Revised

Contaminant Flow and Transport Modeling Report
Beaumont Site 2
Lockheed Martin Corporation
Beaumont, California

Prepared for:

LOCKHEED MARTIN

Prepared by:

TETRA TECH
301 E. Vanderbilt, Suite 450
San Bernardino, California 92408
TC# 23522-0706 / July 2011

Lockheed Martin Enterprise Business Services
Energy, Environment, Safety and Health
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LOCKHEED MARTIN

July 7, 2011

Mr. Daniel Zogaib
Southern California Cleanup Operations
Department of Toxic Substances Control
5796 Corporate Avenue
Cypress, CA 90630

Subject: Submittal of the Revised *Groundwater Flow and Contaminant Transport Modeling Report, Beaumont Site 2, Lockheed Martin Corporation, Beaumont, California*

Dear Mr. Zogaib:

Please find enclosed one hard copy of the body of the report and two CDs of the report and appendices of the Revised *Groundwater Flow and Contaminant Transport Modeling Report, Beaumont Site 2, Lockheed Martin Corporation, Beaumont, California* revised in compliance with responses to comments approved by DTSC on June 14, 2011.

If you have any questions regarding this submittal or would be interested in a conference call to discuss the document prior to providing us with comments, please feel free to contact me at 818-847-9901 or brian.thorne@lmco.com.

Sincerely,

Brian Thorne

Brian Thorne
Project Manager, Beaumont

Enclosures

Copy with Enc:
- Gene Matsushita, LMC (1 pdf and 1 hard copy)
- Sally Drinkard, Camp, Dresser, McKee (1 pdf)
- Thomas J . Villeneuve, Tetra Tech, Inc. (1 pdf and 1 hard copy)
- Hans Kernkamp, Riverside County Waste Management Department (1 pdf)
- Alan Bick, Gibson Dunn (1 pdf)

BUR119 Trans – Beaumont 2 Revised Contaminant Flow and Transport Modeling Report

Department of Toxic Substances Control

Linda S. Adams
Acting Secretary for
Environmental Protection

Leonard E. Robinson
Acting Director
5796 Corporate Avenue
Cypress, California 90630

Edmund G. Brown Jr.
Governor

May 3, 2011

Ms. Denise Kato
Remediation Analyst Senior Staff
Lockheed Martin Corporation
Energy, Environment, Safety & Health
2950 North Hollywood Way, Suite 125
Burbank, California 91505

CONTAMINANT FLOW AND TRANSPORT MODELING REPORT, LOCKHEED MARTIN CORPORATION, BEAUMONT SITE 2, BEAUMONT, CALIFORNIA (Site Code: 400261)

Dear Ms. Kato:

The Department of Toxic Substances Control (DTSC) has reviewed the subject document. Enclosed are comments from DTSC's Geologic Services Unit (GSU).

Please address the enclosed comments by June 3, 2011.

Should you have any questions or comments, please contact me at (714) 484-5483.

Sincerely,

Daniel K. Zogaib
Project Manager
Brownfields and Environmental Restoration Program

Enclosure

cc: See next page.

cc: Mr. Gene Matsushita
Senior Manager
Environmental Remediation
Lockheed Martin Corporation
Energy, Environment, Safety & Health
2950 North Hollywood Way, Suite 125
Burbank, California 91505

Linda S. Adams
Acting Secretary for
Environmental Protection

Department of Toxic Substances Control

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Governor

MEMORANDUM

TO: Daniel Zogaib
Hazardous Substances Engineer
Cleanup Program

FROM: Dina Kourda, CEG dk
Engineering Geologist
Geologic Services Unit (GSU)

DATE: March 14, 2011 – **(Finalized May 2, 2011)**

SUBJECT: CONTAMINANT FLOW AND TRANSPORT MODELING REPORT, BEAUMONT SITE 2, CALIFORNIA, DATED JANUARY 21, 2011

PCA: 11050 SITE CODE: 400261-00 TRACKING #: 1040313

At the request of DTSC Project Manager, Mr. Daniel Zogaib, the Geologic Services Unit (GSU) has reviewed the subject document received on February 16, 2011 for Lockheed Martin Corporation (LMC), Site 2 in Beaumont.

BACKGROUND

On behalf of Lockheed Martin Corporation (LMC), Tetra Tech, Inc. (Tetra Tech) prepared the subject document, for LMC's former Beaumont Site 2 (Jack Rabbit Trail) facility (the "Site"). The Site is a 2,668-acre parcel located southwest of the city of Beaumont in San Bernardino County, California. Grand Central Rocket Company (GCR) purchased the site from the US Government in 1958. The Site was utilized for small rocket motor assembly, testing operations, propellant incineration, and minor disposal activities from 1958 to 1974, when Site closure took place under Lockheed.

According to Tetra Tech, chemicals of concern (COCs) include the following six: perchlorate, trichloroethene (TCE), methylene chloride, bis-(2-ethylhexyl) phthalate, Royal Demolition Explosives (RDX), and arsenic. Arsenic and bis-(2-ethylhexyl) phthalate were also identified, however, arsenic is a likely related to naturally-occurring background and bis-(2-ethylhexyl) phthalate is likely a laboratory contaminant, according to Tetra Tech. Perchlorate has been identified as the primary COC. TCE, methylene chloride, and RDX are considered secondary COCs.

The numerical groundwater transport model was calibrated using data from the Fall of 2006 through Fall 2010 and includes groundwater and perchlorate max flux budget. Due to the considerable uncertainty of the site groundwater conceptual site model (CSM), it is recommended that future data collection and modeling efforts be incorporated in the Feasibility Study. It is also recommended that additional groundwater pumping tests be conducted at the site and supplemental data be collected in the riparian area.

GSU conducted a critical flaw review of the subject document. Any estimated aquifer properties or specifics for hydraulic testing should be reviewed by an expert in this field of study such as an engineer or hydrogeologist who specializes in modeling.

SPECIFIC COMMENTS

1. Table 3-2: Each line in the Notes at the bottom of the table is cut off. The table should be revised accordingly.

2. Table 3-3: Calculations, explanations, and/or rationales should be provided for the determination of the trend in the statistical analysis for each well.

3. Section 8: The acronym for SFR (found on page 4-3) should be defined on this list.

Please do not hesitate to contact me with any questions at 714.484.5408 or dkourda@dtsc.ca.gov.

Peer reviewed by: James Wilkinson, PG

cc: Fred Zanoria, CEG, CHg

Response to Comments
Contaminant Flow and Transport Modeling Report
Lockheed Martin Corporation, Beaumont Site 2
Beaumont, California
dated: May 3, 2011

Comments from DTSC dated May 3, 2011		
Comment	**Response**	**Proposed Action**
General Comment #1 Any estimated aquifer properties or specifics for hydraulic testing should be reviewed by an expert in this field of study such as an engineer or hydrogeologist who specializes in modeling.	The estimated aquifer properties and specifics of the proposed hydraulic testing will be reviewed by an engineer or hydrogeologist that is an expert in this field of study with a specialization in modeling.	Section 6.3, page 6-4 will be revised to note this point following the discussion recommending the hydraulic tests.
Specific Comment #1 Table 3-2: Each line in the Notes at the bottom of the table is cut-off. The table should be revised accordingly.	This document production error will be corrected.	Table 3-2 will be reformatted so that all notes at the end of the table are shown.
Specific Comment #2 Table 3-3: Calculations, explanations, and/or rationales should be provided for the determination of the trend in the statistical analysis for each well.	Statistical analyses were conducted using the Monitoring and Remediation Optimization System (Aziz et al., 2003), which is a database application developed to assist users with groundwater data trend analysis and long term monitoring optimization at contaminated groundwater sites. The application uses the non-parametric Mann-Kendall test to determine whether there are statistically significant increasing or decreasing trends, and linear regression to determine the magnitude of the trend.	Table 3-3 will be revised to add a note to explaining this point. The reference to Aziz et al. (2003) will also be added to Section 7.

Response to Comments
Contaminant Flow and Transport Modeling Report
Lockheed Martin Corporation, Beaumont Site 2
Beaumont, California
dated: May 3, 2011

Comments from DTSC dated May 3, 2011		
Comment	**Response**	**Proposed Action**
Specific Comment #3 Section 8: The acronym for SFR (found on page 4-3) should be defined on this list.	SFR stands for Stream Flow Routing, which is one of the standard MODFLOW modules.	Section 8 will be revised to add the SFR acronym.

Department of Toxic Substances Control

Linda S. Adams
Acting Secretary for
Environmental Protection

Deborah O. Raphael, Director
5796 Corporate Avenue
Cypress, California 90630

Edmund G. Brown Jr.
Governor

June 14, 2011

Ms. Denise Kato
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Burbank, California 91505

CONTAMINANT FLOW AND TRANSPORT MODELING REPORT, LOCKHEED MARTIN CORPORATION, BEAUMONT SITE 2, BEAUMONT, CALIFORNIA (Site Code: 400261)

Dear Ms. Kato:

The Department of Toxic Substances Control (DTSC) has reviewed your responses to our comments regarding subject document and have found them to be acceptable.

Please make the agreed upon changes and submit the final Report by July 14, 2011 for DTSC approval.

Should you have any questions or comments, please contact me at (714) 484-5483.

Sincerely,

Daniel K. Zogaib
Project Manager
Brownfields and Environmental Restoration Program

cc: Mr. Gene Matsushita
Senior Manager
Environmental Remediation
Lockheed Martin Corporation
Energy, Environment, Safety & Health
2950 North Hollywood Way, Suite 125
Burbank, California 91505

REVISED
CONTAMINANT FLOW AND TRANSPORT MODELING REPORT, BEAUMONT SITE 2, LOCKHEED MARTIN CORPORATION, BEAUMONT, CALIFORNIA

Prepared for:

Lockheed Martin Corporation

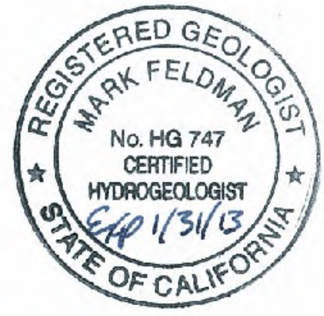
Prepared by:

Tetra Tech, Inc.

July 2011

Bob Johns, PhD
Principal Engineer

Mark Feldman, CHG CEG
Principal Geologist



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EXECUTIVE SUMMARY

A groundwater Conceptual Site Model (CSM), water and perchlorate mass flux budget, and numerical groundwater flow and transport model were developed for LMC Beaumont Site 2, Beaumont, California. The numerical groundwater flow and transport model was calibrated for the Fall 2006 through Fall 2010 period, providing some level of support for key aquifer characteristics including the water and perchlorate mass flux budget.

Key aspects of the model include the following:

- Groundwater occurs in two primary units: the shallow weathered San Timoteo formation and the deeper competent San Timoteo formation;
- There are downward vertical gradients in the upper reaches of Laborde Canyon where there is diffuse recharge of 3 acre feet per year, and there are upward vertical gradients in the south where there is discharge of 2.5 acre feet per year due to evapotranspiration in the riparian area;
- Current total perchlorate mass in the plume is estimated to be approximately 4,400 pounds. Current total perchlorate mass in soils is approximately 800 pounds. Perchlorate appears to be added to the plume at a rate of between 24 and 250 pounds per year due to groundwater and soil sources in Test Bay Canyon and the WDA, while perchlorate appears to be removed from the plume at a rate of less than 1 pound per year due to evapotranspiration in the riparian area; and
- Albeit it slowly, the perchlorate plume at the site generally appears to expanding in mass and size, since perchlorate is currently being added to the plume at rates of between 24 to 250 pounds per year, while perchlorate is being removed from the plume at rates less than 1 pound per year.

However, there is considerable uncertainty in many aspects of the site groundwater CSM, including the following:

- The model predicts a small diffuse recharge rate that averages 0.33 inches per year for a total recharge rate of 3 acre-feet per year, which is uncharacteristically low for an aquifer of this size in this area. While the very low recharge rates are supported by the site data, it is recognized that there are limited data available for the site, making this parameter highly uncertain;
- The model predicts rather large perchlorate source release rates of up to 250 pounds per year, however, the 4 year monitoring period is not long enough to fully establish that such high release rates are warranted. The net effect is that the 4 year model calibration period introduces significant uncertainties in model predictions that project 10 to 20 years into the future.

The groundwater flow and transport model was used to predict the impacts of several site groundwater remedial alternatives on the site groundwater plume. For a No Action Alternative, 2026 groundwater perchlorate concentrations are predicted to be generally similar to current site conditions in the source areas, but the downgradient limits of the plumes are likely to expand to the southern limits of the Offsite riparian area. Due to the uncertainties that now exist in the current model, the model will be updated with newly collected data prior to use in the Feasibility Study

Due to the rather large uncertainties that now exist in the groundwater flow model, it is recommended that future data collection and modeling efforts focus on improving the overall confidence in the flow model and water budget. Therefore, additional site pumping tests are recommended to better constrain the site water budget, so that the model developed in this study can be updated prior to use in detailed remedial design efforts. In addition, given the significant impact the riparian area may have on the plume and the current uncertainty in this area, additional data collection on the riparian area is recommended.

SECTION 1 INTRODUCTION

This Groundwater Flow and Transport Modeling Report (Report) was prepared by Tetra Tech, Inc. (Tetra Tech) on behalf of Lockheed Martin Corporation (LMC) for Beaumont Site 2 (the site), located southwest of the City of Beaumont in Riverside County, California (Figure 1-1). The Report presents the results of groundwater flow and transport modeling activities performed in support of ongoing environmental investigations and future remedial activities at the site.

The objectives of this study are to:

- Develop a conceptual model of the aquifer and perchlorate plume;
- Quantify components of the water and perchlorate mass flux budgets;
- Develop a calibrated numerical groundwater flow and transport model; and
- Utilize the calibrated groundwater flow and transport model to evaluate and aid in the design of groundwater remedial measures at the site.

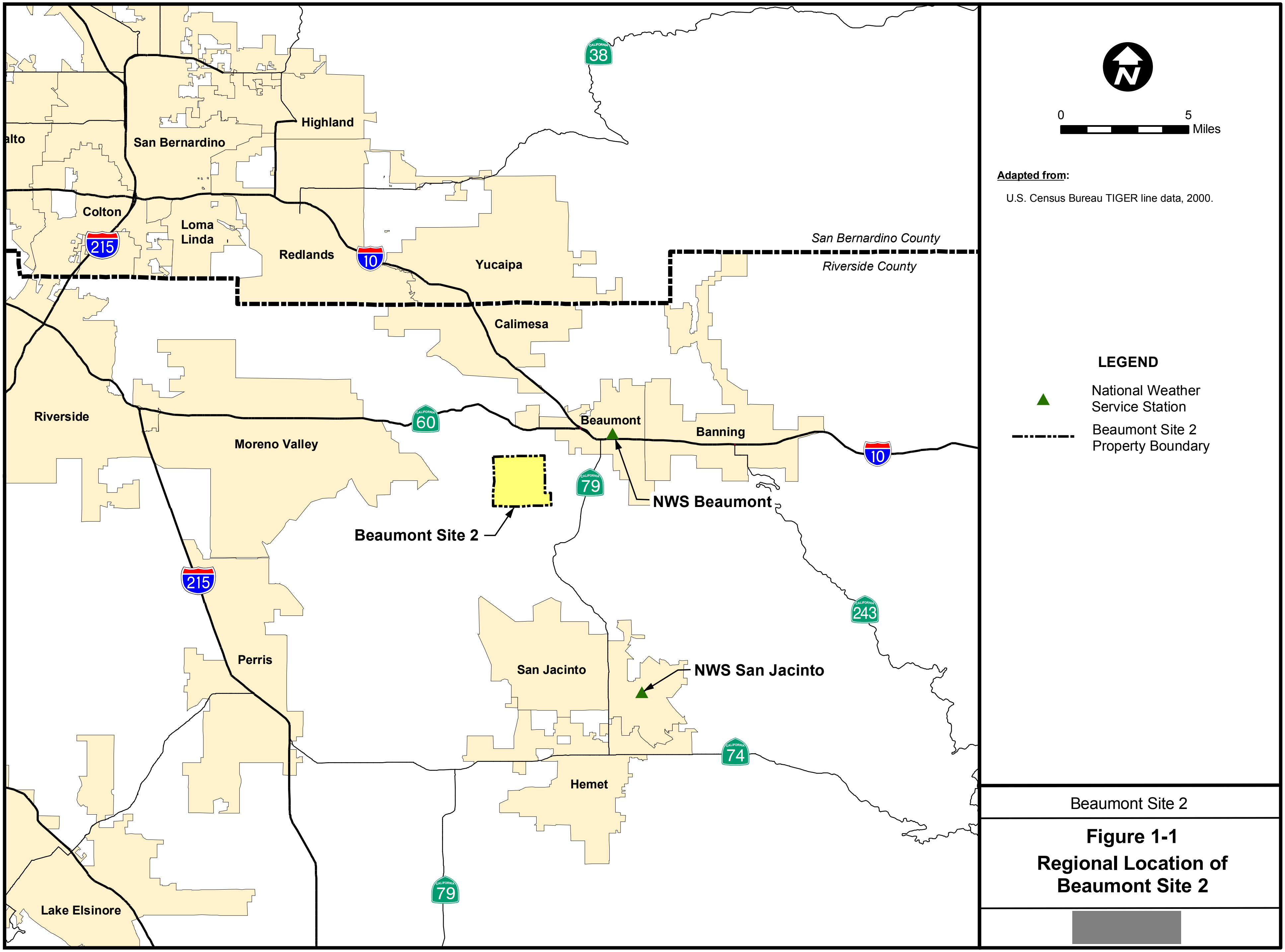
Specific issues addressed using the model include estimating the aquifer water budget and the mass and mass flux of perchlorate in the groundwater plume, and estimating the impact of a riparian area located south of the property boundary on the perchlorate groundwater plume, since the riparian area appears to be providing some degree of attenuation of the plume.

This Report also includes background on the site and prior groundwater modeling activities.

1.1 SITE BACKGROUND

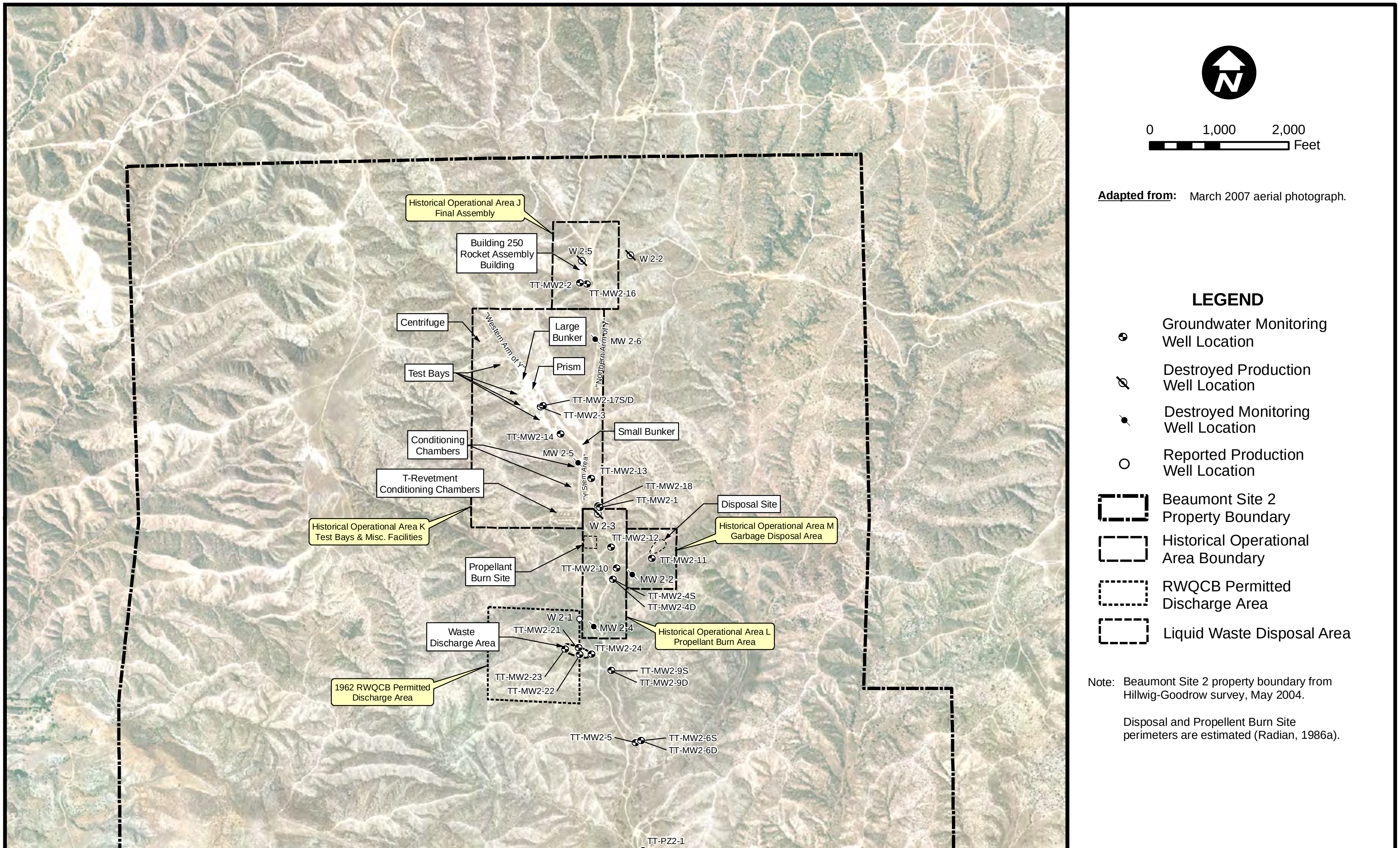
The site consists of 2,668 acre of land located southwest of the City of Beaumont, California (Figure 1-1). Prior to 1958, the site was used for agricultural purposes. Between 1958 and 1974, portions of the site were used as a remote rocket motor test facility. Activities performed at the site during this time included rocket motor assembly, rocket motor testing, and propellant incineration. In 2006, the site was sold to the County of Riverside.

Five primary historical operational areas were identified at the site (Figure 1-2). Area J (Final Assembly Area) consisted of a former building (Building 250) and related facilities which were used for the final assembly and shipment of rocket motors. Area K (Test Bays and Miscellaneous Facilities) included a test centrifuge, 4 rocket motor test bays, 2 bunkers, a large earthen structure



Beaumont Site 2

Figure 1-1
Regional Location of Beaumont Site 2



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Beaumont Site 2

Figure 1-2
Historical Operational Areas and Site Features

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referred to as the "Prism", and 3 groups of conditioning chambers. Area L (Propellant Burn Area) is located immediately south of Area K. Reportedly, large slabs of solid propellant were transported and placed on the ground surface for incineration in Area L. Area M (Garbage Disposal Area) is located in a side canyon; scrap metal, paper, wood, and concrete were disposed in this area. The Waste Discharge Area is located in a small canyon on the western side of Laborde Canyon and consists of 2 shallow basins protected by 2-foot berms, where approximately 5,000 gallons per year of wastes were discharged containing the residue remaining after the manufacturing refuse is burned.

Details on the historical operations at the site and previous environmental investigations are provided in the recent Dynamic Site Investigation and Summary Remedial Investigation (DSI) report (Tetra Tech, 2010a). The DSI report found that two major perchlorate plumes are present in on-site groundwater: one originating in the test bay area, which extends approximately 2,100 feet downgradient from the source area, terminating on-site in Laborde Canyon; and one originating in the WDA, which extends beyond the southern boundary of the site onto the adjacent former Wolfskill property. An investigation in the offsite area (Tetra Tech, 2010b) included installing monitoring wells in an area of riparian vegetation approximately 1,100 feet long, located roughly 100 to 1,200 feet south of the property boundary (Figure 1-3).

To date, groundwater and soil remediation activities have not been conducted at the site. Groundwater level and water quality monitoring has been conducted on a quarterly basis since 2004 to monitor the site groundwater plumes. The results of groundwater monitoring activities are presented in semiannual groundwater monitoring reports prepared twice per year. Each groundwater monitoring report includes a presentation the most current conceptual site model. No previous groundwater modeling studies have been conducted for the site.

1.2 CURRENT GROUNDWATER MODELING ACTIVITIES

The approach for development of the groundwater model includes the following:

- Compiling available data regarding well coordinates, well construction, groundwater levels, lithology, hydraulic conductivity, storativity, porosity, groundwater inflow and outflow, precipitation, recharge, evapotranspiration, surface water flow, and groundwater quality;
- Developing a conceptual hydrogeologic model of the areas and the site plume. This effort included definition of hydrostratigraphic units, boundary conditions, direction of groundwater flow, and preparation of a groundwater and perchlorate mass flux budget;

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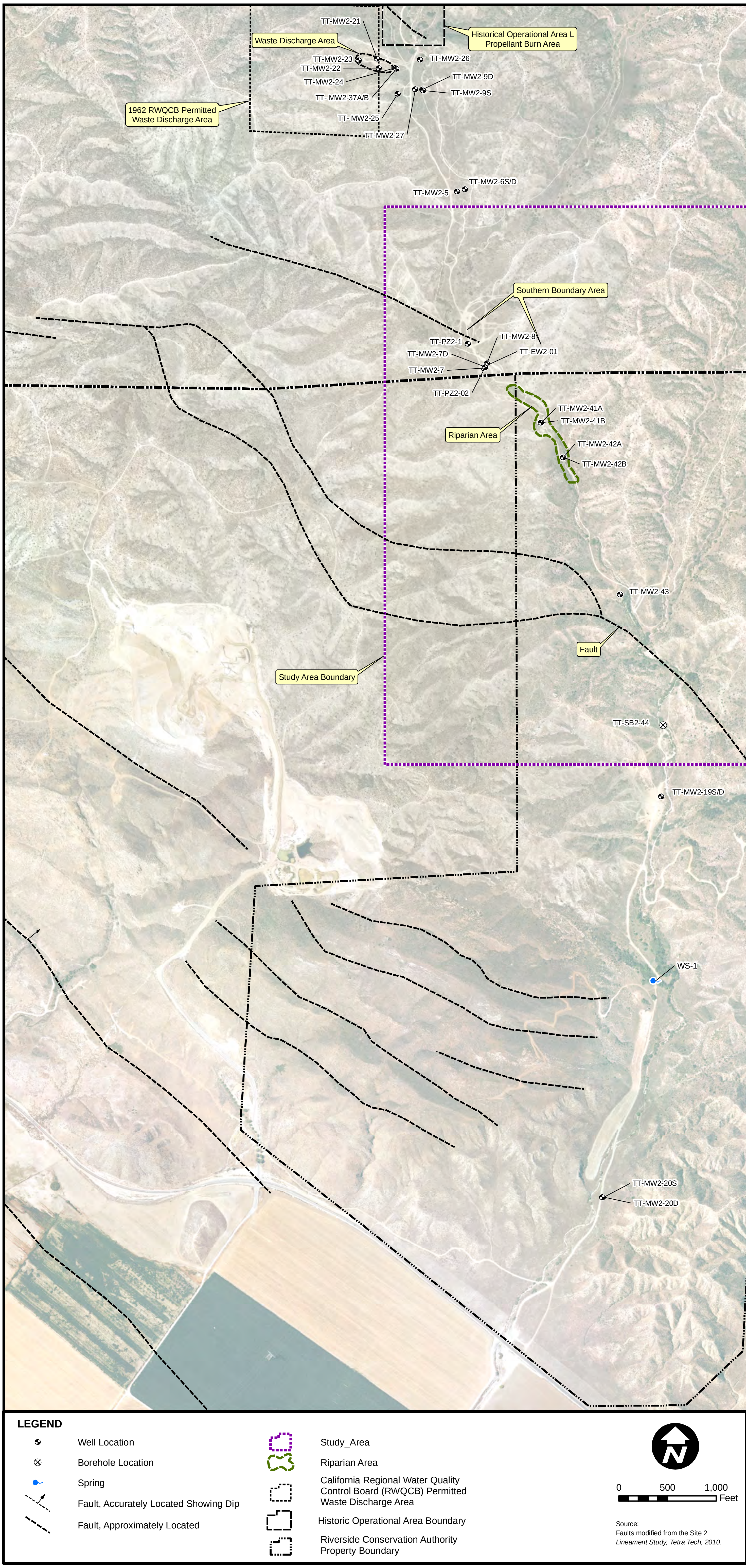

Beaumont Site 2

Figure 1-3

Southern Boundary and Offsite Areas

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- Constructing a groundwater flow and transport model of the area using the MODFLOW2000 (Harbaugh et al., 2000) and MT3D (Zheng and Wang, 1999) software packages;
- Calibrating the groundwater flow and transport model to water level and perchlorate data collected at the site and aquifer characteristics measured in site well tests;
- Evaluating the impact of various alternative remedial options on the site plumes; and
- Documenting the findings of the groundwater flow and transport study in this Report.

The model was developed based upon modeling guidance given in ASTM reports (ASTM, 1996) and groundwater modeling guides (Anderson and Woessner, 1992). Section 2 summarizes the data used in this study. Section 3 presents the groundwater conceptual model. Section 4 presents the groundwater flow and transport model design and calibration. Section 5 presents the groundwater transport model predictions for various remedial alternatives. Section 6 presents the project summary, conclusions and recommendations.

SECTION 2 DATA COLLECTION

This project task involved compiling and evaluating relevant data to support development of the conceptual and numerical models. Existing well information was a key aspect of the data assembled for the model, including information on location coordinates, lithologic logs, water levels and water quality, construction, depths and perforation intervals. Other information sought and considered relevant was surface geology, stream flow discharge, and land use.

Much of this data was recently summarized in the DSI report (Tetra Tech, 2010a) and the Offsite Investigation report (Tetra Tech, 2010b).

2.1 DATA SOURCES

The primary source of data used in this study is the database developed for the Site 2 groundwater monitoring program, which includes the following information:

- Groundwater levels from 2004 through present;
- Groundwater and surface water quality data from 2004 through present;
- Well construction data;
- Applicable GIS data for the ground surface and aquifer;
- Groundwater level data measured continuously in individual wells using pressure transducers;
- Hydraulic conductivity and transmissivity data derived from slug tests and pumping tests; and
- Lithologic and soil quality data.

The transducer groundwater level data was collected to evaluate whether there are diurnal fluctuations in well water levels that may correlate with groundwater removal due to evapotranspiration from plants.

Recently, a groundwater pumping test was been conducted at the site southern boundary (Tetra Tech, Inc., 2010b). Key results of the pumping test indicate that the shallow weathered San Timoteo aquifer transmissivity is only 2 to 10 /day, and the underflow rate down the canyon in the shallow weathered San Timoteo aquifer is on the order of 0.2 to 1 acre-feet per year. This underflow rate is quite low for a groundwater aquifer of this size in this area. A water budget has not been previously proposed for the site, so there is limited basis for comparison of the underflow estimates.

2.2 SLUG TESTS

To supplement the limited hydraulic property data available for the Site, slug tests were conducted in 23 wells. The slug tests included falling-head tests, which were conducted by displacing groundwater in the well upward by inserting a weighted PVC slug, and rising-head tests, which were conducted by displacing groundwater in the well downward by removing the slug.

Prior to conducting each slug test, water levels were measured manually with an electronic water level meter to determine the static groundwater level. An electronic pressure transducer was then suspended in the well, and water levels were monitored manually until static conditions were reestablished. A falling-head test was then conducted by smoothly lowering a weighted PVC slug into the well and securing it in place above the transducer. Once the water level had recovered to static conditions, a rising-head test was conducted by removing the slug and allowing the water level to recover to static conditions. Pressure transducers placed above the water table in wells TT-EW2-1 and TT-MW2-16 were used to monitor barometric pressure changes during each test. At the end of each rising-head test, water level data from the pressure transducer were downloaded to a laptop computer and compensated for barometric pressure effects prior to interpretation.

The slug test data were interpreted using AQTESOLV aquifer test interpretation software (Duffield and Rumbaugh, 1991). Based on hydrogeologic conditions at the Site, the Bouwer-Rice graphical semi-log analysis method (Dawson and Istok, 1991) was used to interpret the rising- and falling-head test data. Two sets of aquifer parameters were obtained from each well as a cross-check on the interpretation results.

Hydraulic conductivity values interpreted from the slug test data are summarized in Table A-1 (Appendix A).. The average of the two hydraulic conductivity values obtained for each well range from 0.00059 feet per day (ft/day) for TT-MW2-19D to 3.5 ft/day for TT-MW2-39. Copies of the slug test interpretation figures and the AQTESOLV input and output files are provided in Appendix A. It should be noted that the results from the slug tests are uncertain, since borehole effects impact results from this type of test, and in many cases, slug tests may underestimate the hydraulic conductivity of the aquifer.

2.3 DATA ANALYSIS

The database includes information and sources of the information for all known wells in the model area. The information gathered was organized to develop components of the water budget, aquifer layers, and geometry.

Since aquifer pumping test data is only available in one area for the shallow weathered San Timoteo Formation, aquifer conductivity data from the site slug tests was converted to aquifer transmissivity based upon aquifer thickness. These and other interpretations are addressed in more detail in the Conceptual Model discussion in Section 3.

2.4 DATA GAPS

The most recent site investigations for the Southern Site Boundary pump test and the Offsite Area have provided valuable data to update the conceptual model, and construct a numerical groundwater flow and transport model at the site. Although there are considerable uncertainties in some aspects of the conceptual model as discussed in Section 3, there do not appear to be any data gaps that would preclude proceeding with the development of a numerical flow and transport model.

SECTION 3 CONCEPTUAL MODEL

Various elements of the groundwater conceptual model are given in earlier site reports (Tetra Tech, 2009; 2010a; 2010b). The reader is referred to these reports for more details and supporting information on the previous groundwater conceptual model.

The updated groundwater conceptual model presented below is consistent with the available site data and the requirements for the numerical flow and transport modeling task. The updated conceptual model includes the definition of the aquifer hydrostratigraphic framework; the sources of recharge and discharge; the definition of soil source areas contributing COCs to groundwater; the definition of other sources of COC inflow and loss; and the definition of the high permeability pathways acting as conduits for plume migration. Figures 3-1 through 3-7 show cross-sections and maps to support and illustrate the following text description of the conceptual model.

3.1 GEOLOGIC FRAMEWORK

The Site is located at the northern end of the Peninsular Ranges geologic province of California (e.g., Norris and Webb, 1990), near the northern tip of the San Jacinto Mountains block (Morton, 2004). This area of the Peninsular ranges is underlain by a thick sequence of Miocene to Pleistocene non marine sedimentary rocks, which are in turn underlain by crystalline basement consisting of Jurassic to Cretaceous age tonalitic and granodioritic plutonic rocks of the Southern California Batholith and metamorphic rocks (primarily marbles and gneisses) of inferred Paleozoic age (Morton, 2004)

The structure of the area is dominated by the San Andreas Fault (SAF) system, which has a restraining bend near San Gorgonio Pass (Dair and Cooke, 2009). On either side of the pass, deformation along the SAF is limited to relatively narrow band along the San Bernardino and Coachella valley strands. Within the San Gorgonio Pass area, the SAF disaggregates into a complex network of active and inactive right lateral, reverse, thrust, and oblique normal faults. The most prominent faults in the area of the Site are the San Jacinto and Claremont faults, both of which are active right lateral strike slip faults related to the SAF system. The San Jacinto fault is located approximately 2 miles south of Site. No faults are shown within the former operational areas of the Site on published geologic maps by Dibblee (2003) and Morton (2004), although a recent lineament study performed at the site by D. Morton (Tetra Tech, 2009) suggests that several

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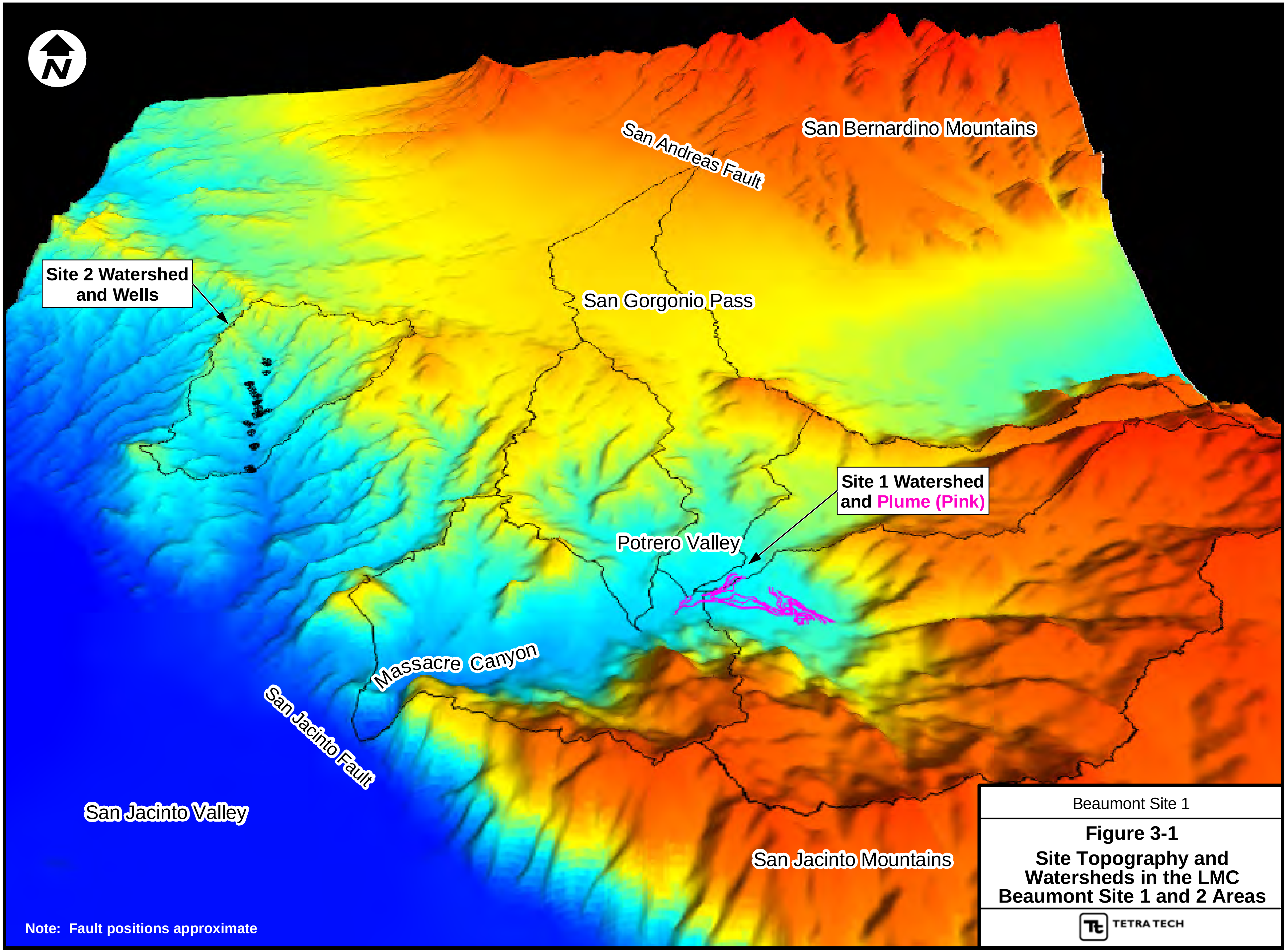

Beaumont Site 1

Figure 3-1

Site Topography and Watersheds in the LMC Beaumont Site 1 and 2 Areas

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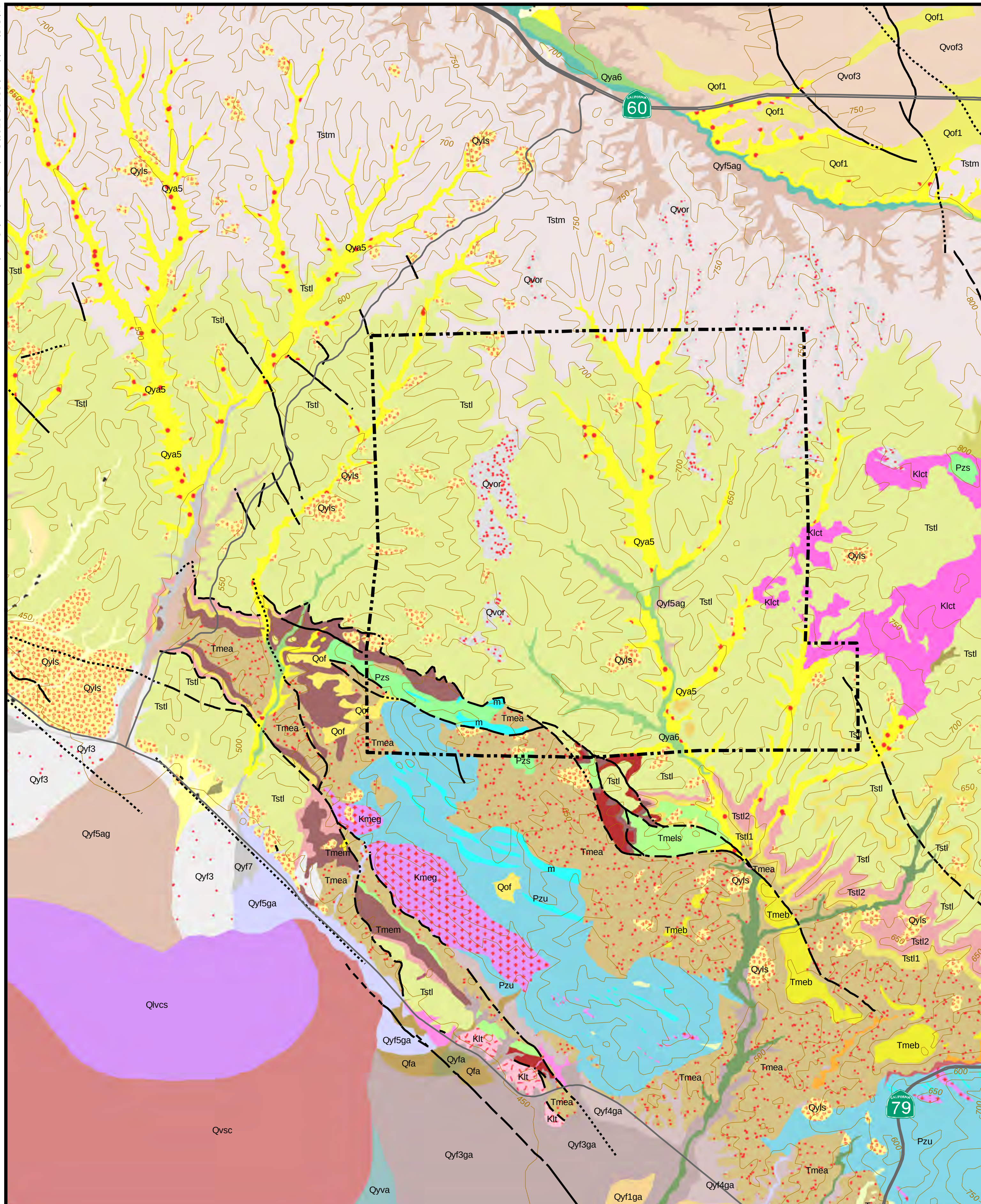

LEGEND

Faults

- Fault-accurately located
- Fault-approximately located
- Fault-concealed
- Fault-inferred

Roads

- Road - primary
- Road - secondary

Ground Surface Elevation Contour (50-meter interval msl)

Beaumont Site 2 Property Boundary

GEOLOGY

Symbol	Description
Qf1	Alluvial fan deposits, Unit 1
Qfa	Alluvial fan deposits, arenaceous
Qfga	Alluvial fan deposits, gravelly sand
Qlvcs	Lacustrine and fluvial deposits, clayey silt
Qoa	Old axial channel deposits
Qoc	Old colluvial deposits
Qof	Old alluvial fan deposits
Qof1	Old alluvial fan deposits, Unit 1
Qof3	Old alluvial fan deposits, Unit 3
Qos	Old surficial deposits, undivided
Qvoa	Very old axial channel deposits
Qvof3	Very old alluvial fan deposits, Unit 3
Qvofa	Very old alluvial fan deposits, arenaceous
Qvor	Very old regolith
Qvsc	Alluvial valley deposits, silty clay
Qwa	Wash deposits, arenaceous
Qwag	Wash deposits, arenaceous gravel
Qya3	Young axial channel deposits, Unit 3
Qya5	Young axial channel deposits, Unit 5
Qya6	Young axial channel deposits, Unit 6
Qyaag	Young axial channel deposits, arenaceous gravel
Qyf	Young alluvial fan deposits
Qyf1	Young alluvial fan deposits, Unit 1
Qyf1ga	Young alluvial fan deposits, Unit 1, gravelly sand
Qyf3	Young alluvial fan deposits, Unit 3
Qyf3ga	Young alluvial fan deposits, Unit 3, gravelly sand
Qyf4ga	Young alluvial fan deposits, Unit 4, gravelly sand
Qyf5ag	Young alluvial fan deposits, Unit 5, arenaceous gravel
Qyf5ga	Young alluvial fan deposits, Unit 5, gravelly sand
Qyf7	Young alluvial fan deposits, Unit 7
Qyfa	Young alluvial fan deposits, arenaceous
Qyfga	Young alluvial fan deposits, gravelly sand
Qyls	Young landslide deposits
Qyva	Young alluvial valley deposits, arenaceous
Qywa	Young wash deposits, arenaceous
Tme	Mount Eden Formation of Fraser (1931)
Tmeus	Mount Eden Formation of Fraser (1931), upper sandstone member
Tmem	Mount Eden Formation of Fraser (1931), mudrock member
Tmels	Mount Eden Formation of Fraser (1931), lower sandstone member
Tmea	Mount Eden Formation of Fraser (1931), arkosic sandstone member
Tmeb	Mount Eden Formation of Fraser (1931), arkosic sandstone member, tongues of monolithic tonalite boulder breccia
Tmec	Mount Eden Formation of Fraser (1931), conglomeratic sandstone member
Tstl	San Timoteo beds of Frick (1921), middle member
Tstl1	San Timoteo beds of Frick (1921), lower member
Tstl2	San Timoteo beds of Frick (1921), lower member, arkosic sandstone
Tstm	San Timoteo beds of Frick (1921), lower member, claystone, siltstone, and sandstone
m	Paleozoic (?) rocks, undifferentiated, marble bodies
Klct	Tonalite of Lamb Canyon, Peninsular Ranges batholith
Klt	Tonalite near mouth of Laborde Canyon, Peninsular Ranges batholith
Kmeg	Granite of Mount Eden, Peninsular Ranges batholith
Pzs	Biotite schist
Pzu	Paleozoic(?) rocks, undifferentiated

Source: Preliminary Digital Geologic Map of the Santa Ana 30' x 60' Quadrangle, Southern California, version 2.0. USGS 2004.

0 1,500 3,000 Feet

Beaumont Site 2

Figure 3-2

Regional Geology

TETRA TECH

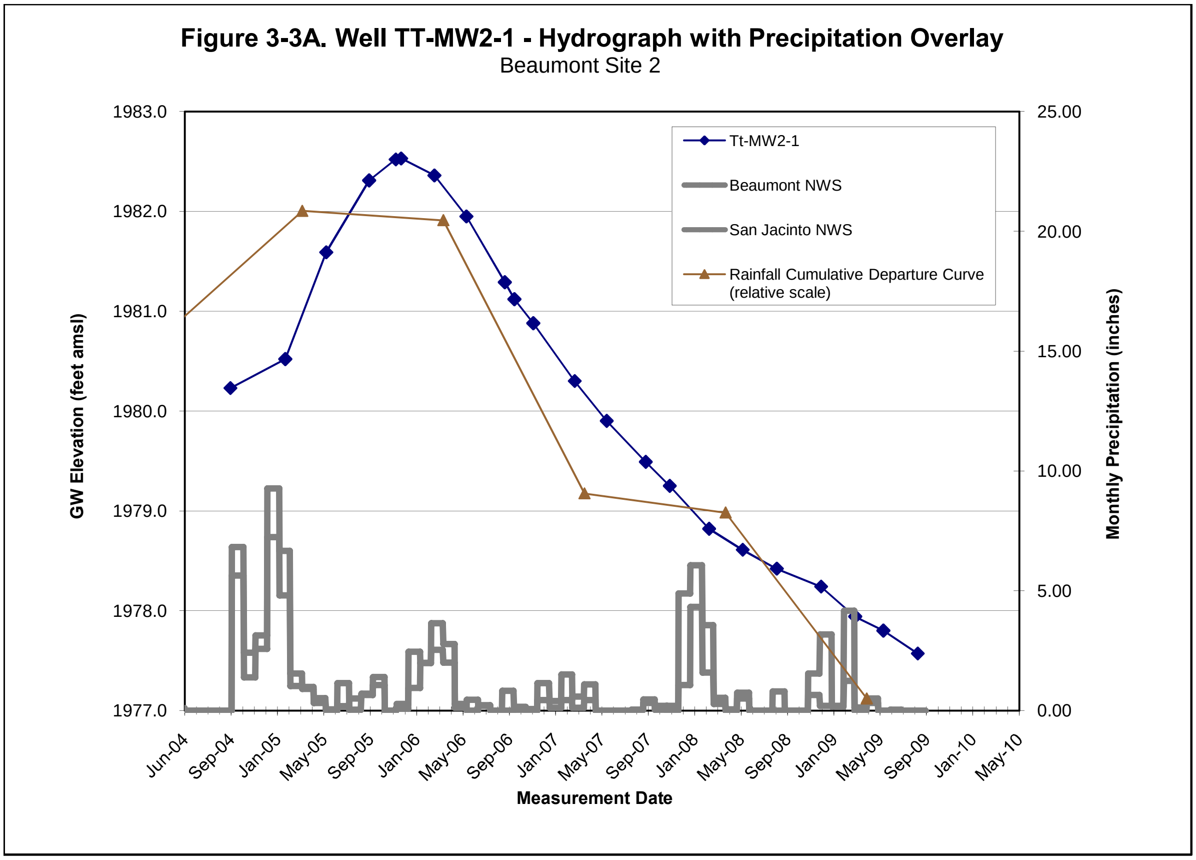
Figure 3-3A. Well TT-MW2-1 - Hydrograph with Precipitation Overlay
Beaumont Site 2
Tt-MW2-1
Beaumont NWS
San Jacinto NWS
Rainfall Cumulative Departure Curve
(relative scale)
GW Elevation (feet amsl)
Monthly Precipitation (inches)
Measurement Date
1983.0
1982.0
1981.0
1980.0
1979.0
1978.0
1977.0
25.00
20.00
15.00
10.00
5.00
0.00
Jun-04
Sep-04
Jan-05
May-05
Sep-05
Jan-06
May-06
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Sep-09
Jan-10
May-10

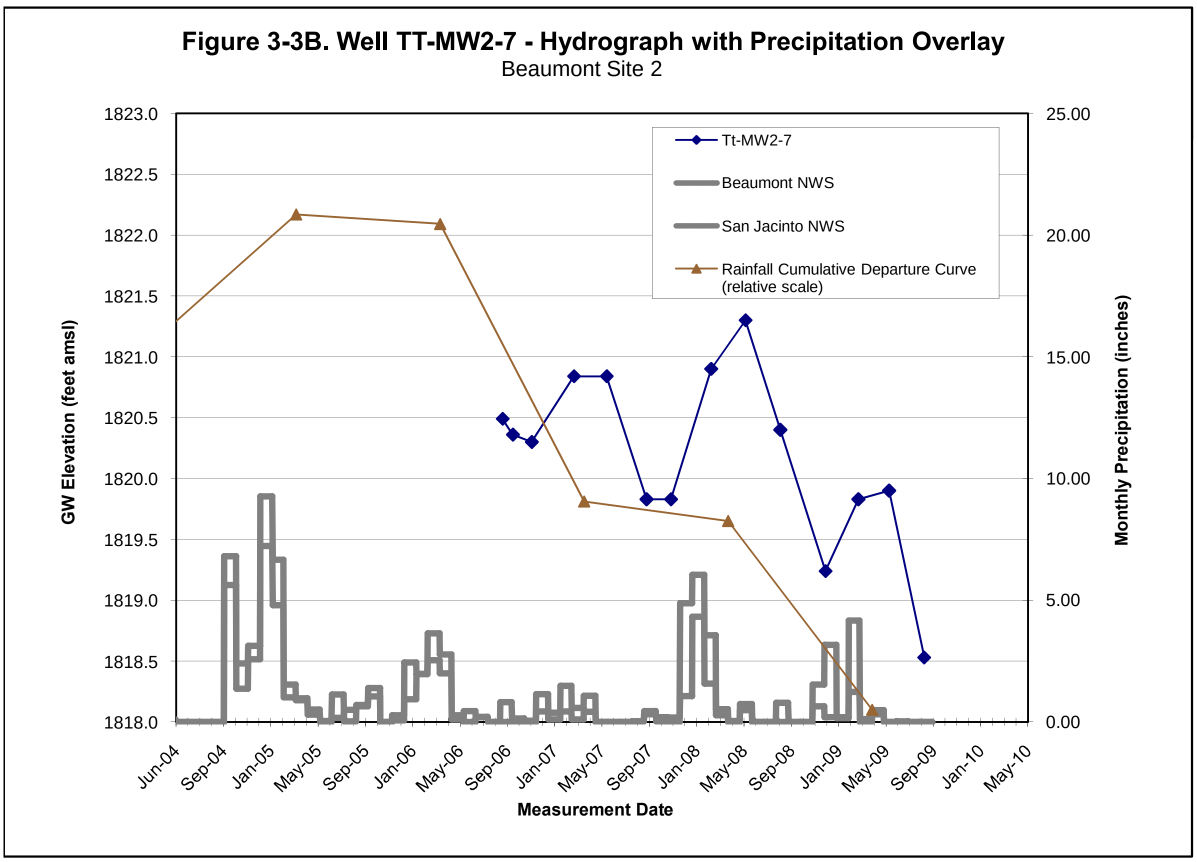
Figure 3-3B. Well TT-MW2-7 - Hydrograph with Precipitation Overlay
Beaumont Site 2
Tt-MW2-7
Beaumont NWS
San Jacinto NWS
Rainfall Cumulative Departure Curve
(relative scale)
GW Elevation (feet amsl)
Monthly Precipitation (inches)
Measurement Date
1823.0
1822.5
1822.0
1821.5
1821.0
1820.5
1820.0
1819.5
1819.0
1818.5
1818.0
25.00
20.00
15.00
10.00
5.00
0.00
Jun-04
Sep-04
Jan-05
May-05
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Jan-09
May-09
Sep-09
Jan-10
May-10

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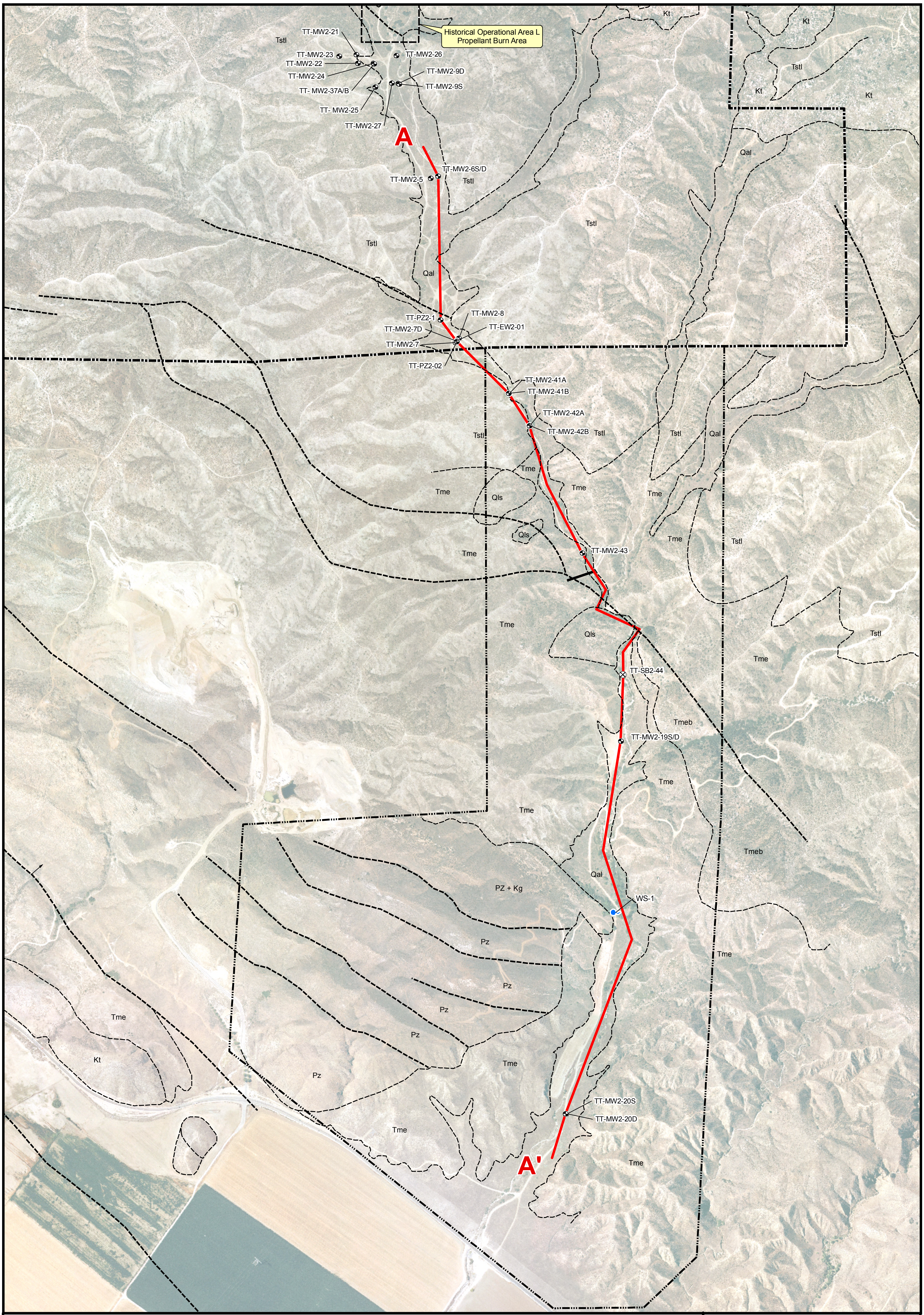


LEGEND

- Well Location
- Borehole Location
- Spring
- Geologic Cross Section Line
- Geophysical Survey Line
- Fault, Accurately Located Showing Dip
- Fault, Approximately Located
- Riverside Conservation Authority Property Boundary
- Historic Operational Area Boundary

Qaf -	Artificial Fill
Qal -	Undifferentiated Quaternary alluvial deposits along canyon floors
Qls -	Quaternary landslide deposits
Tstm -	Middle member of the San Timoteo formation
Tstl -	Lower member of the San Timoteo formation
Tme -	Undifferentiated Mount Eden formation
Tmeb -	Tonalite breccia deposits of the Mount Eden formation
Kg -	Cretaceous biotite monzogranite
Kt -	Cretaceous biotite-hornblende tonalite and hornblende-biotite tonalite
Pz -	Undifferentiated Paleozoic schist, gneiss, and marble

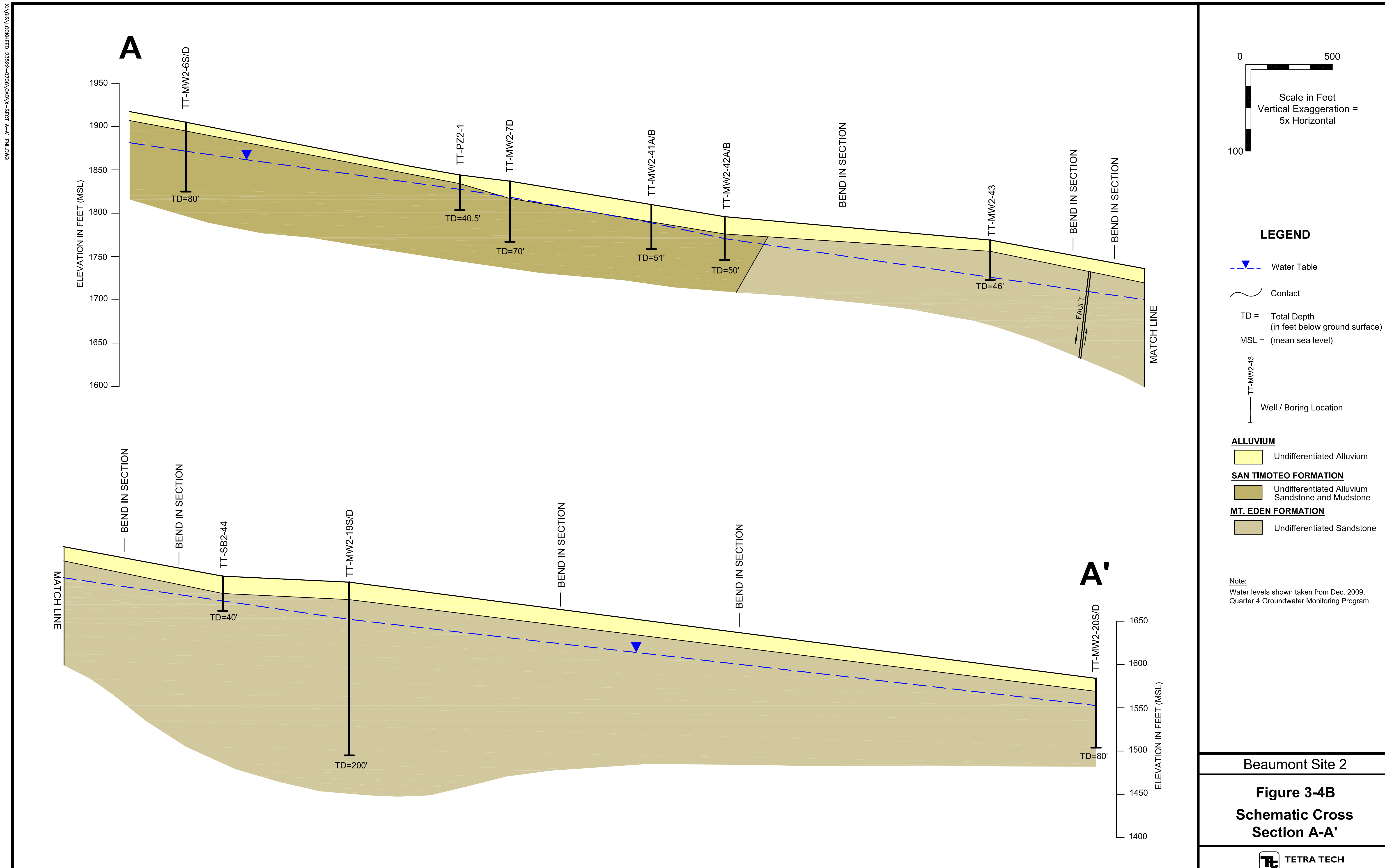
0 500 1,000 Feet

Source:
Faults modified from the Site 2 *Lineament Study, Tetra Tech, 2010.*

Beaumont Site 2

Figure 3-4A

Cross Section Location Map



Beaumont Site 2

Figure 3-4B
Schematic Cross Section A-A'

TETRA TECH

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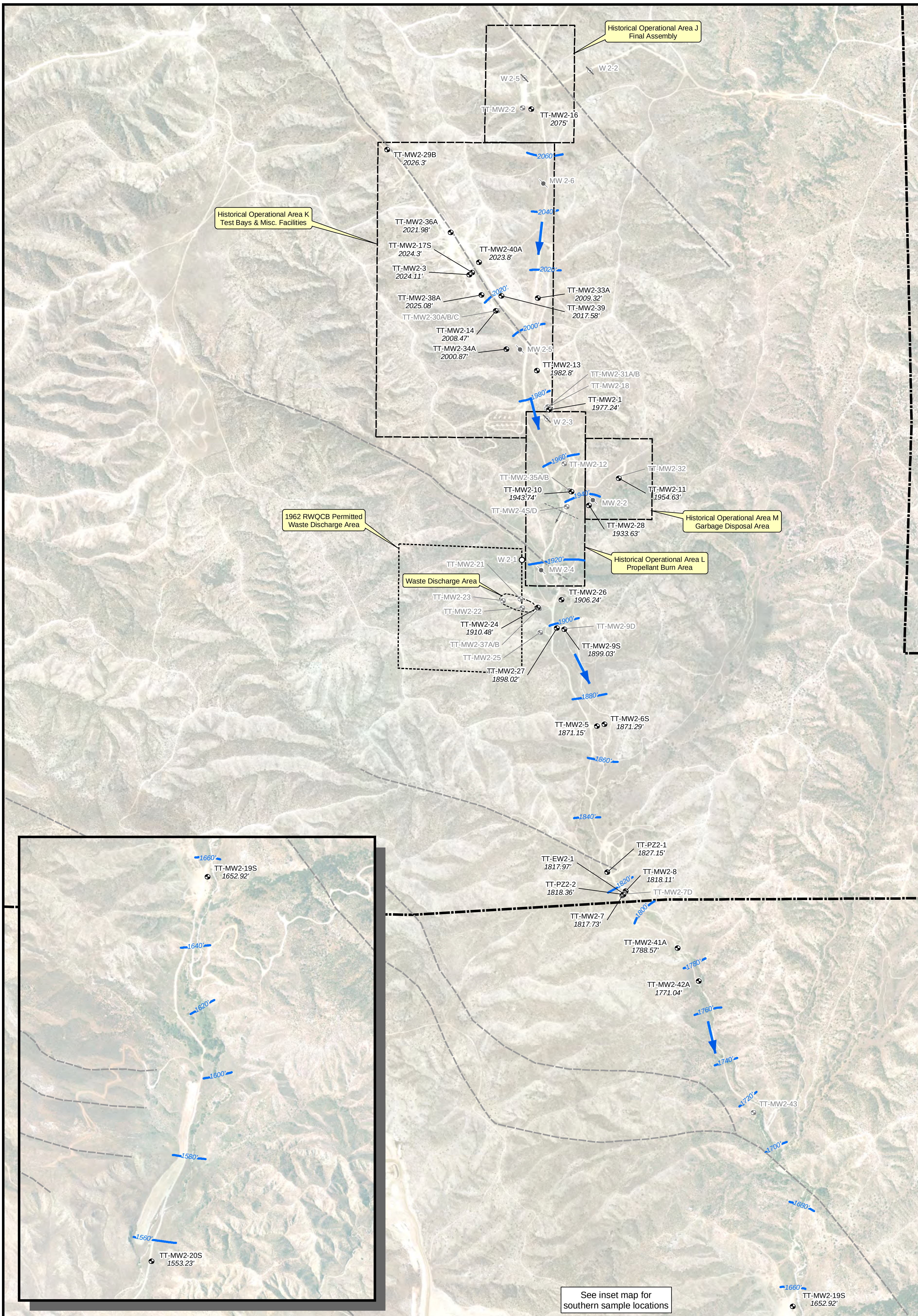

LEGEND

- Well Location
- Destroyed Production Well Location
- Destroyed Monitoring Well Location
- Reported Production Well Location
- Groundwater Elevation Contour
- Groundwater Flow Direction
- Fault, Accurately Located Showing Dip
- Fault, Approximately Located
- California Regional Water Quality Control Board (RWQCB) Permitted Waste Discharge Area
- Historical Operational Area Boundary
- Beaumont Site 2 Property Boundary

0 500 1,000 Feet

Adapted from: April 2007 aerial photograph.

Faults from the *Site 2 Lineament Study, Tetra Tech, 2009.*

Note: Beaumont Site 2 property boundary from Hillwig-Goodrow survey, May 2004.

20-foot groundwater interval.

Groundwater elevations in feet msl.

msl - Mean sea level.

Beaumont Site 2

Figure 3-5

Groundwater Contours December 2009

TETRA TECH

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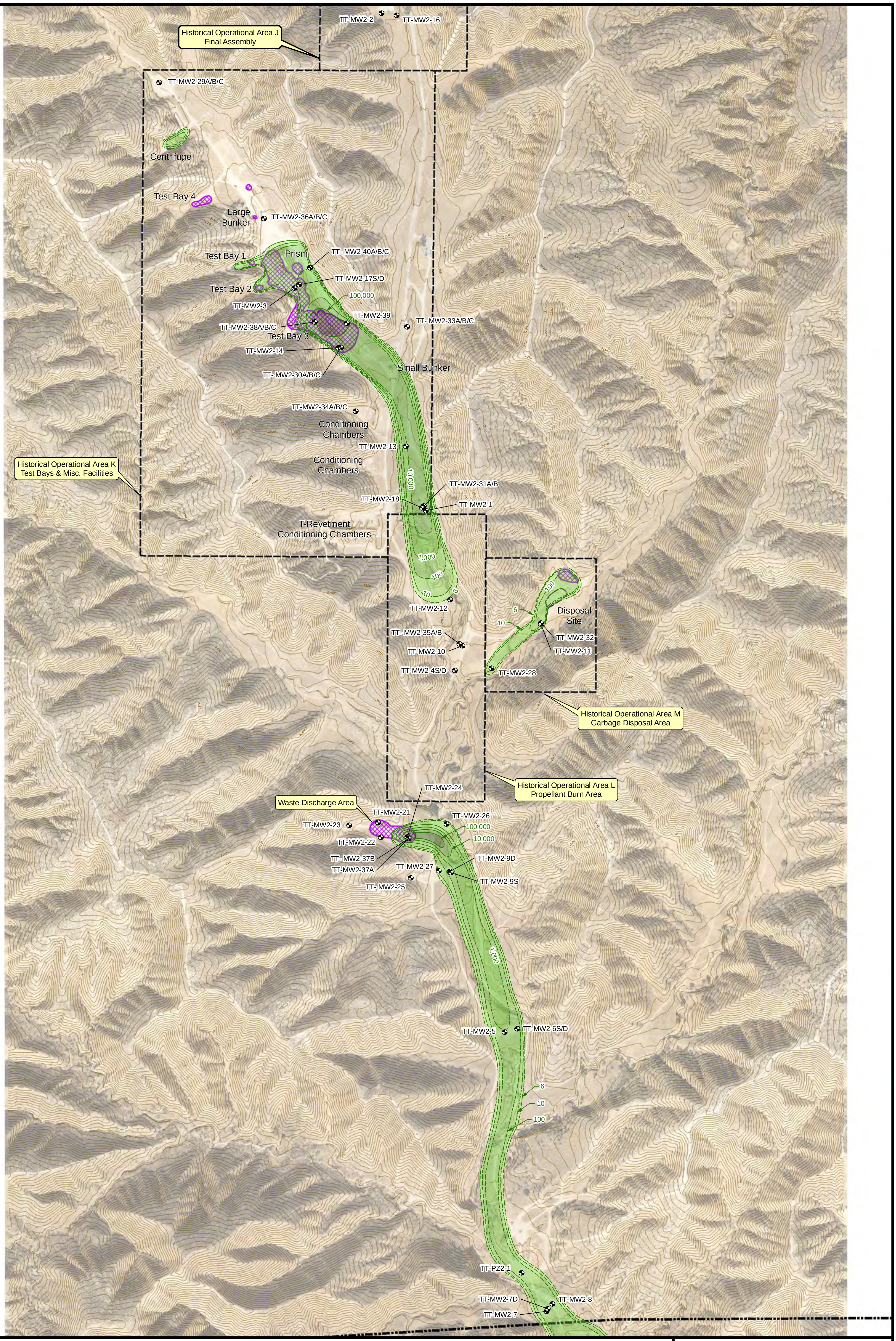


LEGEND

Perchlorate in Groundwater

- 6 µg/L
- 10 µg/L
- 100 µg/L
- 1,000 µg/L
- 10,000 µg/L
- 100,000 µg/L

Perchlorate Soil Source
>µg/kg

Monitoring Well Location

Ground Surface Elevation Contour
(10-foot interval - feet msl)

Historic Operational Area Boundary

Note:

µg/L - Micrograms per liter.

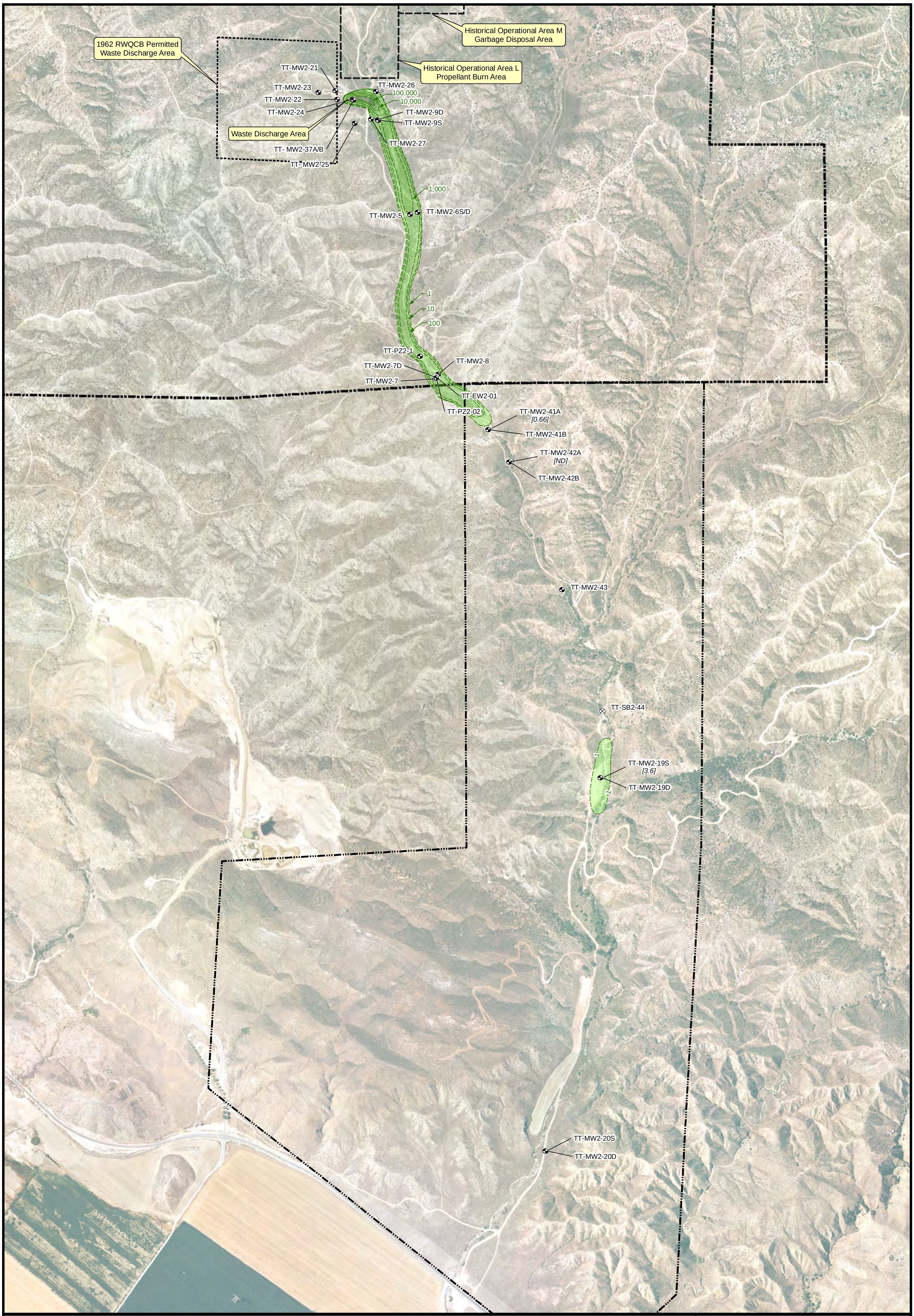
0 300 600
Feet

Beaumont Site 2

Figure 3-6A

Perchlorate Source Areas and Groundwater Impacts

TETRA TECH



LEGEND

- Well Location
- Borehole Location
- Riverside Conservation Authority Property Boundary
- California Regional Water Quality Control Board (RWQCB) Permitted Waste Discharge Area
- Historic Operational Area Boundary
- Beaumont Site 2 Property Boundary

Perchlorate in Groundwater

- 1 µg/L
- 10 µg/L
- 100 µg/L
- 1,000 µg/L
- 10,000 µg/L
- 100,000 µg/L

Note:

[#] - Perchlorate concentration in µg/L.

msl - Mean sea level.

0 500 1,000 Feet

Beaumont Site 2

Figure 3-6B

Extent of Perchlorate Contamination in Groundwater

TETRA TECH

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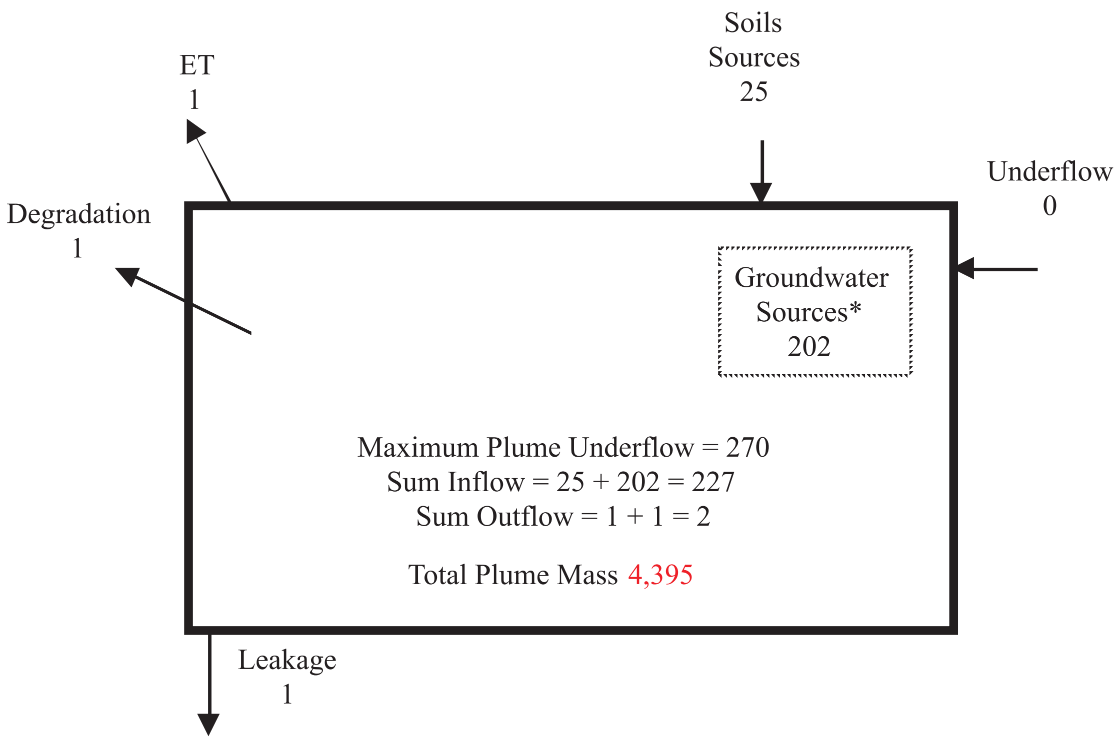
PERCHLORATE



* Existence of groundwater source uncertain
Units are pounds per year, except mass units are pounds

Beaumont Site 2

Figure 3-7

Groundwater Perchlorate Mass Flux Diagram

TETRA TECH

side canyons could be fault-controlled. Morton (2004) mapped several west northwest trending faults in the southwestern corner of the site, which cross Laborde Canyon approximately 3,000 feet south of the southern property boundary.

The San Timoteo anticline, a northwest plunging fold that roughly parallels the San Jacinto Fault Zone, extends along much of the southern portion of the San Timoteo Badlands. The anticline is asymmetric, with a steeply dipping southwestern limb and a gently dipping northeastern limb. The axis of the anticline is located approximately 8,000 feet south of the Site. Mapping by Dibblee (2003) shows bedding near Laborde Canyon dipping generally to the north-northeast, at angles ranging from horizontal to 5°, whereas Morton (2004) shows dips ranging from 12° to 25° toward the northeast and northwest. Field measurements by Tetra Tech support the steeper dip angles indicated by Morton (2004).

The primary geologic units exposed at the site include lower member of the San Timoteo formation (STF) and Quaternary-age alluvium and colluvium. The STF consists primarily of grayish brown fine grained sandstones and mudstones, with localized conglomerate lenses. Well-indurated beds of carbonate cemented, medium- to coarse-grained sandstone are occasionally encountered at depth. The degree of induration of the STF generally tends to increase with depth, although poorly-indurated beds are encountered throughout the section to a depth of at least 250 feet. The STF also appears more indurated at shallow depths in borings drilled in side canyons compared with those drilled near the midline of the major canyons. These observations suggest that the STF is most deeply weathered near the center of the major canyons, and becomes less deeply weathered toward the canyon margins. The STF characteristically forms steep ridges and hillsides throughout the Site. These slopes are typically mantled by a thin regolith veneer; the STF is poorly-exposed except in localized areas with near vertical slopes and in recently-formed gullies.

Quaternary alluvium consists of stratified gravel, sand, silty sand, and silt deposits flooring the major canyons throughout the Site. Colluvium consists mainly of poorly to well graded sand and silty sand with minor gravel. Colluvium characteristically forms steeper slopes than alluvium, and typically occurs as aprons at the base of steep hillsides and flooring minor side canyons with small catchment areas. The colluvium and alluvium likely interfinger laterally along the margins of the main canyons.

Other geologic units exposed primarily to the south of the site include crystalline basement and the Mount Eden formation. The crystalline basement consists of Cretaceous-age plutonic rocks of the Peninsular Ranges batholith and metasedimentary rocks and marbles of inferred Paleozoic age. The crystalline basement is overlain by the Mount Eden formation, which consists of early Pliocene and Miocene sandstones, mudstones, conglomeritic sandstones, and sedimentary breccias,

The site is located in Laborde Canyon, a north-south trending canyon within the San Timoteo Badlands (Figure 3-1). Surface elevations in Laborde Canyon range from 2,700 feet msl on the ridges at the northeastern boundary to about 1,600 feet msl where Laborde Canyon opens into San Jacinto Valley to the south. Former operations at the site were generally restricted to the floor of Laborde Canyon, where elevations range from approximately 2,200 feet msl at the northern site boundary to about 1,800 feet msl near the southern site boundary. The canyon floor slopes at a relatively uniform gradient of 0.03 feet per foot throughout the entire length of Laborde Canyon.

3.2 CONCEPTUAL HYDROSTRATIGRAPHIC MODEL

Groundwater occurs in two primary units: weathered siltstones and sandstones of the San Timoteo formation that are about 20 feet in saturated thickness; and in various individual water-bearing zones in the competent siltstone and sandstone of the San Timoteo formation that are typically from 5 to 10 feet in saturated thickness (Figures 3-4A and 3-4B). The interval between these two water bearing zones is composed of competent, low-yielding siltstone and sandstone of the San Timoteo formation. In one small area of the site near TT-MW2-7, a thin layer of alluvium overlying the weathered San Timoteo formation may be periodically saturated during periods of higher groundwater levels. The north-dipping contact between the San Timoteo formation and Mt. Eden formation occurs approximately one-quarter mile south of the site boundary (just south of TT-MW2-42A/B); groundwater in the offsite area south of TT-MW2-42A/B occurs in the Mt. Eden formation. However, since the groundwater plume is found only in the San Timoteo formation, with the exception of the small stranded portion of the plume observed in TT-MW2-19S, the conceptual model focuses primarily on the San Timoteo formation.

3.3 GROUNDWATER FLOW SYSTEM

Thickness of the saturated weathered San Timoteo formation is roughly 20 feet in site monitoring wells, but values can vary with slightly thicker values in the center of the canyon. The competent San Timoteo formation is estimated to be between 1,500 and 2,000 feet thick, but only the upper

450 feet have been documented in site water supply wells (W2-5) and only the upper 230 feet have been penetrated in site monitoring wells (TT-MW2-30A). A contour map of the top of the competent San Timoteo formation, developed from seismic refraction and boring log data, is given in Appendix B. Based upon field observations during drilling and groundwater level measurements, groundwater in the weathered San Timoteo formation occurs mainly under water-table conditions. Groundwater in the competent San Timoteo is mainly under confined conditions, since water encountered within the formation rises above the top of the saturated beds in monitoring wells.

Recharge and Discharge Areas

Vertical gradients are generally downward in the northern portion of Site 2, and are generally upward in the southern Site 2 area and in the riparian zone to the south of the site boundary. Thus, recharge conditions occur in the northern portion of the plume, and discharge conditions in the southern and offsite portion of the plume. The site groundwater levels suggest that recharge lags large precipitation events by several months, due to the large depth to groundwater. Seasonal and annual changes in groundwater storage estimated from the site groundwater level data are summarized in Table 3-1. The deep percolation recharge rate is estimated to be about 0.1 inch per year based upon seasonal storage increases of 1 to 2 acre-feet per year (Table 3-1), an area of 165 acres, and site underflow calculations based upon the site well test and gradient data. The estimated recharge rate of 0.1 inch per year at Site 2 is substantially lower than the recharge rate of 2.5 inches per year estimated at LMC Beaumont Site 1. The difference can be attributed to two factors: surficial soils at Site 2 are generally very fine-grained (much more so than at Beaumont Site 1), which limits the rate of infiltration; and native and non-native grasses germinate almost immediately after moderate precipitation events at Beaumont Site 2, which suggests that evapotranspiration losses may be very high. Further support for the low recharge rates was also obtained from monitoring well transducer data collected at Site 2 between December 2008 and May 2009, which showed no rise in water levels in monitoring well TT-MW2-13 and two temporary monitoring wells installed in the alluvium on the streambed, and only a 0.2 feet rise in water levels in monitoring well TT-MW-8 despite the over 11 inches of precipitation recorded at the NWS Beaumont Station during this period. In contrast, at nearby LMC Beaumont Site 1, transducer data collected during the same period between December 2008 and May 2009 showed water levels rose 3 feet in MW-70, 3 feet in MW-18, and 15 feet in MW-37. However, because the recharge rate of 0.1 inches per year is atypical for a groundwater basin in this area, an upper bound of 1 inch per year is also used, where the upper bound is based upon more typical recharge rates

Table 3-1
Summary of Aquifer Changes in Storage
LMC Beaumont Site 2

Time Period	Area Description	Area (acres)	Average Change in Groundwater Levels (feet)	Chanage in Aquifer Bulk Volume Storage (acre-feet)	Change in Groundwater Storage[1] (acre-feet)	Wells affected	Average Depth to Groundwater in Area (feet)
Seasonal Changes in Aquifer Storage, First Water Well Locations							
Nov 06 to Mar 07	Offsite Riparian	15	0.87	13	1.3	No wells in area; extrapolated from South Boundary Wells	Probably < 18
Nov 06 to Mar 07	South Boundary	18	0.44	8	0.8	Tt-MW2-7; Tt-MW2-8; Tt-PZ2-1	18
Sep 07 to Nov 07	Test Bay 1	3	0.10	0.3	0.03	Tt-MW2-17S	71
Nov 07 to Feb 08	Offsite Riparian	15	2.00	30	3	No wells in area; extrapolated from South Boundary Wells	Probably < 18
Nov 07 to Feb 08	South Boundary	24	0.88	21	2.1	Tt-MW2-7; Tt-MW2-8; Tt-PZ2-1; Tt-MW2-5;Tt-MW2-6S	18 - 38
Nov 07 to Feb 08	Waste Discharge Area	13	0.31	4	0.4	Tt-MW2-9S	36
Feb 08 to May 08	Test Bay 1	12	0.50	6	0.6	Tt-MW2-17S; Tt-MW2-13; Tt-MW2-14	65 - 71
Dec 08 to Mar 09	Offsite Riparian	15	0.70	10.5	1.05	No wells in area; extrapolated from South Boundary Wells	Probably < 18
Dec 08 to Mar 09	South Boundary	18	0.56	10	1	Tt-MW2-7; Tt-MW2-8; Tt-PZ2-1	18
Dec 08 to Mar 09	Waste Discharge Area	13	0.46	6	0.6	Tt-MW2-9S	18
Feb 09 to May 09	Test Bay 1	12	0.21	2.5	0.25	Tt-MW2-17S; Tt-MW2-13; Tt-MW2-14	65 - 71
Seasonal Changes in Aquifer Storage, San Timoteo Well Locations							
Sep 06 to Nov 06	Propellant Burn Area	4	0.06	0.24	0.00024	Tt-MW2-12	50
Nov 07 to Mar 08	South Boundary	24	0.58	14	0.014	Tt-MW2-6D; Tt-MW2-7D	18-38
Nov 07 to Feb 08	Waste Discharge Area	13	0.31	4	0.004	Tt-MW2-9D	36
Nov 07 to Feb 08	Propellant Burn Area	4	0.05	0.2	0.0002	Tt-MW2-4D	55
Sep 07 to Nov 07	Propellant Burn Area	4	0.03	0.12	0.00012	Tt-MW2-12	50
Dec 08 to Mar 09	South Boundary	18	0.44	8	0.008	Tt-MW2-7D	38
Mar 09 to May 09	Propellant Burn Area	4	0.05	0.2	0.0002	Tt-MW2-12	50

Table 3-1
Summary of Aquifer Changes in Storage
LMC Beaumont Site 2

Time Period	Area Description	Area (acres)	Average Change in Groundwater Levels (feet)	Chanage in Aquifer Bulk Volume Storage (acre-feet)	Change in Groundwater Storage[1] (acre-feet)	Wells affected	Average Depth to Groundwater in Area (feet)
Annual Changes in Aquifer Storage, First Water Well Locations							
Nov 06 to Nov 07	Offsite Riparian	15	-0.40	-6	-0.6		~ 20
Nov 06 to Nov 07	Onsite	96	-0.86	34.37323998	3.437323998	All First Water	18 - 70
Nov 07 to Dec 08	Offsite Riparian	15	-0.45	-6.75	-0.675		~ 20
Nov 07 to Dec 08	Onsite	96	-0.70	28.02566384	2.802566384	All First Water	18 - 70
Dec 08 to Aug 09	Offsite Riparian	15	-0.50	-7.5	-0.75		~ 20
Dec 08 to Aug 09	Onsite	96	-0.28	11.09600793	1.109600793	All First Water	18 - 70
Annual Changes in Aquifer Storage, San Timoteo Well Locations							
Nov 06 to Nov 07	Offsite Riparian	15	-0.04	-0.6	-0.0006		~ 20
Nov 06 to Nov 07	Onsite	96	-0.55	-52.43640955	-0.05243641	All STF	18 - 70
Nov 07 to Dec 08	Offsite Riparian	15	-0.02	-0.3	-0.0003		~ 20
Nov 07 to Dec 08	Onsite	96	-0.51	-49.14217172	-0.049142172	All STF	18 - 70
Dec 08 to Aug 09	Offsite Riparian	15	0.04	0.6	0.0006		~ 20
Dec 08 to Aug 09	Onsite	96	-0.36	-34.90126832	-0.034901268	All STF	18 - 70

Notes:

1. Assumes specific yield value of 0.1 for first water locations and confined storage value of 0.001 for STF Well

for groundwater basins in this area. Shallow groundwater recharge by underflow is not expected to be significant due to the nearby watershed boundaries (see Boundary discussion below). Groundwater discharge is by evapotranspiration from the water table in the southern portion of the site and in the offsite riparian corridor, where the depth to groundwater is about 15 feet; by leakage into the deeper water-bearing zones in the competent San Timoteo in the northern portion of the site, where gradients are downward; and by underflow down the canyon. Currently there does not appear to be groundwater extraction in the area. Groundwater monitoring data show no evidence of mountain front or stream recharge, so it is assumed that the amount of recharge by this mechanism is small. However, since groundwater basins in Southern California often experience mountain front recharge and stream recharge during ephemeral runoff events, and because the monitoring data suggesting that the amount of recharge by mountain front or stream recharge is rather limited, the possibility for mountain front and stream recharge is considered in the model development (Section 4.3).

Groundwater Elevation and Flow Direction

Groundwater flow is generally consistent with the direction of surface water flow and topography. The horizontal hydraulic gradient in the area as measured in the site groundwater monitoring program is 0.030, with little spatial variability except in Test Bay Canyon, where the gradient flattens to 0.005 (Figure 3-5). The lower gradients in Test Bay Canyon are consistent with the higher hydraulic conductivity values (Appendix A, Figure A-4). Vertical gradients are generally downward in the northern Site 2 area, but upward in the southern portion of Site 2 and in the riparian corridor to the south of the site. Depth to groundwater is approximately 60 feet bgs in the northern portion of the site, decreasing to 15 feet bgs at the site boundary and in the offsite riparian area, and increasing to 45 feet bgs south of the San Timoteo/Mt Eden contact. Since the shallowest groundwater area is just above the San Timoteo/Mt Eden contact, it is possible that groundwater may be forced closer to the surface along this contact.

Seasonal and annual variations in water levels measured to date have been relatively small, with the maximum changes in water levels being typically less than 5 feet over the 2004 to 2010 monitoring period. There appears to be a long-term trend in water levels that correlates with measured precipitation (Figures 3-3A and 3-3B). Seasonal trends in water levels are observed in wells TT-MW2-17S and TT-MW2-14 in Test Bay Canyon; in wells TT-MW2-9S, TT-MW2-5, and TT-MW2-6 south of the Waste Discharge Area; and in wells TT-MW2-7, TT-MW2-8, and TT-PZ2-1 near the southern site boundary, but seasonal trends in water levels are remarkably absent in wells in the other areas of the site. The lack of seasonal water level trends in most areas of the site supports the hypothesis that groundwater recharge at the site is small. Two of the areas showing seasonal water level trends (Test Bay Canyon and the Waste Discharge Area) are perchlorate source areas; this may support some level of recharge near the source areas for the two main perchlorate plumes at the site.

3.4 HYDROLOGIC BOUNDARIES

The weathered San Timoteo formation aquifer thins to the east and west towards the margins of Laborde Canyon, where the competent San Timoteo formation is exposed in the canyon walls. Hydrologic boundaries for the competent San Timoteo are not well defined, but for the purposes of this CSM are limited to the area underlying the weathered San Timoteo formation aquifer. The base of the saturated weathered San Timoteo formation is assumed to be a leakage boundary for flow into the competent San Timoteo formation based upon the site water level data, pumping test observations, and the presence of contaminants in the competent San Timoteo formation. Similarly, leakage boundaries likely exist between the various water bearing zones within the competent San Timoteo, though the leakage rates between these units are likely considerably smaller.

3.5 HYDRAULIC PROPERTIES

Aquifer hydraulic conductivity values have a geometric mean around 0.16 feet per day for the weathered San Timoteo formation and 0.04 feet per day for the competent San Timoteo formation (Appendix A). Estimated aquifer transmissivity values are in the range of 10 per day for the weathered San Timoteo formation, and about 1 /day for individual water bearing zones within the competent San Timoteo formation. Specific yield values are assumed to be 10 percent in the weathered San Timoteo formation. Effective porosity values are assumed to be between 2 to 10 percent based upon site conditions and the lithology of the water-bearing zone (USEPA, 1998). Note that a wide range of effective porosity values is considered, which reflects the large uncertainty in this parameter. While a 10 percent effective porosity value is typical for the site lithologic conditions, this value is generally not consistent with the currently observed plume length and hydraulic gradient given the estimated time of perchlorate release; thus the 2 percent value is also used since it is generally consistent with the currently observed plume length and is still within the range of effective porosity values reported for the site lithologic conditions. It should be noted, however, that the 2 percent effective porosity value is based upon current hydraulic gradients, and that gradients at the time of release may have been considerably higher, since substantial quantities of water may have been added to the system. Total porosity values are assumed to be 20 percent. Note the total porosity excludes interbeds and is different from effective porosity, which excludes interbeds and also accounts for fast and slow paths through the remaining beds. Both porosity values are macro- (grid) scale parameters. For calculation purposes, the total porosity is used for rough mass calculations and the effective porosity is used for velocity calculations. Final model porosity values will be estimated during the model calibration process. Aquifer leakance values for leakage between the weathered and competent San Timoteo are estimated to be 2 x 10^{-6} day^{-1} assuming a competent San Timoteo hydraulic conductivity of 0.04 feet per day, a horizontal to vertical hydraulic conductivity ratio of 400, and a thickness of 50 feet between the weathered and competent San Timoteo water bearing zones.

3.6 WATER BUDGET

A preliminary saturated zone water budget is defined as part of the basis for construction of the numerical flow and transport model. For the purposes of this memorandum, a steady-state saturated zone water budget is defined to serve as a guide for developing the steady-state model, focusing on the weathered San Timoteo formation and the upper water-bearing units of the competent San Timoteo formation within the perchlorate plume areas. Since precipitation data and cumulative departure from mean precipitation data show there are prolonged wet and dry periods in this area, a transient water budget was also developed for the site as part of the model development discussed in Section 4.0 of this report. Changes in storage are given in Table 3-1 as 1 to 3 acre-feet per year, to serve as a guide for developing the transient model and water budget. Note that the total change in storage for the entire area was based upon the summed values of the change in storage for each area in Table 3-1, with areas lacking data assigned a value equal to the area weighted average value.

Key elements of the groundwater saturated zone water budget are as follows:

- Weathered San Timoteo Aquifer Recharge – Total recharge to the weathered San Timoteo formation aquifer is estimated to be approximately 2 acre feet per year (see Table 3-1 and recharge discussion in Section 3.3 above). These values are apportioned as follows:
  - Direct Precipitation – Estimated to be about 2 acre feet per year.
  - Direct Recharge from Creek – No significant creek recharge is expected based on the lack of any strong seasonal water level trend in wells near the creek and the lack of any groundwater mounding observed near the stream. However, since site monitoring data are limited and the lack of stream recharge may be somewhat atypical for a groundwater basin in this area, an upper bound for the stream recharge estimate (10 to

20 acre feet per year) is also used. The large range of values between the upper and lower bounds for the stream recharge is indicative of the uncertainty in this element of the CSM.

- Underflow – No underflow occurs into the area due to the location in the upper reaches of an enclosed watershed.
- Injection/Spreading – None.
- Leakage upward from underlying competent San Timoteo – Leakage upward into the weathered San Timoteo from the underlying competent San Timoteo may occur in the far southern areas where gradients are upward and there is evapotranspiration. Upward leakage is estimated to be 0.1 acre feet per year using a leakance factor of 2×10^{-6} day^{-1}, an area of 40 acres, and a head difference of 3 feet.

- Competent San Timoteo Aquifer Recharge – Total recharge to the competent San Timoteo Aquifer is estimated to be 0.4 acre feet per year. These values are apportioned as follows:
  - Leakage – The leakage recharge estimate can be calculated to be 0.4 acre feet per year using the area of 165 acres, a leakance factor of 2×10^{-6} day^{-1}, and head difference of 3 feet between the weathered and competent San Timoteo.
  - Direct Recharge from Creek – No significant creek recharge is expected based the lack of any strong seasonal water level trend in wells near the creek.
  - Underflow – Limited underflow occurs into the area due to the location in the upper reaches of an enclosed watershed.
  - Injection/Spreading – None.

- Weathered San Timoteo Aquifer Discharge – Total discharge from the weathered San Timoteo is estimated to be 2 acre feet per year to balance inflow. These values are apportioned as follows:
  - Extraction – No extraction currently exists in the site area.
  - Evapotranspiration – Evapotranspiration anticipated in the riparian area at rate of 2.33 feet per year for a total discharge of 0.5 to 1 acre feet per year.
  - Discharge to Creek – No significant volume expected based upon depth to groundwater, which is well below the base of the streambed.
  - Underflow – Estimated as 1 acre feet per year based upon difference between recharge, leakage, and evapotranspiration.
  - Leakage to Competent San Timoteo – Leakage to competent San Timoteo is estimated to be 0.4 acre feet per year using a leakance factor of 2×10^{-6} day^{-1}, an area of 165 acres, and a head difference of 3 feet.

- Competent San Timoteo Aquifer Discharge – Total discharge from the competent San Timoteo is estimated to be 0.4 acre feet per year to balance inflow. These values are apportioned as follows:

  - Extraction – No extraction currently exists in the site area.

  - Evapotranspiration – No significant evapotranspiration anticipated due to the large depth to groundwater and the overlying saturated, weathered San Timoteo.

  - Discharge to Creek – No significant volume expected based upon depth to groundwater and the overlying saturated, weathered San Timoteo.

  - Underflow – Estimated to be 0.3 acre-feet per year down the canyon based upon the competent San Timoteo transmissivity value of 3 /day, the gradient of 0.03, and the width of 400 feet.

  - Leakage downward to deeper Competent San Timoteo – Leakage out of the base of the competent San Timoteo is estimated to be 0.1 acre feet per year using a leakance factor of 2 x 10^{-7} day^{-1}, an area of 165 acres, and a head difference of 10 feet. Due to the very small leakage rate into deeper zones, this component of the water budget may be ignored in the numerical model.

  - Leakage upward to overlying Weathered San Timoteo – Leakage upward into the weathered San Timoteo may occur in the far southern areas where gradients are upward and there is evapotranspiration. Upward leakage is estimated to be 0.1 acre feet per year using a leakance factor of 2 x 10^{-6} day^{-1}, an area of 40 acres, and a head difference of 3 feet.

- Surface Water – The site area is characterized by mildly wet winters and warm to hot, dry summers, with the wettest months from December to March. The long term average annual precipitation for the nearby Beaumont and San Jacinto NWS is 14.28 inches and 10.97 inches, respectively. Since 1980 the average annual precipitation has been above the long term average (16.30 inches and 12.06 inches for the Beaumont and San Jacinto NWS respectively) with oscillating periods of drought and heavy precipitation. During the most recent 6 year period between 2004 and 2010 when site groundwater levels are measured, precipitation has been at or above average from 2004 and 2005, then markedly below average from 2006 to 2009. Trends in site groundwater levels appear to correlate well with trends in precipitation (Figures 3-3A and 3-3B). Laborde Canyon forms the principal drainage course through the 2,821 acre site watershed and allows ephemeral storm water to drain southward toward the San Jacinto Valley. Surface water flow in Laborde Canyon is ephemeral in nature and remains dry when there is no rainfall. Consequently, no permanent streams, creeks, or other major surface water bodies occur at the site.

  - Precipitation – Total volume due to precipitation is estimated to be 3,530 acre feet per year for the sub-watersheds above the site boundary based upon precipitation value 15 inches per year and the watershed area of 2,824 acres. Total volume due to precipitation is estimated to be 2,685 acre feet per year for the sub-watersheds below the site boundary based upon precipitation value 15 inches per year and the watershed area of 2,148 acres. Runoff is estimated to be only about 5 percent of precipitation or 180 acre feet per year at the southern site boundary and 317 acre feet per year at the southern boundary of the offsite plume. Note this water budget assumes that much of the precipitation discharges as evapotranspiration from the soils and vadose zone, which is typical for this area (USGS watershed studies in this area show 80 percent or more of precipitation is lost to evapotranspiration; Guay, 2002).

- Streamflow –Annual average streamflow estimated to be 180 - 317 acre feet per year, with no perennial or baseflow.

Some elements of the water budget may not necessarily balance due to uncertainties in parameter values.

The generally low values for the water budget (1 to 2 acre feet per year) and the recharge rate (0.1 inches per year) are supported by the following:

- Site underflow calculations derived from site specific aquifer test and hydraulic gradient data, which estimate weathered San Timoteo underflow rates of 0.2 to 1 acre feet per year across Laborde Canyon at the site boundary;
- Water level hydrographs that show very small seasonal variations in water level elevation, reflecting rather limited recharge;
- Aquifer storage calculations that show seasonal changes in aquifer pore volume on the order of 1 to 3 acre feet per year; and
- The lack of any surfacing groundwater in the discharge area in the south, where the discharge rates must be so small that evapotranspiration alone apparently removes enough groundwater to prevent surface discharge or groundwater within 10 feet of the surface.

However, since these water budget and recharge estimates are low for a groundwater basin of this size in this area, an upper bound for the water budget estimate (10 to 20 acre feet per year) and the recharge rate estimate (1 inches per year) is also used, where the upper bound estimates are based upon more typical recharge rates for groundwater basins in this area. The large range of values between the upper and lower bounds for the water budget is indicative of the large uncertainty in this element of the CSM. This water budget is preliminary to serve as a guide for numerical model construction and calibration. The numerical model (Section 4.0) will also investigate the potential for higher water budget in the sensitivity analysis.

3.7 PLUME/COC CONCEPTUAL SITE MODEL

A summary of the transport aspects of the conceptual model is given in the following sections. Two major groundwater perchlorate plumes have been identified at the site (Figures 3-6A and 3-6B): one related to impacts in southern Test Bay Canyon (Test Bay Canyon plume), and one related to impacts in the WDA (WDA plume). The Test Bay Canyon groundwater plume extends 2,100 feet downgradient from the source area near Test Bay 3, terminating north of well TT-

MW2-12 in Laborde Canyon, with perchlorate concentrations at the source area exceeding 100,000 µg/L. Perchlorate concentrations gradually attenuate to approximately 13,000 µg/L at well TT-MW2-18, and then rapidly attenuate to non-detectable concentrations at well TT-MW2-12, located approximately 625 feet downgradient of TT-MW2-18. The WDA groundwater plume extends approximately 4,000 feet downgradient from the source area in the WDA to a few hundred feet beyond the southern boundary of the site. Maximum perchlorate concentrations at the WDA source area exceed 100,000 µg/L, then gradually attenuate to approximately 500 µg/L at the southern property boundary and to non-detect within a few hundred feet of the southern boundary. Note that the root cause for the differences in Test Bay and WDA plume length are not well known, and this may be attributed to either differences in the volume of water released at each site, or to the underlying groundwater velocity in these locations. The model predictions of plume flowpaths (Figure C-6) would suggest the cause for different plume lengths may be to related to the underlying groundwater velocity in these locations, but the model itself is uncertain, so caution is advised prior to adopting this conclusion. There is also some degree of uncertainty on the actual plume concentrations near the site southern boundary, as the shorter screened wells such as TT-MW2-7 and TT-MW2-8 show higher concentrations of approximately 500 µg/L, while the longer screened wells such as TT-EW2-1 show markedly smaller concentrations which are close to the perchlorate MCL of 6 µg/L.

Minor perchlorate plumes are also present in groundwater at the Centrifuge area in northern Test Bay Canyon, the Garbage Disposal Area in the east of the site (Area M), and in a discontinuous, “stranded” segment of the perchlorate plume located further to the south at TT-MW2-19S. Other than perchlorate, RDX was found in two isolated areas in wells TT-MW2-13 and TT-MW2-24; methylene chloride was found in one well (TT-MW2-22) in the WDA; and TCE was found in two isolated areas at wells TT-MW2-11 and TT-MW2-32 in Area M, and at wells TT-MW2-21, TT-MW2-22, TT-MW2-24, and TT-MW2-37A near the WDA. More recently, 1,4-dioxane has been detected at wells TT-MW2-24, TT-MW2-37A, TT-MW2-22, TT-MW2-26, TT-MW2-9S, and TT-MW2-5, located near and downgradient from the WDA.

Except at the major source areas, the vertical distribution of COCs is primarily limited to the upper water bearing unit within the shallowest 50 feet of the aquifer. At the Test Bay and WDA source areas, the groundwater plume extends about 100 to 150 feet below the water table, which may be attributable to contamination being driven to this depth by the large quantities of water that were likely discharged during the historical release events. This same mechanism may have elongated the plume in the downgradient direction. The plumes are not detached from the soil source areas, indicating the sources are continuing. The current CSM indicates that much of the perchlorate in groundwater may discharge as evapotranspiration in the riparian zone south of the site, although a small amount may continue as underflow further down Laborde Canyon, depending on the magnitude of perchlorate attenuation in the riparian area. The CSM is based upon current source conditions, and little is known about variations in the source conditions over time.

3.7.1 Water Quality and Contaminants of Concern

General minerals data (Table 3-2) indicate that sodium is the dominant cation in nearly all wells, and alkalinity and chloride are the dominant anions. Magnesium and sulfate are generally low in all wells, except that there is a possible increasing trend for sulfate downgradient. There is not a distinct difference in the water quality type in the competent and weathered San Timoteo. There does appear, however, to be a strong correlation between higher chloride concentrations and perchlorate-impacted groundwater (see Table 3-2), as unimpacted wells generally have low chloride, slightly impacted wells generally have moderate chloride, and heavily impacted wells generally have high chloride. Based upon the high chloride concentrations, the source areas may have had degradation occurring in the past, but co-release of chloride with perchlorate also could have occurred and also would explain the high chloride concentrations.

Perchlorate, TCE, and methylene chloride have been classified as primary COPCs, based on elevated concentrations and frequency of detection. Since RDX has been detected at much lower concentrations that are co-located with the primary COPCs, RDX has been classified as a secondary COPC. 1,4-Dioxane has only been discovered recently, and has not yet been classified at a primary or secondary COPC.

COC Migration Pathway and Rates

The primary pathway for contaminant migration in groundwater appears to be the weathered STF that is primarily located beneath the major canyons. Except under the source areas, significant perchlorate concentrations are primarily limited to the first water bearing zone; under the source areas significant perchlorate concentrations extend into deeper water bearing zones, possibly driven to this depth by the large volumes of rinsate water in which the perchlorate was likely released.

Groundwater velocity values are estimated to average about 20 to 90 feet per year in the weathered San Timoteo using a geometric mean hydraulic conductivity value of 0.16 feet per day, a gradient

Table 3-2
Water Quality Data from Monitoring Wells
LMC Beaumont Site 2

Well	Depth	Unit	Sodium (Na^{+1}) (meq/L)	Calcium (Ca^{+2}) (meq/L)	Magnesium (Mg^{+2}) (meq/L)	Chloride (Cl^{-1}) (meq/L)	Alkalinty (Alk^{-1}) (meq/L)	Sulfate (SO_4^{-2}) (meq/L)	Nitrate (NO_3^{-1}) (meq/L)	Perchlorate (µg/L)	TDS (mg/L)
TT-MW2-16	S	STF	5.35	5.90	1.76	2.30	5.90	0.69	0.45	1.9	740
TT-MW2-2	D	STF	5.22	0.27	0.04	1.44	2.05	1.00	0.0008	0.5	370
TT-MW2-3	I	STF	5.61	5.30	1.82	5.13	3.16	0.91	0.29	19,900	685
TT-MW2-17S	S	WSTF	5.74	3.46	1.50	1.44	4.34	1.04	0.37	5,870	555
TT-MW2-17D	D	STF	7.67	3.94	1.13	7.57	1.66	1.28	0.07	79,300	715
TT-MW2-14	S	STF	13.22	3.61	0.71	10.38	2.87	1.64	0.24	34,000	1,000
TT-MW2-13	S	WSTF	8.78	3.40	1.05	7.31	3.44	0.89	0.13	5,540	770
TT-MW2-1	S	WSTF	7.41	2.61	0.78	5.50	2.72	0.80	0.13	4,930	633
TT-MW2-18	D	STF	7.70	0.50	0.09	2.43	3.52	1.23	0.0008	19,700	560
TT-MW2-12	S	WSTF	9.00	0.30	0.04	5.44	1.89	1.53	0.0008	10.0	610
TT-MW2-11	S	WSTF	9.89	2.65	0.48	7.35	3.11	0.70	0.27	195	803
TT-MW2-10	S	WSTF	8.57	2.31	0.34	5.56	3.03	1.50	0.0008	0.5	660
TT-MW2-4S	I	STF	4.70	0.27	0.03	0.89	2.18	0.71	0.01	0.5	300
TT-MW2-4D	D	STF	4.16	0.21	0.02	0.71	1.48	0.90	0.01	0.5	290
TT-MW2-9S	S	STF	8.26	5.95	1.02	4.40	5.33	3.19	0.16	314	930
TT-MW2-9D	I	STF	5.26	0.57	0.06	1.26	1.85	1.72	0.0008	21.3	415
TT-MW2-5	S	WSTF	8.17	4.50	0.75	4.82	3.85	2.83	0.17	1,070	830
TT-MW2-6S	S	WSTF	7.83	4.13	0.59	4.32	4.56	2.94	0.09	304	810
TT-MW2-6D	I	STF	7.61	0.35	0.03	2.93	2.21	2.67	0.0008	0.5	560
TT-MW2-8	S	WSTF	9.26	2.64	0.29	3.89	4.43	3.79	0.11	396	870
TT-MW2-7	S	WSTF	9.43	3.78	0.69	4.71	4.92	3.90	0.11	407	930

Notes:

Data are listed from North to South and by depth for well pai

S=shallow, I=Intermediate, D=Deep, WSTF = weathered San Timoteo, STF = San Timoteo, meq/L = milli-equivalents per lit

meq/L = concentration in mg/L multipled by ion charge and divided by the ion molecular wei

=dominant catior

=dominant anior

=lower TDS in well pai

=perchlorate concentration > 1,000 ug/

See also Stiff diagrams in Tt Quarterly Monitoring Repor of 0.03, and an effective porosity of 0.02 to 0.10. These velocity values are reasonably consistent with the plume length and elapsed time since possible contaminant release (Tetra Tech, 2009).

The groundwater contaminant velocity is equal to the groundwater velocity divided by the contaminant retardation factor. The retardation factor is nearly equal to one for all COCs based upon the very small total organic carbon values detected at the site. For example, using the highest total organic carbon value reported (100 mg/kg), the TCE retardation factor would be only 1.05, and using the mean value (38 mg/kg) the TCE retardation factor would be only 1.02. The RDX and methylene chloride retardation factors would be even closer to one (1.04 and 1.01), respectively, for a 100 mg/kg organic carbon value. Perchlorate is not subject to physical adsorption on organic carbon, so the retardation factor would be 1.00.

COC Time Trends

As shown in Table 3-3, time trends in contaminant data were evaluated using groundwater quality statistical analysis methods. For perchlorate, 38 percent of the wells had no trend, 38 percent of the wells had stable trends, 12 percent of the wells had increasing trends, and 12 percent of the wells had decreasing trends. The increasing trends were in TT-MW2-1, TT-MW2-14, and TT-MW2-26, and the decreasing trends were in TT-MW2-9D, TT-MW2-17S, and TT-MW2-17D.

Contaminant Mass and Plume Volumes

Soil source areas and groundwater impacts for perchlorate, TCE, methylene chloride, and RDX are identified in the recent DSI report (Tetra Tech, 2010a). There are four separate groundwater perchlorate plumes at Site 2 covering a total of approximately 68 acres: the <0.1-acre centrifuge area groundwater plume in the far north of the site (which may be restricted to isolated perched zones within the STF); the 20-acre test bay area groundwater plume in the central portion of the site; the 3-acre garbage disposal area groundwater plume to the east of Laborde Canyon; and the 45-acre WDA groundwater plume in the southern portion of the site that extends a few hundred feet offsite. Groundwater plume thickness is assumed to be 50 feet, except under the sources where it extends up to 150 feet below the water table. Aquifer total porosity is assumed to be 20 percent and the retardation factors are assumed to be 1. The groundwater plume water volume and COCs mass values estimated using the plume concentration maps (Figure 3-6A and 3-6B), aquifer porosity, and retardation factor values are given in Table 3-4. The total groundwater perchlorate plume area is 68 acres, water volume is 748 acre-feet, and mass of perchlorate is 4,395 pounds. Note that this perchlorate mass estimate of 4,395 pounds is highly uncertain due to the limited

Table 3-3
Statistical Analysis of Groundwater Monitoring Data
LMC Beaumont Site 2
Data from Sept 2004 to Sept 2009

Well	Min Date	Max Date	TCE Num Samples	TCE Num Detects	Min (µg/L)	Max (µg/L)	Mean (µg/L)	Trend	TCE Magnitude of Trend (%/yr)	TCE Magnitude of Trend (µg/L/yr)	Min Date	Max Date	Meth Chlor Num Samples	Meth Chlor Num Detects	Min (µg/L)	Max (µg/L)	Mean (µg/L)	Trend	Meth Chlor Magnitude of Trend (%/yr)	Meth Chlor Magnitude of Trend (µg/L/yr)
SW-1	01/28/08	01/28/08	1	0	0.2	0.2	0.2	N/A			01/28/08	01/28/08	1	0	0.5	0.5	0.5	N/A		
SW-2	01/28/08	02/16/09	3	0	0.2	0.2	0.2	N/A			01/28/08	02/16/09	3	0	0.5	0.5	0.5	N/A		
SW-3	01/28/08	02/16/09	2	0	0.2	0.2	0.2	N/A			01/28/08	02/16/09	2	0	0.5	0.5	0.5	N/A		
SW-5	01/28/08	02/16/09	3	0	0.2	0.2	0.2	N/A			01/28/08	02/16/09	3	0	0.5	0.5	0.5	N/A		
SW-6	01/28/08	02/16/09	2	0	0.2	0.2	0.2	N/A			01/28/08	02/16/09	2	0	0.5	0.5	0.5	N/A		
SW-7	01/28/08	02/16/09	2	0	0.2	0.2	0.2	N/A			01/28/08	02/16/09	2	0	0.5	0.5	0.5	N/A		
TT-MW2-1	09/27/04	05/27/08	12	0	0.2	1.0	0.3	S			09/27/04	05/27/08	12	2	0.5	4.2	2.0	NT		
TT-MW2-2	09/27/04	05/20/08	12	0	0.2	1.0	0.3	S			09/27/04	05/20/08	12	3	0.5	4.1	2.2	NT		
TT-MW2-3	09/27/04	11/20/07	17	17	1.2	8.1	4.9	S			09/27/04	11/20/07	17	6	0.5	7.3	2.8	NT		
TT-MW2-4S	09/27/04	05/21/08	11	0	0.2	1.0	0.3	S			09/27/04	05/21/08	11	3	0.5	3.9	2.1	NT		
TT-MW2-4D	09/27/04	11/21/06	9	0	0.2	0.3	0.3	S			09/27/04	11/21/06	9	1	0.5	4.9	2.4	NT		
TT-MW2-5	12/12/05	05/28/09	8	0	0.2	1.0	0.4	S			12/12/05	05/28/09	8	1	0.5	4.8	1.9	NT		
TT-MW2-6S	12/12/05	05/22/08	7	0	0.2	1.0	0.4	S			12/12/05	05/22/08	7	2	0.5	2.8	1.5	NT		
TT-MW2-6D	12/12/05	05/19/09	8	0	0.2	1.0	0.4	S			12/12/05	05/19/09	8	0	0.5	2.6	1.6	S		
TT-MW2-7	10/03/06	05/23/08	10	0	0.2	1.0	0.3	S			10/03/06	05/23/08	10	1	0.5	1.0	0.6	NT		
TT-MW2-7D	01/09/08	11/18/08	5	0	0.2	1.0	0.4	S			01/09/08	11/18/08	5	0	0.5	1.0	0.6	S		
TT-MW2-8	10/03/06	05/23/08	10	0	0.2	1.0	0.3	S			10/03/06	05/23/08	10	0	0.5	1.0	0.6	S		
TT-MW2-9S	10/03/06	05/23/08	8	0	0.2	1.0	0.3	S			10/03/06	05/23/08	8	0	0.5	1.0	0.6	S		
TT-MW2-9D	10/03/06	05/19/09	9	0	0.2	1.0	0.3	S			10/03/06	05/19/09	9	0	0.5	2.6	0.8	S		
TT-MW2-10	10/04/06	05/21/08	8	0	0.2	1.0	0.3	S			10/04/06	05/21/08	8	0	0.5	1.0	0.6	S		
TT-MW2-11	10/05/06	05/20/09	13	13	4.4	8.7	6.3	PI	16.3	1.0	10/05/06	05/20/09	13	0	0.5	2.6	0.7	S		
TT-MW2-12	10/05/06	05/22/08	8	0	0.2	1.0	0.3	S			10/05/06	05/22/08	8	0	0.5	1.0	0.6	S		
TT-MW2-13	10/05/06	05/26/09	12	0	0.2	1.0	0.3	S			10/05/06	05/26/09	12	0	0.5	2.6	0.8	S		
TT-MW2-14	11/20/06	06/02/09	10	0	0.2	2.0	0.7	S			11/20/06	06/02/09	10	9	2.6	380.0	164.4	D	-135.9	-190.2
TT-MW2-16	10/03/06	05/20/08	9	0	0.2	1.0	0.4	S			10/03/06	05/20/08	9	0	0.5	1.0	0.6	S		
TT-MW2-17S	11/20/06	05/29/09	9	0	0.2	1.0	0.3	S			11/20/06	05/29/09	9	0	0.5	2.6	1.0	S		
TT-MW2-17D	11/20/06	06/02/09	11	11	0.5	3.2	0.9	S			11/20/06	06/02/09	11	0	0.5	2.6	0.7	S		
TT-MW2-18	10/04/06	05/27/08	10	0	0.2	1.0	0.3	S			10/04/06	05/27/08	10	0	0.5	1.0	0.6	S		
TT-MW2-19S	06/15/09	06/15/09	1	0	0.5	0.5	0.5	N/A			06/15/09	06/15/09	1	0	0.5	0.5	0.5	N/A		
TT-MW2-19D																				
TT-MW2-20S																				
TT-MW2-20D																				
TT-MW2-21	01/09/08	05/20/09	6	3	0.2	1.6	0.6	I	132.6	0.9	01/09/08	05/20/09	6	4	0.5	7.7	2.4	I	114.0	2.8
TT-MW2-22	01/09/08	05/19/09	8	8	47.0	350.0	182.3	NT			01/09/08	05/19/09	8	8	3.9	750.0	271.4	D	-160.7	-289.3
TT-MW2-23	01/09/08	05/29/09	6	0	0.2	1.0	0.4	S			01/09/08	05/29/09	6	1	0.5	2.6	1.0	NT		
TT-MW2-24	01/09/08	05/29/09	9	9	61.0	110.0	94.9	S			01/09/08	05/29/09	9	2	0.5	2.6	1.5	NT		
TT-MW2-25	11/20/08	09/02/09	5	0	0.2	0.3	0.2	S			11/20/08	09/02/09	5	0	0.2	2.6	0.7	S		
TT-MW2-26	11/20/08	09/02/09	6	0	0.2	0.3	0.2	S			11/20/08	09/02/09	6	1	0.2	2.6	0.6	S		
TT-MW2-27	11/20/08	09/02/09	7	0	0.2	0.3	0.2	S			11/20/08	09/02/09	7	0	0.2	2.6	0.9	S		
TT-MW2-28	02/09/09	09/01/09	4	0	0.2	0.3	0.2	N/A			02/09/09	09/01/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-29B	02/09/09	08/31/09	4	0	0.2	0.3	0.2	N/A			02/09/09	08/31/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-29C	02/09/09	08/31/09	5	0	0.2	0.3	0.2	N/A			02/09/09	08/31/09	5	1	0.2	2.6	0.6	N/A		
TT-MW2-30A	02/13/09	08/26/09	6	0	0.2	0.3	0.2	N/A			02/13/09	08/26/09	6	1	0.2	2.6	0.6	N/A		
TT-MW2-30B	02/13/09	08/26/09	5	0	0.2	0.3	0.2	N/A			02/13/09	08/26/09	5	0	0.2	2.6	1.1	N/A		
TT-MW2-30C	02/13/09	08/26/09	4	0	0.2	0.3	0.2	N/A			02/13/09	08/26/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-31A	02/13/09	09/01/09	4	0	0.2	0.3	0.2	N/A			02/13/09	09/01/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-31B	02/13/09	09/01/09	4	0	0.2	0.3	0.2	N/A			02/13/09	09/01/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-32	02/09/09	09/01/09	4	2	0.2	1.1	0.5	N/A			02/09/09	09/01/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-33A	02/03/09	08/26/09	5	0	0.2	0.3	0.2	N/A			02/03/09	08/26/09	5	0	0.2	2.6	1.1	N/A		
TT-MW2-33B	02/03/09	08/26/09	4	0	0.2	0.3	0.2	N/A			02/03/09	08/26/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-33C	02/03/09	08/26/09	4	0	0.2	0.3	0.2	N/A			02/03/09	08/26/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-34A	02/03/09	08/31/09	4	0	0.2	0.3	0.2	N/A			02/03/09	08/31/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-34B	02/11/09	08/31/09	5	0	0.2	0.3	0.2	N/A			02/11/09	08/31/09	5	0	0.2	2.6	0.6	N/A		
TT-MW2-34C	02/11/09	08/31/09	4	0	0.2	0.3	0.2	N/A			02/11/09	08/31/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-35A	02/13/09	09/01/09	4	0	0.2	0.3	0.2	N/A			02/13/09	09/01/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-35B	02/11/09	09/01/09	4	0	0.2	0.3	0.2	N/A			02/11/09	09/01/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-36A	02/12/09	08/31/09	6	0	0.2	0.3	0.2	N/A			02/12/09	08/31/09	6	1	0.2	2.6	0.6	N/A		
TT-MW2-36B	02/12/09	08/27/09	4	0	0.2	0.3	0.2	N/A			02/12/09	08/27/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-36C	02/13/09	08/27/09	4	0	0.2	0.3	0.2	N/A			02/13/09	08/27/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-37A	02/12/09	09/02/09	4	1	0.2	0.7	0.3	N/A			02/12/09	09/02/09	4	1	0.2	2.6	0.8	N/A		
TT-MW2-37B	02/12/09	09/02/09	4	0	0.2	0.3	0.2	N/A			02/12/09	09/02/09	4	1	0.2	2.6	0.8	N/A		
TT-MW2-38A	03/26/09	08/27/09	4	0	0.2	0.3	0.2	N/A			03/26/09	08/27/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-38B	03/26/09	08/27/09	4	0	0.2	0.3	0.2	N/A			03/26/09	08/27/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-38C	03/26/09	08/27/09	5	0	0.2	0.3	0.2	N/A			03/26/09	08/27/09	5	1	0.2	2.6	0.6	N/A		
TT-MW2-39	03/20/09	08/27/09	8	0	0.2	0.3	0.2	N/A			03/20/09	08/27/09	8	1	0.2	2.6	0.8	N/A		
TT-MW2-40A	04/28/09	08/27/09	4	0	0.2	0.3	0.2	N/A			04/28/09	08/27/09	4	1	0.2	2.6	0.8	N/A		
TT-MW2-40B	04/28/09	08/27/09	4	0	0.2	0.3	0.2	N/A			04/28/09	08/27/09	4	0	0.2	2.6	0.8	N/A		
TT-MW2-40C	04/27/09	08/27/09	4	0	0.2	0.3	0.2	N/A			04/27/09	08/27/09	4	1	0.2	2.6	0.8	N/A		
TT-MW2-PZ1	04/27/09	04/27/09	1	0	0.2	0.2	0.2	N/A			04/27/09	04/27/09	1	0	0.2	0.2	0.2	N/A		
W2-3	11/26/07	11/26/07	5	0	0.2	0.2	0.2	N/A			11/26/07	11/26/07	5	0	0.5	0.5	0.5	N/A		
W2-5	11/19/07	11/19/07	1	0	0.2	0.2	0.2	N/A			11/19/07	11/19/07	1	1	0.5	0.5	0.5	N/A		
WS-1																				
WS-1-TOP																				
WS-2																				

	TCE (# wells)	% Total
"N/A"-Insufficient Data	39	
Blank-No data	6	
"NT" - No Trend	1	3
"S" - Stable	26	90
"I" - Increasing	1	3
"PI" -Probably Increasing	1	3
"D" - Decreasing	0	0
"PD" -Probably Decreasing	0	0
Total Trend Wells	29	100

	Meth Chlor(# wells)	% Total
"N/A"-Insufficient Data	39	
Blank-No data	6	
"NT" - No Trend	10	34
"S" - Stable	16	55
"I" - Increasing	1	3
"PI" -Probably Increasing	0	0
"D" - Decreasing	2	7
"PD" -Probably Decreasing	0	0
Total Trend Wells	29	100

Table 3-3
Statistical Analysis of Groundwater Monitoring Data
LMC Beaumont Site 2
Data from Sept 2004 to Sept 2009

Well	Min Date	Max Date	Perc Num Samples	Perc Num Detects	Min (µg/L)	Max (µg/L)	Mean (µg/L)	Trend	Perchlorate Magnitude of Trend (%/yr)	Perchlorate Magnitude of Trend (µg/L/yr)	Min Date	Max Date	Diox Num Samples	Diox Num Detects	Min (µg/L)	Max (µg/L)	Mean (µg/L)	Trend	1,4-Dioxane Magnitude of Trend (%/yr)	1,4-Dioxane Magnitude of Trend (µg/L/yr)
SW-1	01/28/08	01/28/08	1	0	0.5	0.5	0.5	N/A												
SW-2	01/28/08	02/16/09	3	3	38.3	42.4	40.2	N/A												
SW-3	01/28/08	02/16/09	2	0	0.5	0.5	0.5	N/A												
SW-5	01/28/08	02/16/09	3	2	0.5	2.7	1.8	N/A												
SW-6	01/28/08	02/16/09	2	1	0.5	1.6	1.0	N/A												
SW-7	01/28/08	02/16/09	2	0	0.5	0.5	0.5	N/A												
TT-MW2-1	09/27/04	06/01/09	19	19	2,400.0	11,600.0	6,097.9	I	18.0	1,099.8	09/27/04	02/16/05	2	0	1.1	1.1	1.1	N/A		
TT-MW2-2	09/27/04	05/20/08	12	0	0.4	0.6	0.5	S			09/27/04	02/16/05	3	0	1.1	1.1	1.1	N/A		
TT-MW2-3	09/27/04	11/20/07	17	17	740.0	68,000.0	37,356.5	S			09/27/04	02/16/05	2	0	1.1	1.1	1.1	N/A		
TT-MW2-4S	09/27/04	05/26/09	15	3	0.4	7.3	1.1	NT			09/27/04	02/16/05	2	0	1.1	1.1	1.1	N/A		
TT-MW2-4D	09/27/04	11/21/06	9	0	0.4	0.6	0.5	S			09/27/04	02/16/05	2	0	1.1	1.1	1.1	N/A		
TT-MW2-5	12/12/05	05/28/09	13	13	810.0	1,070.0	912.4	S			06/26/06	09/02/09	3	2	0.0	1.2	0.7	N/A		
TT-MW2-6S	12/12/05	05/19/09	14	14	150.0	304.0	221.1	PD	-13.3	-29.4	05/19/09	05/19/09	1	0	0.4	0.4	0.4	N/A		
TT-MW2-6D	12/12/05	05/19/09	12	3	0.5	2.3	0.8	NT			05/19/09	05/19/09	1	0	0.4	0.4	0.4	N/A		
TT-MW2-7	10/03/06	05/28/09	16	16	370.0	580.0	449.6	NT			11/06/06	05/28/09	2	0	0.4	0.6	0.5	N/A		
TT-MW2-7D	01/09/08	05/27/09	7	1	0.5	2.5	1.1	NT			05/27/09	05/27/09	1	0	0.4	0.4	0.4	N/A		
TT-MW2-8	10/03/06	05/22/09	13	13	263.0	519.0	352.8	S			11/06/06	05/22/09	3	0	0.4	0.6	0.5	N/A		
TT-MW2-9S	10/03/06	05/28/09	11	11	141.0	4,300.0	1,019.5	I	127.4	1,299.0	05/28/09	09/02/09	2	2	6.1	6.8	6.5	N/A		
TT-MW2-9D	10/03/06	05/19/09	11	5	0.5	28.8	7.0	D	-111.2	-7.8	05/19/09	05/19/09	1	0	0.4	0.4	0.4	N/A		
TT-MW2-10	10/04/06	06/01/09	10	0	0.5	2.3	0.7	S												
TT-MW2-11	10/05/06	05/20/09	16	16	191.0	469.0	276.5	NT			05/20/09	05/20/09	1	0	0.4	0.4	0.4	N/A		
TT-MW2-12	10/05/06	06/03/09	10	4	0.5	10.0	2.1	NT												
TT-MW2-13	10/05/06	05/26/09	13	13	2,770.0	6,350.0	3,770.8	S												
TT-MW2-14	11/20/06	06/02/09	11	11	34,000.0	49,500.0	41,518.2	PI	6.4	2,663.4										
TT-MW2-16	10/03/06	05/26/09	11	11	2.7	4.9	3.8	S												
TT-MW2-17S	11/20/06	05/29/09	12	12	1,600.0	5,870.0	2,641.7	D	-45.3	-1,196.3										
TT-MW2-17D	11/20/06	06/02/09	14	14	18,900.0	79,300.0	46,992.9	S												
TT-MW2-18	10/04/06	05/26/09	13	13	12,700.0	20,200.0	15,515.4	D	-8.4	-1,297.9										
TT-MW2-19S	08/08/08	08/24/09	8	6	0.5	5.4	2.7	NT			05/22/09	08/24/09	5	1	0.0	8.7	1.8	N/A		
TT-MW2-19D	07/15/08	08/24/09	8	2	0.1	26.5	5.4	NT			05/22/09	08/24/09	2	0	0.0	0.4	0.2	N/A		
TT-MW2-20S	05/20/08	08/24/09	6	0	0.1	0.5	0.3	S			05/22/09	08/24/09	2	0	0.0	0.4	0.2	N/A		
TT-MW2-20D	05/20/08	08/24/09	6	1	0.1	0.5	0.3	NT			05/22/09	08/24/09	2	0	0.0	0.4	0.2	N/A		
TT-MW2-21	01/09/08	05/20/09	7	0	0.5	2.3	1.1	S			05/20/09	05/20/09	1	0	0.4	0.4	0.4	N/A		
TT-MW2-22	01/09/08	05/19/09	9	0	0.5	2.3	0.9	S			03/20/09	09/01/09	3	3	35.0	45.0	39.0	N/A		
TT-MW2-23	01/09/08	05/29/09	7	2	0.5	2.7	0.9	NT			05/29/09	05/29/09	1	0	0.4	0.4	0.4	N/A		
TT-MW2-24	01/09/08	05/29/09	11	11	109,000.0	190,000.0	143,454.5	NT			05/29/09	09/01/09	3	3	250.0	280.0	266.7	N/A		
TT-MW2-25	11/20/08	09/02/09	6	1	0.1	2.3	0.9	NT			05/20/09	09/02/09	2	0	0.4	31.0	15.7	N/A		
TT-MW2-26	11/20/08	09/02/09	8	8	4.0	64.0	47.8	I	135.9	58.4	05/20/09	09/02/09	3	1	0.0	31.0	11.6	N/A		
TT-MW2-27	11/20/08	09/02/09	11	11	15.0	155.0	51.0	S			05/21/09	09/02/09	4	0	0.4	31.0	15.7	N/A		
TT-MW2-28	02/09/09	09/01/09	5	5	19.0	29.0	25.6	N/A			09/01/09	09/01/09	1	0	31.0	31.0	31.0	N/A		
TT-MW2-29B	02/09/09	08/31/09	5	1	0.1	2.3	1.0	N/A			08/31/09	08/31/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-29C	02/09/09	08/31/09	6	0	0.1	2.3	0.8	N/A			08/31/09	08/31/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-30A	02/13/09	08/26/09	7	7	11,000.0	31,000.0	25,142.9	N/A			08/26/09	08/26/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-30B	02/13/09	08/26/09	7	7	67.0	14,000.0	3,809.6	N/A			08/26/09	08/26/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-30C	02/13/09	08/26/09	5	2	0.1	300.0	62.1	N/A			08/26/09	08/26/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-31A	02/13/09	09/01/09	4	1	0.1	9.6	3.1	N/A			09/01/09	09/01/09	1	0	31.0	31.0	31.0	N/A		
TT-MW2-31B	02/13/09	09/01/09	5	1	0.1	460.0	92.2	N/A			09/01/09	09/01/09	1	0	31.0	31.0	31.0	N/A		
TT-MW2-32	02/09/09	09/01/09	4	1	0.1	2.3	0.8	N/A			09/01/09	09/01/09	1	0	31.0	31.0	31.0	N/A		
TT-MW2-33A	02/03/09	08/26/09	5	1	0.1	2.3	1.0	N/A			08/26/09	08/26/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-33B	02/03/09	08/26/09	4	0	0.1	2.3	0.6	N/A			08/26/09	08/26/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-33C	02/03/09	08/26/09	5	1	0.1	480.0	96.1	N/A			08/26/09	08/26/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-34A	02/03/09	08/31/09	4	3	0.3	2.3	0.8	N/A			08/31/09	08/31/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-34B	02/11/09	08/31/09	5	0	0.1	2.3	0.6	N/A			08/31/09	08/31/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-34C	02/11/09	08/31/09	4	1	0.1	2.3	0.7	N/A			08/31/09	08/31/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-35A	02/13/09	09/01/09	4	0	0.1	2.3	0.8	N/A			09/01/09	09/01/09	1	0	31.0	31.0	31.0	N/A		
TT-MW2-35B	02/11/09	09/01/09	4	0	0.1	2.3	0.6	N/A			09/01/09	09/01/09	1	0	31.0	31.0	31.0	N/A		
TT-MW2-36A	02/12/09	08/31/09	7	4	0.1	20.0	2.9	N/A			08/31/09	08/31/09	2	0	30.0	30.0	30.0	N/A		
TT-MW2-36B	02/12/09	08/27/09	5	3	0.1	11.0	2.6	N/A			08/27/09	08/27/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-36C	02/13/09	08/27/09	5	3	0.3	2.3	1.0	N/A			08/27/09	08/27/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-37A	02/12/09	09/02/09	6	6	7.7	2,100.0	672.3	N/A			05/21/09	09/02/09	3	2	3.3	31.0	12.8	N/A		
TT-MW2-37B	02/12/09	09/02/09	6	2	0.1	210.0	70.2	N/A			05/21/09	09/02/09	2	0	0.4	31.0	15.7	N/A		
TT-MW2-38A	03/26/09	08/27/09	5	5	5,500.0	190,000.0	114,300.0	N/A			08/27/09	08/27/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-38B	03/26/09	08/27/09	5	5	16,000.0	32,000.0	21,400.0	N/A			08/27/09	08/27/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-38C	03/26/09	08/27/09	6	6	0.5	4,200.0	710.9	N/A			08/27/09	08/27/09	2	0	30.0	30.0	30.0	N/A		
TT-MW2-39	03/20/09	08/27/09	10	10	79,000.0	190,000.0	103,900.0	N/A			08/27/09	08/27/09	2	0	30.0	30.0	30.0	N/A		
TT-MW2-40A	04/28/09	08/27/09	4	0	0.1	2.3	0.6	N/A			08/27/09	08/27/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-40B	04/28/09	08/27/09	4	1	0.1	2.8	1.3	N/A			08/27/09	08/27/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-40C	04/27/09	08/27/09	5	4	0.1	12.0	5.3	N/A			08/27/09	08/27/09	1	0	30.0	30.0	30.0	N/A		
TT-MW2-PZ1	04/28/09	04/28/09	1	1	240.0	240.0	240.0	N/A												
W2-3	11/26/07	11/26/07	5	5	4,440.0	4,630.0	4,550.0	N/A												
W2-5	11/19/07	11/19/07	1	1	6.6	6.6	6.6	N/A												
WS-1	05/20/08	08/24/09	7	2	0.1	11.5	2.0	NT												
WS-1-TOP	08/27/08	11/17/08	2	0	0.5	0.5	0.5	N/A												
WS-2	06/03/09	08/24/09	2	1	0.1	0.1	0.1	N/A												

	Perchlorate (# wells)	% Total
"N/A"-Insufficient Data	40	
Blank-No data	0	
"NT" - No Trend	13	38
"S" - Stable	13	38
"I" - Increasing	3	9
"PI" -Probably Increasing	1	3
"D" - Decreasing	3	9
"PD" -Probably Decreasing	1	3
Total Trend Wells	34	100

	1,4-Dioxane (# wells)	% Total
"N/A"-Insufficient Data	54	
Blank-No data	20	
"NT" - No Trend	0	0
"S" - Stable	0	0
"I" - Increasing	0	0
"PI" -Probably Increasing	0	0
"D" - Decreasing	0	0
"PD" -Probably Decreasing	0	0
Total Trend Wells	0	0

Table 3-3
Statistical Analysis of Groundwater Monitoring Data
LMC Beaumont Site 2
Data from Sept 2004 to Sept 2009

Well	RDX Min Date	RDX Max Date	RDX Num Samples	RDX Num Detects	RDX Min (µg/L)	RDX Max (µg/L)	RDX Mean (µg/L)	RDX Trend	RDX Magnitude of Trend (%/yr)	RDX Magnitude of Trend (µg/L/yr)	NDMA Min Date	NDMA Max Date	NDMA Num Samples	NDMA Num Detects	NDMA Min (µg/L)	NDMA Max (µg/L)	NDMA Mean (µg/L)	NDMA Trend	NDMA Magnitude of Trend (%/yr)	NDMA Magnitude of Trend (µg/L/yr)
SW-1																				
SW-2																				
SW-3																				
SW-5																				
SW-6																				
SW-7																				
TT-MW2-1	06/27/06	06/01/09	7	4	0.2	1.6	0.5	D	-29.5	-0.2	09/27/04	06/01/09	8	0	0.0	1.1	0.4	S		
TT-MW2-2											09/27/04	02/16/05	6	0	0.0	1.1	0.6	N/A		
TT-MW2-3	06/27/06	06/27/06	2	0	1.3	1.3	1.3	N/A			09/27/04	06/27/06	8	0	0.0	1.1	0.6	N/A		
TT-MW2-4S	05/26/09	05/26/09	1	0	0.2	0.2	0.2	N/A			09/27/04	05/26/09	5	0	0.0	1.1	0.4	N/A		
TT-MW2-4D											09/27/04	02/16/05	4	0	0.0	1.1	0.6	N/A		
TT-MW2-5	06/26/06	05/28/09	2	0	0.2	1.3	0.8	N/A			06/26/06	05/28/09	3	0	0.0	1.1	0.4	N/A		
TT-MW2-6S	05/19/09	05/19/09	1	0	0.2	0.2	0.2	N/A			05/19/09	05/19/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-6D																				
TT-MW2-7	11/06/06	05/28/09	2	0	0.2	0.2	0.2	N/A			11/06/06	05/28/09	2	0	0.0	0.0	0.0	N/A		
TT-MW2-7D																				
TT-MW2-8	11/06/06	05/22/09	3	0	0.2	0.2	0.2	N/A			11/06/06	05/22/09	2	0	0.0	0.0	0.0	N/A		
TT-MW2-9S	05/28/09	05/28/09	1	0	0.2	0.2	0.2	N/A			05/28/09	05/28/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-9D																				
TT-MW2-10	05/21/08	06/01/09	2	0	0.2	0.2	0.2	N/A			06/01/09	06/01/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-11	10/05/06	05/20/09	2	0	0.2	0.2	0.2	N/A			10/05/06	05/20/09	3	2	0.0	0.0	0.0	N/A		
TT-MW2-12	10/05/06	06/03/09	3	0	0.2	0.2	0.2	N/A			10/05/06	06/03/09	3	2	0.0	0.0	0.0	N/A		
TT-MW2-13	10/09/07	05/26/09	6	6	0.5	0.8	0.6	S			05/26/09	05/26/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-14	11/20/06	06/02/09	4	0	0.2	0.2	0.2	N/A			11/20/06	06/02/09	3	1	0.0	0.0	0.0	N/A		
TT-MW2-16	05/20/08	05/26/09	3	0	0.2	0.2	0.2	N/A			05/26/09	05/26/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-17S	05/29/09	05/29/09	2	0	0.2	0.2	0.2	N/A			05/29/09	05/29/09	2	0	0.0	0.0	0.0	N/A		
TT-MW2-17D																				
TT-MW2-18	10/08/07	05/27/08	2	0	0.2	0.2	0.2	N/A												
TT-MW2-19S	05/22/09	05/22/09	1	0	0.2	0.2	0.2	N/A			05/22/09	06/15/09	3	2	0.0	0.0	0.0	N/A		
TT-MW2-19D																				
TT-MW2-20S	05/22/09	05/22/09	1	0	0.2	0.2	0.2	N/A			05/22/09	05/22/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-20D																				
TT-MW2-21	05/20/09	05/20/09	1	0	0.2	0.2	0.2	N/A			05/20/09	09/02/09	2	2	0.0	0.0	0.0	N/A		
TT-MW2-22	05/19/09	05/19/09	1	0	0.2	0.2	0.2	N/A			05/19/09	05/19/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-23	05/29/09	05/29/09	1	0	0.2	0.2	0.2	N/A			05/29/09	05/29/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-24	05/05/09	05/29/09	3	3	4.7	5.9	5.4	N/A			05/29/09	09/01/09	3	3	0.0	0.1	0.0	N/A		
TT-MW2-25	05/20/09	05/20/09	1	0	0.2	0.2	0.2	N/A			05/20/09	09/02/09	2	2	0.0	0.0	0.0	N/A		
TT-MW2-26	05/20/09	05/20/09	1	0	0.2	0.2	0.2	N/A			05/20/09	09/02/09	2	2	0.0	0.1	0.0	N/A		
TT-MW2-27	05/21/09	05/21/09	2	0	0.2	0.2	0.2	N/A			05/21/09	05/21/09	2	0	0.0	0.0	0.0	N/A		
TT-MW2-28	05/27/09	05/27/09	1	0	0.2	0.2	0.2	N/A			05/27/09	09/01/09	2	2	0.0	0.0	0.0	N/A		
TT-MW2-29B	05/21/09	05/21/09	1	0	0.2	0.2	0.2	N/A			05/21/09	08/31/09	2	1	0.0	0.0	0.0	N/A		
TT-MW2-29C																				
TT-MW2-30A																				
TT-MW2-30B																				
TT-MW2-30C																				
TT-MW2-31A																				
TT-MW2-31B																				
TT-MW2-32																				
TT-MW2-33A	02/10/09	05/27/09	5	0	0.2	1.0	0.4	N/A			05/27/09	05/27/09	2	0	0.0	0.0	0.0	N/A		
TT-MW2-33B	02/10/09	02/24/09	2	0	0.5	1.0	0.8	N/A												
TT-MW2-33C	02/10/09	02/24/09	2	0	0.5	1.0	0.8	N/A												
TT-MW2-34A	02/10/09	05/27/09	4	0	0.2	1.0	0.5	N/A			05/27/09	05/27/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-34B	02/10/09	02/25/09	4	0	0.5	1.0	0.8	N/A												
TT-MW2-34C	02/25/09	02/25/09	1	0	1.0	1.0	1.0	N/A												
TT-MW2-35A																				
TT-MW2-35B																				
TT-MW2-36A	05/29/09	05/29/09	1	0	0.2	0.2	0.2	N/A			05/29/09	08/31/09	3	1	0.0	0.0	0.0	N/A		
TT-MW2-36B																				
TT-MW2-36C																				
TT-MW2-37A																				
TT-MW2-37B																				
TT-MW2-38A	05/26/09	05/26/09	1	0	0.2	0.2	0.2	N/A			05/26/09	05/26/09	1	0	0.0	0.0	0.0	N/A		
TT-MW2-38B																				
TT-MW2-38C																				
TT-MW2-39	05/27/09	05/27/09	2	0	0.2	0.2	0.2	N/A			05/27/09	05/27/09	2	0	0.0	0.0	0.0	N/A		
TT-MW2-40A																				
TT-MW2-40B																				
TT-MW2-40C																				
TT-MW2-PZ1																				
W2-3																				
W2-5																				
WS-1																				
WS-1-TOP																				
WS-2																				

Notes:

Definitions:

%/yr - percent per year
µg/L/yr - microgram per liter per year
mg/L/yr - milligram per liter per year

Statistical analyses were conducted using the Monitoring and Remediation Optimization System (Aziz et al., 2003), which is a database application developed to assist users with groundwater data trend analysis and long term monitoring optimization at contaminated groundwater sites. The application uses the non-parametric Mann-Kendall test to determine whether there are statistically significant increasing or decreasing trends, and linear regression to determine the magnitude of the trend.

	RDX(# wells)	% Total
"N/A"-Insufficient Data	34	
Blank-No data	38	
"NT" - No Trend	0	0
"S" - Stable	1	50
"I" - Increasing	0	0
"PI" -Probably Increasing	0	0
"D" - Decreasing	1	50
"PD" -Probably Decreasing	0	0
Total Trend Wells	2	100

	NDMA (# wells)	% Total
"N/A"-Insufficient Data	32	
Blank-No data	41	
"NT" - No Trend	0	0
"S" - Stable	1	100
"I" - Increasing	0	0
"PI" -Probably Increasing	0	0
"D" - Decreasing	0	0
"PD" -Probably Decreasing	0	0
Total Trend Wells	1	100

Table 3-4
Soil and Groundwater Plume Volume and Mass Estimates
LMC Beaumont Site 2

Media and COCs	Area (acres)	Media Volume (acre-feet)[1]	COC Mass (pounds)	Comment
Soils				
Perchlorate	3.2	40	789	
TCE	0.2	1	1	
Methylene Chloride	0.2	1	17	
RDX	NA	NA	NA	No RDX detected in soils
Groundwater				
Perchlorate-All Areas	68	748	4,395	
Perchlorate-Centrifuge	1	4	0.3	
Perchlorate-Test Bays	20	308	3,058	Higher value of 17,058 (Tetra Tech, 2009) revised downward due to reduction in depth of contamination
Perchlorate-Garbage Disposal Area	3	32	5	
Perchlorate-Waste Discharge Area	45	405	1,331	
TCE	0.6	3	0.76	
Methylene Chloride	0.1	1	0.39	
RDX	1.0	5	0.04	

Notes:

COC - chemical of concern

TCE - trichloroethene

RDX - hexahydro-1,3,5-trinitro-1,3,5-triazine

1. Plume volume is total soil volume for soil sources and total water volume for groundwater sources

amount of site data available and the very heterogeneous nature of the San Timoteo Aquifer at Site 2. Prior estimates of the perchlorate mass estimate were higher at 18,395 pounds (Tetra Tech, 2009); this value has been lowered as subsequent investigation in the Test Bay Canyon and the WDA indicates that the plumes are not as deep as previously assumed. The Test Bay Area plume has 70 percent of the Site 2 plume mass. Note the in addition to the 4,395 pounds of perchlorate in groundwater, there is another 789 pounds of perchlorate in soils above the water table.

For TCE, methlyene chloride, and RDX, the groundwater plume areas are 0.6 acres, 0.1 acres, and 1 acre, respectively; water volume is 3 acre-feet, 1 acre-feet, and 5 acre-feet, respectively; and mass is 0.76 pounds, 0.39 pounds, and 0.04 pounds, respectively. The TCE, methlyene chloride, and RDX groundwater plumes are generally insignificant relative to perchlorate, and only represent localized issues near the few impacted wells due to the generally low concentrations and mass.

3.7.2 Source Areas

Very small soil sources were identified for TCE and methylene chloride, and no soil source was found for RDX (Table 3-4, and Tetra Tech, 2010a). Significant soil sources (Table 3-4 and Figure 3-6A) were found for perchlorate in the areas of Test Bay 1, Test Bay 2, Test Bay 3, and the WDA, with minor perchlorate soil sources in Test Bay 4 and in the Area M garbage disposal area. Total perchlorate mass currently present in soil sources is approximately 800 pounds (Appendix D). Transport of perchlorate from these soil sources through the vadose zone to groundwater is estimated using vadose zone fate and transport models (Appendix E), using the mass values defined in Table 3-4.

Groundwater concentrations are very high for perchlorate, and levels have remained high for approximately 6 years. In addition, the areas with the highest groundwater concentrations are located directly beneath the original suspected release points, which is often an indication that releases are still ongoing. Thus, it is possible that there is a continuing groundwater source where contaminants are tightly trapped in the low permeability saturated aquifer material. This potential groundwater source includes all areas where perchlorate concentrations are over 100,000 μg/L, including the 0.25 acre hot spot of the WDA groundwater plume and the 0.6 acre hot spot area of the Test Bay Canyon groundwater plume. These two areas possibly represent a continuing source of perchlorate to groundwater unless the source of the contamination is remediated. Groundwater concentrations for all other COCs are so low that a groundwater source is unlikely.

3.7.3 Fate and Transport Mechanisms

The following fate and transport mechanisms appear important for the site based upon the site conceptual model and the spatial and time trends in COC concentrations:

- Vadose Zone Transport – Vadose zone transport is primarily a consideration for perchlorate, since the other COCs are essentially not present site soils. Predicting vadose zone transport from the perchlorate soil source areas present in Test Bay Canyon, WDA, and Area M is difficult due to the long time frame, the limited data available, the uncertainty in the geologic/hydrologic conceptual model, and the inability to calibrate a vadose zone transport model. Three primary methodologies are typically used to predict future performance for these types of complex geologic models (SPEE, 1998): analog site (case study) analysis, volumetric analysis, and model simulation analysis. All three methods are useful prediction tools depending on the amount of site specific data available, with the predictions often weighted towards the methodology most appropriate for the site. These methodologies are applied to predicting vadose zone transport from the perchlorate soil source areas as follows:

    - Analog Site (Case Study) Analysis – Analog site analysis involves selecting an analogous geologic site with known properties and performance, and then extrapolating this behavior to the site of interest. Analog site analysis is typically the primary methodology used when there is limited data available for site volumetric calculations or calibrating complex flow and transport simulation models. For Site 2, the historical release of perchlorate from the source areas provides a reasonable analog for future releases, due to similar geologic conditions and the anticipated likelihood of similar conditions in the near future. Since release occurs from both soils and groundwater sources, this methodology presents an upper bound on the release rate from soils, since the contributions from soils and groundwater sources are lumped together in this analysis. The current perchlorate mass in the groundwater plume of 4,395 pounds provides a possible tracer of the past releases of perchlorate from soils and groundwater assuming no loss of perchlorate from the system. Because this mass of 4,395 pounds is thought to have been released over the 35 to 51 years elapsed since the site was operating, this suggests the perchlorate mass flux release rate from the soils and groundwater sources averaged between 86 and 126 pounds per year;

    - Volumetric Analysis – Volumetric analysis involves estimating storage mass volumes and mass flux rates based upon mass balance calculations. Volumetric analysis is typically the primary method used for performance prediction when there is sufficient data available for estimating a mass balance, but insufficient data available for calibrating complex flow and transport simulation models. Mass flux from the perchlorate soil sources can then be estimated using the Test Bay Canyon diffuse recharge rate of 1.4 inches per year (Appendix C) from the calibrated flow model, the perchlorate impacted soil areas and concentrations identified in Figure 3-6A and Appendices D and E, and the total perchlorate mass in the soils from the volumetric analysis in Appendix D (see also Table 3-4 and 3-6). Perchlorate flux from soils using this methodology is estimated to be 7 pounds per year from the test bay area in southern Test Bay Canyon, 0.04 pounds per year from northern Test Bay Canyon, 0.11 pounds per year from Area M, and 16.5 pounds per year from WDA (Table 3-6 and Figure 3-6A). Thus, total perchlorate mass flux from all soil sources is estimated using

Table 3-5
Summary of Model Parameters
LMC Beaumont Site 2

Parameter	Value	Comment
Flow		
Hydraulic Conductivity	0.16 feet/day	weathered San Timoteo (up to 4 feet/day in Test Bay Canyon)
Hydraulic Conductivity	0.04 feet/day	competent San Timoteo
Transport		
Total porosity[1]	0.2	
Effective porosity[2]	0.1	Specific Yield Value (Tetra Tech, 2010b)
Longitudinal dispersivity	40 feet	US EPA, 1998; adjusted during model calibration
Transverse dispersivity	1/10 to 1/3 * α_L	US EPA, 1998
Vertical dispersivity	1/100 to 1/20 * α_L	US EPA, 1998
Dry bulk density[3]	1.8 g/cm^3	site data average
Fraction organic carbon	0 to 0.0002	assumption (TCE Retardation Factor ~ 1.05, Perhclorate Retardation Factor ~ 1.0)
perchlorate degradation rate	0	site data trends

Notes:

α_L - longitudinal dispersivity

g/cm^3 - grams per cubic centimeter

1. The total porosity cited is not the true total porosity that would be measured in a lab sample, but a field scale value for model grid blocks and estimating plume mass. This value excludes lower permeability interbeds in the aquifer, and is hence less than the true total porosity. The 20 percent value is also consistent with the value used in earlier site mass estimates.

2. The effective porosity excludes interbeds and also accounts for fast and slow paths through the remaining beds.

3. The bulk density value is the true aquifer bulk density that would be measured in a lab sample, and thus may appear inconsistent with the field scale total porosity value given above.

Table 3-6
Perchlorate Source Mass Flux Summary
LMC Beaumont Site 2

Parameter	Value	Comments
Unsaturated Zone Sources		
Groundwater diffuse recharge rate	1.4 in/yr	0.12 ft/yr
Test Bay North Area Perchlorate Soil Source		
Area (acres)	0.07	
Perchlorate Mass (lbs)	3	
Perchlorate Mass Flux (lbs/year)	0.04	Soil concentration × area × recharge
Perchlorate Source Duration (years)	83	Mass/mass Flux
Test Bay South Area Perchlorate Soil Source		
Area (acres)	1.9	
Perchlorate Mass (lbs)	356	
Perchlorate Mass Flux (lbs/year)	7.0	Soil concentration × area × recharge
Perchlorate Source Duration (years)	51	Mass/mass Flux
Area M Perchlorate Soil Source		
Area (acres)	0.1	
Perchlorate Mass (lbs)	5	
Perchlorate Mass Flux (lbs/year)	0.11	Soil concentration × area × recharge
Perchlorate Source Duration (years)	41	Mass/mass Flux
Waste Discharge Area Perchlorate Soil Source		
Area (acres)	1.44	
Perchlorate Mass (lbs)	425	
Perchlorate Mass Flux (lbs/year)	16.5	Soil concentration × area × recharge
Perchlorate Source Duration (years)	26	Mass/mass flux
Saturated Zone Sources		
Test Bay Area		
Width across hot spot (feet)	100	Perpendicular to groundwater flow
Perchlorate mass flux (lbs/year)	135	Estimated from underflow rate and concentration contour maps; probability of source uncertain since soil source also contributes to releases
Waste Discharge Area		
Width across hot spot (feet)	50	Perpendicular to groundwater flow
Perchlorate mass flux (lbs/year)	67	Estimated from underflow rate and concentration contour maps; probability of source uncertain since soil source also contributes to releases

Note:

Source duration is considered indefinite for all satuared zone sources unless source remediation is considered volumetric analysis to be approximately 24 pounds. The perchlorate flux estimated at 7 lb/yr in the test bay source area and 16.5 lb/yr in the WDA can be significant in interpreting source history, as past release rates and recharge would have to be much higher in order to account for the mass that is currently in the plume. These both imply that significant water with perchlorate must have been released during operations. The vadose zone simulations also suggest that significant time is required to see the impact from soil sources at the water table, which also suggests significant recharge during operations. Similarly, volumetric analysis and underflow calculations can be used to calculate the release of perchlorate from groundwater perchlorate sources, which is estimated to be up to 202 pounds per year (Table 3-6).

- Model simulation analysis involves using complex flow and transport simulation models, and is typically the primary method used for performance prediction when there is sufficient historical data available for model calibration. The VS2DT Model (Appendix E) is used to predict perchlorate release rates of 15.15 pounds per year, with 10 pounds per year from WDA soils, 5 pounds per year from South Test Bay Canyon soils, 0.05 pounds per year from North Test Bay Canyon soils, and 0.1 pounds per year from Area M soils. However, there is limited data available to directly calibrate the VS2DT model, so the ability to predict the releases using such a complex methodology may be limited. The calibrated groundwater flow and transport model mass balance output can also be used to estimate an indirect bound on the perchlorate release rate from soils, which estimates the total release rate of perchlorate from both soils and groundwater as 247 pounds per year (Section 4).

In summary, a variety of methodologies are used to estimate the perchlorate release rate from soils into groundwater with the results varying between 15 to 25 pounds per year, with an upper bound on the order of 86 to 247 pounds per year estimated from the combined release rate from both groundwater and soil sources. Note that there is a wide range in the possible perchlorate release rates, reflecting significant uncertainty in these values.

- Degradation – Degradation may be important for perchlorate. Biodegradation of perchlorate in groundwater is known to occur when significant levels of organic carbon are present, oxygen and nitrate are depleted, and perchlorate-degrading anaerobic bacteria are present. Analysis of geochemical data indicates these conditions are weakly present at Beaumont Site 2, with the riparian area being the most likely location currently exhibiting degradation potential (based upon high chloride concentrations, the source areas may also have had degradation occurring in the past). The biological reaction for perchlorate is reported to be nearly instantaneous;

- Volatilization – Perchlorate is not subject to volatilization from groundwater;

- Evapotranspiration – Evapotranspiration is likely to be an important perchlorate fate and transport mechanism within the riparian area south of the site, since evapotranspiration accounts for approximately 30 to 100 percent of the groundwater underflow across the site boundary. The mass lost due the physical pumping of groundwater by plant extraction is estimated using evapotranspiration rates and the perchlorate shallow plume maps (see perchlorate mass flux budget section below). However, physical pumping of groundwater only accounts for phytoextraction processes, and additional contaminant mass may also be removed by rhizodegradation processes. The rates for rhizodegradation processes are best estimated from site-specific field studies, since they are highly dependent on plant type and root zone geochemical conditions. Rhizodegradation studies have not yet been conducted at Site 2, so for the purposes of the modeling study, the rhizodegradation rates will be addressed through data analysis methods, model calibration, and model sensitivity analyses;

- Dispersion – Dispersion is likely important for perchlorate given the spatial and temporal variations in flow velocity. Dispersion is estimated through the longitudinal, lateral, and vertical dispersivity values. These factors are dependent on the physical length of the plume. Typically the longitudinal dispersivity is estimated as function of the plume length, the lateral dispersivity is estimated as 10 to 33 percent of the longitudinal dispersivity, and the vertical dispersivity is estimated as 1 to 5 percent of the longitudinal dispersivity (US EPA, 1998). Given the one-half to three-quarter mile long plumes at Site 2, the longitudinal dispersivity is estimated as 40 feet using correlations given by EPA (US EPA, 1998); therefore, the lateral dispersivity is estimated as 4 to 13 feet, and the vertical dispersivity is estimated as 0.4 to 2 feet. These parameters are also typically adjusted during model calibration since direct measurement typically is not possible;

- Sorption – Perchlorate is not subject to sorption, and sorption also is not likely to be very important for the other COCs since organic carbon fraction and hence sorption is small (see “COC Migration Pathway and Rates” discussion in Section 3.7.1 above);

- Extraction/Injection – Groundwater extraction and treatment are not applicable during the historical period; and

- Conceptual Model Transport Properties – Based upon the discussion above, Table 3-5 presents a summary of key model parameters.

This conceptual model is used as the basis for constructing a numerical flow and transport model. Although there are uncertainties in some aspects of the conceptual model, this is typical for hydrogeologic studies, and there do not appear to be any data gaps that would preclude proceeding with development of a numerical flow and transport model or design of remediation systems. As discussed above in the Hydraulic Properties section, the effective porosity value of 2 to 10 percent is considered to be one the larger uncertainties in the site CSM.

3.8 PERCHLORATE MASS FLUX BUDGET

A preliminary groundwater perchlorate mass flux budget is defined as part of the basis for constructing the numerical transport model. The underflow mass flux numbers are uncertain at this point in the study, and subject to change during calibration. Both soil and groundwater sources are considered as part of the conceptual model and perchlorate mass flux budget, with a separate source mass flux rate for the groundwater and soil sources. Source duration for soils sources is estimated based upon the release rates and total mass. Source duration for groundwater sources is estimated based upon case studies at similar sites and the experience to date at this site, which strongly suggests that if left untreated, the groundwater sources would be likely to continue for timescales on the order of several decades. Since the model cases anticipated in this project will be limited to periods on the order of 20 years, the groundwater source releases will continue for the entire future simulation time period if there is no groundwater source remediation.

Key elements of the groundwater perchlorate mass flux budget are as follows:

- Aquifer Recharge – Recharge to the alluvium is primarily from direct precipitation. Perchlorate mass flux for these items is as follows:
  - Direct Precipitation – Perchlorate mass flux for precipitation leaching perchlorate from the soil source areas into groundwater between is estimated to be between 15 to 25 pounds per year (see Table 3-6 and Vadose Zone Transport discussion in Section 3.7.3 above);
  - Recharge from Creeks –There is no significant perchlorate mass flux due to creek recharge, as soils in the creek recharge areas do not appear to be contaminated; and
  - Underflow – There is no significant underflow into the aquifer, so there is also no significant perchlorate inflow from the aquifer boundaries. The maximum perchlorate underflow rate across the entire plume width is approximately 270 pounds per year.
- Aquifer Discharge – Discharge from the aquifer is primarily from evapotranspiration, leakage into deeper aquifers, underflow down the canyon, and possibly degradation. Perchlorate mass flux from these discharge mechanisms are as follows:
  - Evapotranspiration – Using the evapotranspiration rates and perchlorate concentration in the riparian areas, perchlorate mass flux is 1 pound per year;
  - Discharge to Creek – None from groundwater
  - Underflow – Using the underflow rates and perchlorate concentration in the southern aquifer, perchlorate mass flux is 2 pounds per year; and
  - Leakage – Using the leakage rates and perchlorate concentration in the aquifer, perchlorate mass flux is 1 pound per year.
- Sources – Perchlorate also may be added to the plume by the flow of clean groundwater through the aquifer source areas in the Test Bay and WDA area at rates of 135 pounds per year and 67 pounds per year, respectively (Table 3-6).
- Sinks – Perchlorate also may be lost from the plume by degradation in the riparian area, with the maximum loss rates estimated as 1 pounds per year based upon the difference between the riparian area perchlorate inflow rate from the site boundary (2 pounds per year) and the perchlorate loss due to evapotranspiration rates (1 pound per year).
- Net Budget – The net mass flux budget is summarized in a flow diagram in Figure 3-7. Generally, the mass inflow rates are significantly greater than the mass outflow rates, implying the plume mass is still expanding over time. The estimated mass inflow rate

SECTION 4 NUMERICAL TRANSPORT MODEL DEVELOPMENT

The conceptual model presented in Section 3 is used to develop a numerical flow and transport model. The design, construction, and calibration of the numerical flow and transport model are discussed in Section 4. The Numerical Flow and Transport Model is later used in Section 5.0 as a hydrogeologic planning tool to evaluate various remedial and monitoring alternatives for the site.

4.1 MODEL DESIGN AND CONSTRUCTION

Section 4.1 presents the approach used to extend the conceptual model to a numerical groundwater flow model (MODFLOW; Harbaugh et al., 2000) and transport model (MT3D; Zheng and Wang, 1999), including layering, plume extent, boundary conditions, aquifer stresses, hydraulic properties, transport properties, and calibration. Model construction was aided by the use of a pre-processor (GWVistas; Environmental Simulations, Inc., 2008). Files for the MODFLOW/MT3D Models and the GWVistas pre-processor are given in Appendix G (available only on CD in electronic format). A summary of the key MODFLOW/MT3D packages used in the model is given in Table 4-1.

Layering

Based upon the primary units defined in the primary hydrostratigraphic model and the large differences in water levels and perchlorate concentrations observed with depth in the competent San Timoteo, four layers are used for the numerical model. The shallowest layer (1) represents the weathered San Timoteo, with the top of layer 1 defined as the ground surface (note that only the areas below the water table are actually considered saturated in the MODFLOW model) and the base of layer 1 defined as the top of the competent San Timoteo (Appendix B). The second layer (2) represents the upper 25 feet of the competent San Timoteo, with the top of layer 2 defined as the top of the competent San Timoteo and the layer is 25 feet thick. The third layer (3) represents the 25 to 75 foot depth interval of the competent San Timoteo, with the top of layer 3 defined as 25 feet below the top of the competent San Timoteo and the layer is 50 feet thick. The fourth layer (4) represents the 75 to 150 foot depth interval of the competent San Timoteo, with the top of layer 3 defined as 75 feet below the top of the competent San Timoteo and the layer is 75 feet thick. These layer elevations cover the full range of depths in the site monitoring wells, and provide zonation of the competent San Timoteo in order to discretize the strong perchlorate concentration

Table 4-1
MODFLOW/MT3D Package Summary
LMC Beaumont Site 2

Model	Package	Comment
MODLFOW2000	BAS	
	LPF	
	OC	
	PCG	
	RCH	Recharge (time-varying for transient run)
	CHD	Time-varying heads for transient run
	SFR	Stream recharge (sensitivity analysis only)
	ETS1	Segmented ET (time-varying for transient run)
	WEL	Not planned for use
	HFB	Not planned for use
MT3D	BTN	
	ADV	
	DSP	
	SSM	Recharge mass flux (time-varying)
	GCG	
	RCT	Not planned for use in Base Case scenarios due to no sorption and very limited degradation (may be used if calibration and site data supports small amounts of degradation); only used for sensitivity of degradation in riparian area

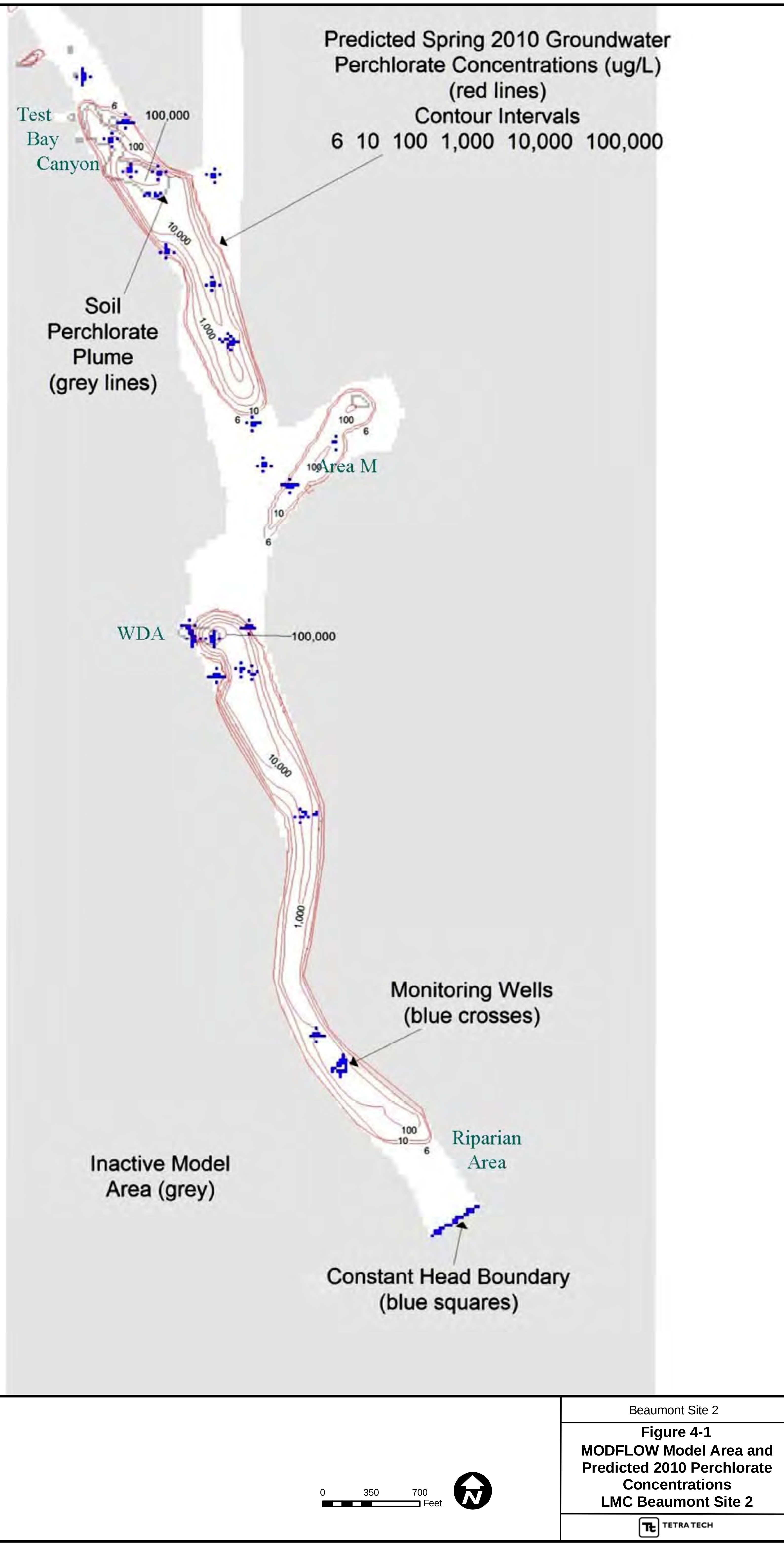
trends versus depth observed under the Test Bay and WDA source areas. Note that any deeper water yielding zones in the San Timoteo are excluded from the model since the plume does not extend to such depths/areas and the water loss due to leakage into such zones is thought to be negligible.

Model Extent

The model areal extent is limited to the 165 acre area where the weathered San Timoteo aquifer is present along the main axis of Laborde Canyon and extending into two tributary canyons (Test Bay Canyon and Area M). The total width and length of the MODFLOW model (Figure 4-1) is 4,600 feet and 13,200 feet, respectively. This covers the entire site from upper Test Bay canyon to well TT-MW2-19, but due to the geometry of the canyon, the width of the active aquifer model area is only approximately 400 feet across the width of the valley floor where the weathered San Timoteo aquifer is present. Those areas under the Test Bay Canyon, WDA, and Area M side canyons with groundwater and/or soil contamination present, as identified in the DSI Report (Tetra Tech, 2010a) and Figure 3-6, are included in the model area. The model origin is located at 6,323,800 feet Easting and 2,263,575 Northing, California State Plane Zone VI (1983 NAD). Grid block sizes of 25 feet are used since they are sufficient to resolve the features of interest at the site, meet the model objectives, and fall within MODFLOW2000/MT3D memory and run time constraints. A constant grid spacing is used since constant grid spacing promotes stability in MODFLOW models. The vertical extent of the model covers the weathered San Timoteo aquifer and the impacted portion of the competent San Timoteo, which extends up to 230 feet bgs. The Mt Eden formation in which groundwater is found in the offsite areas south of TT-MW2-42A/B is excluded from the model since this area is south of the active model area.

Boundary Conditions

Boundary conditions are no-flow conditions against the sides of the valley floor where the saturated weathered San Timoteo aquifer pinches out cross-gradient against non-water yielding competent San Timoteo. Stream boundaries (SFR) are used during the calibration process to consider creek recharge or discharge. Time-varying head flow boundaries are used to account for a small amount of underflow that may enter and leave the aquifer in small boundary areas of the competent San Timoteo in the upper portion of the model and in both the weathered and competent San Timoteo in the lower portion of the model.



Beaumont Site 2

Figure 4-1
MODFLOW Model Area and Predicted 2010 Perchlorate Concentrations
LMC Beaumont Site 2

TETRA TECH

Due to the very limited plume and water level monitoring data south of the riparian area (well TT-MW2-42A/B), and the current objectives of the modeling effort that focus on the perchlorate plume area, the lower canyon area between well TT-MW2-42A/B and TT-MW2-19S/D is not simulated in the model at this time. Instead, the time varying head flow boundaries are be placed south of well TT-MW2-42A/B at the southern edge of the riparian zone, reducing the size of the active area of the model to 110 acres. However, the lower canyon area is conceptually included in the model at this time in case future monitoring data indicates the plume extends south TT-MW2-19. Should that occur, future expansion of the model to the south should be relatively straightforward based upon the current model design.

Leakage is allowed between the weathered San Timoteo, non-water yielding competent San Timoteo, and water yielding competent San Timoteo formations. Horizontal flow barrier (HFB) boundaries are not planned within the model area, since faults are not believed to restrict groundwater flow. Evapotranspiration boundaries will be modeled in the riparian area, with an estimated extinction depth of 30 feet and evapotranspiration rates that vary seasonally per the UC Riverside evapotranspiration rate measurements (Tetra Tech, 2009; 2010b). The segmented evapotranspiration package is used for simulating evapotranspiration, which has a non-linear function relating evapotranspiration to head.

For the transport model:

- Perchlorate concentrations are assumed to be zero at any inflow head boundaries upgradient of the plume and calculated by the model at outflow head boundaries downgradient of the plume;
- Perchlorate concentrations under the soils source area are applied to maintain a mass flux consistent with the vadose zone modeling to be conducted later in this study; and

Perchlorate concentrations in the groundwater source area may be applied to the groundwater flows as a groundwater source if the mass flux estimated from the vadose zone modeling is not sufficient to match the observed monitoring data. Due to the short duration of monitoring at Site 2, this source mass flux rate is likely to be significant source of uncertainty and is treated as a model sensitivity analysis by showing model results with varying source mass flux rates.

Aquifer Stresses

Based upon the conceptual model and water budget, the model considers the following aquifer stresses: diffuse recharge that varies seasonally and inter-annually based upon precipitation, and evapotranspiration from the water table that varies depending upon the depth to groundwater and seasonally. In addition, flows across the model boundaries vary based upon the time-varying water levels measured in the monitoring program, but these boundary flows will be small since there is very little flow into the weathered San Timoteo via boundaries. Stress periods will be quarterly to allow for seasonal variation in aquifer stresses. Transport model time steps are on the order of days to reduce numerical dispersion, with the transport model time step values being calculated internally by the model using the MT3D automatic step-size control procedure (about 1 day).

Initial Ranges for Hydraulic and Transport Properties

The aquifer hydraulic and transport properties are initially as defined in the Hydraulic Properties section above (Section 3.5 and Table 3-5). Aquifer hydraulic conductivity values will vary with depth and area as depicted in Appendix A. Aquifer thicknesses and layer elevations are set based upon weathered San Timoteo and competent San Timoteo thickness values derived from the contour map of the top of the competent San Timoteo (Appendix B). Aquifer-specific yield and effective porosity values are in the range observed in site pumping tests and the conceptual model (0.10). The LPF package will be used to represent elevations and properties, which is the default setting for MODFLOW2000 in GWVistas.

Approach to Steady-State and Transient Flow and Transport Model Calibration

The approach to steady-state and transient calibration is defined considering data availability, variations in aquifer stresses, and the overall model objectives.

Flow

The approach for flow calibration is to perform a steady-state calibration during a period with quasi-steady aquifer stresses and water levels, and then use the calibrated water levels for this period as a starting condition for transient calibration during a period when aquifer stresses change over time. The steady-state calibration time is chosen to be Fall 2006 since (1) water levels at this time were fairly constant and in a range that is typical of site conditions; (2) precipitation values were typical for the water year; and (3) sufficient water level data are available at that time for calibration and assessing trends (prior to Fall 2006, water level data are only available for 8 of the 64 wells at the site). Key steady-state calibration issues will honor the site well testing data, given the constraints of the uncertain site water budget. The transient calibration time is the three and one-half year period from Fall 2006 through Spring 2010, since this is the only period with monitoring data available and there were seasonal trends in aquifer stress during that time period.

Key transient calibration issues are the seasonal and inter-annual variation in evapotranspiration and recharge, per the observed site storage changes (Table 3-1).

Transport

Steady-state calibration of the transport model is not possible since conditions are thought to be far from steady-state. Since the data available is limited to only a few years, and the transport process is slow, the ability to perform a transient calibration of the transport model will be limited. Thus, the transport model calibration will be more qualitative than the flow model. The chosen approach is to simulate transport during the same Fall 2006 through Spring 2010 period used for the MODFLOW calibration, to assess whether the whether the model is consistent with the perchlorate monitoring data during this period, and the perchlorate fluxes estimated in the site conceptual model.

Given the site conditions, if the flow and transport model can reasonably replicate historical conditions, it should provide some level of confidence that the model can be used for future predictions. Note, however, that the time period available for calibration of the model is rather short, which introduces uncertainty into the model predictions.

Calibration Targets

Primary calibration targets for flow are the water levels measured in the site monitoring program during the calibration period, and a calibration constraint will be the uncertain site water budget given in the conceptual model. The riparian area evapotranspiration rate, which is a key component of the conceptual model but is uncertain, provides an approximate calibration constraint

Primary calibration targets for transport will be the perchlorate concentrations measured in the site monitoring program during the calibration period, and a transport calibration constraint will be the site perchlorate mass flux budget given in the conceptual model. In particular, the perchlorate mass fluxes within the plume source area and in the riparian area are calibration constraints, since they are key components of the conceptual model. Due to the limited data available, model validation is not possible.

4.2 MODEL CALIBRATION

4.2.1 Flow Model

The MODFLOW model was calibrated in both steady-state and transient conditions. The term "steady-state" signifies that groundwater levels are relatively stable at that time, and that groundwater inflows and outflows are relatively equal and constant

Steady-State Conditions

Steady-state, saturated flow conditions were simulated using MODFLOW-2000. Groundwater levels at the model head boundaries were set using Fall 2006 water level data. Recharge values were initially determined using the site water balance, and adjusted during calibration. The final calibrated annual average recharge rate in the model was 3 acre-feet per year, with all recharge due to diffuse percolation (see the Sensitivity Analysis in Section 4.3 regarding the potential distribution of recharge between stream recharge and diffuse percolation). Given the average recharge rate of 3 acre-feet per year and the 110-acre active model area, this corresponds to an average diffuse recharge rate of 0.32 inches per year, with recharge rates varying from 0.05 to 2.0 incher per year (Appendix C, Figure C-2) to reflect the high as low recharge rate areas of the site as determined by seasonal fluctuations in water levels (Section 3.6 and Table 3-1). These recharge rates are similar to those reported for the water budget in the transient calibration (see Section 4.2.2). More detailed discussion on the site water budget is given in the transient calibration discussion below, which is typically a better estimate of the overall site water balance, while steady-state calibration typically provides a good indication of the site hydraulic conductivity.

Model hydraulic conductivity values were initially set based upon the main trends in site well data (Appendix A and Section 3.5). The final calibrated values of hydraulic conductivity are given in Figure C-1 in Appendix C and are as follows:

- Hydraulic conductivity values are 1 to 3 feet per day for the shallow weathered San Timoteo (Layer 1). Lower values of 1 foot per day are used along the Southern site boundary, in the Offsite Area, in the Garbage Disposal Area side canyon, along the downgradient edge of the Test Bay Canyon plume, and in the Final Assembly Area. Higher values of 3 feet per day are used in Test Bay Canyon and downgradient of the Liquid Waste Discharge Area. These high and low values correlate with the general trends observed in the site well test data (Appendix A), and subtle changes in the hydraulic gradient such as that observed near the downgradient limit of the Test Bay Plume. These hydraulic conductivity values also resulted in an improved match to observed heads (see Sensitivity Analysis). The hydraulic conductivity values result in weathered San Timoteo aquifer transmissivity values of between 14 and 100 per day, in general agreement with the high end of the values reported in the site well test data;

- Hydraulic conductivity values for the competent San Timoteo are 0.3, 0.1, and 0.01 feet per day for Layers 2, 3, and 4, respectively. These values correlate with the general trends observed in the site well test data such as the decrease in values with depth (Appendix A). These hydraulic conductivity values result in competent San Timoteo aquifer transmissivity values of 7.5, 5, and 0.75 per day for Layers 2, 3, and 4, respectively, in general agreement with the site well test data;

- Vertical hydraulic conductivity values are one-hundred times less than the horizontal hydraulic conductivity values, reflecting the strong vertical water level gradients and the dense interbeds observed in the San Timoteo during drilling; and

- Evapotranspiration was modeled within the riparian area identified in Appendix C, Figure C-3. Maximum evapotranspiration rates were 0.01 feet per day (the seasonal average of the UCR CIMIS data) and the extinction depth was 30 feet. One segment was used to vary the evapotranspiration versus depth (PXDP =0.5 and PETM =0.99), in accordance with the non-linear evapotranspiration depth dependence observed for deep rooted plants (Baird and Maddock, 2005).

These calibrated parameter values compare reasonably well with those given in the conceptual model in Section 3.

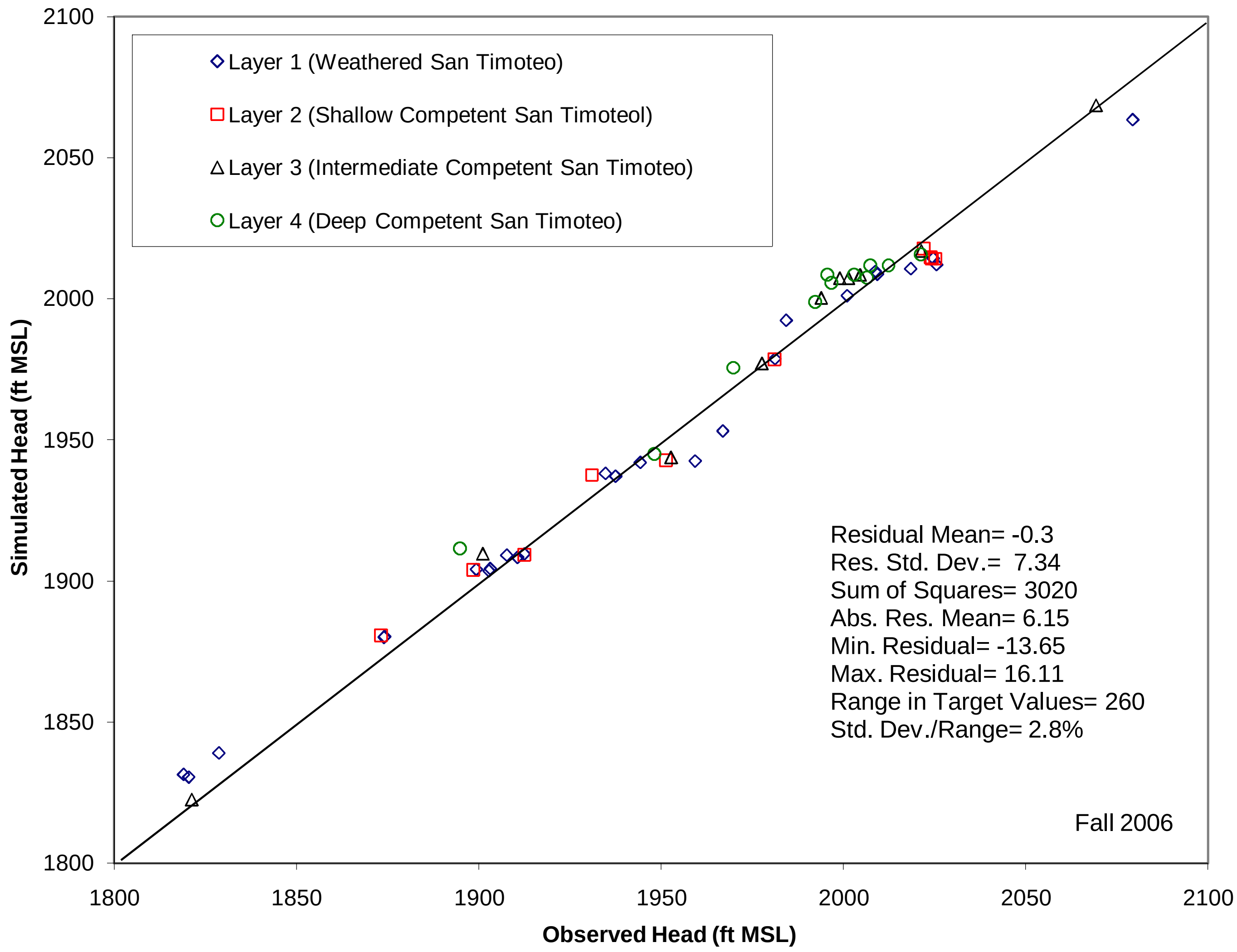
Water Levels

The predicted groundwater elevation for the calibrated steady-state flow model is shown in comparison to the Fall 2006 measured elevations in Figure 4-2. The cross-plot of the simulated and measured water levels shows the comparison is good between simulated and observed water levels for both the weathered San Timoteo (Layer 1) and competent San Timoteo (Layers 2-4) wells. A contour plot of the simulated and observed water levels is given in Appendix C, Figure C-4, showing the model results correlate well with the gradient changes and flow directions observed across the site. A plot of residual errors given in Appendix C, Figure C-5 and the crossplot (Figure 4-2) shows errors are generally less than 5 to 10 feet, with no significant trends in errors across the site. For the steady-state calibration, the mean error was -0.30 feet, the standard deviation of error was 7.3 feet, and the relative error (defined as the ratio of the root mean square (RMS) error to the decline in head across the site) was 2.8 percent. The model predicted water levels also show the following important site features:

- Fairly consistent gradients of 0.03 along nearly the entire length of Laborde Canyon, except for flatter gradients in Test Bay Canyon; and

- Downward vertical gradients of 0.05 in the upper reaches of Laborde Canyon where there are larger recharge rates;

Figure 4-2. Cross-Plot of Simulated and Observed Heads for Steady-State Flow Model Calibration



- Weak upward vertical gradients of 0.008 at the site southern boundary; and
- Upward vertical gradients of 0.12 in the lower reaches of Laborde Canyon where there is discharge due to evapotranspiration.

The values of model head error are also reasonably small based upon groundwater flow model calibration guidance (Anderson and Woessner, 1991), given the complex site conditions.

Water Budget

Notable components of the water budget include the following:

- Recharge rates of 3.0 acre-feet per year due to diffuse recharge;
- No underflow into the weathered San Timoteo aquifer, and underflow of 0.9 acre-feet per year into the competent San Timoteo aquifer;
- Underflow of 1.3 acre-feet per year down Laborde Canyon in the weathered San Timoteo aquifer, and underflow of 1 acre-feet per year down Laborde Canyon in the competent San Timoteo aquifer;
- Evapotranspiration rates of 2.4 acre-feet per year; and
- Net leakage from the weathered San Timoteo into the competent San Timoteo of 0.3 acre-feet per year.

The groundwater water budget for the calibrated steady-state flow model generally falls within the conceptual water budget estimates given in Section 3, and the range of values given for the transient model (Section 4.2.2 and Figure 4-6). However, as noted in the conceptual model in Section 3, this water budget is generally low for an aquifer of this size in this area, and a more thorough discussion of the uncertainty in the water budget is given in the Sensitivity Analysis (Section 4.3) and the Model Limitations (Section 4.4).

Given that the model parameters, water levels, gradients, and water budget agree well with the site conceptual model, the groundwater steady-state flow model appears to be adequately calibrated for steady-state flow conditions.

Plume Transport Considerations

Another consideration for the groundwater flow model calibration is the ability to predict groundwater flow paths that generally coincide with the plume trajectory as estimated by the groundwater plume contour maps at the site. Figure C-6 in Appendix C shows the groundwater flowpaths and travel times estimated using the calibrated groundwater MODFLOW model and the

Figure 4-3. Cross-Plot of Simulated and Observed Heads for Transient Flow Model Calibration

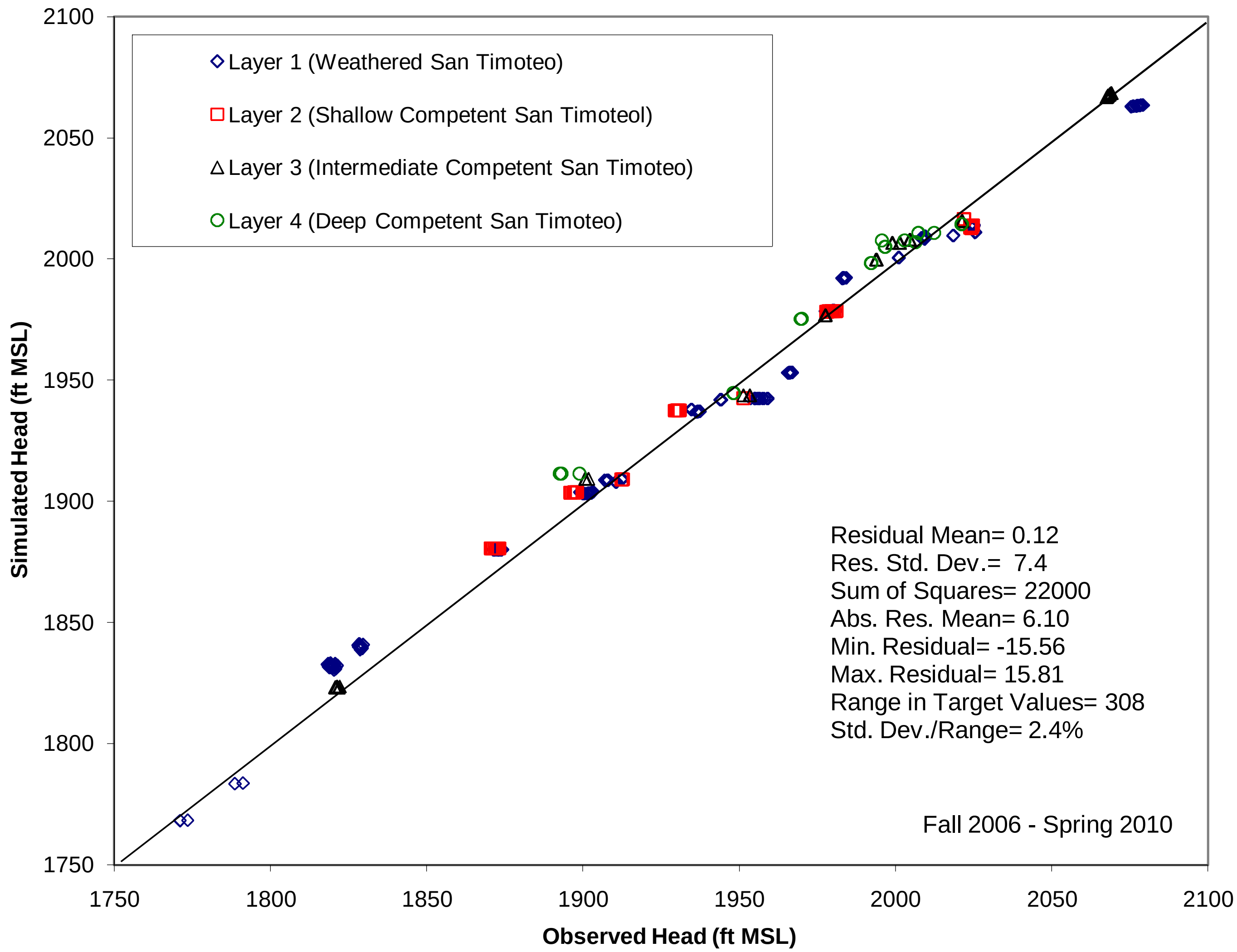


Figure 4-4. Simulated and Observed Hydrographs for Monitoring Well TT-MW2-14

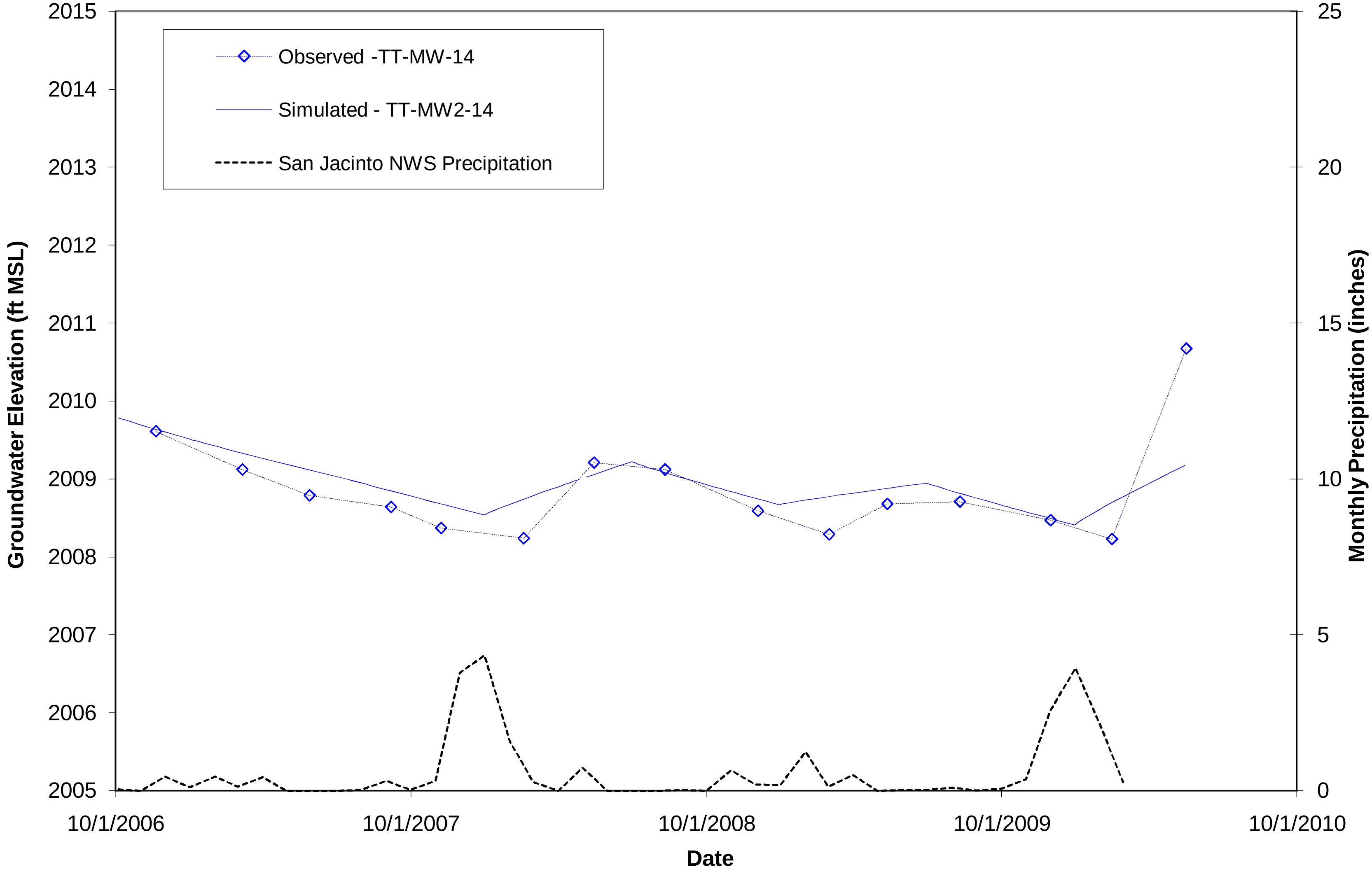


Figure 4-5. Simulated and Observed Hydrographs for Monitoring Well TT-MW2-07

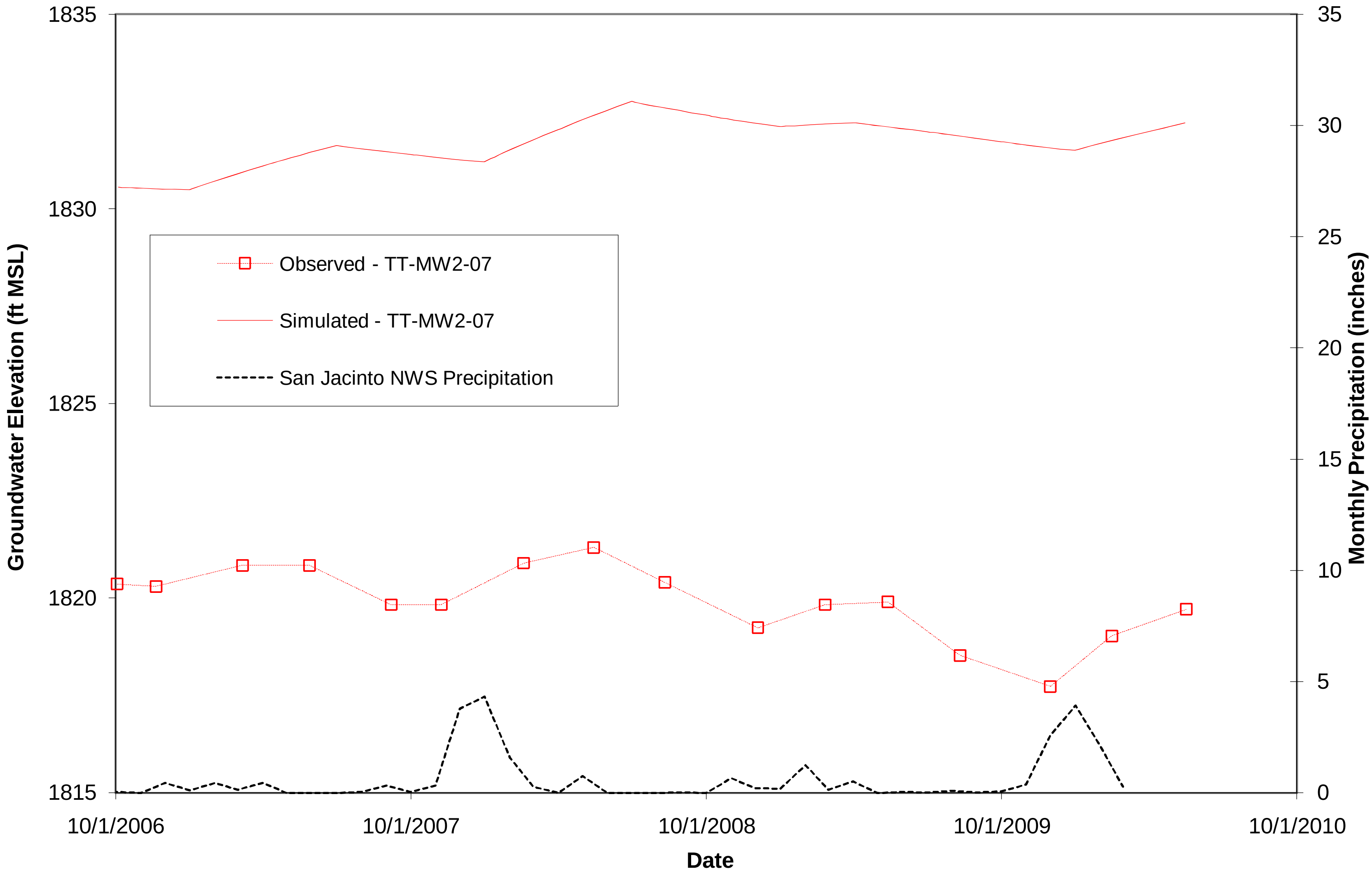
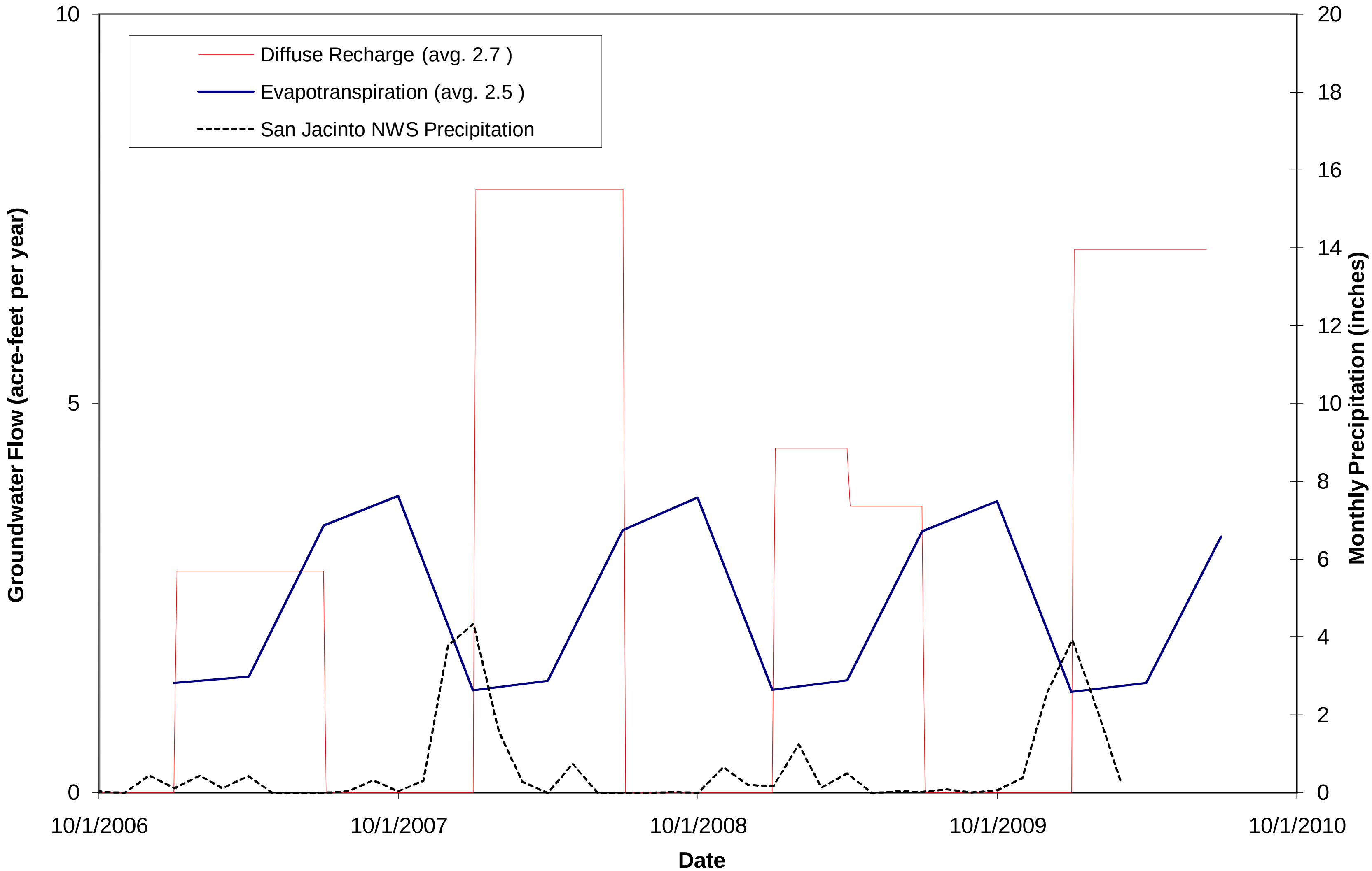


Figure 4-6. Groundwater flows predicted by the model for 2006-2010 transient calibration



MODPATH particle tracking model (Pollock, 1994). The only additional parameter required for the MODPATH model is the aquifer effective porosity, which was set equal to the aquifer specific yield value (10 percent). Travel times from Test Bay Canyon to the southern limit of the Test Bay plume are approximately 40 years and travel times from the Liquid Waste Discharge Area to the riparian area are approximately 25 years. Figure C-6 shows that the groundwater flowpaths for the steady-state model generally follow the centerline of the plume trajectory. These analyses indicate the groundwater flow model is reasonably consistent with the trajectory and age of the groundwater plume at the site. The results of the particle tracking also imply that perchlorate was delivered to the water table rapidly during the operating period, which may imply that the water budget was significantly larger during operations.

Transient Conditions

The transient flow model calibration was conducted for the period from Fall 2006 to through Spring 2010, to calibrate the flow model for the effects of seasonal and inter-annual variations in groundwater recharge and discharge. The primary model calibration parameters were the specific yield and specific storage that are not sensitive to the steady-state calibration. All model parameters, boundary conditions, and starting water levels are identical to those given in the steady-state calibration. In addition, the following parameters are used for the transient calibration:

- Time-varying boundary heads – Water levels in the constant head cells were set to time-varying based upon the monitoring data collected at the site;
- Time-varying diffuse recharge rates – Recharge rates were increased and decreased over time to reflect the variation in precipitation and recharge discussed in the conceptual model water budget (Section 3.6.4);
- Time-varying evapotranspiration rates – Evapotranspiration rates vary due to seasonal and inter-annual variations in the depth to groundwater, as well as seasonal variations in the maximum potential evapotranspiration rate that reaches a minimum of 1.5 feet per year during winter and a maximum of 6.9 feet per year in the summer with an annual average of 3.5 feet per year (California Irrigation Management Information System (CIMIS), 2008). These evapotranspiration rates were recently corroborated by measurements of daily water level fluctuations in the site groundwater monitoring program (Tetra Tech, Inc., 2010b);
- Specific Yield values – Specific yield values were initially determined from the site conceptual model, then adjusted during calibration. Final calibrated specific yield values were uniform at 10 percent, consistent with the predominately fine to moderate-grained units in the shallower portions of the aquifer. The final specific yield values were chosen to match the changes in water levels and aquifer storage observed at the site during the 2006 through 2010 period; and

- Specific Storage Coefficient - Specific storage coefficient values were set based upon pump test data for the site as well as published values (Heath, 1987), with values of 2×10^{-5} $feet^{-1}$ for the weathered San Timoteo and 3.3×10^{-7} $feet^{-1}$ for the competent San Timoteo. Model results were not particularly sensitive to the specific storage coefficient values since the storage effects due to specific yield are so much greater in the unconfined aquifer.

Water Levels

The predicted groundwater elevations for the calibrated transient flow model are shown in comparison to the Fall 2006 through Spring 2010 measured elevations in Figure 4-3. A comparison of simulated and observed water levels over time (hydrographs) for monitoring wells located throughout the site are given in Figures 4-4, 4-5, and C-7 through C-9. For the entire simulation period, the mean water level error was 0.12 feet, the standard deviation of error was 7.4 feet, and the relative error (defined as the ratio of the root mean square (RMS) error to the decline in head across the site cluster) was 2.4 percent. The model predicted water levels also show the following important site features:

- Water levels rise seasonally in response to precipitation in the three main recharge areas defined at the site near the South Boundary (well TT-MW2-7, Figure 4-5), near Test Bay canyon (well TT-MW2-14, Figure 4-4), and near the Liquid Waste Discharge Area (well TT-MW2-9S);
- Water levels fluctuations over time that are generally small, with very small changes in the magnitude and direction of the hydraulic gradient; and
- There is a general small declining trend in water levels over the simulation period with water levels dropping an average of 1 foot per year.

These transient water level trends show the comparison is reasonably good between simulated and observed water levels.

Water Budget

The groundwater water budget for the calibrated transient flow model is summarized in Figure 4-6, which shows changes over time in key groundwater flows. The components of the water balance generally match the conceptual water budget calculations given in Section 3-6 and Table 3-2, and the steady-state model results. Notable components of the transient water budget include the following:

- Total recharge averages 2.7 acre-feet per year, which varies over time in a manner that reflects the precipitation and recharge patterns at the site, with most recharge occurring approximately one quarter after the wet season. Model recharge is zero during the dry season, consistent with observations from the site groundwater monitoring program;

- Evapotranspiration rates from the riparian area average 2.5 acre-feet per year, which compares to evapotranspiration rates of about 2 acre-feet per year estimated in the conceptual model. Evapotranspiration in the model varies over time in a manner that reflects the seasonal fluctuations in evapotranspiration rate;

- Storage declines approximately 1 acre-feet per year;

- No underflow into the weathered San Timoteo aquifer, and underflow of 1.5 acre-feet per year into the competent San Timoteo aquifer;

- Underflow of 2.4 acre-feet per year out of the weathered and competent San Timoteo aquifer; and

- Leakage of groundwater between the weathered and competent San Timoteo averages 0.8 acre-feet per year downward in the north of the site, and 1.5 acre-feet per year upward in the south of the site.

Thus, the transient model water balance is reasonably close to the site conceptual model water budget. Given that the model parameters, water levels, gradients, and water budget agree reasonably well with the site conceptual model, the groundwater transient flow model appears to be adequately calibrated for transient conditions.

4.2.2 Transport Model

The transport model was simulated for perchlorate using the MODLOW model files from the 2006-2010 transient flow model calibration and the Fall 2006 concentrations as model initial conditions. Model parameters, boundary conditions, and starting water levels are identical to those given in the transient flow model calibration. In addition, the following parameters are used for the transport calibration (Table 3-5):

- Effective Porosity – Used values of 10 percent as per the specific yield values;

- Retardation Factor – Set equal to one for perchlorate;

- Perchlorate degradation rates – Assumed no degradation;

- Dispersivity –Used values of 5 feet, 0.5 feet, and 0.05 feet for longitudinal, lateral, and vertical dispersivity, respectively; and

- Source Perchlorate Release Rates – Perchlorate release rates were set to be consistent the perchlorate source mass flux values and areas given in the conceptual model in Section 3.

The final model calibrated longitudinal dispersivity value of 5 feet is rather small for plumes of this scale, as published correlations suggest a value on the order of 33 feet for the Test Bay plume and 41 feet for the WDA plume (USEPA, 1998). The smaller value of 5 feet resulted in a better match to observed data, as larger values tended to spread the plume out into areas that historically have been on the fringes of the plume. Although the very sharp concentration gradients observed on the fringes of the plume are suggestive of small dispersivity values, even with these rather small values of 5 feet, the model still tends to underpredict the extremely sharp concentration gradients at the boundaries of the plume, regardless of the choice of numerical method (i.e., MOC or finite difference).

COC Concentration

A crossplot shows a fair correlation between simulated and observed COC concentrations for the simulation time period (Figure 4-7). Figure 4-1 shows simulated 2010 perchlorate concentrations for comparison to the measured perchlorate concentrations given in Figures 3-6A and 3-6B. Figures 4-8 and 4-9 also show time series plots of simulated and observed concentrations at eight monitoring wells. For the entire simulation period, the relative error for the perchlorate concentration, defined as the ratio of the root mean square error to the range in concentration across the site, is 6.1 percent.

While there is a scattering of the data in Figures 4-7, 4-8, and 4-9, this can be largely attributed due to sub-grid scale variability in well screen locations and aquifer conductivity, as well as the spikes in concentrations that occur over time in a given well that may be the result of sampling error and sub-grid scale variability. Since the conceptual model does not include sub-grid scale variability in monitoring well screen locations and aquifer conductivity, nor processes that would explain such spikes in concentrations over time, the transport model does not do a good job of replicating these small grid-scale and time-scale features of the monitoring data. There are also deviations in time that do not appear to be random such as the time trend in TT-MW2-9S (Figure 4-7 and 4-9), where concentrations increase in over time. The model predicts this increase in concentration in well TT-MW2-9S to occur more quickly than observed, which may suggest the local velocity value near TT-MW2-9S is somewhat lower than simulated. This could be accounted for by a higher local effective porosity value near well TT-MW2-9S. However, due to limited duration of the model time period, and the potential that many other factors such as a lower hydraulic conductivity value or water budget also could account for this discrepancy, it was decided that a simple uniform distribution of effective porosity value is better suited to the uncertain nature of the flow model in its current state. Future modeling efforts conducted when a longer period of record and a more certain flow model calibration is available could consider spatial variability in the effective porosity value to adjust the model behavior in the TT-MW2-9S area.

Figure 4-7 Crossplot of Simulated and Observed Perchlorate Concentrations during Fall 2006 - Spring 2010

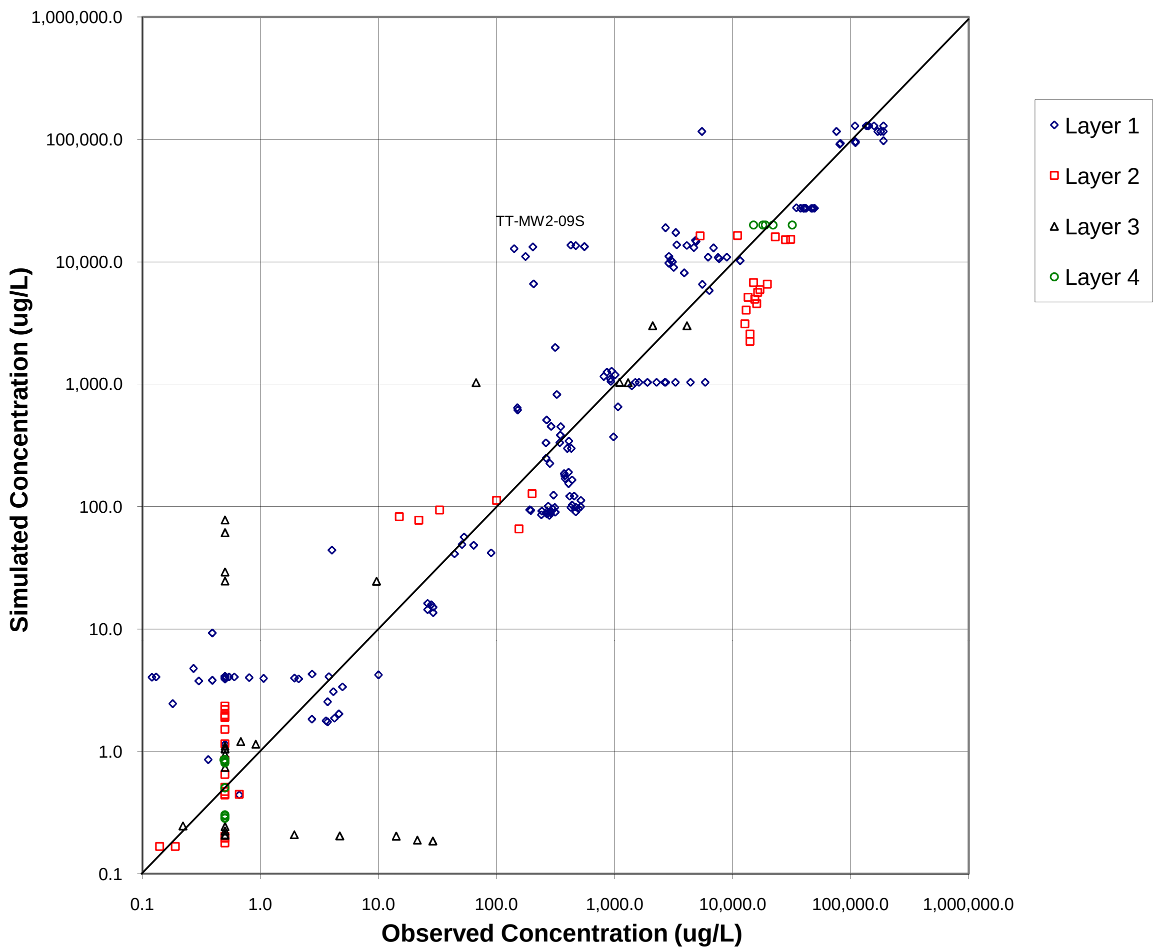


Figure 4-8. Simulated and Observed Perchlorate Concentration over Time for Monitoring Wells TT-MW2-1, TT-MW2-16, TT-MW2-5, and TT-MW2-8

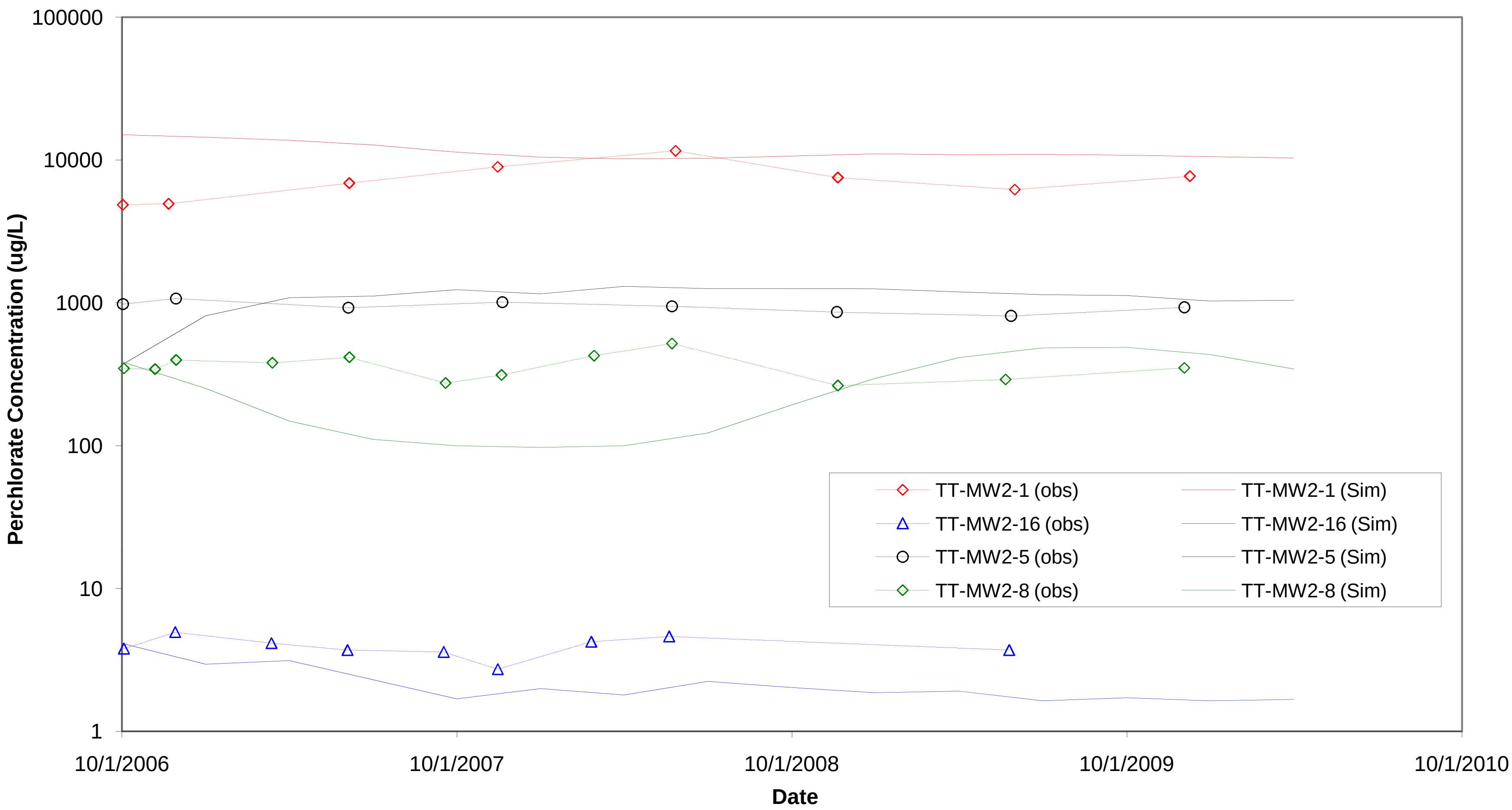
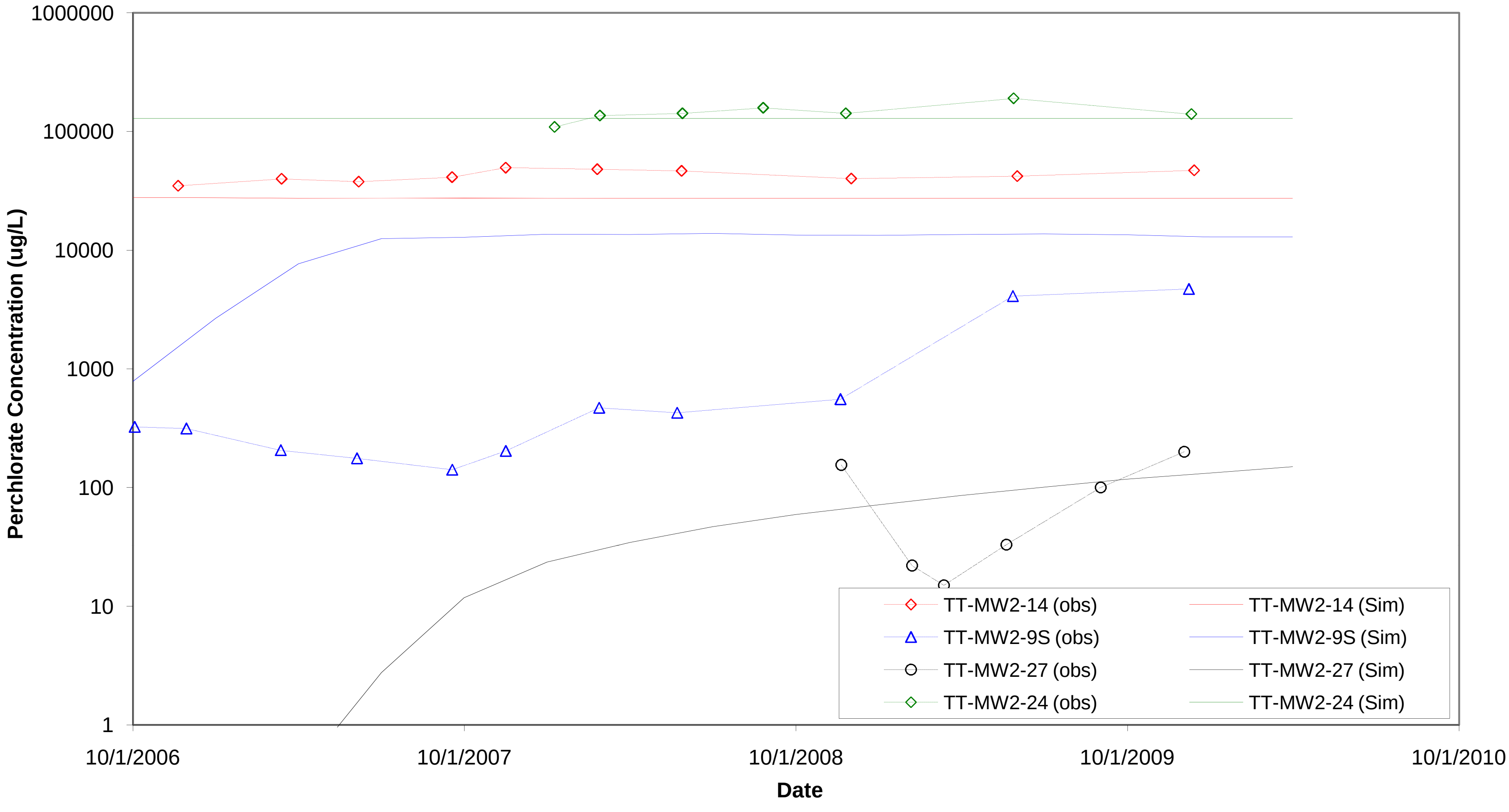


Figure 4-9. Simulated and Observed Perchlorate Concentration over Time for Monitoring Wells TT-MW2-14, TT-MW2-9S, TT-MW2-27, and TT-MW2-24



Additional comparisons of model predicted and observed perchlorate concentrations are as follows:

- Contour plots of the simulated and observed perchlorate concentrations (Figures 4-1 and 3-6A and 3-6B, respectively) generally show a fair comparison between the spatial trends in the model predicted perchlorate contours and the observed perchlorate contours; and
- Time series plots of simulated and observed concentrations for monitoring wells located throughout the site (Figures 4-8 and 4-9), which generally show a fair comparison between the time trends in the model predicted concentrations and the observed perchlorate concentrations.

The model predicted perchlorate concentrations also show the following important site features:

- Hot spots in the plume source areas in Test Bay Canyon, the Garbage Disposal Area, and the WDA;
- Plume migration that follows the boundaries of Laborde Canyon and major side canyons; and
- An overall time trend showing decreasing to stable concentrations in most of the site monitoring wells, generally matching the observed data during the short four-year calibration time period.

Considering the above points, the relative error for the perchlorate concentration of 6.1percent, and the inherent difficulty in re-creating historical source conditions, the comparison between simulated and observed perchlorate concentrations is considered adequate for the purposes of this study. One point of note, however, is that the model tended to overpredict the perchlorate concentrations in the riparian area, which is likely attributed to the unusual nature of the concentrations measured in the site boundary wells, where the very short screened interval wells such as TT-MW2-7 and TT-MW2-8 have quite high concentrations, while the longer screened interval wells such as TT-EW2-1 have concentrations closer to the detection limit. It may be that the data from TT-MW2-7 and TT-MW2-8 are not representative of the average aquifer conditions at the site boundary, which the model was designed to predict.

Perchlorate Mass and Mass Flux Budget

The groundwater perchlorate mass and mass flux budget for the calibrated transport model is summarized in Table 4-2. The components of the perchlorate mass and mass flux budget generally match the conceptual model COC mass and mass flux budget discussed in Section 3-3, Figure 3-7, Table 3-4, and summarized in Table 4-2. Notable components of the perchlorate mass flux budget include the following:

Table 4-2
Transport Model COC Mass and Mass Flux Summary

	Transport Model Predictions		Comment
	Total Mass (pounds)	Mass Flux (pounds/year)	
High Perchlorate Mass Flux Rate Scenario (soil and groundwater sources)			
Sources	987	246.9	Better fit to 2006-2010 water quality data, with percent error of 6.1% vs. 16.2% for low mass flux rate case below
Wells	0	0	
Creek	0	0	
Evapotranspiration	-0.67	-0.17	
Underflow downgradient	1.09E-05	2.74E-06	
Degradation	0	0	
2010 Plume Mass	3,372	NA	
Low Perchlorate Mass Flux Rate Scenario (soil sources only)			
Sources	96	24	Poor fit to 2006-2010 water quality data with percent error of 16.2% vs. 6.1% for high mass flux rate scenario above
Wells	0	0	
Creek	0	0	
Evapotranspiration	-0.67	-0.17	
Underflow downgradient	1.10E-05	2.75E-06	
Degradation	0	0	
2010 Plume Mass	2,756	NA	
Conceptual Model Values (from Section 3)			
Sources	990	247	
Wells	0	0	
Creek	0	0	
Evapotranspiration	-4	-1	
Underflow downgradient	0	0	
Degradation	0	0	
2010 Plume Mass	4,395	NA	

- Total perchlorate plume mass predicted for 2009 is within 25 percent of 2010 observed mass for perchlorate;

- Perchlorate mass flux out of the aquifer due to loss to evapotranspiration is less than 1 pound per year, due to the very low perchlorate concentration in the riparian areas where evapotranspiration is most prevalent;

- Perchlorate mass flux into the aquifer is significantly greater than the mass flux out of the aquifer due to loss to evapotranspiration. This suggests the plume is growing in mass over time;

- The perchlorate source mass flux values (246.9 pounds per year) generally match those estimated using the vadose zone transport methodology in Section 3 (15 to 247 pounds per year). Since there is some uncertainty in the range of perchlorate source mass flux values in the conceptual model (15 to 247 pounds per year), a second model case was evaluated where the MT3D model perchlorate source mass flux value was 24 pounds per year (Table 4-2), but the model relative error for the perchlorate concentration increased to 16 percent from 6.1 percent, supporting the higher mass flux value of 246.9 pounds per year; and

- There is generally fair comparison between the MT3D transport model mass and mass flux values and those estimated in the conceptual model.

Thus, the transport model perchlorate mass and mass flux budget is reasonably close to the site conceptual model perchlorate mass and mass flux budget. Given that the model parameters, concentrations, spatial and temporal concentrations trends, and perchlorate mass and mass flux budget agree reasonably well with the site conceptual model, the groundwater transport model appears to be adequately calibrated.

4.3 SENSITIVITY ANALYSIS

Model sensitivity analyses are conducted to quantify the uncertainty in the calibrated model and rank the importance of model parameters in the calibration process (Anderson and Woessner, 1991). In order to evaluate the sensitivity of the calibrated flow model to various model parameters, a sensitivity analysis was conducted by varying key flow model parameters to values above and below the calibrated values, and calculating the resulting changes in the model water level error and key water budget components such as recharge and evapotranspiration. The maximum and minimum parameter values were chosen based upon the range of data and conditions encountered at the site, and were limited to values that were thought to be reasonable parameter estimates for the site conditions.

Table 4-3 shows the sensitivity analysis results for 50 percent increases and decreases in the following key model parameters: hydraulic conductivity, diffuse recharge rate, and specific yield

Table 4-3
Groundwater Flow Model Sensitivity Analysis
LMC Beaumont Site 2

Flow Model Scenario	Residual Mean (feet)	Residual Standard Deviation (feet)	Minimum Residual (feet)	Maximum Residual (feet)	Relative Error (percent)	Total Recharge (acre-feet per year)	Evapotrans-piration (acre-feet per year)	Comment
Base Case Steady-State Calibration	-0.30	7.34	-13.65	16.11	2.8	3.0	2.4	Fall 2006 water levels
Decrease hydraulic conductivity by 50 percent	-16.00	8.73	-34.17	14.85	3.4	3.0	2.6	high negative skew
Increase hydraulic conductivity by 50 percent	5.05	7.36	-10.94	21.93	2.8	3.0	2.1	high positive skew
Decrease diffuse recharge by 50 percent	7.91	7.27	-8.06	24.83	2.7	1.5	1.1	high positive skew
Increase diffuse recharge by 50 percent	-8.25	8.14	-25.55	15.46	3.1	4.5	3.6	high negative skew
Convert 1.5 AFY diffuse recharge to stream recharge	-0.46	7.35	-13.69	16.88	2.8	3.0	2.4	stream recharge = 2.1 AY, diffuse recharge = 2.1 AFY; no impact to model results
Convert 3.0 AFY diffuse recharge to stream recharge	-0.59	7.31	-13.62	16.94	2.8	3.0	2.4	stream recharge = 4.2 AY, diffuse recharge = 0 AFY; no impact to model results
Base Case Transient Calibration	0.12	7.40	-15.56	15.81	2.4	2.7	2.5	Fall 2006 to Spring 2010 water levels
Decrease specific yield by 50 percent	0.26	7.48	-15.43	15.84	2.4	2.7	2.5	
Increase specific yield by 50 percent	0.08	7.36	-15.61	15.80	2.4	2.7	2.5	

values. A sensitivity analysis was also conducted on the relative contribution of stream and diffuse recharge by varying the stream and diffuse recharge rates between 0, 50, and 100 percent of the total recharge while maintaining total recharge at the calibrated value of 3.0 acre-feet per year The most sensitive model parameter with respect to water level error was the hydraulic conductivity value, while the most sensitive model parameter with respect to water budget was recharge. The sensitivity analysis results show the following:

- The model is not sensitive to the distribution of recharge, supporting the choice of allocating all recharge to diffuse recharge since this better fits the site CSM. In addition, adding the additional model parameters required to simulate both stream and diffuse recharge is not warranted since the additional model parameters result in no significant improvement in the model fit to the observed data.;

- The model is relatively insensitive to specific yield, which is attributed to the very short 4-year transient calibration time period as well as the small water level variations observed during this time period;

- The model is very sensitive to the amount of total recharges since small increases in the total recharge rate from 3.0 to 4.5 acre-feet per year (average diffuse recharge rate of 0.32 inches per year and 0.45 inches per year) results in average model water levels that are almost 10 feet higher than the observed data. This supports the choice of the lower recharge value, since this also better fits the site CSM, though it is noted this recharge value is low for an aquifer in this area; and

- The sensitivity analysis shows that the model is relatively insensitive, with respect to head error, to changes in hydraulic conductivity, recharge, location of recharge, and specific yield. This indicates that other factors beyond head error, such as the CSM and the water budget, need to be considered to have confidence in the model calibration.

The results of this model sensitivity analysis also provide support for the choice of the final calibrated flow model parameters, as the calibration parameter values have low model error, better match the site conceptual model water budget, and are closer to measurements observed in field tests.

In order to evaluate the sensitivity of the transport model to various model parameters, two sensitivity analyses were conducted: varying the effective porosity by 50 percent, and decreasing the perchlorate source mass flux rate from 247 to 24 pounds per year. A 50 percent change in effective porosity has almost no impact on model error, as the relative error remained at 6.1 percent. This is attributed to the very short 4-year transport calibration time period as well as the generally small perchlorate concentration variations observed during this time period. Decreasing the source mass flux to 24 pounds per year increased the model relative error for the perchlorate concentration to 16 percent from 6.1 percent (Table 4-2).

4.4 MODEL UNCERTAINTIES AND LIMITATIONS

The flow and transport model reasonably matches measured water levels, COC concentrations, and the constraints provided by the range of aquifer water and COC mass flux budget values estimated for the site. However, there are significant model uncertainties that limit the predictive ability of the model, most notably:

- Period of Data – Data is available for only a 4 year period to calibrate the model, which introduces significant model uncertainties in model predictions that project 10 to 20 years into the future. For example, the short duration of the calibration period makes if difficult to estimate some model parameters such as effective porosity. Additional monitoring and re-calibration of the model is recommended after several additional years of data are collected.

- Release of Perchlorate from Soils and Groundwater Source Zones – The model predicts rather large perchlorate source release rates of up to 247 pounds per year, assuming there is are soil and groundwater sources supporting the very high groundwater concentrations observed in the aquifer hot spot source areas in Test Bay Canyon and the WDA. However, the 4 year monitoring period is not long enough to establish that groundwater concentrations in the aquifer hot spot source areas are stable. The vadose zone modeling effort show much lower perchlorate flux of 15 to 25 pounds per year into groundwater due to the low recharge rates, but using these low values resulted in large model concentration errors, supporting the choice of higher perchlorate release rates. Thus, the perchlorate release rates of 15 to 247 pounds per year are highly uncertain.

- Recharge Rate – The model predicts a small diffuse recharge rate of 0.33 inches per year for a total recharge rate of 3 acre-feet per year, which is uncharacteristically low for an aquifer of this size in this area. During calibration, many attempts were made to use as high a recharge rate as practical given the site data constraints. As it is, the total recharge rate of 3 acre-feet per year is much higher than the underflow rates of 0.2 to 1 acre-feet per year estimated from the recent Site 2 pumping test at TT-EW2-1. While the very low recharge rates are supported by the site data, it is recognized that there is limited data available for the site, making this parameter highly uncertain. In order to reduce this uncertainty, additional pumping tests are recommended at the site, since it is possible that the TT-EW2-1 pumping test may have been conducted in an area where the aquifer transmissivity is low relative to other site locations.

- Transport Model Uncertainty – Groundwater transport models are generally considered less reliable than groundwater flow models (National Research Council, 1990). At Beaumont Site 2, there is already considerable uncertainty in the groundwater flow model due to the aforementioned issues related to the water budget, and this uncertainty propagates through to the transport model since the flow model results serve as an underlying basis for the transport model. Thus, the Beaumont Site 2 transport model is much less certain than the flow model. From a practical perspective, efforts to improve the reliability of the transport model should first focus on obtaining a more reliable flow model, otherwise adjustments to transport model parameters may be compounding errors present in the flow model. A simple distribution of transport model parameters was used in this modeling effort, and is recommended until a more certain flow model is available.

SECTION 5 MODEL PREDICTIONS

The calibrated flow and transport model presented in Section 4 is used in Section 5 to predict groundwater plume conditions in the site area for the following groundwater remediation and plume management scenarios:

- No Action Alternative- High Source Release Rate;
- No Action Alternative- Low Source Release Rate; and
- Source Removal Alternative.

These model predictions are presented to illustrate various site remediation scenarios that may be evaluated with the model in the site Feasibility Study, however due to the uncertainties that now exist in the current model, the model will be updated with newly collected data prior to use in the Feasibility Study. The intent of the model simulations is to illustrate the model predictions for the following widely different scenarios:

- Source remediation scenarios – scenarios are presented without source treatment and with complete source removal, since these cases present bounding scenarios where most all source remedial cases could be expected to result in perchlorate concentrations and masses that fall between these two alternatives. Note, however, that the presentation of these two extreme alternatives does not in any way suggest a preference or reflect the technical practicability or impracticablity of either alternative; and
- Source release scenarios – scenarios are presented with both high and low source release rates since there is considerable uncertainty in this model parameter.

Presentation of the future scenarios provides a valuable preview of the potential impact of source removal and its impact in the short term on the plume configuration. However, it should be emphasized that due to the considerable uncertainties present in the current model, these scenario results are preliminary and subject to future revision when the model is updated in the future.

The model predictions in Sections 5.1 through 5.4 are made using current water levels and plume concentrations as the model initial conditions. A sixteen year future simulation time period was recently used in the LMC Beaumont Site 1 groundwater model since there was a 16 year calibration period for the Site 1 Model. Since the Site 2 model 4 year calibration period is rather short for predicting long term site groundwater management alternatives, a 16 year future simulation time period was also chosen for the Site 2 Model.

Future hydrologic conditions for the 2010 to 2026 transient model simulation period are estimated by replaying four sequences of the historical hydrologic conditions observed at the site in the 2006 to 2010 four-year calibration period. Future perchlorate source release rates for the model simulation period are estimated from historical perchlorate release rates observed at the site and the vadose zone fate and transport analysis discussed in Sections 3 and 4, and Appendix E. The predicted 2026 perchlorate contour maps for these scenarios are given in Appendix F, and the predicted 2026 perchlorate plume mass estimates are given in Table 5-1.

5.1 NO ACTION ALTERNATIVE - HIGH SOURCE RELEASE RATE

The No Action Alternative - High Source Release Rate case is evaluated as a high-end base case scenario, which consists of current groundwater conditions with continued release of perchlorate from groundwater and soil source areas at the high release rates of 247 pounds per year summarized in Section 3, Section 4, Appendix E, and Table 4-2. The predicted 2026 perchlorate plume concentrations (Figure F-1) are generally similar to current site conditions (Figures 3-6, and 4-1) in the source areas, but the downgradient limits of the plumes have expanded. The Test Bay Canyon plume downgradient limit that now stops just northwest of Area M is predicted to continue to migrate south and commingle with the upper limits of the WDA plume. The WDA plume that now stops just south of the site boundary is predicted to continue to migrate south into the Offsite riparian area, where the higher plume concentrations of 10,000 μg/L are extracted by evapotranspiration, with lower plume concentrations of 1,000 μg/L continuing to migrate to the downgradient limits of the riparian area at the southern model boundary. However, there is considerable uncertainty in this prediction since the model assumes the current plume at the southern property boundary has concentrations that reflect the fairly high concentrations of approximately 500 µg/L observed in the short-screened south boundary wells TT-MW2-7 and TT-MW2-8, as opposed to the longer screened wells in this area where concentrations are just below the 6 μg/L MCL (TT-EW2-1 and the offsite wells). This prediction also assumes that the sharp concentration gradient that now exists at the southern limit of the Test Bay plume near TT-MW2-12 becomes more dispersed, as is more typical of most plumes, as the model has difficulty in maintaining such a sharp longitudinal concentration gradient.

This scenario assumes that perchlorate release rates over the next 16 years will remain at the high end estimate levels of 247 pounds per year, resulting in an increase in plume mass from the current levels of 3,372 pounds to 7,154 pounds (Table 5-1). Based upon site conditions, this appears to be a very environmentally conservative assumption, as there are indications in the site data that perchlorate source release rates may be considerably lower than 247 pounds per year. For example, the site soils data show only 798 pounds of perchlorate is present above the water table,

Table 5-1
2016 Model Predictions
Groundwater Perchlorate Plume Mass (pounds) for various Scenarios

Perchlorate	**Scenario**		
	No Action) High Release Rate (soil and groundwater sources)	**No Action Low Release Rate (only soil sources)**	**Soil and Groundwater Source Removal**
2026 Plume Mass (pounds)	7,154	3,587	3,205
2010 to 2026 Average Source Mass Release Rate (pounds per year)	247	24	0
2010 to 2026 Average Evapotranspiration Mass Extraction Rate (pounds per year)	-10.3	-10.1	-10.1
2010 to 2026 Average Downgradient Underflow Mass Flow Rate (pounds per year)	0.27	0.27	0.27

so almost 3,000 pounds of perchlorate would need to be added to the system by a groundwater source to maintain the high release rates of 240 pounds per year for 16 years. However, due to the short 4 to 6 year duration of the Site 2 perchlorate monitoring data, it is not possible to estimate whether a groundwater source appears likely at Site 2 (in contrast, at LMC Beaumont Site 1, there has been 20 to 25 years of monitoring data that strongly supports the presence of a Site 1 groundwater source). There are minor decreases in plume mass during the 2010-2026 period due to the 10 pounds per year of mass lost to evapotranspiration in the riparian area, and the one-quarter pound per year lost to underflow down the canyon in the shallow weathered San Timoteo formation.

5.2 NO ACTION ALTERNATIVE – LOW SOURCE RELEASE RATE

The No Action Alternative - Low Source Release Rate case is evaluated as a low-end base case scenario, which consists of current groundwater conditions with continued release of perchlorate from source areas at the low release rates of 24 pounds per year summarized in Section 3, Section 4, Appendix E, and Table 4-2. The predicted 2026 perchlorate plume concentrations (Figure F-2) are generally two orders of magnitude lower than current site conditions in the source areas due to the lower source release rates. Similar to the No Action Alternative - High Source Release Rate case, the downgradient limits of the plumes have expanded and are almost identical to those in the No Action Alternative - High Source Release Rate case in Figure F-1. However the area downgradient of the site soils contamination has changed: for Test Bay Canyon the plume hot spot has moved approximately 1,500 feet downgradient and declined in concentration from over 100,000 µg/L to 30,000 µg/L; and for the WDA plume, the plume hot spot has moved approximately 4,000 feet downgradient and declined in concentration from over 100,000 µg/L to 10,000 µg/L. Thus, the No Action Alternative - Low Source Release Rate case results in detachment of the groundwater plume hot spot from the soils plume hot spot, while the No Action Alternative – High Source Release Rate case show no detachment of the groundwater plume hot spot from the soils plume hot spot. Since the current site plume shows no detachment of the groundwater plume hot spot from the soils plume hot spot despite the 35 to 51 year old plume, the limited data available to date suggests that the No Action Alternative – High Source Release Rate case (Section 5.1) may be more likely than the No Action Alternative – Low Source Release Rate case.

This scenario assumes that perchlorate release rates over the next 16 years will remain at the low end estimate levels of 24 pounds per year, resulting in a net increase in plume mass from the current levels of 3,372 pounds to 3,587 pounds (Table 5-1). Based upon site conditions, this appears to be a very environmentally optimistic assumption, as there are indications in the site data that perchlorate source release rates may be considerably higher than pounds per year. For example, the site groundwater and soils data show the site groundwater plume hot spot is essentially located directly underneath the contaminated soils, which is inconsistent with the separation of the site groundwater and soils hot spot predicted by the models. However, due to the short 4 to 6 year duration of the Site 2 perchlorate monitoring data, it is difficult to determine whether the groundwater hot spots at Site 2 are stationary as shown in the No Action Alternative - High Source Release Rate case (Figure F-1). There are minor decreases in plume mass during the 2010-2026 period due to the 10 pounds per year of mass lost to evapotranspiration in the riparian area, and the one-quarter pound per year lost to underflow down the canyon in the shallow weathered San Timoteo formation.

5.3 SOURCE REMOVAL ALTERNATIVE

The Source Removal Alternative is evaluated as an example of a remedial alternative scenario where clean-up actions for the soil and groundwater source areas are effective in stopping the continued release of perchlorate from soil and groundwater sources. This alternative consists of current groundwater conditions with no future release of perchlorate from groundwater and soil source areas. The predicted 2026 perchlorate plume concentrations (Figure F-3) show the source areas are generally below the 6 µg/L perchlorate MCL due to no additional releases from the sources. Similar to the No Action Alternative - Low Source Release Rate case, the downgradient limits of the plumes have expanded and are almost identical to those in the No Action Alternative - Low Source Release Rate case in Figure F-2. Note, however, that removal of mass at the sources would result in more rapid plume depletion, even though it is relatively minor during the 16 year simulation period due to the low groundwater velocity.

This scenario assumes no perchlorate releases from soils or groundwater over the next 16 years, resulting in a small decrease in plume mass due to the 10 pounds per year of mass lost to evapotranspiration in the riparian area, and the one-quarter pound per year lost to underflow down the canyon in the shallow weathered San Timoteo formation.

SECTION 6 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This section presents a summary of the transport modeling effort, including a tabulation of the primary conclusions and recommendations.

6.1 SUMMARY

A Conceptual Site Model (CSM), water and perchlorate mass flux budget, and numerical MODFLOW/MT3D groundwater flow/transport model were developed for the site based upon historical groundwater monitoring and well test data. The numerical groundwater flow and transport model was calibrated for the Fall 2006 through Fall 2010 period. The numerical model provides some level of support for the key hydraulic and transport characteristics of the aquifer, and the water and perchlorate mass flux budget for the aquifer system.

Key aspects of the model include the following:

- Groundwater occurs in two primary units: the shallow weathered San Timoteo formation and the deeper competent San Timoteo formation. The high perchlorate concentration areas of the plume are generally limited to the weathered San Timoteo formation in Test Bay Canyon and WDA source areas where high perchlorate concentration areas extend approximately 100 feet into the competent San Timoteo formation in the areas directly beneath the Test Bay Canyon and WDA source areas. Outside the Test Bay Canyon and WDA source areas, plume concentrations are moderate to low and generally limited to a narrow 400 feet wide plume in the weathered San Timoteo formation;

- Groundwater flow is generally consistent with the direction of surface water flow and topography, with flow to the south at a gradient of 0.03 through Laborde Canyon. The gradient does not vary much along the length of Laborde Canyon, suggesting that aquifer transmissivity is either constant or changing in proportion to the underflow rate;

- There are downward vertical gradients in the upper reaches of Laborde Canyon where there is recharge, and there are upward vertical gradients in the south where there is discharge to the riparian area. There does not appear to be either recharge or discharge to Laborde Creek. Small seasonal water table fluctuations occur in the recharge areas in Test Bay Canyon, near the WDA, and neat the southern site boundary. Generally, no seasonal water table fluctuations occur outside these recharge areas;

- During the 2006-2010 period, total recharge in the weathered San Timoteo is estimated to be 2.7 acre feet per year, with all recharge due to diffuse recharge over the canyon floor. During the 2006-2010 period, total discharge in the weathered San Timoteo is estimated to be 2.5 acre feet per year due to evapotranspiration in the riparian area;

- Perchlorate appears to be added to the plume by the flow of groundwater through an aquifer source area in Test Bay Canyon and the WDA. In addition, perchlorate appears to be added to the plume by the release of perchlorate from soil sources in Test Bay Canyon and the WDA. Current perchlorate mass flux released from all sources is estimated to be in the range between 24 and 250 pounds per year. Current total perchlorate mass in the plume is estimated to be approximately 4,400 pounds. Current total perchlorate mass in soils is approximately 800 pounds;

- Perchlorate released by soil sources is estimated to be on the order of 24 pounds per year, which likely accounts for one-tenth to one-third of the total release rate from both soil and groundwater sources;

- Currently, very little perchlorate is removed from the plume by evapotranspiration in the riparian area due to the low concentrations in that area, but the model predicts that perchlorate removal rates of 10 pounds per year are possible in the 2010-2026 period as the plume migrates into the riparian areas; and

- The extent of the plume appears to be controlled by the build-up of plume mass and extent in the areas between the Test Bay Canyon and WDA sources, and the evapotranspiration sink in the riparian area. A small amount of perchlorate also flows in the plume downgradient of the riparian corridor, assuming no biodegradation of perchlorate in the riparian area;

However, due to the very short model calibration time period, there is still considerable uncertainty in many aspects of the site CSM, including the following:

- The model predicts a small recharge rate of 0.33 inches per year for a total recharge rate of 3 acre-feet per year, which is uncharacteristically low for an aquifer of this size in this area.. While the very low recharge rates are supported by the site data, it is recognized that there is limited data available for the site, making this parameter highly uncertain;

- Data is available for only a 4 year period to calibrate the model, which introduces significant model uncertainties in model predictions that project 10 to 20 years into the future; and

- The model predicts rather large perchlorate source release rates of up to 247 pounds per year, however, the 4 year monitoring period is not long enough to establish that groundwater concentrations in the aquifer hot spot source areas are stable. The vadose zone modeling effort show much lower perchlorate flux of 15 to 25 pounds per year into groundwater due to the low recharge rates, but using these low values resulted in large model concentration errors, supporting the choice of higher perchlorate release rates. Thus, the perchlorate release rates of 15 to 247 pounds per year are highly uncertain.

In general, it should be also be noted that the current calibration is largely predicated on the range in hydraulic conductivity determined from limited hydraulic testing at the site, an estimate of outflow based on the pumping test at the southern end of the site, and estimates of limited seasonal storage changes; any errors in these key site parameters could have significant impacts on the reliability of the current model calibration.

The groundwater flow and transport model was used to predict the impacts on the site groundwater plume for the following site groundwater remedial alternatives:

- A No Action Alternative-High Release Rate Case (Soils and Groundwater Releases);
- A No Action Alternative-Low Release Rate Case (Soils Releases Only); and
- A Source Removal Alternative.

The hydrologic conditions, water budget, and mass flux budget for the future predictions were estimated based upon the historic hydrologic conditions, water budget, and mass flux budget.

6.2 CONCLUSIONS

The following conclusions are presented based upon the CSM, water budget, perchlorate mass flux budget, numerical groundwater flow and transport model calibration, and remedial scenario simulations:

- Currently the groundwater recharge rate to the weathered San Timoteo and underflow rate through the plumes is approximately 3 acre-feet per year, with approximately 90 percent of this flow removed by evapotranspiration in the riparian area and the residual flowing further down Laborde Canyon. While this low water budget is supported by the site well test and monitoring data, it is recognized that the water budget is quite small for an aquifer and plume of this size in this area, so there is considerable uncertainty in the water budget;
- Albeit it slowly, the perchlorate plume at the site generally appears to expanding in mass and size, since perchlorate is currently being added to the plume by sources in Test Bay Canyon and the WDA at rates of approximately 24 to 240 pounds per year, while perchlorate is being removed from the plume at rates less than 1 pound per year in the riparian area;
- Given the 24 to 240 pounds per year of perchlorate being added to the plume and the current perchlorate plume mass of 4,400 pounds, this equates to a plume mass increase of approximately 1 to 7 percent per year;
- Model predictions suggest the following:
  - For a No Action Alternative, 2026 groundwater perchlorate concentrations are predicted to be generally similar to current site conditions in the source areas, but the downgradient limits of the plumes are likely to expand to the southern limit of the Offsite riparian area. However, there is considerable uncertainty in this prediction since

the model assumes the current plume at the southern base boundary has concentrations that reflect the fairly high concentrations observed in the short-screen south boundary wells, as opposed to the longer screener wells in the area where concentrations are just below the 6 µg/L MCL. The model also does not appear capable of maintaining the sharp concentration gradient observed at the southern boundary of the Test Bay plume;

– For a Source Removal Alternative, the source areas are predicted to be generally below the 6 µg/L perchlorate MCL due no releases from the former sources, but the downgradient limits and concentrations of the plumes are almost identical to those in the No Action Alternative. Thus, source removal is unlikely to have a significant impact on the downgradient edges of the plume in the 2010 to 2026 timeframe; and

There is a considerable amount of uncertainty in these conclusions due to the limited calibration that was possible with the groundwater flow and transport model, as well as the uncertain characteristics of the aquifer and plume at the site.

6.3 RECOMMENDATIONS

Based upon the CSM, water and perchlorate mass flux budget, numerical groundwater flow and transport model calibration, and the remedial scenario simulations, it is recommended that the model developed in this study be updated with additional data prior to conducting detailed design of site remedial options. Therefore, the following data collection efforts are suggested to better define key aquifer characteristics in order to improve the predictive capability of the model:

- Additional pumping tests are recommended to better constrain aquifer properties. Possible pumping test locations include the Test Bay Canyon and WDA source areas; at the southern boundary of the Test Bay Canyon plume near TT-MW2-12, and in the offsite riparian area. The estimated aquifer properties and specifics of the proposed hydraulic testing will be reviewed by an engineer or hydrogeologist that is an expert in this field of study with a specialization in modeling;

- Additional groundwater monitoring is recommended over the next few years, including gauging of surface water flows and monitoring water level fluctuations with transducers to detect seasonal fluctuations in the water table in response to precipitation. For example, transducers are currently recording water levels in several wells during the 2010-2011 winter wet season, and these data will be reviewed and used to update the model in the future; and

- Mapping the geologic materials along the stream course through Laborde Canyon is recommended to determine whether the stream base runs over alluvium or low permeability San Timoteo formation. This may help explain the apparent absence of any stream groundwater recharge or discharge.

Due to the rather large uncertainties that now exist in the groundwater flow model, it is recommended that future modeling efforts focus on first improving the overall confidence in the flow model and water budget prior to embarking on a more robust re-calibration of the groundwater transport model parameters.

In addition, given the significant impact the riparian area may have on the plume and the current uncertainty in this area, additional data collection in the riparian area is recommended.

SECTION 7 REFERENCES

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SECTION 8 ACRONYMS

bgs	below ground surface
btoc	below top of casing
BOS	bottom of screen
COPC	chemical(s) of potential concern
CSM	Conceptual Site Model
DTSC	Department of Toxic Substances Control
EC	electrical conductivity
EPA	United States Environmental Protection Agency
ft/ft	feet per foot
ft/day	feet per day
GMP	Groundwater Monitoring Program
HSUs	hydrostratigraphic units
IRM	Interim Removal Action
K	hydraulic conductivity
LAC	Lockheed Aircraft Corporation
LMC	Lockheed Martin Corporation
LPC	Lockheed Propulsion Company
MW	Monitoring well
MCLs	maximum contaminant levels
mg/L	milligrams per liter
msl	mean sea level
µg/L	micrograms/liter
NA	not applicable
NWS	National Weather Service

P	production well
PZ	piezometer
QAL	Quaternary alluvium
SAP	sampling and analysis plan
SFR	Stream Flow Routing
SKR	Stephens' Kangaroo rat
SS	stainless steel
SVOCs	semi-volatile organic compounds
TCE	trichloroethene
TOC	top of casing
TOS	top of screen
Unk.	unknown
U.S.	United States
USFWS	United States Fish and Wildlife Service
VOCs	volatile organic compounds