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California GAMA Program: Tracking Water Quality Changes during Groundwater Banking at Two Sites in San Joaquin County

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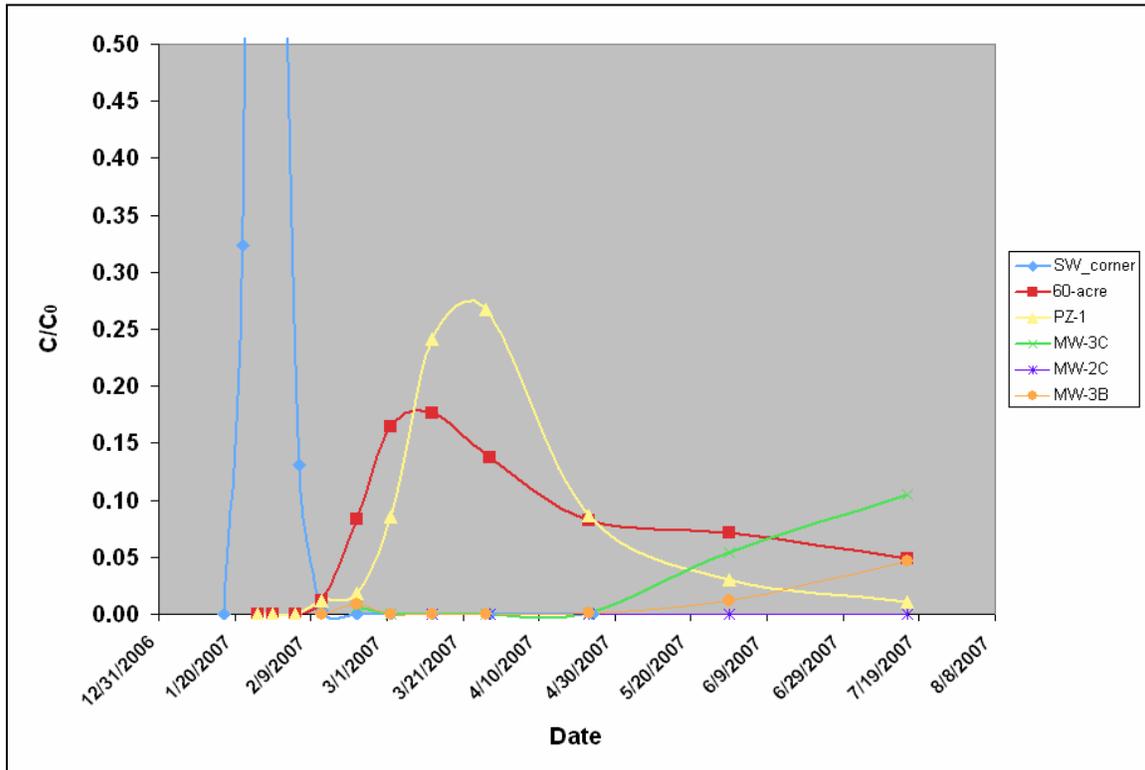
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**GAMA: AMBIENT GROUNDWATER
MONITORING & ASSESSMENT PROGRAM
SPECIAL STUDY**



**California GAMA Program: Tracking Water Quality Changes
During Groundwater Banking at Two Sites in San Joaquin
County**



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Bradley K. Esser**

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Table of Contents

Executive Summary	5
Introduction	7
Methods.....	9
<i>Methods: SF₆ by Gas Chromatography.....</i>	<i>10</i>
<i>Methods: Geochemical Modeling</i>	<i>11</i>
Study Site I: Stockton-East Water District (SEWD).....	12
<i>SEWD: Tracer Test</i>	<i>13</i>
<i>SEWD: Tracer Test Results</i>	<i>14</i>
<i>SEWD: Water Transport and Water Quality Indicators</i>	<i>16</i>
<i>SEWD: Geochemical Modeling</i>	<i>22</i>
<i>SEWD: Discussion of Geochemical Modeling Results.....</i>	<i>24</i>
Study Site II: Morada Lane Detention Pond, Stockton, CA	32
<i>Morada Lane: SF₆ Tracer Test</i>	<i>32</i>
<i>Morada Lane: Isotopic Compositions and Groundwater Age</i>	<i>37</i>
<i>Morada Lane: Water Quality Measurements.....</i>	<i>40</i>
<i>Morada Lane: Noble Gas-Derived Recharge Conditions</i>	<i>47</i>
<i>Morada Lane: Geochemical Modeling.....</i>	<i>48</i>
Summary: Comparing Results from SEWD and Morada Lane... 	51
Acknowledgements.....	53
References	54
 Appendix: Data Tables	
<i>Table A-1: SEWD Water Quality Data.....</i>	<i>A2</i>
<i>Table A-2: SEWD Tracer Data.....</i>	<i>A4</i>
<i>Table A-3: SEWD Noble Gas & Tritium Data.....</i>	<i>A9</i>
<i>Table A-4: SEWD Organic Data</i>	<i>A10</i>
<i>Table A-5: Morada Water Quality Data.....</i>	<i>A11</i>
<i>Table A-6: Morada Tracer Data.....</i>	<i>A12</i>
<i>Table A-7: Morada Noble Gas & Tritium Data</i>	<i>A16</i>
<i>Table A-8: Morada Organic Data</i>	<i>A17</i>

List of Figures

Figure 1. Location of Stockton East Water District (SEWD) and Morada Lane study sites.....	8
Figure 2. Representative GC chromatograms showing signal response near or below the reporting limit.	11
Figure 3. Locations of wells, surface water samples, and tracer water introduction point at SEWD.	13
Figure 4. SF ₆ tracer concentrations in surface water and groundwater samples collected at SEWD. Concentrations are given as ppb SF ₆ in a fixed headspace. A dashed line shows the MDL for this method. Collection date for a full suite of water quality samples is shown as an arrow.....	15
Figure 5. SF ₆ concentrations normalized to the peak concentrations measured in the recharge pond.....	15
Figure 6. West to East cross section of apparent mean ³ H- ³ He ages and percentage of pre-modern (<1955) water in groundwater wells at SEWD. Cross-section and well logs from [Montgomery Watson Harza, 2006].	16
Figure 7. North to South cross section of apparent mean ³ H- ³ He ages and percentage of pre-modern (<1955) water in groundwater wells at SEWD. Cross-section and well logs from [Montgomery Watson Harza, 2006].	17
Figure 8. Calculations (curves) of pre-modern (<1955) water present in groundwater below SEWD. Sample results are shown as dots.	18
Figure 9. Oxygen and hydrogen stable isotope compositions in waters collected at SEWD.....	19
Figure 10. Oxygen stable isotope compositions for samples collected between Jan 26 and May 30, 2007.	20
Figure 11. Arsenic concentrations in surface water and groundwater samples collected at SEWD.	22
Figure 12. Observed and simulated relationships between various geochemical indicators (cation ratios – left; arsenic versus TDS – upper right; vanadium versus δ ¹⁸ O – lower right) measured during the August 2006 sampling round.	25
Figure 13. Temperature and conductivity of water samples collected at SEWD.	27
Figure 14. pH and oxidation reduction potential (ORP) of water samples collected at SEWD.....	28
Figure 15. Dissolved inorganic (DIC) and organic carbon (DOC) of water samples collected at SEWD.	29
Figure 16. Dissolved oxygen (DO) and nitrate concentration of water samples collected at SEWD.	30
Figure 17. Chloride and sulfate concentrations of water samples collected at SEWD.	31
Figure 18. Morada Lane detention basin two (DB2) site showing the location of tracer introduction and the locations where surface water and groundwater samples were taken.....	33
Figure 19. USGS water level measurements at Morada Lane monitoring wells. Water levels are in feet below land surface.	34

Figure 20. Precipitation record (inches) at the Stockton Fire Station from August 2006 to June 2007 (California Department of Water Resources).	34
Figure 21. Results of SF ₆ tracer analysis from Morada Lane surface waters.	35
Figure 22. Results of SF ₆ tracer analysis from Morada Lane surface water and groundwater.	35
Figure 23. Oxygen and hydrogen stable isotope compositions for surface water and groundwater samples collected from the Morada Lane study site.	38
Figure 24. Results of oxygen isotope analysis from Morada Lane surface water and groundwater.	38
Figure 25. Apparent ³ H- ³ He ages, ³ H activity in pCi/L, and recharge temperature (RT) for monitoring wells and public supply wells near the Morada Lane detention basin. The screen depth for each well is shown as a white box. ...	39
Figure 26. Water quality parameters measured in the field at the Morada Lane site.	41
Figure 27. Anion concentrations from samples collected at the Morada Lane site.	42
Figure 28. Trace Element concentrations from samples collected at the Morada Lane site.	43
Figure 29. Dissolved carbon concentration and isotopic composition from samples collected at the Morada Lane site.	44
Figure 30. Oxidative reduction potential and redox-sensitive dissolved gases from samples collected at the Morada Lane site.	45
Figure 31. Parameters derived from noble gas compositions of groundwater near the Morada Lane site.	46
Figure 32. MW1(114') water composition compared to modeled changes in component concentrations; 50-50 mixture of pond water and MW1(220') under various assumptions.	49
Figure 33. MW1(114') water composition compared to modeled changes in component concentrations; 90-10 mixture of pond water and MW1(220') under various assumptions.	49

List of Tables

Table 1. Geochemical and isotopic constituents measured in this study.	8
Table 2. Tracer arrival times in days since the start of the tracer experiment on 10/3/2006. Peak tracer concentrations (C _o) are based on the maximum observed value in the pond.	36

Executive Summary

Under the Special Studies portion of the State Water Resources Control Board's Groundwater Ambient Monitoring and Assessment (GAMA) program, water quality topics of statewide relevance are addressed through focused research studies carried out in collaboration with Lawrence Livermore National Laboratory. The study described here addresses changes in water quality associated with groundwater banking. Geochemical processes associated with groundwater banking, which may entail imported recharge water with very low total dissolved solids (TDS), have received less attention than artificial recharge using treated wastewater or locally-captured water. Improvements to water quality during infiltration have been previously documented and may include removal or degradation of organic compounds and denitrification. However, introduction of water that is substantially out of equilibrium with ambient groundwater can result in mineral precipitation/dissolution reactions, redox reactions, and trace element mobilization that can exert detrimental effects on water quality as well as on local aquifer permeability.

In order to quantify changes in water quality that are a direct result of managed recharge, we introduced an inert dissolved gas tracer at two groundwater banking sites in San Joaquin County near Stockton, an area severely affected by historical and continuing overdraft. Detection of the tracer in nearby wells allows precise determination of the groundwater transit time as well as a measure of the relative proportions of ambient groundwater and recent recharge. Both tracer tests were successful in that the tagged surface water was observed at various wells in the vicinity of the recharge ponds. Many parameters that can be used to assess water source and transport such as groundwater age and stable isotopes of the water molecule, as well as the fate of metals, organics and nitrate were examined along with the introduced gas tracer. This allowed us to constrain the important geochemical and biogeochemical reactions taking place during infiltration and subsequent transport in aquifers.

One study site, operated by Stockton East Water District (SEWD), consists of ponds adjacent to agricultural fields and a surface water treatment plant. Approximately 7000 acre-ft of imported water from New Melones and New Hogan reservoirs are recharged annually. Wells immediately adjacent to the pond had tracer detections 6 to 11 days after the peak tracer detection in the pond, while nested monitoring wells downgradient had detections after 17 days. Production wells are screened below semi-confining units, have groundwater ages indicating that produced water recharged at least several decades ago, and had no tracer detections. A few monitoring wells with short-duration tracer detections were affected by the mound developed after the pond was loaded; subsequent transport was in the direction of the regional groundwater gradient.

Overall groundwater quality in the area is very good, with a maximum nitrate concentration of 17 mg/L (as NO_3^-), total organic carbon < 1 mg/L, and a low frequency of detection of low level volatile organic compounds. Mixing between low TDS recharge water and ambient groundwater, along with typical water-rock reactions such as

carbonate dissolution and cation exchange on clay surfaces control major ion chemistry and result in positive correlations between chloride and sodium, calcium, and bicarbonate ion. The trace elements arsenic, vanadium, and molybdenum, on the other hand, show a sharp increase in concentration in wells strongly affected by recent recharge of imported water. Geochemical modeling shows that surface reactions on hydrous ferric oxides, whereby oxyanions exchange with OH⁻ at near neutral pH, can result in the observed increases in oxyanion-forming trace elements. Arsenic concentrations that hover around the MCL of 10 µg/L are the most significant water quality issue at the SEWD site.

The other study site, operated by the City of Stockton, consists of a storm water detention basin (Morada Lane DB2) which receives imported Mokelumne River water in dry months and storm water runoff during the rainy season. Tracer movement was more complex at this site where groundwater infiltration seems to be controlled by relatively slow vertical movement until it reaches high conductivity lenses that are in hydraulic connection with production wells, whereupon lateral movement occurs at flow rates of up to 30 ft/d (9.7 m/d). Tracer arrived at a nearby drinking water well 119 days after the peak tracer detection in the detention basin, and after 169 days in another production well situated nearly one mile to the west of the pond.

Overall, the quality of the groundwater near the pond is very good – this area is not affected by the saline water intrusion that is a regional problem. Given the different recharge water sources loaded into the pond over the course of the study, it is not surprising that several water quality parameters such as TDS and total organic carbon, vary widely in surface water. The same parameters show a damped, varying pattern in the shallowest monitoring well, and less variation in deeper wells. A stable isotope signature that marks the presence of imported water is observed in monitoring wells up to 300 ft deep, and shows mixing between ambient groundwater and water recharged from the pond.

Redox indicators such as dissolved oxygen as well as redox-sensitive constituents show large variations in dissolved concentrations with depth due to changes in speciation. In particular, nitrate is affected by denitrification in reducing zones, which is mirrored by changes in sulfate concentration due to sulfate reduction. Trace elements such as uranium, vanadium, and arsenic are mobilized and show higher dissolved concentrations in the same zones where redox indicators mark reducing conditions. The redox process proceeds all the way to methane generation, which is present in the shallowest well (where organic carbon from surface water provides an electron donor) and in the deepest portion of the aquifer system (where reduction is presumably driven by solid phases). Potential water quality problems are mobilization of arsenic in shallow groundwater and fast transport to the nearby drinking water well, which has implications for groundwater management when considering potential transport of microbes and viruses.

Introduction

Subsurface storage of excess winter/spring flows or imported water in overdrafted groundwater basins plays a major role in the management of a strained water supply in California. Groundwater banking, or managed underground storage, wherein water from any source is stored in aquifers for later recovery, involves artificial recharge followed by extraction at production wells. Artificial recharge facilities typically consist of spreading ponds, temporary dams on streams, or injection wells, where almost a billion cubic meters of water is intentionally recharged per year statewide.

Artificial recharge entails the introduction of a water composition that is often out of thermodynamic equilibrium with ambient groundwater and local aquifer mineral assemblages. Improvements to water quality (e.g., remineralization of organic material, sorption or biodegradation of organic compounds, denitrification) are often observed during recharge, dramatically so in situations involving agricultural return water and treated wastewater recharge (Clark et al.2004, Davisson et al.2004, Moran and Halliwell, 2003). However, geochemical processes associated with groundwater banking, which may entail recharge water with very low total dissolved solids (TDS), have received less attention. Introduction of water that is substantially out of equilibrium with ambient groundwater can potentially result in mineral precipitation/dissolution reactions, redox reactions, and trace element mobilization that can exert detrimental effects on water quality as well as local aquifer permeability.

In order to constrain the mixing of applied recharge in produced groundwater, we introduced an inert SF₆ gas tracer in applied recharge water at two sites in the San Joaquin Valley, CA and tracked its movement in nearby wells over the following several months. Tracer studies have been previously employed as a means of understanding transport near artificial recharge facilities (Gamlin et al., 2001, Clark et al., 2004, Quast et al., 2006). A number of chemical and isotopic tracers were examined simultaneously to track flow and recharge in these aquifers, and to determine the influence of applied recharge on groundwater quality (Table 1).

The two sites; former agricultural fields adjacent to the Stockton East Water District water treatment plant (called 'SEWD site') and a stormwater detention basin (called 'Morada Lane site') operated by the City of Stockton, are shown on the map in Figure 1. Analytical methods employed at both sites are discussed first, followed by separate discussions of tracer and water quality results from SEWD and Morada Lane; in conclusion results from the two sites are compared. The Morada Lane study was carried out in collaboration with the U.S. Geological Survey (USGS) and the California Department of Water Resources (DWR). The Stockton East Water District, City of Stockton, and San Joaquin County Groundwater Banking Authority all provided valuable information about recharge operations at the sites and assisted with logistics and sampling.

Table 1. Geochemical and isotopic constituents measured in this study.

Constituent	Process or parameter examined
Major ions & trace elements such as Cl ⁻ , NO ₃ ⁻ , SO ₄ ²⁻ , Na, Ca, Fe, Mn, U, and As, low-level VOCs, low-level semi-volatile compounds	Water quality, geochemical reactions
Stable isotopes of the water molecule δ ¹⁸ O and δD	Water source identification*
Isotopes of nitrate δ N and δ O; major dissolved gases	Nitrate source identification & fate of nitrate
DIC and DOC; Carbon isotopes δ ¹³ C	Sources of C, biogeochemical reactions, redox conditions
Tritium and dissolved noble gases	Water transport, groundwater age, recharge conditions
Field water quality parameters pH, TDS, DO, ORP	Redox conditions, changes in water quality *
SF ₆	Water transport tracer*

*Time series analyzed for well water and surface water (up to 15 sampling events)

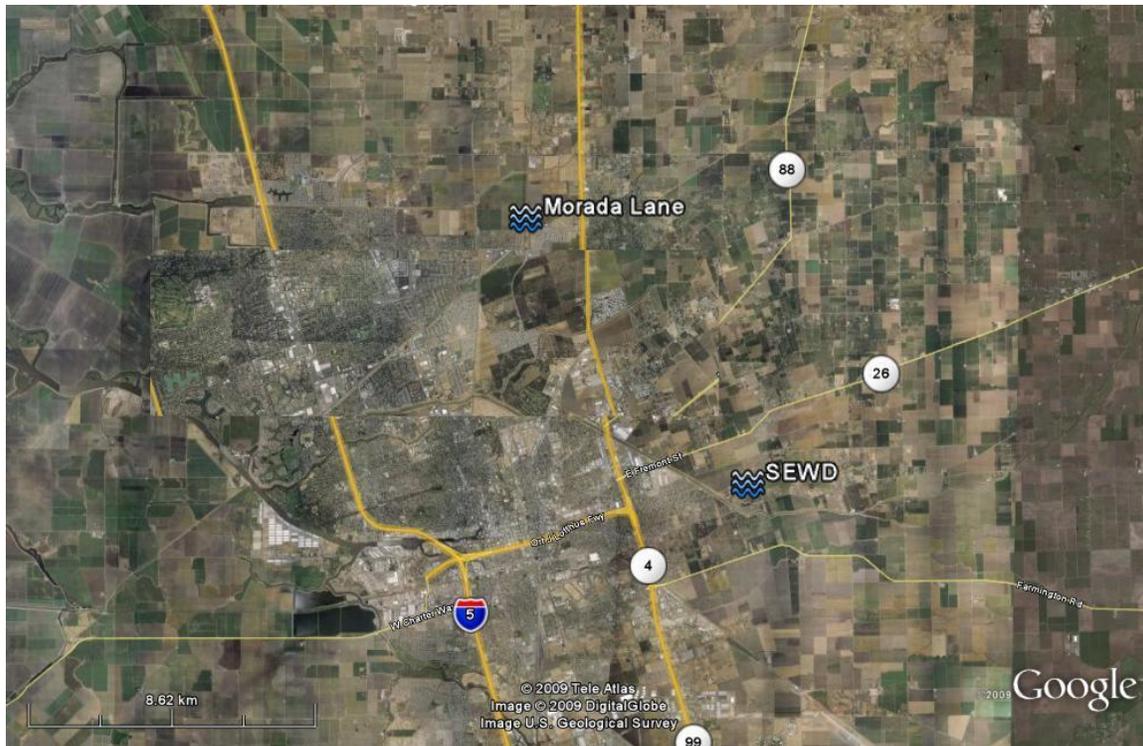


Figure 1. Location of Stockton East Water District (SEWD) and Morada Lane study sites to the east of Stockton, California.

Methods

Surface water and groundwater samples for multiple geochemical and isotopic analyses were collected and analyzed as part of a baseline survey and subsequently during the tracer experiments. Samples were analyzed for major cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+) and anions (SO_4^{2-} , Cl^- , NO_3^-) by ion chromatography using a Dionex DX-600®. Selected trace element concentrations (e.g., As, B, Ba, Co, Cu, Mo, Ni, Sr, V, U, Zn) were measured by inductively coupled plasma mass spectrometry (ICP-MS; ThermoElectron Series X). Dissolved oxygen, pH, and oxidation-reduction potential were measured in the field using a Horiba U-22® water quality parameter field meter. The oxygen isotopic composition of water in groundwater and surface water samples was determined using a VG Prism II® or GV Instruments IsoPrime isotope ratio mass spectrometer and are reported in permil (‰) values relative to the Vienna Standard Mean Ocean Water (SMOW). Dissolved inorganic carbon and its carbon isotope composition were determined using the automated DIC-DOC-IRMS technique (St-Jean, 2003) consisting of an OI Analytical Model 1030 Carbon analyzer and a GV Instruments IsoPrime mass spectrometer. Dissolved organic carbon (DOC) was analyzed via wet oxidation by persulfate. Selected dissolved gases (O_2 , N_2 , CO_2 , CH_4 , and Ar) were measured by membrane inlet mass spectrometry (Kana et al., 1994).

Groundwater age dating by the $^3\text{He}/^3\text{H}$ method has been applied as an aid in quantifying flow and transport on the aquifer scale in a number of studies (e.g., Poreda et al., 1988, Solomon et al., 1992, Ekwurzel et al., 1994). Under this technique, groundwater samples are assigned an apparent age, t , based upon measured abundances of tritium and its daughter product, tritiogenic helium ($^3\text{He}_{\text{trit}}$):

$$t, \text{ years} = -17.8 \times \ln(1 + ^3\text{He}_{\text{trit}}/^3\text{H}) \quad (\text{Equation 1})$$

As part of the age calculation, the measured concentration of ^3He must be corrected for components not related to ^3H decay (Ekwurzel et al., 1994, Aeschbach-Hertig et al., 1999). The resulting inferred groundwater age represents the mean age of the sample subjected to mixing along the flow path from points of recharge to the well screen (Weissmann et al., 2002). The calculated age represents only the age of the portion of the water sample that contains measurable tritium; samples with a ^3H abundance that is too low for accurate age determination (less than 1 pCi/L) are regarded as “pre-modern”, or greater than 50 years in age.

For $^3\text{H}/^3\text{He}$ age dating, sample handling and processing included collection of groundwater samples containing dissolved noble gases in copper tubes filled to prevent exposure to the atmosphere and sealed with a cold weld in the field. Dissolved noble gas concentrations were measured after gas extraction on a vacuum manifold and cryogenic separation of the noble gases using a quadrupole mass spectrometer. The ratio of ^3He to ^4He was measured on a VG5400 mass spectrometer. Tritium was determined

independently by measuring ^3He accumulation after vacuum degassing 0.5-L groundwater samples following a three- to four-week accumulation time. The resulting typical analytical error for groundwater age determination is ± 1 year.

Methods: SF₆ by Gas Chromatography

As part of this study, a highly sensitive technique for measuring dissolved SF₆ concentrations in water was implemented. Analyses of water samples for dissolved sulfur hexafluoride were performed by extracting a known amount of sample, typically 40-43 grams, with 10 mL SF₆-free air in a gas-tight syringe and analyzing the headspace by gas chromatography (GC). Analyses were performed using a Hewlett-Packard 5890 Series II gas chromatograph equipped with a model G1223A electron capture detector (ECD). A Valco two position 10-port valve was installed in the GC and modified for a tandem 2 column configuration, with backflushing of the first column to vent. A 1.0 mL sample loop was used for sample introduction. The analyses were performed with the oven temperature set isothermal at 50°C and ECD temperature set at 300°C, with P5 (5% methane/95% argon) as carrier gas (no make-up gas flow to detector) using a 12 in. x 1/8 in. stainless steel molecular sieve 5A packed column (80/100 mesh, Alltech Associates) for the critical gas chromatographic separation that occurs in the first column. Total run time was 26 sec.

The GC was calibrated using 49 sulfur hexafluoride standards ranging in concentration from 9.3 part per trillion (ppt) to 980 part per billion (ppb). Five separate contiguous calibration curves were constructed to quantify samples throughout the entire range. The GC has a calculated detection limit of 0.6 ppt. Extrapolation of the low level calibration curve with intercept forced through the origin was used to quantify samples below 9.3 ppt but the reporting limit was set at 10 ppt SF₆ in the extracted headspace. A set of seven calibration check standards was used to monitor system stability and selected samples were run in replicate.

Four representative chromatograms are shown in Figure 2. The GC run time was 26 sec (0.43 min.) but except for the Zero Air run, the chromatograms are offset on the x-axis for clarity. Zero Air is an ultrapure synthetic air standard free of SF₆ and was used to extract the SF₆ from the water samples for headspace analysis. The Blank Water chromatogram is the result of extracting an SF₆-free water sample with Zero Air. The small response for SF₆ in this chromatogram was due to minor contamination with room air during sample injection. The next chromatogram shows the response for the 9.3 ppt SF₆ calibration standard, the lowest level calibration standard used. The final chromatogram is a dilution of a surface water sample from the SEWD site, prepared by diluting 100 μL of this sample to 42.65 mL. The dynamic range for this analytical method indicates that one part surface water could be detected in approximately 40,000 parts well water at the SEWD site and one part surface water in 10,000 parts well water at the Morada Lane site, for the concentrations observed in the surface water at each site.

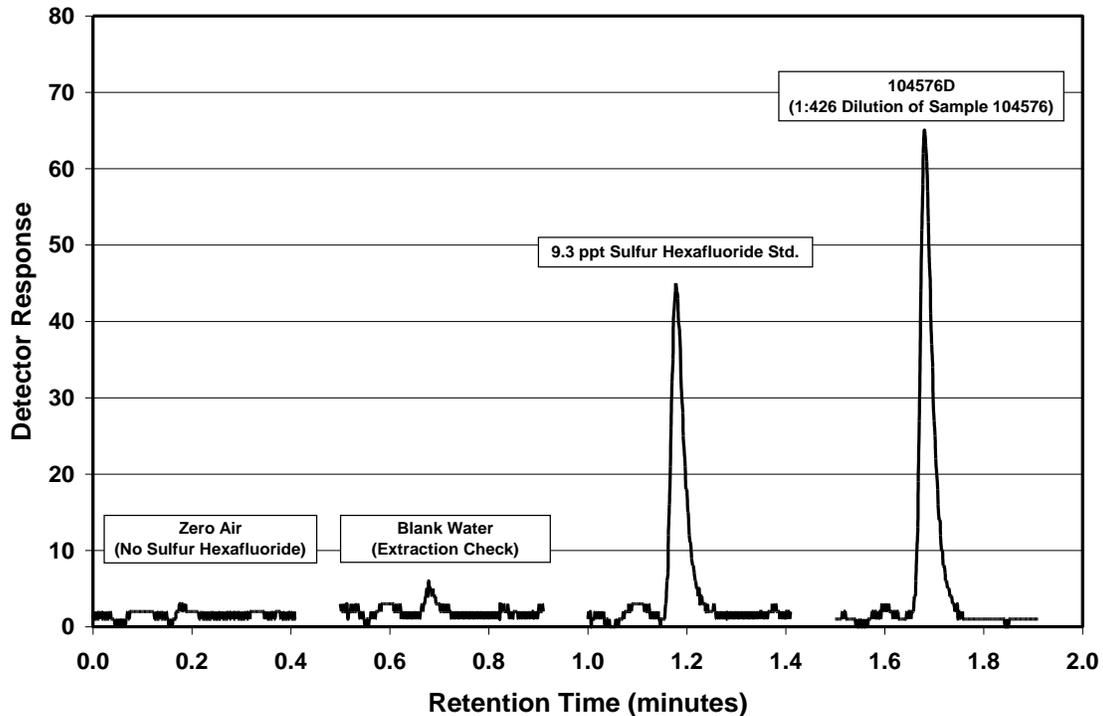


Figure 2. Representative GC chromatograms showing signal response near or below the reporting limit.

Methods: Geochemical Modeling

Changes in water quality parameters as a result of mixing of imported recharge water and groundwater were interpreted with the aid of the PHREEQC geochemical model (Parkhurst and Appelo, 2002). For this study, PHREEQC and its accompanying complexation constant data sets were used to postulate a geochemical model of recharge water-aquifer interactions in the presence of both an ion exchanger and a hydrous ferric oxide phase with a population of active complexation sites, each specified to be in equilibrium with an end-member groundwater composition as an initial condition. The MIX feature of PHREEQC was used to predict the equilibrium concentrations of major ions, trace elements, and pH in response to the incremental displacement of end-member groundwater by recharge water while the mixture was maintained in equilibrium with aquifer mineral surfaces.

Study Site I: Stockton-East Water District (SEWD)

The study area is within the Eastern San Joaquin Ground Water Subbasin (California Department of Water Resources, 2006). The subbasin is several hundred meters (m) of consolidated, partly-consolidated and unconsolidated sedimentary deposits (California Department of Water Resources, 1967). The SEWD site is underlain to a depth of approximately 60 meters by the Pliocene-Pleistocene-age Modesto Formation which is comprised of fluvial arkosic sedimentary materials (Marchand and Allwardt, 1981). Prior to the onset of groundwater pumping, groundwater movement in the alluvial fan deposits was from recharge areas along the foothills of the Sierra Nevada to discharge areas near the San Joaquin Delta. Recharge also occurred as infiltration of surface water along the upstream reaches of rivers and streams crossing the alluvial fan deposits, while groundwater discharge occurred along the lower reaches of these streams (California Department of Water Resources, 1967).

The City of Stockton (population 300,000), about 130 km east of San Francisco (Figure 1), relies on groundwater for over 30% of its public supply (City of Stockton, 2007). In the 1950's, water levels in parts of the subbasin declined to below sea level and chloride concentrations in a number of wells increased (California Department of Water Resources, 1967). Under present-day conditions, ground-water recharge within the subbasin is about $1.11 \times 10^9 \text{ m}^3$ (900,000 acre-feet per year [acre-ft/yr]), pumping exceeds recharge by $1.85 \times 10^9 \text{ m}^3$ (150,000 acre-ft/yr) (CDM, Inc. 2001), and water levels in parts of the subbasin are declining at rates as high as 0.61 m per year (Northeastern San Joaquin County Groundwater Banking authority, 2004).

The Stockton East Water District (SEWD) Water Treatment Plant provides a majority of the drinking water supply to the City of Stockton. The facility receives water from the New Melones and New Hogan Reservoirs in the foothills of the Sierra Nevada some 50 kilometers to the east. Beginning in 2003, the SEWD has been periodically discharging surplus water from these sources into surface impoundment ponds to facilitate groundwater recharge under the Farmington Recharge Program, a joint groundwater storage effort by SEWD, other local water purveyors, and the U.S. Army Corps of Engineers. Each year some 7,000 acre-ft/yr of water is infiltrated into the subsurface; ascertaining the fate of the recharged water is still a major goal. The objectives of the recharge program include drought protection, addressing overdraft, and mitigating saltwater intrusion.

Existing groundwater wells in the vicinity of the recharge ponds include monitoring wells as well as local agricultural supply wells (Figure 3). Well construction details indicate that most of these wells are screened across portions of the Modesto Formation. Exceptions include water supply wells 74-01 and 74-02 which are screened entirely in pre-Modesto sedimentary materials at depths below 60 meters. Past pumping tests have indicated that these two wells are hydraulically isolated to some extent from wells screened at shallower depths (MWH, 2006).

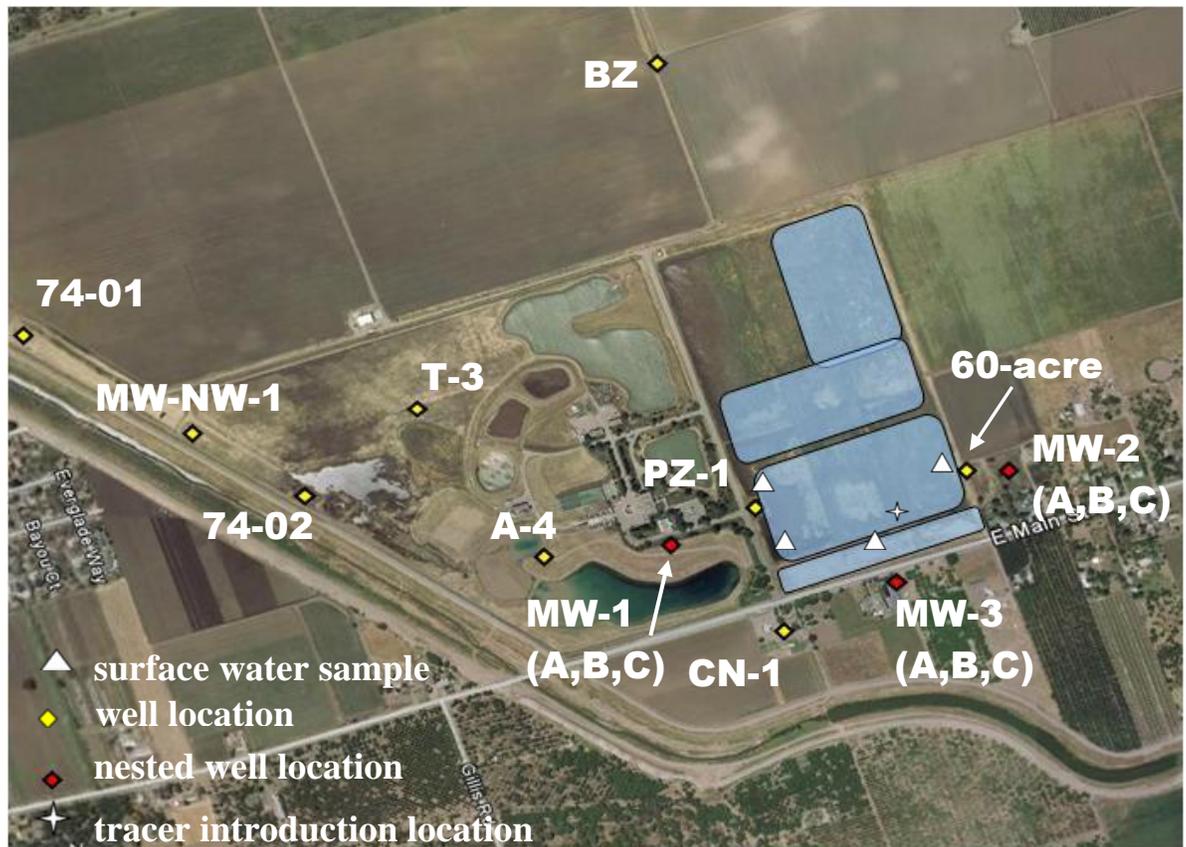


Figure 3. Locations of wells, surface water samples, and tracer water introduction point at SEWD. CWS-35 is off the map to the left.

In August, 2006, 20 samples from the Stockton East Water District groundwater banking facilities were collected in advance of tracer introduction. This sampling campaign had the following goals: 1) to determine background water quality prior to tracer introduction 2) to examine possibilities for the presence of intrinsic tracers such as stable isotope signature or chemical parameters that delineate the imported water component in groundwater 3) to determine which wells to target for tracer sampling, as indicated by groundwater age and intrinsic tracers. Samples were collected for the constituents listed in Table 1 and described in the Methods section; results are described below.

SEWD: Tracer Test

Tracer introduction at the Stockton East Water District (SEWD) groundwater banking site took place from Jan. 17th to Feb. 1st 2007, via bubbling SF₆ gas into a 12” inlet pipe that delivers water to the main infiltration pond. LLNL coordinated tracer introduction to coincide roughly with a change in the imported water source from New Melones (Stanislaus River) water to New Hogan (Calaveras River) water.

Sulfur hexafluoride was introduced using a gas cylinder with a standard regulator and a mass flow controller that kept the gas flow rate at 10 cm³/min. The precise amount of SF₆ that dissolves into the water and is retained in the water depends upon the water temperature and diffusion at the water-atmosphere interface. Vertical mixing of the tracer in the water column depends on the presence/absence of a thermocline, while the degree of horizontal mixing within the pond depends largely on wind duration and speed. The maximum tracer concentration and retention time of the tracer in the surface water body is therefore dependent upon a number of environmental factors and difficult to predict ahead of time. Approximately 125,000 m³ (101.3 acre-ft) of water was tagged with tracer.

Subsequent monthly sampling rounds through mid-2007 entailed collection for tracer and selected analytes in a subset of the groundwater wells. Samples were collected from wells PZ-1, A-4, 74-01, 74-02, 60-Acre, T-3, CN-1, BZ, MW-NW-1, and the MW-1(A,B,C), MW-2(A,B,C), and MW-3(A,B,C) well clusters, each of the latter screened at shallow (10m depth), intermediate (15m depth), and deeper (20m depth) portions of the shallow aquifer (Figure 3). Because the water source for artificial recharge is high elevation, low-TDS water from New Melones reservoir, several intrinsic tracers are present in the artificially recharged water in addition to the SF₆ tracer, which tags a limited portion of the artificially recharged water.

SEWD: Tracer Test Results

Results of tracer analyses are shown in Figure 4 and Figure 5. Tracer observations in surface water samples show that the pond was fairly well-mixed by Feb. 6th (on the falling limb of the tracer curve). Arrival at 60-acre well occurred 17 days after the experiment began, and 10 days after the peak concentration in the pond. Travel to PZ-1 was similarly rapid – 22 days from initiation of the experiment and 20 days from the observed peak in the surface water. Similar arrival times, with much lower concentrations, were observed at nested wells MW3(A,B and C), MW2(A, B, and C); tracer arrived slightly later (27 days) and at extremely low concentrations (about 1 part in 1000 of pond water, or C/C₀ of .001) at wells MW1(A, B, and C). Simultaneous arrival at nested wells MW1(A,B, C) and MW2(A,B,C) indicates that these wells all sample the same shallow aquifer and that transport over this interval is uniform in a vertical sense. Observed concentrations in MW3(A,B,C) peaked on 2/21/07, came down to near background then continued an upward trend through the final sampling event (July, 2007). Results from this set of nested wells indicate ‘fast path’ transport of a small volume of pond water with subsequent transport of pond water as the mound relaxed after the infiltration event. Indeed, following the initial pulse recorded in nearby wells, tracer concentrations continued to increase only in MW3(A,B, C), and in well CN-1, all to the S-SW of the ponds in the direction of the regional gradient (Figure 5). Concentrations are highest in well MW3C; In contrast, the MW1(A, B, and C) and MW2A wells likely catch a just a marginal portion of the ‘plume’ during the time of significant mounding.

Considering tracer travel times to the cluster of MW3 and CN-1 wells, bulk lateral flow rates ranged from 6.5 to 13.7 ft/d. Vertical transport, as determined from tracer arrival in

PZ-1, which is located only 20 ft from the edge of the pond but is screened at a depth of 40 to 65 ft BGS is on the order of 2 ft/d. The very long tails exhibited by the PZ-1 and 60-acre well tracer curves are likely due to slow vertical transport of tracer laden water over those wells' long screened intervals.

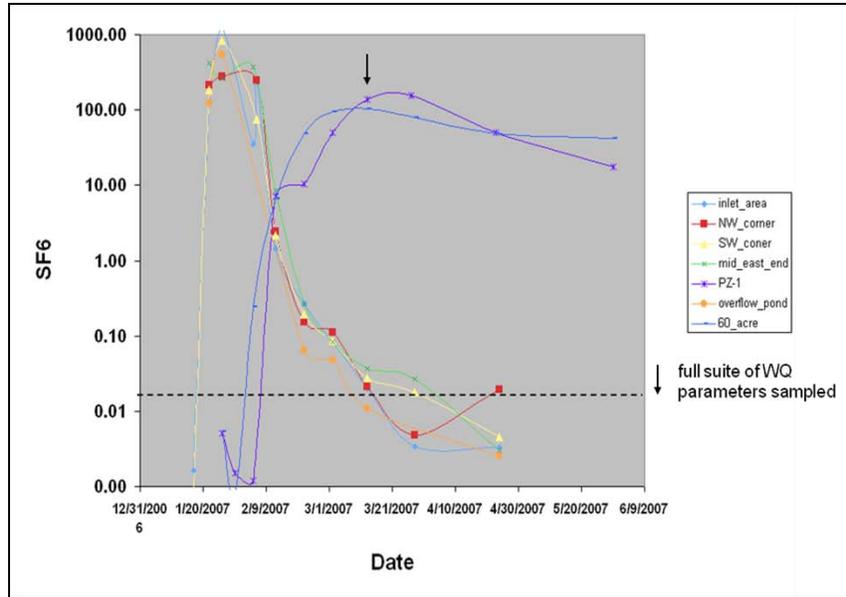


Figure 4. SF₆ tracer concentrations in surface water and groundwater samples collected at SEWD. Concentrations are given as ppb SF₆ in a fixed headspace. A dashed line shows the MDL for this method. Collection date for a full suite of water quality samples is shown as an arrow.

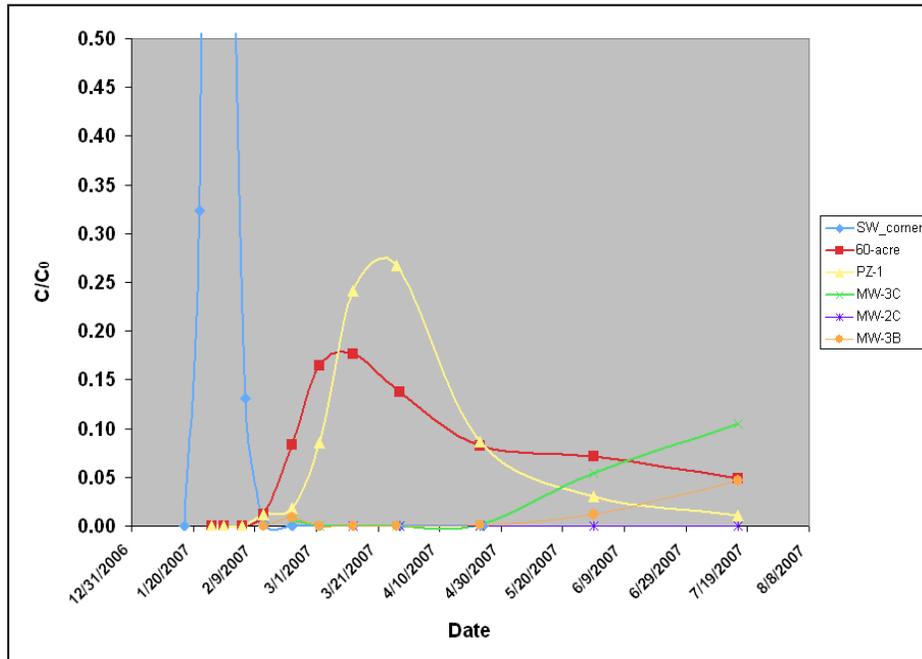


Figure 5. SF₆ concentrations normalized to the peak concentrations measured in the recharge pond.

SEWD: Water Transport and Water Quality Indicators

The $^3\text{H}/^3\text{He}$ age dating method was used to determine a mean groundwater age and to identify the fraction of pre-modern (i.e., recharged prior to approximately 1955; see figs. 6,7,8) water present in groundwater samples collected at the site during the initial sampling in August 2006. Mean groundwater ages for wells adjacent to the ponds (PZ-1, 60-Acre, MW-1A, MW-1B, MW-1C, MW-2A, MW-2B, MW-2C, MW-3A, MW-3B, and MW-3C) were all determined to be less than 2 years (Appendix 1), indicating that the tritium-containing portion of the produced groundwater is transported to the capture zone of these wells over a short time scale. Groundwater sampled from well T-3, which is further from the ponds but screened in alluvium, was found to have a mean age of 3 years. The production wells 74-01, 74-02 have mean ages that indicate that the tritium-containing portion of the produced water recharge several decades ago. Comparing age dating results between these two wells, it is evident that the confining unit (shown on the cross section in

Figure 6) plays a role in preventing transport from the shallow zone in the location of Well 74-02. Pump tests carried out by MWH likewise indicated that the deep and shallow systems are not hydraulically connected on the time scale of the pump test (MWH, 2000).

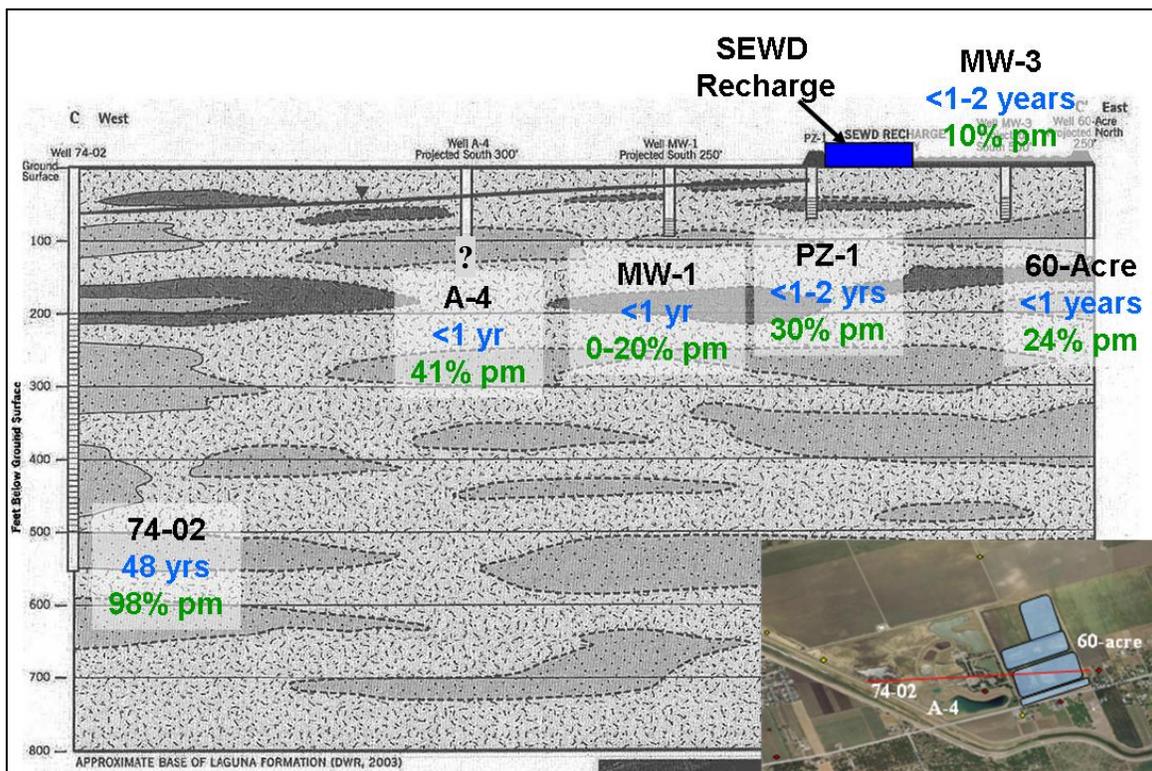


Figure 6. West to East cross section of apparent mean $^3\text{H}-^3\text{He}$ ages and percentage of pre-modern (<1955) water in groundwater wells at SEWD. Cross-section and well logs from [Montgomery Watson Harza, 2006]. Note that the screen interval for well A-4 is not well known, and likely extends across both the shallow and deep aquifers.

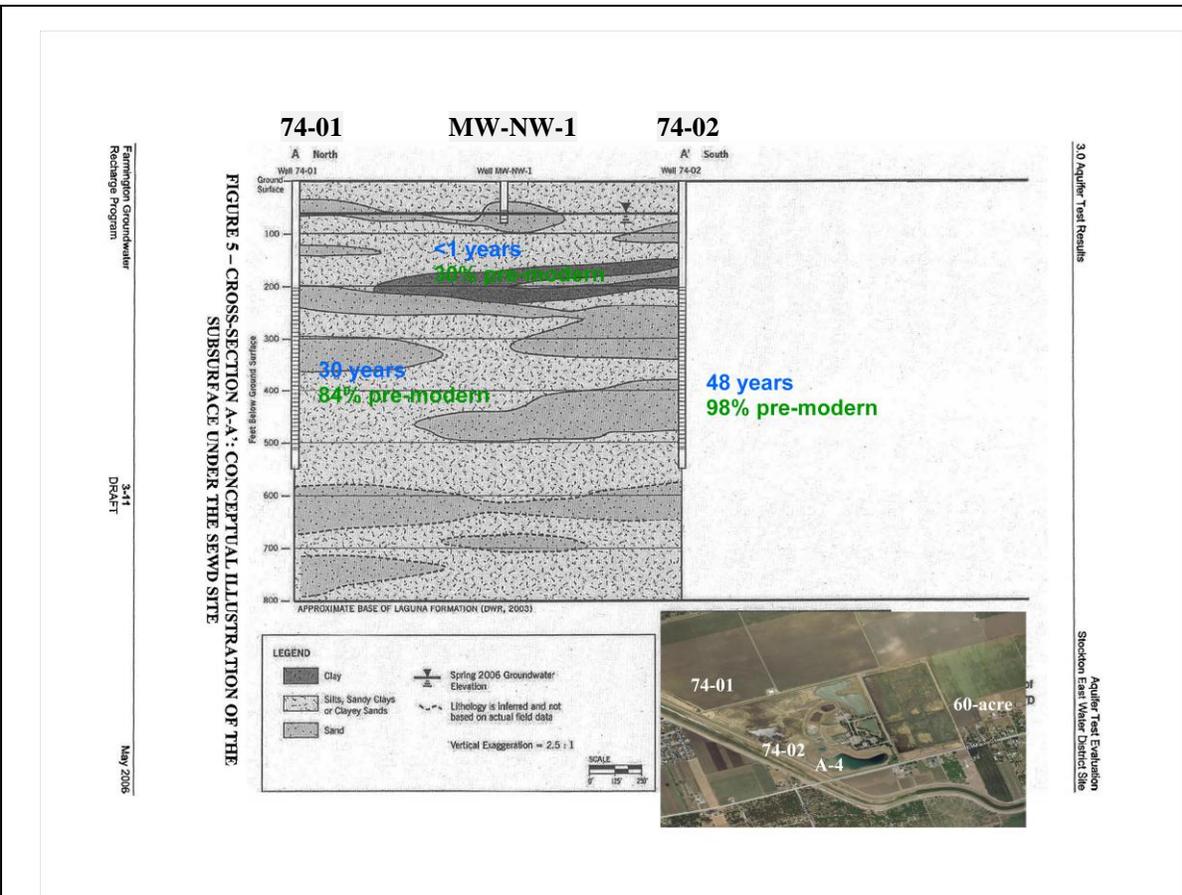


Figure 7. Northwest to Southeast cross section of apparent mean ^3H - ^3He ages and percentage of pre-modern (<1955) water in groundwater wells at SEWD. Cross-section and well logs from (Montgomery Watson Harza, 2006).

In addition to the recently recharged portion of the groundwater, many of these wells tap ambient groundwater that recharged more than several decades ago and does not contain tritium. Comparing the measured tritium with the tritium expected at the time of recharge provides a means for calculation of the fraction pre-modern (Manning et al., 2006; Moran et al., 2003; Figure 8). Because groundwater banking began only a few years ago at this site, the wells draw groundwater with a bimodal age distribution – older ambient groundwater mixed with recent artificially recharged groundwater. Well A-4, which is likely screened across a long interval that includes both the shallow and deep aquifer systems, is an interesting example of this. While its mean tritium-helium age is less than one year, it produces a relatively large fraction of pre-modern water at approximately 40%.

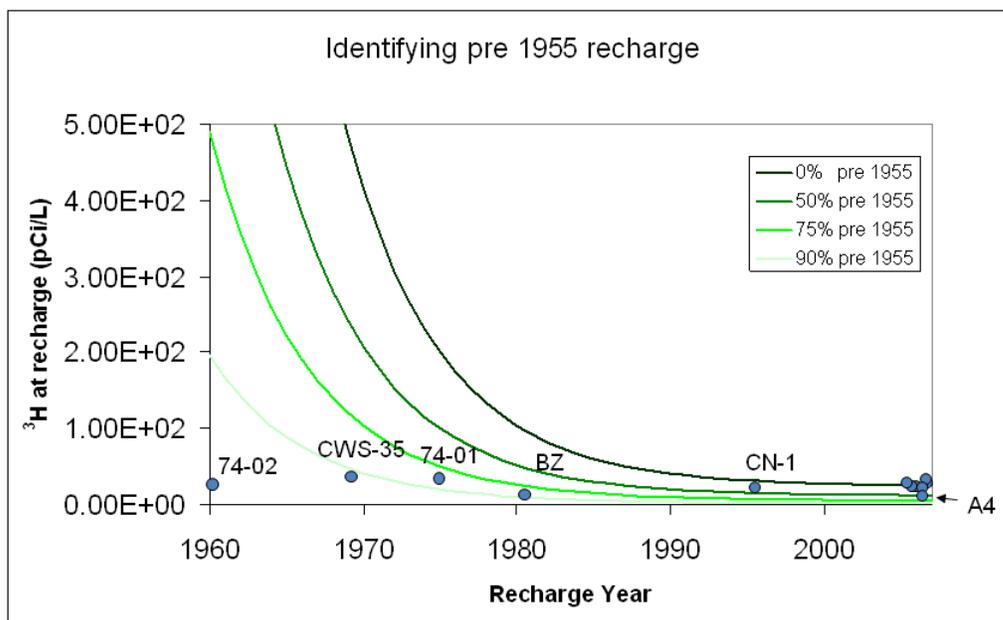


Figure 8. Calculations (curves) of pre-modern (<1955) water present in groundwater below SEWD. Sample results are shown as dots.

Based on information derived from tracer and age dating results, wells were categorized as being strongly affected by recent recharge (“Recharge” wells – PZ-1 and 60-acre), being somewhat affected by recent recharge (“Mixed” wells – nested monitoring well sets MW1, MW2, and MW3, and well CN-1), or being unaffected by the recharge activities either because they are distal or screened only in the deep aquifer system or both (“Deep” wells – 74-01, 74-02, CWS-35, T3, A4, and BZ). Well A-4 is problematic since screen intervals are not known with certainty, and it is closer to the recharge ponds than the other unaffected wells. For the geochemical modeling exercise, the pre-modern fractions were used as a means to estimate the component of imported recharge water present in each groundwater sample as a result of groundwater banking operations, with the tacit assumption that the end-member groundwater mixing component is predominantly pre-modern. These well categories are used in describing the isotope and water quality results that follow.

Another tracer of water source and transport is the stable isotope signature of water. In particular, values of $\delta^{18}\text{O}$ associated with surface water supplies originating in the Sierra Nevada are isotopically light (enriched in ^{16}O relative to ^{18}O) in comparison to those of local groundwater as a result of cooler precipitation temperatures at higher elevation. Measured $\delta^{18}\text{O}$ values in site groundwater and surface water samples are given on Appendix 1. Comparatively high-elevation New Melones reservoir water is characterized by a $\delta^{18}\text{O}$ value of -11.5‰ (sample “North Pond”), background groundwater recharged from local precipitation and runoff is characterized by a $\delta^{18}\text{O}$ value of around -8‰. However, multiple water sources are delivered to the recharge ponds, including sources from the lower elevation New Hogan reservoir, and these water sources are alternated over periods of weeks to months. The resulting pattern in groundwater $\delta^{18}\text{O}$ is complex

and does not provide a clear marker of imported water in site groundwater in comparison to other parameters (Figure 10).

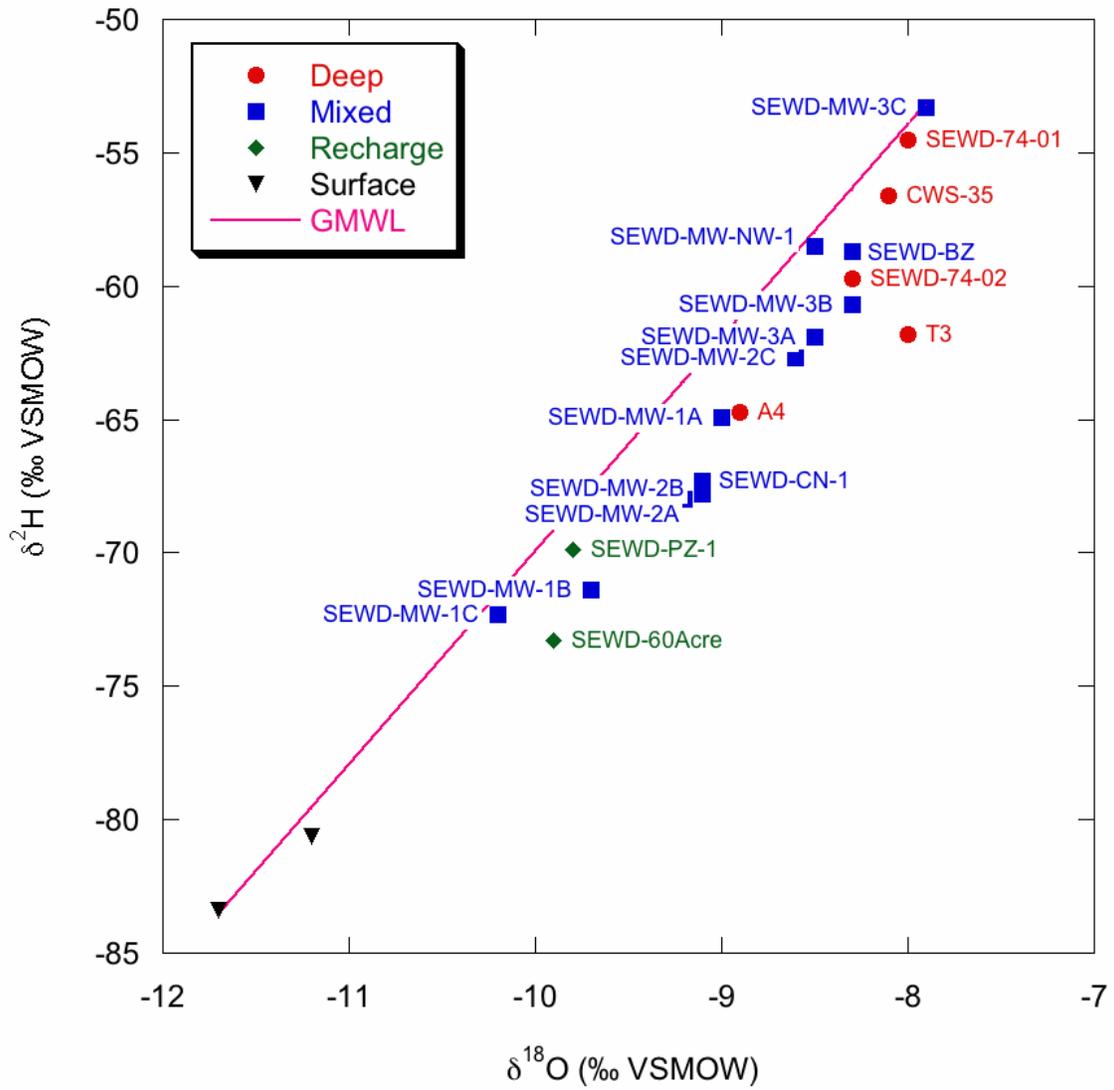


Figure 9. Oxygen and hydrogen stable isotope compositions in waters collected at SEWD.

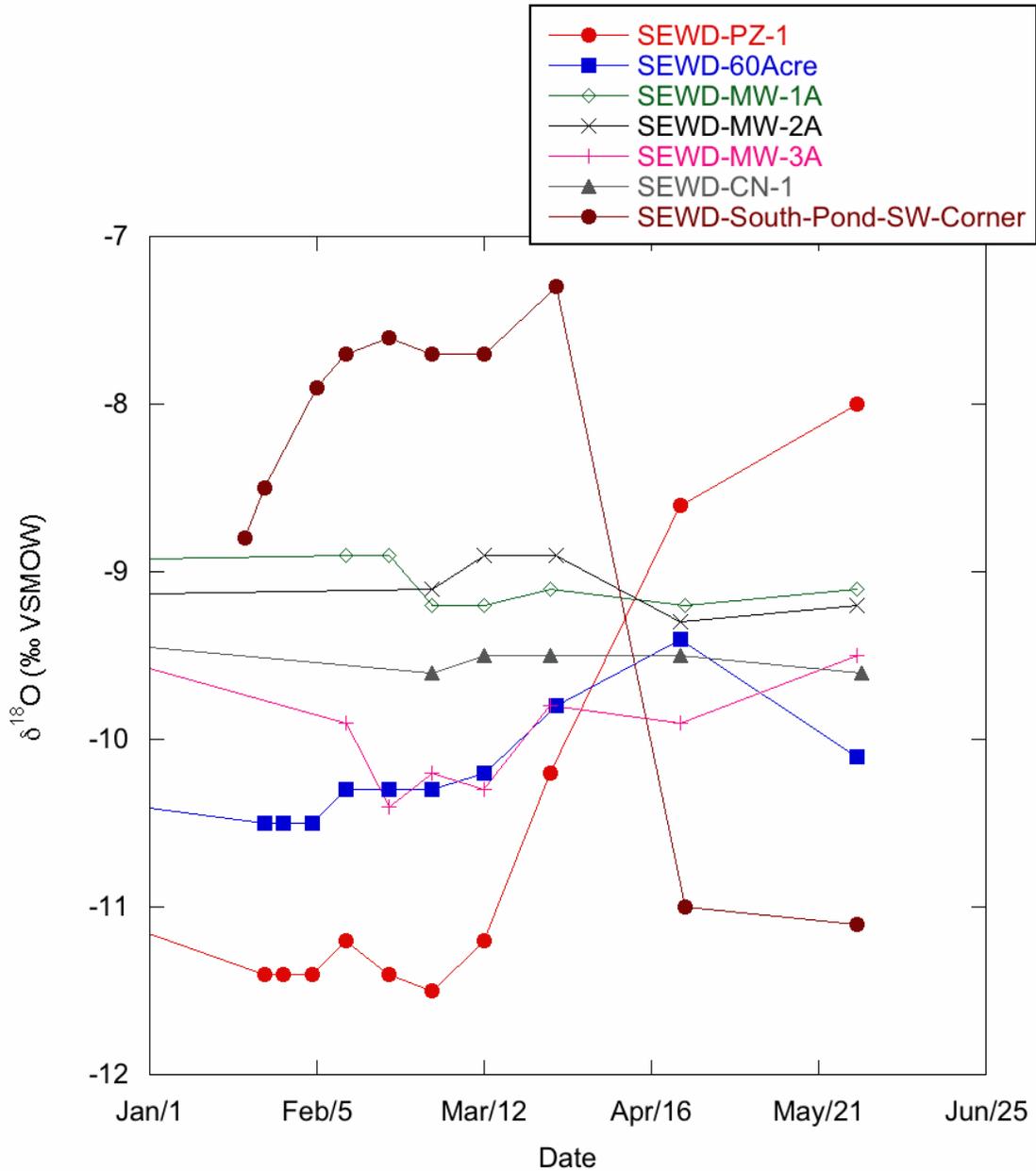


Figure 10. Oxygen stable isotope compositions for samples collected between Jan 26 and May 30, 2007.

Overall groundwater quality in the area is very good, with a maximum nitrate concentration of 17 mg/L (as NO₃⁻), TOC < 1 mg/L, and a low frequency of detection of VOCs. Arsenic concentrations in some wells hover around the MCL of 10 µg/L and are discussed further below. Spatial patterns in field parameters, VOCs, major ions, trace elements, nitrate, and inorganic carbon were examined according to whether wells were categorized as “Recharge”, “Mixed”, or “Deep”; the categories having been assigned using tracer and age results as described above.

Water quality parameters measured using a Horiba U-22 field probe show significant differences between the three water groupings. pH varies in surface water but on average is slightly higher in surface water than in groundwater. Dissolved oxygen and redox potential measurements of groundwater samples indicate the shallow aquifer is generally aerobic. Low concentrations of dissolved organic carbon – generally less than 1 mg/L as carbon – were measured in surface water samples and in some groundwater samples in conjunction with slightly reduced oxygen concentrations, but direct evidence of anaerobic conditions (e.g., dissolved oxygen concentrations below detection limit, reduced or negative redox potentials, excess dissolved N₂ generated via denitrification) was not observed. (Significant excess nitrogen concentrations show that denitrification may be an important process in mitigating the effects of nitrate loading at deep production wells.)

TDS, as indicated by field conductivity is low in surface and “Recharge” water and increases in “Mixed” and “Deep” samples, due to water-rock interaction along flowpaths. With respect to major cations, groundwater samples exhibit a relative enrichment in sodium and potassium at the expense of calcium and magnesium when compared to the pond water composition. This tendency is most pronounced in “Recharge” wells characterized by a significant tracer response (Figure 5) and is likely the result of cation exchange on clay surfaces. In addition, certain trace elements – arsenic, vanadium and molybdenum – are characterized by inverse correlations with TDS in groundwater. Specifically, the concentrations of these elements exhibit a spike in groundwater samples at low TDS values in comparison to imported recharge water samples that contain very low concentrations of these elements. The pattern is particularly evident for “Recharge” and “Mixed” wells that exhibited a significant tracer response.

Dissolved inorganic carbon (mainly bicarbonate ion) concentrations increase significantly from surface water to “Recharge” wells to “Mixed” and “Deep” wells. An inverse correlation exists between dissolved inorganic carbon and $\delta^{13}\text{C}$ that likely reflects mixing of imported surface water ($\delta^{13}\text{C}$ value of -11 to -4 ‰) with local groundwater characterized by lower $\delta^{13}\text{C}$ values (-18 to -16 ‰), the latter likely reflecting biogeochemical processes involving soil CO₂. Because the dissolved organic carbon content of both local groundwater and imported surface water is typically less than 1 mg/L (as carbon) it is unlikely that oxidation of dissolved organic carbon significantly affects the $\delta^{13}\text{C}$ values of dissolved inorganic carbon at the site.

Chloroform is by far the most frequently detected VOC. SEWD operates its recharge and water treatment facilities such that lightly chlorinated water is occasionally loaded into one of the recharge ponds. Chloroform and other trihalomethanes (THMs) act as additional tracers of recent recharge at this site. There is a correlation between chloroform concentrations and $\delta^{18}\text{O}$, with wells having a light (imported) isotope signature tending to have higher chloroform concentrations. Treated imported water is mixed with ambient groundwater with heavier $\delta^{18}\text{O}$ and no THMs.

Further insight into the mechanisms involved in generating the observed water quality changes is gained through results of the geochemical modeling exercise described below.

typical of alluvial materials (Sposito, 1989). No adjustments were made to the values complexation constants provided in the PHREEQC.DAT default data set.

PHREEQC also employs a database developed by Dzombak and Morel (1990) to quantify complexation of trace elements onto an HFO surface. This model assumes “strong” and “weak” binding sites, with abundances of 0.2 mole of weak sites and 0.005 mole of strong sites per mole of Fe(III). Pertinent data include binding site complexation constants for As, Ba, B, Ca, Cu, Mg, Mo, Ni, U, V, and Zn. For this study, 0.07 mole of reactive solid-phase Fe(III) per liter of groundwater was used to provide a reasonable fit to the trace element data, as discussed below. This corresponds to a weight percent abundance of reactive ferric oxyhydroxide as Fe(OH)₃ or FeOOH per unit mass of aquifer material on the order of 0.1%. No adjustments were made to the values complexation constants provided in the Dzombak and Morel (1990) data set.

Definition of a background groundwater composition is needed for use as (1) an end-member in the mixing calculations and (2) as a basis for an initial putative equilibration distribution of species among the ion exchange and HFO surface complexation sites on the solid aquifer material. However, selection of a representative end-member groundwater is nontrivial because of a paucity of monitoring wells that are not in the immediate vicinity of the recharge ponds (i.e., more likely to represent background conditions) and that are also screened in the shallow zone above 60-m depth. In this context, the water composition from well T-3, located several hundred meters west of the recharge ponds, was identified as best representing shallow background groundwater among the wells sampled, as it generally behaves as a near-end-member composition for many of the geochemical trends identified in the data and yet is not strongly influenced by pre-modern water associated with deeper groundwater. For example, the T-1 water composition is characterized by an apparent age of 3 years and fraction pre-modern of only 14%, relatively low $\delta^{13}\text{C}$ and high inorganic carbon values, elevated chloride, nitrate, and sulfate (94th, 83rd, and 100th percentiles, by rank, respectively), elevated calcium, magnesium, and sodium (83rd, 83rd, and 89th percentiles), comparatively low combined sodium and potassium contributions to the cation pool (33rd percentile), indicative of only minimal to moderate cation exchange, elevated barium (78th percentile), elevated boron, nickel, strontium, and uranium (all at the 83rd percentile, respectively), and comparatively low arsenic (17th percentile) and vanadium (44th percentile) among the groundwater samples collected during the August 2006 sampling round.

The selection of recharge water composition for mixing is a less critical issue than the end-member groundwater because the pond water solution is comparatively unbuffered and is not used to equilibrate ion exchange or surface complexation sites on mineral surfaces. The water composition measured in a pond sample collected during the August 2006 sampling round was selected for this purpose.

PHREEQC was used to assess the changes in composition from the T-3 water composition (i.e., background groundwater, or zero pore-volume shift of imported recharge water) to 90% of pore volume of imported recharge water. In this context, a one

pore-volume shift would imply that the pore water in contact with the aquifer mineral assemblage has been replaced by 100% imported recharge water which has been allowed to come into equilibrium with that mineral assemblage. In general, the model reproduced the trends observed in the cation exchange data: the solution is preferentially enriched in sodium and potassium from the exchanger surface in response to the low-TDS but comparatively calcium- and magnesium-rich imported water composition (Figure 12). In comparison to observed trace element concentrations, the model also matched the arsenic concentrations in tracer-impacted wells reasonably well (Figure 12), given that the default Dzombak and Morel (1990) database parameters were not adjusted to match the data. The vanadium and molybdenum concentrations measured in wells characterized by a tracer response exhibit much scatter (the vanadium example is shown on Figure 12); the model only qualitatively captured the trend and magnitude of the concentration changes in response to mixing with recharge water.

SEWD: Discussion of Geochemical Modeling Results

Taken together, the results of this study indicate that mixing of recharge water with ambient groundwater creates a geochemical footprint that includes a shift in the relative abundances of major cations and the mobilization of certain trace elements. Among those trace elements included in the data set, only arsenic(V), vanadium, molybdenum, and uranium are predicted to form anionic complexes at near-neutral pH values, specifically HAsO_4^{2-} , H_2AsO_4^- , H_2VO_4^- , MoO_4^- , $\text{UO}_2(\text{CO}_3)_2^{-2}$, and $\text{UO}_2(\text{CO}_3)_3^{-4}$. Recharge water is characterized by a somewhat elevated pH in comparison to site groundwater, so displacement of oxyanions by OH^- on the HFO binding sites is a plausible explanation for the observed behavior of arsenic, vanadium, and molybdenum. A number of previous studies have suggested this mechanism could play a role in mobilizing arsenic and other trace elements (Rai and Zachara, 1984, Welch et al., 2000, Smedley and Kinniburgh, 2002, Belitz et al., 2003). Among the anionic trace element complexes, uranium is unique in that it does not exhibit an apparent increase in concentration stemming from desorption. The likely reason is that uranium-carbonate complexes may be comparatively weakly adsorbed. Wazne et al. (2003) reported experimental results that indicated that carbonate inhibited adsorption of uranium-VI onto ferrihydrite by forming uranyl carbonate complexes that exhibit a lower affinity to adsorb onto iron hydroxide surfaces at intermediate pH values. The implication is that uranium will exhibit a relatively high affinity for the aqueous phase in carbonate-rich waters. Virtually all uranium in the SEWD shallow groundwater is predicted by PHREEQC to be complexed with carbonate groups, so consequently the HFO surface would not be expected to act as a reservoir for uranium to the extent that it does for arsenic, vanadium, and molybdenum.

As a practical matter, the potential for arsenic mobilization is the main environmental concern associated with groundwater banking at the SEWD site. The U.S. Environmental Protection Agency's maximum contaminant level for arsenic is 10 $\mu\text{g/L}$. Arsenic concentrations in many of the shallow wells – those effected directly by recharge water (e.g., MW-3 cluster) – are on the order of 7-9 $\mu\text{g/L}$, whereas the putative background groundwater composition associated with well T-3 is characterized by an arsenic concentration of approximately 4 $\mu\text{g/L}$. Belitz et al. (2003) report that groundwater

samples collected from alluvial fans on the western side of the San Joaquin Valley are typically characterized by arsenic concentrations less than 5 $\mu\text{g/L}$. (Deep groundwater at this site and at several other locations in the western San Joaquin Valley has elevated arsenic concentrations above or near 10 $\mu\text{g/L}$ (Appendix 1 and Izbicki et al., 2008), which is likely caused by the release of arsenic through the reductive dissolution of iron and manganese hydroxide coating on iron sulfide mineral grains that occurs on very long time scales and generally under reducing conditions.

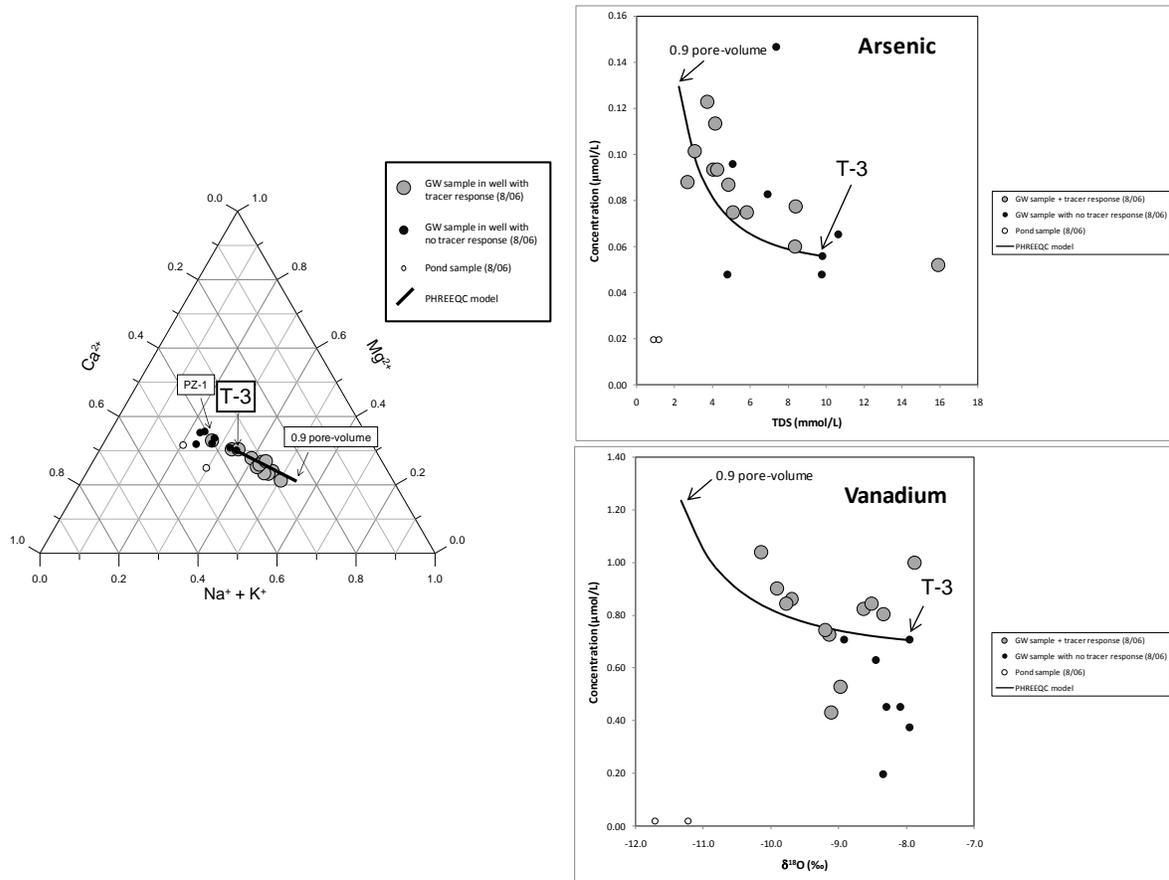


Figure 12. Observed and simulated relationships between various geochemical indicators (cation ratios – left; arsenic versus TDS – upper right; vanadium versus $\delta^{18}\text{O}$ – lower right) measured during the August 2006 sampling round.

Groundwater samples from wells exhibiting a significant tracer response, typically characterized by a low proportion of pre-modern water (large, gray circles) are distinguished from those with low or minimal tracer response (and typically) a high proportion of pre-modern water (small, black circles). Surface water samples are indicated by open circles. Geochemical modeling results, as indicated by black lines, reflect the flushing of up to a 0.9 pore volume of recharge water through ambient aquifer conditions, which are defined as being in equilibrium with the T-3 water composition.

Adsorbed arsenic represents a significant source of groundwater contamination at low concentrations (Gao et al., 2006). Soil arsenic concentration data are not available for the SEWD site. The assumptions employed by the PHREEQC model imply that the aquifer material in equilibrium with the putative T-3 end-member groundwater composition harbors some 15 mg/kg of adsorbed arsenic. Gao et al. (2004) found arsenic concentrations up to 24 mg/kg in sediments collected from the Tulare Lake Bed area in the southern San Joaquin Valley, much of which was leachable by repeated flushing with artificial pore water. However, the soil arsenic concentrations reported by Belitz et al. (2003) on the order of 8-10 mg/kg or higher (for comparatively high soil arsenic concentrations) occurring on the western side of the valley are probably more representative. In this context, the modeled value of 15 mg/kg is somewhat elevated but not unreasonable.

The focus of the geochemical modeling portion of the study has been placed on quantifying water quality responses to the mixing of high-quality, low-total-dissolved-solids recharge water with ambient groundwater via a postulated geochemical model of the underlying aquifer material entailing an ion exchanger and HFO surface. The consistency of model results with major and minor element concentration data, tracer data, and calculated groundwater age provides an additional degree of model validation. As such, the modeling approach provides a plausible quantitative framework with which to predict the potential water quality changes in shallow aquifer systems in response to artificial recharge water composition. Nonetheless, although the results of this study are qualitatively consistent with expectations, it is important to recognize that a number of significant sources of error exist in the interpretation of the data, particularly in regard to the geochemical modeling. The two most important limitations include (1) a very simplified mixing model, most notably the definition of an un-impacted groundwater end-member composition, which may not be available in reality, given the temporally variable recharge history, and (2) slow adsorption-desorption kinetics and/or rate-limiting diffusive transport, both of which could act to impede the ability of the system to achieve thermodynamic equilibrium (Williams et al., 2003; Zhang and Selim, 2005) over the weeks-to-months transport time scales suggested by the tracer test data.

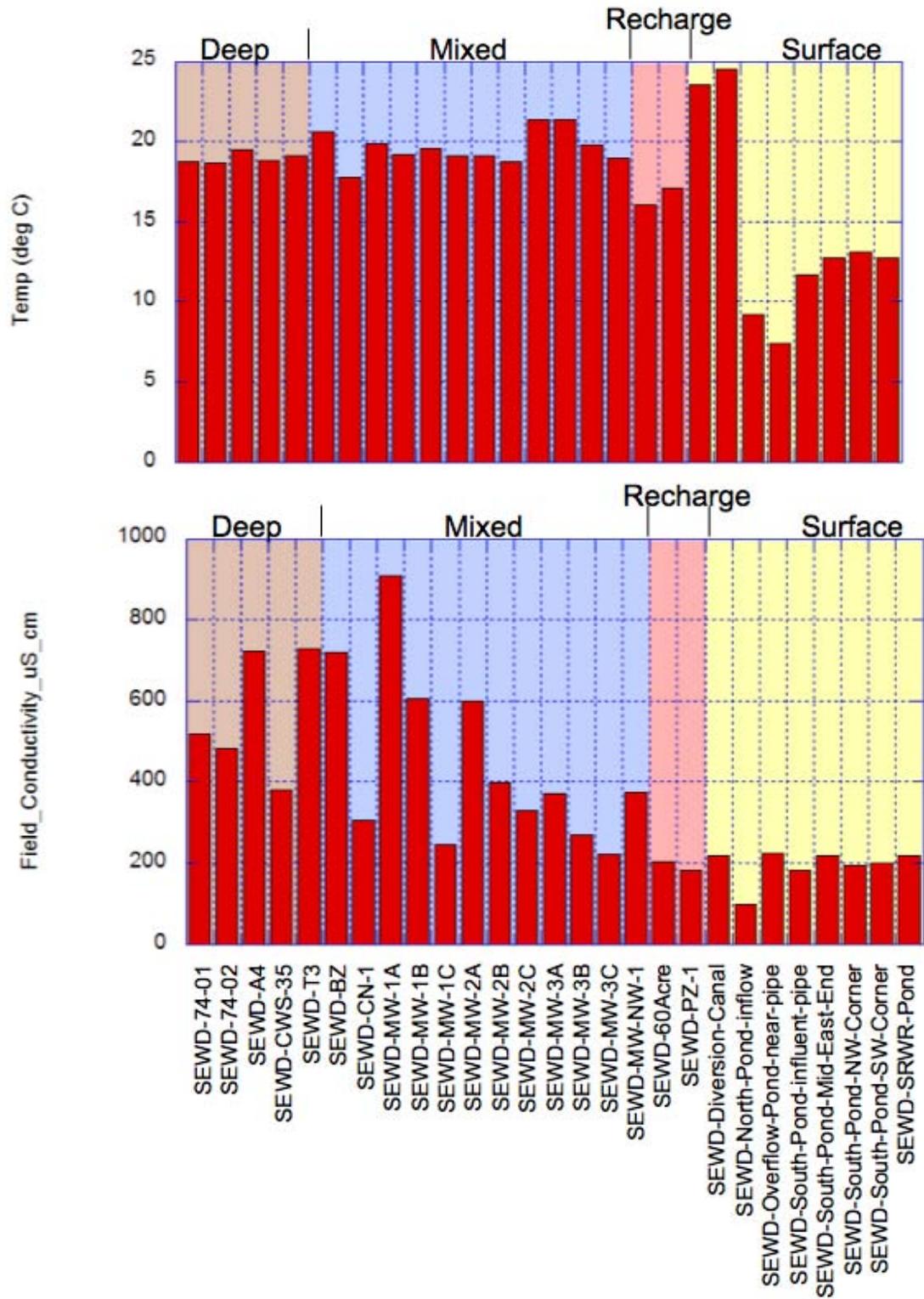


Figure 13. Temperature and conductivity of water samples collected at SEWD.

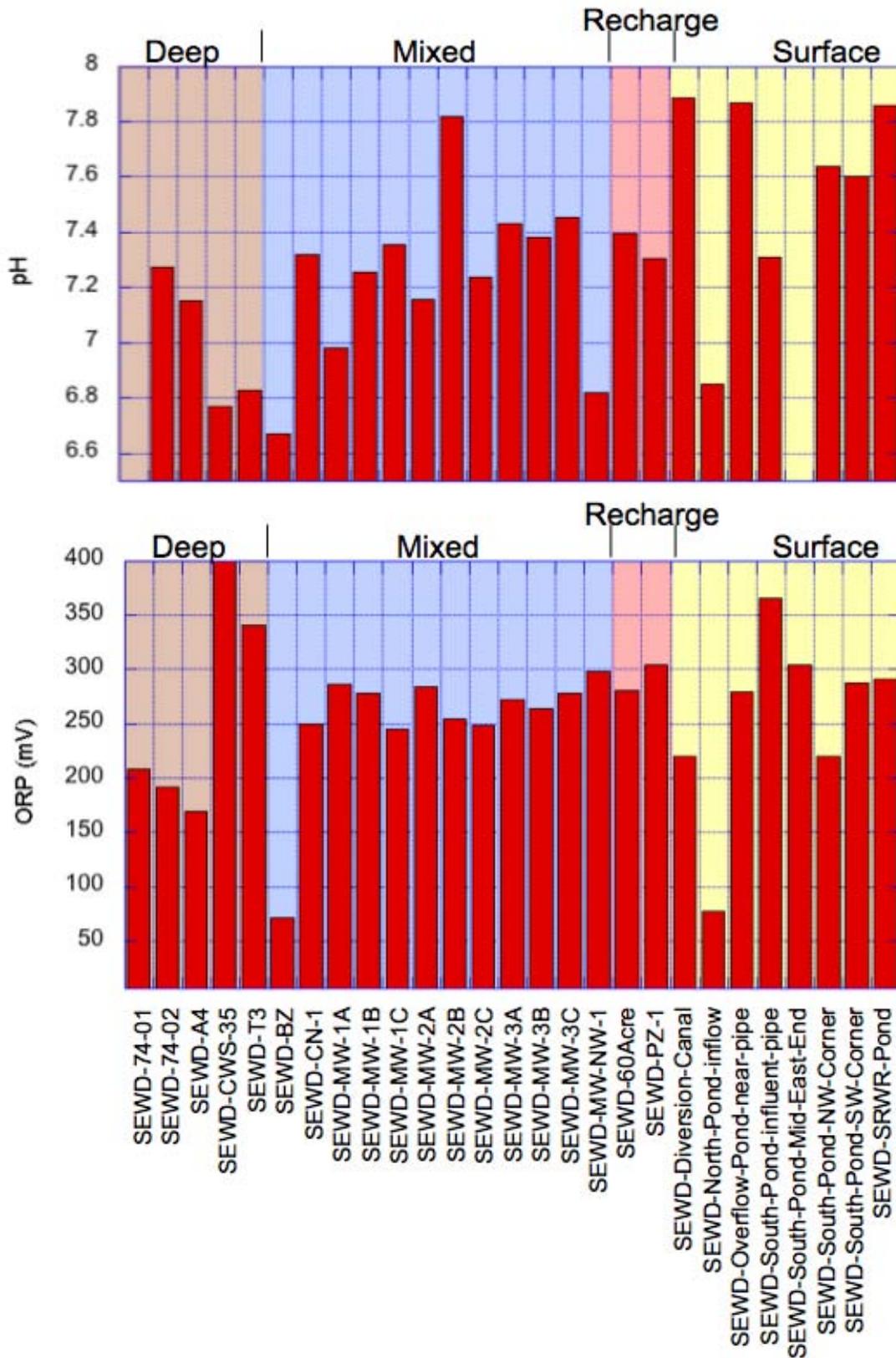


Figure 14. pH and oxidation reduction potential (ORP) of water samples collected at SEWD.

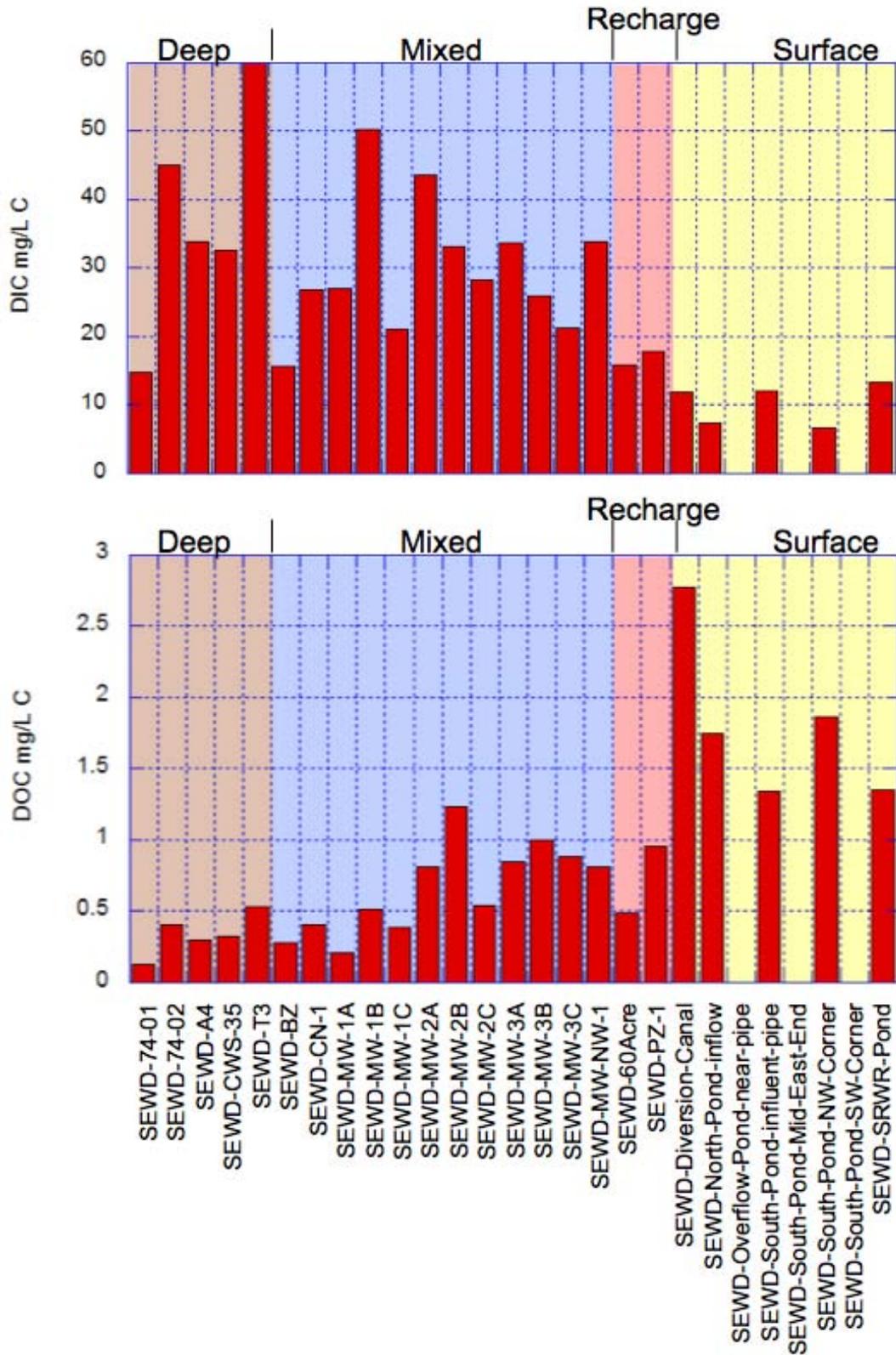


Figure 15. Dissolved inorganic (DIC) and organic carbon (DOC) of water samples collected at SEWD.

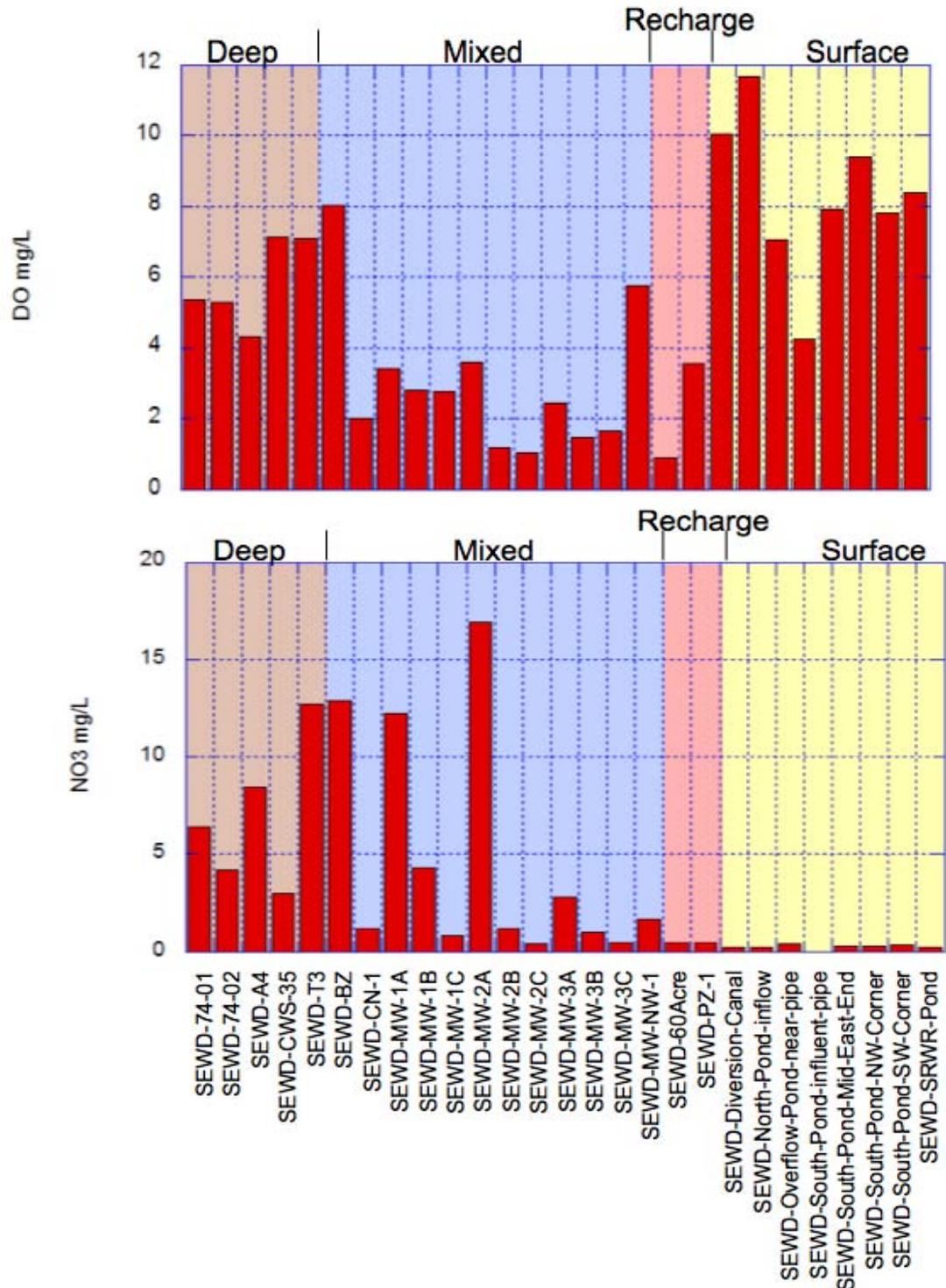


Figure 16. Dissolved oxygen (DO) and nitrate concentration of water samples collected at SEWD.

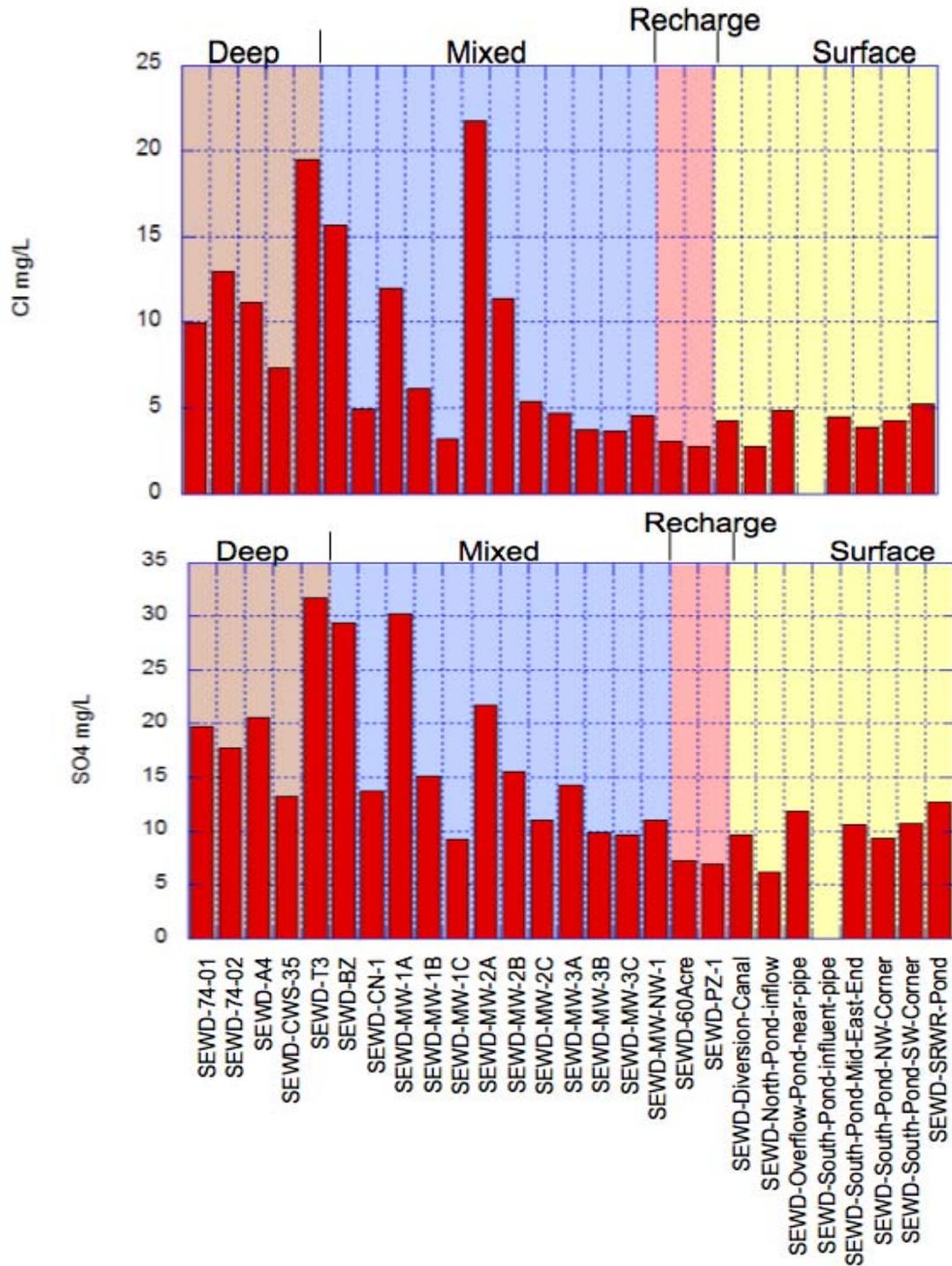


Figure 17. Chloride and sulfate concentrations of water samples collected at SEWD.

Study Site II: Morada Lane Detention Pond, Stockton, CA

Like the SEWD site, the Morada Lane study area is within the Eastern San Joaquin Ground Water Subbasin (California Department of Water Resources, 2006). At the study site, volcanic deposits approximately 200 m below land surface separate overlying alluvial-fan deposits from underlying marine deposits and form the effective base of fresh water. The volcanic deposits are blanketed by a layer of alluvium eroded from these deposits about 30 m thick the remainder of the deposits consist of alluvial-fan deposits eroded primarily from the Sierra Nevada. During the study the regional ground-water gradient at the study site was to the southeast toward the regional pumping depression.

The City of Stockton is using various water sources including imported water, local surface water and storm flow to recharge underlying alluvial aquifers via spreading ponds. Morada Lane Detention Basin 2 (DB2), a 40 hectare (10 acre) pond (Figure 18), is used for storm water retention in spring and winter months and for artificial recharge of imported water in summer and fall. In 2005, approximately 900 acre-ft of Mokelumne River water supplied by the Woodbridge Irrigation District was infiltrated at this site. A similar volume was recharged in 2004. Water was delivered to the pond in 4 to 9 cycles per year, each cycle having a volume of 100 to 200 acre-ft (Condor Earth Technologies, 2006); the final delivery of the 2005 season was tagged with tracer for this study. Subsequent inflow of storm water was not metered.

The USGS-installed wells just adjacent to the pond provided an opportunity to sample water at multiple depths in the aquifer. Five monitoring wells screened at depths of 114, 220, 300, 540 and 635 feet BGS (depths are for the center of 10 ft screens), were sampled for the list of constituents in Table 1. In addition, the two drinking water wells, pond water, and canal water, were sampled for all constituents. In a manner similar to the SEWD site, this study focuses on the travel time and the amount of influence the artificially recharged water has on local wells, along with water quality changes related to the introduction of recharged water such as the interaction between recharge water and aquifer sediments and the fate of organics and nitrate.

Morada Lane: SF₆ Tracer Test

Tracer introduction at the Morada Lane DB2 groundwater banking site took place from Oct. 3 to Oct. 10, 2006. The tracer introduction was coordinated to coincide with the final delivery of the season of imported water from the Woodbridge Irrigation District. Approximately 50 acre-ft of water was loaded into the pond beginning on Oct. 4 and ending on Oct. 12.

Sulfur hexafluoride was introduced using a gas cylinder with a standard regulator and an automatic switching valve that kept the gas flow rate at 20 cm³/min. The precise amount of SF₆ that dissolves into the water and is retained in the water depends upon the water temperature and diffusion at the water-atmosphere interface. Vertical mixing of the tracer

in the water column depends on the presence/absence of a thermocline, while the degree of horizontal mixing within the pond depends largely on wind duration and speed. The maximum tracer concentration and retention time of the tracer in the surface water body is therefore dependent upon a number of environmental factors and difficult to predict ahead of time.



Figure 18. Morada Lane Detention Basin 2 (DB2) site showing the location of tracer introduction and the locations where surface water and groundwater samples were taken. Lysimeters are co-located with the USGS MW-114' monitoring well (MW-114'). Results are tabulated in Appendix A5. Note that the two CWS wells, CWS-19 and CWS-24, are labeled as CSW-19 and CSW-24 in this figure and throughout the text.

Following the tracer introduction, surface water samples were collected regularly from five locations around the retention pond (Figure 18). USGS water level measurements in public and monitor wells, and precipitation at a nearby fire station are shown over the course of the tracer experiment in Figures 19 and 20.

All samples were analyzed for SF₆ concentration and stable isotope compositions of hydrogen and oxygen in the water. Analyzing surface water samples is important because predicting the concentration based on the amount of gas bubbled in is difficult, as discussed above, and because one needs to know the initial, or input concentration for comparison to groundwater results. Results of surface water analyses of SF₆ are shown in Figure 21. SF₆ concentrations in surface and groundwater in this study (Figures 21 and 22) are measured and expressed as concentrations in the gas samples extracted from the water samples, and not as concentrations in the water.

On the second day of the tracer experiment, a sample collected near the tracer introduction point had the highest concentration of SF₆ that was measured in the surface water samples. Apart from this sample, the concentrations in the surface water form a smooth tracer curve input function (Figure 21). The peak in tracer concentration from samples collected around the pond was observed about 9 days after the beginning of tracer input. The width (duration) of the peak of tracer concentrations in the surface water was approximately one month. The similarity of concentrations on the falling limb of the

tracer curve suggests that by about two weeks after the onset of the experiment, the pond was well-mixed with respect to SF₆. The method detection limit is about 1000 times below the maximum observed in the pond, indicating that 0.1% of pond water in the well water would be detectable.

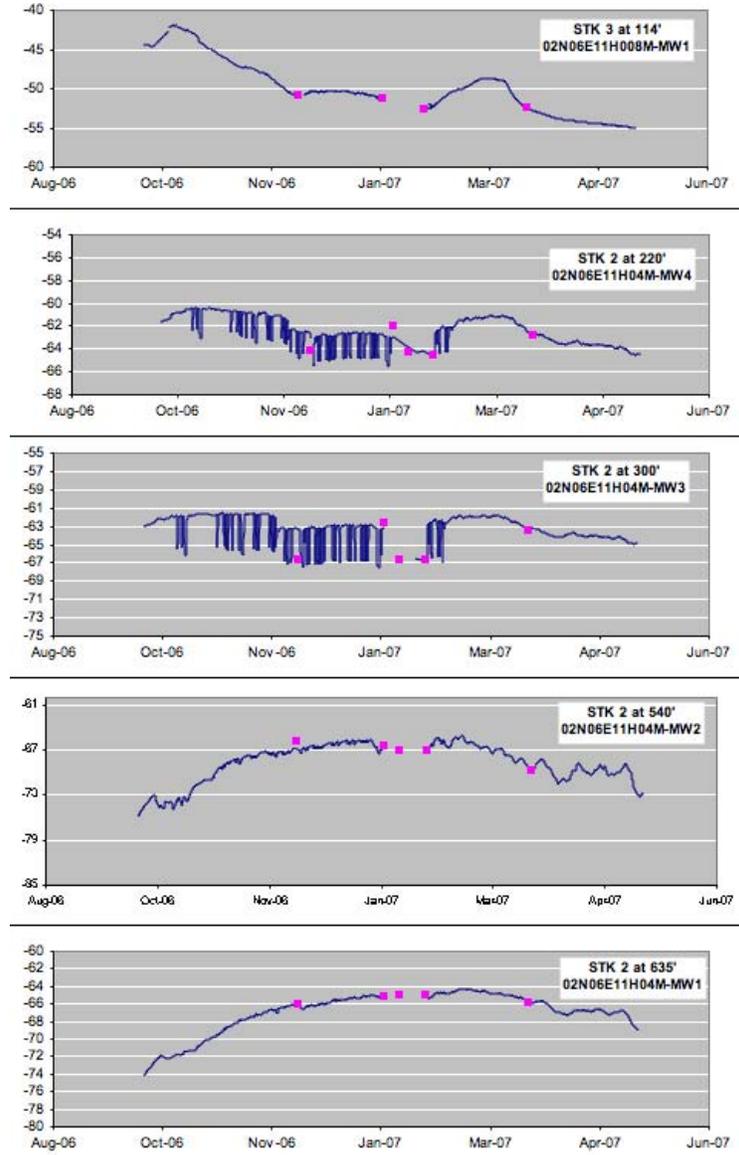


Figure 19. USGS water level measurements at Morada Lane monitoring wells. Water levels are in feet below land surface.

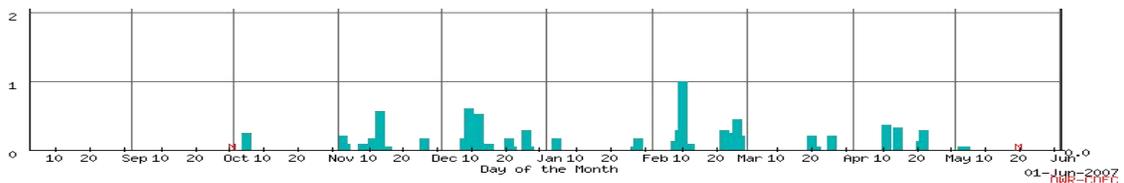


Figure 20. Precipitation record (inches) at the Stockton Fire Station from August 2006 to June 2007 (California Department of Water Resources).

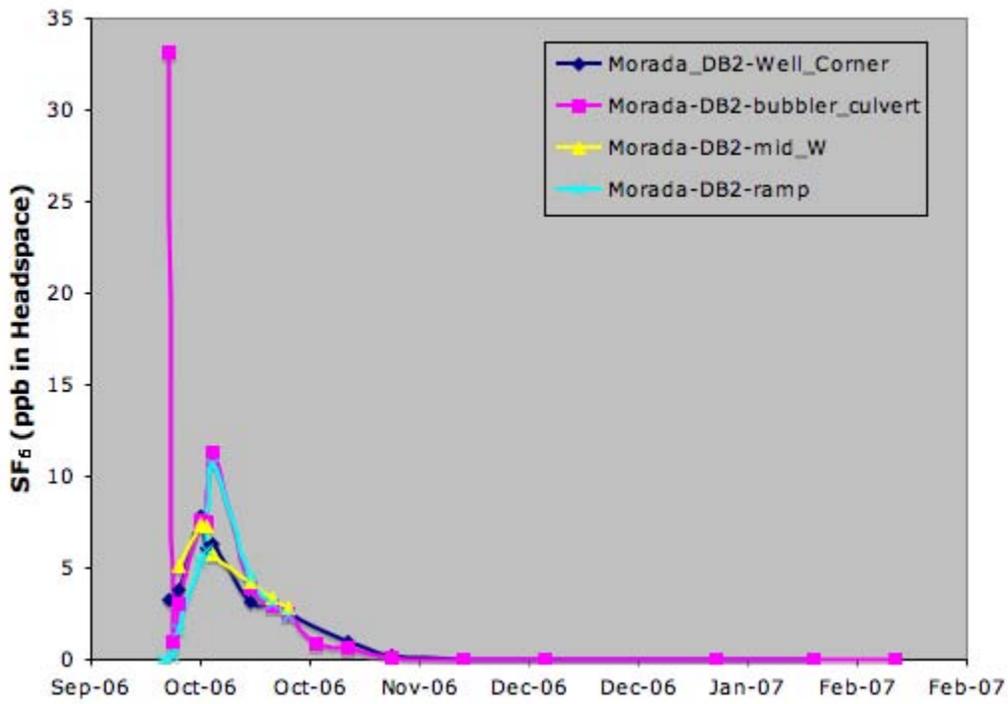


Figure 21. Results of SF₆ tracer analysis from Morada Lane surface waters (locations shown on Figure 18).

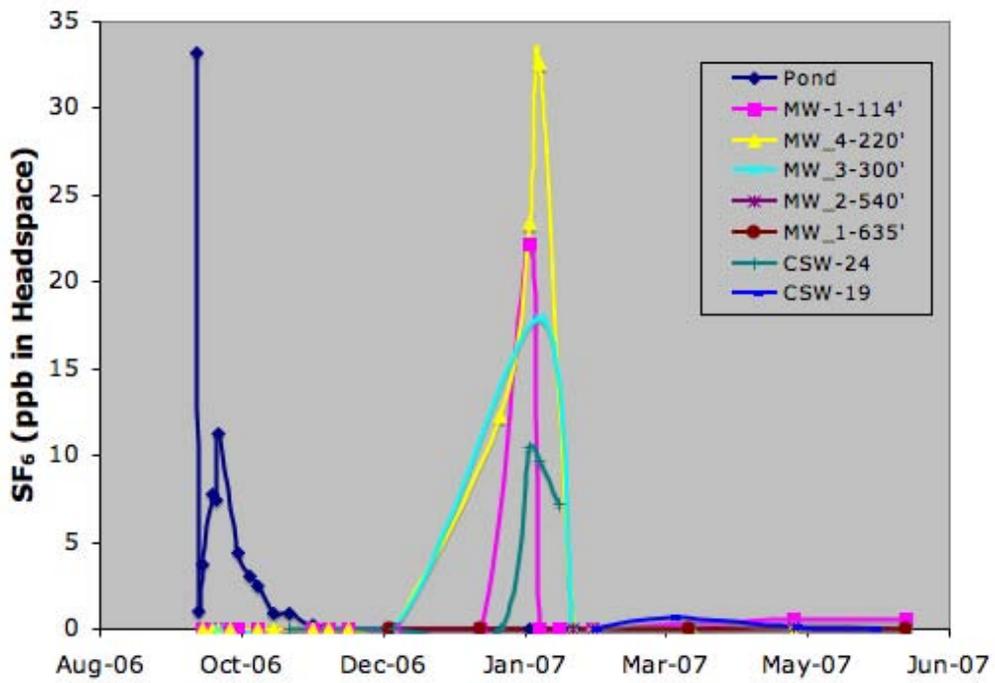


Figure 22. Results of SF₆ tracer analysis from Morada Lane surface water and groundwater.

The surface water with the highest concentration of SF₆ was collected near the inlet of the canal water, close to the tracer injection point. This sample had a temperature of 16.7 °C, which was more than three degrees cooler than the rest of the pond. One possible explanation for the concentration range observed in surface water and wells is that incoming Mokelumne River water is colder and denser than the ambient surface water and moves into the deeper section of the pond. The lower temperature of this water also increases the solubility of SF₆. The cold water may have recharged mainly through the bottom of the pond. Upward diffusion of the tracer would then result in the smooth, mixed curve observed in the upper portion of the pond, which subsequently infiltrates through the sides and bottom of the pond.

The first groundwater samples for SF₆ analysis were collected on Oct. 6, three days after the start of tracer injection into the pond. The shallowest monitoring well (114') had an ambiguous detection of SF₆, above background levels, on 10/10/2006. No other tracer detections were observed in any of the wells sampled during the following two months, as indicated on Figure 22, even though these monitoring wells are in close proximity to the pond. Indeed, water level responses in these wells (which were all outfitted by the USGS with pressure transducers) after infiltration indicate that pressure changes are transmitted efficiently. Water levels rose in the MW-114' foot well almost immediately after the pond was loaded, and in the MW-220' and MW-300' wells after just two days (O'Leary et al., in review). Given the fast response exhibited by water levels, it was somewhat surprising that there were no tracer detections for 12 weeks in wells adjacent to the detention basin. However, tracer appeared in multiple wells in January, 2007.

Table 2. Tracer arrival times in days since the start of the tracer experiment on 10/3/2006. Peak tracer concentrations (C_o) are based on the maximum observed value in the pond.

Location	Distance from pond margin (m, ft)	First Detection (days)	Tracer Maximum (days)	Maximum C/C _o	Calculated Linear Velocity* {ft/day, (m/d)}
Pond		1	1	1.000	NA
Pond margin (shallow)	0'	1	9	0.340	NA
MW-114'	30', 98	119	119	0.667	
MW-220'	60', 197	108	122	0.984	1.6 (0.6)
MW-300'	60', 197	122	122	0.540	
MW-540'	60', 197	175	212	0.002	
MW-635'	60', 197	-	-	-	NA
CSW-24 (long screen)	198', 650	119	119	0.317	22 (6.7)
CSW-19 (long screen)	1557', 5108	169	169	0.021	30 (9.2)

*See text for explanation of determination of velocity at tracer maximum for each well.

Based on the timing of tracer arrival and the concentrations observed in wells relative to surface water, surface water/groundwater interaction is quite complex in the vicinity of the pond. Groundwater from the 114, 220, and 300 foot USGS wells contained concentrations of SF₆ that were higher than the majority of the pond samples, which displayed a smooth peak. However, the sample collected near the tracer injection point on Oct. 6 is matched by the highest detection observed in well water. Concentrations of SF₆ observed at the nearby drinking water well (CSW-24) follow the lower surface water SF₆ concentrations that were measured in the subsequent pond samples.

The arrival time at drinking water CSW-24 was 119 days after the tracer peak in the surface water. The tracer was also detected at CSW-19, one mile to the west of the pond 169 days after the tracer injection. Apparently, the tracer tagged water that had infiltrated from the pond migrated relatively slowly in the vertical direction until it reached the highly conductive zones that are in hydraulic connection with the production well(s). Based on the first arrival of tracer in the MW-220' well, the rate of (mainly vertical) flow to that well is 1.6 ft/d (0.6 m/d). The arrival time at CSW-24 indicates a much higher average (mainly horizontal) flow rate between the MW-220' well and CSW-24 of 22 ft/d (6.7 m/d). The average lateral flow rate calculated in a similar way, based on the arrival at CSW-19, is 30 ft/d (9.2 m/d). The tracer tagged water reached deeper monitoring wells after reaching CSW-24, in keeping with the notion that vertical transport is much slower than lateral transport. An extremely low concentration of SF₆ was observed after 175 days in the MW-540' well; tracer was not detected in the deepest monitoring well. Mixing and dilution due to dispersion during transport between the pond and CSW-24 is the likely reason for the much lower concentrations observed there compared to the MW-220' and MW-300' wells (similarly for the very low concentrations observed at Well CSW-19). For several months following the arrival of tracer tagged water, CSW-24 was not operational. Multilevel samples were collected from CSW-24 by the USGS in June 2006, but no tracer was detected.

Morada Lane: Isotopic Compositions and Groundwater Age

Mokelumne River water, delivered by Woodbridge Irrigation District, has a stable isotope signature that is lighter (more negative) than ambient groundwater in the Stockton area. For example, a sample from the inlet canal had a δ¹⁸O value of -10.9 ‰, while a nearby drinking well had a δ¹⁸O value of -9.2 ‰. The stable isotopes do not exhibit as large a dynamic range as the SF₆. However, there is a detectable dip in the deuterium (to lighter values) in the surface water when the Mokelumne water was introduced to the pond (Figure 24), no change in the 220 ft. well over the same time period, and a small change in δ¹⁸O in the 114 ft. well, but in the opposite direction (gets isotopically heavier). So the stable isotopes are consistent with the SF₆ results in showing no pond water in the groundwater from the tagged pulse of surface water. However, the samples collected at times when the tracer was detected in the wells do not show a decrease in δ¹⁸O as expected, indicating that the imported water makes up a component of the well water.

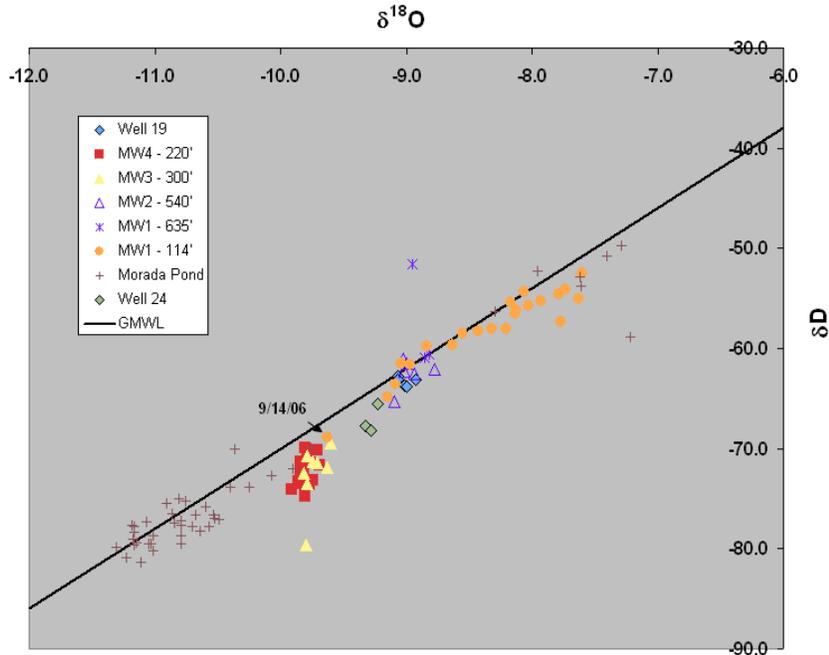


Figure 23. Oxygen and hydrogen stable isotope compositions for surface water and groundwater samples collected from the Morada Lane study site. Well 19 and 24 in legend refer to CSW-19 and CSW-24, and MW 1, 2, 3 & 4 refer the USGS multi-level monitor wells, which are identified only by their depth in the text (e.g., MW-114').

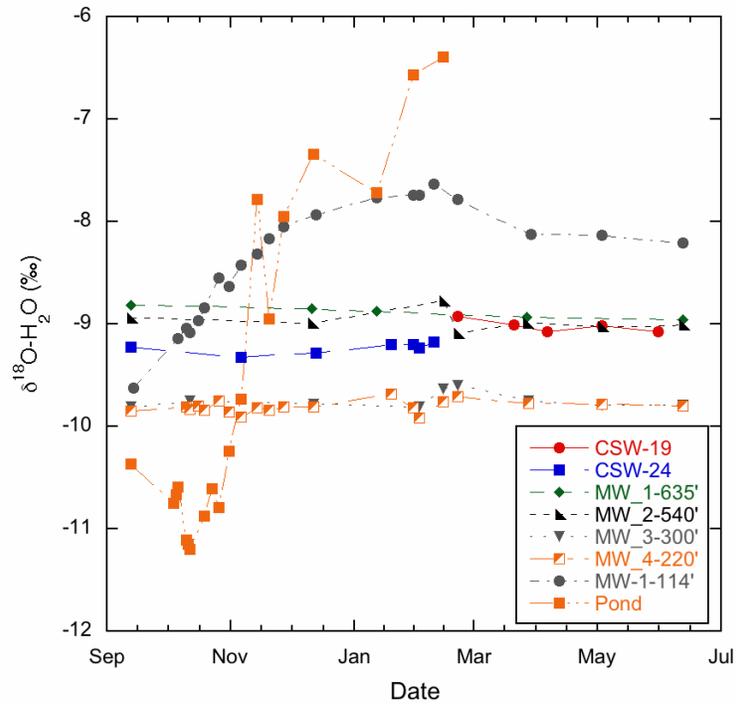


Figure 24. Results of oxygen isotope analysis from Morada Lane surface water and groundwater. MW 1, 2, 3 & 4 refer the USGS multi-level monitor wells, which are identified only by their depth in the text (e.g., MW-114').

Groundwater ^3H - ^3He apparent ages, ^3H activity, and recharge temperatures are shown in relation to well screen depth on Figure 25. In general, the apparent age of groundwater increases with depth. The shallowest monitoring well MW-114', has an apparent age of 2 years, while the deepest monitoring wells have ages beyond the 50-year range that is dateable by the ^3H - ^3He technique. Approximate ages, based on radiogenic ^4He accumulation, indicate that the 540 feet BGS well water produces groundwater with a component that is approximately 3000 years old, while the 635 feet BGS well water produces a component that is approximately 10,000 years old. The monitoring wells at 220 and 300 feet BGS have apparent ages for the tritium-containing portion of the groundwater of 39 and 40 years. (Reconciling these ages with tracer results from these two wells, where a high concentration of tracer was observed on a short time scale, is difficult. Ages reflect the bulk flow rate of the tritium-containing portion of the groundwater. Our hypothesis is that faulty well construction is responsible for the high concentrations of tracer observed in these two monitoring wells.) The top of the production well screens at approximately 200 feet BGS are similar to these mid-depth wells, but both production wells produce water that is 10 to 15 years younger than the monitoring wells. The younger water is likely present in the production wells is likely due to younger water drawn in as pumping leads to formation of a cone of depression as well as aquifer heterogeneity that leads to a wide distribution of water ages when sampled over long screens.

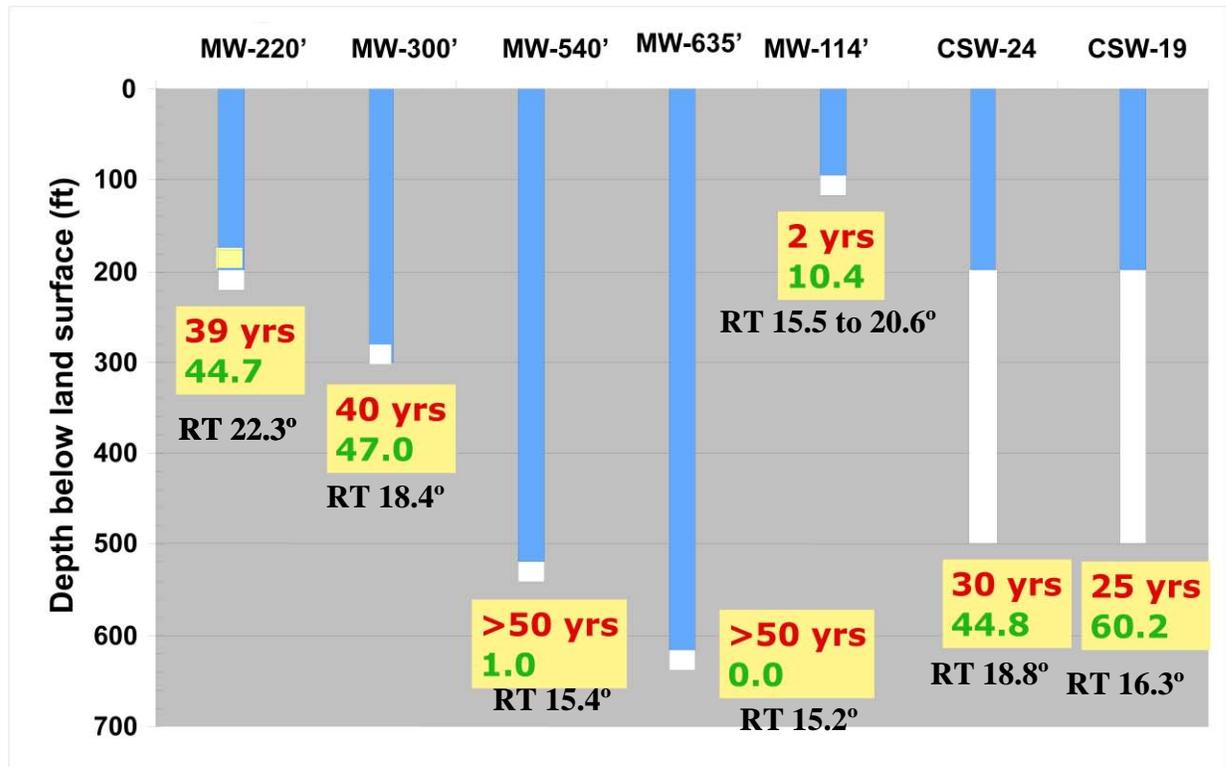


Figure 25. Apparent ^3H - ^3He ages, ^3H activity in pCi/L, and recharge temperature (RT) for monitoring wells and public supply wells near the Morada Lane detention basin. The screen depth for each well is shown as a white box.

Morada Lane: Water Quality Measurements

Figures 26 through 31 show the mean and variation of measured parameters at the public supply wells, monitoring wells and the detention pond for samples collected during this study. For each plot the mean value is shown as a horizontal line, and the minimum and maximum values are shown as a vertical line. These plots allow for the comparison of measured parameters between different levels within the aquifer system and the surface water. In this way, it is possible to examine the relations of measured parameters to processes occurring within the aquifer and in response to the managed aquifer recharge operation.

Measurements taken with a Horiba multi meter during sampling are shown in Figure 26. The pond samples showed the widest range of pH values, ranging from 6.3 to 10. All of the groundwater samples had pH values between 7 and 8, with the two deep monitoring wells showing the highest pH values. The pond also had the widest range of temperatures recorded, reflecting the influence of air temperature changes throughout the year. The 114 foot deep monitoring well (MW-114') shows the highest range of variation in temperature, which may indicate the influence of pond recharge on this well. The pond water had a lower mean conductivity than the groundwater well samples, due to the use of low TDS Mokelumne River water as the recharge source.

Figure 27 shows the concentration ranges for anions in samples from this study. Increased salinity due to sea water intrusion has been documented in this area (Izbicki et al., 2008), however the wells sampled in this study do not appear to have elevated levels of chloride. Nitrate concentrations are generally low in the groundwater and surface water samples. Nitrate may be further reduced in the deepest wells (MW-635' and MW-540') due to reducing conditions deep in the aquifer. Nitrate concentrations are also low in MW-114', which may be related to reduction reactions occurring during the infiltration of pond water. These three wells also show depletions in sulfate concentrations, consistent with sulfate reduction.

The influence of redox conditions is also evident in the trace element concentrations shown in Figure 28. Uranium and vanadium are strongly depleted in the deepest monitoring wells. MW-114' has low concentrations of uranium, similar to the pond samples, but has elevated concentrations of vanadium. Arsenic concentrations are highest in the two deepest monitoring wells, and are consistent with the regional observations of high arsenic concentrations such as those observed at the SEWD site and elsewhere (Izbicki et al., 2008). MW-114' has slightly elevated arsenic concentrations relative to the pond water and to MW-220' and MW-300'. The slight elevation of arsenic in this well may be related to the addition of recharge water that is out of equilibrium with the aquifer sediments, similar to the SEWD site. Unlike the SEWD site, redox chemistry may influence the concentration of arsenic at this well.

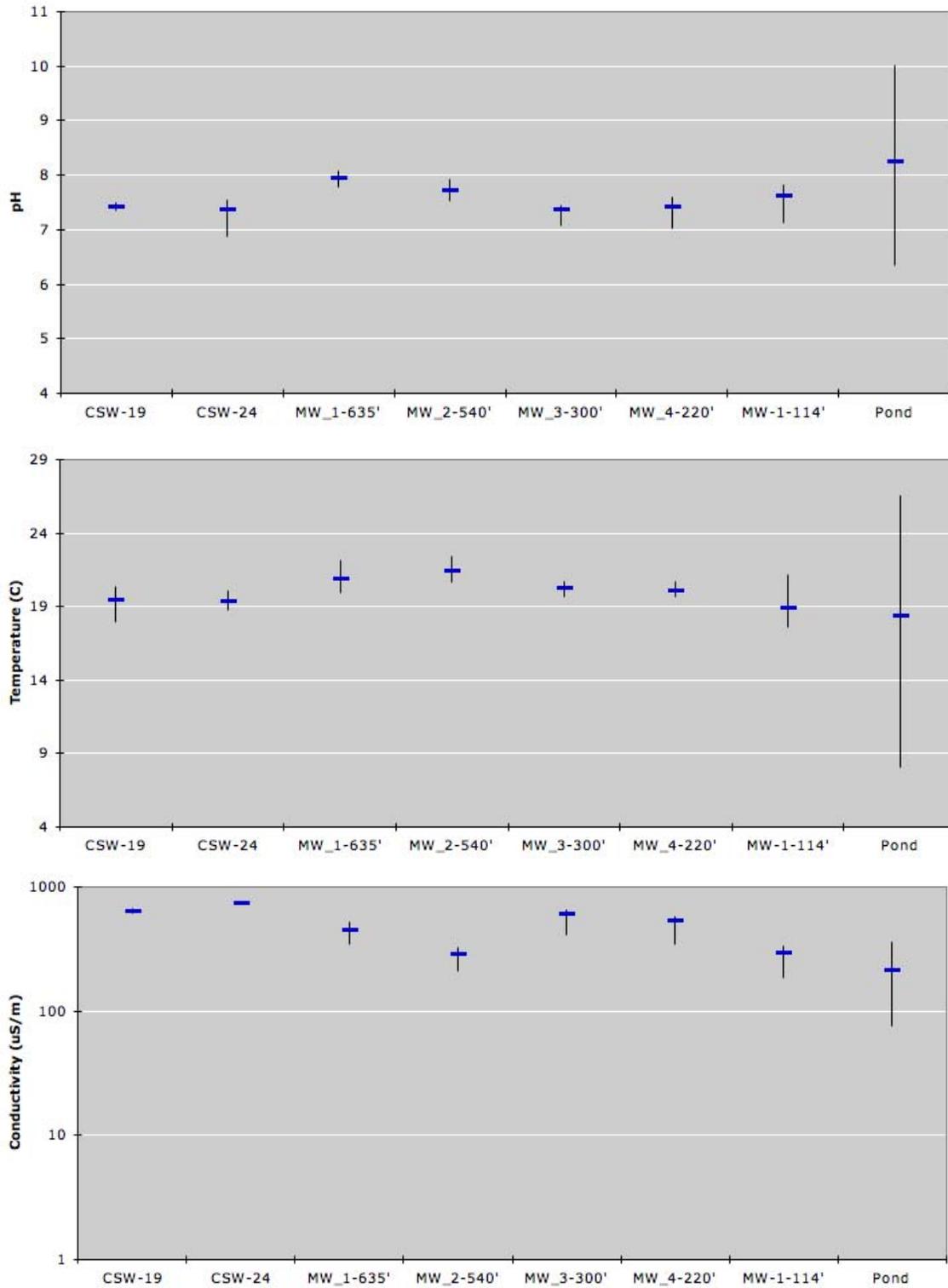


Figure 26. Water quality parameters measured in the field at the Morada Lane site. MW 1, 2, 3 & 4 refer the USGS multi-level monitor wells, which are identified only by their depth in the text (e.g., MW-114').

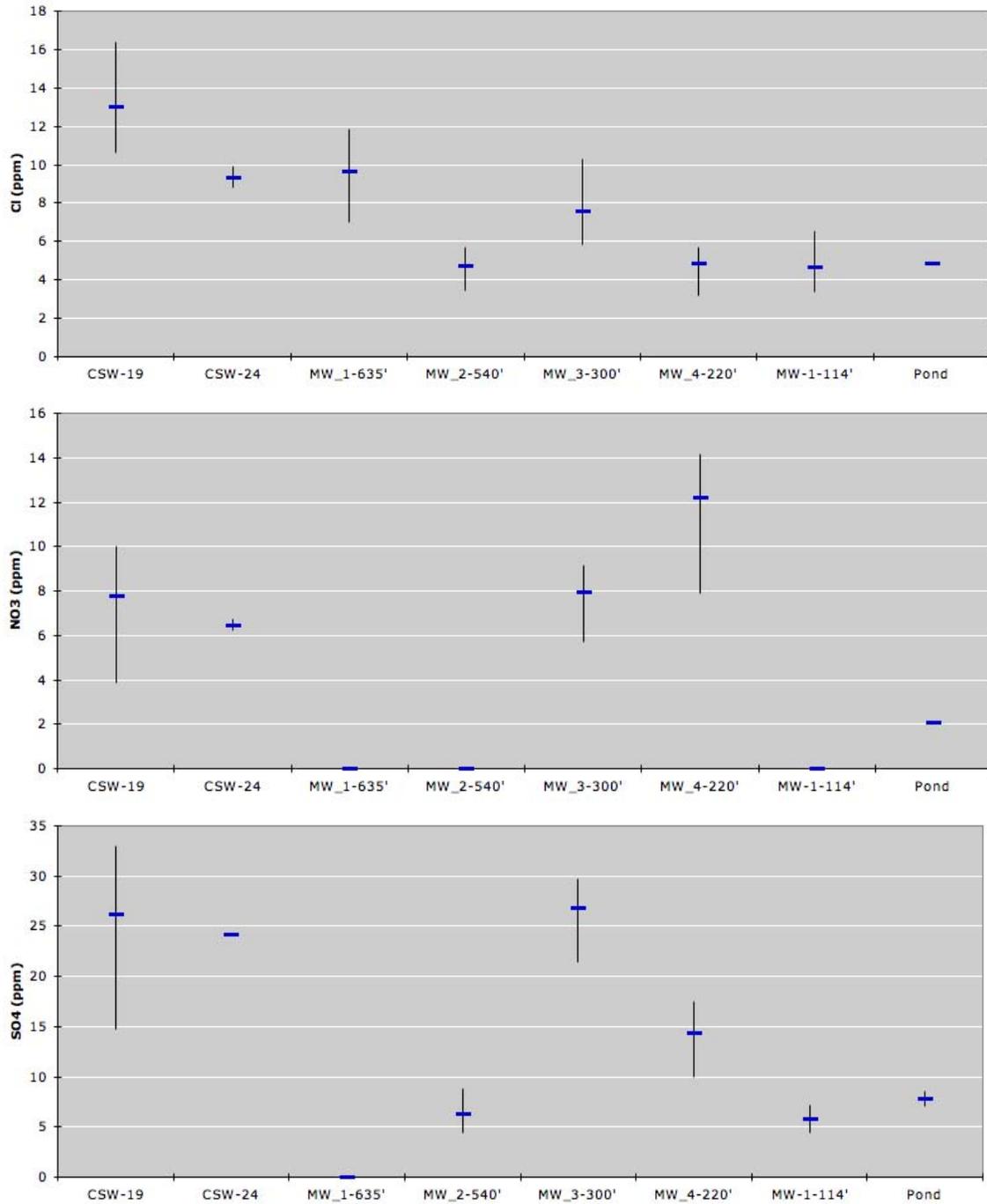


Figure 27. Anion concentrations from samples collected at the Morada Lane site. MW 1, 2, 3 & 4 refer the USGS multi-level monitor wells, which are identified only by their depth in the text (e.g., MW-114').

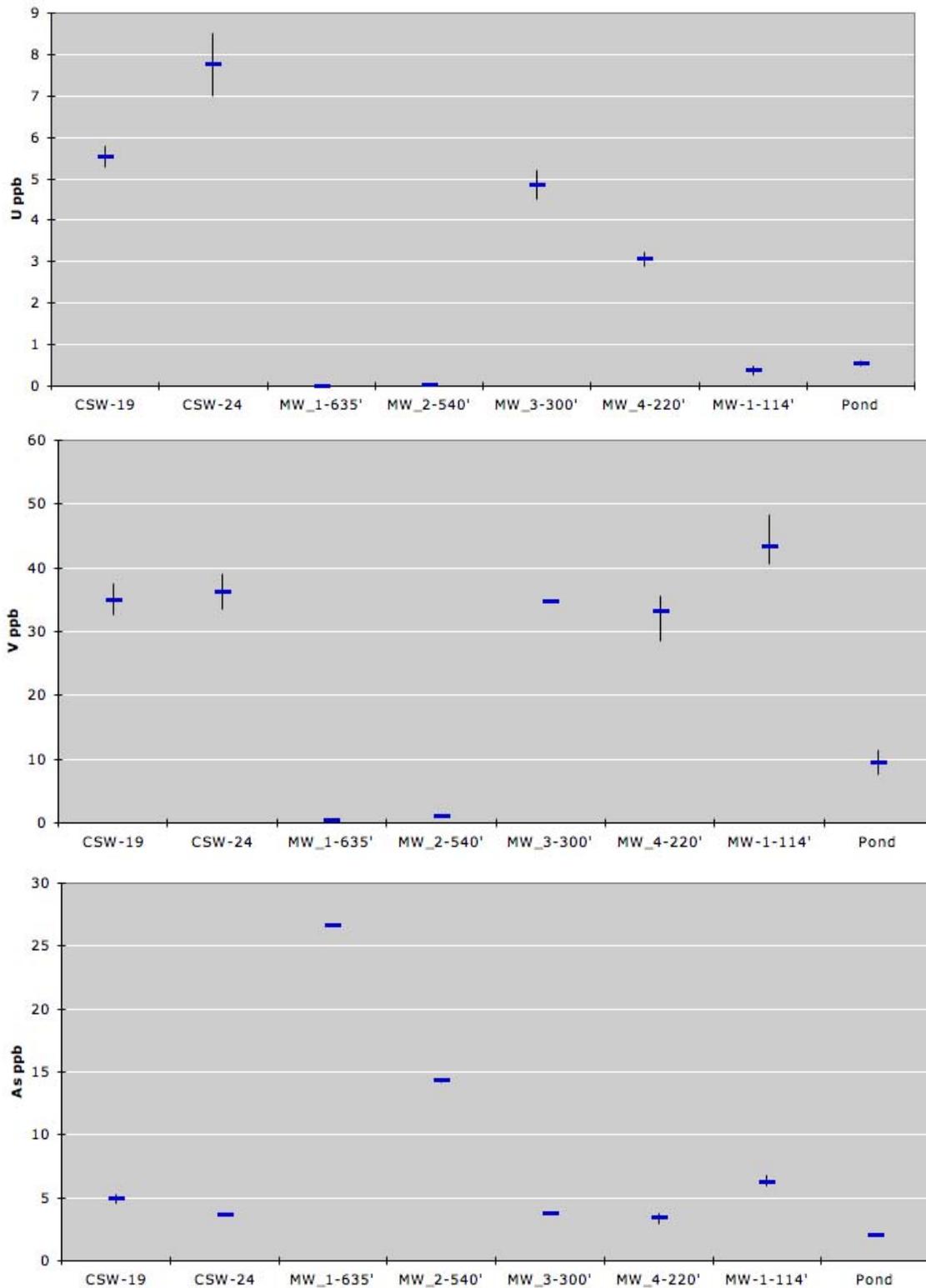


Figure 28. Trace Element concentrations from samples collected at the Morada Lane site. MW 1, 2, 3 & 4 refer the USGS multi-level monitor wells, which are identified only by their depth in the text (e.g., MW-114').

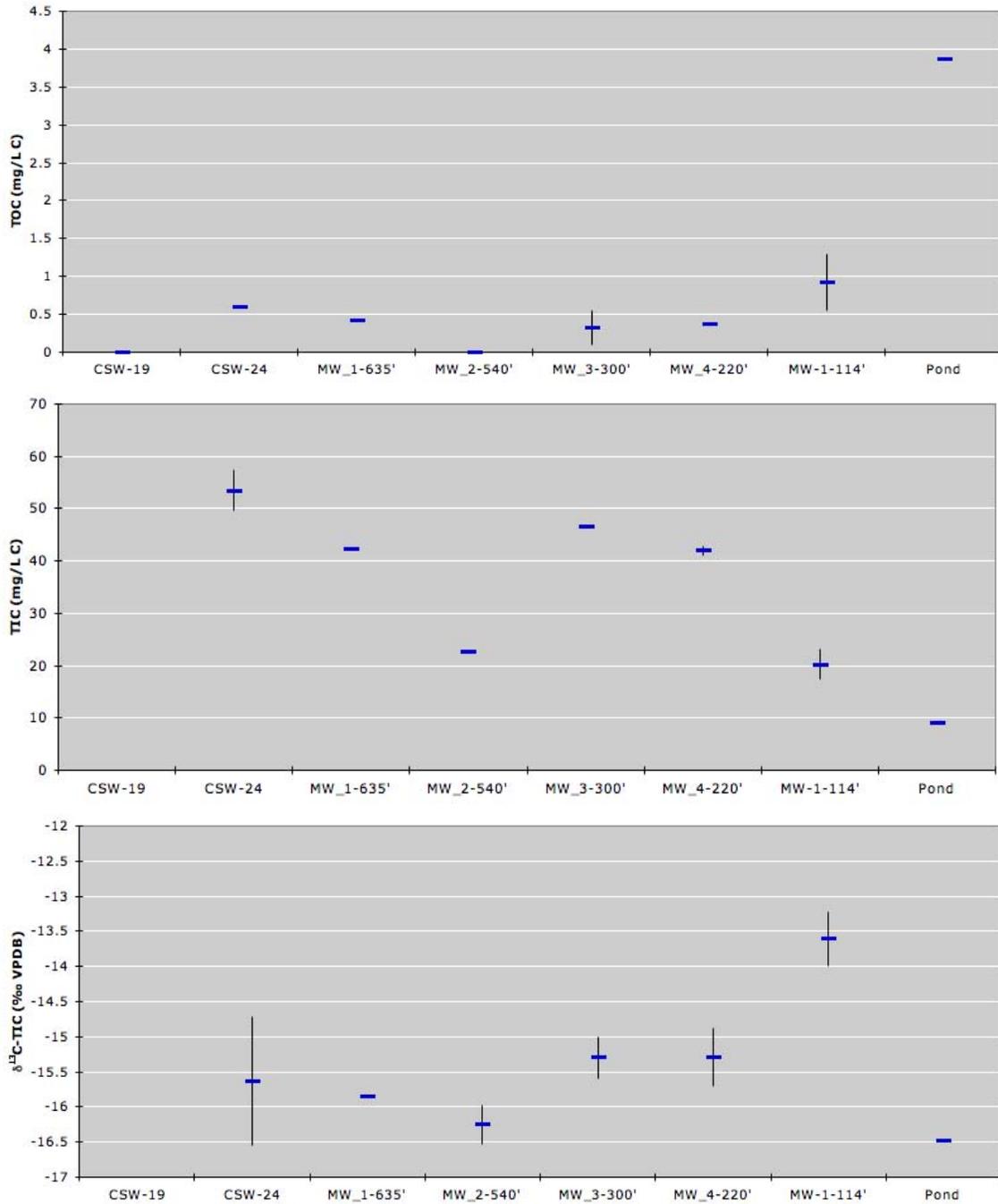


Figure 29. Dissolved carbon concentration and isotopic composition from samples collected at the Morada Lane site. MW 1, 2, 3 & 4 refer the USGS multi-level monitor wells, which are identified only by their depth in the text (e.g., MW-114').

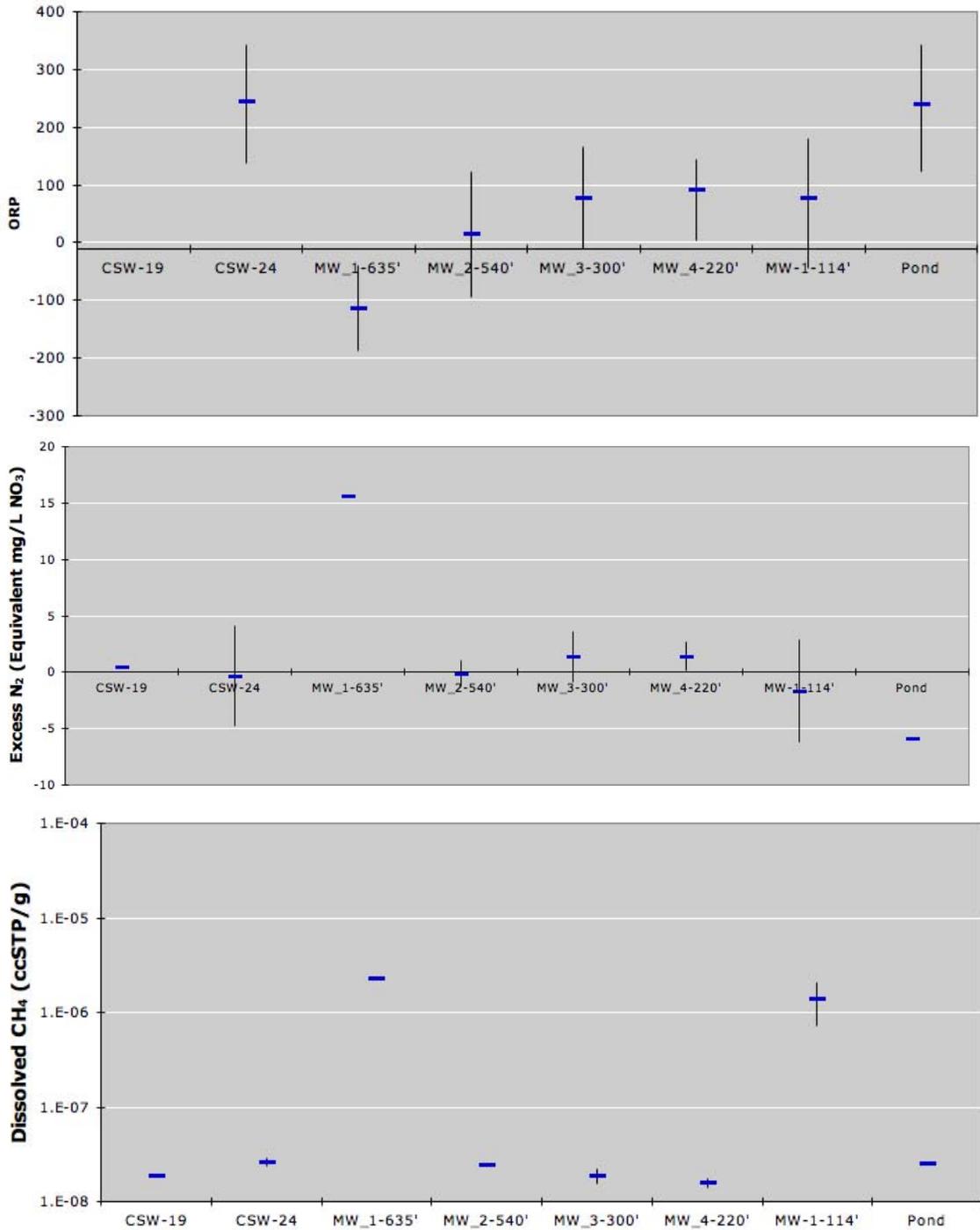


Figure 30. Oxidative reduction potential and redox-sensitive dissolved gases from samples collected at the Morada Lane site. MW 1, 2, 3 & 4 refer the USGS multi-level monitor wells, which are identified only by their depth in the text (e.g., MW-114').

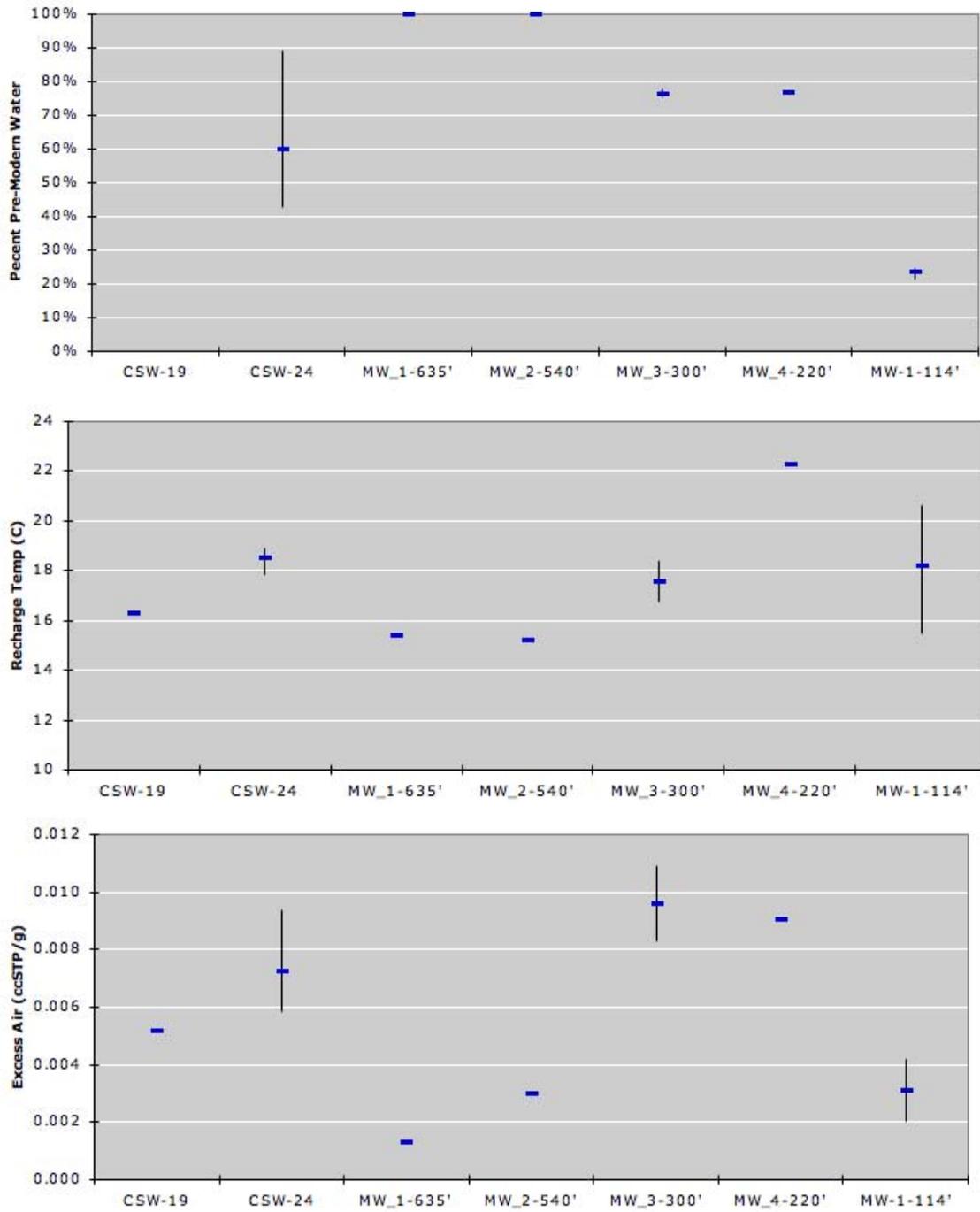


Figure 31. Parameters derived from noble gas compositions of groundwater near the Morada Lane site. MW 1, 2, 3 & 4 refer the USGS multi-level monitor wells, which are identified only by their depth in the text (e.g., MW-114').

The concentration and isotopic composition of dissolved carbon are shown in Figure 29. Total organic carbon (TOC) concentrations were 4-8 times higher in the pond than in the groundwater samples. The shallow monitoring well had the highest observed concentrations of organic carbon. The shallow well was also similar to the pond in having the lowest concentration of total inorganic carbon (TIC). Carbon isotope compositions of total inorganic carbon in most wells were consistent with the incorporation of respired CO₂ during infiltration through the soil zone. The shallow well had the highest $\delta^{13}\text{C}$ values, which may indicate a higher proportion of atmospheric CO₂-equilibrated water. A sample collected from the canal (Appendix 1; not shown in Figure 29) has a $\delta^{13}\text{C}$ value of -11.7 ‰, which may represent an end member for atmospheric CO₂-equilibrated water. Only one sample from the pond was analyzed for its TIC isotope composition, and it had a value of -16.5 ‰, which is much lower than expected for surface water.

Figure 30 combines the results of oxidation reduction potentials (ORP) measured in the field with two redox sensitive dissolved gases (excess N₂ and CH₄) measured using membrane inlet mass spectrometry. The lowest ORP values were measured in the two deepest monitoring wells. The deepest monitoring well (MW-635') contained excess nitrogen and elevated dissolved methane, indicating denitrification and methanogenesis in the deep aquifer system. Elevated methane concentrations were also observed in the shallow monitoring well, which indicate methanogenesis that may occur as a result of redox reactions due to the influence of organic carbon in the recharge from the pond.

Morada Lane: Noble Gas-Derived Recharge Conditions

Figure 31 shows the percentage of pre-modern water, recharge temperature, and excess air concentration, which are calculated from dissolved noble gas and tritium concentrations. The fraction pre-modern (recharged more than approximately 50 years before present) is determined using a plot of tritium in precipitation versus recharge year and comparing a sample's measured tritium to the tritium expected based on the ³H-³He age of the sample (Manning and Thiros, 2005; Moran et al., 2004). Pre-modern water does not contain tritium, and is not reflected in the ³H-³He apparent age of a sample. The two deepest monitoring wells contain no detectable tritium, and are therefore completely pre-modern. The long-screened production CSW-24, has a large range of percent pre-modern values, which may reflect variations in flow with depth during the year. The shallow monitoring well contains approximately 24% pre-modern water.

The recharge temperature indicates the temperature of the water when it was last in contact with the atmosphere during infiltration and recharge. The shallow monitoring well shows the largest variation in recharge temperature, which is consistent with the large variation in discharge temperatures as well as $\delta^{18}\text{O}$ and water quality parameters at this well. The two deepest monitoring wells have recharge temperatures that are approximately 5-6 degrees cooler than the temperatures measured during sampling. An increase in temperature after recharge may indicate warming during to the geothermal gradient with depth, and could also indicate recharge during different climate conditions.

Excess air concentrations are based on the observation of dissolved noble gas concentrations being higher than equilibrium with the atmosphere would permit. The cause of excess air in groundwater is generally attributed to the dissolution of entrapped air bubbles at the water table interface (Aesbach-Hertig et al. 1999; Cey et al., 2008). Managed aquifer recharge operations can have a significant impact on excess air concentrations due to the episodic nature of the recharge. High excess air concentrations are also reported for areas where recharge pond water entraps air from what was originally an unsaturated zone (Heilweil et al., 2004). Excess air concentrations are highest in MW-300' and MW-220', while the shallowest monitoring well (MW-114') has a low concentration of excess air. This pattern is in keeping with tracer results which show a greater contribution of pond recharge in MW-300' and MW-220' than in MW-114'. CSW-24 also has relatively high concentrations of excess air with a significant amount of variability, which may indicate temporal variations in the fraction of water derived from the recharge operation.

Morada Lane: Geochemical Modeling

PHREEQC was used to model the idealized mixing of recharge pond water with ambient shallow background groundwater in an attempt to identify the key geochemical processes affecting the evolution of the aquifer chemistry in response to recharge. Specifically, the mixing model assumed that the water composition measured in MW-114' in February 2007 could be described by a mixture of:

- Pond water composition, as represented by the Morada Pond NE sample collected in September 2006.
- Ambient background groundwater, as represented by the average composition of two sampling rounds collected from MW-220' in Feb and March of 2007. The SF₆ tracer study indicates that this well is influenced by the recharge pond, but the average groundwater age (~18 years) suggests that this influence may be sporadic.
- Dissolved organic carbon.

The mixing model considered six different mixing scenarios, with the results of each compared to the MW-114' water composition measured in February 2007:

1. A non-reactive binary 50-50 mixture of pond water with MW-220' water ("Binary 50-50");
2. A 50-50 mixture of pond water with MW-220' water subject to water-mineral interactions as described below ("50-50 Reactive Mix");
3. The same as (2), but with the mineralization of 0.0001 mol/L organic carbon, modeled as CH₂O, included in the PHREEQC mixing calculations ("50-50 Reactive Mix with OC");
4. A non-reactive binary 90-10 mixture of pond water with MW-220' water ("Binary 90-10");
5. A 90-10 mixture of pond water with MW-220' water subject to water-mineral interactions as described below ("90-10 Reactive Mix");

- The same as (5), but with the mineralization of 0.0001 mol/L organic carbon, modeled as CH₂O, included in the PHREEQC mixing calculations ("90-10 Reactive Mix with OC").

Specific water-mineral reactions accounted for in the reactive mixing model include an ion exchanger and a hydrous ferric oxide surface (as FeOOH) initially in equilibrium with MW-114' water. MnO₂ was also assumed to be present initially. Other mineral phases not initially present but allowed to precipitate by the mixing model upon supersaturation include Cr(OH)₂, Cu₂O, calcite and dolomite, Mn-rich calcite, uraninite, elemental Se, and V₂O₅. Mixing model results are summarized in Figures 32 and 33. For both figures, the y-axis refers to the relative difference, in percent, between the measured concentration of a particular component (element) observed in MW-114' and the predicted concentration, organized by model scenario (1-6, above). Fe & Mn enrichment is truncated on these graphs to allow the other elements to show up against the y-axis.

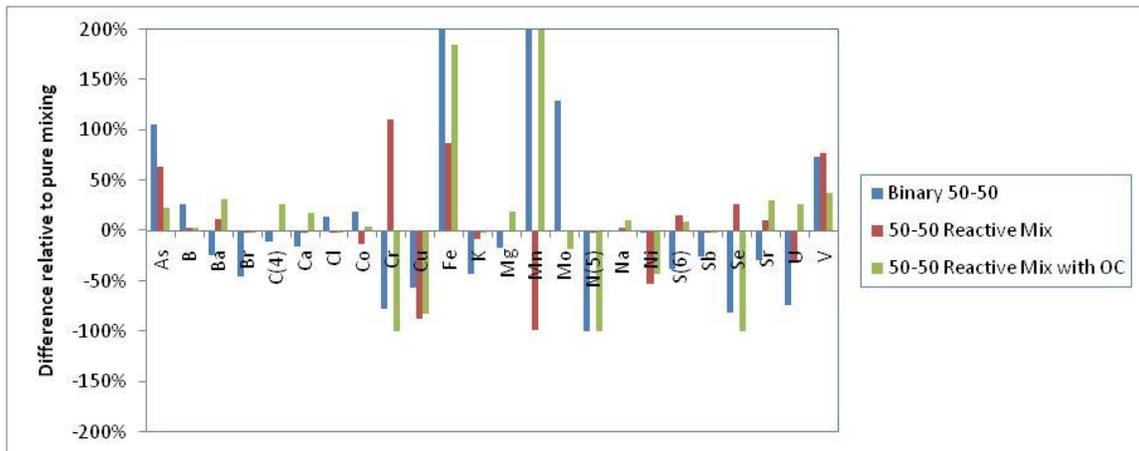


Figure 32. MW-114' water composition compared to modeled changes in component concentrations; 50-50 mixture of pond water and MW-220' under various assumptions.

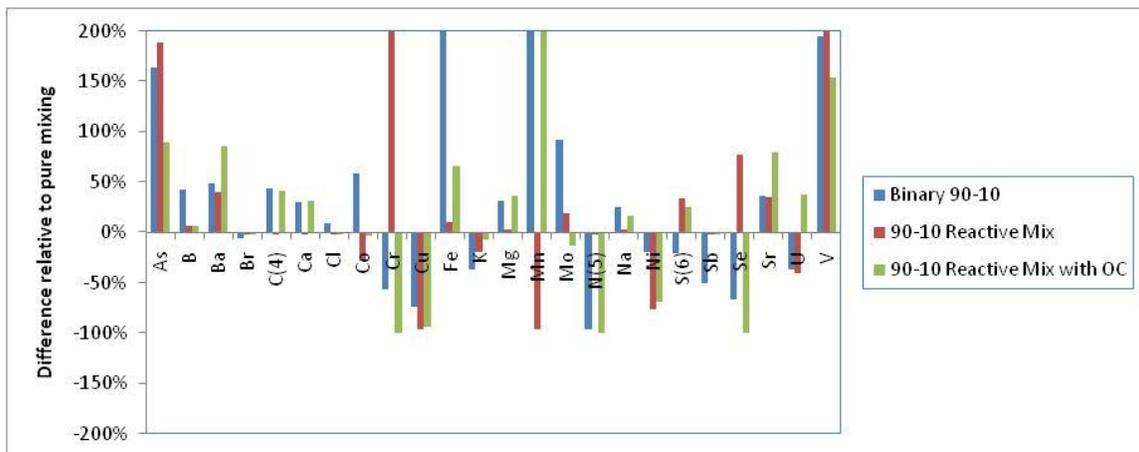


Figure 33. MW-114' water composition compared to modeled changes in component concentrations; 90-10 mixture of pond water and MW-220' under various assumptions.

In summary, both binary mixing models indicate that MW-114' is enriched in As, Fe, Mn, and V and is depleted in Cr, Cu, N(5) - nitrate, and Se as compared to what would be expected under ideal (non-reactive) mixing. The Binary 90-10 mixture model appears to produce a better match to both the non-reactive natural tracers (Br and Cl) than does the Binary 50-50 mixture. In the context of reproducing many of the observed component concentration trends, the 90-10 Reactive Mix with OC model yields a reasonable degree of semi-quantitative agreement between the data and the model with respect to As, Ba, Br, C(4) - DIC, Ca, Cl, Cr, Cu, Fe, Mg, Mn, N(5) - nitrate, Se, Sr, and V. This model, however, did not produce results consistent with the data for Co, Mo, S(6) - sulfate, Sb, and U. Most of the model result stem from predicted changes in pH that impact surface complexation reactions, although redox processes are important for Cr, Fe, Mn, and N(5).

Summary: Comparing Results from SEWD and Morada Lane

The two banking sites discussed here are operated because local and regional aquifers are in overdraft conditions due to historical and ongoing withdrawals for agriculture. Both operations are successful in maintaining reasonably high rates of infiltration and good water quality. Hydrogeologic, geochemical and operational differences explain the observed differences in tracer transport and water quality at the two sites.

With respect to infiltration, pond depth is greater at Morada Lane, while SEWD ponds are ribbed to enhance infiltration. Overall, the infiltration rate is probably higher at SEWD because of more permeable material at infiltration sites. SEWD applies only imported water while at Morada Lane both imported and storm water runoff are infiltrated; in both cases imported water exhibits very low TDS. The effect of recharging storm water at Morada Lane is seen in higher TOC and trace metal concentrations in surface water, but storm water recharge appears to have minimal effect on overall groundwater quality, with the possible exception that infiltrating organic carbon drives the redox process near the sediment-water interface.

Both methods of tracer introduction were successful and tracer curves were established for nearby monitoring wells. Deep, multi-level sampling points were available at Morada Lane but available wells provided very limited spatial coverage, while at SEWD near-field spatial coverage was adequate but there was limited opportunity for acquiring samples at specific depths of interest. An important result with respect to effects on water quality is that overall water quality is good in both settings, and further improved by removal of organic matter during infiltration, but arsenic is released from sediments at a rate that is higher than would be expected for natural infiltration. At SEWD, As release is associated with exchange on hydrous ferric oxides due to a change in pH, while at Morada Lane redox processes with an organic carbon electron donor likely cause As release in near field groundwater.

At both locations, extraction wells are in relatively close proximity to recharge ponds. Pressure is transmitted to nearby monitoring wells almost immediately after infiltration but water mass movement lags and has more complex behavior. Rapid lateral transport of water from the recharge pond to drinking water wells takes place at Morada Lane, while tracer was not observed at SEWD drinking water wells over the course of the study. At both sites, groundwater ages in production wells indicate that the bulk of the produced water has subsurface residence times greater than 20 years. At Morada Lane vertical transport is fairly slow but is followed by rapid lateral transport through high hydraulic conductivity lenses. At SEWD, mounding and lateral transport are rapid and are followed by lateral transport according to the regional groundwater gradient; evidence for significant vertical transport is lacking, but the resolution is poor because of limited sampling points. Production well pumping does not have a direct affect on transport at SEWD, possibly because production wells are screened in a semi-confined unit, which also explains the lack of tracer detections in the production wells. At Morada Lane, a direct, strong effect of pumping is observed due to unconfined conditions, and rapid

lateral transport may have implications for groundwater management when considering potential transport of microbes and viruses to drinking water wells.

Acknowledgements

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California GAMA Program: Tracking Water Quality Changes During Groundwater Banking at Two Sites in San Joaquin County

Appendix A, Data Tables

<i>Data Tables</i>	<i>Page</i>
<i>Table A-1: SEWD Water Quality Data</i>	<i>A2</i>
<i>Table A-2: SEWD Tracer Data</i>	<i>A4</i>
<i>Table A-3: SEWD Noble Gas & Tritium Data</i>	<i>A9</i>
<i>Table A-4: SEWD Organic Data</i>	<i>A10</i>
<i>Table A-5: Morada Water Quality Data</i>	<i>A11</i>
<i>Table A-6: Morada Tracer Data</i>	<i>A12</i>
<i>Table A-7: Morada Noble Gas & Tritium Data</i>	<i>A16</i>
<i>Table A-8: Morada Organic Data</i>	<i>A17</i>

Note: Multiple listings of an individual well in the following tables indicate that the well was sampled on more than one occasion (as indicated by sample date). In select cases, replicate sample splits were run (as indicated by the same sample date and LLNL ID).

Table A-1: SEWD Water Quality Data

LLNL ID	Site	Location	Sample Date	Depth of well screen (ft)	Cl ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	Na (mg/L)	NH ₃ (mg/L)	K (mg/L)	Mg (mg/L)	Mn (mg/L)	Ca (mg/L)	As (ug/L)	U (ug/L)	V (ug/L)	Dissolved CH ₄ (ccSTP/g)	Excess N ₂ (as equiv. mg/L NO ₃ ⁻)	TIC (mg/L)	TOC (mg/L)	δ ¹³ C TIC (‰ VPDB)	d13C-TOC	³ H pCi/L	δ ¹⁵ N NO ₃ ⁻ (‰ Air)	δ ¹⁸ O NO ₃ ⁻ (‰ SMOW)		
104846	SEWD	South Pond	01/22/2007	surface	4.9	<0.4	12.0	5.6	<0.1	1.2	7.8		13.0														
104847	SEWD	South Pond	01/22/2007	surface	4.7	<0.4	11.4	5.5	<0.1	1.1	7.8		12.6														
104848	SEWD	South Pond	01/22/2007	surface	4.5	<0.4	10.9	5.9	<0.1	1.3	10.6		13.6														
104858	SEWD	South Pond	01/26/2007	surface	4.9	<0.4	11.3	5.8	<0.1	1.2	10.3		13.6														
104859	SEWD	South Pond	01/26/2007	surface	4.8	<0.4	11.3	6.1	<0.1	1.2	11.5		15.0														
104860	SEWD	South Pond	01/26/2007	surface	5.1	<0.4	12.3	6.2	<0.1	1.2	12.1		15.6														
104862	SEWD	South Pond	01/26/2007	surface	5.2	<0.4	12.5	4.1	<0.1	0.8	3.9		10.3														
104880	SEWD	South Pond	02/05/2007	surface	3.8	< 0.1	9.1	4.1	<0.1	0.9	3.8		10.5														
104881	SEWD	South Pond	02/05/2007	surface	3.6	< 0.1	8.7	6.2	<0.1	1.3	5.8		15.2														
104882	SEWD	South Pond	02/06/2007	surface	5.3	< 0.1	13.0	6.3	<0.1	1.4	5.4		14.4														
104883	SEWD	South Pond	02/06/2007	surface	5.2	< 0.1	12.8	6.2	<0.1	1.2	5.4		14.6														
104884	SEWD	South Pond	02/06/2007	surface	5.2	< 0.1	12.8	8.2	<0.01	1.5	8.2		16.2														
104969	SEWD	South Pond	03/13/2007	surface	7.6	0.2	17.5	3.1	< .01	0.7	2.2		5.7				2.1E-08	ND	15.1	3.6	-10.6	-24.0	15.6				
105289	SEWD	South Pond	05/30/2007	surface	2.1	< 0.4	6.2																				
105519	SEWD	South Pond	07/16/2007	surface	2.1	< 0.4	5.1							0.6	0.01	3.6			4.7	3.9	-5.7	-25.8					
104302	SEWD	T-3	08/23/2006		19.5	12.7	31.7							4.2	2.73	36.4	2.4E-08	ND	59.9	0.5	-15.1		11.0	7.3	2.4		
105514	SEWD	T-3	07/16/2007		12.6	8.1	18.2							4.5	2.59	34.6			56.0	0.7	-16.3	-29.7		6.0	2.4		

Table A-2: SEWD Tracer Data

LLNL ID	Site	Location	Sample Date	$\delta^{18}\text{O H}_2\text{O}$ (‰ VSMOW)	$\delta^2\text{H H}_2\text{O}$ (‰ VSMOW)	SF6 (ppb in headspace)	Conductivity (uS/cm)	pH	ORP	Temperature (°C)	DO (mg/L)
104267	SEWD	60Acre	08/22/2006	-9.9	-73.3		228	6.7	-8	20.8	2.3
104857	SEWD	60Acre	01/26/2007	-10.5	-75.3	5.5E-03	194	7.4	321	14.0	
104868	SEWD	60Acre	01/30/2007	-10.5	-75.8	7.5E-04	189	7.4	320	17.1	1.8
104879	SEWD	60Acre	02/05/2007	-10.5	-75.6	2.4E-01					
104906	SEWD	60Acre	02/12/2007	-10.3	-73.0	6.8E+00	186	7.6	356	16.0	0.2
104924	SEWD	60Acre	02/21/2007	-10.3		4.8E+01	193	7.5	366	14.8	
104950	SEWD	60Acre	03/02/2007	-10.3		9.6E+01	192	7.6	305	13.2	
104976	SEWD	60Acre	03/13/2007	-10.2	-72.9	1.0E+02	206	7.5	277	15.0	0.3
105090	SEWD	60Acre	03/28/2007	-9.8	-69.0	8.0E+01	214	7.0	341	12.9	2.3
105142	SEWD	60Acre	04/23/2007	-9.4	-67.2	4.8E+01	240	7.5	283	16.3	1.8
105288	SEWD	60Acre	05/30/2007	-10.1	-72.4	4.2E+01	207	7.7	247	20.2	0.2
105512	SEWD	60Acre	07/16/2007	-9.9	-71.6	2.8E+01	217	7.9	177	23.4	4.3
104271	SEWD	74-01	08/22/2006	-8.0	-54.5		512	6.7	83	19.1	5.7
105086	SEWD	74-01	03/26/2007	-8.3	-59.2	5.1E-04					
105153	SEWD	74-01	04/24/2007	-7.7	-55.7	1.5E-03	515	7.5	278	18.9	6.4
105299	SEWD	74-01	05/31/2007	-7.9	-53.9	2.1E-02	527	7.4	265	18.2	4.1
105383	SEWD	74-01	06/12/2007	-8.0	-56.4	5.7E-04					
105797	SEWD	74-01	08/22/2007	-7.9			547	7.3	217	18.5	3.8
105892	SEWD	74-01	08/31/2007	-8.2							
105894	SEWD	74-01	09/06/2007	-8.1							
106021	SEWD	74-01	09/11/2007	-8.2	-56.9	2.5E-04					
106019	SEWD	74-01	11/02/2007	-8.1	-57.2	4.9E-04	364	7.1	258	18.2	3.8
104265	SEWD	74-02	08/22/2006	-8.3	-59.7		419	6.8	72	19.9	5.6
105152	SEWD	74-02	04/24/2007	-8.4	-61.8	5.9E-04	548	7.5	259	18.4	5.8
105298	SEWD	74-02	05/31/2007	-8.3	-57.8	1.4E-03	481	7.6	243	17.8	4.5
105384	SEWD	74-02	06/12/2007	-8.4	-59.4	4.4E-04					
105798	SEWD	74-02	08/22/2007	-8.3			490	7.4	221	18.6	5.9
105893	SEWD	74-02	08/31/2007	-8.6							
105895	SEWD	74-02	09/06/2007	-8.6							
106022	SEWD	74-02	09/11/2007	-8.3	-58.7	2.7E-04					
106018	SEWD	74-02	11/02/2007	-8.6	-60.9	6.5E-04	398	7.1	274	20.0	3.5
104257	SEWD	A4	08/21/2006	-8.9	-64.7		751	6.7	53	20.0	5.0
105084	SEWD	A4	03/27/2007	-8.9	-65.1	3.2E-04	747	7.2	146	18.9	4.6
105151	SEWD	A4	04/24/2007	-9.0	-59.8	2.2E-03	671	7.3	204	19.8	3.9
105297	SEWD	A4	05/31/2007	-9.1	-64.1	3.0E-03	720	7.4	275	19.3	3.9
105513	SEWD	A4	07/16/2007	-9.0	-64.4	1.1E-02	706	7.1	288	20.2	5.0
104270	SEWD	BZ	08/22/2006	-8.3	-58.7		720	6.7	71	20.7	8.0
104300	SEWD	CN-1	08/23/2006	-9.1	-67.3		321	6.7	114	17.6	3.1
104959	SEWD	CN-1	03/02/2007	-9.6		8.0E-04					
104975	SEWD	CN-1	03/13/2007	-9.5	-69.1	8.6E-04	305	7.5	268	18.2	0.8
105080	SEWD	CN-1	03/27/2007	-9.5	-68.9	3.7E-04	313	7.4	302	17.1	2.6
105143	SEWD	CN-1	04/23/2007	-9.5	-68.8	3.5E-03	300	7.5	283	17.8	2.2
105300	SEWD	CN-1	05/31/2007	-9.6	-70.9	9.0E-04	293	7.6	284	18.1	1.4

Table A-2: SEWD Tracer Data

LLNL ID	Site	Location	Sample Date	$\delta^{18}\text{O H}_2\text{O}$ (‰ VSMOW)	$\delta^2\text{H H}_2\text{O}$ (‰ VSMOW)	SF6 (ppb in headspace)	Conductivity ($\mu\text{S}/\text{cm}$)	pH	ORP	Temperature (°C)	DO (mg/L)
105515	SEWD	CN-1	07/16/2007	-9.5	-68.0	3.3E-02	310	7.5	283	17.9	2.3
105796	SEWD	CN-1	08/22/2007	-9.8		3.8E-01	299	7.4	170	17.7	2.3
106020	SEWD	CN-1	11/02/2007	-9.7	-71.7	3.3E-01	216	7.3	274	18.1	2.0
104301	SEWD	CWS-35	08/23/2006	-8.1	-56.6		380	6.8	688	18.8	7.1
104305	SEWD	Diversion Canal	08/23/2006	-8.9	-59.4		196	7.4	216	22.2	12.0
104977	SEWD	Diversion Canal	03/13/2007	-7.8	-52.9	3.0E-03					
105095	SEWD	Diversion Canal	03/28/2007	-7.0	-49.3	5.7E-04					
105301	SEWD	Diversion Canal	05/31/2007	-7.6	-52.5	3.2E-04	243	8.4	225	24.9	8.1
104256	SEWD	MW-1A	08/21/2006	-9.0	-64.9		940	6.7	63	21.3	5.1
104910	SEWD	MW-1A	02/12/2007	-8.9	-61.3	6.8E-03	972	7.0	338	18.8	2.4
104928	SEWD	MW-1A	02/21/2007	-8.9		1.9E-02	892	7.1	355	19.1	2.7
104953	SEWD	MW-1A	03/02/2007	-9.2		5.8E-02	896	7.1	348	19.4	3.2
104972	SEWD	MW-1A	03/13/2007	-9.2	-66.0	1.3E-02	921	7.0	243	21.0	3.5
105081	SEWD	MW-1A	03/27/2007	-9.1	-65.4	8.5E-04	905	6.9	274	19.1	4.5
105148	SEWD	MW-1A	04/24/2007	-9.2	-68.2	4.6E-03	851	7.0	386	20.0	4.8
105291	SEWD	MW-1A	05/30/2007	-9.1	-64.1	2.0E-02	900	7.0	282	20.6	1.1
104255	SEWD	MW-1B	08/21/2006	-9.7	-71.4		569	6.7	95	19.8	3.6
104911	SEWD	MW-1B	02/12/2007	-9.9	-71.0	4.0E-03	655	7.3	332	18.1	1.4
104929	SEWD	MW-1B	02/21/2007	-9.8		9.3E-03	608	7.4	338	18.6	2.0
104954	SEWD	MW-1B	03/02/2007	-10.0		3.5E-02	583	7.4	337	19.0	2.8
104973	SEWD	MW-1B	03/13/2007	-10.0	-69.0	5.8E-03	593	7.3	274	20.0	1.9
105082	SEWD	MW-1B	03/27/2007	-9.9	-72.1	1.3E-03	607	7.2	278	18.9	3.8
105149	SEWD	MW-1B	04/24/2007	-9.7	-68.4	3.7E-03	607	7.3	286	19.7	3.6
105292	SEWD	MW-1B	05/30/2007	-9.7	-69.1	1.2E-02	634	7.4	285	19.8	3.2
104254	SEWD	MW-1C	08/21/2006	-10.2	-72.3		240	6.4	120	19.5	2.9
104955	SEWD	MW-1C	03/02/2007	-10.4		3.6E-02	240	7.6	278	19.2	2.6
104974	SEWD	MW-1C	03/13/2007	-10.4	-72.9	5.8E-03	247	7.6	232	20.2	2.8
105083	SEWD	MW-1C	03/27/2007	-9.7	-68.0	7.8E-04	248	7.4	266	18.4	3.2
105150	SEWD	MW-1C	04/24/2007	-9.8	-59.8	2.0E-03	247	7.5	309	19.9	2.9
105293	SEWD	MW-1C	05/30/2007	-9.7	-69.2	1.7E-02	261	7.7	266	20.4	2.3
104266	SEWD	MW-2A	08/22/2006	-9.2	-68.0		639	6.6	88	20.3	7.5
104951	SEWD	MW-2A	03/02/2007	-9.1		3.7E+00	560	7.4	330	17.9	0.9
104963	SEWD	MW-2A	03/13/2007	-8.9		3.8E-01	648	7.2	342	19.4	3.6
105087	SEWD	MW-2A	03/28/2007	-8.9	-65.7	8.6E-03	623	7.0	385	18.2	3.6
105139	SEWD	MW-2A	04/23/2007	-9.3	-64.8	1.4E-04	550	7.3	314	19.5	2.4
105287	SEWD	MW-2A	05/30/2007	-9.2	-67.7	1.1E-01	582	7.5	244	19.4	3.6
105521	SEWD	MW-2A	07/16/2007	-9.2	-66.8	8.2E-03	653	7.2	280	19.5	4.6
104260	SEWD	MW-2B	08/22/2006	-9.1	-67.8		458	7.0	101	19.7	3.1
104952	SEWD	MW-2B	03/02/2007	-9.3		3.8E+00	397	8.3	295	18.5	
104965	SEWD	MW-2B	03/13/2007	-9.3	-69.0	1.3E-01	403	7.9	305	19.5	
105088	SEWD	MW-2B	03/28/2007	-9.3	-67.2	9.8E-03	389	7.8	338	18.4	1.0
105141	SEWD	MW-2B	04/23/2007	-9.4	-68.6	1.1E-03	381	8.0	269	19.5	1.3
105286	SEWD	MW-2B	05/30/2007	-9.8	-71.2	6.6E-03	359	8.0	220	19.1	1.6

Table A-2: SEWD Tracer Data

LLNL ID	Site	Location	Sample Date	$\delta^{18}\text{O H}_2\text{O}$ (‰ VSMOW)	$\delta^2\text{H H}_2\text{O}$ (‰ VSMOW)	SF6 (ppb in headspace)	Conductivity ($\mu\text{S}/\text{cm}$)	pH	ORP	Temperature (°C)	DO (mg/L)
104261	SEWD	MW-2C	08/22/2006	-8.6	-62.7		329	6.7	110	19.0	2.6
104964	SEWD	MW-2C	03/13/2007	-9.2	-68.0	1.5E-01	340	7.4	322	19.0	
105089	SEWD	MW-2C	03/28/2007	-9.2	-68.7	3.7E-03	321	7.2	323	17.9	1.4
105140	SEWD	MW-2C	04/23/2007	-9.4	-67.1	2.7E-04	338	7.5	284	19.4	0.9
105285	SEWD	MW-2C	05/30/2007	-9.7	-71.9	1.8E-03	323	7.4	202	18.6	0.2
105520	SEWD	MW-2C	07/16/2007	-9.8	-71.4	2.0E-01	319	7.3	267	19.5	3.3
104263	SEWD	MW-3A	08/21/2006	-8.5	-61.9		454	7.0	53	19.2	4.3
104909	SEWD	MW-3A	02/12/2007	-9.9	-75.4	1.7E-02	421	7.5	312	20.1	1.0
104927	SEWD	MW-3A	02/21/2007	-10.4		5.0E+00	279	7.6	327	20.9	
104956	SEWD	MW-3A	03/02/2007	-10.2		3.3E-02	291	7.5	318	21.4	0.7
104967	SEWD	MW-3A	03/13/2007	-10.3	-74.0	6.8E-02	367	7.5	308	22.1	2.0
105077	SEWD	MW-3A	03/27/2007	-9.8	-72.8	8.8E-02	456	7.4	325	20.8	3.4
105144	SEWD	MW-3A	04/23/2007	-9.9	-70.2	8.7E-01	301	7.5	269	23.2	4.3
105296	SEWD	MW-3A	05/30/2007	-9.5	-67.3	4.3E+00	403	7.5	265	23.1	3.9
105518	SEWD	MW-3A	07/16/2007	-9.3	-66.1	1.1E+01	375	7.5	286	22.0	3.8
104259	SEWD	MW-3B	08/21/2006	-8.3	-60.7		303	6.9	7	17.9	2.5
104908	SEWD	MW-3B	02/12/2007	-10.5	-77.7	2.4E-02	252	7.6	295	21.0	
104926	SEWD	MW-3B	02/21/2007	-10.5		4.9E+00	252	7.6	330	20.6	
104957	SEWD	MW-3B	03/02/2007	-10.3		3.0E-02	241	7.4	318	21.0	
104966	SEWD	MW-3B	03/13/2007	-10.7	-79.0	5.5E-02	251	7.6	287	22.2	1.0
105078	SEWD	MW-3B	03/27/2007	-9.1	-66.4	1.1E-01	324	7.3	300	21.1	2.4
105145	SEWD	MW-3B	04/23/2007	-10.2	-74.3	7.7E-01	272	7.3	293	23.2	2.5
105295	SEWD	MW-3B	05/30/2007	-10.0	-70.7	6.8E+00	268	7.4	283	23.7	3.4
105516	SEWD	MW-3B	07/16/2007	-9.8	-69.1	2.8E+01	290	7.5	293	22.3	3.3
104258	SEWD	MW-3C	08/21/2006	-7.9	-53.3		271	6.8	103	18.7	4.5
104925	SEWD	MW-3C	02/21/2007	-10.6		4.0E+00	218	7.7	345	18.7	
104958	SEWD	MW-3C	03/02/2007	-10.8		1.8E-02	201	7.6	316	18.7	0.8
104968	SEWD	MW-3C	03/13/2007	-11.0	-78.0	2.1E-02	205	7.6	294	19.9	
105079	SEWD	MW-3C	03/27/2007	-10.8	-78.2	1.1E-02	210	7.6	295	19.2	2.6
105146	SEWD	MW-3C	04/23/2007	-11.0	-80.0	9.0E-01	210	7.5	304	20.9	1.5
105294	SEWD	MW-3C	05/30/2007	-10.9	-76.9	3.1E+01	227	7.4	291	22.2	2.0
105511	SEWD	MW-3C	07/16/2007	-10.4	-72.9	6.2E+01	261	7.6	311	21.7	1.9
104303	SEWD	MW-NW-1	08/23/2006	-8.5	-58.5		374	6.8	298	19.0	5.8
104272	SEWD	North Pond (inflow)	08/22/2006	-11.2	-80.6		99	6.9	77	24.5	11.7
104845	SEWD	Overflow Pond (near pipe)	01/22/2007	-9.0	-61.9	1.2E+02	197	7.5	273	8.5	2.9
104861	SEWD	Overflow Pond (near pipe)	01/26/2007	-8.2	-55.1	5.4E+02	221	8.1	265	8.4	9.1
104920	SEWD	Overflow Pond (near pipe)	02/21/2007	-7.4		6.5E-02					
104947	SEWD	Overflow Pond (near pipe)	03/02/2007	-7.6		4.8E-02	255	8.0	298	10.8	9.2
104970	SEWD	Overflow Pond (near pipe)	03/13/2007	-7.4	-51.0	1.1E-02					
105156	SEWD	Overflow Pond (near pipe)	04/24/2007	-11.0	-79.1	1.5E-03					
104264	SEWD	PZ-1	08/21/2006	-9.8	-69.9		208	7.0	-13	18.3	1.2
104856	SEWD	PZ-1	01/26/2007	-11.4	-78.8	5.2E-03	150	7.2	324	19.7	3.1
104867	SEWD	PZ-1	01/30/2007	-11.4	-80.5	1.5E-03	147	7.0	340	19.1	3.8

Table A-2: SEWD Tracer Data

LLNL ID	Site	Location	Sample Date	$\delta^{18}\text{O H}_2\text{O}$ (‰ VSMOW)	$\delta^2\text{H H}_2\text{O}$ (‰ VSMOW)	SF6 (ppb in headspace)	Conductivity (uS/cm)	pH	ORP	Temperature (°C)	DO (mg/L)
104878	SEWD	PZ-1	02/05/2007	-11.4	-80.5	1.2E-03					
104903	SEWD	PZ-1	02/12/2007	-11.2	-81.0	7.1E+00	145	7.6	368	19.3	3.8
104923	SEWD	PZ-1	02/21/2007	-11.4		1.0E+01	153	7.5	377	18.4	3.9
104944	SEWD	PZ-1	03/02/2007	-11.5		5.0E+01	151	7.2	425	16.9	4.2
104961	SEWD	PZ-1	03/13/2007	-11.2		1.4E+02	163	7.4	359	16.9	4.5
105085	SEWD	PZ-1	03/27/2007	-10.2	-73.5	1.6E+02	197	7.5	245	14.8	5.1
105147	SEWD	PZ-1	04/23/2007	-8.6	-61.9	5.0E+01	251	7.5	334	13.0	4.4
105290	SEWD	PZ-1	05/30/2007	-8.0	-56.2	1.7E+01	256	7.3	280	14.5	1.8
105517	SEWD	PZ-1	07/16/2007	-10.5	-76.9	6.0E+00	198	7.5	261	18.4	1.4
104273	SEWD	South Pond	08/22/2006	-11.7	-83.4		80	7.1	76	22.5	11.7
104840	SEWD	South Pond	01/17/2007	-9.2	-65.5	1.4E-03	184	7.3	365	7.4	4.2
104841	SEWD	South Pond	01/17/2007			8.6E-04					
104844	SEWD	South Pond	01/22/2007	-8.8	-64.9	1.9E+02	201	7.3	301	8.2	2.7
104846	SEWD	South Pond	01/22/2007	-8.5	-57.6	1.3E+02	218	7.6	286	8.0	3.1
104847	SEWD	South Pond	01/22/2007	-8.6	-165.1	4.1E+02	203	7.8	275	9.6	4.2
104848	SEWD	South Pond	01/22/2007	-9.1	-62.8	2.1E+02	199	7.8	271	7.9	3.5
104858	SEWD	South Pond	01/26/2007	-8.5	-60.8	2.6E+02	208	7.5	325	8.8	9.4
104859	SEWD	South Pond	01/26/2007	-8.7	-60.4	2.8E+02	205	7.9	282	7.8	10.1
104860	SEWD	South Pond	01/26/2007	-8.5	-58.5	8.4E+02	220	8.0	272	8.5	9.6
104862	SEWD	South Pond	01/26/2007	-8.1	-56.1	1.2E+03	229	8.1	264	8.3	9.7
104880	SEWD	South Pond	02/05/2007	-8.0	-55.7	3.7E+02					
104881	SEWD	South Pond	02/05/2007	-8.0	-53.7	3.6E+01					
104882	SEWD	South Pond	02/06/2007	-7.9	-56.4	7.6E+01					
104883	SEWD	South Pond	02/06/2007	-7.9	-56.1	2.4E+02					
104884	SEWD	South Pond	02/06/2007	-8.0	-57.8	2.5E+02					
104902	SEWD	South Pond	02/12/2007	-7.8	-56.0	2.4E+00	237	8.1	319	14.3	10.5
104904	SEWD	South Pond	02/12/2007	-7.7	-55.5	2.1E+00	227	7.9	270	14.5	10.4
104905	SEWD	South Pond	02/12/2007	-7.8	-54.7	1.4E+00	229	8.0	293	13.8	9.8
104907	SEWD	South Pond	02/12/2007	-7.7	-54.4	8.4E+00	211	7.9	323	17.1	9.6
104918	SEWD	South Pond	02/21/2007	-7.7	-51.9	1.5E-01					
104919	SEWD	South Pond	02/21/2007	-7.6		1.9E-01					
104921	SEWD	South Pond	02/21/2007	-7.6		2.7E-01					
104922	SEWD	South Pond	02/21/2007	-7.6		2.6E-01					
104945	SEWD	South Pond	03/02/2007	-7.7		1.1E-01	258	7.4	372	11.1	11.1
104946	SEWD	South Pond	03/02/2007	-7.7		8.5E-02	268	7.6	297	11.7	9.9
104948	SEWD	South Pond	03/02/2007	-7.6		8.3E-02	252	7.9	300	10.4	9.0
104949	SEWD	South Pond	03/02/2007	-7.6		8.3E-02	257	7.2	292	11.3	8.5
104960	SEWD	South Pond	03/13/2007	-7.3		2.1E-02					
104962	SEWD	South Pond	03/13/2007	-7.7		2.8E-02					
104969	SEWD	South Pond	03/13/2007	-7.5	-48.0	2.0E-02	270	8.6	224	20.8	12.6
104971	SEWD	South Pond	03/13/2007	-7.3	-50.0	3.7E-02					
105091	SEWD	South Pond	03/28/2007	-6.6	-45.5	2.7E-02		0.0			
105092	SEWD	South Pond	03/28/2007	-7.4	-54.9	3.4E-03	252	8.0	293	14.1	9.3

Table A-2: SEWD Tracer Data

LLNL ID	Site	Location	Sample Date	$\delta^{18}\text{O H}_2\text{O}$ (‰ VSMOW)	$\delta^2\text{H H}_2\text{O}$ (‰ VSMOW)	SF6 (ppb in headspace)	Conductivity ($\mu\text{S}/\text{cm}$)	pH	ORP	Temperature ($^{\circ}\text{C}$)	DO (mg/L)
105093	SEWD	South Pond	03/28/2007	-7.3	-53.0	1.8E-02					
105094	SEWD	South Pond	03/28/2007	-7.3	-50.8	4.8E-03					
105154	SEWD	South Pond	04/24/2007	-10.9	-80.1	1.9E-02			0		
105155	SEWD	South Pond	04/24/2007	-11.0	-79.0	5.2E-03					
105157	SEWD	South Pond	04/24/2007	-11.2	-80.1	3.8E-03	101	7.6	296	20.7	8.1
105158	SEWD	South Pond	04/24/2007	-10.6	-78.5	3.5E-03					
105289	SEWD	South Pond	05/30/2007	-11.1	-82.9		91	7.2	294	22.6	6.5
105519	SEWD	South Pond	07/16/2007	-11.2	-80.4		100	8.3	248	25.3	11.2
104839	SEWD	South Pond	01/17/2007	-9.0	-63.2	1.6E-03	210	7.1	370	6.1	5.3
104302	SEWD	T-3	08/23/2006	-8.0	-61.8		729	6.8	340	19.1	7.1
105514	SEWD	T-3	07/16/2007	-8.7	-62.0	1.0E-02	804	7.3	288	19.2	7.3

Table A-3: SEWD Noble Gas and Tritium Data

LLNL ID	Site	ion	Sample Date	⁴ He (cc STP/g)	Ne (cc STP/g)	Ar (cc STP/g)	Kr (cc STP/g)	Xe (cc STP/g)	³ H pCi/L	+/-	³ He/ ⁴ He	+/-	Excess Air (cc STP/g)	+/-	Radiogenic ⁴ He (cc STP/g)	Radiogenic ⁴ He error (cc STP/g)	³ H- ³ He age (yr)	³ H- ³ He age error (yr)	Percent Premodern	Recharge Temp. from Xe (deg C)	Recharge Temp. from Xe error (deg C)
104267	SEWD	60ACRE	8/21/2006	5.97E-08	2.44E-07	3.42E-04	7.32E-08	9.55E-09	10.03	0.47	1.37E-06	1.03E-08	0.0028	0.0003	0.00E+00	1.23E-09	0.2	1.0	24%	21.0	1.1
104271	SEWD	74-01	8/21/2006	1.35E-07	4.90E-07	5.13E-04	9.63E-08	1.22E-08	11.81	0.52	1.63E-06	1.22E-08	0.0163	0.0005	4.52E-09	2.61E-09	30.1	1.7	84%	18.0	2.6
104265	SEWD	74-02	8/21/2006	1.60E-07	4.38E-07	4.99E-04	9.55E-08	1.20E-08	10.58	0.48	1.68E-06	1.26E-08	0.0134	0.0005	4.55E-08	2.47E-09	47.8	1.0	98%	17.5	2.2
104257	SEWD	A4	8/20/2006	9.76E-08	3.86E-07	4.54E-04	9.03E-08	1.14E-08	7.78	0.60	1.36E-06	1.02E-08	0.0106	0.0004	0.00E+00	2.02E-09	0.0	4.0	41%	18.3	1.9
104270	SEWD	BZ	8/21/2006	1.41E-07	5.11E-07	5.15E-04	9.71E-08	1.20E-08	8.24	0.45	1.47E-06	1.10E-08	0.0174	0.0006	4.79E-09	2.73E-09	25.1	2.0	82%	19.1	2.8
104300	SEWD	CN-1	8/22/2006	9.36E-08	3.73E-07	4.24E-04	8.48E-08	1.10E-08	10.61	0.48	1.44E-06	1.08E-08	0.0099	0.0004	0.00E+00	1.96E-09	9.6	1.0	27%	19.2	1.8
104301	SEWD	CWS-35	8/22/2006	9.95E-08	3.65E-07	4.37E-04	8.85E-08	1.12E-08	11.24	1.03	1.90E-06	1.42E-08	0.0094	0.0004	4.71E-09	1.90E-09	36.5	1.7	92%	18.2	1.7
104256	SEWD	MW-1A	8/20/2006	4.78E-08	2.08E-07	3.41E-04	7.37E-08	9.83E-09	10.79	0.52	1.36E-06	1.02E-08	0.0008	0.0002	0.00E+00	1.01E-09	0.0	1.0	18%	19.1	1.0
104255	SEWD	MW-1B	8/20/2006	1.00E-07	4.04E-07	4.56E-04	8.83E-08	1.10E-08	10.87	0.49	1.34E-06	1.01E-08	0.0117	0.0004	0.00E+00	2.14E-09	0.0	4.0	18%	21.2	2.2
104255	SEWD	MW-1B	8/20/2006	1.00E-07	4.04E-07	4.56E-04	8.83E-08	1.10E-08	10.50	1.00	1.36E-06	1.02E-08	0.0119	0.0004	0.00E+00	2.13E-09	0.0	3.0	20%	20.2	2.2
104254	SEWD	MW-1C	8/20/2006	8.92E-08	3.40E-07	3.77E-04	7.76E-08	1.03E-08	12.64	0.57	1.37E-06	1.03E-08	0.0083	0.0004	0.00E+00	1.79E-09	0.0	2.0	4%	20.9	1.7
104266	SEWD	MW-2A	8/21/2006	4.82E-08	3.38E-07	3.73E-04	7.43E-08	9.72E-09	11.26	0.56	1.38E-06	1.04E-08	0.0079	0.0004	0.00E+00	1.98E-09	0.3	2.0	14%	22.9	1.7
104260	SEWD	MW-2B	8/21/2006	5.61E-08	2.52E-07	3.69E-04	7.62E-08	1.07E-08	12.46	0.62	1.37E-06	1.03E-08	0.0032	0.0003	0.00E+00	1.26E-09	0.0	1.0	6%	17.2	1.1
104261	SEWD	MW-2C	8/21/2006	9.64E-08	4.09E-07	4.45E-04	8.69E-08	1.10E-08	10.42	0.50	1.39E-06	1.04E-08	0.0115	0.0005	0.00E+00	2.18E-09	2.6	2.0	19%	19.7	2.1
104263	SEWD	MW-3A	8/21/2006	6.92E-08	2.87E-07	3.37E-04	7.10E-08	9.36E-09	11.46	0.56	1.36E-06	1.02E-08	0.0051	0.0003	0.00E+00	1.50E-09	0.0	2.0	13%	22.9	1.4
104259	SEWD	MW-3B	8/21/2006	6.53E-08	2.65E-07	3.27E-04	6.83E-08	9.00E-09	11.49	0.65	1.39E-06	1.04E-08	0.0039	0.0003	0.00E+00	1.37E-09	1.9	1.0	11%	23.7	1.3
104258	SEWD	MW-3C	8/20/2006	5.84E-08	2.45E-07	3.31E-04	7.15E-08	9.53E-09	11.47	0.57	1.36E-06	1.02E-08	0.0030	0.0003	0.00E+00	1.25E-09	0.0	1.0	13%	21.2	1.1
104303	SEWD	MW-NW-1	8/22/2006	6.37E-08	2.76E-07	4.31E-04	9.09E-08	1.20E-08	9.41	0.45	1.37E-06	1.03E-08	0.0045	0.0003	0.00E+00	1.36E-09	-0.1	2.0	29%	bad fit	na
104303	SEWD	MW-NW-1	8/23/2006	6.37E-08	2.76E-07	4.31E-04	9.09E-08	1.20E-08	9.00	1.00	1.36E-06	1.02E-08	0.0095	0.0004	0.00E+00	1.85E-09	0.0	3.0	32%	bad fit	na
104264	SEWD	PZ-1	8/20/2006	4.75E-08	1.98E-07	2.86E-04	6.04E-08	7.93E-09	9.52	0.51	1.39E-06	1.04E-08	0.0002	0.0002	0.00E+00	9.95E-10	2.5	1.0	26%	bad fit	na
104264	SEWD	PZ-1	8/21/2006	4.75E-08	1.98E-07	2.86E-04	6.04E-08	7.93E-09	9.00	1.00	1.37E-06	1.02E-08	0.0017	0.0002	0.00E+00	1.12E-09	-0.4	1.0	32%	23.0	1.1
104302	SEWD	T-3	8/22/2006	7.50E-08	3.22E-07	4.14E-04	8.54E-08	1.13E-08	10.99	0.84	1.39E-06	1.05E-08	0.0070	0.0004	0.00E+00	1.66E-09	3.0	1.0	14%	17.0	1.4

Table A-4: SEWD Organic Data

LLNL ID	Site	Location	Sample Date	TOC (mg/L)	Dichloro methane (ng/L)	MtBE (ng/L)	Chloroform (ng/L)	1_2_Dichloro propane (ng/L)	Bromodichloro methane (ng/L)	Toluene (ng/L)	Tetrachloro ethene (ng/L)	Dibromochloro methane (ng/L)	Bromoform (ng/L)	DEET (ng/L)	Triclosan (ng/L)	Triphenyl phosphate (ng/L)	Norflurazon (ng/L)	Simazine (ng/L)
104267	SEWD	60Acre	08/22/2006	0.79	6	<5	1059	<5	59	<5	<5	<5	<5	ND	ND	ND	ND	46
104906	SEWD	60Acre	02/12/2007	NM	14	<5	1020	<5	43	<5	<5	<5	<5	NM	NM	NM	NM	NM
104976	SEWD	60Acre	03/13/2007	NM	9	<5	958	<5	83	<5	<5	<5	<5	NM	NM	NM	NM	NM
104271	SEWD	74-01	08/22/2006	0.12	11	10	1508	<5	185	<5	<5	8	<5	16	ND	ND	ND	18
105797	SEWD	74-01	08/22/2007	NM	22	14	1509	<5	176	<5	5	8	<5	NM	NM	NM	NM	NM
104265	SEWD	74-02	08/22/2006	0.40	26	11	1754	52	123	<5	9	18	6	ND	ND	15	ND	ND
105798	SEWD	74-02	08/22/2007	NM	21	9	940	54	92	8	8	22	15	NM	NM	NM	NM	NM
104257	SEWD	A4	08/21/2006	0.30	7	11	2287	60	211	<5	13	6	<5	ND	ND	ND	ND	ND
104270	SEWD	BZ	08/22/2006	0.28	14	73	1888	<5	139	<5	25	5	<5	ND	ND	ND	ND	ND
104300	SEWD	CN-1	08/23/2006	0.41	12	12	2850	6	270	<5	<5	9	<5	ND	ND	14	ND	ND
104301	SEWD	CWS-35	08/23/2006	0.32	<5	<5	1611	<5	1872	<5	10	1587	370	ND	ND	29	ND	36
104305	SEWD	Diversion Canal	08/23/2006	2.78	<5	<5	7	<5	<5	6	<5	<5	<5	ND	ND	ND	ND	35
104256	SEWD	MW-1A	08/21/2006	0.21	<5	<5	1431	<5	137	<5	<5	<5	<5	ND	ND	ND	ND	ND
104255	SEWD	MW-1B	08/21/2006	0.51	<5	<5	1235	<5	102	<5	<5	<5	<5	ND	ND	ND	ND	ND
104254	SEWD	MW-1C	08/21/2006	0.39	<5	<5	1215	<5	94	<5	<5	<5	<5	ND	ND	ND	ND	ND
105293	SEWD	MW-1C	05/30/2007	NM	11	<5	1010	<5	64	<5	<5	<5	<5	NM	NM	NM	NM	NM
104266	SEWD	MW-2A	08/22/2006	0.81	<5	<5	136	<5	<5	7	<5	<5	<5	ND	ND	ND	ND	ND
104260	SEWD	MW-2B	08/22/2006	1.23	<5	<5	131	<5	<5	5	<5	<5	<5	ND	ND	ND	ND	ND
104261	SEWD	MW-2C	08/22/2006	0.54	<5	<5	136	<5	7	7	<5	<5	<5	ND	ND	ND	ND	ND
105285	SEWD	MW-2C	05/30/2007	NM	11	<5	113	<5	<5	6	<5	<5	<5	NM	NM	NM	NM	NM
104263	SEWD	MW-3A	08/21/2006	0.85	<5	<5	478	<5	23	5	<5	<5	<5	ND	ND	ND	ND	56
104259	SEWD	MW-3B	08/21/2006	0.99	5	<5	417	<5	13	6	<5	<5	<5	ND	ND	ND	ND	66
104966	SEWD	MW-3B	03/13/2007	NM	9	<5	490	<5	13	<5	<5	<5	<5	NM	NM	NM	NM	NM
104258	SEWD	MW-3C	08/21/2006	0.88	<5	<5	690	<5	36	<5	<5	<5	<5	ND	ND	ND	ND	76
105294	SEWD	MW-3C	05/30/2007	NM	11	<5	734	<5	zzzzzzzz	<5	<5	<5	<5	NM	NM	NM	NM	NM
104303	SEWD	MW-NW-1	08/23/2006	0.81	<5	<5	21	<5	<5	<5	<5	<5	<5	ND	ND	ND	ND	55
104272	SEWD	North Pond (inflow)	08/22/2006	1.74	11	<5	2638	<5	126	<5	<5	8	<5	ND	ND	ND	ND	ND
104264	SEWD	PZ-1	08/21/2006	0.95	7	<5	372	<5	<5	7	<5	<5	<5	ND	ND	ND	ND	31
104944	SEWD	PZ-1	03/02/2007	NM	8	<5	777	<5	40	<5	<5	<5	<5	NM	NM	NM	NM	NM
104961	SEWD	PZ-1	03/13/2007	NM	9	<5	944	<5	74	<5	<5	<5	<5	NM	NM	NM	NM	NM
104840	SEWD	South Pond	01/17/2007	NM	12	5	1593	5	152	5	5	10	5	NM	NM	NM	NM	NM
104969	SEWD	South Pond	03/13/2007	NM	12	<5	3250	<5	417	<5	<5	31	<5	NM	NM	NM	NM	NM
104839	SEWD	South Pond	01/17/2007	NM	12	5	3278	5	405	8	5	27	5	NM	NM	NM	NM	NM
104302	SEWD	T-3	08/23/2006	0.53	8	45	1793	<5	75	<5	8	<5	<5	ND	ND	ND	ND	ND

Table A-5: Morada Water Quality Data

LLNL ID	Site	Location	Sample Date	Depth of well screen (ft)	Cl ⁻ (mg/L)	NO ₂ (mg/L)	SO ₄ (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	As (ug/L)	U (ug/L)	V (ug/L)	Chloroform (ng/L)	Dissolved CH ₄ (ccSTP/g)	Excess N ₂ (as equiv. mg/L NO ₃ -)	TIC (mg/L)	TOC (mg/L)	δ ¹³ C TIC (‰ VPDB)	² H pC/L	δ ¹⁵ N NO ₃ (‰ Air)	δ ¹⁸ O NO ₃ (‰ SMOW)	
104446	Morada	DB2 Pond (Culvert)	09/13/2006	surface	4.9	<0.4	7.0	6.4	2.0	5.9	10.2	2.1	0.48	11.4	13.1	2.54E-08	ND	9.04	3.87	-16.5				
104916	Morada	DB2 Pond (Culvert)	02/14/2007	surface	4.8	2.1	8.5	7.3	2.5	6.3	12.7	2.0	0.61	7.6	101.9								5.2	16.2
105382	Morada	DB2 Pond (Culvert)	06/12/2007	surface	15.7	< 0.4	31.9	20.4	7.3	16.4	37.8													
104440	Morada	CSW-24	09/13/2006	long screen	9.9	6.7	24.1	9.6	3.5	17.9	23.9	3.7	8.53	39.0		2.87E-08	4.1	57.36	0.59	-14.7	24.3	3.8	1.4	
104900	Morada	CSW-24	02/09/2007	long screen	8.8	6.2	24.2	19.1	6.6	37.0	49.5	3.7	7.00	33.4	7.6	2.38E-08	ND	49.53	0.10	-16.5	22.1	6.0	0.4	
104930	Morada	CSW-19	02/21/2007	long screen	12.9	10.0	33.0	16.9	4.7	22.2	46.9	4.5	5.80	37.5	8.6	1.88E-08	0.4		0.10			36.3		
104986	Morada	CSW-19	03/21/2007	long screen	12.1	9.3	31.2	17.3	5.1	20.7	45.2	5.3	5.27	32.5									4.7	0.4
105112	Morada	CSW-19	04/06/2007	long screen	10.6	3.8	14.7	11.3	2.8	9.7	24.8												3.5	0.1
105302	Morada	CSW-19	05/31/2007	long screen	16.4	8.0	25.6	19.6	4.9	18.4	41.2												4.4	0.4
104447	Morada	MW-Lysimeter-47'	09/14/2006	47	3.3	0.6	6.9	5.2	0.3	8.4	13.3		0.51	26.4				17.39	1.37					
104438	Morada	MW-220'	09/13/2006	220	5.1	13.1	15.3	12.8	3.0	33.1	23.3	2.9	3.25	28.4		1.76E-08	0.1	42.92	0.37	-14.9	41.2	3.1	3.1	
104913	Morada	MW-220'	02/14/2007	220	5.5	13.7	14.6	12.6	3.1	21.3	29.3	3.7	2.88	35.4	8.3	1.38E-08	2.7	41.11	0.10	-15.7	46.8	4.1	1.7	
105099	Morada	MW-220'	03/28/2007	220	3.1	7.9	9.9	8.4	2.0	10.8	23.6	3.7	3.10	35.6									3.7	-0.6
105380	Morada	MW-220'	06/12/2007	220	5.7	14.1	17.5	15.1	3.5	18.7	36.9												3.9	0.3
104443	Morada	MW-300'	09/13/2006	300	7.7	8.4	28.9	15.4	4.7	31.8	21.1	3.8	4.50	34.9		2.22E-08	3.7	46.34	0.55	-15.0	47.8	0.4	4.0	
104914	Morada	MW-300'	02/14/2007	300	10.3	8.5	29.7	11.2	3.6	21.1	29.4	3.8	4.90	34.6		1.55E-08	ND	46.85	0.10	-15.6	43.6	4.2	0.6	
105098	Morada	MW-300'	03/28/2007	300	5.8	5.7	21.4	10.3	3.3	14.8	30.9	3.8	5.20	35.0									5.5	-0.6
105379	Morada	MW-300'	06/12/2007	300	6.5	9.1	27.5	16.1	4.9	21.9	41.6												4.3	0.4
104442	Morada	MW-540'	09/13/2006	540	4.6	<0.4	5.2	36.1	3.3	5.4	9.1	14.4	0.03	0.9		2.47E-08	1.0	22.70		-16.0	0.1			
104915	Morada	MW-540'	02/14/2007	540	5.1	< 0.4	6.7	25.5	3.7	7.4	11.2	14.1	0.05	1.3		2.39E-08	ND	22.84	0.10	-16.5	1.0			
105097	Morada	MW-540'	03/27/2007	540	3.4	< 0.4	4.4	16.7	2.4	3.4	8.2	14.4	0.02	0.8										
105378	Morada	MW-540'	06/12/2007	540	5.7	< 0.4	8.8	25.8	3.7	5.6	12.1													
104441	Morada	MW-635'	09/13/2006	635	10.1	<0.4	<0.4	118.0	3.6	1.1	1.9	26.6	<0.01	0.2		2.30E-06	15.6	42.20	0.41	-15.8	-0.2			
105096	Morada	MW-635'	03/27/2007	635	7.0	< 0.4	< 0.1	42.8	2.5	0.9	2.0	26.6	0.01	0.5										
105377	Morada	MW-635'	06/12/2007	635	11.9	< 0.4	< 0.4	74.9	4.8	1.8	4.0													
104444	Morada	MW-114'	09/14/2006	114	3.4	<0.4	5.5	9.4	1.4	10.8	14.6	6.8	0.27	48.4	71.4	7.14E-07	2.9	17.35	1.30	-14.0	10.4			
104877	Morada	MW-114'	02/02/2007	114	6.5	< 0.1	7.2	6.3	1.0	4.8	11.8	6.1	0.46	40.5	21.0	2.07E-06	ND	23.19	0.55	-13.2				
104901	Morada	MW-114'	02/09/2007	114	4.1	< 0.1	4.7	10.8	1.7	13.4	19.1	6.0	0.47	41.0										
105111	Morada	MW-114'	03/29/2007	114	3.8	< 0.4	4.4	7.0	1.0	6.7	14.8													
105381	Morada	MW-114'	06/12/2007	114	5.5	< 0.4	7.0	10.1	1.5	10.2	21.0													

Table A-6: Morada Tracer Data

LLNL ID	Sample Date	Site	Location	$\delta^{18}\text{O H}_2\text{O}$ (‰ VSMOW)	$\delta^2\text{H H}_2\text{O}$ (‰ VSMOW)	SF6 (ppb in headspace)	Conductivity ($\mu\text{S}/\text{cm}$)	pH	ORP	Temperature (°C)	DO (mg/L)
104439	09/14/2006	Morada Lane	Morada Canal	-10.9	-75.4		128	6.94	239	19.5	11.5
104454	10/04/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-10.4	-73.9	33.16					
104508	10/05/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-10.8	-75.3	1.00					
104510	10/06/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-10.6	-76.1	3.09	76	6.34	252	16.7	10.6
104554	10/10/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-11.2	-77.8	7.63				21.4	
104574	10/11/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-11.2	-77.6	7.47				20.5	
105560	10/12/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-11.2	-79.7	11.29				22.9	
104568	10/19/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-10.8	-77.7	3.87	239	8.31	206	20.7	8.8
104543	10/23/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-10.5	-76.6	2.91	230	8.79	275	21.1	10.0
104623	10/26/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-10.8	-75.0	2.51	172	8.25	236	19.7	9.2
104629	10/31/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-10.2	-73.9	0.89				16.2	
104647	11/06/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-9.7	-72.0	0.65	244	8.31	289	21.4	7.1
104659	11/14/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-7.6	-53.7	0.11	305	7.74	144	17.8	8.6
104674	11/20/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-10.0	-72.6		305	7.9	249	17.1	10.2
104681	11/27/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-8.3	-56.3	ND	361	7.53	281	17.1	8.2
104730	12/12/2006	Morada Lane	DB2 Pond (Bubbler at culvert)	-7.4	-50.8	ND	172	7.11	338	11.0	8.5
104836	01/12/2007	Morada Lane	DB2 Pond (Bubbler at culvert)	-9.2	-68.6	ND	328	8.62	224	11.5	6.1
104873	01/30/2007	Morada Lane	DB2 Pond (Bubbler at culvert)	-6.4	-44.6	ND	210	10.01	196	15.8	16.1
104916	02/14/2007	Morada Lane	DB2 Pond (Bubbler at culvert)	-6.4	-43.5	ND	183	8.64	272	13.8	9.1
104511	10/06/2006	Morada Lane	DB2 Pond (East bank)	-10.6	-75.8		177	7.39	185	20.0	9.2
104456	10/04/2006	Morada Lane	DB2 Pond (Northwest corner)			3.23					
104512	10/06/2006	Morada Lane	DB2 Pond (Northwest corner)	-10.6	-78.2	3.76	181	7.51	183	19.9	9.7
104553	10/10/2006	Morada Lane	DB2 Pond (Northwest corner)	-11.0	-78.7	7.81				20.4	
104575	10/11/2006	Morada Lane	DB2 Pond (Northwest corner)	-11.2	-78.4	6.11				20.9	
105559	10/12/2006	Morada Lane	DB2 Pond (Northwest corner)	-11.2	-79.0	6.29				22.3	
104565	10/19/2006	Morada Lane	DB2 Pond (Northwest corner)	-10.8	-79.5	3.20	220	8.74	205	21.4	9.9
104544	10/23/2006	Morada Lane	DB2 Pond (Northwest corner)	-10.8	-77.2	3.09	190	8.85	265	21.4	10.0
104624	10/26/2006	Morada Lane	DB2 Pond (Northwest corner)	-10.7	-77.7	2.45	175	8.54	217	20.2	9.7
104646	11/06/2006	Morada Lane	DB2 Pond (Northwest corner)	-9.8	-69.9	0.94	202	7.79	324	20.6	6.7
104658	11/14/2006	Morada Lane	DB2 Pond (Northwest corner)	-8.0	-52.3	0.21	202	7.24	154	16.0	8.8
104673	11/20/2006	Morada Lane	DB2 Pond (Northwest corner)	-7.9	-54.5		183	8.19	256	15.4	11.2
104682	11/27/2006	Morada Lane	DB2 Pond (Northwest corner)	-7.6	-52.8	0.03	255	8.13	265	15.2	11.9
104731	12/12/2006	Morada Lane	DB2 Pond (Northwest corner)	-7.3	-49.7	ND	175	7.15	342	11.0	8.9
104837	01/12/2007	Morada Lane	DB2 Pond (Northwest corner)	-6.3	-42.2	ND	159	9.27	219	8.1	6.5
104871	01/30/2007	Morada Lane	DB2 Pond (Northwest corner)	-6.8	-47.1	ND	256	9.64	224	15.5	18.5
104446	09/13/2006	Morada Lane	DB2 Pond (Ramp)	-10.4	-70.0		202	8.9	123	26.6	18.6
104455	10/04/2006	Morada Lane	DB2 Pond (Ramp)	-11.1							
104509	10/05/2006	Morada Lane	DB2 Pond (Ramp)	-10.6	-75.6	0.27					
104514	10/06/2006	Morada Lane	DB2 Pond (Ramp)	-10.6	-77.8	1.64					
104555	10/10/2006	Morada Lane	DB2 Pond (Ramp)	-11.1	-79.4	5.41				20.3	
104573	10/11/2006	Morada Lane	DB2 Pond (Ramp)	-11.1	-81.4	6.02				21.0	
105561	10/12/2006	Morada Lane	DB2 Pond (Ramp)	-11.2	-80.9	10.66				23.9	
104567	10/19/2006	Morada Lane	DB2 Pond (Ramp)	-11.0	-79.5	4.41	149	8.29	200	20.1	9.3

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LLNL ID	Sample Date	Site	Location	$\delta^{18}\text{O H}_2\text{O}$ (‰ VSMOW)	$\delta^2\text{H H}_2\text{O}$ (‰ VSMOW)	SF6 (ppb in headspace)	Conductivity ($\mu\text{S/cm}$)	pH	ORP	Temperature (°C)	DO (mg/L)
104542	10/23/2006	Morada Lane	DB2 Pond (Ramp)	-10.5	-77.1	3.03	227	8.78	280	21.1	9.7
104622	10/26/2006	Morada Lane	DB2 Pond (Ramp)	-10.9	-76.6	2.40	171	8.04	244	19.3	8.8
105382	06/12/2007	Morada Lane	DB2 Pond (South bank)	-7.2	-58.9						
104453	10/03/2006	Morada Lane	DB2 Pond (Surface)	-10.5	-77.0	ND					
104457	10/04/2006	Morada Lane	DB2 Pond (Surface)			0.01					
104513	10/06/2006	Morada Lane	DB2 Pond (West bank)	-10.7	-76.7	5.13	177	7.84	178	20.4	9.8
104552	10/10/2006	Morada Lane	DB2 Pond (West bank)	-11.0	-80.2	7.34				20.2	
104576	10/11/2006	Morada Lane	DB2 Pond (West bank)	-11.1	-77.3	7.24				21.2	
105558	10/12/2006	Morada Lane	DB2 Pond (West bank)	-11.3	-79.9	5.77				21.2	
104566	10/19/2006	Morada Lane	DB2 Pond (West bank)	-11.0	-79.5	4.19	144	8.99	196	21.1	11.0
104541	10/23/2006	Morada Lane	DB2 Pond (West bank)	-10.8	-78.7	3.41	169	8.96	289	20.2	10.3
104621	10/26/2006	Morada Lane	DB2 Pond (West bank)	-10.8	-77.4	2.79	167	8.08	245	19.0	9.8
104447	09/14/2006	Morada Lane	MW-Lysimeter-47'	-9.1	-65.0		202	8.9	123	26.6	18.6
104571	10/16/2006	Morada Lane	MW-Lysimeter-47'			ND					
104610	10/19/2006	Morada Lane	MW-Lysimeter-47'			ND					
104609	10/19/2006	Morada Lane	MW-Lysimeter-47'			ND					
104546	10/23/2006	Morada Lane	MW-Lysimeter-47'			ND					
104545	10/23/2006	Morada Lane	MW-Lysimeter-47'			ND					
104628	10/26/2006	Morada Lane	MW-Lysimeter-47'			ND					
104627	10/26/2006	Morada Lane	MW-Lysimeter-47'			ND					
104640	10/31/2006	Morada Lane	MW-Lysimeter-47'			ND					
104639	10/31/2006	Morada Lane	MW-Lysimeter-47'			ND					
104651	11/06/2006	Morada Lane	MW-Lysimeter-47'								
104650	11/06/2006	Morada Lane	MW-Lysimeter-47'								
104665	11/14/2006	Morada Lane	MW-Lysimeter-47'								
104664	11/14/2006	Morada Lane	MW-Lysimeter-47'								
104680	11/20/2006	Morada Lane	MW-Lysimeter-47'			ND					
104679	11/20/2006	Morada Lane	MW-Lysimeter-47'			ND					
104688	11/27/2006	Morada Lane	MW-Lysimeter-47'			ND					
104687	11/27/2006	Morada Lane	MW-Lysimeter-47'								
104444	09/14/2006	Morada Lane	MW-114'	-9.6	-68.9		184	7.66	-44.6	21.2	0.1
104515	10/06/2006	Morada Lane	MW-114'	-9.1	-64.8	ND					
105556	10/10/2006	Morada Lane	MW-114'	-9.0	-61.5	ND					
105563	10/12/2006	Morada Lane	MW-114'	-9.1	-63.6	ND					
104569	10/16/2006	Morada Lane	MW-114'	-9.0	-61.7	ND					
104607	10/19/2006	Morada Lane	MW-114'	-8.8	-59.8	ND					
104626	10/26/2006	Morada Lane	MW-114'	-8.6	-58.5	ND					
104637	10/31/2006	Morada Lane	MW-114'	-8.6	-59.7	ND					
104649	11/06/2006	Morada Lane	MW-114'	-8.4	-58.2	ND					
104661	11/14/2006	Morada Lane	MW-114'	-8.3	-58.0	ND					
104663	11/14/2006	Morada Lane	MW-114'			ND					
104677	11/20/2006	Morada Lane	MW-114'			ND					
104678	11/20/2006	Morada Lane	MW-114'	-8.2	-55.4	ND					

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LLNL ID	Sample Date	Site	Location	$\delta^{18}\text{O H}_2\text{O}$ (‰ VSMOW)	$\delta^2\text{H H}_2\text{O}$ (‰ VSMOW)	SF6 (ppb in headspace)	Conductivity ($\mu\text{S}/\text{cm}$)	pH	ORP	Temperature (°C)	DO (mg/L)
104685	11/27/2006	Morada Lane	MW-114'	-8.0	-55.7	ND					
104686	11/27/2006	Morada Lane	MW-114'	-8.1	-54.3	ND					
104737	12/13/2006	Morada Lane	MW-114'	-7.9	-55.2	ND					
104838	01/12/2007	Morada Lane	MW-114'	-7.8	-57.4	ND	280	7.82	180	17.6	0.3
104872	01/30/2007	Morada Lane	MW-114'	-7.7	-54.1	22.12	308	7.7	211	18.9	0.0
104877	02/02/2007	Morada Lane	MW-114'	-7.7	-52.5	ND	310	7.69	188	19.5	0.0
104901	02/09/2007	Morada Lane	MW-114'	-7.6	-55.0	ND	317	7.77	241	18.1	
104931	02/21/2007	Morada Lane	MW-114'	-7.8	-54.6	0.04	303		243	18.3	0.0
105111	03/29/2007	Morada Lane	MW-114'	-8.1	-56.2						
105180	05/03/2007	Morada Lane	MW-114'	-8.1	-56.6	0.53	316	7.64	194	18.7	0.0
105381	06/12/2007	Morada Lane	MW-114'	-8.2	-58.0	0.56	336	7.13	98	19.1	0.8
104438	09/13/2006	Morada Lane	MW-220'	-9.9	-73.5		345	7.54	4.6	20.3	2.4
104548	10/06/2006	Morada Lane	MW-220'			0.01					
105557	10/10/2006	Morada Lane	MW-220'	-9.8	-72.5	ND					
104564	10/12/2006	Morada Lane	MW-220'	-9.8	-72.6	ND					
104570	10/16/2006	Morada Lane	MW-220'	-9.8	-74.7	ND					
104608	10/19/2006	Morada Lane	MW-220'	-9.8	-71.4	ND					
104625	10/26/2006	Morada Lane	MW-220'	-9.7	-73.2	ND					
104638	10/31/2006	Morada Lane	MW-220'	-9.9	-73.2	ND					
104648	11/06/2006	Morada Lane	MW-220'	-9.9	-74.1	ND					
104660	11/14/2006	Morada Lane	MW-220'	-9.8	-73.5	ND					
104662	11/14/2006	Morada Lane	MW-220'			ND					
104675	11/20/2006	Morada Lane	MW-220'			ND					
104676	11/20/2006	Morada Lane	MW-220'	-9.8	-72.1	ND					
104683	11/27/2006	Morada Lane	MW-220'	-9.8	-73.1	ND					
104684	11/27/2006	Morada Lane	MW-220'	-9.8	-73.6	ND					
104736	12/12/2006	Morada Lane	MW-220'	-9.8	-74.0	ND					
104843	01/19/2007	Morada Lane	MW-220'	-9.7	-71.7	12.23	550	7.32	124	19.8	0.0
104870	01/30/2007	Morada Lane	MW-220'	-9.8	-72.3	23.41	563	7.48	321	19.6	1.0
104875	02/02/2007	Morada Lane	MW-220'	-9.9	-72.5	32.63	568	7.52	313	19.9	1.1
104913	02/14/2007	Morada Lane	MW-220'	-9.8	-71.4	ND	548	7.52	380	20.1	0.9
104932	02/21/2007	Morada Lane	MW-220'	-9.7	-70.1	ND	582	7.61	328	19.8	1.3
105099	03/28/2007	Morada Lane	MW-220'	-9.8	-74.1	ND					
105179	05/03/2007	Morada Lane	MW-220'	-9.8	-71.0	0.06	562	7.46	336	20.6	2.6
105380	06/12/2007	Morada Lane	MW-220'	-9.8	-69.9	ND	583	7.03	144	20.7	3.2
104443	09/13/2006	Morada Lane	MW-300'	-9.8	-72.5		412	7.45	-10.5	20.5	2.9
105562	10/12/2006	Morada Lane	MW-300'	-9.7	-71.3	ND					
104734	12/12/2006	Morada Lane	MW-300'	-9.8	-70.7	ND					
104876	02/02/2007	Morada Lane	MW-300'	-9.8	-71.4	17.91	653	7.46	299	20.0	1.8
104914	02/14/2007	Morada Lane	MW-300'	-9.6	-71.9	ND	648	7.36	356	20.5	1.4
104933	02/21/2007	Morada Lane	MW-300'	-9.6	-69.5	ND	642	7.43	350	19.6	1.4
105098	03/28/2007	Morada Lane	MW-300'	-9.7	-70.6	ND					
105178	05/03/2007	Morada Lane	MW-300'	-9.8	-79.6	0.06	651	7.41	339	20.8	3.4

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LLNL ID	Sample Date	Site	Location	$\delta^{18}\text{O H}_2\text{O}$ (‰ VSMOW)	$\delta^2\text{H H}_2\text{O}$ (‰ VSMOW)	SF6 (ppb in headspace)	Conductivity ($\mu\text{S}/\text{cm}$)	pH	ORP	Temperature (°C)	DO (mg/L)
105379	06/12/2007	Morada Lane	MW-300'	-9.8	-73.5	ND	631	7.06	167	20.6	3.5
104442	09/13/2006	Morada Lane	MW-540'	-8.9	-62.6		211	7.94	-93.6	22.5	0.1
104733	12/11/2006	Morada Lane	MW-540'	-9.0	-61.5	ND					
104915	02/14/2007	Morada Lane	MW-540'	-8.8	-62.1	ND	300	7.53	323	21.1	0.0
104934	02/21/2007	Morada Lane	MW-540'	-9.1	-65.3	ND	295	7.8	321		
105097	03/27/2007	Morada Lane	MW-540'	-9.0	-61.2	0.01					
105177	05/03/2007	Morada Lane	MW-540'	-9.0	-61.0	0.08	308	7.84	283	21.6	0.3
105378	06/12/2007	Morada Lane	MW-540'	-9.0	-62.3	ND	328	7.52	123	20.6	0.4
104441	09/13/2006	Morada Lane	MW-635'	-8.8	-60.6		344	8.09	-114.9	22.2	0.1
104732	12/11/2006	Morada Lane	MW-635'	-8.9	-61.0	ND					
104835	01/12/2007	Morada Lane	MW-635'	-8.9	-62.0	ND	478	8.02	-39	19.9	0.5
105096	03/27/2007	Morada Lane	MW-635'	-8.9	-64.6	ND					
105377	06/12/2007	Morada Lane	MW-635'	-9.0	-51.6	ND	524	7.78	-187	20.7	0.3
104930	02/21/2007	Morada Lane	CSW-19	-8.9	-63.2	ND	649	7.44	407	18.0	2.7
104986	03/21/2007	Morada Lane	CSW-19	-9.0	-63.7	0.71	664	7.35	333	19.9	3.1
105112	04/06/2007	Morada Lane	CSW-19	-9.1	-62.8		602	7.41	340	20.4	2.5
105176	05/03/2007	Morada Lane	CSW-19	-9.0	-63.8	0.15	625	7.5	372	19.8	2.3
105302	05/31/2007	Morada Lane	CSW-19	-9.1	-63.1	ND					
104440	09/13/2006	Morada Lane	CSW-24	-9.2	-65.5		760	6.88	179	20.1	5.2
104645	11/06/2006	Morada Lane	CSW-24	-9.3	-67.8	ND	751	7.54	315	19.8	4.8
104735	12/13/2006	Morada Lane	CSW-24	-9.3	-68.1	ND	732	7.53	343	19.3	6.2
104842	01/19/2007	Morada Lane	CSW-24	-9.2	-66.4	ND	760	7.4	138	18.7	1.8
104869	01/30/2007	Morada Lane	CSW-24	-9.2	-66.3	10.50	727	7.5	324	19.2	4.7
104874	02/02/2007	Morada Lane	CSW-24	-9.2	-65.6	9.71	734	7.35	330	19.2	1.8
104900	02/09/2007	Morada Lane	CSW-24	-9.2	-70.0	7.22	744	7.44	288	19.3	
105423	06/19/2007	Morada Lane	CSW-24-surface	-9.4	-65.1	ND					
105424	06/19/2007	Morada Lane	CSW-24-315'	-9.3	-67.4	ND					
105425	06/19/2007	Morada Lane	CSW-24-350'			ND					
105426	06/20/2007	Morada Lane	CSW-24-420'			ND					
105427	06/20/2007	Morada Lane	CSW-24-450'			ND					
105428	06/20/2007	Morada Lane	CSW-24-481'	-9.4	-67.6	ND					

Table A-7: Morada Noble Gas and Tritium Data

LLNL ID	Site	Location	Sample Date	⁴ He (cc STP/g)	Ne (cc STP/g)	Ar (cc STP/g)	Kr (cc STP/g)	Xe (cc STP/g)	³ H pCi/L	+/-	³ He/ ⁴ He	+/-	Excess Air (cc STP/g)	+/-	Radiogenic ⁴ He (cc STP/g)	Radiogenic ⁴ He error (cc STP/g)	³ H- ³ He age (yr)	³ H- ³ He age error (yr)	Percent Premodern	Recharge Temp. from Xe (deg C)	Recharge Temp. from Xe error (deg C)
104444	Morada	MW-114'	09/14/06	5.82E-08	2.31E-07	3.70E-04	8.28E-08	1.12E-08	10.38	0.48	1.38E-06	1.04E-08	0.0020	0.0003	1.91E-09	1.13E-09	1.7	0.2	21%	15.5	1.0
104877	Morada	MW-114'	02/02/07	6.10E-08	2.69E-07	3.47E-04	7.51E-08	9.89E-09	10.00	0.50	1.37E-06	1.03E-08	0.0042	0.0003	0.00E+00	1.39E-09	-0.4	1.0	25%	20.6	1.2
104737	Morada	MW-114'	12/13/06	5.96E-08	2.50E-07	3.50E-04	7.59E-08	1.03E-08	10.12	0.50	1.36E-06	1.02E-08	0.0031	0.0003	0.00E+00	1.26E-09	0.0	1.0	25%	18.6	1.1
104438	Morada	MW-220'	09/13/06	7.75E-08	3.54E-07	4.03E-04	7.86E-08	1.01E-08	44.68	1.50	4.95E-06	3.71E-08	0.0091	0.0004	0.00E+00	1.88E-09	39.3	0.6	77%	22.3	1.9
104736	Morada	MW-220'	12/12/07						36.70	0.50											
104913	Morada	MW-220'	02/14/07						46.79	1.73											
104736	Morada	MW-220'	12/12/07						38.45	1.47											
104443	Morada	MW-300'	09/13/06						48.75	1.81											
104443	Morada	MW-300'	09/13/06	9.51E-08	3.95E-07	4.81E-04	9.77E-08	1.19E-08	47.00	2.00	4.60E-06	3.45E-08	0.0109	0.0004	0.00E+00	2.05E-09	40.1	0.7	78%	16.7	1.8
104734	Morada	MW-300'	12/12/06	8.20E-08	3.40E-07	4.20E-04	8.28E-08	1.11E-08	51.26	0.50	5.42E-06	4.06E-08	0.0083	0.0004	0.00E+00	1.76E-09	40.0	0.2	75%	18.4	1.6
104914	Morada	MW-300'	02/14/07						63.24	2.83											
104914	Morada	MW-300'	02/14/07						62.77	2.48											
104442	Morada	MW-540'	09/13/06	1.92E-07	2.48E-07	3.74E-04	8.00E-08	1.14E-08	0.06	0.12	1.57E-06	1.18E-08	0.0030	0.0003	1.30E-07	2.88E-09	>50		100%	15.2	1.0
104915	Morada	MW-540'	02/14/07						1.01	0.26											
104441	Morada	MW-635'	09/13/06	1.03E-06	2.21E-07	4.27E-04	8.11E-08	1.11E-08	0.00	0.12	1.15E-06	8.60E-09	0.0013	0.0002	9.75E-07	1.95E-08	>50		100%	bad fit	na
104930	Morada	CSW-19	02/22/07	7.01E-08	2.91E-07	3.91E-04	8.47E-08	1.13E-08	60.25	2.31	3.38E-06	2.54E-08	0.0052	0.0003	0.00E+00	1.48E-09	24.8	0.5	bad fit	16.3	1.2
104440	Morada	CSW-24	09/13/06	7.58E-08	3.68E-07	4.26E-04	8.58E-08	1.11E-08	25.16	1.02	3.68E-06	2.76E-08	0.0094	0.0004	0.00E+00	1.97E-09	41.1	0.7	89%	18.8	1.8
104900	Morada	CSW-24	02/09/07	7.59E-08	3.03E-07	4.12E-04	8.37E-08	1.09E-08	44.87	1.89	3.43E-06	2.57E-08	0.0059	0.0003	0.00E+00	1.54E-09	30.4	0.6	43%	17.8	1.3
104900	Morada	CSW-24	02/09/07	7.47E-08	3.15E-07	4.03E-04	8.56E-08	1.07E-08	42.78	1.73	3.43E-06	2.57E-08	0.0065	0.0003	0.00E+00	1.62E-09	30.9	0.6	48%	18.9	1.4

Table A-8: Morada Organic Data

LLNL ID	Sample Date	Site	Location	TOC (mg/L)	Dichloro methane (ng/L)	MIBE (ng/L)	Chloroform (ng/L)	1,2-Dichloro propane (ng/L)	Bromo dichloro methane (ng/L)	Toluene (ng/L)	Tetrachloro ethene (ng/L)	Dibromo chloro methane (ng/L)	Bromoform (ng/L)	DEET (ng/L)	Triclosan (ng/L)	Triphenyl phosphate (ng/L)	Norflurazon (ng/L)	Simazine (ng/L)
104439	09/14/2006	Morada	Canal	2.2	11	<5	<5	<5	<5	<5	<5	<5	<5	ND	ND	ND	ND	14
104916	02/14/2007	Morada	DB2 Pond (Bubbler at culvert)	NM	12	<5	102	<5	6	16	<5	<5	<5	NM	NM	NM	NM	NM
104446	09/13/2006	Morada	DB Pond (Ramp)	3.5	13	<5	13	<5	<5	12	<5	<5	<5	34	ND	ND	ND	ND
104444	09/14/2006	Morada	MW-114'	1.2	20	<5	71	<5	<5	19	<5	<5	<5	71	ND	66	ND	ND
104877	02/02/2007	Morada	MW-114'	NM	17	<5	21	<5	<5	<5	<5	<5	<5	NM	NM	NM	NM	NM
104438	09/13/2006	Morada	MW-220'	0.4	12	<5	<5	<5	<5	13	<5	<5	<5	24	ND	49	ND	ND
104913	02/14/2007	Morada	MW-220'	NM	9	<5	8	<5	<5	<5	<5	<5	<5	NM	NM	NM	NM	NM
104443	09/13/2006	Morada	MW-300'	0.5	9	<5	<5	<5	6	<5	<5	<5	<5	20	ND	51	ND	ND
104914	02/14/2007	Morada	MW-300'	NM	10	<5	<5	<5	<5	<5	<5	<5	<5	NM	NM	NM	NM	NM
104442	09/13/2006	Morada	MW-540'	0.2	9	<5	<5	<5	29	<5	<5	<5	<5	31	ND	49	ND	ND
104915	02/14/2007	Morada	MW-540'	NM	10	<5	<5	<5	<5	<5	<5	<5	<5	NM	NM	NM	NM	NM
104441	09/13/2006	Morada	MW-635'	0.4	9	<5	<5	<5	9	<5	<5	<5	<5	68	ND	76	ND	ND
104930	02/21/2007	Morada	CSW-19	NM	12	<5	9	13	<5	<5	<5	<5	<5	NM	NM	NM	NM	NM
104440	09/13/2006	Morada	CSW-24	0.7	14	<5	<5	<5	<5	<5	<5	<5	<5	ND	ND	ND	ND	ND
104900	02/09/2007	Morada	CSW-24	NM	11	<5	8	<5	<5	<5	<5	<5	<5	NM	NM	NM	NM	NM