DEPARTMENT OF THE AIR FORCE
60TH CIVIL ENGINEER SQUADRON (AMC)

May 31, 2012

MEMORANDUM FOR DISTRIBUTION

FROM: 60 CES/CEANR
411 Airmen Drive
Travis AFB CA 94535-2001

SUBJECT: Final Technical and Economic Feasibility Analysis Report

1. The attached final report contains the Technical and Economic Feasibility Analysis (TEFA) of the cleanup of groundwater beneath Travis AFB. We conducted this analysis to comply with State Water Resource Control Board Resolution 92-49 and to support the upcoming Basewide Groundwater Record of Decision.

2. We are providing the TEFA report to most parties in CD-ROM format to reduce our paper and document storage requirements. If you have any questions concerning this final report or require additional copies, please contact Mr. Glenn Anderson at (707) 424-4359.

MARK H. SMITH, GS-12, DAF
For Chief, Environmental Restoration

Attachment:
Final Technical and Economic Feasibility Analysis Report

Distribution: (see attached)

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TRAVIS AIR FORCE BASE
ENVIRONMENTAL RESTORATION PROGRAM

Final

Basewide Groundwater Technical and Economic Feasibility Analysis

USACE Contract No. W91238-06-D-0013

Delivery Order DK01

Prepared for:

U.S. Army Corps of Engineers
Omaha District

60 CES
Travis Air Force Base, California

Prepared by:

May 2012

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SECTION 1
Introduction

Travis Air Force Base (AFB) is working with the U.S. Environmental Protection Agency (EPA), California Department of Toxic Substances Control (DTSC), and San Francisco Bay Regional Water Quality Control Board (Water Board) to select remedial actions for 19 contaminated groundwater sites in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

State Water Resources Control Board (SWRCB) Resolution 92-49 (Policies and Procedures for Investigation and Cleanup and Abatement of Discharges under Water Code Section 13304) authorizes Regional Water Boards to require complete cleanup of all waste discharged and restoration of affected water to background conditions (i.e., the water quality that existed before the discharge).

This Technical and Economic Feasibility Analysis (TEFA) for Travis AFB evaluates the technical and economic feasibility of reducing groundwater contaminant concentrations to background levels in accordance with the intent of Resolution 92-49.

1.1 Objective

The primary objective of this TEFA is to comply with the intent of SWRCB Resolution 92-49 and support the selection of cleanup levels for groundwater contaminants in the aquifer beneath Travis AFB. The TEFA takes into consideration the site-specific hydrogeologic and other environmental conditions of the aquifer and the current land use of the overlying property.

1.2 Scope

This TEFA addresses the groundwater medium. Other environmental media present at Travis AFB, including soil, sediment, and surface water, are addressed in the final *North/East/West Industrial Operable Unit Soil, Sediment, and Surface Water Record of Decision* (Travis AFB, 2006) and final *Soil Record of Decision for the West/Annexes/Basewide Operable Unit* (Travis AFB, 2002).

Groundwater contamination resulting from releases of petroleum fuel hydrocarbons is managed under the Travis AFB Petroleum-only Contaminated (POCO) program and is not within the scope of this TEFA. The Water Board is the lead oversight agency for the POCO program, as CERCLA excludes petroleum fuel constituents. Groundwater contamination managed under the POCO program is typically associated with surface and subsurface releases from fuel spills, piping leaks, oil-water separators (OWSs), or underground storage tanks (USTs). The POCO program is involved with the removal of USTs and the remediation of POCO soil and groundwater using risk-based cleanup actions.

1.3 Organization

The organization and content of the TEFA are as follows:

- **Section 1: Introduction.** Provides the objective, scope, and organization of the TEFA.
- **Section 2: Background and Approach.** Describes the physical, administrative, and regulatory background of Travis AFB. Describes the past and current implementation of the CERCLA process at Travis AFB and the approach to conducting the evaluations provided in the TEFA.
- **Section 3: Environmental Factors.** Provides discussions of the nine (9) groundwater-related environmental factors identified in 23 California Code of Regulations (CCR) 2550.4(d)(1) and as referenced in SWRCB Resolution 92-49. The nine (9) factors are as follows:

  A. Physical and chemical characteristics of the waste in the waste management unit

  B. Hydrogeological characteristics of the facility and surrounding land

  C. Quantity of groundwater and direction of groundwater flow

  D. Proximity and withdrawal rates of groundwater users

  E. Current and potential future users of groundwater in the area

  F. Existing quality of groundwater, including other sources of contamination or pollution and their cumulative impact on the groundwater quality

  G. Potential health risks caused by exposure to waste constituents

  H. Potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents

  I. Persistence and permanence of the potential adverse effects

- **Section 4: Analysis of Technical Feasibility.** Provides evaluations of the effectiveness and constructability issues related to expanding remedial alternatives to achieve groundwater cleanup to background levels.
- **Section 5: Analysis of Economic Feasibility.** Provides the rationale for not conducting an economic feasibility analysis on the cleanup of Travis AFB groundwater.
- **Section 6: Summary of Technical and Economic Feasibility Analyses.** Provides discussion of the key aspects of technical and economic feasibility in achieving background concentrations.
- **Appendixes**
  - **Appendix A: Acronyms and Abbreviations**
  - **Appendix B: References**
  - **Appendix C: Remediation Time Frame Estimates**
  - **Appendix D: Response to Comments**

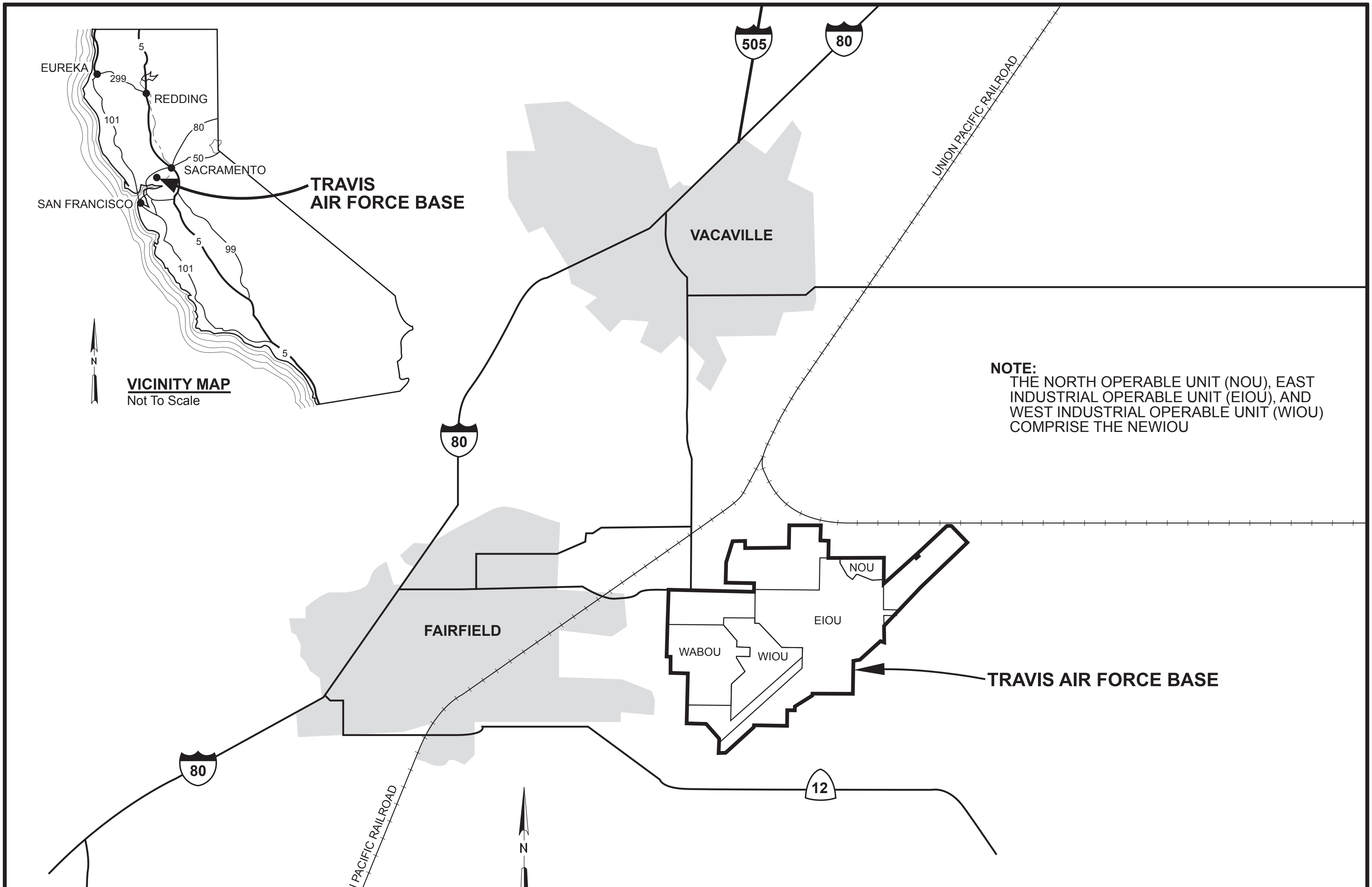

FIGURE 1-1
TRAVIS AFB LOCATION
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL®

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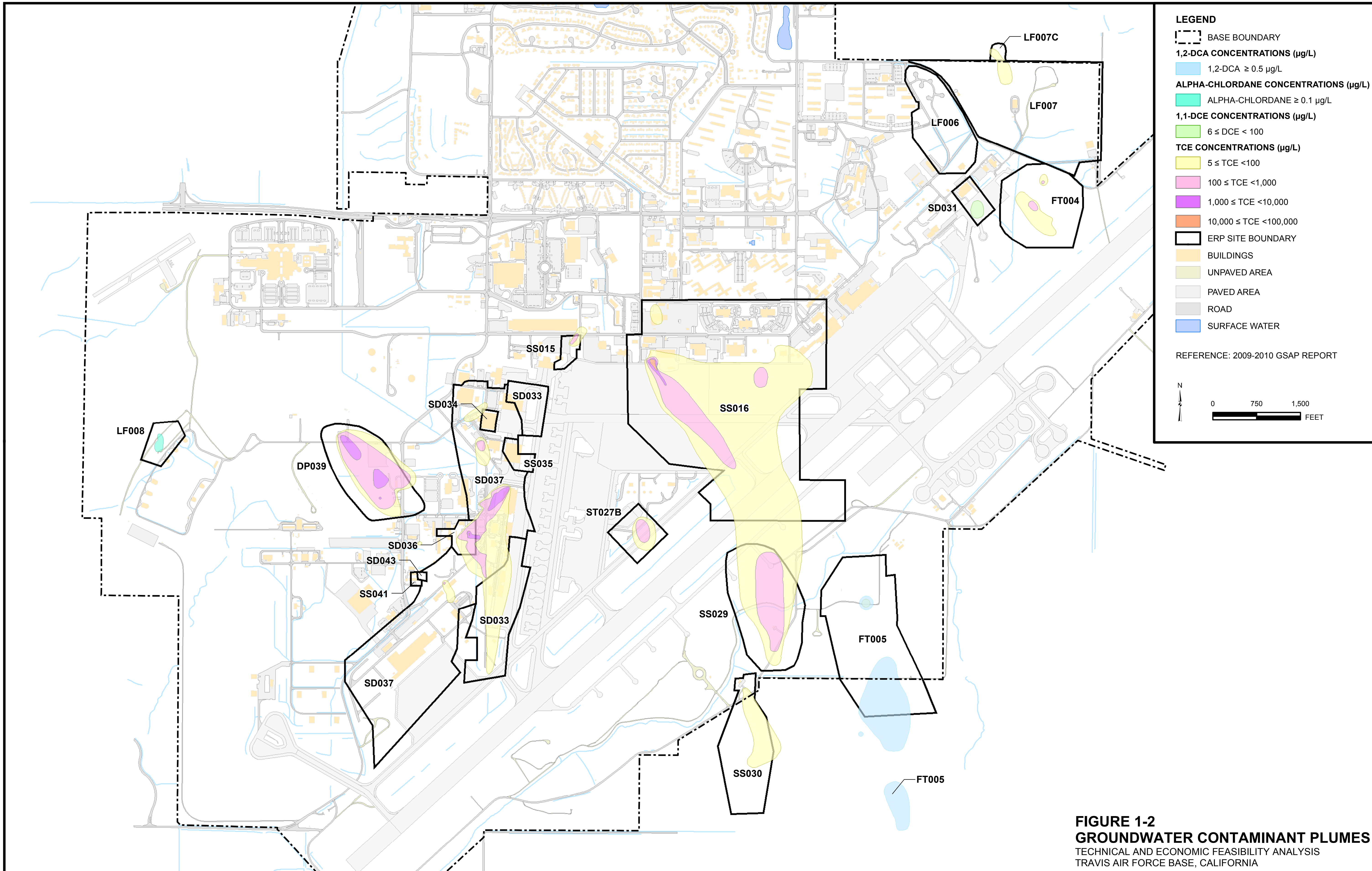

FIGURE 1-2
GROUNDWATER CONTAMINANT PLUMES
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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SECTION 2

Background and Approach

As a result of past waste management and disposal practices, groundwater at Travis AFB is contaminated at multiple locations. To address this groundwater contamination, Travis AFB has implemented the CERCLA process and installed multiple groundwater IRAs. After approximately a decade of interim remediation, Travis AFB is now beginning the transition out of the period of interim remediation and is starting the process to select and implement final remedial actions.

2.1 Overview of Travis AFB

Travis AFB is an active military reservation located midway between San Francisco and Sacramento, California, on low-lying ground within 1 mile of Suisun Marsh, an estuary of San Francisco Bay. It occupies about 6,383 acres of land located 3 miles east of downtown Fairfield and 8 miles south of downtown Vacaville in Solano County. Solano County's estimated population in 2009 was approximately 407,234 (U.S. Census Bureau, 2009a). The 2009 population estimates for Fairfield and Vacaville were 103,586 and 91,991, respectively (U.S. Census Bureau, 2009b). The location of Travis AFB is shown on Figure 2-1.

Travis AFB is part of Air Mobility Command and is host to the 60th Air Mobility Wing and other units. The 60th Air Mobility Wing operates C-5 Galaxy and C-17 Globemaster III cargo aircraft and KC-10 Extender refueling aircraft. The primary missions of Travis AFB, since its establishment in 1943, have been strategic reconnaissance and airlift of freight and troops.

The land use areas of Travis AFB are grouped into the following eight (8) functional categories:

- **Mission –** Uses are closely associated with the airfield and include facilities such as maintenance hangars and docks, avionics facilities, and other maintenance facilities. Aircraft operations facilities include control towers, Base operations, flight simulators, and other instructional facilities.
- **Administrative –** Uses include personnel, headquarters, legal, and other support functions.
- **Community –** Uses include both commercial and service activities. Examples of commercial uses include the Base Exchange, dining halls, service station, and clubs; service uses include the schools, chapel, library, and the family support center.
- **Housing –** Uses include both accompanied housing for families and unaccompanied housing for singles, temporary personnel, and visitors.
- **Base Support/Industrial –** Uses are for the storage of supplies and maintenance of Base facilities and utility systems.

- **Medical –** Uses include facilities for medical support, including the David Grant Medical Center.
- **Outdoor Recreation –** Uses include ball fields, golf course, equestrian center, swimming pools, and other recreational activities.
- **Open Space –** Used as buffers between Base facilities and to preserve environmentally sensitive areas.

The lands surrounding Travis AFB on the northeast and east are primarily used for ranching and grazing. Areas to the south are a combination of agricultural and marshland. A few commercial/light industrial areas are present to the north of the Base. The area west of Travis AFB is predominantly residential.

Land use within the western portion of the Base is varied and consists primarily of open grasslands, light industrial support areas, administrative areas, personnel training areas, ammunition storage, and service/storage areas. Over the remainder of the Base, land use includes two (2) major aircraft runways, one (1) smaller C-17 Southwest Landing Zone under construction, associated taxiways and aircraft parking aprons, numerous hangars, buildings, shops, offices, freight handling and storage areas, and maintenance facilities.

2.2 The CERCLA Process at Travis AFB

In 1983, the Air Force initiated the Installation Restoration Program (IRP) (now the ERP) to investigate the nature and extent of hazardous waste releases to the environment. On the basis of IRP data evaluated by the EPA, Travis AFB was placed on the National Priorities List (NPL) on November 21, 1989 (54 *Federal Register* 48187). Approximately 1 year later, on September 27, 1990, the Air Force, EPA, DTSC, and Water Board negotiated and signed the Federal Facilities Agreement (FFA) (Travis AFB, 1990) that established the framework and schedule for environmental cleanup at Travis AFB.

The Air Force is the lead agency and is responsible for conducting all actions related to the remediation of contaminated groundwater beneath Travis AFB. EPA Region 9, Water Board, and DTSC provide regulatory agency oversight of the actions taken by the Air Force.

2.2.1 Operable Units

Under the original FFA (Travis AFB, 1990), Travis AFB was treated as a single entity with one (1) associated comprehensive cleanup schedule. Then, in May 1993, the FFA was amended to divide the Base into four (4) OUs to facilitate the overall cleanup program. The four (4) OUs are as follows:

- East Industrial Operable Unit (EIOU)
- West Industrial Operable Unit (WIOU)
- North Operable Unit (NOU)
- West/Annexes/Basewide Operable Unit (WABOU)

In October 1995, the EIOU, WIOU, and NOU were combined into the composite NEWIOU. Currently, the OUs at Travis AFB include the NEWIOU and the WABOU. This TEFA takes a Basewide approach and addresses groundwater contamination within both of these OUs.

2.2.2 Environmental Restoration Program Sites

Summary descriptions of the ERP sites within the NEWIOU and WABOU are provided in the following subsections. The locations of current groundwater contaminant plumes are shown on Figure 2-2.

2.2.2.1 NEWIOU ERP Sites

Contaminated groundwater ERP sites within the NEWIOU are as follows:

- **Site FT004 (Fire Training Area [FTA]-3):** Area used for fire training exercises from approximately 1953 through 1962. During this period, waste fuels, oils, and solvents were burned on open ground. Historical practices resulted in groundwater contamination with chlorinated volatile organic compounds (VOCs).
- **Site FT005 (FTA-4):** Area used for fire training exercises from approximately 1962 through 1987. During this period, waste fuels, oils, and solvents were burned on open ground. Historical practices resulted in groundwater contamination with chlorinated VOCs. The contaminant plume extends onto off-base privately owned property.
- **Site LF006 (Landfill 1):** A general refuse landfill that used trench and burn methods from approximately 1943 through 1950. Historical practices resulted in groundwater contamination with chlorinated VOCs and petroleum-fuel hydrocarbons.
- **Sites LF007B, C, and D (Landfill 2):** A general refuse landfill that used trench and cover methods from approximately 1950 through 1970. Historical practices resulted in groundwater contamination with chlorinated VOCs, dioxins, and polychlorinated biphenyls (PCBs). The Site LF007C contaminant plume extends onto off-base privately owned property.
- **Site SS015 (Solvent Spill Area [SSA] and Facilities 808, 1832, 552):** Facilities used between approximately 1964 and 1980 for solvent stripping of aircraft parts, aircraft maintenance and repair, OWS activities, and hazardous waste accumulation. Historical practices resulted in groundwater contamination with chlorinated VOCs.
- **Site SS016 (Oil Spill Area [OSA]; Facilities 11, 13/14, 18, 20, and 42/1941; and Portions of the Storm Sewer System):** Flight line support areas subject to oil spills, degreasing operations, leaking OWS, equipment maintenance and repair, aircraft and vehicle maintenance, hazardous materials storage, aircraft and vehicle washing, and stormwater runoff. Most of the areas were used from the 1940s through the present day. Historical practices resulted in groundwater contamination with chlorinated VOCs.
- **Site ST027-Area B (Facilities 1918, 1919, and 1754):** Formerly used as a test stand area for aircraft engine testing. Currently, only Facility 1918 is used. Historical activities have resulted in contamination of groundwater at the site with primarily petroleum-fuel constituents and TCE. The portion of the plume containing only petroleum-fuel contamination is designated as Site ST027-Area A (Site ST027A) and continues to be managed under the POCO program. The portion of the plume with TCE contamination is designated as Site ST027-Area B (Site ST027B) and is addressed as an ERP site.

- **Site SS029 (Monitoring Well [MW]-329 Area):** Undeveloped land near the southern Base boundary. The historical uses resulting in groundwater contamination with chlorinated VOCs are unknown.
- **Site SS030 (MW-269 Area):** Undeveloped land near the southern Base boundary. Historical practices associated with Building 1125 are believed to have resulted in groundwater contamination with chlorinated VOCs. The contaminant plume extends onto off-base privately owned property.
- **Site SD031 (Facility 1205):** Area used for maintenance and repair of diesel generators, wash rack activities, OWS activities, and aircraft maintenance from approximately 1957 through the present day. Historical practices resulted in groundwater contamination with chlorinated VOCs.
- **Site SD033 (Storm Sewer II, South Gate Area, Facilities 810 and 1917, and West Branch of Union Creek):** Support areas used for management of stormwater runoff, fuel transport, aircraft maintenance, and aircraft washing, including the use of wash racks and OWS. Historical practices resulted in groundwater contamination with chlorinated VOCs, some semivolatile organic compounds (SVOCs), and petroleum-fuel hydrocarbons.
- **Site SD034 (Facility 811):** An active aircraft wash rack facility with OWS and overflow pond. Leaks from the OWS resulted in a layer of Stoddard solvent floating on the groundwater table. The leaking OWS was replaced in 1994. Historical practices resulted in dissolved groundwater contamination with chlorinated VOCs, SVOCs, and petroleum-fuel hydrocarbons (including Stoddard solvent).
- **Site SS035 (Facilities 818/819):** Active facilities used for aircraft repair, painting, and washing. A wash rack with OWS was constructed in 1970. Historical practices resulted in groundwater contamination with chlorinated VOCs.
- **Site SD036 (Facilities 872/873/876):** Facilities 872/873/876 consist of multiple-use shops, including a wash rack and OWS. Current uses include paint shops, electrical shops, landscape maintenance, paint mixing, and paint accumulation. The buildings were constructed in 1953 and are still in use. Historical practices resulted in groundwater contamination with chlorinated VOCs, some SVOCs, and petroleum-fuel hydrocarbons.
- **Site SD037 (Sanitary Sewer System; Facilities 837/838, 919, 977, 981; Ragsdale/V Street Area; and Area G Ramp):** Support areas used for management of domestic and industrial wastewater, aircraft maintenance, heavy equipment maintenance, air cargo handling, vehicle washing, fuel transport, and waste accumulation. Operations began in the 1940s and continue through the present day. Historical practices resulted in groundwater contamination with chlorinated VOCs, some SVOCs, and petroleum-fuel hydrocarbons.

2.2.2.2 WABOU ERP Sites

Contaminated groundwater ERP sites within the WABOU are as follows:

- **Site LF008 (Landfill 3):** An inactive historical landfill consisting of a series of small, unlined trenches used to dispose of old pesticide containers. Historical practices resulted in groundwater contamination with organochlorine pesticides.

- **Site DP039 (Building 755, Travis AFB Battery and Electric Shop):** Prior to 1978, battery acid solutions and solvents were discharged from Building 755 into a sump. These historical practices resulted in contamination of the groundwater with chlorinated VOCs, primarily TCE.
- **Site SS041 (Building 905):** The base Entomology Shop in Building 905 prepared pesticides and herbicides for on-base use from 1983 to 1992. A concrete wash rack in the back of the building was used to clean pesticide applicator vehicles, and the overspray from the washing resulted in pesticide contamination in surface soil and groundwater.
- **Site SD043 (Building 916):** An emergency electric power facility. Historical practices resulted in a release of TCE to the groundwater at this site.

2.3 Previous Implementation of the CERCLA Process

Following placement on the NPL, Travis AFB followed the CERCLA process to investigate site contamination and design and implement appropriate measures at the ERP sites. This process consists of six (6) major steps, as described in Section 300.430 of the National Contingency Plan (NCP):

- Preliminary Assessment/Site Inspection (PA/SI)
- Remedial Investigation (RI)
- Feasibility Study (FS)
- Remedy Selection (Proposed Plan and ROD)
- Remedial Design/Remedial Action (RD/RA)
- Performance Monitoring/Five-year Reviews

Travis AFB successfully implemented the basic six (6)-step CERCLA process. However, the process was modified following completion of the PA/SI/RI/FS sequence to take an <u>interim</u> approach to groundwater remediation. The following list provides a description of the interim remedy approach used to implement the CERCLA process:

1. **Preliminary Assessment/Site Inspection:** Between approximately 1983 and 1994, IRP investigations, data gathering, and work planning were conducted to preliminarily assess the nature of environmental contamination at sites within each of the OUs.
2. **Remedial Investigation:** RIs to characterize the nature and extent of contaminated groundwater at the ERP sites within the NEWIOU and WABOU have been completed (Radian, 1996a [WIOU]; Radian, 1995 [NOU]; Weston, 1995 [EIOU]; CH2M HILL, 1997 [WABOU]). Human health risk assessments (HHRAs) and ecological risk assessments (ERAs) were components of the RIs.
3. **Feasibility Study:** FSs for contaminated groundwater sites within the NEWIOU (Radian, 1996b) and WABOU (CH2M HILL, 1998a) have been finalized.
4. **<u>Interim</u> Remedy Selection:** Groundwater IRAs were selected in the final *Groundwater Interim Record of Decision for the North, East, West Industrial Operable Unit* (NEWIOU Groundwater IROD) (Travis AFB, 1998) and the final *Groundwater Interim Record of Decision for the West/Annexes/Basewide Operable Unit* (WABOU Groundwater IROD) (Travis AFB, 1999).

5. **<u>Interim</u> Remedial Design/Remedial Action:** Following finalization of the two (2) groundwater IRODs, multiple groundwater IRAs were designed, constructed, and entered into interim long-term operation (LTO). Four (4) types of IRAs were implemented either individually or in combination at the sites:
    - Groundwater extraction and treatment (GET) (also known as pump and treat)
    - Monitored natural attenuation (MNA)
    - MNA assessment
    - Free product removal
6. **Performance Monitoring and Five-year Reviews:** Travis AFB has successfully operated and monitored the performance of the multiple IRA GET systems, MNA, MNA assessments, and free product removal for approximately a decade. During this period of interim remediation, each of the IRAs has been evaluated during two (2) five-year reviews (CH2M HILL, 2003a, 2008a). Basewide performance monitoring of the IRAs is routinely conducted and reported under the Travis AFB Groundwater Sampling and Analysis Program (GSAP). Descriptions of groundwater treatment plant operations and maintenance (O&M) activities are regularly reported to the regulatory agencies in monthly data sheets and in annual O&M reports.

For the most part, the IRAs operated successfully during the period of interim remediation from the late 1990s to early 2000s. However, after about a decade of interim remediation, the groundwater at most sites remains contaminated at concentrations that exceed federal and California MCLs. The current distribution of groundwater contamination at Travis AFB is shown on Figure 2-2. Since 2008, Travis AFB has implemented optimization measures to improve the performance of the interim remedies. A brief summary of these optimization measures is provided in the following list. More complete descriptions are provided in the Basewide Groundwater FFS (CH2M HILL, 2011a) and the *Remedial Process Optimization Baseline Implementation Report* (CH2M HILL, 2011b).

- **GET System IRA Optimization –** Over time, the energy-intensive IRA GET systems used at several ERP sites became less efficient and cost-effective as VOC concentrations decreased. Therefore, beginning in 2008, Travis AFB initiated a program of GET IRA optimization. The basic approach to optimizing the IRAs is to discontinue inefficient GET system operation and focus on the VOC plume source zones (i.e., "hot spots") with an in situ treatment technology.

  Through 2010, IRA optimizations have included data gaps investigations followed by source area injections of emulsified vegetable oil (EVO) and installation of bioreactors. The performance of these optimization measures is being monitored for the remainder of the period of interim remediation. If the optimization action proves effective, then that technology may be incorporated into the final remedial action.

  At several sites, the GET IRA systems have been shut down for rebound studies. Travis AFB is monitoring the groundwater to assess if concentrations will remain stable, decrease, or increase without active pumping. Depending on the results of the rebound studies, the GET systems will remain off or be restarted, either fully or at selected extraction wells.

- **MNA Assessments –** After about a decade of data collection, assessments of MNA performance were conducted for the sites where these actions were selected as either the IRA or part of the IRA. Conclusions regarding the MNA assessments are documented in the Natural Attenuation Assessment Report (NAAR) (CH2M HILL, 2010a). The primary conclusion of the NAAR is that the data are sufficient to demonstrate that MNA can be an effective remedy, or part of the remedy, at most sites.

2.4 Current Implementation of the CERCLA Process

As the period of interim remediation concludes, Travis AFB has re-initiated the CERCLA process to develop and implement the final remedial action at each site. The applicable steps in the remedial alternative selection process are described below.

2.4.1 Basewide Groundwater Focused Feasibility Study Alternatives

The FFS described and evaluated potential remedial alternatives to succeed the IRAs after the period of interim remediation is concluded (CH2M HILL, 2011a). Table 2-1 presents the remedial alternatives developed in the FFS and their applicable sites.

TABLE 2-1
Summary of FFS Remedial Alternatives and Applicable Sites
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

FFS Alternative[a,b]	Applicable Site
Alternative 1 – No Action	Site SS041
Alternative 2 – MNA	Sites FT004, FT005, LF006, LF007B, LF007D, LF008, ST027B, SD031, SD033, SD043
Alternative 3 – GET[b]	Sites LF007C, SS029, SS030
Alternative 4 – Bioreactor and GET[b]	Site SS016
Alternative 5 – EVO and EA	Site SS015[c], SD036[c], SD037[c]
Alternative 6 – Bioreactor, Phytoremediation, EVO PRB, and EA	Site DP039[d]
Alternative 7 – Passive Skimming and EA	Site SD034

[a] Groundwater monitoring and land use controls (LUCs) are components of all the alternatives, except No Action.
[b] Includes extraction, conveyance, treatment, and discharge of groundwater.
[c] EVO injection using an area treatment configuration of injection wells within the source area portions of the plumes. EA implemented in the distal portions (i.e., non-source areas) of the plumes located hydraulically downgradient of the EVO treatment zone.
[d] EVO injection using a linear configuration of injection wells to create a PRB to intercept contamination migrating from the hydraulically upgradient source areas of the plume. EA implemented in the distal portions of the plume located hydraulically downgradient of the EVO PRB.

Notes:

EA = enhanced attenuation
PRB = permeable reactive barrier

To assess the appropriate remedial action at each site after the period of interim remediation, the FFS conducted evaluations of the technology processes that compose the current IRAs. The long-term performance of the existing IRA technologies, IRA optimization measures, successful demonstration projects, and treatability studies results were significant factors in this re-evaluation. Additionally, green and sustainable remedial technology processes were also a consideration.

Summary descriptions of the FFS remedial alternatives and applicable sites are provided in the following subsections.

2.4.1.1 Alternative 1 – No Action

The No Action alternative serves as a baseline against which other potential remedial alternatives are compared. This alternative is required for consideration by the NCP. It is evaluated to determine the risks to public health and the environment if no actions were taken. No attempt is made to monitor or remediate groundwater. Alternative 1 is applicable to Site SS041. This site is in a No Further Remedial Action Planned (NFRAP) status. The NFRAP status is documented in a 14 December 2005 consensus statement that was signed by the representatives of the lead and regulatory agencies (Travis AFB, 2005).

2.4.1.2 Alternative 2 – MNA

Under Alternative 2, natural physical, chemical, and/or biological processes are relied upon to achieve RAOs. Alternative 2 is applicable to the current physical and contaminant conditions at the following sites:

- **Sites FT004/SD031 –** plume is stable
- **Site FT005 –** IRA GET system has effectively reduced plume size and concentrations
- **Site LF006 –** plume concentrations are decreasing
- **Site LF007B –** no plume concentrations have been detected above MCLs for several years
- **Site LF007D –** plume concentrations stable or decreasing
- **Site LF008 –** source removal action completed; plume is stable
- **Site ST027B –** geographically isolated and stable plume adjacent to active airfield operations
- **Site SD033 –** plume concentrations decreasing in portion of plume not addressed by IRA GET system
- **Site SS035 –** component site of the WIOU plume; plume concentrations decreasing in portion of plume not addressed by IRA GET system
- **Site SD043 –** IRA GET system has effectively reduced plume size and concentrations

Alternative 2 – MNA is potentially applicable to all Travis AFB sites, either for the contaminant conditions that currently exist or for future contaminant conditions following a period of active remediation using another alternative.

2.4.1.3 Alternative 3 – GET

Alternative 3 entails active groundwater remediation using the GET systems previously installed as part of the IRA at each applicable site. Contaminated groundwater is extracted using horizontal and/or vertical extraction wells, treated at the North Groundwater Treatment Plant (NGWTP) (Site LF007C) or South Base Boundary Groundwater Treatment Plant (SBBGWTP) (Sites SS029 and SS030), and discharged as treated water to the stormwater drainage system. Alternative 3 is applicable to the physical and contaminant conditions at the following sites:

- **Site LF007C –** off-base TCE plume, existing IRA or optimized GET system
- **Site SS029 –** TCE plume near the Base boundary, existing IRA GET system
- **Site SS030 –** off-base TCE plume, existing IRA GET system

2.4.1.4 Alternative 4 – Bioreactor and GET

Alternative 4 combines two (2) technology processes to remediate the Site SS016 plume. The primary components of the alternative include an in situ bioreactor and GET.

- **Bioreactor –** In 2010, an in situ bioreactor at Site SS016 was constructed within the OSA source area as an optimization of the existing IRA. The bioreactor uses enhanced reductive dechlorination (ERD) processes to break down chlorinated VOCs within the source area. Contaminated groundwater from existing horizontal extraction well EW003x16 is recirculated through the bioreactor using a solar-powered pump. As a result of these actions, the continuing source of TCE contamination into the hydraulically downgradient portions of the Site SS016 plume will be greatly reduced. Performance data for the bioreactor will continue to be evaluated for the remainder of the period of interim remediation.

- **GET –** Residual contamination from the OSA source area is addressed by existing vertical groundwater extraction wells EW605x16 and EW610x16. Similarly, groundwater extraction within the Tower Area Removal Action (TARA) portion of Site SS016 continues using the two (2) existing horizontal extraction wells (EW001x16 and EW002x16). Extracted groundwater continues to be treated using liquid-phase granular activated carbon (LGAC) at the Central Groundwater Treatment Plant (CGWTP) and then discharged into the stormwater drainage system.

2.4.1.5 Alternative 5 – EVO and EA

Alternative 5 combines in situ bioremediation with monitored EA. Under this alternative, EVO is injected into the higher concentration source area of a plume to anaerobically degrade chlorinated VOCs through ERD processes. A source area is defined as the portion of the plume with chlorinated VOC concentrations greater than or equal to 1,000 $\mu g/L$. After injection of EVO within the source area, the continuing source of TCE contamination into the hydraulically downgradient portions of the plume is greatly reduced. The physical, chemical, and biological mechanisms of attenuation in these downgradient areas will then be enhanced (i.e., EA). Alternative 5 is applicable to the physical and contaminant conditions at the following sites:

- Site SS015
- Site SD036
- Site SD037

During 2010, the existing groundwater IRAs at Sites SS015, SD036, and SD037 were optimized. Additional source area characterization was conducted, and EVO was injected into the source area portion of the plume at each site. Performance data from the source area EVO injections and attenuation processes in the distal portions of the plumes continue to be evaluated for the remainder of the period of interim remediation.

2.4.1.6 Alternative 6 – Bioreactor, Phytoremediation, EVO PRB, and EA

Alternative 6 combines three (3) in situ bioremediation technology processes and monitored EA to achieve RAOs at Site DP039. The primary alternative components are as follows:

- **In Situ Bioremediation**
  - **Bioreactor –** The bioreactor installed in December 2008 as a technology demonstration project actively treats the source area portion of a solvent plume by pumping contaminated groundwater from a source area extraction well through an organic mulch mixture to reduce contaminant mass and volume via ERD processes. The water trickles through the mulch column and into the aquifer before being captured and recirculated by the extraction well. A sustainable source of electric power to the extraction well pump is provided by solar panels.
  - **Phytoremediation –** A hydraulically downgradient zone of phytoremediation supplements the treatment of the source area plume provided by the bioreactor. Solvent-contaminated groundwater that is not treated by the bioreactor flows beneath a grove of engineer-planted eucalyptus trees. Phytoremediation processes provide additional reductions of contaminant mass and volume.
  - **EVO PRB –** As an optimization to the Site DP039 IRA, an EVO PRB (i.e., a biobarrier) was installed in 2010 to supplement the contaminant reduction provided by the combination of bioreactor and phytoremediation. A permeable wall of EVO was injected across the leading edge of the 500-µg/L TCE isocontour located downgradient of the zone of phytoremediation. At this location, the EVO PRB intercepts and anaerobically degrades most of the chlorinated VOCs migrating with the natural groundwater flow. The PRB thereby reduces the continuing source of contamination into the hydraulically downgradient area of the plume undergoing EA.
- **EA –** Physical, chemical, and/or biological processes are relied upon to remediate the residual contaminants in the distal portion of the Site DP039 plume. After the portion of the plume with higher concentrations is addressed by the combination of bioreactor, phytoremediation, and EVO PRB, the effectiveness of attenuation in the lower concentration distal portions of the plume would be enhanced because contaminant migration originating from the source area would be greatly reduced.

Performance data for the bioreactor, phytoremediation zone, EVO PRB, and area of EA will continue to be evaluated for the remainder of the period of interim remediation.

The IRA GET system at Site DP039 still exists. Active remediation using this system can be resumed if the combination of bioreactor, phytoremediation, EVO PRB, and EA does not perform as expected.

2.4.1.7 Alternative 7 – Passive Skimming and EA

Alternative 7 involves continuing the intermittent removal of free-phase Stoddard solvent from the Site SD034 source area using the existing network of vertical extraction wells previously installed as part of the IRA. In the distal portions of the plume, natural attenuation processes are monitored under the GSAP to address dissolved-phase contamination.

Under Alternative 7, passive skimmers remove free product from Site SD034 source area wells if it is detected during routine monitoring events. From 1998 through 2004, active and passive skimmers were used at Site SD034 to remove floating Stoddard solvent from wells at the site. Since that time, passive skimmers have been periodically used as free product reappears in some of the source area wells. Through 2010, passive skimming has been conducted to remove floating Stoddard solvent from several of the source area wells. During the second quarter of 2010, floating product was found in two (2) site monitoring wells at thicknesses of 0.12 and 0.44 foot. Free-phase Stoddard solvent is limited to the source area and is not migrating (CH2M HILL, 2011c).

Dissolved-phase Stoddard solvent is also limited to the source area. Other petroleum fuel constituents at Site SD034 are commingled with chlorinated VOCs from the surrounding Site SD037 plume and have contributed to the ERD of chlorinated VOCs. The existing Site SD034 monitoring wells would be incorporated into the monitoring of EA within the overall WIOU plume.

The effectiveness of EA in the non-source areas of the plume is enhanced by continuing to conduct passive skimming, if free-phase Stoddard solvent is detected in the site monitoring wells.

2.4.2 Proposed Plan and Record of Decision

The FFS and TEFA reports will support a Basewide Groundwater Proposed Plan and then a Basewide Groundwater ROD. The ROD will formally select the final groundwater cleanup actions necessary to mitigate potential risks to human health and the environment.

2.5 Approach to the Technical and Economic Feasibility Analysis

Although not formally a part of the CERCLA process, this TEFA was conducted to comply with the intent of California SWRCB Resolution 92-49. This resolution provides that Regional Water Boards in California shall “ensure that dischargers are required to clean up and abate the effects of discharges in a manner that promotes attainment of either background water quality, or the best water quality which is reasonable if background levels of water quality cannot be restored, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible; in approving any alternative cleanup levels less stringent than background…” (SWRCB Resolution, Section III G). The groundwater remedial alternatives developed in the FFS are based on the remedial action objective of cleaning up groundwater to chemical-specific MCLs. The TEFA evaluates the technical and economic feasibility of attaining cleanup of groundwater contaminants to concentrations less than the chemical-specific MCLs (hereinafter referred to as “background, but generally the current analytical limits).

In general, the TEFA follows the approach taken in the final Edwards AFB OU 2 TEFA (Edwards AFB, 2009) to the extent that is practical and relevant to the conditions at

Travis AFB. However, the Travis AFB TEFA makes several assumptions to facilitate the evaluations:

- Most of the interim remedies at the Travis AFB groundwater sites would not be able to achieve MCLs or background levels in a reasonable amount of time. The reason for this is that most of the GET systems were either approaching or at asymptotic conditions, and past optimizations of GET systems that involved expansions of the extraction networks were effective for limited amounts of time. So the Air Force's preferred remedies from the FFS represent improved technological approaches that do not have similar asymptotic limitations.
- The TEFA does not compare the benefit of cleaning off-base groundwater from MCLs to background levels with the continued loss of usage of acreage under easements by off-base property owners. Property owners are compensated financially for the restrictions posed by easements upon which remediation takes place.

2.5.1 Approach to "Background" Concentrations

Groundwater contamination at Travis AFB results from the presence of solvents, chlorinated VOCs (primarily TCE), and organochlorine pesticides. The background concentration for these types of organic compounds is nominally zero. However, quantification of groundwater contaminants to a true zero value is technically infeasible with current analytical methods. Therefore, concentration limits greater than background (CLGB) are used in the TEFA. These CLGB will not exceed (1) the MCL established under the Federal Safe Drinking Water Act (SDWA) (CCR, Title 22, Section 64444) or (2) the maximum concentration that would be allowed under other applicable statutes or regulations.

To achieve the objectives of the TEFA, chemical-specific CLGBs are based on the California Department of Health Services (CDHS) *Detection Limits for Purposes of Reporting (DLRs): Regulated Contaminants* (CDHS, 2003) in lieu of the statistical methods referenced in 23 CCR 2550.4 and described in 23 CCR 2550.7. As an example, using this methodology, the CLGB for TCE is 0.5 μg/L, compared with a MCL of 5 μg/L.

This approach is similar to the approach taken in the final Edwards AFB OU 2 TEFA (Edwards AFB, 2009).

2.5.2 Approach to Groundwater Modeling

Groundwater flow and transport modeling was conducted to support the overall goals of the TEFA. Analyses presented in Appendix C are based on the data and models built for the FFS (CH2M HILL, 2011a). The main modeling objective is to estimate the time required for site-specific chemicals of concern (COCs) to achieve background concentrations under the remedial alternatives identified in the FFS. Site-specific, one (1) dimensional solute transport models were used in conjunction with the Travis Basewide Groundwater Flow Model (TBGFM) to provide estimates of the time required to achieve background concentrations. A detailed summary of the groundwater flow and transport modeling is provided in Appendix C.

2.5.3 Approach to Evaluating Expansion of FFS Alternatives

The TEFA evaluated the FFS alternatives that would need to be implemented over a larger area and/or operated for a longer time than is provided for in the FFS to achieve contaminant reduction from MCLs to background levels. The approach to conducting TEFA evaluations for each FFS alternative is summarized as follows:

- **Alternative 1 – No Action** at Site SS041: Under this alternative, no action is taken and no TEFA is required.
- **Alternative 2 – MNA** at Sites FT004, FT005, LF006, LF007B, LF007D, LF008, ST027B, SD031, SD033, and SD043: This alternative relies on natural physical, chemical, and biological processes to remediate groundwater. No active in situ treatment process is employed. The TEFA evaluates the time required for natural attenuation processes to achieve MCLs and the additional time required to achieve background concentrations.
- **Alternative 3 – GET** at Sites LF007C, SS029, and SS030: Under Alternative 3, groundwater extraction wells are used to physically remove contaminants from the aquifer. The extracted groundwater is conveyed to a treatment plant for ex situ treatment using LGAC. The treated groundwater is then discharged to the stormwater drainage system. The TEFA evaluations are based on the time required for the existing GET systems to achieve MCLs and the additional time required to achieve background concentrations.
- **Alternative 4 – Bioreactor and GET** at Site SS016: This alternative uses an in situ bioreactor to treat the OSA source area via ERD processes combined with extraction wells to physically remove contaminants from the hydraulically downgradient portion of the plume. For the TEFA, the following approach is used:
  - **Scenario 1:** Under this scenario, the time required to achieve MCLs with the existing combination of bioreactor and GET (t_{MCL}) is calculated. Then, the additional time required to achieve background concentrations using the same combination of bioreactor and GET is calculated. The amount of time required to achieve background levels (t_{BGD}) will be greater than the estimated time needed to achieve MCLs (t_{MCL}); that is, $t_{BGD} > t_{MCL}$.
  - **Scenario 2:** This scenario involves hypothetical expansion of the existing OSA bioreactor from the approximate 100,000-µg/L chlorinated VOC isocontour to a predetermined 1,000-µg/L isocontour. Operation of the existing GET systems is continued. The time required to achieve background concentrations (t_{BGD}) is then calculated.
  - **Scenario 3:** Under this scenario, the unknown isocontour that defines the extent of a hypothetical expanded treatment zone required to achieve background levels (t_{BGD}) in the same amount of time needed to achieve MCLs (t_{MCL}) is calculated. In contrast to Scenario 2, the extent of the treatment zone is not predetermined, but the cleanup time is constrained to meet the condition of $t_{BGD} = t_{MCL}$. A modified GET system would be installed to address the distal portions of the plume not within the hypothetical expanded treatment zone.

- **Alternative 5 – EVO and EA** at Sites SS015, SS036, and SD037: This alternative involves source area ERD treatment using injected EVO combined with natural attenuation processes in the distal portions of the plume. For the TEFA, the following approach is used:
  - Calculation of t_{MCL} is based on source area treatment within the 1,000-µg/L chlorinated VOC isocontour.
  - The amount of time required to achieve background levels (t_{BGD}) is the same as the estimated time needed to achieve MCLs (t_{MCL}); that is, $t_{BGD} = t_{MCL}$.
  - Calculate the unknown isocontour that defines the extent of the hypothetical expanded treatment zone required to satisfy the condition of $t_{BGD} = t_{MCL}$.
  - Technical and economic feasibility evaluations are based on the location and dimensions of the hypothetical expanded treatment zone.
- **Alternative 6 – Bioreactor, Phytoremediation, EVO PRB, and EA** at Site DP039. This alternative uses three (3) in situ treatment components. The TEFA evaluated an additional downgradient placement of an EVO PRB to achieve background levels. For the TEFA, the following approach is used:
  - Calculation of t_{MCL} is based on an EVO PRB intercepting and treating the downgradient portion of the plume at the 500-µg/L chlorinated VOC isocontour.
  - The amount of time required to achieve background levels (t_{BGD}) is the same as the estimated time needed to achieve MCLs (t_{MCL}); that is, $t_{BGD} = t_{MCL}$.
  - Calculate the unknown isocontour that defines the location of a hypothetical EVO PRB required to satisfy the condition of $t_{BGD} = t_{MCL}$. The plume is intercepted by an expanded hypothetical EVO PRB at this isocontour.
  - Technical and economic feasibility evaluations are based on the required location and dimensions of the hypothetical EVO PRB.
- **Alternative 7 – Passive Skimming and EA** at Site SD034. No active treatment technologies are employed under Alternative 7. Passive skimming is a removal technology and not a treatment process. For the EA component of the alternative, remediation of contaminants will occur gradually by natural physical, chemical, and biological processes. These reductions are quantified by groundwater sampling and analyses under the existing Travis AFB GSAP. In contrast to the alternatives using bioreactor or EVO treatment technologies, this alternative does not use an active treatment component that can be physically expanded. Therefore, the TEFA only evaluates the additional time required to achieve background concentrations. The monitoring well network is part of EA monitoring in the overall WIOU plume. Technical feasibility issues are expected to arise in the future if additional wells are needed in the vicinity of active aircraft maintenance hangars.

SECTION 3

Environmental Factors

In compliance with 23 CCR 2550.4(d)(1), Subsections A through I, as referenced in SWRCB Resolution 92-49, the Air Force considered the following nine (9) groundwater related environmental factors in evaluating technical and economic feasibility for site cleanup to "background:"

A. Physical and chemical characteristics of the waste in the waste management unit

B. Hydrogeological characteristics of the facility and surrounding land

C. Quantity of groundwater and direction of groundwater flow

D. Proximity and withdrawal rates of groundwater users

E. Current and potential future users of groundwater in the area

F. Existing quality of groundwater, including other sources of contamination or pollution and their cumulative impact on the groundwater quality

G. Potential health risks caused by exposure to waste constituents

H. Potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents

I. Persistence and permanence of the potential adverse effects

To put the information in this section into perspective, it is important to consider the following background information. Travis AFB uses approximately 3 million gallons of potable water per day (MGD) during the summer and 1 MGD during the winter. The seasonal variation is due to irrigation demands. This water is surface water from Lake Berryessa and Lake Oroville. This water is conveyed to the Travis Water Treatment Plant (TWTP), which is owned and operated by the City of Vallejo, through the Putah South Canal, the Sacramento River, and the North Bay Aqueduct. From this treatment facility, the City of Vallejo provides potable water to the Base. The Base pays the City of Vallejo $20.50 per acre foot of North Bay Aqueduct raw water, $50.00 per acre foot of higher quality Lake Berryessa water (for a yearly average cost of about $77,000), and about $2.8 million per year to treat the water; power, operate, and maintain the TWTP; and deliver sufficient potable water to Travis AFB to meet its consumption requirements. To recoup these costs, the Base charges on-base tenant organizations an average of $3.77 per 1,000 gallons of drinking water.

Three (3) currently operable groundwater production wells located at the Cypress Lakes Golf Course annex provide a redundant potable water supply to the Base and historically have only provided water in the event of downtime at the TWTP. These production wells are located approximately 3 miles north of Travis AFB and are hydraulically separate from the Base.

To ensure that water is safe to drink, it is disinfected to remove microbial pathogens. This process usually results in the generation of disinfection byproducts (DBPs). Amendments to the SDWA in 1996 required the EPA to develop rules to balance the risks between microbial pathogens and DBPs. The Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR) and Interim Enhanced Surface Water Treatment Rule were the first phase in a rulemaking strategy required by Congress as part of the 1996 Amendments to the SDWA. Currently, the TWTP meets the Stage 1 standards.

The Stage 2 DBPR supplements the Stage 1 rule and requires more stringent disinfection monitoring of water systems. Travis AFB is required to initiate these monitoring requirements in October 2012. To fully evaluate the Base's ability to comply with the Stage 2 DBPR, the Base commissioned a study of the TWTP and the available water resources in the region in 2011.

Weston Solutions, Inc. conducted this study and identified the following six (6) alternatives that could be carried out to meet the Stage 2 requirements:

- Alternative I – Rehabilitate the Existing TWTP
- Alternative II – Construct a New TWTP
- Alternative III – Connect to the City of Fairfield Distribution System
- Alternative IV – Groundwater Extraction System (i.e., groundwater from the Cypress Lakes Golf Course annex)
- Alternative VA – Groundwater Extraction System with New Dry Season TWTP
- Alternative VB – David Grant Medical Center Connection to Fairfield with Groundwater Extraction System

Following qualitative and quantitative evaluations, the recommended alternative was Alternative IV, which would replace the current water supply provided by the City of Vallejo with source water from the Travis AFB Cypress Lakes Golf Course Annex.

The study also considered the installation of groundwater extraction wells within the boundaries of Travis AFB as an alternative to using the Cypress Lakes Golf Course Annex as a water source. The study eliminated this alternative, based on the following rationale: "…wells would be finished in the Fairfield-Suisun Hydrogeologic Basin. This basin is the second largest groundwater basin in Solano County. However, this basin is not used in a significant capacity for domestic supply due to limited alluvial deposits, low yield, and poor water quality. Because of these reasons, this slight variation to the groundwater extraction system alternative has been eliminated from further investigation" (Weston, 2011).

The 2011 Water Study Report also concluded that "…the quality of the groundwater from the Cypress Lakes Golf Course Wells is the best available to Travis AFB," that this alternative "…is by far and away the most affordable solution available to Travis AFB," and that "…it is the least expensive alternative at less than one-third the cost of the closest alternative over the next twenty years of water operation" (Weston, 2011). The costs of Alternative IV are much lower than the other alternatives, because much of the infrastructure is already in place, and water originating from the Cypress Lakes Golf Course is high-quality and does not require secondary treatment. Extracted groundwater would be chlorinated prior to distribution to Travis AFB, but no other treatment process would be required for use as drinking water (Weston, 2011).

Although a final decision has yet to be made, there is a good probability that the Base will proceed with Alternative IV, along with a new redundant drinking water source to comply with future drinking water quality standards.

3.1 Environmental Factor A: Physical and Chemical Characteristics of the Waste in the Waste Management Unit

This section describes the physical and chemical characteristics of groundwater contamination at Travis AFB.

3.1.1 Groundwater Contamination at Travis AFB

Even after approximately a decade of interim remediation, the groundwater at Travis AFB remains contaminated at concentrations that exceed MCLs. Chlorinated VOCs are the most commonly detected contaminants. TCE is the most prevalent of these chlorinated VOCs. This chemical is detected at widely separated sites across the Base, reflecting multiple points of origin. The maximum concentration of TCE detected during 2010 was 151,000 µg/L at Site SS016. During sampling events conducted under the 2009-2010 GSAP, TCE concentrations greater than ten (10) times the MCL of 5 µg/L were also detected at Sites FT004, SS015, ST027B, SS029, SS030, SD033, SD034, SD036, SD037, and DP039. Groundwater contaminants, other than TCE, detected at sites at concentrations above their respective MCL include the following:

- 1,2-dichloroethane (1,2-DCA) at Site FT005
- Alpha-chlordane at Site LF008
- 1,1-dichloroethene (1,1-DCE) at Site SD031

Additional descriptions of groundwater contamination at Travis AFB are provided in Section 3 of the Basewide Groundwater FFS (CH2M HILL, 2011a) and in the *Groundwater Sampling and Analysis Program 2009-2010 Annual Report* (CH2M HILL, 2011c).

3.1.2 Chemicals of Concern

A full listing of the COCs detected in the groundwater at Travis AFB and their respective MCLs is summarized in Table 3.1-1. Groundwater contaminant plumes at Travis AFB are typically characterized by dissolved-phase TCE, related chlorinated VOCs, and some organochlorine pesticides.

3.1.3 Primary Contaminant Sources

The primary sources of groundwater contamination at Travis AFB are releases of liquid solvents and petroleum fuels from past waste management and disposal practices. These releases primarily involved chlorinated solvents, including those containing TCE. Other typical groundwater contaminants include breakdown products from these solvents. Some organochlorine pesticide contamination is found at Site LF008, but these contaminants are not nearly as pervasive as the chlorinated solvents.

In their pure form, the groundwater contaminants are called nonaqueous phase liquids (NAPLs). At Travis AFB, NAPLs include petroleum hydrocarbons (i.e., fuels, lubricants, and non-chlorinated solvents) and chlorinated solvents (primarily TCE). The use of TCE was discontinued in 1982.

TABLE 3.1-1
Summary of Groundwater Sites, Chemicals of Concern, and Maximum Contaminant Levels
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	Operable Unit	Name/Description	Chemical of Concern[a]	MCL[b] (µg/L)
FT004	EIOU	FTA 3	**TCE**	5
			cis-1,2-DCE	6
			Vinyl chloride	0.5
			1,2-DCA	0.5
			Chloroform	100
			Bromodichloromethane	100
			1,1-DCE	6
			1,4-DCB	5
			bis(2-Ethylhexyl)phthalate	4
			Nickel	100
FT005	EIOU	FTA 4	**TCE**	5
			1,2-DCA	0.5
			cis-1,2-DCE	6
			Chloroform	100
			Bromodichloromethane	100
			bis(2-Ethylhexyl)phthalate	4
			Nickel	100
LF006	NOU	Landfill 1	**TCE**	5
			1,1-DCE	6
			TPH-G	5
			TPH-D	100
LF007	NOU	Landfill 2	**TCE**	5
			Benzene	1
			1,4,-DCB	5
			Chlorobenzene	70
			bis(2-Ethylhexyl)phthalate	4
			Vinyl chloride	0.5
			1,1-DCE	6
			1,2-DCA	0.5
			1,2-Dichloropropane	5
LF008	WABOU	Landfill 3	Aldrin	0.023
			Alpha-chlordane	0.1
			Heptachlor	0.01
			Heptachlor epoxide	0.01

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Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	Operable Unit	Name/Description	Chemical of Concern[a]	MCL[b] (µg/L)
SS015	EIOU	SSA and Facility 552	**TCE**	5
			cis-1,2-DCE	6
			Vinyl chloride	0.5
			1,2-DCA	0.5
			PCE	5
			bis(2-Ethylhexyl)phthalate	4
			Nickel	100
			Benzene	1
SS016	EIOU	OSA Facilities 11, 13/14, 20, 42/1941, and 139/144	**TCE**	5
			cis-1,2-DCE	6
			Vinyl chloride	0.5
			Benzene	1
			Chloroform	100
			1,4-DCB	5
			Bromodichloromethane	100
			1,2-DCA	0.5
			1,1-DCE	6
			PCE	5
			bis(2-Ethylhexyl)phthalate	4
			Nickel	100
ST027B	EIOU	TF33, Facilities 1918, 1919, 1020, and 1040	Benzene	1
			TCE	5
			cis-1,2-DCE	6
			Vinyl chloride	0.5
			Toluene	150
			MTBE	13
			TPH-G	5
			TPH-D	100
SS029	EIOU	MW329x29 Area	**TCE**	5
			1,2-DCA	0.5
			cis-1,2-DCE	6
			Benzene	1
			Chloroform	100
			1,1-DCE	6
			Vinyl chloride	0.5
SS030	EIOU	MW269x30 Area	**TCE**	5
			Chloroform	100
			Bromodichloromethane	100
			1,2-DCA	0.5
			Nickel	100

TABLE 3.1-1
Summary of Groundwater Sites, Chemicals of Concern, and Maximum Contaminant Levels
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	Operable Unit	Name/Description	Chemical of Concern[a]	MCL[b] (μg/L)
SD031	EIOU	Facility 1205	TCE	5
			Benzene	1
			1,1-DCE	6
			cis-1,2-DCE	6
			Carbon tetrachloride	0.5
			Chloroform	100
			1,2-DCA	0.5
			Vinyl chloride	0.5
			Nickel	100
SD033	WIOU	Storm Sewer System 2 (former Storm Sewer System B – includes Facilities 810, 1917, and South Gate Area)	**TCE**	5
			1,1-DCE	6
			1,2-DCA	0.5
			cis-1,2-DCE	6
			TPH-G	5
			TPH-D	100
SD034	WIOU	Facility 811	**LNAPL (PD-680)**	NA
			TCE	5
			Vinyl chloride	0.5
			1,1-DCE	6
			Benzene	1
			cis-1,2-DCE	6
			PCE	5
			TPH-G	5
			TPH-D	100
			bis(2-Ethylhexyl)phthalate	4
SS035	WIOU	Facilities 818 and 819	TCE	5
			TPH-D	100
SD036	WIOU	Facilities 872, 873, and 876	**Vinyl chloride**	0.5
			TCE	5
			1,1-DCE	6
			cis-1,2-DCE	6
			1,2-DCA	0.5
			1,1,2-TCA	0.5
			Benzene	1
			Bromodichloromethane	100
			PCE	5
			TPH-G	5
			TPH-D	100
			Methylene chloride	5

TABLE 3.1-1
Summary of Groundwater Sites, Chemicals of Concern, and Maximum Contaminant Levels
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	Operable Unit	Name/Description	Chemical of Concern[a]	MCL[b] (µg/L)
SD037	WIOU	Sanitary Sewer (includes Facilities 837, 838, 981, 919, the Area G Ramp, and Ragsdale/V Area)	1,1-DCE	6
			1,2-DCA	0.5
			Benzene	1
			Bromodichloromethane	100
			Carbon tetrachloride	0.5
			Chloromethane	1.5
			PCE	5
			TCE	5
			Vinyl chloride	0.5
			cis-1,2-DCE	6
			TPH-G	100
			bis(2-Ethylhexyl)phthalate	4
			Naphthalene	20
			TPH-D	100
			MTBE	13
DP039	WABOU	Building 755	**1,1-DCE**	6
			1,2-DCA	0.5
			1,1,1-TCA	0.5
			1,1,2-TCA	0.5
			Acetone	5,110
			Bromodichloromethane	100
			Methylene chloride	5
			PCE	5
			TCE	5
			cis-1,2-DCE	6
			Vinyl chloride	0.5
SS041	WABOU	Building 905	Heptachlor epoxide	0.01
SD043	WABOU	Building 916	TCE	0.5

Source: Table 1-2 of the final Travis AFB GSAP 2009-2010 Annual Report (CH2M HILL, 2011c).

[a] **Bolded** COCs are those detected at a concentration exceeding the MCL during 2010. Historically detected COCs are not bolded.

[b] The lesser of either the federal MCL or California MCL.

Notes:

DCB = dichlorobenzene
LNAPL = light nonaqueous phase liquid
MTBE = methyl tert-butyl ether
NA = not applicable
PCE = tetrachloroethene
TCA = trichloroethane
TPH-D = total petroleum hydrocarbon as diesel
TPH-G = total petroleum hydrocarbon as gasoline

3.1.3.1 Light Nonaqueous Phase Liquids

Petroleum-based NAPLs are generally less dense than water and are referred to as LNAPLs. Because they have a density less than that of water, LNAPLs tend to accumulate (float) on top of the water table. In addition, most petroleum hydrocarbons readily degrade in situ; therefore, plumes of dissolved-phase LNAPL constituents tend to move only short distances beyond the release zones. Travis AFB sites with LNAPL releases are managed under the POCO program and are not within the scope of this TEFA. The POCO presumptive remedy for LNAPL releases is removal of any mobile LNAPL fraction (free product) followed by a program of MNA.

At Site SD034, Stoddard solvent LNAPL is floating on the groundwater table.

3.1.3.2 Dense Nonaqueous Phase Liquids

In contrast to LNAPLs, chlorinated solvents such as TCE are denser than water and are referred to as dense nonaqueous phase liquids (DNAPLs) in their pure form. Because they have a density greater than that of water, DNAPLs are sometimes able to penetrate below the water table. Furthermore, degradation rates for dissolved chlorinated solvents under natural aerobic conditions are low; therefore, dissolved-phase chlorinated solvents tend to form relatively large plumes. The interim remedies implemented for large chlorinated solvent releases at Travis AFB involve GET for the purposes of hydraulic containment and mass removal.

Relatively large chlorinated solvent releases resulting in the probable presence of DNAPL have occurred at Sites SS015, SS016, SD036, SD037, and DP039. TCE releases of lesser magnitude have also occurred at Sites FT004, SS030, SD031, and other sites; but if residual pure-phase TCE does exist at these sites, it is evidently bound up by the capillary forces in the alluvium. The relevant mechanisms are discussed in the following subsections.

3.1.4 Primary Release Mechanisms

The most significant contaminant release mechanism at Travis AFB is deep percolation of the liquid contaminants downward, and laterally along preferential pathways, through the vadose zone and into the saturated zone. The depth to groundwater at Travis AFB is relatively shallow at approximately 10 to 15 feet below ground surface (bgs). Contaminants released at the ground surface have readily migrated through this shallow vadose zone and into the groundwater.

Groundwater, soil, and soil gas sampling results from four (4) RIs (Weston, 1995; Radian 1995, 1996b; CH2M HILL, 1997) indicate relatively low levels of VOC contamination in the soil and soil gas at the ERP sites, while the groundwater has significantly higher concentrations of contamination. No significant VOC soil contamination was found during the RI sampling, and the low levels detected are not expected to adversely impact the groundwater. Concentrations of VOCs in soil and soil gas are consistent with models of diffusion and adsorption from associated groundwater plumes, indicating that the VOC contamination in the soil and soil gas is a result of the underlying contaminated groundwater plume (Travis AFB, 2006).

3.1.4.1 DNAPL Release Mechanisms

Where DNAPLs are released, they may infiltrate through soils following the path of largest pore size or fracture aperture. This typically results in sparse horizontal pools and vertical fingers of DNAPL (Kueper et al., 1989; Cohen et al., 1994). Generally, the volume of DNAPL pools and fingers near the release site is approximately 0.01 to 0.0001 of the overall source zone volume (Sale, 1998). Actually finding DNAPL during site investigations is unlikely. A conceptualization of DNAPL movement through clayey materials, such as those typically found at Travis AFB, is shown on Figure 3.1-1 (Feenstra et al., 1996). Possible migration pathways for a conceptual DNAPL site are illustrated on Figure 3.1-2. Within the lithologic units at Travis AFB, potential paths for downward DNAPL migration include the following:

- **Alluvium –** Joints associated with consolidation, shrinkage, and desiccation cracking, and sand lenses.
- **Bedrock –** Joints and bedding primarily associated with geologic formation and weathering of the sandstone, siltstone, and claystones; the joints are expected to become tighter with increasing depth.

Several of the known TCE releases at Travis AFB were small-volume releases onto surface or near-surface soils that took place over a period of years (discontinued in 1982 at the latest, since the on-base use of TCE ceased at that time). Through capillary forces and adsorption, this TCE may have become immobilized within the vadose zone as ganglia. In this scenario, the near-surface ganglia are then subject to volatilization during repeated cycles of hot summer weather; in fact, surface soil sampling and testing during the RI phase (mid-1990s) encountered virtually no TCE. It is the relatively large-volume releases of TCE that have migrated to greater depths, affecting groundwater.

3.1.4.2 Dissolution of DNAPL Source Zones

A conceptualized depiction of the dissolution of a DNAPL source zone located beneath the water table is shown on Figure 3.1-3. Three (3) snapshots in time are presented on the figure that, depending on the initial mass of the source and properties of the alluvial matrix, could be considered to take place over a matter of decades or centuries. In the first frame, at time t_0, the length of the DNAPL pool stretches from a distance of x_1 to x_4. The dissolution rate is shown to be highest at the upgradient edge, as the moving groundwater slowly erodes the DNAPL pool and carries high-concentration, dissolved-phase contaminants downgradient.

The second frame, representing time t_1, shows a smaller DNAPL pool, the upgradient side of which has been dissolved over time by the passing groundwater. Note that the point of greatest dissolution rate remains at the upgradient edge of the DNAPL pool, although the location of this point has shifted to a distant, x_2, downgradient.

In the third and final frame, the DNAPL pool has continued to reduce in size. Note that the maximum dissolution rate remains at the upgradient edge of the pool and that the magnitude of this dissolution rate remains constant through time until the DNAPL has been completely depleted. The rapid dissolution rate adjacent to the upgradient side of the source translates into a steep concentration gradient that can drive the diffusion of significant amounts of dissolved-phase contaminant mass into stagnant portions of the lithologic units, creating a problematic long-term in situ source of contamination.

Another key feature related to Figure 3.1-3 is that the downgradient dissolved concentrations in groundwater are unchanged as the source dissolves. The implication is that source remediation (or dissolution) does little to improve downgradient water quality until the entire DNAPL source is gone.

3.1.4.3 Groundwater Plume Formation

Groundwater plumes containing chlorinated solvents originate from DNAPL releases. The rate at which DNAPLs partition into groundwater is sufficiently slow that even modest amounts of DNAPL that find their way beneath the water table can persist as sources of groundwater contamination for perhaps decades and effect order-of-magnitude exceedances of MCLs in groundwater. The formation of a plume of dissolved chlorinated solvents in groundwater and soil vapor at a conceptual DNAPL site is shown on Figure 3.1-4.

The distribution of dissolved-phase contamination near a DNAPL source area (e.g., Sites SS016 and DP039) is dominated by the geometry of the DNAPL release as well as the processes of advection and molecular diffusion. At locations further downgradient, other processes begin to dominate. Primary transport processes for near-source and downgradient plumes are discussed in the following subsections.

Near-source Plumes. The movement of a near-source, dissolved, high-concentration solvent plume through a transmissive sand layer is presented on Figure 3.1-5. For time t_1, the dissolved high-concentration plume from the DNAPL source initially moves through higher permeability conduits in a heterogeneous system such as that at Travis AFB. As the plume expands and eventually stabilizes (at time t_2), high-concentration gradients between the highly contaminated groundwater within the preferential flow paths and the less-contaminated groundwater in the low permeability zones drive significant mass transfer into the silt/clay units.

Time t_3 represents the point in time when either final dissolution of the DNAPL source zone (time scale of decades to centuries) or isolation of the DNAPL source zone (either physically or hydraulically) has occurred, and the solute concentrations subsequently decline rapidly in the most accessible/flushable pore space. However, as the concentration gradient shifts, contaminant mass residing in the low-permeability materials is released into the flushable pore space by the process of molecular diffusion that, being driven strictly by concentration gradients, is both slow and occurs at an ever-decreasing rate (i.e., asymptotic behavior).

The implication of the third frame (time t_3) is that even upon "remediation" of the accessible pore space, a concentration gradient still exists within the low-permeability layers that continue to drive a portion of the retained contaminant mass deeper into the clay.

All of this suggests that the attempted remediation of a near-source contaminant plume in a heterogeneous environment may be futile, in that even with the removal of a large percentage of the initially released mass, the presence of a continuing source from the lower-permeability units will require the continued operation of hydraulic remedies and the continued monitoring of groundwater quality.

Downgradient Plumes. The dominant loss and transport mechanisms that govern downgradient, aqueous-phase dissolved plumes differ from those discussed above for

DNAPL source zones and near-source plumes. In downgradient plumes, no steep concentration gradient as described above for near-source plumes occurs; and a combination of physical, chemical, and biological contaminant-loss mechanisms, also referred to as natural attenuation processes, begin to dominate contaminant fate and transport and lead to the eventual stabilization of the plume. The ultimate configuration of the dissolved plume downgradient of the source area is dependent on the collective influences of the processes of adsorption, diffusion, dispersion, biodegradation, and heterogeneity of aquifer properties. These processes are described briefly in this section. For additional information, refer to the Natural Attenuation Assessment Plan (NAAP) (CH2M HILL, 1998b).

As dissolved solvents migrate with the groundwater, a portion of the contaminants may adsorb to organic materials in the soil matrix, and thus become fixed to the soil particle surface. Adsorption is not an irreversible process; as groundwater moves through the aquifer matrix, contaminants may desorb back into groundwater.

The portion of the contaminant that is sorbed to soil and not migrating is said to be "retarded." The extent of retardation is a function of the properties of both the chemical contaminant and the soil. While this process does not actively destroy contaminant mass, if the rate of migration is retarded to a significant degree, biodegradation processes will have more time to act on the contaminant plume and degrade the contaminant of interest.

Molecular diffusion attempts to equalize solute concentrations by moving solute from high concentration zones to low concentration zones. The driving force for diffusion is differential concentrations, and the effect of diffusion is to increase the volume of contaminated groundwater, while decreasing the concentration. Diffusion is generally a slow process but may be significant in systems where the groundwater velocity is low, as is the case at many sites at Travis AFB.

Hydrodynamic dispersion tends to spread, or disperse, the solute front as it moves through the aquifer. Spreading in the direction of flow is referred to as longitudinal dispersion, which usually has a much stronger influence than spreading perpendicular to the direction of flow, or transverse dispersion (Freeze and Cherry, 1979). Dispersion also occurs at a field scale because of the heterogeneity in hydraulic properties of geologic materials present at a particular site (Gelhar et al., 1992). At Travis AFB, the complex geometry of the more permeable sand lenses occurring within the lower-permeability silt and clay alluvial matrix almost certainly imparts additional dispersion of migrating solute plumes beyond what would occur on a pore scale alone.

Biodegradation of chlorinated compounds typically proceeds through reductive dehalogenation, but may also occur through electron donor reactions and cometabolism. Reductive dehalogenation occurs anaerobically and results in the degradation of the chlorinated compounds found in Travis AFB groundwater such as PCE, TCE, 1,2-DCE, and vinyl chloride. These processes are described in detail in the NAAP (CH2M HILL, 1998b).

If biodegradation is occurring at rates that are significant with respect to the mass flux of contaminant through the aquifer, this process can ultimately balance with the advective transport mechanism and lead to a plume that is stable in configuration over time. In the absence of significant degradation rates, dispersion and dilution will ultimately lead to a stable plume. However, the influence of these processes is limited, and plumes stabilized by these processes will likely have a much greater areal extent than those limited by biodegradation processes. If the aquifer downgradient of the DNAPL source has a pronounced heterogeneity in permeability, such as a preferred transport pathway, this site feature may significantly influence the ultimate configuration of the downgradient plume.

3.1.5 Secondary Contaminant Sources

Secondary sources are those environmental media that may be affected by releases from primary sources. Potential secondary sources at Travis AFB include VOC-affected subsurface soil and soil gas. Soil gas is considered the only significant secondary source. No significant VOC contamination has been detected in subsurface soil.

Stoddard solvent, an LNAPL floating on the water table at Site SD034, is also considered a secondary contaminant source.

3.1.6 Secondary Release Mechanisms

The secondary release mechanism is volatilization of VOCs in groundwater into the soil pore spaces (i.e., soil gas). Under the pressure differential between aboveground and belowground environments, VOC vapors in soil gas can migrate upward through the soil matrix. Soil gas migration would be most prevalent along permeable preferential pathways within the vadose zone. Manmade features such as utility conduits, pipelines, storm drains, and sanitary sewers may create preferential pathways for soil gas migration, as the fill around such features is typically more permeable than the surrounding soil.

There would be some attenuation of soil gas concentrations as it migrated upward because of adsorption and degradation. Factors affecting vapor migration are related to soil properties, properties of the VOCs, and source properties (depth to the groundwater plume and concentration). The most important factors directly affecting VOC vapor transport into buildings are related to the building properties, including soil/building pressure difference, cracks within the foundation, utility corridors, the air exchange rate, and the building volume.

3.1.7 Distribution of Groundwater Contamination

The current areal distribution of groundwater contamination at Travis AFB is shown on Figure 3.1-6. More detailed plan and cross sectional views of the individual plumes are shown on the figures provided at the back of this subsection. On these figures, the indicator COC representing each plume is delineated to both the chemical-specific MCL and background isocontour. For example, at Site FT004, the indicator COC is TCE, and isocontours are shown for both the MCL of 5 μg/L and the background concentration of 0.5 μg/L.

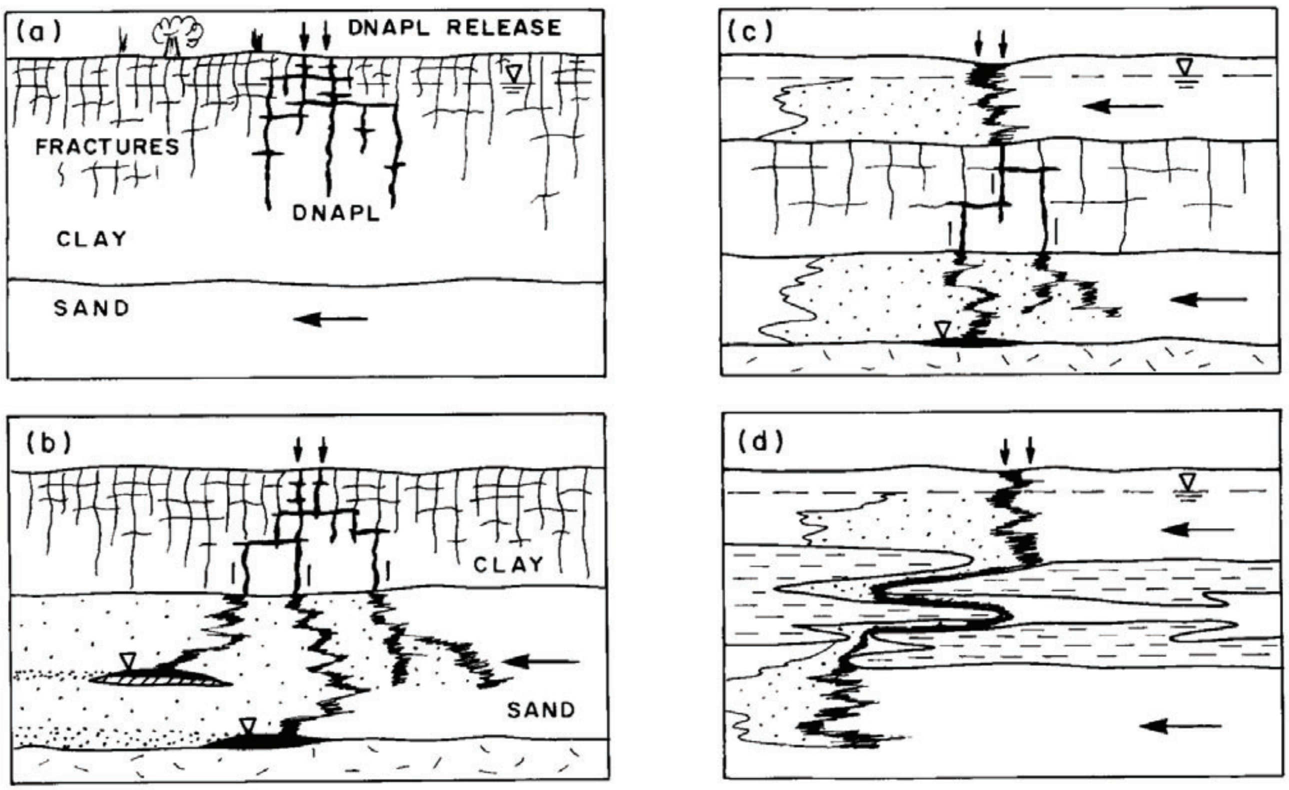

FIGURE 3.1-1
CONCEPTUAL DNAPL MOVEMENT THROUGH CLAYEY SOILS
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

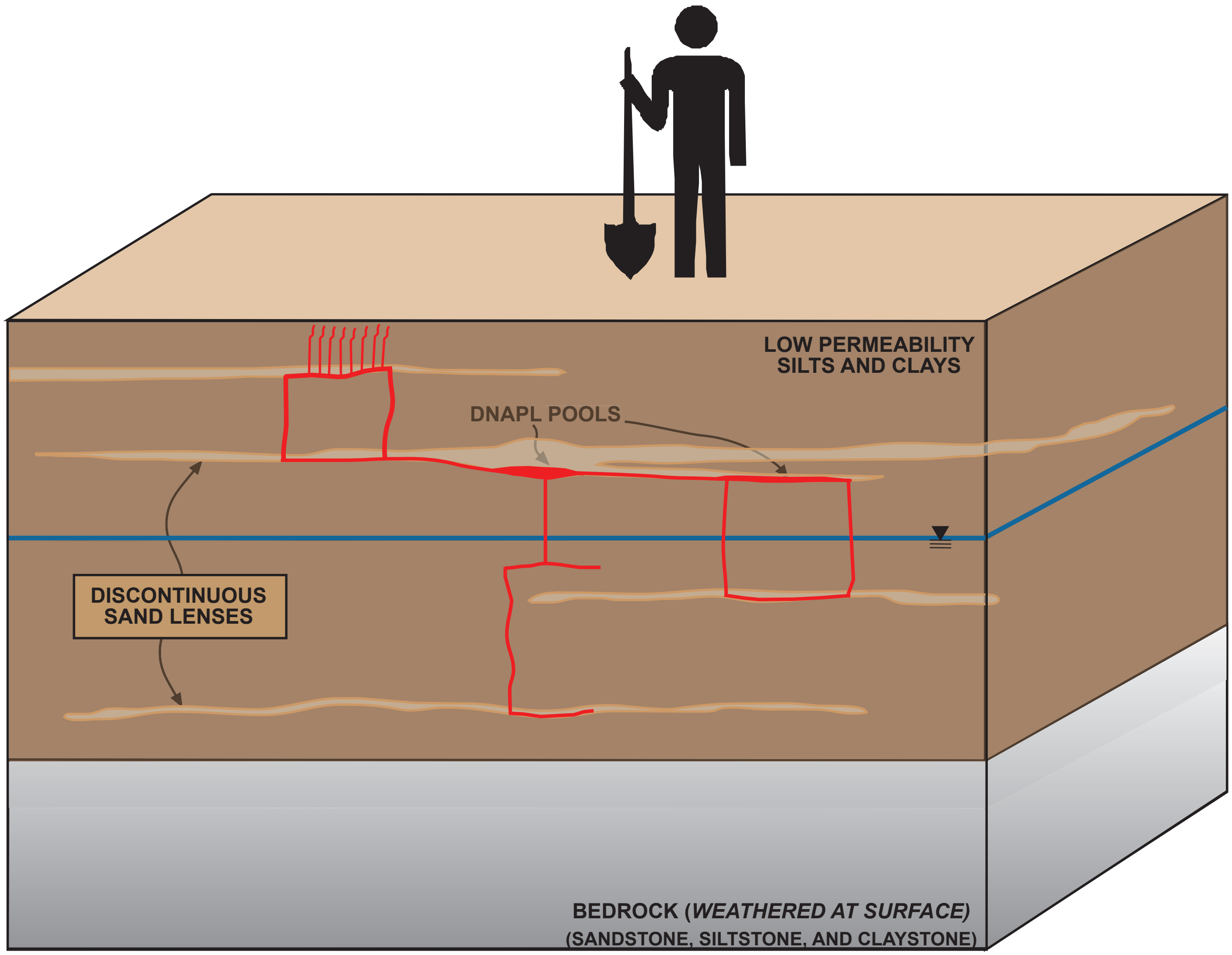

FIGURE 3.1-2
CONCEPTUAL DNAPL SOURCE ZONE
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

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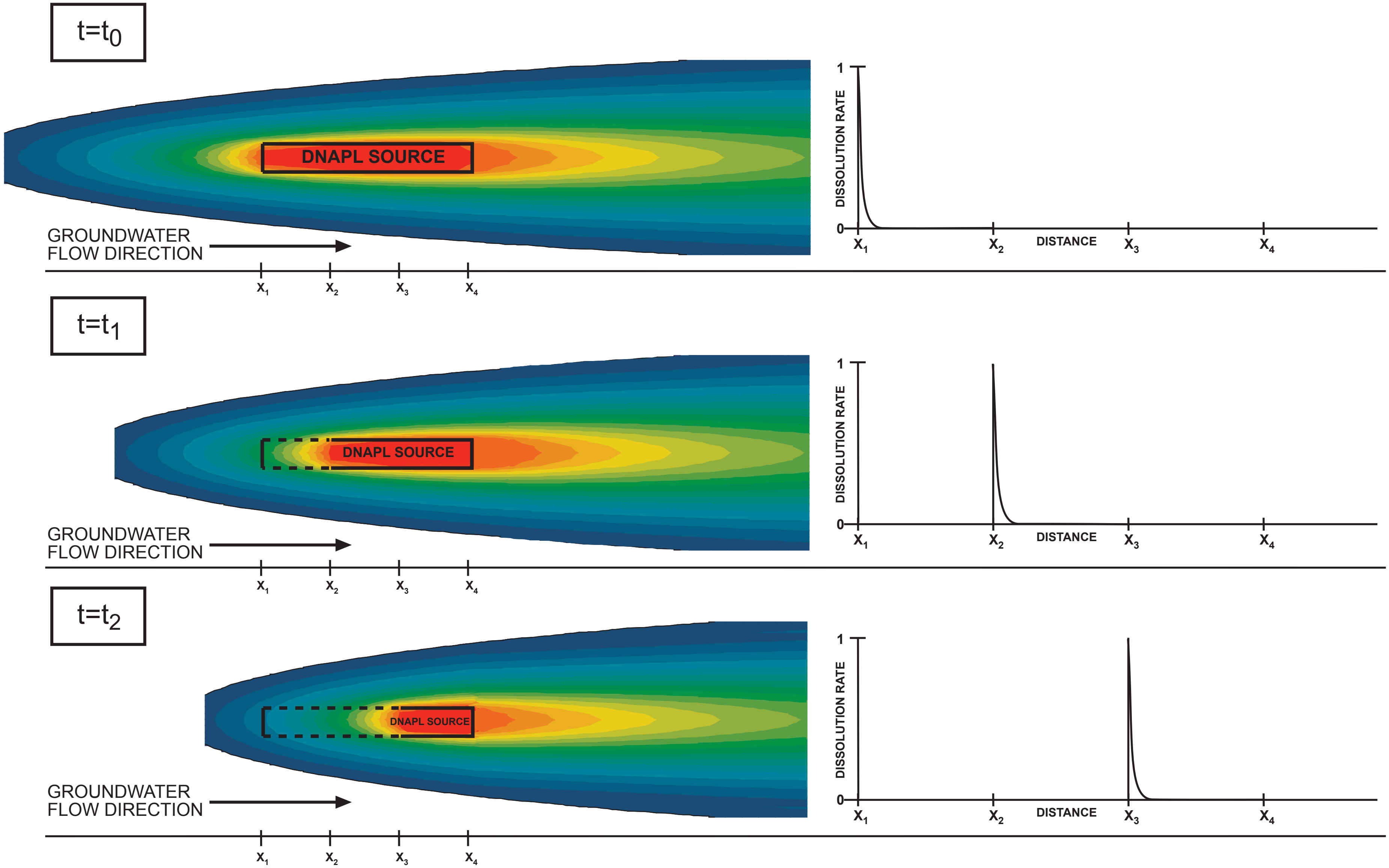

FIGURE 3.1-3
CONCEPTUAL DNAPL SOURCE ZONE DISSOLVING OVER TIME
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

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CH2MHILL®

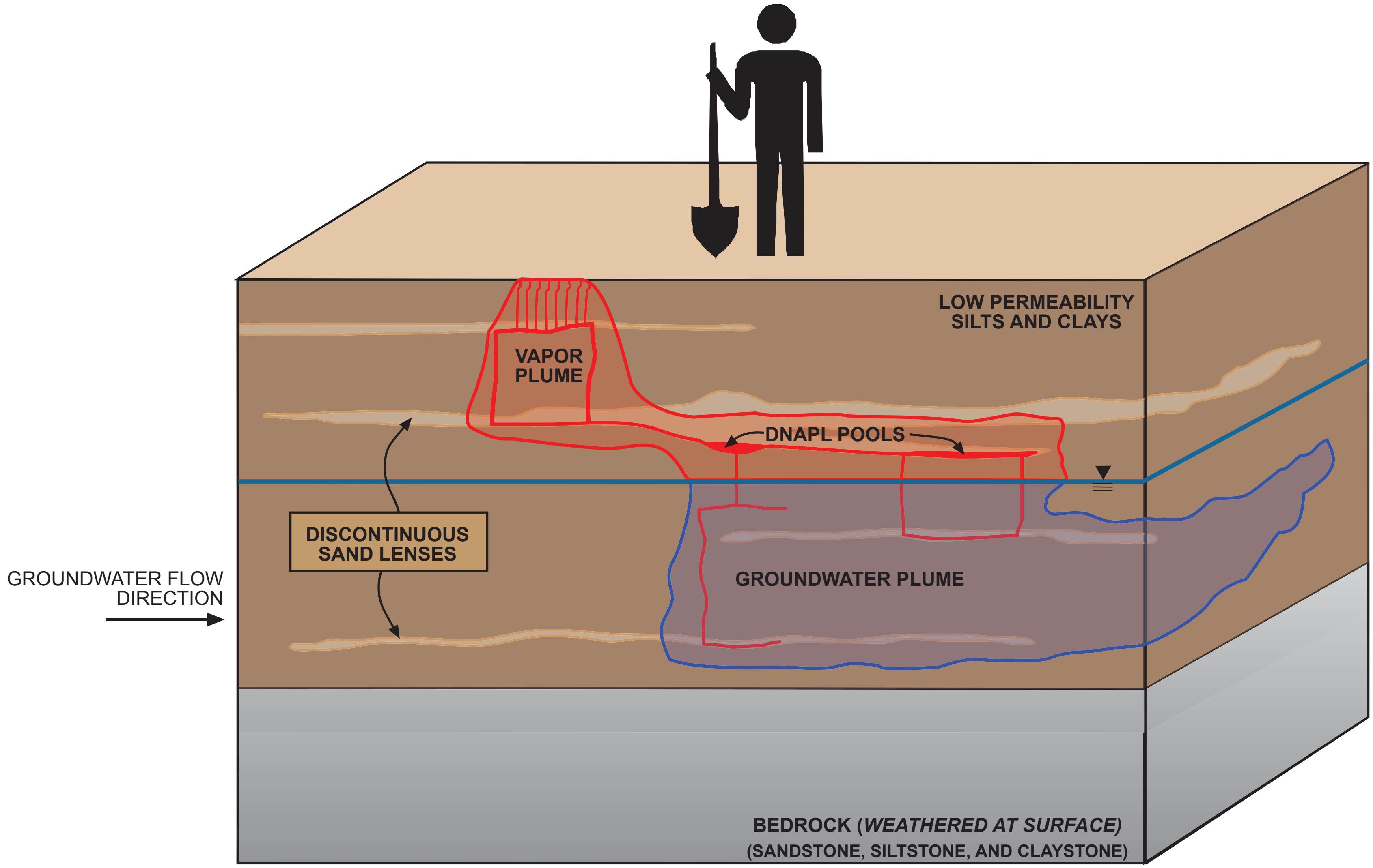
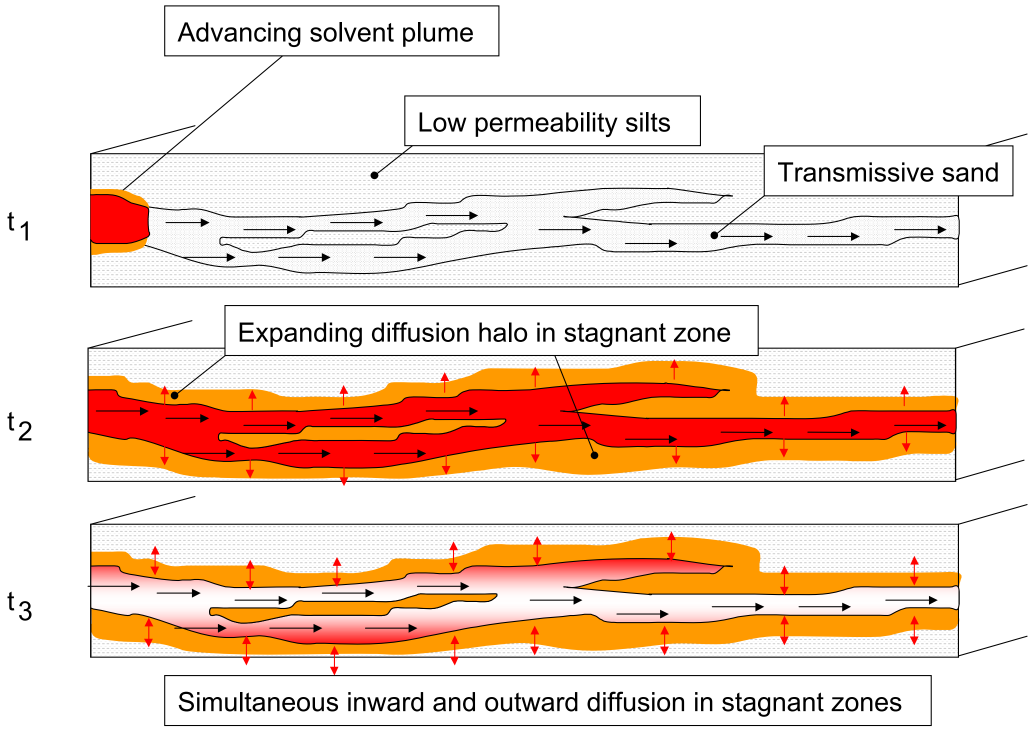


FIGURE 3.1-4
CONCEPTUAL PLUME FORMATION AT A DNAPL SITE
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL®

ES092311092348RDD_3.1-4



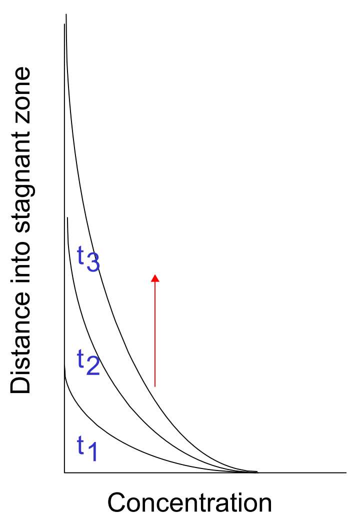


FIGURE 3.1-5
ADVANCING SOLVENT PLUME IN LAYERED ALLUVIUM
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL®

ES092311092348RDD_3.1-5

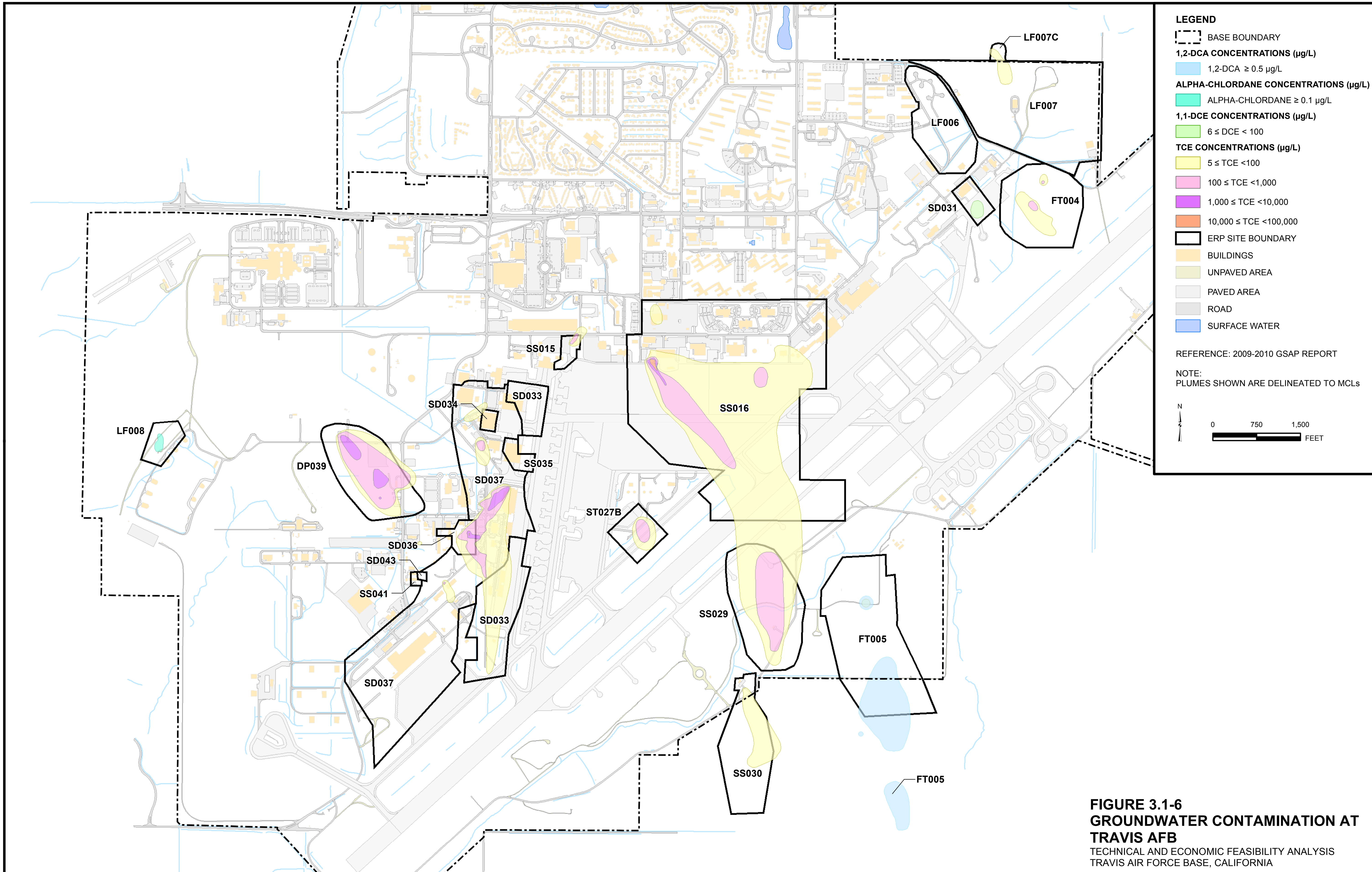


FIGURE 3.1-6
GROUNDWATER CONTAMINATION AT TRAVIS AFB
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_1-6_GW_CONTAMINATION_TEFA.MXD MSCHROCK 10/3/2011 12:41:20 PM

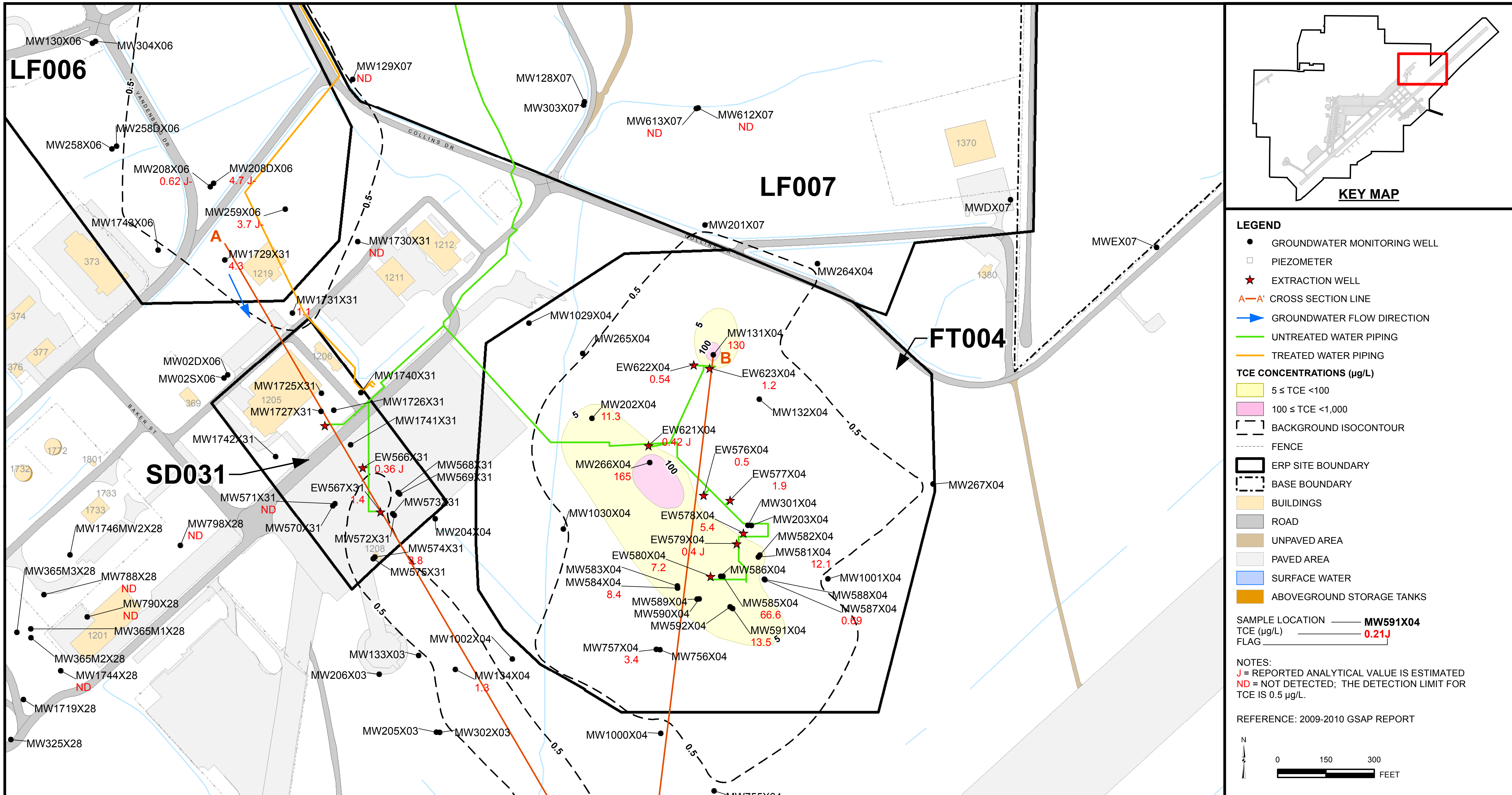


FIGURE 3.1-7
TCE DISTRIBUTION AT SITES FT004/SD031
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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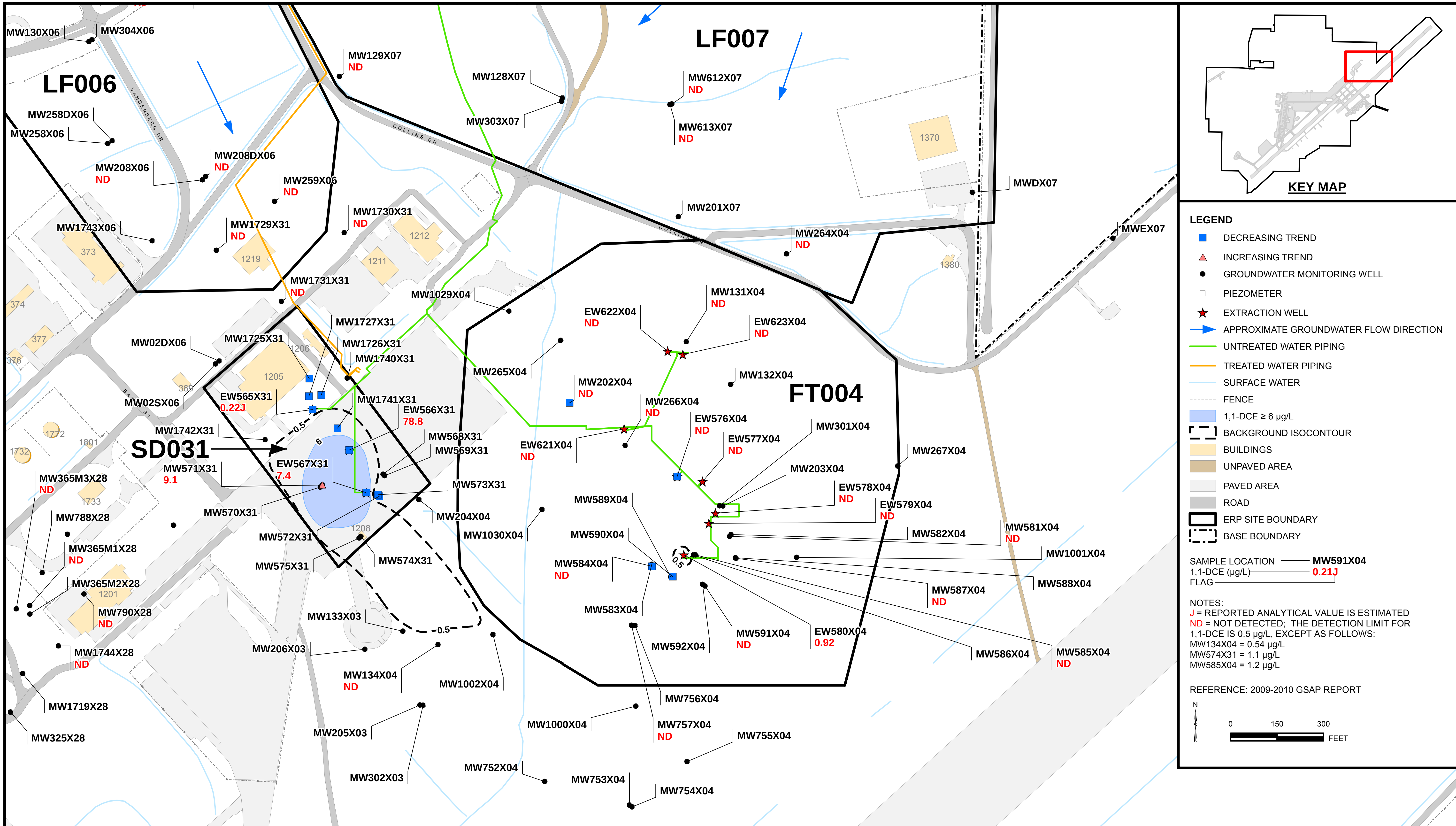

FIGURE 3.1-8
1,1-DCE DISTRIBUTION AT SITES FT004/SD031
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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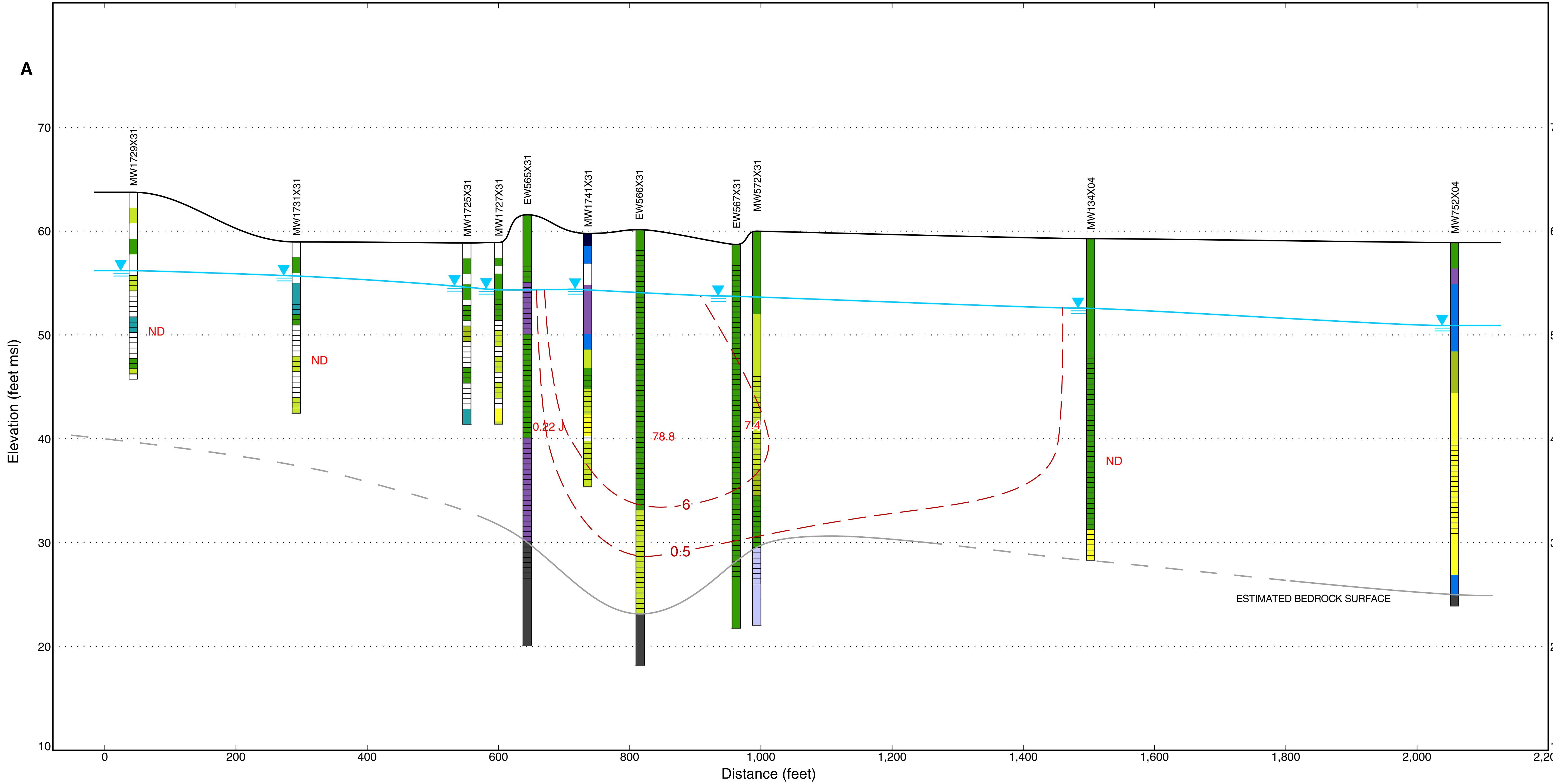

SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 1,1-DCE CONCENTRATION (µg/L) DETECTED IN 2010

– – 6 – – APPROXIMATE 1,1-DCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 16:1 (H:V)

ND = NOT DETECTED; THE DETECTION LIMIT FOR 1,1-DCE IS 0.5 µg/L, EXCEPT AT WELL MW134x04 WHERE IT IS 0.54 µg/L

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- SILTY SAND (SM)
- POORLY GRADED SAND (SP)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-9
SITE SD031 CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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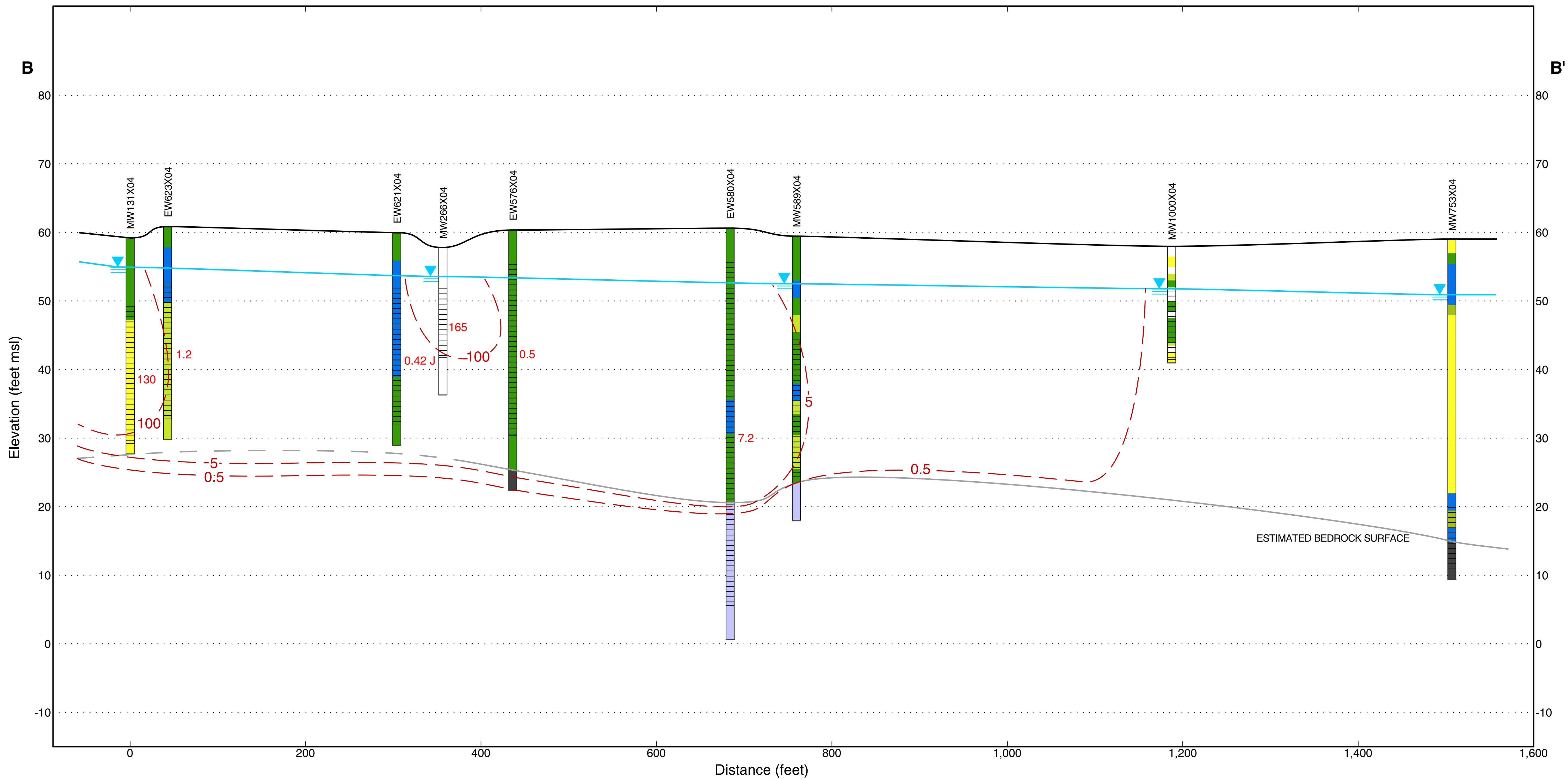
ES092811144130SAC Figure_3.1-9.ai 09.29.2011 tdaus



SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

– – 5 – – APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 8:1 (H:V)

SOIL AND LITHOLOGY

NO SAMPLE/NO RECOVERY
FILL/ASPHALT
TOPSOIL/ORGANIC SOIL
WELL GRADED GRAVEL (GW)
POORLY GRADED GRAVEL (GP)
SILTY GRAVEL (GM)
CLAYEY GRAVEL (GC)
WELL GRADED SAND (SW)
SILTY SAND (SM)
POORLY GRADED SAND (SP)
CLAYEY SAND (SC)
SILT (ML)
ELASTIC SILT (MH)
LEAN CLAY (CL)
FAT CLAY (CH)
SILTSTONE
SANDSTONE
SHALE
ALLUVIUM (NO DATA)

FIGURE 3.1-10
SITE FT004 CROSS SECTION B–B'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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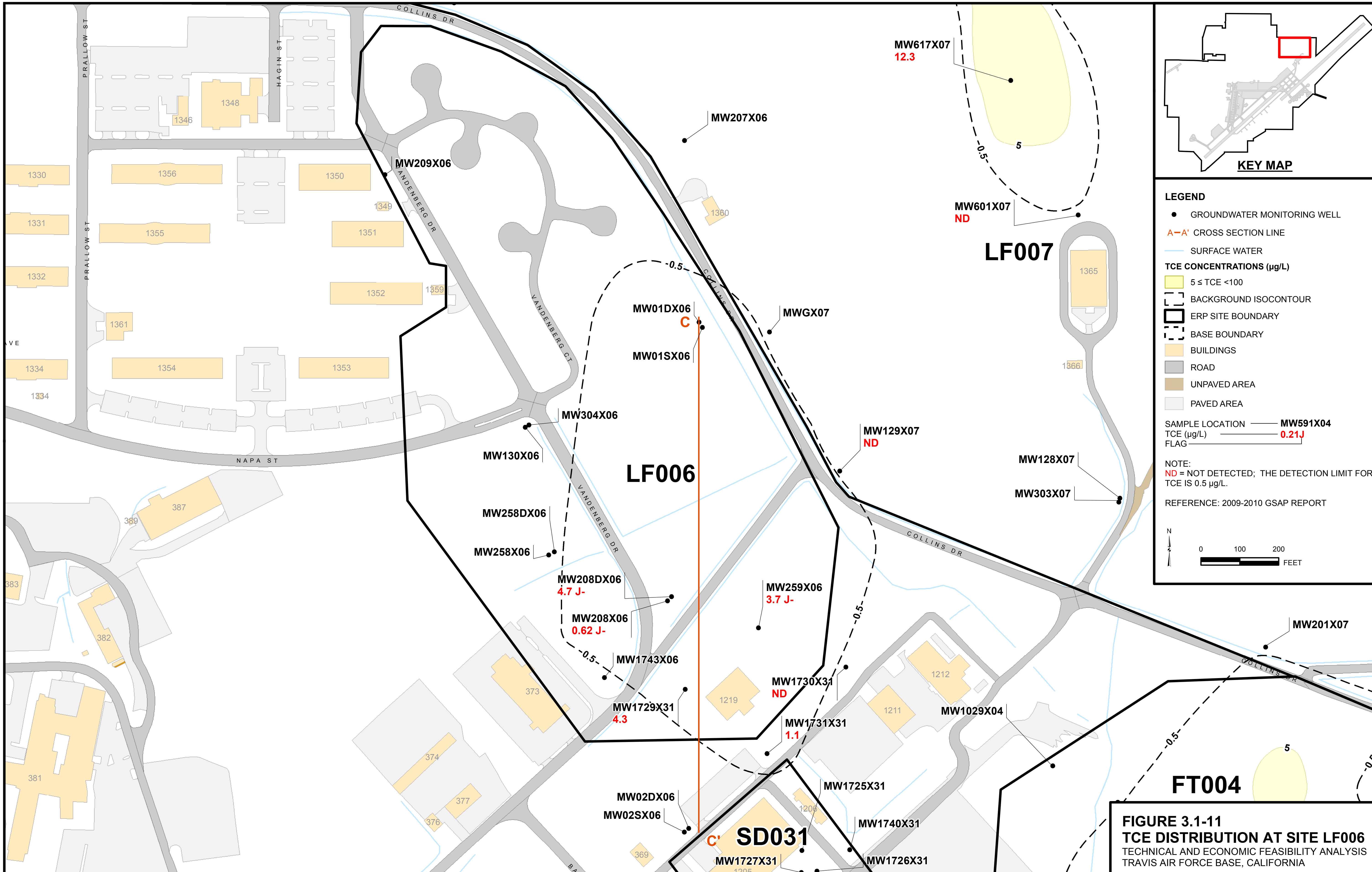
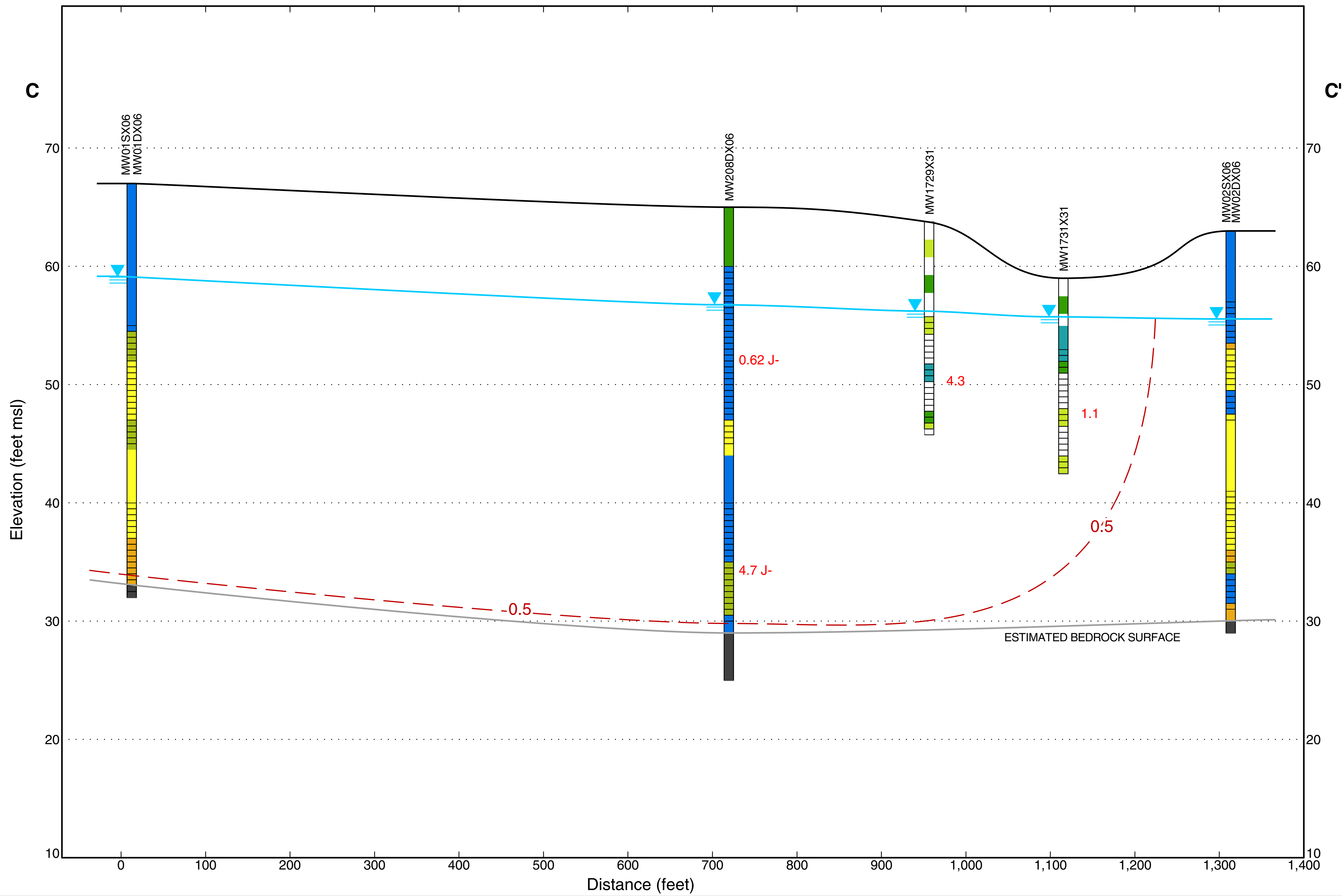


FIGURE 3.1-11
TCE DISTRIBUTION AT SITE LF006
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_1-11_TCE_LF006_TEFA.MXD MSCHROCK 10/3/2011 5:20:35 PM



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

— —5— — APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 14:1 (H:V)

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- SILTY SAND (SM)
- POORLY GRADED SAND (SP)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-12
SITE LF006 CROSS SECTION C–C'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

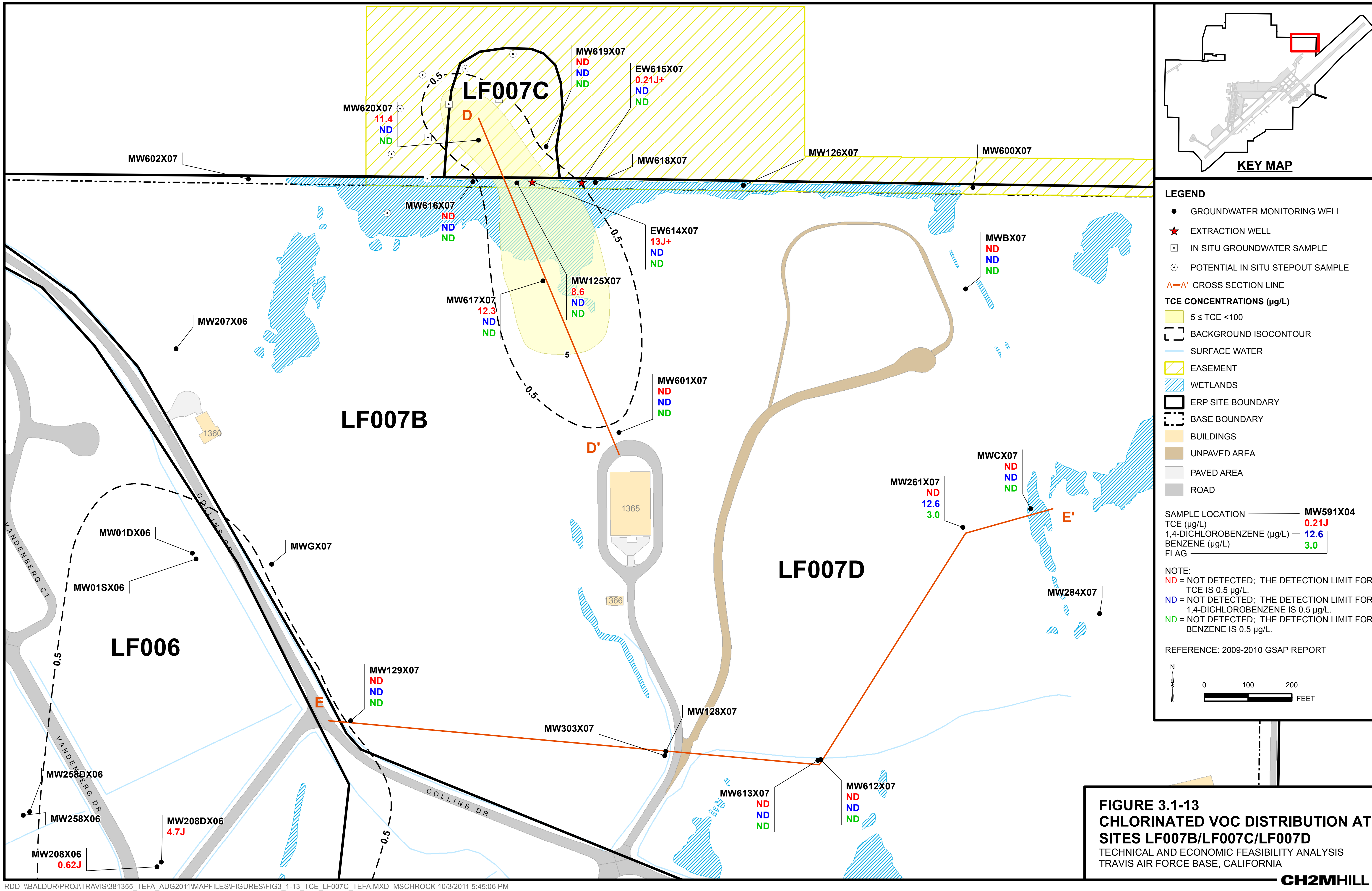
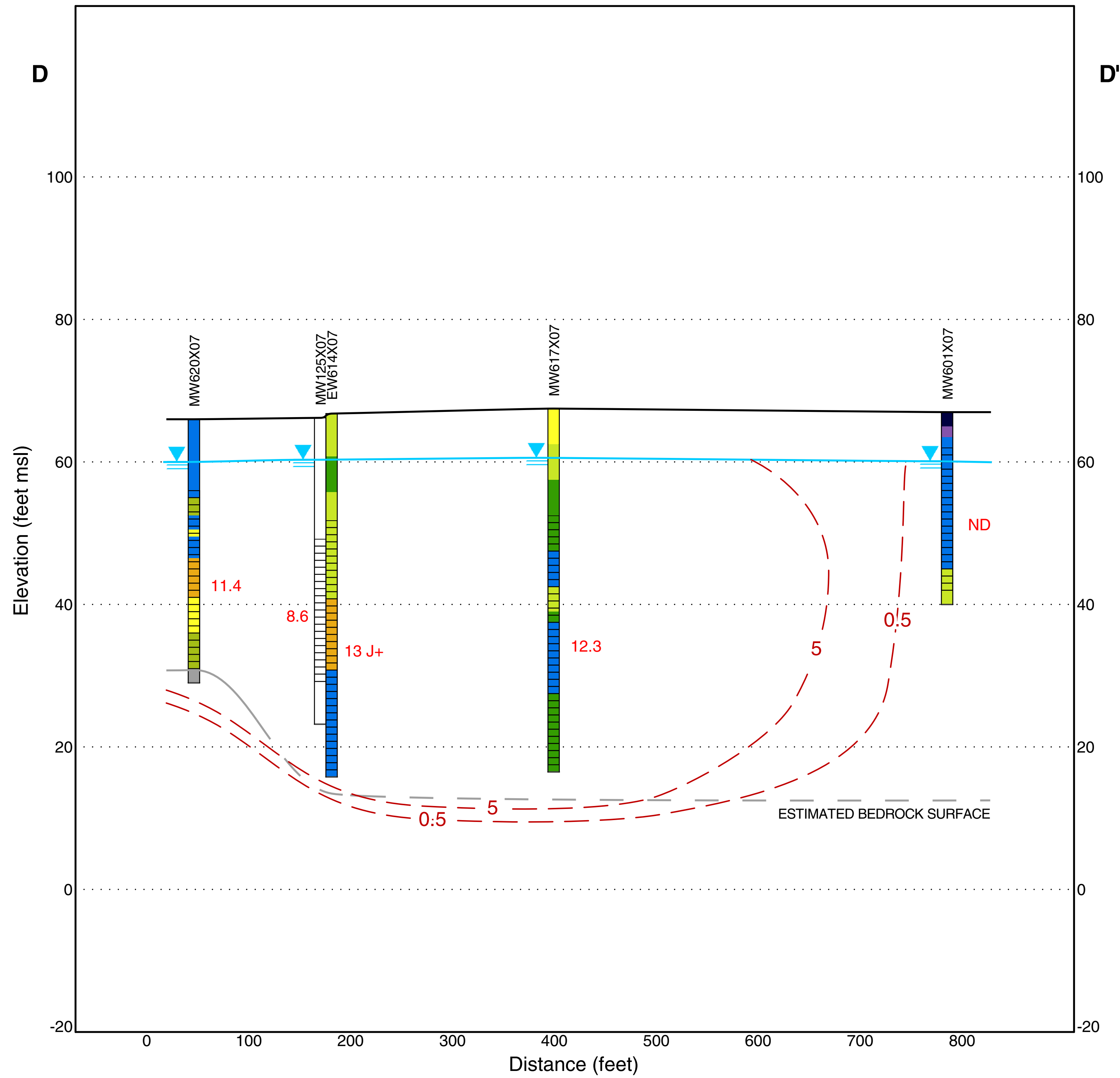


FIGURE 3.1-13
CHLORINATED VOC DISTRIBUTION AT SITES LF007B/LF007C/LF007D
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA



SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN SECOND QUARTER 2010

— — 5 — — APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 7:1 (H:V)

ND = NOT DETECTED; THE DETECTION LIMIT FOR TCE IS 0.5 µg/L

SOIL AND LITHOLOGY

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- POORLY GRADED SAND (SP)
- SILTY SAND (SM)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-14
SITE LF007C CROSS SECTION D–D'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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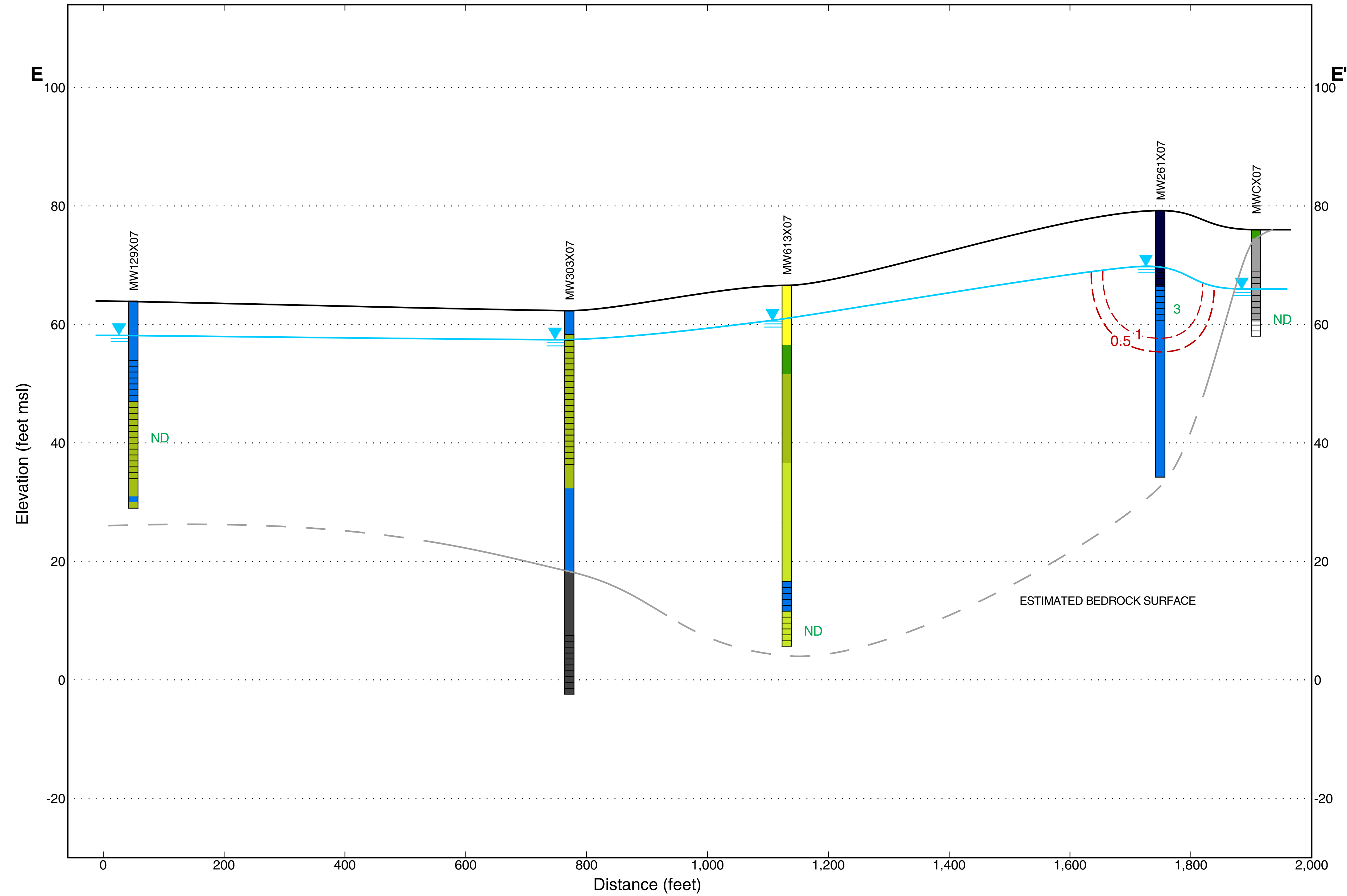

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

3 BENZENE CONCENTRATION (µg/L) DETECTED IN 2010

--0.5-- APPROXIMATE BENZENE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 10:1 (H:V)

ND = NOT DETECTED; THE DETECTION LIMIT FOR BENZENE IS 0.5 µg/L

SOIL AND LITHOLOGY

NO SAMPLE/NO RECOVERY
FILL/ASPHALT
TOPSOIL/ORGANIC SOIL
WELL GRADED GRAVEL (GW)
POORLY GRADED GRAVEL (GP)
SILTY GRAVEL (GM)
CLAYEY GRAVEL (GC)
WELL GRADED SAND (SW)
SILTY SAND (SM)
POORLY GRADED SAND (SP)
CLAYEY SAND (SC)
SILT (ML)
ELASTIC SILT (MH)
LEAN CLAY (CL)
FAT CLAY (CH)
SILTSTONE
SANDSTONE
SHALE
ALLUVIUM (NO DATA)

FIGURE 3.1-15
SITE LF007D CROSS SECTION E–E'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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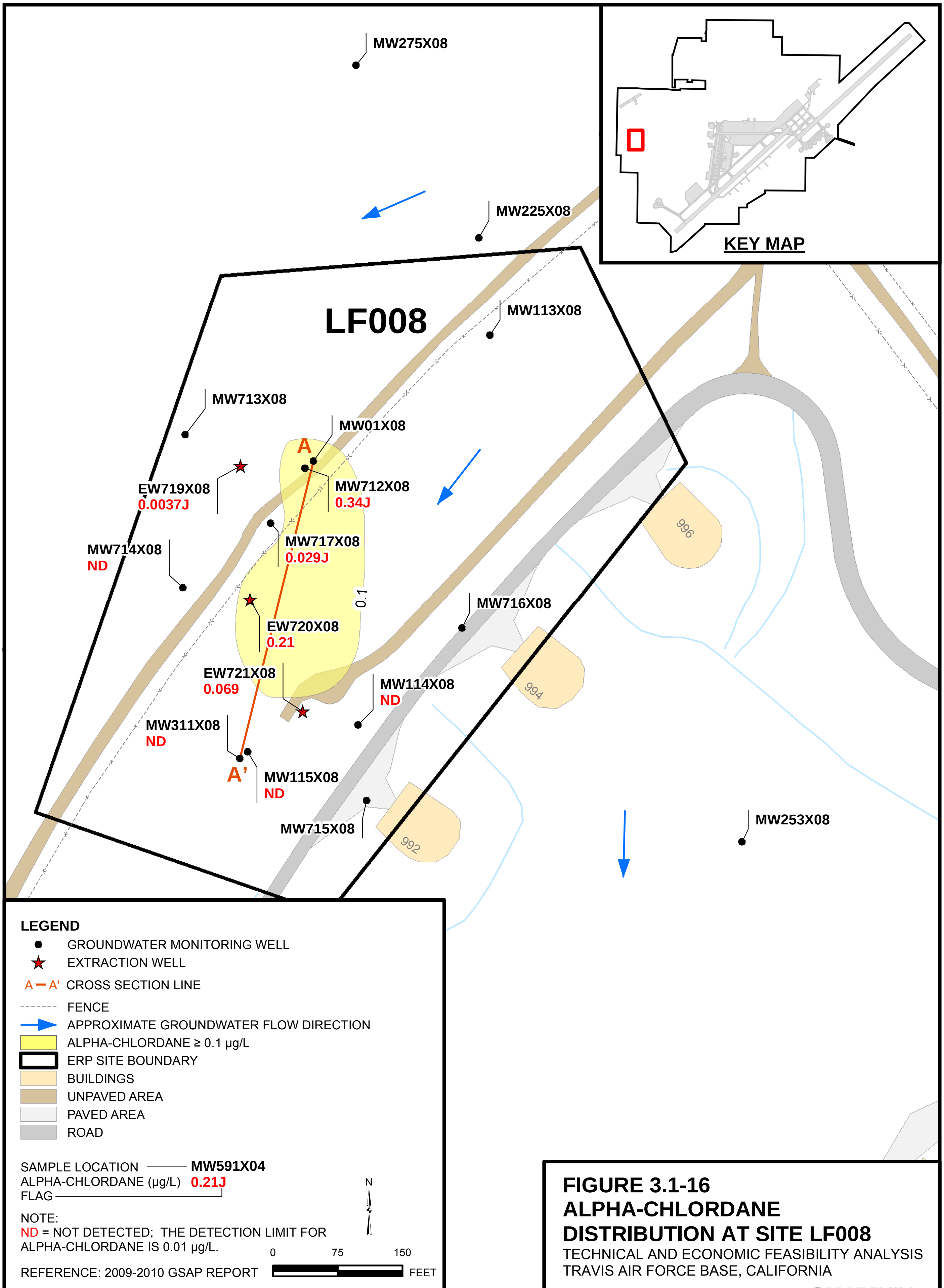

FIGURE 3.1-16
ALPHA-CHLORDANE DISTRIBUTION AT SITE LF008
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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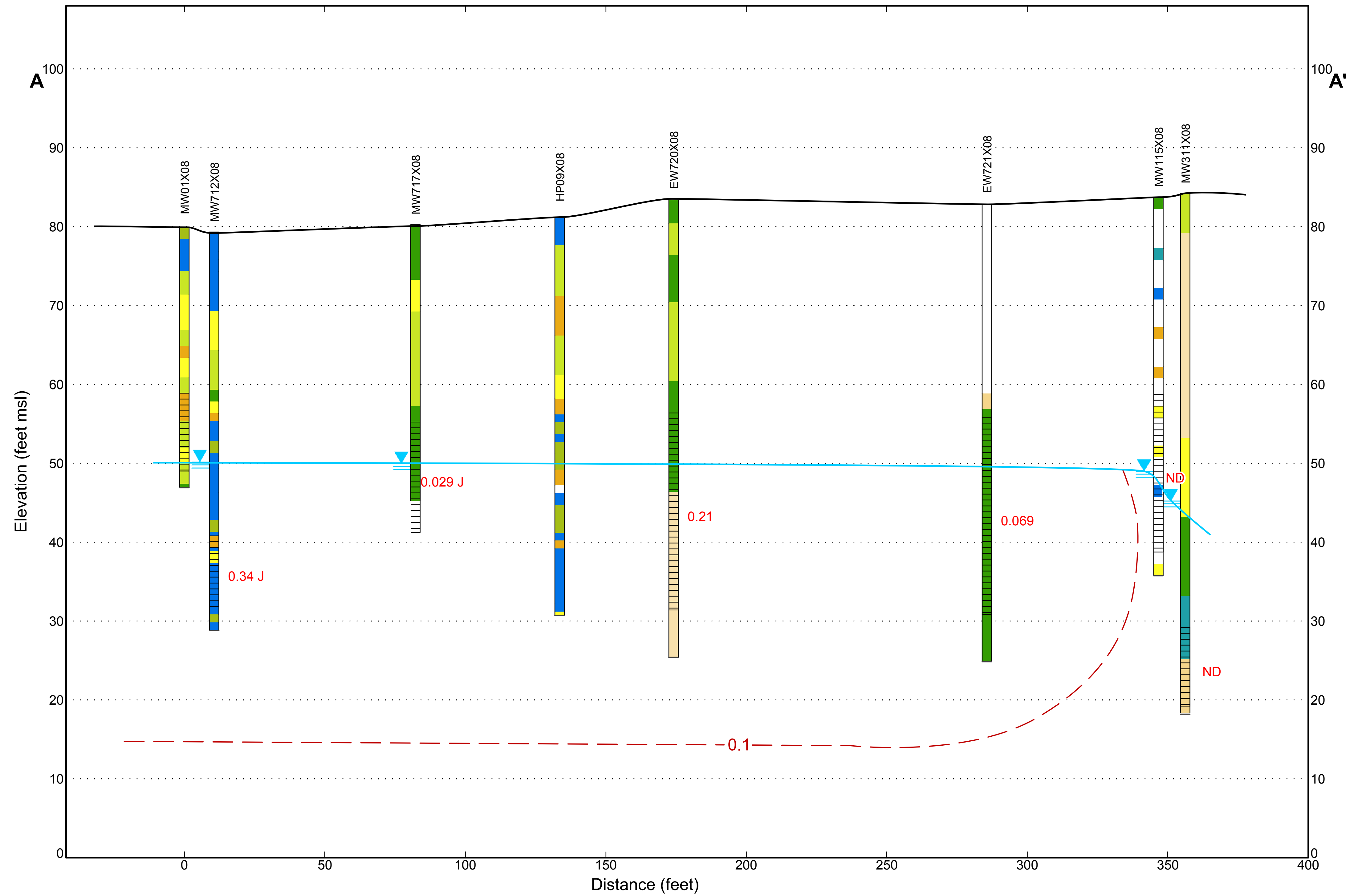


SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

0.69 ALPHA-CHLORDANE CONCENTRATION (µg/L) DETECTED IN 2010

--0.1-- APPROXIMATE ALPHA-CHLORDANE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 3:1 (H:V)

ND = NOT DETECTED; THE DETECTION LIMIT FOR ALPHA-CHLORDANE IS 0.01 µg/L

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- SILTY SAND (SM)
- POORLY GRADED SAND (SP)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-17
SITE LF008 CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\FFS\GPJ\TRAVIS_2010_SAMPLING_EVENT.GPJ;
ES092811144130SAC Figure_3.1-17.ai 09.29.2011 tdaus

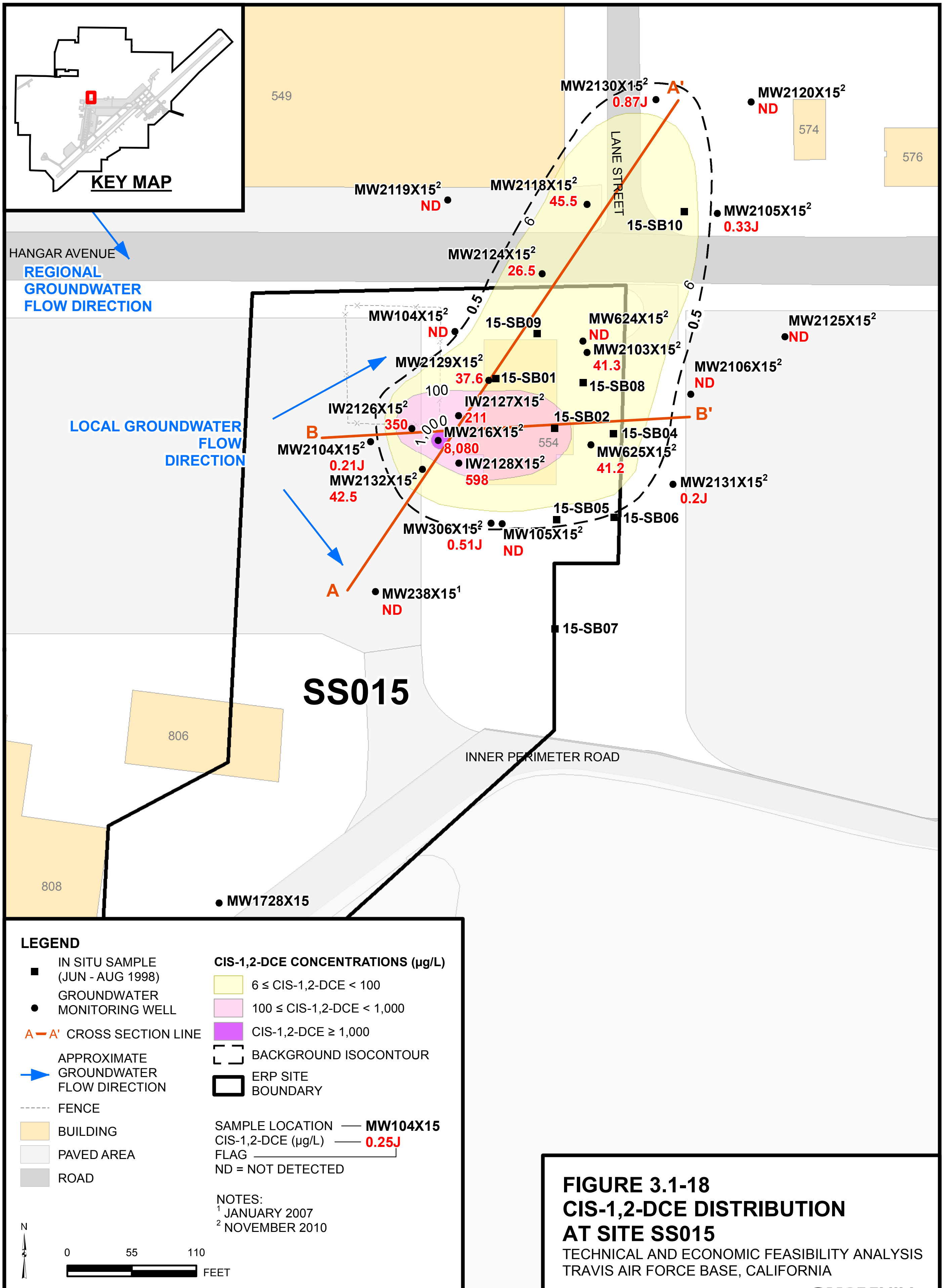
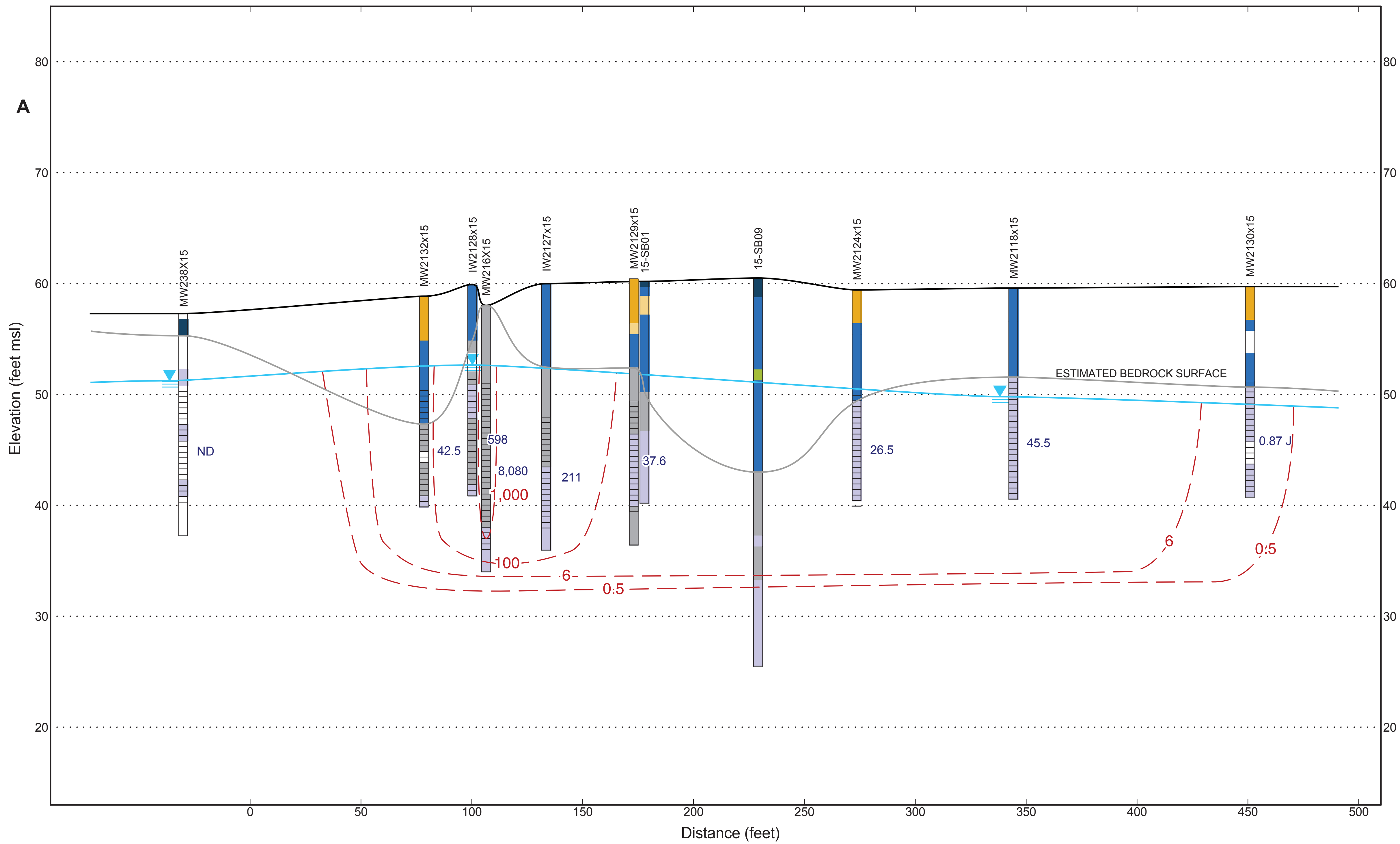


FIGURE 3.1-18
CIS-1,2-DCE DISTRIBUTION AT SITE SS015
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA



SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2009 GROUNDWATER ELEVATION (ft MSL)

41 CIS-1,2-DICHLOROETHENE CONCENTRATION (µg/L) DETECTED IN 2010

– – 0.5 – – APPROXIMATE CIS-1,2-DICHLOROETHENE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 5:1 (H:V)

NOTE: Some soil boring logs have been reinterpreted due to recent field observations.

SOIL AND LITHOLOGY

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- POORLY GRADED SAND (SP)
- SILTY SAND (SM)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-19
SITE SS015 CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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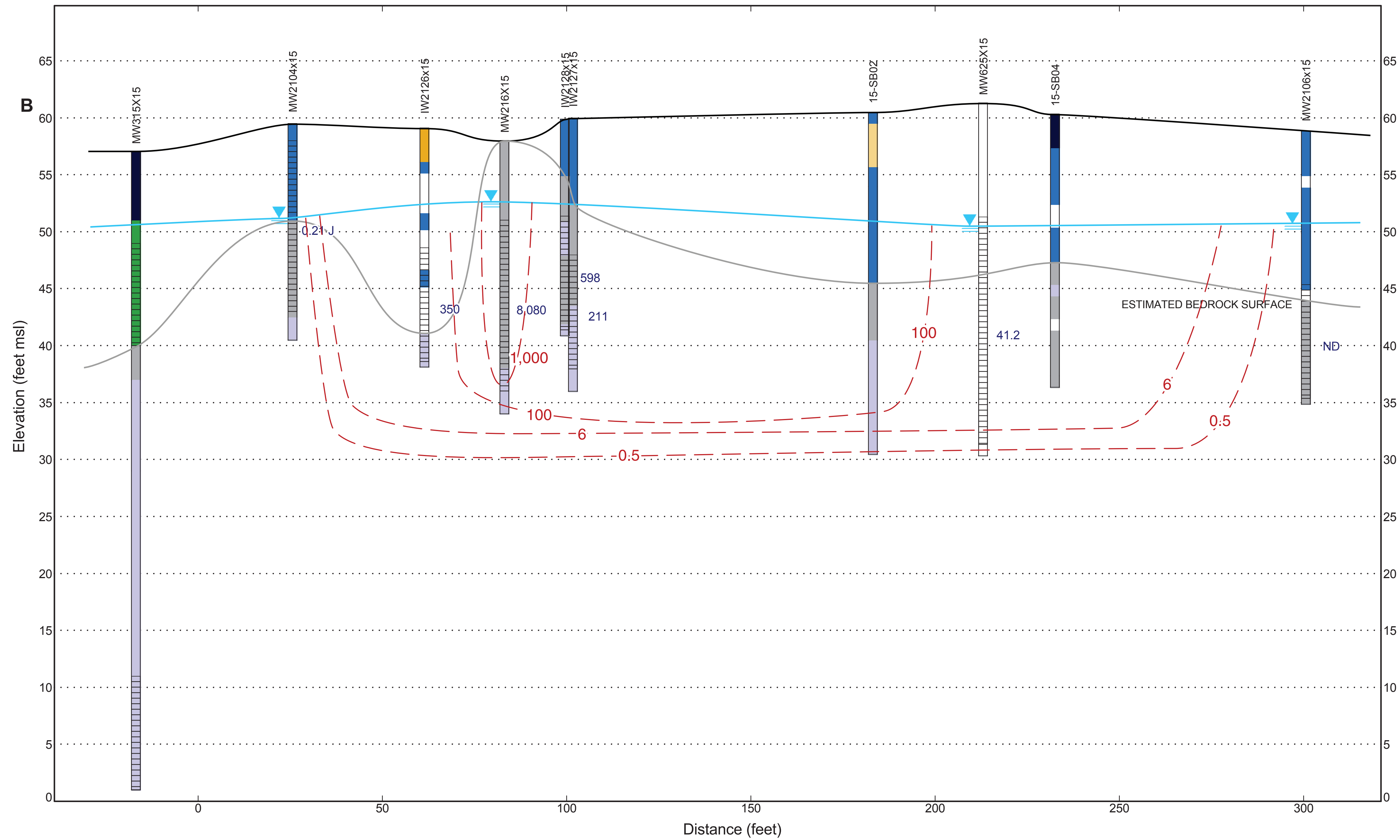
ES092811144130SAC Figure_3.1-19.ai 10.04.2011 tdaus



SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2009 GROUNDWATER ELEVATION (ft MSL)

41 CIS-1,2-DICHLOROETHENE (µg/L) CONCENTRATION DETECTED IN 2010

--0.5-- APPROXIMATE CIS-1,2-DICHLOROETHENE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 3.1:1 (H:V)

NOTE: Some soil boring logs have been reinterpreted due to recent field observations.

SOIL AND LITHOLOGY

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- POORLY GRADED SAND (SP)
- SILTY SAND (SM)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-20
SITE SS015 CROSS SECTION B–B'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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ES092811144130SAC Figure_3.1-20.ai 10.04.2011 tdaus

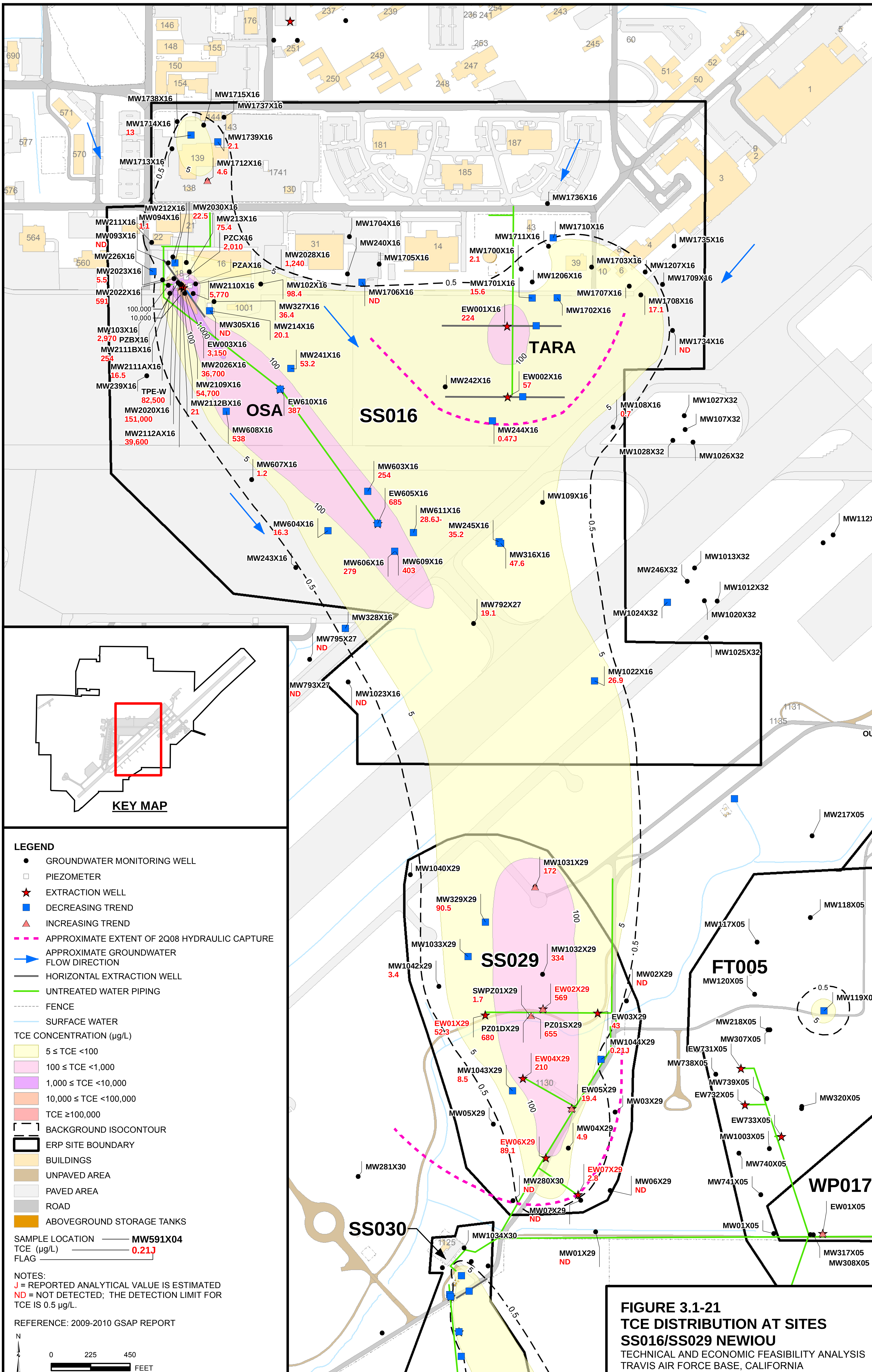


FIGURE 3.1-21
TCE DISTRIBUTION AT SITES SS016/SS029 NEWIOU
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_1-21_TCE_SS016_SS029_TEFA.MXD MSCHROCK 10/4/2011 12:59:28 AM

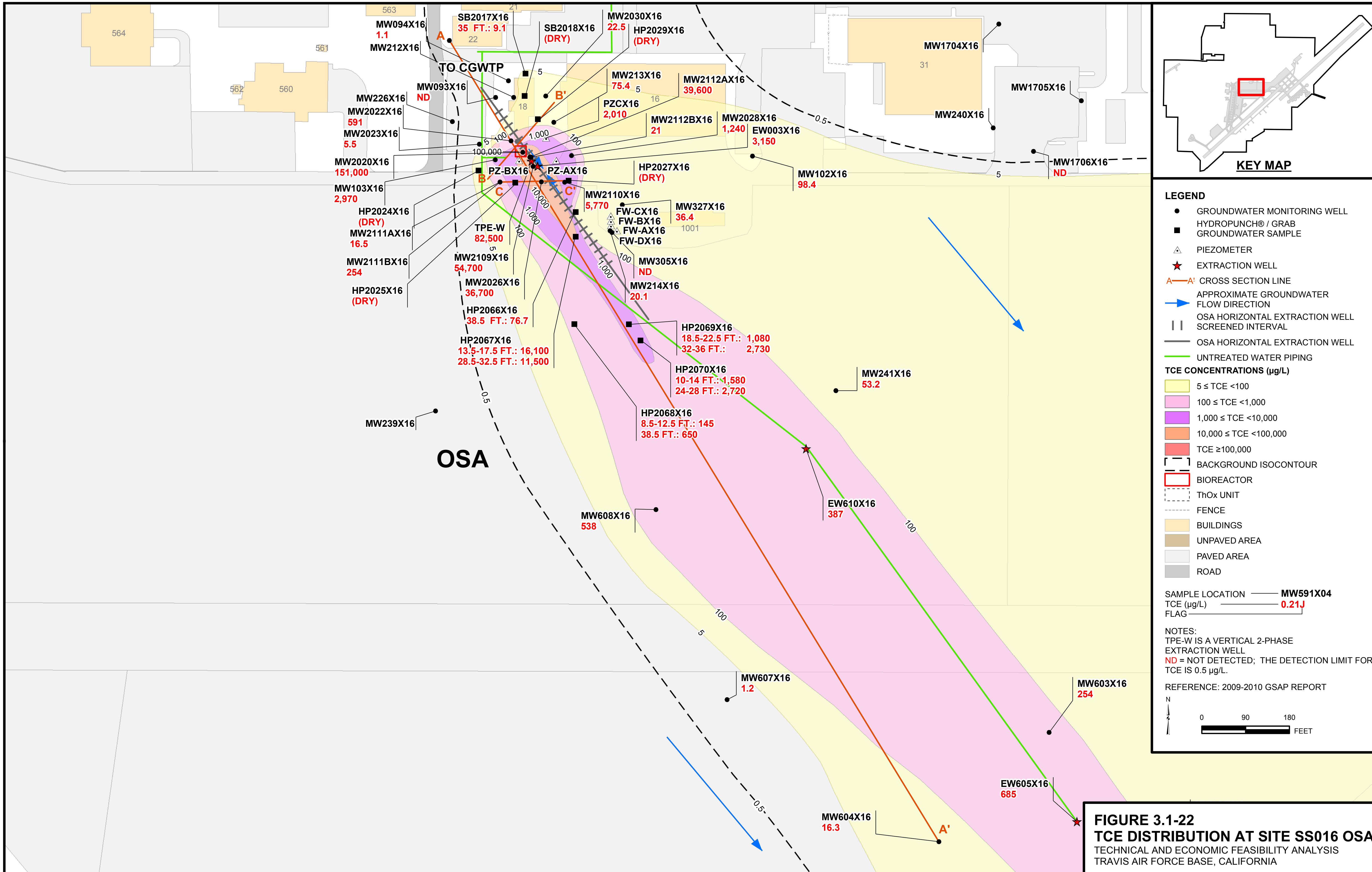


FIGURE 3.1-22
TCE DISTRIBUTION AT SITE SS016 OSA
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

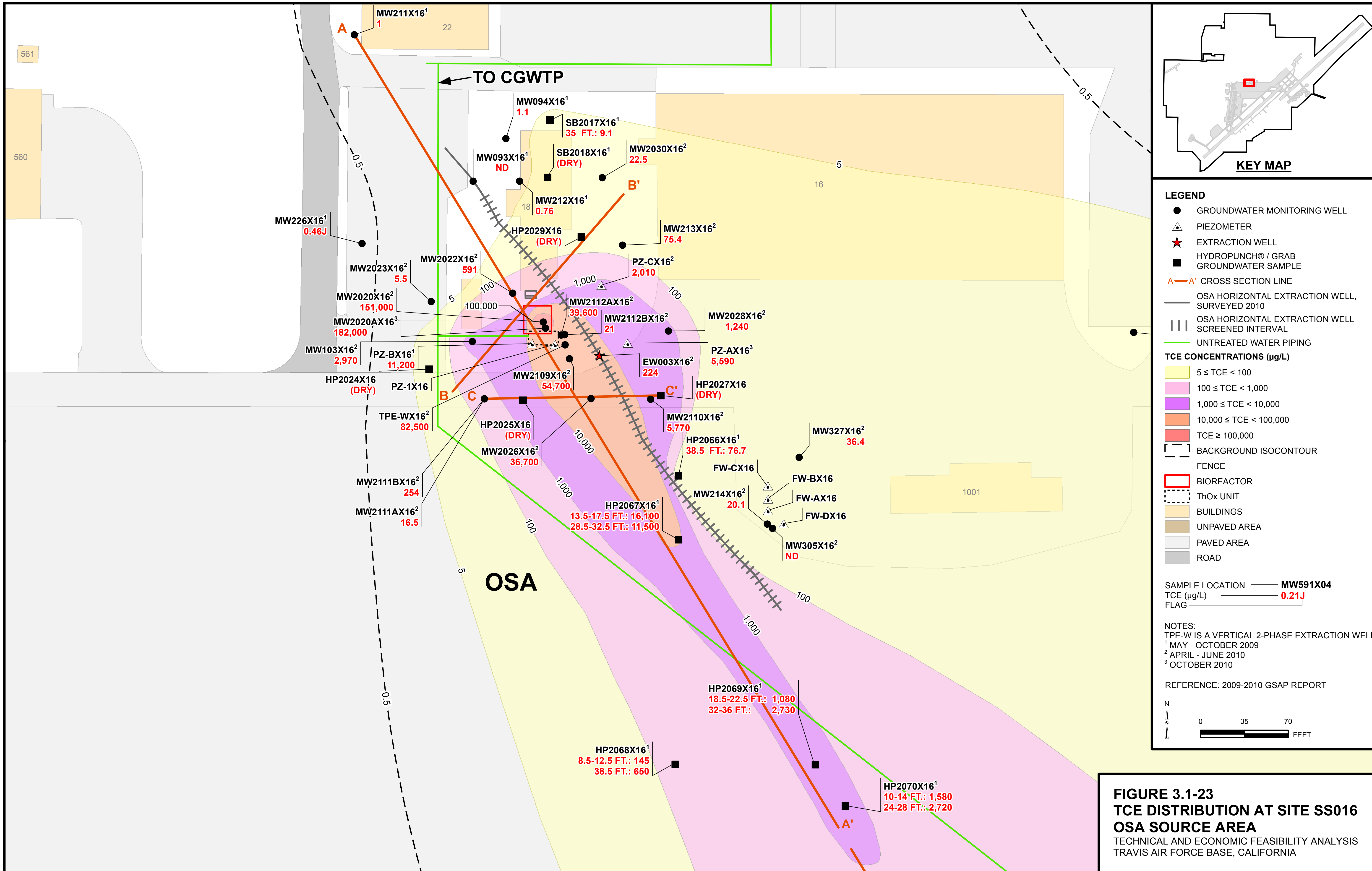
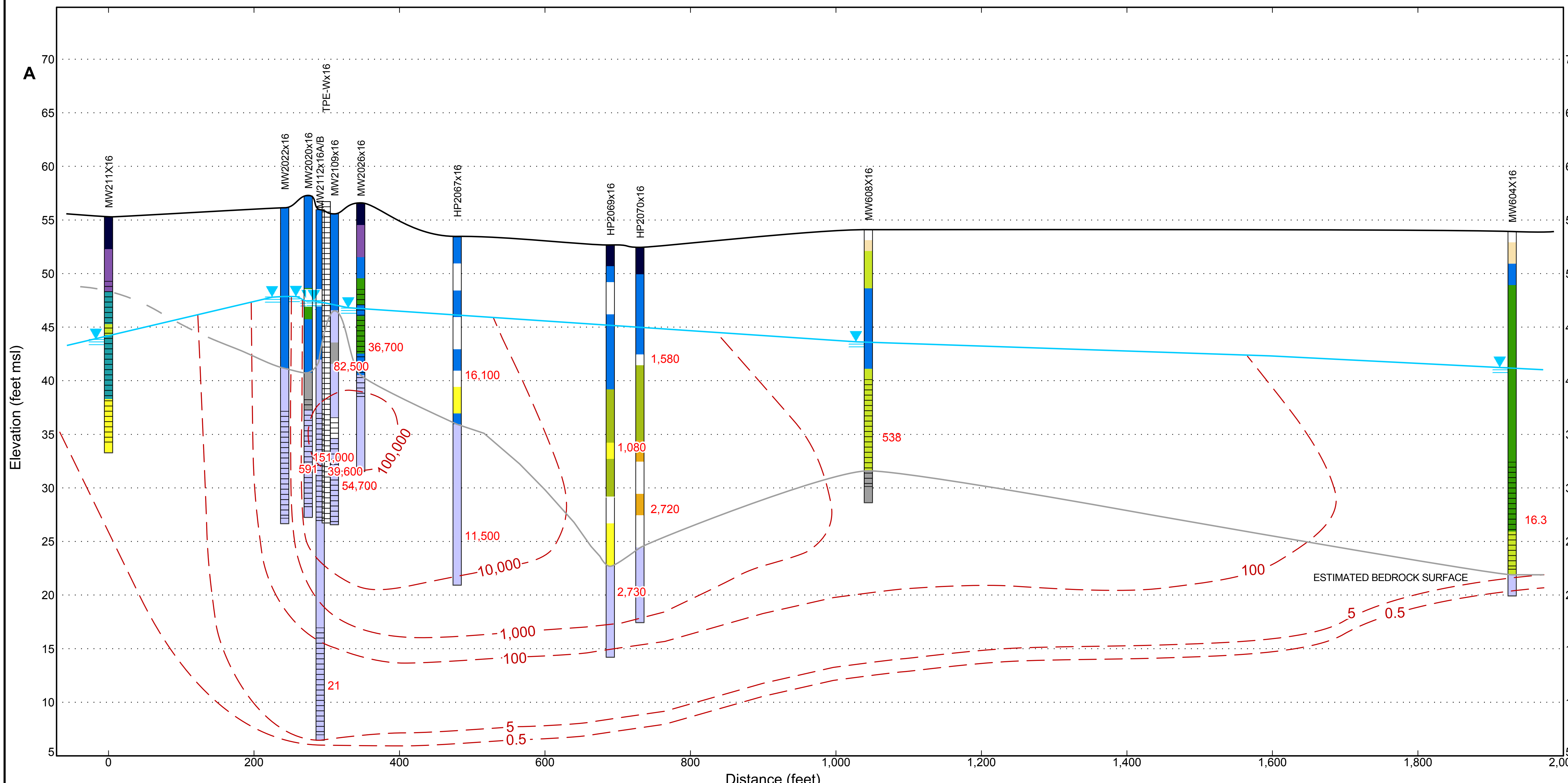


FIGURE 3.1-23
TCE DISTRIBUTION AT SITE SS016
OSA SOURCE AREA
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_1-23_TCE_OSA_SS016_ZOOM_TEFA.MXD MSCHROCK 10/5/2011 11:43:25 AM



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

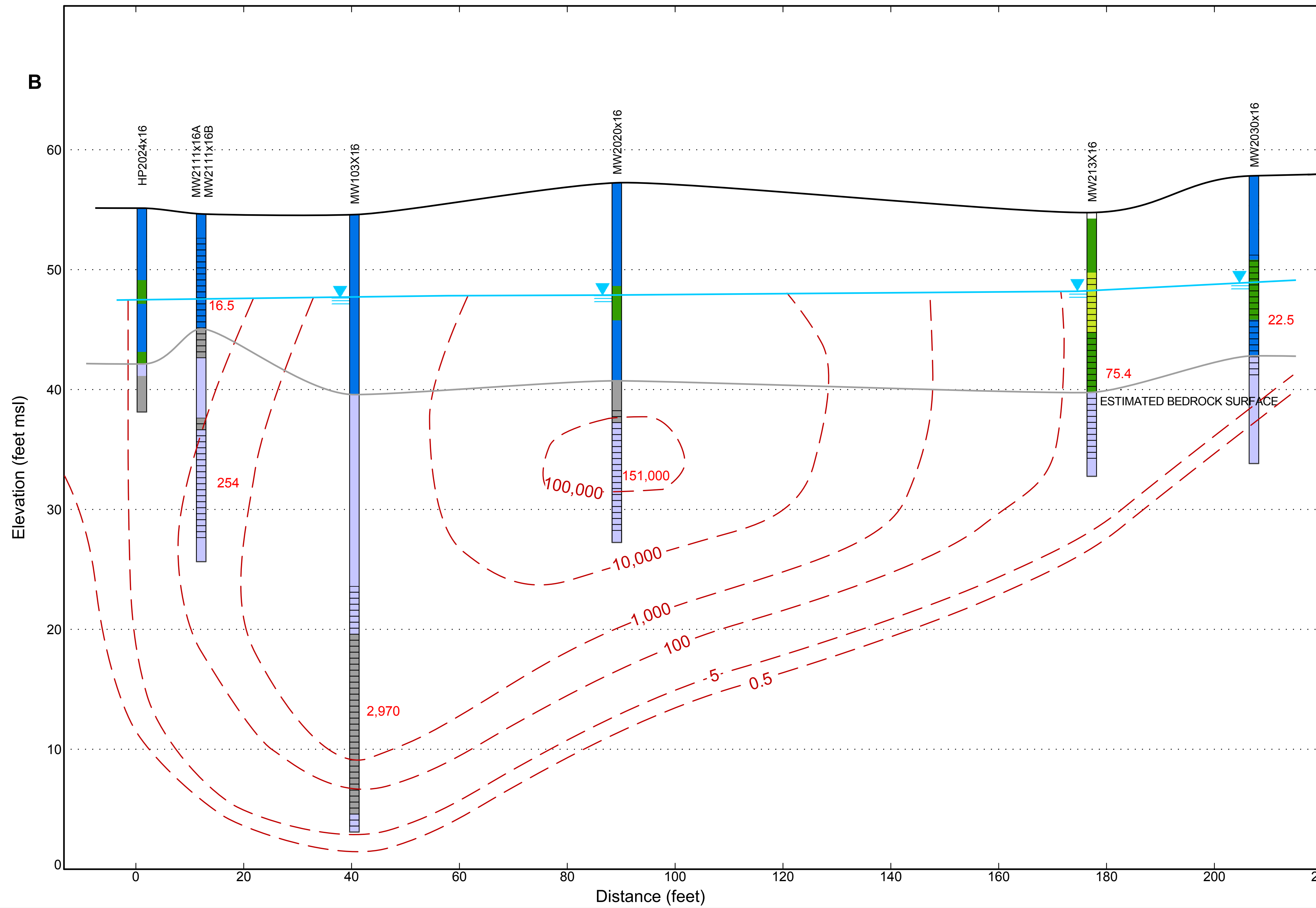
--5-- APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 15:1 (H:V)

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- SILTY SAND (SM)
- POORLY GRADED SAND (SP)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-24
SITE SS016 CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

--5-- APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 2.2:1 (H:V)

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- SILTY SAND (SM)
- POORLY GRADED SAND (SP)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-25
SITE SS016 CROSS SECTION B–B'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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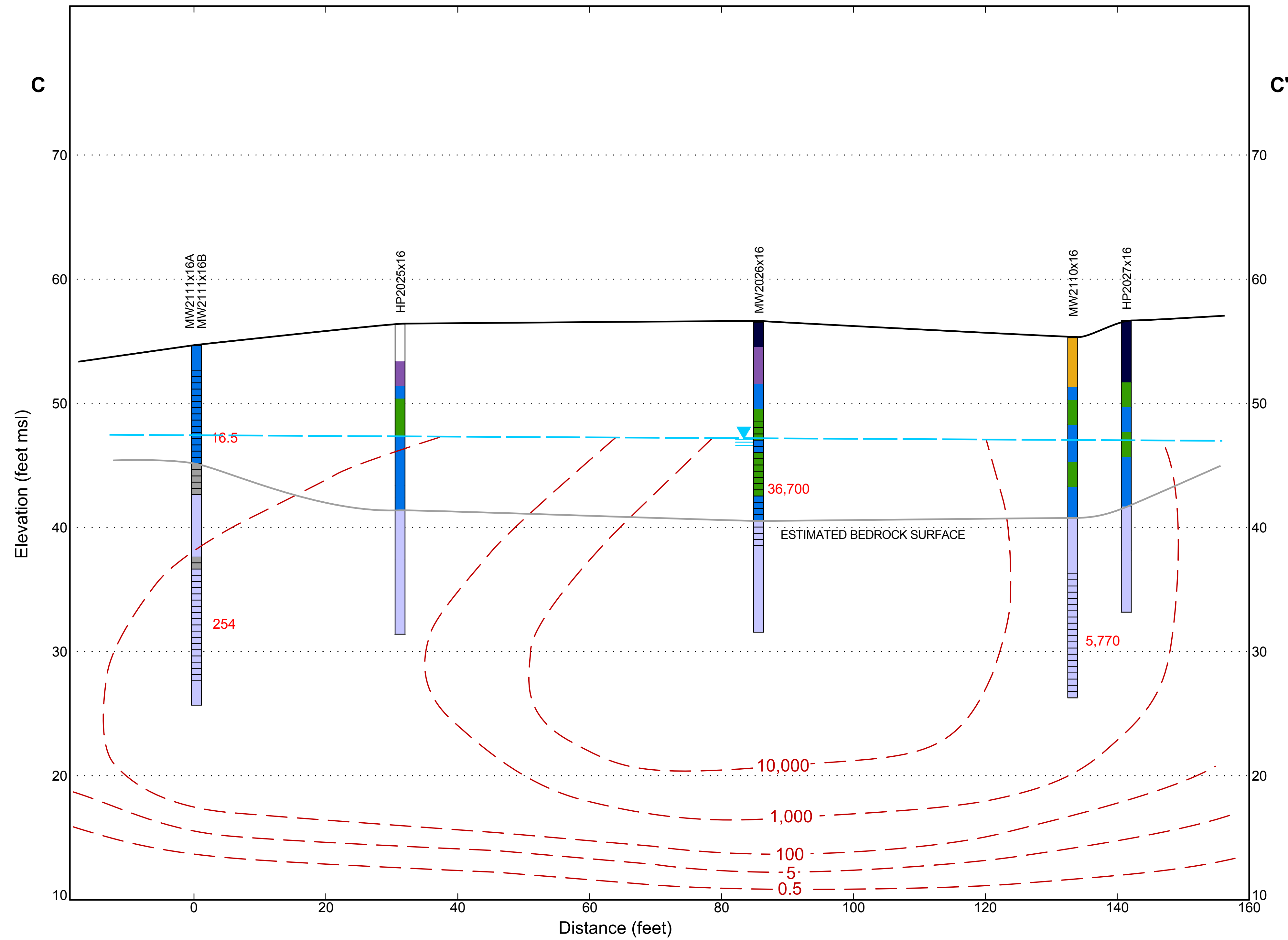
ES092811144130SAC Figure_3.1-25.ai 09.29.2011 tdaus



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

– – 5 – – APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 2:1 (H:V)

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- SILTY SAND (SM)
- POORLY GRADED SAND (SP)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-26
SITE SS016 CROSS SECTION C–C'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

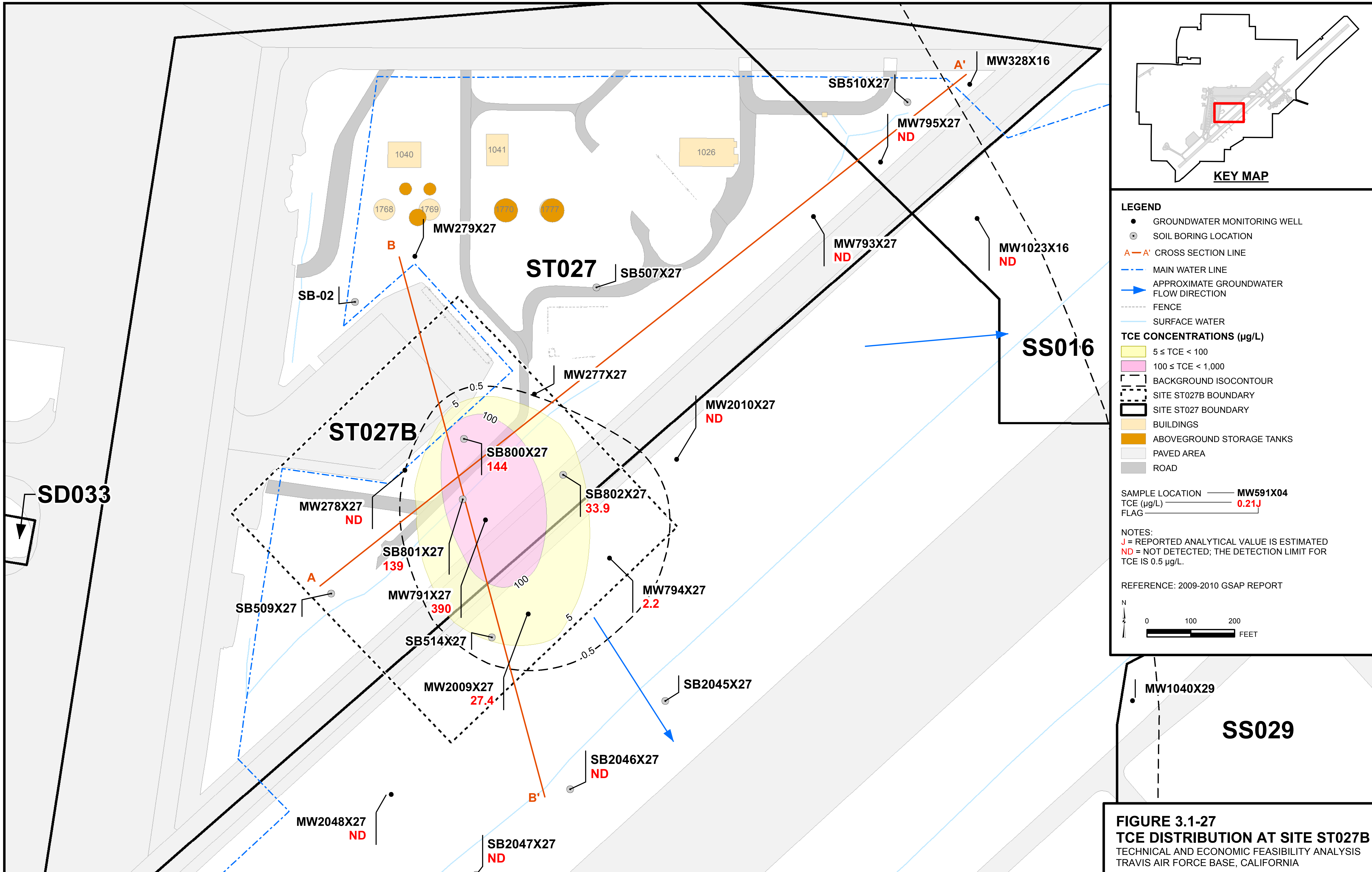
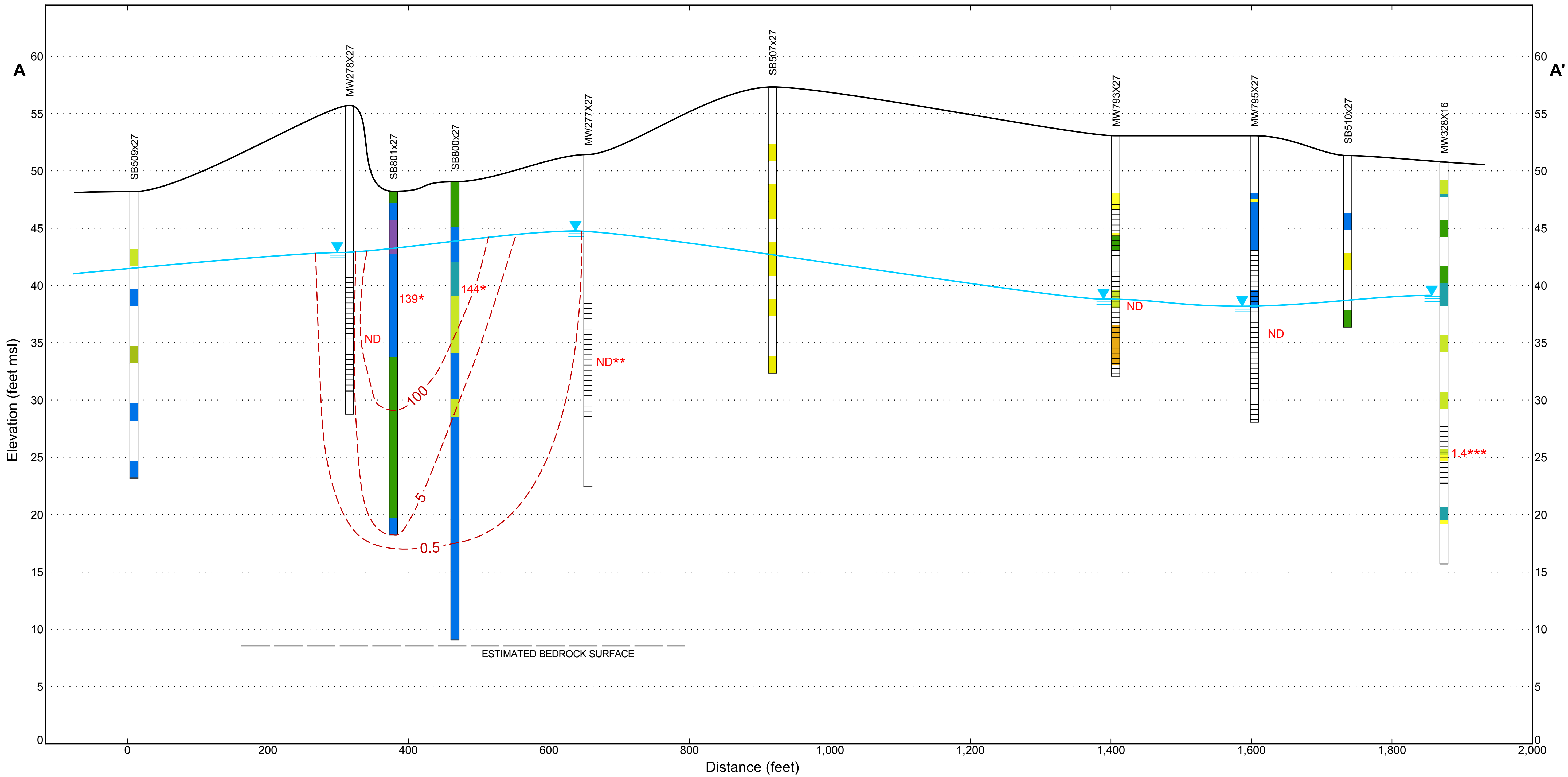


FIGURE 3.1-27
TCE DISTRIBUTION AT SITE ST027B
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_1-27_TCE_ST027B_TEFA.MXD MSCHROCK 10/4/2011 11:12:58 PM



SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

--0.5-- APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

* HYDROPUNCH SAMPLES COLLECTED IN 2009

** SAMPLE COLLECTED SECOND QUARTER 2008

*** SAMPLE COLLECTED SECOND QUARTER 2009

SCALE EXAGGERATION - 16:1 (H:V)

ND = NOT DETECTED; THE DETECTION LIMIT FOR TCE IS 0.5 µg/L

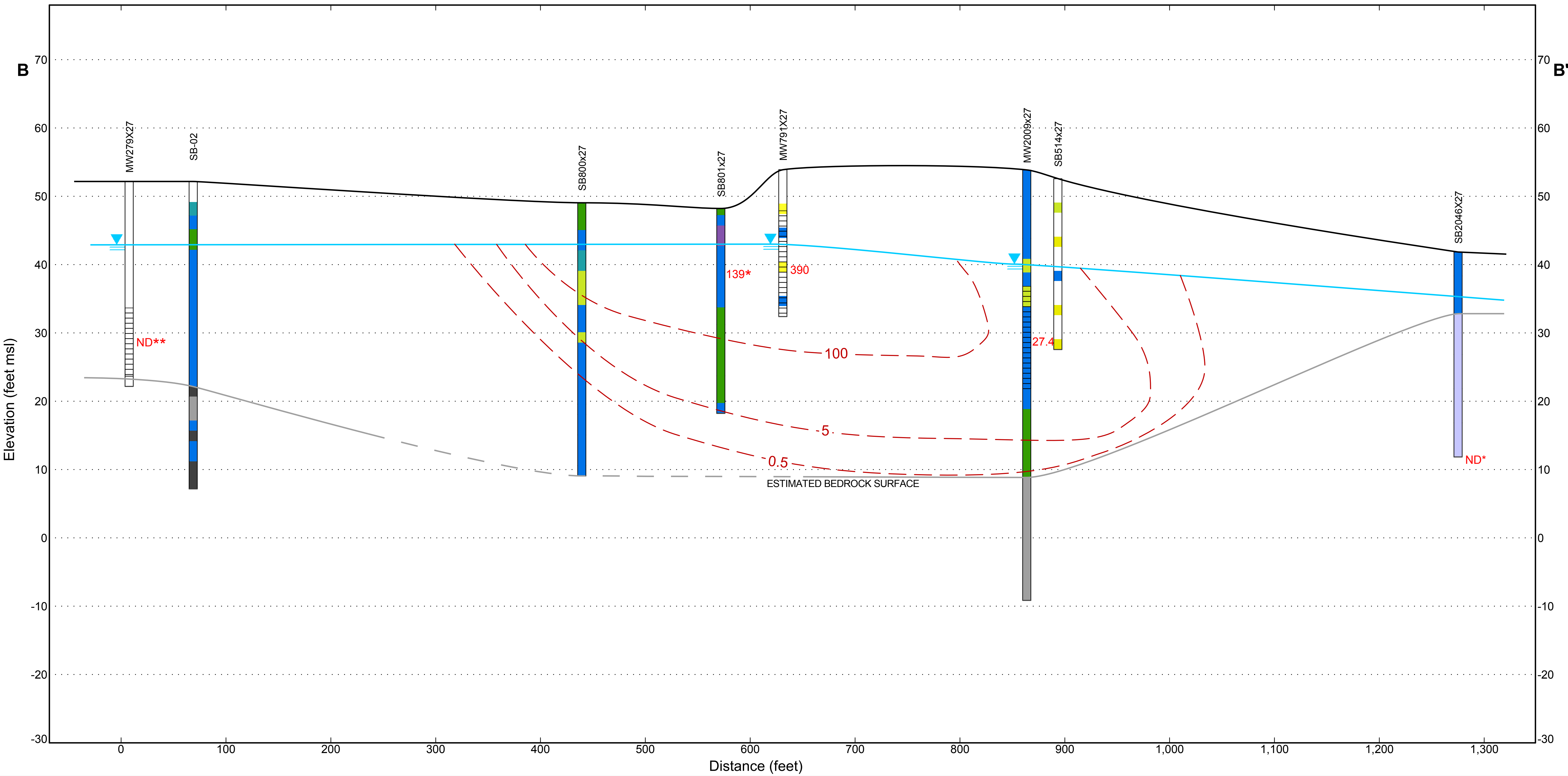
SOIL AND LITHOLOGY

NO SAMPLE/NO RECOVERY
FILL/ASPHALT
TOPSOIL/ORGANIC SOIL
WELL GRADED GRAVEL (GW)
POORLY GRADED GRAVEL (GP)
SILTY GRAVEL (GM)
CLAYEY GRAVEL (GC)
WELL GRADED SAND (SW)
SILTY SAND (SM)
POORLY GRADED SAND (SP)
CLAYEY SAND (SC)
SILT (ML)
ELASTIC SILT (MH)
LEAN CLAY (CL)
FAT CLAY (CH)
SILTSTONE
SANDSTONE
SHALE
ALLUVIUM (NO DATA)

FIGURE 3.1-28
SITE ST027B CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\FFS\GPJ\TRAVIS_2010_SAMPLING_EVENT.GPJ;
ES082009007SAC Figure_3.1-28.ai 10.04.2011 tdaus



SOIL AND LITHOLOGY

- SCREEN INTERVAL
- APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)
- 6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010
- — — 5 — — APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION
- * HYDROPUNCH SAMPLES COLLECTED IN 2009
- ** SAMPLE COLLECTED SECOND QUARTER 2008
- SCALE EXAGGERATION - 6.5:1 (H:V)
- ND = NOT DETECTED; THE DETECTION LIMIT FOR TCE IS 0.5 µg/L

NO SAMPLE/NO RECOVERY	WELL GRADED SAND (SW)	FAT CLAY (CH)
FILL/ASPHALT	SILTY SAND (SM)	SILTSTONE
TOPSOIL/ORGANIC SOIL	POORLY GRADED SAND (SP)	SANDSTONE
WELL GRADED GRAVEL (GW)	CLAYEY SAND (SC)	SHALE
POORLY GRADED GRAVEL (GP)	SILT (ML)	ALLUVIUM (NO DATA)
SILTY GRAVEL (GM)	ELASTIC SILT (MH)	
CLAYEY GRAVEL (GC)	LEAN CLAY (CL)	

FIGURE 3.1-29
SITE ST027B CROSS SECTION B–B'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\FFS\GPJ\TRAVIS_2010_SAMPLING_EVENT.GPJ;
ES092811144130SAC Figure_3.1-29.ai 09.29.2011 tdaus

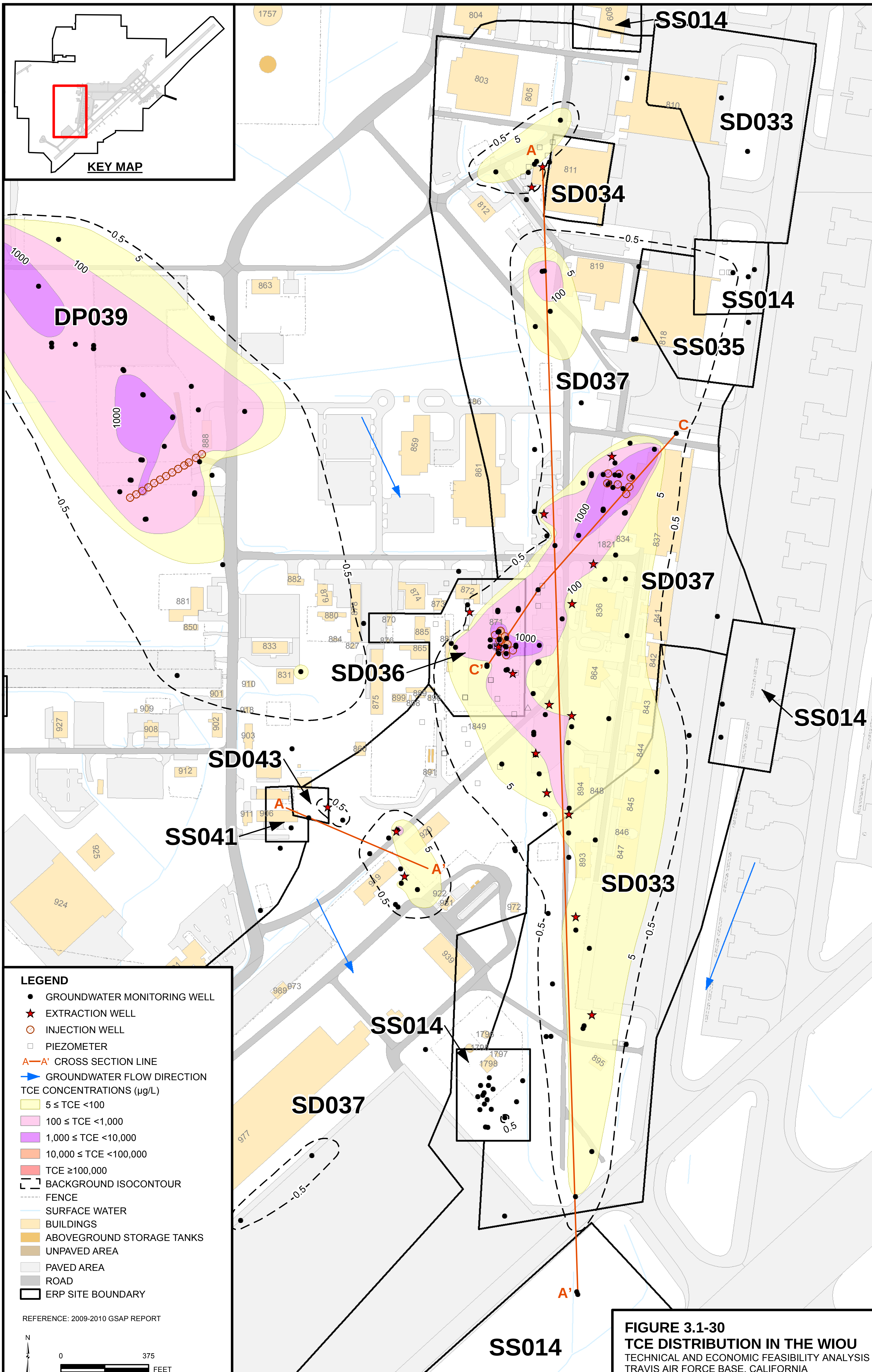


FIGURE 3.1-30
TCE DISTRIBUTION IN THE WIOU
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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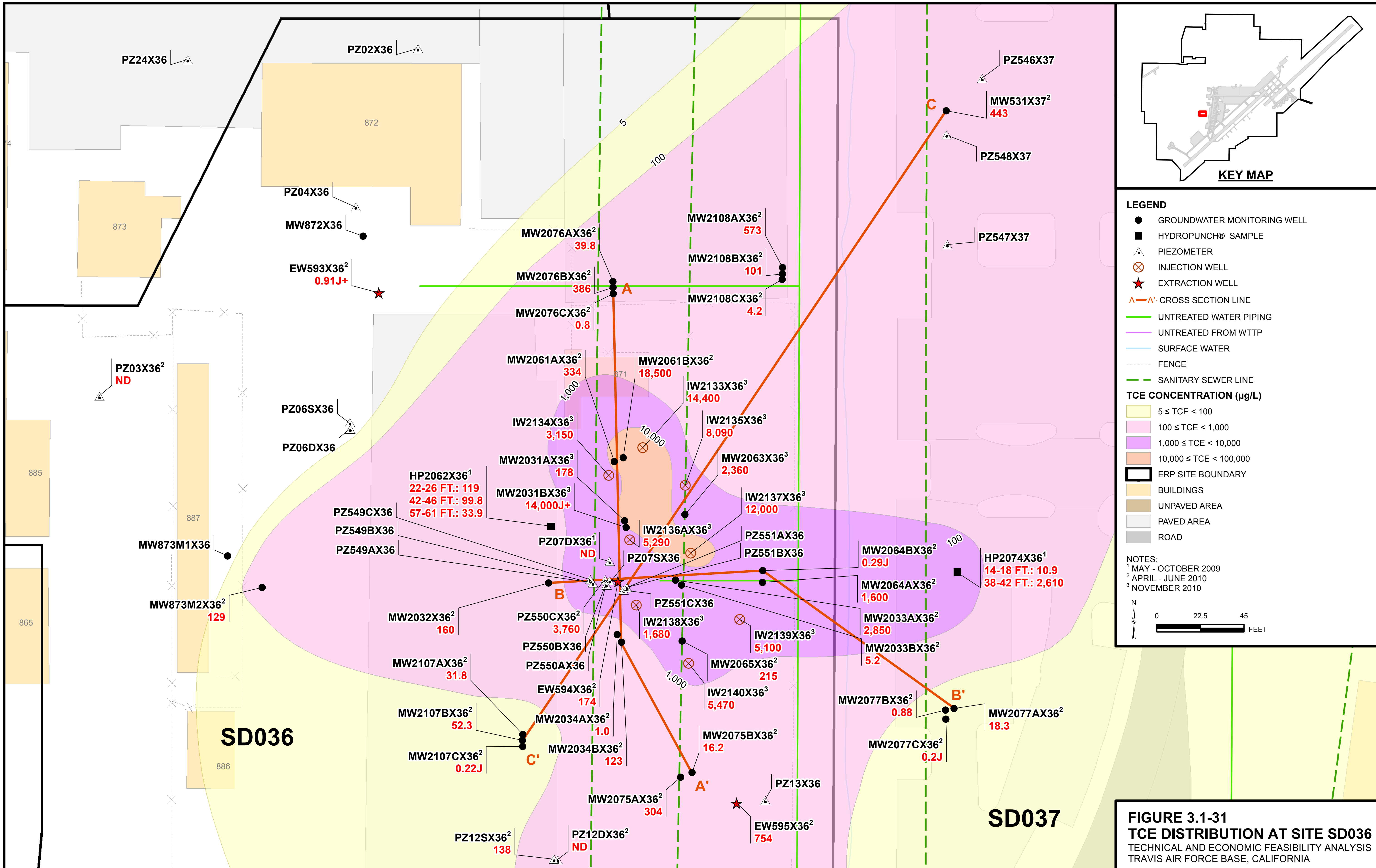
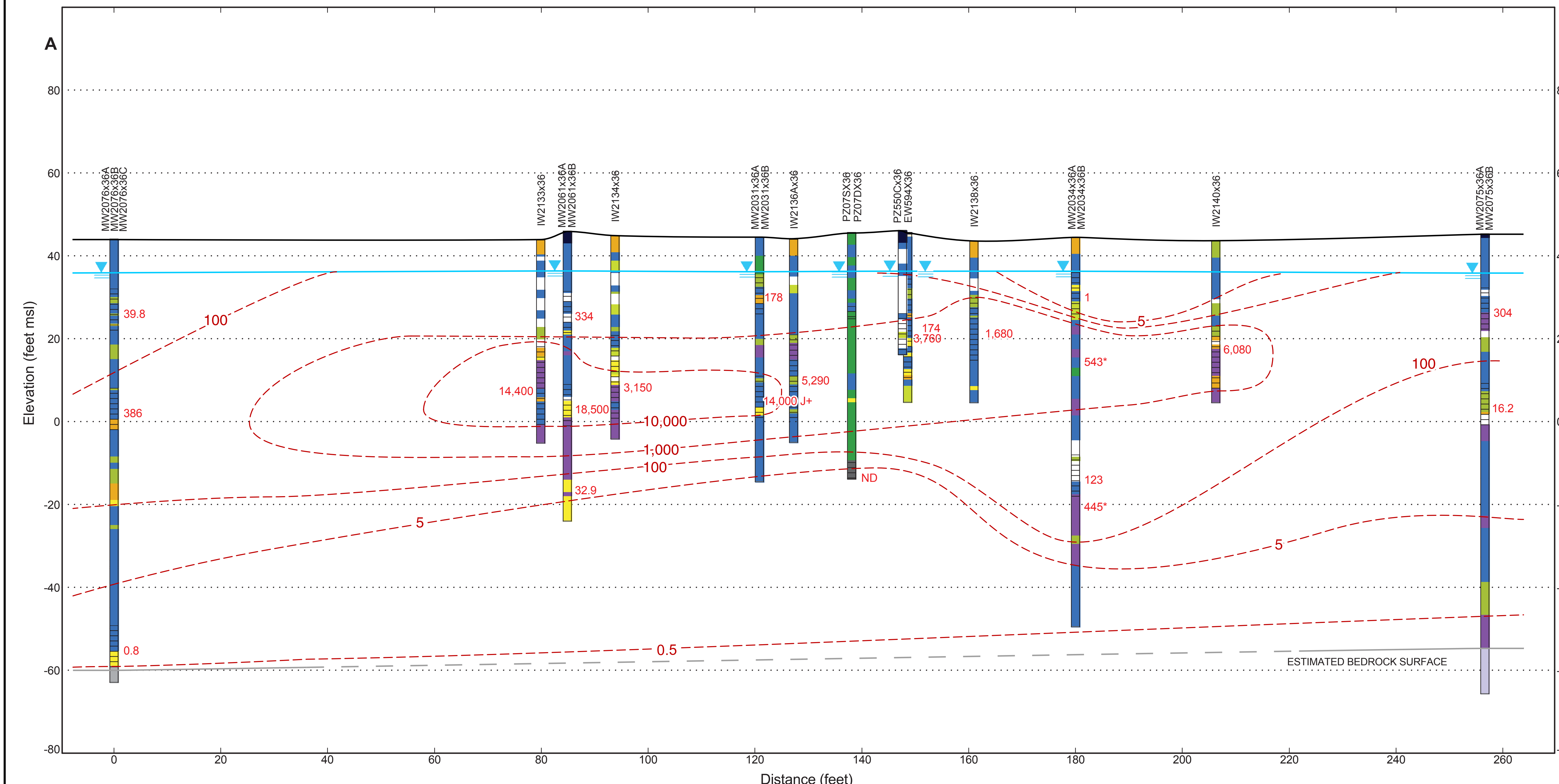


FIGURE 3.1-31
TCE DISTRIBUTION AT SITE SD036
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_1-31_TCE_SD036_ZOOM_TEFA.MXD MSCHROCK 10/4/2011 11:20:45 PM



SOIL AND LITHOLOGY

SCREEN INTERVAL	
APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)	
6.7	TCE CONCENTRATION (μg/L) DETECTED IN 2010
– – 5 – –	APPROXIMATE TCE ISOCONCENTRATION CONTOUR (μg/L) BASED ON MAX 2010 DETECTION
*	HYDROPUNCH GROUNDWATER SAMPLES
SCALE EXAGGERATION - 0.75:1 (H:V)	

NO SAMPLE/NO RECOVERY
FILL/ASPHALT
TOPSOIL/ORGANIC SOIL
WELL GRADED GRAVEL (GW)
POORLY GRADED GRAVEL (GP)
SILTY GRAVEL (GM)
CLAYEY GRAVEL (GC)
WELL GRADED SAND (SW)
POORLY GRADED SAND (SP)
SILTY SAND (SM)
CLAYEY SAND (SC)
SILT (ML)
ELASTIC SILT (MH)
LEAN CLAY (CL)
FAT CLAY (CH)
SILTSTONE
SANDSTONE
SHALE
ALLUVIUM (NO DATA)

FIGURE 3.1-32
SITE SD036 CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\FFS\GPJ\TRAVIS_2010_SAMPLING_EVENT.GPJ;
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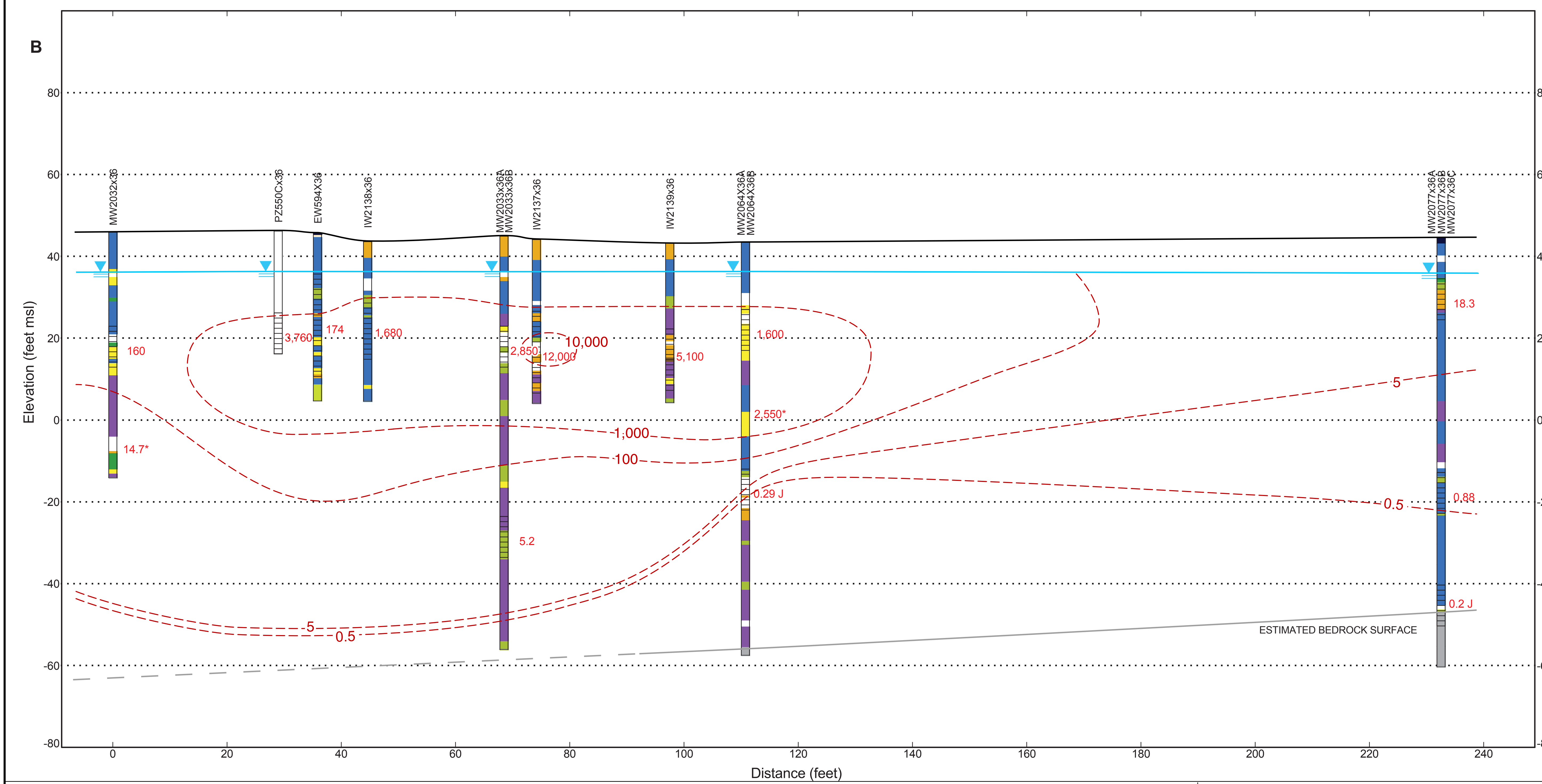


SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

– – 5 – – APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

* HYDROPUNCH GROUNDWATER SAMPLES

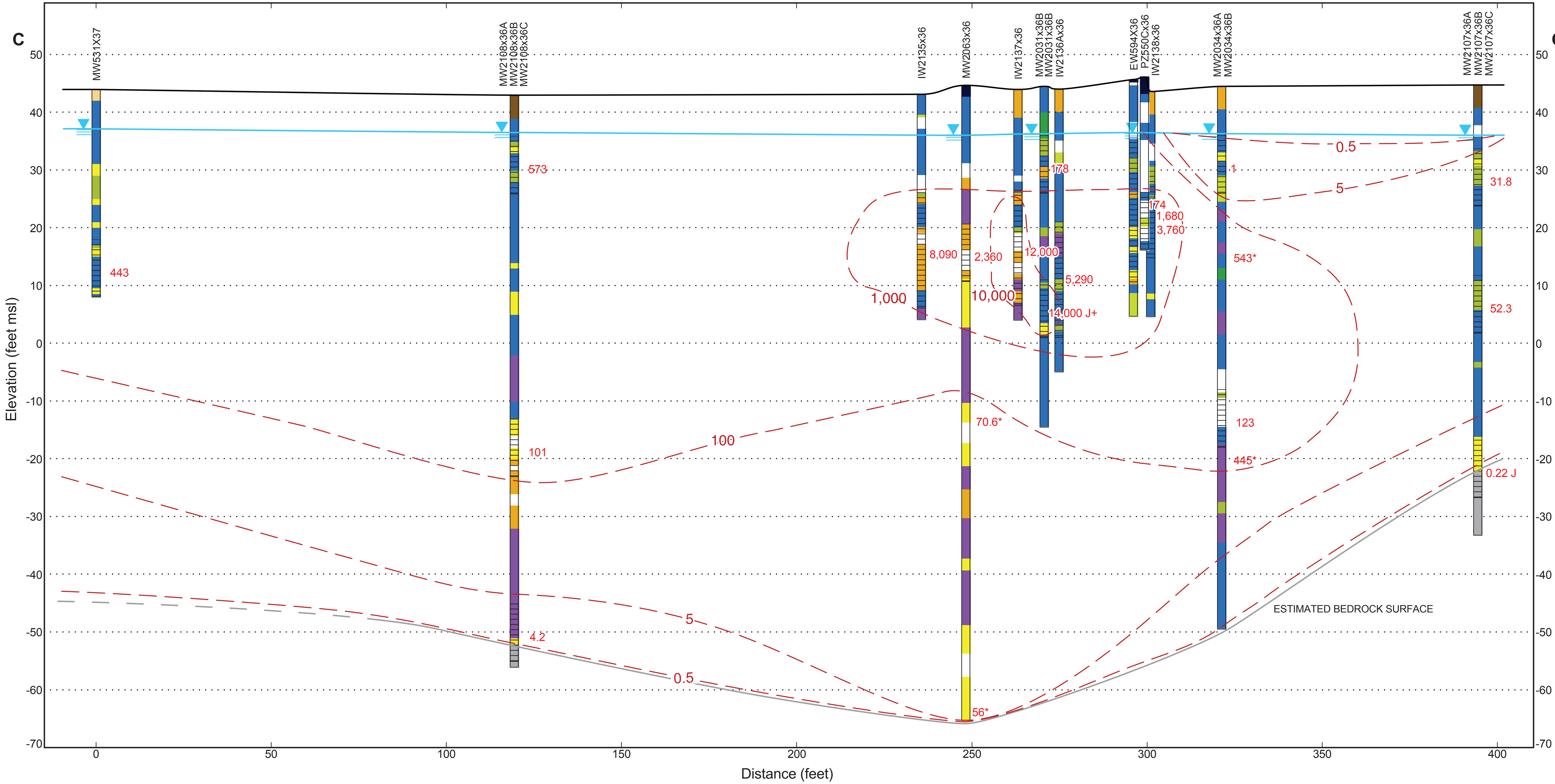
SCALE EXAGGERATION - 0.7:1 (H:V)

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- POORLY GRADED SAND (SP)
- SILTY SAND (SM)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-33
SITE SD036 CROSS SECTION B–B'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\FFS\GPJ\TRAVIS_2010_SAMPLING_EVENT.GPJ;
ES092811144130SAC Figure_3.1-33.ai 09.29.2011 tdaus



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

5 APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

* HYDROPUNCH GROUNDWATER SAMPLES

SCALE EXAGGERATION - 1.65:1 (H:V)

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- SILTY SAND (SM)
- POORLY GRADED SAND (SP)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE ALLUVIUM (NO DATA)
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-34
SITE SD036 CROSS SECTION C–C'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\2011\TRAVIS_2011.GPJ;
ES092811144130SAC Figure_3.1-34.ai 09.29.2011 tdaus

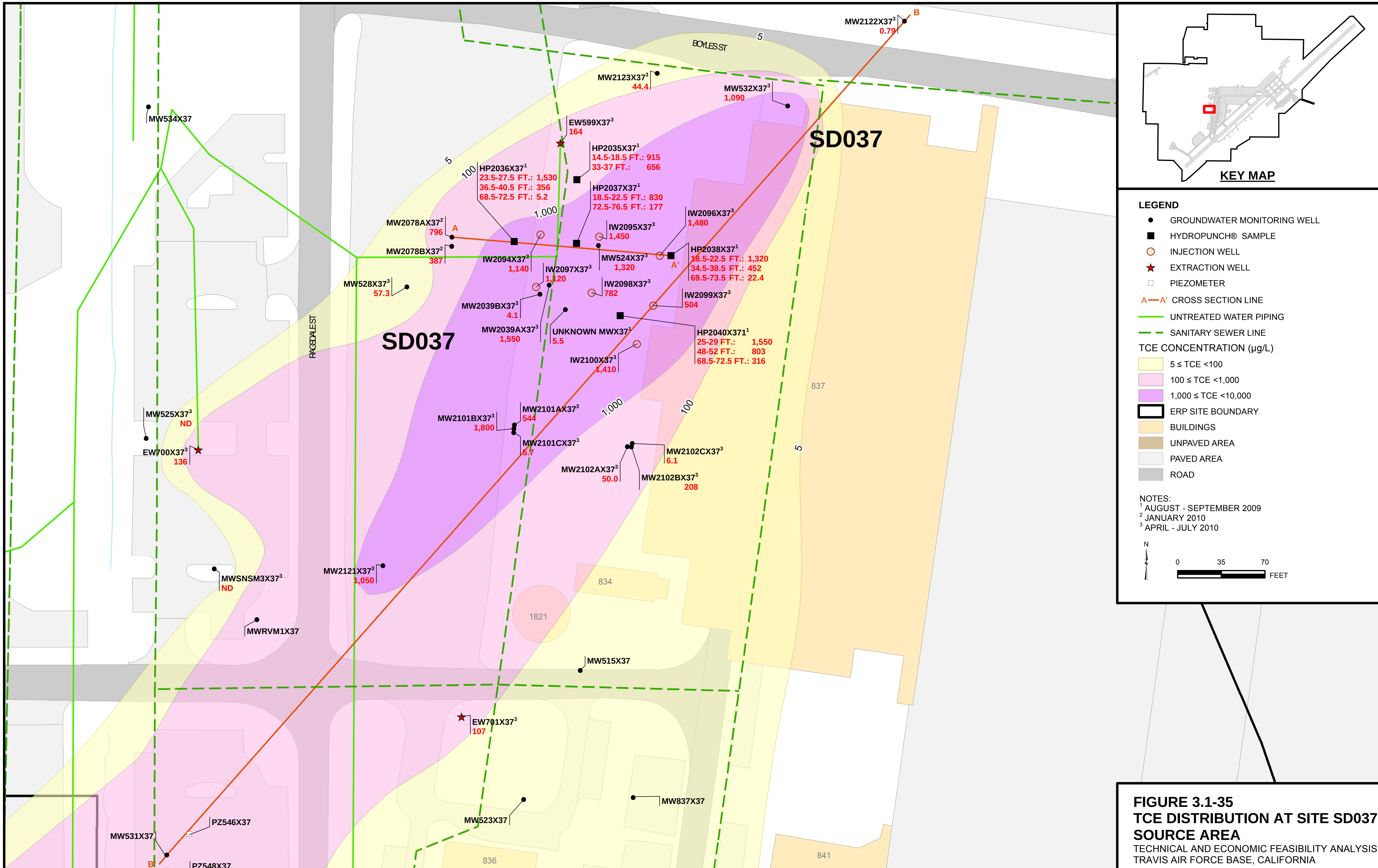
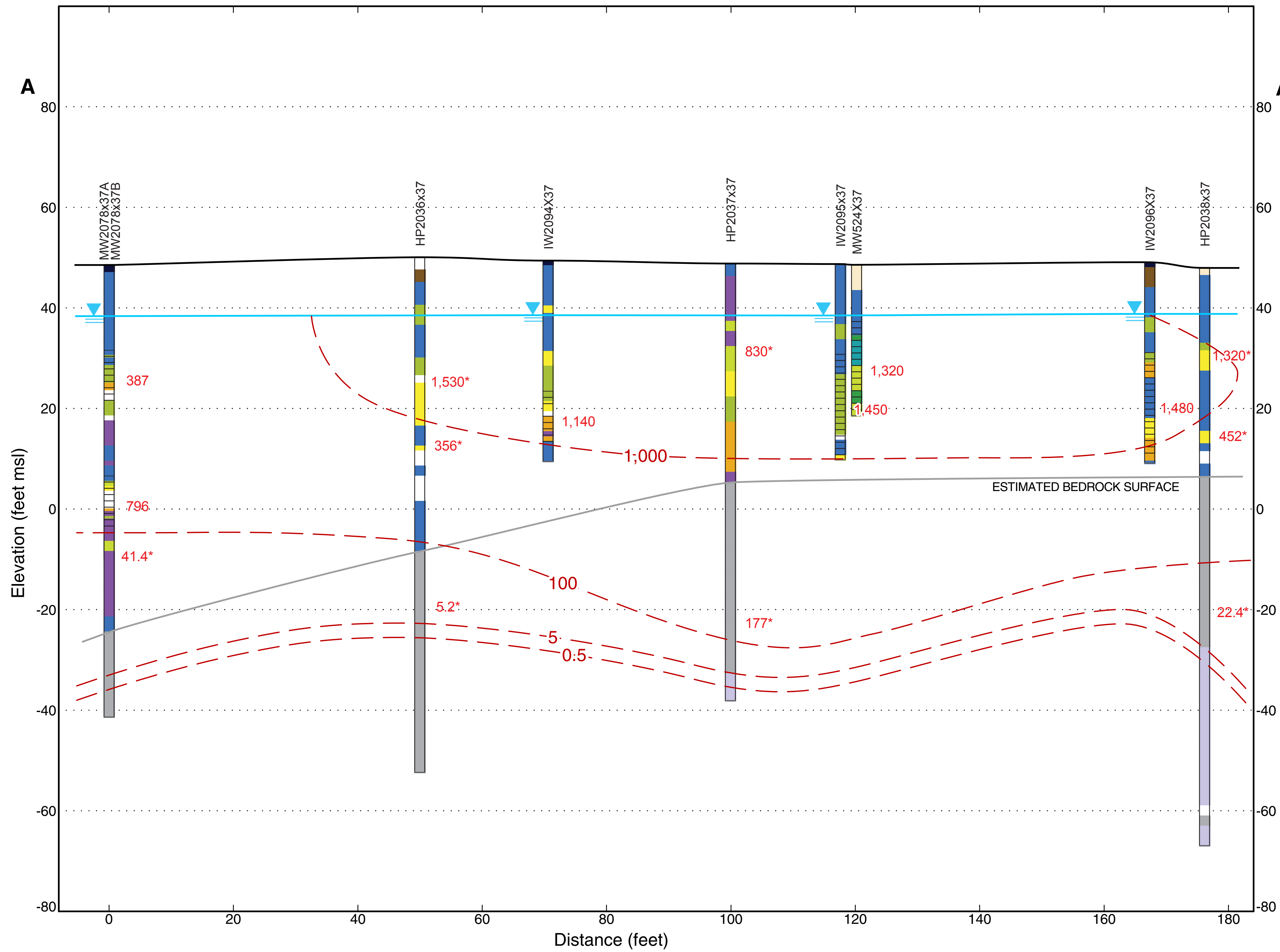


FIGURE 3.1-35
TCE DISTRIBUTION AT SITE SD037 SOURCE AREA
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_1-35_TCE_SD037_HOTSPOT_TEFA.MXD MSCHROCK 10/4/2011 11:26:47 PM



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

5 APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

* HYDROPUNCH GROUNDWATER SAMPLES

SCALE EXAGGERATION - 0.8:1 (H:V)

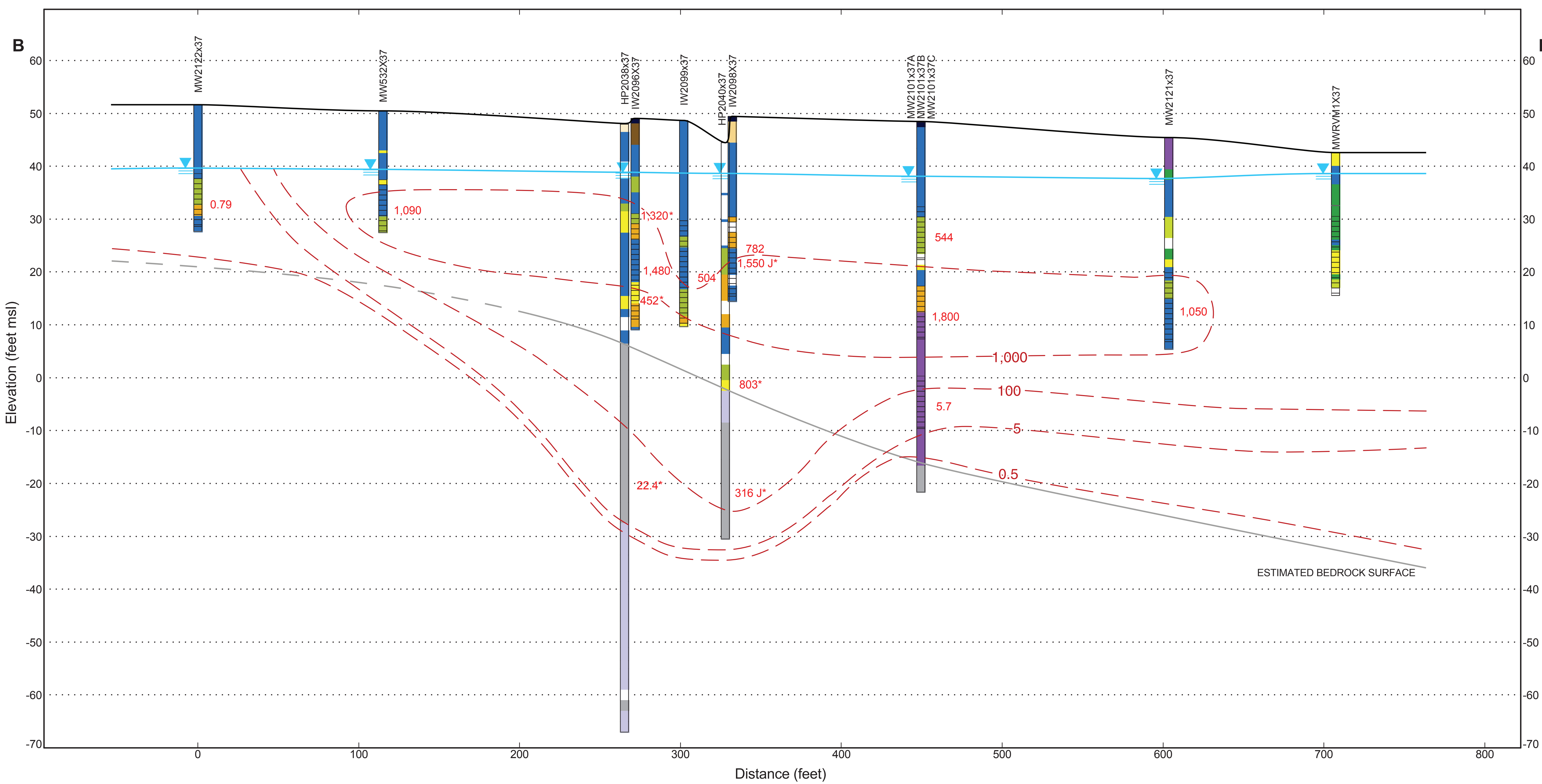
NO SAMPLE/NO RECOVERY
FILL/ASPHALT
TOPSOIL/ORGANIC SOIL
WELL GRADED GRAVEL (GW)
POORLY GRADED GRAVEL (GP)
SILTY GRAVEL (GM)
CLAYEY GRAVEL (GC)

WELL GRADED SAND (SW)
SILTY SAND (SM)
POORLY GRADED SAND (SP)
CLAYEY SAND (SC)
SILT (ML)
ELASTIC SILT (MH)
LEAN CLAY (CL)

FAT CLAY (CH)
SILTSTONE
SANDSTONE
SHALE
ALLUVIUM (NO DATA)

FIGURE 3.1-36
SITE SD037 CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

5 APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

* HYDROPUNCH GROUNDWATER SAMPLES

SCALE EXAGGERATION - 3.25:1 (H:V)

NO SAMPLE/NO RECOVERY

FILL/ASPHALT

TOPSOIL/ORGANIC SOIL

WELL GRADED GRAVEL (GW)

POORLY GRADED GRAVEL (GP)

SILTY GRAVEL (GM)

CLAYEY GRAVEL (GC)

WELL GRADED SAND (SW)

SILTY SAND (SM)

POORLY GRADED SAND (SP)

CLAYEY SAND (SC)

SILT (ML)

ELASTIC SILT (MH)

LEAN CLAY (CL)

FAT CLAY (CH)

SILTSTONE ALLUVIUM (NO DATA)

SANDSTONE

SHALE

ALLUVIUM (NO DATA)

FIGURE 3.1-37
SITE SD037 CROSS SECTION B–B'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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ES092811144130SAC Figure_3.1-37.ai 09.29.2011 tdaus

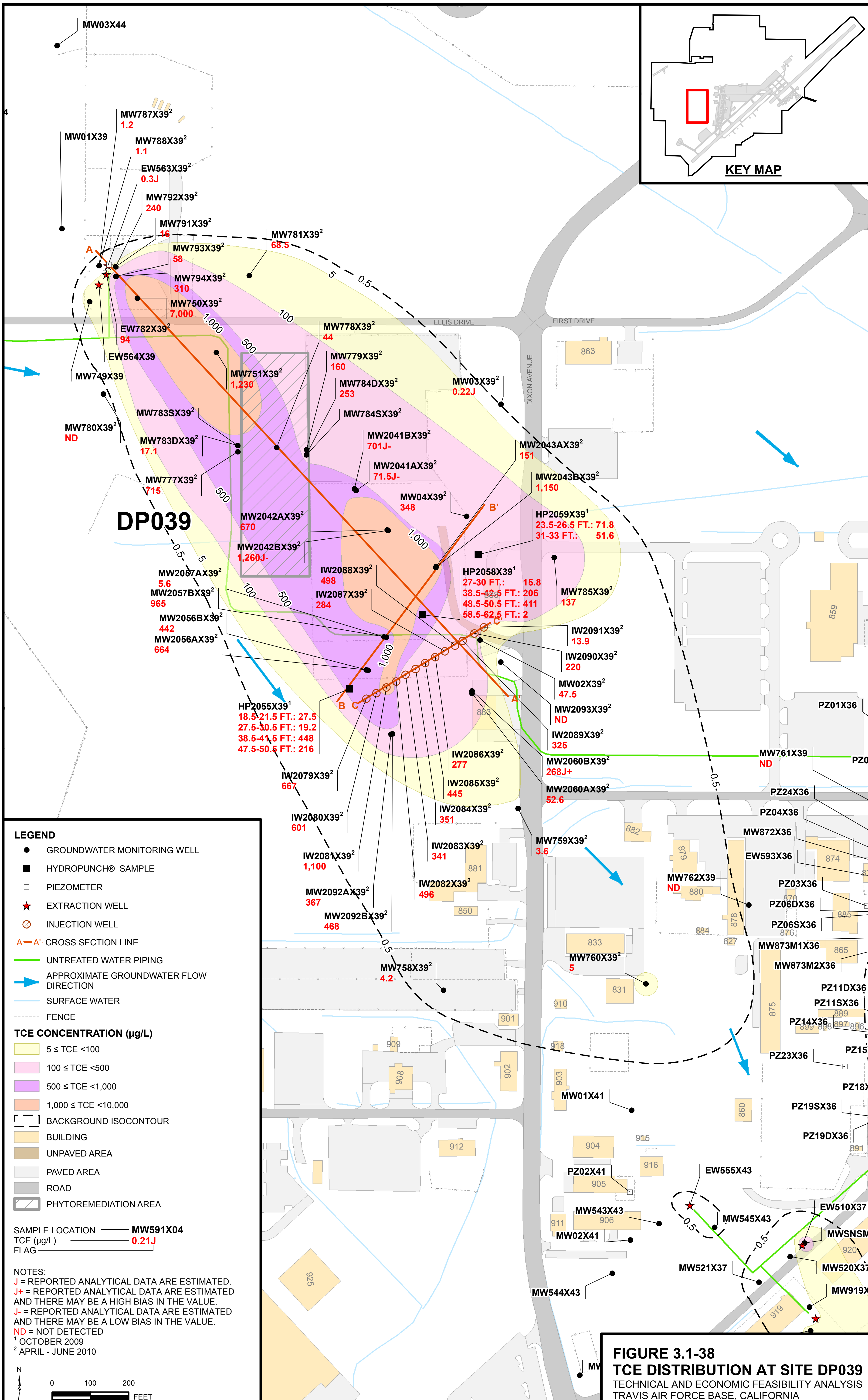
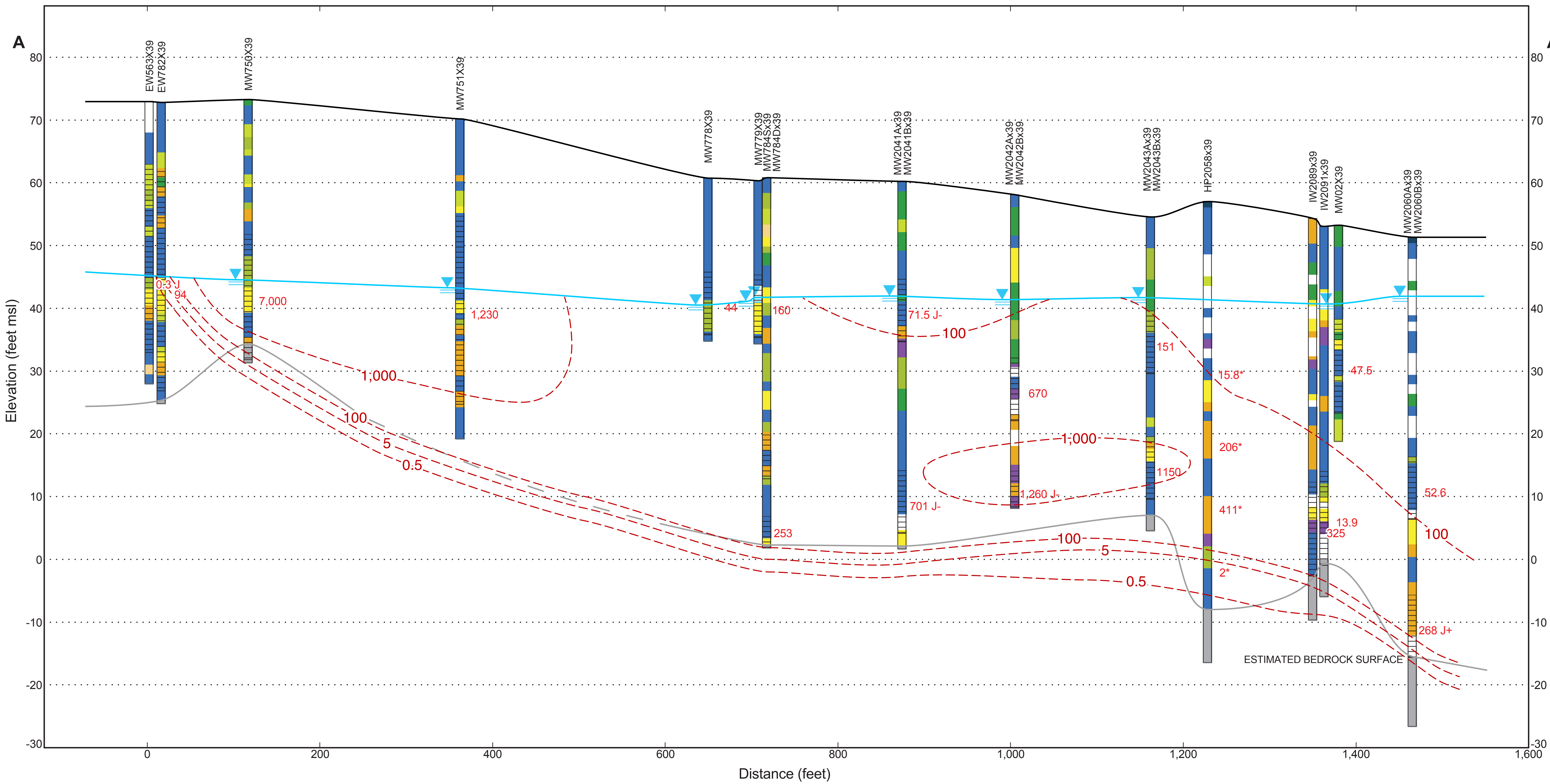


FIGURE 3.1-38
TCE DISTRIBUTION AT SITE DP039

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_1-38_TCE_DP039_ZOOM_TEFA.MXD MSCHROCK 10/4/2011 10:21:54 PM



SOIL AND LITHOLOGY

SCREEN INTERVAL	
APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)	
6.7	TCE CONCENTRATION (µg/L) DETECTED IN 2010
5	APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION
*	HYDROPUNCH GROUNDWATER SAMPLES
SCALE EXAGGERATION - 7.3:1 (H:V)	

NO SAMPLE/NO RECOVERY
FILL/ASPHALT
TOPSOIL/ORGANIC SOIL
WELL GRADED GRAVEL (GW)
POORLY GRADED GRAVEL (GP)
SILTY GRAVEL (GM)
CLAYEY GRAVEL (GC)
WELL GRADED SAND (SW)
SILTY SAND (SM)
POORLY GRADED SAND (SP)
CLAYEY SAND (SC)
SILT (ML)
ELASTIC SILT (MH)
LEAN CLAY (CL)
FAT CLAY (CH)
SILTSTONE
SANDSTONE
SHALE
ALLUVIUM (NO DATA)

FIGURE 3.1-39
SITE DP039 CROSS SECTION A-A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\2011\TRAVIS_2011.GPJ;
ES092811144130SAC Figure_3.1-39.ai 09.29.2011 tdaus

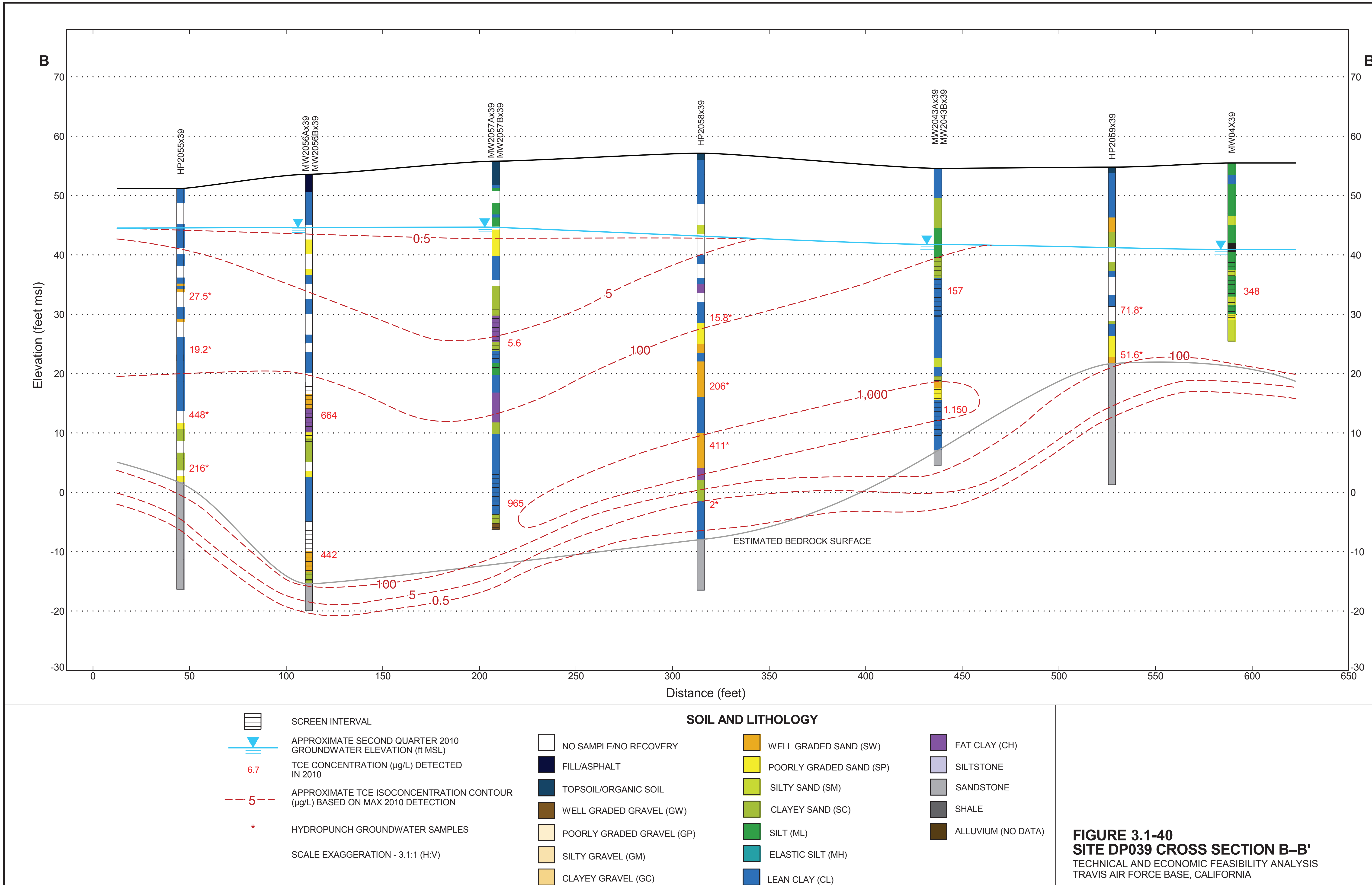
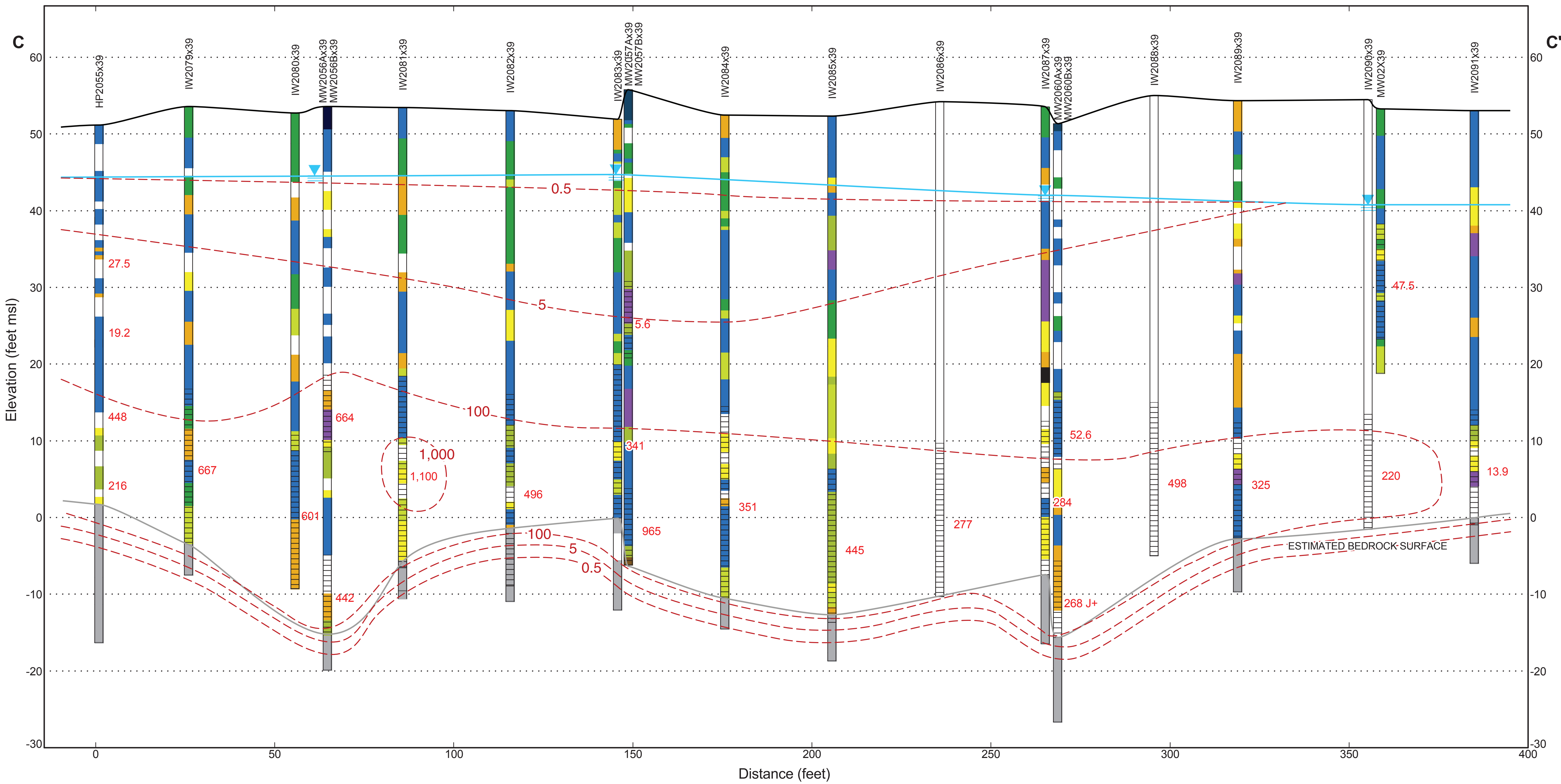


FIGURE 3.1-40
SITE DP039 CROSS SECTION B–B'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\2011\TRAVIS_2011.GPJ;
ES092811144130SAC Figure_3.1-40.ai 09.29.2011 tdaus



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

– – 5 – – APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

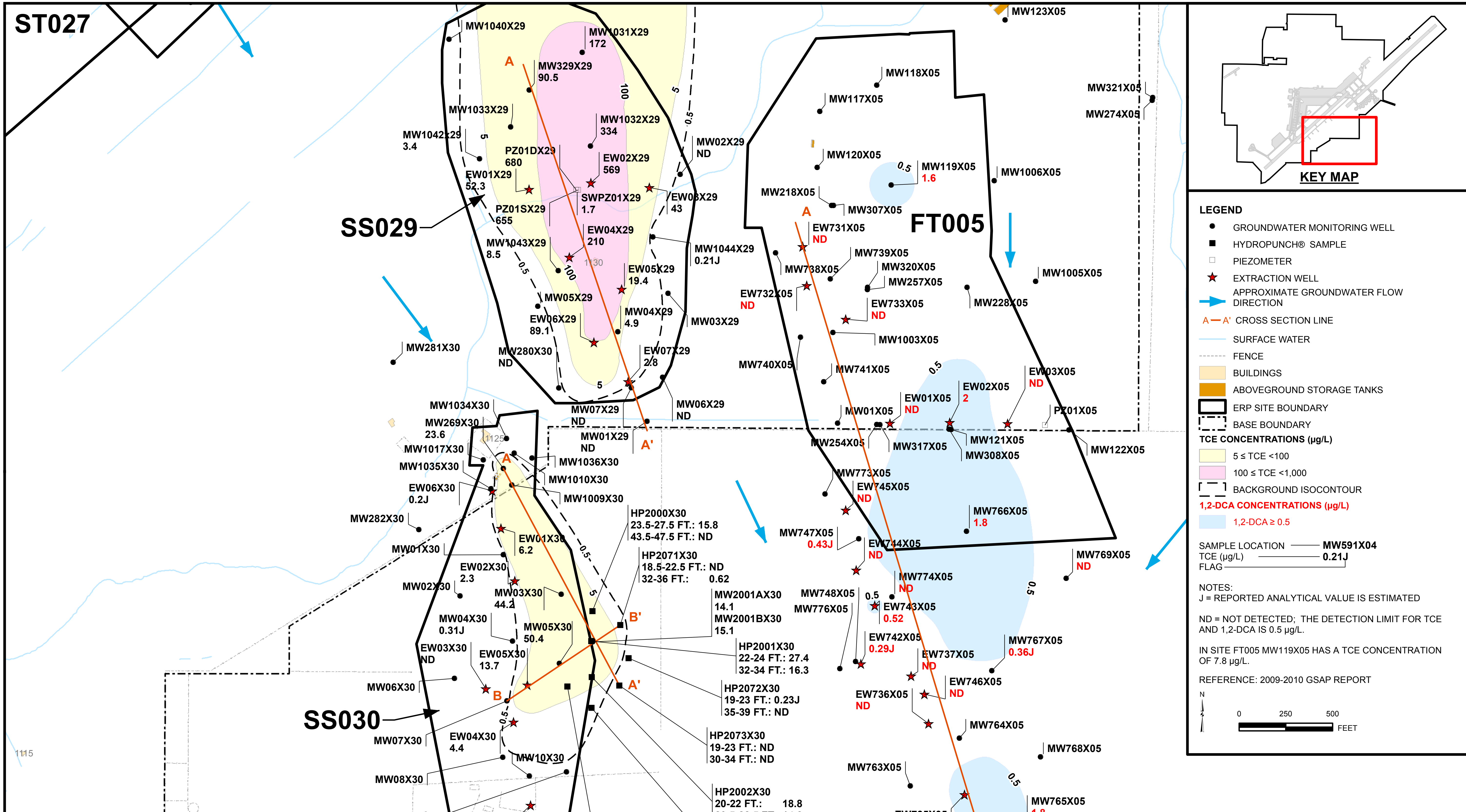
SCALE EXAGGERATION - 2.15:1 (H:V)

NO SAMPLE/NO RECOVERY
FILL/ASPHALT
TOPSOIL/ORGANIC SOIL
WELL GRADED GRAVEL (GW)
POORLY GRADED GRAVEL (GP)
SILTY GRAVEL (GM)
CLAYEY GRAVEL (GC)
WELL GRADED SAND (SW)
POORLY GRADED SAND (SP)
SILTY SAND (SM)
CLAYEY SAND (SC)
SILT (ML)
ELASTIC SILT (MH)
LEAN CLAY (CL)
FAT CLAY (CH)
SILTSTONE
SANDSTONE
SHALE
ALLUVIUM (NO DATA)

FIGURE 3.1-41
SITE DP039 CROSS SECTION C–C'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

A:\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\2011\TRAVIS_2011.GPJ;
ES092811144130SAC Figure_3.1-41.ai 09.29.2011 tdaus



LEGEND

- GROUNDWATER MONITORING WELL
- HYDROPUNCH® SAMPLE
- PIEZOMETER
- EXTRACTION WELL
- APPROXIMATE GROUNDWATER FLOW DIRECTION
- A — A' CROSS SECTION LINE
- SURFACE WATER
- FENCE
- BUILDINGS
- ABOVEGROUND STORAGE TANKS
- ERP SITE BOUNDARY
- BASE BOUNDARY

TCE CONCENTRATIONS (μg/L)

- 5 ≤ TCE <100
- 100 ≤ TCE <1,000
- BACKGROUND ISOCONTOUR

1,2-DCA CONCENTRATIONS (μg/L)

- 1,2-DCA ≥ 0.5

SAMPLE LOCATION — MW591X04
TCE (μg/L) — 0.21J
FLAG

NOTES:
J = REPORTED ANALYTICAL VALUE IS ESTIMATED

ND = NOT DETECTED; THE DETECTION LIMIT FOR TCE AND 1,2-DCA IS 0.5 μg/L.

IN SITE FT005 MW119X05 HAS A TCE CONCENTRATION OF 7.8 μg/L.

REFERENCE: 2009-2010 GSAP REPORT

N

0 250 500
FEET

FIGURE 3.1-42
TCE DISTRIBUTION AT SITES SS029/SS030 AND 1,2-DCA DISTRIBUTION AT SITE FT005
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_1-42_DCA_FT005_TEFA.MXD MSCHROCK 10/4/2011 11:53:26 PM

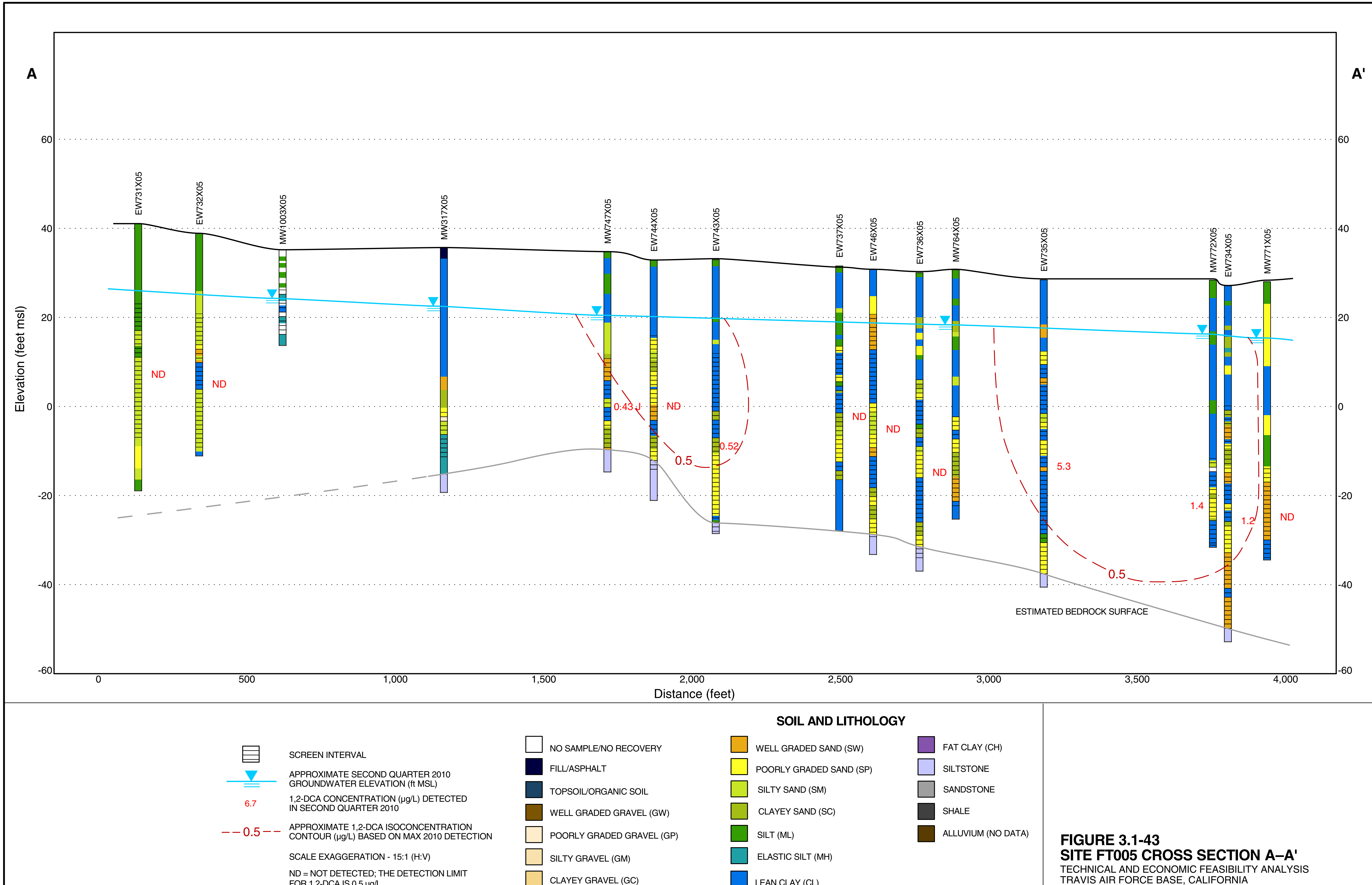
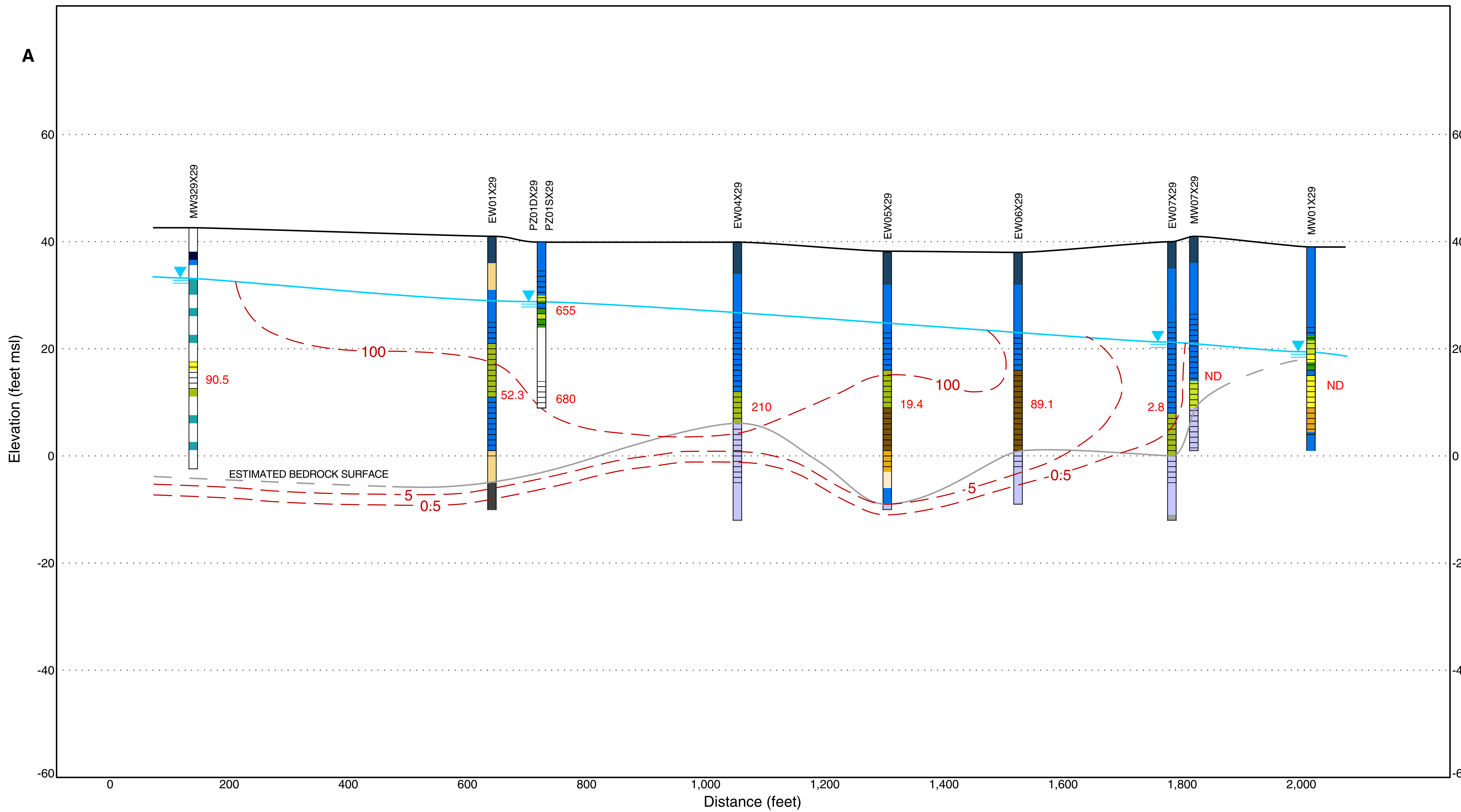


FIGURE 3.1-43
SITE FT005 CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINTFILES\TRAVIS_AFB_GINT_SECTIONS\MASTER_DATA\TRAVIS051110\TRAVIS_2010_SAMPLING_EVENT.GPJ;
ES092811144130SAC Figure_3.1-43.ai 09.29.2011 tdaus



SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN SECOND QUARTER 2010

5 APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 9:1 (H:V)

ND = NOT DETECTED; THE DETECTION LIMIT FOR TCE IS 0.5 µg/L

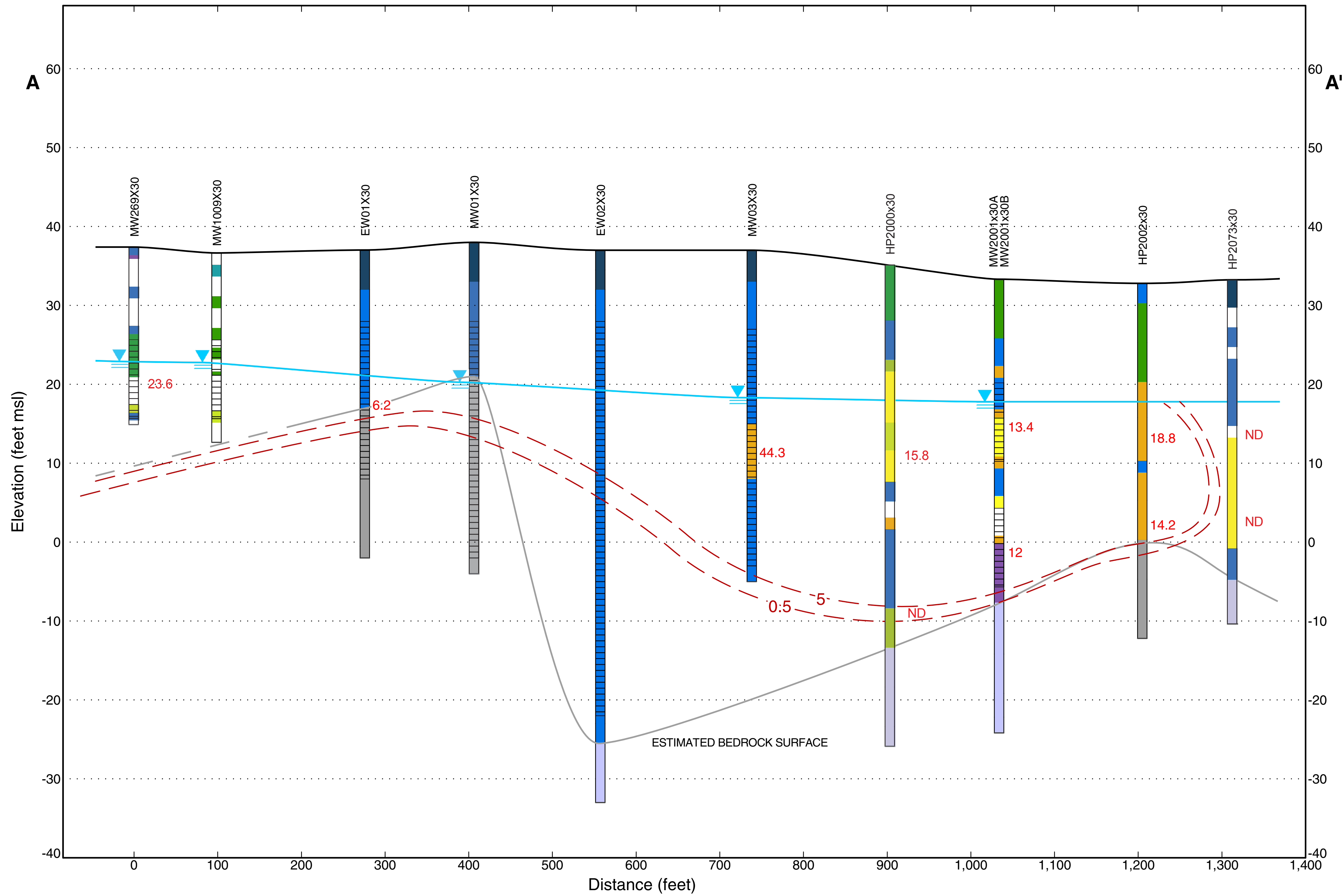
SOIL AND LITHOLOGY

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- POORLY GRADED SAND (SP)
- SILTY SAND (SM)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-44
SITE SS029 CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\TRAVIS_AFB_GINT_SECTIONS\MASTER_DATA\TRAVIS 051110\TRAVIS_2010_SAMPLING_EVENT.GPJ;
ES092811144130SAC Figure_3.1-44.ai 09.29.2011 tdaus



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

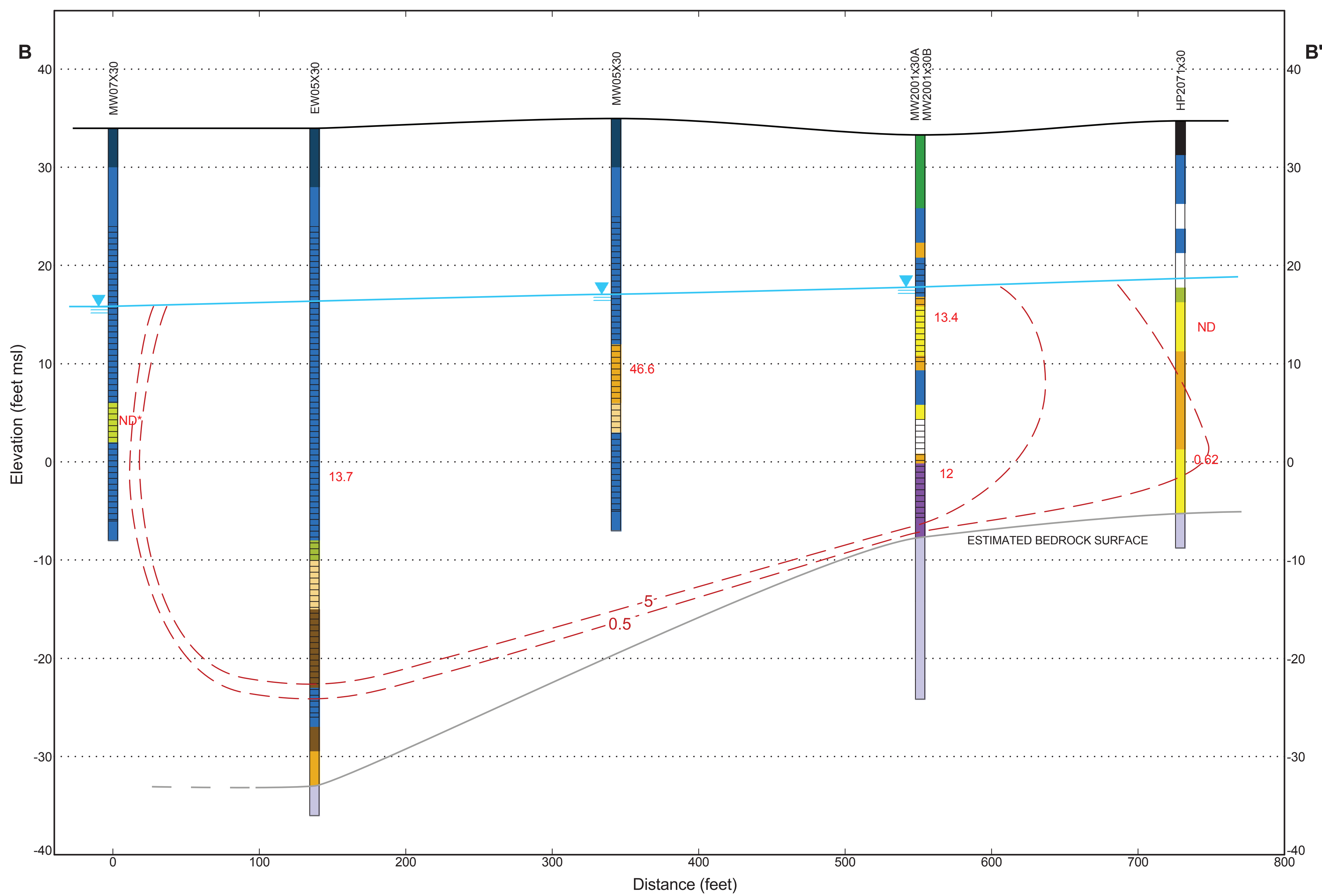
5 APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

SCALE EXAGGERATION - 9.5:1 (H:V)

- NO SAMPLE/NO RECOVERY
- FILL/ASPHALT
- TOPSOIL/ORGANIC SOIL
- WELL GRADED GRAVEL (GW)
- POORLY GRADED GRAVEL (GP)
- SILTY GRAVEL (GM)
- CLAYEY GRAVEL (GC)
- WELL GRADED SAND (SW)
- SILTY SAND (SM)
- POORLY GRADED SAND (SP)
- CLAYEY SAND (SC)
- SILT (ML)
- ELASTIC SILT (MH)
- LEAN CLAY (CL)
- FAT CLAY (CH)
- SILTSTONE
- SANDSTONE
- SHALE
- ALLUVIUM (NO DATA)

FIGURE 3.1-45
SITE SS030 CROSS SECTION A–A'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL



SOIL AND LITHOLOGY

SCREEN INTERVAL

APPROXIMATE SECOND QUARTER 2010 GROUNDWATER ELEVATION (ft MSL)

6.7 TCE CONCENTRATION (µg/L) DETECTED IN 2010

5 APPROXIMATE TCE ISOCONCENTRATION CONTOUR (µg/L) BASED ON MAX 2010 DETECTION

* SAMPLE COLLECTED JUNE, 2009

SCALE EXAGGERATION - 7:1 (H:V)

NO SAMPLE/NO RECOVERY
FILL/ASPHALT
TOPSOIL/ORGANIC SOIL
WELL GRADED GRAVEL (GW)
POORLY GRADED GRAVEL (GP)
SILTY GRAVEL (GM)
CLAYEY GRAVEL (GC)

WELL GRADED SAND (SW)
SILTY SAND (SM)
POORLY GRADED SAND (SP)
CLAYEY SAND (SC)
SILT (ML)
ELASTIC SILT (MH)
LEAN CLAY (CL)

FAT CLAY (CH)
SILTSTONE
ALLUVIUM (NO DATA)
SANDSTONE
SHALE
ALLUVIUM (NO DATA)

FIGURE 3.1-46
SITE SS030 CROSS SECTION B–B'
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\YOSEMITE\PROJ\TRAVISAIRFORCEBASE\COMMONFILES\GINT FILES\2011\TRAVIS_2011.GPJ;
ES092811144130SAC Figure_3.1-46.ai 10.04.2011 tdaus

3.2 Environmental Factor B: Hydrogeological Characteristics of the Facility and Surrounding Land

This section describes the hydrogeologic characteristics of the subsurface at Travis AFB and surrounding areas. Additional descriptions of these characteristics are provided in Section 3 of the Basewide Groundwater FFS (CH2M HILL, 2011a) and in the final GSAP 2009-2010 Annual Report (CH2M HILL, 2011c).

3.2.1 Geologic Setting

The following subsections describe the geomorphology, stratigraphy and geologic history, and lithologic units at Travis AFB.

3.2.1.1 Geomorphology

Travis AFB is on the western edge of the Sacramento Valley segment of the Great Valley Geomorphic Province. The Great Valley Province is a southeast-trending, sediment-filled basin. The Coast Range Geomorphic Province, which consists of folded and uplifted bedrock mountains, lies to the west of Travis AFB (Thomasson et al., 1960; Olmstead and Davis, 1961).

The geomorphology of Travis AFB is characterized by gently sloping alluvial plains and fans overlying undulating bedrock. Coalescing, low-relief fans were deposited by the Ulatis, Union, Alamo, Laurel, and Suisun creeks in the area. Most of the alluvial material was deposited before the last period of glaciation during the Pleistocene Epoch and is referred to as Older Alluvium. Drainages were incised into the alluvial fans during the last glaciation in response to the global lowering of the sea level. During the last 15,000 years, as sea levels have risen, the drainages have refilled with alluvium. This material is referred to as Younger Alluvium. Topographic relief in the form of low ridges is provided by outcrops of sedimentary rocks characterized as bedrock in the Travis AFB area. These outcrops are mantled by colluvium deposited by sheetwash and mass wasting from the ridges. The colluvium interfingers with the alluvium, and the two (2) units are indistinguishable in the field.

3.2.1.2 Stratigraphy and Geologic History

Older Alluvium makes up most of the sediment found on the Base. Alluvium beneath Travis AFB ranges in thickness from 0 to about 110 feet. The alluvium is underlain by bedrock consisting of semi-consolidated to consolidated sedimentary units; the alluvium and bedrock are sometimes difficult to distinguish in the field. The alluvium consists primarily of silts and clays that are low in permeability and do not transmit groundwater readily. More permeable units, such as sands and gravels, are geographically restricted and occur as lenses rather than as continuous beds that may be correlated from place to place. A geologic map and generalized cross section illustrating the alluvium and shallow bedrock units in the vicinity of Travis AFB are shown on Figures 3.2-1 and 3.2-2.

Alluvium was carried in several streams (such as Union Creek) that have migrated laterally across the Base. Coarse sands and gravels are deposited in the streambed and immediately adjacent to the stream levee; finer silts and clays are deposited away from the stream during flood events. Consequently, the discontinuous sand lenses are usually elongated parallel to streams and are contained in an overall matrix of fine-grained silts and clays in the vicinity of Travis AFB. Sand lenses throughout the Base trend south-southeast. These discontinuous permeable zones are preferential pathways that create anisotropic groundwater flow in the horizontal plane.

Bedrock in the area includes Tertiary and Pliocene sedimentary rocks overlying Late Cretaceous sedimentary rocks. Individual stratigraphic units outcropping on the Base include, from oldest to youngest, the Domengine Sandstone, the Nortonville Shale, the Markley Sandstone, and the Tehama Formation. Outcrops of the relatively resistant bedrock units form most of the topographic high points on the Base. For example, the Markley Sandstone outcrops in the northeastern corner of the Base and forms the low ridge separating the WIOU from the EIOU (refer to Figure 3.2-1). The Domengine Sandstone forms Hospital Hill at the Consolidated Support Center (the old Base hospital). The Tehama Formation creates the low hills that make up the relief in the western part of the Base in the WABOU.

The northwest-southeast trending axes of folds in the rocks are evident in the bedrock outcrops on the Base. Erosion of the less-resistant bedrock units, such as the Nortonville Shale, formed the low areas that were later filled with alluvium. These valleys, created by down-cutting of ancient streams into the folded bedrock during the Pleistocene Epoch, are filled with alluvium, as described. The folded units are observed to plunge to the southeast; the depth to bedrock in the alluvium-filled valleys increases to the south.

3.2.1.3 Lithologic Units

Two (2) primary lithologic units underlay Travis AFB. The origin and composition of these units are described below.

Alluvium. The vast majority of surface deposits at Travis AFB are alluvial sediments. This alluvial unit has relatively low permeability and is composed primarily of silt and clay with minor amounts of sand. The sand units occur as small heterogeneous lenses that are laterally discontinuous across the Base. The alluvium is predominantly fluvial in origin; however, some colluvium eroded from bedrock uplands may also be present. All of the unconsolidated sediments discussed in this conceptual site model are referred to as the alluvium.

Bedrock. The bedrock beneath Travis AFB is primarily sandstone and shale (see discussion above for Formation names and ages). The top of the bedrock unit is weathered to varying degrees and varying thickness. Consequently, bedrock generally becomes increasingly competent with depth. The composition of the most weathered portions reflects the composition of the parent material (sand and silt) and therefore may have similar permeability to the overlying alluvium. No field testing of bedrock permeability has been conducted at the Base, but unweathered bedrock is likely to have much lower permeability than the alluvium.

3.2.2 Groundwater

Travis AFB is located along the eastern edge of the Fairfield-Suisun Hydrologic Basin, a hydrologically distinct structural depression adjacent to the Sacramento Valley segment of the Central Valley Province. The primary water-bearing deposits at Travis AFB are the coarse-grained sediments (sand and gravel) within the extremely heterogeneous Older Alluvium and Younger Alluvium. At Travis AFB, alluvium reaches a maximum thickness of approximately 110 feet. The depth to groundwater at Travis AFB is typically 10 to 15 feet bgs. In general, groundwater elevations have remained relatively constant over time. Groundwater elevations typically fluctuate from 2 to 5 feet in between fall and spring, with the maximum elevations in spring and the minimum elevations in fall.

The regional groundwater gradient is generally toward the south or southeast. Groundwater recharge occurs from the direct infiltration of rainfall on the valley surface and from the infiltration of runoff through local streambeds and creek beds. Natural groundwater discharge occurs at the marshlands near Potrero Hills, south of Travis AFB (Thomasson et al., 1960).

The groundwater flow system at Travis AFB is influenced by the configuration of alluvium and bedrock at the Base. Flow within the alluvium is consistently to the south, as indicated by the groundwater elevation map shown on Figure 3.2-3. However, three (3) groundwater mounds are visible on the figures. Groundwater in the immediate vicinity of a mound flows radially away from the mound and then rejoins the regional southerly flow. This flow occurs because bedrock geologic materials in the vicinity of the mound are less permeable than materials surrounding the mound.

One (1) of the mounds is in the extreme northeastern corner of the Base in the vicinity of Site LF007 (Landfill 2). This site is above a shallow bedrock ridge composed of Markley Sandstone. In the vicinity of this mound, groundwater flows off-base to the north for a short distance before moving either east or west to follow the regional gradient. This has resulted in the off-base TCE groundwater contamination originating from Site LF007C.

A second groundwater mound is located in the northeastern corner of the Base, about 3,500 feet southwest of the mound at Site LF007. This mound is beneath a high point of surface topography known as Hospital Hill, formed by an outcrop of Domengine Sandstone. Between these two (2) mounds in northeastern Travis AFB, the groundwater flows south-southeast, paralleling a depression in the bedrock filled with alluvium underlain by Nortonville Shale.

A third mound is in the western corner of the Base in the WABOU. The mound also corresponds to a high point of surface topography formed by near-surface and outcropping Tehama Formation materials. Groundwater in this area flows away from the mound to both the north and the south. The north-flowing groundwater curves to the east and then to the southeast, following the regional gradient.

Shallow bedrock also influences groundwater flow in the central portion of the Base. A northwest-to-southeast-trending ridge of Markley Sandstone runs approximately along the boundary of the WIOU and the EIOU; it results in a groundwater flow divide in the groundwater elevation contours (refer to Figure 3.2-3). Groundwater in this area flows southeast or southwest away from the divide that also may form a barrier to the movement of contaminants. The ridge plunges to the south, however, and probably affects groundwater flow less in the southern portion of the Base.

Groundwater contours on each side of the ridge of Markley Sandstone in the central portion of the Base (refer to Figure 3.2-3) indicate the diverging directions of flow in the valleys filled with alluvium. The more permeable alluvium provides a preferential pathway for groundwater flow.

3.2.2.1 Aquifer Stratigraphy

The aquifer system underlying Travis AFB should be viewed as a single leaky and heterogeneous aquifer system of unconsolidated alluvium, as opposed to one (1) with multiple and distinct aquifers. The sediments consist primarily of fine-grained silts and clays with interbedded sand lenses that do not correlate well from one (1) location to another. The depth to bedrock is fairly shallow (i.e., a few feet to tens of feet); thus, the saturated thickness of the aquifer is small compared with the length of the groundwater contaminant plumes. It is not usually possible to predict with confidence where the more permeable sand lenses may be encountered or interconnected.

The saturated alluvium thickness at Travis AFB is typically up to 80 feet, and averages approximately 28 feet. Localized thicknesses up to about 100 feet are found in the vicinity of Site SD036. A map of the saturated alluvium thickness at Travis AFB and vicinity is shown on Figure 3.2-4. This map was generated by subtracting the elevation of the bedrock surface from the elevation of the steady state water table using the latest version of the TBGFM.

3.2.2.2 Groundwater Flow Velocity

Groundwater at Travis AFB is found under unconfined or semi-confined conditions and flows in a predominantly horizontal direction. Typical groundwater flow rates in the alluvium in the Base area are on the order of 100 to 200 feet per year (ft/year), assuming an effective porosity of 20 percent, which is typical for the fine-grained sediments encountered at the Base.

3.2.2.3 Horizontal and Vertical Gradients

The following subsections briefly describe the groundwater horizontal and vertical gradients at Travis AFB. More complete information is provided in the regularly issued GSAP reports.

Horizontal Gradients. Groundwater at Travis AFB flows primarily south, except where groundwater mounds or depressions exist. Local variations in flow direction are the result of the subsurface geology and groundwater pumping. The groundwater elevation contours shown on Figure 3.2-3 indicate the direction and magnitude of groundwater flow (i.e., from higher to lower potential). Typically, the horizontal gradients in the alluvium at Travis AFB range from 0.004 to 0.008 feet per foot (ft/ft). Where groundwater mounds exist, the horizontal gradients are relatively steep (approximately 0.02 ft/ft) when compared with the horizontal gradients in the alluvial basins away from the mounds. The horizontal gradients typically observed in bedrock are approximately 0.01 ft/ft.

Vertical Gradients. In general, the magnitudes of vertical gradients in the alluvium at Travis AFB are less than 0.1 ft/ft. Only a well pair at Site LF008 (MW115x08 and MW311x08) consistently indicates a relatively large downward vertical gradient (-0.1 ft/ft). This downward vertical gradient reflects the location of Site LF008 in a groundwater recharge zone on a topographic high point for the Base. Groundwater tends to flow downward away from these high points.

The greatest upward vertical gradient in the alluvium encountered during recent GSAP events was 0.1 ft/ft at Site SS015 well pair MW624x15/MW2103x15 and at Site DP039 well pair MW2057Ax39/MW2057Bx39. These are new monitoring well pairs (installed in 2010); therefore, it is unknown whether a large upward gradient is typical for these locations. However, the vertical gradients calculated at the six (6) other new Site DP039 well pairs were less than 0.1 ft/ft in magnitude, and the direction of the gradient was variable.

The vertical gradient in alluvium-bedrock well pairs typically has an upward gradient ranging from 0.001 ft/ft downward to 0.1 ft/ft upward. The one (1) well pair that is an exception is MW214x16/MW305x16 at 0.001 ft/ft downward. However, historically, this well pair has had an upward or neutral vertical gradient.

The vertical gradient is defined as the difference in groundwater elevations between two (2) adjacent wells divided by the vertical distance between the midpoints of the well screens. The vertical gradient is used to evaluate the potential for groundwater to flow upward (positive gradient) or downward (negative gradient).

3.2.2.4 Hydraulic Conductivity

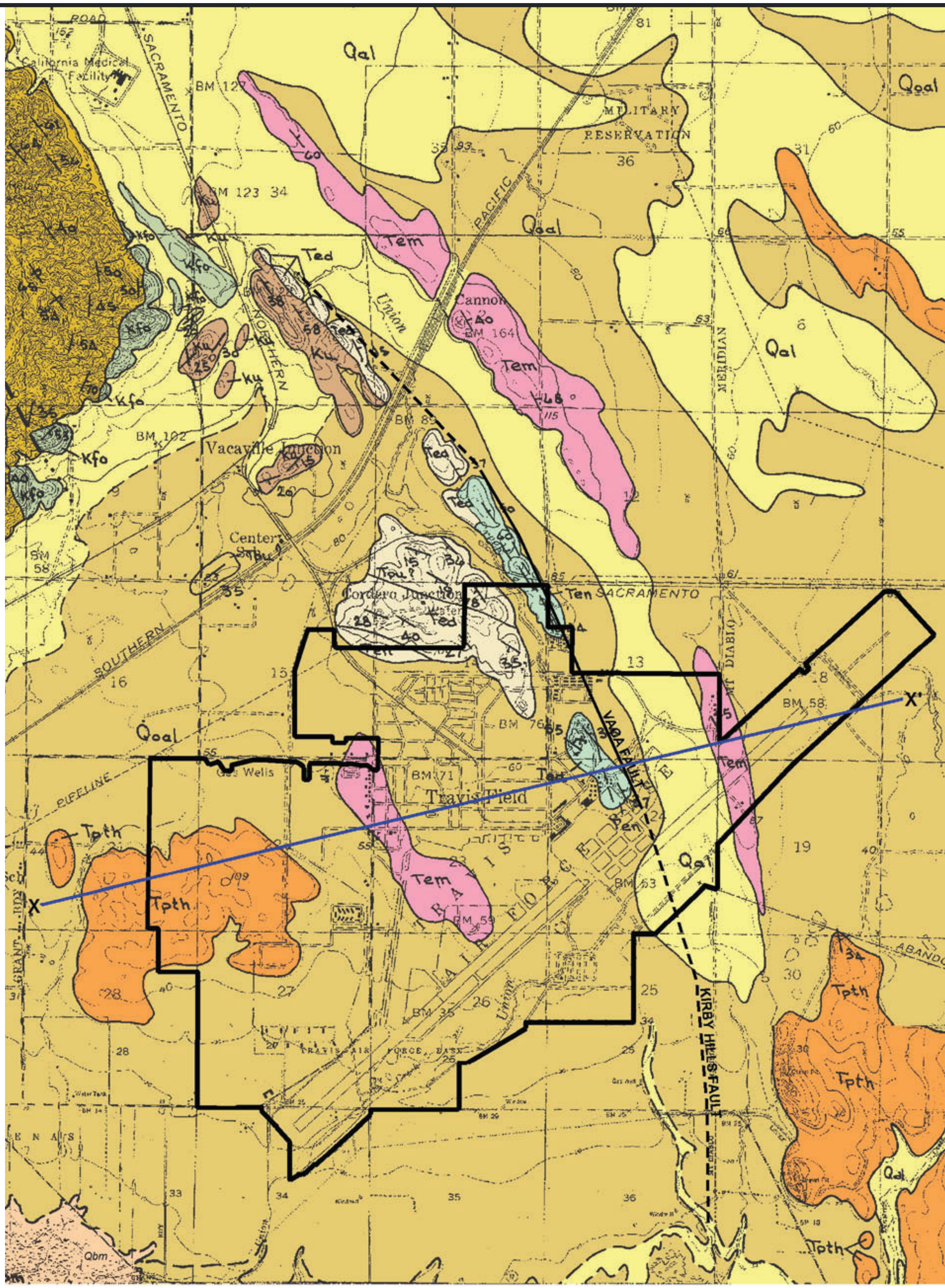
The bulk horizontal hydraulic conductivity of the alluvium at Travis AFB and vicinity is up to 35 feet per day (ft/day) (1×10^{-2} centimeters per second [cm/sec]) and averages approximately 22 ft/day (8×10^{-3} cm/sec). A map of the bulk horizontal hydraulic conductivity in the alluvium is shown on Figure 3.2-5.

Bulk horizontal hydraulic conductivity is calculated by dividing the alluvium transmissivity (Figure 3.2-6) by the saturated alluvium thickness (Figure 3.2-4).

3.2.2.5 Transmissivity

The alluvium transmissivity at Travis AFB and vicinity is up to 2,500 square feet per day (ft^2/day) and averages approximately 600 ft^2/day. A map of the total alluvium transmissivity is shown on Figure 3.2-6.

The transmissivity is a measure of the volume of water that is horizontally transmitted by the saturated alluvium thickness under a unit horizontal hydraulic gradient (Fetter, 1988). The basis for the map on Figure 3.2-6 is the TBGFM (CH2M HILL, 2008).



LEGEND

- *Qal*-YOUNGER ALLUVIUM
- Qbm-BAY MUD
- *Qoal*-OLDER ALLUVIUM
- Tpth-TEHAMA FORMATION
- *Tem*-MARKLEY SANDSTONE
- *Ten*-NORTONVILLE SHALE
- *Ted*-DOMENGINE SANDSTONE
- *Tpu*-UNNAMED FORMATION
- *Kfo*-FORBES FORMATION
- *Kg*-GUINDA FORMATION

N

0 1500 3000 FEET

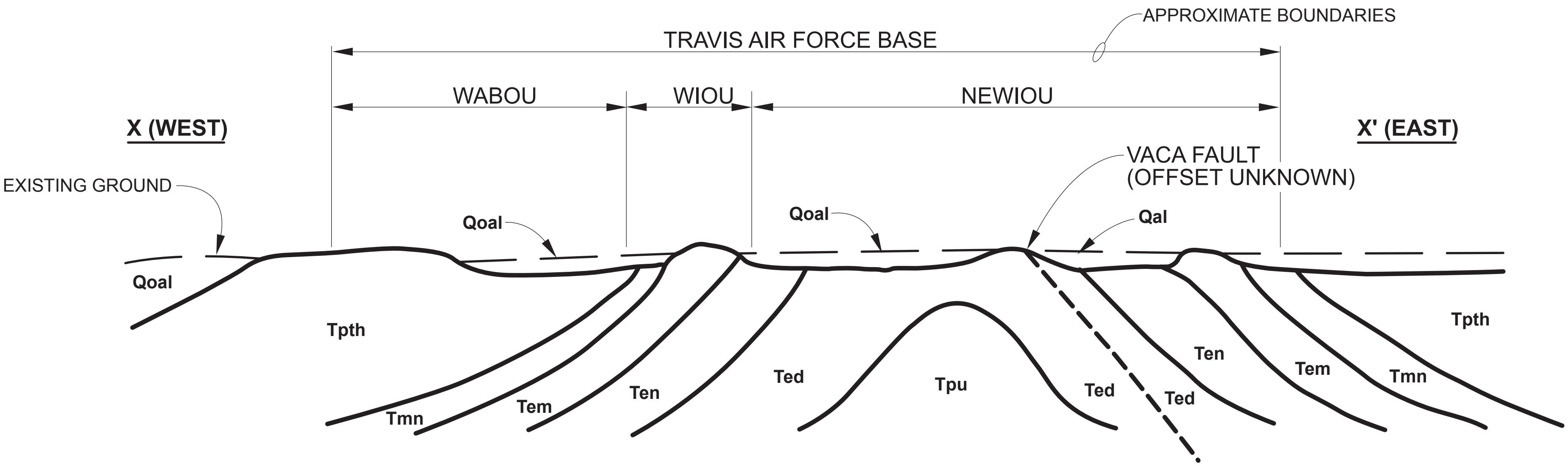
SCALE IS APPROXIMATE

ES092311092348RDD_3.2-1

FIGURE 3.2-1
GEOLOGIC MAP OF TRAVIS AFB AND VICINITY

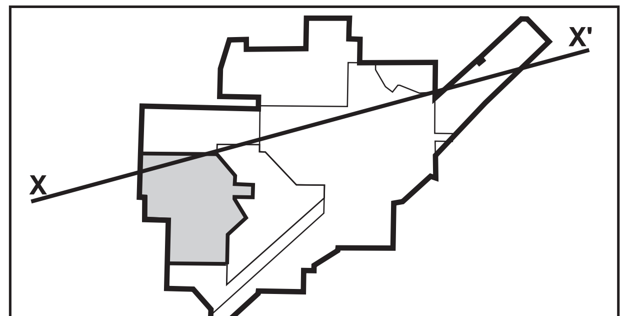
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL®



CROSS SECTION

NOT TO SCALE



KEY MAP

LEGEND

	QUATERNARY
Qal	ALLUVIUM
Qoal	OLDER ALLUVIUM
	TERTIARY
Tpth	TEHAMA FORMATION
Tmn	NEROLY SANDSTONE
Tem	MARKELY SANDSTONE
Ten	NORTONVILLE SHALE
Ted	DOMENGINE SANDSTONE
Tpu	UNNAMED FORMATION

FIGURE 3.2-2
SCHEMATIC GEOLOGIC CROSS SECTION
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL®

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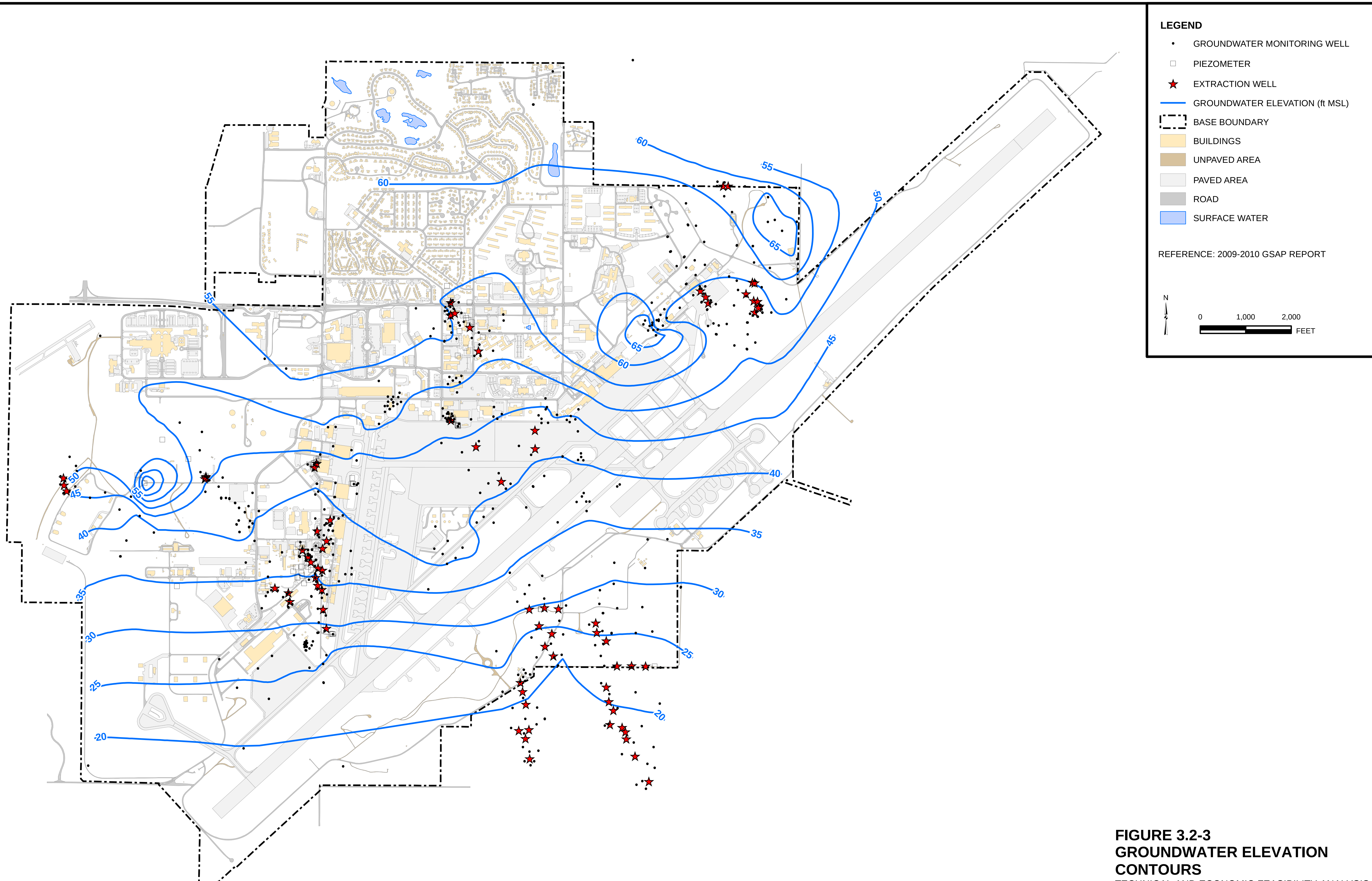
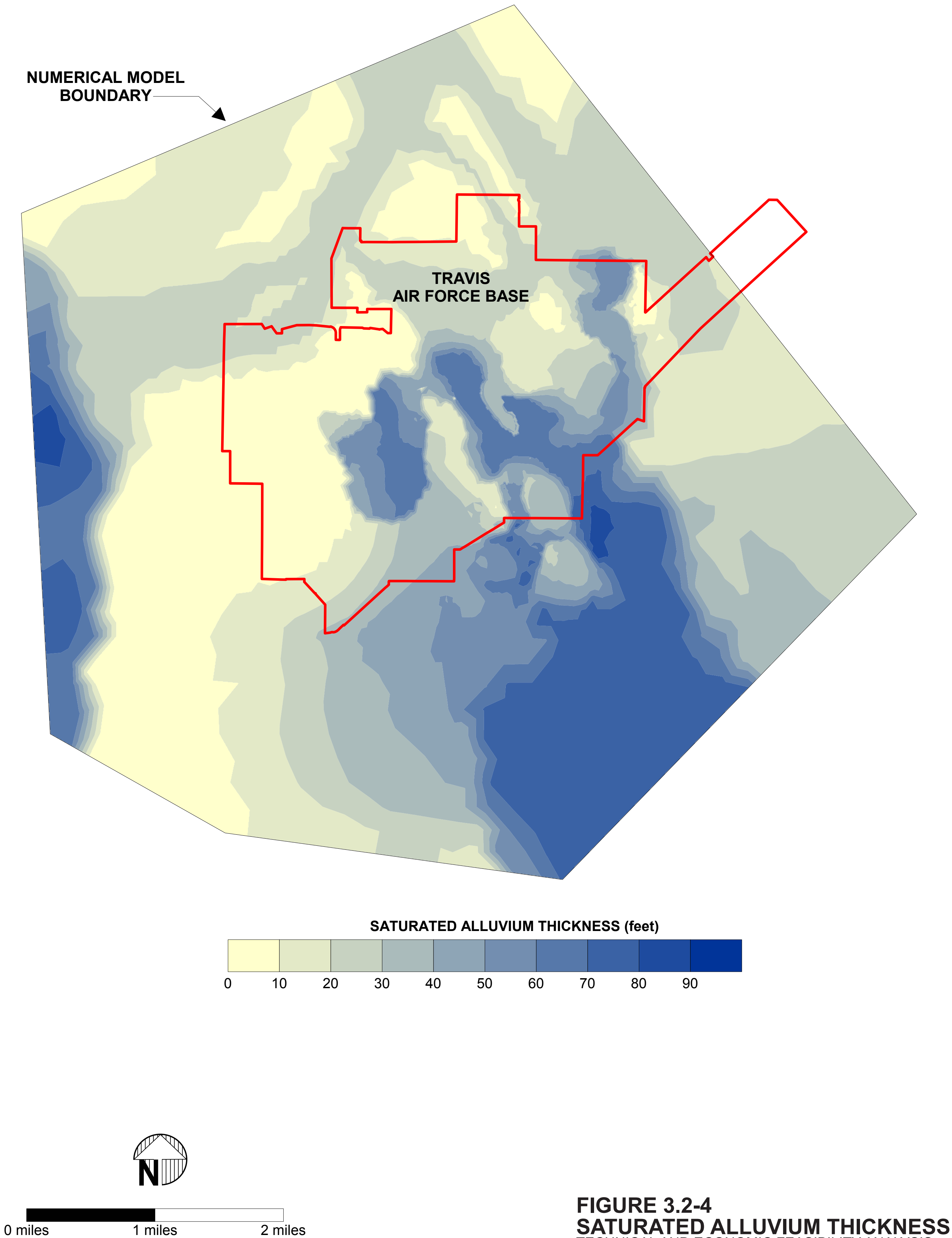


FIGURE 3.2-3
GROUNDWATER ELEVATION CONTOURS
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

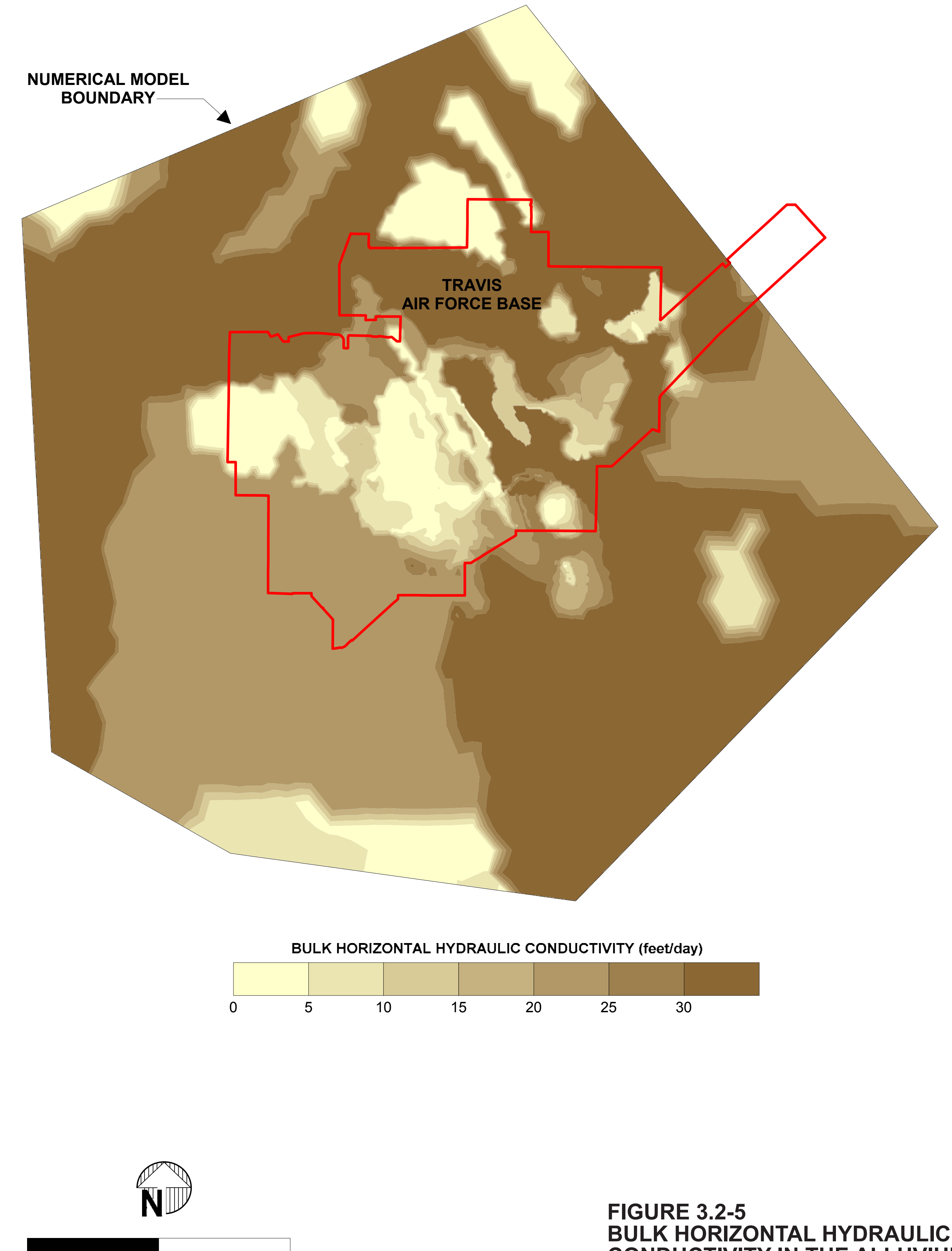
RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGURES\FIG3_2-3_GWELEVCONTOURS_TEFA.MXD MSCHROCK 10/5/2011 12:00:06 AM

CH2MHILL



ES092311092348RDD_3.2-4

FIGURE 3.2-4
SATURATED ALLUVIUM THICKNESS
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA
CH2MHILL



ES092311092348RDD_3.2-5

FIGURE 3.2-5
BULK HORIZONTAL HYDRAULIC CONDUCTIVITY IN THE ALLUVIUM
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

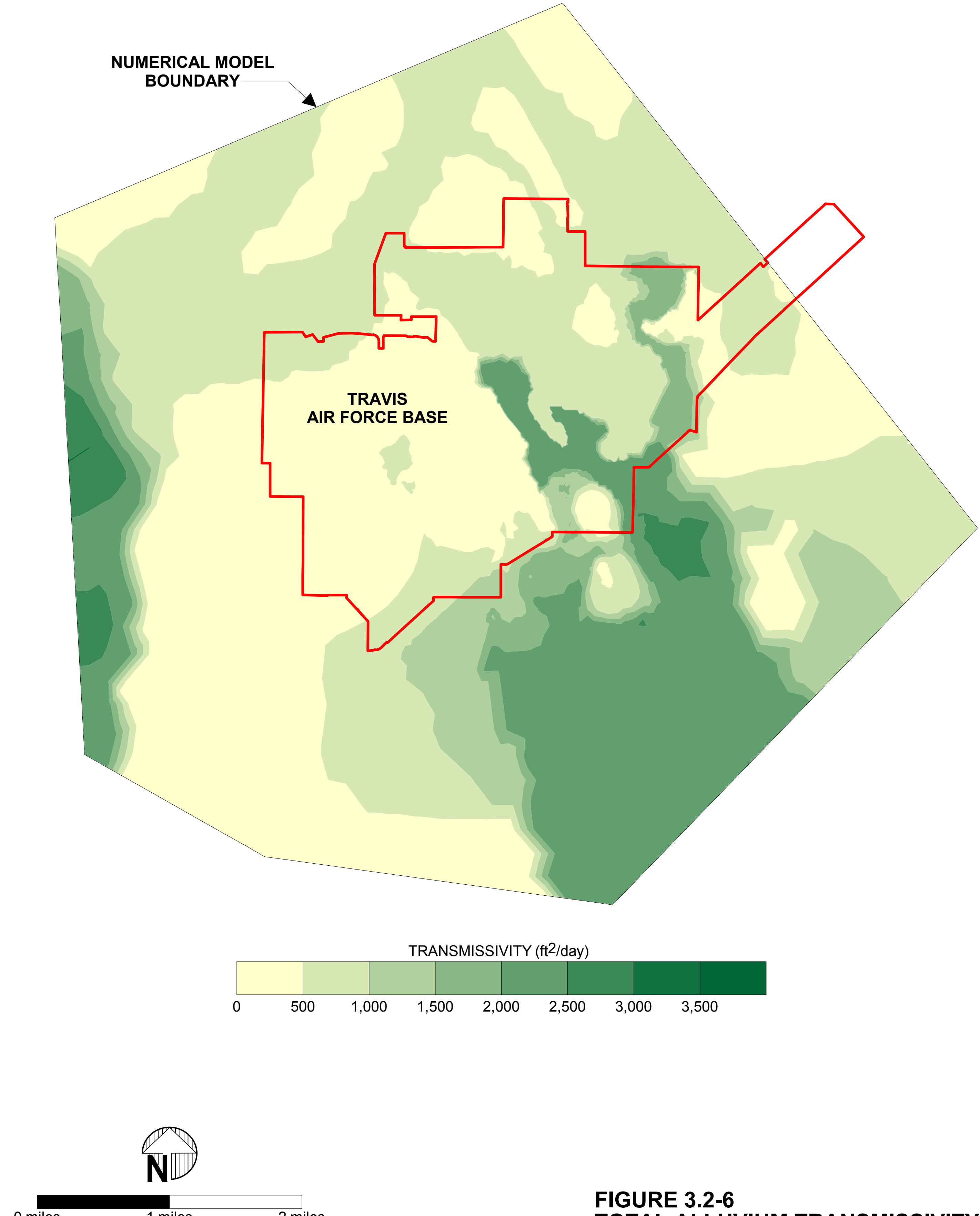


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FIGURE 3.2-6
TOTAL ALLUVIUM TRANSMISSIVITY
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

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3.3 Environmental Factor C: Quantity of Groundwater and Direction of Groundwater Flow

This subsection provides estimates of contaminant plume areas, estimates of the volume of contaminated groundwater, and the groundwater flow direction.

3.3.1 Plume Areas and Volumes

The areal extent of groundwater contamination at Travis AFB, as defined by chemical-specific MCLs, is approximately 12,285,201 square feet (282 acres). The areal extent is 53 percent greater when defined by background concentrations and encompasses approximately 18,755,868 square feet (430 acres).

A summary of the groundwater contamination plume areas and volumes is provided in Table 3.3-1. Plume areas and volumes are provided on the basis of both the chemical-specific MCL and background isocontours. Typically, plume areas and volumes are greater when defined by the background isocontour (e.g., Site FT004). However, at Sites FT005 and LF008, the isocontour defining the MCL plume and background plume is the same. Therefore, the plume areas and volumes are identical.

TABLE 3.3-1
Estimated Areas and Volumes of Contaminated Groundwater
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	Indicator Contaminant[a]	Cleanup Standard	Plume Area (square feet)	Plume Volume (cubic feet)[b]	Free Product Volume (cubic feet)[c]
FT004	TCE	MCL (5 µg/L)	250,893	1,455,179	-
		Background (0.5 µg/L)	1,271,387	7,374,045	-
		Percent Increase	*407*		-
FT005	1,2-DCA	MCL (0.5 µg/L)	1,258,142	11,323,278	-
		Background (0.5 µg/L)	1,258,142	11,323,278	-
		Percent Increase	*0*		-
LF006	TCE	MCL (5 µg/L)	0	0	-
		Background (0.5 µg/L)	732,418	3,955,057	-
		Percent Increase	*100*		-
LF007B	TCE	MCL (5 µg/L)	0	0	-
		Background (0.5 µg/L)	0	0	-
		Percent Increase	*0*		-
LF007C	TCE	MCL (5 µg/L)	110,330	485,452	-
		Background (0.5 µg/L)	206,234	907,430	
		Percent Increase	*87*		
LF007D[d]	Benzene	MCL (1 µg/L)	31,000	248,000	-
		Background (0.5 µg/L)	31,000	248,0000	-
		Percent Increase	*0*		-

TABLE 3.3-1
Estimated Areas and Volumes of Contaminated Groundwater
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	Indicator Contaminant[a]	Cleanup Standard	Plume Area (square feet)	Plume Volume (cubic feet)[b]	Free Product Volume (cubic feet)[c]
LF008	Alpha chlordane	MCL (0.1 µg/L)	33,368	233,576	-
		Background (0.1 µg/L)	33,368	233,576	-
		Percent Increase	*0*		-
SS015	TCE	MCL (5 µg/L)	55,994	78,392	-
		Background (0.5 µg/L)	74,936	104,910	-
		Percent Increase	*34*		-
SS016/SS029	TCE	MCL (5 µg/L)	7,112,191	41,250,708	-
		Background (0.5 µg/L)	8,732,454	50,648,233	-
		Percent Increase	*23*		-
ST027B	TCE	MCL (5 µg/L)	183,134	1,281,938	-
		Background (0.5 µg/L)	306,965	2,148,755	-
		Percent Increase	*68*		-
SS030	TCE	MCL (5 µg/L)	455,647	1,822,588	-
		Background (0.5 µg/L)	727,365	2,909,460	-
		Percent Increase	*60*		-
SD031	1,1-DCE	MCL (6 µg/L)	54,255	260,424	-
		Background (0.5 µg/L)	206,794	992,611	-
		Percent Increase	*281*		-
WIOU[e]	TCE	MCL (5 µg/L)	1,626,667	13,664,003	-[f]
		Background (0.5 µg/L)	3,030,249	25,454,092	-
		Percent Increase	*86*		-
DP039	TCE	MCL (5 µg/L)	1,144,580	9,614,472	-
		Background (0.5 µg/L)	2,175,556	18,274,670	-
		Percent Increase	*90*		-
SS041[g]	Heptachlor epoxide	MCL (0.01 µg/L)	0	0	-
		Background (0.01 µg/L)	0	0	-
		Percent Increase	0	0	-
		Total based on MCL	**12,316,201**	**85,673,067**	
		Total based on Background	**18,786,868**	**124,574,117**	
		Percentage Increase	***53***		

[a] Groundwater contaminant with greatest areal extent.
[b] Groundwater pore volume estimated from the saturated thickness and a porosity of 20 percent.
[c] Free phase Stoddard solvent.
[d] Contamination is limited to a small area in the vicinity of MW261x07. Plume areas and volumes are based on an approximate 100 foot plume radius around this well. The MCL and background plume areas and volumes are assumed to be equal.
[e] Plume areas and volumes for Sites SD033, SD034, SS035, SD036, SD037, and SD043 comprise the overall WIOU plume. The site contaminant plumes are inseparably commingled and addressed as a single plume.
[f] Stoddard solvent floating product is found intermittently only at Site SD034.
[g] Site SS041 is in NFRAP status. No contaminants have been detected at this site.

Note:

- = NA; floating product is intermittently found only at Site SD034.

At Site LF006, TCE is not found at a concentration equal to or greater than the MCL. Therefore, only the background isocontour defines the area and volume of the plume.

At Sites LF007B and SS041, indicator contaminants are not quantifiable to either MCL or background concentrations. Therefore, no plume areas or volumes are defined by MCL or background isocontours.

Plan view figures and cross sections of each listed site plume are provided in Section 3.1.

3.3.2 Groundwater Flow Direction and Rate

Groundwater at Travis AFB flows primarily south, except where groundwater mounds or depressions exist. Local variations in flow direction are the result of the subsurface geology and groundwater pumping conducted as part of interim remediation. The groundwater elevation contours shown on Figure 3.2-3 indicate the direction and magnitude of groundwater flow. The annual groundwater flow through the alluvial aquifer system underlying the Base is approximately 1,300 gpm (2,100 acre-feet per year). The total amount of groundwater stored in the aquifer underlying the Base is approximately 14,300 acre-feet (4.66 billion gallons).

The amount of groundwater stored within the portions of the aquifer contaminated at concentrations greater than or equal to MCLs is about 641 million gallons. Similarly, based on background concentrations, the volume of contaminated groundwater stored in the aquifer is about 932 million gallons.

3.4 Environmental Factor D: Proximity and Withdrawal Rates of Groundwater Users

Groundwater underlying Travis AFB is not used for human consumption or agricultural, industrial, or domestic purposes.

Interim remediation of contaminated groundwater using GET has been conducted at Travis AFB for over a decade. Summaries of the average extraction flow rates and the total volume of groundwater extracted during the most recent 4 years of GET system operation (2008-2011) are provided in Tables 3.4-1, 3.4-2, 3.4-3, and 3.4-4. The annual variations in groundwater flow rates and volumes extracted are mainly attributable to ongoing GET system optimizations, routine maintenance, and extraction well networks being fully or partially turned on/off during rebound studies.

The contaminated groundwater was extracted using a combination of horizontal and vertical extraction wells, treated using LGAC at three (3) treatment plants (CGWTP, NGWTP, and SBBGWTP), and then discharged to the stormwater drainage system.

One (1) privately owned domestic water well (DWSET1x30) is located at the southern extent of Site SS030. The amount and rate of groundwater production from this privately owned well is unknown, because the well is not equipped with a flow meter.

Property adjacent to the south and east sides of Travis AFB is zoned agricultural and consists exclusively of dry land stock grazing not relying on groundwater.

TABLE 3.4-1
Summary of Groundwater Remediation Extraction Rates and Volumes in 2011
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Groundwater Treatment Plant	Average Groundwater Extraction Rate (gpm)	Annual Volume of Extracted Groundwater (gallons)
CGWTP	33.1	16,700,000
NGWTP	0.2	57,642
SBBGWTP	86.0	44,000,000
Total		**60,757,642**

Source: 2011 Annual Remedial Process Optimization Report

Note:

gpm = gallon(s) per minute

TABLE 3.4-2
Summary of Groundwater Remediation Extraction Rates and Volumes in 2010
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Groundwater Treatment Plant	Average Groundwater Extraction Rate (gpm)	Annual Volume of Extracted Groundwater (gallons)
CGWTP	38.3	15,700,560
NGWTP	0.3	55,540
SBBGWTP	101.5	47,918,200
Total		**63,674,300**

Source: 2010 Annual Remedial Process Optimization Report (CH2M HILL, 2011d).
Note:
gpm = gallon(s) per minute

TABLE 3.4-3
Summary of Groundwater Remediation Extraction Rates and Volumes in 2009
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Groundwater Treatment Plant	Average Groundwater Extraction Rate (gpm)	Annual Volume of Extracted Groundwater (gallons)
CGWTP	57.3	21,729,940
NGWTP	11.0	357,000
SBBGWTP	80.0	35,829,400
Total		**57,916,340**

Source: 2009 Annual Remedial Process Optimization Report (CH2M HILL, 2010b).

TABLE 3.4-4
Summary of Groundwater Remediation Extraction Rates and Volumes in 2008
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Groundwater Treatment Plant	Average Groundwater Extraction Rate (gpm)	Annual Volume of Extracted Groundwater (gallons)
CGWTP	65.7	31,523,000
NGWTP	8.1	4,115,000
SBBGWTP	89.0	45,857,000
Total		**81,495,000**

Source: 2008 Annual Remedial Process Optimization Report (CH2M HILL, 2009).

3.5 Environmental Factor E: Current and Potential Future Uses of Groundwater in the Area

3.5.1 Current On-base Groundwater Use

No on-base wells are currently used for potable water production at Travis AFB, and none are planned for the future.

3.5.2 Current Off-base Groundwater Use

Travis AFB overlies the Suisun-Fairfield Valley groundwater basin. According to the Water Quality Control Plan for the San Francisco Bay Basin, beneficial uses for groundwater in the Suisun-Fairfield Valley groundwater basin are municipal and domestic water supply, industrial process and industrial service water supply, and agricultural water supply. Approximately 3,562 acre-feet per year of groundwater is pumped for agricultural use from the Suisun-Fairfield Valley groundwater basin. Although there are 15 public water supply wells within the Suisun-Fairfield Valley groundwater basin, they do not serve a municipal population. The nearest city to Travis AFB is Fairfield, California, which uses surface water rather than groundwater for their municipal water supply. Downgradient of Travis AFB is the brackish water of Suisun Marsh.

Currently, one (1) privately owned domestic water well (DWSET1x30) is located at the southern extent of Site SS030. No contaminants that may have originated from Travis AFB have been detected in this well, but it is routinely sampled under the Travis AFB GSAP.

3.5.3 Potential Future Use of Groundwater in the Area

No future use of the groundwater underlying Travis AFB is planned. As described in Section 3, it is likely that the current combination of the City of Vallejo and Cypress Lakes Golf Course Annex water supplies will be entirely replaced by water originating solely from the Cypress Lakes Golf Course Annex, including a new backup water source to provide redundancy.

3.6 Environmental Factor F: Existing Quality of Groundwater, Including Other Sources of Contamination or Pollution and their Cumulative Impact on the Groundwater Quality

An assessment of groundwater quality starts with the groundwater contaminants from past waste management and industrial practices. It also considers the presence of dissolved metals and other naturally occurring chemicals that exceed drinking water standards.

To put this information into perspective, it is helpful to compare the quality of the Base groundwater with that of a groundwater source used by a municipal water supplier, such as the City of Vacaville. Based on this assessment, the aquifer beneath Travis AFB can be described as low quality and undesirable as a source of potable water. For this reason, the Base groundwater is not used for on-base human consumption or agricultural, industrial, or other domestic purposes.

The following subsections describe the factors affecting the quality of groundwater at Travis AFB in more detail.

3.6.1 Chlorinated Organic Chemicals

Groundwater quality at Travis AFB is degraded by the presence of chlorinated VOCs and some organochlorine pesticides that resulted from past industrial practices. There are no current sources of groundwater contamination from on-base activities and no known off-base sources of contamination that are affecting the on-base groundwater quality.

More complete descriptions of groundwater contamination at Travis AFB are provided in Section 3.1 of this TEFA and in Section 3 of the FFS (CH2M HILL, 2011a).

3.6.2 Metals

Naturally occurring metals are typically found in groundwater. Previous CERCLA remedial investigations at Travis AFB concluded that although such metals are present, they are not the result of past waste management and industrial practices and are not COCs.

3.6.2.1 Total Metals

Naturally occurring concentrations of total metals (i.e., unfiltered) include aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, copper, hexavalent chromium, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, silicon, silver, sodium, thallium, vanadium, and zinc. Comparisons of total metals concentrations with MCLs are provided in Table 3.6-1.

- **Primary MCL Exceedances –** The average measured concentrations of aluminum, antimony, cadmium, chromium, lead, mercury, nickel, and thallium exceed the primary MCL. The maximum measured concentrations of barium, beryllium, and selenium also exceed the primary MCL.
- **Secondary MCL Exceedances –** The average measured concentrations of aluminum, iron, and manganese exceed the secondary MCL. The maximum measured concentration of silver also exceeds the secondary MCL.

3.6.2.2 Dissolved Metals

Naturally occurring concentrations of dissolved metals (i.e., field filtered) include aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, copper, hexavalent chromium, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, silicon, silver, sodium, thallium, vanadium, and zinc. Comparisons of dissolved metals concentrations with MCLs are provided in Table 3.6-1.

- **Primary MCL Exceedances –** The average measured concentrations of antimony, cadmium, lead, nickel, and thallium exceed the primary MCL. The maximum measured concentrations of aluminum, arsenic, barium, beryllium, chromium, mercury, and selenium also exceed the primary MCL.
- **Secondary MCL Exceedances –** The average measured concentrations of aluminum, iron, and manganese exceed the secondary MCL.

3.6.3 Groundwater Quality Parameters

Comparisons of the groundwater quality parameter measured at Travis AFB with primary and secondary MCLs and similar measurements obtained from the City of Vacaville groundwater production wells (City of Vacaville, 2011) are provided in Table 3.6-2. Additional discussion of these comparisons is provided in the following subsections.

3.6.3.1 Comparison of Travis AFB Groundwater Quality Parameters with MCLs

Several naturally occurring groundwater constituents detected at Travis AFB exceed primary and/or secondary MCLs. The following list summarizes those exceedances.

- **Primary MCL Exceedances** – The maximum and/or mean concentrations of fluoride, sulfate, nitrate, nitrite, and turbidity detected in the Travis AFB groundwater exceed the primary MCL as follows:
  - **Fluoride –** The maximum fluoride concentration detected in groundwater exceeds the primary MCL. The maximum concentration is 12.1milligrams per liter (mg/L), compared to the primary MCL of 2.0 mg/L.
  - **Sulfate –** The maximum sulfate concentrations exceed the primary MCL. The maximum concentration is 19,900 mg/L, compared to the primary MCL of 500 mg/L.
  - **Nitrate –** The maximum nitrate concentration exceeds the primary MCL. The maximum concentration is 350 mg/L, compared to the primary MCL of 10 mg/L.
  - **Nitrite –** The maximum nitrite concentration exceeds the primary MCL. The maximum concentration is 57 mg/L, compared to the primary MCL of 1.0 mg/L.
  - **Turbidity –** The maximum and mean turbidity values exceed the primary MCL. The maximum and mean values measured are 596 and 27.1 nephelometric turbidity units (NTUs). The primary MCL is 1 to 5 NTUs.

- **Secondary MCL Exceedances** – The maximum and/or mean concentrations of pH, sulfate, total dissolved solids (TDS), and turbidity detected in the Travis AFB groundwater exceed the secondary MCL as follows:
  - **pH –** The minimum and maximum pH values exceed the secondary MCL. The minimum and maximum values measured are 4.13 and 8.63. The secondary MCL is 6.5 to 8.5.
  - **Sulfate –** The maximum sulfate concentration exceeds the secondary MCL. The maximum concentration is 19,900 mg/L, compared to the secondary MCL of 250 mg/L.
  - **TDS –** The maximum and mean TDS concentrations exceed the secondary MCL. The maximum and mean concentrations are 51,300 and 1,000 mg/L. The secondary MCL is 500 mg/L. Also, under SWRCB Resolution 88-63 – Sources of Drinking Water, "All surface and ground waters of the State are considered to be suitable, or potentially suitable, for municipal or domestic water supply and should be so designated by the Regional Board with the exception of : Surface and ground waters where: [Item 1a.] The TDS exceed 3,000 mg/L (5,000 µS/cm, electrical conductivity) and it is not reasonably expected by the Regional Boards to supply a public water system…" Historical data, primarily obtained during the mid-1980s through mid-2000s, indicate that naturally occurring concentrations of TDS have exceeded the 3,000 mg/L standard at 97 monitoring locations/dates across the Base, including geographically separate Sites FT004, FT005, LF007, SS015, ST018, and ST027.
  - **Turbidity –** The maximum and mean turbidity values exceed the primary MCL. The maximum and mean values measured are 596 and 27.1 NTUs. The primary MCL is 1 to 5 NTUs.

3.6.3.2 Comparison of Travis AFB Groundwater with City of Vacaville Groundwater

Comparisons between the groundwater parameters measured at City of Vacaville production wells and the monitoring wells at Travis AFB are also provided in Table 3.6-2. These comparisons show that the water quality underlying the Base is of overall lesser quality than that used by the City of Vacaville.

- **Alkalinity, total –** The maximum and mean total alkalinity concentrations exceed the range detected in the City of Vacaville wells. The maximum and mean concentrations are 1,080 and 326.7 mg/L. The range of concentrations for the City of Vacaville wells is 161 to 305 mg/L.
- **Fluoride –** The maximum and mean fluoride concentrations exceed the range detected in the City of Vacaville wells. The maximum and mean concentrations are 12.1 and 0.5 mg/L. The range of concentrations for the City of Vacaville wells is 0.2 to 0.4 mg/L.
- **Hardness –** The maximum and mean hardness concentrations exceed the range detected in the City of Vacaville wells. The maximum and mean concentrations are 537 and 372 mg/L. The range of concentrations for the City of Vacaville wells is 84 to 330 mg/L.

- **Nitrate –** The maximum nitrate concentration exceeds the range detected in the City of Vacaville wells. The maximum concentration is 350 mg/L. The range of concentrations for the City of Vacaville wells is 2 to 17.6 mg/L.
- **pH –** The maximum and mean pH values are outside the range detected in the City of Vacaville wells. The maximum and mean values are 8.63 and 6.96. The range of values for the City of Vacaville wells is 7.7 to 8.2.
- **Sulfate –** The maximum and mean sulfate concentrations exceed the range detected in the City of Vacaville wells. The maximum and mean concentrations are 19,900 and 72 mg/L. The range of concentrations for the City of Vacaville wells is 22 to 66 mg/L.
- **Total Organic Carbon (TOC) –** The maximum and mean TOC concentrations exceed the range detected in the City of Vacaville wells. The maximum and mean concentrations are 2,970 and 3.05 mg/L. The range of concentrations for the City of Vacaville wells is non-detect to 0.05 mg/L.
- **Turbidity –** The maximum and mean turbidity values exceed the range detected in the City of Vacaville wells. The maximum and mean values are 596 and 27.1 NTUs. The range of concentrations for the City of Vacaville wells is 0.5 to 2.6 NTUs.

3.6.4 Summary of Travis AFB Groundwater Quality

The quality of the groundwater underlying Travis AFB is poor. In addition to the degradation of water quality resulting from the presence of chlorinated organic contaminants, the groundwater contains naturally occurring constituents at concentrations exceeding primary and/or secondary MCLs.

A variety of naturally occurring metals are present at Travis AFB with many of them historically measured at concentrations exceeding MCLs.

Also, concentrations of TDS often exceed the drinking water source standard established in SWRCB Resolution 88-63.

The presence of inorganic constituents causes Travis AFB groundwater to compare unfavorably with groundwater used by the City of Vacaville.

The key aspects of the assessment of groundwater quality at Travis AFB include the following:

- The groundwater quality at Travis AFB is degraded at multiple locations by the presence of chlorinated VOCs, primarily TCE and related compounds, originating from historical waste management and disposal practices.
- Naturally occurring [dissolved] metal concentrations have been measured at concentrations exceeding both the primary and secondary MCLs throughout the Base.
- Five (5) (dissolved) metals have average concentrations exceeding the primary MCLs with three (3) also exceeding the secondary MCLs. Nine (9) (unfiltered) metals have average concentrations exceeding the primary MCLs with the dissolved metals included.

- Naturally occurring concentrations of fluoride, sulfate, nitrate, nitrite, and turbidity exceed the primary MCL at multiple locations.
- Naturally occurring levels of pH, sulfate, TDS, and turbidity exceed the secondary MCL at multiple locations.
- Concentrations of TDS exceed 3,000 mg/L at multiple locations/dates across the Base. A provision in SWRCB Resolution 88-63 – Sources of Drinking Water, Item 1a. states that such concentrations are "not reasonably expected by Regional Boards to supply a public water system."
- In comparison to water quality parameters measured at the City of Vacaville production wells, groundwater at Travis AFB is of lower quality. Concentrations of alkalinity, fluoride, hardness, nitrate, pH, sulfate, TOC, and turbidity measured at Travis AFB are all greater than those measured in the City of Vacaville wells.

TABLE 3.6-1
Summary of Groundwater Parameters (Metals)
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Analyte	Unit	Field Filtered	Primary[a] MCL	Secondary[a] MCL	Travis AFB Groundwater Concentrations[b,c]		
					Minimum	Maximum	Mean
Total Dissolved Metals							
Aluminum	mg/L	Y	1	0.2	0.0002	**10**	**0.3**
Antimony	mg/L	Y	0.006	--	0.0002	**0.4**	**0.1**
Arsenic	mg/L	Y	0.01	--	0.00001	**0.1**	0.006
Barium	mg/L	Y	1	--	0.0005	**4**	0.3
Beryllium	mg/L	Y	0.004	--	0.000002	**0.005**	0.002
Boron	mg/L	Y	--	--	0.0003	90	6
Cadmium	mg/L	Y	0.005	--	0.00001	**0.2**	**0.006**
Calcium	mg/L	Y	--	--	0.1	1000	200
Chromium	mg/L	Y	0.05	--	0.00001	**2**	0.03
Cobalt	mg/L	Y	--	--	0.00004	0.08	0.02
Copper	mg/L	Y	1.3	1	0.00003	0.08	0.02
Hexavalent chromium	mg/L	Y	0.05	--	0.002	0.04	0.007
Iron	mg/L	Y	--	0.3	0.0003	**30**	**0.7**
Lead	mg/L	Y	0.015	--	0.0001	**2**	**0.08**
Magnesium	mg/L	Y	--	--	0.01	800	70
Manganese	mg/L	Y	--	0.05	0.0001	**30**	**0.6**
Mercury	mg/L	Y	0.002	--	0.00003	**0.01**	0.0003
Molybdenum	mg/L	Y	--	--	0.0001	0.2	0.06
Nickel	mg/L	Y	0.1	--	0.00006	**6**	**0.2**
Potassium	mg/L	Y	--	--	0.005	200	4
Selenium	mg/L	Y	0.05	--	0.000005	**0.2**	0.007
Silicon	mg/L	Y	--	--	0.02	30	20
Silver	mg/L	Y	--	0.1	0.00001	0.07	0.02
Sodium	mg/L	Y	--	--	0.03	2000	300
Thallium	mg/L	Y	0.002	--	0.0001	**600**	**3**
Vanadium	mg/L	Y	--	--	0.00004	0.1	0.02
Zinc	mg/L	Y	--	5	0.00004	4	0.05

TABLE 3.6-1
Summary of Groundwater Parameters (Metals)
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Analyte	Unit	Field Filtered	Primary[a] MCL	Secondary[a] MCL	Travis AFB Groundwater Concentrations[b,c]		
					Minimum	Maximum	Mean
Total Metals							
Aluminum	mg/L	N	1	0.2	0.01	**300**	**10**
Antimony	mg/L	N	0.006	--	0.002	**3**	**0.2**
Arsenic	mg/L	N	0.01	--	0.0006	**0.3**	0.01
Barium	mg/L	N	1	--	0.0009	**7**	0.4
Beryllium	mg/L	N	0.004	--	0.00009	**0.05**	0.003
Boron	mg/L	N	--	--	0.1	0.6	0.4
Cadmium	mg/L	N	0.005	--	0.0002	**2**	**0.006**
Calcium	mg/L	N	--	--	0.02	7000	200
Chromium	mg/L	N	0.05	--	0.0004	**20**	**0.5**
Cobalt	mg/L	N	--	--	0.0005	1	0.02
Copper	mg/L	N	1.3	1	0.0005	0.7	0.03
Hexavalent chromium	mg/L	N	0.05	--	0.001	0.04	0.005
Iron	mg/L	N	--	0.3	0.002	**500**	**20**
Lead	mg/L	N	0.015	--	0.0005	**2**	**0.05**
Magnesium	mg/L	N	--	--	0.02	1000	70
Manganese	mg/L	N	--	0.05	0.0004	**700**	**2**
Mercury	mg/L	N	0.002	--	0.0000004	**0.9**	**0.003**
Molybdenum	mg/L	N	--	--	0.001	0.5	0.03
Nickel	mg/L	N	0.1	--	0.002	**7**	**0.2**
Potassium	mg/L	N	--	--	0.4	200	5
Selenium	mg/L	N	0.05	--	0.0001	**1**	0.01
Silicon	mg/L	N	--	--	2	30	20
Silver	mg/L	N	--	0.1	0.0005	**60**	0.07
Sodium	mg/L	N	--	--	0.2	20000	800
Thallium	mg/L	N	0.002	--	0.0005	**0.2**	**0.005**
Vanadium	mg/L	N	--	--	0.0006	1	0.06
Zinc	mg/L	N	--	5	0.002	**60**	0.1

[a] Primary and Secondary MCLs provided per California regulations.
[b] Water quality data provided for monitoring wells only for measurements occurring prior to 2008.
[c] Bold values signify exceedances of MCLs.

Note:

-- = No standard exists for this field.

TABLE 3.6-2
Summary of Groundwater Parameters
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Analyte	Unit	Primary MCL	Secondary MCL	City of Vacaville Groundwater Concentrations	Travis AFB Groundwater Concentrations*		
					Minimum	Maximum	Mean
Alkalinity							
Bicarbonate	mg/L	–	–	–	8	960	320
Carbonate	mg/L	–	–	–	0.44	120	6.7
Total	mg/L	–	–	161 to 305	8.44	1,080	326.7
Chloride	mg/L	–	–	–	0.122	5,100	209
Conductivity	µmhos/cm	–	900	471 to 846	0.00088	99.9	1.23
Dissolved oxygen	mg/L	–	–	–	0	9.1	6.51
Fluorides	mg/L	2.0	–	0.2 to 0.4	0.00025	**12.1**	0.5
Hardness	mg/L	–	–	84 to 330	188	537	372
Nitrate	mg/L	10	–	2 to 17.6	0.0005	**350**	2
Nitrite	mg/L	1.0	–	–	0.0001	**57**	0.1
Oxidation reduction potential	mV	–	–	–	-179	276	107
pH	–	–	6.5 to 8.5	7.7 to 8.2	**4.13**	**8.63**	6.96
Phosphorus	mg/L	–	–	–	0.000363	3	0.5
Sulfate	mg/L	500	250	24 to 66	0.026	**19,900**	72
Total dissolved solids	mg/L	–	500	–	10	**51,300**	**1,000**
Temperature	°C	–	–	–	17.23	22.97	19.77
Total organic carbon	mg/L	–	–	ND to 0.05	0.1	2,970	3.05
Turbidity	NTU	1 to 5	5	0.5 to 2.6	0	**596**	**27.1**

* Bold values signify exceedances of MCLs.

Notes:

– = not applicable or not established
°C = degree(s) Celsius
µmhos/cm = micromho(s) per centimeter
mV = millivolt(s)
ND = not detected

3.7 Environmental Factor G: Potential Health Risks Caused by Human Exposure to Waste Constituents

To evaluate the potential human health risks posed by contaminated groundwater at Travis AFB, each groundwater site received a human health risk assessment (HHRA), and the results of those assessments were reported in the following RI reports:

- NOU RI Report (Radian, 1995)
- EIOU RI Report (Weston, 1995)
- WIOU RI Report (Radian, 1996a)
- WABOU RI Report (CH2M HILL, 1997)

3.7.1 Historical Human Health Risks

To determine whether a site required a remedial action, the HHRAs calculated the cancer and noncancer risks for each contaminant, using default values associated with both the residential and industrial scenarios. Each calculation consisted of four (4) steps: an identification of chemicals of potential concern, an exposure assessment, a toxicity assessment, and a risk characterization. The end product of each HHRA was an excess lifetime cancer risk value for a carcinogen and a hazard index for a noncarcinogen. Decisions concerning the need for remedial action were based on whether the cumulative excess lifetime cancer risks exceeded 1×10^{-6} or the hazard index exceeded 1.

The following tables provide the COCs and calculated risks prior to the start of groundwater IRAs:

- NEWIOU FS Table 1-2: Summary of NOU Areas, Media, and Contaminants Recommended for Evaluation. For Sites LF006 and LF007 (Radian, 1996b).
- NEWIOU FS Table 1-3: Summary of EIOU Areas, Media, and Contaminants Recommended for Evaluation. For Sites FT004, FT005, SS015, SS016, SS029, SS030, and SD031 (Radian, 1996b).
- NEWIOU FS Table 1-5: Summary of WIOU Areas, Media, and Contaminants Recommended for Evaluation. For Sites SD033, SD034, SS035, SD036, and SD037 (Radian, 1996b).
- WABOU FS Table 2-2: COCs and COECs by Medium and Associated Risk. Recommended for Evaluation. For Sites DP039, SS041, SD043, and LF008 (CH2M HILL, 1998a).

Site ST027 was historically managed under the Travis AFB POCO program which does not require a risk assessment to be conducted. As a result, Site ST027 was not included in any of the four (4) OU-specific RIs, two (2) OU-specific FSs, or two (2) groundwater IRODs. In 2007-2008, POCO investigations discovered a small, previously unknown TCE plume at concentrations greater than the IRG in the southwestern part of Site ST027. This area of TCE contamination has been designated as Site ST027-Area B, or Site ST027B. The TCE contamination probably originated from undocumented releases between the southern edge of the aircraft test pad and Taxiway November. Groundwater contamination within this portion of the site is now administered under the ERP. Petroleum fuel contamination found within the remainder of the site, now designated as Site ST027A, continues to be administered under the POCO program.

3.7.2 Current Human Health Risks

After approximately a decade of interim groundwater remediation, the COC concentrations and their associated potential risks to human health have decreased at all groundwater sites. At some sites, the COC concentrations have reached or exceeded the interim cleanup goals or interim remediation goals that were established in the two (2) Travis AFB Groundwater IRODs. At the remaining sites, the COC concentrations are still above these goals, and land use controls have been established at these sites to ensure that the exposure pathways between the groundwater contaminants and both on-base workers and off-base residents are incomplete.

3.8 Environmental Factor H: Potential Damage to Wildlife, Crops, Vegetation, and Physical Structures Caused by Exposure to Waste Constituents

ERAs conducted during the four (4) RIs conducted at Travis AFB found no potential ecological risk to animals or plants, because the depth to contaminated groundwater ensures that the exposure pathway between them is incomplete.

There is no agricultural production at Travis AFB. Grazing management units on the Base rely on rainfall and are not irrigated using groundwater resources.

No potential damage to physical structures is anticipated from exposure to groundwater contaminants.

3.9 Environmental Factor I: Persistence and Permanence of the Potential Adverse Effects

The aquifer at Travis AFB is typically aerobic. Chlorinated VOCs, such as TCE, do not readily degrade under aerobic conditions. Remediation time frame calculations indicate that several areas of groundwater contamination at Travis AFB will persist in excess of 100 years. A summary of the forecast cleanup times required to achieve MCLs and background concentrations is provided in Table 3.9-1. The numerical modeling used to derive the cleanup times is described in Appendix C.

Currently, multiple contaminant plumes at Travis AFB are under interim remediation. For the most part, the IRAs operated successfully during the period of interim remediation which started in the late 1990s to early 2000s. However, even after about a decade of interim remediation, the groundwater at most sites remains contaminated at concentrations that exceed MCLs.

The probable presence of residual DNAPLs at several locations (i.e., Sites SS015, SS016, SD036, SD037, and DP039) contributes to the estimated extended amounts of time before either MCLs or background concentrations are achieved. Section 3.1.3 discusses the technical issues related to the presence of DNAPLs.

The solubility of a contaminant is related to the presence of DNAPLs in the aquifer. DNAPLs are much more likely to be present and to persist when the contaminant, such as TCE, has a low solubility. The presence of DNAPLs greatly increases the time required for remediation, because the DNAPLs dissolve very slowly in groundwater and require only a small mass to sustain dissolved concentrations of contamination above either MCL or background cleanup standards for a long period. Section 3.1.4 discusses the primary release mechanisms that result in the persistence of dissolved solvents in groundwater.

TABLE 3.9-1
Comparison of Time Estimates to Achieve MCLs and Background Concentrations
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

ERP Site	Primary COC and Cleanup Concentration (MCL/Background) (µg/L)	FFS Remedial Alternative	Time to Achieve MCL* (years)	Time to Achieve Background* (years)	Comments
FT004	TCE (5.0/0.5)	Alternative 2 – MNA	35	65	
FT005	1,2-DCA (0.5/0.5)	Alternative 2 – MNA	43	43	Off-base plume. Low MCL is equal to background concentration. Plume underwent interim remediation GET. Therefore, no biodegradation data are available and biodegradation effects are not included in the analysis.
LF006	TCE (5.0/0.5)	Alternative 2 – MNA	5	59	No COC detected above MCL in 2010.
LF007B	TCE (5.0/0.5)	Alternative 2 – MNA	0	0	TCE concentrations are already below MCLs and background.
LF007C	TCE (5.0/0.5)	Alternative 3 – GET	26	53	Off-base plume. GET system expansion pending in late 2011, if required and site conditions allow access (vernal pool).
LF007D	Benzene (1.0/0.5)	Alternative 2 – MNA	> 100	> 100	Benzene concentrations stable between 2 and 3 µg/L over the past 10 years.
LF008	Alpha chlordane (0.1/0.1)	Alternative 2 – MNA	> 100	> 100	Organochlorine pesticide with low mobility and lack of biodegradation mechanisms.
SS015	cis-1,2-DCE (6.0/0.5)	Alternative 5 – EVO and EA	70	> 100	Times required to achieve MCLs and background are based on remediation of dissolved-phase contamination. The possible presence of residual DNAPL in the Site SS015 source area will increase the time required to achieve MCLs and background.
SS016/SS029	TCE (5.0/0.5)	Alternative 4 – Bioreactor and GET	> 100	> 100	Installation of the bioreactor in the OSA source area included physical removal of the highest concentrations of chlorinated VOCs, but some residual DNAPL likely remains. The times required to achieve MCLs and background are based on remediation of dissolved-phase contamination. Assuming only dissolved-phase contamination, the estimated times to achieve MCLs and background are estimated at 62 and 86 years. However, the probable presence of residual DNAPLs at Site SS016 will extend this time because they provide a continuing source of dissolved-phase contamination. Therefore, a qualitative assessment of greater than 100 years provides a more appropriate estimate of the cleanup time.
ST027B	TCE (5.0/0.5)	Alternative 2 – MNA	50	80	Adjacent to active aircraft airfield operations.
SS030	TCE (5.0/0.5)	Alternative 3 – GET	22	46	Off-base plume.
SD031	1,1-DCE (6.0/0.5)	Alternative 2 – MNA	15	> 100	Plume underwent interim remediation GET. Therefore, no biodegradation data are available and biodegradation effects are not included in the analysis.
WIOU (SD033, SD043)	TCE (5.0/0.5)	Alternative 2 – MNA	60	90	Component sites of overall WIOU plume.
WIOU (SD034)	TCE (5.0/0.5)	Alternative 7 – Passive Skimming and EA	60	90	Component site of overall WIOU plume. Intermittent detection of free-phase Stoddard solvent floating on groundwater table.
WIOU (SD036, SD037)	TCE (5.0/0.5)	Alternative 5 – EVO and EA	60	90	Component sites of overall WIOU plume. Times required to achieve MCLs and background are based on remediation of dissolved-phase contamination. The possible presence of residual DNAPLs within the Site SD036 and SD037 source areas may extend this time because they provide a continuing source of dissolved-phase contamination.
DP039	TCE (5.0/0.5)	Alternative 6 – Bioreactor, Phytoremediation, EVO PRB, and EA	65	90	Times required to achieve MCLs and background are based on remediation of dissolved-phase contamination. The time required to achieve MCLs and background considers the duration required for relatively high TCE concentrations in the Site DP039 source area to migrate to the PRB and the natural attenuation time frame for TCE exiting the PRB. If not remediated by the bioreactor, the possible presence of residual DNAPL in source area will likely increase the cleanup times.
SS041	Heptachlor epoxide (0.01/0.01)	Alternative 1 – No Action	0	0	No detectable COCs. Site is in NFRAP status.

* Calculations for the time required to achieve MCL and background concentrations are provided in Appendix C.

SECTION 4

Analysis of Technical Feasibility

The analysis of technical feasibility starts with the requirements that a remedial action must meet to achieve a particular cleanup level and then considers the physical infrastructure, base activities, and mission restrictions that would prevent these requirements from being met. This section discusses the technical feasibility of hypothetical cleanup actions to achieve background concentrations in the Travis AFB groundwater plumes.

4.1 Overall Technical Feasibility

Overall, it is not technically feasible to achieve cleanup of most of the contaminated groundwater beneath Travis AFB to background concentrations.

The Site SS016 plume poses the most technical challenges in terms of remedy implementation. This large portion of Travis AFB groundwater contamination underlies areas of active airfield operations, including concrete parking ramps and taxiways. Increasing the construction requirements of the FFS remedial alternative for this plume to reach background levels would pose serious adverse impacts to the Base's military mission.

Another key problematic issue regarding the technical feasibility of attaining background concentrations is the required scope of treatment. The FFS evaluates treatment of plume source areas to achieve an MCL cleanup objective. Much more aggressive treatment would be required to achieve cleanup to background levels in the same amount of time. This expanded treatment would require the construction of hundreds of additional injection wells and the injection of tens of thousands of gallons of additional carbon substrate to induce reductive dechlorination. Because the treatment areas are located in active industrial areas, it is likely that the additional treatment infrastructure would interfere with their industrial activities. Also, this treatment would be inefficient, because it would be extended from the relatively high concentration source areas into the much lower concentration distal portions of the plumes.

Evaluations of the technical feasibility of cleanup to background concentrations under the individual FFS remedial alternatives are provided in the following subsections.

4.2 Alternative 1 – No Action

No remedial action is taken under Alternative 1 – No Action. Therefore, technical feasibility is not evaluated.

4.3 Technical Feasibility of Achieving Background Concentrations under Alternative 2 – MNA

It is technically feasible to achieve background concentrations at the applicable sites under FFS Alternative 2 – MNA. However, additional remediation time and larger networks of monitoring wells would be required. This assessment assumed that the expanded monitoring well networks will not adversely impact local Base activities or be placed in a restricted area.

Under Alternative 2, contaminant plumes undergo natural physical, chemical, and/or biological processes until cleanup levels are achieved. Estimates of the time to reduce contaminant concentrations to MCLs and the additional time to achieve background levels at sites for which MNA is the Air Force preferred remedy are provided in Table 4-1.

TABLE 4-1
Comparisons of Time to Achieve Cleanup Standards under Alternative 2 – MNA
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

	Time to Achieve Cleanup Standard (years)*			
Site	**MCL**	**Background**	**Percent Increase**	**Comment**
FT004	35	65	86	
FT005	43	43	0	1,2-DCA is the primary COC. Low MCL of 0.5 µg/L is the same as the background concentration.
LF006	5	59	> 100	
LF007B	0	0	0	Chlorinated VOC concentrations are already below MCLs and background concentrations.
LF007D	> 100	> 100	0	Benzene concentrations have been stable between 2 and 3 µg/L over 10 years of monitoring.
LF008	> 100	> 100	0	Organochlorine pesticide with low mobility and lack of biodegradation mechanisms.
ST027B	50	80	60	Activities restricted by adjacent active airfield operations.
SD031	15	> 100	> 100	Plume underwent interim GET. Therefore, no biodegradation data are available and biodegradation effects are not included in the analysis.
SD033	60	90	50	Component site of overall WIOU plume.
SD043	60	90	50	Component site of overall WIOU plume.

* Additional discussion regarding groundwater cleanup time estimates and methodologies is provided in Appendix C.

4.4 Technical Feasibility of Achieving Background Concentrations under Alternative 3 – GET

It is technically feasible to achieve background concentrations at the applicable sites under FFS Alternative 3 – GET. No additional GET system components would be needed. However, additional remediation time would be required for the GET systems to remediate to background concentrations.

Under Alternative 3, groundwater extraction wells are used to physically remove contaminants from the aquifer. The extracted groundwater is conveyed to a treatment plant for ex situ treatment using LGAC. The treated groundwater is then discharged to the stormwater drainage system. Estimates of the time to reduce contaminant concentrations to MCLs and the additional time to achieve background concentrations using the existing extraction systems are provided in Table 4-2.

TABLE 4-2
Comparisons of Time to Achieve Cleanup Standards under Alternative 3 – GET
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

	Time to Achieve Cleanup Standard (years)*			
Site	**MCL**	**Background**	**Percent Increase**	**Comment**
LF007C	26	53	> 100	Off-base plume underlies a vernal pool.
SS029	62	86	39	Plume is hydraulically downgradient and commingled with contaminants from the SS016 plume.
SS030	22	46	> 100	Off-base plume.

* Additional discussion regarding groundwater cleanup time estimates and methodologies is provided in Appendix C.

This analysis assumes that the GET systems will not reach asymptotic conditions before reaching both MCLs and background levels. Because other Travis AFB GET systems did reach asymptotic conditions during their periods of interim remediation, this assumption may not be valid.

It would be technically feasible to expand the GET systems if future performance data indicate this action is warranted. However, the Site SS029 GET system is near an aircraft taxiway and runway. Expansion of this GET system would be difficult to implement, may violate several Federal Aviation Administration regulations, and would likely pose an adverse impact to the military mission of Travis AFB.

4.5 Technical Feasibility of Achieving Background Concentrations under Alternative 4 – Bioreactor and GET

It is not technically feasible to expand plume treatment to achieve background concentrations at Site SS016 under FFS Alternative 4 – Bioreactor and GET.

Alternative 4 uses an in situ bioreactor to treat the Site SS016 OSA source area and extraction wells to physically remove contaminants from the downgradient portion of the plume. Extracted groundwater is conveyed to the CGWTP for ex situ treatment using LGAC. The treated groundwater is then discharged to the stormwater drainage system.

This portion of Travis AFB groundwater contamination underlies active military aircraft parking aprons, taxiways, and runways. Extending the bioreactor treatment zone, or employing another in situ treatment process, is not feasible. These actions would disrupt active airfield operations and pose serious adverse impacts to the Base's military mission.

Three (3) source zone treatment scenarios are evaluated in the following subsections.

4.5.1 Scenario 1 – Existing Combination of Bioreactor and GET

Scenario 1 involves remediation using the existing combination of Site SS016 OSA source area bioreactor located within the 100,000-µg/L TCE isocontour (approximately 200 square feet) and continued operation of the Site SS016/SS029 GET system. It is theoretically possible to eventually achieve background concentrations under this scenario, because no expansion of existing infrastructure is required into restricted areas of flight line operations. However, indefinite additional remediation time would be required because of the uncertain presence of residual DNAPLs.

Estimates of the time to reduce contaminant concentrations to MCLs and the additional time to achieve background concentrations under Scenario 1 are provided in Table 4-3. The treatment zone under Scenario 1 is shown on Figure 4-1.

TABLE 4-3
Comparisons of Time to Achieve Cleanup Standards under Alternative 4 – Bioreactor and GET – Scenario 1
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	Time to Achieve Cleanup Standard (years)		Percent Increase	Comment
	MCL	Background		
SS016 Scenario 1[a]	> 100	> 100	-[b]	OSA source area treatment via the bioreactor installed within the 100,000-µg/L isocontour.

[a] Existing treatment area, additional time required to achieve background concentrations. Continued operation of existing bioreactor within the 100,000-µg/L TCE isocontour and continued operation of GET system. Additional discussion regarding cleanup time estimates and methodologies is provided in Appendix C.
[b] Installation of a bioreactor in the OSA source area included physical removal of the highest concentrations of chlorinated VOCs, but some residual DNAPL likely remains. The times to achieve MCLs and background are based on remediation of dissolved contamination only and are estimated at 62 and 86 years (a 39 percent increase). However, the probable presence of residual DNAPL will indefinitely extend these times because they provide a continuing source of dissolved contamination. Therefore, a qualitative assessment of greater than 100 years provides a more appropriate estimate of the times to achieve both MCLs and background.

Residual DNAPL is probably present within the OSA source area. This DNAPL would significantly increase the time to achieve cleanup goals. Dissolved solvents outside the bioreactor treatment zone would not readily degrade because of the continuing source of contaminants provided by the DNAPL. Accordingly, the time to achieve either MCLs or background would be greatly extended beyond estimates developed by assuming only dissolved-phase contamination. Even with an extended period of remediation, the bioreactor treatment zone would likely not propagate far enough under the aircraft parking apron to effectively remediate solvent contamination emanating from zones of residual DNAPL.

4.5.2 Scenario 2 – Expanding Source Area Treatment to 1,000-×g/L TCE Isocontour

Scenario 2 involves a hypothetical expansion of the Site SS016 OSA treatment zone from the 100,000-µg/L TCE isocontour to the 1,000-µg/L TCE isocontour. Operation of the Site SS016/SS029 GET system is continued. The estimated time to achieve background (t_{BGD}) under this scenario is 86 years. The hypothetical expanded treatment zone under Scenario 2 is shown on Figure 4-2.

Under this hypothetical scenario, source area treatment using a bioreactor is expanded to encompass the 1,000-µg/L TCE isocontour. This isocontour extends approximately 500 feet hydraulically downgradient of the existing OSA bioreactor and underlies an active aircraft parking ramp. The area encompassed is approximately 35,500 square feet. Installation of a bioreactor of this scale would presumably include removal of all DNAPL that originated from the OSA, such that only dissolved-phase contamination remains.

Installation of a bioreactor in this area of active airfield operations is not technically feasible. A bioreactor of the required dimensions would result in an area unusable for aircraft traffic and parking. A bioreactor consists primarily of degradable organic mulch. This mulch is not suitable for military aircraft wheel loads. Additionally, the mulch would settle over time and create surface depressions also unacceptable for aircraft. These issues would have a serious adverse impact to the military mission of Travis AFB.

Even if an in situ treatment process less disruptive than a bioreactor could be employed (e.g., EVO injection), treating the plume down to the 1,000-µg/L TCE isocontour is technically infeasible. The estimated treatment area would be approximately 35,500 square feet within the OSA portion of the plume. Such an area would require approximately 19 new injection wells and 20,700 gallons of EVO. However, the limited permeability of the saturated alluvium in this area would likely preclude effective injection of a treatment medium, such as EVO. Furthermore, installation of even a limited number of wells for EVO injection within the area of active airfield operations would pose serious adverse impacts to the military mission of the Base.

The overall time to achieve background for the combined Site SS016/SS029 plume is approximately 86 years in the absence of DNAPL.

4.5.3 Scenario 3 – Expanding Source Area Treatment to 60-×g/L TCE Isocontour

Scenario 3 is based on a hypothetical expansion of the treatment zone such that the time required to achieve MCLs is equal to the time to achieve background (t_{BGD} = 62 years = t_{MCL}) assuming only dissolved-phase contamination. For this condition to be satisfied, the Site SS016/SS029 plume would need to be treated down to the 60-µg/L TCE isocontour. A summary of the time required to reduce contaminant concentrations to MCLs/background and the required areas of treatment is provided in Table 4-4. The extent of the hypothetical treatment zone under Scenario 3 is shown on Figure 4-3.

Under this hypothetical scenario, source area treatment using a bioreactor would be expanded to encompass the 60-µg/L TCE isocontour. This isocontour extends approximately 2,400 feet hydraulically downgradient of the existing OSA bioreactor and underlies an active aircraft parking ramp, a taxiway, and comes within approximately 350 feet of a runway. Installation of a bioreactor in this area of active airfield operations is not technically feasible. As under Scenario 2, a bioreactor of the required dimensions would result in an area unusable for aircraft traffic. A bioreactor consists primarily of degradable organic mulch. This mulch is not suitable for military aircraft wheel loads. Additionally, the mulch would settle over time and create surface depressions also unacceptable for aircraft. These issues would have a serious adverse impact to the military mission of Travis AFB.

TABLE 4-4
Comparisons of Area Treatment Requirements under Alternative 4 – Bioreactor and GET – Scenario 3
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

		Treatment Requirement to Achieve MCL		Treatment Requirement to Achieve Background		
Site	**Cleanup Time (years)**	**Isocontour Defining Extent of Treatment (µg/L)**	**Treatment Area (square feet)**	**Isocontour Defining Extent of Treatment (µg/L)**	**Treatment Area (square feet)**	**Percent Increase in Treatment Area**
SS016 Scenario 3[a]	62[b]	> 100,000	200	60	873,322 (OSA) 882,7856 (SS029) 1,756,078 (total)	≫ 100

[a] Variable treatment area, fixed time. Hypothetical expansion of treatment area to the 60-µg/L isocontour to achieve background in the same amount of time as to achieve MCL (t_{MCL} = t_{BKG} = 62 years). Additional discussion regarding groundwater cleanup time estimates and methodologies is provided in Appendix C.
[b] Time required to achieve MCLs and background assuming all DNAPLs are removed and only dissolved-phase contamination is present.

Even if an in situ treatment process less disruptive than a bioreactor could be employed (e.g., EVO injection), treating the plume down to the 60-µg/L TCE isocontour to achieve t_{BGD} = 62 years = t_{MCL} is technically infeasible. The estimated treatment area would be approximately 873,322 square feet within the OSA portion of the plume and an additional 882,756 square feet within the Site SS029 portion (total of 1,756,078 square feet). Such an area would require approximately 945 new injection wells and 1,023,000 gallons of injected EVO. Installation of this number of wells and injecting this volume of EVO within areas of active airfield operations would pose serious adverse impacts to the military mission of the Base.

Under either treatment process, a modified GET system would need to be installed. New extraction wells would be installed to address lower concentrations of contaminants in the distal portions of the plume not within the hypothetical expanded treatment zone. The existing Site SS016 OSA and Site SS029 extraction wells would be within the expanded treatment zone. Therefore, groundwater extraction within these areas would necessarily be discontinued to avoid disrupting ERD treatment processes.

4.6 Technical Feasibility of Achieving Background Concentrations under Alternative 5 – EVO and EA

It may be technically feasible to achieve background concentrations under FFS Alternative 5 – EVO and EA. Hypothetically, the EVO treatment zones could be expanded to achieve cleanup of groundwater to background concentrations in the same amount time required to achieve MCLs. However, hundreds of closely spaced injection wells and over half a million gallons of EVO would be required. Installing the required number of wells and injecting the required volume of EVO is theoretically possible, but would encounter many practical problems. Surface infrastructure, such as buildings, shops, and aircraft maintenance hangars, would restrict access to many drilling locations and make obtaining full treatment of the plume uncertain. Similar problems in obtaining complete treatment would arise because of the presence of subsurface infrastructure such as sanitary sewer pipelines and stormwater drains. The trenches containing these pipelines often cause serious difficulties during the pressure injection of EVO (e.g., short-circuiting). Also, the required scope of construction activities would likely have an adverse impact on the military mission of the Base.

Alternative 5 involves ERD treatment facilitated by EVO injection in the source area combined with natural attenuation processes in the distal portions of the plumes. The technical feasibility of achieving background levels is based on hypothetically expanding the EVO treatment zone such that the time required to achieve MCLs is equal to the time to achieve background ($t_{MCL} = t_{BGD}$).

For the $t_{MCL} = t_{BGD}$ condition to be satisfied, the Site SS0015 plume would need to be treated with additional EVO injection down to the 83-µg/L cis-1,2-DCE isocontour and the WIOU plume down to the 40-µg/L TCE isocontour. A summary of the time required to reduce contaminant concentrations to MCLs/background and the required areas of treatment is provided in Table 4-5. The extents of the hypothetical treatment zones are shown on Figures 4-4 and 4-5.

TABLE 4-5
Comparisons of Area Treatment Requirements under Alternative 5 – EVO and EA
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

		Treatment to Achieve MCL		**Expanded Treatment to Achieve Background**		
Site	**Cleanup Time[a] (years)**	**Isocontour Defining Extent of Treatment (µg/L)**	**Treatment Area (square feet)**	**Isocontour Defining Extent of Treatment (µg/L)**	**Treatment Area (square feet)**	**Percent Increase in Treatment Area**
SS015	70	1,000	175	83	11,342	≫ 100
WIOU[b]	60	1,000	77,666	40	1,038,741	≫ 100
	Total		**77,841**		**1,050,083**	≫ 100

[a] Time to achieve cleanup to MCL is equal to the time to achieve cleanup to background ($t_{MCL} = t_{BKG}$). Additional discussion regarding groundwater cleanup time estimates and methodologies is provided in Appendix C.
[b] Component sites of the overall WIOU plume include SD033, SD034, SS035, SD036, SS041, and SD043.

The hypothetical combined EVO treatment area would be approximately 1,050,083 square feet. To address the heterogeneous nature of the low-permeability alluvium, vertical injection wells would need to be spaced approximately 40 feet apart, with an average screen length of 42 feet. To fully treat the required area would require approximately 556 new injection wells and 557,200 gallons of EVO.

The effectiveness of in situ treatment systems is primarily influenced by the hydrogeologic and contaminant properties at the site. Groundwater contamination at Travis AFB can be successfully treated under Alternative 5 provided that an ERD treatment zone can be created in proximity to the contaminants. Three (3) key parameters determine the effectiveness of treatment:

- Treatability
- Permeability
- Presence of DNAPL

4.6.1 Treatability

The primary parameter for successful treatment is the ability of native microbes to degrade the contaminants. At Travis AFB, ongoing demonstrations of ERD treatment using injected EVO substrate have shown that native anaerobic bacteria are capable of fully degrading chlorinated VOCs to non-toxic byproducts. Travis AFB will continue to assess the performance of these treatment demonstrations for the remainder of the period of interim remediation.

4.6.2 Permeability

The permeability of the aquifer materials controls the distribution of liquid substrate (i.e., EVO). Fine-grained aquifer media (e.g., silts and clays) have lower intrinsic permeability than coarse-grained media (e.g., sands and gravels). It typically takes longer to clean up a low-permeability aquifer than a higher-permeability aquifer. Soil structure and stratification are particularly important in bioremediation, because they affect how liquid substrates are distributed in the aquifer. The stratification of soils with different permeability can result in increased flow in the more permeable strata and reduced flow through the less permeable strata. This preferential flow behavior can lead to reduced effectiveness and extended remediation times for less permeable strata.

The aquifer at Travis AFB is characterized as a single, leaky, low-permeability system of unconsolidated alluvium. The sediments consist primarily of fine-grained silts and clays with interbedded sand lenses that do not correlate well from location to location. Therefore, to address the heterogeneous nature of the low-permeability alluvium, a close spacing of vertical injection wells is needed to adequately distribute the liquid substrates used in bioremediation (i.e., injected EVO).

4.6.3 Presence of Dense Nonaqueous Phase Liquids

Some residual DNAPL may be present within the source areas of Sites SS015, SD036, and SD037 even after a decade of interim remediation. DNAPL is not amenable to direct treatment, particularly in clays. However, ERD treatment is effective on dissolved contaminants, and long persistence time of EVO in the subsurface supports the long-term treatment of source zones. Additional information on in situ source zone treatment technologies is provided in the final Basewide Groundwater FFS (CH2M HILL, 2011a).

4.7 Technical Feasibility of Achieving Background Concentrations under Alternative 6 – Bioreactor, Phytoremediation, EVO PRB, and EA

It is technically feasible to achieve background concentrations under FFS Alternative 6 – Bioreactor, Phytoremediation, EVO PRB, and EA. In concept, an EVO PRB treatment zone could be installed at Site DP039 to achieve cleanup of groundwater to background concentrations in the same amount time required to achieve MCLs. However, a larger number of PRB injection wells and a larger volume of EVO would be required.

The EVO PRB component of Alternative 6 involves ERD treatment facilitated by EVO injection combined with natural attenuation processes in the distal portions of the plumes. The existing EVO PRB intercepts the plume at the 500-µg/L TCE isocontour. The technical feasibility of achieving background levels is based on hypothetically installing a new EVO PRB such that the time required to achieve MCLs is equal to the time to achieve background (t_{MCL} = t_{BGD}).

For the t_{MCL} = t_{BGD} condition to be satisfied, a hypothetical EVO PRB would need to be installed at the leading edge of the 185-µg/L TCE isocontour. This isocontour encompasses an area of approximately 612,093 square feet. A summary of the time required to reduce contaminant concentrations to MCLs/background and the required areas of treatment is provided in Table 4-6. The location and extent of the hypothetical EVO PRB are shown on Figure 4-6.

TABLE 4-6
Comparisons of Area Treatment Requirements under Alternative 6 – Bioreactor, Phytoremediation, EVO PRB, and EA
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

		Treatment to Achieve MCL		Expanded Treatment to Achieve Background		
Site	Cleanup Time* (years)	Isocontour Defining EVO PRB Location (µg/L)	Length of EVO PRB (feet)	Isocontour Defining Extended EVO PRB Location (µg/L)	Length of EVO PRB (feet)	Percent Increase in PRB Length
DP039	65	500	400	185	690	72

*Time to achieve cleanup to MCL is equal to the time to achieve cleanup to background (t_{MCL} = t_{BKG}). Additional discussion regarding groundwater cleanup time estimates and methodologies are provided in Appendix C.

A hypothetical EVO PRB would be approximately 690 feet in length and placed to intercept the Site DP039 contaminant plume at the 185-µg/L TCE isocontour. To address the heterogeneous nature of the low-permeability alluvium, vertical injection wells would need to be spaced approximately 30 feet apart and with an average screen length of 20 feet. To create the required length of EVO PRB would require approximately 23 new injection wells and 7,314 gallons of injected EVO.

As with Alternative 5, groundwater contamination can be successfully treated under Alternative 6 provided that an ERD treatment zone can be created to intercept contaminants as they migrate with the natural hydraulic gradient. Three (3) key parameters determine the effectiveness of treatment:

- Treatability
- Permeability
- Presence of DNAPL

4.7.1 Treatability

The primary parameter for successful treatment is the ability of native microbes to degrade the contaminants. At Travis AFB, ongoing demonstrations of ERD treatment at the existing Site DP039 bioreactor and other EVO injection demonstrations have shown that native anaerobic bacteria are capable of fully degrading chlorinated VOCs to non-toxic byproducts. Travis AFB will continue to assess the performance of these treatment demonstrations for the remainder of the period of interim remediation.

Potential expansion of phytoremediation treatment is not evaluated. This is mainly because it would take new trees in an expanded planting area a considerable amount of time to develop a root structure large enough to promote the cleanup of the high concentrations of dissolved solvents that have migrated beyond the bioreactor at the source area.

4.7.2 Permeability

The permeability of the aquifer materials controls the distribution of liquid substrate (i.e., EVO). Fine-grained aquifer media (e.g., silts and clays) have lower intrinsic permeability than coarse-grained media (e.g., sands and gravels). It typically takes longer to clean up a low-permeability aquifer than a higher-permeability aquifer. Soil structure and stratification are particularly important in bioremediation, because they affect how liquid substrates are distributed in the aquifer. The stratification of soils with different permeability can result in increased flow in the more permeable strata and reduced flow through the less permeable strata. This preferential flow behavior can lead to reduced effectiveness and extended remediation times for less permeable strata.

The aquifer at Travis AFB is characterized as a single, leaky, low-permeability system of unconsolidated alluvium. The sediments consist primarily of fine-grained silts and clays with interbedded sand lenses that do not correlate well from location to location. Therefore, to address the heterogeneous nature of the low-permeability alluvium, a close spacing of vertical injection wells is needed to adequately distribute the liquid substrates used in bioremediation (i.e., injected EVO).

4.7.3 Presence of Dense Nonaqueous Phase Liquids

DNAPL contaminants are not amenable to direct treatment, particularly in clays. Contaminants must be dissolved in the groundwater or adsorbed onto more permeable sediments in order to be treated. Some residual DNAPL may still be present within the Site DP039 source area even after more than a decade of interim remediation. However, the existing bioreactor is expected to provide effective long-term remediation of dissolved contamination within the historical source area from the slow dissolution of possible residual DNAPL.

4.8 Technical Feasibility of Achieving Background Concentrations under Alternative 7 – Passive Skimming and EA

This alternative does not use a treatment component, and no technical feasibility issues need to be addressed.

No treatment technologies are employed under Alternative 7. Passive skimming is a removal technology and not a treatment process. For the EA component of the alternative, remediation of contaminants will occur gradually by natural physical, chemical, and biological processes. These reductions are quantified by groundwater sampling and analyses under the existing Travis AFB GSAP.

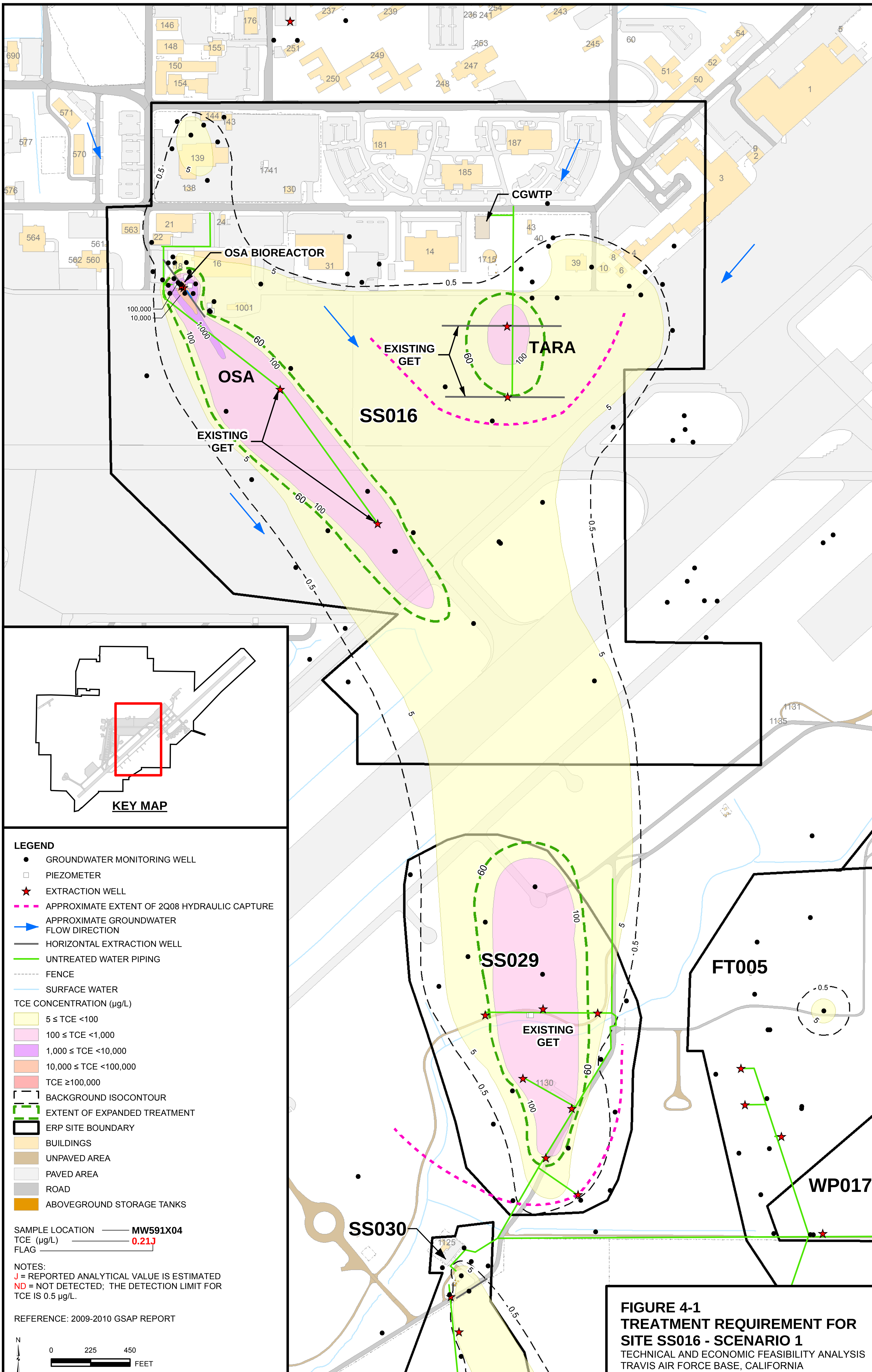
In contrast to the alternatives using bioreactor or EVO treatment technologies, this alternative does not use an active treatment component that can be physically expanded. The wells used for passive skimming and the network of EA monitoring wells are adequate. Therefore, the TEFA only evaluates the additional time required to achieve background concentrations using the existing remedy components. Free product removal using passive skimming is currently conducted only intermittently and is expected to decrease over time. No technical feasibility issues are expected to arise in the future if additional wells are needed to supplement passive skimming removal or the EA monitoring components of the remedy.

4.9 Summary of the Technical Feasibility of Achieving Background Concentrations

Overall, it is not technically feasible to achieve cleanup of all contaminated groundwater at Travis AFB to background concentrations. A large volume of contaminated groundwater lies underneath thick layers of concrete that make up active parking ramps, taxiways, and runways (e.g., Site SS016). The expansion of groundwater treatment systems in the vicinity of hangars and other supporting airfield infrastructure can be problematic, depending on the type of activities and the restrictions associated with those structures. However, the Air Force has agreed to applicable or relevant and appropriate requirements (ARARs) in the FFS to be carried forward to the Record of Decision that will clean up all contaminated groundwater on Travis AFB to risk-based MCLs and does not consider a groundwater remedial action to be complete until the MCL for each COC is achieved.

For those areas of groundwater contamination where background cleanup levels might be achieved, the duration of groundwater treatment would have to be extended and/or the scope of treatment would have to be expanded. This expanded treatment requirement would result in the construction of hundreds of additional injection wells and the injection of tens of thousands of gallons of additional carbon substrate. Because many of these additional wells would be physically located in the distal portions of plumes where contaminant concentrations are lower, the amount of contaminant treated per unit volume of injected EVO would decrease, and this treatment approach would become less efficient.

The technical feasibility assessment made several assumptions that may not be valid. For those sites that will rely on GET technologies for groundwater cleanup, the assumption is that the treatment systems will not reach asymptotic conditions prior to the achievement of background levels (or even MCLs). However, as contaminant concentrations drop, an asymptotic state becomes a plausible outcome and would result in either a switch to a different cleanup technology or a realization that background levels cannot be achieved.



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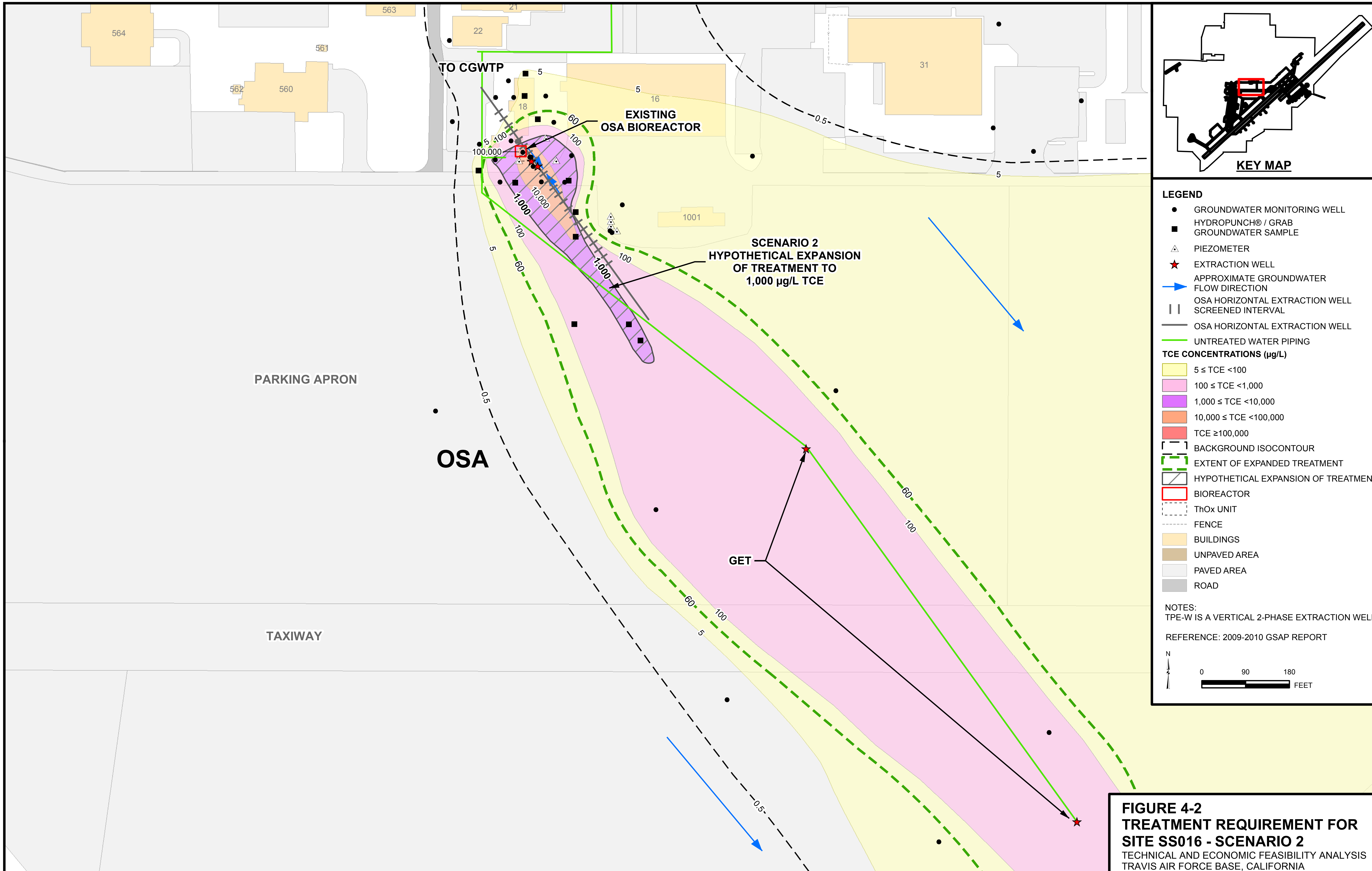

FIGURE 4-2
TREATMENT REQUIREMENT FOR SITE SS016 - SCENARIO 2
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA
CH2MHILL

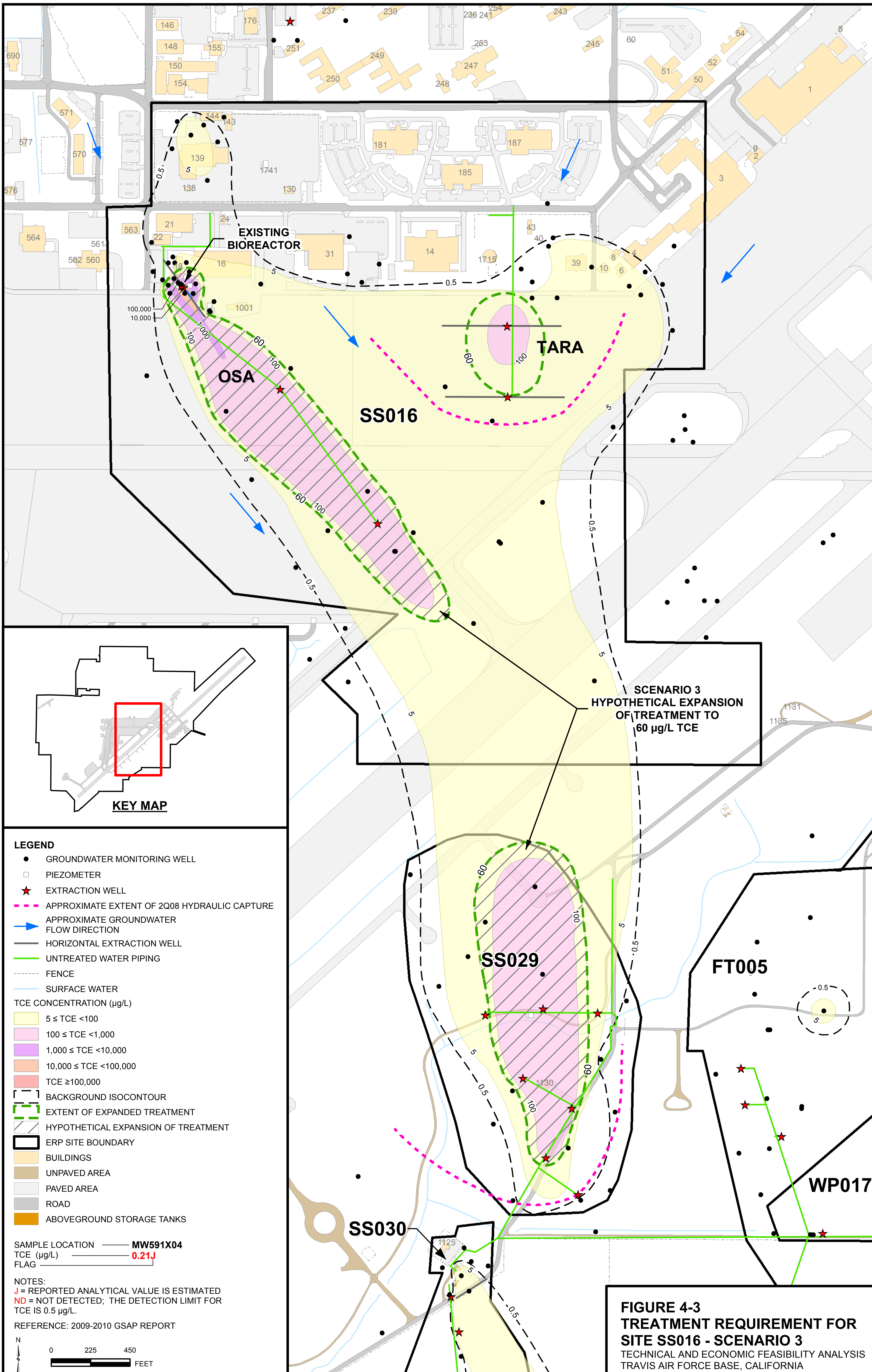

FIGURE 4-3
TREATMENT REQUIREMENT FOR SITE SS016 - SCENARIO 3
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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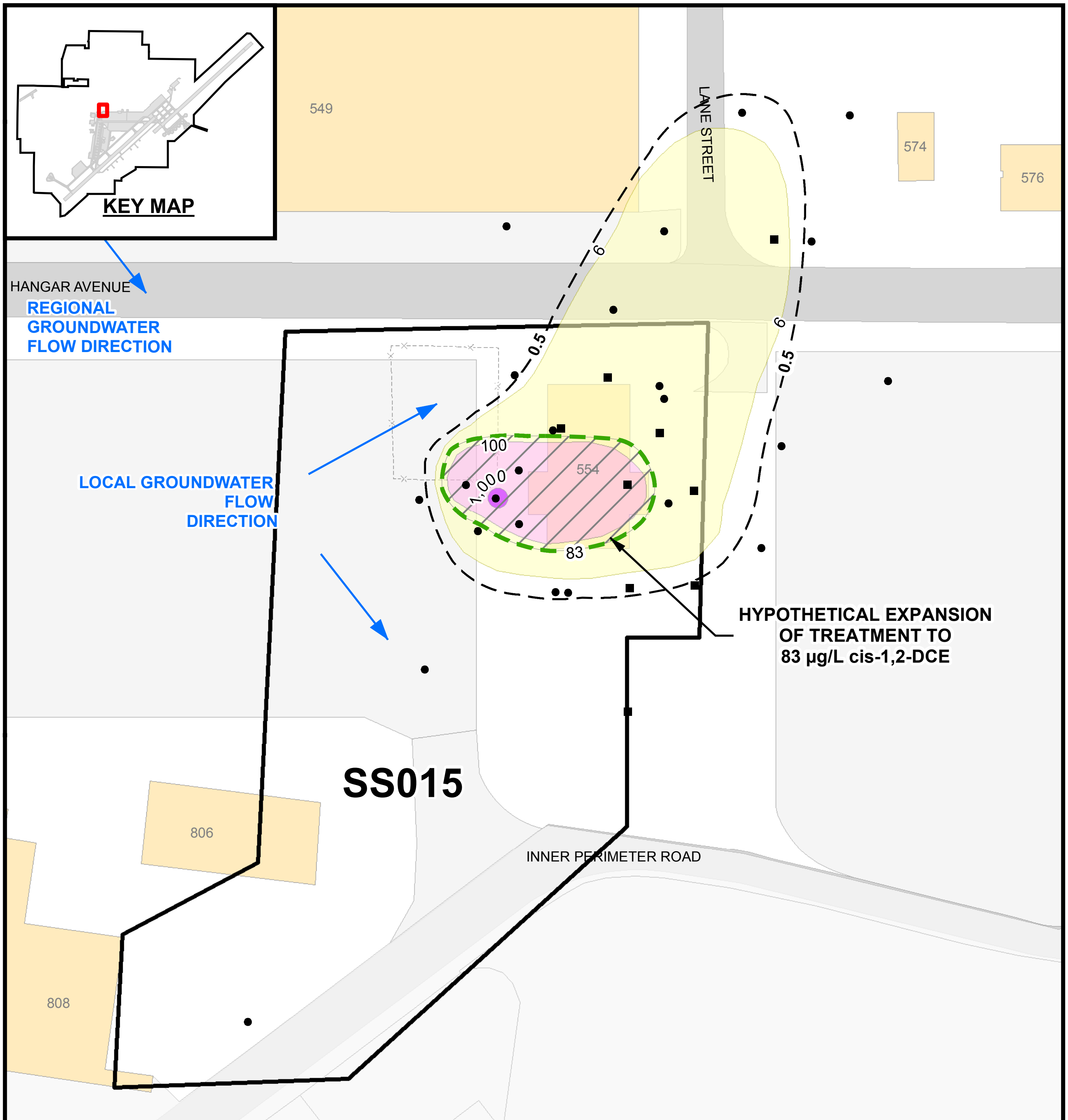

LEGEND

- IN SITU SAMPLE (JUN - AUG 1998)
- GROUNDWATER MONITORING WELL
- A — A' CROSS SECTION LINE
- APPROXIMATE GROUNDWATER FLOW DIRECTION
- FENCE
- BUILDING
- PAVED AREA
- ROAD

CIS-1,2-DCE CONCENTRATIONS (µg/L)

- 6 ≤ CIS-1,2-DCE < 100
- 100 ≤ CIS-1,2-DCE < 1,000
- CIS-1,2-DCE ≥ 1,000
- BACKGROUND ISOCONTOUR
- EXTENT OF EXPANDED TREATMENT
- HYPOTHETICAL EXPANSION OF TREATMENT
- ERP SITE BOUNDARY

N

0 55 110 FEET

FIGURE 4-4
TREATMENT REQUIREMENTS FOR SITE SS015
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

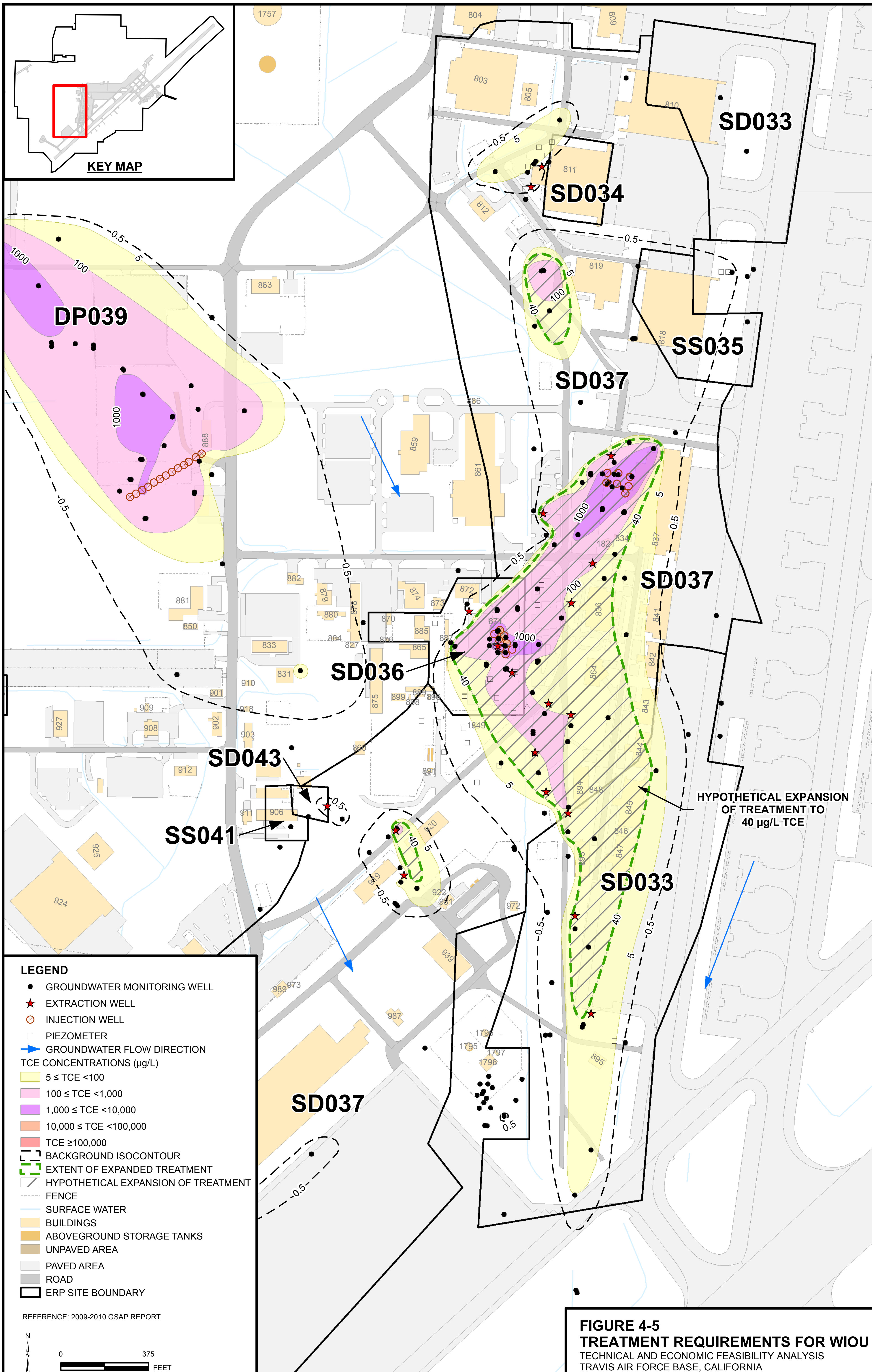

FIGURE 4-5
TREATMENT REQUIREMENTS FOR WIOU
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

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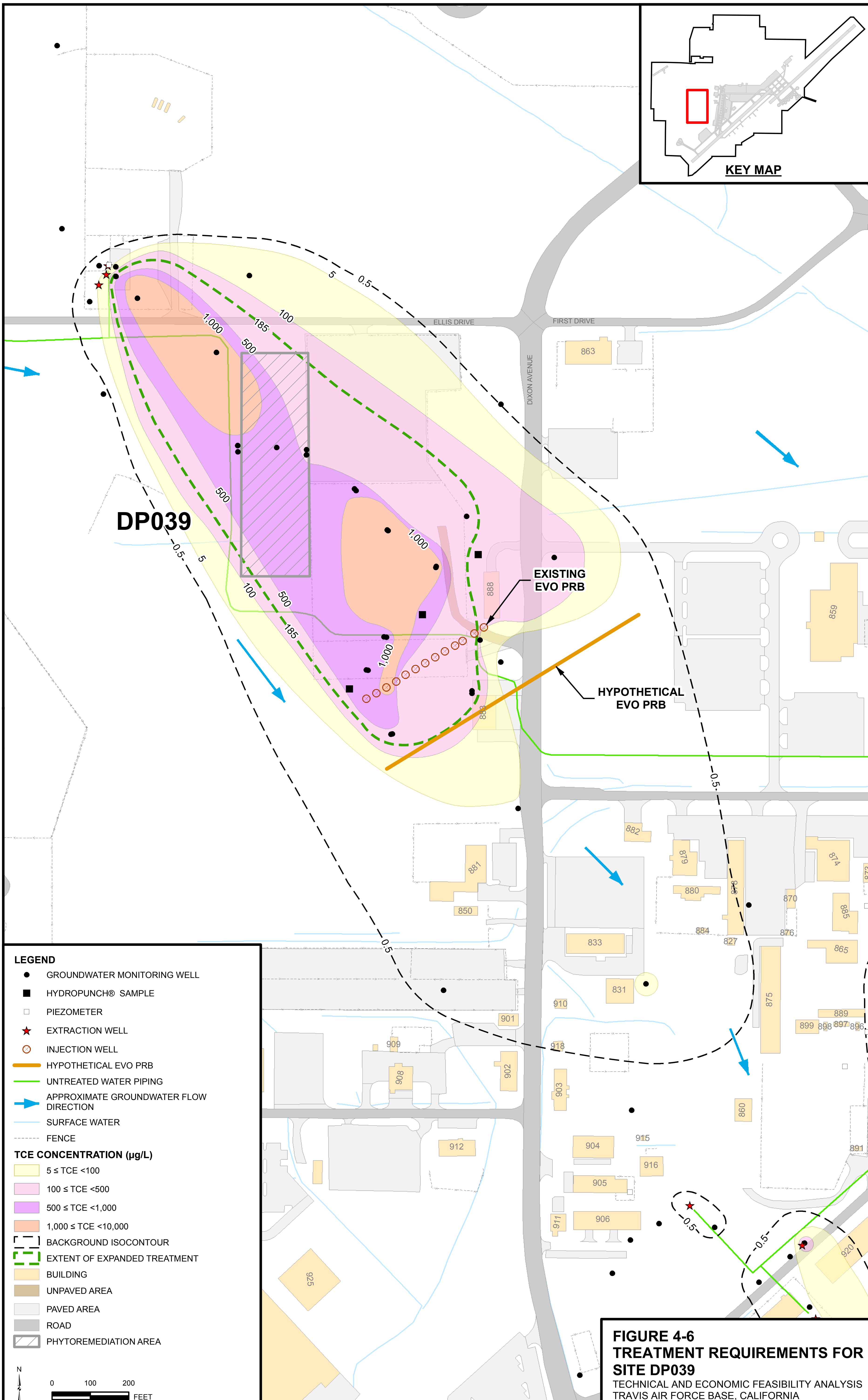

FIGURE 4-6
TREATMENT REQUIREMENTS FOR SITE DP039
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

SECTION 5

Analysis of Economic Feasibility

SWRCB Resolution 92-49, Section III H.1.b.defines the term “economic feasibility” as

> *“an objective balancing of the incremental benefit of attaining further reductions in the concentrations of constituents of concern as compared with the incremental cost of achieving those reductions. The evaluation of economic feasibility will include consideration of current, planned, or future land use, social, and economic impacts to the surrounding community including property owners other than the discharger. Economic feasibility, in this Policy, does not refer to the discharger's ability to finance cleanup…”*

Because the costs of cleanup alone do not drive an economic feasibility determination, this type of assessment would normally use the nine (9) factors analyzed in Section 3 to compare the expected incremental benefit of cleaning a site’s groundwater to “background” to the estimated cost to achieve the more stringent cleanup standard. However, the technical portion of this analysis has already concluded that it is not technically feasible to achieve cleanup of all contaminated groundwater at Travis AFB to background concentrations. Therefore, an economic analysis of a groundwater remediation that targets a cleanup level that cannot be technically achieved is problematic. An economic feasibility determination for the groundwater beneath Travis AFB would not provide any useable information to support the selection of groundwater cleanup levels.

The Air Force and the Water Board have discussed this issue and agreed that the technical feasibility evaluation as described in Section 4 is sufficient to meet the requirements of SWRCB Resolution 92-49.

SECTION 6

Summary of Technical and Economic Feasibility Analyses

Overall, it is not technically feasible to achieve cleanup of all contaminated groundwater at Travis AFB to "background" concentrations. This conclusion is based on the presence of a large volume of contaminated groundwater beneath airport infrastructure, such as concrete parking ramps, taxiways, and runways. The expansion of groundwater treatment systems in the vicinity of hangars, fuel hydrant systems, and other supporting airfield infrastructure would be difficult or impossible, depending on the nature of the industrial activities and the restrictions associated with them.

The FFS used an MCL cleanup standard to evaluate the ability of various technologies to treat contaminant plumes (CH2M HILL, 2011a). Much more aggressive treatment would be required to achieve groundwater cleanup to "background" concentrations using the FFS alternatives. Also, if Travis AFB receives increased mission requirements and additional military units as a result of future base closures and reorganizations, the ability to expand treatment systems would become more challenging.

For the entirety of Travis AFB, the hypothetical expansion of active groundwater treatment, using EVO injection as the least disruptive method of remediation, would require up to 1,533 additional injection wells and 1,642,000 gallons of EVO. This hypothetical expansion of treatment would need to take place within areas of active flight line operations, so it would have serious and unacceptable adverse impacts to the military mission of Travis AFB and therefore is not technically feasible. However, the Air Force established ARARs in the FFS that will clean up all contaminated groundwater on Travis AFB to risk-based MCLs and agreed to carry them forward into the Groundwater ROD. The Air Force does not consider a groundwater remedial action to be complete until the MCL for each COC is achieved.

Because the cleanup of all contaminated groundwater to "background" levels is not feasible, the conduct of an economic feasibility analysis would not yield any meaningful results. SWRCB Resolution 92-49, Section III H.1.b.defines the term "economic feasibility" as

> *"an objective balancing of the incremental benefit of attaining further reductions in the concentrations of constituents of concern as compared with the incremental cost of achieving those reductions. The evaluation of economic feasibility will include consideration of current, planned, or future land use, social, and economic impacts to the surrounding community including property owners other than the discharger. Economic feasibility, in this Policy, does not refer to the discharger's ability to finance cleanup…"*

Since the cleanup costs alone do not drive an economic feasibility determination, this assessment would normally use the nine (9) environmental factors from SWRCB Resolution 92-49 to compare the expected incremental benefit of cleaning contaminated groundwater to “background” levels to the estimated cost to achieve this more stringent cleanup standard.

As described above, the technical feasibility analysis concluded that it was not technically feasible to achieve the cleanup of all contaminated groundwater at Travis AFB to “background” concentrations. Therefore, an economic feasibility analysis of a groundwater remediation that needs to achieve a technically unachievable cleanup level would be problematic. As a result, an economic feasibility determination for the groundwater beneath Travis AFB would not produce any usable information that could support the selection of groundwater cleanup levels. Both the Air Force and the Water Board have discussed this issue and concluded that the technical feasibility analysis alone is sufficient to meet the requirements of SWRCB Resolution 92-49.

Appendix A
Acronyms and Abbreviations

APPENDIX A

Acronyms and Abbreviations

°C	degree(s) Celsius
µg/L	microgram(s) per liter
µmhos/cm	micromho(s) per centimeter
AFB	Air Force Base
AFCESA	Air Force Civil Engineer Support Agency
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
CCR	California Code of Regulations
CDHS	California Department of Health Services
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Regulations
CGWTP	Central Groundwater Treatment Plant
CLGB	concentration limits greater than background
cm/sec	centimeter(s) per second
COC	chemical of concern
DBP	disinfection byproduct
DBPR	Disinfectants and Disinfection Byproducts Rule
DCA	dichloroethane
DCB	dichlorobenzene
DCE	dichloroethene
DNAPL	dense nonaqueous phase liquid
DTSC	Department of Toxic Substances Control
EA	enhanced attenuation
EIOU	East Industrial Operable Unit
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment

ERD	enhanced reductive dechlorination
ERP	Environmental Restoration Program
ESTCP	Environmental Security Technology Certification Program
EVO	emulsified vegetable oil
FFA	Federal Facilities Agreement
FFS	basewide groundwater focused feasibility study
FS	feasibility study
ft/day	feet per day
ft^2/day	square feet per day
ft/ft	feet per foot
ft/year	feet per year
FTA	Fire Training Area
GET	groundwater extraction and treatment
gpm	gallon(s) per minute
GSAP	Groundwater Sampling and Analysis Program
HHRA	human health risk assessment
IRA	interim remedial action
IROD	Interim Record of Decision
IRP	Installation Restoration Program
J	reported analytical value is estimated (data flag)
LGAC	liquid-phase granular activated carbon
LNAPL	light nonaqueous phase liquid
LTO	long-term operation
LUC	land use control
MCL	maximum contaminant level
mg/L	milligram(s) per liter
MGD	million gallons per pay
MNA	monitored natural attenuation
msl	mean sea level
MTBE	methyl tert-butyl ether

mV	millivolt(s)
MW	monitoring well
NA	not applicable
NAAP	natural attenuation assessment plan
NAAR	natural attenuation assessment report
NAPL	nonaqueous phase liquid
NCP	National Contingency Plan
ND	not detected
NEWIOU	North, East, West Industrial Operable Unit
NFRAP	No Further Remedial Action Planned
NGWTP	North Groundwater Treatment Plant
NOU	North Operable Unit
NPL	National Priorities List
NTU	nephelometric turbidity unit(s)
O&M	operations and maintenance
OSA	Oil Spill Area
OU	operable unit
OWS	oil-water separator
PA	preliminary assessment
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
POCO	petroleum-only contaminated
PRB	permeable reactive barrier
RD/RA	remedial design/remedial action
Regional Water Board	California Regional Water Quality Control Board
RI	remedial investigation
ROD	record of decision
RPM	Remedial Program Manager
RPO	Remedial Process Optimization
SBBGWTP	South Base Boundary Groundwater Treatment Plant

SDWA	Safe Drinking Water Act
SI	site inspection
SSA	Solvent Spill Area
SVOC	semivolatile organic compound
SWRCB	State Water Resources Control Board
TARA	Tower Area Removal Action
t_{BGD}	time required to achieve background levels
TBGFM	Travis Basewide Groundwater Flow Model
TCA	trichloroethane
TCE	trichloroethene
TDS	total dissolved solids
TEFA	technical and economic feasibility analysis
t_{MCL}	time needed to achieve maximum contaminant levels
TOC	total organic carbon
TPH-D	total petroleum hydrocarbon as diesel
TPH-G	total petroleum hydrocarbon as gasoline
TWTP	Travis Water Treatment Plant
UST	underground storage tank
VOC	volatile organic compound
WABOU	West/Annexes/Basewide Operable Unit
Water Board	San Francisco Bay Regional Water Quality Control Board
WIOU	West Industrial Operable Unit

Appendix B
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APPENDIX B
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Appendix C
Remediation Time Frame Estimates

APPENDIX C

Remediation Time Frame Estimates

C.1 Introduction

This appendix documents the application of screening-level solute transport models for multiple sites at Travis Air Force Base (AFB or Base), California, in support of the overall goals of the Basewide Groundwater Technical and Economic Feasibility Analysis (TEFA). Volatile organic compounds (VOCs) represent the most prevalent class of chemicals of concern (COCs) in groundwater. Of the VOCs present in groundwater at the Base, trichloroethene (TCE) is the most common COC, although 1,1-dichloroethene (DCE), 1,2-dichloroethane (DCA), cis-1,2-DCE, and alpha-chlordane are also groundwater COCs at individual sites.

The following sites were evaluated on an individual basis in this TEFA: Sites FT004, FT005, LF006, LF007B, LF007C, LF007D, LF008, SS015, SS016/SS029, ST027B, SS030, SD031, DP039, and the West Industrial Operable Unit (WIOU), which is considered in a single analysis given the commingled nature of the COC plumes in this area (the WIOU includes Sites SD033, SD034, SD036, SS037, SS041, and SD043) (Figure C-1; figures are located at the end of this appendix).

The type of analysis conducted for each site was dependent on the Air Force preferred remedial alternative from the Basewide Groundwater Focused Feasibility Study (FFS) (CH2M HILL, 2011). The time required to achieve background concentration (t_{BGD}) is a critical parameter in evaluating the sites. The t_{BGD} is defined herein as the time required after Calendar Year 2011 for site-specific COC concentrations in groundwater to decrease below their respective background concentrations. The background concentration for chlorinated VOCs is nominally zero. However, quantification of groundwater contaminants to a true zero value is technically infeasible with current analytical methods. Therefore, concentration limits greater than background (CLGB) are used. These CLGB will not exceed (1) the maximum contaminant level (MCL) established under the Federal Safe Drinking Water Act (SDWA) (California Code of Regulations [CCR], Title 22, Section 64444) or (2) the maximum concentration that would be allowed under other applicable statutes or regulations. Chemical-specific CLGBs are based on the California Department of Health Services (CDHS) *Detection Limits for Purposes of Reporting (DLRs): Regulated Contaminants* (CDHS, 2003) in lieu of the statistical methods referenced in 23 CCR 2550.4 and described in 23 CCR 2550.7. As an example, using this methodology, the CLGB for TCE is 0.5 microgram per liter (µg/L), compared with an MCL of 5 µg/L. This approach is similar to the approach taken in the final Edwards AFB Operable Unit (OU) 2 TEFA (Edwards AFB, 2009).

In this analysis, t_{BGD} is compared with the time required after Calendar Year 2011 for site-specific COC concentrations in groundwater to decrease below their respective maximum contaminant level (MCL) (t_{MCL}), which was referred to as "remediation time frame" in the FFS (CH2M HILL, 2011). In addition to estimating t_{BGD}, a hypothetical expansion of the remedial alternative treatment zone, as defined in the FFS (CH2M HILL, 2011), was evaluated for Sites SS016/SS029, DP039, and WIOU. This approach was used in the final Edwards AFB OU 2 TEFA (Edwards AFB, 2009) and is adopted in this TEFA. In this approach, the extent of a hypothetical expanded treatment zone is estimated such that t_{BGD} is equal to t_{MCL}. Specific details of the Air Force's preferred remedial alternatives, as identified in the FFS and modeling objectives, are discussed in the following section.

C.2 Groundwater Remedial Alternatives and Modeling Objectives

The modeling objectives for the TEFA are summarized by groundwater remedial alternative and are provided as follows:

- **Alternative 1 – No Action** at Site SS041. Under this alternative, it is assumed that no remedial action would take place, so no TEFA is required.
- **Alternative 2 – Monitored Natural Attenuation (MNA)** at Sites FT004, FT005, LF006, LF007B, LF007D, LF008, ST027B, SD031, SD033, and SD043. This alternative assumes that attenuation of COC concentrations would only rely on natural physical, chemical, and/or biological processes to remediate groundwater. The modeling objective for sites under Alternative 2 is to forecast t_{MCL} and t_{BGD} to facilitate the TEFA evaluation.
- **Alternative 3 – Groundwater Extraction and Treatment (GET)** at Sites LF007C, SS029, and SS030. Under Alternative 3, groundwater extraction wells would continue to physically remove COCs from the aquifer. The extracted groundwater would be conveyed to a treatment plant for ex situ treatment. The treated groundwater would then be discharged to the stormwater drainage system. The modeling objective for sites under Alternative 3 is to forecast t_{MCL} and t_{BGD} to facilitate the TEFA evaluation.
- **Alternative 4 – Bioreactor and GET** at Site SS016. Under Alternative 4, either the existing or an expanded in situ bioreactor, would be used to treat the Oil Spill Area (OSA) source area via enhanced reductive dechlorination (ERD) processes combined with extraction wells to physically remove TCE from the hydraulically downgradient portions of the plumes. The modeling objectives for sites under Alternative 4 are as follows:
  - **Objective 1:** Forecast t_{MCL} and t_{BGD} to facilitate the TEFA evaluation based on the existing bioreactor in situ treatment zone.
  - **Objective 2:** Forecast t_{BGD} to facilitate the TEFA evaluation for an expansion of source area treatment from the vicinity of the existing bioreactor to treat TCE concentrations greater than and equal to 1,000 µg/L.
  - **Objective 3:** Estimate the extent of TCE contamination near the OSA source area that would need to undergo in situ treatment via an expanded bioreactor or EVO injection to satisfy the condition of $t_{BGD} = t_{MCL}$.
- **Alternative 5 – Emulsified Vegetable Oil (EVO) Injection and Enhanced Attenuation (EA)** at Site SS015 and WIOU. This alternative assumes the OSA source area would undergo ERD treatment using injected EVO combined with natural attenuation

processes in the distal portions of the TCE plume. The modeling objectives for sites under Alternative 5 are as follows:

- **Objective 1:** Evaluate t_{MCL} and t_{BGD} to facilitate the TEFA evaluation.
- **Objective 2:** Estimate the extent of TCE contamination near the OSA source area that would need to undergo in situ ERD treatment via injected EVO to satisfy the condition of $t_{BGD} = t_{MCL}$.

- **Alternative 6 – Bioreactor, Phytoremediation, EVO Permeable Reactive Barrier (PRB), and EA** at Site DP039. This alternative assumes the implementation of three (3) in situ treatment technologies, including a bioreactor, phytoremediation, and a PRB using EVO injection. The modeling objectives for the site under Alternative 6 are as follows:
  - **Objective 1:** Evaluate t_{MCL} and t_{BGD} to facilitate the TEFA evaluation.
  - **Objective 2:** Estimate the extent of TCE contamination that would need to undergo in situ treatment via the EVO PRB to satisfy the condition of $t_{BGD} = t_{MCL}$. The TCE plume emanating from the hydraulically upgradient source area would be intercepted by the EVO PRB at this estimated downgradient extent of TCE contamination.

C.3 Contaminant Transport Modeling

In general, most sites would undergo either a GET- or an MNA/EA-type analysis depending on the preferred remedial alternative at each site. The GET analyses were performed to provide estimates of t_{BGD} for the zone(s) of hydraulic capture from operation of extraction wells, and the MNA/EA analyses were performed to provide estimates of t_{BGD} associated with implementation of MNA/EA. All estimates of t_{MCL} discussed in this appendix were taken from the FFS (CH2M HILL, 2011). Given the uncertainty in forecasts of t_{MCL} and t_{BGD}, such forecasts were limited to 100 years after Calendar Year 2011 (no later than Calendar Year 2111). GET analyses were performed using the Travis Basewide Groundwater Flow Model (TBGFM) (CH2M HILL, 1998, 2003, 2008), which uses the code MicroFEM version 4.10.14 (Hemker, 2011). The MNA/EA analyses were performed using HYDRUS-1D version 4.14 (Šimůnek et al., 2008, 2009). The generalized modeling approach for each type of analysis is presented below and is followed by a description of the site-specific models. These analyses were performed using the 2009 COC concentration data, except for Site SS015, which includes 2010 data from the recently installed wells at that site. The analyses presented in this appendix are based on the data and models built for the FFS (CH2M HILL, 2011).

The models presented in this appendix do not account for the potential presence of dense nonaqueous phase liquids (DNAPLs). Simulated concentrations are assumed to be in the dissolved phase. The presence of residual DNAPL at a site would present a continuing source of dissolved-phase contamination and increase t_{MCL} and t_{BGD} beyond the estimates provided in this appendix.

A more complete discussion of DNAPL is presented in Sections 3.1.3 and 3.1.4. The basic principle stated in these sections is that dissolved-phase groundwater concentrations located hydraulically downgradient of a DNAPL source will stay unchanged until the source has been entirely dissolved.

C.3.1 GET Analysis Methodology

The GET analyses were performed using the TBGFM. The TBGFM was constructed using MicroFEM, which is a groundwater modeling code developed in The Netherlands. MicroFEM is a three (3)-dimensional, finite-element groundwater modeling code that operates in a Windows® environment and can be used to solve groundwater flow problems for unconfined, semiconfined, and confined aquifer systems. The current version of the program (4.10) can simulate groundwater flow systems with up to 25 numerical layers and 250,000 surface nodes. MicroFEM is capable of modeling saturated, single-density groundwater flow in layered aquifer systems.

The TBGFM is a steady-state model and was originally developed in 1998. The TBGFM was updated and recalibrated using the available data in 2003 and 2008 (CH2M HILL, 2003, 2008). The current analysis uses the 2008 TBGFM, but the pumping rates at extraction wells have been updated to reflect 2009 conditions. The COC plume shapes have also been updated based on data collected in 2009 and 2010 (CH2M HILL, 2010). The COC plume shapes are presented on Figure C-2.

The TBGFM was used to calculate t_{BGD} and t_{MCL} for the GET systems at Sites SS016/SS029 and SS030. Calculations were not conducted for the Site LF007C GET system because too much uncertainty currently exists about the groundwater flow field at that site. Additional investigations are planned in 2011-2012 to resolve those uncertainties.

This type of analysis is based on a flushing calculation. For each GET analysis, a particle was started at each model node within the zone of hydraulic capture of the respective GET system, tracked upgradient (in reverse), and stopped when they reached areas with COC concentrations below the specified MCL or background concentration. The stopping point for each particle depended on whether t_{BGD} or t_{MCL} was being forecast. The path that a particle takes in the model is called a simulated groundwater flowline in this appendix. The model outputs a file containing information for each flowline, including the total time of travel along the flowline. This time of travel is an estimate of the duration for water with COC concentrations below the MCL or background concentration to reach a given model node within the zone of hydraulic capture. In other words, it is the time to flush one (1) pore volume of clean water to a given model node within the zone of hydraulic capture of a particular GET system.

The t_{BGD} and t_{MCL} are then calculated using Equation D-1 (van der Molen, 1973), as follows:

$$t = \frac{-\ln\left({}^{Ct}/_{Co}\right)}{\left({}^{f}/_{T} + k\right)} \tag{D-1}$$

where:

Ct	=	COC-specific remediation goal
Co	=	initial (recent) COC concentration at a given model node
f	=	flushing efficiency
T	=	time to flush one (1) pore volume of clean water to a given model node within the hydraulic capture zone
k	=	first-order biodegradation rate constant
t	=	time required to reduce a Co to Ct at a given model node

The *f* values typically vary between 0.2 to 0.6 and are heavily dependent on soil texture (van der Molen, 1973). Coarser-textured soils tend to have higher *f* values. The *f* value was calibrated to match the historical COC concentration trend at a monitoring well within the hydraulic capture zone to provide a site-specific value of *f*. This was done by taking the last observed COC concentration (i.e., *Co*) for a given well and then using Equation D-1 to forecast *Ct* values at different times with different values assumed for *f*. First-order biodegradation was assumed to be occurring at all TCE sites, and the associated *k* value was estimated by forecasting TCE concentration trends that looked visually consistent with the historical TCE concentration trends measured at MW751x39. The process of estimating the *k* value is discussed in more detail below. Concentration data for other COCs were not available to estimate *k* values. Thus, to be conservative, first-order biodegradation of the other COCs was not assumed to be occurring at these sites.

C.3.2 MNA and EA Analysis Methodology

Two (2) approaches were used to estimate t_{BGD} under MNA and EA conditions. For Sites LF006, LF007B, LF007D, and SS015, t_{BGD} was calculated for individual wells according to the approach described in *Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies* (EPA, 2002). This approach allows for evaluation of reduction in contaminant concentration over time and estimating the time to achieve a particular remediation goal at a well location if it is in the plume source area.

For sites with a GET system, t_{BGD} for the portion of the plume beyond the hydraulic capture extent of the GET system, in the distal portions of the plume, were also estimated. Extrapolating the forecast attenuation rates for COC concentrations at wells within the hydraulic capture zone of the GET system to contaminated areas outside of the hydraulic capture zone would result in an underestimation of t_{MCL} and t_{BGD}, if a given remedial alternative includes turning the GET system off. Therefore, a different approach (modeling) was used to estimate t_{BGD} at these sites. The MNA and EA analysis used to estimate t_{BGD} for Sites FT004, FT005, ST027B, SD031, DP039, and the WIOU sites is described in the following paragraphs.

The screening-level transport models for the MNA and EA analyses were developed using a code named HYDRUS-1D version 4.14 (Šimůnek et al., 2008, 2009). This code was selected for the following reasons:

- Project scope required use of a model to estimate t_{BGD}.
- Given the project scope and limited knowledge of site-specific COC transport mechanisms, a screening-level model was considered appropriate.
- HYDRUS-1D provides more flexibility in how source terms are simulated, as compared with other screening-level solute transport codes (e.g., BIOSCREEN[1] and 3DADE[2]).
- HYDRUS-1D provides the option of simulating dual-domain transport processes. This provides the opportunity to consider back-diffusion of contaminant mass from less

[1] http://www.epa.gov/ada/download/models/bioscrn.pdf (accessed 10/6/2011)
[2] http://www.ars.usda.gov/Services/docs.htm?docid=8916 (accessed 10/6/2011)

permeable mass storage zones in the subsurface, which tends to prolong remediation time frames.

- HYDRUS-1D is in the public domain, a product of more than 10 years of development, in wide use, and well documented.

HYDRUS-1D numerically solves the Richards equation for one (1)-dimensional (1D) variably saturated flow. For the current application, HYDRUS-1D was set up so that the modeled system remained fully saturated along a 1D profile (see Figure C-2 for the location of all MNA and EA simulated groundwater flowlines, which are used to establish the 1D profiles for HYDRUS-1D). The 1D profile locations were defined with the aid of the TBGFM as follows. Groundwater particles were initiated at selected upgradient "source" locations at each site and allowed to track forward (i.e., downgradient). The flowlines generated from this exercise were evaluated to see if they traveled through areas with high COC concentrations and if their flow directions were consistent with the overall shapes of the COC plumes. In most cases, the flowlines provided an adequate basis for selecting a 1D flow profile for HYDRUS-1D; however, in some locations, the flowlines were adjusted slightly within the COC plumes to better capture their overall shapes. Once the 1D profiles were established for each COC plume of interest, groundwater elevations at both the upgradient and downgradient ends of the 1D profile were pulled from the TBGFM and prescribed to each end of the 1D profiles in HYDRUS-1D.

HYDRUS-1D was set up to solve the advection-dispersion-biodegradation transport equation with dual-domain mass transfer to simulate COC transport along the 1D profile. The dual-domain transport formulation was implemented to more accurately account for transport processes with the goal of improving the predictive capabilities over what could have been achieved with a traditional single-domain transport formulation. With the dual-domain transport formulation, the transport equations account for 1D COC transport in the aqueous phase with first-order biodegradation and first-order COC mass transfer between the mobile and immobile porosity in the subsurface. Additionally, the HYDRUS-1D models, as formulated for this particular application, include the assumption of steady-state groundwater flow conditions along the 1D profiles.

The simulated hydraulics along the HYDRUS-1D profile models were adjusted to maintain consistency with the simulated hydraulics along the profile locations within the TBGFM. This was done because the TBGFM has been calibrated to match groundwater elevations at the Base. After the hydraulics were calibrated in a given HYDRUS-1D model, COC concentration data were extracted from the COC plume maps (Figure C-2) and input into HYDRUS-1D as the initial concentration profile. The initial concentration profiles in both the mobile and immobile domains were set equal. The HYDRUS-1D models were then run forward in time to estimate t_{BGD} for a given remedial alternative.

The following describes the parameterization of the HYDRUS-1D models:

- Saturated hydraulic conductivity (K_s) – This parameter is variable along the distance profile and was initially extracted from the TBGFM. Values were modified as necessary to calibrate groundwater elevations from the TBGFM groundwater elevation profile.

- Hydraulic gradient – This parameter is dependent on the locations of the profile endpoints and variable K_s values along the profiles. Prescribed heads at each endpoint of the profile were taken from the TBGFM.

- Mobile porosity = 0.15. This value was estimated based on professional judgment and is within the range of literature values (Payne et al., 2008).
- Bulk density = 1.65 grams per cubic centimeter (g/cm^3). This value was estimated based on professional judgment.
- Total porosity = 0.38. This value was calculated using Equation D-2 as follows:

$$\theta = 1 - \frac{\rho_b}{\rho_s} \tag{C-2}$$

where:

θ = total porosity
ρ_b = bulk density (1.65 g/cm^3)
ρ_s = particle density (2.65 g/cm^3)

- Immobile porosity = 0.23. This value was calculated as the difference between the total porosity and the mobile porosity.
- Longitudinal dispersivity – This value was estimated based on the relevant COC plume lengths (Figure C-2) and the Xu and Eckstein (1995) equation, as modified by Al-Suwaiyan (1996) and shown in Equation C-3 as follows:

$$D = 3.28 \times 0.82 \times \left[\log_{10}\left(\frac{L_p}{3.28} \right) \right]^{2.446} \tag{C-3}$$

where:

D = longitudinal dispersivity, in units of feet
L_p = plume length, in units of feet

- Distribution coefficient (K_d) – K_d is the product of the fraction of organic carbon (f_{oc}) and soil organic carbon-water partitioning coefficient (K_{oc}). K_{oc} values were estimated from literature values, and an f_{oc} value of 0.1 percent was used based on professional judgment. K_{oc} values used in the models are as follows: TCE = 67.7 milliliters per gram (mL/g), 1,2-DCA = 44 mL/g, 1,1-DCE = 35 mL/g, cis-1,2-DCE = 44 mL/g, alpha-chlordane = 86,650 mL/g (EPA, 2008).

The dual domain mass transfer (DDMT) coefficients were calculated on a site-specific basis using dimensional analysis via a Type I Damköhler Number (*DaI*), according to Equation C-4 as follows (Haggerty et al., 2004):

$$\mathrm{DaI} = \frac{\alpha \mathrm{L}}{\mathrm{V_s}} \tag{C-4}$$

The only exception is at Site DP039, where the DDMT coefficient was calibrated to historical COC concentration trends. When an advecting solute undergoes first-order mass transfer between the mobile and immobile domains, the *DaI* is approximately equal to the product of the DDMT coefficient (α) and solute plume length (L) divided by the solute velocity (V_s). The *DaI* can be generalized as the ratio of the mass transfer timescale to the advection timescale. As the magnitudes of these timescales approach consistent values (as *DaI* approaches unity), if sufficient solute mass resides in the immobile domain to cause back diffusion into the mobile domain, then one would expect to observe greater tailing in time-series solute concentration plots (i.e., chemographs) (Haggerty et al., 2004). Thus, to provide the most conservative estimate of α, the *DaI* was set equal to one (1) in each of the calculations, and solute plume lengths and solute velocities were computed based on available site data and the TBGFM to compute α values.

A *k* value for all TCE plumes was estimated from concentration data at Site DP039. Figure C-3 shows the location of MW751x39, which was specifically used to estimate a *k* value. This well was chosen because it is beyond the zone of capture of the extraction wells at the site and near the approximate plume centerline. This well has also been regularly sampled for approximately 10 years. The Site DP039 HYDRUS-1D model was used to estimate a TCE *k* value and a site-specific α value by forecasting TCE concentration trends that looked visually consistent with the historical TCE concentration trends at the well. Figure C-4 shows the measured and forecast TCE concentrations for MW751x39. Forecast TCE concentrations were estimated by assuming that the extraction wells at Site DP039 were shut off, and the current plume was allowed to migrate downgradient. The forecast TCE concentrations were created using a TCE *k* value equivalent to a biodegradation half-life of 9.5 years. Because similar site-specific data were not available to estimate *k* values for alpha-chlordane, 1,2-DCA, and 1,1-DCE (at Sites LF008, FT005, and SD031, respectively), biodegradation was not considered in the evaluations of these chemicals. Overall, these parameter values are consistent with site information and literature values for shallow materials underlying the Base.

C.3.3 Site-specific Analyses

C.3.3.1 Site FT004

The preferred remedial alternative at Site FT004 is to discontinue operation of the GET system and begin MNA. Figure C-2 shows the simulated groundwater flowline at Site FT004 (solid green line). The similarity in groundwater elevation profiles between the HYDRUS-1D model and the TBGFM on Figure C-5 indicates that the HYDRUS-1D model is well calibrated in terms of hydraulics. Table C-1 presents the HYDRUS-1D model input parameters. Figure C-6 shows the results of the MNA analysis. The Calendar Year 2011 concentration profile shown on Figure C-6 is the model's initial condition and was generated using the plume shapes presented on Figure C-2 and observed TCE concentration data at the individual wells within the plumes. Thus, the initial concentration profile shows greater variability than the more generalized plume shapes shown on Figure C-2. Forecast TCE concentration versus distance curves show that t_{BGD} under MNA conditions is approximately 65 years (Calendar Year 2076) (Figure C-6). Table C-2 summarizes the modeling results.

TABLE C-1
HYDRUS-1D Input Parameters for Site FT004
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Model	Profile Length (feet)	COC	Dispersivity (feet)	K_d (mL/g)	*k* (days^{-1})	α (days^{-1})	Aqueous Diffusivity (cm^2/s)
MNA only	13,020	TCE	24	0.067	2.0E-04	1.4E-04	9.1E-06

Note:
cm^2/s = square centimeter(s) per second

TABLE C-2
Comparisons of Time to Achieve Cleanup Standards under Alternative 2
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	COC (MCL, background concentration) (µg/L)	t_{MCL} (years)*	t_{BGD} (years)	Comment
FT004	TCE (5, 0.5)	35	65	-
FT005	1,2-DCA (0.5, 0.5)	43	43	1,2-DCA is a primary COC. MCL of 0.5 µg/L is the same as the background concentration.
LF006	TCE (5, 0.5)	5	60	-
LF007B	TCE (5, 0.5)	0	0	Chlorinated VOC concentrations already below MCLs and background concentrations.
LF007D	Benzene (1, 0.5)	> 100	> 100	-
LF008	Alpha chlordane (N/A, 0.1)	> 100	> 100	-
ST027B	TCE (5, 0.5)	50	80	-
SD031	1,1-DCE (6, 0.5)	15	> 100	-

* Obtained from the FFS (CH2M HILL, 2011).

Note:

N/A = not applicable

C.3.3.2 Site FT005

The preferred remedial alternative for Site FT005 is to discontinue operation of the GET system and begin MNA. To perform the MNA analysis, a HYDRUS-1D model was developed to estimate t_{BGD}. Figure C-2 shows the simulated groundwater flowline for the MNA analysis at Site FT005 (dashed green line). The similarity in groundwater elevation profiles between the HYDRUS-1D model and the TBGFM on Figure C-7 indicates that the HYDRUS-1D model is well calibrated, in terms of hydraulics. Table C-3 presents the HYDRUS-1D model parameters used for the Site FT005 HYDRUS-1D model. Figure C-8 shows the results of the MNA analysis. The Calendar Year 2011 concentration profile shown on Figure C-8 is the model's initial 1,2-DCA concentration condition and was generated using the plume shapes presented on Figure C-2 and observed 1,2-DCA concentration data at the individual wells within the plumes. Thus, the initial concentration profile shows greater variability than the more generalized plume shapes shown on Figure C-2. Forecast 1,2-DCA concentration versus distance curves show that the estimated t_{BGD} under MNA conditions is approximately 43 years (Calendar Year 2054). Table C-2 summarizes the modeling results.

Site-specific 1,2-DCA concentration data were not sufficient to calculate an independent *k* value; therefore, the attenuation effect of biodegradation was not included in the estimates.

TABLE C-3
HYDRUS-1D Input Parameters for Site FT005
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Model	Profile Length (feet)	COC	Dispersivity (feet)	K_d (mL/g)	k (days^{-1})	α (days^{-1})	Aqueous Diffusivity (cm^2/s)
MNA	3,600	1,2-DCA	22	0.044	N/A	4.9E-04	1.0E-05

Note:
N/A = not applicable because first-order biodegradation was not included for the Site FT005 analyses.

C.3.3.3 Site LF006

The preferred remedial alternative for Site LF006 is a continuation of MNA. Figure C-1 shows the location of Site LF006. Although total petroleum hydrocarbon as diesel (TPH-D) and total petroleum hydrocarbon as gasoline (TPH-G) have been detected sporadically at the site, TCE is the only COC.

In the FFS (CH2M HILL, 2011), only two (2) of the twelve (12) monitoring wells in the MNA assessment network had COC concentrations exceeding the MCL. For the TEFA, a first-order attenuation rate constant was calculated for these two (2) wells: MW208Dx06 and MW259x06 (Figures C-9 and C-10, respectively; Figure C-11 shows these and other nearby well locations). The first-order attenuation rate constant calculated for wells MW208Dx06 and MW259x06 is approximately 0.061 and 0.035 per year, respectively (equivalent to TCE attenuation half-lives of approximately 11 and 20 years). At these rates, TCE concentrations at the site would be expected to reach background by 2071 (using data from MW259x06, which would presumably take the longest to reach background), which would be equivalent to a t_{BGD} of approximately 60 years. Table C-2 summarizes the results.

C.3.3.4 Site LF007B

No COCs exceed background concentrations at Site LF007B; therefore, t_{BGD} is 0 years. Figure C-1 shows the location of Site LF007B.

C.3.3.5 Site LF007C

At Site LF007C, the preferred remedial alternative is Alternative 3. Under Alternative 3, operation of the optimized GET system would continue. During 2012, the Site LF007C GET system will be optimized to improve overall effectiveness. A data gaps investigation was conducted in October 2011 to more fully characterize the off-base portion of the TCE plume. Following evaluation of the characterization data, additional extraction wells might be installed to improve hydraulic capture and augment removal of TCE from the off-base portion of the TCE plume.

Groundwater flow directions are uncertain at Site LF007C (CH2M HILL, 2008). It appears that there may be diverging groundwater flow near the center of the TCE plume. The current version of the TBGFM does not indicate a diverging groundwater flow field. Given the uncertainty in the actual groundwater flow field, a GET analysis using the TBGFM was not conducted. Instead, a first-order attenuation trend line was fit to concentration data from well MW125x07, which is within the zone of capture of EW614x07 (Figure C-11). This analysis indicates that TCE concentrations at MW125x07, where the highest concentrations have been observed at Site LF007C, could decrease to below background concentrations in approximately 53 years (Calendar Year 2064) if observed TCE concentration trends continue (Figure C-12). Table C-4 summarizes the modeling results.

TABLE C-4
Comparisons of Time to Achieve Cleanup Standards under Alternative 3
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	COC (MCL, background concentration) (µg/L)	t_{MCL} (years)*	t_{BGD} (years)
LF007C	TCE (5, 0.5)	26	53
SS030	TCE (5, 0.5)	22	46

* Obtained from the FFS (CH2M HILL, 2011).

C.3.3.6 Site LF007D

At Site LF007D (Figure C-1), the preferred remedial alternative is Alternative 2 (MNA). Benzene and 1,4-dichlorobenzene (DCB) are the only COCs that have been consistently detected at the site at concentrations exceeding MCLs.

As of 2010, MW261x07 continued to exceed the MCL for DCB. Figure C-11 shows the location of MW261x07. As such, first-order attenuation rate constants were calculated for this well for DCB and benzene, because concentrations of these COCs continue to exceed MCLs for groundwater. The first-order attenuation rate constant calculated for DCB at well MW261x07 is approximately 0.07 per year (equivalent to a DCB attenuation half-life of approximately 10 years) (Figure C-13). At this attenuation rate, the DCB concentrations would be expected to reach background concentrations (0.5 µg/L) in 2059, resulting in a t_{BGD} of approximately 48 years.

The benzene concentration detected in 2010 at MW261x07 was 3 µg/L. Following the same protocol for DCB, a first-order attenuation rate constant of approximately 0.0002 per year was calculated for benzene at MW261x07 (equivalent to a benzene attenuation half-life of approximately 3,450 years) (Figure C-14). At this attenuation rate, benzene concentrations would be expected to continue to exceed the background concentration for more than 100 years at this location. The overall t_{BGD} estimate for this site is therefore controlled by benzene concentrations, resulting in a t_{BGD} estimate for Site LF007D of more than 100 years. Table C-2 summarizes the results for Site LF007D.

C.3.3.7 Site LF008

The preferred remedial alternative at Site LF008 is Alternative 2 (MNA). Under the remedial alternative, operation of the existing GET system would be discontinued. The GET system is currently undergoing a rebound study.

The primary and most widespread COC at Site LF008 is the pesticide alpha-chlordane. The physical properties of this type of chemical result in low subsurface mobility because of strong sorption of the chemical to the soil. For comparison, the K_{oc}, which describes how strongly a chemical sorbs to soil material, for TCE is 67 mL/g, whereas the K_{oc} for alpha-chlordane is 86,650 mL/g (EPA, 2008). Given the extreme K_{oc} of alpha-chlordane and presumed lack of biodegradation, the t_{BGD} for both GET and MNA are assumed to be greater than 100 years. Table C-2 summarizes the results for Site LF008.

C.3.3.8 Site SS015

Figure C-15 shows the cis-1,2-DCE plume at Site SS015. Cis-1,2-DCE is the COC with the highest concentration at the site and thus is the focus of this analysis. The preferred remedial alternative at Site SS015 is Alternative 5 (EVO and EA). At Site SS015, implementation of the preferred remedial alternative would consist of injection of EVO into the source area followed by monitoring.

An EA analysis was not performed for Site SS015. The uncertainty in the geology, groundwater flow direction, and contaminant behavior complicate the estimation of a t_{BGD}. Groundwater locally flows to the north, opposite of the regional gradient (Figure C-15) for an unknown distance. Groundwater flow north from the Base boundary in this area eventually meets and changes direction with the southerly regional groundwater flow gradient. However, the precise location of this reversal in groundwater flow direction is unknown, as is its impact on cis-1,2-DCE transport. Given the local complexities at this site, a HYDRUS-1D model was not constructed.

A point attenuation rate calculation was performed for Site SS015 using Equation C-5, as follows:

$$t = \frac{-ln\left({C_t}/{C_o}\right)}{k} \qquad \text{C-5}$$

where:

C_t = the background concentration for cis-1,2-DCE of 0.5 µg/L
C_o = initial cis-1,2-DCE concentration after EVO injection (1,000 µg/L)
k = first-order attenuation rate constant
t = time required to reduce C_o to C_t

The cis-1,2-DCE first-order attenuation rate was assumed to be equal to the *k* rate of TCE (2.0E-04 days^{-1}) estimated for Site DP039.

Using Equation C-5, t_{BGD} was calculated to be greater than 100 years. Equation C-5 was also rearranged to estimate the contamination (i.e., concentration) extent to which the cis-1,2-DCE plume would need to be treated to reach background concentration in the same time frame required to reach the MCL (70 years) (CH2M HILL, 2011). This value was calculated to be approximately 83 µg/L. Thus, in order to reach background concentrations in 70 years, the cis-1,2-DCE plume would need to undergo source treatment such that concentrations would be no greater than 83 µg/L after source treatment.

Residual DNAPLs are probably present within the Site SS015 source area. The effect of these DNAPLs on the t_{MCL} and t_{BGD} would be significant. Dissolved-phase concentrations outside the EVO treatment zone would not readily degrade because of the continuing source of contaminants provided by the DNAPL sources. Accordingly, t_{MCL} and t_{BGD} would be extended beyond the estimates presented herein. Additional discussion of DNAPLs is provided in Sections 3.1.3 and 3.1.4.

C.3.3.9 Sites SS016 and SS029

The estimates for t_{BGD} for Sites SS016 and SS029 are combined because VOC contamination (primarily TCE) is migrating from Site SS016 into Site SS029, resulting in a comingled plume. The preferred remedial alternative for Site SS016 is Alternative 4, which uses an in situ bioreactor combined with the existing GET system. The remedial alternative at Site SS029 is Alternative 3 (GET).

Under Alternative 4, an in situ bioreactor was installed in the Site SS016 OSA source area during 2010. The bioreactor uses ERD processes to break down chlorinated VOCs within the OSA. These actions seek to minimize the adverse effects associated with the original source of TCE, which contributed contaminant mass into the downgradient portions of Site SS016. Residual contamination from the OSA would be partly addressed through operation of EW605x16 and EW610x16 (Figure C-16). Contamination that is not hydraulically captured by these wells would flow downgradient toward and be captured by the Site SS029 extraction system.

Three (3) objectives were included in the analysis for Sites SS016 and SS029, and all three (3) analyses were based on the GET methodology.

Objective 1. Objective 1 was to calculate t_{BGD} and t_{MCL} under the preferred remedial alternative of continued operation of the existing bioreactor and operation of the GET system. Installation of the bioreactor in the OSA source area included physical removal of the highest concentrations of chlorinated VOCs, but some residual DNAPL likely remains. The probable presence of residual DNAPLs will indefinitely extend t_{BGD} and t_{MCL} because they provide a continuing source of dissolved-phase contamination. Therefore, a qualitative assessment of greater than 100 years provides a more appropriate estimate of t_{BGD} and t_{MCL} (Table C-5). Additional discussion of DNAPLs is provided in Sections 3.1.3 and 3.1.4.

TABLE C-5
Comparisons of Time to Achieve Cleanup Standards under Alternative 4 Objective 1 at Sites SS016 and SS029
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	COC (MCL, Background Concentration) (µg/L)	t_{MCL} (years)	t_{BGD} (years)
SS016 Objective 1	TCE	> 100	> 100

Objective 2. Objective 2 was to calculate t_{BGD} when the preferred remedial alternative was expanded to treat down to the 1,000-µg/L TCE contour in the OSA source area (Figure C-16). In this scenario, the Site SS016 and SS029 GET systems were assumed to continue to operate. For modeling purposes, concentrations within the 1,000-µg/L TCE contour were not included in the GET analysis to account for the expanded zone of treatment. The flushing efficiency for the GET analysis was calibrated using TCE chemographs for MW241x16, MW603x16, and MW611x16 and Equation D-1 to forecast TCE concentrations with future trends that are consistent with historical trends at the respective wells (Figure C-16). The calibrated flushing efficiency was 0.6, which corresponds to a sandy loam soil; the calibration curves are presented on Figure C-17. Given the size of the expanded treatment zone, it is more reasonable to assume that all DNAPL was removed. Thus, this scenario assumes that

only dissolved-phase contamination exists. Figure C-18 shows the flushing time distribution for the Site SS016/SS029 plume to achieve background. Assuming only dissolved-phase contamination, t_{BGD} was estimated to be 86 years.

Objective 3. Objective 3 was to identify the isocontour that defines the extent of an expanded in situ bioreactor or EVO injection treatment zone required to reach background concentration in the same time frame required to reach the MCL in the absence of DNAPL. It was estimated that t_{MCL} for dissolved-phase contamination was 62 years (CH2M HILL, 2011). Given the complexities of this site because of the likely presence of DNAPL and the complex flow system, this calculation is based on dissolved-phase concentrations and is meant to provide an illustrative example. Results from an iterative modeling approach indicate that to achieve background concentrations everywhere within the Site SS016/SS029 plume in 62 years, TCE concentrations within the comingled plume could be no greater than 60 µg/L after targeted in situ treatment. Figure C-19 shows the flushing time distribution for the commingled plume containing initial TCE concentrations no greater than 60 µg/L. Figure C-20 shows the treatment zone required to meet Objective 3.

C.3.3.10 Site ST027B

The preferred remedial alternative at Site ST027B is Alternative 2 (MNA). Figure C-2 shows the simulated groundwater flowline for the MNA analysis at Site ST027B (solid purple line). The similarity in groundwater elevation profiles between the HYDRUS-1D model and the TBGFM on Figure C-21 indicates that the HYDRUS-1D model is well calibrated, in terms of hydraulics. Table C-6 presents the model parameters used for the Site ST027B HYDRUS-1D model. Figure C-22 shows the results of the MNA analysis. Forecast TCE concentrations versus distance curves indicate that t_{BGD} under MNA assumptions is approximately 80 years (Calendar Year 2091). Table C-2 summarizes the modeling results.

TABLE C-6
HYDRUS-1D Input Parameters for Site ST027B
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Model	Profile Length (feet)	COC	Dispersivity (feet)	K_d (mL/g)	k (days^{-1})	α (days^{-1})	Aqueous Diffusivity (cm^2/s)
MNA	8,120	TCE	19	0.067	2.0E-04	1.4E-04	9.1E-06

C.3.3.11 Site SS030

The preferred remedial alternative at Site SS030 is Alternative 3, a continuation of the existing GET system. The flushing efficiency for the GET analysis was calibrated using the TCE chemograph for MW04x30 and Equation C-1 to forecast TCE concentrations with future trends that are consistent with historical trends. This well was chosen because it is beyond the zone of capture of the extraction wells. This well has also been regularly sampled for approximately 10 years. The well location is shown on Figure C-23. The calibrated flushing efficiency is 0.3, which corresponds to a clay soil; the calibration curve is presented on Figure C-24. Figure C-25 shows the flushing time distribution for the Site SS030 plume. Based on the GET analysis, t_{BGD} is approximately 46 years. Table C-4 summarizes the results.

C.3.3.12 Site SD031

The preferred remedial alternative at Site SD031 is Alternative 2 (MNA). Figure C-2 shows the simulated groundwater flowline for the MNA analysis at Site SD031 (solid blue line). The similarity in groundwater elevation profiles between the HYDRUS-1D model and the TBGFM on Figure C-26 indicates that the HYDRUS-1D model is well calibrated, in terms of hydraulics. Table C-7 presents the model parameters used for the Site SD031 HYDRUS-1D model. Figure C-27 shows the results of the MNA analysis. The Calendar Year 2011 concentration profile shown on Figure C-27 is the model's initial concentration condition and was generated using the 1,1-DCE plume shapes presented on Figure C-2 and observed 1,1-DCE concentration data at the individual wells within the plume. Thus, the initial 1,1-DCE concentration profile shows greater variability than the more generalized plume shapes shown on Figure C-2. Forecast 1,1-DCE concentration versus distance curves indicate that the estimated t_{BGD} under MNA is greater than 100 years (simulated 1,1-DCE concentrations are still greater than background concentrations at Calendar Year 2111). Table C-2 summarizes the modeling results.

TABLE C-7
HYDRUS-1D Input Parameters for Site SD031
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Model	Profile Length (feet)	COC	Dispersivity (feet)	K_d (mL/g)	k (days^{-1})	α (days^{-1})	Aqueous Diffusivity (cm^2/s)
MNA	6,000	1,1-DCE	10.5	0.035	N/A	3.1E-03	1.0E-05

Note:
N/A = not applicable because first-order biodegradation was not included for the Site SD031 analysis.

Site-specific 1,1-DCE concentration data were not sufficient to calculate an independent biodegradation rate; therefore, the attenuation effect of biodegradation was not included in the estimate.

C.3.3.13 Site DP039

The preferred remedial alternative at Site DP039 is Alternative 6. Alternative 6 includes maintaining the bioreactor in the source area, maintaining the phytoremediation area, maintaining the EVO PRB, and initiating EA (Figure C-28). The PRB was installed in 2010 to coincide approximately with the 500-µg/L TCE contour.

Objective 1. Objective 1 was to calculate both t_{MCL} and t_{BGD}. Given the complexity of the Site DP039 remedial alternative, four (4) separate models were developed for the EA analysis. The first three (3) HYDRUS-1D models were used to forecast TCE concentrations from the downgradient edge of the bioreactor's zone of influence to the PRB (Figure C-29). The purpose of these models was to forecast the time-series TCE concentrations entering the PRB from upgradient. Three (3) models were required so that the effect of the phytoremediation area could be explicitly included. The first model simulated the portion of the TCE plume upgradient of the phytoremediation area; the second model simulated the portion of the TCE plume in the phytoremediation area; and the third model simulated the portion of the TCE plume between the downgradient edge of the phytoremediation area and the PRB (Figure C-29). These three (3) models were linked so that the time-series TCE concentrations exiting the upgradient model became the input to the downgradient model.

Table C-8 presents the parameter values used for the HYDRUS-1D EA analysis upgradient of the PRB.

TABLE C-8
HYDRUS-1D Input Parameters for Site DP039
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Model	Profile Length (feet)	COC	Dispersivity (feet)	K_d (mL/g)	k (days^{-1})	α (days^{-1})	Aqueous Diffusivity (cm^2/s)
GET and MNA	9,100	TCE	29	0.067	2.0E-04	5E-05	9.1E-06
EA							
Upgradient of phytoremediation area	210	TCE	11	0.067	2.0E-04	5E-05	9.1E-06
Phytoremediation area	250	TCE	12.5	0.067	6.0E-04	5E-05	9.1E-06
Between phytoremediation area and PRB	660	TCE	20	0.067	2.0E-04	5E-05	9.1E-06
Downgradient of PRB	7,980	TCE	16	0.067	2.0E-04	5E-05	9.1E-06

The HYDRUS-1D model upgradient of the PRB simulated TCE conditions below the phytoremediation area, where in addition to the calibrated biodegradation half-life (9.5 years from MW751x39), TCE is also removed by trees at an estimated rate of 2 pounds per year (Parsons, 2010). Given the limitations of the 1D modeling approach, the additional mass of TCE removed by the trees was implemented in HYDRUS-1D by reducing the biodegradation half-life to below the initial value of 9.5 years, but only in the model transecting the phytoremediation area (Figure C-29). The reduced biodegradation half-life in this model was estimated to be 3.1 years, after accounting for the 2-pound-per-year removal of TCE in the phytoremediation area. The time-series TCE concentrations from the phytoremediation area model were then used as the input to the third model, which represented the area between the downgradient edge of the phytoremediation area and PRB (Figure C-29). Figure C-30 shows the forecast time-series TCE concentration data entering the PRB.

The fourth HYDRUS-1D model was used to forecast time-series TCE concentrations in groundwater exiting the PRB and flowing downgradient of the treatment area. This is the portion of the TCE plume that would undergo EA. Once beyond the TCE plume, the flowline (i.e., profile) joins the larger Site DP039 flowline shown on Figure C-2. A time-variable concentration boundary condition was used at the upgradient boundary of this model to simulate the influx of TCE entering the PRB from upgradient of the PRB. The TCE concentration assigned at this boundary was based on the output from the observation node from the upgradient HYDRUS-1D model. Any TCE concentrations greater than 500 µg/L entering the simulated PRB were reduced to 500 µg/L because of the assumed effect of the PRB, whereas TCE concentrations less than 500 µg/L entering the PRB were left unchanged. This is a conservative approach because, in reality, there would be some beneficial reduction in TCE concentrations less than 500 µg/L, as well. Table C-8 presents the model parameters used for the HYDRUS-1D model simulating the EA analysis downgradient of the PRB. Figure C-31 shows the results of the EA analysis, and Table C-9 summarizes the results. Forecast TCE concentration versus distance curves indicate that t_{BGD} under EA is approximately 90 years (i.e., around calendar year 2101). The concentration versus distance curves (Figure C-31) show that the time frame is controlled by the time that it takes for the forecast TCE concentrations downgradient of the PRB to decrease below the background concentration. Figure C-31 shows that the upper portion of the plume under active remediation drops below background concentration before the lower portion under natural attenuation despite higher concentrations in the upper portion.

TABLE C-9
Comparisons of Time to Achieve Cleanup Standards under Alternative 6 at Site DP039
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	COC (MCL, background concentration) (µg/L)	t_{MCL} (years)*	t_{BGD} (years)
DP039	TCE (5, 0.5)	65	90

* Obtained from the FFS (CH2M HILL, 2011).

Residual DNAPLs are probably present within the Site DP039 source area. The effect of these DNAPLs on the time required to achieve cleanup goals would be significant. Dissolved-phase concentrations outside the bioreactor treatment zone would not readily degrade because of the continuing source of contaminants provided by the DNAPL sources. Accordingly, the time to achieve either MCLs or background would be greatly extended beyond the estimates. Additional discussion of DNAPLs is provided in Sections 3.1.3 and 3.1.4.

Objective 2. Objective 2 was to determine the isocontour that defines the location of a hypothetical EVO PRB required to reach background concentration in the same time frame required to reach the MCL. To simplify this part of the analysis, it was assumed that the remedial actions upgradient of and including the PRB were fully effective. To achieve Objective 2, a modified version of the HYDRUS-1D model representing the plume downgradient of the PRB (Table C-8) was used. Because the remedial actions at Site DP039 were assumed to be fully effective, no time-variable concentration boundary condition was used at the upgradient boundary of this model. Thus, an iterative approach was used to determine the location along the axis of the plume at which to start the flowline. In this scenario, the downgradient edge of the hypothetical PRB represents the beginning point of the flowline. It was determined that the flowline could be started at the 185-µg/L TCE isocontour in order to achieve background concentrations in 65 years. Figure C-32 shows the location of the hypothetical PRB.

C.3.3.14 WIOU

The WIOU plume comprises Sites SD033, SD034, SD036, SS037, SS041, and SD043 (Figure C-33). For the purposes of this evaluation, all sites within the WIOU were considered in one (1) analysis. The preferred remedial alternative for the WIOU is Alternative 5. EVO would be injected into the source areas at Sites SD036 and SD037. The approach for the remainder of the WIOU would be EA.

Objective 1. The first objective was to calculate t_{BGD}. The EA would consist of EVO injection into the remaining Site SD036 and SD037 source areas to treat TCE concentrations exceeding 1,000 µg/L. For modeling purposes, it was assumed that the treatment process (EVO injection) would reduce concentrations within the source areas to 1,000 µg/L.

HYDRUS-1D was used for the EA analysis. Figure C-2 shows the simulated groundwater flowline for the EA analysis at the WIOU (blue dashed line). The similarity in groundwater elevation profiles between the HYDRUS-1D model and the TBGFM on Figure C-34 indicates that the HYDRUS-1D model is well calibrated, in terms of hydraulics. Table C-10 presents the model parameters used for the WIOU HYDRUS-1D model. Figure C-35 shows the results of the EA analysis. The Calendar Year 2011 concentration profile shown on Figure C-35 is the model's initial concentration condition and was generated using the plume shapes presented on Figure C-2 and observed TCE concentration data at the individual wells within the plumes. Thus, the initial concentration profile shows greater variability than the more generalized plume shapes because the profile passes through multiple localized plumes and extraction systems. Forecast TCE concentration versus distance curves indicate that t_{BGD} under EA is approximately 90 years (Calendar Year 2101) (Figure C-35). Table C-11 summarizes the results.

TABLE C-10
HYDRUS-1D Input Parameters for Site WIOU
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Model	Profile Length (feet)	COC	Dispersivity (feet)	K_d (mL/g)	k (days^{-1})	α (days^{-1})	Aqueous Diffusivity (cm^2/s)
EA	12,080	TCE	42	0.067	2.0E-04	1.3E-05	9.1E-06

TABLE C-11
Comparisons of Time to Achieve Cleanup Standards under Alternative 5 at WIOU
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	COC (MCL, background concentration) (µg/L)	t_{MCL} (years)*	t_{BGD} (years)
WIOU	TCE	60	90

* Obtained from the FFS (CH2M HILL, 2011).

Residual DNAPLs are probably present within the Site SD036 and Site SD037 source areas. The effect of these DNAPLs on the time required to achieve cleanup goals would be significant. Dissolved-phase concentrations outside the EVO treatment zone would not readily degrade because of the continuing source of contaminants provided by the DNAPL sources. Accordingly, the time to achieve either MCLs or background would be greatly extended beyond the estimates. Additional discussion of DNAPLs is provided in Sections 3.1.3 and 3.1.4.

Objective 2. Objective 2 was to determine the maximum TCE concentration that could remain in the plume such that $t_{BGD} = t_{MCL}$. The HYDRUS-1D model was used to achieve Objective 2. Initial model concentrations in the mobile domain were decreased in an attempt to satisfy the condition $t_{MCL} = t_{BGD}$. Concentrations in the immobile domain were left unchanged. This is because the EVO will most likely have limited effectiveness at actively treating concentrations in the immobile domain. However, even when all simulated TCE was removed from the mobile domain, the background concentration could not be achieved in 60 years. Simulations showed that concentrations would need to be reduced to no greater than 40 µg/L everywhere along the flowline in both the mobile and immobile domains to achieve background concentrations in 60 years. Figure C-36 shows the treatment zone required such that $t_{BGD} = t_{MCL}$.

C.4 Model Summary

A summary of model results is provided in Table C-12.

TABLE C-12
Summary of Groundwater Modeling Results
Basewide Groundwater Technical and Economic Feasibility Analysis, Travis Air Force Base, California

Site	COC (MCL, background concentration) (µg/L)	t_{MCL} (years)*	t_{BGD} (years)	Isocontour of Expanded Treatment Zone such that $t_{MCL} = t_{BGD}$ (µg/L)
Alternative 2				
FT004	TCE (5, 0.5)	35	65	-
FT005	1,2-DCA (0.5, 0.5)	43	43	-
LF006	TCE (5, 0.5)	5	60	-
LF007B	TCE (5, 0.5)	0	0	-
LF007D	Benzene (1, 0.5)	> 100	> 100	-
LF008	Alpha chlordane (N/A, 0.1)	> 100	> 100	-
ST027B	TCE (5, 0.5)	50	80	-
SD031	1,1-DCE (6, 0.5)	15	> 100	-
Alternative 3				
LF007C	TCE (5, 0.5)	26	53	-
SS030	TCE (5, 0.5)	22	46	-
Alternative 4				
SS016/SS029	TCE (5, 0.5)	> 100	> 100	60
Alternative 5				
SS015	cis-1,2-DCE (6, 0.5)	70	> 100	83
WIOU	TCE (5, 0.5)	60	90	40
Alternative 6				
DP039	TCE (5, 0.5)	65	90	185

* Obtained from the FFS (CH2M HILL, 2011).

C.5 Limitations

Mathematical models can only approximate processes of physical systems. Models are inherently inexact, because the mathematical description of the physical system is imperfect and the understanding of interrelated physical processes is incomplete. The models described in this appendix are good tools that, when used carefully, can provide useful insight into transport processes within the physical system. However, such models are no substitute for continued monitoring of COC trends at available wells over the next several years to confirm the stage of plume evolution (i.e., advancing, stable, or retracting) and to continually refine the conceptual site model.

The time frames provided in this appendix were taken directly from the model output for comparative purposes and do not reflect the level of precision implied in the estimate. While it is impossible to quantify the uncertainty associated with estimates of remediation time frames, it would be appropriate to round up such estimates to the nearest decade or more for planning purposes.

C.6 References

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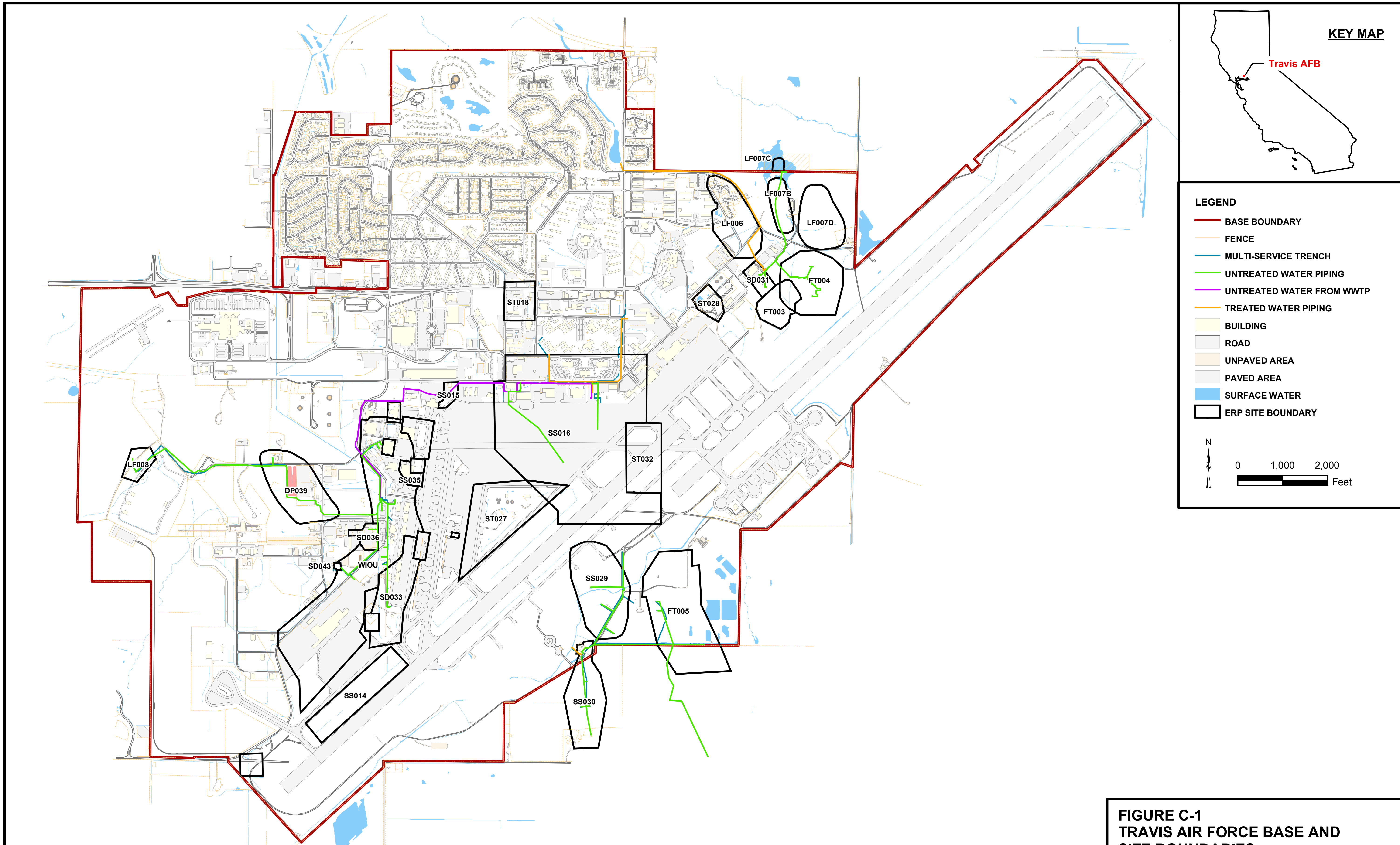


FIGURE C-1
TRAVIS AIR FORCE BASE AND SITE BOUNDARIES
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\BALDUR\PROJ\TRAVIS\APPENDIX_D\MAPFILES\8NOV2010_EDITS\FIGD-1_GW_REMEDIATION_AREAS.MXD MSCHROCK 12/9/2010 11:48:09

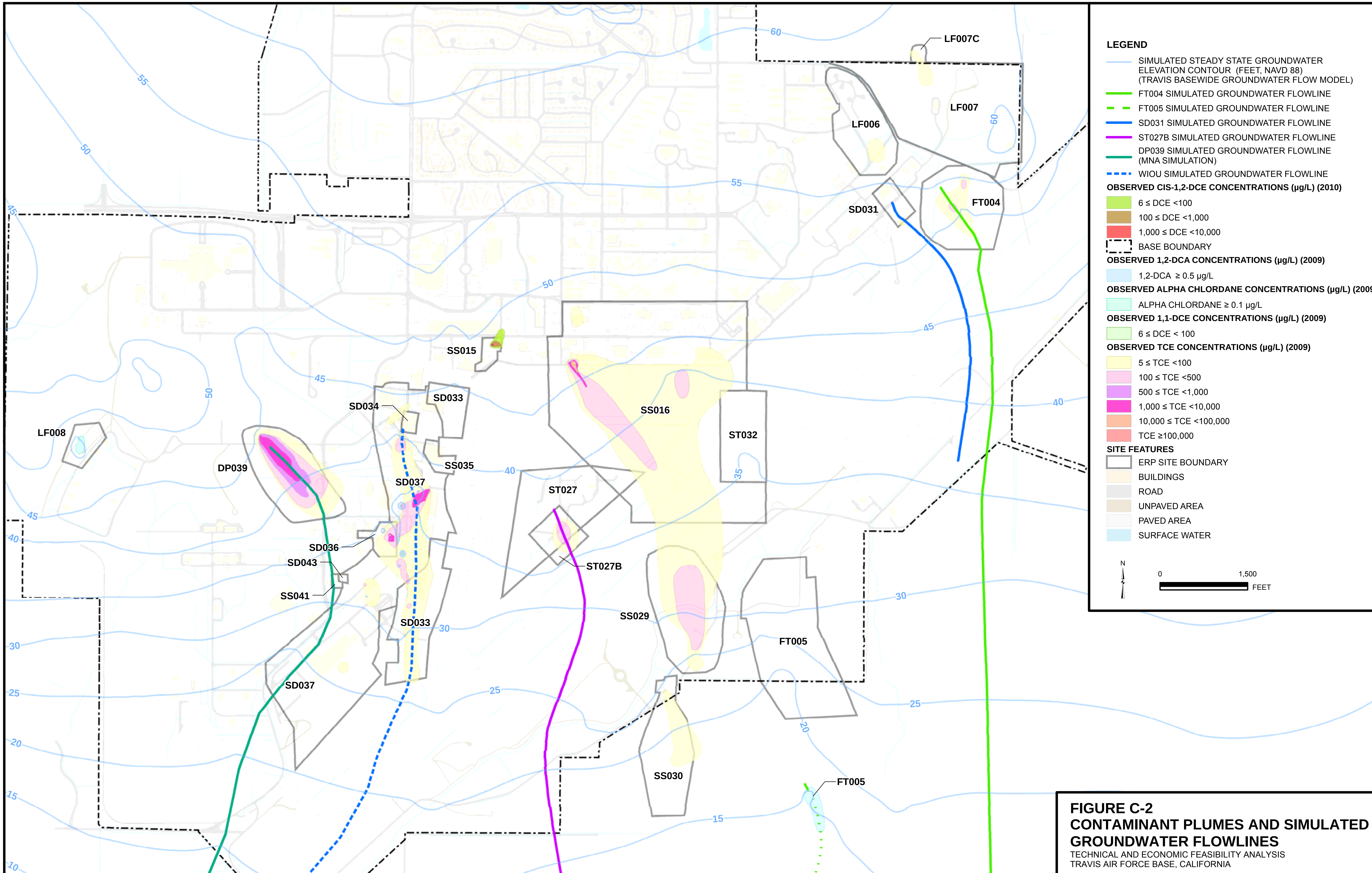


FIGURE C-2
CONTAMINANT PLUMES AND SIMULATED GROUNDWATER FLOWLINES
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

RDD \\BALDUR\PROJ\TRAVIS\381355_TEFA_AUG2011\MAPFILES\FIGD-2_PLUME_NETWORK_ECOTECH.MXD DMEADOWS 10/7/2011 10:46:09 AM

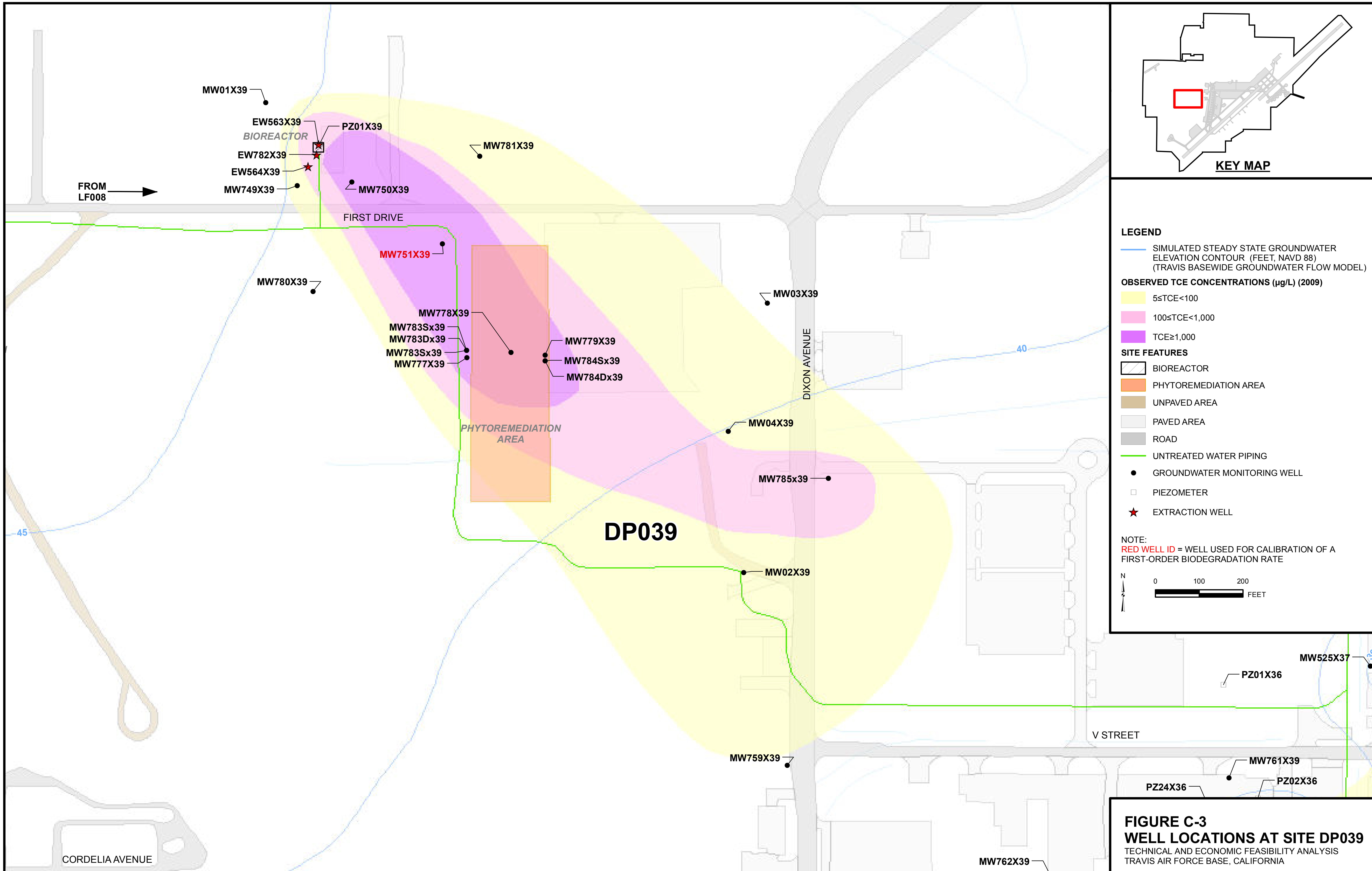
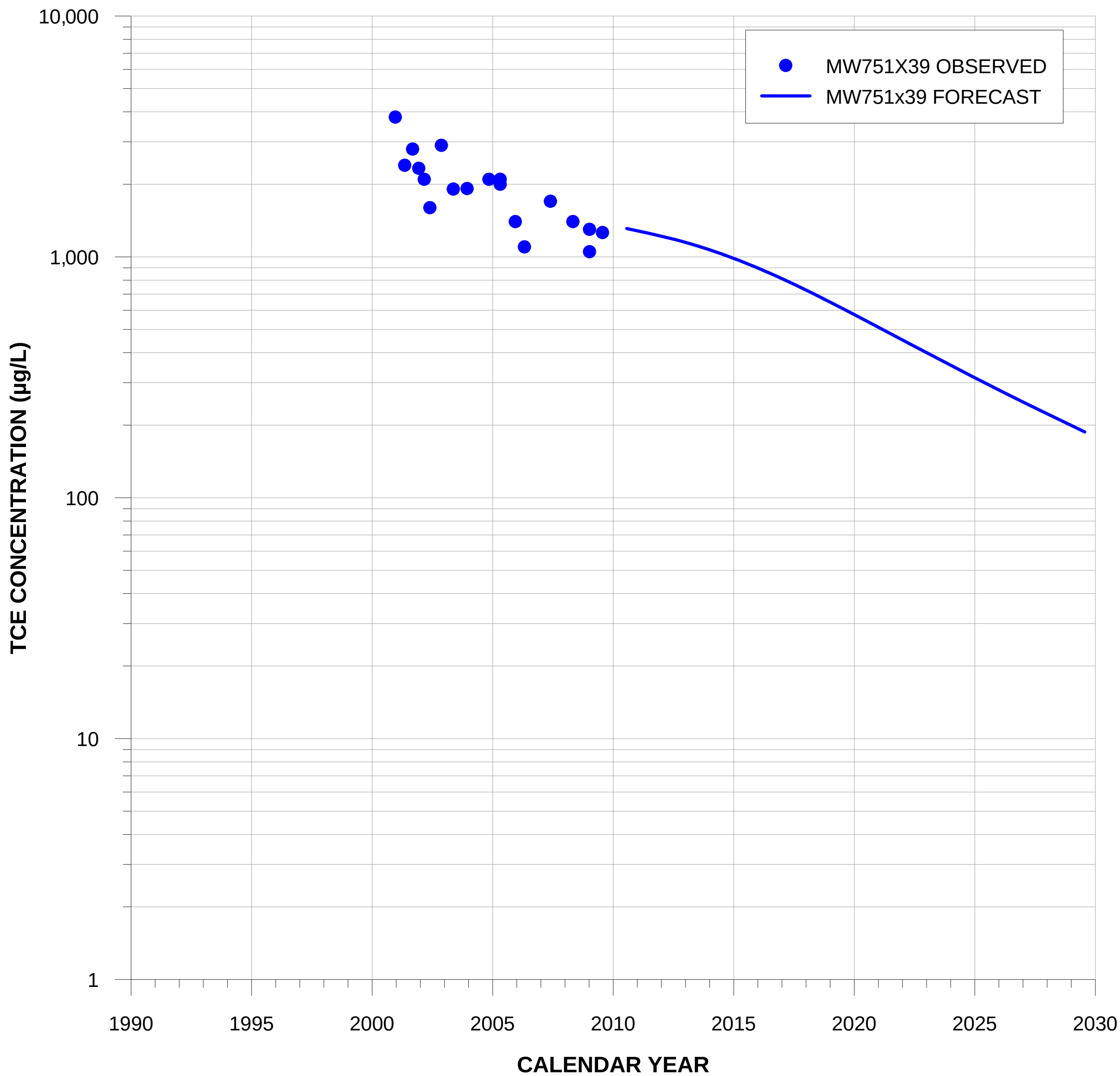


FIGURE C-3
WELL LOCATIONS AT SITE DP039
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

\\BALDUR\PROJ\TRAVIS\APPENDIX_D\MAPFILES\8NOV2010_EDITS\FIGD-3_WELLS_DP039.MXD MSCHROCK 12/14/2010 00:20:35

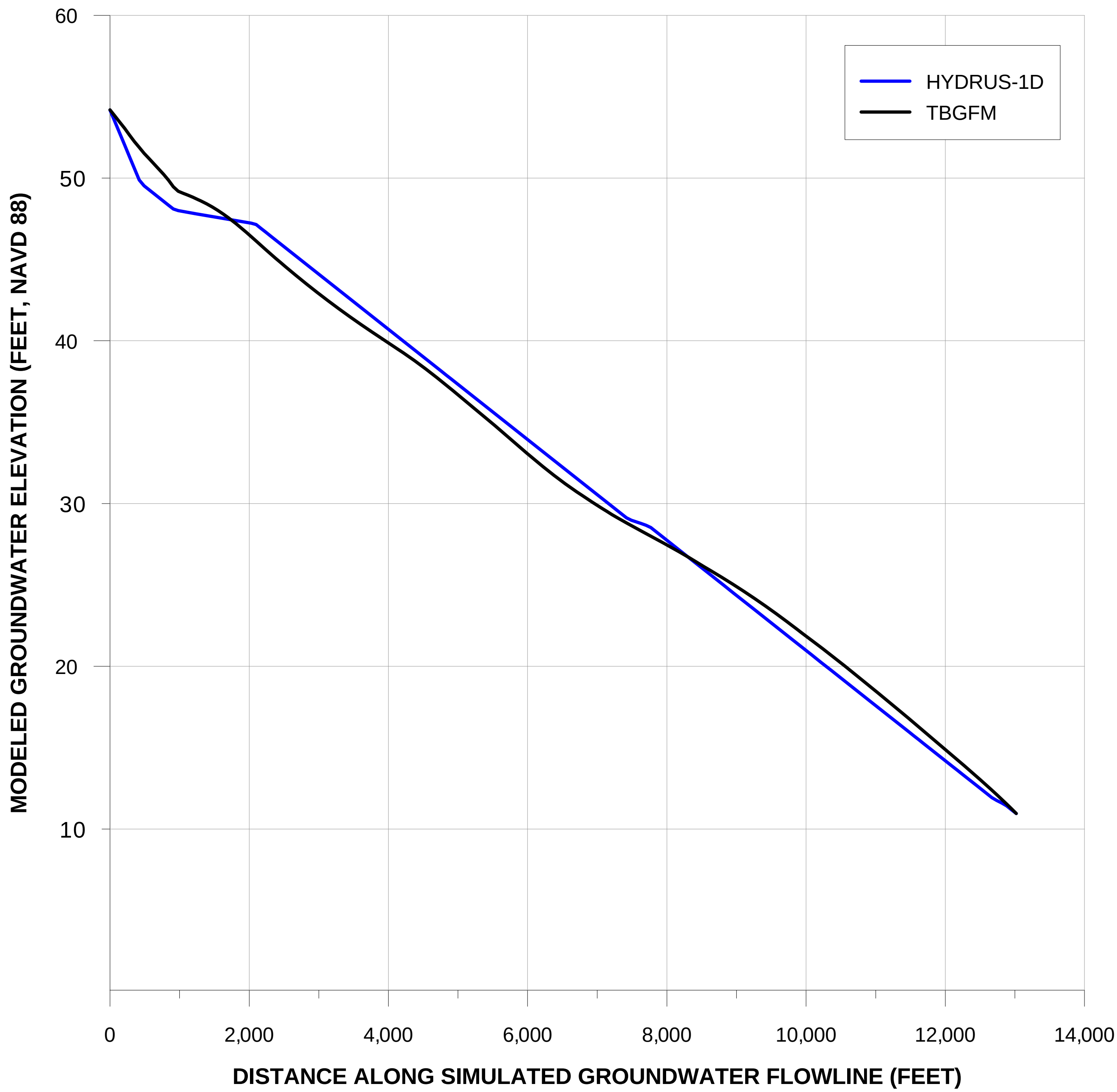


NOTE
FORECAST CONCENTRATIONS CALCULATED USING
A BIODEGRADATION HALF-LIFE OF 9.5 YEARS.

FIGURE C-4
HISTORICAL AND FORECAST TCE CONCENTRATIONS AT MW751x39
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-4_DP039_Decay_Cal_TCE.grf

CH2MHILL



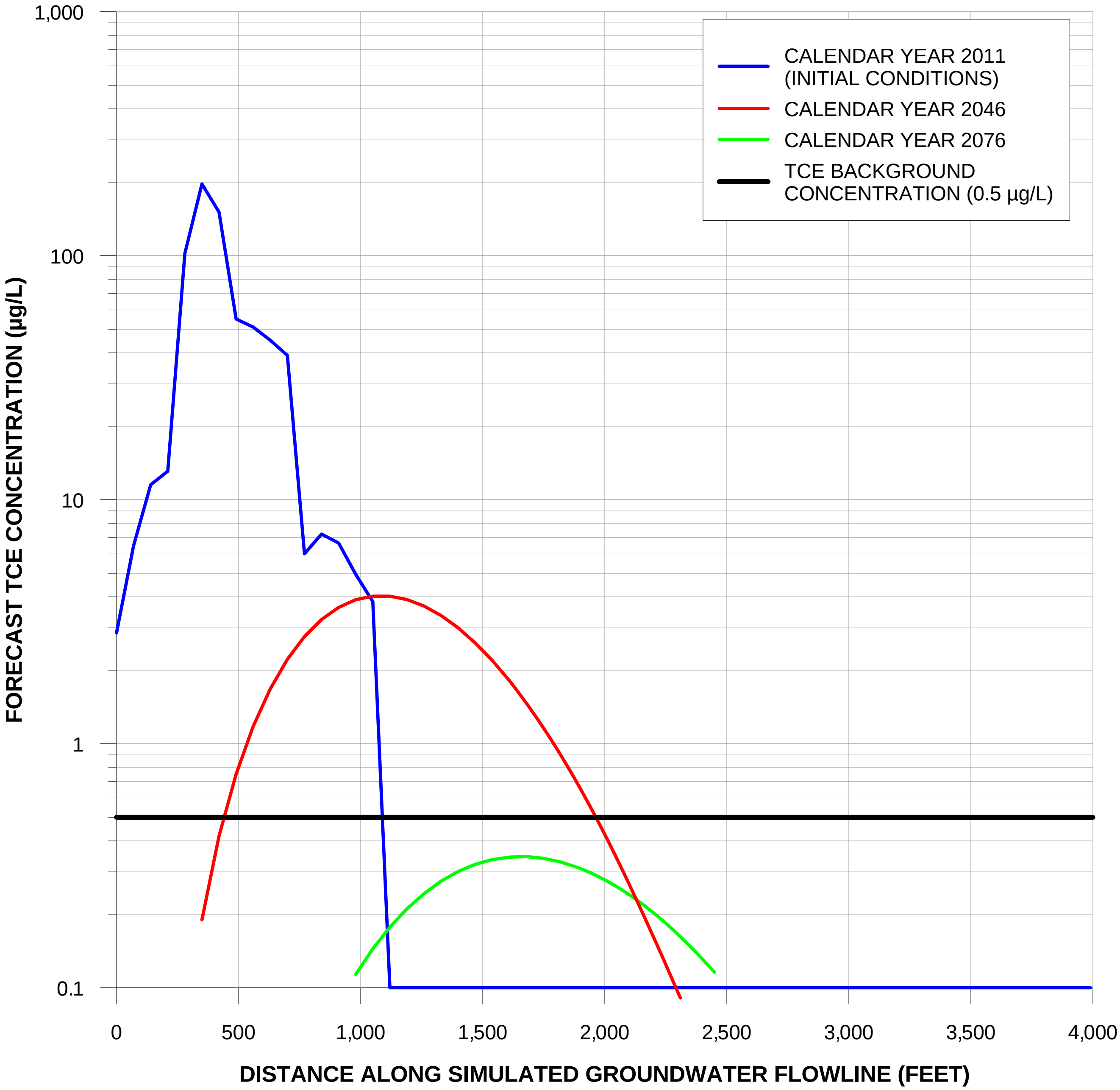
NOTES
1. SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.
2. TBGFM = TRAVIS BASEWIDE GROUNDWATER FLOW MODEL

FIGURE C-5
COMPARISON OF MODELED GROUNDWATER ELEVATIONS AT SITE FT004

TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-5_FT004_Head_Comparison.grf

CH2MHILL

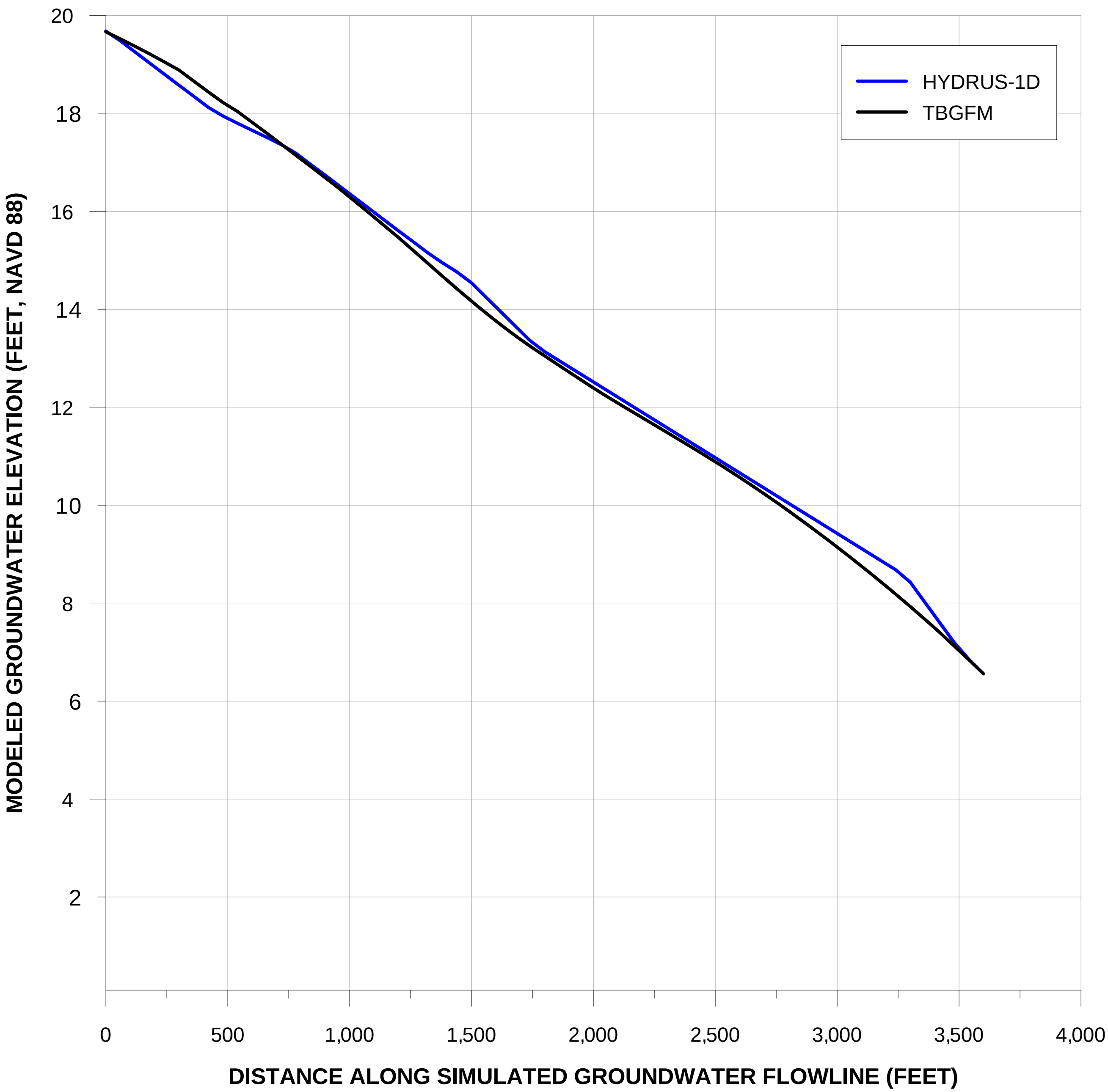


NOTE
SITE FT004 SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.

FIGURE C-6
FORECAST SITE FT004 TCE CONCENTRATIONS UNDER ALTERNATIVE 2
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-6_FT004_Conc_vs_Distance_MNA_with_GET.grf

CH2MHILL

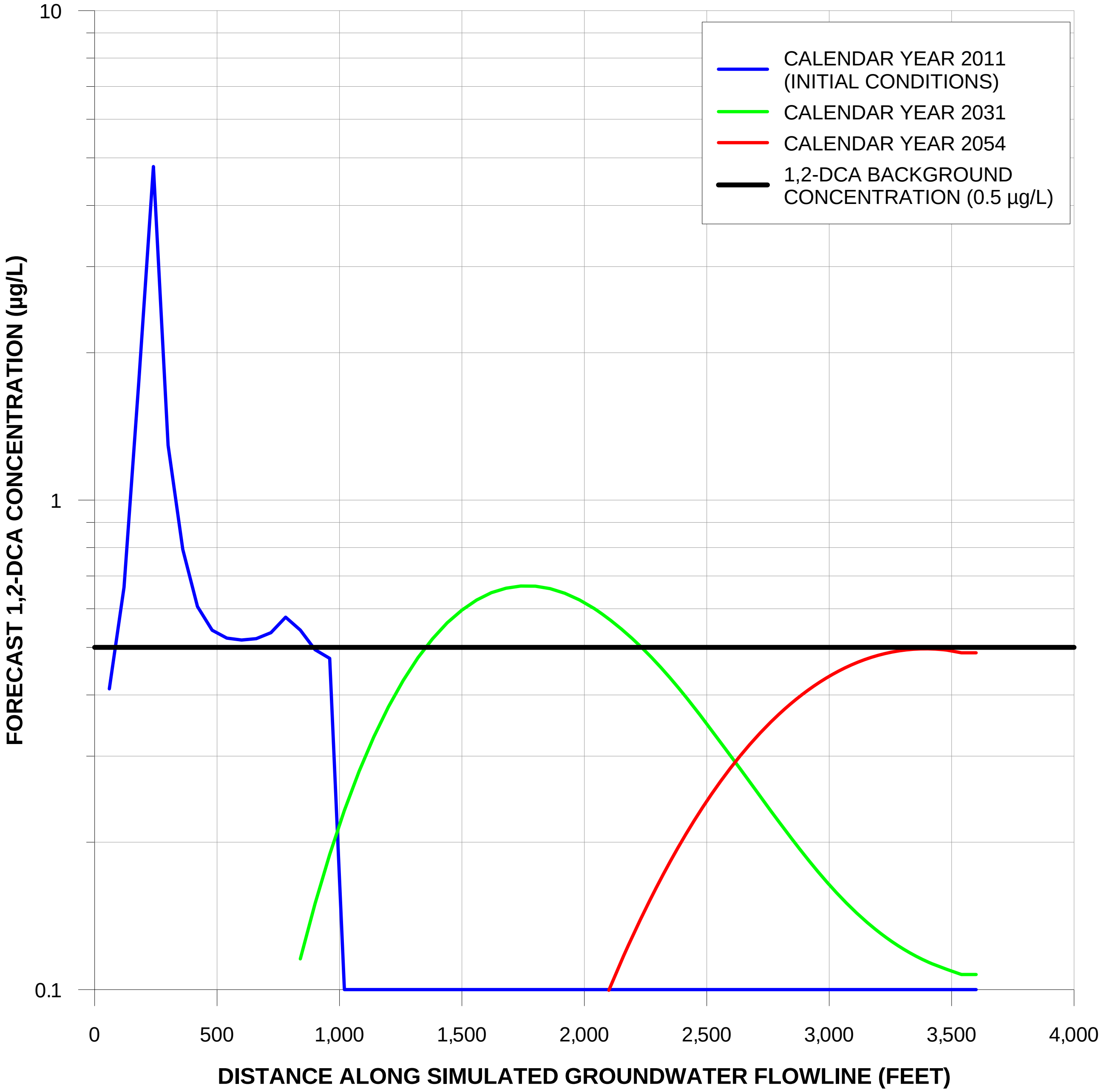


NOTES
1. SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.
2. TBGFM = TRAVIS BASEWIDE GROUNDWATER FLOW MODEL

FIGURE C-7
COMPARISON OF MODELED GROUNDWATER ELEVATIONS AT SITE FT005
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-7_FT005_Head_Comparison.grf

CH2MHILL



NOTE
SITE FT005 SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.

FIGURE C-8
FORECAST SITE FT005 1,2-DCA CONCENTRATIONS UNDER ALTERNATIVE 2
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-8_FT005_Conc_vs_Distance.grf

CH2MHILL

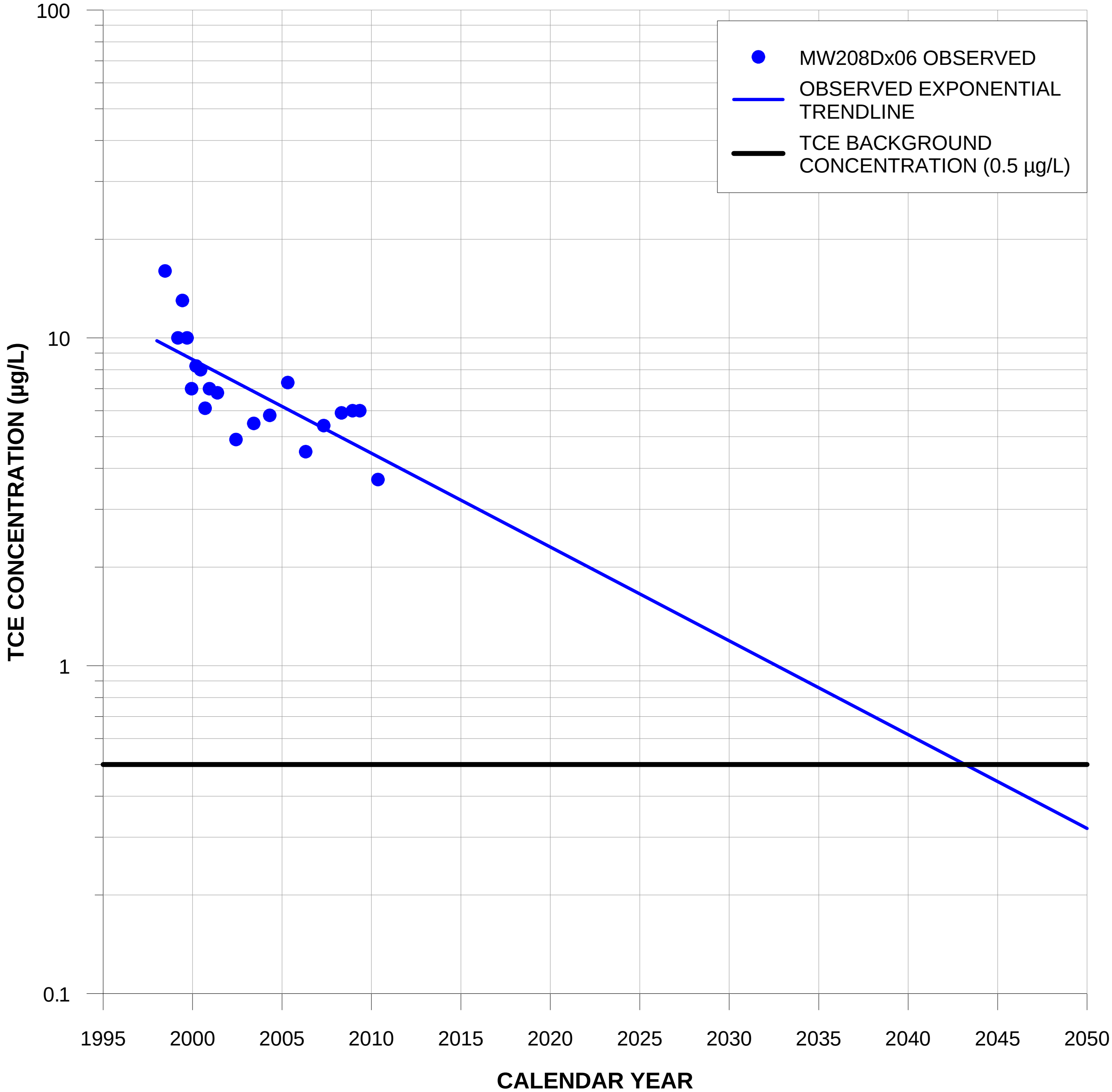


FIGURE C-9
MW208Dx06 TCE CONCENTRATION DATA AND OBSERVED TRENDLINE
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

MW208Dx06_TCE.grf

CH2MHILL

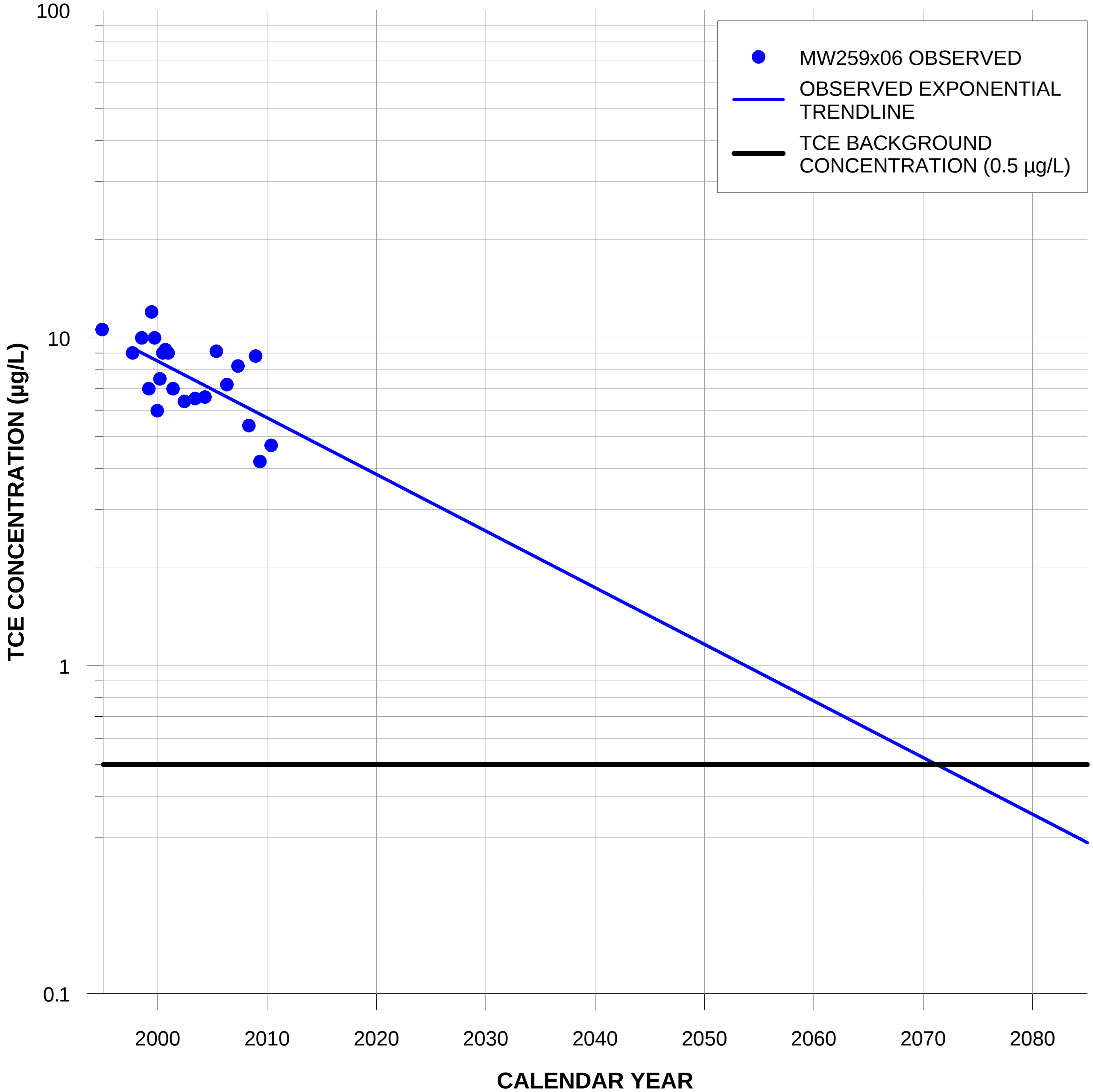


FIGURE C-10
MW259x06 TCE CONCENTRATION DATA AND OBSERVED TRENDLINE
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

MW259x06_TCE.grf

CH2MHILL

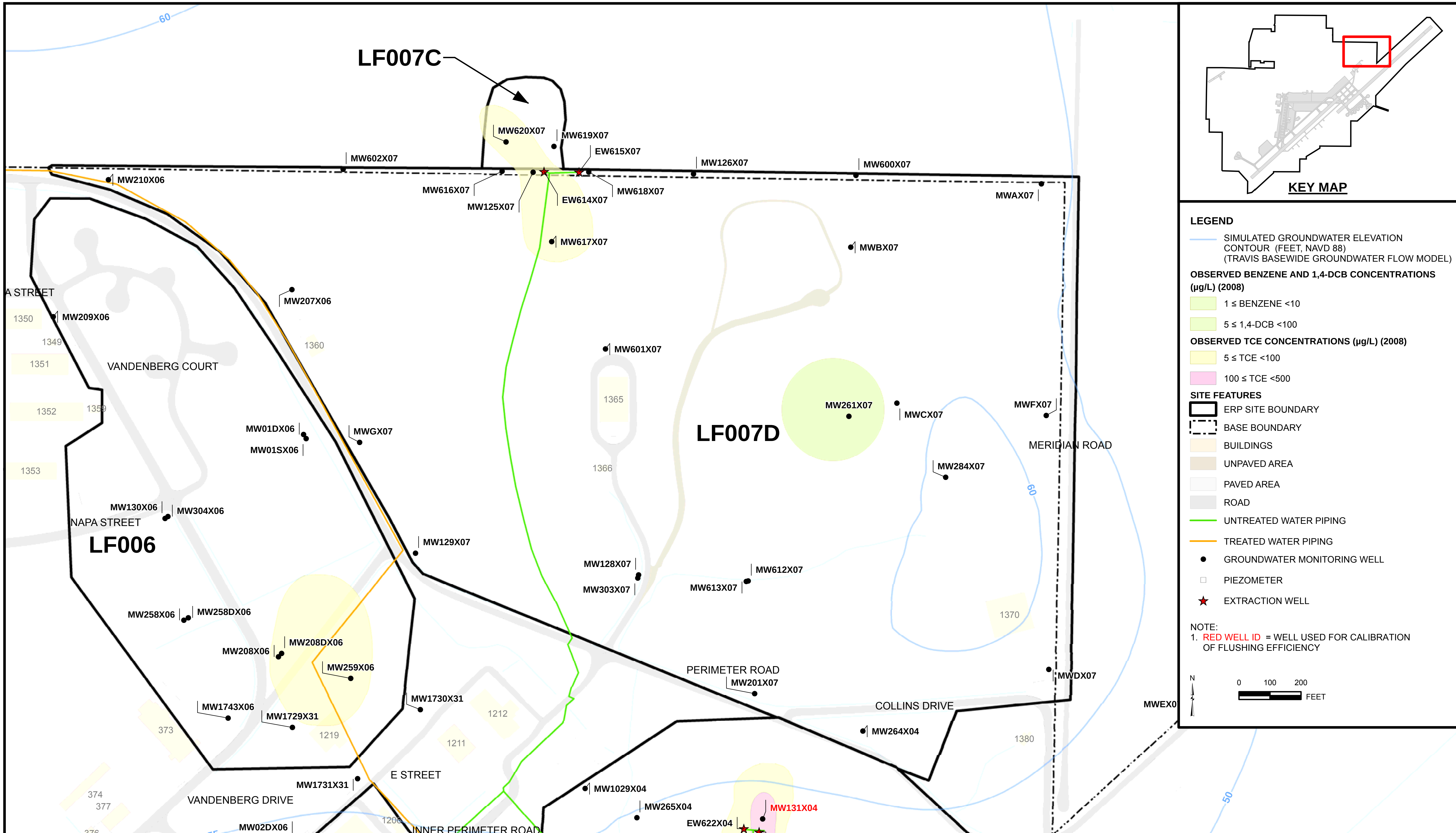


FIGURE C-11
WELL LOCATIONS AT SITES LF006 AND LF007
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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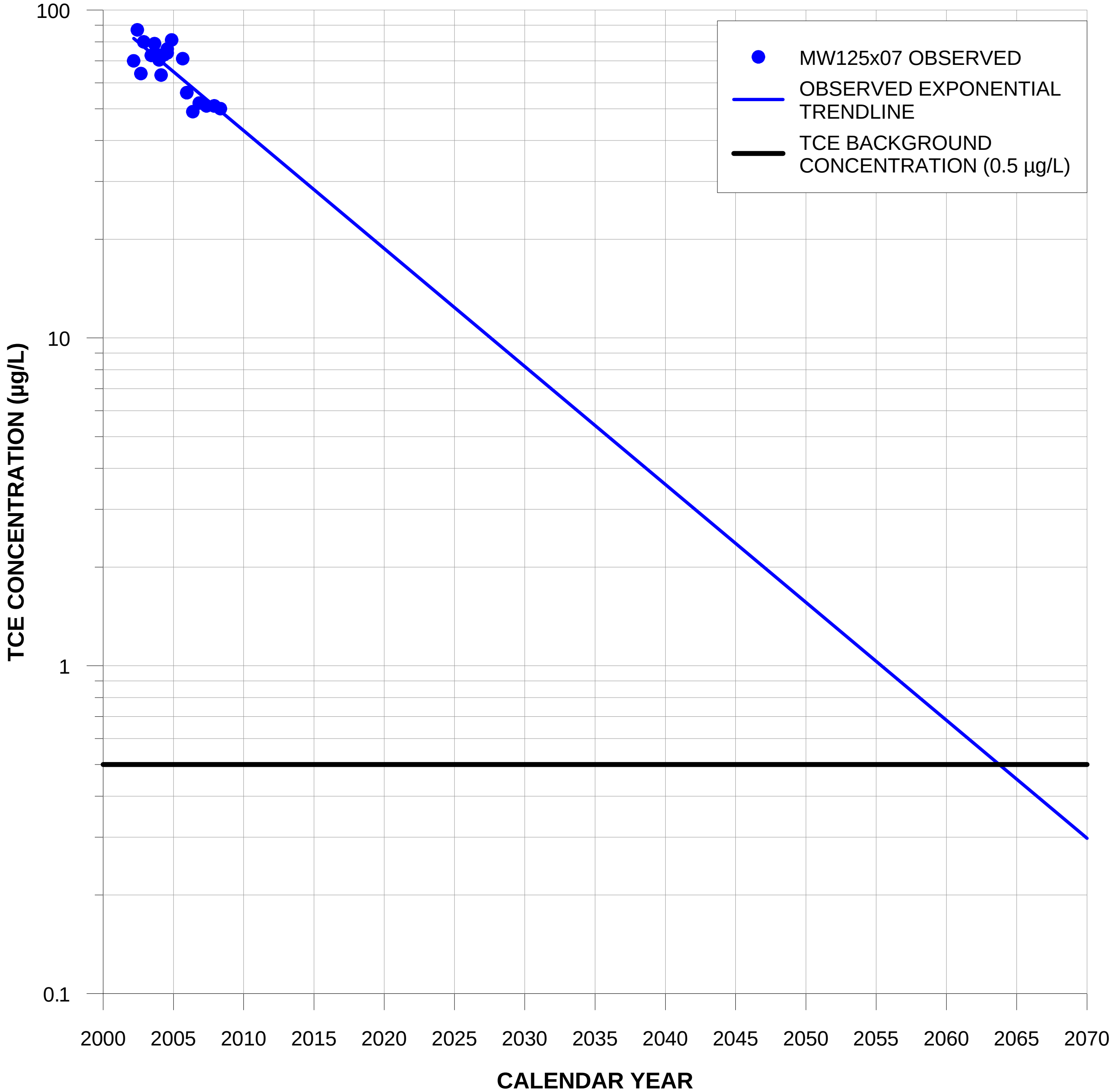

FIGURE C-12
MW125x07 TCE CONCENTRATION DATA AND OBSERVED TRENDLINE
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-12_LF007_Analysis_TCE.grf

CH2MHILL

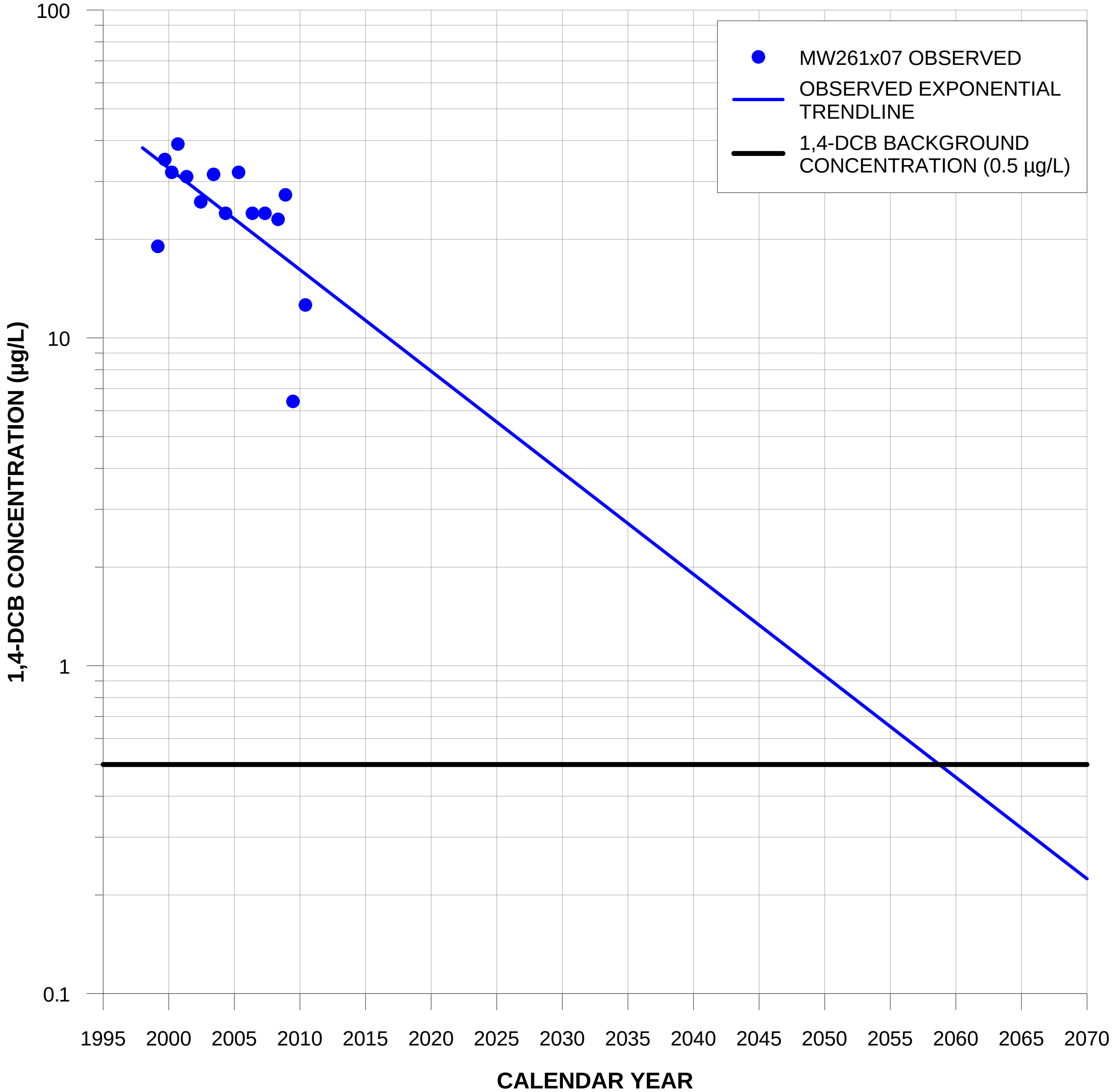

FIGURE C-13
MW261x07 1,4-DCB CONCENTRATION DATA AND OBSERVED TRENDLINE
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

MW261x07_DCB.grf

CH2MHILL

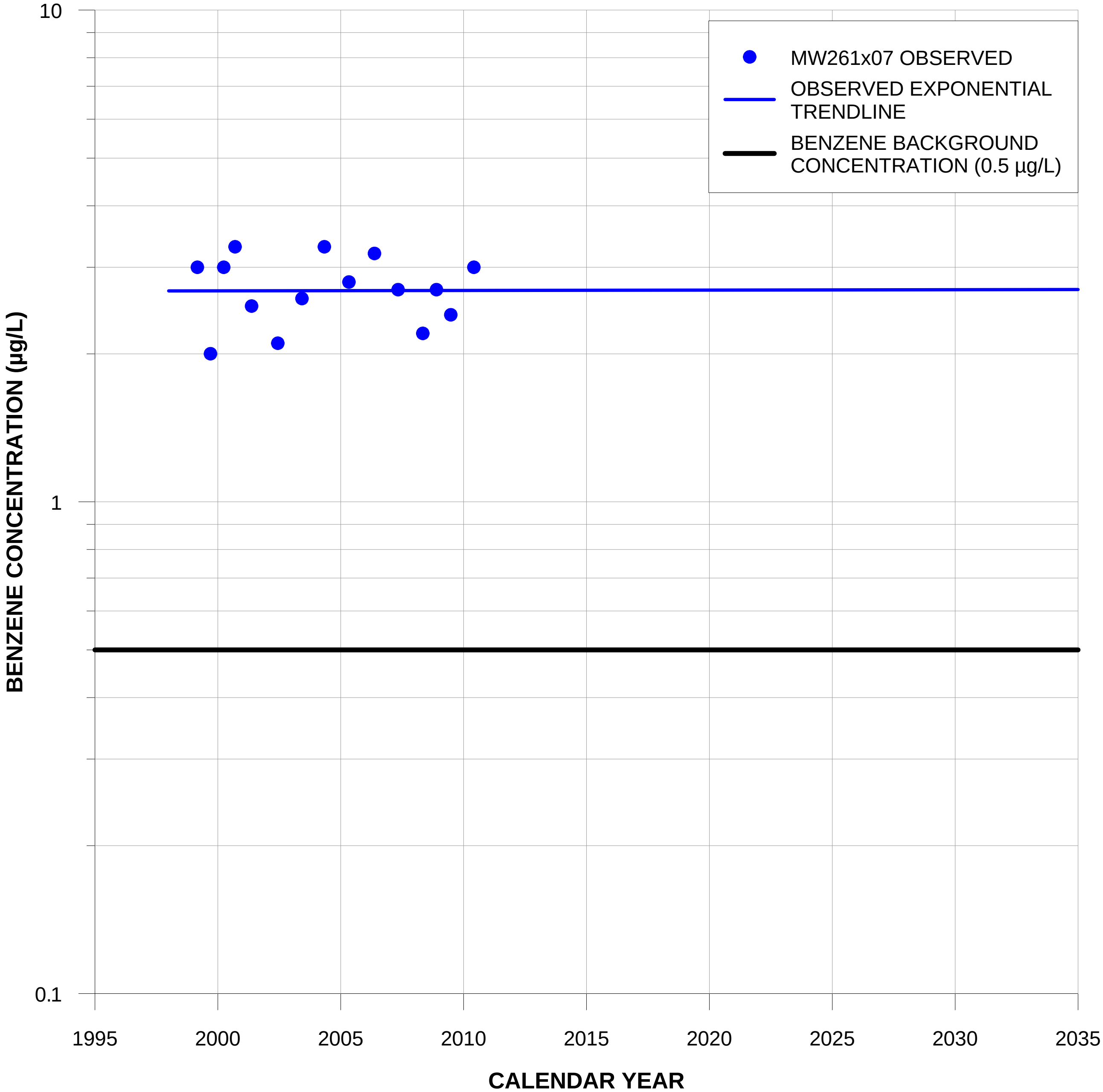

FIGURE C-14
MW261x07 BENZENE CONCENTRATION DATA AND OBSERVED TRENDLINE
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

MW261x07_benzene.grf

CH2MHILL

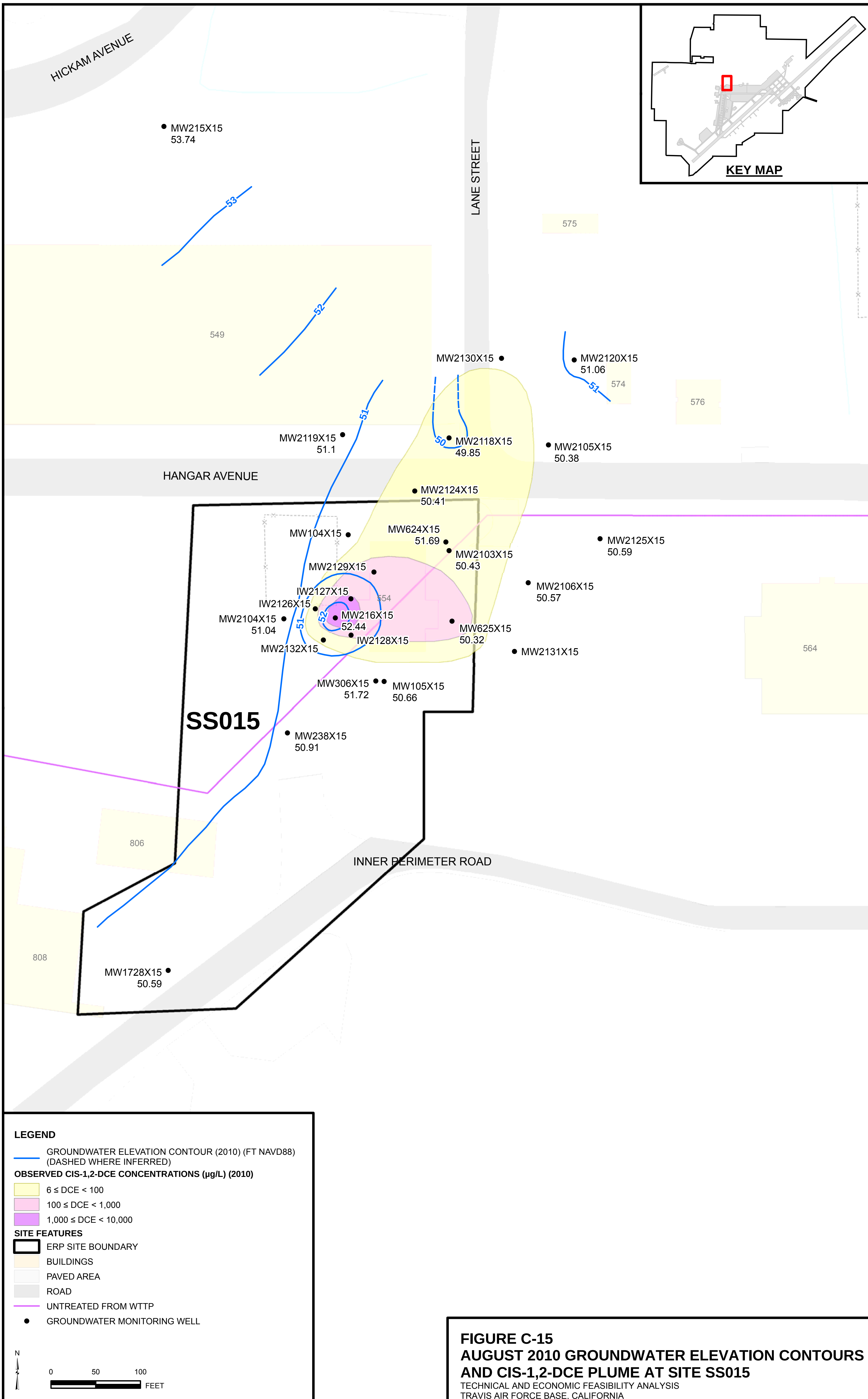

FIGURE C-15
AUGUST 2010 GROUNDWATER ELEVATION CONTOURS AND CIS-1,2-DCE PLUME AT SITE SS015
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

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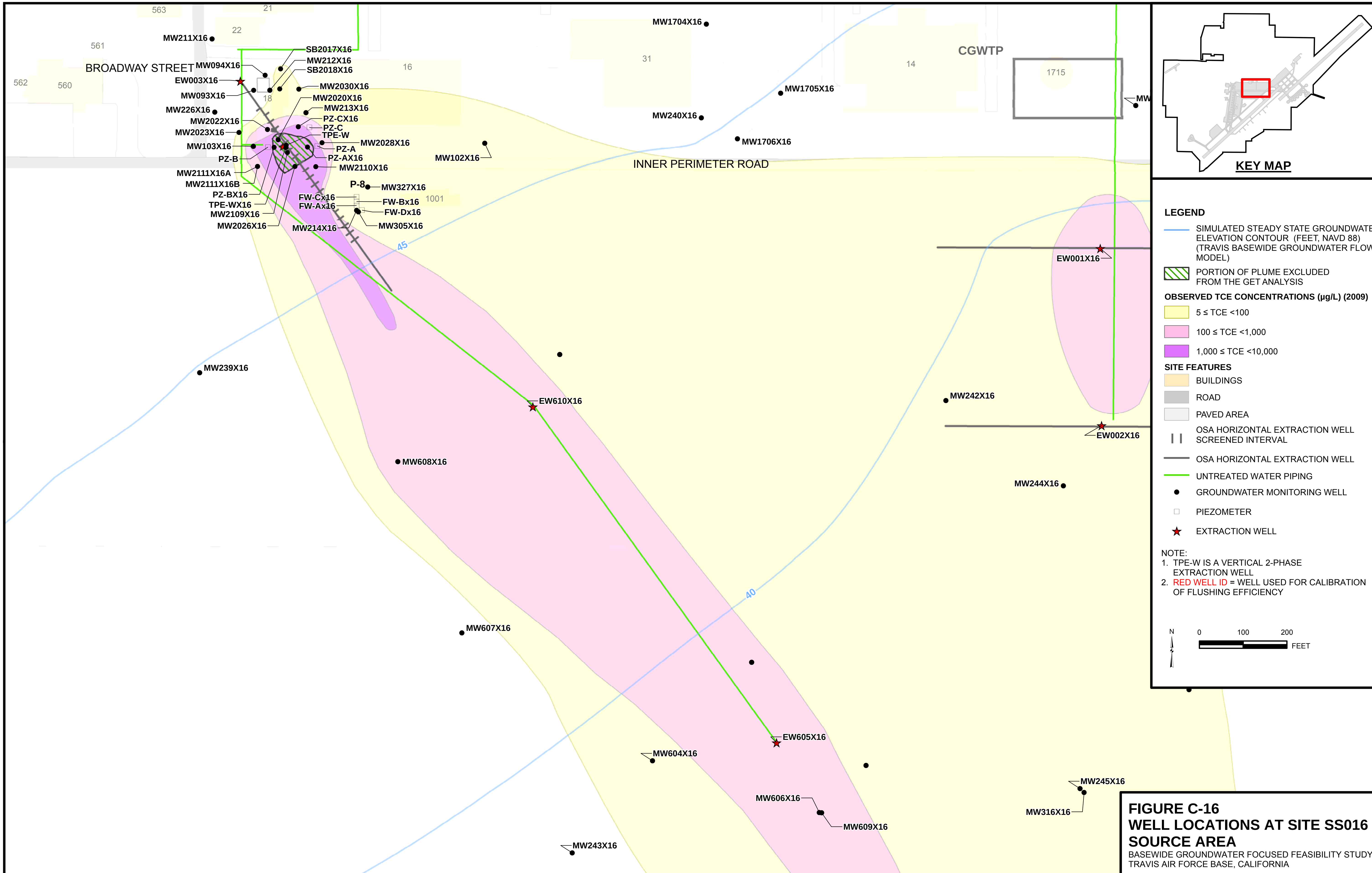
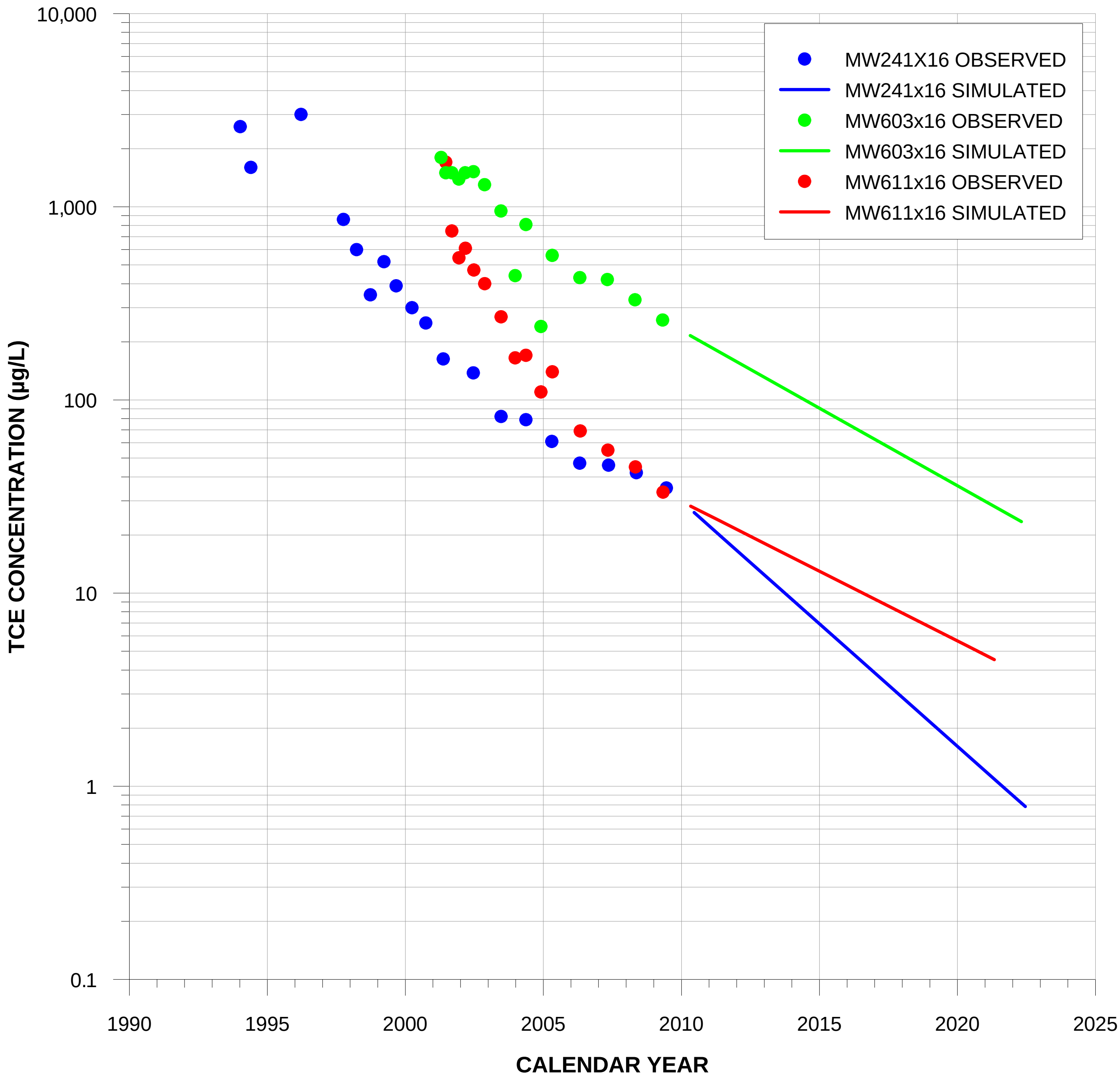


FIGURE C-16
WELL LOCATIONS AT SITE SS016 SOURCE AREA
BASEWIDE GROUNDWATER FOCUSED FEASIBILITY STUDY
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL



NOTE
FORECAST CONCENTRATIONS CALCULATED
USING A FLUSHING EFFICIENCY OF 0.6.

FIGURE C-17
HISTORICAL AND FORECAST TCE CONCENTRATIONS AT MW241x16, MW611x16, AND MW603x16
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-17_SS016_Flushing_Cal.grf

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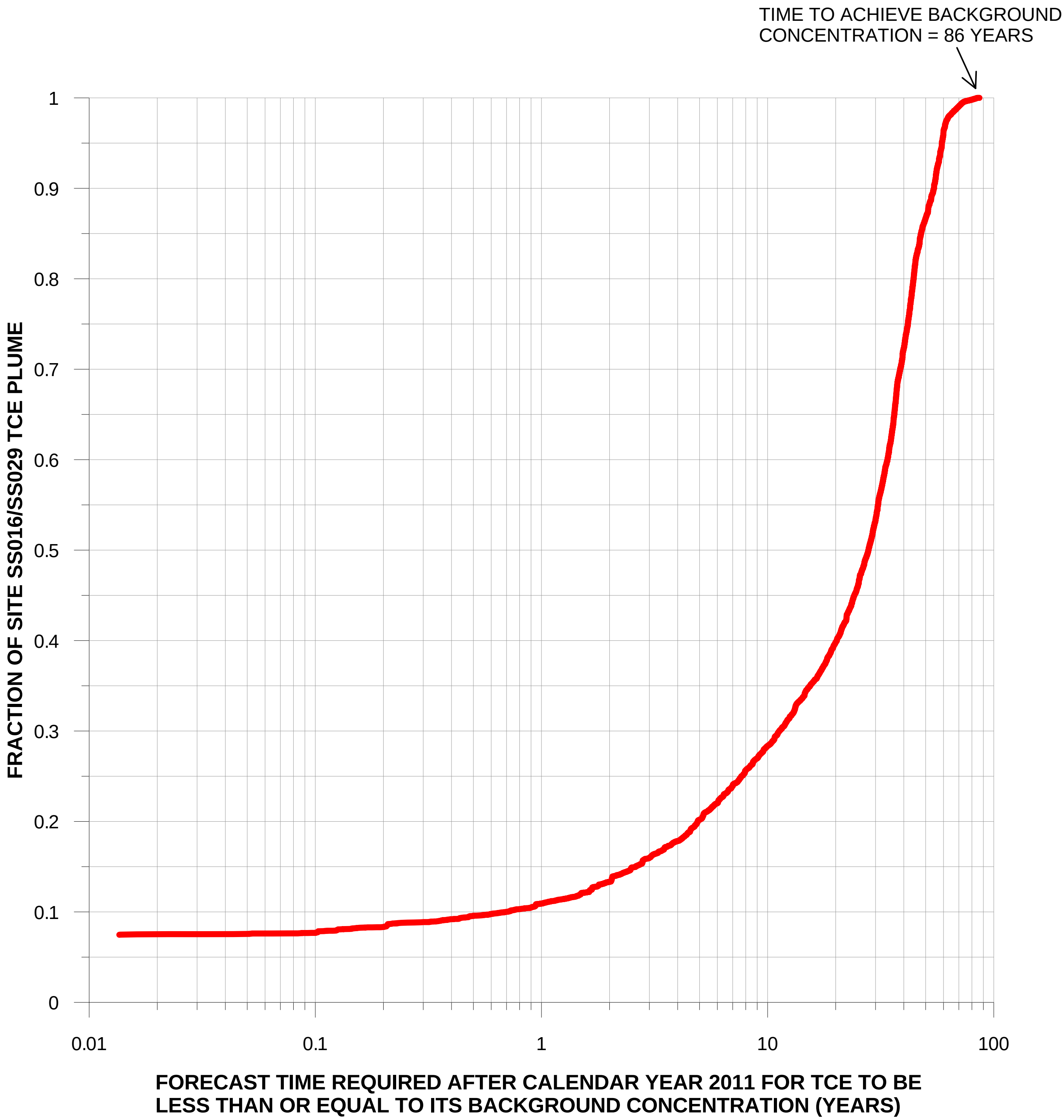
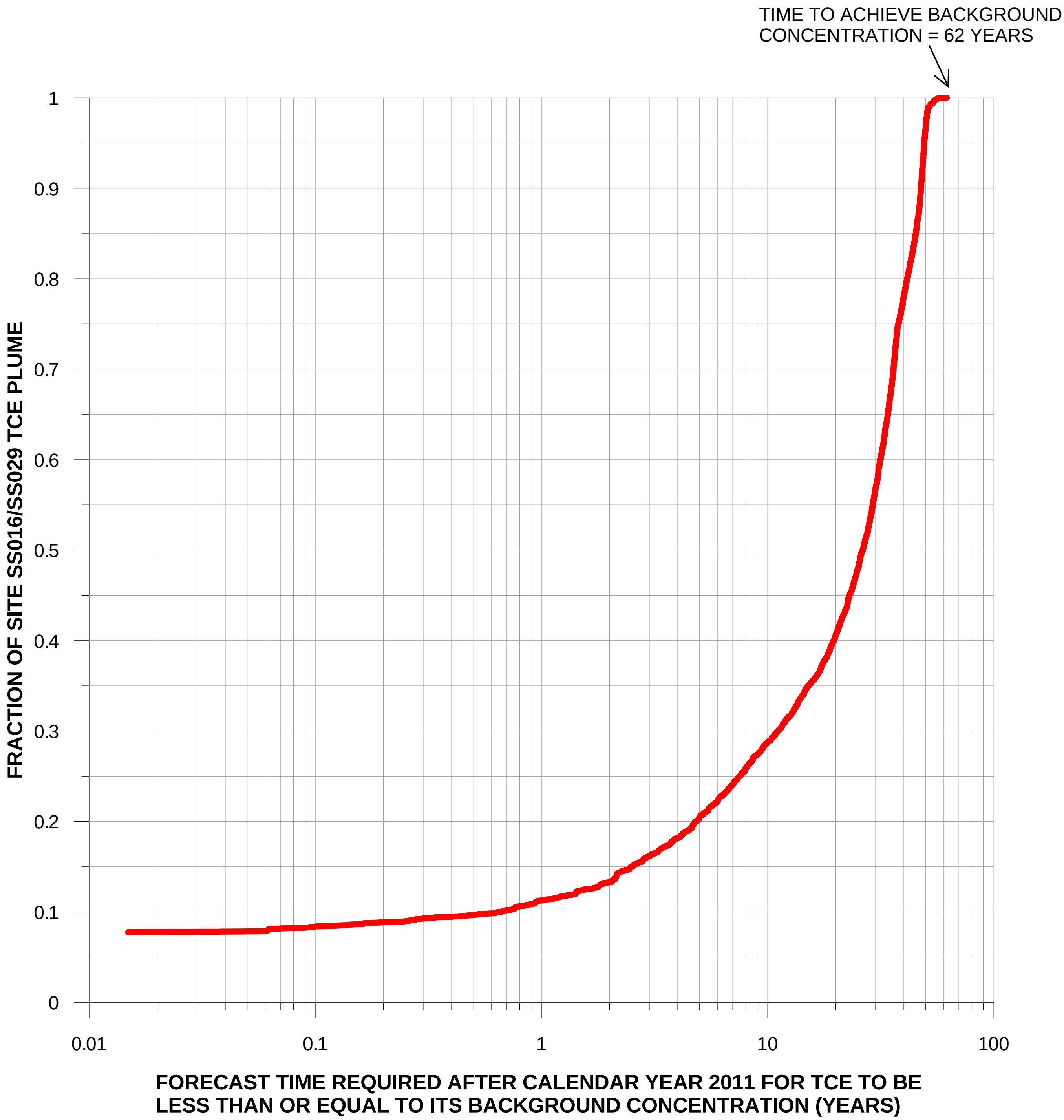


NOTE
PLUME DEFINED BY BACKGROUND CONCENTRATION.

FIGURE C-18
FLUSHING TIME DISTRIBUTION FOR SITE SS016/SS029
TCE PLUME TO ACHIEVE BACKGROUND CONCENTRATION
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-18_SS016_GET_Cum_TTC.grf

CH2MHILL



NOTE
PLUME DEFINED BY BACKGROUND CONCENTRATION.

FIGURE C-19
FLUSHING TIME DISTRIBUTION FOR SITE SS016/SS029 TCE PLUME TO ACHIEVE OBJECTIVE THREE
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

FigureD-19_SS016_GET_Cum_TTC_Obj3.grf

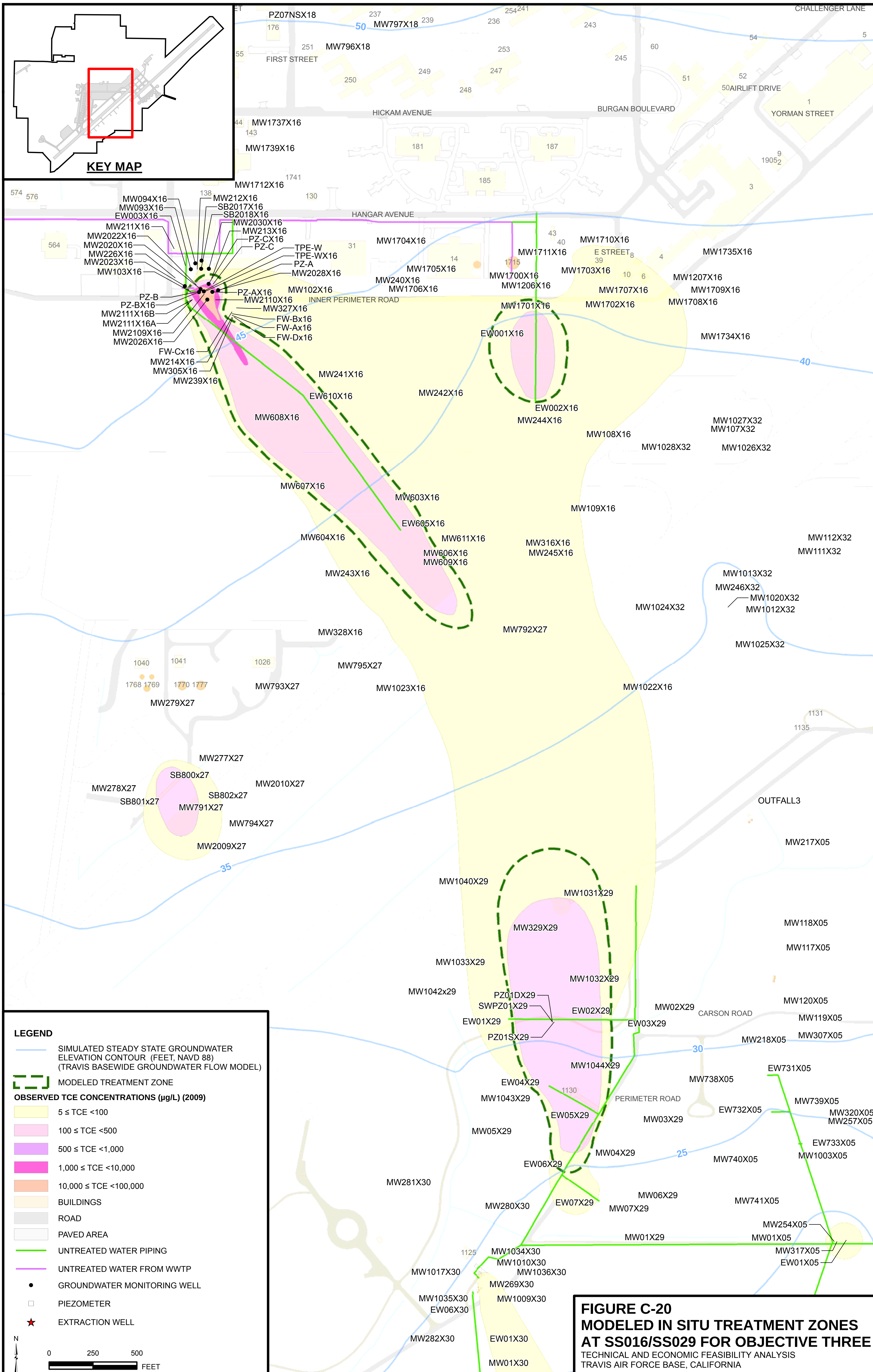


FIGURE C-20
MODELED IN SITU TREATMENT ZONES AT SS016/SS029 FOR OBJECTIVE THREE
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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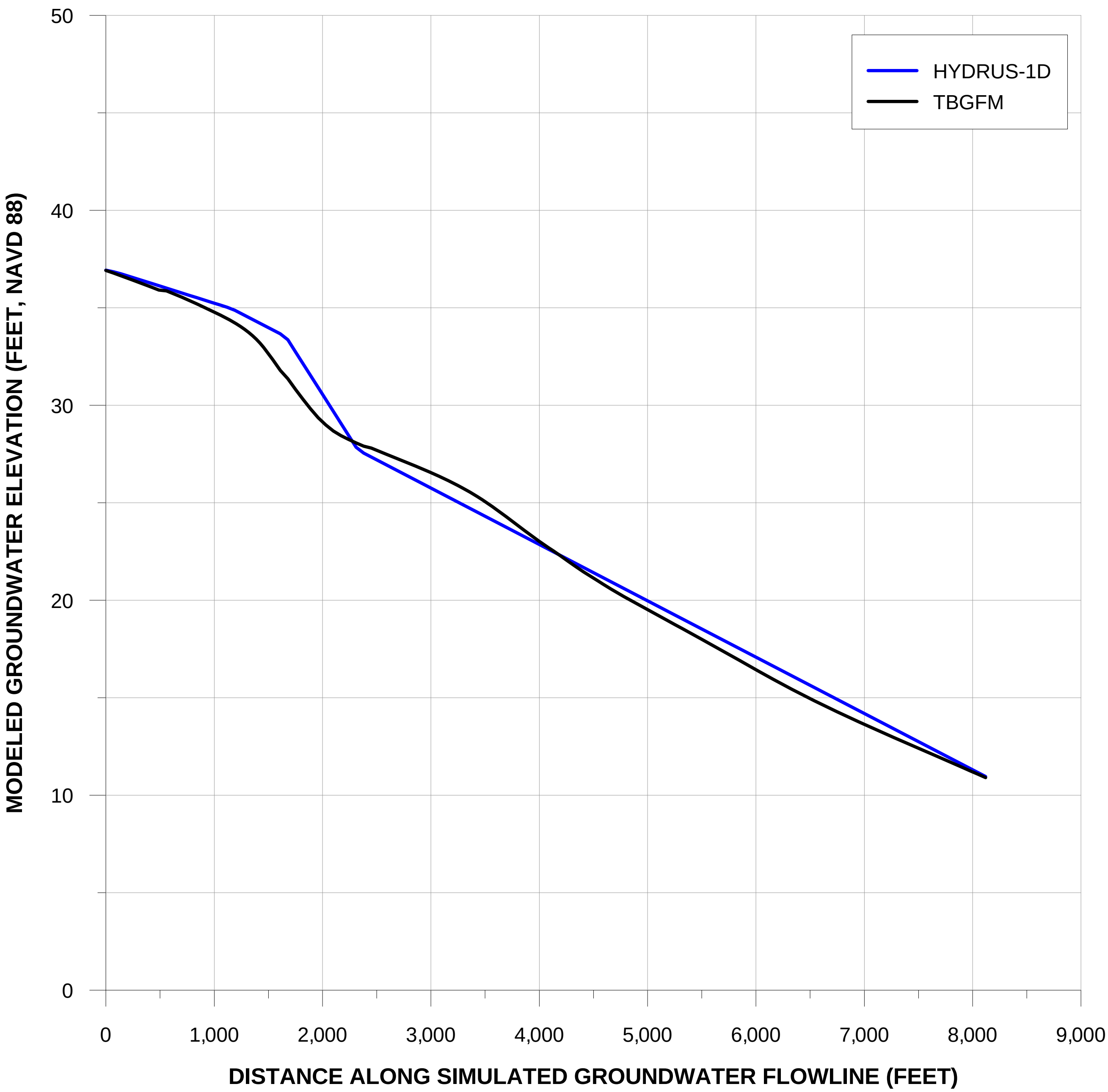


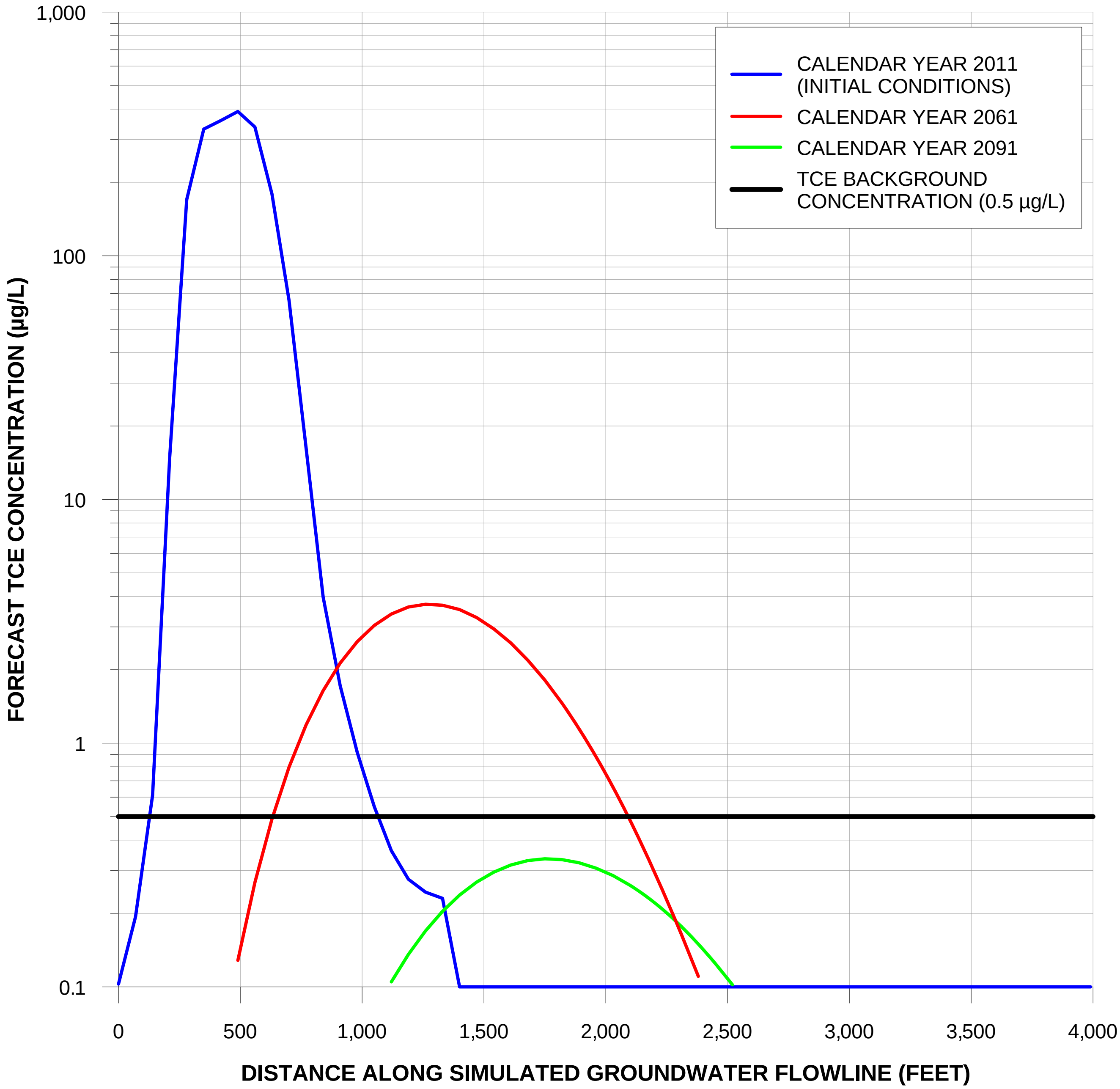
NOTES
1. SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.
2. TBGFM = TRAVIS BASEWIDE GROUNDWATER FLOW MODEL

FIGURE C-21
COMPARISON OF MODELED GROUNDWATER ELEVATIONS AT SITE ST027B

TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-21_ST027B_Head_Comparison.grf

CH2MHILL



NOTE
SITE ST027B SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.

FIGURE C-22
FORECAST SITE ST027B TCE CONCENTRATIONS UNDER ALTERNATIVE 2
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-22_ST027_Conc_vs_Distance.grf

CH2MHILL

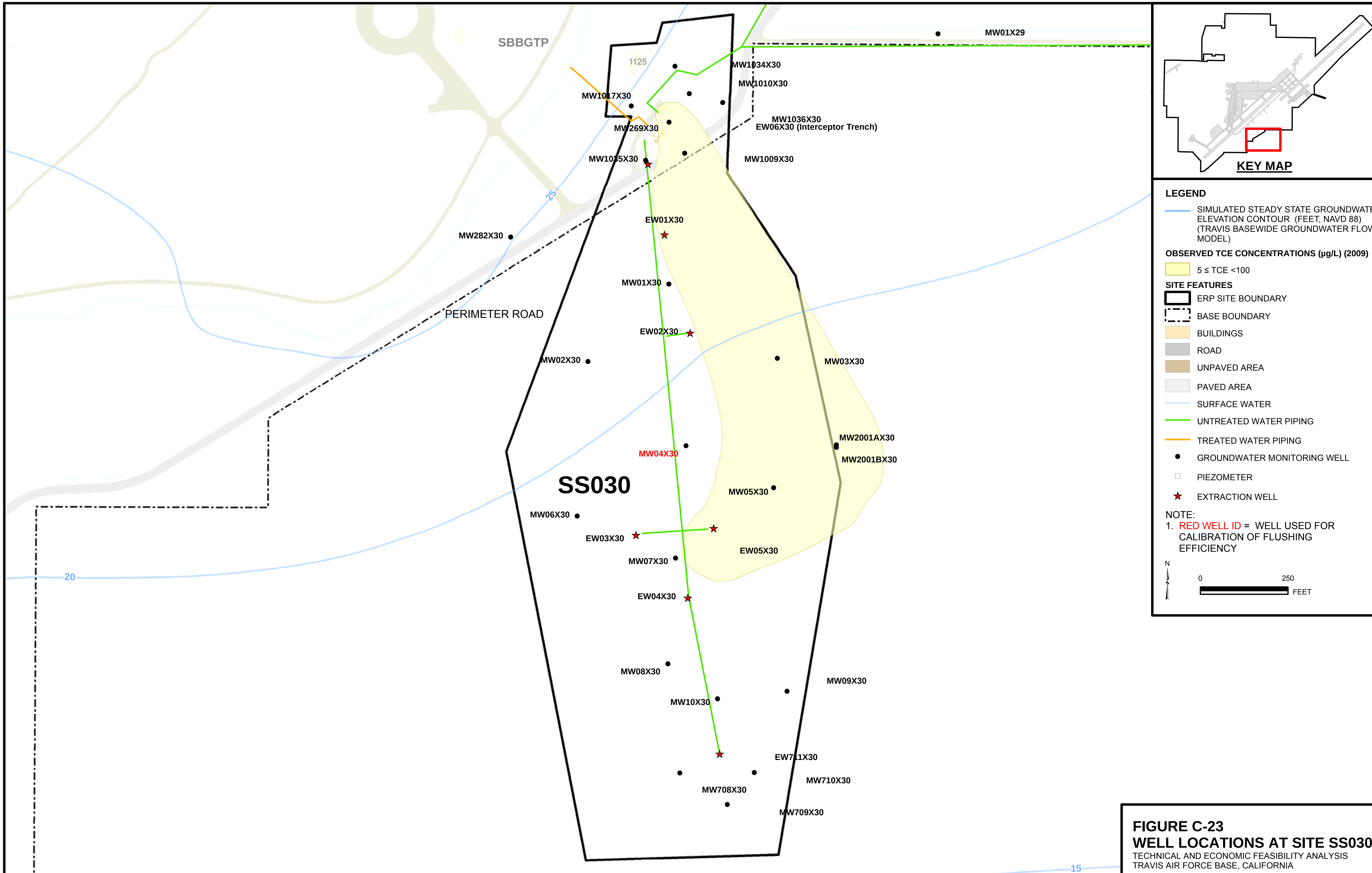
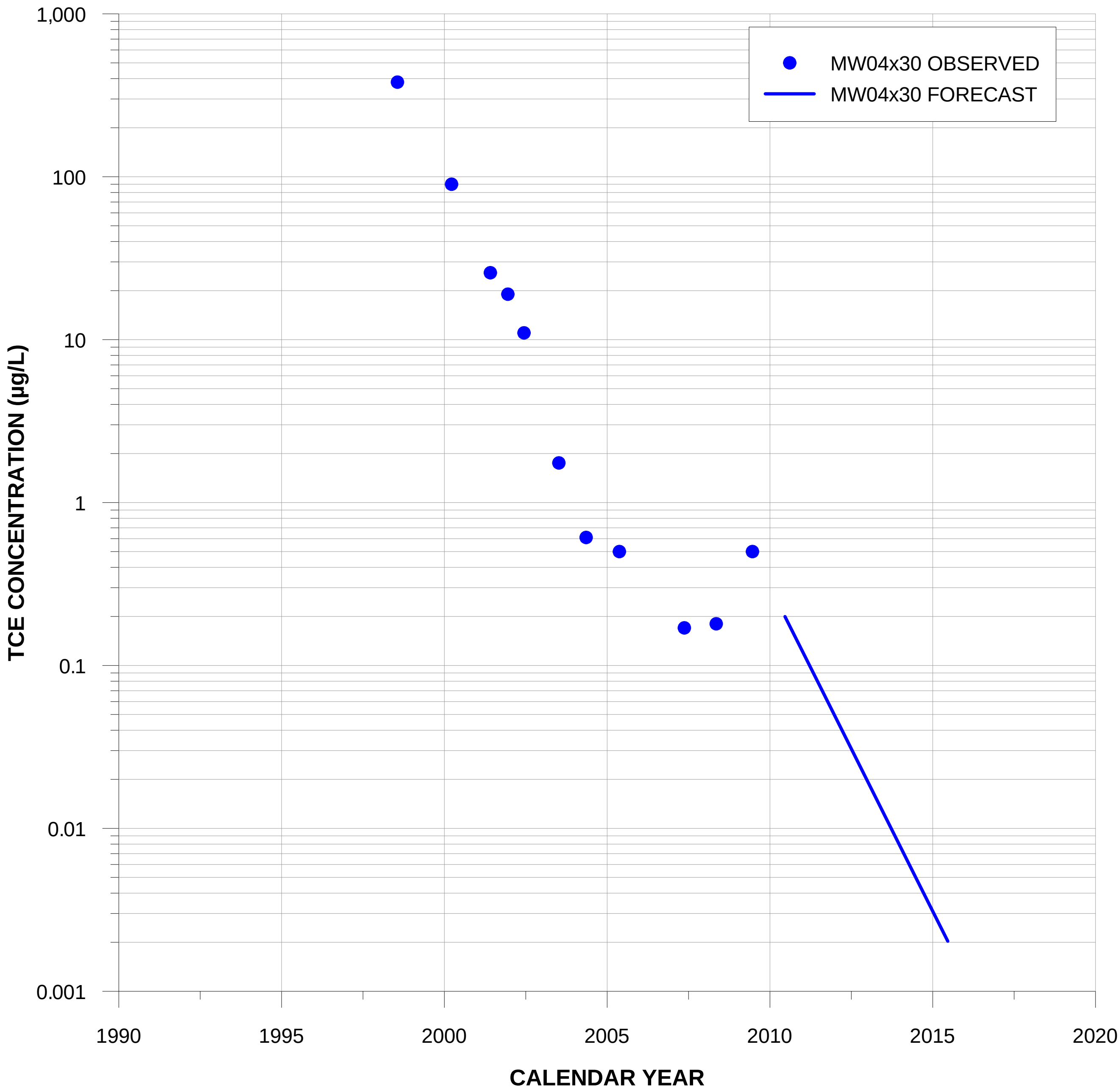


FIGURE C-23
WELL LOCATIONS AT SITE SS030
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\BALDUR\PROJ\TRAVIS\APPENDIX_D\MAPFILES\8NOV2010_EDITS\FIGD-22_WELLS_SS030.MXD MSCHROCK 12/9/2010 12:04:39

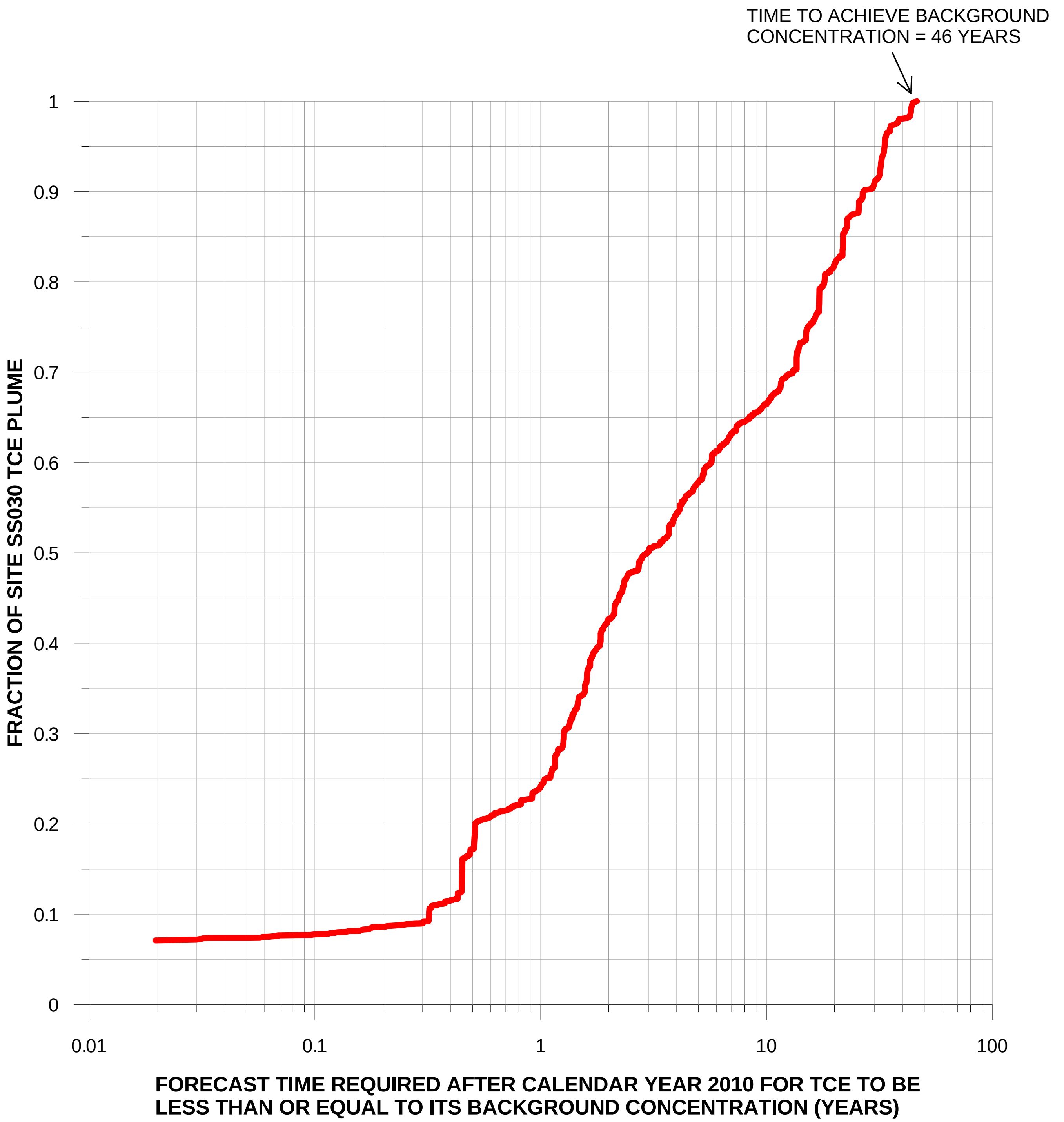


NOTE
FORECAST CONCENTRATIONS CALCULATED
USING A FLUSHING EFFICIENCY OF 0.3.

FIGURE C-24
HISTORICAL AND FORECAST TCE CONCENTRATIONS AT MW04x30
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-24_SS030_Flushing_Cal.grf

CH2MHILL



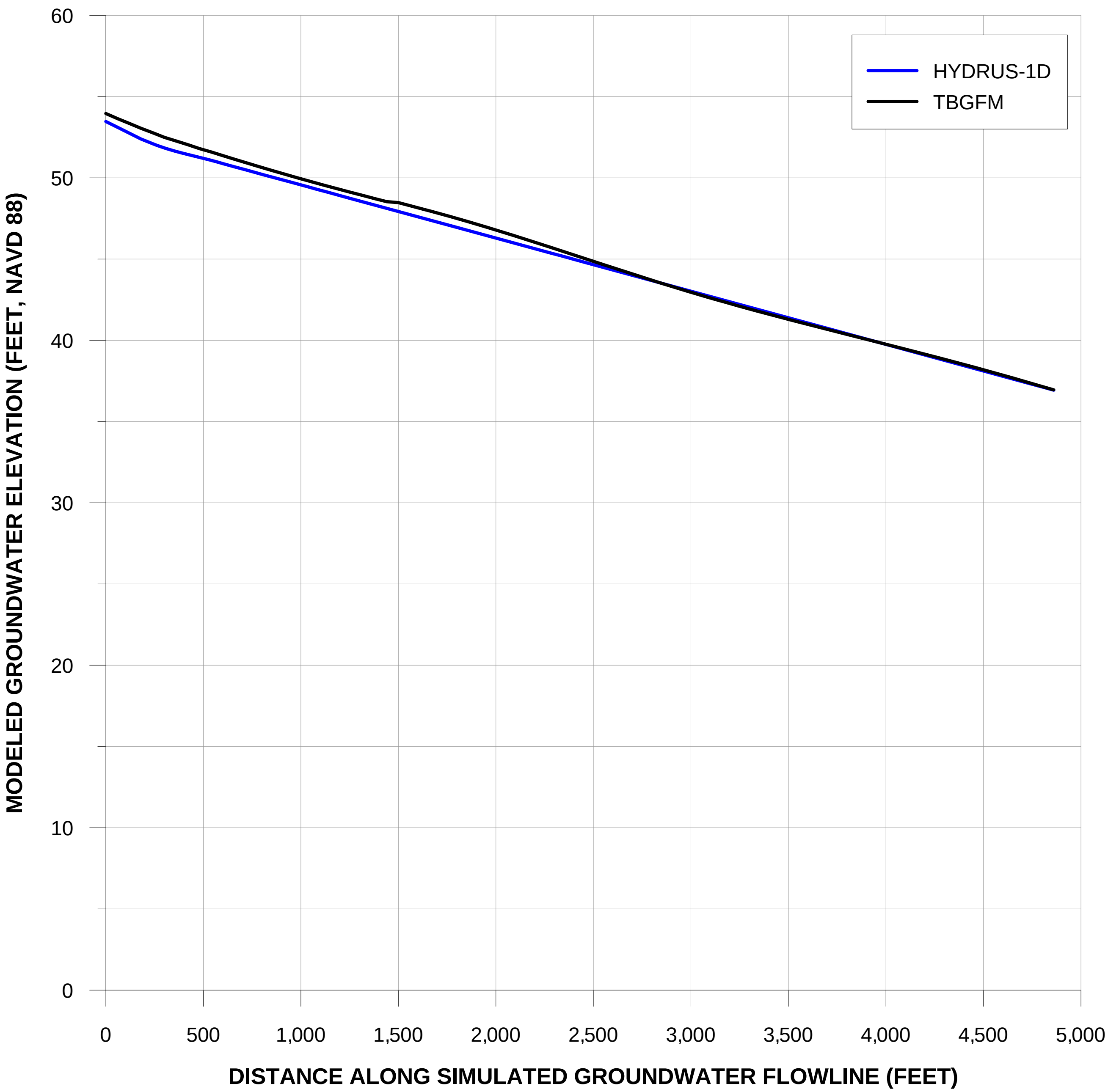
NOTE
PLUME DEFINED BY BACKGROUND CONCENTRATION.

FIGURE C-25
FLUSHING TIME DISTRIBUTION FOR THE SITE SS030 TCE PLUME

TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-25_SS030_GET_Cum_TTC.grf

CH2MHILL

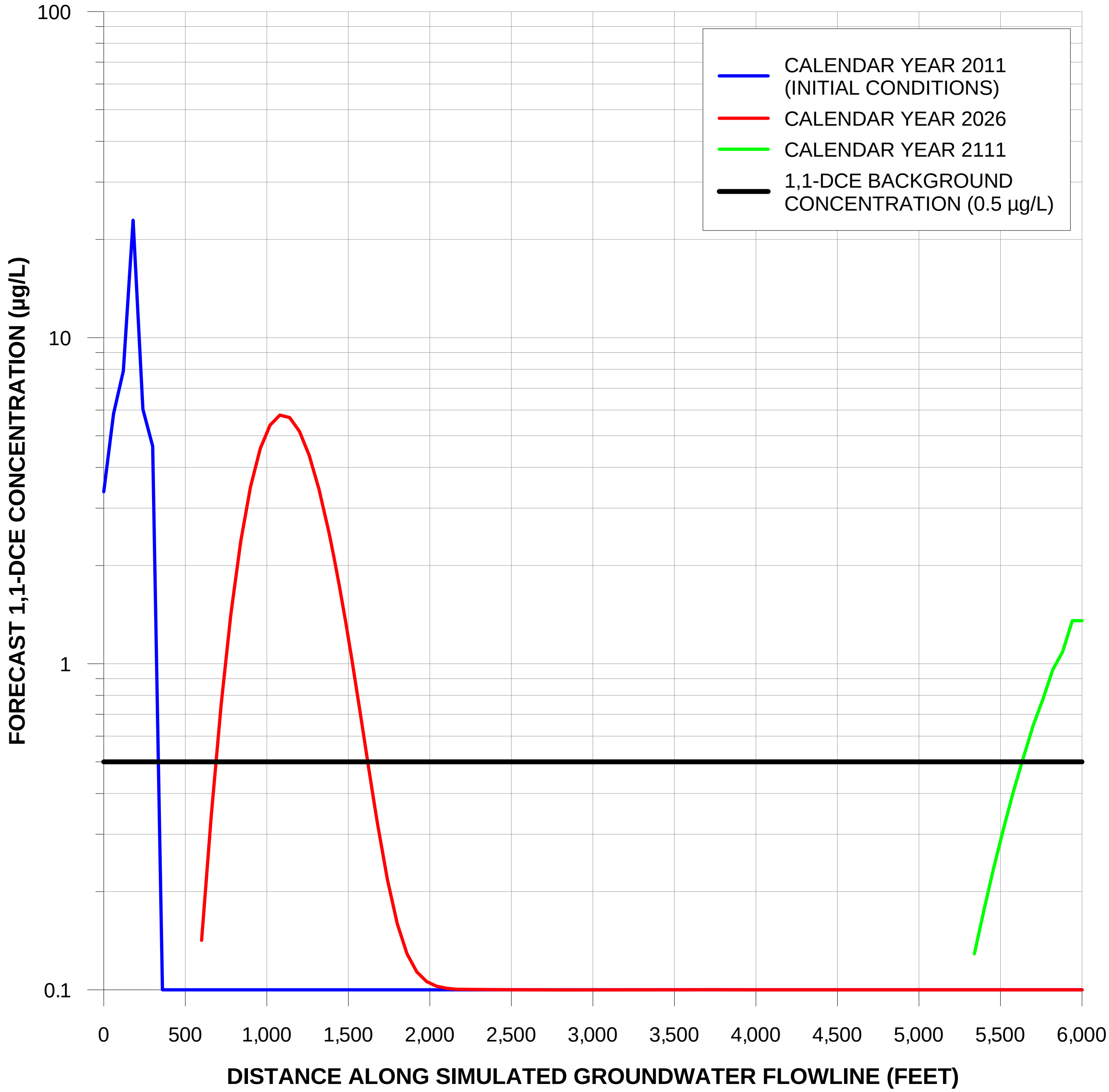


NOTES
1. SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.
2. TBGFM = TRAVIS BASEWIDE GROUNDWATER FLOW MODEL

FIGURE C-26
COMPARISON OF MODELED GROUNDWATER ELEVATIONS AT SITE SD031
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-26_SD031_Head_Comparison.grf

CH2MHILL



NOTE
SITE SD031 SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.

FIGURE C-27
FORECAST SITE SD031 1,1-DCE CONCENTRATIONS UNDER ALTERNATIVE 2
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-27_SD031_Conc_vs_Distance.grf

CH2MHILL

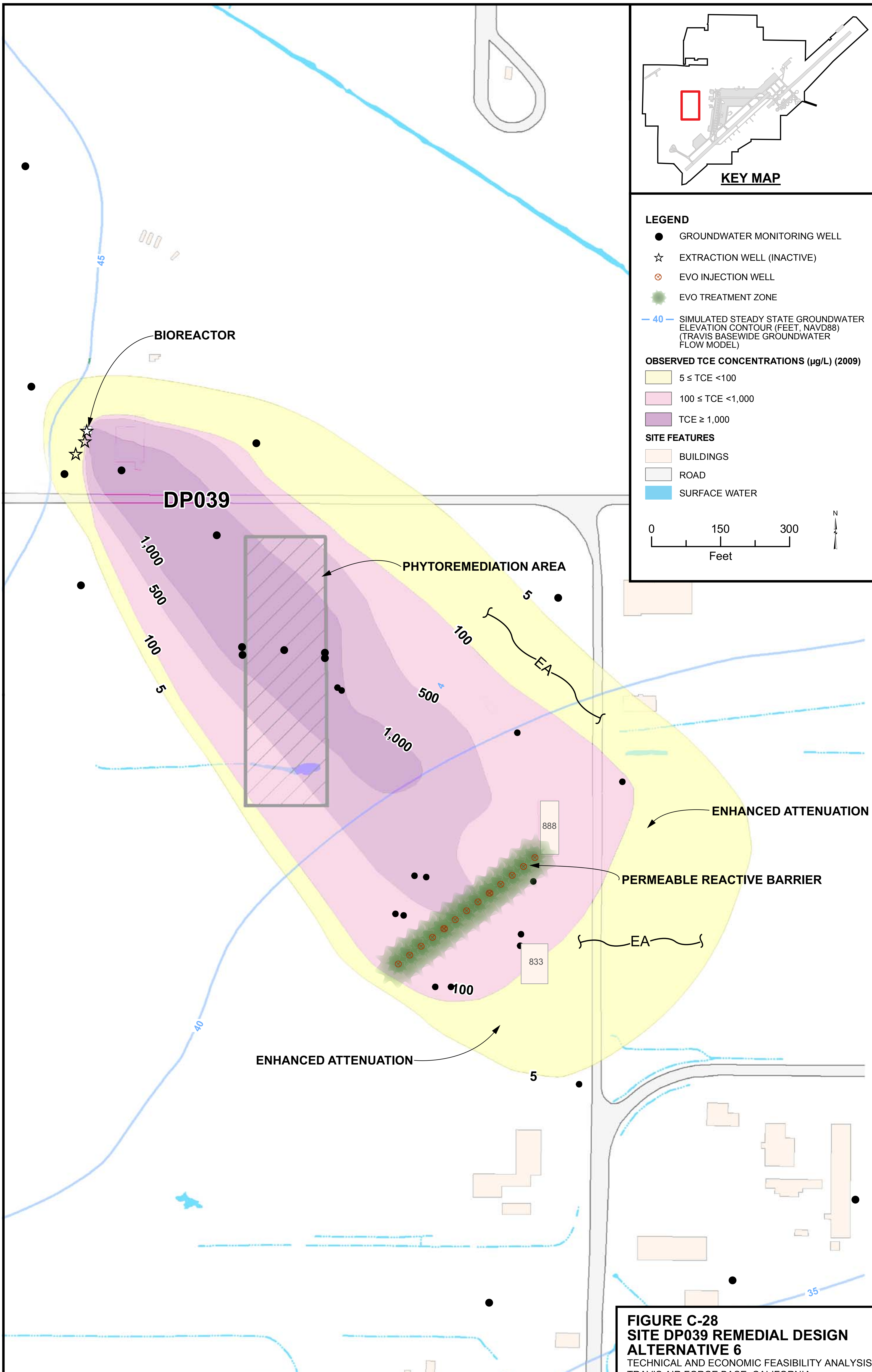


FIGURE C-28
SITE DP039 REMEDIAL DESIGN ALTERNATIVE 6
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA
CH2MHILL

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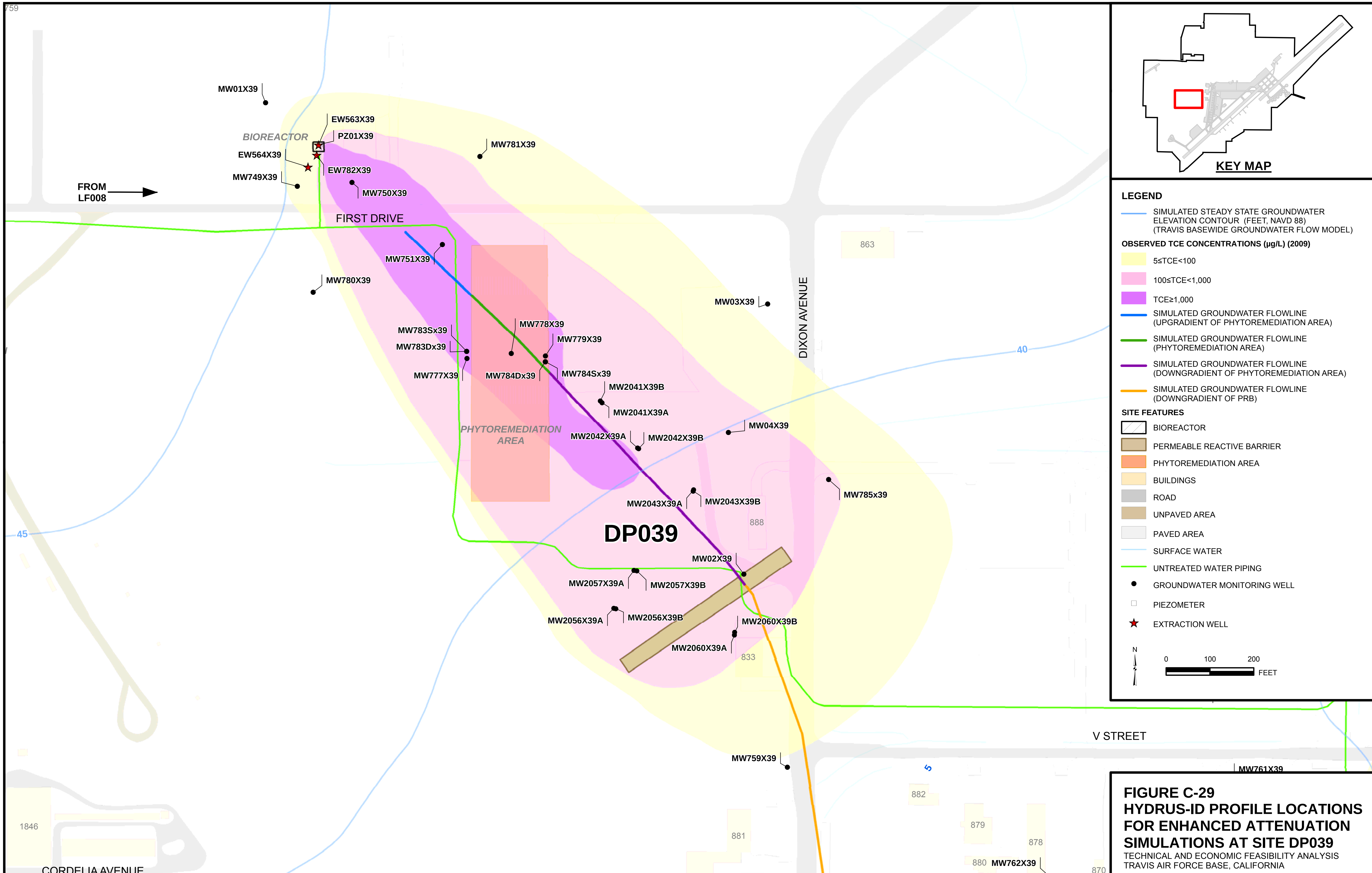


FIGURE C-29
HYDRUS-ID PROFILE LOCATIONS FOR ENHANCED ATTENUATION SIMULATIONS AT SITE DP039
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

\\BALDUR\PROJ\TRAVIS\APPENDIX_D\MAPFILES\8NOV2010_EDITS\FIGD-32_FLOW_DP039_V2.MXD MSCHROCK 12/27/2010 13:54:37

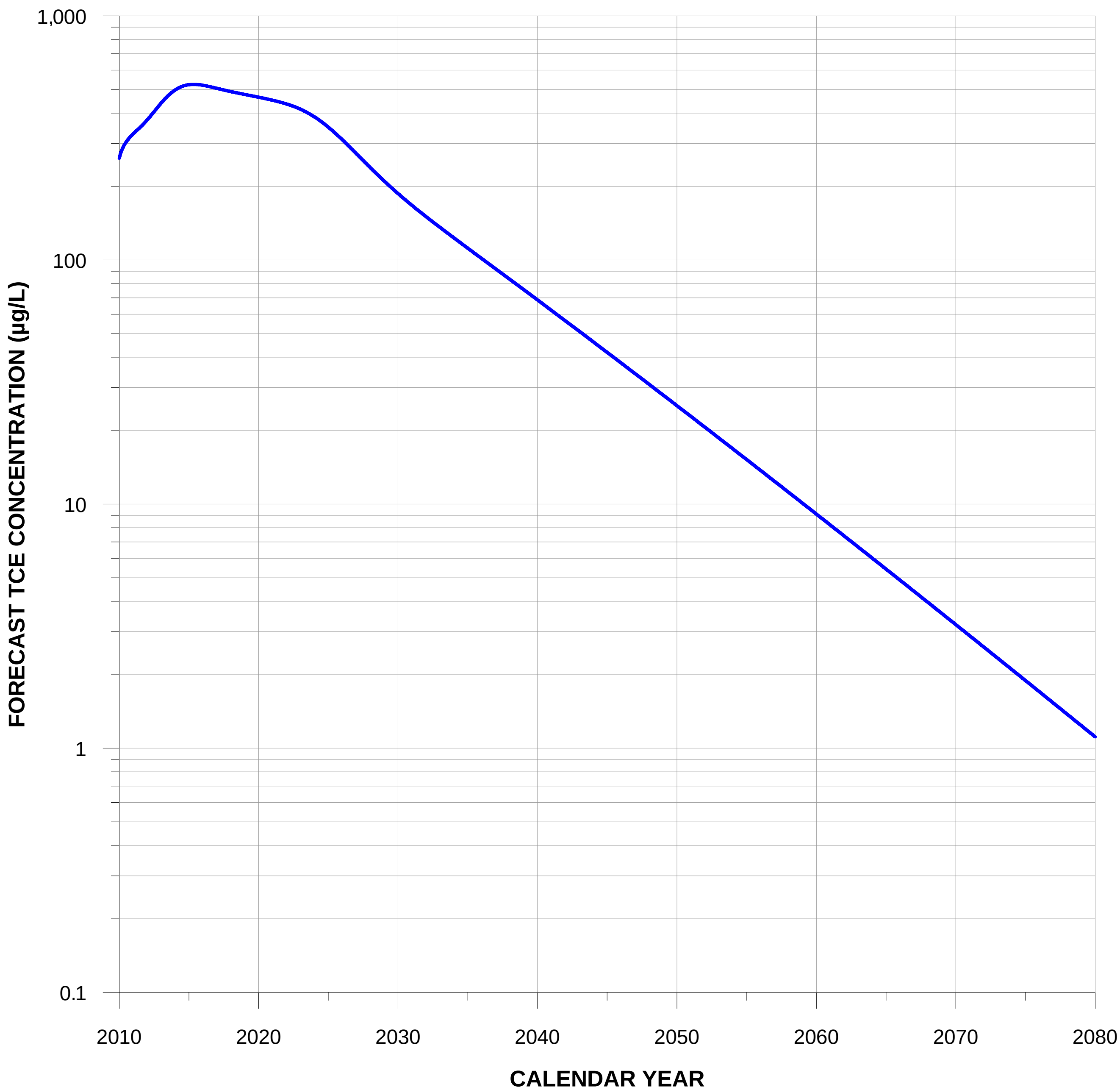
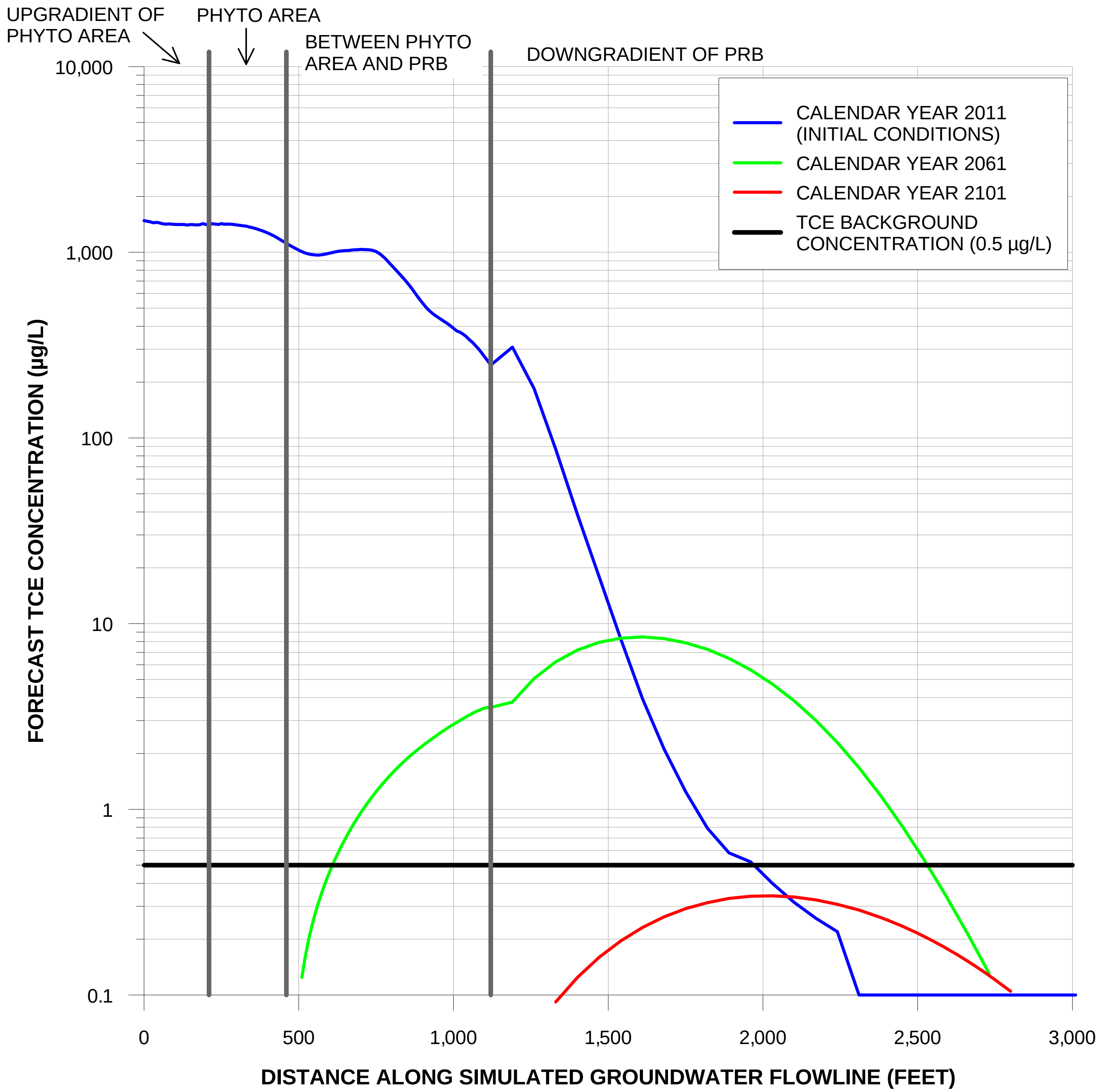


FIGURE C-30
FORECAST TCE CONCENTRATION ENTERING THE DP039 PERMEABLE REACTIVE BARRIER
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-30_DP039_ObsNode_Output.grf

CH2MHILL



NOTE
SITE DP039 SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2 and D-28.

FIGURE C-31
FORECAST SITE DP039 TCE CONCENTRATIONS UNDER ALTERNATIVE 6
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-31_DP039_MNA_PostRem_v2_from_3_model_subsections.grf

CH2MHILL

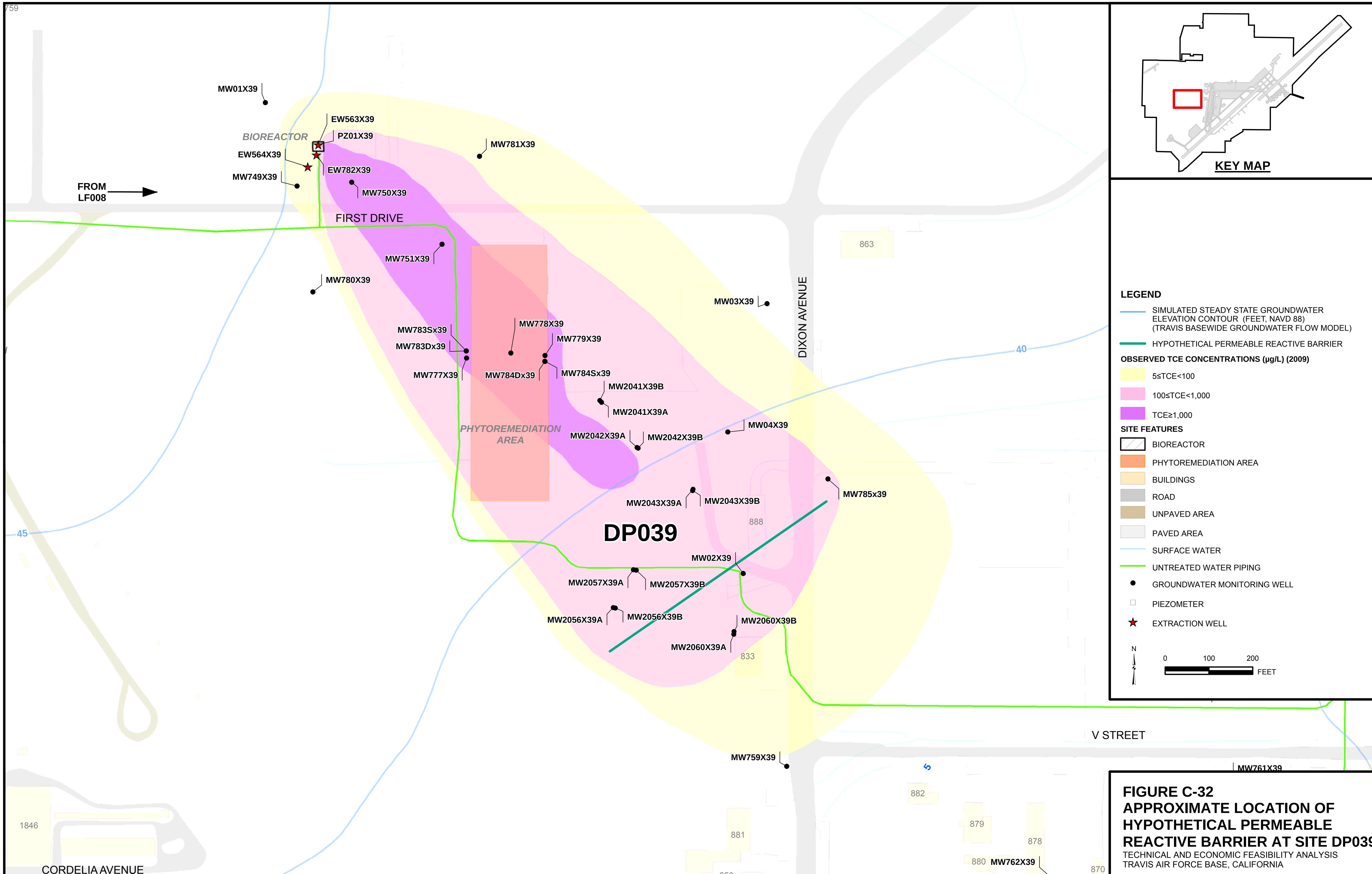


FIGURE C-32
APPROXIMATE LOCATION OF HYPOTHETICAL PERMEABLE REACTIVE BARRIER AT SITE DP039
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

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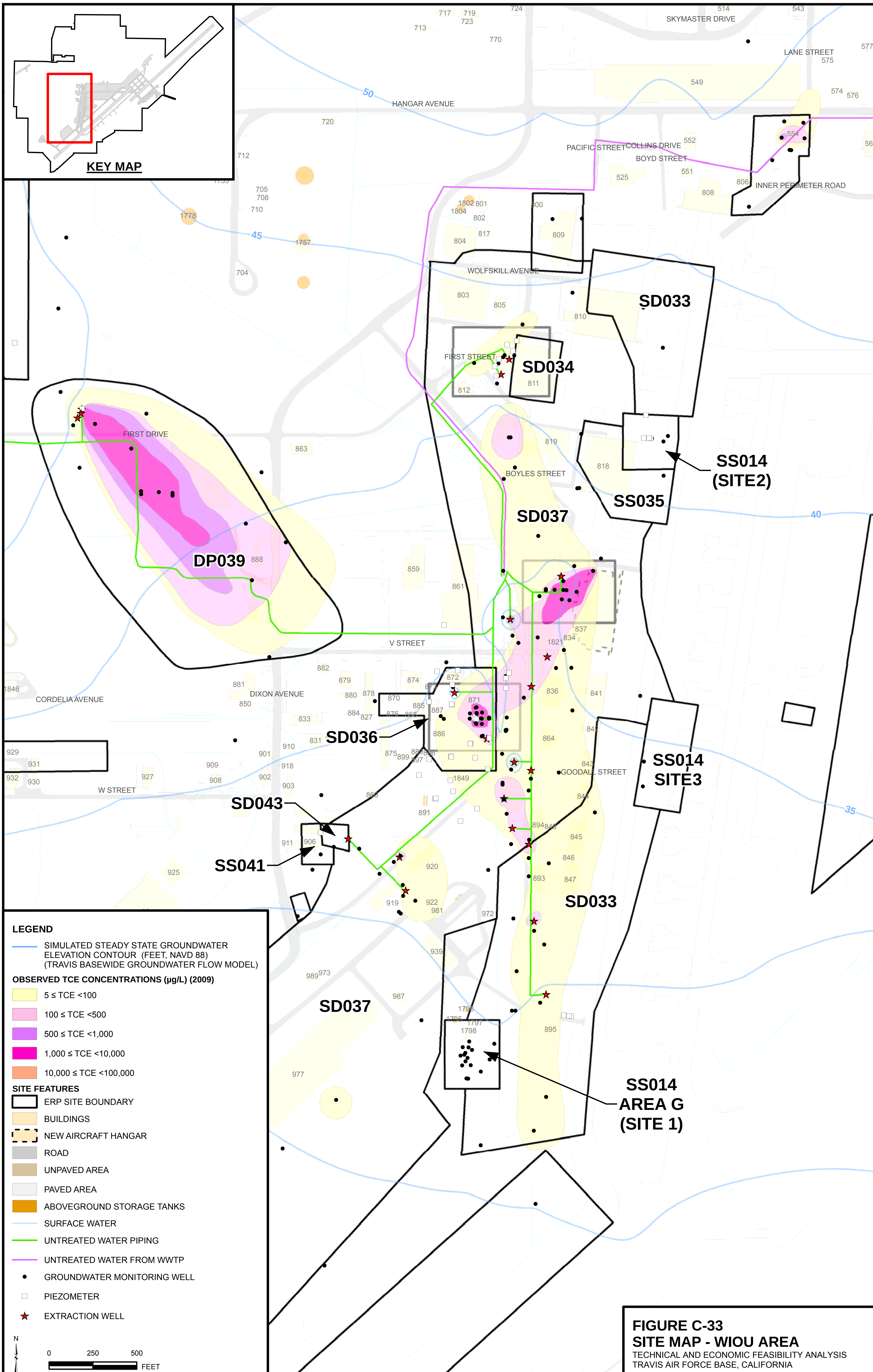
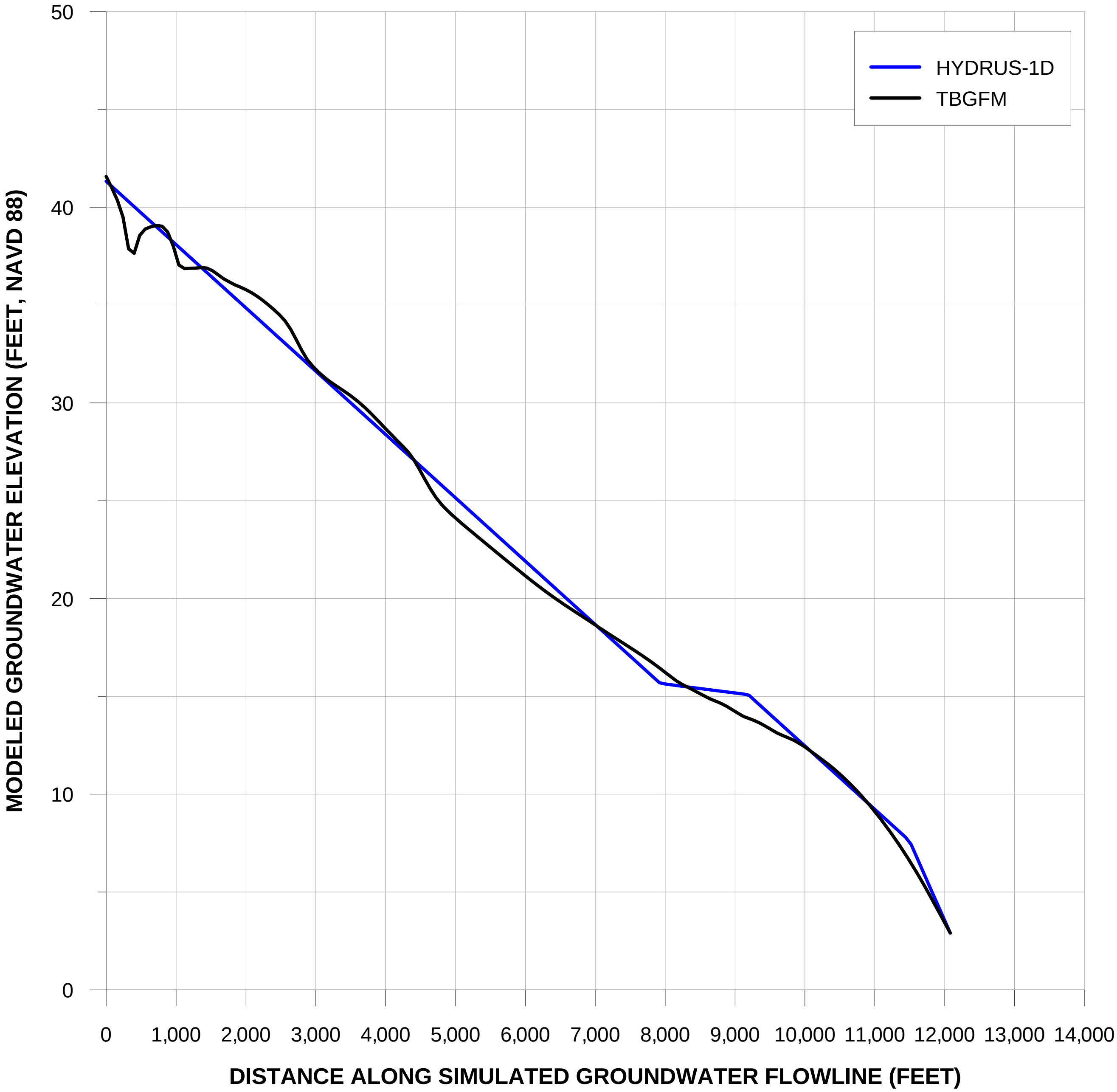


FIGURE C-33
SITE MAP - WIOU AREA
TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

CH2MHILL

\\BALDUR\PROJ\TRAVIS\APPENDIX_D\MAPFILES\8NOV2010_EDITS\FIGD-35_WIOU_SITE.MXD MSCHROCK 12/9/2010 12:13:27



NOTES
1. SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.
2. TBGFM = TRAVIS BASEWIDE GROUNDWATER FLOW MODEL

FIGURE C-34
COMPARISON OF MODELED GROUNDWATER ELEVATIONS AT WIOU

TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS
TRAVIS AIR FORCE BASE, CALIFORNIA

FigureD-34_WIOU_Head_Comparison.grf

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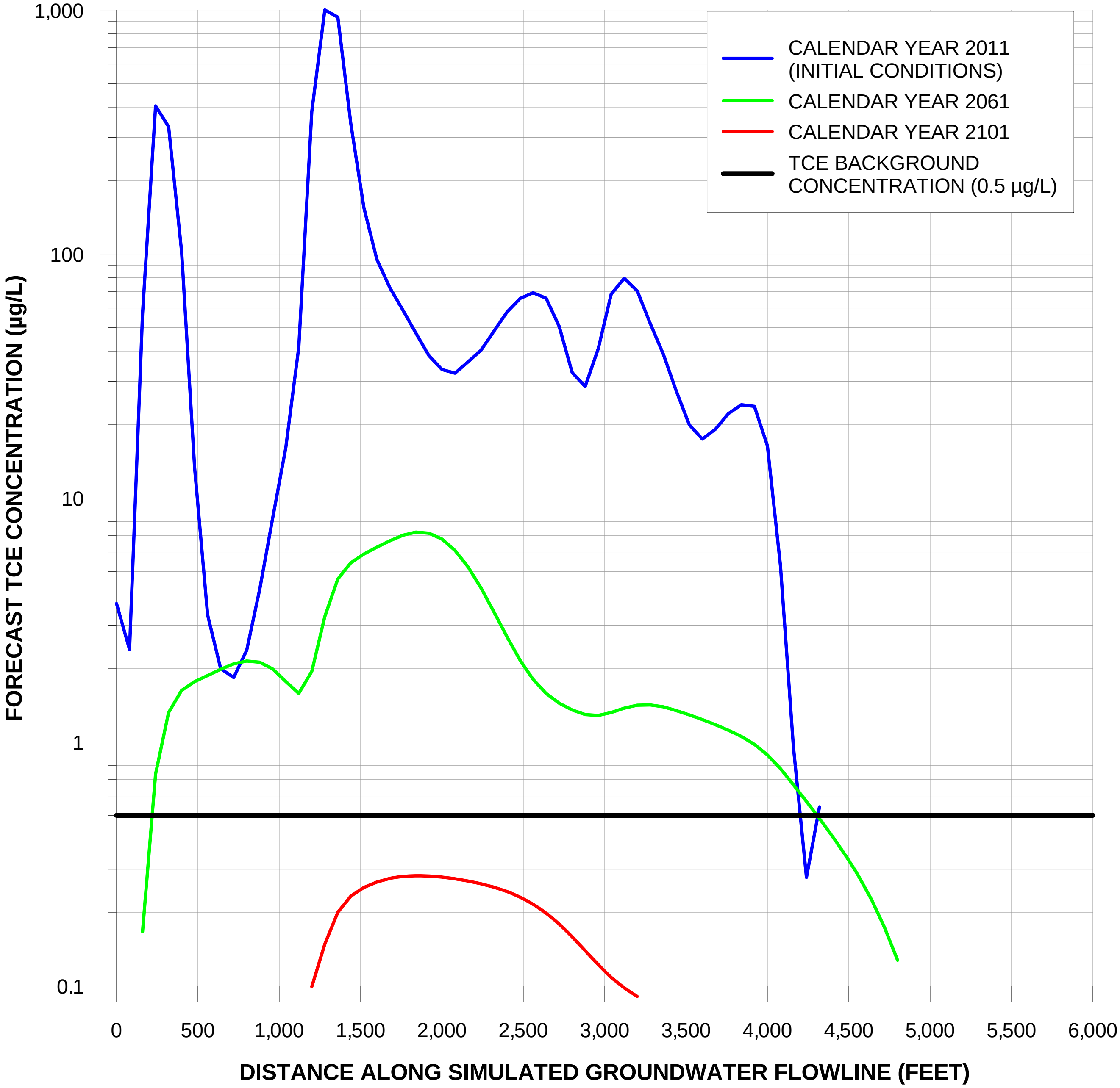

NOTE
WIOU SIMULATED GROUNDWATER FLOWLINE SHOWN ON FIGURE D-2.

FIGURE C-35
FORECAST WIOU TCE CONCENTRATIONS UNDER ALTERNATIVE 5
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FigureD-35_WIOU_Conc_vs_Distance.grf

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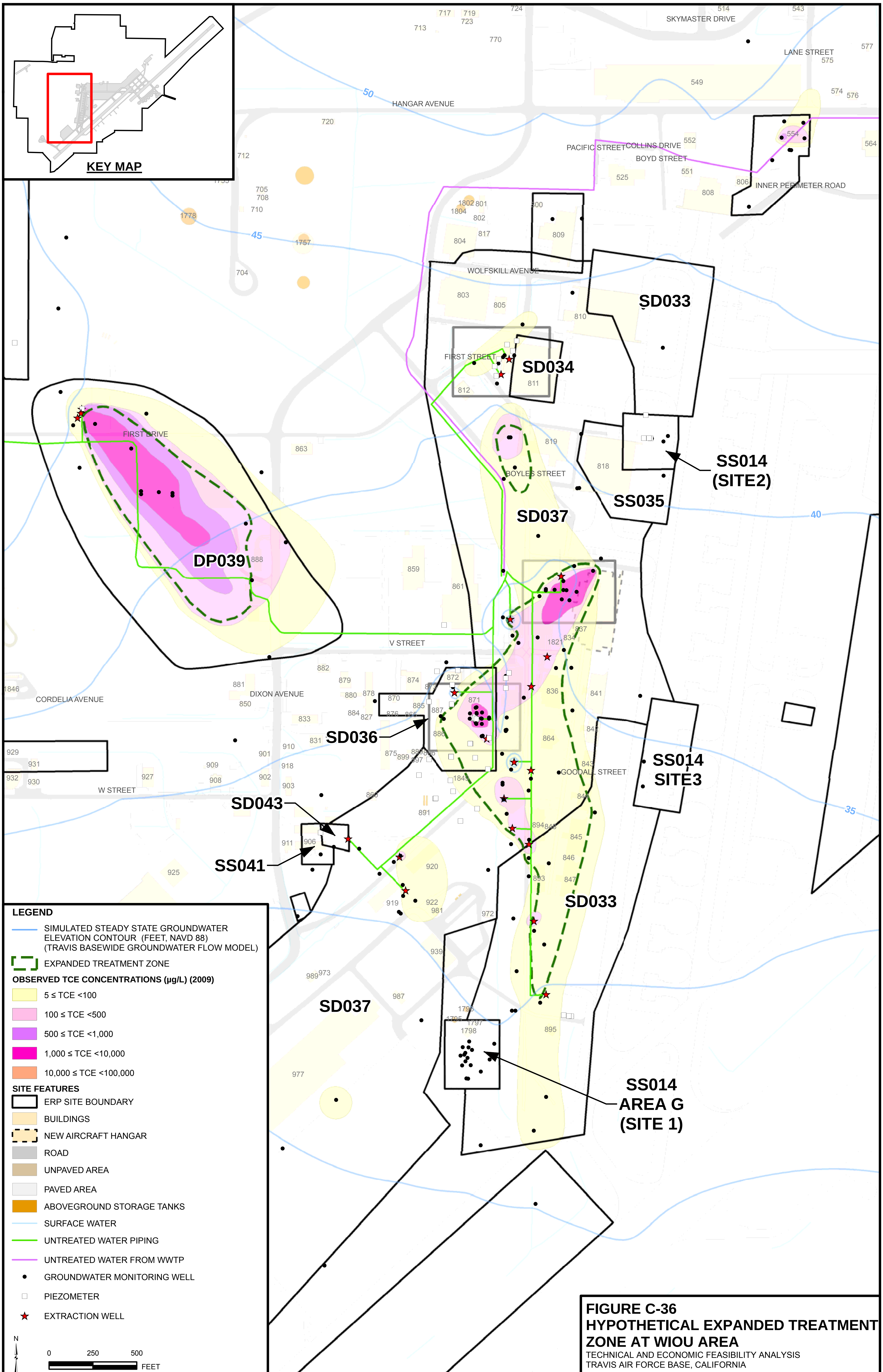

FIGURE C-36
HYPOTHETICAL EXPANDED TREATMENT ZONE AT WIOU AREA
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Appendix D
Response to Comments

Response to Water Board Comments on the Draft Technical and Economic Feasibility Analysis		
No.	**Comments**	**Responses**
1	There is no determination of the lowest groundwater concentrations that **are** technically and economically achievable. The remedial alternatives for each site have been already chosen in the feasibility study, and the same alternatives will be carried over without change into the upcoming proposed plan and ROD. The TEFA is left with the task of seeing if the alternatives already chosen can be incrementally changed to achieve another, lower groundwater concentration. The analysis would make more sense if there was more freedom to change a remedial alternative for any given site, in other words, if the TEFA had preceded and been able to influence the final feasibility study. As currently written, the TEFA presents foregone conclusions.	We acknowledge that we did not recognize where the TEFA fits in the ROD schedule until its importance in the remedy selection process for California installations was mentioned during the 2011 Air Force Technology Transfer Workshop. By that time, we were in the middle of the production of the Feasibility Study (FS) and could not start on the TEFA until the FS was finalized. In retrospect, we should have started the discussion on the TEFA much earlier in the remedy selection process. In some cases, the FS did some of the preliminary work to identify the feasibility of attaining cleanup levels in a reasonable amount of time. For example, pump-and-treat technologies that were part of several interim remedies were reaching asymptotic conditions; therefore, they were not expected to reach MCLs, much less background levels. MNA, a less aggressive strategy, was also not expected to reach MCLs in a timely manner at the larger plumes. The TEFA could have influenced the decision-making in the FS, as long as it was not overshadowed by any of the nine CERCLA evaluation criteria. We revised significant portions of the TEFA to get it more in line with California Resolution 92-49. In particular, we clarified the relationship between the nine (9) evaluation factors identified in 23 CCR 2550.4(d)(1), Subsections A through I, as discussed in Section 3, and the evaluation of economic feasibility presented in Section 5.
2	The TEFA states that it **is** technically and economically feasible to meet a background groundwater concentration at several sites. The TEFA then contradicts these conclusions by stating "Travis AFB comprises the overall "site" addressed by the TEFA. Therefore, the technical and economic feasibility of potential remedial actions to achieve background concentrations collectively addresses all groundwater contamination at Travis AFB." The individual sites, however, have always been analyzed separately and should be treated similarly in the TEFA. For example, different remedial alternatives have already been chosen for the various sites; the TEFA in fact carries separate technical and economic analyses for each site; and presumably Travis will ask for closure on individual sites and not the collective sites. For these reasons, we request that a separate conclusion be determined for each site rather than insisting that achieving background levels be found feasible or not 'collectively' for all sites at Travis. There is no reason why some sites cannot be cleaned up to a greater degree than others.	The TEFA views Travis AFB as one site, because there is only one budget to fund the cleanup of the base. To determine economic feasibility, it is very challenging, if not impossible, to subdivide a cleanup funding source into 19 separate portions and evaluate the attainment of background levels at each site on its portion. Also, the estimated cost to reach background levels at a site may seem reasonable, because it gives the erroneous impression that this estimated cost reflects the only Air Force groundwater liability on Travis AFB. However, when the estimated cost of reaching background levels for all sites is totaled, the economic infeasibility of reaching background levels becomes apparent. Thus, one reason why some sites should not be cleaned up to a greater degree than others is that a greater effort at one site would result in a corresponding lesser effort at another site, resulting in a potential inability to reach MCLs as the cleanup level. This would require an ARARs waiver and would probably not be supported by the Air Force. However, we revised significant portions of the TEFA to get it more in line with California Resolution 92-49. Specifically, the revisions clarify how economic feasibility for a site with multiple plumes should be evaluated. The key revisions are described as follows: We revised Section 2.5 – Approach to the Technical and Economic Feasibility Analysis as follows: "Although not formally a part of the CERCLA process, this TEFA was conducted to comply with the intent of California SWRCB Resolution 92-49. This resolution provides that Regional Water Boards in California shall "ensure that dischargers are required to clean up and abate the effects of discharges in a manner that promotes attainment of either background water

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		quality, or the best water quality which is reasonable if background levels of water quality cannot be restored, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible; in approving any alternative cleanup levels less stringent than background….” (SWRCB Resolution, Section III G). The groundwater remedial alternatives developed in the FFS are based on the remedial action objective of cleaning up groundwater to chemical-specific MCLs. The TEFA evaluates the technical and economic feasibility of attaining cleanup of groundwater contaminants to concentrations less than the chemical-specific MCLs (hereinafter referred to as “background, but generally the current analytical limits). • In general, the TEFA follows the approach taken in the final Edwards AFB OU 2 TEFA (Edwards AFB, 2009) to the extent that is practical and relevant to the conditions at Travis AFB. However, the Travis AFB TEFA makes several assumptions to facilitate the evaluations: • Most of the interim remedies at the Travis AFB groundwater sites would not be able to achieve MCLs or background levels in a reasonable amount of time. The reason for this is that most of the GET systems were either approaching or at asymptotic conditions, and past optimizations of GET systems that involved expansions of the extraction networks were effective for limited amounts of time. So the Air Force’s preferred remedies from the FFS represent improved technological approaches that do not have similar asymptotic limitations. • The TEFA included the quantity of contaminated groundwater that is extracted from off-base extraction wells in its economic analyses, even though this will overestimate the yield from the portion of the aquifer beneath Travis AFB. The reason for this is that it is difficult to separate the off-base and on-base well yields over a long interim remediation period, taking into account extraction well downtimes from maintenance and repair periods as well as fluctuating well yields. • The TEFA does not compare the benefit of cleaning off-base groundwater from MCLs to background levels with the continued loss of usage of acreage under easements by off-base property owners. Property owners are compensated financially for the restrictions posed by easements upon which remediation takes place.” We deleted Section 2.5.1 – Approach to Site Designation in its entirety and renumbered the remaining sections. We revised the last bullet item (Alternative 7 – Passive Skimming and EA at Site SD034) in Section 2.5.3 by adding the following new last sentence: “Technical feasibility issues are expected to arise in the future if additional wells are needed in the vicinity of active aircraft maintenance hangars.”

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		We revised the introductory paragraph of Section 3 – Environmental Factors as follows: “In compliance with 23 CCR 2550.4(d)(1), Subsections A through I, as referenced in SWRCB Resolution 92-49, the Air Force considered the following nine groundwater related environmental factors in evaluating technical and economic feasibility for site cleanup to “background:” We revised the paragraphs following the alphabetical list of environmental factors in Section 3 as follows: “To put the information in this section into perspective, it is important to consider the following background information. Travis AFB uses approximately 3 million gallons of potable water per day (MGD) during the summer and 1 MGD during the winter. The seasonal variation is due to irrigation demands. This water is surface water from Lake Berryessa and Lake Oroville. This water is conveyed to the Travis Water Treatment Plant (TWTP), which is owned and operated by the City of Vallejo, through the Putah South Canal, the Sacramento River, and the North Bay Aqueduct. From this treatment facility, the City of Vallejo provides potable water to the Base. The Base pays the City of Vallejo $20.50 per acre foot of North Bay Aqueduct raw water, $50.00 per acre foot of higher quality Lake Berryessa water (for a yearly average cost of about $77,000), and about $2.8 million per year to treat the water; power, operate, and maintain the TWTP; and deliver sufficient potable water to Travis AFB to meet its consumption requirements. To recoup these costs, the Base charges on-base tenant organizations an average of $3.77 per 1,000 gallons of drinking water. Three (3) currently operable groundwater production wells located at the Cypress Lakes Golf Course annex provide a redundant potable water supply to the Base and historically have only provided water in the event of downtime at the TWTP. These production wells are located approximately 3 miles north of Travis AFB and are hydraulically separate from the Base. To ensure that water is safe to drink, it is disinfected to remove microbial pathogens. This process usually results in the generation of disinfection byproducts (DBPs). Amendments to the SDWA in 1996 required the EPA to develop rules to balance the risks between microbial pathogens and DBPs. The Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR) and Interim Enhanced Surface Water Treatment Rule were the first phase in a rulemaking strategy required by Congress as part of the 1996 Amendments to the SDWA. Currently, the TWTP meets the Stage 1 standards. The Stage 2 DBPR supplements the Stage 1 rule and requires more stringent disinfection monitoring of water systems. Travis AFB is required to initiate these monitoring requirements in October 2012. To fully evaluate the Base’s ability to comply with the Stage 2 DBPR, the Base commissioned a study of the TWTP and the available water resources in the region in 2011.

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		Weston Solutions, Inc. conducted this study and identified the following six (6) alternatives that could be carried out to meet the Stage 2 requirements: • Alternative I – Rehabilitate the Existing TWTP • Alternative II – Construct a New TWTP • Alternative III – Connect to the City of Fairfield Distribution System • Alternative IV – Groundwater Extraction System (i.e., groundwater from the Cypress Lakes Golf Course annex) • Alternative VA – Groundwater Extraction System with New Dry Season TWTP • Alternative VB – David Grant Medical Center Connection to Fairfield with Groundwater Extraction System Following qualitative and quantitative evaluations, the recommended alternative was Alternative IV, which would replace the current water supply provided by the City of Vallejo with source water from the Travis AFB Cypress Lakes Golf Course Annex. The study also considered the installation of groundwater extraction wells within the boundaries of Travis AFB as an alternative to using the Cypress Lakes Golf Course Annex as a water source. The study eliminated this alternative, based on the following rationale: "…wells would be finished in the Fairfield-Suisun Hydrogeologic Basin. This basin is the second largest groundwater basin in Solano County. However, this basin is not used in a significant capacity for domestic supply due to limited alluvial deposits, low yield, and poor water quality. Because of these reasons, this slight variation to the groundwater extraction system alternative has been eliminated from further investigation" (Weston, 2011). The 2011 Water Study Report also concluded that "…the quality of the groundwater from the Cypress Lakes Golf Course Wells is the best available to Travis AFB," that this alternative "…is by far and away the most affordable solution available to Travis AFB," and that "…it is the least expensive alternative at less than one-third the cost of the closest alternative over the next twenty years of water operation" (Weston, 2011). The costs of Alternative IV are much lower than the other alternatives, because much of the infrastructure is already in place, and water originating from the Cypress Lakes Golf Course is high-quality and does not require secondary treatment. Extracted groundwater would be chlorinated prior to distribution to Travis AFB, but no other treatment process would be required for use as drinking water (Weston, 2011). Although a final decision has yet to be made, there is a good probability that the Base will proceed with Alternative IV, along with a new redundant drinking water source to comply with future drinking water quality standards."

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		We revised Section 3.5.3 as follows: “No future use of the groundwater underlying Travis AFB is planned. As described in Section 3, it is likely that the current combination of the City of Vallejo and Cypress Lakes Golf Course Annex water supplies will be entirely replaced by water originating solely from the Cypress Lakes Golf Course Annex, including a new backup water source to provide redundancy.” We extensively revised Section 3.6 to better support the assessment of groundwater at Travis AFB as having low quality. New text sections and a new table were added to compare the concentrations of naturally occurring metals and other inorganic constituents with primary and secondary MCLs and with the City of Vacaville groundwater. We revised added a new last sentence to Section 4.3 as follows: “It is technically feasible to achieve background concentrations at the applicable sites under FFS Alternative 2 – MNA. However, additional remediation time and larger networks of monitoring wells would be required. This assessment assumed that the expanded monitoring well networks will not adversely impact local Base activities or be placed in a restricted area.” We added the following new paragraphs following Table 4-2 in Section 4.4: “This analysis assumes that the GET systems will not reach asymptotic conditions before reaching both MCLs and background levels. Because other Travis AFB GET systems did reach asymptotic conditions during their periods of interim remediation, this assumption may not be valid. It would be technically feasible to expand the GET systems if future performance data indicate this action is warranted. However, the Site SS029 GET system is near an aircraft taxiway and runway. Expansion of this GET system would be difficult to implement, may violate several Federal Aviation Administration regulations, and would likely pose an adverse impact to the military mission of Travis AFB.” We revised Section 4.9 – Summary of the Technical Feasibility of Achieving Background Concentrations as follows: “Overall, it is not technically feasible to clean up most of the contaminated groundwater at Travis AFB to background concentrations. A large volume of contaminated groundwater lies underneath thick layers of concrete that make up active parking ramps, taxiways, and runways (e.g., Site SS016). The expansion of groundwater treatment systems in the vicinity of hangars and other supporting airfield infrastructure can be problematic, depending on the type of activities and the restrictions associated with those structures.

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		For those sites where the achievement of background cleanup levels is technically feasible, the duration of groundwater treatment would have to be extended and/or the scope of treatment would have to be expanded. This expanded treatment requirement would result in the construction of hundreds of additional injection wells and the injection of tens of thousands of gallons of additional carbon substrate. Because many of these additional wells would be physically located in the distal portions of plumes where contaminant concentrations are lower, the amount of contaminant treated per unit volume of injected EVO would decrease, and this treatment approach would become less efficient. The technical feasibility assessment made several assumptions that may not be valid. For those sites that will rely on GET technologies for groundwater cleanup, the assumption is that the treatment systems will not reach asymptotic conditions prior to the achievement of background levels (or even MCLs). However, as contaminant concentrations drop, this becomes a plausible outcome.” We replaced the introductory paragraph to Section 5 as follows: “This section provides evaluations of the economic feasibility of remediating Travis AFB groundwater contamination to background concentrations. These evaluations are developed by combining two (2) approaches. First, economic feasibility is evaluated in consideration of the nine (9) evaluation factors identified in 23 CCR 2550.4(d)(1), Subsections A through I, as described in Section 3. Then, estimates are developed for each remedial alternative and site to quantify the costs that would be required to achieve MCLs and the additional hypothetical costs that would be required to achieve background concentrations.” We also replaced the text of Section 5.1 as follows: **5.1 Overall Economic Feasibility** SWRCB Resolution 92-49, Section III H.1.b.defines the term “economic feasibility” as *“an objective balancing of the incremental benefit of attaining further reductions in the concentrations of constituents of concern as compared with the incremental cost of achieving those reductions. The evaluation of economic feasibility will include consideration of current, planned, or future land use, social, and economic impacts to the surrounding community including property owners other than the discharger. Economic feasibility, in this Policy, does not refer to the discharger's ability to finance cleanup…”* Thus, the costs of cleanup alone, as subsequently described in this section, do not drive an economic feasibility determination. The incremental benefit of cleaning a site’s groundwater to “background” includes an evaluation of the expected benefit of that water considering the nine (9) factors analyzed in Section 3. These evaluations indicate that the incremental costs of achieving a concentration limit less than MCLs is not economically feasible at any site on Travis AFB.

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		5.1.1 Summary of the Key Evaluation Factors The key aspects of the nine (9) 23 CCR 2550.4(d)(1) evaluation factors relevant to an evaluation of economic feasibility are summarized in the following list (more complete descriptions of each evaluation factor are provided in Sections 3.1 through 3.9): • **Environmental Factor A: Physical and Chemical Characteristics of Waste in the Waste Management Unit** (Section 3.1) – Chlorinated VOCs are the most commonly detected dissolved groundwater contaminants. – DNAPLs are likely present in the source zones of Sites SS015, SD036, SD037, and DP039. – TCE is the most prevalent of the chlorinated VOCs detected in the groundwater. – Related chlorinated VOCs, including 1,2-DCA; 1,1-DCE; vinyl chloride; and organochlorine pesticides, primarily alpha chlordane, are also present. • **Environmental Factor B: Hydrogeological Characteristics of the Facility and Surrounding Land** (Section 3.2) – The vast majority of surface deposits are alluvial sediments. This alluvium is composed primarily of fine-grained silt and clay with minor amounts of sand. – The aquifer system should be viewed as a single, leaky and heterogeneous aquifer of unconsolidated alluvium, as opposed to one with multiple and distinct aquifers. – Depth to groundwater is typically 10 to 15 feet bgs. – The alluvial aquifer is relatively thin, with an average saturated thickness of approximately 30 feet. – The silt and clay alluvium has low permeability and does not readily transmit groundwater. Aquifer tests indicate the yield of most remediation extraction wells is between 0.1 and 25 gpm, with an average yield of approximately 4 gpm. – Typical groundwater flow rates are on the order of 100 to 200 feet per year, assuming an effective porosity of 20 percent, which is typical of the fine-grained sediments encountered at the Base.

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		• **Environmental Factor C: Quantity of Groundwater and Direction of Groundwater Flow** (Section 3.3) – Each year, approximately 1,300 gpm (2,100 acre-feet per year) flow through the alluvial aquifer system underlying the Base. The total amount of groundwater stored in the aquifer underlying the Base is approximately 14,300 acre-feet (4.66 billion gallons). – The amount of groundwater stored within the portions of the aquifer contaminated at concentrations greater than or equal to MCLs is about 641 million gallons. Similarly, based on background concentrations, the volume of contaminated groundwater stored in the aquifer is about 932 million gallons. – The regional groundwater flow is consistently towards to south or southeast. Local variations in flow directions are the result of subsurface geology and groundwater pumping conducted as part of interim remediation. • **Environmental Factor D: Proximity and Withdrawal Rates of Groundwater Users** (Section 3.4) – Groundwater underlying Travis AFB is not used for human consumption, agricultural, industrial, or domestic purposes. – Interim remediation of contaminated groundwater has been conducted at multiple sites for over a decade. – During 2011, a total of approximately 60,757,642 gallons of groundwater was extracted, treated, and discharged. A portion of this treated groundwater was derived from off-base extraction well networks. – Historical groundwater extraction rates were higher because of larger scale pumping. – Property adjacent to Travis AFB, south and east, is zoned agricultural and consists exclusively of dry land stock grazing, which does not rely on groundwater. • **Environmental Factor E: Current and Potential Future Uses of Groundwater in the Area** (Section 3.5) – No on-base wells are currently used for potable water production, and none are planned for the future. – Currently, the TWTP, owned and operated by the City of Vallejo, treats raw water from Lake Berryessa and the North Bay Aqueduct to supply the Base with potable water. Three (3) operable groundwater production wells located at the Cypress Lakes Golf Course Annex of Travis AFB provide a redundant water supply capability to the Base. These production wells are located approximately 3 miles north of Travis AFB and are hydraulically separate from the Base.

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		– Current seasonal water consumption at the Base ranges from approximately 3.13 MGD in the summer to 1.02 MGD in the winter (Weston, 2011). – During 2011, the Air Force Civil Engineer Support Agency (AFCESA) issued a report that documented the results of a water study and analyses to evaluate alternatives to the Base's current water supply. Six (6) alternatives were evaluated as part of the study (Weston, 2011). – The 2011 report recommended Alternative IV, which would replace the current water supply provided by the City of Vallejo with source water drawn exclusively from the Travis AFB Cypress Lakes Golf Course Annex. – A variation of Alternative IV considered installation of groundwater extraction wells within the boundaries of Travis AFB. However, this variation was eliminated because the report concluded the following: "…wells would be finished in the Fairfield-Suisun Hydrogeologic Basin. This basin is the second largest groundwater basin in Solano County. However, this basin is not used in a significant capacity for domestic supply due to limited alluvial deposits, low yield, and poor water quality. Because of these reasons, this slight variation to the groundwater extraction system alternative has been eliminated from further investigation" (Weston, 2011). – There are no plans to use groundwater from the aquifer underlying Travis AFB. It is likely that the recommendations of the 2011 water study and analysis report will be adopted (Weston, 2011). In the future, production wells at the Cypress Lakes Golf Course Annex may supply all the potable water to the Base along with a new source of redundant water supply. Regardless, no use of the aquifer underlying Travis AFB is planned. • **Environmental Factor F: Existing Quality of Groundwater, Including Other Sources of Contamination or Pollution and Cumulative Impact on Groundwater Quality** (Section 3.6) – Groundwater contamination is the result of historical waste management and disposal practices. These practices have been discontinued. – There are no current sources of groundwater contamination from on-base activities. – There are no known off-base sources of contamination that are affecting the on-base groundwater quality. – A variety of naturally occurring metals are present at Travis AFB with many of them historically measured at concentrations exceeding MCLs. – Concentrations of TDS exceed 3,000 mg/L at multiple locations/dates across the Base. A provision in SWRCB Resolution 88-63 – Sources of Drinking Water, Item 1a. states that such concentrations are "not reasonably expected by Regional Boards to supply a public water system."

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		– Primary MCLs are exceeded for naturally occurring, non-contaminant parameters including fluorides, nitrate, nitrite, sulfate, and turbidity. Secondary MCLs are exceeded for conductivity, pH, sulfate, TDS, and turbidity. – On-base groundwater quality has been degraded by the presence of chlorinated VOCs and organochlorine pesticides. Within multiple plumes, these contaminants are present at concentrations exceeding primary Federal and California MCLs. • **Environmental Factor G: Potential Health Risks Caused by Human Exposure to Waste Constituents** (Section 3.7) – Human health risk assessments were conducted for all groundwater sites to determine the need for remedial action. – After approximately a decade of interim remediation, the concentrations of COCs have decreased, but still exceed MCLs within most plumes. – There are no current receptors of contaminated groundwater. Travis AFB has established land use controls to ensure that the exposure pathways to on-base workers and off-base residents are incomplete. • **Environmental Factor H: Potential Damage to Wildlife, Crops, Vegetation, and Physical Structures Caused by Exposure to Waste Constituents** (Section 3.8) – No risks are posed to animal or plant receptors because of the depth to contaminated groundwater. – There is no agricultural production at Travis AFB. Grazing management units rely on rainfall and are not irrigated using extracted groundwater. – No potential damage to physical structures is anticipated from exposure to contaminated groundwater. • **Environmental Factor I: Persistence and Permanence of Potential Adverse Effects** (Section 3.9) – The aquifer is typically aerobic and not readily conducive to degradation of chlorinated VOCs such as TCE. – Remediation times for the various plumes to achieve MCLs are forecast to range from 5 to greater than 100 years. – Remediation times to achieve background concentrations are greater than for MCLs and range from 43 to greater than 100 years.

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		These factors, along with estimates of the costs required to achieve MCLs and the additional costs required to achieve background concentrations, are the bases for the evaluation of economic feasibility. **5.1.2 Value Assessment of Travis AFB Groundwater** The overall premise behind State Resolution 92-49 is that all waters of the State have value, so this assessment quantifies the value of the drinking water that Travis AFB uses each year and then compares it with the cost to extract and treat Travis AFB groundwater to drinking water standards. If the value of the water that is supplied to the Base exceeds the cost to use Travis AFB groundwater as a drinking water source, then the aquifer underlying the Base has untapped value. If the cost to extract and treat groundwater exceeds the value of the drinking water that is supplied by the City of Vallejo, then the Base aquifer is of little or no value. Before the groundwater underlying Travis AFB can acquire value, it must be available for use as a potable water supply. Currently, the water used at Travis AFB is surface water from Lake Berryessa and the North Bay Aqueduct. From these sources, it is conveyed to the TWTP, which is owned and operated by the City of Vallejo. From this treatment facility, the City of Vallejo currently provides potable water to the Base. Three (3) groundwater production wells located at the Cypress Lakes Golf Course Annex currently provide a redundant source of potable water supply. These production wells are located approximately 3 miles north of Travis AFB and are hydraulically separate from the Base. Section 3 states the water usage at Travis AFB, including seasonal impacts and the costs of that water. However, the Base's budget for FY11/12 for water is in excess of $2.8 million; $77,000 of this budget is spent on raw water. As will be shown in the following sections, the construction of a groundwater extraction system to meet the Base water needs is both technically and economically infeasible. Even after treating groundwater to remove COCs, additional treatment would be required to use it as drinking water. Also, the use of this aquifer as a partial source of drinking water (similar to the Cypress Lakes Golf Course Annex) would require the construction of an on-base water treatment system to remove naturally occurring chemicals and disinfect the water. Construction of a treatment plant and supporting infrastructure may be impossible because of the acreage requirements and impact on Base activities, and its construction and operation costs would be prohibitively expensive. In consideration of the key evaluation factors summarized above, as provided in 23 CCR Section 2550.4(d)(1), and the current and zoned land use, social, and economic impacts to the surrounding community, including the adjacent property owners, the groundwater underlying Travis AFB has no value, and there is no economic benefit to continuing remediation beyond MCLs to achieve background concentration levels.

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		5.1.3 Water Study and Analysis Report Findings As described in Section 3, Travis AFB commissioned a study of the TWTP and the available water resources in the region in 2011 to assist with the decision on how to meet more stringent drinking water system monitoring requirements. Some of the analyses from this study are also relevant to the evaluations of economic feasibility conducted in the TEFA and supplement the analyses of the costs required to remediate to MCLs and the additional costs to remediate to background. In summary, the water study identified corrective actions that could be taken to address DBP exceedances in the existing Travis AFB water distribution system (Weston 2011). Six (6) different alternatives were evaluated as part of the study. These alternatives included the following: • Alternative I – Rehabilitate the Existing TWTP • Alternative II – Construct a New TWTP • Alternative III – Connect to the City of Fairfield Distribution System • Alternative IV – Groundwater Extraction System (i.e., groundwater from the Cypress Lakes Golf Course Annex) • Alternative VA – Groundwater Extraction System with New Dry Season TWTP • Alternative VB – David Grant Medical Center Connection to Fairfield with Groundwater Extraction System Following qualitative and quantitative evaluations, the recommended alternative was Alternative IV, which would replace the current water supply provided by the City of Vallejo with source water from the Travis AFB Cypress Lakes Golf Course Annex. The study also considered a variation on the alternative of using the Cypress Lakes Golf Course Annex as a source of water. This variation considered the installation of groundwater extraction wells within the boundaries of Travis AFB. However, this variation was eliminated because the report concluded the following: "…wells would be finished in the Fairfield-Suisun Hydrogeologic Basin. This basin is the second largest groundwater basin in Solano County. However, this basin is not used in a significant capacity for domestic supply due to limited alluvial deposits, low yield, and poor water quality. Because of these reasons, this slight variation to the groundwater extraction system alternative has been eliminated from further investigation" (Weston, 2011). This conclusion is consistent with the technical feasibility evaluations conducted as part of this TEFA.

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		In terms of economic feasibility, the 2011 water study report also concluded that "…the quality of the groundwater from the Cypress Lakes Golf Course Wells is the best available to Travis AFB," and that this alternative "…is by far and away the most affordable solution available to Travis AFB," and "…it is the least expensive alternative at less than one-third the cost of the closest alternative over the next twenty years of water operation" (Weston, 2011). The estimated capital cost for Alternative IV is $9,310,000, with annual O&M costs of $1,481,000 and a present value through 2030 of $30,700,000. These costs are much lower than the other alternatives, because much of the infrastructure is already in place and water originating from the Cypress Lakes Golf Course Annex is high quality and does not require secondary treatment. Extracted groundwater would be chlorinated prior to distribution to Travis AFB, but no other treatment process would be required for use as drinking water (Weston, 2011). **5.1.3.1 Hypothetical Use of the Travis AFB Aquifer** The relevant conclusions of the 2011 water study (Weston, 2011) are consistent with the TEFA evaluations of economic feasibility. In order to hypothetically supply potable water at the current 3.13 MGD summer demand rate with on-base production wells, at an average sustained pumping rate of 4 gpm, approximately 523 wells, associated conveyance pipelines, and a centralized treatment facility with a capacity of at least 3.13 MGD would be required. Construction of such a water supply system for the low-yield and low-quality aquifer at Travis AFB is both technically and economically infeasible. Even if it is assumed that enough extraction wells could be installed in the low-yield aquifer to supply 3.13 MGD, the cost of the required secondary treatment plant would be similar to that evaluated under Alternative II in the 2011 water study and analysis report. Under that alternative, a new off-base treatment plant would have capital costs of approximately $51,166,000, annual O&M costs of $3,530,000, and a present value cost through 2030 of $101,800,000 (Weston, 2011). However, even these cost-prohibitive estimates are entirely hypothetical because, in reality, the predominantly silt and clay alluvial aquifer could probably not supply the current demand of 3.13 MGD and is even less likely capable of providing the estimated future demand of 4.72 MGD in 2030. The costs for secondary treatment would be in addition to the remedial alternative costs described in Section 5.2, because treating COC-contaminated groundwater to MCLs or background would not be adequate for human consumption. Additional treatment of this water would be needed to make it available for use as drinking water because of the presence of naturally occurring chemicals that exceed primary and/or secondary MCLs (e.g., nitrate, nitrite, sulfate, and TDS). These secondary treatment costs would have to be incurred before an economic benefit for the groundwater could be realized. These extensive treatment requirements are cost-prohibitive when considering the cost-effectiveness of using water from the Cypress Lakes Golf Course Annex (Weston, 2011).

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		5.1.3.2 Hypothetical Use of Remediation Groundwater Conclusions regarding the economic infeasibility of utilizing groundwater in the Travis AFB aquifer are further supported if only the volume of groundwater extracted by remediation efforts is considered. Site-specific COCs are currently removed from this extracted groundwater by the three (3) existing treatment plants operating at the Base (i.e., the CGWTP, NGWTP, and SBBGWTP). The existing three (3) treatment plants have maximum design capacities of 616 gpm (0.89 MGD), but have historically operated at total maximum rate of approximately 323 gpm (0.46 MGD, or 52 percent of total capacity). The 2011 Water Study Report (Weston, 2011) evaluated the construction of a new off-base 4.72 MGD capacity TWTP under Alternative II. In actuality, Travis AFB would be required to build a new TWTP on-base because of security protection reasons and decommissioning of the old plant, which would result in a slight increase to the cost of this alternative. Construction of a similar, but scaled-down, on-base facility to treat a total remediation system design capacity flow rate of 616 gpm (0.89 MGD) for use as drinking water would have proportional capital costs of approximately $14,459,000, annual O&M costs of $1,004,000, and a present value cost through 2030 of approximately $28,946,000. These cost-prohibitive estimates are also entirely hypothetical, because the Base does not currently have the infrastructure to collect all extracted water from the three (3) treatment plants to one (1) location and does not have the acreage to construct a new water treatment and disinfection facility. Also, the costs for secondary treatment would be in addition to the remedial alternative costs described in Section 5.2, because the treatment of COC-contaminated groundwater to MCLs or background would not be adequate for human consumption. These additional costs for secondary treatment would need to be incurred before an economic benefit for use as drinking water could be realized.” We added the following new reference to Appendix B – References: “Weston. 2011. *Travis Air Force Base Water Study and Analysis – Final Report.* Department of the Air Force, Travis AFB, California. Contract #FA8903-08-D-8784, Task Order #SK04. June.” We also revised the first paragraph in Section 5.3- Economic Feasibility of Achieving Background Concentrations under Alternative 2 – MNA as follows: “It is not economically feasible to achieve background concentrations at the applicable sites under FFS Alternative 2 – MNA. The economic feasibility analysis in Section 5.1 above demonstrates the additional remediation costs detailed below in achieving background at these sites achieve no economic benefit.”

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		Similarly, we revised the first paragraph in Section 5.4- Economic Feasibility of Achieving Background Concentrations under Alternative 3 – GET as follows: "It is not economically feasible to achieve background concentrations at the applicable sites under FFS Alternative 3 – GET. The economic feasibility analysis in Section 5.1 above demonstrates the additional remediation costs detailed below in achieving background at these sites achieve no economic benefit." We added the following last sentence to the first paragraph of Section 5.5 - Economic Feasibility of Achieving Background Concentrations under Alternative 5 – EVO and EA: "The economic feasibility analysis in Section 5.1 above demonstrates the additional remediation costs detailed below in achieving background achieve no economic benefit." And, we added the following last sentence to the first paragraph of Section 5.6 - Economic Feasibility of Achieving Background Concentrations under Alternative 6 – Bioreactor, Phytoremediation, EVO PRB, and EA: "Further, the economic feasibility analysis in Section 5.1 above demonstrates the additional remediation costs detailed below in achieving background achieve no economic benefit." We revised Section 5.9 – Summary of Economic Feasibility as follows: "From a basewide perspective, achieving background contaminant concentrations by extending the duration of remediation and/or expanding the scope of remediation is not economically feasible. SWRCB Resolution 92-49, Section III H.1.b.defines the term "economic feasibility" as *"an objective balancing of the incremental benefit of attaining further reductions in the concentrations of constituents of concern as compared with the incremental cost of achieving those reductions. The evaluation of economic feasibility will include consideration of current, planned, or future land use, social, and economic impacts to the surrounding community including property owners other than the discharger. Economic feasibility, in this Policy, does not refer to the discharger's ability to finance cleanup…"* Thus, the costs of cleanup alone do not drive an economic feasibility determination. The incremental benefit of cleaning a site's groundwater to "background" includes an evaluation of the expected benefit of that water considering the nine (9) factors analyzed in Section 3 and the factors mentioned above. In full consideration of these factors, no economic benefit would be realized by cleaning up the groundwater underlying Travis AFB to background concentrations. Further, the aquifer underlying Travis AFB could not provide a sufficient volume of groundwater to meet the needs of the Base even if it were of acceptable quality in terms of primary and secondary MCLs. Aquifer tests conducted at the various ERP sites indicate the yield of most extraction wells is between 0.1 and 25 gpm, with an average yield of approximately 4 gpm. Current seasonal water consumption at the Base ranges from approximately 3.13 MGD in the summer to 1.02 MGD in the winter (Weston, 2011). In comparison, the maximum amount of

<table>
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<tr><td></td><td></td><td>groundwater extracted from the aquifer during ongoing interim remediation efforts was approximately 349 gpm (0.5 gallons per day), or approximately 16 percent of the current summer demand. To hypothetically supply the 3.13 million MGD summer demand with on-base production wells, at an average sustained pumping rate of 4 gpm, would require approximately 523 wells, associated conveyance pipelines, and a centralized treatment facility with a capacity of at least 3.13 MGD. Installation of 523 extraction wells across Travis AFB is technically infeasible. If uniformly distributed, one (1) extraction well would be required for approximately each 10 acres of land surface. This density of wells, and the associated conveyance pipelines, could not be installed without serious adverse impacts to the military mission of the Base and is not technically feasible.

Even if the required number of extraction wells could be installed, secondary treatment would be required in addition to the scope of expanded remedial alternatives. This is because treating COC-contaminated groundwater to MCLs or background would not be adequate for human consumption. Additional treatment of this water would be needed to make it available for use as drinking water because of non-COCs exceeding primary and/or secondary MCLs (e.g., nitrate, nitrite, sulfate, and TDS). Construction of such an extraction, conveyance, and treatment water supply system for the low-yield and low-quality aquifer at Travis AFB contributes toward the finding of technical infeasibility, especially in consideration of the existing high-quality municipal water supply already being provided to the Base.”

We also added the following last sentence to the first paragraph of Section 6.3 – Key Aspects of Economic Feasibility: “The key aspect in assessing economic feasibility is included in SWRCB Resolution 92-49. Specifically, SWRCB Resolution 92-49, Section III H.1.b.defines the term “economic feasibility” as

“an objective balancing of the incremental benefit of attaining further reductions in the concentrations of constituents of concern as compared with the incremental cost of achieving those reductions. The evaluation of economic feasibility will include consideration of current, planned, or future land use, social, and economic impacts to the surrounding community including property owners other than the discharger. Economic feasibility, in this Policy, does not refer to the discharger's ability to finance cleanup…”

Thus, the costs of cleanup alone do not drive an economic feasibility determination. The incremental benefit of cleaning a site’s groundwater to “background” includes an evaluation of the expected benefit of that water considering the nine (9) factors analyzed in Section 3 and the factors mentioned above. In full consideration of these factors, no economic benefit would be realized by cleaning up the groundwater underlying Travis AFB to background concentrations.”

To further support the evaluation of economic feasibility, we also extensively revised the cost summary tables in Section 5 – Analysis of Economic Feasibility and the more detailed cost information provided in Appendix C – Cost Estimates.</td></tr>
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3	The TEFA appears to bias its overall conclusion that meeting lower groundwater concentrations are infeasible by considering only the feasibility of expanding existing treatment for every site, which is clearly infeasible for several sites. The TEFA also states, however, that for many sites, extending the operating time of the current remedial alternative will achieve lower groundwater concentrations. For many sites, the additional time is not significantly greater than that required to achieve the MCL, nor is the present value of the additional expenses much greater. The TEFA also forecloses the option of running the current remedial alternatives for longer periods of time by stating that The determining factors for technical and economic feasibility are related to the required scope of expanded groundwater treatment. This summary is therefore focused on the technical and economic issues relevant to hypothetically expanding treatment systems. This statement effectively preempts any further evaluation.	We revised the statement in the second paragraph of Section 6 – Summary of Technical and Economic Feasibility Analyses, cited in the comment, as follows: “The determining factors for technical and economic feasibility are related to the duration of remediation and/or the required scope of expanded groundwater treatment. This summary is therefore focused on the technical and economic issues relevant to hypothetically expanding treatment systems or extending the duration of remedial action.” The TEFA evaluations include the feasibility of expanding treatment and also include the option of running the current alternatives for longer periods of time. • For sites under Alternative 2 – MNA, the times required to achieve MCLs and the additional times required to achieve background are summarized in Table 4-1. No expansion of treatment is evaluated for MNA because no treatment process is employed. • For sites under Alternative 3 – GET, the times required to achieve MCLs and the additional times required to achieve background are summarized in Table 4-2. No expansion of treatment is evaluated for the GET systems, because no in situ treatment process is employed and the existing GET systems are the most appropriate remediation technology for the conditions at Sites LF007C, SS029, and SS030. • For Site SS016 under Alternative 4 – Bioreactor and GET, the time required to achieve MCLs and the additional time required to achieve background using the current interim remedial action is described in Section 4.5.1 and summarized in Table 4-3 (both times are > 100 years). Two (2) scenarios for the hypothetical expansion of bioreactor treatment are discussed in Sections 4.5.2 and 4.5.3. Additionally, hypothetical treatment using EVO injection in lieu of an expanded bioreactor is also evaluated in Section 4.5.3. • For Sites SS015 and the WIOU (including Sites SD037 and SD037), under Alternative 5 – EVO and EA, the time required to achieve MCLs and background using the current interim remedial action are summarized in Table 4-5. For these analyses, the time to achieve MCLs and background are held equal (i.e., based on the time to achieve MCLs) and the required extent of expanded hypothetical treatment using EVO injection is evaluated under this time constraint. • For Site DP039 under Alternative 6, the time required to achieve MCLs and background using the current interim remedial action are summarized in Table 4-6. For these analyses, the time to achieve MCLs and background are held equal (i.e., based on the time to achieve MCLs) and the required extent of expanded hypothetical treatment using another EVO PRB is evaluated under this time constraint.

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		Generally, as the operating time for a remedial alternative increases, the uncertainty associated with its long-term operations and maintenance also increases. For example, the treatment systems associated with the current interim remedies require a greater amount of maintenance and repair/replacement, and this trend is expected to continue and get worse over time. It is impossible to model the result of a system breakdown and its impact on the progress toward achieving cleanup levels, but the probability for this to occur over time increases. So, the option of running the current remedial alternatives for longer periods is likely to be cost prohibitive and increases the potential for failure to achieve the desired cleanup levels. That leaves the option of increasing the areal extent of the active remedy, because this reduces the mass of the dissolved contaminant that has to be removed through natural attenuation and increases the likelihood that natural processes will be able to reach MCLs and continue to background levels.

Attachment D-1

California Regional Water Quality Control Board
San Francisco Bay Region

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Edmund G. Brown Jr.
Governor

May 4, 2012
File No. 2129.2047
CIWQS Place ID 268603

U.S. Air Force
Attn Mark H. Smith,
Chief, Environmental Restoration
60 CES/CEANR
411 Airmen Dr.
Travis AFB CA 94535-2001

Subject: Water Board Staff comments, Revised Draft Basewide Groundwater Technical and Economic Feasibility Analysis (TEFA)

Dear Mr. Smith:

This letter contains Water Board staff's final comments on the subject document and subsequent response to comments. The draft version of the TEFA was dated December 15, 2011 and we submitted comments dated January 31, 2012. The Air Force then submitted a Response to Comments dated March 19, 2012, to which we responded on April 13, 2012. Lastly, the Air Force responded again on April 17, 2012.

Water Board staff have been supportive of using the State of California maximum contaminant levels for drinking water (MCLs) as a general guidepost for clean-up, but continue to maintain that SWRCB Resolution 92-49 requires Travis to justify why it cannot clean-up sites to the background level. Thus we required the submission of the TEFA and the TEFA revisions.

Water Board staff concur with the TEFA as revised by the Air Force comments of April 17, 2012 and find them complete. Staff also concur with the revisions of Section 4.9 of the TEFA which state that "overall it is not technically feasible to achieve cleanup of all contaminated groundwater at Travis AFB to background concentrations" and that "the Air Force has agreed to ARARs in the focused Feasibility Study to be carried forward to the Record of Decision that will clean up all contaminated groundwater on Travis AFB to risk-based MCLs and does not consider a groundwater remedial action to be complete until the MCL for each COC is achieved."

Finally, Water Board staff also concurs with the revisions of Section 5 of the TEFA which state that "an economic analysis of a groundwater remediation that targets a cleanup level that cannot be technically achieved is problematic. An economic feasibility determination for the groundwater beneath Travis AFB would not provide any useable information to support the selection of groundwater cleanup levels. The Air Force and the Water Board have discussed this issue and agreed that the technical feasibility evaluation as described in Section 4 is sufficient to meet the requirements of SWRCB Resolution 92-49."

If you should have any questions, please feel free to contact me at (510) 622-2347 or by email at afriedman@waterboards.ca.gov.

Sincerely,

Alan D. Friedman
2012.05.04
08:42:16 -07'00'

Alan D. Friedman, P.E.

Water Resource Control Engineer