Revised

# Numerical Groundwater Transport Model Development
# Lockheed Martin Beaumont Site 1
# Beaumont, California

Prepared for:

LOCKHEED MARTIN

TETRA TECH

301 E. Vanderbilt Way, Suite 450
San Bernardino, California 92408

TC# 23521-0704 /July 2011

Lockheed Martin Corporation, Shared Services
Energy, Environment, Safety and Health
2950 North Hollywood Way, Suite 125 Burbank, CA 91505
Telephone: 818.847.0197 Facsimile: 818.847.0256

LOCKHEED MARTIN

July 11, 2011

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

Subject: Submittal of the Revised *Numerical Groundwater Transport Model Development, Lockheed Martin Beaumont Site 1, 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 *Numerical Groundwater Transport Model Development, Lockheed Martin Beaumont Site 1, Beaumont, California* revised in compliance with responses to comments approved by DTSC on June 28, 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 T. Thorne

Brian Thorne
Project Manager, Beaumont

Enclosures

Copy: Eddy Konno, Department of Fish and Game (electronic copy)
Gene Matsushita, LMC (electronic and hard copy)
Sally Drinkard, CDM (electronic copy)
Tom Villeneuve, Tetra Tech (electronic copy)
Alan Bick, Gibson Dunn (electronic copy)

BUR 120 Trans - Revised Numerical Groundwater Contaminant Transport Model Development

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

February 23, 2011

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

NUMERICAL GROUNDWATER TRANSPORT MODEL DEVELOPMENT, LOCKHEED MARTIN CORPORATION, BEAUMONT SITE 1, BEAUMONT, CALIFORNIA (Site Code: 400200)

Dear Ms. Kato:

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

Please address GSU's comments by March 23, 2011.

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

Sincerely,

Daniel K. Zogaib

Daniel K. Zogaib
Project Manager
Brownfields and Environmental Restoration Program

cc: Mr. Gene Matsushita
Senior Manager
Environmental Remediation
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2950 North Hollywood Way, Suite 125
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Department of Toxic Substances Control

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Governor

**MEMORANDUM**

**TO:** Daniel Zogaib
Hazardous Substances Engineer
Cleanup Program

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

**DATE:** February 9, 2011 – **(February 16, 2011 – FINAL)**

**SUBJECT:** SITE 1 NUMERICAL GROUNDWATER TRANSPORT MODEL DEVELOPMENT, BEAUMONT, CALIFORNIA, DATED APRIL 27, 2010

PCA: 11050 SITE CODE: 400200-00 TRACKING #: 1040163

At the request of DTSC Project Manager, Mr. Daniel Zogaib, the Geologic Services Unit (GSU) has reviewed the subject document received on October 21, 2010 for Lockheed Martin Corporation (LMC), Site 1 in Beaumont.

## BACKGROUND

On behalf of LMC, Tetra Tech, Inc. (Tetra Tech) prepared the subject document for LMC's former Beaumont Site 1 (Potrero Creek) facility (the "Site"). The Site is located approximately 70 miles east of Los Angeles in the city of Beaumont in San Bernardino County, California.

Defective solid rocket propellant was washed out of motor casings with groundwater supplied by a former production well (W-1), now properly abandoned. A high-pressure water jet was used to flush propellant from the motor casings in the Rocket Motor Production Area (Area B). The solid propellant pieces produced from the washout activities were collected in a sieve and later packed into drums and taken to the Burn Pit Area (BPA) landfill (Area C) for burning.

The three primary soil chemicals of potential concern (COPCs) are perchlorate, trichloroethylene (TCE), and poly-chlorinated biphenyls (PCBs). Perchlorate is the most extensive soil COPC at the Site, while TCE and PCBs are detected in a few areas of the Site. Although 1,4-dioxane is also a primary COPC with respect to groundwater, it has

not been detected in soil other than isolated locations outside the BPA (the primary source area for all COPCs) at concentrations near the method detection limit (MDL) (0 005-0 031 milligrams per kilogram [mg/Kg]); therefore, 1,4-dioxane is not considered a primary soil COPC in these areas. The primary groundwater COPCs which are detected most frequently and at the highest concentrations are perchlorate, 1,1-dichloroethene (1,1-DCE), TCE, and 1,4-dioxane.

The numerical groundwater transport model was calibrated using data from 1992 through 2009 and simulates the quasi-steady state plume conditions observed. Based on the revised conceptual site model (CSM), water budget, contaminants of concern (COC) mass flux budget, numerical groundwater transport model calibration, and remedial scenario simulations, it is recommended that the ***revised*** model developed in this study be used to evaluate more specific remedial options in the upcoming Feasibility Study.

GSU conducted a critical flaw review of the subject document.

## GENERAL COMMENTS

1 GSU recommends using defined-flux nodes instead of upgradient fixed head nodes. Using fixed head nodes makes the model difficult to calibrate and because too much or too little water can be let into the model inadvertently.

2 Each item in the model should show the associated measurement uncertainly. This is especially important for evapotranspiration. This uncertainty should be discussed in the text as well at the table.

3. Internal fault structures should be incorporated into the model as they appear to affect the plume shape and groundwater flow and contouring.

4. The values used for conductivities appear to be higher than what is usual for the type of material being represented. Values should be verified, because conductivities that are off by a factor of two mean plume velocities are off by the same amount. Capture zones of the wells will change accordingly.

5 The fraction of rainfall for recharge is not a constant, or even linear, but more resembles an exponential function. Using a constant fraction likely overestimates recharge in dry years. Since recharge affects evapotranspiration, problems with recharge may lead to problems in evapotranspiration calculations. If rainfall has been overestimated, then evapotranspiration, may have, in turn, also been overestimated to compensate. California Irrigation Management Information System (CIMIS) is not enough; good estimates of leaf-area index are preferred. Four (4) acre-feet/year per acre requires year-round dense riparian growth, which past site visits did not confirm.

6 The uncertainties of flow estimates should be described based on comments provided. Better calculations of input values and their associated uncertainties should be used.

**SPECIFIC COMMENTS**

1. FIGURES: Beginning with Figure 3-2 and many figures thereafter, the illustrations are unclear and difficult to read. The document should be resubmitted with legible figures.

2 Page 3-13: It should be specified if Figures 3-6 through 3-9 depict current and/or historical concentrations.

3. Page 3-32, Section 3.2.3: "and Site **F—3** is difficult . . ." should be changed to "and Site **F-33** is difficult."

4. Page 3-35: "Given the 7,200 foot long plume at Beaumont Site 1, the longitudinal dispersivity would be estimated using methods summarized in USEPA **(1998).as 50 feet**, the lateral dispersivity is estimated . . ." This statement should be revised to correct typos.

5 Page 6-2: Although remedial alternatives Options B and C are referenced in another document, they should be defined herein.

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 - NUMERICAL GROUNDWATER TRANSPORT MODEL DEVELOPMENT
## LOCKHEED MARTIN BEAUMONT SITE 1, BEAUMONT, CALIFORNIA, DATED OCTOBER 2010.

Before responding to the comments we would like to point out that this groundwater contaminant transport model is the second phase of a two phase numerical modeling program. The initial phase involved the development of a groundwater flow model (Tetra Tech, 2010a) that has been reviewed and approved by DTSC and that the second phase of modeling (contaminant transport) and this report are based on that initial modeling (groundwater flow). Information from the flow model document was not repeated, but incorporated by reference.

| **Comments from DTSC, dated February 23, 2011** | | |
|---|---|---|
| **Comment** | **Response** | **Proposed Action** |
| **General Comment #1**<br>GSU recommends using defined-flux nodes instead of upgradient fixed head nodes. Using fixed head nodes makes the model difficult to calibrate and because too much or too little water can be let into the model inadvertently. | As indicated in the Flow Model report (Tetra Tech, 2010a), the model uses primarily defined-flux nodes and a few time-varying constant head cells southeast of the BPA where water levels are based upon the monitoring data collected at the site. As indicated in the Flow Model report, the total flow through these time-varying constant head cells constitute only 3 acre-feet per year of the total 246 acre-feet per year of flow into the model, which is about 1 percent of the total flow.<br>The model was intentionally designed to assure that the amount of water entering the model at upgradient time variant constant head nodes is small and consistent with the site CSM, The model calibration indicates that for a 16 year calibration period when water levels vary over very large historical ranges of up to 80 feet, that the inflows are reasonable and a small percentage of the overall water balance.<br>This model design is within recommended guidelines for model boundary conditions (ASTM, 1996 and Anderson and Woessner, 1992), which indicate that the model cannot be designed without at least some constant head nodes. Therefore, it is impractical to remove these time variant constant head nodes since it would remove the reference head required in MODFLOW, and using a few head nodes actually makes the model easier to calibrate, not more difficult.<br>Thus, since the current model boundary conditions are well designed; there is no benefit in using defined-flux nodes; and using defined-flux is likely impractical since it would remove the small number of head nodes that are required within MODFLOW for the model to operate properly, no change to these boundary conditions appears warranted. | No changes to the document or model, as the current model time-varying constant head cells southeast of the BPA are appropriate, and the fluxes associated with this boundary are appropriate. |

| Comments from DTSC, dated February 23, 2011 | | |
|---|---|---|
| **Comment** | **Response** | **Proposed Action** |
| **General Comments #2**<br>Each item in the model should show the associated measurement uncertainty. This is especially important for evapotranspiration. This uncertainty should be discussed in the text as well at the table. | Uncertainty in model parameters is already discussed in detail in both the transport model report and the flow model report, where sensitivity to parameter uncertainty is addressed in the model flow and transport model calibration sensitivity analysis. In the sensitivity analysis (see for example Table 4-1 of Tetra Tech, 2010a and Appendix D of Tetra Tech, 2010b), model parameters were varied within ranges determined based upon the associated measurement uncertainty. The resulting impact of this uncertainty was noted within the report. For example, the text referring to Appendix D (Tetra Tech, 2010b) notes the large uncertainty in perchlorate half-life and its associated impact on the plume. | No change to the document. |
| **General Comments #3**<br>Internal fault structures should be incorporated into the model as they appear to affect the plume shape and groundwater flow and contouring. | As indicated in detail in the Flow Model report (Tetra Tech, 2010a) and on page 3-1 of the Transport model report, the model incorporates internal fault structures using the USGS HFB package to generate partial flow boundaries across the Potrero Fault. | No changes to the document or model, as the model already incorporates internal fault structures. |

| Comments from DTSC, dated February 23, 2011 | | |
|---|---|---|
| **Comment** | **Response** | **Proposed Action** |
| **General Comments #4**<br>The values used for conductivities appear to be higher than what is usual for the type of material represented. Values should be verified, because conductivities that are off by a factor of two mean plume velocities are off by the same amount. Capture zones of wells will change accordingly. | Tetra Tech believes the conductivity values used in the model are appropriate and representative of the Site. The values used for hydraulic conductivities of the alluvium vary from 1 to 75 feet per day and average 4 feet per day for the shallow low permeability alluvium and 22 feet per day for the deeper high permeability alluvium, which are reasonable values given the site specific pumping and slug test results and the general nature of the geologic material. For example, note that:<br>1. The geologic material encountered in most site wells consists of coarse grained sands, with gravels also encountered in many wells near the base of the alluvium. Published hydraulic conductivity values range from 0.3 to 1,640 feet per day for coarse sand and 100 to 10,000 feet per day for gravels (USEPA, 1998); and<br>2. A long-term aquifer performance test was conducted at well EW-19 in 2008 that was completed in the permeable alluvial material. Multiple observation wells were used in the analysis and hydraulic conductivity based on this test was estimated at 46 feet per day. Aquifer tests were also conducted at the site during design of the pump and treat system that operated for many years. Hydraulic conductivity values as high as 300 to 400 feet per day were reported for these site pumping tests in the 1990s (Radian Corporation, 1992). The model calibration process included consideration of the long term operations of the pump and treat system, increasing the reliability of the calibration.<br>Thus, it is clear the model hydraulic conductivities are appropriate based upon the site specific well test data; and typical ranges of published hydraulic conductivities for similar geologic materials. | No changes to the document or model, as the model hydraulic conductivities are appropriate and representative. |

| Comments from DTSC, dated February 23, 2011 | | |
|---|---|---|
| **Comment** | **Response** | **Proposed Action** |
| **General Comments #5**<br>The fraction of rainfall for recharge is not a constant, or even linear, but more resembles an exponential function. Using a constant fraction likely overestimates recharge in dry years. Since recharge affects evapotranspiration, problems with recharge may lead to problems in evapotranspiration calculations. If rainfall has been overestimated, then evapotranspiration, may have, in turn also been overestimated to compensate. California Irrigation Management Information System (CIMIS) is not good enough; good estimates of leaf-area index are preferred. Four (4) acre-feet per year requires year-round dense riparian growth, which past site visits did not confirm. | Tetra Tech agrees with the comment that the fraction of rainfall for recharge is not a constant. That is why the model was constructed and calibrated with a fraction of rainfall for recharge that is not a constant, and which resembles an exponential function with a cut-off of 12 inches per year (i.e., no recharge when it rains less than 12 inches per year). This is documented in the Flow Model report, and supported by the published references cited in the report.<br>See also (1) the plot of aquifer recharge rates given in Figure 3-5 from the Transport Model report and (2) the correlation between aquifer recharge volume and precipitation given in Table 3-3 of the flow model report (Tetra Tech, 2010a), both of which clearly show recharge is not a constant fraction of precipitation and increases exponentially. Thus, this comment does not adequately reflect how the model was constructed and calibrated as documented in the Flow Model report.<br>Note the average model evapotranspiration rate is about 2.8 feet per year (139 acre-feet per year evapotranspiration divided by the 50 acre riparian areas). Also, site plant survey studies are currently being conducted to estimate plant evapotranspiration in the riparian area based upon factors such as plant density and type. | No changes to the document or model, as the model already incorporates a fraction of rainfall for recharge that is not a constant and which resembles an exponential function. |
| **General Comments #6**<br>The uncertainties of flow estimates should be described based upon comments provided. Better calculations of input values and their associated uncertainties should be used. | The uncertainties of flow estimates are discussed in the prior Flow Model report (Tetra Tech, 2010a). | No change to the document. |

| Comments from DTSC, dated February 23, 2011 | | |
|---|---|---|
| **Comment** | **Response** | **Proposed Action** |
| **Specific Comment #1**<br>FIGURES: Beginning with Figure 3-2 and many figures thereafter, the illustrations are unclear and difficult to read. The document should be resubmitted with legible figures. | Comment noted. | Figures 3-2 through 3-9 will be revised to make them more readable. |
| **Specific Comment #2**<br>Page 3-13: It should be specified if Figures 3-6 through 3-9 depict current and/or historical concentrations. | These figures represent current conditions. | The text will be revised on Page 3-13 to indicate that Figures 3-6 through 3-9 represent current conditions. |
| **Specific Comment #3**<br>Page 3-32, Section 3.2.3: "and Site F-3 is difficult…" should be changed to "and Site F-33 is difficult" | The typographical error within the text will be revised as requested. | The text will be revised on Page 3-32 to indicate "and Site F-33 is difficult" |

| Comments from DTSC, dated February 23, 2011 | | |
|---|---|---|
| **Comment** | **Response** | **Proposed Action** |
| **Specific Comment #4**<br>Page 3-35: Given the 7,200 foot long plume at Beaumont Site 1, the longitudinal dispersivity would be estimated using methods summarized in USEPA (1998). as 50 feet, the lateral dispersivity is estimated." This statement should be revised to correct typos. | The typographical error within the text will be revised as requested. | The text was revised on Page 3-35 to indicate "Given the 7,200 foot long plume at Beaumont Site 1, the longitudinal dispersivity would be estimated using methods summarized in USEPA (1998) as 50 feet. The lateral dispersivity is estimated at 5 to 17 feet, and the vertical dispersivity is estimated at 0.5 to 2.5 feet using methods summarized in USEPA (1998)." |

| Comments from DTSC, dated February 23, 2011 | | |
|---|---|---|
| **Comment** | **Response** | **Proposed Action** |
| **Specific Comment #5**<br>Page 6-2, Although remedial alternatives Options B and C are referenced in another document, they should be defined herein. | Text from the Flow Model report will be added to define remedial alternatives Options B and C. | The text was revised on Page 6-2 to indicate "The expanded RMPA extraction/injection system Options B or C consist of the addition of two new extraction wells and two new re-injection wells in order to expand the total RMPA extraction and re-injection rates to 91 gpm. The difference between Option B and C is the placement of the new extraction wells, with Option C placing one new extraction well closer to the BPA than the location used in Option B." |

**References:**

ASTM, 1996. Guide for Application for Groundwater Flow Model to a Site Specific Problem (D 5447-93); Guide for Determining Boundary Conditions in Groundwater Flow Modeling (D 5609-94); Guide for Comparing Groundwater Flow Model Simulations to Site Specific Information (D 5490-93); and others given in ASTM Standards on Analysis of Hydrologic Parameters and Groundwater Modeling, ASTM Publication Number 03-418096-38, ASTM, West Conshohocken, PA, 1996.

Anderson, M.P. and W.W. Woessner, 1992. Applied Groundwater Modeling Simulation of Flow and Advective Transport. Academic Press, Inc.

Radian Corporation, 1992. Lockheed Propulsion Company Beaumont Test Facilities Hydrogeologic Study, December 1992.

Tetra Tech, Inc., 2010a. Transient Groundwater Model Report, Numerical Flow Model Development, Lockheed Martin Corporation, Beaumont Site 1 Beaumont, California, January 2010.

Tetra Tech, Inc., 2010b. Numerical Groundwater Transport Model Development, Lockheed Martin, Beaumont Site 1 Beaumont, California, October 2010.

US Environmental Protection Agency (EPA), 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water, Office of Research and Development, EPA/600/R-98/128, September 1998.

Department of Toxic Substances Control

*Linda S. Adams*
Acting Secretary for
Environmental Protection

Deborah O. Raphael, Director
5796 Corporate Avenue
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*Edmund G. Brown Jr.*
Governor

June 28, 2011

Mr. Brian T. Thorne
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NUMERICAL GROUNDWATER TRANSPORT MODEL DEVELOPMENT, LOCKHEED MARTIN CORPORATION, BEAUMONT SITE 1, BEAUMONT, CALIFORNIA (Site Code: 400200)

Dear Mr. Thorne:

The Department of Toxic Substances Control (DTSC) has reviewed your responses to our comments regarding the subject document. Please make the agreed upon revisions to the document and resubmit it to DTSC for approval.

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

Sincerely,

Daniel K. Zogaib

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**

# NUMERICAL GROUNDWATER TRANSPORT MODEL DEVELOPMENT, LOCKHEED MARTIN BEAUMONT SITE 1, BEAUMONT, CALIFORNIA

Prepared for:

Lockheed Martin Corporation

Prepared by:

Tetra Tech, Inc.

July 2011

Bob Johns, PhD
Project Manager

Ben Weink, P.G. California 8037
Beaumont Site 1 Manager

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## APPENDICES

# EXECUTIVE SUMMARY

This Groundwater Transport Modeling Report was prepared by Tetra Tech, Inc. on behalf of Lockheed Martin Corporation and presents the results of groundwater flow and transport modeling activities for Beaumont Site 1, Beaumont, California. A Conceptual Site Model (CSM), water and COC mass flux budget, and numerical groundwater flow and transport model were developed based upon the site historical groundwater monitoring and remedial operations data.

The numerical groundwater transport model was calibrated for the 1992 through 2009 period, and found to be capable of simulating the quasi- steady state plume conditions observed during that period. Key aspects of the transport model include the following:

- Perchlorate, 1,4-dioxane, 1,1-DCE, and TCE appear to be added to the plume by the flow of groundwater through a one (1) acre aquifer source area in the BPA. In addition, perchlorate appears to be added to the plume by the release of perchlorate from soil sources in the BPA, RMPA, and to a lesser extent at Site F-33. Current COC mass flux released from all sources is estimated as follows: 19 pounds per year for 1,1-DCE; 9 pounds per year for TCE; 156 pounds per year for perchlorate; and 4 pounds per year for 1,4-dioxane. Current total COC mass in the groundwater plume is estimated as follows: 450 pounds for 1,1-DCE; 370 pounds for TCE; 3,300 pounds for perchlorate; and 90 pounds for 1,4-dioxane. Current total COC mass in soils is 1,800 pounds for perchlorate with no other COCs present in soils;

- In the BPA, soil sources account for approximately 30 to 50 percent of the BPA perchlorate source, with groundwater sources accounting for the remaining 50 to 70 percent of perchlorate and all the 1,4-dioxane, 1,1-DCE, and TCE. In the RMPA, the only source is for perchlorate released from soils;

- In the riparian area, all COCs appear to be removed from the plume by evapotranspiration at rates of 8 pounds per year for 1,1-DCE, 12 pounds per year for TCE, 20 pounds per year for perchlorate, and 2 pounds per year for 1,4-dioxane; in addition perchlorate is removed by biodegradation in the riparian area at rates of 134 pounds per year;

- Generally, the plume at the site appears to be in a quasi- steady state conditions where COCs are added to the plume in the BPA and RMPA source areas at rates of approximately 188 pounds per year, which are nearly equal to the COC removal rates from the plume of approximately 177 pounds per year in the riparian area; and

- The lateral and vertical extent of the plume appears to be controlled by the build-up of plume mass and extent in the areas between the BPA and RMPA source areas, and the evapotranspiration and biodegradation sinks in the riparian area.

The groundwater transport model was used to predict future impacts on the site groundwater plume for several site groundwater remedial alternatives, including a No Action Alternative; Source Removal Alternatives; and expanded RMPA extraction/injection system Alternatives.

Model predictions suggest the following:

- For a No Action Alternative, 2026 groundwater COC concentrations are likely to be quite similar to the current conditions, as future COC mass, release, and removal rates during the next 16 years are thought to be similar to the current rates;

- For a Source Removal Alternative without operation of the RMPA extraction/injection system, 2026 groundwater COC concentrations are likely to be reduced by one to two orders of magnitude below current conditions or the No Action Alternative at and immediately downgradient of the BPA/RMPA source areas, but similar to the current conditions in the downgradient riparian areas of the site. The predicted 2026 plume COC mass estimates are reduced by 74 percent in comparison to the No Action Alternative;

- For an Alternative with an expanded RMPA extraction/injection system without Source Removal, 2026 groundwater COC concentrations are likely to be reduced by one to two orders of magnitude below current conditions or the No Action Alternative in the areas downgradient of the RMPA system, but similar to the current conditions or the No Action Alternative at and immediately downgradient of the BPA/RMPA source areas. The predicted 2026 COC plume mass estimates are reduced by 13 to 25 percent in comparison to the No Action Alternative; and

- For an Alternative with an expanded RMPA extraction/injection system with Source Removal, 2026 groundwater COC concentrations are likely to be reduced by one to two orders of magnitude below current conditions or the No Action Alternative in both the source areas and the areas downgradient of the RMPA system. The predicted 2026 COC mass estimates are reduced by 84 to 88 percent in comparison to the No Action Alternative.

Based upon the CSM, water budget, COC mass flux budget, numerical groundwater transport model calibration, and remedial scenario simulations, it is recommended that the model developed in this study be used to evaluate more specific remedial options developed as part of the upcoming site Feasibility Study. In addition, if the Feasibility Study appears likely to recommend groundwater remedial action at the Burn Pit Area, additional data collection on the Burn Pit Area well capacity and aquifer characteristics is recommended to aid with detailed remedial design.

# SECTION 1 INTRODUCTION

This Groundwater Transport Modeling Report (Report) was prepared by Tetra Tech, Inc. (Tetra Tech) on behalf of Lockheed Martin Corporation (LMC) and presents the results of groundwater transport modeling activities for the Beaumont Site 1 (Site). The Site is located southwest of the City of Beaumont, Riverside County, California (Figure 1-1).

The objectives of this study are to:

- Develop a conceptual model of the plume and contaminants of concern (COCs);
- Quantify components of the COCs mass flux budget;
- Develop a calibrated numerical groundwater transport model; and
- Utilize the calibrated groundwater transport model to evaluate and aid in the design of groundwater remediation measures at the site.

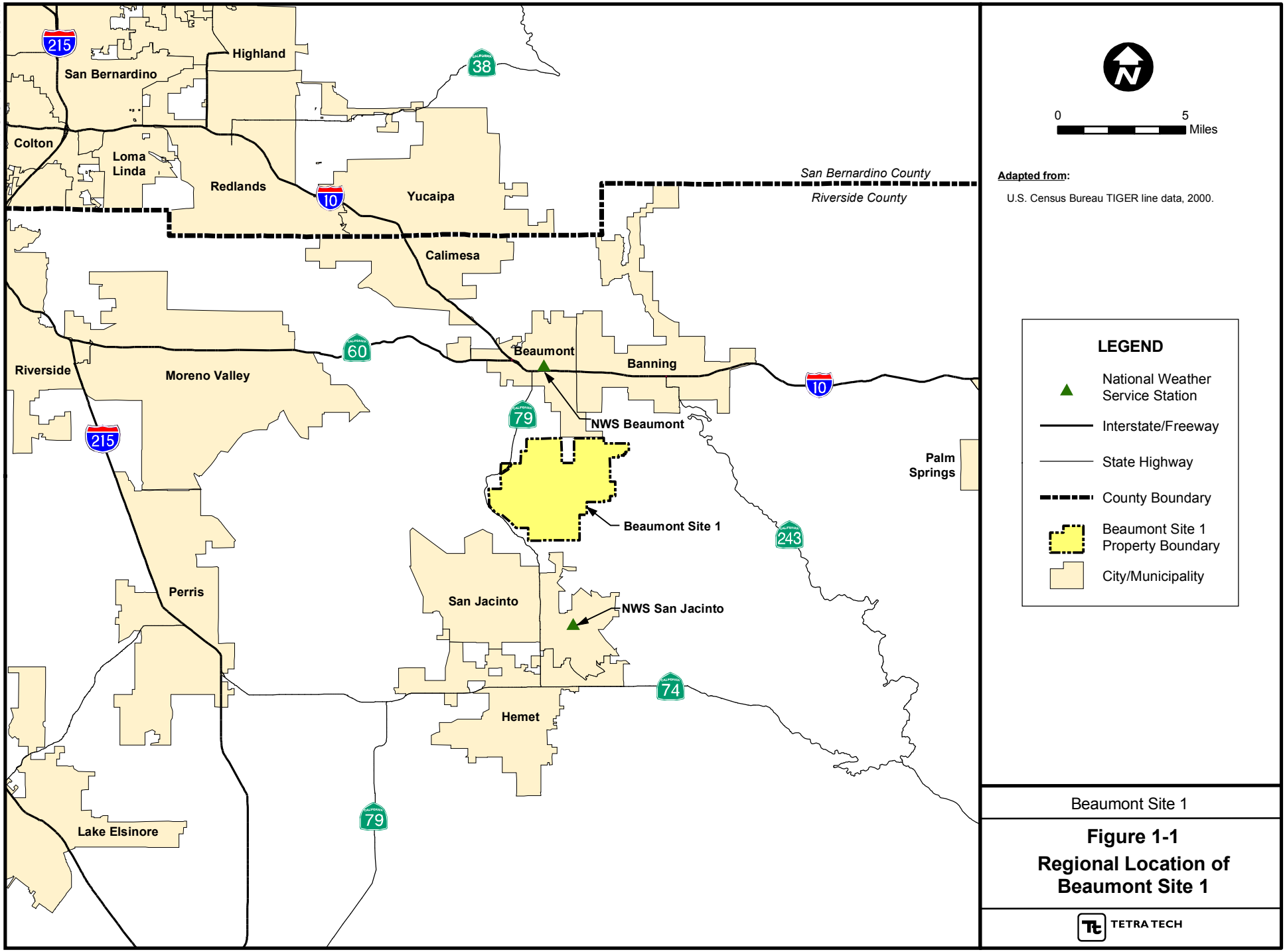
Specific issues to be addressed using the model include estimating the mass and mass flux of the various site COCs, and estimating the impact of the riparian area on the COCs mass flux budget, since the riparian area appears to be providing some degree of phytoremediation of the plume.

This Report also includes background on the Site and prior groundwater modeling activities. The transport modeling work builds upon the recently completed site groundwater flow model (Tetra Tech, 2010).

## 1.1 SITE BACKGROUND

The Site is a 9,117-acre parcel located south of Beaumont, California. The Site was primarily used for ranching prior to 1960. From 1960 to 1974, the Site was used by Lockheed Propulsion Company (LPC) for solid rocket motor and ballistics testing. Activities at the Site also included burning of process chemicals and waste rocket propellants in an area commonly referred to as the burn pit area (BPA).

Nine (9) primary historical operational areas have been identified at the Site. A Site historical operational areas and features map is presented as Figure 1-2. Each historical operational area was used for various activities associated with rocket motor assembly, testing, and propellant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215
Highland
San Bernardino
38
Colton
Loma
Linda
Redlands
10
Yucaipa
San Bernardino County
Riverside County
Calimesa
60
Beaumont
Banning
Riverside
Moreno Valley
10
79
NWS Beaumont
215
Palm
Springs
Beaumont Site 1
243
Perris
San Jacinto
NWS San Jacinto
74
Hemet
79
Lake Elsinore
0
5
Miles
Adapted from:
U.S. Census Bureau TIGER line data, 2000.
LEGEND
National Weather Service Station
Interstate/Freeway
State Highway
County Boundary
Beaumont Site 1 Property Boundary
City/Municipality
Beaumont Site 1
Figure 1-1
Regional Location of Beaumont Site 1
TETRA TECH

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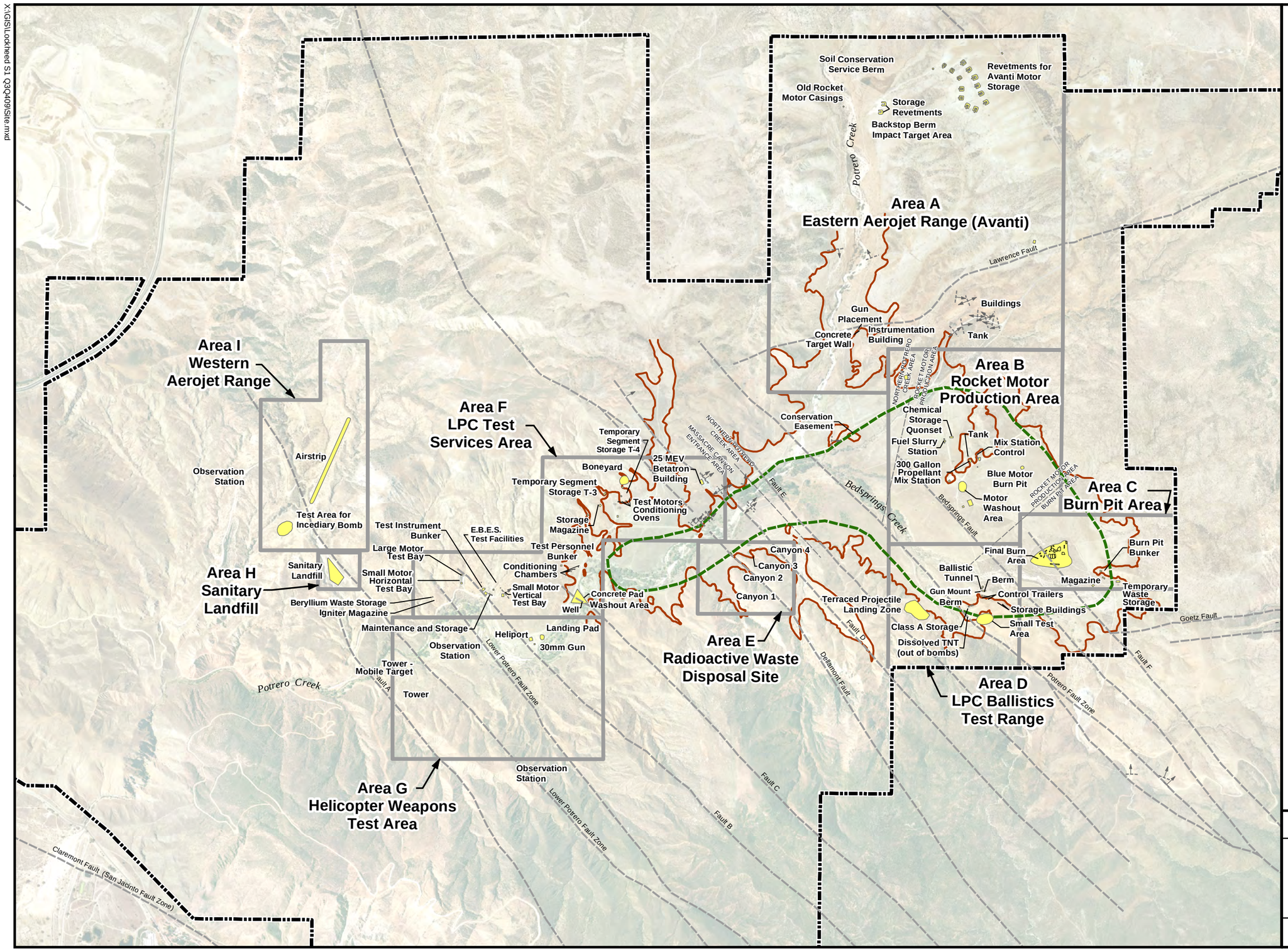


0 1,000 2,000 Feet

Adapted from: March 2007 aerial photograph.

Faults from structural analysis of Potrero Valley, *Lineament and Geologic Mapping Study, Tetra Tech, 2009.*

## LEGEND

- Fault, Accurately Located Showing Dip
- Fault, Approximately Located
- Bedrock/Alluvium Surface Contact
  Dashed where inferred
- Historic Feature Location
- Conservation Easement Boundary
- Beaumont Site 1
  Property Boundary
- Historical Operational
  Area Boundary

Notes: Beaumont Site 1 property boundary is approximate.

Beaumont Site 1

**Figure 1-2**
**Historical Operational Areas, Site Features, and Conservation Easement**

TETRA TECH

incineration. It is likely that the large quantities of water used during operations at the RMPA and F33 would have resulted in high loadings of water and perchlorate to groundwater. Significant groundwater contamination was found in Site investigations in the Rocket Motor Production Area (RMPA) and the BPA (see plumes depicted in Figures 3-6 through 3-9).

Two groundwater remediation systems were historically installed and operated at the Site: the RMPA Groundwater Extraction and Injection System and a combined dual-phase groundwater/SVE remedial system in the BPA. The RMPA Groundwater Extraction and Injection System operated from August 1994 through December 2002. Groundwater was extracted from wells EW-1 and EW-2, treated, and re-injected into wells IW-1 to IW-5. A total of 124 million gallons of groundwater was extracted and re-injected from the Bedsprings Creek alluvium during this period at an average rate of about 30 to 55 gpm. Upon shutdown, the RMPA system had extracted a cumulative total equal to three-quarters of a pore volume of the 400 µg/L Total VOCs plume targeted for cleanup, or about one-quarter of a pore volume of the entire plume. The combined dual-phase groundwater/SVE remedial system was operated at the BPA from August 1994 through July 1998 to treat soils and very shallow groundwater in low permeability bedrock of the Mt Eden formation, extracting groundwater at a total system flowrate of 2 gpm and soil vapors at a total system flowrate of approximately 200 SCFM. Upon shut-down, the BPA two-phase system had reduced soil vapor concentrations from 147,800 ppbv to 1,370 ppbv.

Groundwater level and water quality monitoring has been conducted on a quarterly basis from 1990 through 2008 to monitor the site groundwater plume, and the progress of the BPA and RMPA remedial operations. The results of groundwater monitoring activities are summarized twice per year along with a presentation the most current site conceptual model in the site groundwater monitoring semi-annual reports.

## 1.2 PREVIOUS GROUNDWATER MODELING ACTIVITIES

A three-dimensional finite element groundwater flow model was developed for the Site in 1993 (Radian, 1993). The model included the Quaternary alluvium and a 20 foot thick weathered Mt Eden formation in the Potrero and Bedsprings Valleys, and was calibrated for steady-state conditions using 1992 water levels. Documentation on the water budget and hydraulic parameters for the model is limited, with the diffuse recharge reported to be at a rate of 1.7 inches per year and evapotranspiration reported to be at a rate of 3.65 feet per year. This modeling effort indicated that 60 gpm would be needed to maintain hydraulic control over the 1,130 feet wide target zone,

which was the 400 ug/L Total VOCs isopleth within the RMPA. The model files for this 1993 finite element groundwater flow model were not available for review and use in this study. No prior groundwater transport modeling work has been undertaken at the Site.

Recently, an updated groundwater flow model was completed for the Site (Tetra Tech, 2010), developing a Conceptual Site Model (CSM), water budget, and numerical groundwater flow model based upon the site historical groundwater monitoring, remedial operations data, and the November 2008 pumping test data collected from Middle Potrero Creek. Key aspects of the model include the following:

- Groundwater occurs in four primary units: shallow low permeability Quaternary alluvium, deep high permeability Quaternary alluvium/weathered Mount Eden, the competent Mount Eden Formation, and the granitic basement. The plume is generally limited to the alluvial units;

- During the 1992-2008 period, total recharge to the alluvium is estimated to be 246 acre feet per year with 110 acre feet per year due to diffuse recharge over the valley floor and 136 acre feet due to recharge from creeks; and

- During the 1992-2008 period, total discharge from the alluvium is estimated to be 218 acre feet per year with 139 acre-feet per year due to evapotranspiration from the riparian area, 71 acre feet per year due to discharge to Potrero Creek, and 8 acre feet per year due to leakage down into the Mt Eden. During the 1992-2008 period, aquifer storage also increased by 28 acre feet per year.

The transport modeling work builds upon this groundwater flow model.

## 1.3 CURRENT GROUNDWATER MODELING ACTIVITIES

The approach for development of the model includes the following:

- Compiling and assembling data regarding historic well pumping, 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 Potrero Creek and Bedsprings Creek areas and the site plume. This effort included definition of hydrostratigraphic units, boundary conditions, direction of groundwater flow, and preparation of a groundwater and COC mass flux budget;

- Constructing a groundwater transport model of the area using MODFLOW2000 (Harbaugh et al., 2000) and MT3D (Zheng and Wang, 1999);

- Calibrating the transport model to COC data collected from the site and the COC mass flux budget;
- Evaluating the impact on the site plume of various alternative remedial options for the site; and
- Documenting the study findings 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 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 assembling 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, pumping rates, construction, depths and perforation intervals. Other information sought and considered relevant was surface geology, stream flow discharge, and land use.

Data sources, data analysis, and data gaps were recently summarized in the groundwater flow model report (Tetra Tech, 2010). Additional data collected since the completion of the groundwater flow model include the following:

- Dynamic Site Investigation – The Dynamic Site Investigation (DSI) (Tetra Tech, 2009), which summarizes key groundwater and soils source areas for the site COCs; and
- Organic carbon data – Data on aquifer solid phase organic carbon fraction to quantify the potential for the retardation of the VOCs in the plume was recently collected at two wells drilled in the riparian area (Table 2-1). These data indicate that the aquifer solid organic carbon averages 2,767 mg/kg in Wells MW-101 and MW-102, which corresponds to a retardation factor for TCE and 1,1-DCE of 2.4 and 1.8, respectively. The corresponding retardation factor for 1,4-dioxane is very close to one (1.2).

Although there are uncertainties in some aspects of the conceptual model as discussed in Section 3, this is typical for hydrogeologic studies, and there do not appear to be any data gaps that would preclude proceeding with the development of a numerical transport model.

Table 2-1
Organic Carbon Data from Wells MW-101 and MW-102

| Well-Depth (ft bgs) | Lab Sample No. | Organic Carbon (TOC), mg/kg | Depth (ft bgs) | Comments | Moisture Content (%) | Density lb/cu ft | Gravity, gm/cc | Total Porosity (%) |
|---|---|---|---|---|---|---|---|---|
| MW-102-35 | A9K1217-01 | 940 | 35 | | 17.4 | 114.6 | 2.696 | 31.88 |
| MW-102-40 | A9K1217-02 | 780 | 40 | | 16.1 | 115.7 | 2.684 | 30.92 |
| MW-102-45 | A9K1217-03 | 1,100 | 45 | | 28.1 | 95.2 | 2.72 | 43.91 |
| MW-102-50 | A9K1217-04 | 7,200 | 50 | | 25.6 | 99.3 | 2.704 | 41.15 |
| MW-101-9 | A9K1217-05 | 3,700 | 9 | | | | | |
| MW-101-9DUP | A9K1217-06 | 1,900 | 9 | | | | | |
| MW-101-19 | A9K1217-07 | 9,800 | 19 | | | | | |
| MW-101-21 | A9K1217-08 | 8,200 | 21 | | | | | |
| MW-101-29 | A9K1217-09 | 2,900 | 29 | | | | | |
| Mean MW-101 | | 2,505 | | | | | | |
| Geomean MW-101 | | 1,552 | | | | | | |
| Mean MW-102 | | 5,300 | | | | | | |
| Geomean MW-102 | | 4,394 | | | | | | |
| Mean All | | 4,058 | | | 21.8 | 106.2 | 2.70 | 36.97 |
| Geomean All | | 2,767 | | | | "=1.70 gm/cc" | | |
| Min All | | 780 | | | | | | |
| Max All | | 9,800 | | | | | | |

| Chemical | Koc (L/kg) (US EPA, 1998) | Kd[1] (L/kg) Geomean All | Retardation Factor[2] (Geomean All) | Kd[1] (L/kg) Min All | Retardation Factor[2] (Min All) | Kd[1] (L/kg) Max All | Retardation Factor[2] (Max All) |
|---|---|---|---|---|---|---|---|
| TCE | 107 | 0.17 | 1.79 | 0.05 | 1.22 | 0.61 | 3.80 |
| 1,1-DCE | 64.6 | 0.10 | 1.48 | 0.03 | 1.13 | 0.37 | 2.69 |
| 1,4-dioxane | 17 | 0.03 | 1.13 | 0.01 | 1.04 | 0.10 | 1.44 |

[1] $Kd = 0.58*TOC*Koc/10^6$

[2] $R = 1+(density/62.4)*Kd/porosity$

Equations from US EPA, 1998

# SECTION 3 CONCEPTUAL MODEL

## 3.1 GROUNDWATER FLOW CONCEPTUAL MODEL

The groundwater conceptual model was recently updated in the recent groundwater numerical flow model report (Tetra Tech, 2010). Key flow-related elements of the conceptual model include the following:

- Groundwater occurs in four primary units: shallow low permeability Quaternary alluvium, deep high permeability Quaternary alluvium/weathered Mount Eden, the competent Mount Eden Formation, and the granitic basement (Figures 3-1 and 3-2). The basement rocks provide a base for the shallow water bearing groundwater in the alluvium and weathered Mount Eden, since groundwater in the basement rocks is confined and only found in weathered or fracture zones;

- A small unconfined alluvial basin is found in Bedsprings Creek Valley near the confluence of Potrero and Bedsprings Creeks, with a 100-200 foot thick sequence of saturated recent alluvium located between the Potrero and Bedsprings Faults. All alluvial groundwater eventually discharges as either evapotranspiration or to Potrero Creek as the alluvium pinches out against the Mount Eden, although this pinchout occurs downgradient of the extent of the plume as defined by the COC MCLs;

- Groundwater flow is generally consistent with the direction of surface water flow and topography, with flow to the northwest at a gradient of 0.002 through the Bedsprings Creek alluvium turning southwest through the canyon at a gradient of 0.01 to 0.02 (Figure 3-3). There are downward vertical gradients in the alluvium in the southeast of the site where there is recharge, and there are upward vertical gradients in the alluvium in the northwest and west of the site where there is discharge to the riparian area and to Potrero Creek. There are significant fluctuations of groundwater levels on a seasonal basis in the burn pit area, which have the potential to impact continuing source releases. A small artesian zone with heads above ground surface occurs in the area with upward vertical gradients near the confluence of Bedsprings and Potrero Creeks, associated with the partial barrier effect of the faults in the area;

- Hydrologic Boundaries for the alluvium (Figure 3-4) are primarily no-flow conditions where the alluvium pinches out at the perimeter of the valley; a leakage boundary at the base of the alluvium; a flow recharge boundary along and under Bedsprings Creek; a flow discharge boundary along Potrero Creek; and partial flow barrier boundaries across Potrero Fault.;

- Aquifer hydraulic conductivity values are from 1 to 30 feet per day for the alluvium. Hydraulic conductivity values vary with depth and have a geometric mean of 4 feet per day for the shallow alluvium; 22 feet per day for the deep alluvium; 0.1 foot per day for the competent Mount Eden Formation; and 0.01 foot per day for the granite. Hydraulic conductivity values also vary by area, with the highest values between the RMPA and BPA

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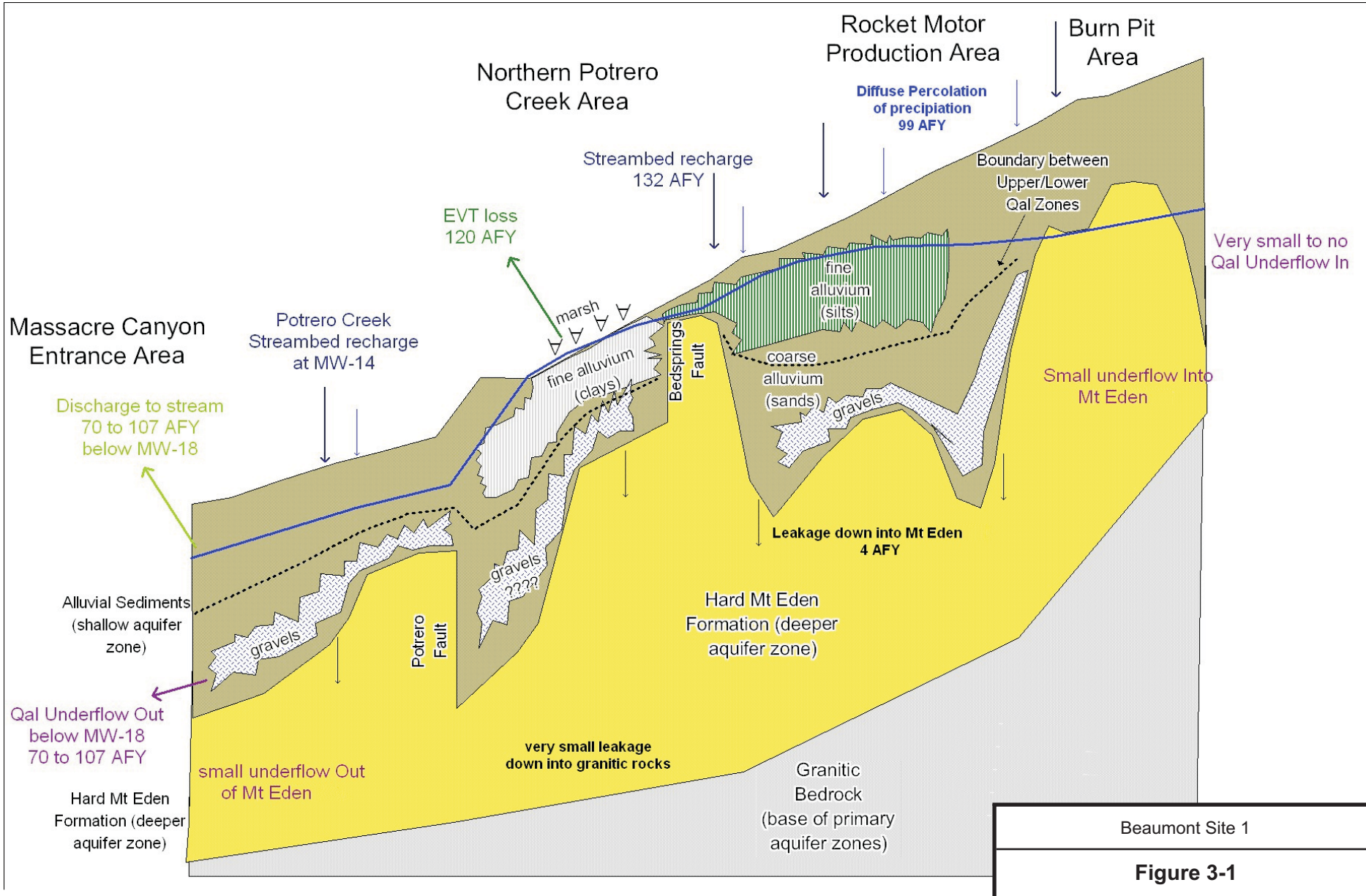



Illustration not to scale.

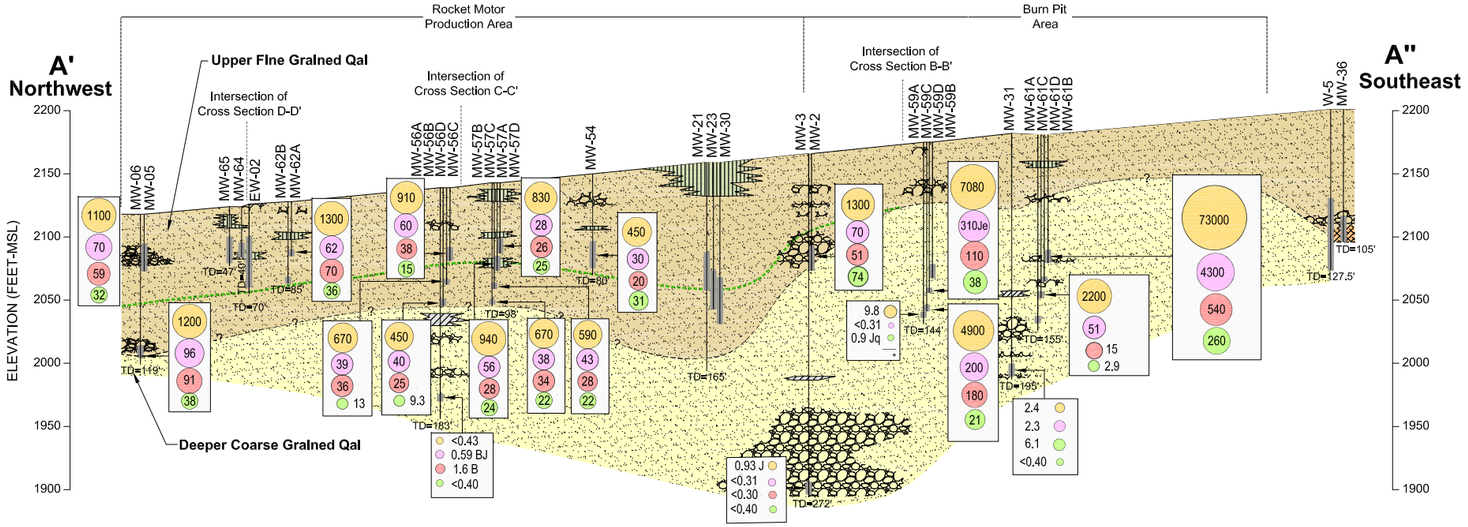
Beaumont Site 1

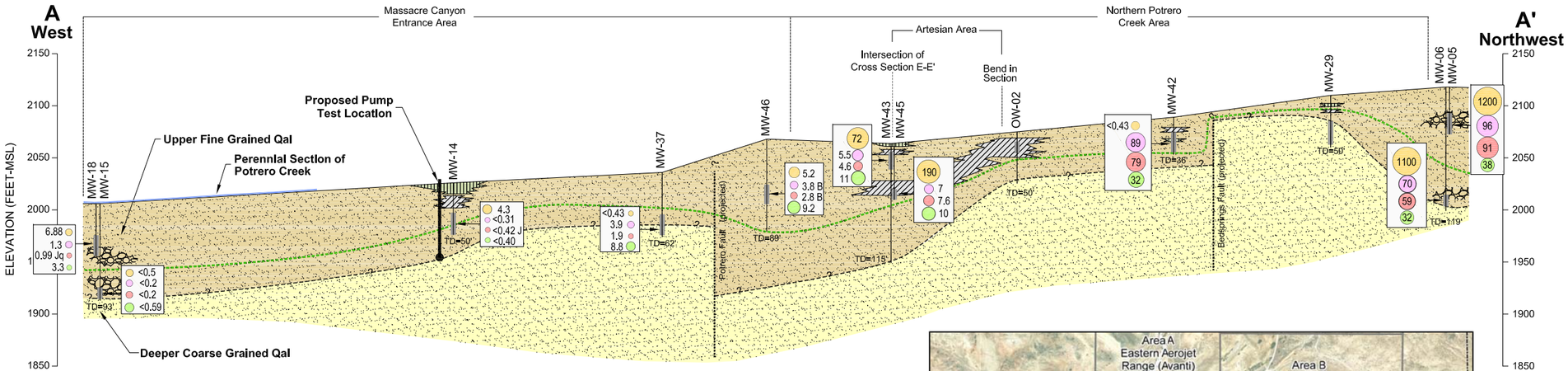
**Figure 3-1**

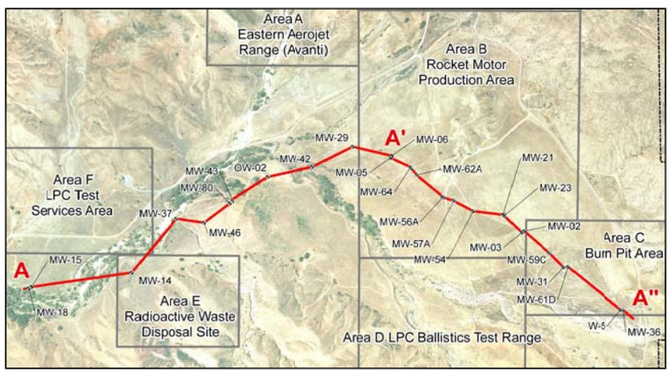
**Updated Hydrostratigraphic Conceptual Model**

TETRA TECH

X:\GIS\LOCKHEED 25241-01-06011X-SEC A CSM.DWG




0 600

Scale in Feet
Vertical Exaggeration = 5x Horizontal

120

**Adapted from:**

Faults from Hydrogeologic Investigations for Water Resources Development, Leighton and Associates, 1983.

## LEGEND

Concentrations in µg/L

- 500 Perchlorate
- 200 1,1-DCE
- 200 TCE
- 50 1,4-Dioxane
- —— No Analysis

- Clay
- Silt
- Sand and Gravel
- Sandstone with some gravelly layering
- Weathered Granite or Granitic Boulder
- Boundary Between Upper and Lower Qal Zones
- Inferred Contact
- Well
- Screened Interval
- TD=60' Total Boring Depth (feet)

Notes: COPC concentrations shown from 2nd Quarter 2006 Groundwater Monitoring Event, unless noted.

* 2Q02 Groundwater Monitoring Event.

B - The sample result is less than 5 times (10 times for common organic laboratory contaminants) the blank contamination. The result qualified for blank contamination is considered not to have originated from the environmental sample, since cross-contamination is suspected.

e - A holding time violation occured.

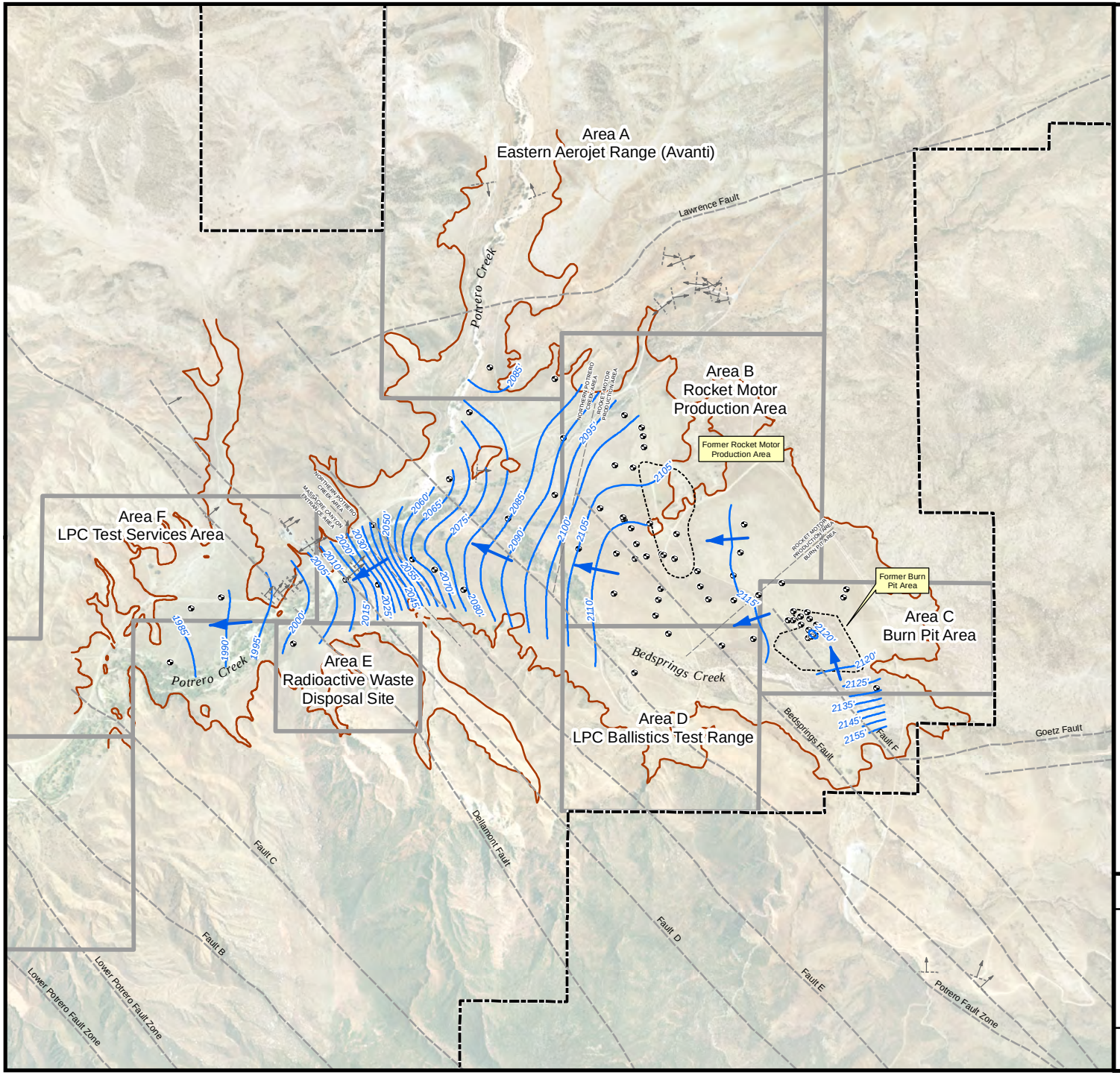
J - Analyte was positively identified and the reults is usable; however, the analyte concentration reported is an estimated value.

k - The analyte was found in the field blank.

Beaumont Site 1

# Figure 3-2
# Geologic Cross Section A-A'-A"

TETRA TECH




0 1,000 2,000 Feet

Adapted from:

Semiannual Groundwater Monitoring Report, Third and Fourth Quarter 2006. Lockheed Martin Corp., Beaumont Site 1. Tetra Tech, Inc.

Faults from structural analysis of Potrero Valley, *Lineament and Geologic Mapping Study, Tetra Tech, 2009.*

**LEGEND**

- Well Location
- Groundwater Flow Direction
- Groundwater Elevation Contour (mean sea level, dashed where inferred)
- Bedrock/Alluvium Surface Contact (Dashed where inferred)
- Fault, Accurately Located Showing Dip
- Fault, Approximately Located
- Historical Operational Area Boundary
- Beaumont Site 1 Property Boundary

Beaumont Site 1

**Figure 3-3**
**Dry Period (September 2006) Groundwater Contour for Alluvium and Shallow Mount Eden Formation Wells**

TETRA TECH

X:\GIS\Lockheed 25241-01-0601\GW_Cont_Sep DRY.mxd

X:\GIS\Lockheed 25241-01-0601\MODFLOW_Boundary.mxd

Monitoring Wells

Model River Boundary Conditions (green)

Model Horizontal Flow Barrier Boundary Conditions (purple)

Model Evapotranspiration Boundary Conditions (yellow)

Model Head Boundary Conditions (blue)

Model Evapotranspiration Boundary Conditions (yellow)

Model Inactive Area (gray)

Model Horizontal Flow Barrier Boundary Conditions (purple)

Monitoring Wells

Model River Boundary Conditions (green)

Model Head Boundary Conditions (blue)

MATCH LINE

MATCH LINE

Model River Boundary Conditions (green)

0 500 1,000 Feet

Beaumont Site 1

**Figure 3-4**
**MODFLOW Model Boundary Conditions for Shallow Alluvium/Weathered Mt. Eden (Layer 1)**

TETRA TECH

and low values below the RMPA. Aquifer transmissivity values are roughly 1,500 per day in the deep high permeability alluvium; 150 per day in the shallow low permeability alluvium; and 20 per day in the wells screened in the competent Mt Eden. Model transmissivity values are 20 per day in the BPA, 1,500 per day in the area between the RMPA and BPA, 100 to 500 per day in the lower RMPA, and 2,500 per day in middle Potrero Creek. A high model transmissivity in the area between the BPA and RMPA coincides with the flat gradients and thicker alluvium observed in this area; and

- During the 1992-2008 period (Figure 3-5), total recharge to the alluvium is estimated to be 246 acre feet per year with 110 acre feet per year due to diffuse recharge over the valley floor and 136 acre feet due to recharge from creeks. During the 1992-2008 period, total discharge from the alluvium is estimated to be 218 acre feet per year with 139 acre-feet per year due to evapotranspiration from the riparian area, 71 acre feet per year due to discharge to Potrero Creek,

and 8 acre feet per year due to leakage down into the Mt Eden. During the 1992-2008 period, aquifer storage also increased by 28 acre feet per year.

The reader is referred to the recent flow model report for more details and supporting information on the groundwater conceptual model.

The remainder of Section 3 presents a plume/COC conceptual model based upon the recently completed flow conceptual model. The plume/COC conceptual model includes all flow-related elements of the groundwater conceptual model, as well as the definition of soil source areas contributing COCs to groundwater, the definition of other sources of COCs inflow and loss, and the definition of the high permeability pathways acting as conduits for plume migration.

## 3.2 PLUME/COC CONCEPTUAL SITE MODEL

This section proposes a groundwater plume/COC conceptual model that is consistent with the available site data and the requirements for the numerical transport modeling task. Figures 3-1, 3-2 and 3-6 through 3-9 show cross-sections and contour maps to support and illustrate the following text description of the conceptual model. The reader is also referred to prior site reports (Tetra Tech, 2009, and 2010) for additional supporting information on the groundwater conceptual model.

A summary of the transport aspects of the plume/COC conceptual model is given in the following sections.

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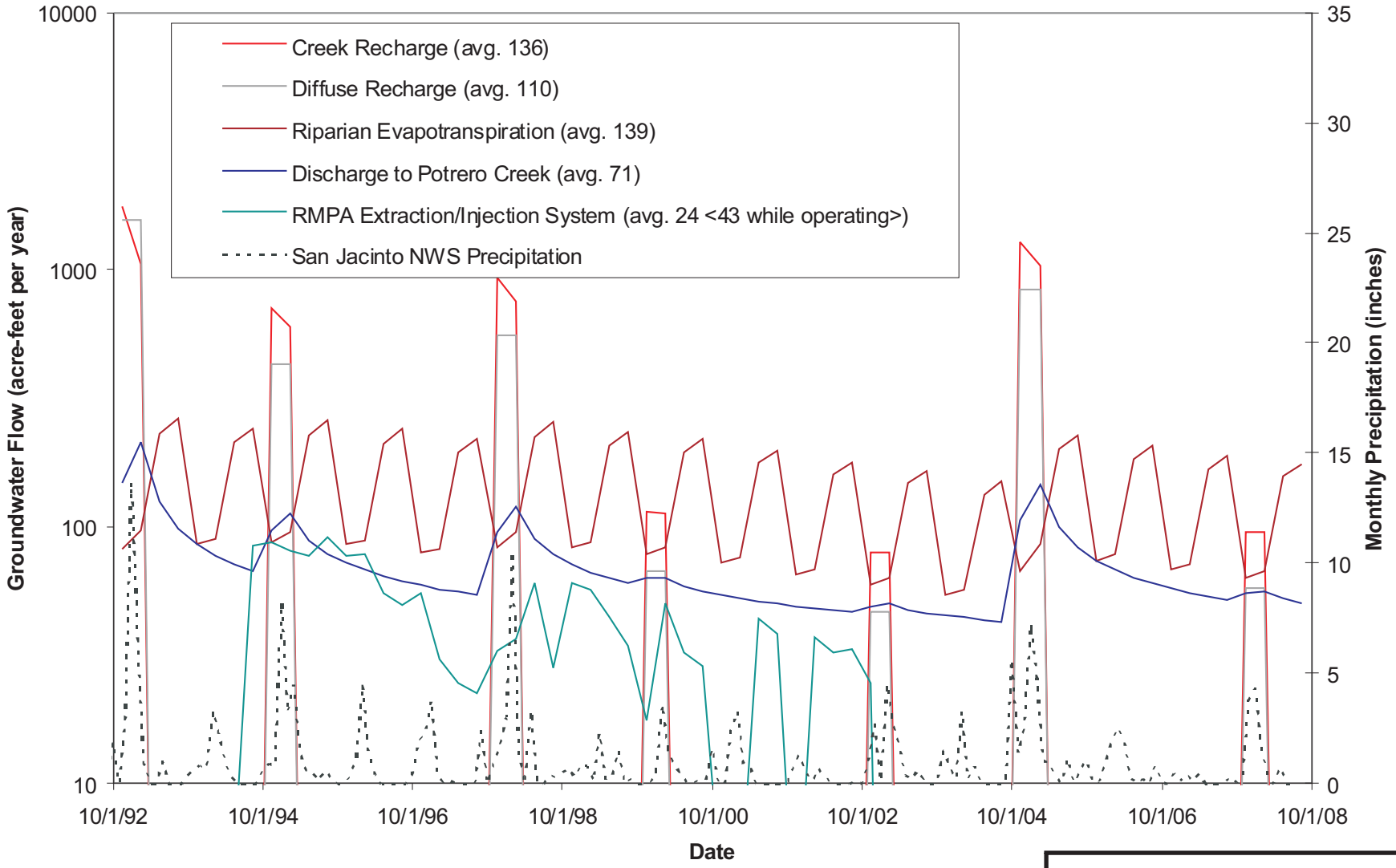


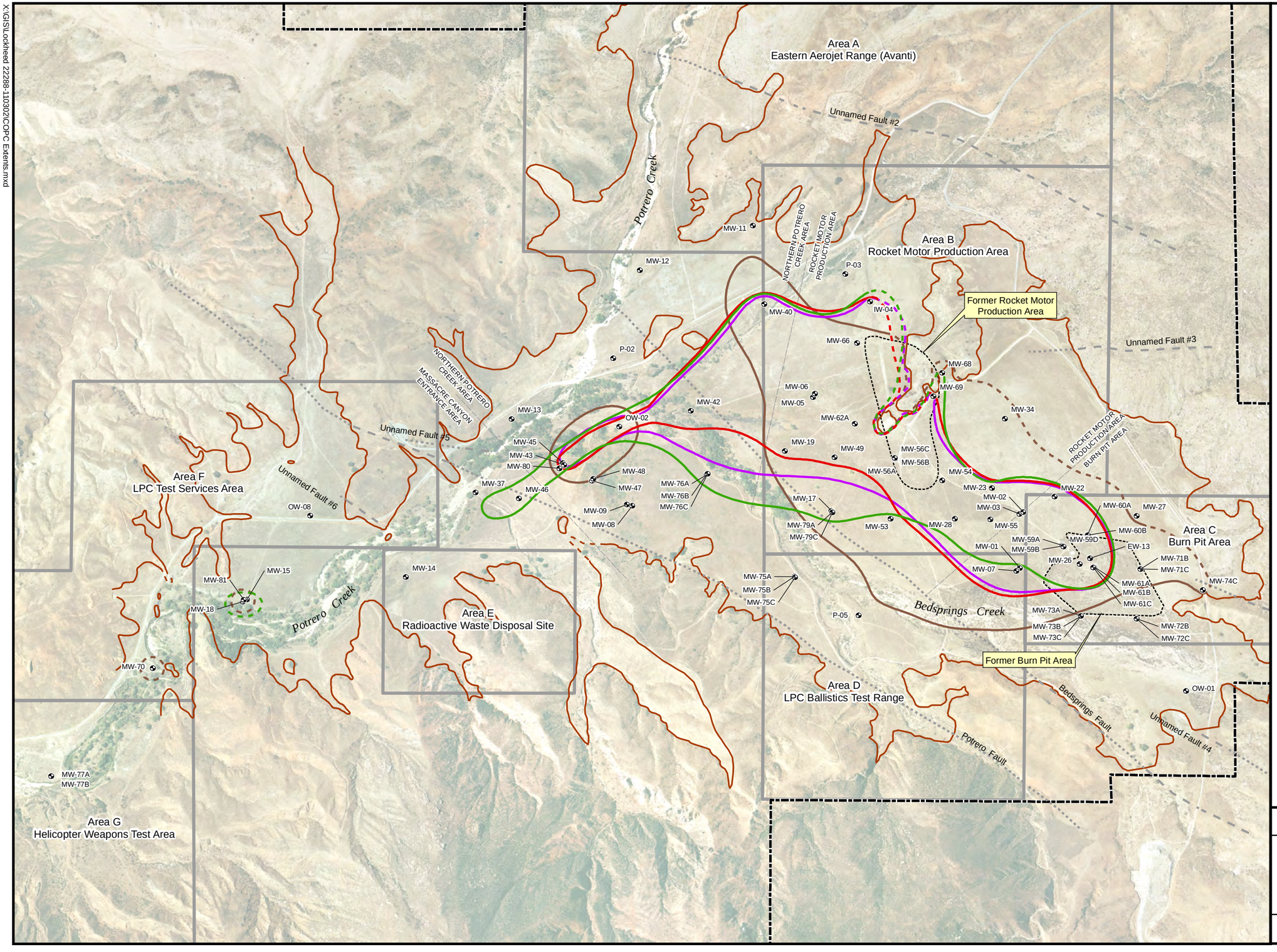

Beaumont Site 1

**Figure 3-5**

**Groundwater Flow Predicted by the Model for 1992-2008 Transient Calibration**

TETRA TECH

X:\GIS\Lockheed 22288-110302\COPC Exents.mxd




0 500 1,000 Feet

Adapted from: March 2007 aerial photograph.

Well locations from Hillwig and Goodrow survey, 2003.

## LEGEND

- Groundwater Monitoring Well
- Perchlorate (6.0 µg/L MCL)-Dashed Where Inferred
- 1,1 DCE (6.0 µg/L MCL)-Dashed Where Inferred
- Trichloroethene (5.0 µg/L MCL)-Dashed Where Inferred
- 1,4-Dioxane (3.0 µg/L DWNL)-Dashed Where Inferred
- Historical Operational Area Boundary
- Approximate Location of Fault
- Approximate Location of Buried Fault
- Mount Eden/Alluvium Surface Contact
- Beaumont Site 1 Property Boundary

Notes:

Beaumont Site 1 property boundary is approximate.

Contours adapted from *Semiannual Groundwater Monitoring Report First Quarter and Second Quarter 2008, Tetra Tech.*

1,1-DCE - 1,1-Dichloroethene

DWNL - California Department of Health Services drinking water notification level.

MCL - Maximum Contaminant Level.

µg/L - Micrograms per liter.

Beaumont Site 1

**Figure 3-6**

**Primary COPC Extents for Alluvium and Shallow Mount Eden Formation**

TETRA TECH

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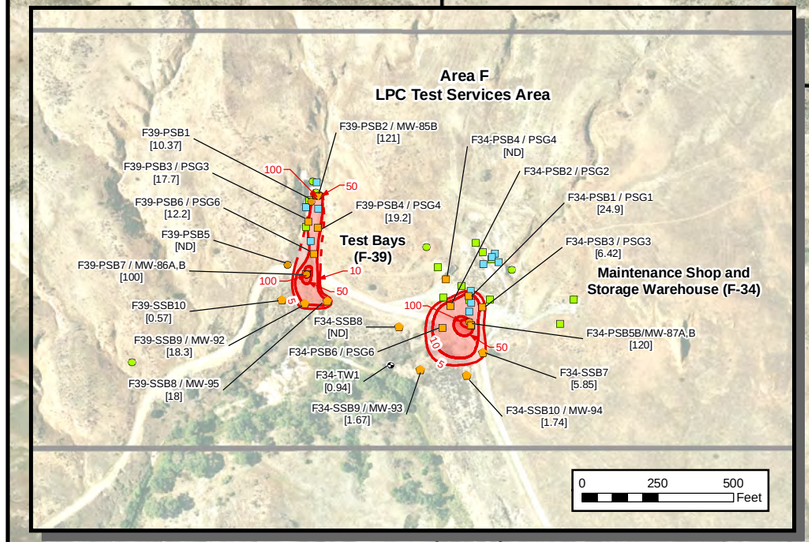




0 500 1,000 Feet

**Adapted from:** March 2007 aerial photograph.

## LEGEND

Sample Locations

- Primary Soil Boring, 2008
- Secondary Soil Boring
- Primary Soil Boring/Soil Vapor, 2008
- Soil Vapor, 2002
- Soil Boring/Soil Vapor, 2007
- Soil Boring, 2004
- Soil Boring/Soil Vapor, 2004
- Well

Trichloroethene (TCE) in Soil

- VOC Soil Source Area

Trichloroethene (TCE) Concentration in Groundwater

- >5 µg/L
- >10 µg/L
- >50 µg/L
- >100 µg/L
- >1,000 µg/L

- Alluvium / Bedrock contact
- Beaumont Site 1 Property Boundary
- Historical Operational Area Boundary

Note:

[ # ] - TCE results in µg/L.

µg/L - Micrograms per liter.

[ND] - Non-Detect.

Boring symbols with no labels indicate sample was not tested at depth interval.

Beaumont Site 1

**Figure 3-8**

**TCE Soil Source Area and Groundwater Impacts**

TETRA TECH

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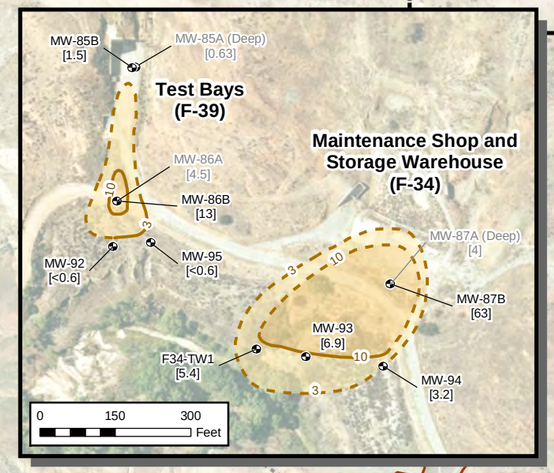





0 500 1,000 Feet

Adapted from: March 2007 aerial photograph.

## LEGEND

MW-01 Well ID

600 1,4-Dioxane Concentration

1,4-Dioxane in Soil

1,4-Dioxane Soil Source Area

1,4-Dioxane Concentration in Groundwater

>3

>10

>100

>1,000

Mt. Eden/Alluvium Surface Contact
(dashed where inferred)

Beaumont Site 1
Property Boundary

Notes: Beaumont Site 1 property boundary is approximate.

contour interval 3, 10, 100, 1,000.

Beaumont Site 1

**Figure 3-9**

**1,4-Dioxane Source Area and Groundwater Impacts**

TETRA TECH

### 3.2.1 Contaminants of Concern

The Contaminants of Concern (COCs) are perchlorate, 1,4-dioxane, 1,1-DCE, and TCE (Tetra Tech, 2009). There are also minor amounts of cis-1,2-DCE, 1-1,DCA, 1,2-DCA, and 1,1,1-TCA present. At Site 1, 1,1,1-TCA was originally considered a COC, but the concentrations of 1,1,1-TCA quickly declined to trace levels in the early 1990s. Since the loss of 1,1,1-TCA from the plume also was coincident with increases in 1,1-DCE plume concentrations, and the transformation of 1,1,1-TCA to 1,1-DCE is a documented attenuation route for 1,1,1-TCA, the loss of 1,1,1-TCA is attributed to transformation to 1,1-DCE. Total VOC concentrations and mass in the Site 1 plume are currently dominated by TCE and 1,1-DCE; other VOCs such as 1,1,1-TCA, 1,1-DCA and 1,2-DCA contribute very little to the current groundwater VOC mass and risk.

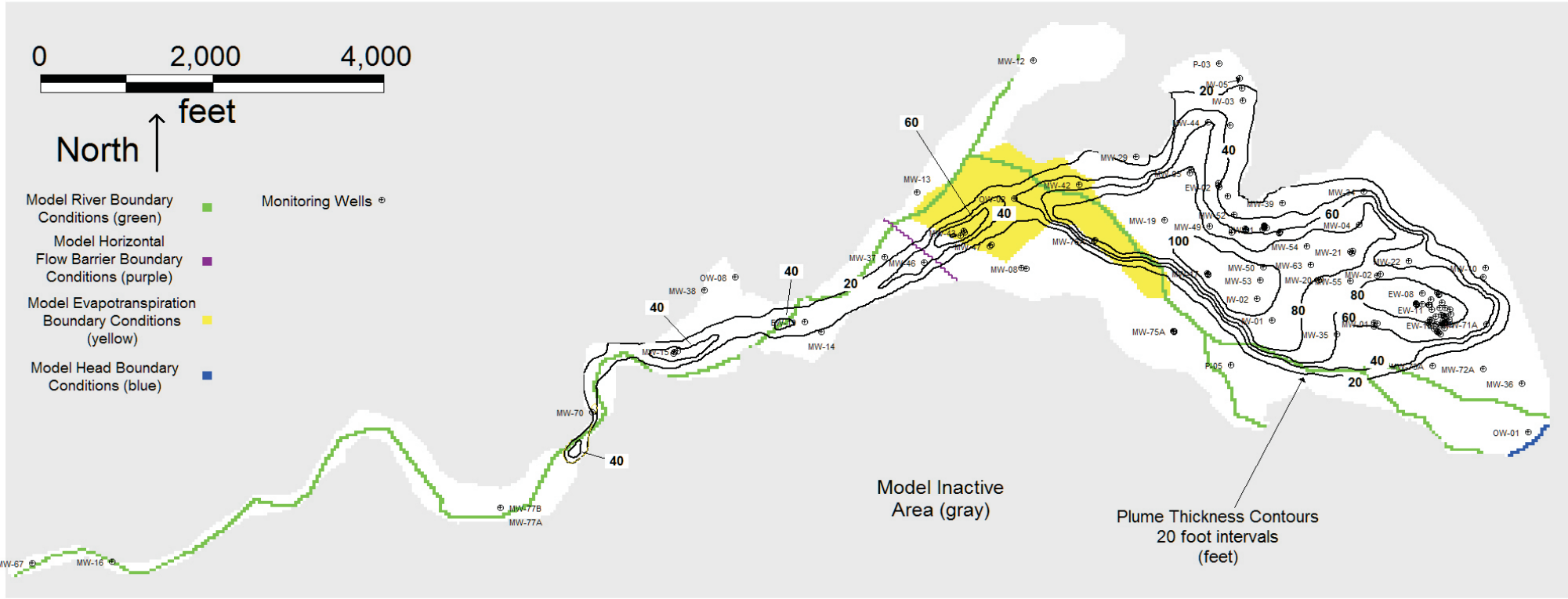
Maps depicting the distribution of site contaminants are given for the alluvium/weathered Mount Eden in Figures 3-6 through 3-9 (taken from Tetra Tech, 2009). There is generally one distinct plume at Site 1 that covers approximately 278 acres, although the plume area does vary by COC due the varying concentrations and MCLs of the COCs. There are also small portions of the Site 1 plume that appear as separate islands of contamination further down Potrero Creek near wells MW-14, MW-18, and MW-70. However, this generally occurs as portions of the single Site 1 plume increase and decrease relative to MCLs, with trace levels of COCs generally found between the main plume and the smaller plume bodies. However, an additional perchlorate source is also present downgradient of the main COC plume at the F-33 site, which impacts MW-70 and the plume shape. The highest concentrations of contaminants have consistently been reported in groundwater samples collected from shallow screened wells located in the former BPA, and concentrations appear to rapidly decrease down gradient of the footprint of the former BPA. Although the lateral concentration trends are fairly well defined by the monitoring network and aquifer system boundaries, the vertical concentration trends are less well known, especially at areas without vertically paired wells. The vertical distribution of contaminants and plume thickness in groundwater was estimated by comparing COC data from vertically paired wells. The top of groundwater contamination typically occurs at the water table, with contamination typically decreasing with depth. An exception is in the riparian area, where deep well concentrations are either equal to or even higher than shallow wells. The COCs are generally restricted to the alluvium and weathered Mt. Eden, except in the BPA where sporadic detections of trace contamination may extend into bedrock. Estimates show the plume thickness generally ranges from 25 to 90 feet (Figure 3-10). Outside the BPA, contamination is generally not observed in the

competent Mount Eden and granite formations (Tetra Tech, 2009). Contour maps of site contaminants are not given for the Mount Eden or granite because of the limited data; the large number of non-detects; and the general lack of a spatial trend in these units. Contamination observed in the weathered Mount Eden formation is lumped with the alluvium (Tetra Tech, 2009). The plume maps given in Figures 3-6 through 3-9 reflect the highest concentration observed at any depth – or a depth maximum value. The plume maps given in Figures 3-6 through 3-9 reflect current conditions. While Figures 3-6 through 3-9 are good depictions of the plume concentration for the entire saturated plume thickness in the riparian areas and the RMPA, they are somewhat higher than the concentration observed at depth in the BPA where there is a more distinct trend in concentrations versus depth. Appendix A gives separate COC plume contour maps for the shallow and deep alluvium/weathered Mount Eden that will be used in the transport model.

**COC Migration Pathway and Rates**

The primary pathway for contaminant migration in groundwater appears to be the coarse-grained, high permeability alluvium/weathered Mount Eden that is primarily located at depth and in the center of valleys. The Potrero Fault acts to restrict groundwater and plume migration. However, based upon COC detections in groundwater downgradient of the fault, the Potrero Fault is only a partial barrier to COC migration. Groundwater velocity values are estimated from the product of the hydraulic gradient and hydraulic conductivity divided by effective porosity. The aquifer effective porosity is estimated to be 10 percent, or approximately equal to the aquifer specific yield value in the recent Site 1 transient groundwater flow model calibration (Tetra Tech, 2010). The hydraulic gradient for Site 1 varies from values of 0.002 to 0.015, with smaller values in the upper portion of the plume in Bedsprings Creek and larger values in Potrero Creek. The hydraulic conductivity for alluvium/weathered Mount Eden varies from 1 to 30 feet per day, with larger values in the upper portion of the plume in Bedsprings Creek and smaller values in the riparian area. The hydraulic gradient and hydraulic conductivity values in the recent groundwater model were used with the effective porosity to calculate groundwater velocity values. Groundwater velocity varies from 400 to 2,000 feet per year, but is typically 600 feet per year within the main plume area. Therefore, groundwater transport times are approximately 12 to 15 years across the 7,200 foot long plume. These groundwater velocity and transport time values are generally consistent with the observed length of the plume, the elapsed time since contaminant release, and other aspects of the conceptual model.

X:\Public\Lockheed- Beaumont\Site 1 Transport Model TML\MC1_NumTrnsMdl_TML\MC1_NumTrnsMdl_TM_PDR\Graphics\Fig_10.cdr




Beaumont Site 1

**Figure 3-10**

**Plume Thickness Contour Map**

TETRA TECH

The groundwater contaminant velocity is equal to the groundwater velocity divided by the contaminant retardation factor. The retardation factor is assumed to be equal to one for perchlorate and very nearly equal to one (1.07 to 1.2) for 1,4-dioxane. For the chlorinated organics TCE and 1,1-DCE, which can adsorb onto organic carbon in the aquifer solids, the retardation factor in the riparian area is estimated to be 2.36 and 1.82, respectively (Table 2-1). Outside the riparian area organic carbon content data are not available, so the TCE and 1,1-DCE retardation factor is estimated to be 1.44 and 1.28, respectively, based upon the lowest organic carbon value measured in the riparian area (940 mg/kg).

**COC Time Trends**

As given in Table 3-1, time trends in contaminant data for the entire site period of record from August 1986 through June 2009 were evaluated. Note that due to more limited sampling for perchlorate and 1,4-dioxane, the perchlorate and 1,4-dioxane period of record is effectively shorter than for the other contaminants. Time trends for the entire period show 43 percent of the data show predominantly a “stable” trend, 28 percent of the data show “no predominant trend”, 25 percent of the data show predominantly a “decreasing” trend, and only 4 percent of the data show predominantly an “increasing” trend. The statistical analysis confirms the observation that the overall extent and magnitude of the plume is relatively unchanged over the nearly 20 year monitoring period. The one major exception is 1,1,1-TCA, where time trends for the entire period show approximately one-half of the wells show predominantly a “decreasing” trend. This is attributed to 1,1,1-TCA degradation (see “Contaminants of Concern” above). A minor exception is also noted in the vicinity of the RMPA extraction and treatment system, where most contaminants show a decreasing trend attributed to the impact of the extraction system operation. In the BPA, the majority of the wells show stable or no trends over time, reflecting the persistence of the source in this area.

**Contaminant Mass and Plume Volumes**

The total groundwater plume area is 278 acres, water volume is 3,018 acre-feet, and mass of all COCs is 4,141 to 6,265 pounds (Table 3-2). The plume mass and extent is generally driven by perchlorate, although in the riparian area of Bedsprings Creek the other COCs define the plume limits since perchlorate is generally below MCLs. There have been modest decreases of 316 pounds in the Total VOC plume mass between 1990 (estimated as 1,351 pounds in 1990; Radian 1993) and 2009, which appears to correlate fairly well with the 205 pounds of the Total VOCs extracted and treated by the RMPA groundwater and extraction system (Table 3-3). The somewhat

**Table 3-1**
**Statistical Analysis of Groundwater Monitoring Data**
**LMC Beaumont Site 1**
**Data from August 1986 to June 2009**

| | TCE | | TCE Mean | | TCE Magnitude of Trend | | DCE | | 1,1-DCE Mean | | 1,1-DCE Magnitude of Trend | | Perc | | Perc Mean | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Well** | **Num Samples** | **Num Detects** | **(µg/L)** | **Trend** | **(%/yr)** | **(µg/L/yr)** | **Num Samples** | **Num Detects** | **(µg/L)** | **Trend** | **(%/yr)** | **(µg/L/yr)** | **Num Samples** | **Num Detects** | **(µg/L)** | **Trend** |
| **EW-01** | 11 | 11 | 140.0 | D | -7.5 | -10.4 | 12 | 12 | 290.0 | PD | -16.1 | -46.6 | | | | |
| **EW-02** | 10 | 10 | 150.0 | I | 3.1 | 4.6 | 12 | 12 | 260.0 | PD | -9.2 | -23.9 | | | | |
| **EW-08** | 5 | 5 | 10.0 | S | | | 5 | 5 | 17.0 | S | | | | | | |
| **EW-09** | 5 | 5 | 140.0 | NT | | | 5 | 5 | 420.0 | S | | | | | | |
| **EW-10** | 4 | 4 | 220.0 | I | 17.5 | 38.57 | 5 | 5 | 810.0 | S | | | | | | |
| **EW-11** | 8 | 8 | 530.0 | NT | | | 15 | 15 | 1,000.0 | NT | | | | | | |
| **EW-12** | 11 | 11 | 1,300.0 | NT | | | 15 | 15 | 2,600.0 | S | | | | | | |
| **EW-13** | 23 | 23 | 1,400.0 | I | 3.9 | 55.2 | 28 | 28 | 7,500.0 | I | 4.5 | 339.7 | 10 | 1 | 1,900.0 | D |
| **EW-14** | 4 | 4 | 430.0 | S | | | 5 | 5 | 2,100.0 | S | | | | | | |
| **EW-15** | 13 | 13 | 1,400.0 | NT | | | 17 | 17 | 8,200.0 | NT | | | 1 | 0 | 140,000.0 | N/A |
| **EW-16** | 12 | 12 | 1,600.0 | NT | | | 16 | 16 | 7,200.0 | NT | | | | | | |
| **EW-18** | 10 | 10 | 1,600.0 | NT | | | 16 | 16 | 5,900.0 | S | | | | | | |
| **F33-TW1** | 2 | 1 | 0.2 | N/A | | | 2 | 2 | 0.5 | N/A | | | 0 | 0 | 0.2 | N/A |
| **F33-TW2** | 4 | 0 | 0.1 | S | | | 4 | 2 | 0.3 | S | | | 0 | 0 | 0.2 | S |
| **F33-TW3** | 4 | 3 | 0.4 | D | -81.8 | -0.3 | 4 | 3 | 0.7 | S | | | 0 | 0 | 0.2 | S |
| **F33-TW4** | 2 | 0 | 0.1 | N/A | | | 2 | 2 | 0.3 | N/A | | | 0 | 0 | 0.2 | N/A |
| **F33-TW5** | 2 | 0 | 0.1 | N/A | | | 2 | 0 | 0.1 | N/A | | | 0 | 0 | 0.2 | N/A |
| **F33-TW6** | 4 | 0 | 0.1 | S | | | 4 | 0 | 0.1 | S | | | 0 | 0 | 0.2 | S |
| **F34-TW1** | 2 | 1 | 0.4 | N/A | | | 2 | 1 | 0.1 | N/A | | | 0 | 0 | 0.1 | N/A |
| **IW-01** | 1 | 1 | 2.0 | N/A | | | 1 | 1 | 3.0 | N/A | | | | | | |
| **IW-02** | 2 | 2 | 8.4 | N/A | | | 2 | 2 | 26.0 | N/A | | | | | | |
| **IW-03** | 3 | 3 | 39.0 | N/A | | | 3 | 3 | 230.0 | N/A | | | | | | |
| **IW-04** | 9 | 9 | 9.9 | NT | | | 10 | 9 | 24.0 | NT | | | 5 | 2 | 240.0 | D |
| **IW-05** | 2 | 2 | 22.0 | N/A | | | 2 | 2 | 140.0 | N/A | | | | | | |
| **MW-01** | 11 | 11 | 280.0 | PD | -1.2 | -3.3 | 11 | 11 | 230.0 | D | -1.6 | -3.7 | 7 | 0 | 890.0 | PD |
| **MW-02** | 12 | 12 | 210.0 | D | -3.1 | -6.4 | 16 | 16 | 350.0 | D | -3.9 | -13.8 | 8 | 1 | 3,000.0 | S |
| **MW-03** | 10 | 6 | 0.9 | NT | | | 10 | 4 | 0.9 | NT | | | 2 | 1 | 17.0 | NT |
| **MW-04** | 14 | 14 | 140.0 | D | -4.5 | -6.3 | 18 | 18 | 120.0 | D | -7.9 | -9.5 | 2 | 0 | 1,300.0 | N/A |
| **MW-05** | 17 | 17 | 130.0 | S | | | 23 | 23 | 160.0 | D | -3.1 | -4.9 | 9 | 1 | 2,900.0 | D |
| **MW-06** | 13 | 13 | 13.0 | NT | | | 13 | 12 | 22.0 | NT | | | 5 | 2 | 220.0 | NT |
| **MW-07** | 15 | 15 | 34.0 | NT | | | 19 | 18 | 12.0 | NT | | | 7 | 1 | 170.0 | NT |
| **MW-08** | 10 | 2 | 0.3 | S | | | 10 | 1 | 0.3 | S | | | 2 | 3 | 79.0 | NT |
| **MW-09** | 10 | 0 | 0.2 | S | | | 10 | 0 | 0.2 | S | | | 1 | 2 | 13.0 | NT |
| **MW-10** | 12 | 8 | 6.9 | NT | | | 14 | 11 | 8.6 | NT | | | 1 | 0 | 52.0 | N/A |
| **MW-100** | 2 | 0 | 0.1 | N/A | | | 2 | 0 | 0.1 | N/A | | | 0 | 0 | 0.1 | N/A |
| **MW-11** | 15 | 8 | 2.4 | NT | | | 20 | 13 | 2.2 | NT | | | 3 | 1 | 21.0 | NT |
| **MW-12** | 9 | 0 | 0.2 | S | | | 9 | 0 | 0.3 | S | | | 1 | 2 | 15.0 | NT |
| **MW-13** | 15 | 3 | 4.7 | NT | | | 15 | 3 | 6.0 | NT | | | 1 | 2 | 8.8 | NT |
| **MW-14** | 11 | 4 | 3.4 | PD | -0.9 | 0.0 | 11 | 3 | 1.6 | PD | -5.0 | -0.1 | 7 | 1 | 20.0 | NT |
| **MW-15** | 17 | 14 | 1.0 | I | 4.5 | 0.0 | 17 | 14 | 2.6 | NT | | | 1 | 2 | 7.6 | NT |
| **MW-16** | 5 | 0 | 0.2 | S | | | 5 | 0 | 0.2 | S | | | 0 | 0 | 25.0 | S |
| **MW-17** | 20 | 18 | 9.6 | S | | | 24 | 22 | 11.0 | D | -4.7 | -0.5 | 9 | 1 | 680.0 | S |
| **MW-18** | 17 | 16 | 2.2 | D | -3.1 | -0.1 | 17 | 17 | 5.3 | D | -3.5 | -0.2 | 13 | 1 | 13.0 | S |
| **MW-19** | 22 | 22 | 8.5 | I | 4.7 | 0.4 | 27 | 27 | 20.0 | I | 4.8 | 1.0 | 8 | 1 | 170.0 | NT |
| **MW-20** | 9 | 9 | 57.0 | D | -7.0 | -4.0 | 13 | 13 | 61.0 | D | -8.0 | -4.9 | 3 | 0 | 440.0 | N/A |
| **MW-21** | 2 | 2 | 78.0 | N/A | | | 2 | 2 | 240.0 | N/A | | | | | | |
| **MW-22** | 11 | 11 | 73.0 | NT | | | 11 | 11 | 120.0 | PD | -4.2 | -5.1 | 6 | 1 | 600.0 | NT |
| **MW-23** | 3 | 3 | 33.0 | N/A | | | 3 | 3 | 54.0 | N/A | | | 1 | 0 | 48.0 | N/A |
| **MW-24** | 3 | 3 | 2,000.0 | N/A | | | 3 | 3 | 6,100.0 | N/A | | | 1 | 0 | 5,100.0 | N/A |
| **MW-26** | 19 | 19 | 2,700.0 | S | | | 24 | 24 | 3,800.0 | NT | | | 7 | 0 | 7,800.0 | D |
| **MW-27** | 8 | 4 | 6.1 | PD | -5.6 | -0.3 | 8 | 3 | 5.9 | NT | | | 4 | 1 | 19.0 | NT |
| **MW-28** | 7 | 7 | 19.0 | NT | | | 7 | 7 | 27.0 | NT | | | 5 | 0 | 120 | I |
| **MW-29** | 6 | 6 | 42.0 | PI | 6.7 | 2.8 | 11 | 11 | 33.0 | S | | | | | | |
| **MW-30** | 5 | 4 | 4.6 | NT | | | 5 | 3 | 18.0 | NT | | | 3 | 0 | 62.0 | N/A |
| **MW-31** | 8 | 4 | 4.9 | NT | | | 8 | 4 | 8.8 | NT | | | 5 | 0 | 2.6 | I |
| **MW-32** | 9 | 4 | 2.6 | NT | | | 9 | 3 | 2.6 | NT | | | 2 | 1 | 0.7 | NT |
| **MW-34** | 12 | 9 | 11.0 | NT | | | 12 | 7 | 13.0 | NT | | | 7 | 1 | 59.0 | NT |
| **MW-35** | 12 | 4 | 1.0 | PD | -3.9 | 0.0 | 12 | 3 | 1.5 | PD | -5.3 | -0.1 | 1 | 2 | 0.5 | NT |
| **MW-36** | 19 | 10 | 1.5 | PD | -2.2 | 0.0 | 23 | 13 | 1.5 | NT | | | 2 | 3 | 4.9 | NT |
| **MW-37** | 12 | 7 | 1.5 | NT | | | 12 | 10 | 2.6 | PI | 3.5 | 0.1 | 1 | 2 | 0.5 | NT |
| **MW-38** | 4 | 1 | 0.7 | NT | | | 4 | 1 | 3.5 | NT | | | 1 | 0 | 1.8 | N/A |
| **MW-39** | 9 | 9 | 68.0 | I | 6.0 | 4.1 | 13 | 13 | 94.0 | NT | | | 1 | 0 | 810.0 | N/A |
| **MW-40** | 13 | 13 | 29.0 | S | | | 18 | 18 | 20.0 | PD | -1.9 | -0.4 | 8 | 0 | 740.0 | S |
| **MW-41** | 12 | 12 | 150.0 | S | | | 17 | 17 | 160.0 | D | -9.6 | -15.4 | | | | |
| **MW-42** | 14 | 14 | 100.0 | D | -2.0 | -2.05 | 18 | 18 | 160.0 | D | -3.4 | -5.38 | 5 | 1 | 65.0 | D |
| **MW-43** | 6 | 6 | 11.0 | S | | | 7 | 7 | 27.0 | D | -5.7 | -1.5 | 5 | 0 | 96.0 | S |
| **MW-44** | 8 | 8 | 170.0 | NT | | | 13 | 13 | 200.0 | D | -4.5 | -9.1 | | | | |
| **MW-45** | 11 | 11 | 20.0 | D | -4.7 | -0.9 | 11 | 11 | 36.0 | D | -6.3 | -2.3 | 8 | 0 | 230.0 | D |
| **MW-46** | 11 | 9 | 2.6 | NT | | | 11 | 10 | 3.3 | S | | | 3 | 2 | 6.4 | NT |
| **MW-47** | 10 | 1 | 0.4 | NT | | | 10 | 1 | 0.5 | NT | | | 8 | 0 | 11.0 | D |
| **MW-48** | 6 | 1 | 0.6 | NT | | | 6 | 1 | 3.2 | NT | | | 0 | 0 | 0.2 | S |
| **MW-49** | 19 | 19 | 26.0 | S | | | 24 | 23 | 53.0 | NT | | | 7 | 0 | 700.0 | S |
| **MW-50** | 12 | 12 | 43.0 | NT | | | 17 | 17 | 170.0 | D | -24.8 | -42.2 | 1 | 0 | 270.0 | N/A |
| **MW-51** | 12 | 12 | 91.0 | D | -9.4 | -8.5 | 17 | 16 | 270.0 | D | -24.8 | -67.1 | | | | |
| **MW-52** | 13 | 13 | 160.0 | D | -8.2 | -13.1 | 18 | 18 | 440.0 | D | -14.3 | -63.0 | | | | |
| **MW-53** | 8 | 8 | 21.0 | D | -7.3 | -1.5 | 8 | 8 | 71.0 | D | -11.8 | -8.4 | 6 | 1 | 210.0 | D |
| **MW-54** | 8 | 8 | 130.0 | PD | -6.1 | -8.0 | 8 | 8 | 480.0 | NT | | | 6 | 0 | 780.0 | S |
| **MW-55** | 15 | 15 | 160.0 | NT | | | 20 | 20 | 340.0 | NT | | | 5 | 0 | 1,300.0 | I |
| **MW-56A** | 16 | 13 | 42.0 | D | -8.0 | -3.4 | 21 | 18 | 66.0 | D | -11.0 | -7.2 | 1 | 2 | 0.6 | NT |
| **MW-56B** | 10 | 10 | 48.0 | S | | | 10 | 10 | 75.0 | D | -2.3 | -1.8 | 5 | 0 | 340.0 | S |
| **MW-56C** | 19 | 19 | 100.0 | D | -3.2 | -3.2 | 24 | 24 | 130.0 | D | -5.0 | -6.5 | 7 | 0 | 920.0 | PD |
| **MW-56D** | 8 | 8 | 94.0 | D | -2.8 | -2.6 | 9 | 9 | 210.0 | D | -5.1 | -10.7 | 3 | 0 | 660 | N/A |
| **MW-57A** | 13 | 13 | 120.0 | D | -3.9 | -4.7 | 18 | 18 | 220.0 | PD | -5.3 | -11.6 | 3 | 0 | 1,100.0 | N/A |
| **MW-57B** | 7 | 7 | 71.0 | S | | | 7 | 7 | 120.0 | D | -3.9 | -4.7 | 3 | 0 | 540.0 | N/A |
| **MW-57C** | 6 | 6 | 82.0 | D | -3.2 | -2.6 | 6 | 6 | 220.0 | D | -5.1 | -11.2 | 2 | 0 | 640.0 | N/A |
| **MW-57D** | 7 | 7 | 160.0 | D | -4.7 | -7.5 | 7 | 7 | 370.0 | D | -6.9 | -25.4 | 3 | 0 | 1,100.0 | N/A |
| **MW-58A** | 8 | 8 | 75.0 | D | -3.1 | -2.3 | 9 | 9 | 150.0 | D | -5.0 | -7.5 | 3 | 0 | 270.0 | N/A |
| **MW-58B** | 6 | 6 | 53.0 | D | -4.5 | -2.4 | 6 | 6 | 98.0 | D | -8.2 | -8.0 | 3 | 0 | 570.0 | N/A |
| **MW-58C** | 8 | 8 | 110.0 | PD | -4.2 | -4.7 | 8 | 8 | 260.0 | D | -6.9 | -17.9 | 3 | 0 | 1,000.0 | N/A |

**Table 3-1**
**Statistical Analysis of Groundwater Monitoring Data**
**LMC Beaumont Site 1**
**Data from August 1986 to June 2009**

| | TCE | | TCE Mean | | TCE Magnitude of Trend | | DCE | | 1,1-DCE Mean | | 1,1-DCE Magnitude of Trend | | Perc | | Perc Mean | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Well** | **Num Samples** | **Num Detects** | **(µg/L)** | **Trend** | **(%/yr)** | **(µg/L/yr)** | **Num Samples** | **Num Detects** | **(µg/L)** | **Trend** | **(%/yr)** | **(µg/L/yr)** | **Num Samples** | **Num Detects** | **(µg/L)** | **Trend** |
| **MW-58D** | 15 | 15 | 150.0 | D | -5.3 | -7.9 | 20 | 20 | 200.0 | D | -6.9 | -13.7 | 5 | 0 | 670.0 | NT |
| **MW-59A** | 7 | 7 | 16.0 | NT | | | 7 | 6 | 12.0 | S | | | 2 | 0 | 590.0 | N/A |
| **MW-59B** | 13 | 13 | 260.0 | PD | -1.9 | -4.9 | 18 | 18 | 340.0 | D | -2.9 | -9.9 | 4 | 0 | 4,400.0 | S |
| **MW-59C** | 7 | 7 | 82.0 | I | 7.2 | 5.9 | 8 | 8 | 130.0 | NT | | | 3 | 0 | 4,400.0 | N/A |
| **MW-59D** | 15 | 15 | 250.0 | NT | | | 16 | 16 | 390.0 | NT | | | 12 | 0 | 6200 | I |
| **MW-60A** | 15 | 15 | 130.0 | I | 8.8 | 11.4 | 15 | 15 | 220.0 | I | 6.0 | 13.2 | 10 | 0 | 4,500.0 | I |
| **MW-60B** | 10 | 10 | 7.7 | PI | 3.5 | 0.3 | 11 | 11 | 33.0 | I | 6.6 | 2.2 | 6 | 0 | 1,600.0 | D |
| **MW-61A** | 9 | 9 | 190.0 | D | -4.1 | -7.8 | 10 | 10 | 4,200.0 | NT | | | 3 | 0 | 11,000.0 | N/A |
| **MW-61B** | 12 | 12 | 2,000.0 | D | -2.9 | -58.4 | 13 | 13 | 12,000.0 | D | -3.1 | -368.2 | 6 | 0 | 87,000.0 | PD |
| **MW-61C** | 7 | 7 | 12.0 | NT | | | 7 | 7 | 60.0 | NT | | | 4 | 1 | 3,100.0 | D |
| **MW-61D** | 3 | 3 | 4.3 | N/A | | | 3 | 3 | 48.0 | N/A | | | | | | |
| **MW-62A** | 18 | 18 | 120.0 | D | -3.1 | -3.7 | 24 | 24 | 160.0 | D | -6.3 | -10.1 | 8 | 0 | 1,300.0 | S |
| **MW-62B** | 4 | 4 | 180.0 | NT | | | 5 | 5 | 470.0 | D | -30.7 | -144.2 | | | | |
| **MW-63** | 5 | 5 | 37.0 | S | | | 9 | 9 | 64.0 | NT | | | 1 | 0 | 1,500.0 | N/A |
| **MW-64** | 1 | 1 | 140.0 | N/A | | | 1 | 1 | 890.0 | N/A | | | 1 | 0 | 1,700.0 | N/A |
| **MW-65** | 3 | 3 | 130.0 | N/A | | | 3 | 3 | 530.0 | N/A | | | | | | |
| **MW-66** | 17 | 17 | 160.0 | S | | | 22 | 22 | 160.0 | D | -2.3 | -3.7 | 9 | 0 | 1,300.0 | S |
| **MW-67** | 11 | 0 | 0.3 | S | | | 11 | 0 | 0.2 | S | | | 0 | 0 | 0.3 | S |
| **MW-68** | 7 | 1 | 0.5 | NT | | | 7 | 7 | 1.7 | NT | | | 7 | 0 | 3,500.0 | PI |
| **MW-69** | 7 | 7 | 12.0 | S | | | 7 | 7 | 5.6 | S | | | 7 | 0 | 2,300.0 | S |
| **MW-70** | 9 | 1 | 0.3 | S | | | 8 | 1 | 0.5 | NT | | | 4 | 2 | 10.0 | NT |
| **MW-71A** | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | | 0 | 0 | 0.2 | S |
| **MW-71B** | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | | 5 | 0 | 300.0 | I |
| **MW-71C** | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | | 4 | 1 | 220.0 | S |
| **MW-72A** | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | | 0 | 0 | 0.2 | S |
| **MW-72B** | 4 | 0 | 0.4 | S | | | 4 | 0 | 0.4 | S | | | 0 | 0 | 0.2 | S |
| **MW-72C** | 4 | 0 | 0.4 | S | | | 4 | 0 | 0.4 | S | | | 1 | 2 | 5.7 | NT |
| **MW-73A** | 4 | 0 | 0.4 | S | | | 4 | 0 | 0.4 | S | | | 4 | 0 | 2.4 | NT |
| **MW-73B** | 4 | 0 | 0.4 | S | | | 4 | 0 | 0.4 | S | | | 1 | 2 | 7.6 | NT |
| **MW-73C** | 4 | 0 | 0.4 | S | | | 4 | 0 | 0.4 | S | | | 0 | 0 | 0.2 | S |
| **MW-74A** | 4 | 0 | 0.4 | S | | | 4 | 0 | 0.4 | S | | | 3 | 1 | 3.2 | S |
| **MW-74B** | 5 | 0 | 0.4 | S | | | 5 | 0 | 0.4 | S | | | 5 | 0 | 16.0 | S |
| **MW-74C** | 4 | 0 | 0.4 | S | | | 4 | 0 | 0.4 | S | | | 4 | 0 | 10.0 | I |
| **MW-75A** | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | | 0 | 0 | 0.3 | S |
| **MW-75B** | 6 | 0 | 0.3 | S | | | 6 | 0 | 0.3 | S | | | 4 | 1 | 1.5 | D |
| **MW-75C** | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | | 0 | 0 | 0.3 | S |
| **MW-76A** | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | | 0 | 0 | 0.3 | S |
| **MW-76B** | 6 | 0 | 0.3 | S | | | 6 | 0 | 0.3 | S | | | 0 | 0 | 0.2 | S |
| **MW-76C** | 4 | 1 | 0.6 | NT | | | 4 | 4 | 2.4 | NT | | | 0 | 0 | 0.3 | S |
| **MW-77A** | 4 | 0 | 0.4 | S | | | 5 | 0 | 0.3 | S | | | 0 | 0 | 0.3 | S |
| **MW-77B** | 6 | 0 | 0.3 | S | | | 6 | 0 | 0.3 | S | | | 0 | 0 | 0.2 | S |
| **MW-78** | 5 | 4 | 1.5 | NT | | | 5 | 5 | 4.6 | S | | | 5 | 0 | 22.0 | D |
| **MW-79A** | 5 | 1 | 0.3 | NT | | | 5 | 0 | 0.3 | S | | | 0 | 0 | 0.3 | S |
| **MW-79C** | 4 | 4 | 6.6 | S | | | 4 | 4 | 6.7 | S | | | 4 | 0 | 80.0 | S |
| **MW-80** | 5 | 1 | 0.5 | NT | | | 5 | 4 | 1.4 | NT | | | 0 | 0 | 0.3 | S |
| **MW-81** | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | | 0 | 0 | 0.3 | S |
| **MW-82** | 4 | 0 | 0.1 | S | | | 4 | 0 | 0.1 | S | | | 0 | 0 | 0.2 | S |
| **MW-83** | 4 | 1 | 0.2 | S | | | 4 | 2 | 0.3 | S | | | 0 | 0 | 0.2 | S |
| **MW-84A** | 2 | 0 | 0.1 | N/A | | | 2 | 0 | 0.2 | N/A | | | 2 | 0 | 1.7 | N/A |
| **MW-84B** | 2 | 0 | 0.1 | N/A | | | 2 | 0 | 0.2 | N/A | | | 0 | 0 | 0.2 | N/A |
| **MW-85A** | 2 | 0 | 0.1 | N/A | | | 2 | 0 | 0.1 | N/A | | | 0 | 0 | 0.3 | N/A |
| **MW-85B** | 2 | 2 | 65.0 | N/A | | | 2 | 0 | 0.1 | N/A | | | 0 | 0 | 0.5 | N/A |
| **MW-86A** | 2 | 0 | 0.1 | N/A | | | 2 | 0 | 0.1 | N/A | | | 0 | 0 | 0.2 | N/A |

**Table 3-1**
**Statistical Analysis of Groundwater Monitoring Data**
**LMC Beaumont Site 1**
**Data from August 1986 to June 2009**

| Perchlorate[1] | | Diox | | 1,4-Dioxane[2] | | | | 1,1,1,-TCA | | 1,1,1-TCA | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnitude of Trend | | | | Mean | | Magnitude of Trend | | | | Mean | | Magnitude of Trend | |
| (%/yr) | (µg/L/yr) | Num Samples | Num Detects | (µg/L) | Trend | (%/yr) | (µg/L/yr) | Num Samples | Num Detects | (µg/L) | Trend | (%/yr) | (µg/L/yr) |
| | | | | | | | | 11 | 11 | 19 | D | -16.1 | -3.1 |
| | | | | | | | | 12 | 12 | 37.0 | D | -17.5 | -6.5 |
| | | | | | | | | 3 | 3 | 11.0 | N/A | | |
| | | | | | | | | 5 | 5 | 22.0 | NT | | |
| | | | | | | | | 5 | 5 | 190.0 | D | -48.2 | -91.60 |
| | | | | | | | | 15 | 14 | 49.0 | D | -14.2 | -6.9 |
| | | | | | | | | 15 | 15 | 110.0 | NT | | |
| -36.5 | -694.0 | 10 | 10 | 1,800.0 | NT | | | 28 | 21 | 84.0 | D | -13.0 | -10.92 |
| | | 1 | 1 | | N/A | | | 5 | 5 | 380.0 | NT | | |
| | | | | 590.0 | | | | 17 | 16 | 270.0 | NT | | |
| | | | | | | | | 16 | 15 | 270.0 | D | -19.0 | -51.3 |
| | | | | | | | | 16 | 15 | 160.0 | D | -20.5 | -32.7 |
| | | 2 | 2 | 3.0 | N/A | | | 2 | 0 | 0.1 | N/A | | |
| | | 4 | 4 | 3.0 | NT | | | 4 | 0 | 0.1 | S | | |
| | | 4 | 4 | 3.6 | S | | | 4 | 0 | 0.1 | S | | |
| | | 2 | 2 | 2.7 | N/A | | | 2 | 0 | 0.1 | N/A | | |
| | | 2 | 2 | 2.6 | N/A | | | 2 | 0 | 0.1 | N/A | | |
| | | 4 | 4 | 2.4 | S | | | 4 | 0 | 0.1 | S | | |
| | | 2 | 2 | 3.3 | N/A | | | 2 | 0 | 0.1 | N/A | | |
| | | | | | | | | 1 | 1 | 1.0 | N/A | | |
| | | | | | | | | 1 | 1 | 6.2 | N/A | | |
| | | | | | | | | 2 | 2 | 43 | N/A | | |
| -65.7 | -157.8 | 7 | 7 | 22.0 | PD | -3.7 | -0.8 | 9 | 2 | 3.2 | NT | | |
| | | | | | | | | 1 | 1 | 76.0 | N/A | | |
| -0.9 | -8.3 | 6 | 6 | 2.5 | S | | | 11 | 11 | 59.0 | D | -8.2 | -4.8 |
| | | 6 | 6 | 110.0 | S | | | 16 | 15 | 63.0 | D | -12.9 | -8.1 |
| | | 5 | 1 | 0.3 | S | | | 9 | 2 | 0.4 | NT | | |
| | | 1 | 1 | 14.0 | N/A | | | 18 | 17 | 15.0 | D | -14.6 | -2.2 |
| -4.2 | -122.9 | 8 | 8 | 27.0 | NT | | | 21 | 18 | 36.0 | D | -8.5 | -3.1 |
| | | 5 | 4 | 16.0 | NT | | | 12 | 6 | 2.0 | NT | | |
| | | 6 | 4 | 6.3 | NT | | | 19 | 13 | 7.3 | D | -11.4 | -0.8 |
| | | 6 | 2 | 1.1 | NT | | | 10 | 1 | 0.3 | S | | |
| | | 7 | 6 | 4.1 | NT | | | 10 | 1 | 0.2 | S | | |
| | | 1 | 1 | 0.5 | N/A | | | 15 | 11 | 0.7 | NT | | |
| | | 2 | 0 | 0.6 | N/A | | | 2 | 0 | 0.1 | N/A | | |
| | | 4 | 1 | 0.3 | S | | | 20 | 13 | 0.5 | S | | |
| | | 6 | 2 | 1.0 | NT | | | 9 | 1 | 0.3 | NT | | |
| | | 11 | 1 | 0.3 | S | | | 15 | 2 | 0.4 | NT | | |
| | | 7 | 3 | 1.1 | NT | | | 11 | 2 | 0.5 | NT | | |
| | | 13 | 12 | 6.5 | D | -0.2 | 0.0 | 16 | 1 | 0.4 | NT | | |
| | | 3 | 1 | 1.1 | N/A | | | 5 | 0 | 0.2 | S | | |
| | | 8 | 8 | 28.0 | PD | -9.1 | -2.5 | 24 | 22 | 5.3 | D | -7.5 | -0.4 |
| | | 13 | 11 | 5.8 | S | | | 17 | 3 | 0.4 | PD | -2.8 | 0.0 |
| | | 8 | 8 | 61.0 | S | | | 27 | 20 | 2.2 | D | -3.2 | -0.1 |
| | | 3 | 2 | 3.8 | N/A | | | 14 | 10 | 12.0 | D | -14.6 | -1.8 |
| | | | | | | | | 2 | 2 | 110.0 | N/A | | |
| | | 6 | 6 | 39.0 | NT | | | 11 | 7 | 19.0 | D | -12.6 | -2.4 |
| | | | | | | | | 3 | 2 | 16.0 | N/A | | |
| | | | | | | | | 3 | 2 | 660.0 | N/A | | |
| -2.8 | -216.52 | 7 | 7 | 350.0 | NT | | | 24 | 22 | 190.0 | D | -12.0 | -22.8 |
| | | 5 | 2 | 1.8 | NT | | | 8 | 2 | 1.2 | NT | | |
| 7.7 | 9.3 | 5 | 5 | 51 | NT | | | 7 | 3 | 2.6 | NT | | |
| | | | | | | | | 11 | 9 | 1.1 | PD | -5.8 | -0.1 |
| | | 3 | 2 | 3.9 | N/A | | | 5 | 2 | 1.0 | NT | | |
| 3.4 | 0.1 | 5 | 2 | 0.9 | NT | | | 8 | 2 | 2.3 | NT | | |
| | | 5 | 1 | 0.3 | S | | | 9 | 2 | 0.7 | NT | | |
| | | 7 | 1 | 0.4 | S | | | 12 | 4 | 1.0 | NT | | |
| | | 8 | 1 | 0.4 | S | | | 12 | 4 | 0.8 | D | -5.4 | 0.0 |
| | | 8 | 2 | 1.1 | NT | | | 23 | 13 | 0.5 | D | -2.5 | 0.0 |
| | | 9 | 8 | 5.5 | S | | | 12 | 1 | 0.3 | NT | | |
| | | 1 | 1 | 0.5 | N/A | | | 4 | 1 | 0.9 | NT | | |
| | | 1 | 1 | 10.0 | N/A | | | 13 | 13 | 9.4 | D | -9.1 | -0.9 |
| | | 8 | 7 | 18.0 | S | | | 18 | 10 | 1.8 | D | -9.2 | -0.2 |
| | | | | | | | | 17 | 17 | 7.8 | D | -12.1 | -0.9 |
| -42.4 | -27.54 | 8 | 8 | 26.0 | S | | | 19 | 10 | 17.0 | D | -9.9 | -1.7 |
| | | 5 | 5 | 14.0 | S | | | 7 | 2 | 1.6 | PD | -8.5 | -0.1 |
| | | | | | | | | 13 | 13 | 11.0 | D | -7.5 | -0.8 |
| -5.0 | -11.4 | 8 | 8 | 12.0 | D | -4.2 | -0.51 | 11 | 4 | 3.2 | D | -10.4 | -0.33 |
| | | 7 | 6 | 8.2 | S | | | 11 | 3 | 0.4 | PD | -2.6 | 0.0 |
| -7.2 | -0.8 | 8 | 2 | 2.1 | NT | | | 10 | 1 | 0.3 | NT | | |
| | | 4 | 2 | 2.8 | NT | | | 6 | 1 | 0.4 | NT | | |
| | | 7 | 6 | 15.0 | S | | | 24 | 23 | 5.1 | D | -6.9 | -0.4 |
| | | 1 | 1 | 10.0 | N/A | | | 17 | 17 | 16.0 | D | -20.5 | -3.3 |
| | | | | | | | | 17 | 17 | 13.0 | D | -12.3 | -1.6 |
| | | | | | | | | 18 | 18 | 27.0 | D | -14.6 | -3.9 |
| -11.5 | -24.2 | 6 | 6 | 7.3 | PD | -14.6 | -1.1 | 8 | 4 | 6.5 | PD | -11.7 | -0.8 |
| | | 6 | 6 | 19.0 | NT | | | 8 | 4 | 92.0 | D | -16.1 | -14.8 |
| 7.2 | 93.1 | 5 | 5 | 43.0 | NT | | | 20 | 18 | 12.0 | D | -8.6 | -1.0 |
| | | 5 | 2 | 12.0 | NT | | | 21 | 16 | 2.2 | D | -8.3 | -0.2 |
| | | 5 | 4 | 6.3 | S | | | 9 | 5 | 5.4 | D | -10.5 | -0.6 |
| -7.9 | -72.6 | 7 | 7 | 21.0 | NT | | | 24 | 22 | 9.3 | D | -9.5 | -0.9 |
| | | 3 | 3 | 22 | N/A | | | 8 | 6 | 9.9 | D | -14.6 | -1.4 |
| | | 3 | 3 | 25.0 | N/A | | | 18 | 18 | 12.0 | D | -11.0 | -1.3 |
| | | 3 | 3 | 27.0 | N/A | | | 7 | 6 | 8.5 | D | -10.7 | -0.9 |
| | | 2 | 2 | 23.0 | N/A | | | 6 | 6 | 13.0 | D | -10.5 | -1.4 |
| | | 3 | 3 | 30.0 | N/A | | | 7 | 6 | 21.0 | D | -13.4 | -2.8 |
| | | 3 | 3 | 23.0 | N/A | | | 9 | 7 | 10.0 | D | -14.6 | -1.5 |
| | | 3 | 3 | 27.0 | N/A | | | 6 | 5 | 9.0 | D | -14.5 | -1.3 |
| | | 3 | 3 | 25.0 | N/A | | | 8 | 7 | 19.0 | D | -14.6 | -2.8 |

**Table 3-1**
**Statistical Analysis of Groundwater Monitoring Data**
**LMC Beaumont Site 1**
**Data from August 1986 to June 2009**

| Perchlorate[1] | | Diox | | | | 1,4-Dioxane[2] | | 1,1,1,-TCA | | | | 1,1,1-TCA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnitude of Trend | | | | Mean | | Magnitude of Trend | | | | Mean | | Magnitude of Trend | |
| (%/yr) | (µg/L/yr) | Num Samples | Num Detects | (µg/L) | Trend | (%/yr) | (µg/L/yr) | Num Samples | Num Detects | (µg/L) | Trend | (%/yr) | (µg/L/yr) |
| | | 5 | 5 | 27.0 | NT | | | 20 | 19 | 15.0 | D | -13.9 | -2.1 |
| | | 2 | 1 | 0.4 | N/A | | | 6 | 4 | 1.8 | D | -6.6 | -0.1 |
| | | 4 | 4 | 44.0 | S | | | 18 | 15 | 17.0 | D | -14.2 | -2.4 |
| | | 3 | 3 | 22.0 | N/A | | | 8 | 5 | 5.3 | PD | -11.1 | -0.6 |
| 2.2 | 135.9 | 12 | 12 | 43 | NT | | | 16 | 11 | 12 | D | -11.4 | -1.4 |
| 30.7 | 1,380.6 | 10 | 10 | 97.0 | NT | | | 14 | 12 | 1.6 | D | -3.5 | -0.1 |
| -4.5 | -72.5 | 6 | 4 | 2.0 | I | 16.1 | 0.3 | 10 | 4 | 0.7 | D | -5.7 | 0.0 |
| | | 3 | 3 | 26.0 | N/A | | | 10 | 8 | 20.0 | D | -10.7 | -2.1 |
| -4.5 | -3,940.3 | 6 | 6 | 400.0 | S | | | 13 | 11 | 440.0 | D | -11.4 | -50.1 |
| -14.2 | -439.3 | 4 | 4 | 4.5 | S | | | 7 | 3 | 6.6 | D | -10.1 | -0.7 |
| | | | | | | | | 3 | 3 | 3.3 | N/A | | |
| | | 8 | 7 | 31.0 | S | | | 24 | 22 | 35.0 | D | -13.6 | -4.8 |
| | | | | | | | | 5 | 5 | 90.0 | D | -36.5 | -32.9 |
| | | 1 | 1 | 25.0 | N/A | | | 9 | 9 | 4.4 | PD | -12.3 | -0.5 |
| | | 1 | 1 | 46.0 | N/A | | | 1 | 1 | 48.0 | N/A | | |
| | | | | | | | | 3 | 3 | 35.0 | N/A | | |
| | | 9 | 9 | 24.0 | NT | | | 22 | 16 | 5.2 | D | -14.6 | -0.8 |
| | | 11 | 4 | 0.5 | I | 9.5 | 0.1 | 11 | 0 | 0.3 | S | | |
| 5.1 | 179.0 | 7 | 7 | 3.8 | I | 26.3 | 1.00 | 7 | 0 | 0.2 | S | | |
| | | 7 | 7 | 9.0 | S | | | 7 | 0 | 0.2 | S | | |
| | | 9 | 9 | 2.4 | NT | | | 9 | 0 | 0.2 | S | | |
| | | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.2 | S | | |
| 13.3 | 39.9 | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.2 | S | | |
| | | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.2 | S | | |
| | | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.2 | S | | |
| | | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | |
| | | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | |
| | | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | |
| | | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | |
| | | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | |
| | | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | |
| | | 5 | 2 | 1.0 | NT | | | 5 | 0 | 0.3 | S | | |
| 19.0 | 1.9 | 4 | 0 | 0.3 | S | | | 4 | 0 | 0.3 | S | | |
| | | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | |
| -39.4 | -0.6 | 6 | 0 | 0.3 | S | | | 6 | 0 | 0.3 | S | | |
| | | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | |
| | | 5 | 4 | 1.6 | NT | | | 5 | 0 | 0.3 | S | | |
| | | 6 | 0 | 0.3 | S | | | 6 | 0 | 0.3 | S | | |
| | | 4 | 4 | 6.4 | S | | | 4 | 0 | 0.3 | S | | |
| | | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | |
| | | 6 | 0 | 0.3 | S | | | 6 | 0 | 0.3 | S | | |
| -30.7 | -6.7 | 5 | 4 | 1.9 | NT | | | 5 | 0 | 0.3 | S | | |
| | | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | |
| | | 4 | 4 | 3.7 | S | | | 4 | 1 | 0.4 | NT | | |
| | | 5 | 5 | 4.7 | NT | | | 5 | 0 | 0.3 | S | | |
| | | 5 | 0 | 0.3 | S | | | 5 | 0 | 0.3 | S | | |
| | | 4 | 4 | 2.6 | NT | | | 4 | 0 | 0.1 | S | | |
| | | 4 | 4 | 3.2 | S | | | 4 | 0 | 0.1 | S | | |
| | | 2 | 0 | 0.3 | N/A | | | 2 | 0 | 0.2 | N/A | | |
| | | 2 | 0 | 0.3 | N/A | | | 2 | 0 | 0.2 | N/A | | |
| | | 2 | 1 | 0.3 | N/A | | | 2 | 0 | 0.1 | N/A | | |
| | | 2 | 1 | 0.6 | N/A | | | 2 | 0 | 0.1 | N/A | | |
| | | 2 | 1 | 1.3 | N/A | | | 2 | 0 | 0.1 | N/A | | |

Table 3-2
2009 Aquifer Plume Volume and Mass Estimates
Beaumont Site 1

| Site and COCs | Area above MCL (acres) | Water Volume above MCL (acre-feet) | Mass (pounds) using maximum concentration at any depth | Mass (pounds) using depth averaged concentration | Comment |
|---|---|---|---|---|---|
| Site 1 | | | | | |
| Perchlorate | 227 | 2,529 | 5,083 | 3,364 | |
| 1,1-DCE | 154 | 1,742 | 575 | 362 | |
| TCE | 145 | 1,550 | 460 | 314 | |
| 1,4-dioxane | 179 | 2,081 | 147 | 102 | |
| All COCs | 278 | 3,018 | 6,265 | 4,141 | All COCs driven by Perchlorate except in the Riparian Areas where it drops below MCL |
| All VOCs | 154 | 1,742 | 1,035 | 676 | All VOCs driven by TCE and 1,1-DCE |
| | | | | | |

**Table 3-3**
**Site 1 RMPA Groundwater Extraction Volumes and Mass Removals**

| Quarterly Period | Start Date | End Date | End Cumulative Volume (gallons) | Period Volume (gals) | EW-1 Volume (gals) | EW-1 1,1-DCE Concentration (ug/L) |
|---|---|---|---|---|---|---|
| 1 | 10/1/92 | 12/31/92 | 0 | 0 | 0 | 1,150.0 |
| 2 | 12/31/92 | 4/1/93 | 0 | 0 | 0 | 646.0 |
| 3 | 4/1/93 | 7/1/93 | 0 | 0 | 0 | 566.0 |
| 4 | 7/1/93 | 10/1/93 | 0 | 0 | 0 | 486.0 |
| 5 | 10/1/93 | 12/31/93 | 0 | 0 | 0 | 406.0 |
| 6 | 12/31/93 | 4/1/94 | 0 | 0 | 0 | 326.0 |
| 7 | 4/1/94 | 7/2/94 | 414,900 | 414,900 | 362,208 | 246.0 |
| 8 | 7/2/94 | 10/1/94 | 7,280,293 | 6,865,393 | 5,993,488 | 166.0 |
| 9 | 10/1/94 | 12/31/94 | 14,368,100 | 7,087,807 | 6,187,656 | 86.0 |
| 10 | 12/31/94 | 4/2/95 | 20,955,274 | 6,587,174 | 5,750,603 | 79.5 |
| 11 | 4/2/95 | 7/2/95 | 27,260,665 | 6,305,391 | 5,504,606 | 73.0 |
| 12 | 7/2/95 | 10/1/95 | 34,662,335 | 7,401,670 | 6,461,658 | 73.3 |
| 13 | 10/1/95 | 1/1/96 | 40,969,880 | 6,307,545 | 5,506,487 | 73.5 |
| 14 | 1/1/96 | 4/1/96 | 47,292,135 | 6,322,255 | 5,519,329 | 73.8 |
| 15 | 4/1/96 | 7/1/96 | 51,757,459 | 4,465,324 | 3,898,228 | 74.0 |
| 16 | 7/1/96 | 10/1/96 | 55,814,639 | 4,057,180 | 3,541,918 | 78.5 |
| 17 | 10/1/96 | 12/31/96 | 60,324,400 | 4,509,761 | 3,937,021 | 83.0 |
| 18 | 12/31/96 | 4/1/97 | 62,803,174 | 2,478,774 | 2,163,970 | 77.5 |
| 19 | 4/1/97 | 7/1/97 | 64,811,557 | 2,008,383 | 1,753,318 | 72.0 |
| 20 | 7/1/97 | 10/1/97 | 66,642,257 | 1,830,700 | 1,598,201 | 80.5 |
| 21 | 10/1/97 | 12/31/97 | 69,318,507 | 2,676,250 | 2,336,366 | 88.9 |
| 22 | 12/31/97 | 4/1/98 | 72,276,092 | 2,957,585 | 2,581,972 | 92.8 |
| 23 | 4/1/98 | 7/2/98 | 77,164,382 | 4,888,290 | 4,267,477 | 96.7 |
| 24 | 7/2/98 | 10/1/98 | 79,458,682 | 2,294,300 | 2,002,924 | 95.2 |
| 25 | 10/1/98 | 12/31/98 | 84,404,382 | 4,945,700 | 4,317,596 | 93.6 |
| 26 | 12/31/98 | 4/2/99 | 89,064,282 | 4,659,900 | 4,068,093 | 76.3 |
| 27 | 4/2/99 | 7/2/99 | 92,684,984 | 3,620,702 | 3,160,873 | 59.0 |
| 28 | 7/2/99 | 10/1/99 | 95,470,784 | 2,785,800 | 2,432,003 | 59.0 |
| 29 | 10/1/99 | 1/1/00 | 96,917,385 | 1,446,601 | 1,262,883 | 59.0 |
| 30 | 1/1/00 | 4/1/00 | 100,996,385 | 4,079,000 | 3,560,967 | 59.0 |
| 31 | 4/1/00 | 7/1/00 | 103,626,414 | 2,630,029 | 2,296,015 | 59.0 |
| 32 | 7/1/00 | 10/1/00 | 105,974,414 | 2,348,000 | 2,049,804 | 59.0 |
| 33 | 10/1/00 | 12/31/00 | 106,286,414 | 312,000 | 272,376 | 59.0 |
| 34 | 12/31/00 | 4/1/01 | 106,574,414 | 288,000 | 251,424 | 59.0 |
| 35 | 4/1/01 | 7/1/01 | 110,128,414 | 3,554,000 | 3,102,642 | 59.0 |
| 36 | 7/1/01 | 10/1/01 | 113,252,414 | 3,124,000 | 2,727,252 | 59.0 |
| 37 | 10/1/01 | 12/31/01 | 113,433,354 | 180,940 | 157,961 | 59.0 |
| 38 | 12/31/01 | 4/1/02 | 116,438,259 | 3,004,905 | 2,623,282 | 59.0 |
| 39 | 4/1/02 | 7/2/02 | 119,066,423 | 2,628,164 | 2,294,387 | 59.0 |
| 40 | 7/2/02 | 10/1/02 | 121,796,594 | 2,730,171 | 2,383,439 | 59.0 |
| 41 | 10/1/02 | 12/31/02 | 123,789,093 | 1,992,499 | 1,739,452 | 59.0 |
| 42 | 12/31/02 | 4/2/03 | 0 | 0 | 0 | |
| 43 | 4/2/03 | 7/2/03 | 0 | 0 | 0 | |
| 44 | 7/2/03 | 10/1/03 | 0 | 0 | 0 | |

**Table 3-3**
**Site 1 RMPA Groundwater Extraction Volumes and Mass Removals**

| Quarterly Period | Start Date | End Date | End Cumulative Volume (gallons) | Period Volume (gals) | EW-1 Volume (gals) | EW-1 1,1-DCE Concentration (ug/L) |
|---|---|---|---|---|---|---|
| 45 | 10/1/03 | 1/1/04 | 0 | 0 | 0 | |
| 46 | 1/1/04 | 4/1/04 | 0 | 0 | 0 | |
| 47 | 4/1/04 | 7/1/04 | 0 | 0 | 0 | |
| 48 | 7/1/04 | 10/1/04 | 0 | 0 | 0 | |
| 49 | 10/1/04 | 12/31/04 | 0 | 0 | 0 | |
| 50 | 12/31/04 | 4/1/05 | 0 | 0 | 0 | |
| 51 | 4/1/05 | 7/1/05 | 0 | 0 | 0 | |
| 52 | 7/1/05 | 10/1/05 | 0 | 0 | 0 | |
| 53 | 10/1/05 | 12/31/05 | 0 | 0 | 0 | |
| 54 | 12/31/05 | 4/1/06 | 0 | 0 | 0 | |
| 55 | 4/1/06 | 7/2/06 | 0 | 0 | 0 | |
| 56 | 7/2/06 | 10/1/06 | 0 | 0 | 0 | |
| 57 | 10/1/06 | 12/31/06 | 0 | 0 | 0 | |
| 58 | 12/31/06 | 4/2/07 | 0 | 0 | 0 | |
| 59 | 4/2/07 | 7/2/07 | 0 | 0 | 0 | |
| 60 | 7/2/07 | 10/1/07 | 0 | 0 | 0 | |
| 61 | 10/1/07 | 1/1/08 | 0 | 0 | 0 | |
| 62 | 1/1/08 | 4/1/08 | 0 | 0 | 0 | |
| 63 | 4/1/08 | 7/1/08 | 0 | 0 | 0 | |
| 64 | 7/1/08 | 10/1/08 | 0 | 0 | 0 | |
| Sum All VOCs = 93 KG | | | Totals | 123,789,093 | 108,067,878 | |

White = Measured Concentration
Yellow = Interpolated Concentration

**Table 3-3**
**Site 1 RMPA Groundwater Extraction Volumes and Mass Removals**

| EW-1 1,1-DCE Mass Removal (Kg) | EW-1 TCE Concentration (ug/L) | EW-1 TCE Mass Removal (Kg) | EW-1 1,1,1 TCA Concentration (ug/L) | EW-1 1,1,1 TCA Mass Removal (Kg) | EW-1 DCAs Concentration (ug/L) | EW-1 DCAs Mass Removal (Kg) |
|---|---|---|---|---|---|---|
| | 360.0 | | 75.0 | | 48.0 | |
| | 101.6 | | 68.0 | | 42.0 | |
| | 102.8 | | 60.3 | | 36.4 | |
| | 104.0 | | 52.6 | | 30.9 | |
| | 105.2 | | 44.9 | | 25.3 | |
| | 106.4 | | 37.1 | | 19.8 | |
| 0.34 | 107.6 | 0.15 | 29.4 | 0.04 | 14.2 | 0.02 |
| 3.77 | 108.8 | 2.47 | 21.7 | 0.49 | 8.7 | 0.20 |
| 2.01 | 110.0 | 2.58 | 14.0 | 0.33 | 3.1 | 0.07 |
| 1.73 | 97.5 | 2.12 | 14.0 | 0.30 | 4.5 | 0.10 |
| 1.52 | 85.0 | 1.77 | 14.0 | 0.29 | 5.9 | 0.12 |
| 1.79 | 81.0 | 1.98 | 12.3 | 0.30 | 5.2 | 0.13 |
| 1.53 | 77.0 | 1.60 | 10.7 | 0.22 | 4.5 | 0.09 |
| 1.54 | 73.0 | 1.53 | 9.0 | 0.19 | 3.7 | 0.08 |
| 1.09 | 69.0 | 1.02 | 7.3 | 0.11 | 3.0 | 0.04 |
| 1.05 | 92.5 | 1.24 | 7.2 | 0.10 | 2.0 | 0.03 |
| 1.24 | 116.0 | 1.73 | 7.0 | 0.10 | 1.0 | 0.01 |
| 0.63 | 101.4 | 0.83 | 6.6 | 0.05 | 2.4 | 0.02 |
| 0.48 | 86.7 | 0.58 | 6.2 | 0.04 | 3.7 | 0.02 |
| 0.49 | 86.5 | 0.52 | 4.9 | 0.03 | 2.7 | 0.02 |
| 0.79 | 86.3 | 0.76 | 3.6 | 0.03 | 1.6 | 0.01 |
| 0.91 | 89.2 | 0.87 | 5.4 | 0.05 | 5.7 | 0.06 |
| 1.56 | 92.0 | 1.49 | 7.2 | 0.12 | 9.8 | 0.16 |
| 0.72 | 84.5 | 0.64 | 6.0 | 0.05 | 6.4 | 0.05 |
| 1.53 | 77.0 | 1.26 | 4.8 | 0.08 | 3.0 | 0.05 |
| 1.17 | 77.0 | 1.19 | 5.0 | 0.08 | 1.5 | 0.02 |
| 0.71 | 77.0 | 0.92 | 4.8 | 0.06 | 0.5 | 0.01 |
| 0.54 | 77.0 | 0.71 | 5.0 | 0.05 | 1.0 | 0.01 |
| 0.28 | 77.0 | 0.37 | 5.0 | 0.02 | 1.0 | 0.00 |
| 0.80 | 77.0 | 1.04 | 5.0 | 0.07 | 1.0 | 0.01 |
| 0.51 | 77.0 | 0.67 | 5.0 | 0.04 | 1.0 | 0.01 |
| 0.46 | 77.0 | 0.60 | 5.0 | 0.04 | 1.0 | 0.01 |
| 0.06 | 77.0 | 0.08 | 5.0 | 0.01 | 1.0 | 0.00 |
| 0.06 | 77.0 | 0.07 | 5.0 | 0.00 | 1.0 | 0.00 |
| 0.69 | 77.0 | 0.90 | 5.0 | 0.06 | 1.0 | 0.01 |
| 0.61 | 77.0 | 0.79 | 5.0 | 0.05 | 1.0 | 0.01 |
| 0.04 | 77.0 | 0.05 | 5.0 | 0.00 | 1.0 | 0.00 |
| 0.59 | 77.0 | 0.76 | 5.0 | 0.05 | 1.0 | 0.01 |
| 0.51 | 77.0 | 0.67 | 5.0 | 0.04 | 1.0 | 0.01 |
| 0.53 | 77.0 | 0.69 | 5.0 | 0.05 | 1.0 | 0.01 |
| 0.39 | 77.0 | 0.51 | 5.0 | 0.03 | 1.0 | 0.01 |
| | | | | | | |
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**Table 3-3**
**Site 1 RMPA Groundwater Extraction Volumes and Mass Removals**

| EW-1 1,1-DCE Mass Removal (Kg) | EW-1 TCE Concentration (ug/L) | EW-1 TCE Mass Removal (Kg) | EW-1 1,1,1 TCA Concentration (ug/L) | EW-1 1,1,1 TCA Mass Removal (Kg) | EW-1 DCAs Concentration (ug/L) | EW-1 DCAs Mass Removal (Kg) |
|---|---|---|---|---|---|---|
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| 32.66 | | 35.15 | | 3.57 | | 1.41 |

**Table 3-3**
**Site 1 RMPA Groundwater Extraction Volumes and Mass Removals**

| EW-2 Volume (gals) | EW-2 1,1-DCE Concentration (ug/L) | EW-2 1,1-DCE Mass Removal (Kg) | EW-2 TCE Concentration (ug/L) | EW-2 TCE Mass Removal (Kg) | EW-2 1,1,1 TCA Concentration (ug/L) | EW-2 1,1,1 TCA Mass Removal (Kg) |
|---|---|---|---|---|---|---|
| 0 | 955.0 | | 110.0 | | 314.7 | |
| 0 | 595.8 | | 87.0 | | 39.9 | |
| 0 | 547.8 | | 110.3 | | 38.3 | |
| 0 | 499.9 | | 133.6 | | 36.8 | |
| 0 | 451.9 | | 156.9 | | 35.2 | |
| 0 | 403.9 | | 180.1 | | 33.7 | |
| 52,692 | 355.9 | 0.07 | 203.4 | 0.04 | 32.1 | 0.01 |
| 871,905 | 308.0 | 1.02 | 226.7 | 0.75 | 30.6 | 0.10 |
| 900,151 | 260.0 | 0.89 | 250.0 | 0.85 | 29.0 | 0.10 |
| 836,571 | 195.0 | 0.62 | 190.0 | 0.60 | 22.0 | 0.07 |
| 800,785 | 130.0 | 0.39 | 130.0 | 0.39 | 15.0 | 0.05 |
| 940,012 | 132.5 | 0.47 | 130.0 | 0.46 | 13.8 | 0.05 |
| 801,058 | 135.0 | 0.41 | 130.0 | 0.39 | 12.5 | 0.04 |
| 802,926 | 137.5 | 0.42 | 130.0 | 0.40 | 11.3 | 0.03 |
| 567,096 | 140.0 | 0.30 | 130.0 | 0.28 | 10.0 | 0.02 |
| 515,262 | 133.5 | 0.26 | 143.0 | 0.28 | 11.0 | 0.02 |
| 572,740 | 127.0 | 0.28 | 156.0 | 0.34 | 12.0 | 0.03 |
| 314,804 | 102.5 | 0.12 | 155.0 | 0.18 | 9.8 | 0.01 |
| 255,065 | 78.0 | 0.08 | 154.0 | 0.15 | 7.5 | 0.01 |
| 232,499 | 114.5 | 0.10 | 154.0 | 0.14 | 6.6 | 0.01 |
| 339,884 | 151.0 | 0.19 | 154.0 | 0.20 | 5.6 | 0.01 |
| 375,613 | 158.5 | 0.23 | 171.5 | 0.24 | 7.2 | 0.01 |
| 620,813 | 166.0 | 0.39 | 189.0 | 0.44 | 8.7 | 0.02 |
| 291,376 | 174.5 | 0.19 | 177.5 | 0.20 | 7.4 | 0.01 |
| 628,104 | 183.0 | 0.44 | 166.0 | 0.39 | 6.0 | 0.01 |
| 591,807 | 146.5 | 0.33 | 166.0 | 0.37 | 5.0 | 0.01 |
| 459,829 | 110.0 | 0.19 | 166.0 | 0.29 | 6.0 | 0.01 |
| 353,797 | 115.0 | 0.15 | 166.0 | 0.22 | 5.5 | 0.01 |
| 183,718 | 120.0 | 0.08 | 166.0 | 0.12 | 5.0 | 0.00 |
| 518,033 | 125.0 | 0.25 | 166.0 | 0.33 | 4.5 | 0.01 |
| 334,014 | 130.0 | 0.16 | 166.0 | 0.21 | 4.0 | 0.01 |
| 298,196 | 130.0 | 0.15 | 166.0 | 0.19 | 4.0 | 0.00 |
| 39,624 | 130.0 | 0.02 | 166.0 | 0.02 | 4.0 | 0.00 |
| 36,576 | 130.0 | 0.02 | 166.0 | 0.02 | 4.0 | 0.00 |
| 451,358 | 130.0 | 0.22 | 166.0 | 0.28 | 4.0 | 0.01 |
| 396,748 | 130.0 | 0.20 | 166.0 | 0.25 | 4.0 | 0.01 |
| 22,979 | 130.0 | 0.01 | 166.0 | 0.01 | 4.0 | 0.00 |
| 381,623 | 130.0 | 0.19 | 166.0 | 0.24 | 4.0 | 0.01 |
| 333,777 | 130.0 | 0.16 | 166.0 | 0.21 | 4.0 | 0.01 |
| 346,732 | 130.0 | 0.17 | 166.0 | 0.22 | 4.0 | 0.01 |
| 253,047 | 130.0 | 0.12 | 166.0 | 0.16 | 4.0 | 0.00 |
| 0 | | | | | | |
| 0 | | | | | | |
| 0 | | | | | | |

**Table 3-3**
**Site 1 RMPA Groundwater Extraction Volumes and Mass Removals**

| EW-2 Volume (gals) | EW-2 1,1-DCE Concentration (ug/L) | EW-2 1,1-DCE Mass Removal (Kg) | EW-2 TCE Concentration (ug/L) | EW-2 TCE Mass Removal (Kg) | EW-2 1,1,1 TCA Concentration (ug/L) | EW-2 1,1,1 TCA Mass Removal (Kg) |
|---|---|---|---|---|---|---|
| 0 | | | | | | |
| 0 | | | | | | |
| 0 | | | | | | |
| 0 | | | | | | |
| 0 | | | | | | |
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| 0 | | | | | | |
| 0 | | | | | | |
| 0 | | | | | | |
| 15,721,215 | | 9.28 | | 9.87 | | 0.68 |

**Table 3-3**
**Site 1 RMPA Groundwater Extraction Volumes and Mass Removals**

| EW-2 DCAs Concentration (ug/L) | EW-2 DCAs Mass Removal (Kg) |
|---|---|
| 150.0 | |
| 131.9 | |
| 113.9 | |
| 95.8 | |
| 77.8 | |
| 59.7 | |
| 41.7 | 0.01 |
| 23.6 | 0.08 |
| 5.6 | 0.02 |
| 5.4 | 0.02 |
| 5.3 | 0.02 |
| 4.9 | 0.02 |
| 4.5 | 0.01 |
| 4.1 | 0.01 |
| 3.7 | 0.01 |
| 2.9 | 0.01 |
| 2.0 | 0.00 |
| 3.0 | 0.00 |
| 3.9 | 0.00 |
| 3.4 | 0.00 |
| 2.9 | 0.00 |
| 7.6 | 0.01 |
| 12.2 | 0.03 |
| 8.1 | 0.01 |
| 4.0 | 0.01 |
| 1.5 | 0.00 |
| 3.2 | 0.01 |
| 3.3 | 0.00 |
| 3.4 | 0.00 |
| 3.5 | 0.01 |
| 3.6 | 0.00 |
| 3.6 | 0.00 |
| 3.6 | 0.00 |
| 3.6 | 0.00 |
| 3.6 | 0.01 |
| 3.6 | 0.01 |
| 3.6 | 0.00 |
| 3.6 | 0.01 |
| 3.6 | 0.00 |
| 3.6 | 0.00 |
| 3.6 | 0.00 |
| | |
| | |
| | |

**Table 3-3**
**Site 1 RMPA Groundwater Extraction Volumes and Mass Removals**

| EW-2 DCAs Concentration (ug/L) | EW-2 DCAs Mass Removal (Kg) |
|---|---|
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| | 0.33 |

larger loss in Total VOC plume mass (316 pounds) than the extraction removal (205 pounds) may reflect either *in situ* plume attenuation; or the limited precision of the plume mass estimates.

### 3.2.2 Source Areas

Soil source areas and groundwater impacts for VOCs, perchlorate, and 1,4-dioxane are identified in the recent DSI investigation (Tetra Tech, 2009; see also Figures 3-7 through 3-9). Generally, significant VOCs were not detected in recent site soil samples, including the suspected source areas in the BPA. One small portion of the BPA did show TCE concentrations as high as 11,000 µg/ in soil gas samples. However, based upon these soil gas samples, the mass of TCE in soils only amounts to approximately 7 pounds (Table 3-4), and the soil water phase concentrations in soils only amounts to approximately 33 µg/L. Given the very high groundwater TCE concentrations (as high as approximately 5,000 µg/L) and mass (250-350 pounds), it appears unlikely there is enough TCE in the soils in this area to provide a significant continuing source to the aquifer and the TCE detected in soil gas near the BPA may be due to offgassing of TCE from the groundwater plume. Thus, TCE in groundwater is likely maintained at the current high levels due almost solely to the TCE releases from the groundwater sources discussed below. A 1,4-dioxane soil source area is also defined in the same area as the TCE soils source. However, given the very low 1,4-dioxane soil concentrations, the 1,4-dioxane mass and concentration in soils is very small relative to the mass and concentration in groundwater and unlikely to represent a significant 1,4-dioxane source. The only significant soil source areas identified are for perchlorate

(Table 3-4 and Appendix B), with perchlorate concentrations over 10,000 µg/kg and a total perchlorate mass on the order of 1,800 pounds. These perchlorate soil sources are located primarily in the BPA (1,117 pounds), the F-33 area (211 pounds), and the B-11 area (331 pounds). Given that the plume contains approximately 3,000 to 5,000 pounds of perchlorate at concentrations as high as 71,000 µg/L, these perchlorate soil sources appear to be a significant contributor to sustaining the perchlorate levels observed in groundwater (see Mass Flux discussion below). The transport of perchlorate from these source areas through the vadose zone to groundwater is addressed in the Section 3.2.3 (Fate and Transport Mechanisms) and Appendix C.

NAPL has not been identified at the site, and generally the groundwater VOC concentrations are not indicative of NAPL (10 percent of the VOC solubility limit; US EPA, 1998). However, groundwater concentrations are within about 1 percent of the VOC solubility limit in a 1 acre portion of the BPA, and levels have remained this high for approximately 20 years despite the successful remediation of the site vadose zone soils by SVE in the mid 1990s. Thus, it is likely

Table 3-4
COC Source Mass Flux Summary

## Unsaturated Zone Sources

| | | Comments | |
|---|---|---|---|
| Groundwater Diffuse Recharge Rate | 2.42 in/yr | 0.20 | ft/yr |
| Soil Water Content | 0.10 | | |
| Soil Air Content | 0.20 | | |

**BPA TCE Soil Source (Figure 3-8)**

| | | |
|---|---|---|
| area, acres | 10 | |
| thickness, feet | 50 | |
| Total Soil TCE Concentration, ug/kg | 3 | equilibrium with soil gas |
| Soil Gas TCE Concentration, ug/cm m | 11,000 | |
| Soil Water Conc ug/l | 33 | equilibrium with soil gas |
| bulk density, kg/cu m | 1,700 | |
| soil volume, L | 13,653 | area x thickness |
| soil mass, Kg | 20,479 | volume x bulk density |
| TCE Mass pounds | 7 | Total Soil Con x soil mass |
| TCE Mass Flux, pounds per year | 0.29 | Soil Water Conc x area x recharge |
| TCE Source Duration, year | 25 | Mass/Mass Flux |

**BPA (C-22) Perchlorate Soil Source (Figure 3-7)**

| | | |
|---|---|---|
| area, acres | 3.08 | |
| Total Soil Concentration, ug/Kg >200 | 200 | |
| area acres | 1.4 | |
| Total Soil Concentration, ug/Kg >1,000 | 1000 | |
| area acres | 0.3 | |
| Total Soil Concentration, ug/Kg >10,000 | 25000 | |
| Perchlorate Mass lbs | 1117 | |
| Perchlorate Mass Flux, pounds per year | 73.5 | Soil Water Conc x area x recharge |
| Perchlorate Source Duration, year | 15.2 | Mass/Mass Flux |

**RMPA (B-11) Perchlorate Soil Source (Figure 3-7)**

| | | |
|---|---|---|
| area, acres | 5.34 | |
| Total Soil Concentration, ug/Kg >200 | 200 | |
| area acres | 0.3 | |
| Total Soil Concentration, ug/Kg >1,000 | 1000 | |
| Perchlorate Mass lbs | 331 | |
| Perchlorate Mass Flux, pounds per year | 10.7 | Soil Water Conc x area x recharge |
| Perchlorate Source Duration, year | 30.8 | Mass/Mass Flux |

**RMPA (B-9/B-19) Perchlorate Soil Source (Figure 3-7)**

| | | |
|---|---|---|
| area, acres | 5.28 | |
| Total Soil Concentration, ug/Kg >200 | 200 | |
| area acres | 0.05 | |
| Total Soil Concentration, ug/Kg >1,000 | 1000 | |
| Perchlorate Mass lbs | 91.6 | |
| Perchlorate Mass Flux, pounds per year | 9.0 | Soil Water Conc x area x recharge |
| Perchlorate Source Duration, year | 10.2 | Mass/Mass Flux |

**RMPA (B-10/B-20) Perchlorate Soil Source (Figure 3-7)**

| | | |
|---|---|---|
| area, acres | 0.638 | |
| Total Soil Concentration, ug/Kg >200 | 200 | |
| area acres | 0.05 | |
| Total Soil Concentration, ug/Kg >1,000 | 1000 | |
| Perchlorate Mass lbs | 28.78 | |
| Perchlorate Mass Flux, pounds per year | 1.4 | Soil Water Conc x area x recharge |
| Perchlorate Source Duration, year | 20.9 | Mass/Mass Flux |

Table 3-4
COC Source Mass Flux Summary

**RMPA (B-14) Perchlorate Soil Source (Figure 3-7)**

| | | |
|---|---|---|
| area, acres | 0.35 | |
| Total Soil Concentration, ug/Kg >200 | 200 | |
| area acres | 0.05 | |
| Total Soil Concentration, ug/Kg >1,000 | 1000 | |
| Perchlorate Mass lbs | 28.78 | |
| Perchlorate Mass Flux, pounds per yea | 0.9 | Soil Water Conc x area x recharge |
| Perchlorate Source Duration, year | 31.6 | Mass/Mass Flux |

**F-33 Perchlorate Soil Source (Figure 3-7)**

| | | |
|---|---|---|
| area, acres | 0.506887052 | |
| Total Soil Concentration, ug/Kg >200 | 200 | |
| area acres | 0.253443526 | |
| Total Soil Concentration, ug/Kg >1,000 | 1000 | |
| Perchlorate Mass lbs | 211 | |
| Perchlorate Mass Flux, pounds per yea | 2.5 | Soil Water Conc x area x recharge |
| Perchlorate Source Duration, year | 84.4 | Mass/Mass Flux |

| | |
|---|---|
| Sum all Areas, Pounds | 1,808 |
| Sum all Areas, Pounds Per Year | 98 |

## Saturated Zone Sources

**BPA**

| | | |
|---|---|---|
| Width across hot spot, feet | 225 | perpendicular to groundwater flow |
| Perchlorate Mass Flux, pounds per yea | 46 | Estimated by Flow Model and Contour Maps; probablility of source uncertain since soil source also contributes to releases |
| 1,4-dioxane Mass Flux, pounds per yea | 3 | Estimated by Flow Model and Contour Maps; probablility of source fairly certain since no soil source contributes to releases |
| TCE Mass Flux, pounds per year | 11 | Estimated by Flow Model and Contour Maps; probablility of source fairly certain since no soil source contributes to releases |
| 1,1-DCE Mass Flux, pounds per year | 14 | Estimated by Flow Model and Contour Maps; probablility of source fairly certain since no soil source contributes to releases |

**RMPA**

| | | |
|---|---|---|
| Width across hot spot, feet | 500 | perpendicular to groundwater flow |
| Perchlorate Mass Flux, pounds per yea | 15 | Estimated by Flow Model and Contour Maps; probablility of source uncertain since soil source also contributes to releases |
| 1,4-dioxane Mass Flux, pounds per yea | 1 | Estimated by Flow Model and Contour Maps; probablility of source fairly certain since no soil source contributes to releases |
| TCE Mass Flux, pounds per year | 5 | Estimated by Flow Model and Contour Maps; probablility of source fairly certain since no soil source contributes to releases |
| 1,1-DCE Mass Flux, pounds per year | 4 | Estimated by Flow Model and Contour Maps; probablility of source fairly certain since no soil source contributes to releases |

Source Duration is considered indefinite for all satuared zone sources unless source remediation is considered

that there is a continuing groundwater source in this small area of the site, where contaminants are tightly trapped in the low permeability aquifer material in the BPA. This area likely represents a continuing source of VOC to groundwater unless the source of the contamination is remediated. These groundwater source areas account for the tailing effect often observed at sites like Beaumont Site 1, where cleanup times typically take longer than those predicted based on flushing and desorption. This area likely also represents a source of 1,4-dioxane given the high and stable levels of 1,4-dioxane in the groundwater, with no apparent 1,4-dioxane source in the soils. Given the high and stable levels of perchlorate in the groundwater in this area, there may also be a groundwater source for perchlorate, though this is less clear since a perchlorate soils source is also present in the BPA that may explain the perchlorate currently found in groundwater. One other area that may potentially be a groundwater source area is in the B-11 area, since groundwater VOCs and perchlorate concentrations in the B-11 area are elevated relative to the surrounding plume. However, the high B-11 area plume concentrations may also be a result of impacts from the B-11 perchlorate soils source, and/or migration of the plume to the northeast during wet period water level conditions.

### 3.2.3 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 COCs concentrations. While it is likely that the large quantities of water used during operations at the RMPA and F33 would have resulted in high loadings of water and perchlorate to groundwater, this does not impact the model calibration or prediction since this occurred long before the modeling period.

- 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 at the BPA, RMPA, and Site F--33 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 1, 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 3,400 pounds provides a tracer of the past releases of perchlorate from soils and groundwater assuming no loss of perchlorate from the system. Since this mass is thought to have been released over the 35 to 49 years elapsed since the site was operating, this suggests the perchlorate mass flux release rate from the soils and groundwater sources averaged between 69 and 97 pounds per year. Considering that approximately 1,700 pounds of perchlorate is thought to have been removed from the plume by evapotranspiration and biodegradation in the riparian area, this would increase the perchlorate mass flux release rate from the soils and groundwater sources to between 104 to 146 pounds per year. Therefore, the perchlorate mass flux release rate from the soils based upon this historical analysis should be less than 104 to 146 pounds per year. Using this same methodology and the current plume masses for the other COCs, the historical mass flux release rate from soils and groundwater would be 3 to 5 pounds per year for 1,4-dioxane, and 10 to 23 pounds per year for 1,1-DCE, and TCE;

– 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. For Site 1, the perchlorate mass estimate of 1,808 pounds using the soils data collected in the DSI investigation (Appendix B) provides a reasonable limit on the total amount of future releases. While the timeframe over which perchlorate will be released in the future is not known, given the current perchlorate release rates of 104 to 146 pounds per year, the current perchlorate mass of 1,808 pounds suggests a time period of 12 to 18 years, which seems reasonable given the site history and trends. Mass flux from the perchlorate soil sources can alternatively be estimated using the average diffuse recharge rate of 2.4 inches per year from the calibrated flow model, the perchlorate soil areas and concentrations identified in Figure 3-7, and the total perchlorate mass in the soils (Table 3-4). Perchlorate flux using this methodology is estimated to be 73 pounds per year from the BPA soils at C-22, with 11 pounds per year from the RMPA soils at B-11, and 14 pounds per year from the other areas (Table 3-4 and Figure 3-7). In all likelihood, these estimates would represent an upper bound, since release rates most likely will decline over time.

– 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 C) is used to predict perchlorate release rates of 41 pounds per year, with 28 pounds per year from BPA soils, 13 pounds per year from RMPA soils, and 0.1 pounds per year from F-33 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. An indirect bound on the release rate of the perchlorate release rates from soils can also be obtained using the mass flux balance output from

the calibrated groundwater flow and transport model (Section 4), which estimates the total release rate of perchlorate from both soils and groundwater as 153 pounds per year. This value of 153 pounds per year for both soils and groundwater sources compares quite well with the 104 to 146 pounds per year for both soils and groundwater sources estimated using Analog Site Analysis.

In summary, a variety of methodologies are used to estimate the perchlorate release rate from soils into groundwater with the results varying between 40 to 73 pounds per year, with an upper bound on the order of 150 pounds per year estimated from the combined release rate from both groundwater and soil sources.

- Degradation – Degradation is very important for 1,1,1-TCA and perchlorate, as 1,1,1-TCA concentrations throughout the plume declined over time to low-trace levels, and perchlorate concentrations in the riparian zone decline over distance to trace levels. Based upon the site conditions, 1,1,1-TCA appears to have undergone abiotic transformation to 1,1-DCE (US EPA, 1998). Rate constants for the abiotic transformation of 1,1,1-TCA to 1,1-DCE are reported as 0.27 $year^{-1}$ (US EPA, 1998). A site specific 1,1,1-TCA rate constant of 0.5 $year^{-1}$ is estimated using the trend magnitudes given for 1,1,1-TCA in Table 3-1. 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 (ITRC, 2005 and 2007). Analysis of geochemical data indicates these conditions are present in the Beaumont Site 1 riparian zone (Tetra Tech, 2009), and is a likely explanation for the lack of perchlorate observed in the riparian zone groundwater. Observations in the F-33 area also provide strong evidence of rapid degradation of perchlorate at the site. The biological reaction for perchlorate is reported to be nearly instantaneous (ITRC, 2005 and 2007). Site specific perchlorate reaction rates can be estimated (US EPA, 1998) using the ratio of the contaminant to an inert tracer and the travel time in groundwater. This results in perchlorate reaction rates of 2 $year^{-1}$ at Site 1, assuming 1,4-dioxane is an inert tracer and the 4 year travel time from the RMPA area to the riparian zone. The biological reaction for 1,1-DCE and TCE is reported to be fairly slow (US EPA, 1998). Using the ratio of 1,1-DCE and TCE to 1,4-dioxane and the travel time from the RMPA area to the riparian zone, site specific 1,1-DCE and TCE reaction rates are similarly estimated to be 0.02 and 0.04 $year^{-1}$, respectively;

- Volatilization – 1,4-dioxane and perchlorate are not subject to volatilization from groundwater. Volatilization from groundwater also does not appear to be very important for the VOCs, as soil gas samples do not show very elevated VOCs. For example, the TCE detected at up to 11,000 µg/ in the BPA soil gas samples equates through equilibrium partitioning to a soil water phase concentration of only 33 µg/L and a soil TCE mass of about 7 pounds, which compares to measured groundwater TCE concentrations as high as 5,000 µg/L and a groundwater plume TCE mass of 250-359 pounds. The assumption that volatilization from groundwater is no longer important at the site is consistent with the low levels of VOCs remaining in the BPA after remediation and the low soil gas results in the DSI investigation;

- Evapotranspiration – Evapotranspiration is likely to be a very important COC fate and transport mechanism since evapotranspiration accounts for approximately 60 percent of the groundwater budget and the concentrations of many COCs decline markedly in the riparian

zone. The mass lost due the physical pumping of groundwater by plant extraction is estimated using the groundwater flow model evapotranspiration rates and the COCs shallow plume maps (see COC 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 (ITRC, 2009). 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 Beaumont Site 1, so for the purposes of the modeling study, the rhizodegradation rates will be addressed through data analysis, model calibration, and model sensitivity analyses;

- Dispersion – Dispersion is likely important for all COC 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 using methods summarized in USEPA (1998), 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 7,200 foot long plume at Beaumont Site 1, the longitudinal dispersivity would be estimated using methods summarized in USEPA (1998) as 50 feet. The lateral dispersivity is estimated as 5 to 17 feet, and the vertical dispersivity is estimated as 0.5 to 2.5 feet using methods summarized in USEPA (1998). These parameters are also typically adjusted during model calibration since direct measurement typically is not possible, and an upper end parameter range is set at for longitudinal dispersivity at 720 feet using the using methods summarized in USEPA (1998). Note that at this site, large dispersivity values may be needed to explain the high longitudinal concentration gradients observed downgradient of the BPA;

- Sorption – 1,4-dioxane and perchlorate are not subject to physical adsorption, though these contaminants may be retained hydraulically due to the low permeability of some areas of the aquifer. Sorption is likely to have some impact for the VOCs in the riparian area since organic carbon fraction values are moderately high, with TCE and 1,1-DCE retardation factors estimated to be 2.36 and 1.82, respectively. Outside the riparian zone, sorption for TCE and 1,1-DCE is likely to have only a small impact on the plume;

- Extraction/Injection – Groundwater extraction and treatment removed VOCs from the aquifer during 1994 through 2002 at the rates shown in Table 3-3. Perchlorate and 1,4-dioxane were not removed by treatment, although they were transported from the EW-1 and EW-2 extraction locations to the IW-01 through IW-05 injection locations. For transport model purposes, the mass of perchlorate and 1,4-dioxane injected will be set to match the mass extracted. For future simulations, the mass of all COCs removed will be calculated within the model based upon COC concentrations and the extraction rate, and the mass injected will be set to zero since it is assumed treatment will be modified to remove perchlorate and 1,4-dioxane; and

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

**Table 3-5**
**Summary of Tranport Model Parameters**
**Beaumont Site 1**

| Parameter | Value | Comments |
|---|---|---|
| *Transport* | | |
| Total porosity | 0.2 | Radian 1992 Hydrogeologic Study; Tetra Tech, 2010 |
| Effective porosity | 0.1 | Flow Model Specific Yield Value, Tetra Tech, 2010 |
| Longitudinal dispersivity | 50 feet | US EPA, 1998 |
| Transverse dispersivity | 1/10 to 1/3 * $\alpha_L$ | US EPA, 1998 |
| Vertical dispersivity | 1/100 to 1/20 * $\alpha_L$ | US EPA, 1998 |
| Dry bulk density | 1.7 g/cm3 | site data average |
| Fraction organic carbon | 0.00094 to 0.0027 | 0.0027 for riparian area and 0.00094 elsewhere: results in Retardation Factors of 1.26 - 1.8 for TCE, 1.16 - 1.5 for 1,1-DCE, and 1.04-1.14 for 1,4-dioxane |
| perchlorate degradation rate | 2 $year^{-1}$ | riparian area only |
| TCE degradation rate | 0.04 $year^{-1}$ | riparian area only |
| 1,1-DCE degradation rate | 0.02 $year^{-1}$ | riparian area only |
| 1,4-dioxane degradation rate | 0 $year^{-1}$ | conservative transport |

**Definitions:**

$\alpha_L$ - 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 inconsitent with the field scale total porosity value given above.

## 3.3 COC MASS FLUX BUDGET

A preliminary groundwater COC 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 COC mass flux budget, with a separate source mass flux rate for the groundwater and soil sources, and each COC. Source duration for soils sources is estimated based upon the release rates and total mass, though this method is really only important for perchlorate since TCE has only a very small soils mass, and 1,4-dioxane and 1,1-DCE are essentially not present in soils. 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 be continued for the entire future simulation time period if there is no groundwater source remediation.

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

### 3.3.1 Aquifer Recharge

Recharge to the alluvium is primarily from direct precipitation, creek recharge, and injection. COC mass flux for these items is as follows:

- Direct Precipitation – The main soil source is for perchlorate, and the total perchlorate flux from soils is estimated using a variety of methods to be approximately 40 to 73 pounds per year (See Vadose Zone Transport Discussion above). There is also one small TCE soils source in the BPA, with a mass flux of approximately one-third of a pound per year. There is no significant COC mass flux from soils for 1,1-DCE and 1,4-dioxane;

- Recharge from Creeks – For all COCs, there is no significant COC mass flux due to creek recharge, as soils in the creek recharge areas do not appear to be contaminated;

- Underflow – There is no significant underflow into the alluvium, so there is also no significant COC inflow from the alluvium boundaries. Soils are also assumed to be free from contamination at the upgradient limits of the alluvium. Within the alluvium, there are possible internal groundwater sources treated as underflow (see discussion below). The maximum COC underflow rates across the entire plume width are approximately 30-40 pounds per year for 1,1-DCE; 20-30 pounds per year for TCE; 200-400 pounds per year for perchlorate; and 8-12 pounds per year for 1,4-dioxane (Figure 3-11). These flux values decrease slightly with distance below the BPA until reaching the riparian area, where they decrease markedly. The decline in mass flux rate through the riparian area is greatest for perchlorate and least for 1,4-dioxane, with 1,4-dioxane having one of the higher COC mass

flux rates in portions of the riparian area even though 1,4-dioxane has the lowest mass flux rate in the BPA. Figure 3-11 also shows an apparent rebound in perchlorate mass flux below the riparian area that may be attributed to the limited precision of the mass flux estimates, or potentially the back end of a pulse of higher concentration releases since site monitoring data has shown possible pulses of COCs moving through the Potrero Creek area. This area is further complicated by strong upward vertical hydraulic gradients and upward vertical concentration gradients; and

- Injection – There is no significant mass flux due to injection for TCE and 1,1-DCE, since these chemicals were removed during treatment prior to re-injection. Perchlorate and 1,4-dioxane were not removed during treatment prior to re-injection, so the perchlorate and 1,4-dioxane mass flux was estimated as 10 and 0.12 pounds per year, respectively, using the average historical re-injection rate (40 acre-feet per year) and the concentrations in the extraction area (400 µg/L for perchlorate and 5 µg/L for 1,4-dioxane).

### 3.3.2 Aquifer Discharge

Discharge from the alluvium is primarily from evapotranspiration, discharge to Potrero Creek, extraction, and leakage into deeper aquifers. COC mass flux for these are as follows:

- Extraction – Mass flux values for 1,1-DCE and TCE average 2.6 and 2.8 pounds per year, respectively (Table 3-3). Mass flux values for perchlorate and 1,4-dioxane mass flux are 10 and 0.12 pounds per year (see injection section above);

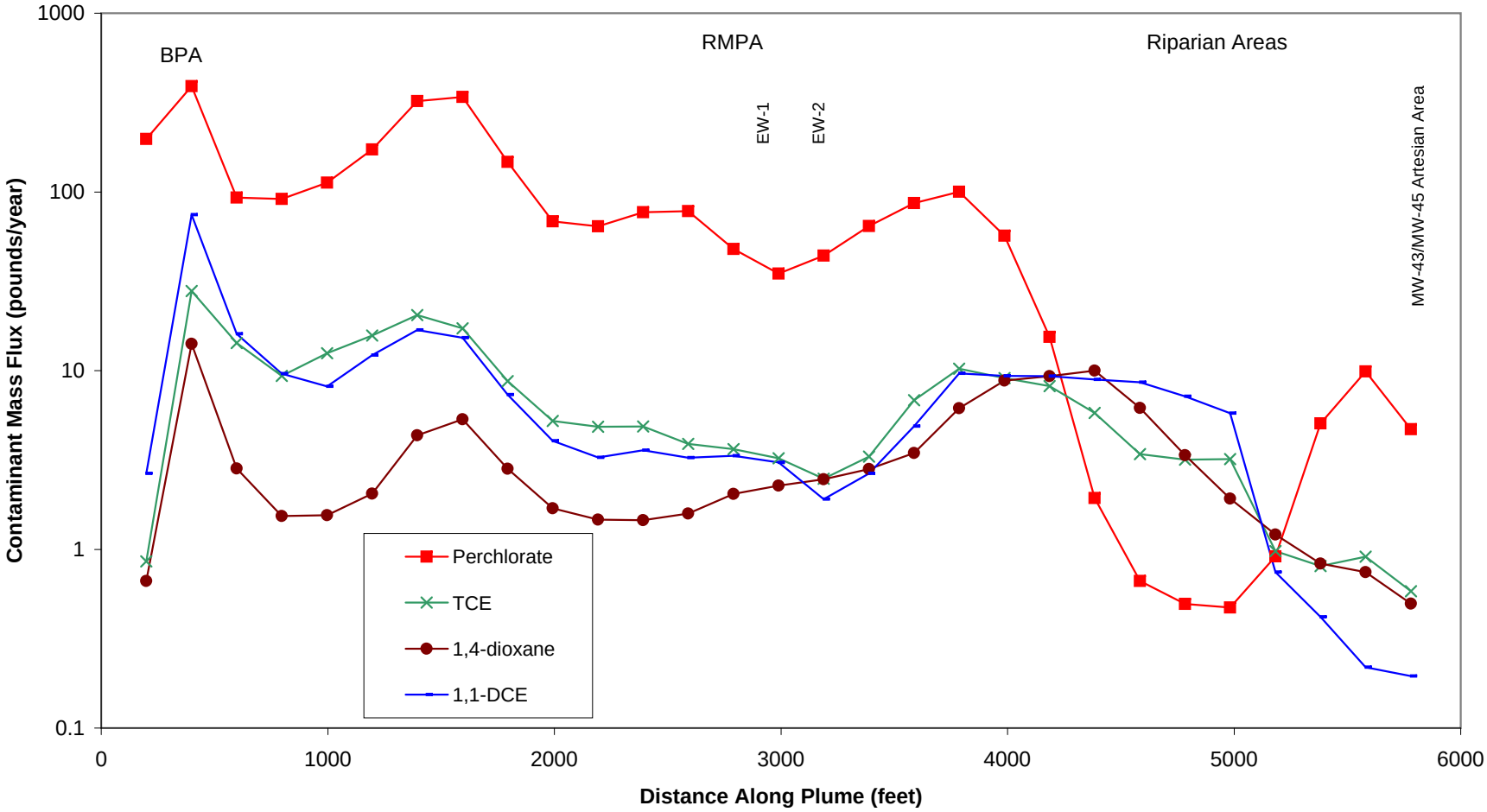
- Evapotranspiration – Using the average evapotranspiration rates in the riparian areas (Figure 3-5) and the shallow COC maps in the riparian areas (Appendix A), COC mass flux is estimated as follows: 18 pounds per year for 1,1-DCE; 19 pounds per year for TCE; 40 pounds per year for perchlorate; and 8 pounds per year for 1,4-dioxane. Historical and current values are thought to be approximately the same, since concentrations and flows have not changed significantly over time in the riparian area;

- Discharge to Potrero Creek – Using the average creek discharge rate into lower Potrero Creek (Figure 3-5) and the shallow data in lower Potrero Creek, historical COC mass flux is estimated as follows: 8 pounds per year for 1,1-DCE; 3 pounds per year for TCE; 5 pounds per year for perchlorate; and 2 pounds per year for 1,4-dioxane. Historical and current values differ since concentrations appear to have decreased over time in lower Potrero Creek; current mass flux values are approximately 1 pounds per year for 1,1-DCE; 0.3 pounds per year for TCE; 0.5 pounds per year for perchlorate; and 0.2 pounds per year for 1,4-dioxane;

- Underflow – There is no significant underflow out of the alluvium, so there is no significant COC outflow from the alluvium boundaries. Internally within the alluvium, there are potential COC sinks (see discussion below); and

- Leakage – Using the leakage rate into deeper Mount Eden and the deep aquifer COC concentrations, COC mass flux is estimated as follows: less than 0.5 pounds per year for 1,1-DCE and TCE; less than 1 pounds per year for perchlorate; and less than 0.1 pounds per year for 1,4-dioxane.

**Figure 3-11. COC mass flux rate across the entire plume width at various locations along plume.**



### 3.3.3 Sources

COCs also appear to be added to the plume by the flow of clean groundwater through the aquifer source areas in the BPA and possibly the RMPA. Using the COC mass flux maps estimated in the groundwater model (Tetra Tech, 2010), mass flux due to underflow through the 225 foot wide BPA groundwater source area is estimated as follows (Table 3-4): 14 pounds per year for 1,1-DCE; 11 pounds per year for TCE; 46 pounds per year for perchlorate; and 3 pounds per year for 1,4-dioxane. Similarly, mass flux due to underflow through the possible 500 foot wide RMPA groundwater source area is estimated as follows: 4 pounds per year for 1,1-DCE; 5 pounds per year for TCE; 15 pounds per year for perchlorate; and 1.4 pounds per year for 1,4-dioxane. These groundwater source release estimates are quite uncertain, however, the transport modeling work will also provide an assessment on the likely magnitude of current groundwater source release rates. Mass flux from both groundwater and soil sources can also be estimated from the current plume volume and time elapsed since release (see Vadose Zone Transport discussion above), which gives independent estimates of 104 to 146 pounds per year for perchlorate; 3 to 5 pounds per year for 1,4-dioxane; and 10 to 23 pounds per year for 1,1-DCE, and TCE.

### 3.3.4 Sinks

COCs appear to be lost from the plume by degradation in the riparian area. The loss is most obvious for perchlorate, although COC trends suggest some degree of attenuation may also be occurring for 1,1-DCE and TCE. Using the COC decay rates given above, the COC mass flux rate into the riparian areas, and the 4 year residence time in the riparian area, the mass loss rate due to degradation in the riparian area is estimated as follows: 3 pounds per year for 1,1-DCE; 2 pounds per year for TCE; 63 pounds per year for perchlorate; and 0 pounds per year for 1,4-dioxane. There is considerable uncertainty in these degradation estimates, however, the transport modeling work will also provide an assessment on the likely magnitude of groundwater degradation rates.

### 3.3.5 Net Budget

The net mass flux budget is summarized in flow diagrams in Figure 3-12. Generally, the mass inflow rates are approximately equal to the mass outflow rates, given the limited precision of these estimates. The flux diagram for perchlorate may imply accumulation of mass, but this is due to uncertainty in these estimates, and values will be refined during model calibration. The annual mass inflow/outflow rates are also approximately 0.1 to 0.05 of the total plume mass, implying approximately a 10 to 20 year residence time in the plume. This 10 to 20 year residence time in the

plume is generally consistent with the 12 to 15 year transport time across the plume and the historical site conditions.

This groundwater COC mass flux budget is preliminary to serve as a guide for the model construction and calibration. Some elements of the COC mass flux budget may be revised during the model calibration process.

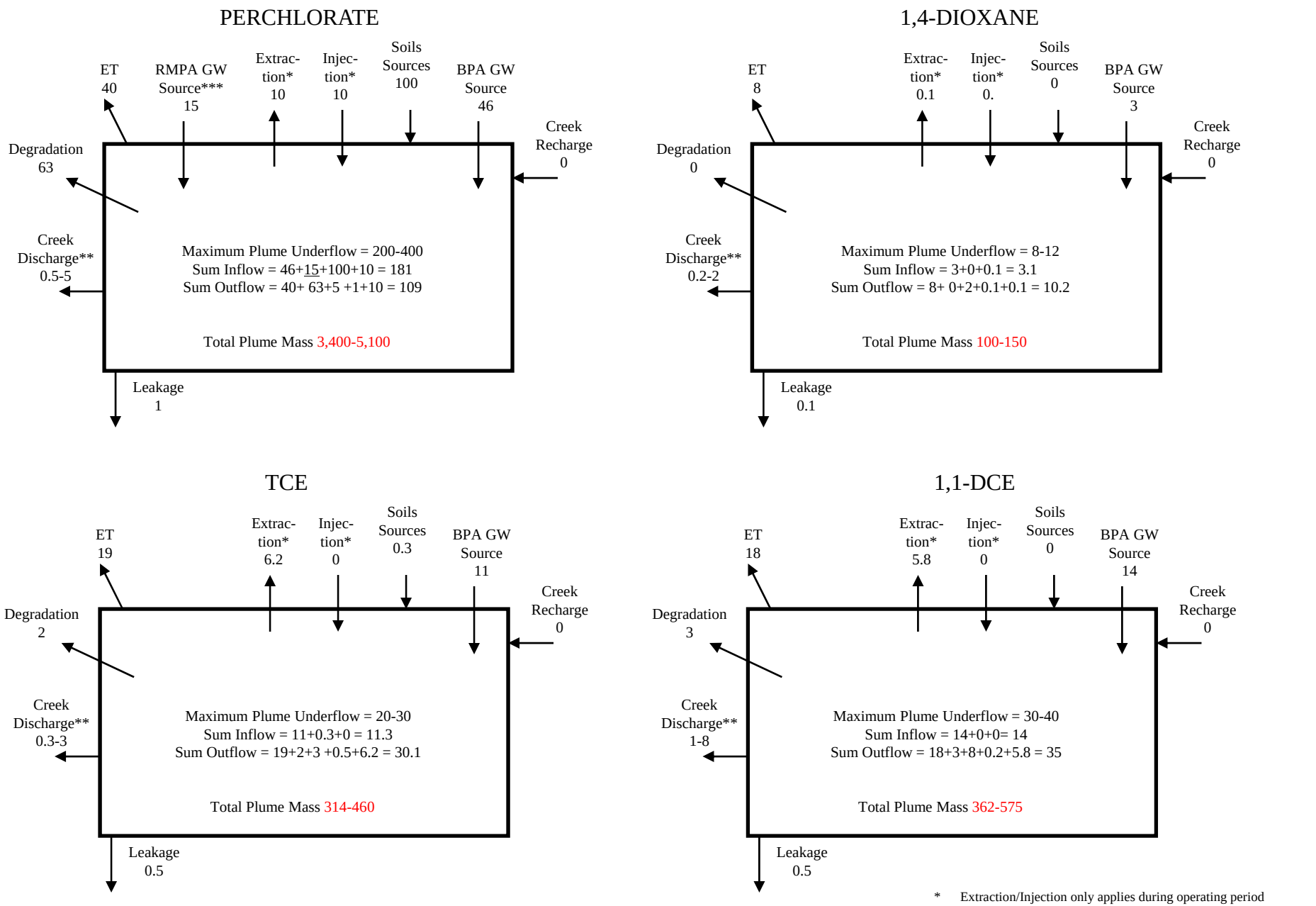



Figure 3-12. COC Mass Flux Diagrams

# SECTION 4 NUMERICAL TRANSPORT MODEL DEVELOPMENT

The conceptual model presented in Section 3 and the previous MODFLOW groundwater flow model (Harbaugh et al., 2000; and Tetra Tech, 2010) are used to develop a numerical transport model. The design, construction, and calibration of the numerical transport model are discussed in Section 4. The Numerical 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 to extend this plume/COC conceptual model to a numerical MT3D groundwater transport model (Zheng and Wang, 1999), including layering, plume extent, boundary conditions, aquifer stresses, transport properties, and calibration. Model construction was aided by the use of a pre-processor (Environmental Simulations, Inc., 2008), which also was used for construction of the flow model. Files for the MODFLOW/MT3D Models and the GWVistas pre-processor are given in Appendix G (available only on CD in electronic format).

**Layering**

Based upon the four primary units defined in the hydrostratigraphic model (shallow Quaternary alluvium, deep Quaternary alluvium/weathered Mount Eden, competent Mount Eden Formation, and the granitic/metasedimentary basement complex), four layers were used in the numerical flow model. This layering scheme appears adequate for the transport model given the plume/COC conceptual model and the objectives of this modeling study. Depending on the model calibration results and the final groundwater remedy selected for the site, refinement of the transport model layering may be considered in the future, however, refinement does not appear to be warranted at this time.

**Model Extent**

The model areal extent is limited to the 665 acre area where the saturated alluvium is present (Figure 3-4). The grid block size of 35 feet used in the flow model is sufficient for transport modeling in order to resolve the features of interest at the site, reduce numerical dispersion, 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 and reduces numerical dispersion in the transport model. The vertical extent of the model covers the entire saturated alluvium and Mount Eden formation, and extends 127 feet into the granite.

The plume extent and concentrations for the alluvium/weathered Mount Eden will be set based upon the shallow and deep plume contour maps given in Appendix A. The plume extent for the competent Mount Eden and granite will be set to zero.

**Boundary Conditions**

Boundary conditions are no-flow conditions against the sides of the valley floor; river boundaries (RIV) under Potrero and Bedspring Creeks; time varying head inflow boundaries in a very small area in the upper portion of the model; leakage between the alluvium and Mount Eden formations and the Mount Eden and granite; horizontal flow barrier (HFB) boundaries at the Potrero Fault; evapotranspiration boundaries in the riparian area; and diffuse recharge. For the transport model, COC concentrations are assigned as zero at all inflow boundaries, except for the perchlorate concentrations at the soil sources, where the model is configured to match the mass flux values given in Table 3-4. COC concentrations will be assigned by model calculations at all outflow boundaries. Internally within the model domain, COC concentrations at the BPA groundwater sources will be assigned concentrations to match groundwater monitoring data and the mass flux values given in Table 3-4.

**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; stream recharge/discharge that varies seasonally and inter-annually based upon precipitation and streamflows; evapotranspiration from the water table that varies depending upon the depth to groundwater; and well extraction/injection that varies based upon the historical operating data for the RMPA groundwater extraction and treatment system. In addition, flows across the model boundaries vary based upon the time-varying water levels measured in the monitoring program, but these flows are small since there is very little flow into the alluvium via boundaries. Stress periods are quarterly to allow seasonal variation in aquifer stresses. These flow stress periods are adequate for the transport model. In addition, the transport model uses transport model time steps that refine the transport model in time relative to the flow model stress periods. Transport model time steps are typically on the order of days to reduce numerical dispersion; the final transport

model time step values used are those calculated internally by the model using the automatic step-size control procedure (typically about 1 day).

**Initial Ranges for Transport Properties**

The initial ranges for aquifer transport properties were set as defined in the "Conceptual Model Transport Properties" in Section 3 (Table 3-5).

**Approach to Transport Model Calibration**

The approach to Transport Model Calibration considers data availability, variations in aquifer stresses, the overall transport model objectives, and the flow model calibration time periods available. Since the COC data shows only minor variations in the extent and magnitude of the plume over time, the approach is to perform a quasi-historical calibration during the flow model calibration time period. Since the starting point for the transport calibration is the 1992 period, the 1992 concentrations will be used as the model initial condition and the model will be run up to today assuming current releases apply to the historical period. Since the groundwater transit time through the plume is on the order of 12 to 15 years, the model simulation time period should be sufficient to evaluate whether these initial concentration conditions and source releases rates are reasonably consistent with the monitoring data collected since 1992. This will evaluate whether the model transport properties and source release rates are consistent with historical monitoring data from the site, which show quasi-steady state plume conditions during the monitoring period. Given the site conditions, if the transport model can reasonably replicate historical conditions, it should provide some level of confidence that the model can be used in the same manner for future predictions.

**Calibration Targets**

Primary calibration targets will be the COC concentrations measured in the site monitoring program during the calibration period, and the site mass flux budget given in the conceptual model, including the mass removal at the extraction system since high quality data are available for this parameter. In particular, the mass flux outflow at the lower end of the valley and the evapotranspiration losses in the riparian area are good calibration targets since they are key components of the conceptual model.

## 4.2 MODEL CALIBRATION

The transport model was simulated for all four COCs (perchlortate, 1-4-dioxane, 1,1-DCE, and TCE) using the MODLOW model files from the flow model calibration (Tetra Tech, 2010) and

the Fall 1992 concentrations for each COC as model initial conditions. Model parameters, boundary conditions, and starting water levels are identical to those given in the 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 – Used values of 1 for perchlorate and 1-4-dioxane, 1.44 to 2.36 for TCE, and 1.28 to 1.82 for 1,1-DCE as per the conceptual model in Section 3;
- COC degradation rates – Assumed no degradation for TCE, 1,1-DCE, and 1,4-dioxane. Used values of 2 $year^{-1}$ for perchlortate in the riparian area (half-life of 126 days) and 0 $year^{-1}$ (no degradation) for perchlortate outside the riparian area;
- Dispersivity –Used values of 50 feet, 5 feet, and 0.5 feet for longitudinal, lateral, and vertical dispersivity, respectively;
- Source COC Release Rates – COC release rates were set to be consistent with the groundwater concentrations measured at the source area and the COC source mass flux values given in the conceptual model in Section 3. This includes source areas for all COCs at the BPA and for perchlorate in the RMPA and F-33 areas (Figure 4-1 and Table 4-1); and
- Reinjection concentrations – Reinjection concentrations were set at zero for TCE and 1,1-DCE since these COCs were removed during treatment prior to re-injection. Reinjection concentrations for perchlorate and 1,4-dioxane were set by trial and error at 429 and 5 µg/L to match the mass extracted from EW-01 and EW-02, since perchlorate and 1,4-dioxane were not removed during treatment prior to re-injection.

**COC Concentration**

A crossplot shows fair comparison between simulated and observed COC concentrations for the simulation time period (Figure 4-2). For the entire simulation period, the relative error for the COCs concentration, defined as the ratio of the root mean square error to the range in concentration across the site, is 6.5 percent for perchlorate, 6.5 percent for 1,4-dioxane, 6.3 percent for 1,1-DCE, and 6.9 percent for TCE. While there is a wide scattering the data in Figure 4-2, this is largely attributed due to sub-grid scale variability in well screen locations and aquifer conductivity, as well as the large spikes in concentrations that occur randomly over time in a given well that most likely are a result of sampling error. 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 large spikes in concentrations randomly 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.

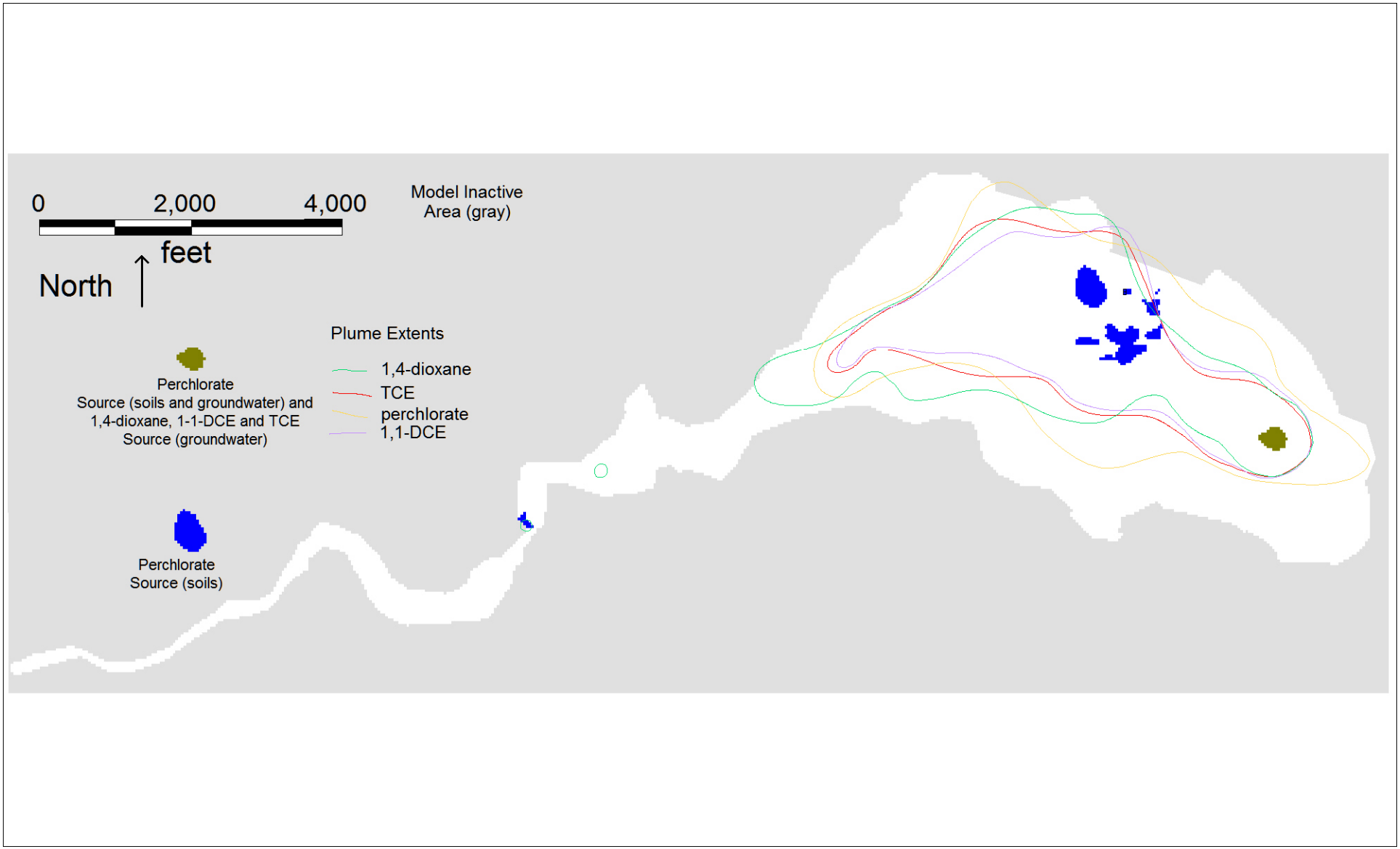



Figure 4-1. MT3D Model Source Areas

Table 4-1
Transport Model COC Mass and Mass Flux Summary

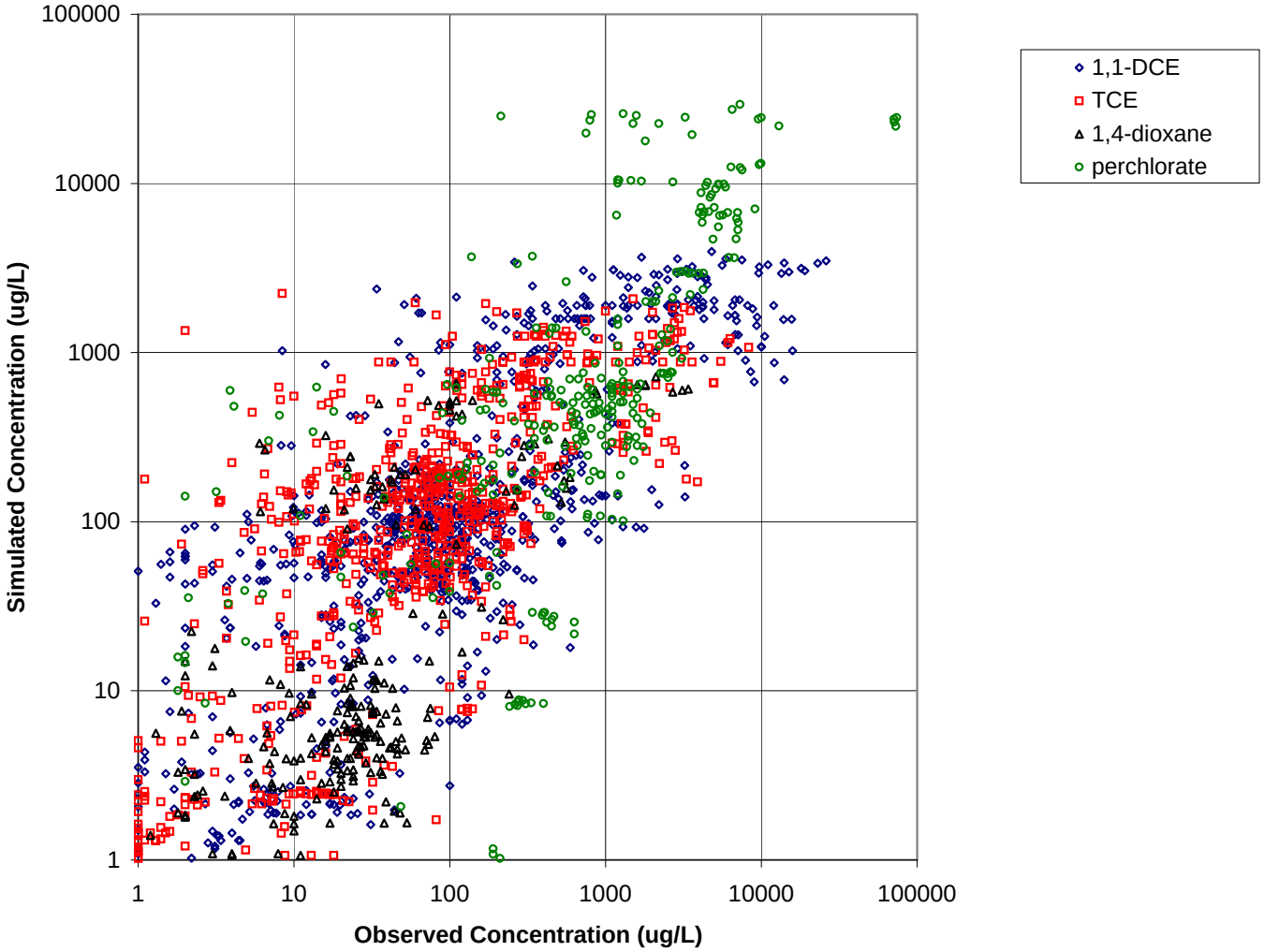
| TRANSPORT MODEL PREDICTIONS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Perchlorate | | 1-4-Dioxane | | 1-1-DCE | | TCE | |
| | Total Mass (pounds) | Mass Flux (pounds/year) | Total Mass (pounds) | Mass Flux (pounds/year) | Total Mass (pounds) | Mass Flux (pounds/year) | Total Mass (pounds) | Mass Flux (pounds/year) |
| Sources | 2,501 | 156* | 62 | 3.9 | 303 | 19.0 | 144 | 9.0 |
| Wells** | -423 | -26 | -5 | -0.3 | -95 | -6.0 | -109 | -6.8 |
| Creek | -15 | -1 | -2 | -0.2 | -4 | -0.2 | -5 | -0.3 |
| Evapotranspiration | -313 | -20 | -33 | -2.1 | -118 | -7.4 | -170 | -10.6 |
| Degradation | -2,139 | -134 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2009 Storage | 3,217 | NA | 81 | NA | 492 | NA | 355 | NA |

* 144 for BPA, 12 for RMPA, and < 1 for F-33

| CONCEPTUAL MODEL VALUES (from Section 3) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Perchlorate | | 1-4-Dioxane | | 1-1-DCE | | TCE | |
| | Total Mass (pounds) | Mass Flux (pounds/year) | Total Mass (pounds) | Mass Flux (pounds/year) | Total Mass (pounds) | Mass Flux (pounds/year) | Total Mass (pounds) | Mass Flux (pounds/year) |
| Sources | 2,576 | 161 | 48 | 3.0 | 224 | 14.0 | 181 | 11.3 |
| Wells** | -443 | -28 | -8 | -0.5 | -93 | -5.8 | -99 | -6.2 |
| Creek | -22 | -1 | -10 | -0.6 | -32 | -2.0 | -13 | -0.8 |
| Evapotranspiration | -640 | -40 | -128 | -8.0 | -288 | -18.0 | -304 | -19.0 |
| Degradation | -1,008 | -63 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2009 Storage | 3,400 | NA | 100 | NA | 362 | NA | 314 | NA |

** For TCE and 1,1-DCE wells, represents net loss due to removal in treatment, but for perchlorate and 1,4-dioxane wells doe not represent net loss since extraction is balanced by reinjection

**Figure 4-2 Comparison of Simulated and Observed COC Concentrations during 1992-2009**



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

- Contour plots of the simulated and observed 2009 COCs concentrations (Appendix D, Figures D-1 through D-4), which generally show a fair comparison between the spatial trends in the model predicted contours and the observed COC contours; and

- Time series plots of simulated and observed concentrations for twelve (12) monitoring and extraction wells located throughout the site (Appendix E), which generally show a fair comparison between the time trends in the model predicted concentrations and the observed COC concentrations.

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

- Hot spots for all COCs in the plume source area in the BPA and for pechlorate in various locations of the RMPA;

- Plume migration that follow the Bedsprings Creek and Potrero Creek valleys;

- Significant decreases in plume concentration with distance from the source area due to dilution, which is especially apparent near the BPA where the plume transitions from the lower permeability Mt Eden formation to the higher permeability alluvium;

- Large decreases in COC concentrations across the riparian area where evapotranspiration has a significant impact on all COC and degradation also impacts perchlorate;

- Fairly good comparisons in the TCE and 1,1-DCE time trends in the extraction wells EW-01 and EW-02 (Figures E-2, and E-3);

- An overall time trend showing decreasing to stable concentrations in most of the site monitoring wells, generally matching the observed data; and

- A plume nose for TCE and 1-1,DCE that extends northeast around the Mt Eden outcrop in the RMPA, due to seasonal fluctuations in water groundwater flow direction that pushes pulses of COCs into this area. Note this nose in the plume occurs for TCE and 1,1-DCE without the presence of any soil or groundwater sources in the RMPA.

Considering the above points, the relative error for the COCs concentration of 6 to 7 percent, and the inherent difficulty in re-creating historical source conditions, the comparison between simulated and observed COCs concentrations is considered adequate for the purposes of this study.

**COC Mass and Mass Flux Budget**

The groundwater COC mass and mass flux budget for the calibrated transport model is summarized in Table 4-1. The components of the COC mass and mass flux budget generally matches the conceptual model COC mass and mass flux budget given in Section 3-3, Figure 3-12,

Table 3-4, and as summarized in Table 4-1. Notable components of the transient mass flux budget include the following:

- Total COC plume mass predicted for 2009 is within 6 percent of 2009 observed mass for perchlorate; 19 percent of 2009 observed mass for 1,4-dioxane; 48 percent of 2009 observed mass for 1,1-DCE, and 36 percent of observed 2009 mass for TCE;

- COC mass and mass flux into the aquifer is within 14 percent of the mass and mass flux out of the aquifer due to loss to evapotranspiration, wells, streams, and biodegradation (perchlorate only). This suggests the plume is nearly at steady-state conditions, which also is reflected in the plume mass being relatively constant over the 1992 through 2009 simulation period. While is it noted that there are some discrepancies between certain elements of the mass and mass flux, these discrepancies are attributed to the inherent uncertainty of transport model predictions rather than any true significant deviation from the aforementioned plume steady-state conditions;

- There is generally good comparison between the transport model mass and mass flux values estimated at the extraction well locations for TCE and 1,1,-DCE;

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

- The perchlorate mass flux values from sources in the RMPA reasonably match estimated using vadose zone transport methodology in Section 3, suggesting there are no groundwater perchlorate sources in the RMPA. This is consistent with all the other COCs that do not show a groundwater source in the RMPA; and

- The perchlorate mass flux values from sources in the BPA are about twice those estimated using vadose zone transport methodology in Section 3, suggesting there is a groundwater perchlorate sources in the RMPA. This is consistent with all the other COCs that show a groundwater source in the BPA.

Thus, the transport model COC mass and mass flux budget is reasonably close to the site conceptual model COC mass and mass flux budget. Given that the model parameters, concentrations, spatial and temporal concentrations trends, and COC 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

In order to evaluate the sensitivity of the transport model to various model parameters, a sensitivity analysis was conducted by varying key model parameters such as the perchlorate degradation rate, the TCE and 1,1-DCE retardation factor, and the removal rate of COC by evapotranspiration to evaluate the resulting changes in the model predictions.

The model predictions for riparian zone perchlorate half-lives of 12.6 days, 42 days, and no degradation are given in Appendix D (Figures D-5, D-6, and D-7) for comparison with the model base case with a perchlorate half-life of 126 days (Figure D-1). Shorter perchlorate half-lives result in better comparison to observed data in the upper portion of the riparian area where concentrations are below detection limits, but poorer comparison to observed data in the artesian portion of the riparian area near OW-02 where concentrations are greater than 10 to 100 µg/L. Conversely, longer perchlorate half-lives of 42 days to 126 days results in poorer comparison to observed data in the upper portion of the riparian area where concentrations are below detection limits, but better comparison to observed data in the artesian portion of the riparian area near OW-02 where concentrations are greater than 10 to 100 µg/L. No perchlorate degradation (Figure D-7) results in poor comparison to observed data, with the perchlorate plume extending far down Potrero Creek canyon. While there is some uncertainty in the appropriate perchlorate half-life, primarily due to the perchlorate plume behavior near OW-02, the large difference between simulated and observed data for the no degradation case suggests perchlorate degradation is an important component of the model.

The model predictions for 1,1-DCE and TCE retardation factors of 1 (no sorption) are given in Appendix D (Figures D-8 and D-9) for comparison with the model base case with 1,1-DCE and TCE sorption (Figures D-3 and D-4). While there is some small impact of sorption on the predicted concentrations in the riparian area, generally the effects of sorption are small on even the downgradient extent of the plume. This is attributed to the large impact evapotranspiration has on the plume in the riparian area, as illustrated by the model TCE results with no removal due to evapotranspiration (Appendix D, Figure D-10), which generally shows plume migration across the riparian area and down Potrero Creek canyon.

Given these sensitivity results, the perchlorate degradation rate and impacts of evapotranspiration have rather large impacts on the plume shape relative to the current plume conditions, while 1,1-DCE and TCE sorption in the plume have rather small impacts on the plume shape relative to the current plume conditions. The sensitivity analysis results also demonstrate that the model is not excessively sensitive to model parameters, and provide support for the choice of the final calibrated model parameters.

## 4.4 MODEL UNCERTAINTIES AND LIMITATIONS

The transport model reasonably matches measured COC concentrations and the groundwater COC mass flux budget estimated for the site. However, there are model uncertainties that may limit the predictive ability of the model, most notably:

- Mass of COC in Source Zones – Except for perchlorate where mass has been detected and quantified in site soils, the mass of the other COCs (1,4-dioxane, 1,1-DCE, and TCE) in saturated zone source areas is not known. Based upon the historical data collected at the site and the modeling results for the last 16 years, future releases of 1,4-dioxane, 1,1-DCE, and TCE from the groundwater source area for another 16 year period seems plausible, but there is significant uncertainty in the length of time the BPA source would continue to impact groundwater. Thus, the duration of any continuing future releases from the BPA source area is a key model uncertainty. In addition, current perchlorate release rates from the remaining BPA soil source areas is estimated to be 40 to 73 pounds per year (Appendix C), or only about 28 to 51 percent of the 144 pounds per year released from the total combined groundwater/soil source in the BPA. This suggests that in addition to the BPA soils source, a significant perchlorate groundwater source is also present in the BPA, while the other COCs are released only from groundwater in the BPA. Note that the total combined groundwater/soil source release rate in the RMPA (12 pounds per year) and F-33 Area (0.1 pounds per year) reasonably match the current perchlorate release rates from the remaining RMPA and F-33 soil source areas of 13 to 0.1 pounds per year (Appendix C), suggesting that a groundwater source does not exist for perchlorate in the RMPA or F-33 Areas. This is similar to the other COCs that have no groundwater or soil sources in the RMPA or F-33 Areas.

- Perchlorate degradation rate and capacity – This model treats perchlorate degradation rate in the riparian area as a first order decay process, with a perchlorate half-life on the order of 1 to 4 months. Perchlorate degradation is likely a more complicated process that is dependent on the availability of organic carbon and the redox conditions in the aquifer, both of which are currently favorable for perchlorate degradation. However, the future availability of organic carbon and the future aquifer redox conditions are not well known, so the future perchlorate degradation rate and ultimate aquifer capacity for perchlorate degradation is uncertain.

- VOC sorption rate in the riparian area – This model considers the impact of 1,1-DCE and TCE sorption in the riparian area via the use of retardation factors that are higher than values in other parts of the site, based upon limited TOC data recently collected in new wells MW-101 and MW-102 (Table 2-1). However, since there is limited organic carbon data for the aquifer solids in the riparian area, there is some uncertainty in the magnitude and extent of 1,1-DCE and TCE sorption in the riparian area.

- COC release rate from Source Zones – The release rate of perchlorate has been quantified based upon the perchlorate mass present in site soils and the vadose zone model, and the release rate of the other COCs (1,4-dioxane, 1,1-DCE, and TCE) in the saturated zone source areas has been quantified based upon the conceptual model calculations and the calibration of the transport model. Thus, the COC release rate from source zones is not well known, but it likely has a significant impact on future COC concentrations.

- COC migration pathway from BPA Source Zone – The model predictions show a COC migration pathway from the BPA Source Zone that takes the plume northeast of the BPA before turning to the northwest, which is due to the seasonal water table fluctuations that turn the water level flow direction to the northeast of the BPA during high recharge years. However, despite the northeast flow direction observed in the site water level monitoring data during these high recharge years, the plume monitoring data continues to suggest a predominant northwest plume orientation that is somewhat at odds with the model predictions. This difference between the model predictions and the observed plume data may be attributed to local variations in hydraulic conductivity near the BPA that are not included in the model that may channel the plume to the northwest. While this model limitation has limited impact on the far field plume transport, it could impact extraction well placement in a BPA source area remediation alternative. Therefore, more detailed hydraulic testing of aquifer conditions near the BPA may be needed to proceed with detailed design of a BPA source area remediation alternative. However, the need for this additional hydraulic testing is not clear at this time, since it is not clear that the final site remedy will contain a BPA source area remediation alternative.

# SECTION 5 MODEL PREDICTIONS

The base case calibrated 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 management scenarios:

- No Action Alternative;
- Source Removal Alternative;
- Operation of an Expanded RMPA Groundwater Extraction and Injection System (Options B and C) without Source Removal; and
- Operation of an Expanded RMPA Groundwater Extraction and Injection System (Options B and C) with Source Removal.

These model predictions are presented to illustrate various site remediation scenarios that may be evaluated with the model in the upcoming site Feasibility Study. The intent of the model simulations is to illustrate the model predictions for two widely different source remediation scenarios, one without any source treatment and another with complete source removal, since these removal cases present bounding scenarios where most all source remedial cases could be expected to result in COC concentrations and masses that fall between these two alternatives. However, the presentation of these two extreme alternatives does not in any way suggest a preference or the technical practicality of either alternative.

The model predictions in Sections 5.1 through 5.4 are made using current water levels and plume concentrations as the model initial conditions. Future hydrologic conditions for the 2010 to 2026 transient model simulation period are estimated from historical variations in hydrologic conditions observed at the site as discussed in the recent groundwater flow model report (Tetra Tech, 2010). Future COC source release rates for the model simulation period are estimated from historical variations in COC release rates observed at the site and the vadose zone fate and transport analysis discussed in Section 3 and Appendix C. The predicted 2026 COC contour maps for these scenarios are given in Appendix F, and the predicted 2026 COC plume mass estimates are given in Table 5-1.

## 5.1 NO ACTION ALTERNATIVE

The No Action Alternative is evaluated as a base case scenario, which consists of current groundwater conditions with continued release of COCs from groundwater and soil source areas at the release rates summarized in Section 3, 4, and Appendix C (Table 4-1).

The predicted 2026 COC plume concentrations (Figures F-1 through F-4) and mass estimates (Table 5-1) are generally similar to current site conditions, which is consistent with the observation that the site plume is near a steady-state condition. This prediction assumes that COC release rates over the next 16 years will remain at the historical levels. Based upon site conditions, this appears to be a reasonable but somewhat conservative assumption, as there are some indications in the site data that plume mass and hence COC source release rates have declined somewhat over time.

## 5.2 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 COCs from soil and groundwater sources. This alternative consists of current groundwater conditions with no future release of COCs from groundwater and soil source areas.

The predicted 2026 COC concentrations (Figures F-5 through F-8) are generally similar to current site conditions (Figures D-1 through D-4) or the No Action Alternative (Figures F-1 through F-4) in the far downgradient areas of the RMPA and in the riparian zone, but concentrations at and immediately downgradient of the BPA and RMPA source areas have declined by one to two orders of magnitude. The predicted 2026 COC mass estimates (Table 5-1) are reduced by approximately 74 percent in comparison to the No Action Alternative or to current site conditions.

## 5.3 OPERATION OF AN EXPANDED RMPA GROUNDWATER EXTRACTION AND INJECTION SYSTEM WITHOUT SOURCE REMOVAL

The Expanded RMPA Groundwater Extraction and Injection System without Source Removal Alternative is evaluated as an example of a remedial alternative scenario where pump and treat is used to provide hydraulic control of the main plume, but no direct source removal or clean-up is undertaken. This alternative consists of current groundwater conditions with continued future release of COCs from groundwater and soil source areas at the release rates summarized in

Table 5-1
2016 Model Predictions
Groundwater COC Plume Mass (pounds) for various Remedial Alternatives

| | Remedial Alternative | | | | | |
|---|---|---|---|---|---|---|
| COC | No Action | Source Removal | RMPA Groundwater Extraction System Option B without Source Removal | RMPA Groundwater Extraction System Option C without Source Removal | RMPA Groundwater Extraction System Option B with Source Removal | RMPA Groundwater Extraction System Option C with Source Removal |
| Perchlorate | 2,898 | 692 | 2,530 | 2,149 | 431 | 309 |
| 1,4-dioxane | 88 | 29 | 72 | 63 | 15 | 13 |
| 1,1-DCE | 376 | 95 | 334 | 299 | 60 | 46 |
| TCE | 236 | 99 | 191 | 172 | 58 | 48 |
| Sum All COCs | 3,598 | 915 | 3,126 | 2,682 | 564 | 416 |
| Percent Reduction from No Action | NA | 75% | 13% | 25% | 84% | 88% |

Section 3, 4, and Appendix C (Table 4-1), and expansion and operation of the RMPA Groundwater Extraction and Injection System to achieve full containment of the main plume using either Option B or Option C identified in the recent groundwater flow modeling report (Tetra Tech, 2010).

The predicted 2026 COC concentrations (Figures F-9 through F-16) are generally similar to current site conditions (Figures D-1 through D-4) or the No Action Alternative (Figures F-1 through F-4) at and immediately downgradient of the BPA and RMPA source areas, but concentrations in the far downgradient areas of the RMPA and the riparian zone have declined by one to two orders of magnitude. The downgradient extent of the plume has also been reduced by approximately one-half mile. The predicted 2026 COC mass estimates (Table 5-1) are reduced by 13 percent for Option B and 25 percent for Option C in comparison to the No Action Alternative or to current site conditions. Comparing Options B and C, Option C would appear more favorable as it results in greater reductions in COC mass.

## 5.4 OPERATION OF AN EXPANDED RMPA GROUNDWATER EXTRACTION AND INJECTION SYSTEM WITH SOURCE REMOVAL

The Expanded RMPA Groundwater Extraction and Injection System with Source Removal Alternative is evaluated as an example of a remedial alternative scenario where pump and treat is used to clean-up the downgradient plume and clean-up of the sources is effective in stopping the continued release of COCs from soil and groundwater sources. This alternative consists of current groundwater conditions with no future release of COCs from groundwater and soil source areas, and expansion and operation of the RMPA System to achieve full containment of the main plume using either Option B or C identified in the recent groundwater flow modeling report (Tetra Tech, 2010).

The predicted 2026 COC concentrations (Figures F-17 through F-24) have declined by one to two orders of magnitude, relative to current site conditions (Figures D-1 through D-4) or the No Action Alternative (Figures F-1 through F-4), throughout the entire plume and the downgradient extent of the plume have been reduced by approximately one-half mile. The predicted 2026 COC mass estimates (Table 5-1) are reduced by 84 percent for Option B and 88 percent for Option C in comparison to the No Action Alternative or to current site conditions. Comparing Options B and C, Option C would appear more favorable as it results in greater reductions in COC mass and somewhat lower COC concentrations.

# SECTION 6 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Section 6 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 COC mass flux budget, and numerical MODFLOW/MT3D groundwater flow/transport model were developed for the site based upon historical groundwater monitoring and remedial operations data. The numerical groundwater transport model was calibrated for the 1992 through 2009 period. The numerical model further confirmed the key hydraulic and transport characteristics of the aquifer, and the water and COC mass flux budget for the aquifer system. The numerical model was also capable of simulating the quasi- steady state plume conditions observed in the groundwater monitoring data during the 1992 through 2009 period.

Key aspects of the model include the following:

- Perchlorate, 1,4-dioxane, 1,1-DCE, and TCE appear to be added to the plume by the flow of groundwater through an aquifer source area in the BPA. In addition, perchlorate appears to be added to the plume by the release of perchlorate from soil sources in the BPA, RMPA, and to a lesser extent at Site F-33. Current COC mass flux released from all sources is estimated as follows: 19 pounds per year for 1,1-DCE; 9 pounds per year for TCE; 156 pounds per year for perchlorate; and 4 pounds per year for 1,4-dioxane. Current total COC mass in the plume is estimated as follows: 450 pounds for 1,1-DCE; 370 pounds for TCE; 3,300 pounds for perchlorate; and 90 pounds for 1,4-dioxane. Current total COC mass in soils is 1,800 pounds for perchlorate with no other COCs present in soils;

- In the BPA, soil sources account for approximately 30 to 50 percent of the BPA perchlorate source, with groundwater sources accounting for the remaining 50 to 70 percent. In the RMPA, the only source is for perchlorate released from soils;

- Over 90 percent of the perchlorate and all the 1,4-dioxane, 1-1,DCE, and TCE are released from a small, 1 acre area in the BPA. In the RMPA, approximately 10 percent of the perchlorate is released from various soils sources, and there are no releases or source present for 1,4-dioxane, 1-1,DCE, or TCE;

- All COCs appear to be removed from the plume by evapotranspiration in the riparian area at rates of 8 pounds per year for 1,1-DCE; 12 pounds per year for TCE; 20 pounds per year for perchlorate; and 2 pounds per year for 1,4-dioxane. In addition, perchlorate appears to be removed from the plume by biodegradation due to the reducing aquifer conditions in the

riparian area at rates of 133 pounds per year. Other more minor COC removals from the plume occur by discharge to Potrero Creek. Future COC removal rates in the riparian areas during the next 16 years are thought to be similar to the current COC removal rates in the riparian if no further action is taken at the site; and

- The lateral and vertical extent of the plume appears to be controlled by the build-up of plume mass and extent in the areas between the sources in the BPA and RMPA areas, and the evapotranspiration and biodegradation sinks in the riparian area. Other more minor COC excursions of the plume may occur by discharge in the groundwater flowing across the Potrero Fault and down Potrero Creek, when groundwater flows, COC concentrations, and COC mass flux rates may temporarily exceed the attenuation capacity of the riparian zone;

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

- A No Action Alternative;
- A Source Removal Alternative;
- An expanded RMPA extraction/injection system (Options B or C) without Source Removal Alternative; and
- An expanded RMPA extraction/injection system (Options B or C) with Source Removal Alternative.

The expanded RMPA extraction/injection system Options B and C consist of the addition of two new extraction wells and two new re-injection wells in order to expand the total RMPA extraction and re-injection rates to 91 gpm. The difference between Option B and C is the placement of the new extraction wells, with Option C placing one new extraction well closer to the BPA than the location used in Option B. 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. Future COC release and removal rates during the next 16 years for the No Action Alternative are thought to be similar to the current rates.

## 6.2 CONCLUSIONS

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

- Generally, the plume at the site appears to be in a quasi- steady state conditions where COCs are added to the plume in the BPA and RMPA source areas at rates of approximately 188 pounds per year, which are approximately equal to the COC removal rates from the plume of approximately 177 pounds per year in the riparian area;

- Given the current plume mass of approximately 4,000 pounds and mass flux rates of approximately 200 pounds per year, the overall residence time in the plume is on the order of 20 years. This 20 year time period is similar to the transport time within the plume;
- The riparian area appears to have a significant impact on the extent of the plume, as COCs are removed from the plume in the riparian area at a rate of 177 pounds per year that is nearly equal to the rate that COCs are added to the plume (188 pounds per year);
- Model predictions suggest the following:
  - For a No Action Alternative, 2026 groundwater COC concentrations are likely to be quite similar to the groundwater COC concentrations currently observed at both the BPA/RMPA source areas and in the downgradient riparian areas of the site;
  - For a Source Removal Alternative, 2026 groundwater COC concentrations are likely to be reduced by one to two orders of magnitude below current conditions or the No Action Alternative at and immediately downgradient of the BPA/RMPA source areas, but similar to the current conditions in the downgradient riparian areas of the site. The predicted 2026 COC plume mass estimates (Table 5-1) are reduced by 74 percent in comparison to the No Action Alternative;
  - For an Alternative with an expanded RMPA extraction/injection system without Source Removal, 2026 groundwater COC concentrations are likely to be reduced by one to two orders of magnitude below current conditions or the No Action Alternative in the areas downgradient of the RMPA system, but similar to the current conditions or the No Action Alternative at and immediately downgradient of the BPA/RMPA source areas. The predicted 2026 COC plume mass estimates (Table 5-1) are reduced by 13 to 25 percent in comparison to the No Action Alternative;
  - For an Alternative with an expanded RMPA extraction/injection system with Source Removal, 2026 groundwater COC concentrations are likely to be reduced by one to two orders of magnitude below current conditions or the No Action Alternative in both the source areas and the areas downgradient of the RMPA system. The predicted 2026 COC plume mass estimates (Table 5-1) are reduced by 84 to 88 percent in comparison to the No Action Alternative; and
  - Expanding the RMPA extraction/injection system using Option C appears preferable to Option B as it results in lower overall site COC concentrations and greater COC mass removals

While there is some uncertainty in these conclusions due to the inherent nature of groundwater transport model predictions, the long period of site monitoring data and the experience from prior site remedial actions should limit the level of uncertainty.

## 6.3 RECOMMENDATIONS

Based upon the CSM, water and COC mass flux budget, numerical groundwater transport model calibration, and remedial scenario simulations, it is recommended that the model developed in this study be used to evaluate the more specific remedial options that will be developed as work progresses on the upcoming site Feasibility Study. In addition, if the Feasibility Study appears

likely to recommend groundwater remedial action at the Burn Pit Area, additional data collection on well capacity and aquifer characteristics in the Burn Pit Area is recommended to acquire the data needed to proceed with detailed design of a groundwater remedial action at the Burn Pit Area.

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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 |
| 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 |