initial solution calculations.

Initial solution 1.

-----Solution composition-----

Elements	Molality	Moles
C(4)	2.278e-003	2.278e-003
Ca	1.723e-003	1.723e-003
Cl	5.077e-003	5.077e-003
Fe(2)	3.172e-006	3.172e-006
Fe(3)	3.580e-014	3.580e-014
Mg	2.100e-003	2.100e-003
Na	5.052e-003	5.052e-003
S(6)	2.729e-003	2.729e-003
Tmp	2.800e-002	2.800e-002

-----Description of solution-----

pH = 7.500
pe = -3.360
Activity of water = 0.999
Ionic strength = 1.712e-002
Mass of water (kg) = 1.000e+000
Total alkalinity (eq/kg) = 2.135e-003
Total CO2 (mol/kg) = 2.278e-003
Temperature (deg C) = 15.000
Electrical balance (eq) = 3.338e-005
Percent error, 100*(Cat-|An|)/(Cat+|An|) = 0.14
Iterations = 8

Appendix D: Model Input/Output for Continuum Model (Continued)

PHT3D (Output)

Total H = 1.110146e+002

Total O = 5.552381e+001

-----Redox couples-----

Redox couple	pe	Eh (volts)
Fe(2)/Fe(3)	-3.8333	-0.2192

-----Distribution of species-----

Species	Molality	Log Activity	Log Molality	Log Activity	Gamma
OH-	1.624e-007	1.424e-007	-6.789	-6.846	-0.057
H+	3.527e-008	3.162e-008	-7.453	-7.500	-0.047
H2O-0.01	1.080e-009	1.080e-009	-8.967	-8.967	-0.000
H2O	5.551e+001	9.992e-001	1.744	-0.000	0.000
C(4)	2.278e-003				
HCO3-	2.067e-003	1.829e-003	-2.685	-2.738	-0.053
CO2	1.512e-004	1.518e-004	-3.820	-3.819	0.002
MgHCO3+	2.620e-005	2.306e-005	-4.582	-4.637	-0.055
CaHCO3+	1.978e-005	1.750e-005	-4.704	-4.757	-0.053
NaHCO3	4.529e-006	4.547e-006	-5.344	-5.342	0.002
CO3-2	3.522e-006	2.156e-006	-5.453	-5.666	-0.213
CaCO3	2.784e-006	2.795e-006	-5.555	-5.554	0.002
MgCO3	1.960e-006	1.967e-006	-5.708	-5.706	0.002
FeHCO3+	3.160e-007	2.782e-007	-6.500	-6.556	-0.055
NaCO3-	1.197e-007	1.054e-007	-6.922	-6.977	-0.055
FeCO3	7.837e-008	7.868e-008	-7.106	-7.104	0.002
Ca	1.723e-003				
Ca+2	1.481e-003	9.064e-004	-2.829	-3.043	-0.213
CaSO4	2.194e-004	2.203e-004	-3.659	-3.657	0.002
CaHCO3+	1.978e-005	1.750e-005	-4.704	-4.757	-0.053
CaCO3	2.784e-006	2.795e-006	-5.555	-5.554	0.002
CaOH+	5.400e-009	4.753e-009	-8.268	-8.323	-0.055
Cl	5.077e-003				
Cl-	5.077e-003	4.455e-003	-2.294	-2.351	-0.057
FeCl+	1.063e-008	9.355e-009	-7.974	-8.029	-0.055
FeCl+2	1.953e-024	1.172e-024	-23.709	-23.931	-0.222
FeCl2+	3.679e-026	3.238e-026	-25.434	-25.490	-0.055
FeCl3	1.437e-029	1.443e-029	-28.843	-28.841	0.002

Appendix D: Model Input/Output for Continuum Model (Continued)

PHT3D (Output)

Fe(2)	3.172e-006					
Fe+2	2.460e-006	1.521e-006	-5.609	-5.818	-0.209	
FeHCO3+	3.160e-007	2.782e-007	-6.500	-6.556	-0.055	
FeSO4	2.992e-007	3.004e-007	-6.524	-6.522	0.002	
FeCO3	7.837e-008	7.868e-008	-7.106	-7.104	0.002	
FeCl+	1.063e-008	9.355e-009	-7.974	-8.029	-0.055	
FeOH+	7.970e-009	7.016e-009	-8.099	-8.154	-0.055	
FeHSO4+	6.955e-014	6.121e-014	-13.158	-13.213	-0.055	
Fe(3)	3.580e-014					
Fe(OH)3	2.449e-014	2.459e-014	-13.611	-13.609	0.002	
Fe(OH)2+	1.077e-014	9.483e-015	-13.968	-14.023	-0.055	
Fe(OH)4-	5.311e-016	4.675e-016	-15.275	-15.330	-0.055	
FeOH+2	2.236e-018	1.342e-018	-17.651	-17.872	-0.222	
FeSO4+	1.608e-022	1.415e-022	-21.794	-21.849	-0.055	
Fe+3	3.227e-023	1.210e-023	-22.491	-22.917	-0.426	
Fe(SO4)2-	4.532e-024	3.989e-024	-23.344	-23.399	-0.055	
FeCl+2	1.953e-024	1.172e-024	-23.709	-23.931	-0.222	
FeCl2+	3.679e-026	3.238e-026	-25.434	-25.490	-0.055	
FeHSO4+2	2.037e-029	1.223e-029	-28.691	-28.913	-0.222	
FeCl3	1.437e-029	1.443e-029	-28.843	-28.841	0.002	
Fe2(OH)2+4	5.726e-034	7.433e-035	-33.242	-34.129	-0.887	
Fe3(OH)4+5	0.000e+000	0.000e+000	-44.032	-45.417	-1.385	
H(0)	7.586e-012					
H2	3.793e-012	3.808e-012	-11.421	-11.419	0.002	
Mg	2.100e-003					
Mg+2	1.804e-003	1.115e-003	-2.744	-2.953	-0.209	
MgSO4	2.676e-004	2.686e-004	-3.573	-3.571	0.002	
MgHCO3+	2.620e-005	2.306e-005	-4.582	-4.637	-0.055	
MgCO3	1.960e-006	1.967e-006	-5.708	-5.706	0.002	
MgOH+	5.709e-008	5.025e-008	-7.243	-7.299	-0.055	
Na	5.052e-003					
Na+	5.016e-003	4.422e-003	-2.300	-2.354	-0.055	
NaSO4-	3.163e-005	2.784e-005	-4.500	-4.555	-0.055	
NaHCO3	4.529e-006	4.547e-006	-5.344	-5.342	0.002	
NaCO3-	1.197e-007	1.054e-007	-6.922	-6.977	-0.055	
NaOH	9.195e-010	9.232e-010	-9.036	-9.035	0.002	
O(0)	0.000e+000					
O2	0.000e+000	0.000e+000	-72.951	-72.949	0.002	
S(6)	2.729e-003					
SO4-2	2.210e-003	1.342e-003	-2.656	-2.872	-0.217	
MgSO4	2.676e-004	2.686e-004	-3.573	-3.571	0.002	
CaSO4	2.194e-004	2.203e-004	-3.659	-3.657	0.002	

Appendix D: Model Input/Output for Continuum Model (Continued)

PHT3D (Output)

NaSO4-	3.163e-005	2.784e-005	-4.500	-4.555	-0.055
FeSO4	2.992e-007	3.004e-007	-6.524	-6.522	0.002
HSO4-	3.803e-009	3.347e-009	-8.420	-8.475	-0.055
FeHSO4+	6.955e-014	6.121e-014	-13.158	-13.213	-0.055
FeSO4+	1.608e-022	1.415e-022	-21.794	-21.849	-0.055
Fe(SO4)2-	4.532e-024	3.989e-024	-23.344	-23.399	-0.055
FeHSO4+2	2.037e-029	1.223e-029	-28.691	-28.913	-0.222
Tmp	2.800e-002				
Tmp	2.800e-002	2.811e-002	-1.553	-1.551	0.002

-----Saturation indices-----

Phase	SI	log IAP	log KT	
Calcite	-0.28	-8.71	-8.43	CaCO3
CO2(g)	-2.48	-3.82	-1.34	CO2
Dolomite	-0.48	-17.33	-16.85	CaMg(CO3)2
Fe(OH)3(a)	-5.31	-0.42	4.89	Fe(OH)3
Goethite	0.58	-0.42	-1.00	FeOOH
Gypsum	-1.33	-5.92	-4.58	CaSO4:2H2O
H2(g)	-8.31	-11.42	-3.11	H2
Hematite	2.39	-0.84	-3.22	Fe2O3
O2(g)	-70.04	-72.95	-2.91	O2
Siderite	-0.66	-11.48	-10.83	FeCO3

End of simulation.

Reading input data for simulation 2.

EQUILIBRIUM_PHASES 1

Calcite 0.000000e+000 6.400000e+001 # comp 26
Dolomite 0.000000e+000 8.000000e+000 # comp 27
Gypsum 0.000000e+000 8.000000e-002 # comp 28
Fe(OH)3(a) 0.000000e+000 4.000000e-014 # comp 29

END

End of simulation.

Appendix D: Model Input/Output for Continuum Model (Continued)

PHT3D (Output)

```
-----
Reading input data for simulation 3.
-----

      KINETICS 1
        Pyrite # 34
        parms 1.600000e+001 6.700000e-001 5.000000e-001 -1.100000e-001
1.150000e+002
        m0 2.091160e-002
        Arsenopyrite # 35
        parms 1.000000e-002
        m0 2.091160e-002
        Fe(OH)3(a) # 36
        parms 2.000000e-013
        m0 4.000000e-014
      END

-----
End of simulation.
-----

-----
Reading input data for simulation 4.
-----

      EXCHANGE 1
        X 0.000000e+000
        NaX 9.000000e-003
        MgX2 1.640000e-002
        CaX2 2.350000e-002
      END

-----
End of simulation.
-----
```

Appendix E: Model Input/Output for Discontinuum Model

PHT3D (Input)

SOLUTION 1 # [K,I,J] = 1,1,1

units mol/kgw

water 1.0

temp 1.500000e+001

pH 7.500000e+000 # comp 24

pe -3.360000e+000 # comp 25

C(4) 2.277700e-003 # comp 1

C(-4) 0.000000e+000 # comp 2

Ca 1.723100e-003 # comp 3

Cl 5.077200e-003 # comp 4

Fe(2) 3.172200e-006 # comp 5

Fe(3) 3.580000e-014 # comp 6

K 0.000000e+000 # comp 7

Mg 2.099600e-003 # comp 8

N(5) 0.000000e+000 # comp 9

N(3) 0.000000e+000 # comp 10

N(0) 0.000000e+000 # comp 11

Amm 0.000000e+000 # comp 12

Na 5.052000e-003 # comp 13

O(0) 0.000000e+000 # comp 14

S(-2) 0.000000e+000 # comp 15

S(6) 2.729000e-003 # comp 16

As(3) 0.000000e+000 # comp 17

As(5) 0.000000e+000 # comp 18

Si 0.000000e+000 # comp 19

Tmp 2.800000e-002 # comp 20

END

EQUILIBRIUM_PHASES 1

Calcite 0.000000e+000 6.400000e+001 # comp 26

Dolomite 0.000000e+000 8.000000e+000 # comp 27

Gypsum 0.000000e+000 8.000000e-002 # comp 28

Fe(OH)3(a) 0.000000e+000 4.000000e-014 # comp 29

END

KINETICS 1

Pyrite # 34

-parms 1.600000e+001 6.700000e-001 5.000000e-001 -1.100000e-001

1.150000e+002

-m0 4.000000e-002

Arsenopyrite # 35

-parms 5.000000e-003

-m0 4.000000e-001

Appendix E: Model Input/Output for Discontinuum Model (Continued)

PHT3D (Input)

```
Fe(OH)3(a) # 36
    -parms 2.000000e-013
    -m0 4.000000e-014
END
EXCHANGE 1
    X 0.000000e+000
    NaX 9.000000e-003
    MgX2 1.640000e-002
    CaX2 2.350000e-002
END
COPY solution 1 2-61180
COPY equilibrium_phases 1 2-61180
COPY exchange 1 2-61180
COPY kinetics 1 2-61180
END
PRINT
    -reset false
END
# Start of contents postfix.phrq
SURFACE 1-60375
#Hfo_w Fe(OH)3(a) equilibrium_phase 0.2 5.34e-04
Hfo_w Fe(OH)3(a) kinetic 0.2 5.34e-04
Hfo_s Fe(OH)3(a) kinetic 0.005
#-equil 1
-diffuse_layer

KNOBS
-step_size 5
-pe_step_size 2
-diagonal_scale true
-tolerance 1e-16
-iterations 600

SELECTED_OUTPUT
-reset false
-file as.sel

USER_PUNCH
-start
# Simulation Number and Step No (0 = initial solution)
5 PUNCH sim_time cell_no
34 PUNCH -LA("H+")
```

Appendix E: Model Input/Output for Discontinuum Model (Continued)

PHT3D (Input)

```
35 PUNCH -LA("e-")
40 PUNCH KIN("Fe(OH)3(a)")
50 PUNCH MOL("Hfo_wH2AsO4") + MOL("Hfo_wHAsO4-") +
MOL("Hfo_wOHAsO4-3")
53 PUNCH MOL("Hfo_wH2AsO3")
-end
```

END

End of contents postfix.phrq

Appendix E: Model Input/Output for Discontinuum Model (Continued)

PHT3D (Output)

Input file: phinp.dat
Output file: phout.dat
Database file: pht3d_datab.dat

Reading data base.

SOLUTION_MASTER_SPECIES
SOLUTION_SPECIES
PHASES
EXCHANGE_MASTER_SPECIES
EXCHANGE_SPECIES
RATES
RATES
SURFACE_MASTER_SPECIES
SURFACE_SPECIES
END

Reading input data for simulation 1.

SOLUTION 1 # [K,I,J] = 1,1,1
units mol/kgw
water 1.0
temp 1.500000e+001
pH 7.500000e+000 # comp 24
pe -3.360000e+000 # comp 25
C(4) 2.277700e-003 # comp 1
C(-4) 0.000000e+000 # comp 2
Ca 1.723100e-003 # comp 3
Cl 5.077200e-003 # comp 4
Fe(2) 3.172200e-006 # comp 5
Fe(3) 3.580000e-014 # comp 6
K 0.000000e+000 # comp 7
Mg 2.099600e-003 # comp 8
N(5) 0.000000e+000 # comp 9
N(3) 0.000000e+000 # comp 10
N(0) 0.000000e+000 # comp 11
Amm 0.000000e+000 # comp 12
Na 5.052000e-003 # comp 13
O(0) 0.000000e+000 # comp 14

Appendix E: Model Input/Output for Discontinuum Model (Continued)

PHT3D (Output)

S(-2) 0.000000e+000 # comp 15
S(6) 2.729000e-003 # comp 16
As(3) 0.000000e+000 # comp 17
As(5) 0.000000e+000 # comp 18
Si 0.000000e+000 # comp 19
Tmp 2.800000e-002 # comp 20
END

Beginning of initial solution calculations.

Initial solution 1.

-----Solution composition-----

Elements	Molality	Moles
C(4)	2.278e-003	2.278e-003
Ca	1.723e-003	1.723e-003
Cl	5.077e-003	5.077e-003
Fe(2)	3.172e-006	3.172e-006
Fe(3)	3.580e-014	3.580e-014
Mg	2.100e-003	2.100e-003
Na	5.052e-003	5.052e-003
S(6)	2.729e-003	2.729e-003
Tmp	2.800e-002	2.800e-002

-----Description of solution-----

pH = 7.500
pe = -3.360
Activity of water = 0.999
Ionic strength = 1.712e-002
Mass of water (kg) = 1.000e+000
Total alkalinity (eq/kg) = 2.135e-003
Total CO2 (mol/kg) = 2.278e-003
Temperature (deg C) = 15.000
Electrical balance (eq) = 3.338e-005
Percent error, $100 * (\text{Cat} - |\text{An}|) / (\text{Cat} + |\text{An}|)$ = 0.14
Iterations = 8
Total H = 1.110146e+002

Appendix E: Model Input/Output for Discontinuum Model (Continued)

PHT3D (Output)

Total O = 5.552381e+001

-----Redox couples-----

Redox couple	pe	Eh (volts)
Fe(2)/Fe(3)	-3.8333	-0.2192

-----Distribution of species-----

Species	Molality	Log Activity	Log Molality	Log Activity	Gamma
OH-	1.624e-007	1.424e-007	-6.789	-6.846	-0.057
H+	3.527e-008	3.162e-008	-7.453	-7.500	-0.047
H2O-0.01	1.080e-009	1.080e-009	-8.967	-8.967	-0.000
H2O	5.551e+001	9.992e-001	1.744	-0.000	0.000
C(4)	2.278e-003				
HCO3-	2.067e-003	1.829e-003	-2.685	-2.738	-0.053
CO2	1.512e-004	1.518e-004	-3.820	-3.819	0.002
MgHCO3+	2.620e-005	2.306e-005	-4.582	-4.637	-0.055
CaHCO3+	1.978e-005	1.750e-005	-4.704	-4.757	-0.053
NaHCO3	4.529e-006	4.547e-006	-5.344	-5.342	0.002
CO3-2	3.522e-006	2.156e-006	-5.453	-5.666	-0.213
CaCO3	2.784e-006	2.795e-006	-5.555	-5.554	0.002
MgCO3	1.960e-006	1.967e-006	-5.708	-5.706	0.002
FeHCO3+	3.160e-007	2.782e-007	-6.500	-6.556	-0.055
NaCO3-	1.197e-007	1.054e-007	-6.922	-6.977	-0.055
FeCO3	7.837e-008	7.868e-008	-7.106	-7.104	0.002
Ca	1.723e-003				
Ca+2	1.481e-003	9.064e-004	-2.829	-3.043	-0.213
CaSO4	2.194e-004	2.203e-004	-3.659	-3.657	0.002
CaHCO3+	1.978e-005	1.750e-005	-4.704	-4.757	-0.053
CaCO3	2.784e-006	2.795e-006	-5.555	-5.554	0.002
CaOH+	5.400e-009	4.753e-009	-8.268	-8.323	-0.055
Cl	5.077e-003				
Cl-	5.077e-003	4.455e-003	-2.294	-2.351	-0.057
FeCl+	1.063e-008	9.355e-009	-7.974	-8.029	-0.055
FeCl+2	1.953e-024	1.172e-024	-23.709	-23.931	-0.222
FeCl2+	3.679e-026	3.238e-026	-25.434	-25.490	-0.055
FeCl3	1.437e-029	1.443e-029	-28.843	-28.841	0.002
Fe(2)	3.172e-006				

Appendix E: Model Input/Output for Discontinuum Model (Continued)

PHT3D (Output)

Fe+2	2.460e-006	1.521e-006	-5.609	-5.818	-0.209
FeHCO3+	3.160e-007	2.782e-007	-6.500	-6.556	-0.055
FeSO4	2.992e-007	3.004e-007	-6.524	-6.522	0.002
FeCO3	7.837e-008	7.868e-008	-7.106	-7.104	0.002
FeCl+	1.063e-008	9.355e-009	-7.974	-8.029	-0.055
FeOH+	7.970e-009	7.016e-009	-8.099	-8.154	-0.055
FeHSO4+	6.955e-014	6.121e-014	-13.158	-13.213	-0.055
Fe(3)	3.580e-014				
Fe(OH)3	2.449e-014	2.459e-014	-13.611	-13.609	0.002
Fe(OH)2+	1.077e-014	9.483e-015	-13.968	-14.023	-0.055
Fe(OH)4-	5.311e-016	4.675e-016	-15.275	-15.330	-0.055
FeOH+2	2.236e-018	1.342e-018	-17.651	-17.872	-0.222
FeSO4+	1.608e-022	1.415e-022	-21.794	-21.849	-0.055
Fe+3	3.227e-023	1.210e-023	-22.491	-22.917	-0.426
Fe(SO4)2-	4.532e-024	3.989e-024	-23.344	-23.399	-0.055
FeCl+2	1.953e-024	1.172e-024	-23.709	-23.931	-0.222
FeCl2+	3.679e-026	3.238e-026	-25.434	-25.490	-0.055
FeHSO4+2	2.037e-029	1.223e-029	-28.691	-28.913	-0.222
FeCl3	1.437e-029	1.443e-029	-28.843	-28.841	0.002
Fe2(OH)2+4	5.726e-034	7.433e-035	-33.242	-34.129	-0.887
Fe3(OH)4+5	0.000e+000	0.000e+000	-44.032	-45.417	-1.385
H(0)	7.586e-012				
H2	3.793e-012	3.808e-012	-11.421	-11.419	0.002
Mg	2.100e-003				
Mg+2	1.804e-003	1.115e-003	-2.744	-2.953	-0.209
MgSO4	2.676e-004	2.686e-004	-3.573	-3.571	0.002
MgHCO3+	2.620e-005	2.306e-005	-4.582	-4.637	-0.055
MgCO3	1.960e-006	1.967e-006	-5.708	-5.706	0.002
MgOH+	5.709e-008	5.025e-008	-7.243	-7.299	-0.055
Na	5.052e-003				
Na+	5.016e-003	4.422e-003	-2.300	-2.354	-0.055
NaSO4-	3.163e-005	2.784e-005	-4.500	-4.555	-0.055
NaHCO3	4.529e-006	4.547e-006	-5.344	-5.342	0.002
NaCO3-	1.197e-007	1.054e-007	-6.922	-6.977	-0.055
NaOH	9.195e-010	9.232e-010	-9.036	-9.035	0.002
O(0)	0.000e+000				
O2	0.000e+000	0.000e+000	-72.951	-72.949	0.002
S(6)	2.729e-003				
SO4-2	2.210e-003	1.342e-003	-2.656	-2.872	-0.217
MgSO4	2.676e-004	2.686e-004	-3.573	-3.571	0.002
CaSO4	2.194e-004	2.203e-004	-3.659	-3.657	0.002
NaSO4-	3.163e-005	2.784e-005	-4.500	-4.555	-0.055

Appendix E: Model Input/Output for Discontinuum Model (Continued)

PHT3D (Output)

FeSO4	2.992e-007	3.004e-007	-6.524	-6.522	0.002
HSO4-	3.803e-009	3.347e-009	-8.420	-8.475	-0.055
FeHSO4+	6.955e-014	6.121e-014	-13.158	-13.213	-0.055
FeSO4+	1.608e-022	1.415e-022	-21.794	-21.849	-0.055
Fe(SO4)2-	4.532e-024	3.989e-024	-23.344	-23.399	-0.055
FeHSO4+2	2.037e-029	1.223e-029	-28.691	-28.913	-0.222
Tmp	2.800e-002				
Tmp	2.800e-002	2.811e-002	-1.553	-1.551	0.002

-----Saturation indices-----

Phase	SI	log IAP	log KT	
Calcite	-0.28	-8.71	-8.43	CaCO3
CO2(g)	-2.48	-3.82	-1.34	CO2
Dolomite	-0.48	-17.33	-16.85	CaMg(CO3)2
Fe(OH)3(a)	-5.31	-0.42	4.89	Fe(OH)3
Goethite	0.58	-0.42	-1.00	FeOOH
Gypsum	-1.33	-5.92	-4.58	CaSO4:2H2O
H2(g)	-8.31	-11.42	-3.11	H2
Hematite	2.39	-0.84	-3.22	Fe2O3
O2(g)	-70.04	-72.95	-2.91	O2
Siderite	-0.66	-11.48	-10.83	FeCO3

End of simulation.

Reading input data for simulation 2.

```

EQUILIBRIUM_PHASES 1
  Calcite 0.000000e+000 6.400000e+001 # comp 26
  Dolomite 0.000000e+000 8.000000e+000 # comp 27
  Gypsum 0.000000e+000 8.000000e-002 # comp 28
  Fe(OH)3(a) 0.000000e+000 4.000000e-014 # comp 29
END

```

End of simulation.

Appendix E: Model Input/Output for Discontinuum Model (Continued)

PHT3D (Output)

```
-----
Reading input data for simulation 3.
-----

      KINETICS 1
        Pyrite # 34
        parms 1.600000e+001 6.700000e-001 5.000000e-001 -1.100000e-001
1.150000e+002
        m0 4.000000e-002
        Arsenopyrite # 35
        parms 5.000000e-003
        m0 4.000000e-001
        Fe(OH)3(a) # 36
        parms 2.000000e-013
        m0 4.000000e-014
      END

-----
End of simulation.
-----

-----
Reading input data for simulation 4.
-----

      EXCHANGE 1
        X 0.000000e+000
        NaX 9.000000e-003
        MgX2 1.640000e-002
        CaX2 2.350000e-002
      END

-----
End of simulation.
-----
```

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models

Discontinuum Model with FracMan Generated Horizontal Fracture Networks

PHT3D (Input)

```
SOLUTION 1 # [K,I,J] = 1,1,1
    units mol/kgw
    water 1.0
    temp 1.500000e+001
    pH 7.500000e+000 # comp 24
    pe -3.360000e+000 # comp 25
    C(4) 2.277700e-003 # comp 1
    C(-4) 0.000000e+000 # comp 2
    Ca 1.723100e-003 # comp 3
    Cl 5.077200e-003 # comp 4
    Fe(2) 3.172200e-006 # comp 5
    Fe(3) 3.580000e-014 # comp 6
    K 0.000000e+000 # comp 7
    Mg 2.099600e-003 # comp 8
    N(5) 0.000000e+000 # comp 9
    N(3) 0.000000e+000 # comp 10
    N(0) 0.000000e+000 # comp 11
    Amm 0.000000e+000 # comp 12
    Na 5.052000e-003 # comp 13
    O(0) 0.000000e+000 # comp 14
    S(-2) 0.000000e+000 # comp 15
    S(6) 2.729000e-003 # comp 16
    As(3) 0.000000e+000 # comp 17
    As(5) 0.000000e+000 # comp 18
    Si 0.000000e+000 # comp 19
    Tmp 2.800000e-002 # comp 20
END
EQUILIBRIUM_PHASES 1
    Calcite 0.000000e+000 1.066667e+002 # comp 26
    Dolomite 0.000000e+000 1.333333e+001 # comp 27
    Gypsum 0.000000e+000 1.333333e-001 # comp 28
    Fe(OH)3(a) 0.000000e+000 6.666667e-014 # comp 29
END
KINETICS 1
    Pyrite # 34
    -parms 1.600000e+001 6.700000e-001 5.000000e-001 -1.100000e-001
    1.150000e+002
    -m0 6.666667e-002
    Arsenopyrite # 35
```

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal Fracture Networks

PHT3D (Input)

```
-parms 1.000000e-002
      -m0 6.666667e-001
      Fe(OH)3(a) # 36
      -parms 2.000000e-013
      -m0 6.666667e-014
END
EXCHANGE 1
      X 0.000000e+000
      NaX 9.000000e-003
      MgX2 1.640000e-002
      CaX2 2.350000e-002
END
COPY solution 1 2-61180
COPY equilibrium_phases 1 2-61180
COPY exchange 1 2-61180
COPY kinetics 1 2-61180
END
PRINT
      -reset false
END
```


Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal Fracture Networks

PHT3D (Output)

Input file: phinp.dat
Output file: phout.dat
Database file: pht3d_datab.dat

Reading data base.

SOLUTION_MASTER_SPECIES
SOLUTION_SPECIES
PHASES
EXCHANGE_MASTER_SPECIES
EXCHANGE_SPECIES
RATES
RATES
SURFACE_MASTER_SPECIES
SURFACE_SPECIES
END

Reading input data for simulation 1.

SOLUTION 1 # [K,I,J] = 1,1,1
units mol/kgw
water 1.0
temp 1.500000e+001
pH 7.500000e+000 # comp 24
pe -3.360000e+000 # comp 25
C(4) 2.277700e-003 # comp 1
C(-4) 0.000000e+000 # comp 2
Ca 1.723100e-003 # comp 3
Cl 5.077200e-003 # comp 4
Fe(2) 3.172200e-006 # comp 5
Fe(3) 3.580000e-014 # comp 6
K 0.000000e+000 # comp 7
Mg 2.099600e-003 # comp 8
N(5) 0.000000e+000 # comp 9

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal Fracture Networks

PHT3D (Output)

N(3) 0.000000e+000 # comp 10
N(0) 0.000000e+000 # comp 11
Amm 0.000000e+000 # comp 12
Na 5.052000e-003 # comp 13
O(0) 0.000000e+000 # comp 14
S(-2) 0.000000e+000 # comp 15
S(6) 2.729000e-003 # comp 16
As(3) 0.000000e+000 # comp 17
As(5) 0.000000e+000 # comp 18
Si 0.000000e+000 # comp 19
Tmp 2.800000e-002 # comp 20

END

Beginning of initial solution calculations.

Initial solution 1.

-----Solution composition-----

Elements	Molality	Moles
C(4)	2.278e-003	2.278e-003
Ca	1.723e-003	1.723e-003
Cl	5.077e-003	5.077e-003
Fe(2)	3.172e-006	3.172e-006
Fe(3)	3.580e-014	3.580e-014
Mg	2.100e-003	2.100e-003
Na	5.052e-003	5.052e-003
S(6)	2.729e-003	2.729e-003
Tmp	2.800e-002	2.800e-002

-----Description of solution-----

pH = 7.500
pe = -3.360
Activity of water = 0.999
Ionic strength = 1.712e-002

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal Fracture Networks

PHT3D (Output)

Mass of water (kg) = 1.000e+000
 Total alkalinity (eq/kg) = 2.135e-003
 Total CO2 (mol/kg) = 2.278e-003
 Temperature (deg C) = 15.000
 Electrical balance (eq) = 3.338e-005
 Percent error, 100*(Cat-|An|)/(Cat+|An|) = 0.14
 Iterations = 8
 Total H = 1.110146e+002
 Total O = 5.552381e+001

-----Redox couples-----

Redox couple	pe	Eh (volts)
Fe(2)/Fe(3)	-3.8333	-0.2192

-----Distribution of species-----

Species	Molality	Log Activity	Log Molality	Log Activity	Gamma
OH-	1.624e-007	1.424e-007	-6.789	-6.846	-0.057
H+	3.527e-008	3.162e-008	-7.453	-7.500	-0.047
H2O-0.01	1.080e-009	1.080e-009	-8.967	-8.967	-0.000
H2O	5.551e+001	9.992e-001	1.744	-0.000	0.000
C(4)	2.278e-003				
HCO3-	2.067e-003	1.829e-003	-2.685	-2.738	-0.053
CO2	1.512e-004	1.518e-004	-3.820	-3.819	0.002
MgHCO3+	2.620e-005	2.306e-005	-4.582	-4.637	-0.055
CaHCO3+	1.978e-005	1.750e-005	-4.704	-4.757	-0.053
NaHCO3	4.529e-006	4.547e-006	-5.344	-5.342	0.002
CO3-2	3.522e-006	2.156e-006	-5.453	-5.666	-0.213
CaCO3	2.784e-006	2.795e-006	-5.555	-5.554	0.002
MgCO3	1.960e-006	1.967e-006	-5.708	-5.706	0.002
FeHCO3+	3.160e-007	2.782e-007	-6.500	-6.556	-0.055
NaCO3-	1.197e-007	1.054e-007	-6.922	-6.977	-0.055
FeCO3	7.837e-008	7.868e-008	-7.106	-7.104	0.002
Ca	1.723e-003				

**Appendix F: Model Input/Output for Discontinuum FracMan DFN Models
(Continued)**

Discontinuum Model with FracMan Generated Horizontal Fracture Networks

PHT3D (Output)

Ca+2	1.481e-003	9.064e-004	-2.829	-3.043	-0.213
CaSO4	2.194e-004	2.203e-004	-3.659	-3.657	0.002
CaHCO3+	1.978e-005	1.750e-005	-4.704	-4.757	-0.053
CaCO3	2.784e-006	2.795e-006	-5.555	-5.554	0.002
CaOH+	5.400e-009	4.753e-009	-8.268	-8.323	-0.055
Cl	5.077e-003				
Cl-	5.077e-003	4.455e-003	-2.294	-2.351	-0.057
FeCl+	1.063e-008	9.355e-009	-7.974	-8.029	-0.055
FeCl+2	1.953e-024	1.172e-024	-23.709	-23.931	-0.222
FeCl2+	3.679e-026	3.238e-026	-25.434	-25.490	-0.055
FeCl3	1.437e-029	1.443e-029	-28.843	-28.841	0.002
Fe(2)	3.172e-006				
Fe+2	2.460e-006	1.521e-006	-5.609	-5.818	-0.209
FeHCO3+	3.160e-007	2.782e-007	-6.500	-6.556	-0.055
FeSO4	2.992e-007	3.004e-007	-6.524	-6.522	0.002
FeCO3	7.837e-008	7.868e-008	-7.106	-7.104	0.002
FeCl+	1.063e-008	9.355e-009	-7.974	-8.029	-0.055
FeOH+	7.970e-009	7.016e-009	-8.099	-8.154	-0.055
FeHSO4+	6.955e-014	6.121e-014	-13.158	-13.213	-0.055
Fe(3)	3.580e-014				
Fe(OH)3	2.449e-014	2.459e-014	-13.611	-13.609	0.002
Fe(OH)2+	1.077e-014	9.483e-015	-13.968	-14.023	-0.055
Fe(OH)4-	5.311e-016	4.675e-016	-15.275	-15.330	-0.055
FeOH+2	2.236e-018	1.342e-018	-17.651	-17.872	-0.222
FeSO4+	1.608e-022	1.415e-022	-21.794	-21.849	-0.055
Fe+3	3.227e-023	1.210e-023	-22.491	-22.917	-0.426
Fe(SO4)2-	4.532e-024	3.989e-024	-23.344	-23.399	-0.055
FeCl+2	1.953e-024	1.172e-024	-23.709	-23.931	-0.222
FeCl2+	3.679e-026	3.238e-026	-25.434	-25.490	-0.055
FeHSO4+2	2.037e-029	1.223e-029	-28.691	-28.913	-0.222
FeCl3	1.437e-029	1.443e-029	-28.843	-28.841	0.002
Fe2(OH)2+4	5.726e-034	7.433e-035	-33.242	-34.129	-0.887
Fe3(OH)4+5	0.000e+000	0.000e+000	-44.032	-45.417	-1.385
H(0)	7.586e-012				
H2	3.793e-012	3.808e-012	-11.421	-11.419	0.002
Mg	2.100e-003				
Mg+2	1.804e-003	1.115e-003	-2.744	-2.953	-0.209
MgSO4	2.676e-004	2.686e-004	-3.573	-3.571	0.002

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal Fracture Networks

PHT3D (Output)

MgHCO3+	2.620e-005	2.306e-005	-4.582	-4.637	-0.055
MgCO3	1.960e-006	1.967e-006	-5.708	-5.706	0.002
MgOH+	5.709e-008	5.025e-008	-7.243	-7.299	-0.055
Na	5.052e-003				
Na+	5.016e-003	4.422e-003	-2.300	-2.354	-0.055
NaSO4-	3.163e-005	2.784e-005	-4.500	-4.555	-0.055
NaHCO3	4.529e-006	4.547e-006	-5.344	-5.342	0.002
NaCO3-	1.197e-007	1.054e-007	-6.922	-6.977	-0.055
NaOH	9.195e-010	9.232e-010	-9.036	-9.035	0.002
O(0)	0.000e+000				
O2	0.000e+000	0.000e+000	-72.951	-72.949	0.002
S(6)	2.729e-003				
SO4-2	2.210e-003	1.342e-003	-2.656	-2.872	-0.217
MgSO4	2.676e-004	2.686e-004	-3.573	-3.571	0.002
CaSO4	2.194e-004	2.203e-004	-3.659	-3.657	0.002
NaSO4-	3.163e-005	2.784e-005	-4.500	-4.555	-0.055
FeSO4	2.992e-007	3.004e-007	-6.524	-6.522	0.002
HSO4-	3.803e-009	3.347e-009	-8.420	-8.475	-0.055
FeHSO4+	6.955e-014	6.121e-014	-13.158	-13.213	-0.055
FeSO4+	1.608e-022	1.415e-022	-21.794	-21.849	-0.055
Fe(SO4)2-	4.532e-024	3.989e-024	-23.344	-23.399	-0.055
FeHSO4+2	2.037e-029	1.223e-029	-28.691	-28.913	-0.222
Tmp	2.800e-002				
Tmp	2.800e-002	2.811e-002	-1.553	-1.551	0.002

-----Saturation indices-----

Phase	SI	log IAP	log KT	
Calcite	-0.28	-8.71	-8.43	CaCO3
CO2(g)	-2.48	-3.82	-1.34	CO2
Dolomite	-0.48	-17.33	-16.85	CaMg(CO3)2
Fe(OH)3(a)	-5.31	-0.42	4.89	Fe(OH)3
Goethite	0.58	-0.42	-1.00	FeOOH
Gypsum	-1.33	-5.92	-4.58	CaSO4:2H2O
H2(g)	-8.31	-11.42	-3.11	H2
Hematite	2.39	-0.84	-3.22	Fe2O3
O2(g)	-70.04	-72.95	-2.91	O2

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal Fracture Networks

PHT3D (Output)

Siderite -0.66 -11.48 -10.83 FeCO₃

End of simulation.

Reading input data for simulation 2.

EQUILIBRIUM_PHASES 1

Calcite 0.000000e+000 6.400000e+001 # comp 26

Dolomite 0.000000e+000 8.000000e+000 # comp 27

Gypsum 0.000000e+000 8.000000e-002 # comp 28

Fe(OH)₃(a) 0.000000e+000 4.000000e-014 # comp 29

END

End of simulation.

Reading input data for simulation 3.

KINETICS 1

Pyrite # 34

parms 1.600000e+001 6.700000e-001 5.000000e-001 -1.100000e-001
1.150000e+002

m0 4.000000e-002

Arsenopyrite # 35

parms 1.000000e-002

m0 4.000000e-001

Fe(OH)₃(a) # 36

parms 2.000000e-013

m0 4.000000e-014

END

End of simulation.

**Appendix F: Model Input/Output for Discontinuum FracMan DFN Models
(Continued)**

Discontinuum Model with FracMan Generated Horizontal Fracture Networks

PHT3D (Output)

Reading input data for simulation 4.

EXCHANGE 1
X 0.000000e+000
NaX 9.000000e-003
MgX2 1.640000e-002
CaX2 2.350000e-002

END

End of simulation.

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal and Vertical Fracture Networks

PHT3D (Input)

```
SOLUTION 1 # [K,I,J] = 1,1,1
    units mol/kgw
    water 1.0
    temp 1.500000e+001
    pH 7.500000e+000 # comp 24
    pe -3.360000e+000 # comp 25
    C(4) 2.277700e-003 # comp 1
    C(-4) 0.000000e+000 # comp 2
    Ca 1.723100e-003 # comp 3
    Cl 5.077200e-003 # comp 4
    Fe(2) 3.172200e-006 # comp 5
    Fe(3) 3.580000e-014 # comp 6
    K 0.000000e+000 # comp 7
    Mg 2.099600e-003 # comp 8
    N(5) 0.000000e+000 # comp 9
    N(3) 0.000000e+000 # comp 10
    N(0) 0.000000e+000 # comp 11
    Amm 0.000000e+000 # comp 12
    Na 5.052000e-003 # comp 13
    O(0) 0.000000e+000 # comp 14
    S(-2) 0.000000e+000 # comp 15
    S(6) 2.729000e-003 # comp 16
    As(3) 0.000000e+000 # comp 17
    As(5) 0.000000e+000 # comp 18
    Si 0.000000e+000 # comp 19
    Tmp 2.800000e-002 # comp 20
END
EQUILIBRIUM_PHASES 1
    Calcite 0.000000e+000 1.066667e+002 # comp 26
    Dolomite 0.000000e+000 1.333333e+001 # comp 27
    Gypsum 0.000000e+000 1.333333e-001 # comp 28
    Fe(OH)3(a) 0.000000e+000 6.666667e-014 # comp 29
END
KINETICS 1
    Pyrite # 34
    -parms 1.600000e+001 6.700000e-001 5.000000e-001 -1.100000e-001
1.150000e+002
```


Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal and Vertical Fracture Networks

PHT3D (Input)

```
-m0 3.333333e-002
  Arsenopyrite # 35
  -parms 5.000000e-003

-m0 3.333333e-002
  Fe(OH)3(a) # 36
  -parms 2.000000e-013
  -m0 6.666667e-014

END
EXCHANGE 1
  X 0.000000e+000
  NaX 9.000000e-003
  MgX2 1.640000e-002
  CaX2 2.350000e-002

END
```

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal and Vertical Fracture Networks

PHT3D (Output)

Input file: phinp.dat
Output file: phout.dat
Database file: pht3d_datab.dat

Reading data base.

SOLUTION_MASTER_SPECIES
SOLUTION_SPECIES
PHASES
EXCHANGE_MASTER_SPECIES
EXCHANGE_SPECIES
RATES
RATES
SURFACE_MASTER_SPECIES
SURFACE_SPECIES
END

Reading input data for simulation 1.

SOLUTION 1 # [K,I,J] = 1,1,1
units mol/kgw
water 1.0
temp 1.500000e+001
pH 7.500000e+000 # comp 24
pe -3.360000e+000 # comp 25
C(4) 2.277700e-003 # comp 1
C(-4) 0.000000e+000 # comp 2
Ca 1.723100e-003 # comp 3
Cl 5.077200e-003 # comp 4
Fe(2) 3.172200e-006 # comp 5
Fe(3) 3.580000e-014 # comp 6
K 0.000000e+000 # comp 7
Mg 2.099600e-003 # comp 8
N(5) 0.000000e+000 # comp 9

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal and Vertical Fracture Networks

PHT3D (Output)

N(3) 0.000000e+000 # comp 10
N(0) 0.000000e+000 # comp 11
Amm 0.000000e+000 # comp 12
Na 5.052000e-003 # comp 13
O(0) 0.000000e+000 # comp 14
S(-2) 0.000000e+000 # comp 15
S(6) 2.729000e-003 # comp 16
As(3) 0.000000e+000 # comp 17
As(5) 0.000000e+000 # comp 18
Si 0.000000e+000 # comp 19
Tmp 2.800000e-002 # comp 20
END

Beginning of initial solution calculations.

Initial solution 1.

-----Solution composition-----

Elements	Molality	Moles
C(4)	2.278e-003	2.278e-003
Ca	1.723e-003	1.723e-003
Cl	5.077e-003	5.077e-003
Fe(2)	3.172e-006	3.172e-006
Fe(3)	3.580e-014	3.580e-014
Mg	2.100e-003	2.100e-003
Na	5.052e-003	5.052e-003
S(6)	2.729e-003	2.729e-003
Tmp	2.800e-002	2.800e-002

-----Description of solution-----

pH = 7.500
pe = -3.360
Activity of water = 0.999
Ionic strength = 1.712e-002

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal and Vertical Fracture Networks

PHT3D (Output)

Mass of water (kg) = 1.000e+000
 Total alkalinity (eq/kg) = 2.135e-003
 Total CO2 (mol/kg) = 2.278e-003
 Temperature (deg C) = 15.000
 Electrical balance (eq) = 3.338e-005
 Percent error, $100 * (\text{Cat} - |\text{An}|) / (\text{Cat} + |\text{An}|)$ = 0.14
 Iterations = 8
 Total H = 1.110146e+002
 Total O = 5.552381e+001

-----Redox couples-----

Redox couple	pe	Eh (volts)
Fe(2)/Fe(3)	-3.8333	-0.2192

-----Distribution of species-----

Species	Molality	Log Activity	Log Molality	Log Activity	Gamma
OH-	1.624e-007	1.424e-007	-6.789	-6.846	-0.057
H+	3.527e-008	3.162e-008	-7.453	-7.500	-0.047
H2O-0.01	1.080e-009	1.080e-009	-8.967	-8.967	-0.000
H2O	5.551e+001	9.992e-001	1.744	-0.000	0.000
C(4)	2.278e-003				
HCO3-	2.067e-003	1.829e-003	-2.685	-2.738	-0.053
CO2	1.512e-004	1.518e-004	-3.820	-3.819	0.002
MgHCO3+	2.620e-005	2.306e-005	-4.582	-4.637	-0.055
CaHCO3+	1.978e-005	1.750e-005	-4.704	-4.757	-0.053
NaHCO3	4.529e-006	4.547e-006	-5.344	-5.342	0.002
CO3-2	3.522e-006	2.156e-006	-5.453	-5.666	-0.213
CaCO3	2.784e-006	2.795e-006	-5.555	-5.554	0.002
MgCO3	1.960e-006	1.967e-006	-5.708	-5.706	0.002
FeHCO3+	3.160e-007	2.782e-007	-6.500	-6.556	-0.055
NaCO3-	1.197e-007	1.054e-007	-6.922	-6.977	-0.055
FeCO3	7.837e-008	7.868e-008	-7.106	-7.104	0.002
Ca	1.723e-003				

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal and Vertical Fracture Networks

PHT3D (Output)

Ca+2	1.481e-003	9.064e-004	-2.829	-3.043	-0.213
CaSO4	2.194e-004	2.203e-004	-3.659	-3.657	0.002
CaHCO3+	1.978e-005	1.750e-005	-4.704	-4.757	-0.053
CaCO3	2.784e-006	2.795e-006	-5.555	-5.554	0.002
CaOH+	5.400e-009	4.753e-009	-8.268	-8.323	-0.055
Cl	5.077e-003				
Cl-	5.077e-003	4.455e-003	-2.294	-2.351	-0.057
FeCl+	1.063e-008	9.355e-009	-7.974	-8.029	-0.055
FeCl+2	1.953e-024	1.172e-024	-23.709	-23.931	-0.222
FeCl2+	3.679e-026	3.238e-026	-25.434	-25.490	-0.055
FeCl3	1.437e-029	1.443e-029	-28.843	-28.841	0.002
Fe(2)	3.172e-006				
Fe+2	2.460e-006	1.521e-006	-5.609	-5.818	-0.209
FeHCO3+	3.160e-007	2.782e-007	-6.500	-6.556	-0.055
FeSO4	2.992e-007	3.004e-007	-6.524	-6.522	0.002
FeCO3	7.837e-008	7.868e-008	-7.106	-7.104	0.002
FeCl+	1.063e-008	9.355e-009	-7.974	-8.029	-0.055
FeOH+	7.970e-009	7.016e-009	-8.099	-8.154	-0.055
FeHSO4+	6.955e-014	6.121e-014	-13.158	-13.213	-0.055
Fe(3)	3.580e-014				
Fe(OH)3	2.449e-014	2.459e-014	-13.611	-13.609	0.002
Fe(OH)2+	1.077e-014	9.483e-015	-13.968	-14.023	-0.055
Fe(OH)4-	5.311e-016	4.675e-016	-15.275	-15.330	-0.055
FeOH+2	2.236e-018	1.342e-018	-17.651	-17.872	-0.222
FeSO4+	1.608e-022	1.415e-022	-21.794	-21.849	-0.055
Fe+3	3.227e-023	1.210e-023	-22.491	-22.917	-0.426
Fe(SO4)2-	4.532e-024	3.989e-024	-23.344	-23.399	-0.055
FeCl+2	1.953e-024	1.172e-024	-23.709	-23.931	-0.222
FeCl2+	3.679e-026	3.238e-026	-25.434	-25.490	-0.055
FeHSO4+2	2.037e-029	1.223e-029	-28.691	-28.913	-0.222
FeCl3	1.437e-029	1.443e-029	-28.843	-28.841	0.002
Fe2(OH)2+4	5.726e-034	7.433e-035	-33.242	-34.129	-0.887
Fe3(OH)4+5	0.000e+000	0.000e+000	-44.032	-45.417	-1.385
H(0)	7.586e-012				
H2	3.793e-012	3.808e-012	-11.421	-11.419	0.002
Mg	2.100e-003				
Mg+2	1.804e-003	1.115e-003	-2.744	-2.953	-0.209

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal and Vertical Fracture Networks

PHT3D (Output)

MgSO4	2.676e-004	2.686e-004	-3.573	-3.571	0.002
MgHCO3+	2.620e-005	2.306e-005	-4.582	-4.637	-0.055
MgCO3	1.960e-006	1.967e-006	-5.708	-5.706	0.002
MgOH+	5.709e-008	5.025e-008	-7.243	-7.299	-0.055
Na	5.052e-003				
Na+	5.016e-003	4.422e-003	-2.300	-2.354	-0.055
NaSO4-	3.163e-005	2.784e-005	-4.500	-4.555	-0.055
NaHCO3	4.529e-006	4.547e-006	-5.344	-5.342	0.002
NaCO3-	1.197e-007	1.054e-007	-6.922	-6.977	-0.055
NaOH	9.195e-010	9.232e-010	-9.036	-9.035	0.002
O(0)	0.000e+000				
O2	0.000e+000	0.000e+000	-72.951	-72.949	0.002
S(6)	2.729e-003				
SO4-2	2.210e-003	1.342e-003	-2.656	-2.872	-0.217
MgSO4	2.676e-004	2.686e-004	-3.573	-3.571	0.002
CaSO4	2.194e-004	2.203e-004	-3.659	-3.657	0.002
NaSO4-	3.163e-005	2.784e-005	-4.500	-4.555	-0.055
FeSO4	2.992e-007	3.004e-007	-6.524	-6.522	0.002
HSO4-	3.803e-009	3.347e-009	-8.420	-8.475	-0.055
FeHSO4+	6.955e-014	6.121e-014	-13.158	-13.213	-0.055
FeSO4+	1.608e-022	1.415e-022	-21.794	-21.849	-0.055
Fe(SO4)2-	4.532e-024	3.989e-024	-23.344	-23.399	-0.055
FeHSO4+2	2.037e-029	1.223e-029	-28.691	-28.913	-0.222
Tmp	2.800e-002				
Tmp	2.800e-002	2.811e-002	-1.553	-1.551	0.002

-----Saturation indices-----

Phase	SI	log IAP	log KT	
Calcite	-0.28	-8.71	-8.43	CaCO3
CO2(g)	-2.48	-3.82	-1.34	CO2
Dolomite	-0.48	-17.33	-16.85	CaMg(CO3)2
Fe(OH)3(a)	-5.31	-0.42	4.89	Fe(OH)3
Goethite	0.58	-0.42	-1.00	FeOOH
Gypsum	-1.33	-5.92	-4.58	CaSO4:2H2O
H2(g)	-8.31	-11.42	-3.11	H2

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal and Vertical Fracture Networks

PHT3D (Output)

Hematite	2.39	-0.84	-3.22	Fe2O3
O2(g)	-70.04	-72.95	-2.91	O2
Siderite	-0.66	-11.48	-10.83	FeCO3

End of simulation.

Reading input data for simulation 2.

EQUILIBRIUM_PHASES 1

Calcite 0.000000e+000 8.000000e+001 # comp 26
Dolomite 0.000000e+000 1.000000e+001 # comp 27
Gypsum 0.000000e+000 1.000000e-001 # comp 28
Fe(OH)3(a) 0.000000e+000 5.000000e-014 # comp 29

END

End of simulation.

Reading input data for simulation 3.

KINETICS 1

Pyrite # 34
parms 1.600000e+001 6.700000e-001 5.000000e-001 -1.100000e-001
1.150000e+002
m0 5.000000e-002
Arsenopyrite # 35
parms 1.000000e-002
m0 5.000000e-001
Fe(OH)3(a) # 36
parms 2.000000e-013
m0 5.000000e-014

END

Appendix F: Model Input/Output for Discontinuum FracMan DFN Models (Continued)

Discontinuum Model with FracMan Generated Horizontal and Vertical Fracture Networks

PHT3D (Output)

End of simulation.

Reading input data for simulation 4.

```
EXCHANGE 1
      X 0.000000e+000
      NaX 9.000000e-003
      MgX2 1.640000e-002
      CaX2 2.350000e-002
```

END

End of simulation.
