Draft RCRA Facility Groundwater Remedial Investigation Report Area IV

Santa Susana Field Laboratory Ventura County, California

Prepared for:

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Prepared under:
US Department of Energy, EM Consolidated Business Center
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August 2018

Draft RCRA Groundwater Facility Investigation Report (GW RFI) Area IV Santa Susana Field Laboratory Ventura County, California

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Acronyms and Abbreviations

1,1-DCE	1,1-dichloroethene
1,2-DCE	1,2-dichloroethene
<	less than
aka	also known as
AEC	Atomic Energy Commission
AI	Atomic International
Am	americium
amsl	above mean sea level
AOC	Areas of Concern
ASER	Annual Site Environmental Report
AST	Above ground storage tank
Ba	barium
BEDMS	Boeing Environmental Data Management System
bgs	below ground surface
Boeing	The Boeing Company
BTV	background threshold value
BVE	Bedrock Vapor Extraction
C-8	Corehole-8
$CaCO_3$	calcium carbonate
CDM Smith	CDM Federal Programs Corporation
CHHSL	California Human Health Screening Levels
cis-1,2-DCE	cis-1,2-dichloroethene
Cl	chloride
Cm	curium
CMS	Corrective measures study
cm/s	centimeters per second
Co	cobalt
CO	Consent Order
COC	contaminant of concern
CO_2	carbon dioxide
Cs	cesium
CSIA	Compound Specific Isotope Analysis
CSM	conceptual site model
DCE	dichloroethene
Dhc	*Dehalococcoides spp.*
DL	detection limit
DNAPL	Dense non-aqueous phase liquid
DO	dissolved oxygen
DOE	United States Department of Energy
DRH	Diesel range hydrocarbons
DTSC	Department of Toxic Substances Control
EFH	Extractable Fuel Hydrocarbons
EIS	environmental impact statement
EPA	United States Environmental Protection Agency
ESADA	Empire State Atomic Development Authority
ETEC	Energy Technology Engineering Center
Eu	Europium

EV	Electron volt
F-	Fluoride
FAL	Field Action Level
FEHM	Finite Element Heat and Mass Transfer Code
FLUTe™	Flexible Liner Underground Technologies
FSDF	Former Sodium Disposal Facility
FS Work Plan	Feasibility Study Work Plan
ft	feet or foot
ft/ft	foot per foot
GETS	groundwater extraction treatment system
GIA	Groundwater Investigation Area
GIS	Geographic Information System
gpd	gallons per day
gpm	gallons per minute
GRH	Gasoline range hydrocarbons
GRC	Groundwater Resources Consultants
GSU	Geologic Services Unit
Guelph	University of Guelph
GWIM	groundwater interim measure
HEPA	high efficiency particulate air
HGL	Hydrogeologic Inc.
HMSA	Hazardous Materials Storage Area
HWMF	Hazardous Waste Management Facility
K	potassium
K_b	bulk hydraulic conductivity
KEWB	Kinetics Experiment Water Boiler
K_m	hydraulic conductivity
LAGriT	Los Alamos Grid Tool Box
LANL	Los Alamos National Laboratory
LMEC	Liquid Metals Engineering Center
MCL	maximum contaminant level
µg/kg	microgram per kilogram
µg/L	microgram per liter
umho/cm	microhoms per centimeter
MCP	Maximum concentration permissible
MDC	minimum detectable concentration
me/L	millimole per liter
mg/L	milligram per liter
mg/kg	milligram per kilogram
mL/g	milliliters per gram
Mn	manganese
Mn-54	Manganese-54
MNA	monitored natural attenuation
MSL	Mean sea level
MWH	MWH Americas, Inc.
NASA	National Aeronautics and Space Administration
NBZ	Northern Buffer Zone
NCY	New Conservation Yard
ND	non-detect
NDMA	N-nitrosodimethyamine

NO_2	nitrite
NO_3	nitrate
NORM	naturally occurring radioactive material
OCY	Old Conservation Yard
OEHHA	Office of Environmental Health Hazard Assessment
ORP	oxidation reduction potential
OS	off-site
OSWER	Office of Solid Waste and Emergency Response
%	percent
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PCR	polymerase chain reaction
pCi/g	picocuries per gram
pCi/L	picocuries per liter
PDU	Process Development Unit
pg/L	picogram per liter
PHG	Public Health Goal
ppb	parts per billion
PQL	Practical quantification limit
Pu	plutonium
PZ	piezometer
RBSL	Risk-based screening level
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
RI	Remedial Investigation
RIHL	Rockwell International Hot Laboratory
RMHF	Radioactive Materials Handling Facility
RPT	reaction products tank
RTL	Reference Threshold Level
SAP	Sampling and Analysis Plan
SCTI	Sodium Component Testing Installation
SCTL	Sodium Component Testing Laboratory
Shall Drill	Shaw Portable Core Drill
Sn	tin
SNAP	Systems Nuclear Auxiliary Power
Sr-90	Strontium-90
SRE	Sodium Reactor Experiment
SSFL	Santa Susana Field Laboratory
SSME	Space Shuttle Main Engine
SVOCs	semi-volatile organic compounds
SWMU	solid waste management unit
TCA	trichloroethane
TCE	Trichloroethene
TDS	total dissolved solids
Te	tellurium
Th	thorium
TOC	total organic carbon
TPH	total petroleum hydrocarbon
U	Uranium

U-235	Uranium-235
U_3O_8	Uranium oxide
UCL	upper confidence limit
USDA	US Department of Agriculture
UST	underground storage tank
VC	vinyl chloride
VOCs	volatile organic compounds
WBNS	Water Boiler Neutron Source
WQSAP	Water Quality Sampling and Analysis Plan

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Section 1

Introduction

This Resource Conservation and Recovery Act (RCRA) Groundwater Facility Investigation (GW RFI) Report addresses the findings of groundwater investigations performed by the United States Department of Energy (DOE) for its responsible sites and locations within Area IV of the Santa Susana Field Laboratory (SSFL). The report has been revised from the June 16, 2017 Preliminary Draft (CDM Smith 2017b) based on comments received from the California Department of Toxic Substances Control (DTSC) on March 26, 2018. Those comments and the responses to how the Preliminary Draft has been revised are included in Appendix F of this report.

This GW RFI Report documents the findings from numerous investigations within Area IV, in addition to studies performed in accordance with the Area IV GW RFI Work Plan (CDM Smith 2015a) and Field Sampling Plan Addenda (CDM Smith 2017c, and 2018a). The RFI Report has been prepared to meet the requirements of the California DTSC per the 2007 Consent Order on Corrective Action (CO) (DTSC 2007). The report was completed by CDM Federal Programs Corporation (CDM Smith) under contract DE-EM0001128, task order DE-DT0003515, with DOE.

1.1 Purpose and Scope of DOE Area IV Groundwater RFI Report

This report summarizes and evaluates historic and current data and site conditions using the extensive database that ultimately will support development of the recommendations for the groundwater remediation that will be addressed in the subsequent Corrective Measures Study (CMS). The report evaluates investigative data collected through mid-year 2018. The investigative findings presented in this document are for the DOE responsible activities within Area IV and represent partial completion of the overall Groundwater GW RFI for SSFL. The site-wide RFI will ultimately be completed for multiple locations within SSFL as a combined effort of The Boeing Company (Boeing; Areas I, III, and IV), the National Aeronautics and Space Administration (NASA; Areas I and II), and DOE (Area IV) with each participant completing activities for their respective responsibilities.

This GW RFI Report only documents the results of investigative activities for locations under DOE responsibility for Area IV [at SWMUs and Areas of Concern for Area IV as presented in Attachment 4 of the 2007 CO]. Area IV groundwater investigation and cleanup responsibilities have been divided per the 2007 CO to be implemented by DOE and Boeing. DOE has also accepted responsibility for the investigation of the tritium plume that was not specifically designated in the 2007 CO. **Figure 1-1** shows specific locations of the divided responsibilities and **Table 1-1** provides a listing of the Area IV groundwater investigation responsibilities per Attachment 4 of the 2007 CO along with a summary of groundwater conditions at each groundwater investigation area (GIA). Within Table 1-1, wells are associated with their adjacent GIA, although it is recognized that any well could monitor more than one GIA. Attachment 4 of the CO names the solid waste management units (SWMUs) and leach fields (also termed Areas of

Concern) and identifies either DOE, NASA, or Boeing with the lead in investigation. Boeing and NASA will be reporting results separately for areas under their responsibilities.

Site investigation work conducted by DOE in Area IV in 2014 to 2018 was also performed to address deficiencies noted by the DTSC in the 2009 Groundwater RI Report (MWH 2009a). These issues include completion of source characterization, further definition of the nature and extent of groundwater contamination, evaluation of seeps and springs as contaminant pathways, evaluation of faults as controlling factors for plume migration, and flow and transport modeling supporting the conceptual site model (CSM). This DOE Area IV GW RFI Report is also based on discussions between DOE and DTSC relative to groundwater data gaps and data needs for completion of site characterization.

Trichloroethene (TCE) is the most frequently reported groundwater contaminant in Area IV groundwater. Tetrachloroethylene (PCE) is the primary groundwater contaminant at Buildings 4059/4057/4626 Systems Nuclear Auxiliary Power (SNAP) and support facilities. The solvent 1,1,1-trichloroethane (1,1,1-TCA) is found only at the Former Sodium Disposal Facility (FSDF). Perchlorate was historically present at the FSDF area. Other groundwater contaminants [beyond tritium and strontium-90 [Sr-90]] observed in groundwater above the groundwater reference values[1] include the metals cadmium, copper, molybdenum, nickel, and selenium. Localized areas of petroleum and nitrate contamination are also present.

Table 1-1. Relationship of Groundwater Investigation Area Responsibilities with 2007 Consent Order

Area IV Location	2007 CO[1] Responsibility	Associated Wells[2]	Notes
Building 56 Landfill (WQSAP GIA #16)[3]	DOE SWMU 7.1	PZ-124, RS-16, RD-07, RD-74, DD-143	Bedrock groundwater impacted by TCE up to 52 µg/L.
Building 4133 HWMF	DOE SWMU 7.2	RS-25, RD-19	RCRA Permit Closure; no identified groundwater impact.
FSDF Building 4886 (WQSAP GIA #17)	DOE SWMU 7.3	RS-18, RS-54, PZ-098, PZ-100, RD-21, RD-22, RD-23, RD-33A, RD-33B, RD-33C, RD-54A, RD-54B, RD-54C, RD-57, RD-64, RD-65, DS-46, DD-139, DD-140	Impacted by TCE and perchlorate, concentrations of TCE up to 1,600 µg/L in shallow wells, 230 µg/L in deeper wells. Perched groundwater zone not present in 2015 and 2016.
Old Conservation Yard, Container Storage Area, and Fuel Tanks	DOE SWMU 7.4	PZ-151, RD-14, WS-07	Low detections of TCE.
Building 4100 Trench	DOE SWMU 7.5	RD-20	No identified groundwater impact.
RMHF (WQSAP GIA #13)	DOE SWMU 7.6 Leach field AI-Z5[4]	RS-28, RD-19, RD-27, RD-30, RD-34A, RD-34B, RD-34C, RD-63, RD-98, DD-143	RCRA Permit Closure; Shallow and bedrock groundwater impacted by TCE up to 11 µg/L. Sr-90 at 33 pCi/L at the RMHF leach field site. Leach field removed; site partially remediated.
Building 4020 – Rockwell International Hot Lab	DOE SWMU 7.7	RD-13, PZ-103	Low concentrations of TCE in PZ-103 (<5 µg/L) may be associated with Building 4020 leach field

[1] Groundwater reference values are comparison water quality concentration limits used to assess whether a measured contaminant concentration is indicative of a chemical or radionuclide of concern.

Table 1-1. Relationship of Groundwater Investigation Area Responsibilities with 2007 Consent Order

Area IV Location	2007 CO[1] Responsibility	Associated Wells[2]	Notes
Tritium Plume - Buildings 4010 to 4059 Systems Nuclear Auxiliary Power (SNAP) Facilities DOE Leach field 2 (AI-Z7) (WQSAP GIA #14)	DOE Leach Field AI-Z6 and AI-Z7	RD-87, RD-88, RD-89/DD-147, RD-90, RD-93, RD-94, RD-95	Bedrock groundwater impacted by tritium up to 40,000 pCi/L (2014). Strong downward trend in tritium concentrations observed since 2008. Leach fields removed; may not be tritium source.
New Conservation Yard	Boeing SWMU 7.8	PZ-055, PZ-113, PZ-114, PZ-115, RD-15, RD-92	No identified groundwater impact.
ESADA Chemical Storage Yard	Boeing SWMU 7.9	-	See Boeing GW RI Report for wells associated with ESADA (Boeing & MWH 2017)
Building 4005/4006 Coal Gasification PDU	Boeing SWMU 7.10 Leach Field AI-Z8	PZ-041, PZ-122, RD-29, RS-27	Co-located with HMSA; perched groundwater impacted by TCE. Leach field removed.
Building 4029 Reactive Metals Storage Yard	DOE SWMU 7.11	No wells.	RCRA Permit Closure with Building 4133 (HWMF) SWMU 7.2 (above)
Buildings 4059/4057/4626 Systems Nuclear Auxiliary Power (SNAP) and support facilities	DOE SWMU 7.12[5]	PZ-109, RD-24, RD-25 (abandoned), RD-28 (abandoned), RD-96, RD-97, DS-43, DD-142	Source may be Building 4626; Bedrock groundwater impacted by low concentration of TCE and PCE.
Southeast Drum Yard Area	Boeing SWMU 7.12 Leach Field AI-Z9	ES-31, PZ-051, PZ-052, PZ-106, PZ-107, PZ-110, PZ-111, PZ-112, RS-11, RD-24, RD-16	Sporadic detections of TCE below 1 µg/L.
SRE Complex Area	Boeing SWMU 7.12 Leach field AI-Z1	PZ-150, PZ-160, PZ-161, RS-25, RS-36, RD-18, RD-19, RD-85, RD-86, RD-102	Sporadic detections of TCE below 1 µg/L; leach field removed.
Building 4065 (Metals Clarifier Laboratory) and DOE Leach Fields	DOE SWMU 7.12 Leach fields AI-Z10, AI-Z12, AI-Z13, AI-Z14, AI-Z15	PZ-005, PZ-103, PZ-104, PZ-105, DD-145	Low detections of TCE in shallow groundwater, 8.7 µg/L in 2014 with a decreasing trend, includes DOE Leach field 3.
Building 4457 HMSA (WQSAP GIA #15)	DOE SWMU 7.12 Leach field AI-Z8	PZ-041, PZ-108, PZ-109, PZ-120, PZ-121, PZ-122, PZ-162, PZ-163, RD-24, RD-29, DD-144, DD-146, DD-147	Perched (shallow) groundwater impacted by TCE up to 90 µg/L
Area IV Pond Dredge Area	Boeing SWMU 7.12 Leach fields AI-Z2, AI-Z3, AI-Z4	RD-13	No identified groundwater impact.
Area IV Leach Fields			
Building 4003	Boeing Leach field AI-Z1		See SWMU 7.12
DOE Leach Fields 1 Building 4064 SRE Fissionable Fuels Storage	DOE Leach field AI-Z2	DS-45, DS-47	Leach field removed. No contamination in 2016
DOE Leach Fields 1 Building 4030 A6 Counting Room	DOE Leach field AI-Z3	DS-44	Mentioned as possible source for contaminants in SE Drum storage RD-16. However, the VOCs detected in nearby soils are not consistent with those observed at RD-16. Leach field removed.
DOE Leach fields 1	DOE Leach field AI-Z4	RD-17	Leach field removed.

Table 1-1. Relationship of Groundwater Investigation Area Responsibilities with 2007 Consent Order

Area IV Location	2007 CO[1] Responsibility	Associated Wells[2]	Notes
Building 4093 Neutron Radiography Building			Mentioned as possible source for contaminants in SE Drum storage RD-16. However, the VOCs detected in nearby soils are not consistent with those observed at RD-16.
RMHF Building 4021 Leach Field (WQSAP GIA #13)	DOE Leach field AI-Z5 SWMU 7.6	RS-28, RD-19, RD-27, RD-30, RD-34A, RD-34B, RD-34C, RD-63, RD-98, DD-143	RCRA Permit Closure; Shallow and bedrock groundwater impacted by TCE up to 11 µg/L. Sr-90 at 33 pCi/L at the RMHF leach field. Leach field removed; site partially remediated.
Building 4028 Shield Test Irradiation Reactor Facility	DOE Leach field AI-Z6	RD-89	Included in tritium plume area.
Tritium Plume - Buildings 4010/4012 (WQSAP GIA #14)[2]	DOE per WQSAP Tritium Plume not specified in 2007 CO AOC. Leach field AI-Z7	RD-87, RD-88, RD-89, RD-90, RD-93, RD-94, RD-95	Bedrock groundwater impacted by tritium up to 40,000 pCi/L (2014). Strong downward trend in tritium concentrations observed since 2008. Leach field removed; may not be tritium source.
Building 4005/4006 Coal Gasification PDU	Boeing Leach field AI-Z8 SWMU 7.10	PZ-041, PZ-108, PZ-120, PZ-121, PZ-122, RS-27, RD-29	Co-located with HMSA; perched groundwater impacted by TCE. Leach field removed.
Building 4011 Aerospace Support	Boeing Leach field AI-Z9	PZ-106	Leach field removed. Part of Boeing Leach fields RFI area
Building 4383 Liquid Metals Engineering Center DOE Leach Field 3	DOE Leach field AI-Z10 SWMU 7.12	PZ-005, PZ-104, PZ-105, DD-145	Leach field removed.
Building 4009 Organic Moderated Reactor, Sodium Graphite Reactor	DOE Leach field AI-Z11 SWMU 7.12	PZ-102 RD-91	Leach field removed.
Building 4020 Rockwell Hot Lab and leach field	DOE Leach field AI-Z12 SWMU 7.12	RD-13, PZ-103	Low concentrations of TCE may be associated with Building 4055. Leach field removed.
Building 4373 Mechanical Component/Counting DOE RFI Leach Field 3 (WQSAP GIA #18)	DOE Leach field AI-Z13 SWMU 7.12	PZ-005, PZ-104, PZ-105	Former leach field site; no groundwater impact. Discussed with Metals Clarifier Groundwater.
Building 4363 SNAP Critical Facility DOE RFI Leach Field 3 (WQSAP GIA #18)	DOE Leach field AI-Z14 SWMU 7.12	PZ-005, PZ-104, PZ-105, DD-145	Former leach field site; no groundwater impact. Discussed with Metals Clarifier Groundwater.
Building 4353 Organics Reactor Development Building DOE RFI Leach Field 3	DOE Leach Field AI-Z15 SWMU 7.12	PZ-005, PZ-104, PZ-105, DD-145	Leach field removed
Groundwater Investigation Areas not previously identified			
Building 4100 Advanced Epithermal Thorium Reactor	Not specified in 2007 CO or WQSAP	PZ-102 RD-91	Boeing-owned building; bedrock groundwater impacted by TCE up to 270 µg/L in RD-91.

Notes:

[1] 2007 Consent Order on Corrective Action. DTSC Docket No. P3-07/08-003

[2] Some wells may be applicable to more than one site; most-representative well is listed in Table

[3] WQSAP = Haley & Aldrich, 2010. Site-Wide Water Quality Sampling and Analysis Plan. Revision 1, December

[4] AI-Zx is the leach field identifier presented in the 2007 Consent Order

[5] SMWU 7.12 was identified as Areas of Concern in the CO, incorporating several leach fields.

Table 1-1. Relationship of Groundwater Investigation Area Responsibilities with 2007 Consent Order

Area IV Location	2007 CO[1] Responsibility	Associated Wells[2]	Notes

µg/L – micrograms per liter
pCi/L – picocuries per liter
Boeing – The Boeing Company
DOE – Department of Energy
EPA – United States Environmental Protection Agency
ESADA – Empire State Atomic Development Authority
FSDF – Former Sodium Disposal Facility
GIA – groundwater investigation areas in WQSAP. WQSAP did not address all locations in Area IV.
HMSA – Hazardous Materials Storage Area
HWMF – Hazardous Waste Management Facility
NCY – New Conservation Yard
OCY – Old Conservation Yard
PCE - tetrachloroethene
RCRA – Resource Conservation Recovery Act
RFI – RCRA Facility Investigation
RMHF – Radioactive Materials Handling Facility
SE – southeast
SRE – Sodium Reactor Experiment
Sr-90 – Strontium 90
SWMU – solid waste management unit
TCE - trichloroethene
VOCs – volatile organic compounds
WQSAP – Water Quality Sampling and Analysis Plan

Boeing, NASA, and DOE have collaborated in the production of an overall SSFL Groundwater RFI Summary Report (in development) that contains common information for all areas of the SSFL. Therefore, a description of entire SSFL history, geology, hydrogeology, comments/responses on the 2009 Groundwater RI Report, and regulatory basis for this report are not included in this document. The reader is referred to the SSFL Groundwater RI Summary Report for general site details.

This document incorporates by reference and where necessary summarizes the results of historical groundwater investigations completed for SSFL. Where necessary to support conclusions, some text has been extracted from those reports and referenced accordingly.

1.2 Area IV Historical Activities

This section provides a brief history of Area IV and the groundwater investigation activities performed to identify the nature and extent of impacted groundwater. Section 2 provides a more detailed summary of groundwater investigative work related to specific GIAs.

Area IV occurs in the western portion of SSFL (**Figure 1-2**). While Areas I, II, and III were primarily used for the testing of rocket engines, work within Area IV focused on energy research. Rockwell International created its Atomic International (AI) division in the mid-1950s to conduct nuclear research in Area IV, some of which was funded by the Atomic Energy Commission (AEC). From the late 1950s through 1988, nuclear research, including the testing of 10 small reactors, took place in Area IV. The AEC leased a 90-acre parcel from AI that was named the Energy Technology Engineering Center (ETEC) (**Figure 1-3**). A significant focus of research at ETEC was management of liquid metals, mostly sodium, potassium and mercury. Not all of the work performed at SSFL was for the government as commercial energy research operations also took place in Area IV.

During its most active period (1960s and 1970s) Area IV contained over 200 numbered structures[2]. When a specific research project ended and there was no future need for the structure, the respective building(s) and associated structures were removed. Today only 22 structures remain in Area IV, 18 owned by DOE and four by Boeing, the current land owner. Numerous soil cleanup actions occurred in Area IV since the mid-1960s, either as a response to spills or discovery of a radionuclide or chemical release. Some groundwater extraction and treatment has occurred as a part of aquifer testing, but prior cleanup has focused on soil and bedrock.

Groundwater source investigations were conducted between 1996 and 2006. These investigations included soil and soil gas sampling conducted at the RFI SWMUs that were identified during earlier SSFL preliminary site assessments. Area IV was divided into five RFI study groups (3, 5, 6, 7 and 8) with RFI Group 3 primarily centered in Area II and RFI Group 5 overlapping with Area III. For the purposes of the Area IV GW RFI, Area IV was divided into 22 groundwater investigation areas to evaluate sources and groundwater impacts. Some of these areas are building or source specific, and some are a grouping of potential sources such as leach fields. The Area IV GIAs are shown in **Figure 1-1** and described in **Table 1-2**. DOE has responsibility for 14 of the 22 GIAs while Boeing is responsible for the remaining 8 areas in Area IV.

Table 1-2 – Groundwater Investigation Area Descriptions

Groundwater Investigation Area Name	Responsibility	Description
1. FSDF Building 4886	DOE	FSDF used for removal of liquid sodium from metallic objects. The area was also used for drum storage and waste disposal. FSDF and adjacent areas subjective to several cleanup actions; no structures or wastes remain.
2. Building 4100 Trench	DOE	Located northeast of B4100, the trench was used for burning and disposal of construction debris. Cleaned out in the 1960s the trench was covered over by paving of 24th Street.
3. Building 56 Landfill	DOE	Site used primarily for deposition of bedrock from Building 56 excavation; the surface was used for drum storage and some waste disposal occurred also. Drums have been removed
4. Buildings 4057/4059/4626	DOE	Area of bedrock groundwater impacted by low concentrations of TCE and PCE. Source not identified but may have been near Building 4057. Only Building 4057 remains.
5. Building 4457 HMSA	DOE	Not a specific building but an area in north central Area IV where energy research was performed (B4024, B4025, B4026, 4356, 4457) and chemicals used that collectively contributed to observed groundwater TCE contamination.
6. Tritium Plume – Bedrock groundwater impacted by tritium; Leach Field AI-Z6/Building 4028 (believed not to have ever existed per 2007 CO) and DOE	DOE	Area between former reactor buildings 4059 and 4027 impacted by tritium. Specific source is not known.

[2] Numbers were assigned to all structures in Area IV including buildings, sheds, tanks, transformer pads, and parking lots. Not all structures were occupied.

Table 1-2 – Groundwater Investigation Area Descriptions

Groundwater Investigation Area Name	Responsibility	Description
Leachfield 1 - AI-Z7/Buildings 4010 and 4012		
7. RMHF – Near surface bedrock and shallow groundwater impacted by TCE and Strontium-90 (Sr-90) at the RMHF leach field site (AI-Z5); Building 4021	DOE	RMHF was used for storage and processing of nuclear wastes. Wastewaters were discharged to a leach field. RMHF being subject to a RCRA closure; buildings remain.
8. Old Conservation Yard (OCY) – Includes Container Storage Yard and Fuel Tanks. Low detections of TCE.	DOE	Primarily used for storage of salvageable materials. Also used for disposal of construction materials. Some materials stored in drums. Two 1.5-million-gallon diesel storage tanks. All materials have been removed.
9. Metals Clarifier Laboratory (Building 4065)/DOE Leach Fields 3 (AI-Z10/Building 4383; AI-Z12/Building 4020, AI-Z13/Building 4373, AI-Z14/Building 4363, AI-Z15/Building 4353	DOE	Building 4065 had multiple uses: vacuum test facility, chemical and metallographic analysis repair, and instrument repair. Area included multiple leach fields. All buildings removed. Area of perched groundwater contamination by TCE.
10. DOE Area IV Leach Fields - AI-Z2/Building 4064 (DOE);	DOE	Leach fields associated with former nuclear support facilities located in the northeastern portion of Area IV. All buildings removed.
11. DOE Area IV Leachfields 2 - AI-Z3/Building 4030 (DOE); - AI-Z4/Building 4093	DOE	Leach fields associated with former nuclear support facilities located in the northeastern portion of Area IV. All removed.
12. Buildings 4009 – Leach Field AI-Z11	DOE for Leach Field AI-Z11	Building 4009 was used for nuclear research early, and then for sodium studies and as an engineering lab. Boeing owned building.
13. Building 4133 Hazardous Waste Management Facility (HWMF)/Building 4029 Reactive Metals Storage Yard. No groundwater impact.	DOE	Building 4029 was used for the storage of materials containing liquid sodium while Building 4133 was used for treatment of those materials, replacing the RMHF. Both buildings are under a RCRA Closure Permit.
14. Rockwell International Hot Lab Building 4020	DOE	Former nuclear material and fuel handling facility. Building removed. Ownership transferred to DOE.
15. Empire State Atomic Development Authority (ESADA) Chemical Storage Yard	Boeing	ESADA had buildings, drum storage yard, and pistol range. ESADA was connected by piping to the FSDF. Buildings and drums have been removed.
16. Building 4005/4006 - Process Development Unit (includes Leach Field AI-Z8)	Boeing	Originally constructed for non-nuclear research; some work with depleted/enriched uranium occurred. Last used for molten salt combustion tests, and a coal gasification study. All buildings removed.
17. Sodium Reactor Experiment Complex Area – Sporadic detections of TCE below 1 µg/L, Area includes Leach Field AI-Z1/Building 4003.	Boeing	Sodium Reactor Experiment area (also referred to as SRE Watershed). All buildings have been removed and the excavated area backfilled.
18. New Conservation Yard (NCY) – Replaced OCY as point for materials storage.	Boeing	Used for storage/salvage of metal debris and equipment. Also contained an ash pile from

Table 1-2 – Groundwater Investigation Area Descriptions

Groundwater Investigation Area Name	Responsibility	Description
		adjacent Building 4040. All debris has been removed.
19. Southeast Drum Storage Yard – Sporadic detections of TCE below 1 µg/L. This area also includes Leach Field AI-Z9/Building 4011.	Boeing	Used for storage of between 50 and 100 drums of unknown content. The drums were also used in forklift exercises.
20. Area IV Pond Dredge Area	Boeing	Used for disposal of material dredged from Silvernale Pond and R2 Pond during the 1960s.
21. Building 4100. Former nuclear and support building. One well RD-91 impacted by TCE	Boeing	Multiple use building owned by Boeing.
22. Building 4008 Warehouse	Boeing	Building 008 incorrectly listed in RFA as Area I leach field. Included as Boeing Area IV Leach Field RFI site (from page 60 of CO).

Notes:
µg/L – micrograms per liter
CO – Consent Order
DOE – Department of Energy
ESADA - Empire State Atomic Development Authority
FSDF – Former Sodium Disposal Facility
HWMF - Hazardous Waste Management Facility
NCY – New Conservation Yard
OCY – Old Conservation Yard
PCE – tetrachloroethene
RCRA – Resource Conservation and Recovery Act
RFA – RCRA Facility Assessment
RFI – RCRA Facility Investigation
RMHF - Radioactive Materials Handling Facility
SRE - Sodium Reactor Experiment
TCE – trichloroethene

Soil investigations for presence of contaminants occurred during two periods. The first was the 1995 to 2008 RFI. The second was the Administrative Order on Consent Soil Characterization Program that was completed between October 2012 and June 2014. During this time, approximately 5,850 surface and subsurface soil samples were collected. This soil data, coupled with approximately 2,260 soil samples collected during the RFI period, has produced a dataset for identification of potential groundwater source areas.

Area IV groundwater remediation included 10-years of groundwater pumping using Radioactive Materials Handling Facility (RMHF) well RD-63 between 1994 and 2005 (approximately 4.3 million gallons of water were extracted). TCE concentrations in RD-63 were reduced from a high of 20 micrograms per liter (µg/L) in 1998 to 6 µg/L in 2005, with a small rebound to 11 µg/L following cessation of pumping. TCE concentrations in RD-63 have since slowly declined to 6 µg/L in 2018. Adjacent monitoring wells RS-28 and RD-30 also responded to pumping with TCE concentrations decreasing in RS-28 from 47 µg/L (1994) to 15 µg/L (2005) with no discernable rebound. When last sampled in 2017 (dry in 2016), the TCE concentration in RS-28 was non-detect. TCE concentrations in RD-30 decreased from about 30 µg/L (1994) to 11 µg/L (2005) and was measured at 3.2 µg/L in 2017. Well RD-63 groundwater elevations recovered very slowly following pumping indicating a very tight bedrock formation at the RMHF.

Groundwater extraction tests were performed at the FSDF using wells RS-54, RD-54A, RD-54B, and RD-23. The pumping of RD-54A, 1996 to 1999 reduced TCE from nearly 600 µg/L to about 200 µg/L, with no observed rebound. TCE in RD-54A was 3.1 µg/L in 2016 and 3.9 J in 2017. The well at the FSDF with the highest TCE concentration is shallow well RS-54A which was 1,600 µg/L in 2014; the well was dry in 2015 and 2016. Following the winter of 2016 and 2017 that exhibited slightly above average rainfall, RS-54 exhibited 1,100 µg/L of TCE and 11,000 µg/L of 1,1,1-TCA. RS-54 is 46 feet deep and the RS-54 data illustrate that the TCE source is harbored in near surface fractures of the sandstone bedrock. RS-54A, installed immediately next to RS-54, has never exhibited elevated TCE concentrations.

RS-54 was subject to a groundwater interim measure starting in November 2017. The well was pumped down to the level of the pump intake, about 2 feet above the well bottom, and allowed to recover. From November 6, 2017 to June 20, 2018, RS-54 was pumped 24 times with 331 gallons removed (CDM Smith 2018b). Towards the end of pumping in February, March, and June 2018, it took one to two months for RS-54 to recover, illustrating the tightness of the fractures harboring groundwater.

The data collected during the pumping of well RD-21 (located between the FSDF and ESADA) illustrate the tightness of bedrock in the southwestern portion of Area IV. There was no water elevation responses in adjacent wells during pumping. RD-21 was pumped from January 1997 through mid-2002 at about 173 gallons per day (gpd). TCE concentrations decreased from about 800 µg/L to about 200 µg/L during pumping, but the well exhibited a rebound to 600 µg/L.

Other notable investigative work in Area IV include the drilling of coreholes Trit-1 and Trit-2 (in 2005) within the tritium plume to characterize bedrock pore-water for tritium concentration. The drilling of corehole 8 (C-08) at the FSDF (in 2005) was also completed to assess concentrations of TCE in the bedrock pore-water at that location.

Section 2.0 of this report provides more details on the groundwater investigation and remediation in Area IV. Section 1.3 below provides an overview of other physicochemical conditions that affect groundwater in Area IV.

1.3 Overview of Area IV Groundwater Conditions

Groundwater in Area IV consists of two units. The first unit is shallow groundwater within the alluvium, weathered bedrock overlying competent bedrock, and near-surface bedrock fractures (termed Near-surface groundwater). The second unit is found in the competent, fractured bedrock that underlies alluvium and weathered bedrock (termed the Chatsworth Formation groundwater). The Near-surface groundwater can either be perched above the Chatsworth Formation groundwater or be in contact with the bedrock aquifer, as is observed within central Area IV where Chatsworth Formation groundwater level elevation is the highest. In many locations of Area IV, near-surface groundwater is dependent on rainfall. Less than average rainfall occurred during years 2014 through 2016 when many of the wells that are screened within the alluvium, weathered bedrock and the upper competent bedrock were dry prior to the above average winter rains of 2016-2017 and some Near-surface wells exhibited water.

The readily extractable groundwater in the competent Chatsworth Formation primarily occurs in bedrock fractures. The amount of water produced at any one well is dependent on the number and size of fractures the well encounters. Across Area IV, well productivity varies greatly because the fracture network varies by location.

Groundwater elevations in the Chatsworth Formation bedrock also varies across Area IV. The highest groundwater elevations observed in RD-17, within the east-central portion of Area IV, was 1,791 feet above mean sea level (amsl) in January 2016 and 1,795 feet amsl in March 2017. Along the boundaries of Area IV (north and west) groundwater elevations are significantly lower, consistent with the terrain that drops precipitously downward and away from Area IV. Chatsworth Formation groundwater elevation at RD-33A at the FSDF was 1,581 feet amsl in May 2016 and 1,582 feet in March 2017. Chatsworth Formation groundwater elevation at RD-59A located on Brandeis property to the west of the FSDF was 1,314 feet amsl in April 2016 and 1316 feet amsl in March 2017. Chapter 3.0 provides additional information on groundwater elevations across Area IV.

At the SSFL, groundwater flow initiates with surface water infiltration from rainfall into alluvial soils. There is no surface water drainage flow into Area IV from adjacent areas. Water that infiltrates the soil is lost either by evaporation, uptake by plants (evapotranspiration), or held in the vadose zone by pore pressure with only a small percentage of the water accumulating as groundwater within weathered bedrock. Infiltrating surface water that comes in contact with the bedrock can enter into the Chatsworth Formation groundwater via bedrock fractures, faults, or other structures. Groundwater movement in the Chatsworth Formation bedrock is then controlled by the bedrock matrix and fracture network. Some of the groundwater diffuses into the bedrock matrix from the fractures. Contaminants released in to the shallow groundwater will follow similar pathways.

Groundwater migration within fractures in the Chatsworth Formation groundwater moves either downward or laterally depending on trend of the fracture at the source location. Some of the groundwater flow moves laterally from Area IV toward the sides of the Simi Hills. As groundwater flow moves closer to the hillside surface, the water can be taken up by phreatophytic plants (plants rooted into bedrock fractures containing water) and/or released to the surface as seeps and springs. The seeps and springs currently being monitored north of Area IV are shown on **Figure 1-4**. Chapter 5.0 provides results of the groundwater samples collected from the seep wells.

Of the 14 GIAs within Area IV being addressed by DOE; only 7 of exhibit groundwater contamination. The seven GIAs with identified groundwater contamination are summarized below. A description of all 14 GIAs is summarized in Table 2-2 and are described in more detail in Section 5.

- FSDF TCE plume – the highest concentration of TCE observed in Area IV was at shallow well RS-54. When sampled in 2013, the laboratory reported 1,600 µg/L TCE. RS-54 was dry in 2015 and 2016, but exhibited 1,100 µg/L in 2017. Well RD-23 adjacent to the FSDF exhibited TCE at 160 µg/L in 2014, 19 µg/L in 2016 and 34 µg/L in 2017. RS-54 also exhibits the solvent 1,1,1-TCA but the bedrock area impacted by 1,1,1-TCA is primarily located in the vicinity of RS-54.

- Building 56 Landfill – Bedrock well RD-07 exhibited 57 µg/L TCE in 2014, 50 µg/L TCE in 2016, and 29 µg/L TCE in 2017. Bedrock well DD-141 installed in June 2016 at the toe of the landfill was non-detect for TCE in 2016 and 2017.

- Buildings 4057/4059/4626 tetrachloroethene (PCE) plume – This is the only location in Area IV with PCE-impacted groundwater above its MCL. Shallow well PZ-109 at Building 4057 has always exhibited the highest PCE concentrations with 55 µg/L PCE in 2016 and 42 µg/L in 2017. RD-25 at the Building 4059 exhibited 27 µg/L PCE before its abandonment in 2004. Replacement well DD-142 exhibited 12 µg/L PCE in 2016 and 4.6 µg/L in 2017.

- Hazardous Materials Storage Area (HMSA) – The HMSA is in the area of highest groundwater elevation in Area IV and exhibits TCE contamination. Well PZ-108 contained 79 µg/L TCE in 2014, was dry in 2016, and exhibited 160 µg/L in 2017. Bedrock well DD-144 installed in January 2016 contained 98 µg/L TCE in March 2016, 190 µg/L in October 2016, and 170 µg/L in March 2017.

- Metals Clarifier – A shallow, low concentration area of TCE contamination, associated with the former Metals Clarifier Building 4065, is located in the south-central part of Area IV. There were several leach fields in this area. The 2014 TCE concentration in shallow well PZ-105 was 8.7 µg/L. All shallow wells at the Metals Clarifier were dry in 2016. In 2017, only well PZ-105 at 7.9 µg/L exhibited TCE above the MCL. Bedrock well DD-145 installed in the middle of the Metals Clarifier area was less than 1 µg/L for 2016 and 2017 sampling events

- Radioactive Materials Handling Facility (RMHF) – There are two different groundwater contaminants associated with the RMHF: TCE and Sr-90. Both are found in groundwater north of the RMHF. The source of the contaminants is believed to be caused by waste releases into the former RMHF leach field. Well RD-63 down drainage from the leach field has shown TCE concentrations decrease from 11 µg/L in 2007 to 6.2 µg/L in 2017. A small groundwater area impacted by Sr-90 at the former leach field is believed to be where Sr-90 is bound to shallow bedrock. When groundwater elevations were the highest recorded in 2011, Sr-90 concentration in well RD-98 was 183 picocuries per liter (pCi/L). In 2016 groundwater elevations were lowest since 2009 and the Sr-90 concentration in well RD-98 was 26.5 pCi/L. In 2017 the concentration of Sr-90 increased to 114 pCi/L following the winter rains.

- Tritium Plume – Groundwater impacted by radioactive hydrogen (termed tritium) is present in the north-central part of Area IV. Tritium concentrations since 2007 have decreased by over 50 percent since 2004, with the highest recent (2017) tritium concentration measured in bedrock well RD-90 was 38,300 pCi/L.

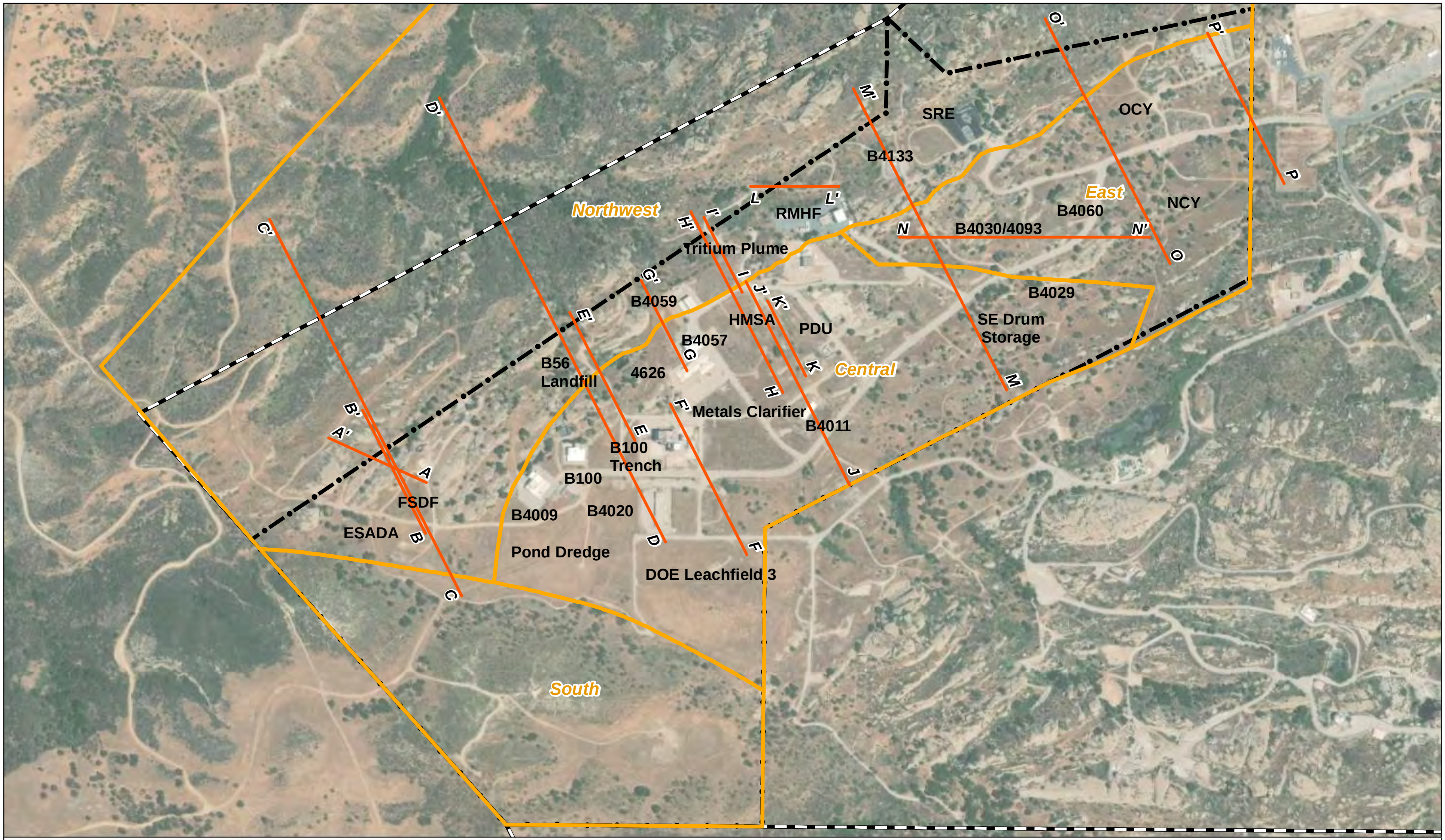
1.4 Relationship of GW RFI Report with Support Documents

This GW RFI Report summarizes more than 30 years of groundwater investigation activities at Area IV of the SSFL. The groundwater investigation efforts are reported in a myriad of documents developed over the 25-year time frame. This document does not repeat details presented in many of those documents but incorporates important study findings in GIA descriptions in Section 5. Section 2.2 provides a listing and summary of the documents reviewed and used in developing this GW RFI Report. Some key support documents are included as an appendix.

1.5 Organization of Area IV GW RFI Report

The GW RFI Report contains eight sections:

- **Section 1 – Introduction** – Provides scope, purpose and objectives of Area IV groundwater RI, and background information for the GW RFI Report.
- **Section 2 – Area IV Groundwater Investigation History** – Provides a summary level overview of the groundwater investigative work performed within Area IV.
- **Section 3 – Area IV Geology** – Describes the geological and structural factors, as well as the environmental setting of Area IV.
- **Section 4 – Area IV Hydrogeology** – Describes the Area IV hydrogeological setting and modeling parameters related to the environmental conditions.
- **Section 5 – Area IV Nature and Extent of Groundwater Contamination** – Presents by DOE-responsible GIAs, a description of history of chemical use, chemicals of concern, nature and extent of groundwater contamination, and an assessment of remaining source material.
- **Section 6 – Transport and Flow Numeric Modeling** – Provides the results of numeric modeling of the transport of groundwater contaminants from source locations.
- **Section 7 – Summary and Conclusions** – Summarizes the findings of the groundwater investigative work for Area IV and introduces GIAs requiring further assessment in the Corrective Measures Study.
- **Section 8 – References**
- **Appendices**
  - **Appendix A – Boring Logs**
  - **Appendix B – Historic Well Results Data Tables**
  - **Appendix C – Numerical Modeling Report**
  - **Appendix D – Contaminant Attenuation Assessment**
  - **Appendix E – Soil Gas Result Figures**
  - **Appendix F – DTSC March 26, 2018 Comments/DOE Responses on Preliminary Draft Groundwater RI Report**



LEGEND

- Cross Section
- Hydrogeologic Area
- Area IV Boundary
- SSFL Property Boundary

0 425 850 Feet

Notes:
- Original GIS Layers provided by MWH/Boeing; updated by CDM Smith as needed.
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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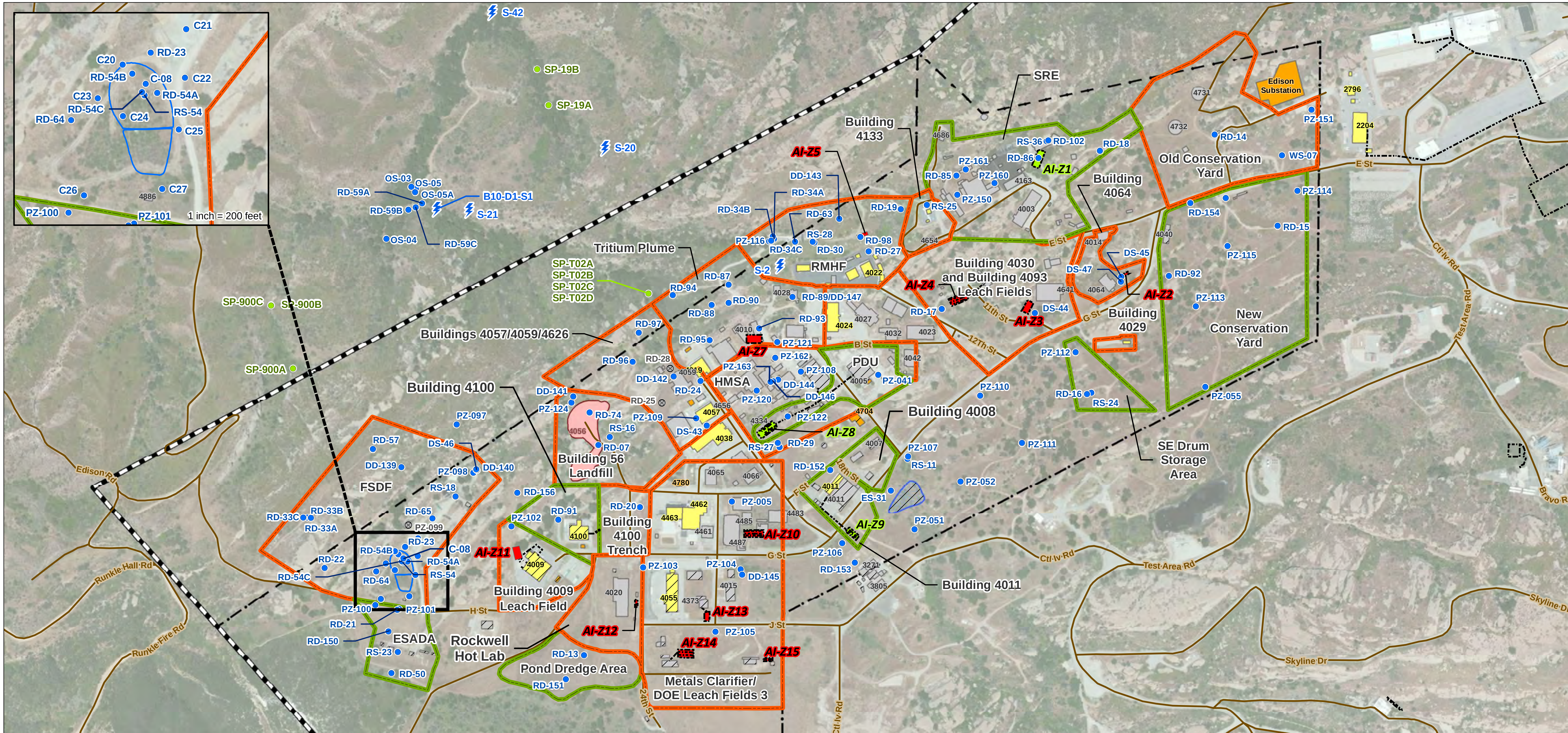
CDM Smith

PLATE 1
Cross Section Locations



LEGEND

- Abandoned Well
- Well/Piezometer
- Seep Well
- Seep
- Road Centerline

Responsibility*
- Boeing
- DOE

Groundwater Investigation Area
- Boeing
- DOE

- Existing Landfill
- Existing Structure
- Existing Substation
- Former Pond
- Demolished Structure
- Boeing Structure
- Former FSDF Pond
- Area IV Boundary
- SSFL Property Boundary

0 275 550 Feet

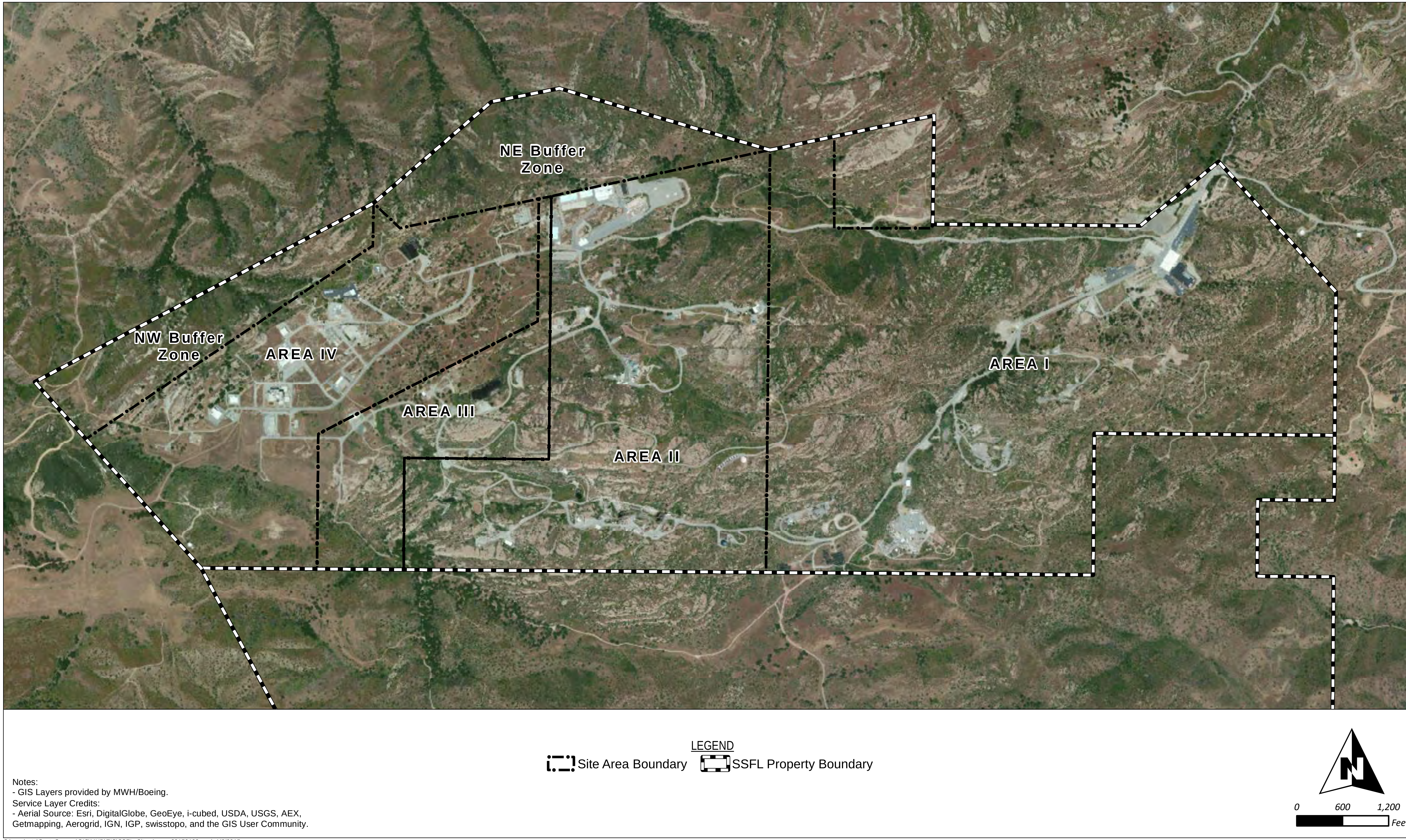
Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

C:_projects\SantaSusana\GIS\MXD\Groundwater\RI\2018\SSFL_GWRI_Investigation_Areas_Revised_20180821.mxd 8/22/2018

CDM Smith

FIGURE 1-1
Area IV Groundwater Investigation Areas



Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

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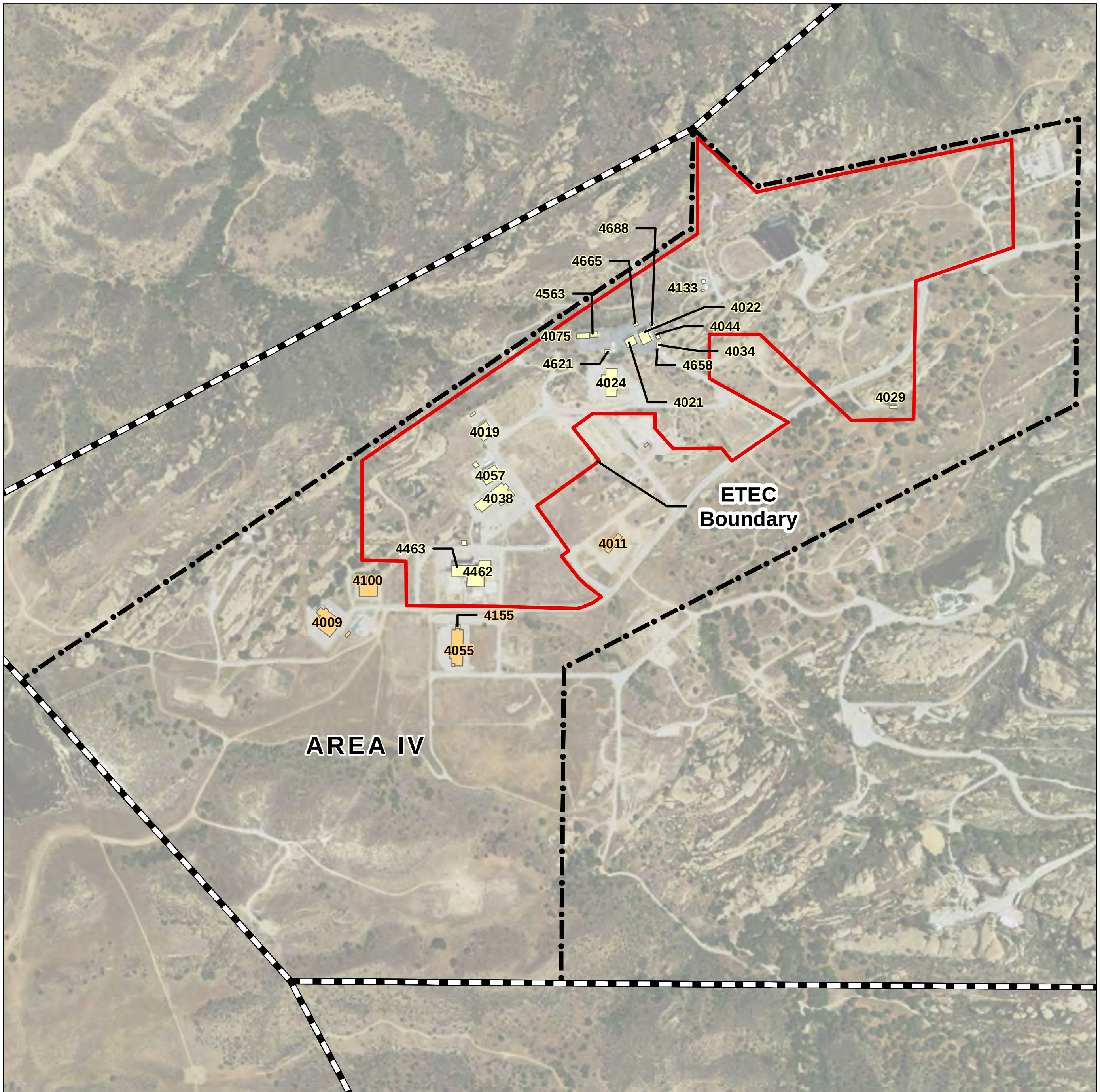
CDM Smith

FIGURE 1-2
SSFL Site Area Designations



LEGEND

ETEC Boundary

Department of Energy

DOE Structure

Boeing Structure

Area IV Boundary

SSFL Property Boundary

0 425 850 Feet

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

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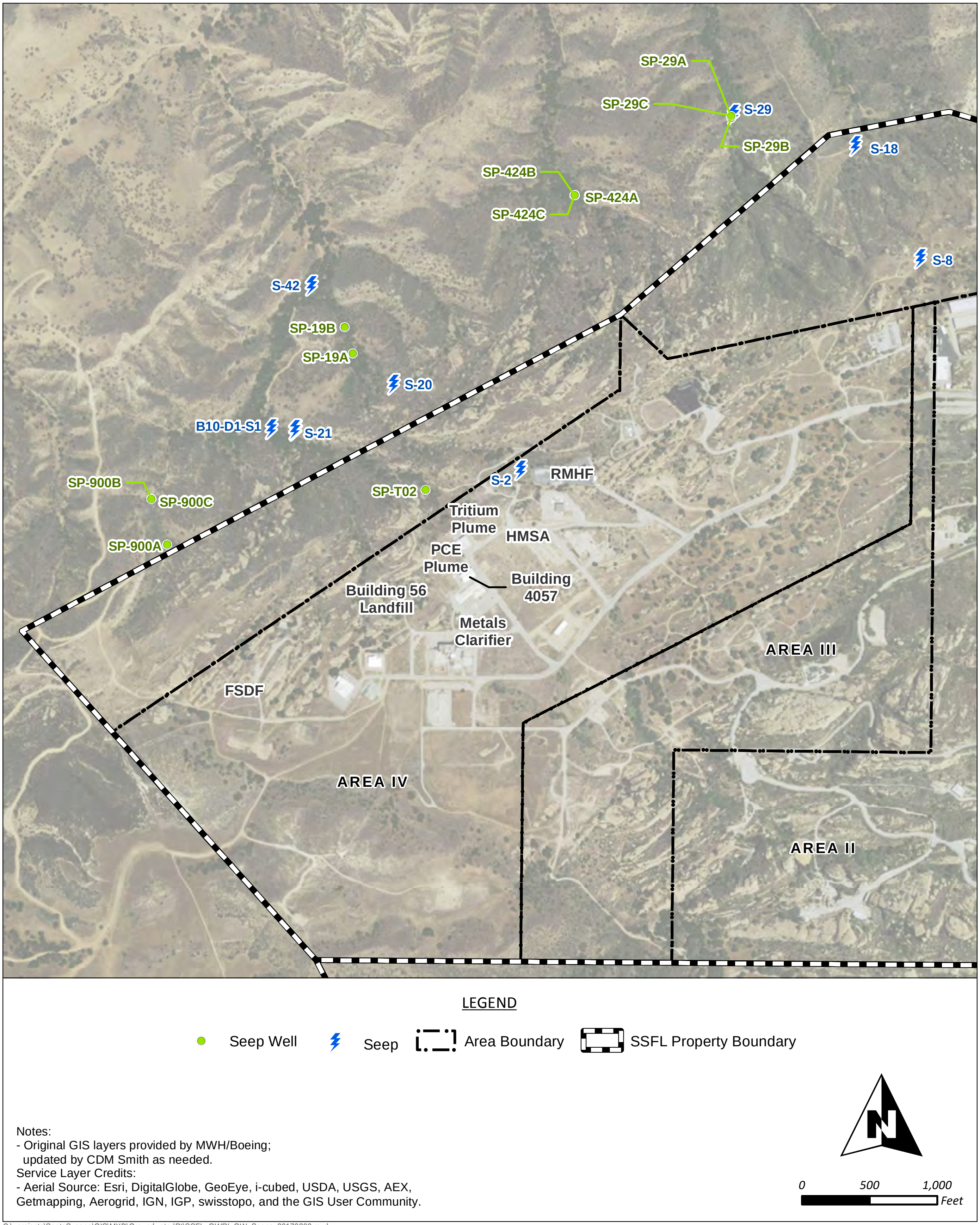
CDM Smith

FIGURE 1-3
ETEC Boundary



Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

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CDM Smith

FIGURE 1-4
Seeps and Springs Associated with Area IV

Section 2

Area IV Groundwater Investigation History

This section of the Area IV GW RFI Report presents both an overview of the groundwater investigative work performed within Area IV for the past 30 years and the findings from recent investigations in Area IV. The presentation is by two periods, investigative work performed prior to the release of the 2009 GW RI Report (MWH 2009a) and work performed subsequently that addressed DTSC comments on the 2009 GW RI Report. This section also provides a summary of the groundwater monitoring well network, groundwater treatability studies recently completed by Boeing, NASA, and DOE, and the FSDF Groundwater Interim Measure (GWIM).

2.1 Pre-2009 Groundwater Investigative Work

The planning, implementation, and reporting of groundwater investigative work in Area IV are presented in a series of environmental documents, starting with the 1986 Annual Environmental Report (Rockwell International 1987). These annual environmental reports first completed by Rockwell for DOE, and then by Boeing after they acquired portions of the SSFL, provide insights into early groundwater investigative activities and findings between the 1980s and early 2000s. Although originally focused on radiological monitoring of air and soil, the annual environmental reports were expanded in 1986 to include groundwater characterization. The 1986 report describes a 'recent hydrologic study of SSFL' and provides gross alpha/gross beta data for water supply wells and several shallow monitoring wells (Rockwell International 1987).

The 1989 environmental report presents radionuclide data collected by USEPA. This includes the discovery of tritium in water sampled by USEPA in the Building 4059 french drain and FSDF well RD-23 (Rockwell 1990). These findings initiated additional investigations by Rockwell as to the source of the tritium at Building 4059, but it was not until 2004 when the tritium plume wells were installed that the full extent of tritium-impacted groundwater was better understood. The 1989 report also introduced a section devoted to groundwater to describe the SSFL-wide groundwater monitoring program that had been in place since 1984. The first shallow monitoring wells at Area IV were installed in 1985. The first bedrock well, RD-07, was installed in 1986 and 17 additional bedrock wells installed in 1989, and the presence of TCE in groundwater documented.

The 1992 environmental report identifies three areas with TCE contamination – the RMHF, well RD-07 at the Building 56 Landfill, and the FSDF; and one location with PCE contamination - well RD-25 at Building 4059. The report also describes the installation of two 3-well clusters at the FSDF (RD-33A, RD-33B, and RD-33C) and RMHF (RD-34A, RD-34B, RD-34C); and the proposal to install groundwater extraction wells at the RMHF (RD-63) and the FSDF (Rockwell International 1993). The extraction well at the FSDF is assumed to be RD-54A, as RD-21 had already been installed.

The 1994 environmental report discusses installation and testing of well RD-63 in the drainage northwest of the RMHF and the planned testing of the new extraction well installed at the FSDF

(Rockwell International 1995). The testing of RD-63 involved pumping at 2 gallons per minute (gpm) and treatment using 'a portable carbon adsorption unit.'

The 1999 environmental report, prepared by The Boeing Company, provided some groundwater extraction data for RMHF well RD-63 and FSDF well RD-54A. Approximately 107,000 gallons and 2.7 million gallons of groundwater had been extracted from the FSDF and RMHF, respectively, and treated cumulatively through 1999 (Boeing 2000).

The 1999 Annual Groundwater Monitoring Report (Boeing 2000) documents a more structured groundwater monitoring program for SSFL with established well sampling frequencies (e.g., quarterly, annually), well analytical suites, and a summary of groundwater extraction and treatment operations. The results of groundwater sampling since 1999 have been reported in quarterly and annual documents.

The 2000 environmental report (Boeing 2001) and 2000 Annual Groundwater Monitoring Report (Haley & Aldrich 2001) provided additional groundwater extraction information. Pumping to lower the groundwater elevation near Building 4059 to keep groundwater from entering the basement involved wells RD-24, RD-25, and RD-28. A total of 1.9 million gallons were extracted from these wells in 2000. Pumping to remove TCE from groundwater at RMHF well RD-63 and the FSDF cumulatively removed 2.7 million gallons and 118,000 gallons, respectively (Boeing 2001). The 2001 environmental report states that wells RD-21 and RS-54 were used to extract groundwater near ESADA and the FSDF, with the cumulative volume reported as 118,000 gallons and the cumulative extracted volume from RMHF well RD-63 was 3.0 million gallons (Boeing 2002).

The 2002 environmental report states that groundwater extraction at the FSDF started in 1995. Only well RS-54 was pumped in 2002. The cumulative extracted groundwater volume through 2002 for FSDF wells was reported at 123,000 gallons. The cumulative amount for the Building 4059 wells was 2.6 million gallons and for RD-63, 3.3 million gallons (Boeing 2003). The cumulative volumes for the FSDF, Building 4059, and the RMHF reported for 2003 were 123,000 gallons, 3.4 million gallons, and 3.4 million gallons, respectively (Boeing 2004). This annual environmental report also states that ion exchange resin was used at the FSDF to remove perchlorate from extracted groundwater. No pumping at the FSDF occurred in 2004. The cumulative extraction amounts for the Building 4059 wells was reported at 3.8 million gallons and for RD-63 at 3.5 million gallons. Wells RD-25 and RD-28 were abandoned in 2004 during building demolition (Boeing 2005). Only RD-63 was pumped in 2005 and 2006, with cumulative volume of pumped water reported at 4.3 million gallons (Boeing 2007). Groundwater extraction was suspended in 2006.

Between 1986 and 2009, a number of documents were released presenting planning efforts and results of groundwater investigations conducted in Area IV. **Table 2-1** provides a compilation of representative documents and their relationship to the overall groundwater investigation. Key findings provided in these reports are presented in following sections of this report.

Table 2-1 Representative Reports and Plans Documenting Area IV Groundwater Investigative Activities

Report/Document	Groundwater Investigation Area(s) Addressed	Summary of Contents
Status Review – RMDF Leach Field, September 1978. Rockwell International, October 4, 1978.	RMHF	Provides a description of the bedrock fracture conditions still impacted by Sr-90 following the excavation of the RMHF leach field.
RMDF Leach Field Decontamination Final Report. Rockwell International, September 15, 1982.	RMHF	Describes the removal of the leach field and accessible Sr-90 contaminated bedrock.
Phase II Groundwater Investigation, Santa Susana Field Laboratory. GRC, October 29, 1986.	B56 Landfill	Lithologic log of RD-07.
CERCLA Program Phase II - Site Characterization. DOE ETEC, May 29, 1987.	B56 Landfill, FSDF	Provides prior sampling results for soil and groundwater.
Environmental Survey Preliminary Report, DOE Activities at SSFL. DOE, February 1989.	RMHF, Rockwell International Hot Laboratory, FSDF, SRE Watershed, Building 4059, B56 Landfill, Old Conservation Yard (OCY), Building 100 Trench, Building 4029, Building 4005 – Process Development Unit, ESADA Chemical Storage Yard, SE Drum Storage Yard, Building 4133	Presents preliminary findings of the first phase of an environmental survey to assess operating facilities, environmental problems, and areas of environmental risk. Includes assessments of adequacy of the monitoring program at that time.
Phase II Investigation Report. Investigation of Soil and Shallow Groundwater, SSFL Area IV. GRC, May 17, 1989.	RMHF, OCY, NCY, Building 4133, Southeast Drum Storage Area, ESADA Chemical Use Area, Building 4100 Trench	Soil source investigation data. Recommendations for installation of two shallow and 16 deep wells.
Summary Review of Preliminary Assessments/Site Inspections of Rockwell International SSFL. Ecology and Environment, Inc., July 19, 1989.	FSDF, SRE Watershed, Building 4059, B56 Landfill, RMHF, OCY, ESADA Chemical Storage Yard, Building 4100 Trench, S.E. Drum Storage Yard, NCY, Building 4133	Prepared for USEPA Region 9. Intended to be a facility-wide presentation of potential hazardous waste disposal locations.
Environmental Survey Preliminary Report Final Action Plan, DOE Activities at SSFL. DOE and Rockwell International, October, 1989.	FSDF, SRE Watershed, Building 4059, RMHF, OCY, B56 Landfill, ESADA, B4100 Trench, SE Drum Storage Yard, NCY, Building 4133	Presents planned actions for soil remediation at FSDF and SRE; plans for installation of 17 deep and 1 shallow monitoring wells; plans for groundwater extraction using RD-07 and plans for additional soil characterization.
Phase III Report. Investigation of Groundwater Conditions SSFL Area IV. GRC, December 5, 1989.	FSDF, RMHF, OCY, NCY, Building 4133, Southeast Drum Storage Area, ESADA Chemical Use Area, Building 4100 Trench	Documents sampling of wells RS-18, RD-21, RD-22, RD-23 (FSDF); RS-16, RD-7 (B56 Landfill); RD-24, RD-25, RD-28 (Building 4059); RS-28, RD-27, RD-30 (RMHF); RD-14, WS-7 (OCY); RD-15 (NCY); RS-25, RD-19 (Building 4133) RS-24, RD-16 (Southeast Drum Storage Area): RS-23, RD-21 (ESADA); RD-20 (Building 4100 Trench).
Well Compendium. GRC, April 19, 1990.	Building 4059, RMHF	Well logs for RD-24, RD-25, and RD-27 (RMHF).

Table 2-1 Representative Reports and Plans Documenting Area IV Groundwater Investigative Activities

Report/Document	Groundwater Investigation Area(s) Addressed	Summary of Contents
Hydrogeologic Assessment Report, Lower Pond Building 4886, FSDF. GRC, June 12, 1990.	FSDF	Description of facility history, surface and subsurface hydrology, soil properties, well network.
Completion Report, Cluster Well Sites RD-33, RD-34, and RD-51. GRC, April 24, 1992.	FSDF, RMHF	Documentation of installation of RD-33A, -33B, and -33C in NBZ below FSDF; and RD-34A, 34B, and 34C in drainage below RMHF.
Results and Comparison of Geophysical and Video Camera Logging of RD-21, RD-22 and RD-23. GRC, August 19, 1992.	FSDF	Provides well completion diagrams for RD-21, RD-22, RD-23; video and geophysical logging results.
Current Conditions Report and Draft RCRA Facility Investigation Work Plan, Area IV, SSFL. ICF Kaiser Engineers, October 1993.	B56 Landfill, Building 4133, FSDDF, OCY, Building 4100 Trench, RMHF, Rockwell International Hot Laboratory, NCY, ESADA Chemical Storage Yard, Process Development Unit, Building 4029, Leachfields	Provides operational history; soil/soil gas and surface water sampling results.
Hydrogeologic Conditions B/886 FSDF Area SSFL. GRC, April 15, 1994.	FSDF	Description of FSDF hydrogeologic investigation work, wells, site hydrogeology and water quality. Provides construction details for RS-54, RD-54A, RD-54B, RD-54C.
Final RCRA Facility Assessment Report for Rockwell International Corporation. SAIC, May 1994.	B56 Landfill, Building 4133, FSDF, OCY, Building 4100 Trench, RMHF, Rockwell International Hot Laboratory, NCY, ESADA Chemical Storage Yard, Process Development Unit, Building 4029, SRE Watershed, Building 4059, Inactive Sanitary Leachfields, Southeast Drum Storage Yard	Prepared for the entirety of SSFL for USEPA Region 9. Provides findings of site visit and records review.
RCRA Facility Investigation Work Plan Addendum. Ogden Environmental, March 1995.	B56 Landfill	Proposes additional characterization work at the B56 Landfill.
Summary of Groundwater Conditions at and in the Regional Vicinity of the FSDF. GRC, May 16, 1995.	FSDF	Provides description of investigation history, hydrogeology, and well completion details for RD-50, RD-57, RD-59A, RD-59B, RD-59C, RD-64, and RD-65.
Results of RD-63 Pilot Extraction Test, RMDF Area, Santa Susana Field Laboratory. GRC, May 22, 1995.	RMHF	Reports 3 months of extraction of RD-63; identified a sustained pumping rate of 2 gallons per minute; radius of influence was 600 feet.
Geophysical and Hydrogeologic Testing Surveys. Harding Lawson Associates, November 2, 1995.	B56 Landfill, FSDF	Geophysical logging; packer testing and aquifer testing of RD-07 and RD-50.
Project Impacts of Long-term groundwater Extraction Well RD-63 – RMDF Area. GRC, April 22, 1996.	RMHF	Modeling of groundwater extraction indicated that pumping of RD-63 could have a hydraulic capture zone of 150 to 200 feet.

Table 2-1 Representative Reports and Plans Documenting Area IV Groundwater Investigative Activities

Report/Document	Groundwater Investigation Area(s) Addressed	Summary of Contents
Results of Pilot Groundwater Extraction Test at the B/866 FSDF. GRC, May 14, 1996.	FSDF	Provides the results of pumping from RS-54, RD23, and RD-54A over a 98-day period. A 24-hour pump test of RD-21, and 35 days for RD-64, and RD-65 were also performed.
RCRA Facility Investigation Work Plan Addendum, SSFL. Ogden Environmental, September 1996.	B56 Landfill, OCY, Rockwell International Hot Lab, NCY	Proposes additional soil sampling.
Results of Well RD-63 Pilot Interim Groundwater Extraction Test and Treatment Operations April through October, 1996. GRC, January 20, 1997.	RMHF	Update of data being collected during 6 months of pumping and treatment of RD-63 groundwater. RD-63 TCE concentrations ranged 7.2 to 15 µg/L.
Hydraulic Communication Study, Santa Susana Field Laboratory. GRC, June 3, 1997.	RMHF, FSDF, Building 4059	A site wide hydraulic study during which all pumping wells were shut off for 30 days, water level responses monitored, and then monitoring re-initiation of pumping.
Final FSDF SSFL Characterization Report. ICF Kaiser, August 17, 1997.	FSDF	FSDF soil contaminant characterization report.
Expansion of Construction Dewatering at Building 059, Area IV. GRC, January 6, 1999.	Building 4059	Planning document for dewatering of B56 excavation pit, and pumping from RD-25 and RD-28 to lower water in B4059 basement.
Monitoring Well RD-74 Completion Report. GRC, March 4, 1999.	B56 Landfill	Documentation of installation of RD-74.
Monitoring Well Drilling, Construction and Testing Progress Summary for January and February 1999. GRC, February 22, 1999.	B56 Landfill	Documentation on development and first sampling of RD-74.
Draft Final Interim Measures Workplan for Soil Cleanup at the FSDF. IT Corporation, July 9, 1999.	FSDF	The plan for contaminated soil removal at the FSDF.
Results of Dewatering Pit B/056. Area IV. GRC, July 23, 1999.	Building 4059	Report assesses potential for dewatering the B56 excavation as a measure to reduce recharge potential for the B4059 basement.
Results of Enhanced Dewatering Building 059. GRC, September 10, 1999.	Building 4059	Provides data on the pumping of RD-25 and RD-28 to lower groundwater elevation within the Building 4059 basement; response of pumping to lowered groundwater elevations in RD-07, RD-20, RD-74.
Final Report for Decontamination and Decommissioning of FSDF. Boeing, October 5, 1999.	FSDF	Report documents history and the activities resulting in the decommissioning and destruction of the FSDF.

Table 2-1 Representative Reports and Plans Documenting Area IV Groundwater Investigative Activities

Report/Document	Groundwater Investigation Area(s) Addressed	Summary of Contents
Infiltration Modeling Report, FSDF Interim Measures Backfill. IT Corporation, May 2000.	FSDF	Discusses the hydraulic conductivity properties of the backfill soil used as cover over the FSDF site.
RCRA Facility Investigation Work Plan Addendum Amendment. Ogden Environmental, June 2000a.	Rockwell International Hot Lab, Building 59, Building 4065, Former Hazardous Materials Storage Area, and Pond Dredge Area,	Provides facility description and associate well data for the facilities. Provides additional soil characterization details.
RCRA Facility Investigation, Shallow Zone Groundwater Investigation Work Plan, SSFL. Ogden Environmental, December 2000b.	SSFL and Area IV	Describes rationale for installation of piezometers throughout SSFL, including Area IV.
Annual Groundwater Monitoring Report SSFL, 1999. GRC, 2000.	SSFL overall	First comprehensive sampling results report for SSFL, includes Area IV wells installed through January 1999. Summarizes the use of the water supply well network as an industrial water source.
Work Plan for Additional Field Investigations Former Sodium Disposal Facility Chatsworth Formation Operable Unit. MWH, December 2001.	FSDF	Documents the plan for geophysical logging of wells, installation of FLUTe systems, drilling of corehole 8, and pump tests using RD-21.
RCRA Facility Investigation Work Plan Addendum, B56 Landfill. MWH, May 2003.	B56 Landfill	Provides facility history, prior investigation results, and proposed investigation activities.
Site Inspection Report, ETEC/Area IV. Weston Solutions, September 2003.	Off-site	Prepared for USEPA Region 9. Provides results of soil sampling on Brandeis-Bardin Institute, Santa Monica Mountains Conservancy, and Bell Canyon properties.
Near-Surface Groundwater Characterization Report, SSFL. MWH, November 2003.	SSFL and Area IV	Provides construction details for piezometers and initial water quality results.
Proposed Area IV Monitoring Wells. Haley & Aldrich, March 3, 2004.	Tritium Plume, Building 4100, Building 4064, Building 4059	Plan for installation of wells RD-90 (tritium plume), RD-91, (Building 4100), and RD-92 (Building 4064). Discloses proposal to abandon wells RD-25 and RD-28 at Building 4059.
Data Summary, Construction and Testing of Monitoring Wells RD-90, RD-91, and RD-92; and Abandonment of Wells RD-25 and RD-28, GRC June 16, 2004.	Tritium Plume, Building 4100, Building 4064, Building 4059	Well completion and sampling data for RD-90, RD-91 and RD-92; record of abandonment of RD-25 and RD-28.
Data Summary, Construction and Testing of Monitoring Wells RD-89, RD-93, RD-94, and RD-95. Haley & Aldrich, August 2005.	Tritium Plume	Documents installation and initial sampling of these tritium plume wells.

Table 2-1 Representative Reports and Plans Documenting Area IV Groundwater Investigative Activities

Report/Document	Groundwater Investigation Area(s) Addressed	Summary of Contents
Report of Result Former Sodium Disposal Facility Groundwater Characterization. MWH, February 2006a.	FSDF	Provides a summary of hydrogeological and contaminant source conditions for FSDF.
Proposed Area IV Monitoring Wells RD-96 and RD-97. Haley & Aldrich, April 14, 2006.	Tritium Plume	Plan for installation of two wells at tritium plume, RD-96 and RD-97.
Final Status Survey Report: Characterization and Final Status Survey – RMHF. Boeing, June 9, 2006.	RMHF	Provides surficial soil survey data post soil removal action at the RMHF.
Group 6 – Northeastern Portion of Area IV RCRA Facility Investigation Report. MWH, September 2006.	NCY, OCY, SRE Watershed, Building 4064 Leachfield	Describes for each SWMU, history, investigative work, and soil/soil gas, groundwater, and surface water data.
Final Characterization and Final Status Survey Report: RMHF Facility Holdup Pond (Site 4614). Cabrera Services, March 2007.	RMHF	Describes the Cs-137 impacted soil removal action from earthen-lined pond that once received run-off from the RMHF.
Group 8 – Western Portion of Area IV RCRA Facility Investigation Report, SSFL. MWH, September 2007.	B4009 Leachfield, B56 Landfill, ESADA, FSDF	Describes for each SWMU, history, investigative work, and soil/soil gas, groundwater, and surface water data.
Data Summary, Construction and Testing of Core Borings SB_Ttrit-01 and SB_Trit-02. Haley & Aldrich, October, 19, 2007.	Tritium Plume	Documents corehole logging and sampling of pore water for presence of tritium.
RCRA Facility Investigation Work Plan Addendum RMHF RFI Site. MWH, March 2008.	RMHF	Provides site history, previous sampling results, proposed additional sampling.
Draft Work Plan for Shallow Well Installation at SRE. MWH, May 2, 2008.	SRE	Plan for installation of well RS-36.
Well Construction Activities at the Former SRE Site. Haley & Aldrich, August 25, 2008.	SRE	Documents installation of piezometers PZ-150, PZ-160, and PZ-161.
Drilling, Construction, and Testing of Monitor Well RD-98. Haley and Aldrich, August 29, 2008.	RMHF Leachfield	Documents construction detail and initial sampling of RD-98.
RCRA Facility Investigation Work Plan Addendum Second Amendment RMHF. MWH, October 2008.	RMHF	Addresses DTSC comments on March 2008 submittal.
Group 5 – Central Portion of Areas III and IV, RCRA Facility Investigation Report, SSFL. CH2MHill, November 2008.	Boeing Area IV Leach Field, Pond Dredge Area, PDU, Southeast Drum Storage Yard, Building 4065 Metals Clarifier, Building 4100 Trench, DOE Leach Fields 1/2/3, Hazardous Materials Storage, Rockwell International Hot Lab, Building 4059 SNAP	Describes for each SWMU, history, investigative work, and soil/soil gas, groundwater, and surface water data.

Table 2-1 Representative Reports and Plans Documenting Area IV Groundwater Investigative Activities

Report/Document	Groundwater Investigation Area(s) Addressed	Summary of Contents
Group 7 – Northern Portion of Area IV, RCRA Facility Investigation Report, SSFL. MWH, June 2009.	Building 4029, Building 4133, RMHF	Describes for each SWMU, history, investigative work, and soil/soil gas, groundwater, and surface water data.
Review of 2006 and 2007 Data, Seeps and Springs Study, SSFL. Pierce and Cherry, University of Guelph, June 2, 2009.	Off-site	Sampling data for springs S-19 and FPD-424 in drainage below RMHF. Off-site well OS-3 downgradient from the FSDF.
Draft Site-Wide Groundwater Remedial Investigation Report, SSFL. MWH, December 2009.	SSFL Site-Wide	A compendium and interpretation of hydrogeological property data, numeric modeling, and contaminant transport/fate concepts.
Groundwater Remedial Investigation Data Gap Sampling and Analysis Plan (SAP). MWH, 2010.	SRE, FSDF	Addresses plan to install of well RD-102 at SRE pond. Trenching to evaluate potential for geologic structures to control groundwater flow at the FSDF.
Site-Wide Water Quality Sampling and Analysis Plan, SFFL – Revision 1. Haley & Aldrich, December 2010.	RMHF, Building 4010 Leach Field (Tritium Plume), Hazardous Materials Storage Area, B56 Landfill, FSDF, DOE Leach Fields (B4363, B4373)	A site-wide groundwater sampling and laboratory analysis plan. Addresses wells to be monitored for water level and sampled for water quality based on identified groundwater impact areas.
Technical Memorandum, Seeps and Spring Study, Installation of Well Clusters: Overview of 2011 Field Work. Pierce et al, May 7, 2012.	SP-19 seep probe cluster in drainage below the RMHF	Provides completion information and water quality data for the SP-19 probe cluster (two wells).
Final Groundwater Report, Area IV Radiological Study, SSFL. HGL, July 24, 2012a.	Sampling of all wells in Area IV for radionuclide characterization	As part of USEPA's Area IV radiological study, HGL sampled all accessible wells in Area IV in August/September 2010 and again in March/April 2011.
Results of Geologic Mapping and Excavations along the Western and Eastern FSDF Structures (Photolineaments) Area IV. MWH, May 2013.	FSDF	Provides an assessment of geological conditions near the FSDF using trenching to identify presence of faults or narrow zones of fractured rocks. Concludes that the fractures are not faults.
Technical Memorandum, Area IV Seeps Investigation, SSFL. Pierce et al., University of Guelph, October 28, 2014.	S-21, 19A, 19B seep probes in drainage below RMHF; 900A, 900B, 900C seep probes downgradient of the FSDF	Provides probe completion information and water quality data for these seep probes.
Former Sodium Disposal Facility Groundwater Interim Measures Aquifer Testing and Treatment, Conceptual Workplan, December CDM Smith, 2014	FSDF	Describes FSDF current conditions and the scope of a groundwater interim action pumping a treating of water extracted from well RS-54
Area IV RCRA Facility Investigation Groundwater Work Plan, CDM Smith, August 2015.	FSDF, B56 Landfill, Buildings 4057/4059, HMSA, RMHF, Buildings 4030/4093, Building 4064, Metals Clarifier	Addresses new well installation/data gap needs, selective interval testing of wells at the FSDF, B56 Landfill.

Table 2-1 Representative Reports and Plans Documenting Area IV Groundwater Investigative Activities

Report/Document	Groundwater Investigation Area(s) Addressed	Summary of Contents
Report on Annual Groundwater Monitoring, Area IV, 2016, North Wind, April 2017	Area IV groundwater network that are the responsibility of DOE	Provides the results for the new wells installed in Area IV during 2016, along with wells identified in the CO.
Work/Implementation Plan for Source Area Investigation at the FSDF Area IV, Santa Susana Field Laboratory, CDM Smith 2017	FSDF Near surface-groundwater	Provides the rationale and field procedures for testing of soil gas at the FSDF using membrane interface probe (MIP) and passive soil gas collection procedures.
Technical Memorandum – FSDF Source Investigation Progress Report – August 2018, CDM Smith	FSDF	Provides the results of MIP readings and passive soil gas sampling at the FSDF
Area IV Work Plan Addendum Area IV Source Investigations, CDM Smith March 2018	FSDF, Building 4009 leach field, HMSA	Provides a description of passive soil gas sample locations and sampling activities
Letter from John Jones, DOE, to Mark Malinowski, DTSC, providing the work scope and status of the FSDF GWIM March 2018	FSDF Well RS-54	Provides the rationale for the GWIM at the FSDF and interim results
Area IV Bedrock Investigation at the HMSA – Work Plan Addendum, CDM Smith, April 2018	HMSA	Addresses installation of two bedrock and two perched wells at the HMSA
Area IV Bedrock Investigation at the FSDF – Field Sampling Plan Addendum, CDM Smith, April 2018	FSDF	Addresses installation of shallow bedrock core holes as part of the source investigation at the FSDF
Technical Memorandum Soil Gas Source Investigation for FSDF, Building 4009, and HMSA, CDM Smith, August 2018	FSDF, Building 4009 Leach Field, HMSA	Addresses results of passive soil gas samples

A significant change addressing the implementation of groundwater investigation and cleanup at SSFL (including Area IV) occurred in 2007 when the DTSC issued the CO to Boeing, NASA, and DOE (DTSC 2007). The CO identifies the requirements and processes for completing groundwater and soils characterization for the entirety of SSFL. The CO identifies the two Area IV hazardous waste management units, Buildings 4029 and 4133, and the RMHF, as RCRA closure units.

In 2009, MWH released the *Draft Site-Wide Groundwater Remedial Investigation Report, Santa Susana Field Laboratory, Ventura County, California*. The focus of the 2009 Groundwater RI Report was general site-wide groundwater, hydrogeological descriptions, and contaminant fate and transport mechanisms. DTSC provided comments on the 2009 Groundwater RI Report on December 21, 2011 (Malinowski 2011a). The following are DTSC's general comments and DOE's explanation on how they are addressed in this GW RFI Report.

1. The 2009 Groundwater RI Report is incomplete and is organized in a manner difficult to review.

DOE issued the Area IV Groundwater RCRA Facility Investigation Work Plan (GW RFI Work Plan) in August 2015 (CDM Smith 2015a) that describes DOE's plan to complete characterization of Area IV. The GW RFI Work Plan included descriptions of the SWMUs along with the degree of groundwater impacts and issues for each groundwater investigation area known at time of work plan development. Because bedrock and contaminant release conditions are known to vary across Area IV, DOE developed individual site conceptual models reflecting those conditions. The field work that was implemented per the Work Plan was completed in August 2016. Follow on work was completed Fall of 2017 through the Spring 2018 to address data gaps at the FSDF, Building 4009 leach field, and the HMSA. The results of the fieldwork have been combined with prior and other ongoing work in other areas of SSFL to complete the Site-Wide Groundwater RFI for DOE portions of Area IV.

2. The transport of contaminants onsite and offsite cannot be predicted.

   DOE contracted with Baylor University to update the groundwater flow model for Area IV incorporating recent site data. DOE does recognize that flow and contaminant transport cannot be predicted with 100% certainty, but the model revisions produce an output reflective of historic and current data. Recent data collected from new monitoring wells and the installation and sampling of seep monitoring probes helps to address some of this uncertainty.

3. The impact of numerous faults at the site on the groundwater flow and contaminant movement is not supported by site-specific field data and is oversimplified.

   DOE believes that fault structures may have a greater influence on contaminant migration in locations of SSFL other than Area IV, but in this report DOE has used the most current fault information for structures within and near Area IV for the contaminant migration assessment.

4. There is insufficient characterization of release locations to determine if these areas can and/or should be remediated.

   In August 2015, DOE issued its plan to address Area IV groundwater characterization deficiencies. Following DTSC approval, DOE implemented the work plan, installed new monitoring wells, and collected additional hydrogeological property data. This has allowed for a greater understanding of contaminant presence and migration potential for the SWMUs. Additional source investigation was conducted during the Spring of 2018.The discussion of SWMUs and groundwater impact areas, as was discussed in the GW RFI Work Plan (CDM Smith 2015a), has been revised in this report to provide additional details on contaminant sources and releases.

2.2 Post-2009 Groundwater Investigative Work

The focus of the MWH 2009 Groundwater RI Report was on general site-wide groundwater issues, hydrogeological descriptions, and contaminant fate and transport mechanisms. Much of the investigative work described below was a result of the findings and agency requirements. The following is a summary of follow-up work completed after 2009 Groundwater RI Report up through the completion of the GW RFI Work Plan that is referenced within this GW RFI Report. Representative documents for post-2009 investigation and planning are also summarized on **Table 2-1**. In addition, The Site-Wide Water Quality Sampling and Analysis Plan Revision 1 (WQSAP; Haley and Aldrich 2010) standardized sample collection and analysis for SSFL. Data generated after use of WQSAP in 2010 is considered more representative of current groundwater conditions in Area IV. The WQSAP provides standard practices for water level measurements and purging and sampling of the wells. The plan also included monitoring frequency and parameters to be measured in selected wells. The WQSAP increased data usability and confidence that current site conditions are being documented and reported.

Following the release of the 2009 Groundwater RI Report, MWH released the Groundwater Data Gap Sampling and Analysis Plan (MWH 2010). For Area IV, this plan addressed installation of well RD-102 at the SRE pond, evaluation of geological structures near the FSDF that may control groundwater flow, and installation and sampling of seeps (seep monitoring probes) to the north and northwest of Area IV.

Monitoring well RD-102 at the SRE pond was installed in November 2011. Investigation of the "lineaments" near the FSDF was performed in January 2012 by trenching through alluvium and into weathered bedrock in the area north of Building 4100. It was determined that the geological structures observed in this area represent "narrow zones of intensely fractured rock" and should not be classified as faults (MWH 2013).

Groundwater seep investigations post-2009 included installation of additional seep monitoring probes (shallow monitoring points) and sampling of seeps when groundwater is present. MWH (2010) and Pierce et al. (2012a, b) describe proposed seep investigation work north of Area IV. Three seep clusters were installed north of Area IV: SP-19 in October 2011, SP-900 in October 2013, and SP-T02 in December 2013 and January 2014. Details of installation and results of sampling are provided in Section 5.0 of this Report.

Based on comments provided by DTSC on the 2009 Groundwater RI Report, DOE conducted a data gap analysis of groundwater data needs. The data gaps and work proposed to collect the needed information are described in the GW RFI Work Plan (CDM Smith 2015a). The work plan describes new wells, their locations and depths, and required laboratory analyses of groundwater samples to close data gaps. The work plan addressed removal of FLUTe systems that may be masking presence of contaminants and selective sampling of well borehole intervals to identify zones of contamination. The work plan also addressed analytical testing needs for selected existing wells to complete the groundwater database.

Per the GW RFI Work Plan, twelve new wells were installed during the winter/spring of 2016: three wells at the FSDF, one well at the B56 landfill, two wells addressing the B4059/4057 PCE plume, one well at the HMSA, one well associated with the Metals Clarifier, one well in the RMHF leachfield drainage, two wells at the Building 4064 leachfield, and one well at the Buildings 4030/4093 leachfield.

During the summer of 2016, FLUTe systems were removed from wells RD-23, RD-64, RD-65, RD-54A and core hole C-8. Video and geophysical logging of these wells were performed to identify fractures that would be potential pathways for contaminant migration. Identified fracture zones were then subject to packer-testing sampling and analyses. During the fall of 2017, soil gas was sampled at the FSDF to identify remaining sources, and the interim groundwater measure initiated at the FSDF. During March and April 2018, source investigations were continued at the FSDF, Building 4009 leach field site, and at the HMSA. Near-surface bedrock cores will drilled at the FSDF in May and June 2018 to locate fractures containing TCE.

A description of the groundwater characterization activities and analytical results are provided in a series of technical memoranda and are incorporated into the site descriptions provided in Section 5.

2.3 Area IV Monitoring Well Network

Table 2-2 provides well completion information for Area IV wells discussed in this text. **Figure 1-1** shows the locations of the wells in relation to the GIAs. Appendix A provides a compendium of well construction and completion details.

Table 2-2. Area IV Well Completion Details

Near-Surface Well Network				Bedrock Well Network			
Well ID	Well Depth (ft)	Screen/Open Borehole (ft)	Installation Month-Year	Well ID	Well Depth (ft)	Screen/Open Borehole (ft)	Installation Month-Year
ES-31	25	11.6-25	Jan-87	RD-07	300	25-300	Jan-86
PZ-05	45	25-45	Nov-00	RD-13	160	30-160	Jul-89
PZ-41	29.6	19-29	Jan-01	RD-14	125	30-125	Jul-89
PZ-51	27	5-15	Dec-00	RD-15	152	30-152	Jul-89
PZ-52	30	18.9-28.9	Dec-00	RD-16	220	30-220	Aug-89
PZ-55	29.5	19-29	Jan-01	RD-17	125	30-125	Aug-89
PZ-97	44.5	33-43	Oct-01	RD-18	240	30-240	Jul-89
PZ-98	37.5	24-34	Oct-01	RD-19	135	30-135	Jul-89
PZ-99	ABD	ABD	ABD	RD-20	127	30-127	Jul-89
PZ-100	16.5	5.7-15.7	Oct-01	RD-21	175	30-175	Aug-89
PZ-101	27	10-20	Oct-01	RD-22	440	30-440	Aug-89
PZ-102	59.2	48.5-59.2	Oct-01	RD-23	440	30-440	Aug-89
PZ-103	39	26-39	Oct-01	RD-24	150	30-150	Aug-89
PZ-104	38.5	18-28	Oct-01	~~RD-25~~	~~175~~	~~30-175~~	~~Aug-89~~
PZ-105	28	17-27	Oct-01	RD-27	150	30-150	Aug-89
PZ-106	35	18-28	Oct-01	~~RD-28~~	~~150~~	~~30-150~~	~~Aug-89~~
PZ-107	11	5-10	Oct-01	RD-29	100	30-100	Aug-89
PZ-108	30	26-30	Oct-01	RD-30	75	30-75	Aug-89
PZ-109	36.5	25-35	Oct-01	RD-33A	320	100-320	Sep-91
PZ-110	17.5	7-17	Oct-01	RD-33B	415	360-415	Sep-91
PZ-111	20	7.5-17.5	Oct-01	RD-33C	520	480-520	Sep-91
PZ-112	35	24-34	Oct-01	RD-34A	60	16-60	Sep-91
PZ-113	15	7-15	Oct-01	RD-34B	415	360-415	Sep-91
PZ-114	48.2	37-47	Oct-01	RD-34C	520	480-520	Sep-91
PZ-115	40	25-40	Oct-01	RD-50	195	18-195	May-93
PZ-116	34	22-32	Oct-01	RD-54A	278	119-278	Aug-93
PZ-120	26	15-25	Mar-03	RD-54B	437	379-437	Aug-93
PZ-121	33	15-25	Mar-03	RD-54C	638	557-638	Jul-93
PZ-122	27.5	15.5-25.5	Mar-03	RD-57	419	19.5-419	Feb-94
PZ-124	31	11.3-31	Mar-03	RD-59A	58	21-58	May-94
PZ-150	27.5	17.5-27.5	Aug-08	RD-59B	214	178-214	May-94
PZ-151	82	69.5-79.5	Aug-08	RD-59C	398	345-397	May-94
PZ-160	27	17-27	Aug-08	RD-63	230	20-230	Oct-94
PZ-161	28	18-28	Aug-08	RD-64	398	19-398	May-94

Table 2-2. Area IV Well Completion Details

Near-Surface Well Network				Bedrock Well Network			
Well ID	Well Depth (ft)	Screen/Open Borehole (ft)	Installation Month-Year	Well ID	Well Depth (ft)	Screen/Open Borehole (ft)	Installation Month-Year
PZ-162	41	31-41	April-18	RD-65	397	19-397	Aug-94
PZ-163	40	30-40	April-18	RD-74	101	30-101	Jan-99
RS-11	17.5	10-18.5	Jun-85	RD-85	90	20-90	Aug-04
RS-16	20.5	16.5-20.5	Jun-85	RD-86	80	20-80	Aug-04
RS-18	13	7.5-13	Jun-85	RD-87	60	20-60	Aug-04
RS-23	13	8-13	Aug-88	RD-88	30	20-30	Aug-04
RS-24	8.5	4-8.5	Aug-88	~~RD-89~~	~~50~~	~~30-50~~	~~May-05~~
RS-25	13.5	8.5-13.5	Aug-88	RD-90	125	20-125	Mar-04
RS-27	9	5-9	Aug-88	RD-91	140	20-140	Mar-04
RS-28	19	14-19	Aug-89	RD-92	105	20-105	Mar-04
RS-36	20	3-18	Aug-89	RD-93	60	20-60	May-05
RS-54	38	7-38	Aug-93	RD-94	35	20.5-35	May-05
DS-43	84	28-84	Feb-16	RD-95	80	50-80	May-05
DS-44	91	19-91	Jan-16	RD-96	90	20-90	Mar-06
DS-45	75	18-75	Jan-16	RD-97	74.5	20-74.5	Apr-06
DS-46	52	37-52	Feb-16	RD-98	65	20-65	Jun-08
C-20	61	7-61	Jun-18	RD-102	100	30-100	Nov-11
C-21	53	11-53	Jun-18	C-8	400	65-400	Apr-02
C-22	58	6-58	Jun-18	RD-150	170	40-170	Apr-16
C-23	61	8-61	Jun-18	RD-151	130	40-130	May-16
C-24	62	10-62	Jun-18	RD-152	60	20-60	Apr-16
C-25	63	6-63	May-18	RD-153	55	20-55	May-16
C-26	58	14-58	May-18	RD-154	145	40-145	May-16
C-27	63	16.5-63	May-18	RD-155	115	40-115	May-16
				RD-156	170	40-170	June-16
				DS-47	145	19-145	Mar-16
				DD-139	206	19-206	Feb-16
				DD-140	167	60-167	Feb-16
				DD-141	133	19.5-133	Jun-16
				DD-142	91	34-91	Feb-16
				DD-143	100	19.7-100	Jun-16
				DD-144	71	38-71	Jan-16
				DD-145	82	27-82	Feb-16
				DD-146	140	120-140	Jul-18
				DD-147	257	30-257	May-18
				WS-07	700	216 to 400	Circa 1954

Notes:
ft-feet, ID-identification, Jan-January, Feb-February, Mar-March, Apr-April, Jun-June, Jul-July, Aug-August, Oct-October, Nov-November, Dec-December, ABD-abandoned
RD-25 and RD-28 were abandoned in 2004 during the demolition of Building 4059
PZ-99 was abandoned in 2006 as a part of installation of Outfall 005
The depth of RD-89 was deepened in May 2018 approximately 50 ft to 257 ft bgs and renamed DD-147

Groundwater investigations within Area IV were initiated in 1985[1] with the installation of three Near-surface monitoring wells (RS-11, RS-16, and RS-18) above the bedrock interface at depths between 13 and 20.5 feet below ground surface (bgs). Eight additional Near-surface wells (ES-31,

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[1] Three wells were installed at the SRE site in the early 1970s, but there is no evidence that the wells were ever sampled.

RS-23, RS-24, RS-25, RS-27, RS-28, RS-36, and RS-54[2]) were installed between January 1987 and August 1993. These shallow wells are usually dry, exhibiting groundwater following significant rainfall events or in above average rainfall years. A total of 33 piezometers were installed between November 2000 and August 2008 (**Table 2-2**) to monitor groundwater that lies above the top of competent bedrock. One piezometer (PZ-99) was abandoned in 2006 during installation of the storm water control system northeast of the FSDF. Two piezometers were installed in 2018 by CDM Smith.

Shallow wells and piezometers consist of traditional blank well casing, well screen, and filter (sand) pack. Bedrock wells generally consist of steel conductor casing extending from the ground surface through the alluvium that terminated at the top of competent bedrock. The well boring was then continued through the competent bedrock to its total depth. The bedrock wells are termed "open borehole" because there is no well casing or screen beyond the surface conductor casing in the well. The borehole is open from the bottom of the conductor casing to its total depth. The conductor casing prevents soil and weathered rock from collapsing into the borehole. When installed sufficiently deep into bedrock, the casing also prevents Near-surface groundwater from artificially communicating with the deeper Chatsworth Formation groundwater. In some wells, the conductor casing may not have been advanced into competent, unweathered bedrock and, therefore, isolation of the alluvium/weathered bedrock zone at these locations is questionable.

The first bedrock monitoring well (RD-07) was installed at the Building 56 landfill in 1986; 48 additional bedrock wells were installed from July 1989 and June 2006. Two of the 49 bedrock wells (RD-25 and RD-28) were abandoned in 2004 during the demolition of Building 4059.

Following the release of the 2009 Groundwater RI Report (MWH 2009a), RD-102 was installed at the SRE pond site in November 2011. Twelve more wells were installed in 2016 to address data gaps evaluated in the 2015 GW RFI Work Plan (CDM Smith 2015a). Boeing installed 7 wells in Area IV in 2017 (RD-150 to RD-156). CDM Smith deepened the location of RD-29 (renamed DD-147) to 257 feet bgs in May 2018 and installed a deeper well at the HMSA center (DD-146, 140 ft bgs) in June 2018.

Monitoring probes have been installed at groundwater seep locations in the Northern Buffer Zone and on Brandeis property north of Area IV. **Table 2-3** provides completion details for the probes (also termed seep clusters) and **Figure 1-1** illustrates their locations. Results of sampling of the probes are presented in Chapter 5 of this report in relation to the groundwater investigation area that the seep probes monitor.

Table 2-3. Seep Cluster Construction Details

Seep Probe	Date of Installation	Depth (feet bgs)	Screen Interval (feet bgs)	Outer Diameter (inches)	Material
SP-T02A	Dec 2013	9.48	7.5-9.48	0.840	PVC
SP-T02B	Dec 2013	12.42	10-12.42	0.840	PVC
SP-T02C	Jan 2014	24.3	19-24.3	0.840	PVC
SP-T02D	Dec 2013	35.18	30-35	0.840	PVC
SP-19A	Oct 2011	10.0	7-10	1.05	PVC
SP-19B	Oct 2011	18.83	16-18.8	1.05	PVC

[2] Note – monitoring wells installed across SSFL were numbered using a sequencing process. Breaks in number sequence indicates a well in the sequence was installed elsewhere at SSFL.

Table 2-3. Seep Cluster Construction Details

Seep Probe	Date of Installation	Depth (feet bgs)	Screen Interval (feet bgs)	Outer Diameter (inches)	Material
SP-29A	NA	3.8	3.3-3.8	0.5	NA
SP-29B	NA	16.2	14.7-16.2	0.5	NA
SP-29C	NA	21.9	Water-filled Packer	1.65 core	NA
SP-424A	NA	8.8	3.3-8.8	0.5	NA
SP-424B	NA	16.9	15-16.9	0.5	NA
SP-424C	NA	19.6	16.6-19.6	0.5	NA
SP-900A	Oct 2013	10.0	3.73-10	0.840	PVC
SP-900B	Oct 2013	18.41	16-18.41	0.840	PVC
SP-900C	Oct 2013	30.3	26.5-30	0.840	PVC

Notes:
Dec – December
Jan – January
Oct – October
PVC – Polyvinyl chloride
NA – Not available
bgs – below ground surface

2.4 Treatability Studies

A feasibility study work plan (FS Work Plan) (MWH 2009b) was developed to identify and assess potential groundwater contaminant treatment technologies for the entire SSFL that ultimately would be addressed in a CMS. Four technologies were identified in the FS Work Plan (MWH 2009c) for further study. These include: (1) vapor extraction in the unsaturated bedrock; (2) *In situ* chemical oxidation; (3) enhanced biological reduction, and; (4) thermal treatment. A description of these studies and their outcomes are presented below.

Bedrock Vapor Extraction Field Experiment

The bedrock vapor extraction (BVE) treatability study was developed to evaluate the removal of VOCs, with TCE being the most prevalent VOC observed in groundwater (CH2M Hill 2015). The performance criteria for the BVE field experiment were to: (1) determine air removal production from the extraction well; (2) determine VOC mass flow rate over time; (3) assess vacuum response in fractures and rock matrix; (4) improve understanding of lithologic and/or structural variations and their impacts on formation flow paths; and, (5) understand the diffusive response of VOCs from the rock matrix blocks post treatment. The BVE study involved the use of an existing groundwater monitoring well HAR-19 retrofitted to serve as a vapor extraction well. The well is located at the Bowl RI site in Area I. Adjacent monitoring wells and probes were used to monitor subsurface responses to the vapor extraction. The targeted depth of the test was 87 to 89 feet bgs based on the presence of a fracture network. The BVE system was operated over a three-week period, work days only. During this time period approximately 30 pounds of total VOCs were removed. Vacuum responses were observed in wells/probes up to 378 feet away from the vapor extraction well.

Chemical Oxidation

The chemical oxidation study involved injecting potassium permanganate, an oxidizing agent, into the subsurface bedrock and groundwater followed by evaluating the chemical distribution within the bedrock, its movement, and the ability to reduce contaminant mass (TCE and breakdown chemicals) (CH2M Hill 2016). The objectives of the study were to: (1) evaluate the effectiveness of delivery of the oxidant into the fractured bedrock; (2) assess the extent of oxidation of VOCs in the rock matrix; (3) assess the natural oxidant demand of the rock matrix; (4) assess the magnitude and extent of reactive minerals that could affect oxidation of VOCs; and, (5) assess the interaction of oxidation precipitants on the overall processes.

For this technology to be effective, the potassium permanganate must be able to move from the point of injection into the bedrock matrix to come in contact with the VOCs, and oxidize the VOCs to simpler molecules. Groundwater contamination at the Area I Instrument and Equipment Laboratory site was selected for this study.

The study proved successful for injecting potassium permanganate into the subsurface and demonstrating that the chemical could be transported in bedrock fractures away from the injection site. However, the study was unsuccessful in meeting its primary objective, which was the reduction of contaminant mass in the subsurface. The natural oxygen demand of the bedrock system interfered with the chemicals ability to interact with TCE and dechlorinate the chemical. TCE concentrations in groundwater rebounded after the potassium permanganate completed its interactions with the bedrock matrix (CH2M Hill 2016).

Bedrock Thermal Treatment Literature Evaluation

A literature review evaluation of the application of *in situ* thermal treatment of fractured bedrock was a performed to address the Treatability Study requirement (CDM Smith 2016d). Originally, the first step of this study was to be performed in the laboratory using bedrock core and focused on evaluating the level of heating that would be required to enhance mass removal from bedrock. However, DOE budget limitations precluded the laboratory study. DOE discussed the issue with DTSC and both parties agreed to complete a literature review to determine how and where subsurface thermal treatment in bedrock to depths of 900 feet had been accomplished.

The literature review identified several sites across the United States where *in situ* thermal was successful at TCE removal in the subsurface; however, only one of these applications extended to 110 feet bgs with all other site applications less than 90 feet bgs. No record was found of an attempt to apply thermal treatment at depths greater than 110 feet bgs (CDM Smith 2016d).

Biostimulation to Treat Chlorinated Ethenes in the Chatsworth Formation

This report, prepared by Freedman and Yu of Clemson University[3], provides the results of laboratory studies conducted to evaluate dichlorination of TCE. This study had three objectives: 1) to determine the effect of biostimulation of the rate of TCE reduction in bedrock; 2) to determine if biostimulation enhances transformation of TCE and cis-1,2-DCE to vinyl chloride and ethenes; and 3) to assess the effect of biostimulation on transformation of TCE and cis-DCE in the rock matrix. Two types of microcosm studies were performed, one using crushed cores and the second using intact bedrock cores. The investigators determined that biostimulation within crushed core microcosms using lactate, a hydrogen release compound (termed HRC), and emulsified vegetable oil (EVO) resulted in significantly improved rates of TCE reduction to cis-DCE, compared with control microcosms. Biostimulation using lactate also enhance reductive

[3] Freeman, D.L and R. Yu, 2017. Final Report, Laboratory Evaluation of Biostimulation to Treat Chlorinated Ethenes in the Chatsworth Formation, Santa Susana Field Laboratory, Ventura County, California. June 26.

dichlorination of DCE to vinyl chloride and ethene. This suggested that the bacterium *Dehalococcoides* was present. Use of the HRC and EVO chemicals did not show a similar degradation extent. The investigators were not able to replicate the degree of dichlorination in the intact core microcosms, however.

2.5 FSDF Groundwater Interim Measure

The groundwater interim measure (GWIM) study proposed for the FSDF resulted from a request made by DTSC to implement groundwater control measures at locations where elevated TCE concentrations exist in groundwater. This requirement was applicable to Area IV at the FSDF where well RS-54 had historically exhibited TCE concentrations exceeding 1,000 µg/L. When sampled in 2013, RS-54 exhibited 1,600 µg/L of TCE. Water level elevations in RS-54 have been measured annually and the well was dry in the 2014 to early 2017 timeframe.

The *Draft Santa Susana Field Laboratory Former Sodium Disposal Facility Groundwater Interim Measures Implementation Plan* (CDM Smith 2015b) was developed for constructing and operating a groundwater treatment system at the FSDF to address the GWIM requirement. DOE discussed the requirements with DTSC and California Regional Water Quality Control Board on December 7, 2015 and completed the GWIM conceptual design.

DOE could not implement the plan until after the 2016-2017 winter rains re-saturated fractures with VOCs at RS-54. DOE initiated pumping of RS-54 in November 2017, pumping the well dry and allowing it to recover for subsequent pumping. Pumping occurred periodically and by June 2018, approximately 330 gallons had been removed. Section 5.2 provides details regarding the FSDF GWIM and pumping of RS-54.

Section 3

Area IV Geology

3.1 Geology Overview

Area IV of the SSFL is located in the Simi Hills, a northeast- southwest trending sub-range of the Santa Monica Mountains, in the Transverse Ranges physiographic province of California. Most of Area IV is a topographic high, with decreasing elevation to the north and south from Area IV boundaries. The elevation of Area IV (**Figure 3-1**) ranges between 1,300 feet amsl within the Northern Buffer Zone (NBZ) to 2,150 feet amsl along the southwestern boundary of Area IV. Along the northwestern boundary of Area IV, the land slopes steeply toward Simi Valley. Burro Flats, which exhibits the least variability in topography, is located in the central portion of Area IV. Burro Flats is where the majority of development occurred, and ranges in elevation between 1,780 and 1,860 feet amsl.

Bedrock is exposed at the ground surface over approximately 40 percent of Area IV and the NBZ (i.e., there is no soil in these areas). The remainder of Area IV is covered with weathered bedrock, colluvium, and alluvium derived from both the Chatsworth and Santa Susana Formations. The soil type and distribution in Area IV and the NBZ is shown on **Figure 3-2**. A layer of soil approximately 5 to 10 feet thick covers much of Area IV. Whereas, soil at Burro Flats can be up to 20 feet thick. Colluvial and alluvial soil is also found at the base of hill slopes, topographic lows, and along stream drainages. Fill material is present over much of the developed or formerly-developed areas of Area IV.

Much of geologic understanding of the SSFL was developed by Boeing and NASA for their respective areas. This report relies primarily on the findings of Boeing's and NASA's work regarding surficial geology and fault discussion. However, descriptions of the subsurface geology have been updated based on the results of recent bedrock borings.

Figure 3-3 is the revised geologic map of SSFL. It was modified since the issuance of the 2009 Groundwater RI Report with the modifications based on the analyses provided in the report *Draft Hydrogeologic Characterization of Faults* (Faults Report, MWH 2016b). As described in the faults report, the basis for the mapping of faults is as follows:

> *The distribution and naming of geologic units and faults in Figure 1-1 (of MWH 2016b) is largely consistent with the draft GWRI (MWH 2009). The detailed delineation of exposed faults and fine-grained units has been modified, however, based on more recent work by Cilona and others (2015, 2016; Appendices B and C). They investigated the geometry, orientation, and distribution of SSFL fractures and faults using Google Earth and drone and helicopter aerial photography, followed by detailed field observation. For areas outside those recently mapped, the map is based on Diblee [sic] (1992), Yerkes and Campbell (2005), and MWH (2009). Matching these maps to the recently mapped area was assisted through inspection of contoured high-resolution LiDAR ground-surface elevations. Areas of alluvium, colluvium, and fill that partially obscure*

bedrock and fault exposures are delineated based on inspection of aerial and satellite photographs, previously existing maps, and LiDAR data.

It is important to note that Area IV differs geologically in three ways from other areas of the SSFL. First, the degree of bedrock fracturing in Area IV is less extensive than the other areas of the Site (Wagner and Perkins 2009; COLOG 2016). The bedrock in Area IV has been measured to have about 36% lower matrix hydraulic conductivity compared to the site-wide sample set (MWH 2006a). In addition, Area IV hydrogeology appears to be less influenced by faults and there is not a fault running through the center of Area IV. This is visually apparent on **Figure 3-3** when comparing Area IV to Area I, II, and III.

3.2 Geologic Formations and Structures

The Chatsworth and Santa Susana Formations are the two geologic formations that underlie Area IV.

3.2.1 Chatsworth Formation

The Cretaceous Period (65 to 140 million years ago) Chatsworth Formation underlies approximately 80 percent of Area IV and consists primarily of over 6,000 feet of massive thickly-bedded sandstone with lesser amounts of interbedded shale, siltstone, and conglomerate. **Figure 3-4** provides a generalized stratigraphic column illustrating the relationship of these units. The Chatsworth Formation is divided into upper and lower units. The Lower Chatsworth Formation is exposed (or outcrops) only in the southeastern portion of the SSFL, south of Area I (**Figure 3-3**). The Upper Chatsworth Formation is subdivided into upper and lower stratigraphic "packages" referred to as Sandstone 2 and Sandstone 1, respectively. Area IV is primarily underlain by Sandstone 2, which comprises three coarser-grained members separated by two finer-grained members. These members from oldest to youngest are: Silvernale, SPA, Lower Burro Flats, ELV, and Upper Burro Flats. The finer-grained members (the SPA and ELV members) contain at least 50 percent siltstone or shale interbedded with sandstone. A third thinner and less continuous fine-grained unit, the Lot Bed, is found in the lower section of the Upper Burro Flats member in the northwest part of Area IV.

Figure 3-5 is the Area IV geologic map with field-measured strike and dip of bedding, faults and deformation bands. **Figure 3-5** is the SSFL geologic map as presented in the *Report on Annual Groundwater Monitoring, 2014* (CDM Smith 2015c). It is important to note that this map presents updated geologic interpretations made since issuance of the 2009 Groundwater RI Report but not presented in the 2016 Faults report. Of interest are the deformation bands and Western and Eastern FSDF Structures at the FSDF. These structures have been updated on **Figures 3-3 and 3-5** based on the 2016 Faults Report.

Beds of the Chatsworth Formation have been previously reported as striking approximately N70°E and dipping 25° to 35° to the northwest (MWH 2006c). Strike and dip specific to Area IV was generated using a three-dimensional model (Leapfrog©) and fine-grained unit outcrops mapped in the field (**Figure 3-6**). In the model, a planar surface orientated with the original SSFL strike and dip was projected along the topographic surface and compared to the mapped surface expression of the fine-grained units shown on the geologic base map.

With little topographic relief at the Burro Flats plateau, adjustment of the strike and dip using the Shale 2, SPA, ELV or Lot Bed was not evident. However, when projecting the original SSFL strike and dip along the Shale 3 unit, an area with greater topographic relief, it was observed that the SRE/RMHF photo lineament was observed to have good correspondence to the contact between the Upper Burro Flats member and the Shale 3 fine-grained unit. Since the SRE/RMHF was identified as an aerial photo lineament and no structural features have been observed or mapped, it was concluded that lineament is most likely a stratigraphic contact and not a fault.

DOE acknowledges the uncertainty associated with this geologic interpretation of the SRE/RHF lineament. An alternative interpretation is that the lineament is a fault supported by two observations at the site: 1) lack of the Shale 3 unit being mapped (discussed below) and, 2) enhanced east-west fracturing and hydraulic conductivity north of the RMHF (discussed in Section 4).

Although there are areas on the geologic base map that do not show the Shale 3 as being present, lack of this unit may be explained by the steep and difficult terrain of the area, accessibility limitation, minor lithologic differences in the shale interval [interbedded medium-grained sandstone and fine-grained units comprised of thin-bedded fine- and medium-grained sandstone, siltstones, and shale (**Figure 3-4**)]. Additionally, this area is located hydraulically downgradient and physically outside of the Area IV and NBZ, and thus was not extensively investigated.

Lines of evidence that support strike and dip for Area IV included boring logs, groundwater conditions, and erosion features. Boring logs[1] recorded during the installation of bedrock monitoring wells were evaluated for evidence of fractures, fine-grained units, rig chatter, and water production while drilling. These observations generally support the presence of fine-grained units at depth when compared to the model's projected geologic unit at depth.

Fine-grained units control groundwater elevations throughout much of Area IV. When evaluating water elevations and geologic members/units, there is strong correlation between the model's projected geologic unit at depth and groundwater elevations.

Erosion features such as slope changes, locations of drainages, and presence of capstones show a good correlation between the model's projected geologic unit and surface topography.

Data collected as part of the logging and coring of monitoring wells drilled into bedrock were used to aid in identifying the presence of geologic units below Area IV. **Figure 3-7** illustrates the monitoring well network. Cross-sections of the geologic units provided in this section are based on logging profiles of wells in this network.

Plate 1 provides the locations of cross-sections that are described in Sections 3, 4, and 5 of this report. **Figure 3-8** presents the stratigraphic column in cross section across the central portion of Area IV. The orientation of the cross section is perpendicular to strike of the fine-grained units. This figure and all cross-section figures project fine-grained units at a strike and dip azimuths of 333° and 25°, respectively. It is important to note that the projected interval may not contain the fine-grained unit. These fine-grained units are discontinuous at the SSFL and the lack of detection

[1] The boring logs developed for Area IV wells are included as **Appendix A** of this report.

at a specific interval may be the result of a slightly different strike/dip, poor geologic recognition during drilling, or that the unit was never deposited or the unit has since been eroded at a specific boring location. Discontinuity of fine-grained beds are particularly true for the thinner Lot Bed. Fine-grained beds are shown in cross sections as continuous. Refinement of the stratigraphic column at specific locations within Area IV will be performed during the CMS, if required.

3.2.2 Santa Susana Formation

The Santa Susana Formation is only found in the southern portions of Area IV and the southwestern-most portions of Area III (**Figure 3-3**). The Santa Susana Formation is separated from the Chatsworth Formation by the Burro Flats Fault. The formation is younger Eocene and Paleocene in age and according to *Geologic Map of the Calabasas Quadrangle* (Dibblee 1992), is comprised of four mapable units. The uppermost (youngest) unit outcrops in Area IV and consists of gray micaceous claystone and siltstone with few minor thin sandstone beds. Within Area IV, this unit has not been studied in the field. The only historic operations on the Santa Susana Formation were two former water storage tanks located at the top of the hill, about 1,000 feet southeast of RD-50.

3.2.3 Structures

The SSFL is located on the south flank of an approximately east-west striking, westward plunging syncline. Beds of the Chatsworth Formation at the SSFL on average strike and dip at N70°E and dipping 25° to 35° to the northwest (MWH 2006b). As previously described, within Area IV, strike and dip are projected at N63°E, 25°NW. Geologic structure data collected and analyzed are provided in the *Faults Report* (MWH 2016b).

In summary, there are five categories of geologic structures present at the SSFL, faults/fault zones, deformation bands, lineaments, fractures and joints. These structures are introduced here and discussed specifically in Area IV in Section 3.3.

As presented in the *Faults Report* (MWH 2016b), three types of fault traces have been mapped across SSFL as illustrated in **Figure 3-3.** Mapping is based on a subset of fault classifications defined by U. S. Geological Survey standards (Federal Geographic Data Committee 2006). Interpretations of fault traces shown on **Figure 3-3** are based on the following criteria:

1. Location accurate, identity and existence certain (solid line).

2. Location inferred, identity and existence certain (dashed line).

3. Location inferred, identity and existence uncertain (dashed and queried line).

The two major sets of faults and fault zones found within Areas I and II are not found in the core of Area IV. The Burro Flats Fault is found south of Area IV, and a possible extension of the North Fault may occur north of the NBZ.

Burro Flats Fault

The Burro Flats Fault trends west-northwest to east-southeast in the southern part of Area IV as shown on **Figure 3-3**. The Geologic Map of Calabasas Quadrangle (Dibblee 1992) illustrates that rocks on the north side of the fault are displaced upward relative to those on the south side resulting in Cretaceous Age Chatsworth Formation beds juxtaposed against the younger Santa

Susana Formation to the south. The Burro Flats Fault also displays apparent left-lateral strike slip displacement (MWH 2016b).

The *Faults Report* (MWH 2016b) provides the following summary of field investigations and associated conclusions for the Burro Flats Fault:

- The Burro Flats Fault crosses the entire southern width of SSFL and is the dominant fault of the surrounding nearby region.
- The length of the Burro Flats Fault is reported as 32,800 feet (10,000 meters).
- Most field investigation work performed to identify the fault, including trenching, was conducted in Areas II and III.
- The mapped fault zone is approximately 200 feet wide where it crosses the southern portion of Area III and the southwestern corner of Area II.
- Shallow trenches excavated into sandstone along the fault zone's southern margin encountered ancillary faults, fault gouge, intense fracturing, breccia, and deformation folding.
- Clusters of shallow monitoring wells installed adjacent to groundwater seeps below Area II and along the southwest drainage where it crosses the fault have been used to monitor the hydraulic influence of the fault when WS-9A is pumped.
- The Burro Flats Fault zone exhibits aspects of both a partial hydraulic barrier and a zone of enhanced hydraulic connectivity.
- Evidence of a partial hydraulic barrier along the Burro Flats Fault includes groundwater-level differences across the fault.

The *Faults Report* (MWH 2016b) concludes:

> *As a well-developed regional strike-slip fault, a hydraulic barrier effect may be expected along much of the Burro Flats fault as a result of cumulative cataclasis, repeated strain of the already weakened fault core, and limited damage-zone growth* (page 4-13). It is reasonable to assume partial hydraulic barrier is fairly continuous along this well-developed fault along its eastern extent south of Area IV. The Burro Flats Fault in Area IV is inferred to be a barrier to flow across the fault based on calibration requirements of the groundwater flow model. Sensitivity analyses with the flow model indicate that the hydraulic conductivity of the three segments of the Burro Flats Fault near the FSDF must be within a range of low conductivities to obtain an acceptably accurate match to observations used in the model calibration.

North Fault

Figure 3-3 shows the location of the North Fault. Information presented on the North Fault in the *Faults Report* (MWH 2016b) include the following:

- The North Fault extends 1.5 miles west from the Shear Zone across the northern boundaries of Areas I, II, and III. It consists of several strands within a zone up to several hundred feet wide with a well-defined geomorphic expression.
- The North Fault exhibits a variety of hydraulic influences depending on location and depth (MWH 2016b, Appendix L, Figures 74 through 89).
- North of Area IV the North Fault dissipates into a wide zone of deformation bands which may be a partial hydraulic barrier contributing to a steep northward hydraulic gradient.

Damage and shear zones of a fault are manifested as either enhanced permeability, partial or complete hydraulic barrier, or no effect on groundwater movement. Fault rock may be relatively permeable in areas with low-clay content, forming a disaggregation or fragmentation zone with similar or greater permeability than the host rock (MWH 2016b). The Fault Report further states that the Shear Zone has a fault core of enhanced continuity and low permeability as a result of shale smearing (Cilona and Johnson 2015). This hydraulic barrier is responsible for cross-fault head differences ranging up to 400 feet historically during periods of heavy groundwater pumping west of the fault (MWH 2016b).

Deformation Bands

Deformation bands have been mapped across SSFL, typically in proximity to some fault zones and incipient faults extending beyond the end of mapped fault traces (MWH 2009a). Deformation bands are generated as a result of strain localization along pre-existing shear joints in relatively coarse-grained, high-porosity rocks. Compared to other fracture types, deformation bands have enhanced cohesion and reduced permeability as a result of processes that include compaction, catalases, phyllosilicate smearing, and mineral precipitation (MWH 2016). These low-permeability features reduce bulk permeability and may contribute to anisotropy where similarly oriented (Kolyukhin et al. 2009).

Lineaments

Lineaments are structural features that have been observed in aerial photographs but are not definable as faults or deformation bands due to the lack of exposure on the surface (MWH 2009a).

Fractures and Joints

Fractures and joints are prevalent throughout the Chatsworth Formation and may be important conduits for groundwater and contaminant movement. A study of approximately 1,000 joints found in the Chatsworth Formation at the SSFL (Wagner and Perkins 2009) found that about 70 percent of the joints belonged to one of two "sets." One set of fractures trends to the northwest and the other to the northeast. Both joint sets dip steeply (greater than 60˚). Less than 2 percent of the joints observed in outcrops dipped at less than 30˚. However, water-producing open fractures along bedding planes have also been observed in geophysical borehole logs. Joints in the sandstone beds were observed to terminate in relatively thin shale beds resulting in decreased connectivity of joint sets across lithologic contacts. Where multiple joint sets are present, there may be lateral connectivity but limited vertical connectivity due to the presence of shale beds. Wagner and Perkins (2009) measured joint density (the number of joints per 100 feet in a direction perpendicular to the trend of the joint set) from Google Earth™ imagery. Joint spacing is proportional to bedding thickness and as a result, the relatively thinner interbedded shale beds would have a predicted higher frequency of joints/fractures even though these may not be as prominent and identifiable in outcrop in the sandstones.

Fracture density is lower in Area IV than other areas of the SSFL. Across Burro Flats, the fracture density is less than 0.5 fracture per 100 feet. In the RMHF and SRE area, as well as the extreme south west of Area IV, fracture density is 1 to 2 per 100 feet (Wagner and Perkins 2009).

3.3 Topography, Geology, and Soils of Area IV Study Areas

Distinct differences in surficial and subsurface geology were used to divide Area IV into four hydrogeologic areas to evaluate differences in geologic strata and structures that influence localized groundwater presence and flow. The areas, shown on **Figure 3-9** include:

- The South hydrogeologic area: located south of the Burro Flats Fault is within the Santa Susana Formation; thus, geologically distinct from the remainder of Area IV. There are no groundwater investigation areas within the South hydrogeologic area.
- The Northwest hydrogeologic area: located along the western and northern boundaries of Area IV, the area includes the western edge of the Burro Flats from the Lot Bed west to the western limit of the NBZ. The Northwest hydrogeologic area extends along the entire northwest boundary of Area IV and includes the topographically rugged area of the Northern Buffer Zone. Bedrock cores show this area to exhibit tighter bedrock with fewer fractures compared to other locations in Area IV. Groundwater investigation areas within the Northwest area include the FSDF, the Building 56 Landfill, the RMHF, and the SRE watershed.
- The Central hydrogeologic area corresponds to the majority of the Burro Flats area. At the surface this area exhibits the flattest terrain (minimal relief) with least bedrock outcrops. The Tritium Plume, HMSA, and Metals Clarifier/DOE Leach Fields 3 are located in the Central hydrogeologic area.
- The East hydrogeologic area: east of Central Area IV and south of the Northwest hydrogeologic area. Although the east area lacks steep terrain seen in the Northwest area, the area exhibits extensive bedrock outcrops. The Old Conservation Yard, Building 4029, and Building 4030 and Building 093 Leach Fields are located in the East hydrogeologic area.

Soil boring logs developed as part of collection of alluvium soil samples have been used to identify soil thickness and groundwater monitoring well logs were used to define area stratigraphy. **Figure 3-7** illustrates the Area IV well network. **Table 3-1** presents the geologic unit intercepted by each monitoring well within each hydrogeologic study area. The following sections present the topography, soil, stratigraphy and geologic structures for each hydrogeologic area.

Cross-sectional figures are presented in the following subsections that illustrate the geological stratigraphy. The intercept of geologic units for each well is based on the application of a 3-D model (Leapfrog©) that projects the geologic unit at the borehole location. This intercept is shown as a top and bottom intercept in feet bgs. Boring logs were reviewed at these depths to confirm the presence of the unit. In most cases, the geologic unit was identified or suspected at, within, or very close to the geologic unit's assumed interval thickness. In some borings, no determination could be made because the boring was not logged.

3.3.1 South Hydrogeologic Area – Topography, Soil, Stratigraphy, and Structures

The South hydrogeologic area (**Figure 3-9**) comprises the Santa Susana Formation. Topographically the land in the south hydrogeologic area rises from approximately 1,920 feet amsl near the fault to over 2,150 feet amsl at the top of a prominent hill (**Figure 3-1**).

3.3.1.1 Geologic and Soil Description and Mapping

Soils in the South hydrogeologic area have been mapped as Calleguas-Arnold complex with 30 to 50 percent eroded slopes, Zamora loam with 9 to 15 percent slopes and Graviota rocky sandy loam with 15 to 50 percent slopes (USDA 2014a, b, c, d) (**Figure 3-2**). The entire area is underlain by the Santa Susana Formation. Near well RD-50, unconsolidated materials derived from the weathered Santa Susana Formation consist of silty and sandy clays. At the top of the hill, soils are light colored and are derived from weathering of a shell-rich layer of the Santa Susana Formation.

The rock strata strike to the northeast and dip to the northwest at about 40˚ (Dibblee 1992). The northern slope of the larger hill southeast of RD-50 (Dibblee 1992) has a northeast–southeast strike with a 20˚ dip (shown as 20˚, but uncertain) to the southwest. This markedly different strike of the northern slope may indicate relatively more deformed beds of the Santa Susana Formation south of the Burro Flats Fault than is observed in the Chatsworth Formation north of the fault.

3.3.1.2 Borehole Lithology and Fracture Evaluation

One bedrock well, RD-50 (**Figure 3-7**) is situated within the Santa Susana Formation, immediately south of the Chatsworth Formation (Burro Flats Fault) (Boeing & MHW 2017). Because the well is located in Boeing's area of responsibility, ESADA, and located south of the Burro Flats Fault, the reader is directed to Boeing's RI report for information on this area.

3.3.1.3 Fault Identification and Interpretation

The Burro Flats Fault southeast of Area IV is discussed in detail in the Faults Report (MWH 2016b). Subsequent to that submittal, Boeing has re-analyzed and interpreted the fault data. The final conclusion is presented in Boeing's Groundwater RI report (Boeing & MHW 2017). There are no data on the geologic properties of the Burro Flat Fault within Area IV; however, the influence of the fault on groundwater is discussed in Section 4.

3.3.2 The Northwest Hydrogeologic Area – Topography, Soil, Stratigraphy, and Structures

3.3.2.1 Geologic and Soil Description and Mapping

Topographically, the Northwest hydrogeologic area is a continuation of the Burro Flats portion of Area IV, but it does exhibit more bedrock outcrops than the Central hydrogeologic area. The US Department of Agriculture (USDA) classifies soils in this area predominantly as sedimentary rock landscape with slopes of 30 to 50 percent. Logs for boreholes in the area indicate a relatively thin

(0 to 3 feet) layer of alluvial material except in drainage pathways where alluvium is up to 8 feet thick (e.g., at boring RD-34).

Surface-water drainage in the southwestern end of the Northwest hydrogeologic area flows north along pathways that cut through the ridges of sandstone (at an angle to geologic strike) into pathways trending northeast (along geologic strike) and ultimately to a drainage pathway that flows off-site to the northwest. In the area near the RMHF and SRE, the surface drainage pathway strikes east-west with flow initially to the west and then to the north.

The lithology of the Upper Chatsworth Formation is predominantly sandstone, beds of fine to coarse sand, with interbedded siltstones and shale beds (**Figure 3-4**). The interbedded fine-grained units within the sandstone vary along strike. The Lot Bed is identified as the most discontinuous fine-grained unit found in the Upper Burro Flats Member. The Shale 3, ELV, SPA, and Shale 2 maybe discontinuous locally but are generally present within Area IV. The sandstone beds include 5- to 10-ft thick well- indurated beds interbedded with generally thicker beds of weakly-cemented, friable and fractured sandstone.

Upper members of the Chatsworth Formation outcrop in the Northwest hydrogeologic area including the fine-grained Lot Bed that bounds the northeast side of the area, the upper half of the Upper Burro Flats member, and the Shale 3 member. **Figure 3-10** is a cross section of this area that shows these beds strike to the northeast and dip 25° to the northwest. The Lot Bed is discontinuous to both the northeast and southwest. However, discontinuous beds may be present at depth, so, the Lot Bed is shown as continuous on all cross sections. **Figure 3-11** present the relationship between fine-grained units (Shale 2, SPA, ELV, and Lot Bed) between the RD-33 and RD-54 cluster wells.

Sandstone at the surface is expressed as bedrock ridges as shown as outcrops on **Figure 3-1**. These sandstone ridges are generally well cemented, relatively competent, massive, and lacking faults as shown in **Figure 3-3**. Between the ridges of outcropping sandstone and immediately underlying the soil (where present), is a zone of weathered sandstone bedrock that extends to depths of 20 feet as shown in boring log RD-64 to 60 feet in DD-142.

Two parallel north-south trending lineaments (**Figure 3-5**) have been identified in the western portion of the Northwest area at the FSDF. The lineaments are denoted as Western and Eastern FSDF Structure were investigated by MWH (2013) and determined to be deformation bands with little displacement, rather than fault structures. These deformation bands correspond to two of three north-south trending drainages found in the southwestern corner of Area IV. These structures are not classified as faults in the *Faults Report* (MWH 2016b) although the projected locations are shown on **Figure 3-3**.

A third lineament that runs across the locations of the SRE Watershed-RMHF is referred to as the SRE/RMHF lineament. Its presence was observed as linear bedrock features during the removal of the basement of Building 4143 at the SRE and removal of the RMHF leach field. This lineament trends approximately east-west generally following the drainage from the RMHF westward and the drainage from the SRE eastward. The lineament was mapped remotely and no confirmatory field investigation was performed (MWH 2016b). Using boring logs, water-level elevations, geologic mapping of lithologic units and structures, and a three-dimensional projection of the exposed trace lineament into the subsurface and the SRE/RMHF lineament was found to be the contact between the top of Upper Burro Flats member and the bottom of the Shale 3 unit in this area.

3.3.2.2 Borehole Lithology and Fracture Evaluation

The upper part of the Upper Burro Flats member, as described in well logs from the Northwest hydrogeologic area, consists of sandstone. The depth of weathered rock varies from less than two feet to as much as 60 feet at DD-142. Several 1-foot thick shale beds are found throughout the Upper Burro Flats member in the Northwest hydrogeologic area. These shale beds are generally moderately to heavily weathered, indicating that they have been conduits for water either currently or in the past. However, this lens generally contains clay-filled fractures that restricts water movement. The fine-grained lenses are also discontinuous. The Lot Bed is observed in the subsurface in borings on the east side of the Northwest hydrogeologic area in monitoring wells DD-142 and RD-18.

Video logs of three wells in the southern part of the Northwest hydrogeologic area indicate that fractures are present in monitoring wells RD-54C, RD-57, and RD-65. The majority of the fractures were classified as “structural” although bedding-plane fractures were also observed. The majority of the fractures are thin, closed or less than 1/16th of an inch wide. The largest fractures in each well include:

- RD-54C: a $^1/_{16}$- to $^1/_2$-inch-wide structural fracture found in a zone of fractures at a depth of about 185 feet bgs;
- RD-57: a ¼- to $^3/_4$-inch-wide fracture found at a depth of 213.7 feet bgs;
- RD-65: a ¼-inch-wide fracture and associated soft zone of rock at a depth of 315 feet bgs.

The frequency of fractures in the upper 100 to 200 feet of bedrock in the Northwest hydrogeologic zone (i.e., along geologic strike) increases in number to the northeast with the least fracture density identified for the FSDF location. However, the size and frequency of subsurface fractures in the Northwest area is far less than seen in other areas at SSFL.

The fractures found in the sandstone are predominantly high-angle (45˚ to vertical) fractures although some bedding-plane fractures are also noted in the well logs. The fractures in the Upper Chatsworth Formation at well DD-139, located in the southwestern end of the area, are both bedding-plane and vertical fractures and noted to be small-aperture or “tight” and, therefore, impedes groundwater movement. One high-angle fracture at 109 feet bgs in well DD-139 was noted to be “open” with some clay and sand. The relatively thin (1 to 2 feet thick) shale beds found within the sandstone are fractured. Shale beds in boring DD-140 are assumed to have open fractures as drilling fluid water was lost to the formation during drilling at a depth of 95 to 96 feet bgs. Fractures were also noted in wells DD-141 and DD-143 at depths between 65 and 69 feet bgs.

3.3.2.3 Fault and Lineament Identification and Interpretation

The Faults Report (MWH 2016b) presents the current understanding of faults within Area IV. As noted on **Figure 3-3**, the North Fault is shown as 'location inferred, identity and existence uncertain'.

As stated in the Faults Report (MWH 2016b), Corehole C-08 in the FSDF encountered gouge, slickensides, and dip-slip faulting from 230 to 310 feet bgs. Further review of the data suggest that interval was mistakenly identified as a dip-slip fault when in fact, the interval is the ELV member.

The Faults Report also notes that slickensides were logged in borings RD-89 and RD-96 in the north-central portion of Area IV. Slickensides or slickenside-like mineral formation were reported at a depth of 44 to 49 feet bgs in boring RD-89, and at a depth of 70 feet bgs in boring RD-96. Although reported as slickenside-like, this interval is believed to be fine-grained material and not evidence of localized faulting.

The presence of the North Fault continuing from north of Areas I, II, and III is speculative given there is no surficial evidence of the fault north of Area IV. However, the numerical modeling of contaminant transport presented in Chapter 6 models movement assuming the presence and absence of the fault.

3.3.3 Central Hydrogeologic Area – Topography, Soil, Stratigraphy, and Structures

The terrain in this area is relatively level, slopes gently to the southeast, and exhibits fewer rock outcrops than in other locations of Area IV.

3.3.3.1 Geologic and Soil Description and Mapping

Although much of the soil in the Central hydrogeologic area has been disturbed during construction and demolition of site facilities, the native soils have been mapped as Zamora loam with 2 to 15 percent slopes. The thickness of soil is typically greater than 6 feet and is greater than 12 feet is some areas.

The lower portion of the Upper Burro Flats member, the ELV member, Lower Burro Flats member, and the SPA member subcrop immediately below overlying soils in the Central hydrogeologic area (**Figure 3-12**). Outcrops of the Lower Burro Flats member are present along the eastern side of the Central hydrogeologic area. The Silvernale member, which outcrops east of Area IV, is found at depth beneath the SPA member due to the approximate 25-degree northwestern dip of the beds. The ELV member strikes northeast-southwest through the center of the area; beds of the ELV member dip at about 25° to the northwest. The Lower Burro Flats member underlies soils east of the ELV member and the Upper Burro Flats member underlies soils to the west of the ELV member (**Figure 3-4**).

3.3.3.2 Borehole Lithology and Fracture Evaluation

The characteristic lithologies of the Central hydrogeologic area include sandstone of the Lower Burro Flats member, found east of the ELV member (**Figure 3-3**) and the Upper Burro Flats member, found west of the ELV member. The lithologies of the Central hydrogeologic area are shown in cross-section (**Figure 3-12)**. A significant amount of interbedded siltstone and shale is present, in some cases correlating to the SPA and ELV fine-grained members, interbedded with thin beds of sandstone.

In the eastern half of the area, the Lower Burro Flats member sandstone is interbedded with fine-grained beds of shale and siltstone. Well RD-13 was drilled through the Lower Burro Flats member in the southern part of the Central area. The upper 17 feet consists of sandy clay derived from heavily weathered Lower Burro Flats member sandstone and shale. From 17 to 39 feet bgs, yellow-brown weathered sandstone overlies a blue-gray calcareous siltstone. Although siltstone is reported from 39 to 160 feet bgs on this boring log, the projected depth of the SPA unit begins at 153 to 192 feet bgs in the three-dimensional model.

Northeast of boring RD-13, at boring DD-145, several thinner (1 to 14-ft thick) beds of shale and siltstone are found in the upper 43 feet of bedrock. At boring RD-16, in the northeastern part of the Central hydrogeologic area, the upper 28 feet of sandstone is underlain by nearly 200 feet of siltstone and shale with minor interbedded sandstone as shown in the boring log. The SPA unit is projected to encounter the borehole at a depth of 122 to 164 feet bgs in the three-dimensional model.

Well RD-20 was drilled on or near the ELV bed in the Central hydrogeologic area. In this boring, the ELV is believed to be present from the ground surface to a depth of 22 feet bgs.

On the western part of the Central hydrogeologic area (at borings DS-43 and DD-144) the yellow-brown and dark bluish-gray, well to poorly graded, fine to medium-grained Upper Burro Flats member of the Chatsworth Formation is present. This member is weathered, weakly cemented and moderately fractured to a depth of about 40 feet bgs.

Within the upper 83 feet of sandstone at boring DS-43 there are few thin stringers or beds of shale. Within boring DS-43 the dark bluish gray, laminated, weakly-cemented shale of the ELV member is encountered from a depth of 87 feet to at least 93 feet (the bottom of the boring).

The factures are found in the sandstone units of the Central hydrogeologic area are frequently found as single vertical fractures or thin (generally less than 1 foot thick) horizontal fracture zones.

3.3.3.3 Fault Identification and Interpretation

There are no known faults in the Central hydrogeologic area that could affect its hydrogeology (**Figure 3-3**).

3.3.4 East Hydrogeologic Area – Topography, Soil, Stratigraphy, and Structures

3.3.4.1 Geologic and Soil Description and Mapping

The East hydrogeologic area is characterized by sandstone outcroppings similar to the Northwest hydrogeologic area. Where present, soils are relatively thin (0 to 3 feet thick) although up to 8 feet thick in some limited areas. The soils have been mapped by the USDA as Saugus sandy loam with 5 to 30 percent slopes (**Figure 3-2**). Surface water drainage is generally north to south.

The East hydrogeologic area is underlain by the Upper Burro Flats member and fine sandstone and shales of the ELV member, Lower Burro Flats and SPA members (**Figure 3-13**). The Lower

Burro Flats member contains well indurated beds of sandstone. These well-cemented massive sandstone beds outcrop about 250 feet east of well DS-47 as a ridge of massive sandstone.

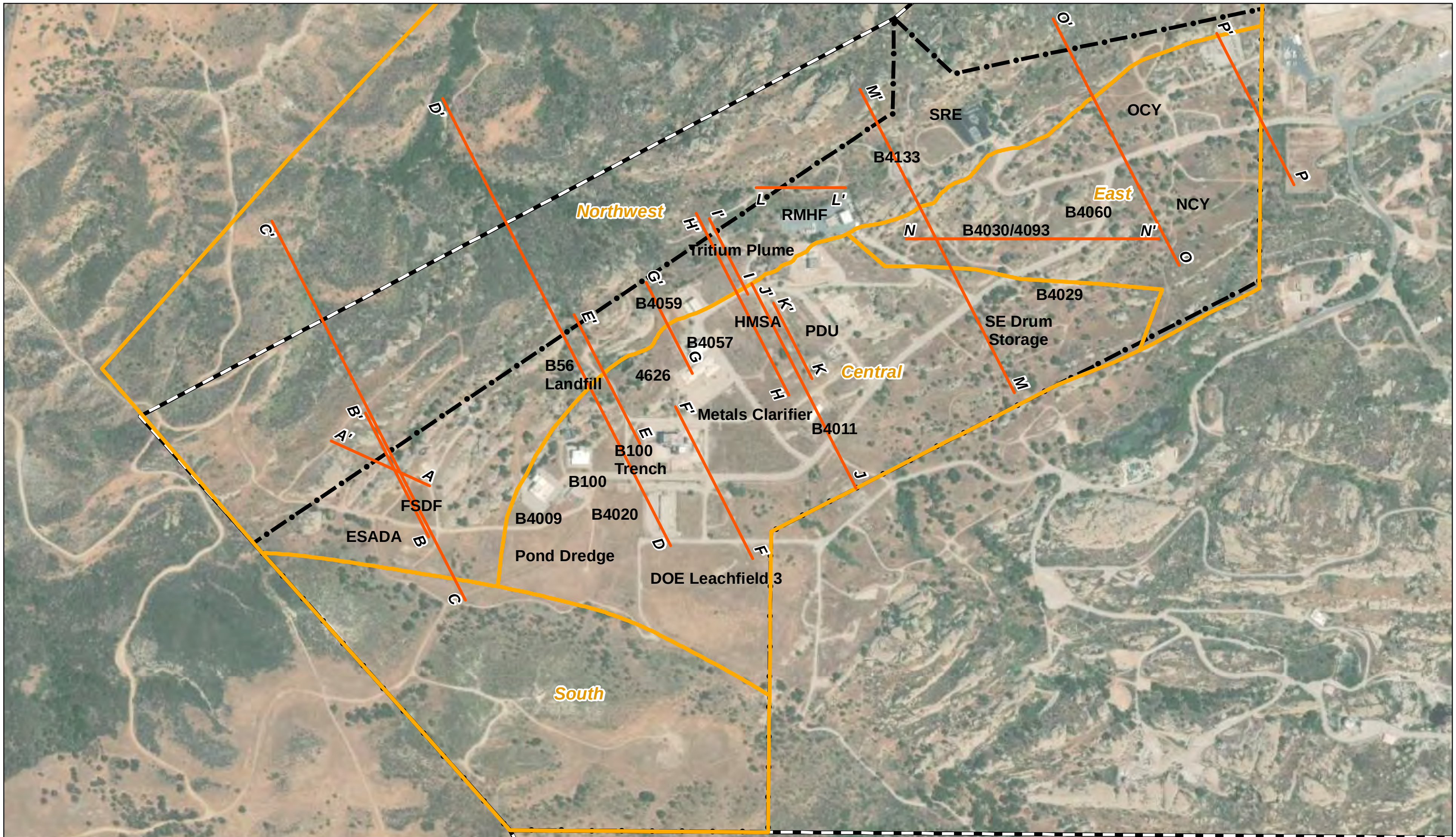
3.3.4.2 Borehole Lithology and Fracture Evaluation

As in the Central hydrogeologic area, the lithologies of the Lower Burro Flats member found in the eastern half of the East hydrogeologic area are interbedded sandstone and siltstone. Wells DS-44, DS-45, and DS-47 are all screened within the ELV member.

West of the ELV member, at wells RD-154 and RD-155, only sandstone was encountered to depths of 145 feet and 115 feet, respectively. However, the boreholes were advanced using an air rotary drill and no rock core samples were collected. The ELV is projected to be present between a depth of 49 to 83 feet bgs in boring RD-154, and 13 to 47 feet bgs in RD-155.

3.3.4.3 Fault Identification and Interpretation

There are no known faults in the East hydrogeologic study area that could affect the hydrogeology (**Figure 3-3**).



LEGEND

- Cross Section
- Hydrogeologic Area
- Area IV Boundary
- SSFL Property Boundary

N

0 425 850 Feet

Notes:
- Original GIS Layers provided by MWH/Boeing; updated by CDM Smith as needed.
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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CDM Smith

PLATE 1
Cross Section Locations

LEGEND

- 20ft. Contour
- Rock Outcrop
- Area IV Boundary
- SSFL Property Boundary
- Escarpment

Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

0 425 850 Feet

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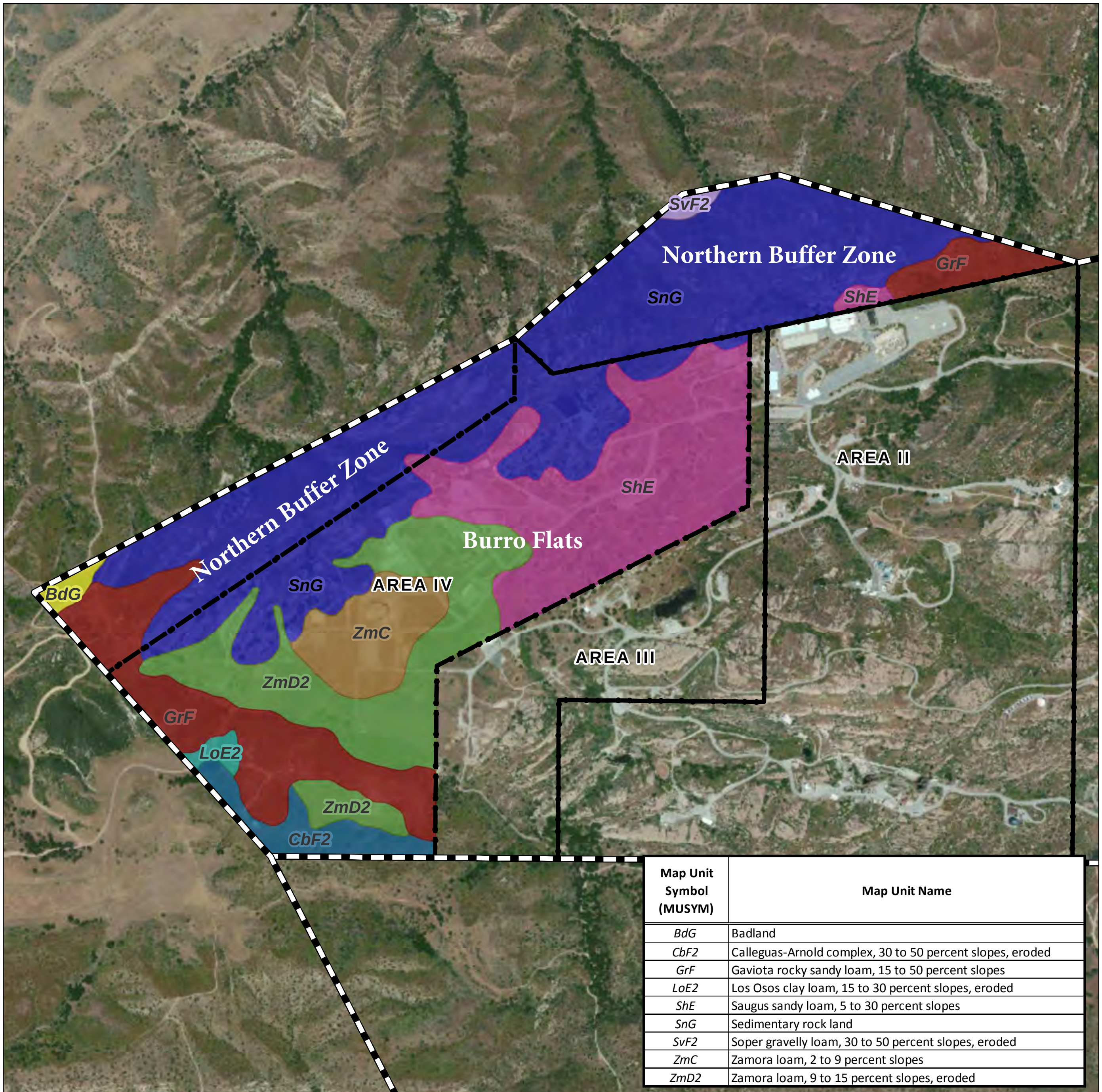
CDM Smith

FIGURE 3-1
Area IV Topography



Map Unit Symbol (MUSYM)	Map Unit Name
BdG	Badland
CbF2	Calleguas-Arnold complex, 30 to 50 percent slopes, eroded
GrF	Gaviota rocky sandy loam, 15 to 50 percent slopes
LoE2	Los Osos clay loam, 15 to 30 percent slopes, eroded
ShE	Saugus sandy loam, 5 to 30 percent slopes
SnG	Sedimentary rock land
SvF2	Soper gravelly loam, 30 to 50 percent slopes, eroded
ZmC	Zamora loam, 2 to 9 percent slopes
ZmD2	Zamora loam, 9 to 15 percent slopes, eroded

LEGEND

Soil Map Unit (SSURGO)

- BdG
- CbF2
- GrF
- LoE2
- ShE
- SnG
- SvF2
- ZmC
- ZmD2
- Area Boundary
- SSFL Property Boundary

Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.
- SSURGO Soil Source: Soil Survey Geographic (SSURGO) Database, U.S. Department of Agriculture, Natural Resources Conservation Service (12/16/2013).

N

0 700 1,400 Feet

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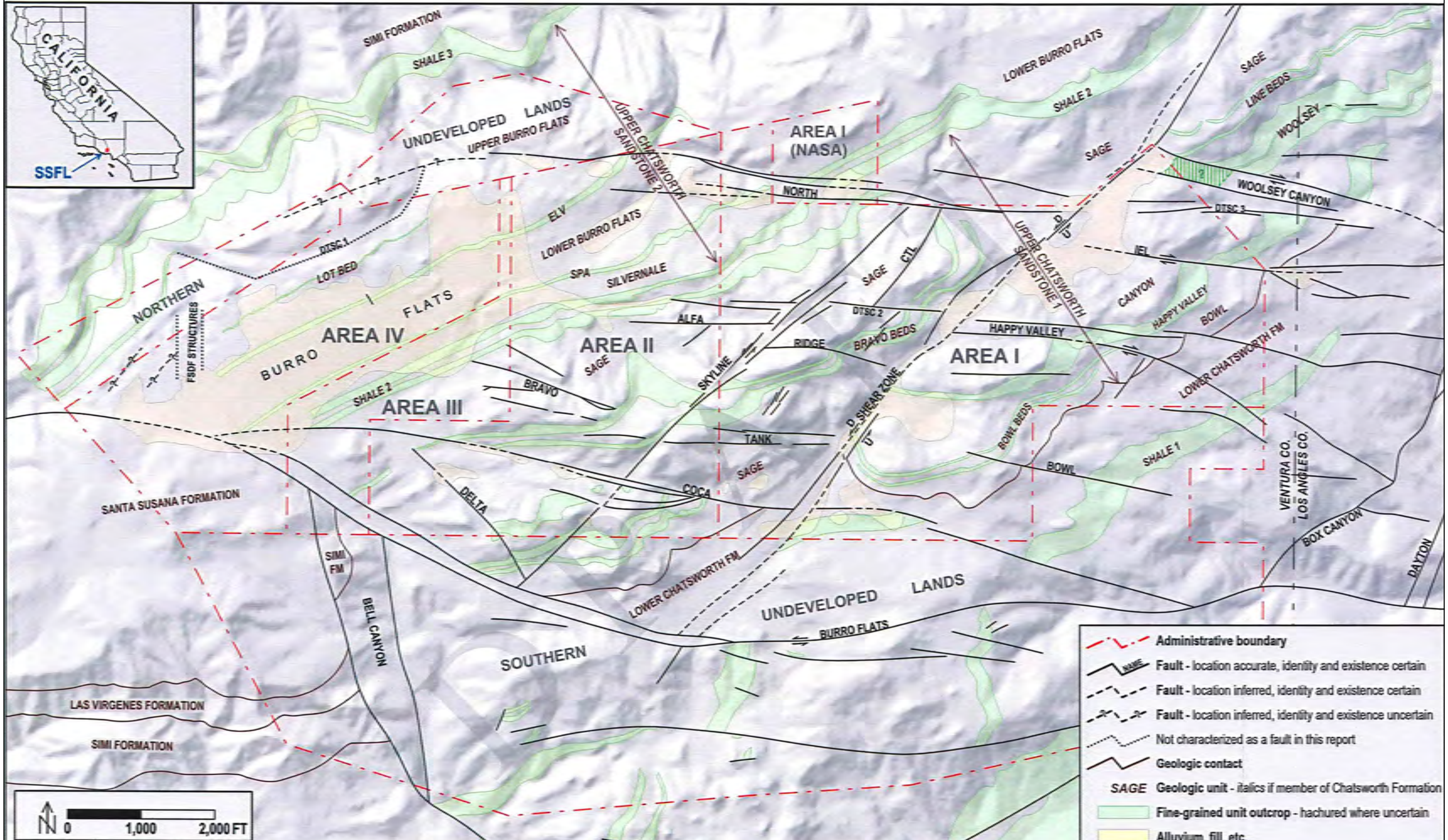
CDM Smith

FIGURE 3-2
Soil Type and Distribution in Area IV



Sources: Cilona and others, 2016; Yerkes and Campbell,2005; Diblee, 1992; MWH, 2009.

Source: MWH 2015 Annual Report

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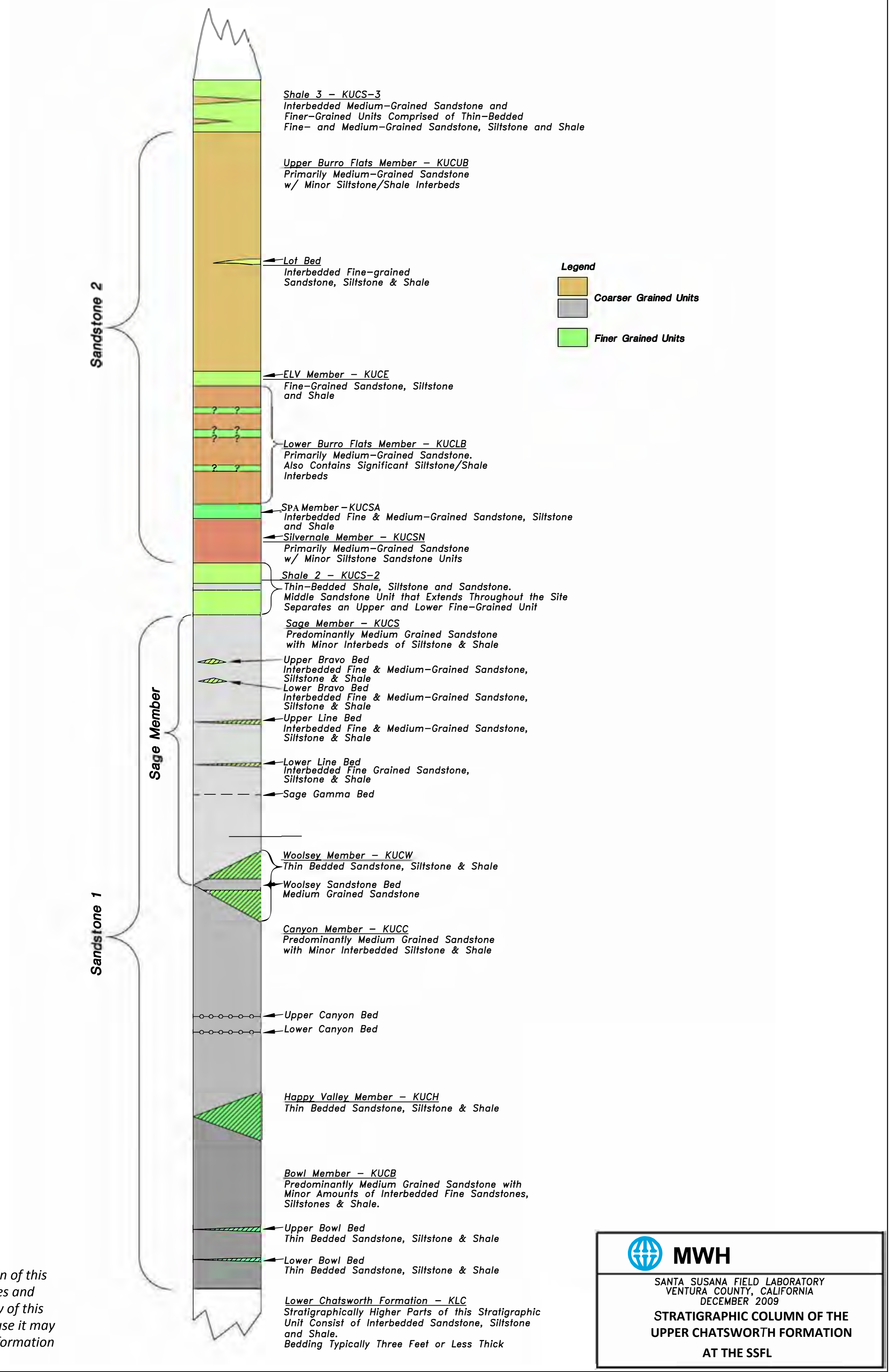
CDM Smith

FIGURE 3-3

Map of SSFL Faults and Geologic Unit Exposures



Please Note: The original version of this figure includes colorized features and shading. A black and white copy of this figure should not be used because it may not accurately represent the information presented.

Source: MWH 2009, SSFL Groundwater RI Report

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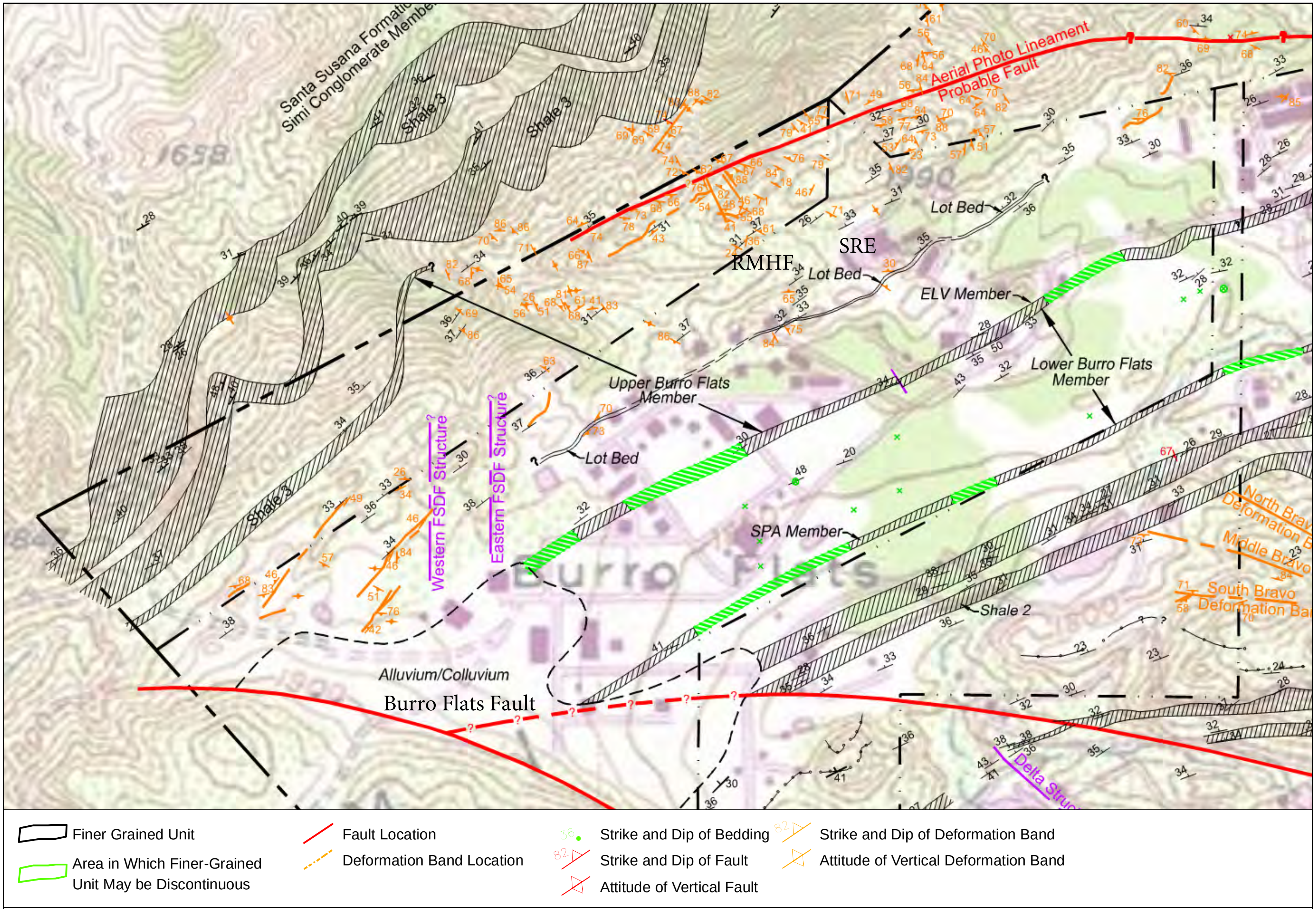
FIGURE 3-4

Stratigraphic Column of Upper Chatsworth Formation



Source: MWH 2014 Annual Report, Figure 2 - SSFL Geologic Map

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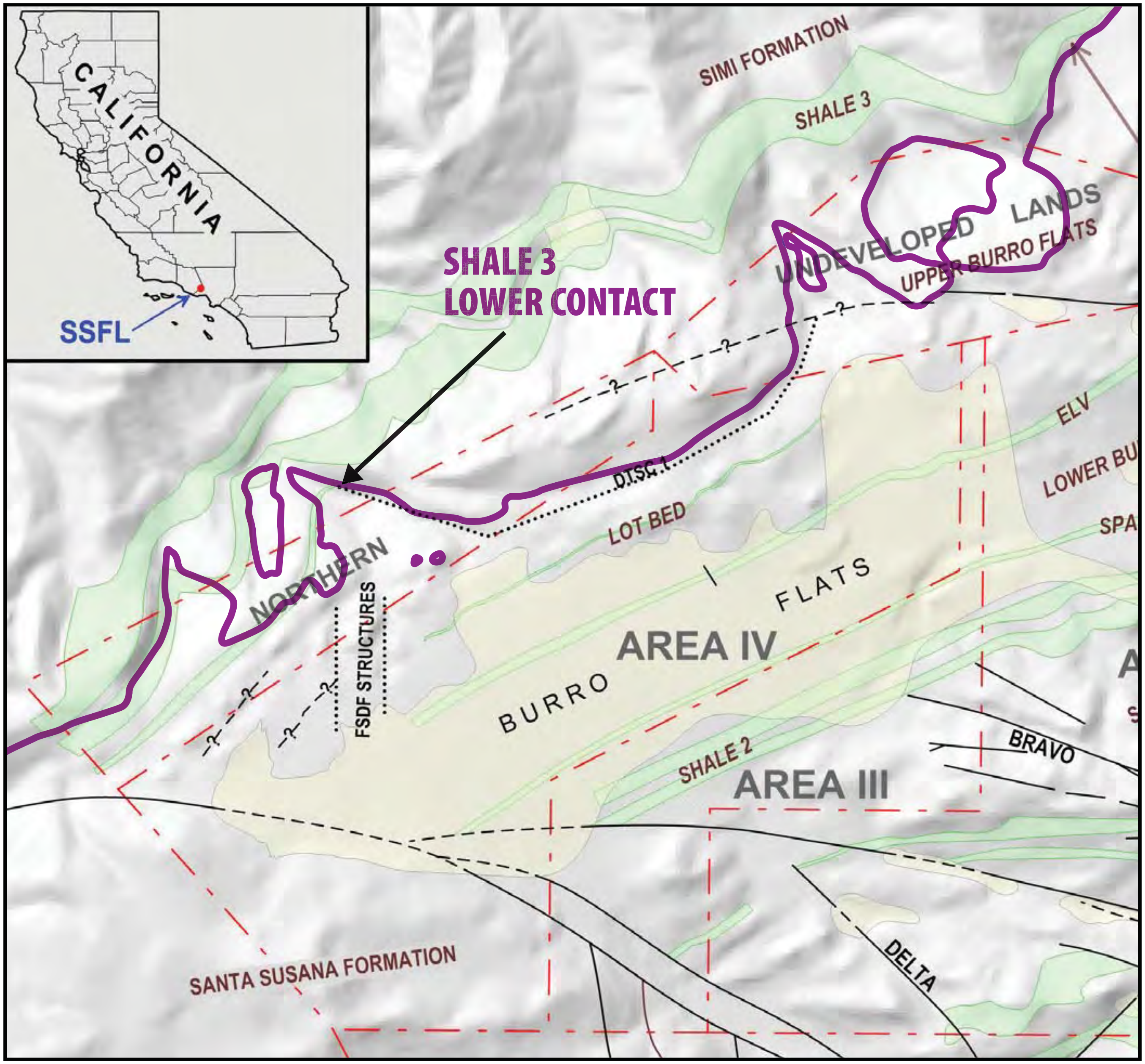
CDM Smith

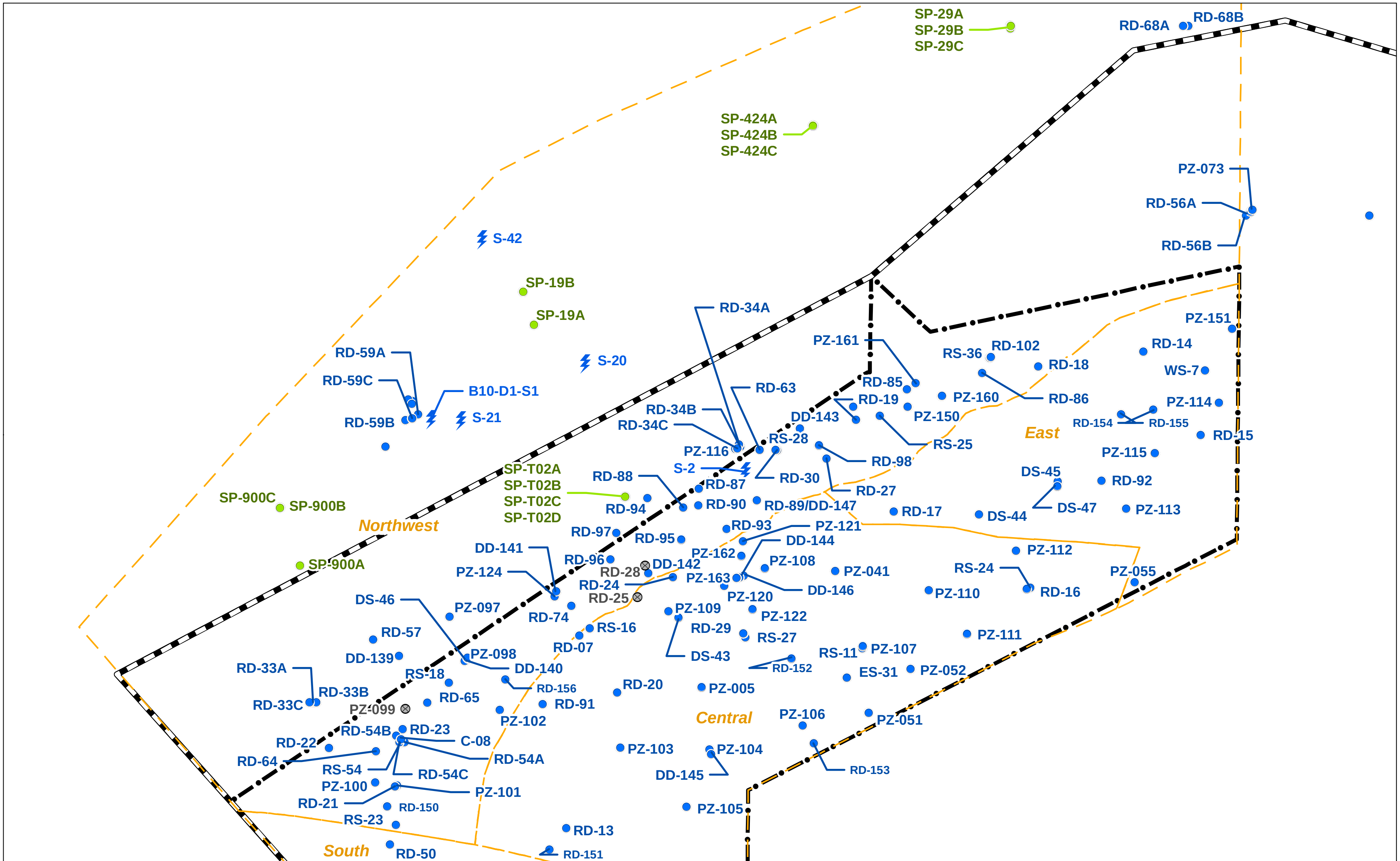
FIGURE 3-5
Area IV Geologic Map with Bedding, Fault, and Deformation Band Strike and Dip Measurements



CDM Smith

FIGURE 3-6

Shale 3 Contact Along Northern Portions of Area IV



LEGEND

- Well/Piezometer
- Abandoned Well
- Seep Well
- Seep
- Hydrogeologic Area
- Area IV Boundary
- SSFL Property Boundary

0 500 1,000 Feet

N

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- *Well PZ-099 abandoned in 2006.
- **Wells RD-25 and RD-28 abandoned in April 2004.

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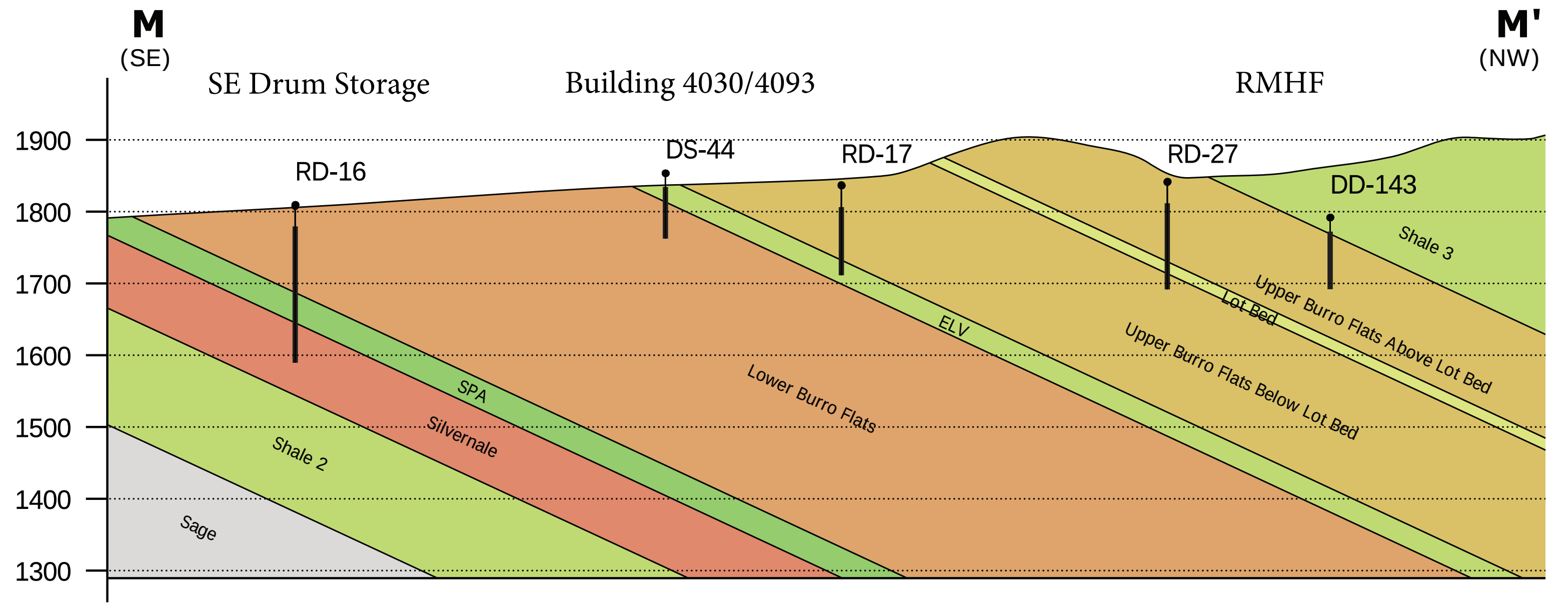
CDM Smith

FIGURE 3-7
Area IV Groundwater Monitoring Network

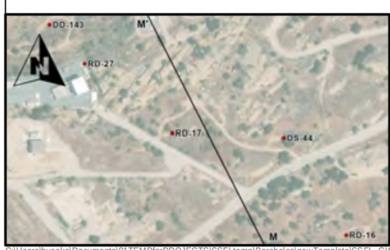


Cross section line is drawn perpendicular to strike of Fine-Grained Units in Area IV. Cross section shows topographic surface along the cross section line. Monitoring wells may appear above or below the topographic surface depending on relationship of the well to the cross section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.



Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

0ft 600ft

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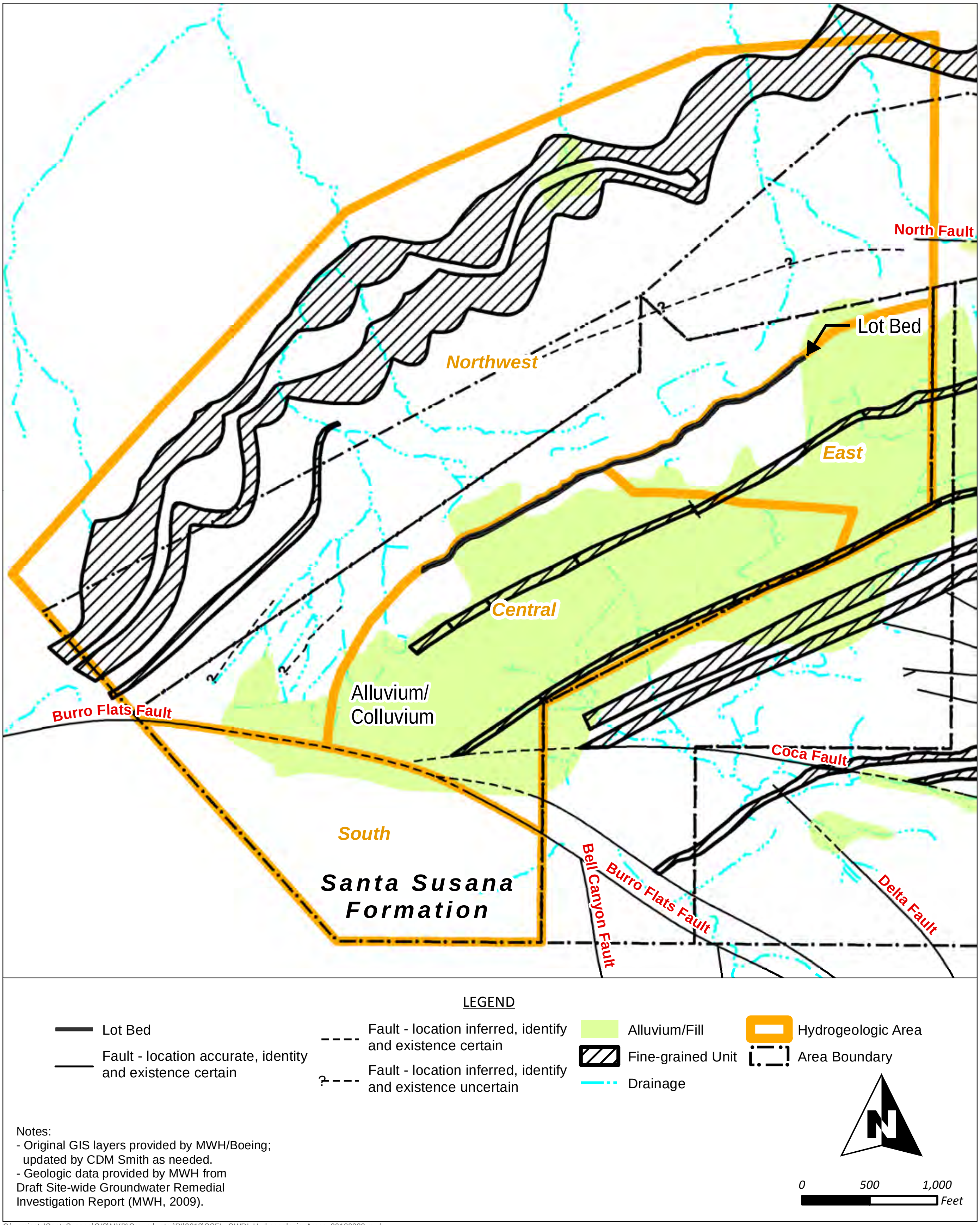
CDM Smith

FIGURE 3-8

Cross Section of Central Area IV



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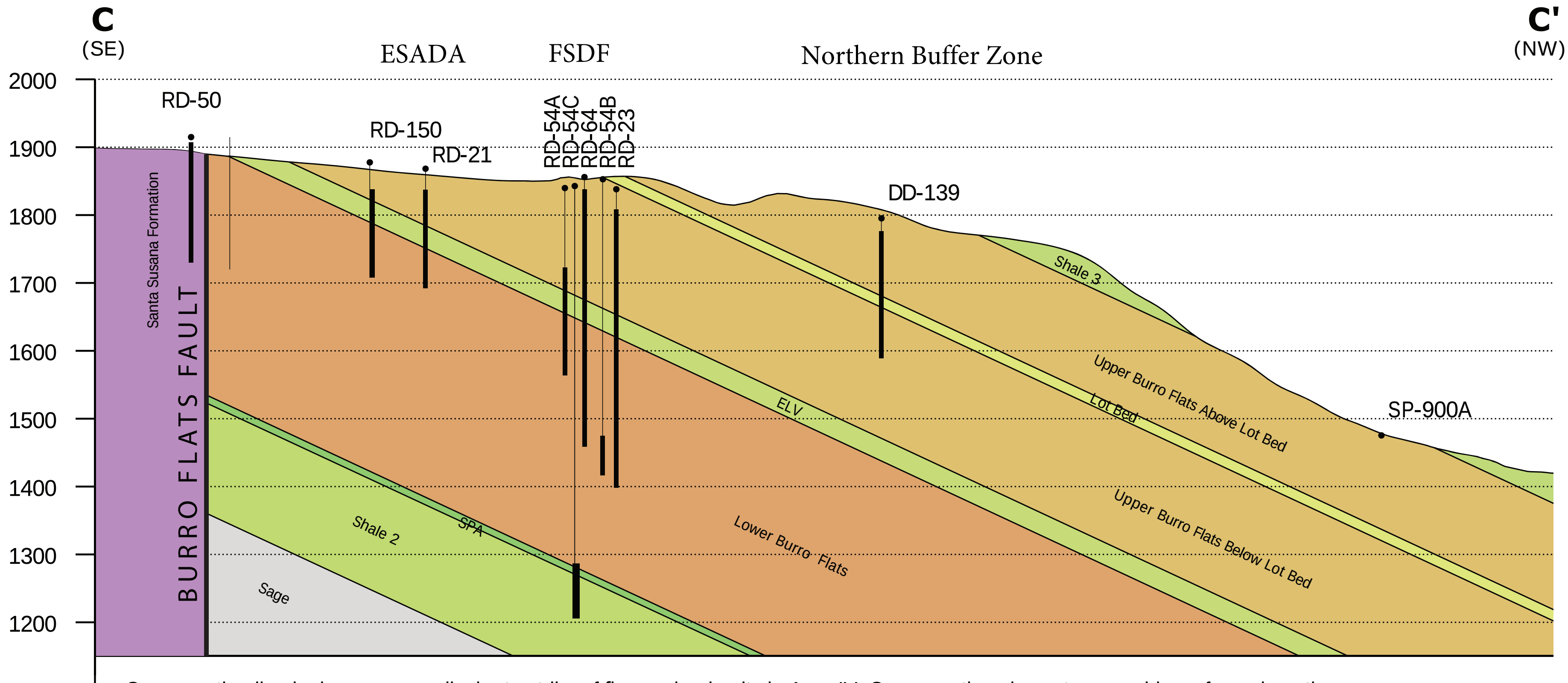
CDM Smith

FIGURE 3-9
Area IV Hydrogeologic Investigation Areas

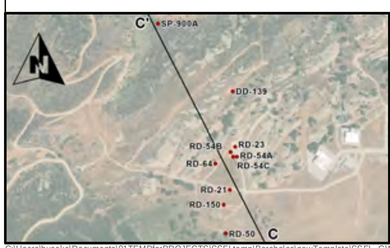


Cross section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross-section shows topographic surface along the cross section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross section line.

The thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.



Notes:
- GIS Layers provided by MWH/Boeing.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

0ft 600ft

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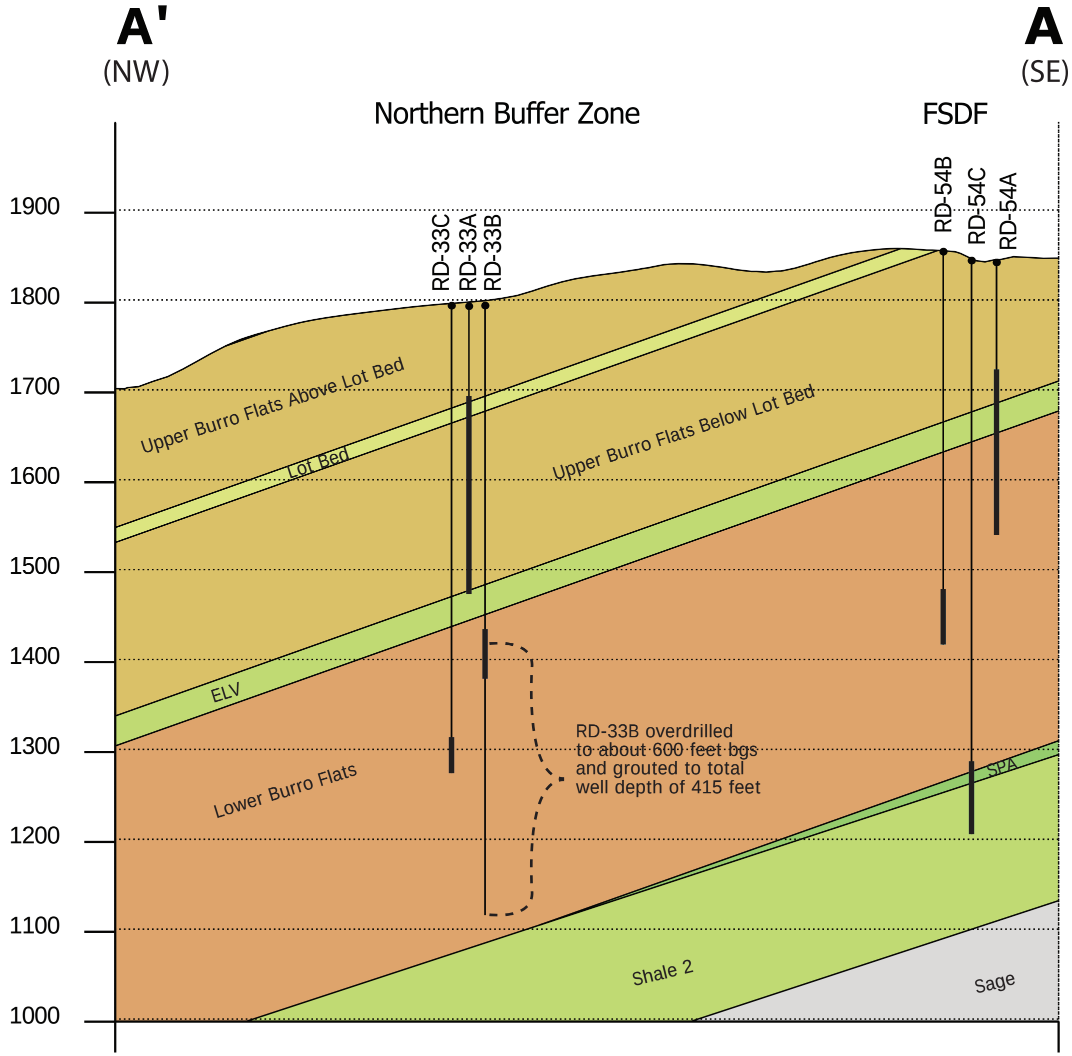
FIGURE 3-10

Cross Section of Northwest Hydrogeologic Area



Cross section line is not drawn perpendicular to strike of Fine-Grained Units in Area IV. Cross section shows topographic surface along the cross section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

Notes:
- GIS Layers provided by MWH/Boeing.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

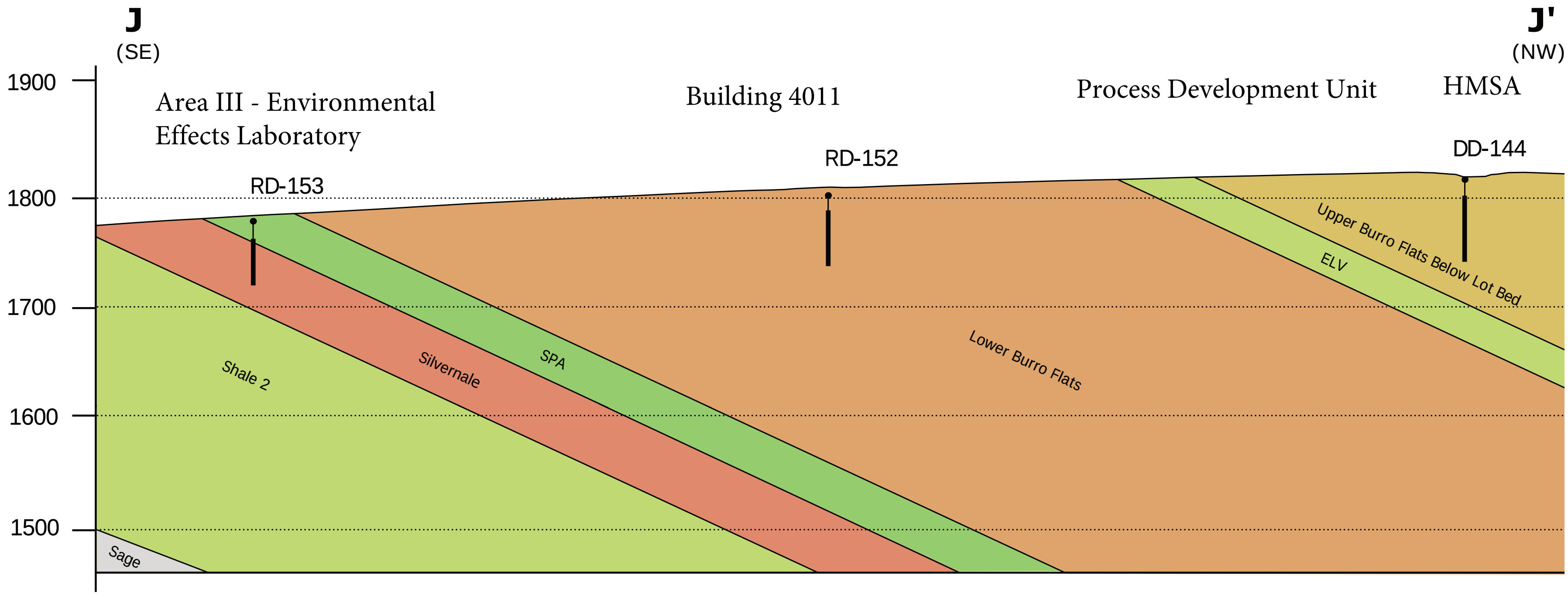
- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

0ft 600ft

CDM Smith

FIGURE 3-11

Cross Section of RD-33A, B, C and RD54A, B, C



Cross section line is drawn perpendicular to strike of Fine-Grained Units in Area IV. Cross section shows topographic surface along the cross section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross section line.

The thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

Notes:
- GIS Layers provided by MWH/Boeing.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

0ft 600ft

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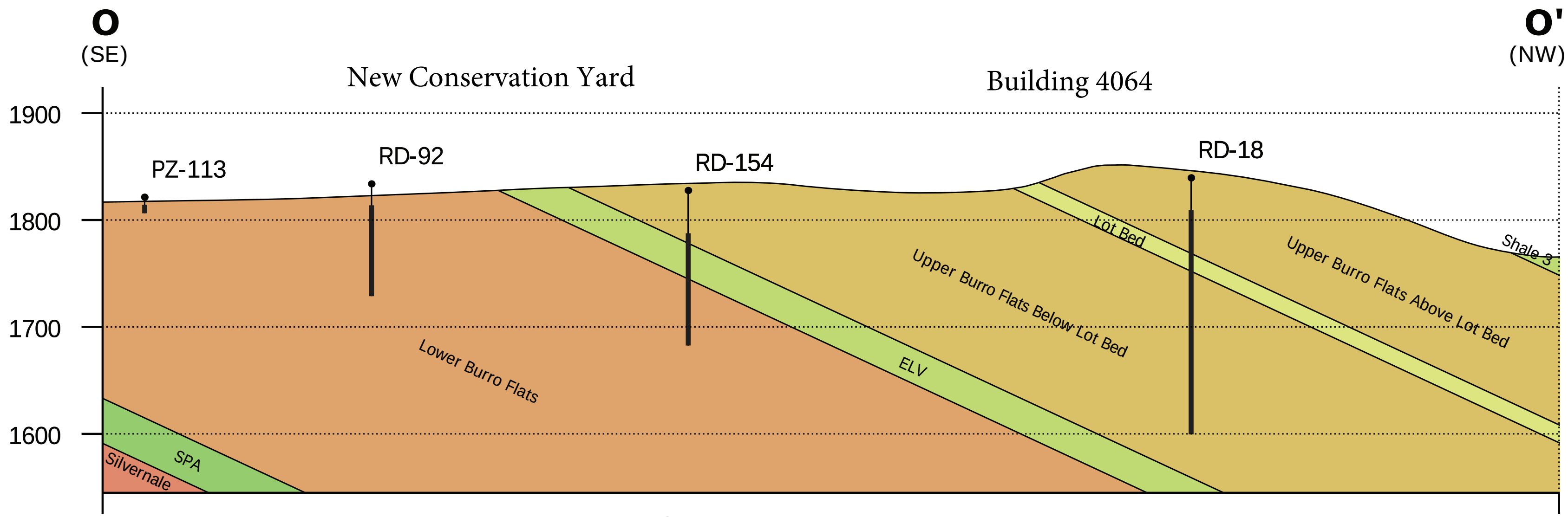
FIGURE 3-12
Cross Section for Central Hydrogeologic Area

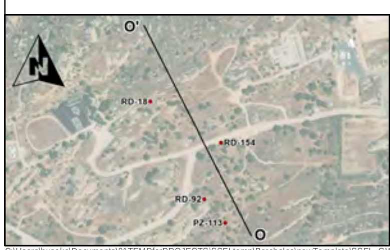


Cross-section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross section shows topographic surface along the cross-section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross-section line.

The thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.



Notes:
- GIS Layers provided by MWH/Boeing.
(AI-Zxx).
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

0ft 600ft

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FIGURE 3-13

Cross-Section of East Hydrogeologic Area

Table 3-1 Geologic Units Encountered in Monitoring Well Borings

Hydrogeologic Study Area	Borehole	Depth to bottom of conductor casing (ft bgs)	Depth of Borehole (ft bgs)	Top of Intercept (ft bgs)	Bottom of Intercept (ft bgs)	Projected Intercept of Geologic Unit using 3-D Model *
Central	DD-144	38	71	0	71	Upper Burro Flats Below Lot Bed
	DD-145	27	82	71	82	Lower Burro Flat
	DD-146	120	140			
	DD-147	30	257			
	DS-43	28	84	82	87	Upper Burro Flats Below Lot Bed
				87	93	ELV
	RD-07	25	300	0	167	Upper Burro Flats Below Lot Bed
				167	200	ELV
				200	300	Lower Burro Flat
	RD-13	25	300	0	153	Lower Burro Flat
				153	192	SPA
				192	300	Shale 2
	RD-151	40	130	0	128	Lower Burro Flat
				128	130	SPA
	RD-152	20	60	0	60	Lower Burro Flat
	RD-153	20	55	0	19	SPA
				19	55	Silvernale
	RD-16	30	220	0	122	Lower Burro Flat
				122	164	SPA
				164	220	Silvernale
	RD-20	30	127	0	22	ELV
				22	127	Lower Burro Flat
	RD-24	30	150	0	150	Upper Burro Flats Below Lot Bed
	RD-25	30	175	0	175	Upper Burro Flats Below Lot Bed
	RD-29	30	100	0	100	Lower Burro Flat
	RD-91	20	140	0	52	Upper Burro Flats Below Lot Bed
				52	85	ELV
				85	140	Lower Burro Flat
	RS-11	10	19	0	19	Alluvium
				19	19	Lower Burro Flat
	RS-16	17	21	0	21	Upper Burro Flats Below Lot Bed
	RS-24	4	9	0	9	Alluvium
				9	9	Lower Burro Flat
	RS-27	5	9	0	1	Alluvium
				1	9	Lower Burro Flat
East	DS-44	19	91	0	1	Alluvium
				1	7	Upper Burro Flats Below Lot Bed
				7	40	ELV
				40	91	Lower Burro Flat
	DS-45	18	75	0	2	Alluvium
				2	5	Upper Burro Flats Below Lot Bed
				5	38	ELV
				38	95	Lower Burro Flat
	DS-47	19	145	0	3	Alluvium
				3	28	ELV
				28	145	Lower Burro Flat
	RD-14	30	125	0	125	Upper Burro Flats Below Lot Bed
	RD-15	30	152	0	152	Lower Burro Flat

Table 3-1 Geologic Units Encountered in Monitoring Well Borings

Hydrogeologic Study Area	Borehole	Depth to bottom of conductor casing (ft bgs)	Depth of Borehole (ft bgs)	Top of Intercept (ft bgs)	Bottom of Intercept (ft bgs)	Projected Intercept of Geologic Unit using 3-D Model *
East	RD-154	40	145	0	1	Alluvium
				1	49	Upper Burro Flats Below Lot Bed
				49	83	ELV
				83	145	Lower Burro Flat
	RD-155	40	115	0	13	Upper Burro Flats Below Lot Bed
				13	47	ELV
				47	115	Lower Burro Flat
	RD-17	30	125	0	104	Upper Burro Flats Below Lot Bed
				104	125	ELV
	RD-92	20	105	0	105	Lower Burro Flat
	WS-07	216	400	0	47	Upper Burro Flats Below Lot Bed
				47	81	ELV
				81	400	Lower Burro Flat
Northwest	C-08	65	400	0	1	Alluvium
				1	168	Upper Burro Flats Below Lot Bed
				168	201	ELV
				201	400	Lower Burro Flat
	DD-139	19	206	0	1	Alluvium
				1	114	Upper Burro Flats Above Lot Bed
				114	131	Lot Bed
				131	206	Upper Burro Flats Below Lot Bed
	DD-140	60	167	0	27	Upper Burro Flats Above Lot Bed
				27	44	Lot Bed
				44	169	Upper Burro Flats Below Lot Bed
	DD-141	20	133	0	2	Alluvium
				2	47	Upper Burro Flats Above Lot Bed
				47	63	Lot Bed
				63	133	Upper Burro Flats Below Lot Bed
	DD-142	34	91	0	3	Alluvium
				3	26	Upper Burro Flats Above Lot Bed
				26	43	Lot Bed
				43	91	Upper Burro Flats Below Lot Bed
	DD-143	20	100	0	22	DTSC 1 - Shale 3
				22	100	Upper Burro Flats Above Lot Bed
	DS-46	37	52	0	29	Upper Burro Flats Above Lot Bed
				29	46	Lot Bed
				46	52	Upper Burro Flats Below Lot Bed
	RD-102	30	100	0	5	Alluvium
				5	100	Upper Burro Flats Above Lot Bed
	RD-150	40	170	0	55	Upper Burro Flats Below Lot Bed
				55	88	ELV
				88	170	Lower Burro Flat
	RD-156	40	170	0	160	Upper Burro Flats Below Lot Bed
				160	170	ELV
	RD-18	30	240	0	71	Upper Burro Flats Above Lot Bed
				71	87	Lot Bed
				87	240	Upper Burro Flats Below Lot Bed
	RD-19	30	135	0	1	Alluvium
				1	36	DTSC 1 - Shale 3
				36	135	Upper Burro Flats Above Lot Bed

Table 3-1 Geologic Units Encountered in Monitoring Well Borings

Hydrogeologic Study Area	Borehole	Depth to bottom of conductor casing (ft bgs)	Depth of Borehole (ft bgs)	Top of Intercept (ft bgs)	Bottom of Intercept (ft bgs)	Projected Intercept of Geologic Unit using 3-D Model *
Northwest	RD-21	30	175	0	83	Upper Burro Flats Below Lot Bed
				83	116	ELV
				116	175	Lower Burro Flat
	RD-22	30	440	0	35	Upper Burro Flats Above Lot Bed
				35	52	Lot Bed
				52	245	Upper Burro Flats Below Lot Bed
				245	278	ELV
				278	440	Lower Burro Flat
	RD-23	30	440	0	185	Upper Burro Flats Below Lot Bed
				185	218	ELV
				218	440	Lower Burro Flat
	RD-27	30	150	0	111	Upper Burro Flats Above Lot Bed
				111	128	Lot Bed
				128	150	Upper Burro Flats Below Lot Bed
	RD-28	30	150	0	2	Alluvium
				2	45	Upper Burro Flats Above Lot Bed
				45	62	Lot Bed
				62	150	Upper Burro Flats Below Lot Bed
	RD-30	30	75	0	75	Upper Burro Flats Above Lot Bed
	RD-33A	100	320	0	106	Upper Burro Flats Above Lot Bed
				106	123	Lot Bed
				123	316	Upper Burro Flats Below Lot Bed
				316	320	ELV
	RD-33B	360	415	0	103	Upper Burro Flats Above Lot Bed
				103	119	Lot Bed
				119	312	Upper Burro Flats Below Lot Bed
				312	346	ELV
				346	678	Lower Burro Flat
	RD-33C	480	520	0	111	Upper Burro Flats Above Lot Bed
				111	128	Lot Bed
				128	321	Upper Burro Flats Below Lot Bed
				321	354	ELV
				354	520	Lower Burro Flat
	RD-34A	11	320	0	20	DTSC 1 - Shale 3
				20	167	Upper Burro Flats Above Lot Bed
				167	184	Lot Bed
				184	320	Upper Burro Flats Below Lot Bed
	RD-34B	360	415	0	27	DTSC 1 - Shale 3
				27	175	Upper Burro Flats Above Lot Bed
				175	191	Lot Bed
				191	384	Upper Burro Flats Below Lot Bed
				384	415	ELV
	RD-34C	480	520	0	20	DTSC 1 - Shale 3
				20	167	Upper Burro Flats Above Lot Bed
				167	184	Lot Bed
				184	377	Upper Burro Flats Below Lot Bed
				377	410	ELV
				410	520	Lower Burro Flat
	RD-54A	119	278	0	1	Alluvium
				1	153	Upper Burro Flats Below Lot Bed
				153	186	ELV
				186	278	Lower Burro Flat

Table 3-1 Geologic Units Encountered in Monitoring Well Borings

Hydrogeologic Study Area	Borehole	Depth to bottom of conductor casing (ft bgs)	Depth of Borehole (ft bgs)	Top of Intercept (ft bgs)	Bottom of Intercept (ft bgs)	Projected Intercept of Geologic Unit using 3-D Model *
	RD-54B	379	437	0	191	Upper Burro Flats Below Lot Bed
				191	224	ELV
				224	437	Lower Burro Flat
	RD-54C	557	638	0	162	Upper Burro Flats Below Lot Bed
				162	195	ELV
				195	562	Lower Burro Flat
				562	574	SPA
				574	638	Shale 2

Table 3-1 Geologic Units Encountered in Monitoring Well Borings

Hydrogeologic Study Area	Borehole	Depth to bottom of conductor casing (ft bgs)	Depth of Borehole (ft bgs)	Top of Intercept (ft bgs)	Bottom of Intercept (ft bgs)	Projected Intercept of Geologic Unit using 3-D Model *
Northwest	RD-57	20	419	0	1	Alluvium
				1	10	DTSC 1 - Shale 3
				10	166	Upper Burro Flats Above Lot Bed
				166	183	Lot Bed
				183	376	Upper Burro Flats Below Lot Bed
				376	409	ELV
				409	419	Lower Burro Flat
	RD-59A	21	58	0	57	DTSC 1 - Shale 3
				57	58	Upper Burro Flats Above Lot Bed
	RD-59B	178	214	0	47	DTSC 1 - Shale 3
				47	200	Upper Burro Flats Above Lot Bed
				200	214	Lot Bed
	RD-59C	345	397	0	48	DTSC 1 - Shale 3
				48	201	Upper Burro Flats Above Lot Bed
				201	217	Lot Bed
				217	397	Upper Burro Flats Below Lot Bed
	RD-63	20	230	0	140	Upper Burro Flats Above Lot Bed
				140	156	Lot Bed
				156	230	Upper Burro Flats Below Lot Bed
	RD-64	19	398	0	182	Upper Burro Flats Below Lot Bed
				182	215	ELV
				215	398	Lower Burro Flat
	RD-65	19	397	0	6	Lot Bed
				6	199	Upper Burro Flats Below Lot Bed
				199	232	ELV
				232	397	Lower Burro Flat
	RD-74	30	101	0	5	Alluvium
				5	38	Upper Burro Flats Above Lot Bed
				38	55	Lot Bed
				55	101	Upper Burro Flats Below Lot Bed
	RD-85	20	90	0	45	DTSC 1 - Shale 3
				45	90	Upper Burro Flats Above Lot Bed
	RD-86	20	80	0	80	Upper Burro Flats Above Lot Bed
	RD-87	20	60	0	60	Upper Burro Flats Above Lot Bed
	RD-88	20	30	0	30	Upper Burro Flats Above Lot Bed
	RD-89	30	50	0	1	Alluvium
				1	50	Upper Burro Flats Above Lot Bed
	RD-90	20	125	0	99	Upper Burro Flats Above Lot Bed
				99	116	Lot Bed
				116	125	Upper Burro Flats Below Lot Bed
	RD-93	20	60	0	33	Upper Burro Flats Above Lot Bed
				33	49	Lot Bed
				49	60	Upper Burro Flats Below Lot Bed
	RD-94	21	35	0	8	Alluvium
				8	35	Upper Burro Flats Above Lot Bed
	RD-95	50	80	0	3	Alluvium
				3	64	Upper Burro Flats Above Lot Bed
				64	80	Lot Bed
	RD-96	20	90	0	90	Upper Burro Flats Above Lot Bed
	RD-97	20	75	0	75	Upper Burro Flats Above Lot Bed
	RD-98	20	65	0	65	Upper Burro Flats Above Lot Bed

Table 3-1 Geologic Units Encountered in Monitoring Well Borings

Hydrogeologic Study Area	Borehole	Depth to bottom of conductor casing (ft bgs)	Depth of Borehole (ft bgs)	Top of Intercept (ft bgs)	Bottom of Intercept (ft bgs)	Projected Intercept of Geologic Unit using 3-D Model *
Northwest	RS-18	8	13	0	12	Lot Bed
				12	13	Upper Burro Flats Below Lot Bed
	RS-23	8	13	0	8	Upper Burro Flats Below Lot Bed
				8	13	ELV
	RS-25	9	14	0	14	DTSC 1 - Shale 3
	RS-28	14	19	0	9	Alluvium
				9	19	Upper Burro Flats Above Lot Bed
	RS-36	3	18	0	18	Upper Burro Flats Above Lot Bed
	RS-54	7	38	0	38	Upper Burro Flats Below Lot Bed
Santa Susana Form.	RD-50			0	195	

* Intercept of geologic unit is projected onto the borehole and shown on table. Boring logs were reviewed at these depths to confirm the presence of the unit. In most cases, the geologic unit was suspected at, within, or very close the geologic unit's assumed interval thickness. In some borings, no determination could be made because the boring was not logged (i.e., RD-150 through RD-156).

Color shaded cells in the 'Top of Intercept' or 'Bottom of Intercept' columns indicates that the open borehole is open to the geologic unit shown in the 'Projected Intecept of Geologic Unit using 3-D Model'.
ft bgs = feet bgs

Section 4

Area IV Hydrogeology

This section presents general groundwater characteristics and local groundwater by the four hydrogeologic areas introduced in Section 3. Groundwater in Area IV occurs as:

- Near-surface groundwater in the alluvial soil and/or weathered bedrock that is not in direct connection with the Chatsworth Formation groundwater,
- Near-surface groundwater in the alluvial soil and/or weathered Chatsworth Formation bedrock that is in direct connection with Chatsworth Formation groundwater, and
- Chatsworth Formation groundwater in the unweathered (competent) bedrock.

Each of these groundwater units are directly or indirectly recharged by precipitation; typical rainfall at SSFL is 18.6 inches per year. The rate of groundwater recharge by rainfall is dependent on surface geology, local topography, and vegetation.

The majority of precipitation either evaporates, is taken up by plants, or is lost as runoff. The remainder replenishes the Near-surface groundwater zone via infiltration that eventually passes through the shallow groundwater zone to replenish the Chatsworth Formation groundwater (MWH 2009a). The estimated average recharge rate from the surface into groundwater is less than 2 inches per year, based on chloride mass balance analysis and flow calculation in the vadose zone (MWH 2009a). A revision to this estimate has been proposed by Manna et al. (2016) to range from approximately 0.33 to 1.75 inches per year. The winter rainfall between 2012 and summer of 2016 was dryer than normal, resulting in less recharge and limited near surface groundwater within Area IV. The winter (wet season) of 2016-2017 experienced increased rainfall, one effect being groundwater being found in near-surface bedrock fractures in 2017 and 2018.

As rainwater infiltrates into the Near-surface zone and Chatsworth Formation, it flows downward through the vadose zone until it encounters groundwater or an impermeable layer. Infiltrating groundwater moves through the system according to hydraulic head and interconnected permeability found in the bedrock. Groundwater is removed from the hydrogeologic system through discharge via groundwater seeps and springs located on the slopes northwest of the NBZ, and uptake by plants.

The monitoring wells installed to assess groundwater presence and quality consist of two types: Near-surface wells assessing alluvium/weathered bedrock conditions and bedrock core wells. Shallow wells and piezometers consist of traditional blank well casing, well screen, and filter (sand) pack. Bedrock wells generally consist of steel conductor casing extending from the ground surface through the alluvium and terminated in competent bedrock with the continuation of the borehole through competent bedrock to its total depth. The bedrock wells are termed “open borehole” because there is no well casing or screen beyond the surface conductor casing in the well. The borehole is open from the bottom of the conductor casing to its total depth. The conductor casing prevents soil and weathered rock from collapsing into the borehole. When installed sufficiently deep into bedrock, the casing also prevents Near-surface groundwater from artificially communicating with the deeper Chatsworth Formation groundwater. In some wells, the conductor casing may not have been advanced into competent, unweathered bedrock and, therefore, isolation of the alluvium/weathered bedrock zone at these locations is questionable.

Section 4.1 provides an overview of the Near-surface groundwater conditions for Area IV. Section 4.2 provides an overview of the Chatsworth Formation groundwater below Area IV. Section 4.3 presents the differences in hydrogeology for each of the hydrogeologic study areas introduced in Section 3. Area IV monitoring well borings were used to provide data on geologic properties listed in **Table 3-1** (in Section 3.0). This table summarizes the geologic unit projected to be intercepted by monitoring well borehole for each hydrogeologic area. Piezometers that were installed in alluvium above competent bedrock and are not presented in **Table 3-1**.

4.1 Near-Surface Groundwater

Near-surface groundwater beneath portions of Area IV can exist in the alluvium and weathered bedrock. Near-surface groundwater is not always present. In this situation, only the Chatsworth Formation groundwater would be present. As previously stated, the near-surface groundwater may be found at the weathered bedrock-competent bedrock interface, this condition results in no or very little hydraulic communication with the upper Chatsworth Formation groundwater. Near-surface groundwater is generally monitored using piezometers (designated "PZ") and shallow monitoring wells (designated "RS" and "ES"). Commonly, Near-surface groundwater in Area IV is found along drainage features and near outcrops of the fine-grained members of the Chatsworth Formation. It is most prominent in the central portion of Area IV. The fine-grained shale members (i.e., SPA and ELV members) are less permeable than the sandstone members and, therefore, are more likely to create a shallow, and sometimes perched, water table. The extent of Near-surface groundwater varies considerably depending on the season and the amount of precipitation. A comparison of water levels in Near-surface groundwater wells in April 2011 (a "wet"[1] year) to those in the February 2014, (a "dry" year) is shown on **Figures 4-1 and 4-2**, respectively. In 2016, following an extended and severe drought, no significant Near-surface groundwater was present in Area IV.

Potentiometric surface maps have not been developed for Near-surface groundwater because of their limited data points. However, water level data illustrate that there is a groundwater mound across Area IV. This is consistent with the understanding that Near-surface groundwater is structurally-controlled above fine-grained units.

4.2 Chatsworth Formation Groundwater

Figure 4-3 presents the July 2016 groundwater elevation contour map for the Chatsworth Formation. Groundwater monitoring wells are assigned to the geologic 'unit' they monitor. **Table 3-1** presents the total depth of each well borehole, the open borehole interval, and unit(s)

[1] Below-average precipitation has occurred during nine of the past 10 years at the SSFL site. Use of an earlier "wet" year (i.e., 2004 with annual precipitation of 28.60 inches of rain) was not selected because of the lack of groundwater elevation data during that period.

intercepted by the open borehole. The term 'unit' refers to both fine- and coarse-grained units presented within a specific formation in the stratigraphic column (**Figure 3-4)**.

As shown in **Table 3-1** and cross-section depictions, several bedrock wells monitor multiple units due to the absence of casing and screen. For example, C-08 is 400 feet deep and intersects the: Upper Burro Flats Member (ground surface to 162 feet bgs); the ELV Member (162 to 196 feet bgs); and the Lower Burro Flats Member (196 feet to 400 feet bgs).

A three-dimensional computer model (Leapfrog©) was used to project the geologic unit intercepted by each monitoring well. The assignment of a specific geologic unit for each well is based on the projection of the unit by the model.

Figure 4-3 shows the potentiometric surface of the Chatsworth Formation groundwater; however, these contours cannot directly be used to interpret groundwater flow direction and gradient, because flow is controlled by the presence and interconnectedness of fractures and fine-grained units that function as hydraulic barriers. There are many open boreholes that fully penetrate fine-grained units and provide a hydraulic conduit between the geologic units (**Table 3-1**). This hydraulic communication between sandstone units (or degree of water mobility) may not have been present prior to advancement of these boreholes. The relatively low bulk permeability (Boeing Groundwater RFI report, 2017) of the Shale 2 (1×10^{-7} centimeters/second (cm/sec)), the fine-grained units (SPA, ELV (5×10^{-7} cm/sec), and Lot Bed (1×10^{-7} cm/sec)), and Shale 3 (1×10^{-7} cm/sec) are assumed to be one of the factors that reduce groundwater movement, thereby producing mounding effects. The relationship of the groundwater and fine-grained units are shown on cross sections for each hydrogeologic area and are discussed below.

The potentiometric surface map for July 2016 (**Figure 4-3**) shows the groundwater mound below the surface of Burro Flats. The southwest/northeast trending groundwater divide discussed previously is evident on this figure. Groundwater on the northwestern side of the divide has a propensity to move vertically downward and laterally to the northwest, while groundwater on the southeastern side of the divide migrates vertically downward and then laterally to the southeast. However, exact flow patterns in the complexly fractured/jointed and tilted bedrock regime are difficult to predict from potentiometric surfaces. Groundwater discharges to canyon and hillslope springs/seeps are estimated to account for about one-half of all site groundwater under non-pumping conditions (MWH 2009a).

The effective porosity of the rock matrix (i.e., the degree of interconnected pore spaces of the Chatsworth Formation) is about 14 percent. By comparison, the secondary porosity (space in the interconnected fractures) is much smaller, at about 0.01 percent (MWH 2009a). Groundwater storage in the Chatsworth Formation primarily occurs within the sandstone matrix porosity (about 14 percent) while groundwater flow occurs primarily through fractures (0.01 percent).

Hydraulic conductivity is the proportionality constant that describes the ease with which water can move through pore spaces and/or fractures. Hydraulic conductivity depends on the permeability of the rock and on the degree of saturation. Both matrix and bulk hydraulic conductivity measurements for the Chatsworth Formation have been made across the SSFL, as discussed below.

- Matrix hydraulic conductivity is a measurement of the unfractured rock including the interconnected open pore spaces between the sand grains that comprise the rock. The matrix hydraulic conductivity for the Burro Flats Member of the Upper Chatsworth Formation has been estimated from measurements taken of unfractured core samples. The measured matrix hydraulic conductivity ranged between 1×10^{-7} to slightly less than 1×10^{-6} centimeters per second (cm/s) (MWH 2009a).

- Bulk hydraulic conductivity is a measurement of the matrix hydraulic conductivity including the influence of other lithologic features, primarily fractures. Bulk hydraulic conductivity for the Sandstone 2 members (Burro Flats, ELV, SPA, and Silvernale) has been estimated between 8.3×10^{-8} cm/s and 8.1×10^{-5} cm/s (MWH 2009a).

- The geometric mean bulk hydraulic conductivity of fractured Chatsworth formation sandstone at SSFL is approximately 5×10-5 cm/s and is generally one to three orders of magnitude greater than the unfractured sandstone. Sandstone members of the Sandstone 1 sedimentary package have a geometric mean bulk hydraulic conductivity of approximately 1×10-4 cm/s, whereas sandstone members of the Sandstone 2 package have a lower geometric mean bulk hydraulic conductivity of 4×10-6 cm/s as a result of lower fracture density, a greater proportion of fine-grained interbeds, and possible local stress conditions (Boeing 2017).

The bedrock has low bulk hydraulic conductivities overall relative to most unconsolidated porous media aquifers. The low conductivities are characteristically restrictive to groundwater movement. However, the subsurface data suggest bedrock fractures are interconnected horizontally and vertically. The bedding parallel fractures and joints are hydraulically active with evidence of fracture interconnectivity. Table 4-1 presents hydraulic conductivities across SSFL.

4.3 Groundwater Evaluation by Hydrogeologic Area

As was discussed in Section 3.0 and shown on Figure 3-9, Area IV was divided into four hydrogeologic study areas based on observed differences in geology and hydrogeologic properties. The first study area represents the Santa Susana Formation in southern Area IV (South Hydrogeologic Area). The second study area is the western and northern portions of Area IV characterized by tighter bedrock with few fractures. The third study area is central Area IV, with the observed groundwater mound/highest groundwater surface elevations. The fourth study area is eastern Area IV, which is an extension of the Central Hydrogeologic Area, but with greater bedrock outcrops. Descriptions of the hydrogeology and the data used to characterize these four areas are provided in the following subsections.

4.3.1 South Hydrogeologic Area

4.3.1.1 Near-Surface Groundwater

There are no piezometers or wells completed in the Near-surface groundwater in the South hydrogeologic area; thus, no characteristics are presented.

4.3.1.2 Santa Susana Formation Groundwater

According to water chemistry analysis for well RD-50 conducted by MWH (2017), well RD-50 is situated within the Santa Susana Formation, immediately south of the Chatsworth Formation (Burro Flats fault). As is discussed in Section 5.3 regarding the hydrogeology of the FSDF, the

Santa Susanna formation and Burro Flats fault are not controlling influences on groundwater movement north of the fault. DOE used data collected from the wells at the FSDF to develop the understanding of the influence of the Santa Susana formation on groundwater movement.

4.3.2 Northwest Hydrogeologic Area

DOE GIAs within the Northwest Hydrogeologic Area include the FSDF and RMHF. A total of 47 bedrock and 14 Near-surface wells are located within or bordering this area; (Table 3-1 and Figure 3-7).

4.3.2.1 Near-Surface Groundwater

A total of 14 near-surface wells are completed in the Near-surface groundwater zone in the Northwest Hydrogeologic Area. Prior to the current drought, Near-surface groundwater occurred in several areas corresponding to localized surface water drainage areas near the following sites:

- FSDF area (wells RS-18, RS-23, RS-54, PZ-100, PZ-101, and PZ-102);
- Building 56 Landfill (wells RS-16 and PZ-124);
- RMHF (wells RS-28 and PZ-116); and,
- SRE and Building 4133 (wells RS-25, PZ-150, PZ-160, and PZ-161)

The occurrence of Near-surface groundwater in this area is directly related to drought conditions. Near-surface groundwater elevations in these areas in April 2011 during a wet period are presented in **Figure 4-1**. Near-surface groundwater elevations are generally aligned with topography; highest within central Area IV and lower towards the boundary of Area IV where the topography drops off to the northwest.

Figure 4-2 presents the presence of Near-surface groundwater in February 2014, during a dry period. A comparison of these two figures show a marked decrease in the lateral extent of observed Near-surface groundwater.

The occurrence of Near-surface groundwater in April 2016 (later in the drought) was limited to three wells: RS-18, RS-25, and PZ-124. In July 2016, shallow groundwater at these locations was dry. The winter rains of 2016-2017 were slightly above average and groundwater returned to RS-18 and RS-25.

4.3.2.2 Chatsworth Formation Groundwater

A total of 47 monitoring wells have been installed in the Chatsworth Formation groundwater within or adjacent to the Northwest hydrogeologic area to monitor groundwater quality (**Figure 3-7** and **Table 3-1)** four were installed as three-well clusters (RD-33, RD-34, RD-54, and RD-59) Chatsworth Formation groundwater generally flows to the northwest and southeast, with approximately half of the groundwater flux discharging to surface water via seeps or springs located in the lower elevations on the western and northern sides of the Northwest hydrogeologic area. The remaining groundwater flux continues to travel as groundwater in a northwest and southeast direction depending on the location of the observation.

The potentiometric surface map (**Figure 4-3**) for Chatsworth Formation groundwater shows hydraulic gradients are generally directed toward the northwest and southeast from the center of

Area IV, consistent with the northeast-southwest trending hydrogeologic boundary. In July 2016, groundwater elevations in the Chatsworth Formation ranged from a high of 1,788 feet amsl at RD-17 in central Area IV to a low of 1,300 feet amsl northwest of the northern buffer zone at the RD-59A (**Figure 4-3**). This relatively steep horizontal gradient roughly mirrors the local surface topography. Variations in this northwesterly gradient are seen in the vicinity of the Building 56 Landfill and the northeastern end of the hydrogeologic area. Though exact flow pathways are difficult to predict as the contours near the Building 56 Landfill indicate a westerly flow direction before turning to the northwest. In the northeast, the general horizontal flow direction is toward to the north. This variation corresponds approximately to the southwestern terminus of the Lot Bed. Groundwater may also be accumulating behind the northwest-dipping fine-grained Lot Bed before flowing south, around the end of the bed. Although the FSDF structures have been investigated, some uncertainty remains as to whether these structures influence local groundwater flow direction. The variation in flow direction may be attributed to these structures.

Average, minimum, and maximum vertical gradients for Area IV well clusters exposed to different vertical sections of the Chatsworth Formation aquifer were calculated as the difference in head divided by the vertical distance between open-interval (i.e., screened or uncased) mid-points and are reported in the 2009 Groundwater RI Report. Following review of post-2009 RI data and additional insight pertaining to which hydrogeologic unit is being monitored (via 3-dimensional model evaluation), it was determined that an Area IV-scale approach to vertical gradients was more applicable to understanding the local hydrogeologic conditions at the site. To be reflective of current hydrogeologic conditions, groundwater elevations collected in 2016 were used for this evaluation.

The determination of vertical gradients at the FSDF is difficult to assess because due of the length of open borehole that is also in hydraulic communication with more than one hydrogeologic unit. Specifically, wells RD-21, RD-54A, RD64, and RD-23 are open boreholes that allow communication between the Upper and Lower Burro Flats members (**Figure 4-4 and Table 3-1**). Water elevations generally are present within the ELV interval. **Figure 4-4** shows the projected depth for the ELV, ranging between 25° and 30° in dip.

RD-54B is open to only the Lower Burro Flats member. RD-23, RD-54A, and RD-64, open to Upper and Lower Burro Flats member and are in communication with each other as shown in pumping tests performed at RD-54B. Because of this communication, RD-54B and RD-23, RD-54A, and RD-64 water levels have equilibrated. RD-54B should not be used to represent water levels in the Lower Burro Flats member because RD-54B is in communication with RD-23 and RD-64 with open boreholes of 410 and 379 feet, respectively. To obtain a representative water level of the Lower Burro Flats member and not influence by the ELV, an isolated monitoring well from open boreholes would be required.

RD-54C has water levels that are similar to water levels measured in RD-54A, RD-54B, RD-64, and RD-23 (**Figure 4-4**). A plausible explanation is that RD-54C is in communication with these wells and the pumping test performed at RD-54B did not have a long enough duration to see the pumping effects in RD-54C.

General downward gradients for the Northwest hydrogeologic area are better represented by wells located near the RMHF. A downward gradient is present between RD-30, RD-63, and RD-

34A (**Figure 4-5 and 4-6**). Downward gradients are expected within the Burro Flats plateau and along northwest-sloping escarpment that forms the border of the Burro Flats plateau. Beyond the escarpment and shown at the RD-34 cluster, an upward gradient is present as indicated by higher water level in RD-34C than RD-34B (**Figure 4-7)**. Hydrograph of RD-34A/-34B and RD-34C demonstrate the higher water level elevation in RD-34C than those measured in RD-34A and RD-34B (**4-7**).

Further northwest of Area IV and the escarpment, upward gradients are also seen at cluster well RD-59. This well cluster monitors the Shale 3 and Upper Burro Flats member (**Figure 4-8**). Groundwater from the mountain generally results in upward gradients of as much as 0,5 foot/foot (MWH 2009). The potentiometric surfaces in RD-59B and RD-59C are above the ground surface, which result in artesian flow when the well caps are removed.

Springs and seeps occur when the potentiometric surface is equal or greater than the topographic elevations. Observed springs and seeps within the Northwestern Hydrogeologic Area (SP-900, SP-T02, S-19, S-20, S-21, and S-42) are shown on **Figure 3-7**.

Figure 4-9 presents a cross section representing the central portion of the Northwest hydrogeologic area. The divide for the groundwater present in Upper Burro Flats member occurs near DD-144 located in the adjacent Central hydrogeologic area. At the Northwest hydrogeologic area, there is no apparent groundwater mound and generally, groundwater elevations in the lower and upper members follow surface topography. During normal precipitation years, groundwater discharges occur at the surface as a spring/seep at SP-T02.

During the six to seven years that FLUTe™ multi-level systems were in place in several of the open borehole wells, water level measurements were collected from 10-ft long "ports" open to different depth intervals in a single borehole. Although these data could have allowed vertical hydraulic gradient calculations within a single borehole, FLUTe liner design, installation and maintenance make any data collected questionable. In addition, pressure transducers used to collect the data may have malfunctioned (MWH 2009a). Because of these issues and significant changes in contaminants detected in the monitoring wells while the FLUTe™ liners were installed, the systems were removed in 2013 and 2016 so other interval-specific testing could be performed in selected open boreholes.

Draw-down packer testing conducted at well RD-07 in 1995 indicates a hydraulic conductivity of 0.003 feet per day (ft/day) (1×10^{-6} cm/sec) consistent with published values for a tight sandstone (Harding Lawson 1995). The authors of the report state the value fell "within expected range of hydraulic conductivities for a tight sandstone" (Harding Lawson 1995).

Isolated-interval groundwater sampling (using packer assemblies) was performed by CDM Smith and COLOG between June and August 2016. The testing procedures and results are described in the technical memorandum titled *2016 Isolated Interval Groundwater Sampling using Packers in Area IV Wells, Santa Susana Field Laboratory (SSFL), Ventura County, California* (CDM Smith 2016). The primary objective of the sampling was to assess groundwater quality at specific depth intervals in existing bedrock wells. During sample collection, some qualitative information about the nature of the fracture system was also obtained. A total of six bedrock monitoring wells (C-08, RD-07, RD-23, RD-33A, RD-64, and RD-65) within the southern portion of the Northwest hydrogeologic area were sampled (**Figure 3-7**) (CDM Smith 2016). The C-08 porewater profile indicated several intervals in the vadose zone where TCE was present in the sandstone matrix.

A single or a straddle packer configuration (two packers) were used to isolate 40 intervals in the open boreholes of the six wells. Several of the intervals included fractures or fracture zones that were above the current static water levels. **Table 4-2** provides information on the location, depth and chemical results for each interval.

The following is a summary of hydrogeologic data obtained from the testing:

- The potentiometric elevation is controlled by fracture recharge. In many wells, a fracture that produces water is present at or slightly above the current water table elevation.
- The Northwest hydrogeologic area fractures and local bedrock have low bulk hydraulic conductivity as groundwater sampling was either extremely slow or not possible due to the tightness of the fractures or fine-grained formation.
- The fractures in bedrock appear to be the primary conduits for contaminant migration; however, groundwater could not be extracted from all fractures and not all fractures filled with groundwater exhibited contamination.

Several aquifer tests were performed in the Northwest hydrogeologic area from 1994 to 2006 that provide valuable data regarding aquifer properties. The first testing was performed using well RD-63 in the drainage below the RMHF (GRC 1997a). The second testing included pumping of wells RS-54, RD-23, RD-54A, and RD-54B at the FSDF, and well RD-21 located near ESADA (GRC 1995c and MWH 2006a).

Well RD-63 was installed in 1994 for use in removal of TCE contaminated water near the RMHF. This well was pumped intermittently from 1994 to 2006. During extraction from RD-63, responses in nearby monitoring wells (RD-34A, RD-34B, RD-34C, RD-19, RD-27, RD-30 and RS-28) were monitored to assess hydrogeologic properties (GRC 1995a). Initially, RD-63 was pumped at a rate of 9 gpm and then lowered to a sustainable pumping rate of 2.1 to 2.2 gpm. Initially RD-63 was pumped for three months and a total of 276,450 gallons of water were extracted during the test. Water levels declined in all of the monitoring wells. Pumping effects ranged from a decline of 3.57 feet at RD-27 to a decline of 31.49 feet at RD-30.

When the initial pumping at well RD-63 was stopped, the water levels recovered 35 feet. Wells RD-34B and RD-30 both recovered 6 and 7 feet, respectively. Well RD-34A recovered approximately 9 feet. These three wells (RD-30, RD-34B and RD-34A) all responded similarly with connection to the termination of pumping at RD-63.

More extensive pumping of RD-63 occurred for six-months in 1996. Water levels in adjacent well RD-34A declined 34.17 feet in well RD-30 located 50 feet away, the decline was 30.65 feet, in well RD-19 located 500 feet cross to upgradient the decline was 6.55 feet, and a decline of 3.29 feet was recorded for RD-17 located 800 feet to the southeast (GRC 1997a).

Following these tests, pumping of RD-63 resumed on an intermittent basis and in all 4.3 million gallons of water were removed.

The SRE/RMHF lineament can be interpreted as either a surface expression of the Shale 3 unit or a fault. Response of monitoring wells RD-30 and RD-RD-19 to pumping RD-63 can support both interpretations. These monitoring wells are located in a drainage that is suspected to be the result of increased fracturing along a west/east strike. Strike of the drainage is obtuse to the projection of the Shale 3 unit or the fault.

In 1997, an interim measure was initiated for the extraction and treatment of groundwater from well RD-21 topographically upgradient of the FSDF. This interim measure remained operational until 2002. Typical extraction rates averaged about 173 gallons per day (gpd; MWH 2006a). During and following pumping there were no responses in water levels in surrounding monitoring wells indicating no conductivity of groundwater at RD-21 with wells at the FSDF. Given the volume of water extracted during this six-yearlong interim measure, a response at wells within the FSDF from pumping RD-21 would be expected. Lack of response may be explained by the presence of fine-grained ELV layer that may prevent communication and the fact that RD-21 is both topographically and hydraulically upgradient from the FSDF. Additionally, groundwater present in RD-21 has a differently contaminant signature (i.e., carbon tetrachloride is present but not at the FSDF) further suggesting that there is no connection between the areas.

A pumping test using well RD-54B was conducted in 2003 to evaluate the bulk hydraulic conductivity (Kb) of the Chatsworth Formation bedrock in the FSDF area (MWH 2006a). Groundwater was extracted at rates varying from 2 gpm initially to 0.3 gpm at the end of the test for of for 165 days. This pumping induced approximately 160 feet of drawdown in well RD-54B. Measurements were made in 16 adjacent wells that were fitted with pressure transducers. The test resulted in a geometric mean Kb value of 6 x 10^{-7} cm/sec. The data indicate that the bedrock fracture network near the FSDF not appreciably enhance the Kb of the Chatsworth Formation groundwater (MWH 2006a). Six of the 16 wells located as far as 400 feet from the pumping well showed measurable drawdown. Wells RD-21 and RD-50 Located 500 and 750 feet to the south did not show a response to this pumping.

Shorter duration pumping tests were performed using FSDF wells RS-54, RD-23, and RD-54A in 1994 (GRC 1995c). The affects to local hydrogeology were the same as observed during the pumping of wells RD-54B and RD-21; little or no response was observed in monitoring wells outside of the FSDF. These data demonstrate that bedrock groundwater elevation and flow are controlled by fine-grained units and fractures. Though fractures are present, the formation is relatively tight, and the rate of groundwater flow both laterally and vertically is slow.

Hydraulic responses to pumping in western SSFL are reduced by the relatively low hydraulic conductivity of Sandstone 2. In 2006, well RD-54B was pumped at a rate of 0.12 gpm for 165 days, achieving measurable drawdown in 6 of 16 monitored wells at a maximum distance of 400 feet. Although these results demonstrated interconnectivity of the fracture network, they also suggest that the fracture network within Sandstone 2 is less conductive (i.e., smaller effective fracture apertures and/or lower fracture density) than elsewhere within SSFL (MWH, 2006).

4.3.3 Central Hydrogeologic Area

GIAs within the Central Hydrogeologic Area include Buildings 4057/4059/4626, HMSA, Tritium Plume, Metals Clarifier/DOE Leach Fields 3, and Building 100 Trench. A total of 16 bedrock wells are located within the Central Hydrogeologic Area with adjacent Northwest area wells also used to characterize groundwater (Table 3-1 and Figure 3-7). There are 17 Near-surface groundwater wells in this area. No aquifer testing or discrete interval sampling has been conducted in this area. Limited hydrogeologic data is available for the Central hydrogeologic area, as discussed below.

4.3.3.1 Near-Surface Groundwater

Overall, the highest Near-surface groundwater elevations in Area IV are located in the Central hydrogeologic area (historically close to 1,800 feet amsl). Groundwater elevations decrease outward to the west, southwest and southeast of the Central hydrogeologic area. Near-surface groundwater was present across nearly the entire Central hydrogeologic area during the wet period in 2011 (**Figure 4-1**) and in portions of this area in 2014 (**Figure 4-2**). This area is underlain by the SPA and ELV (fine-grained units) and the Lot Bed of the Chatsworth Formation, which inhibit groundwater movement and allow Near-surface groundwater to accumulate above the beds.

During dry years (**Figure 4-2)**, Near-surface groundwater is present between the ELV member and the Lot Bed. Near-surface groundwater occurred only in well PZ-108 in spring and summer of 2016 as a result of the drought. PZ-108 is located on the western edge of the Central hydrogeologic area and west of the ELV outcrop. The groundwater elevation at well PZ-108 in April 2016 (1,785 feet MSL) is approximately 18 feet lower than it was in April 2011 (1,801 feet MSL).

4.3.3.2 Chatsworth Formation Groundwater

Bedrock groundwater occurs in the Lower and Upper Burro Flats members of the Chatsworth Formation in the Central hydrogeologic area. The Chatsworth Formation groundwater potentiometric surface (**Figure 4-3)** shows mounding in this area with groundwater flow to the northwest, southwest and southeast from a high of 1,781.55 in DD-144 feet amsl in July 2016**.**

There are no Chatsworth Formation well clusters in the Central hydrogeologic area evaluate vertical gradient.

Although not conducted as a GWIM, groundwater extraction was conducted 1995 through 1984 to control seepage of groundwater into the basement at former Building 4059. Monitoring well RD-24 was initially used as a pumping well for controlling groundwater that seeped into the Building 4059 basement (GRC 1999b). The year 2000 Annual Site Environmental Report (ASER) mentions that groundwater was extracted at wells RD-25 and RD-28 adjacent to Building 4059 as a continued attempt to dewater the building's basement. Interim pumping continued until 2004 when the building was removed and wells RD-25 and RD-28 were abandoned. GRC (1999b) notes that three weeks after initiation of pumping of RD-25 and RD-28 water level in the Building 4059 basement declined 3 inches. After eight weeks of pumping the water level declined 12 inches. The report further notes that after eight weeks of pumping, water levels in RD-07, 400 feet to the west, had dropped about 7.8 feet, and 1.3 feet in RD-20 located 550 feet to the south.

Groundwater was also pumped from the Building 56 excavation in 1999 to assess whether that location could be used to lower the water table to prevent seepage into the Building 4059 basement. Groundwater levels in the excavation had been measured to be between 15 to 30 feet higher than the lower basement level of Building 4059 (GRC 1999a). Groundwater was pumped from the Building 56 excavation at a rate of 36 to 52 gallons per minute which resulted in a 49-foot drop in the water level elevation over a period of five months in 1999 (from 1,796 to 1,747 feet amsl). Water level elevations in adjacent monitoring wells RD-25, RD-28, RD-7, and RD-74 also dropped by approximately 3, 1.5, 3, and 7 feet, respectively, during this time (GRC 1999a).

The responses in water level elevations in adjacent monitoring wells from the various pumping activities illustrated that the norther portion of the Central hydrogeologic area is hydraulically interconnected in a fairly uniform way in various horizontal directions.

4.3.4 East Hydrogeologic Area

GIAs in the East Hydrogeologic Area include the Buildings 4064, 4030, and 4093 leach fields, and the OCY. There are 9 bedrock monitoring wells used to characterize these GIAs. No aquifer testing or discrete interval sampling has been conducted in this area.

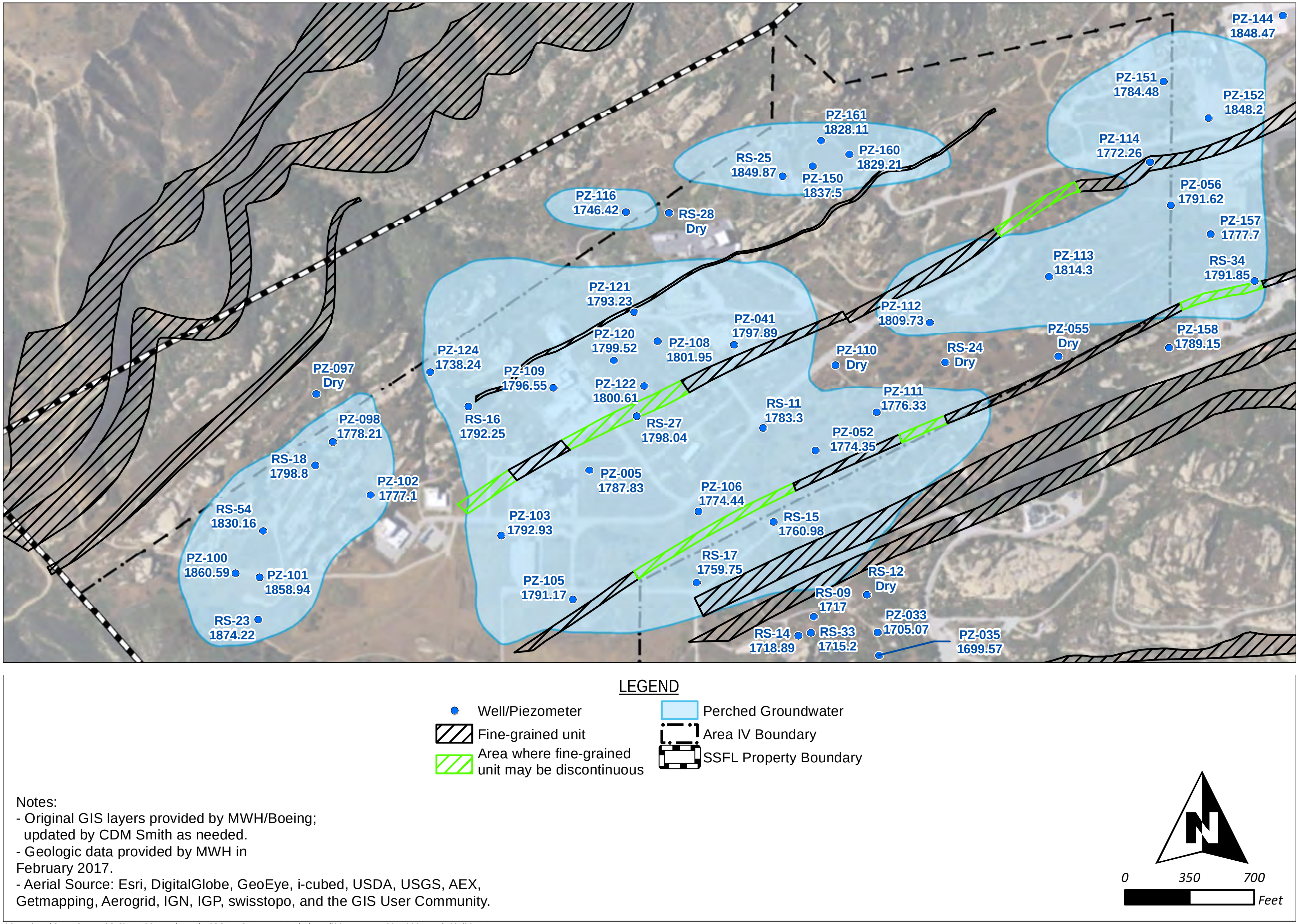
4.3.4.1 Near-Surface Groundwater

Near-surface groundwater in the East hydrogeologic area is mapped based on the well network (**Figures 4-1 and 4-2**). Wells drilled at the leach field GIAs (DS-44, DS-45, and DS-47) in 2016 did not encounter Near-surface groundwater. In 2016, Near-surface groundwater was only found at well PZ-151 in the northeastern-most portion of the East hydrogeologic area. Groundwater was present in PZ-151 throughout 2016 (CH2M Hill 2017). Similar to the Central hydrogeologic area, the East hydrogeologic area is underlain by the SPA and ELV fine-grained units that inhibit vertical movement of groundwater and allow Near-surface groundwater to accumulate above the beds.

4.3.4.2 Chatsworth Formation Groundwater

Bedrock groundwater occurs in the Lower and Upper Burro Flats members of the Chatsworth Formation in the East hydrogeologic area. Potentiometric surface contours indicate that Chatsworth Formation hydraulic gradients are directed toward the north, northeast and northwest in this area (**Figure 4-3**). This may be due in part to the groundwater elevation high caused by the fine-grained units observed in the adjacent Central hydrogeologic area. Mounded groundwater flows north or northeast around the north end of the Lot Bed.

There are no Chatsworth Formation well clusters to measure vertical gradients in the East hydrogeologic area.



Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- Geologic data provided by MWH in February 2017.
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

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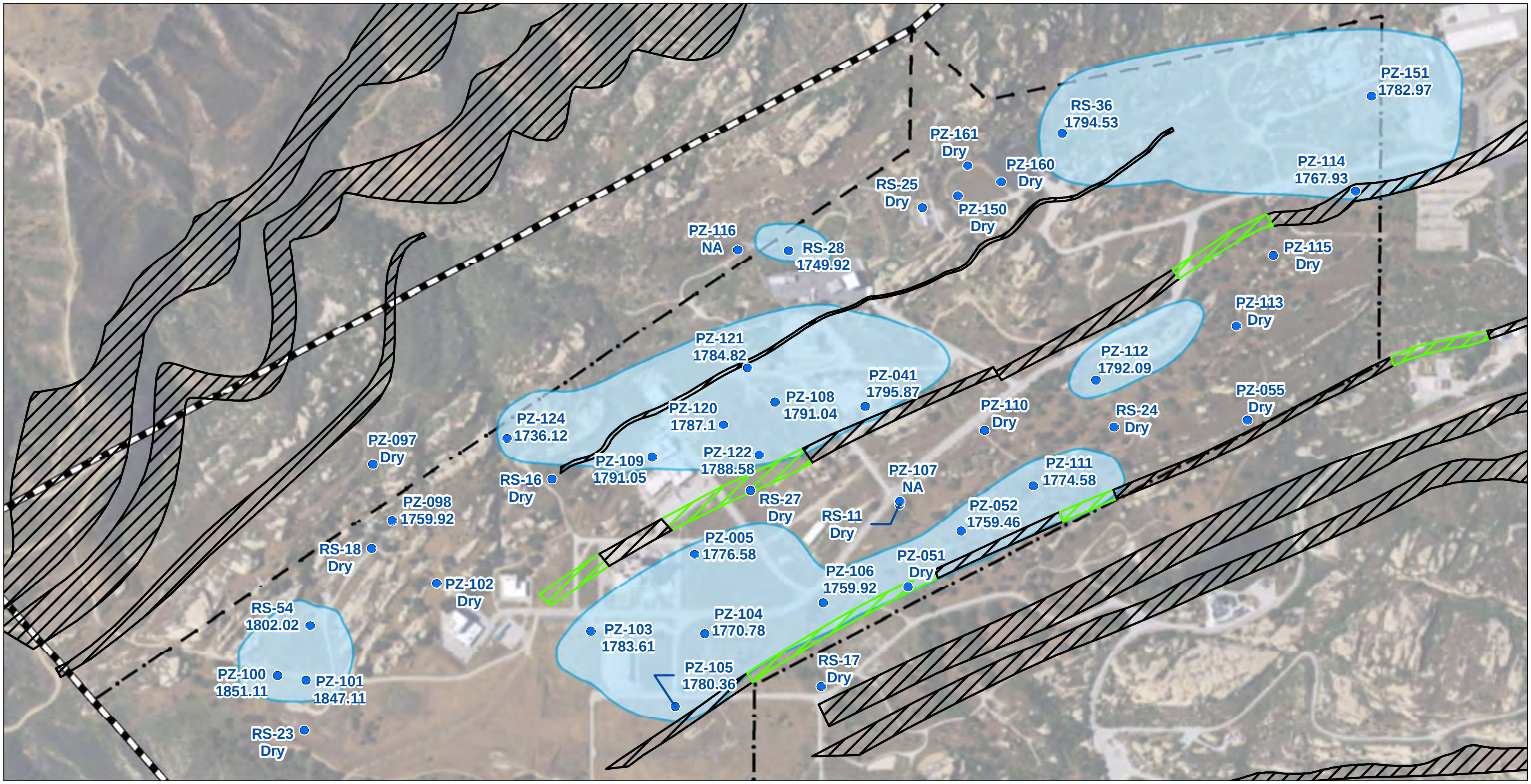
CDM Smith

FIGURE 4-1
Near-Surface Groundwater During April 2011 (Wet Period)



LEGEND

- Well/Piezometer
- Fine-grained unit
- Area where fine-grained unit may be discontinuous
- Perched Groundwater
- Area IV Boundary
- SSFL Property Boundary

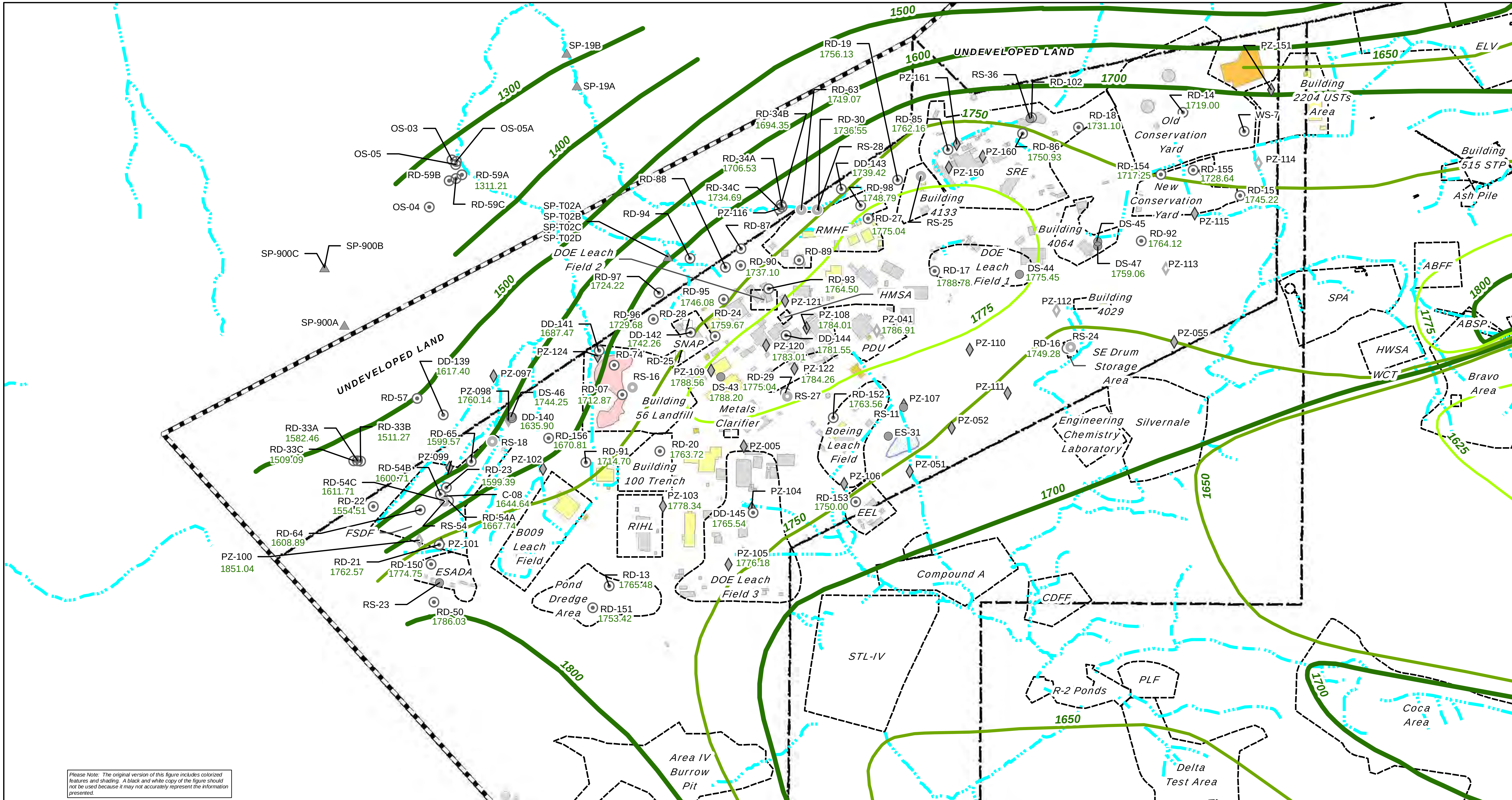
Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- Geologic data provided by MWH in February 2017.
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

0 350 700 Feet

C:_projects\SantaSusana\GIS\MXD\Groundwater\RI\SSFL_GWRI_DryPeriod_February2014_Letter_20170607.mxd 6/7/2017

CDM Smith

FIGURE 4-2
Near-Surface Groundwater During February 2014 (Dry Period)



Legend

Well Type and Groundwater Zone

Groundwater Monitoring Wells
- Groundwater Monitoring Well, Perched
- Groundwater Monitoring Well, Near Surface
- Groundwater Monitoring Well, Chatsworth Formation

Piezometers
- Piezometer, Perched
- Piezometer, Near Surface

Seeps/Springs
- Seep/spring

Other
- Abandoned Well
- Abandoned Piezometer
- Corehole

Basemap
- Drainage
- RI Site Boundary
- Area IV Boundary
- SSFL Property Boundary

Structures
- Existing Landfill
- Existing Structure
- Existing Substation
- Former Pond
- Demolished Structure

Approximate Groundwater Elevation Contours (feet above sea level)
- 25
- 50
- 100
- 1771.65 Groundwater Level Elevation in feet above mean sea level

Notes:
GIS layers provided by MWH/Boeing.
Information used to develop the groundwater elevation contours includes topography; the approximate elevations of identified seeps and springs; water levels measured in seep piezometers gauged during 2018; historical water level data for wells and piezometers not gauged during the first quarter of 2018; and the recognition that groundwater level discontinuities coincide with certain fault segments and other geologic structures.

1 inch = 550 feet

0 275 550 825 1,100 Feet

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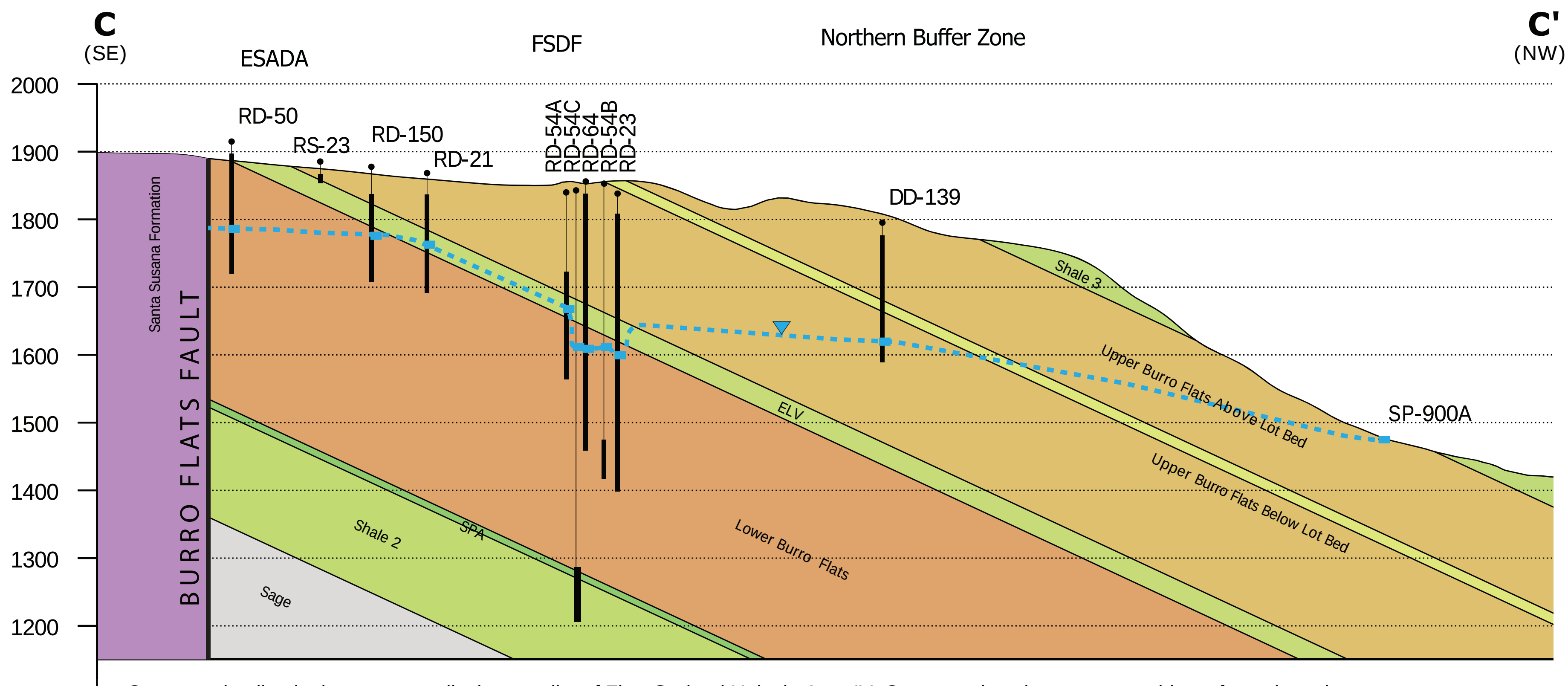
FIGURE 4-3

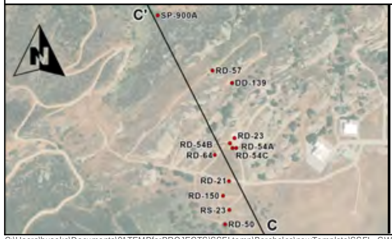
Bedrock Wells Groundwater Surface Elevation Map, First Quarter 2018



Cross section line is drawn perpendicular to strike of Fine-Grained Units in Area IV. Cross section shows topographic surface along the cross section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross section line. Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.



Notes:
- GIS Layers provided by MWH/Boeing.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS
- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND
- Groundwater Level
- Water Table

0ft 600ft

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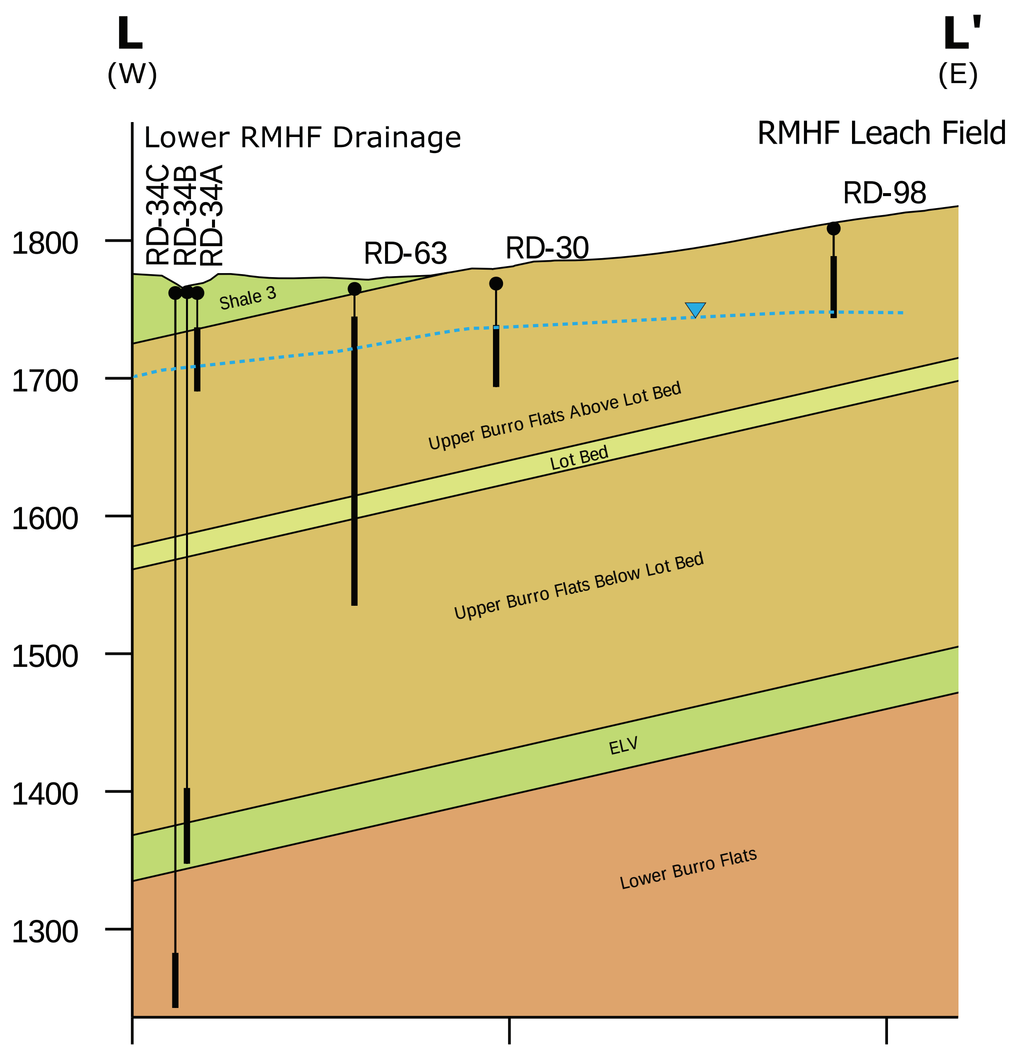
CDM Smith

FIGURE 4-4

Cross Section Through Western Area IV

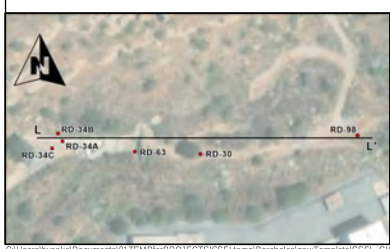


Cross section line is NOT drawn perpendicular to strike of Fine-Grained Units in Area IV. Instead, cross section drawn West to East. Cross section shows topographic surface along the cross section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.



Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 300ft

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FIGURE 4.5a

Cross Section of RMHF

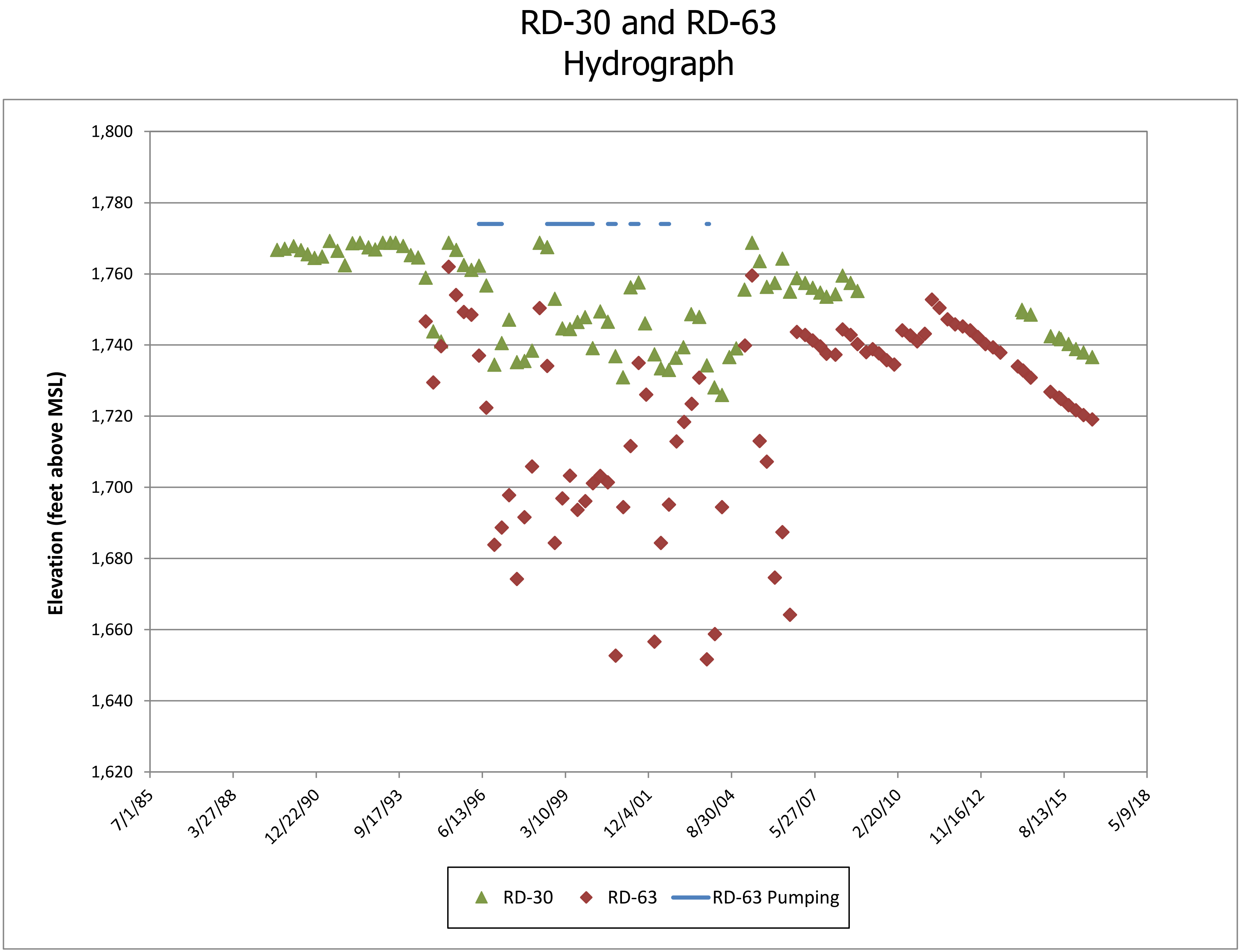


FIGURE 4-6

RD-30/RD-63 Hydrograph

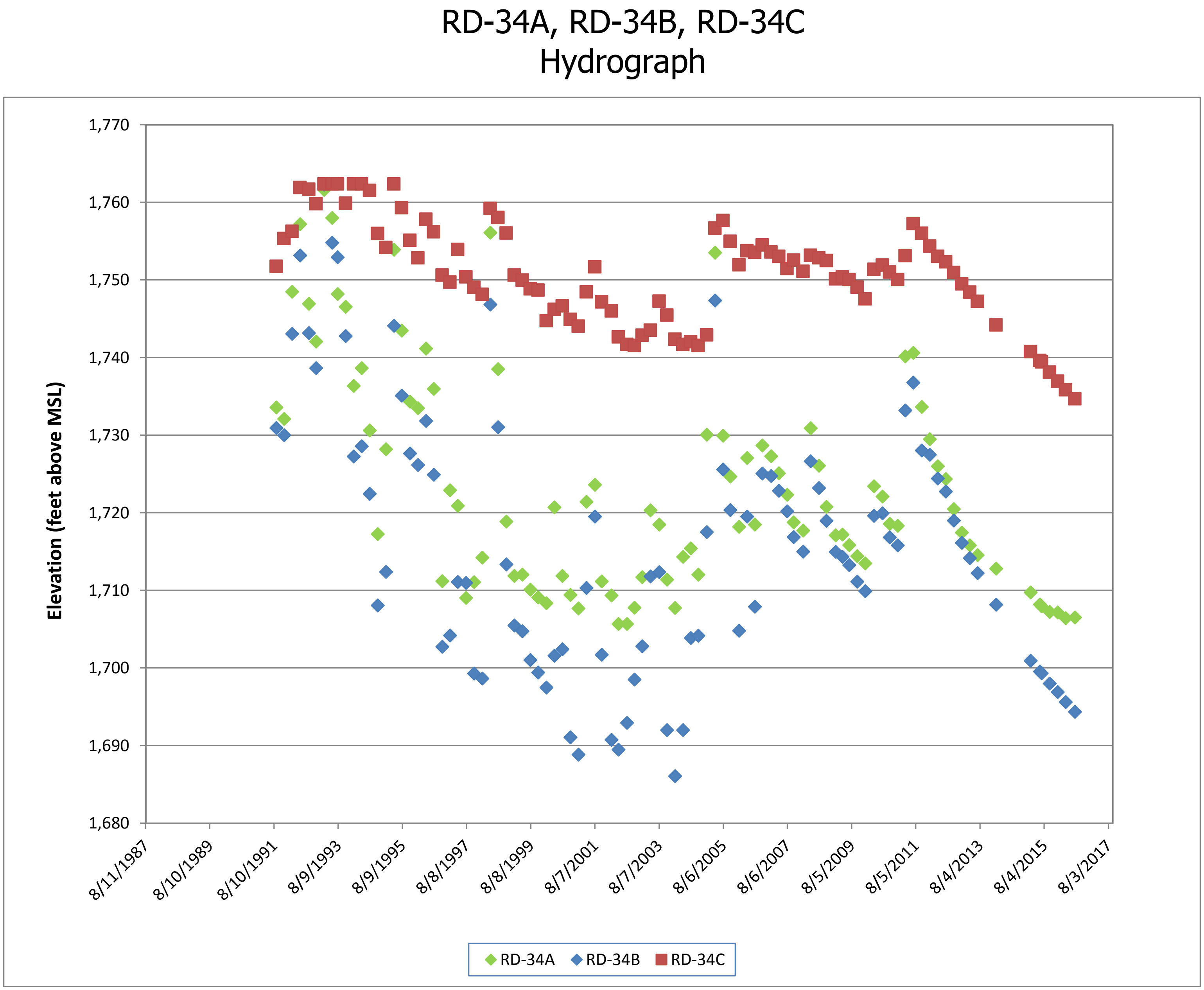
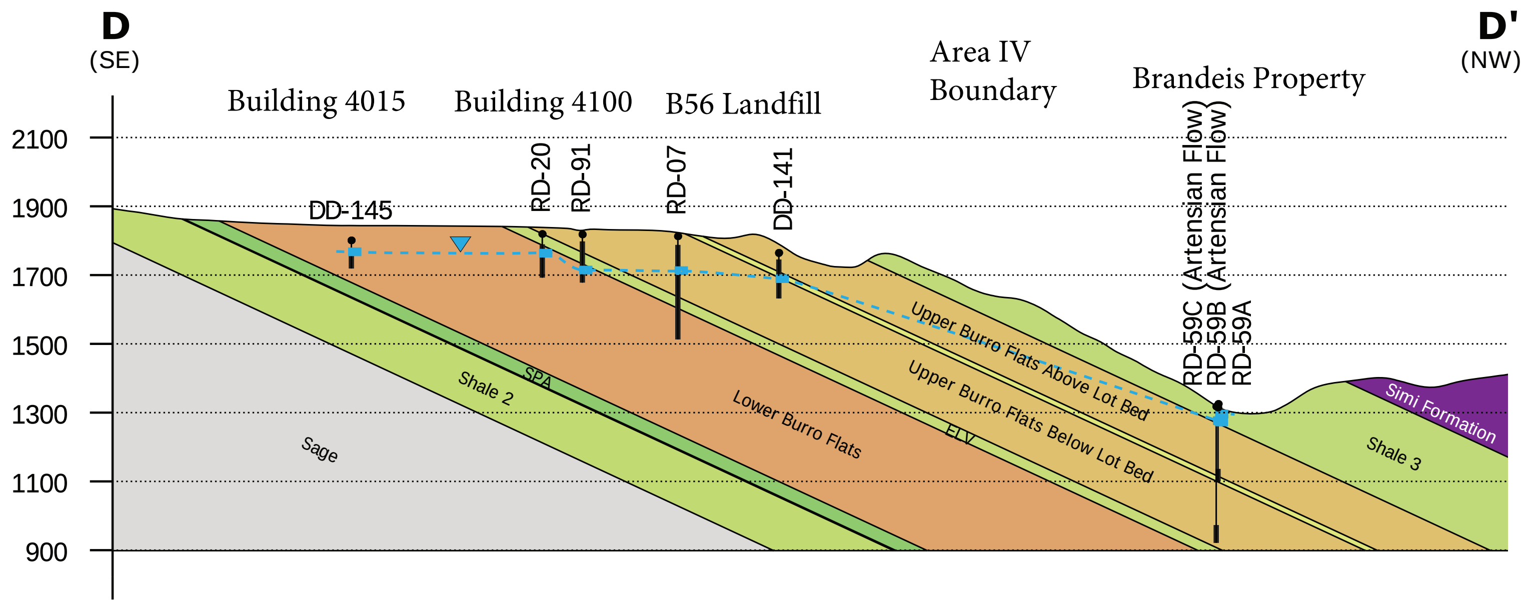


FIGURE 4-7

RD-34A/RD-34B/RD-34C Hydrograph

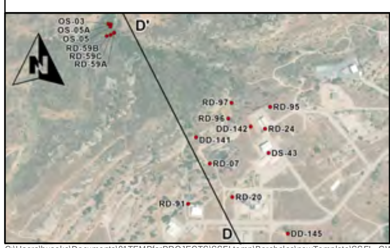


Cross section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross-section shows topographic surface along the cross-section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross-section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.



Notes:
- GIS Layers provided by MWH/Boeing.
* - Leach Fields labeled using unique ID (AI-Zxx).
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

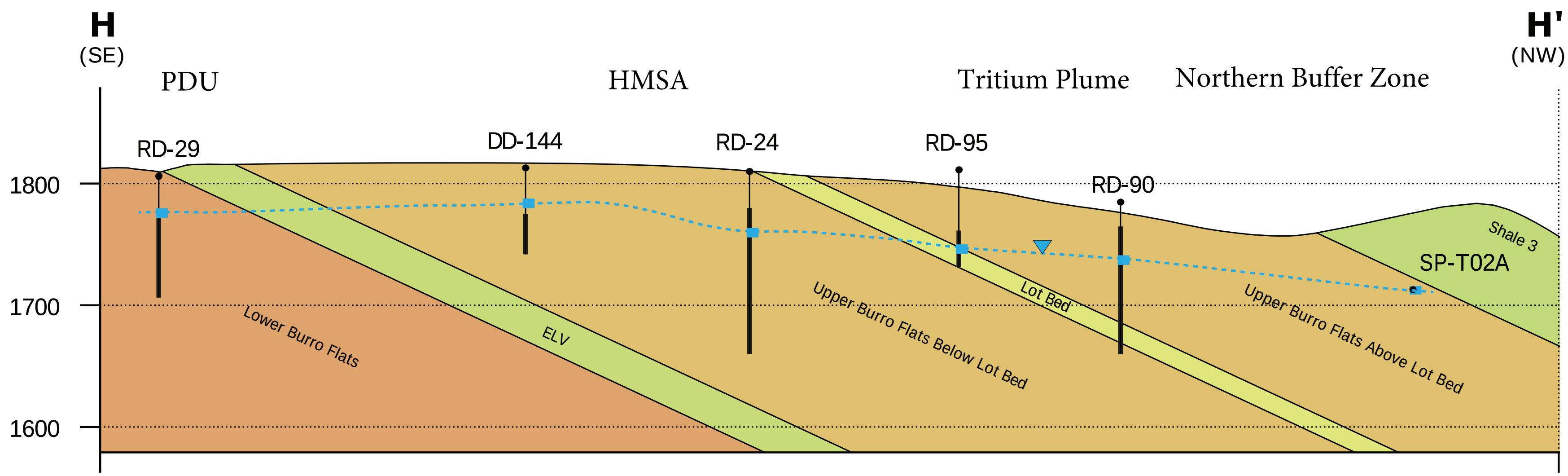
GEOLOGIC LAYERS
- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND
- Groundwater Level
- Water Table

0ft 600ft

FIGURE 4-8

Cross Section through Central Area IV & RD-59 Well Cluster



Cross-section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross-section shows topographic surface along the cross-section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross-section line. Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

Notes:
- GIS Layers provided by MWH/Boeing.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community..

GEOLOGIC LAYERS

- Shale 3
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- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 600ft

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FIGURE 4-9

Cross Section through Central Area IV

Table 4-1 - Hydraulic Conductivity Summary for SSFL

Well	SSFL Area	Well Depth	Geologic Unit at Surface	Geologic Unit at Depth	Lab Tests of Unfractured Rock Core	Single-Well Pumping Tests		FLUTe Port Slug Tests			Multiple-Well Pumping Tests		Packer Tests	Earth Tide Analysis
		(ft)			K (cm/s)	K (cm/s)	note	Port	K (cm/s)	note	K (cm/s)	note	K (cm/s)	K (cm/s)
C-7	II	420	LBF	L&UBF	3.2E-07								7.9E-05	
					7.1E-07									
					3.2E-07									
					5.9E-07									
					1.5E-08									
					1.1E-07									
					2.5E-07									
					9.9E-08									
					3.8E-07									
					6.4E-08									
					1.4E-08									
					6.0E-07									
					4.3E-08									
					3.9E-08									
					1.6E-07									
					7.0E-08									
					3.1E-07									
RD-9	II	200	LBF	LBF							2.8E-05	P		
											8.1E-05	O		
											4.8E-05	C-J		
RD-55A	III	106	CFZ	SLVN?	2.5E-10	1.9E-04	P							
					6.7E-06	1.2E-04	R							
					2.2E-06									
					1.1E-05									
RD-55B	III	250	CFZ	LBF?		6.8E-07	P							
						2.1E-06	R							
RD-60	III	126	UBF	UBF		<1.0E-6	*							
WS-11	III	677	SH2	SLVN, LBF		2.0E-06	R							
WS-SP	III	203	LBF	LBF		2.8E-06	R							

Well	SSFL Area	Well Depth	Geologic Unit at Surface	Geologic Unit at Depth	Lab Tests of Unfractured Rock Core	Single-Well Pumping Tests		FLUTe Port Slug Tests			Multiple-Well Pumping Tests		Packer Tests	Earth Tide Analysis
		(ft)			K (cm/s)	K (cm/s)	note	Port	K (cm/s)	note	K (cm/s)	note	K (cm/s)	K (cm/s)
C-8	IV	400	UBF	UBF	4.1E-07			5	6.5E-06	E				
					5.0E-08			5	1.2E-06	L				
					6.3E-08			6	6.8E-06	E				
					4.8E-07			6	1.5E-06	L				
					2.4E-07			7	6.3E-06	E				
					7.9E-07			7	1.2E-06	L				
					1.9E-07			8	1.8E-06	E				
					5.8E-07			8	5.6E-08	L				
					5.4E-07			9	4.9E-06	E				
					1.8E-07			9	4.2E-07	L				
					6.4E-07			10	9.5E-07	E				
					1.5E-07			10	8.5E-08	L				
					2.6E-07									
					1.4E-07									
					1.0E-07									
					6.1E-07									
RD-13	IV	160	LBF	LBF		6.3E-06	P							
						5.3E-06	R							
RD-14	IV	125	UBF	UBF		2.2E-05	P							
RD-15	IV	152	LBF	L&UBF		5.0E-06	P							
RD-16	IV	220	LBF	LBF		2.1E-06	P							
						1.3E-06	R							
RD-17	IV	125	UBF	UBF		3.9E-06	P							
						2.4E-06	R							
RD-18	IV	240	UBF	UBF		5.9E-07	P							
RD-19	IV	135	UBF	UBF		<1.0E-6	*							
RD-20	IV	127	UBF	UBF		1.4E-05	P							
						3.2E-05	R							

Well	SSFL Area	Well Depth	Geologic Unit at Surface	Geologic Unit at Depth	Lab Tests of Unfractured Rock Core	Single-Well Pumping Tests		FLUTe Port Slug Tests			Multiple-Well Pumping Tests		Packer Tests	Earth Tide Analysis
		(ft)			K (cm/s)	K (cm/s)	note	Port	K (cm/s)	note	K (cm/s)	note	K (cm/s)	K (cm/s)
RD-21	IV	175	UBF	UBF		<1.0E-6	*	1	1.4E-06					
								2	3.5E-05					
								3	3.1E-05					
								4	6.9E-05					
								5	3.8E-06					
RD-22	IV	440	UBF	UBF		<1.0E-6	*	1	2.2E-05					
								2	2.4E-05					
								3	2.0E-05					
								4	2.1E-05					
								5	2.3E-05					
								6	7.8E-06					
RD-23	IV	440	UBF	UBF		<1.0E-6	*							
RD-24	IV	150	Lot Bed	UBF		5.8E-06	P							
						7.3E-06	R							
RD-25	IV	175	Lot Bed	UBF		2.2E-06	P							
RD-27	IV	150	UBF	UBF		8.3E-06	P							
						8.7E-06	R							
RD-29	IV	100	ELV	UBF		1.9E-06	P							
						3.1E-06	R							
RD-30	IV	75	UBF	UBF		3.4E-05	P							
RD-54A	IV	278	UBF	UBF		<1.0E-6	*							
RD-54B	IV	437	UBF	UBF		<1.0E-6	*				6.0E-07	M		
											9.7E-07	Tm		
											5.7E-07			
RD-63	IV	230	UBF	UBF		2.8E-05	P				9.3E-06	P		
						3.0E-05	R				2.6E-05	O		
											2.4E-05	O		
											1.6E-05	DD		
											1.8E-05	C-J		
											1.6E-05	Tm		
											1.7E-05			
RD-64	IV	398	UBF	UBF		1.3E-06	P							

Well	SSFL Area	Well Depth	Geologic Unit at Surface	Geologic Unit at Depth	Lab Tests of Unfractured Rock Core	Single-Well Pumping Tests		FLUTe Port Slug Tests			Multiple-Well Pumping Tests		Packer Tests	Earth Tide Analysis
		(ft)			K (cm/s)	K (cm/s)	note	Port	K (cm/s)	note	K (cm/s)	note	K (cm/s)	K (cm/s)
RD-65	IV	397	UBF	UBF		1.0E-05	P	4	2.2E-05					
								5	2.9E-06					
								10	1.4E-06					
								11	8.3E-08					
WS-7	IV	700	LBF, SLVN	UBF		3.1E-05	R							
RD-33A	NUL (IV)	320	UBF	UBF		<1.0E-6	*	1	3.8E-05					
								2	9.5E-06					
								3	2.1E-05					
								4	4.0E-05					
								5	5.7E-05					
								6	4.0E-05					
RD-33B	NUL (IV)	240	UBF	UBF		1.2E-06	P							
RD-33C	NUL (IV)	520	UBF	UBF		8.5E-06	P							
						5.2E-05	R							
RD-34A	NUL (IV)	60	UBF	UBF		3.3E-05	R							
RD-34B	NUL (IV)	240	UBF	UBF		3.1E-06	P							
RD-34C	NUL (IV)	450	UBF	UBF		7.7E-06	P							
RD-56A	NUL (IV)	398	UBF	UBF		2.6E-06	P							
						5.7E-06	R							
RD-57	NUL (IV)	419	UBF	UBF		1.0E-05								
						6.0E-06								

Abbreviations:

NUL (IV) northern undeveloped lands near Area IV
UBF Upper Burro Flats member
ELV ELV fine-grained member
LBF Lower Burro Flats member
SLVN Silvernale member
CFZ Coca fault zone

P - pumping
R - recovery
*Non-producing wells assigned minimum value of K=6E-7 cm/s

E - early time
L - late time

P - pumping well
O - observation well
C-J - Cooper-Jacob solution
Tm - Theim equation
DD - distance-drawdown estimate
M - Moench method

Table 4-2 - Packer Testing Results - FSDF Wells and RD-07

WELL ID	Interval Depth ft bgs	Interval Description	Packer Configuration	Date Completed	Sample Name	Start/End Time of Sampling	Static Water Level (ft bgs)	Packer Isolation	Pumping Rate/Volume Purged	Parameter Stabilization	Sample Collection Method	Analytical Results (µg/L)	Packer Sampling Comments/Observations
C-08 Open borehole sample information collected prior to interval sampling Water level (5-3-16) = 197.45' bgs. Water sample (5-3-16), low-flow pump depth = 253' bgs. Results TCE - 1 ppb C-1,2-DCE - 1 T-1,2_DCE - ND	0 to 65'	Conductor Casing											
	65' to 101'	65' to 101' bgs. Productive fracture at 100' bgs and TCE in porewater at 91' bgs. Top of bottom packer set at 101' bgs.	Straddle*	6/30/2016	N/A	N/A	N/A	Packer inflated to 300 PSI with no indication of leakage.	N/A	N/A	N/A		The packer configuration for this interval is the same as the 128'-148' interval as any water accumulating above the top packer represents the combined inflow of fractures from above. However, there was no groundwater found to accumulate above the top packer after allowing to accumulate overnight.
	128' to 148'	128' to 148' bgs. Productive fractures 141' - 145' bgs and TCE in porewater 141' - 148' bgs. Top of bottom packer set at 148' bgs. Bottom of top packer set at 128' bgs.	Straddle	6/30/2016	N/A	N/A	N/A	Packer inflated to 300 PSI with no indication of leakage.	N/A	N/A	N/A		No groundwater was found to accumulate within the 128'-148' interval after letting the packers sit inflated overnight. There were no indications of packer leakage.
	180' to 200'	180' to 200' bgs. Productive fractures 180' - 200' bgs. Top of bottom packer set at 200' bgs. Bottom of top packer set at 180' bgs.	Straddle*	6/29/2016	C-8(195)_062916_01_L	1611 06/28/16-1030 6/29/16	197.16	No indication of leakage. See transducer data file.	N/A	N/A	Disposable Bailer	TCE - 1 1,2-C-DCE - 0.9	The packer configuration for this interval is the same as the 200-220' interval as any water accumulating above the top packer represents the combined water inflow from fractures above. Approximately 2 feet of water above the top packer had accumulated overnight and was sampled via bailer.
	197.16'	Open borehole Static Water Level (SWL) prior to interval sampling (6-28-16)											
	200' to 220'	200' to 220' bgs. Productive fractures 200' - 214' bgs. Top of bottom packer set at 220' bgs. Bottom of top packer set at 200' bgs.	Straddle	6/29/2016	C-8(212)_062916_01_L C-8(212)_062916_36_L Duplicate	0818-0924	197.16	No indication of leakage*. See transducer data file.	300 mL per min/ 20 liters	Yes	Low-flow with positive displacement pump	TCE - 2 1,2-C-DCE - 2	The packer and sample pump configuration at this interval prevented the use of a transducer below the bottom packer to monitor hydraulic connection between the packer interval and the column below. However, the packer pressure did not lower from 300 PSI during the entire sample interval indicating a packer seal.
	230' to 235'	230' to 235' bgs. Captures open fractures. Top of bottom packer set at 235' bgs. Bottom of top packer set at 230' bgs.	Straddle	7/5/2016	C-8(232)_070516_01_L	1425-1640	197.24	No indication of leakage. See transducer data file.	130 mL per min/ 22 liters	Yes	Low-flow with positive displacement pump	TCE - ND 1,2-C-DCE - 0.5	Interval purged at 18mL/min. Parameters stabilized after 2 hrs 20 mins of purging.
	258' to 263'	258' to 263' bgs. Captures conductive fractures. Top of bottom packer set at 263' bgs. Bottom of top packer set at 258' bgs.	Straddle	7/5/2016	C-8(260)_070516_01_L C-8(260)_070516_36_L Duplicate	0920-1140	197.24	No indication of leakage. See transducer data file.	45 mL per min/about 6 liters	Yes	Low-flow with positive displacement pump	TCE - ND 1,2-C-DCE - 1	Negative pressure observed in middle transducer only at start of test. Water reached surface after 10 mins of purging and surged for length of test. Parameters stablized and sample collected.
	306' to 311'	306' to 311' bgs. Cpautres open fractures. Top of bottom packer set at 311' bgs. Bottom of top packer set at 306' bgs.	Straddle	7/1/2016	C-8(308)_070116_01_L C-8(308)_070116_36_L Duplicate	6/30/16: 1440-1650 07/01/16: 0700 - 0730	197.24	No indication of leakage. See transducer data file.	N/A	No	Sample collected from within tubing	TCE - ND 1,2-C-DCE - ND	Two attempts were made to pump water out of this interval with the pump running for 40 and 30 minutes respectively. Both instances resulted in no groundwater making it to the surface, however groundwater made it to within several feet of the ground surface on the second attempt and a sample was collected from within the sample tubing near the pump.
	400'	Total depth of corehole											

WELL ID	Interval Depth ft bgs	Interval Description	Packer Configuration	Date Completed	Sample Name	Start/End Time of Sampling	Static Water Level (ft bgs)	Packer Isolation	Pumping Rate/Volume Purged	Parameter Stabilization	Sample Collection Method	Analytical Results (µg/L)	Packer Sampling Comments/Observations
RD-07 ** Open borehole sample information collected prior to interval sampling Water level (2-29-16) = 98.24' bgs. Water sampled (3-3-16), low-flow pump depth = 150' bgs. Results TCE - 50 C-1,2-DCE - 3.4 T-1,2-DCE - ND	0' to 25'	Conductor Casing											
	25' to 73'	25' to 73' bgs. Intercepts fractures above 73' bgs; apparent slow infiltration; thin zone. Top of bottom packer set at 73' bgs.	Straddle*	7/18/2016	Not Sampled	07/15/16: 1408 07/18/16: 1000	N/A	No indication of leakage. See transducer data file.	N/A	N/A	N/A		No groundwater was found to accumulate within the 25'-73' interval after letting the packers sit inflated over the weekend. There were no indications of packer leakage.
	99.96	Open borehole SWL prior to interval sampling (7-11-16)											
	120' - 125'	120' - 125' bgs. Captures open fracutres and iron staining. Top of bottom packer set at 125' bgs. Bottom of top packer set at 120' bgs.	Straddle	7/27/2016	RD-07(122)_072716_01_L	0740 - 1930	215.16	No indication of leakage. See transducer data file.	500 mL per min/57 liters purged	Yes, except DO and ORP*.	Low-flow with positive displacement pump	TCE - 61 C-1,2-DCE - 4	This zone purged easily, about 1 gal first 4 minutes of pumping. Slowed to 400 mL/ min to collect WQ parameters.
	184' to 189'	184' - 189' bgs. Captures open fracutres. Top of bottom packer set at 189' bgs. Bottom of top packer set at 184' bgs.	Straddle	7/27/2016	RD-07(186)_072716_01_L	1115 - 1322	215.16	No indication of leakage. See transducer data file.	500 mL per min/ 57 liters purged	Yes, except DO and ORP*.	Low-flow with positive displacement pump	TCE - 26 C-1,2-DCE - 2	This zone purged easily, about 1 gal first 4 minutes of pumping. Slowed to 400 mL/ min to collect WQ parameters.
	198' to 203'	198' - 203' bgs. Captures open fracutres. Top of bottom packer set at 203' bgs bottom of top packer set at 198' bgs.	Straddle	7/26/2016	RD-07(200)_072616_01_L	1340 - 1500	215.16	No indication of leakage. See transducer data file.	500 mL per min/ 57 liters purged	Yes, except DO and ORP*.	Low-flow with positive displacement pump	TCE - 4 C-1,2-DCE - 0.9	This zone purged easily, about 1 gal first 4 minutes of pumping. Slowed to 400 mL/ min to collect WQ parameters.
	248' to 253'	248' - 253' bgs. Captures open fractures. Top of bottom packer set at 253' bgs bottom of top packer set at 248' bgs.	Straddle	7/15/2016	RD-07(250)_071516_01_L RD-07(250)_071516_36_L Duplicate	1027-1200	99.53	Drawdown below packer interval. See data file. No drop in bottom packer pressure from 500 PSI.	150 mL per min/ 15 liters purged	Yes	Low-flow with positive displacement pump	TCE - 27 C-1,2-DCE - 2	Total gallons purged does not match sample time and flow rate due to several failed attempts to purge and sample the interval where parameters failed to stabilize before pump or controller failure. Parameters did stabilize on the third day of attempts.
	280' to 285'	280' - 285' bgs. Captures open fracutres. Top of bottom packer set at 285' bgs bottom of top packer set at 280' bgs.	Straddle	7/12/2016	RD-07(282)_071216_01_L	1151-1555.	99.96	Drawdown below packer interval. See data file. No drop in bottom packer pressure from 520 PSI.	40 mL per min / about 38 liters	Yes, except DO and ORP*.	Low-flow with positive displacement pump	TCE - 6 C-1,2-DCE - 2	Sample needed to be collected before full stabilization due to FedEx shipment cut-off time. DO and ORP also suspect false-positives due to introduction of air into water quality meter's flow through cell at a very low flow rate. The positive displacement pump has a discontinuous flow that surges without constant flow.
	300'	Total depth of borehole											

Table 4-2 - Packer Testing Results - FSDF Wells and RD-07

WELL ID	Interval Depth ft bgs	Interval Description	Packer Configuration	Date Completed	Sample Name	Start/End Time of Sampling	Static Water Level (ft bgs)	Packer Isolation	Pumping Rate/Volume Purged	Parameter Stabilization	Sample Collection Method	Analytical Results (µg/L)	Packer Sampling Comments/Observations
RD-23 Open borehole sample information collected prior to interval sampling Water level (5-3-16) = 239.38' bgs. Water sample (5-3-16), low-flow pump depth = 265' bgs. Result TCE - 19 C-1,2-DCE - 3 T-1,2-DCE - 5	0' to 30'	Conductor Casing											
	30' to 232'	30' to 232' bgs. Spans fractures at 211' - 214' and 219' - 222' bgs. Top of bottom packer set at 222' bgs.	Single	7/12/2016	RD-23(232)_071216_01_L	07/11/16 : 1700 07/12/16: 0830	228.96*	No drop in pressure from packer.	N/A	N/A	Disposable Bailer	TCE - 13 C-1,2-DCE - 1	Packer was set to 232 ft bgs below the initial 228' target. Note water level is not static, but what was measured above the packer (approximately 3 feet of water).
	238.99'	Open borehole SWL prior to interval sampling (7-6-16)											
	241' to 246'	241' - 246' bgs. Productive fractures at 245' bgs. Top of bottom packer set at 246' bgs bottom of top packer set at 241' bgs.	Straddle*	7/11/2016	RD-23(243)_071216_01_L RD-23(243)_071216_36_L Duplicate	0915-1135*	NM	No drop in pressure from either packer. See data file for transducer responses.	200 mL per min/ about 10 liters removed	Yes	Low-flow with positive displacement pump	TCE - 7 C-1,2-DCE - 1 T-1,2-DCE - 0.6	Configuration of packers at water table prevented the use of transducers (not enough room within drop pipe without getting equipment stuck, pump housing needs to be submerged in order to work). The interval purged dry immediately after parameter stabilization and was allowed to recharge for approximately 1 hour prior to sampling.
	263' to 268'	263' - 268' bgs. Productive fractures at 266-268' bgs. Top of bottom packer set at 268' bgs bottom of top packer set at 263' bgs.	Straddle	7/7/2016	RD-23(265)_070716_01_L RD-23(265)_070716_36_L Duplicate	0846-1425	240.3	No drop in pressure from either packer. See data file for transducer response.	55 mL per min/15 liters removed	Yes	Low-flow with positive displacement pump	TCE - 13 C-1,2,-DCE - 2 T-1,2-DCE - 2	Samples collected after paramters stabilized and 4 gals purged.
	272' to 277'	272' - 277' bgs. Captures fractures in this zone. Top of bottom packer set at 277' bgs bottom packer set at 272' bgs.	Straddle	7/6/2016	RD-23(275)_070616_01_L	1436-1615	238.99	No drop in pressure from either packer. Drawdown observed below bottom packer. See data file for transducer response.	215 Per min/ 22 liters removed	No	Low-flow with positive displacement pump	TCE - 30 1,1-DCE - 0.6 C-1,2-DCE - 3 T-1,2,-DCE - 3	One packer volume less piping volume removed prior to sampling due to no parameter stabilization after approximately 2 hours of purging.
	300' to 305'	300' - 305' bgs. Productive fractures at 303' bgs. Top of bottom packer set at 305' bgs bottom of top packer set at 300' bgs.	Straddle	7/13/2016	RD-23(302)_071316_01_L	1135-1535	239.23	No drop in pressure from either packer. Drawdown observed below bottom packer. See data file for transducer response.	N/A	N/A	Low-flow with positive displacement pump	TCE - 9 C-1,2-DCE - 1 T-1,2-DCE - 1	Interval did not produce water that reached ground surface after 4 hours of purging. A sample was collected near the pump within the sample tubing train.
	440'	Total depth of borehole											
RD-33A Open borehole sample information collected prior to interval sampling Water level (5-5-16) = 213.20' bgs . Water sample (5-5-16), low-flow pump depth = 240' bgs. Results TCE - 7 C-1,2-DCE - 1 T-1,2-DCE - ND	0' to 100'	Conductor Casing											
	100' to 204.5'	100' to 204.5' bgs. Intercepts fractures above static water level. Top of bottom packer set at 204.5' bgs.	Single	7/29/2016	Not Sampled	N/A	208.88	None	N/A	N/A	N/A		Overnight - no water
	208.88'	Open borehole SWL prior to interval sampling (7-27-16)											
	210' to 215'	210' - 215' bgs. Captures fractures at 211.7 to 212.7' bgs. Top of bottom packer set at 215' bgs bottom of top packer set at 210' bgs.	Straddle	8/3 - 8/4	RD-33A(212)_080416_01_L	08/03/16: 1450 - 1535 08/04/16: 0652 - 0955	212.98	No drop in pressure from either packer. See data file for transducer responses.	60 mL per min/22 liters removed	No	Low-flow with positive displacement pump	TCE - ND C-1,2-DCE - ND T-1,2-DCE - ND	Pumping was started on 8/3 and pump rate from 450 mL/min to a trickle in one hour. Pumping stopped at end of day. Sample collected on 8/4.
	217' to 222'	217' - 222' bgs. Captures temperature deviation at 200' bgs. Top of bottom packer set at 222' bgs bottom of top packer set at 217' bgs.	Straddle	8/3/2016	RD-33A(219)_080316_01_L	0954 -1359	212.24	No drop in pressure from either packer. See data file for transducer responses.	15 mL per min/ 7.5 liters removed	Yes, except DO and ORP*.	Low-flow with positive displacement pump	TCE - 2 C-1,2-DCE - 0.8J T-1,2-DCE - 0.7J	First attempt of test started at 0658 and stopped at 0744 due to problem with pump. COLOG found and fixed leak in line at packer. Test started over sampled after removal of 2 gallons
	230' to 235	230' - 235' bgs. Captures conductivity deviation from 222' bgs to 240' bgs. Top of bottom packer set at 230' bgs bottom of top packer set at 230' bgs.	Straddle	8/2/2016	RD-33A(232)_080216_01_L	1237 -1500	209.18	No drop in pressure from either packer. See data file for transducer responses.	pumped at 190 mL per min/ 22 liters removed	Yes, except DO and ORP*.	Low-flow with positive displacement pump	TCE - 2 C-1,2-DCE - 0.9J T-1,2-DCE - 0.8J	This zone purged at 190 mL/min with water to the surface after 10 minutes of pumping. Sample collected after removal of one well volume
	239' to 244'	239' - 244' bgs. Captures conductivity deviation and cacies change at 239' bgs. Top of bottom packer set at 244' bgs bottom of top packer set at 239' bgs.	Straddle	8/2/2016	RD-33A(241)_080216_01_L	0741 - 1143	212.17	No drop in pressure from either packer. See data file for transducer responses.	pumped at 90 ml per min/ 22 liters removed	Yes, except DO and ORP*.	Low-flow with positive displacement pump	TCE - 2 C-1,2-DCE - 0.8J T-1,2-DCE - 0.7J	This zone purged at 90 mL/min with water to the surface after 10 minutes of pumping. Sample collected after removal of one well volume
	291' to 296'	291' - 296' bgs. Captures fractures at 292' bgs. Top of bottom packer set at 296' bgs bottom of top packer set at 291' bgs.	Straddle	7/29/2016	RD-33A(293)_072916_01_L	1137 - 1227	211.42	Colog noted some changes in the bottom tranducer indicating communication with lower zone	0.5 gallons per minute / 22 liters removed	Yes, except DO and ORP*.	Low-flow with positive displacement pump	TCE - 6 C-1,2-DCE - 1 T-1,2-DCE - 1	This zone purged at 90 mL/min with water to the surface after 10 minutes of pumping. Sample collected after removal of one well volume
	297' to 302'	297' - 302' bgs. Captures water communication with 291' - 296' bgs (interval tested above). Top of bottom packer set at 302' bgs bottom of top packer set at 297' bgs.	Straddle	8/1/2016	RD-33A(299)_080116_01_L	0826 - 0906	211.74	Change in the lower transducer indicated communication with lower depths	430 mL per min/ 22 liters removed	No	Low-flow with positive displacement pump	TCE - 6 C-1,1-DCE - 0.9J C-1,2-DCE - 1 T-1,2-DCE - 0.9	Lower transducer indicated commication with lower intervals. Limited WQ data due to meter malfucntion during test.
	302' to 320'	302' - 320' bgs. Captures water communication with 297' - 302' bgs (interval tested above). Bottom of top packer set at 302' bgs. Bottom packer not inflated.	Straddle	8/1/2016	Not Sampled	1110-1355	211.74	During pumping, water level above the upper transducer decreased by 3' and test stopped.	330 mL per min/ 11 liters removed	NA	NA		Straddle packer placed at interval and only top packer inflated. Test stopped and no sample collected due to communication with upper intervals. After purging for 2.5 hrs, water level above upper transducer decreased by 3 ft.
	315' to 320'	315' - 320' bgs. Interval tested to determine bottom of communication zones noted from 297' - 320' bgs. Bottom of top packer set at 315' bgs. Bottom packer not inflated.	Single	8/4/2016	NA	NA	212.98		NA	NA	NA		Unable to pump water to the surface, no sample collected.
	320'	Total depth of borehole											

Table 4-2 - Packer Testing Results - FSDF Wells and RD-07

WELL ID	Interval Depth ft bgs	Interval Description	Packer Configuration	Date Completed	Sample Name	Start/End Time of Sampling	Static Water Level (ft bgs)	Packer Isolation	Pumping Rate/Volume Purged	Parameter Stabilization	Sample Collection Method	Analytical Results (µg/L)	Packer Sampling Comments/Observations
RD-64 Water level on 5-4-16 = 253.21' bgs. Water sample (5-4-16), low-flow pump depth = 285' bgs. Results TCE 14 C-1,2-DCE - 40 T-1,2-DCE - 0.6	0' to 19'	Conductor Casing											
	19' to 69'	19' to 69' bgs. SWL 272' bgs. Intercepts coarse sand at 68' bgs. Packer set at 69' bgs	Single	7/20/2016	7/22/2016	7/20/16: 0600 7/22/16: 0920	272	None	N/A	N/A	Bailer	TCE - 2	Overnight - Two nights; 0.45' of water over packer
	19' to 173'	19' to 173' bgs. Intercepts fractures at 166 - 173' bgs. Top of bottom packer set at 173' bgs	Single	7/20/2016	Not Sampled	N/A	N/A	No drop in inflation pressure.	N/A	N/A	N/A		overnight - no water
	19' to 204'	19' to 204' bgs. Intercepts fractures at 202 - 203' bgs. Top of bottom packer set at 244' bgs	Single	7/18/2016	RD-64(204)_071816_01_L	07/15/16: 1215 07/18/16: 0820	NM	No drop in inflation pressure.	N/A	N/A	Disposable Bailer	TCE - 130 1,2-DCE - 11 T-1,2-DCE - 0.7	Approximately 1.5 ft of water was above the packer after leaving over weekend and one night.
	19' to 242'	19' to 242' bgs. Intercepts interbeds at 240 - 242' bgs. Top of bottom packer set at 241' bgs	Single	7/15/2016	RD-64(242)_071516_01_L	07/14/16: 1552 07/15/16: 0724	NM	No drop in inflation pressure.	N/A	N/A	Disposable Bailer	TCE - 68 C-1,2-DCE - 6	Approximately 1' of water was above the packer after leaving overnight.
	248.78'	Open borehole SWL prior to interval sampling (7-14-16)											
	267' to 272'	267' to 272' bgs. Captures fractures in this zone. Top of bottom packer set at 272' bgs. Bottom of top packer set at 267' bgs.	Straddle	7/19/2016	RD-64(269)_071916_01_L RD-64(269)_071916_36_L Duplicate	0809-1115	244.46	No drop in inflation pressures. See data file for transducer responses.	1-15 mL per minute/ 3 liters purged	Yes, except DO and turbidity	Low-flow with positive displacement pump	TCE - 16 C-1,2-DCE - 4	Water surged during 4 hr test. Tubing removed from well and deepest water collected from tubing.
	295' to 300'	295' to 300' bgs. Captures lowest fractures in this borehole. Top of bottom packer set at 300' bgs. Bottom of top packer set at 295' bgs.	Straddle	7/14/2016	RD-64(297)_071416_01_L	1030-1430	248.78	No drop in inflation pressures. See data file for transducer responses.	N/A	N/A	Low-flow with positive displacement pump	TCE - 21 C-1,2-DCE - 5 T-1,2-DCE - 0.6	No groundwater reached the surface after 4 hours of pumping. A sample was collected within the sample tubing train near the pump.
	398'	Total depth of borehole											

WELL ID	Interval Depth ft bgs	Interval Description	Packer Configuration	Date Completed	Sample Name	Start/End Time of Sampling	Static Water Level (ft bgs)	Packer Isolation	Pumping Rate/Volume Purged	Parameter Stabilization	Sample Collection Method	Analytical Results (µg/L)	Packer Sampling Comments/Observations
RD-65 *** Open borehole sample information collected prior to interval sampling Water level (2-22-16) = 219.05' bgs. Water sample (3-10-16), low-flow pump depth = 265' bgs. Results TCE- 14 1,1-DCA - 1.1 1,1-DCE - 4 C-1,2-DCE - 3.6 T-1,2-DCE - 3.5	0' to 19'	Conductor Casing											
	19' to 174'	19' to 174' bgs. Intercepts seeps at 162' and 171' bgs. Top of packer set at 174' bgs;	Single	7/20/2016	Not Sampled	N/A	N/A	No drop in inflation pressure	N/A	N/A	N/A		DRY Single packer set 07/19/16 at 1500. On 07/20/16 at 0700,no water observed on top of packer at unstaruated zone.
	19' to 217.5	19' to 217.5' bgs. Intercepts seeps from 208' through 221' bgs. Top of packer set at 217.5' bgs; sample collected immediately above the SWL..	Single	7/25/2016	RD-65(217.5)_072516_01_L	07/22/16: 1310 07/25/16: 0630	N/A	No drop in inflation pressure.	Bailed about 200 ml	N/A	Disposable Bailer	TCE - 12 1,1-DCA - 0.9 1,1-DCE - 2 C-1,2-DCE - 2 T-1,2-DCE - 1	Water collected on top of packer over the weekend, 2.2 ft present.
	221.02'	Open borehole SWL prior to interval sampling (7-20-16)											
	220' to 225'	220' to 225' bgs. Captures fractures in this zone and first water. Top of bottom packer set at 225' bgs. Bottom of top packer set at 220' bgs.	Straddle	7/26/2016	RD-65(222)_072616_01_L RD-65(222)_072616_36_L	0630-1043	222.78	No drop in inflation pressures. See data file for transducer responses.	10 mL per minute/ 11 liters purged	Yes, except DO and turbidity	Low-flow with positive displacement pump	TCE - 8 1,1-DCA - 1 1,1-DCE - 3 C-1,2-DCE - 3 T-1,2,-DCE 2	Negative pressure observed in middle transducer during 4 hr pump test. Water reached surface at 0800, 1.5 hrs after puming. Tubing removed from well and deepest water collected from tubing.
	275' to 280'	275' to 280' bgs. Captures fractures in this zone and iron staining. Top of bottom packer set at 280' bgs. Bottom of top packer set at 275' bgs.	Straddle	7/22/2016	RD-65(277)_072206_01_L	0839-1120	222.78	No drop in inflation pressures. See data file for transducer responses.	40-240 mL per minute/ 22 liters purged	Yes, except DO and turbidity	Low-flow with positive displacement pump	TCE - 5 1,1-DCA - 0.9 1,1-DCE - 3 C-1,2-DCE - 4 T-1,2,-DCE 5	Water at surface at 0846, 7 mins after start of pumping. First hour of pumping at 240 mL/min, then slowed to surging ranging from 40-120 gal/min.
	314' to 319'	314' to 319' bgs. Captures fractures in this zone and iron staining. Top of bottom packer set at 319' bgs. Bottom of top packer set at 314' bgs.	Straddle	7/21/2019	RD-65(316)_072116_01_L	0935-1330	217.51	No drop in inflation pressures. See data file for transducer responses.	No pumping rate or volume pumped	NM	Sample collected from within tubing	TCE - 4 1,1-DCA - 1 1,1-DCE - 2 C-1,2-DCE - 3 T-1,2,-DCE 2	Negative pressure observed in middle transducer during 4 hr pump test. Water reached surface at end of pump test. Tubing removed from well and deepest water collected from tubing.
	322' to 327'	322' to 327' bgs. Captures fractures in this zone. Top of bottom packer set at 327' bgs. Bottom of top packer set at 322' bgs.	Straddle	7/20/2016	RD-65(324)_072016_01_L	1023-1433	221.02	No drop in inflation pressures. See data file for transducer responses.	No pumping rate or volume pumped	NM	Sample collected from within tubing	TCE - 7 1,1-DCA - 1 1,1-DCE - 3 C-1,2-DCE T-1,2-DCE - 2	Negative pressure observed in middle transducer during 4 hr pump test. Water reached surface at end of pump test. Tubing removed from well and deepest water collected from tubing.
	397'	Total depth of borehole											

Notes:
* - See Packer Sampling Comments/Observations
** - RD-07 FLUTe was removed on 1-28-13. This well was sampled as part of the 1st Quarter 2016 sampling event by North Wind.
*** - RD-65 FLUTe was removed on 2-27-13. This well was sampled as part of the 1st Quarter 2016 sampling event by North Wind.
N/A - Not applicable
NM - Not measured.
SWL - Static Water Level
µg/L - microgram per liter

Section 5

Nature and Extent of Contamination – Groundwater Investigation Areas

Many groundwater samples have been collected from the Area IV monitoring wells since 1986. The sample results have been reviewed and evaluated to determine contaminants of concern (COCs) from the many detections of chemical constituents and to assess areas of impacted groundwater. The historical sampling data (from date of well installation through the spring of 2018) for each well are presented in **Appendix B** and are used throughout Section 5.0 to define the nature and extent and trends of these COCs over time. The following sections provide the COCs for Area IV groundwater and an assessment of the nature and extent of these COCs in each of the 14 GIAs.

5.1 Identification of Groundwater Contaminants of Concern

Data from groundwater samples from piezometers, near-surface wells, and bedrock (Chatsworth Formation) wells (open boreholes) are used to determine the nature (the chemicals) and extent of impacted groundwater in Area IV. The COCs were identified based on their frequency of detection throughout Area IV and/or the consistency of detection in a specific well. The results were also compared to their respective groundwater screening levels to identify exceedances. This evaluation was also supported by the results of soil samples collected throughout Area IV. COCs identified in Area IV groundwater predominantly include VOCs, and to lesser extent 1,4-dioxane, metals, perchlorate, radionuclides, petroleum hydrocarbons, and nitrate. These specific COCs are discussed below.

5.1.1 Volatile Organic Compounds

Table 5.1-1 provides a listing of VOCs in groundwater samples collected throughout Area IV and their frequency of detection. It includes the number of samples that exceed their respective groundwater screening levels.[1] Exceedance of the screening level for a chemical was a primary mechanism for identifying a groundwater COC. The following is a list of VOCs evaluated as COCs based on that comparison:

- TCE
- cis-1,2-DCE
- trans-1,2-TCE
- 1,1-DCE
- Vinyl chloride
- PCE
- 1,1,1-TCA

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[1] Groundwater screening levels are groundwater concentration comparison values used to assess the possible presence of a groundwater contaminant; see Haley & Aldrich (2010) for their derivation.

- 1,1-DCA
- 1,2-DCA
- 1,4-Dioxane
- Carbon tetrachloride
- Benzene

TCE, a solvent used to clean metals of impurities, is the most frequently observed groundwater contaminant in Area IV data. It has been detected in groundwater samples collected at several locations within Area IV. It was detected at concentrations in excess of its groundwater screening level (5 µg/L) in approximately 27 percent of the samples (Table 5.1-1). The highest concentration of TCE observed in Area IV was 4,500 µg/L in a 1994 sample collected from well RS-54 (FSDF). (Note: tables providing the historical results for all Area IV wells are included in **Appendix B**.) **Figure 5.1-1** illustrates the historic (i.e., 2000 to 2010) distribution of TCE and **Figure 5.1-2** illustrates the distribution between 2011 and 2017. Degradation compounds of TCE including cis-1,2-DCE, trans-1,2-DCE, and 1,1-DCE are also COCs due to their relationship to TCE. Although vinyl chloride is infrequently observed in groundwater samples (less than 1 percent of all samples), it is included as a COC as a TCE degradation product.

PCE is also a solvent observed in Area IV groundwater samples, but to lesser extent and at lesser concentrations than TCE. PCE was detected at concentrations in excess of its screening level (5 µg/L) in approximately 2 percent of the samples, but is retained as a COC due to its consistent presence at the Buildings 4057/4059/4626 GIA. **Figure 5.1-3** illustrates the presence of PCE as determined by samples collected 2011 through 2017 (see Section 5.6 for a discussion of the PCE groundwater data). PCE degrades to TCE and degradation chemicals observed in samples containing PCE most likely includes TCE, cis-1,2-DCE, trans-1,2-DCE and 1,1-DCE.

1,1,1-TCA, 1,1-DCA, and 1,2-DCA are also reported in well samples collected at the FSDF. **Figure 5.1-4** illustrates the wells where 1,1,1-TCA has been observed in samples during the period 2000 to 2017. 1,1,1-TCA reported in 1996 in well RS-54 was the highest Area IV concentration observed in groundwater (15,000 µg/L). When sampled in 2017, 1,1,1-TCA was still present in RS-54 at an elevated concentration (11,000 µg/L). For comparison, the highest concentration of TCE observed in Area IV was 4,500 µg/L in a 1994 sample collected from well RS-54.

1,4-Dioxane, formally used as a stabilizer in some TCE products, has periodically been observed in wells where TCE and/or TCE daughter products are also detected. 1,4-Dioxane was detected in seven of the ten Area IV wells once fitted with FLUTe™ liners (RD-21, RD-23, RD-33A, RD-54A, RD-57, RD-64, and RD-65). Prior to insertion of the liners in these Area IV wells, 1,4-dioxane had not been detected (see Appendix B tables). The 1,4-dioxane concentrations in these wells generally show a decreasing trend. The presences of 1,4-dioxane in these wells may be the result of incomplete decontamination or decontamination procedures (i.e., use of soaps that contain 1,4-dioxane).

Carbon tetrachloride has been reported only in wells RD-21 and RD-59A. Carbon tetrachloride has been reported consistently in samples from RD-21, but only twice in RD-59A in 1995 and 1997. It has not been detected in the 50 groundwater samples collected from RD-59A since 1997, and its early presence in RD-59A may be a sampling or analytical artifact. Carbon tetrachloride has not been detected in FSDF wells, and because RD-21 is hydrogeologically separate from the FSDF, its presence in RD-21 may be due to a separate source.

Benzene has been detected above the groundwater screening level[2] (1 µg/L) in wells RS-54, RD-21, RD-33A, RD-57, and RD-64. With the exception of RS-54, all these wells were once fitted with FLUTe™ liners and the detections of benzene followed the installation of the FLUTe™ liners. Benzene was also detected below the groundwater screening level following FLUTe™ installation in wells RD-22, RD-50, and RD-54A. As a result of the detection of benzene in RS-54, it will remain a COC for the FSDF.

Toluene was detected twice in well RD-50 above the groundwater screening level at the same time the FLUTe™ liner was installed. It has not been detected since removal of the FLUTe™ liner and toluene is not considered a COC.

Methylene chloride was reported in 0.8% of groundwater samples above its groundwater screening level. Methylene chloride is a typical laboratory sample contaminant. There are no documented soil sources of methylene chloride in Area IV and its presence in historic samples is assumed to be a laboratory contaminant.

Maps showing the distributions of all VOCs in groundwater for Area IV are presented in the Area IV 2015, 2016, and 2017 annual groundwater reports (CDM Smith 2016a; North Wind 2017: North Wind 2018).

5.1.2 Metals

The section describes the findings of sampling of soil and groundwater for metals. The objective of the section is to discuss the adequacy of the data and well network for metals monitoring. The metal contaminants of concern (COCs) for soils were identified in the Chemical Data Summary Report (CDSR) (CDM Smith 2017). The metals COCs were identified based on their frequency of detection above background and/or an evaluation of hot spots (locations with concentration elevated concentrations). The metals evaluation in this section applies to locations that are identify as being DOE responsibilities per the 2007 CO.

Table 5.1-2 provides the metals frequency of detection in groundwater and frequency of exceedance of the groundwater screening levels. Although aluminum, boron, cadmium, cobalt, copper, lead, manganese, molybdenum, potassium, selenium, strontium, thallium, and vanadium exceeded their screening levels in at least 5 percent of groundwater samples, these metals were not automatically identified as groundwater COCs. Soils data for Area IV were reviewed to determine which of the metals exceeded soil background before identification of which the metal would be considered a COC for groundwater.

Metals differ from VOCs in that most metals naturally occur in groundwater. This was considered for determination of COCs because exceedance of a metals groundwater screening value does not specifically make a metal a COC. Natural background variability can attribute to screening level

[2] Groundwater screening levels are groundwater concentration comparison values used to assess the possible presence of a groundwater contaminant; see Haley & Aldrich (2010) for their derivation.

exceedance. Professional judgment, including location of well to a source area and presence of other groundwater contaminants in a well was used for identifying metals COCs.

For this evaluation, hotspots of metals contamination are defined as the location of a soil sample, or group of soil samples, containing concentrations of a particular metal that exceed 100 times or 10 times the soil background concentration established by DTSC. Concentrations exceeding 100 times background are an indication of a source of metals contamination that has the potential to have impacted groundwater. Locations where concentrations exceed 10 times are also evaluated as indications of a potential release to the environment.

The locations of soil exceeding 10 times and 100 times background for each metal COC were plotted on separate maps. Wells or piezometers located down gradient of each hotspot for each metal were noted. Where available, historical groundwater analytical data were reviewed to see if trends of elevated, increasing, or decreasing metals concentrations were apparent in wells located near metals hotspots. Different sampling methods have been employed over the many years of groundwater sampling at Area IV and the NBZ. To eliminate artifacts in the data that may be caused by inconsistencies in the sampling method, data older than 2009 were not used unless they were the only data available. If no wells were located downgradient of a hotspot, a potential data gap in the well network was identified.

Metals adsorbed to fine particulate matter in groundwater samples can result in higher detected concentrations. Historical data can include both analyses of both filtered (dissolved metals fraction) or unfiltered (total metals fraction). The fraction that was analyzed was taken into account during this evaluation; that is, concentrations in comparable samples (filtered or unfiltered) were compared to identify trends. Typically, regulatory agencies compare unfiltered groundwater (total metals) analytical results to criteria and if both unfiltered and filtered sample data are available only the unfiltered data are discussed.

Note that some soil metal hotspots and some wells were not located in portions of Area IV that were designated as DOE responsibility in the 2007 CO. Soil hotspots and wells located in areas that are Boeing's responsibility were not evaluated for this section of the report.

The locations of hotspots of the individual COC metals are describe below along with the presence of nearby, downgradient monitoring points (monitoring wells, piezometers or seeps).

Antimony

There are no locations of antimony with concentrations greater than 100 times its soil background value.

Antimony concentrations in soil near the Metals Clarifier (Building 4065) exceed 10 times the background value. The closest wells in that area are piezometers that have been dry in recent years (PZ-005, PZ-104 and PZ-105), and recently-installed bedrock well DD-145. Although data are limited, there are no historical detections of antimony above screening levels (2.5 μg/L) in any of three piezometers. In March 2016 antimony was detected at concentrations below screening levels in DD-145.

Other areas with soil exceeding 10 times the background value include:

- HMSA (PZ-121); antimony was not detected in 2008 filtered and unfiltered samples.
- DOE Leach Field 2 Building 4010 (near AI-Z7).

- OCY; there are no monitoring points immediately downgradient of area of elevated soil concentrations. Antimony was not detected in RD-14 (side gradient of the elevated soil concentrations) in 2014 in either filtered or unfiltered samples.

Cadmium

Cadmium concentrations in soil in the central part of the Old Conservation Yard (OCY), just upgradient of monitoring well RD-14, exceeds 100 times the background value. Cadmium was not detected groundwater samples collected from RD-14 in 2014 (or any other year for which data are available).

Lower concentrations of cadmium (exceeding 10 times the background value) were found in soil near the Metals Clarifier. Cadmium was detected, below the groundwater screening level, in the total metals sample from PZ-104 in 2014. Cadmium was detected in one total (unfiltered) metals sample from DD-145 in March 2016, but not in a field duplicate collected at the same time. Cadmium was not detected in the groundwater sample collected in October 2016. It is likely that the detection of cadmium in March 2016 was associated with fine particulates in the sample.

Cadmium was also detected exceeding 10 times the background value in soil at the DOE Leach Field 1. DS-47 is located downgradient of the leach field. Although cadmium was not detected in DS-47 in 2016, the detection limit (0.27 µg/L) was slightly above the screening level (0.2 µg/L).

Hexavalent Chromium

There are no soils that exceed 10 or 100 times the soil background value for hexavalent chromium in DOE responsibilities.

Lead

There are no soils with concentrations of lead that exceed 100 times the background value in DOE groundwater investigation areas. There is one soil sample in the HMSA that exceeded 10 times the background value. PZ-108 and DD-144 are located downgradient from the elevated soil concentrations. Lead has been detected in unfiltered groundwater from PZ-108 periodically since 2012. All detected concentrations are estimated concentrations well below the screening level (11 µg/L). Lead was also detected in unfiltered samples from DD-144 in 2016 at concentrations (0.37 J to 0.56 J µg/L) below the groundwater screening level.

At the DOE Leach Field 2, lead was found at concentrations exceeding 10 times soil background in samples collected immediately upgradient of bedrock monitoring well RD-93. RD-93 was sampled once in 2014; lead was not detected in the filtered or unfiltered samples.

Lead concentrations greater than 10 times background value were detected in DOE Leach Field 1 soil. Monitoring well DS-47 is screened in the shallow bedrock downgradient of the Leach Field and was sampled twice in 2016. Lead concentrations in both filtered and unfiltered samples range from 1.0 to 2.8 µg/L. These concentrations are below the groundwater screening level.

Methyl Mercury

There are no soils in DOE responsibilities containing concentrations of methyl mercury greater than 10 times the background value.

Mercury

Two samples from the DOE Leach Field 3 area contained more than 100 times the mercury background value. In addition, several other samples in the area exceeded 10 times the background value. Piezometer PZ-105 monitors shallow groundwater downgradient and to the southeast of the hotspot. No mercury was detected in PZ-105 in 2008, 2009, 2017, or 2018.

Soil mercury concentrations also exceeded 100 times the soil background value near Building 4065, the Metals Clarifier. PZ-005 and PZ-104 are located downgradient in the near-surface groundwater. PZ-005 was non-detect for mercury in the 2017 sample. Bedrock well DD-145 monitors groundwater downgradient in the in the Chatsworth Formation groundwater; groundwater from DD-145 was non-detect from mercury in the 2018 sample.

Mercury concentrations above 100 times the background value are also found on the southern boundary and northern boundary of the Old Conservation Yard (OCY). There are no groundwater monitoring points downgradient of the northern edge of the OCY. Bedrock monitoring well RD-14 is downgradient of the southern boundary hotspot. Groundwater from RD-14 was sampled three times for dissolved metals between 2006 and 2008. Dissolved mercury was not detected in these samples. Since 2008 RD-14 was sampled one time, in 2014, but the sample was not analyzed for mercury.

Three soil samples in the area of the former ponds at the FSDF exceeded 10 times the background value for mercury. Groundwater in this area is monitored by several near-surface and bedrock wells. Mercury was detected in an unfiltered sample from Near-surface groundwater monitoring well, RS-54, in 2008 at a concentration, 0.064 J µg/L close to the screening level of 0.063 µg/L. Mercury concentrations in groundwater at shallow bedrock wells RD-54A or RD-23 have not exceeded screening levels in recent (post 2008) years.

<u>Selenium</u>

There are soils containing greater than 100 times the background value of selenium.

Selenium is present in soils near the Metals Clarifier (Building 4065) at concentrations greater than 10 times its background value. PZ-005, the piezometer closest to this location, was sampled one time in 2002. Selenium was not detected in the groundwater from PZ-005, but the detection limit (3.51 µg/L) was more than twice the screening level (1.6 µg/L). In PZ-105, located about 750 feet downgradient from Building 4065, selenium was detected at concentrations exceeding the groundwater screening value twice in 2008, but has not been detected, or was detected below the screening value, since that time. Selenium was detected at an estimated concentration (1.7 J µg/L) just above the screening value one time in 2006. Selenium was detected in all samples (filtered and unfiltered) from upper bedrock well DD-145, located downgradient of the Metals Clarifier. This well was sampled twice in 2016; a field duplicate sample from DD-145 was collected during both sampling events. All concentrations were close to the screening level of 1.6 µg/L; only the total sample collected in October 2016 (1.7 J µg/L) exceeded the screening level. The field duplicate of this sample had a concentration of 1.5 J µg/L (i.e. just below the screening level).

More than 5,894 soil samples were analyzed for selenium and only 1 exceeded 10 times the background value. However, there are numerous locations where selenium concentrations in groundwater exceed the screening values. Therefore, the source of selenium in groundwater is considered to be natural geologic materials; the source of selenium in groundwater is not considered to be site-related.

<u>Silver</u>

There are locations where concentrations of silver exceed 100 times the background soil value: the Metals Clarifier (Building 4065), and the OCY.

Downgradient of the Metals Clarifier, silver was detected at PZ-005 in 2002, but the data were qualified due to associated blank contamination. Silver was not detected in PZ-105 or in the

Chatsworth Formation well, DD-145. PZ-104, collocated with DD-145 was dry in 2016. No silver was detected in groundwater from PZ-104 in 2014, the last time it was sampled.

The silver contamination greater than 100 times the LUT value in soil at the OCY is located just upgradient of monitoring well RD-14. Many of the soil samples from the OCY exceeded 10 times the background value for silver. Silver was not detected in the total metals analyses of the sample from RD-14 in February 2014. Silver was also not detected in dissolved metals fractions analyzed in 2006 and 2008.

Just east of DD-145 and PZ-104 there is a significant area containing soil with silver concentrations exceeding 10 times the soil background value. This area, which falls within the DOE Leach Field 3 investigation area, is side gradient of PZ-104 and DD-145. Other areas where silver concentrations exceed 10 times the LUT value include:

- DOE Leach Field 2, monitored by RD-93. Silver was not detected in 2014.
- DOE Leach Field 1, monitored by RD-17 (silver was not detected in 2014) and DS-44 (silver not detected in 2016).

Zinc

There are no areas where zinc contamination in soils exceeds 100 times its background soil value.

Zinc concentrations in soil at the Metals Clarifier (Building 4065) exceed 10 times the background value. Zinc was not detected in the 2002 groundwater sample from PZ-005 and was mostly undetected in samples from PZ-105. Detected concentrations (90.7 µg/L in a filtered sample collected in 2008) are below the groundwater screening level of 6,300 µg/L. Low concentrations (below 6 µg/L) were detected in bedrock well DD-145 in 2016.

Metals Groundwater Contamination in DOE Groundwater Investigation Areas

Some COC metals hotspots are found with DOE Groundwater Investigation Areas. These areas of high metals concentrations and the piezometers found down gradient and near the soil contamination are described for each Groundwater Investigation area, below. The concentrations of the soil COC metals in groundwater with time is also described.

No areas of metals concentrations exceeding 10 times the background soil value are located at the RMHF, Building 4064 Leach Field, Building 4133/Building 4029 Hazardous Waste Management Facility and Building 4020 Rockwell Hot Lab Groundwater Investigation Areas.

FSDF

Mercury was detected in soil about 250 feet west of the former FSDF ponds at concentrations exceeding 10 times its background value. The most heavily contaminated soil (from the former pond areas) has been removed during prior remedial actions. Groundwater in the FSDF is adequately monitored in both the Near-surface and Chatsworth groundwater.

Monitoring well RD-22 is the closest monitoring well downgradient of the mercury contamination and the RD-33 well cluster is located further (about 430 feet) downgradient of the mercury-contaminated soil. Mercury has not been detected in these wells.

RS-54, a shallow well in the former FSDF ponds (upgradient of the elevated mercury soil concentrations), was sampled many times from 1993 to 2008, and again in 2017 and 2018. As expected at this location, several metals were frequently detected above screening values.

Bedrock monitoring well DD-140 is located about 650 feet approximately along geologic strike from the mercury contamination in soil. DD-139 is located down gradient from DD-140 and was sampled in March and November 2016. Mercury was non-detect in both wells for 2018 groundwater samples.

<u>Building 100 Trench</u>
There areas of lead and antimony contaminated soil (exceeding 10 times the respective LUT values) in the Building 100 Trench groundwater investigation area. Bedrock monitoring well RD-20 is located about 150 to 200 feet from this contamination. RD-20 was sampled one time, in 2014, since 1989; lead and antimony were not detected in the filtered or unfiltered sample.

<u>Building 56 Landfill</u>
Only one soil sample exceeding 10 times the background value of any metal was collected at the Building 56 landfill area. The sample, which contained mercury at concentrations above 10 times the background value was collected close to bedrock monitoring well RD-74. This well as only sampled in 1999. Mercury was not detected in the samples, however, the detection limits (0.2 µg/L) exceeded the screening level 0.063 µg/L. Well DD-141 is located downgradient of RD-74 and was sampled for mercury in 2016 and 2018 and mercury was non-detect for both samples. Because the area of elevated mercury contamination in soil is limited, and it wasn't detected down gradient, the soil in this area is not considered to be a significant source of mercury in groundwater.

<u>Building 4057/4059/4626</u>
Soil in one location in this groundwater investigation area contains silver at a concentration that exceeds 10 times the background value. The location is close to Near-surface piezometer PZ-109 and shallow bedrock well DS-43, although both points are slightly up gradient of the soil sample location. Silver has not been detected above the screening level in PZ-109 or DS-43. Bedrock monitoring well DD-142 is located 200 feet down gradient of the soil contamination; silver was not detected in this well. Because the area of elevated silver contamination in soil is limited, and it was not detected down gradient, the soil in this area is not considered to be a significant source of silver in groundwater.

<u>HMSA (Building 4457)/Tritium Plume</u>
Antimony was detected in multiple soil samples in the HMSA and Tritium Plume groundwater investigation areas at concentrations that exceeded 10 times the background value. One area of antimony-contaminated soil is located upgradient of Near-surface piezometer PZ-121, and the other is immediately upgradient of RD-93. Piezometer PZ-121 has not been sampled since 2008. At that time, antimony was not detected in groundwater. Bedrock well RD-93 is downgradient of both areas of the antimony contaminated soil; antimony was not detected in RD-93 in 2014. Because multiple, closely-spaced soil samples exceeded 10 times the antimony background value, further monitoring of PZ-121 (when there is water) and RD-93 for antimony is recommended.

Lead was also detected in soil immediately upgradient of RD-93 in the Tritium Plume Area but was not detected in that well when it was sampled in 2014.

<u>OCY</u>
Silver exceeds 10 times the soil background value at multiple locations in the OCY. Concentrations in soil immediately upgradient of bedrock well RD-14 exceed 100 times the background value. RD-14 has been sampled one time, in 2014, since 2008. Silver was not detected in that sample.

Cadmium is also found in soil immediately upgradient of RD-14 at concentrations exceeding 10 and 100 times its background value. Cadmium was not detected about screening values in RD-14 in 2014.

Mercury was also found in multiple soil samples at the northern boundary of the OCY at concentrations 10 and (in one location) 100 times its background value. Cadmium, lead and silver area also found in the northern part of the OCY at concentrations exceeding 10 times its background value. There are no monitoring wells downgradient to the northern boundary of the OCY.

Metals Clarifier/DOE Leach Fields 3

Several COC metals exceeded 10 or 100 times their LUT value in soil at one location adjacent to the Metals Clarifier Building. These metals include antimony, cadmium, mercury, lead, silver and zinc. Piezometer PZ-005 is installed down gradient of the metals-contaminated soil; but it has been dry since 2002. At that time the unfiltered sample did not contain concentrations of any of these metals that exceeded their screening levels except for silver. However, the silver concentration was qualified because it was detected in the associated method blank. The next closest monitoring points are PZ-104, a Near-surface groundwater piezometer, and DD-145, a bedrock monitoring well, are located about 475 feet from the Metals Clarifier. No soil COC metals were detected in either PZ-104 or DD-145 at concentrations exceeding screening levels.

The DOE Leach Fields 3 investigation area is located south of the Metals Clarifier building, but is also monitored by PZ-104, PZ-105 and DD-145. Mercury is found in soil in the DOE Leach Field 3 area at several locations at concentrations exceeding 10 times its background value and at one location exceeding 100 times the background value. PZ-105 was sampled in 2008, 2009, 2014 and 2015. Only samples from 2008 and 2009 were analyzed for mercury; no mercury was detected. In 2014 and 2015 no mercury was detected.

No soil COC metals have been detected in DD-145 at concentrations exceeding screening levels. However, the samples were not analyzed for mercury.

Building 4030 and 4093 Leach Fields (DOE Leach Field 1)

Mercury and silver were detected in the DOE Leach Field 1 groundwater investigation area, at multiple locations, at concentrations above 10 times their soil background values. Lead was detected above 10 times its soil background value in one location. Shallow bedrock well DS-44 and bedrock well RD-17 monitor ground water near the area of mercury and silver soil contamination. Mercury in the 2017 sample from RD-17 was non-detect. Concentrations of silver in DS-44 groundwater exceeded the screening level in unfiltered samples collected in March and November 2016. DS-44 was non-detect for mercury for a 2018 sample.

The location of lead contamination in soil is upgradient of shallow bedrock well DS-47. Concentrations of lead in the 2016 unfiltered samples, 1.0 and 2.4 μg/L, are below the lead groundwater screening level of 11 μg/L.

Building 4009 Leach Field

Antimony is found in two locations in the Building 4009 Leach Field groundwater investigation area at concentrations exceeding 10 times the soil background value. Piezometer PZ-102, screened in the Near Surface groundwater, is located immediately downgradient of the antimony hotspots. PZ-102 was only sampled one time, in 2003, and antimony was not detected. However, the detection limits for antimony, 5.6 μg/L, are more than twice the screening level of 2.5 μg/L. About 475 feet further down gradient a cluster of monitoring points PZ-098, DS-46 and, DD-140 monitor the groundwater in the Near-surface (PZ-109 and DS-46), bedrock (DD-140), respectively. PZ-098, like PZ-102 (typically dry) was only sampled in 2003, antimony was not detected, and detection limits exceeded the screening level. There were no elevated metals concentration in DS-46 for the 2018 sample. At DD-140 antimony was detected in the unfiltered sample at concentrations (3 µg/L) exceeding the groundwater screening level in 2016. Other COC metals detected in this unfiltered sample at concentrations exceeding screening levels include cadmium (a concentration of 0.38 µg/L and screening level of 0.2 µg/L), lead (13 µg/L with a groundwater screening level of 11 µg/L). These three metals were not detected in the filtered sample; therefore, they may be present at elevated concentrations due to particulates in the sample. The sample turbidity was greater than 1,000 NTUs.

The evaluation of soil metal COCs and the existing groundwater monitoring network at the DOE responsibility groundwater investigation areas has shown three broad conclusions:

- There are some existing wells, particularly shallow wells, that have not had sufficient water to sam.
- ple in recent years. Additional data are needed from these points to confirm, or demonstrate the absence of impacts of, metal COCs in soil on groundwater.
- There are some smaller, isolated areas of metals hotspots in soil, that do not appear to have impacted groundwater.
- There are two locations where no monitoring well exists downgradient of a location of multiple metals that exceed 10 or 100 times the LUT value. Additional monitoring wells are recommended in these two areas (the Metals Clarifier and north of the northern border of the OCY.)

These conclusions and recommendations are being carried forward into the Corrective Measures Study where the well network adequacy is being evaluated for overall future groundwater monitoring purposes**.**

5.1.3 Perchlorate

Historically, perchlorate has been reported in 19 percent of groundwater samples (with 7 percent exceeding the screening value (MCL) of 6 µg/L. The samples that exceed the screening level were found near the FSDF (**Figure 5.1-5a**). Perchlorate was detected at well RD-07 located at the Building 56 Landfill, but only following installation of a FLUTe™ liner.

Perchlorate in groundwater in Area IV is likely related to historical usage as a rocket engine igniter. In recent years (see **Figure 5.1-5b**), perchlorate exceeded its screening level of 6 µg/L only in well RD-21, upgradient of the FSDF. Drums containing wastes generated outside of Area IV are known to have been stored near the vicinity of RD-21.

5.1.4 Radionuclides

The radionuclides of concern for Area IV groundwater includes radionuclides identified by USEPA in its groundwater and soil radiological study results as potential soil and groundwater contaminants (HGL 2012a, b). The primary radionuclide groundwater contaminants reported by USEPA were tritium and Sr-90. Tritium is associated with the location of several former reactor buildings, and Sr-90 is found at the RMHF leach field site.

For the remaining radionuclides, data reported from USEPA's radiological study identified cesium-137 (Cs-137), Sr-90, americium-241, cobalt-60, curium-243/244, europium-152, nickel-59, plutonium-238, and plutonium-239/240 as potential soil radionuclides of concern (HGL 2012b). Cs-137 and Sr-90 were the most frequently observed radionuclides in soil and have also been detected in groundwater samples. Of the remaining radionuclides, americium-241, cobalt-60, curium-245/246, and europium-152 have been observed in more than one groundwater sample (**Table 5.1-3**). USEPA determined that the uranium and radium results most likely reflected natural groundwater background variability (HGL 2014b). The locations where radionuclides have been observed in groundwater will be discussed later in text for each of the groundwater investigation areas. **Figures 5.1-6** and **5.1-7** illustrates where Cs-137 and Sr-90, respectively, have been observed in groundwater samples.

5.1.5 Total Petroleum Hydrocarbons

TPH-like chemicals have been reported in groundwater samples, but by different methods and chemical names. Typically TPH has been reported by number of carbons comprising a compound, but there has been an overlap in carbon range for the reported results. For this purpose of presenting TPH results in this GW RFI Report, TPH has been separated into two ranges: light TPH range and heavy TPH range. The historic data were grouped as follows:

The light TPH range consists of the following analytes:

Diesel Range Organics (DRO) C12-C14
E Fuel Hydrocarbons (EFH) C12-C14
Kerosene Range Organics (KRO) C11-C14
EFH C8-C11
Gasoline Range Organics (GRO) C5-C12
GRO C6-C12
GRO C8-C11
GRO C6-C10

The heavy TPH range consists of the following analytes:

DRO C20-C30
DRO C21-C30
EFH C21-C30
EFH C30-C40
DRO C10-C28
DRO C14-C20
DRO C15-C20
EFH C14-C20

The historic database also contains other organic chemicals, such as toluene and methanol, as TPH, those chemicals were not included as TPH as they are captured as part of the VOCs.

Figure 5.1-8a illustrates the locations by well where the maximum concentration of TPH by carbon range was detected for Area IV wells historically. **Figure 5.1-8b** illustrates the 2016/2017 TPH data for Area IV wells. Comparison of the two figures illustrates decreasing concentrations and presence for TPH. The distribution of TPH coincides with some GIAs. Sample analysis for TPH will continue under the groundwater monitoring program, but TPH presence will not be discussed further in this report.

5.1.6 Other Groundwater Chemicals

Other chemicals selected for analysis in Area IV groundwater include N-nitrosodimethylamine (NDMA), nitrate, and fluoride. NDMA was included in the Area IV groundwater analytical suite due to its presence elsewhere at SSFL. It was analyzed 115 times in samples from Area IV wells and was never detected. Therefore, NDMA is not a groundwater COC.

Nitrate has been reported in groundwater samples from Area IV wells above its groundwater screening level. The distribution of nitrate in groundwater (**Figure 5.1-9**) does not seem to correspond with specific GIAs. It is possible that the presence of nitrate relates to leakage from the former sewage piping. Because the sewer system was deactivated in 2014 and there is no longer use of the sewer system, there is no longer a source for nitrate in Area IV.

Fluoride has been detected in groundwater samples from Area IV wells only occasionally above its groundwater screening level. Fluoride was also part of the analytical suite for the soil investigation (CDM Smith 2017). Fluoride was observed above background in 3.79% of the soil samples.

5.1.7 Use and Interpretation of Historic Data

Sections 5.3 through 5.15 present the nature and extent of groundwater contamination for each GIA with a focus on data collected after 2010. Historic data, particularly the data from the 1990s, was identified as suspect due to several data quality issues. Elevated metal concentrations were reported during one or two sampling events and could not be confirmed with subsequent sampling. Other observed data quality issues include the apparent misidentification of some chemicals, significant differences in split and duplicate sample results, and the non-replication of some results in subsequent samples. This does not suggest that earlier data are being ignored in the discussion of nature and extent of contamination; rather, it means that all lines of evidence are used to determine whether the groundwater at specific well locations is impacted or not. The historic data also lacks clear documentation on how historic samples were collected. When determining impacts to groundwater, it is important to distinguish between the four groundwater sampling procedures used for open borehole wells. Specifically, the purge and pumping procedures used for pre-2010 samples are not well understood. Most samples are likely to have been collected following removal of three casing volumes of water from the well. Further, a dedicated pump, a decontaminated portable pump, or a decontaminated or disposable bailer may have been used to collect groundwater samples. Samples collected from an open borehole well using any of these techniques are considered a composite sample because a mixture of groundwater from all exposed borehole is created. The method does not limit the exposed interval within the open borehole to collect a discrete sample. Pre-2010 groundwater data is important in establishing initial conditions and contaminant trends during the 'early monitoring period', more recent data have been considered more representative because of improved documentation, sample collection techniques, and analytical methods.

The FLUTe™ systems installed in Area IV wells were not necessarily designed (i.e., sampling port placement) for FSDF bedrock fracture conditions and ports did not correspond with fractures with TCE. Groundwater samples exhibited significantly different TCE results prior to FLUTe™ liners, during the period of FLUTe™ port sampling, and following FLUTe™ removal (see Section 5.3 for a presentation of the results). Water quality data obtained during the FLUTe™ period must be used with professional judgement and discretion and not used for presence/absence of contamination or contaminant trends.

The Site-Wide Water Quality Sampling and Analysis Plan Revision 1 (WQSAP; Haley and Aldrich 2010) standardized sample collection and analysis for SSFL. Data generated after use of the WQSAP in 2010 is considered more representative of current groundwater conditions in Area IV. The WQSAP provides standard practices for water level measurements and purging and sampling of the wells. The plan also included monitoring frequency and parameters to be measured in selected wells. The WQSAP increased data usability and confidence that current site conditions are being documented and reported.

There may be variability and limitation on the interpretation and use of the recent data set. The procedure for low flow sampling described in the WQSAP specifies groundwater sampling using dedicated pumps or a portable pump decontaminated between each well. The portable low-flow sampling pump is lowered until approximately 25 percent of the water column is above the pump and 75 percent of the water column is below the pump. Because contaminant flow into the wells is through fractures, placement of the pump near or away from a fracture can affect groundwater results. The groundwater surface elevations, the starting point for pump placement have been decreasing in recent years. This mean that the pumps can be placed lower in the well borehole, possibly closer or further from a water bearing fracture. A change in groundwater contaminant concentration may be an artifact of pump placement, and not necessarily a change in groundwater quality within any specific well.

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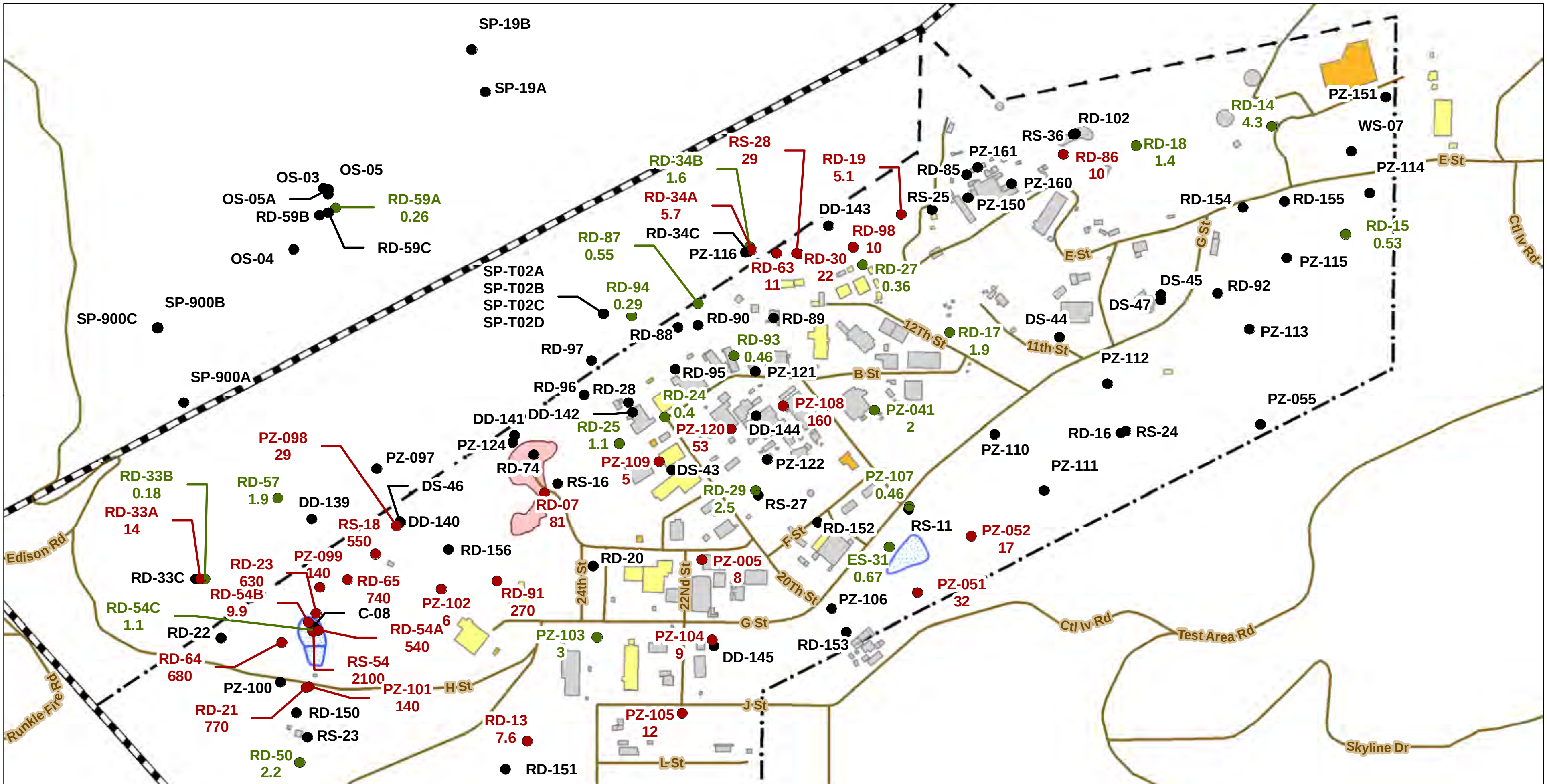

LEGEND

- TCE Detected above MCL of 5 ug/L
- TCE above detection limit, below MCL
- Well/Piezometer
- Abandoned Well

- Existing Landfill
- Existing Structure
- Existing Substation
- Former Pond
- Demolished Structure

- Road Centerline
- Area IV Boundary
- SSFL Property Boundary

Notes:
- MCLs are taste/odor thresholds.
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

N

0 350 700 Feet

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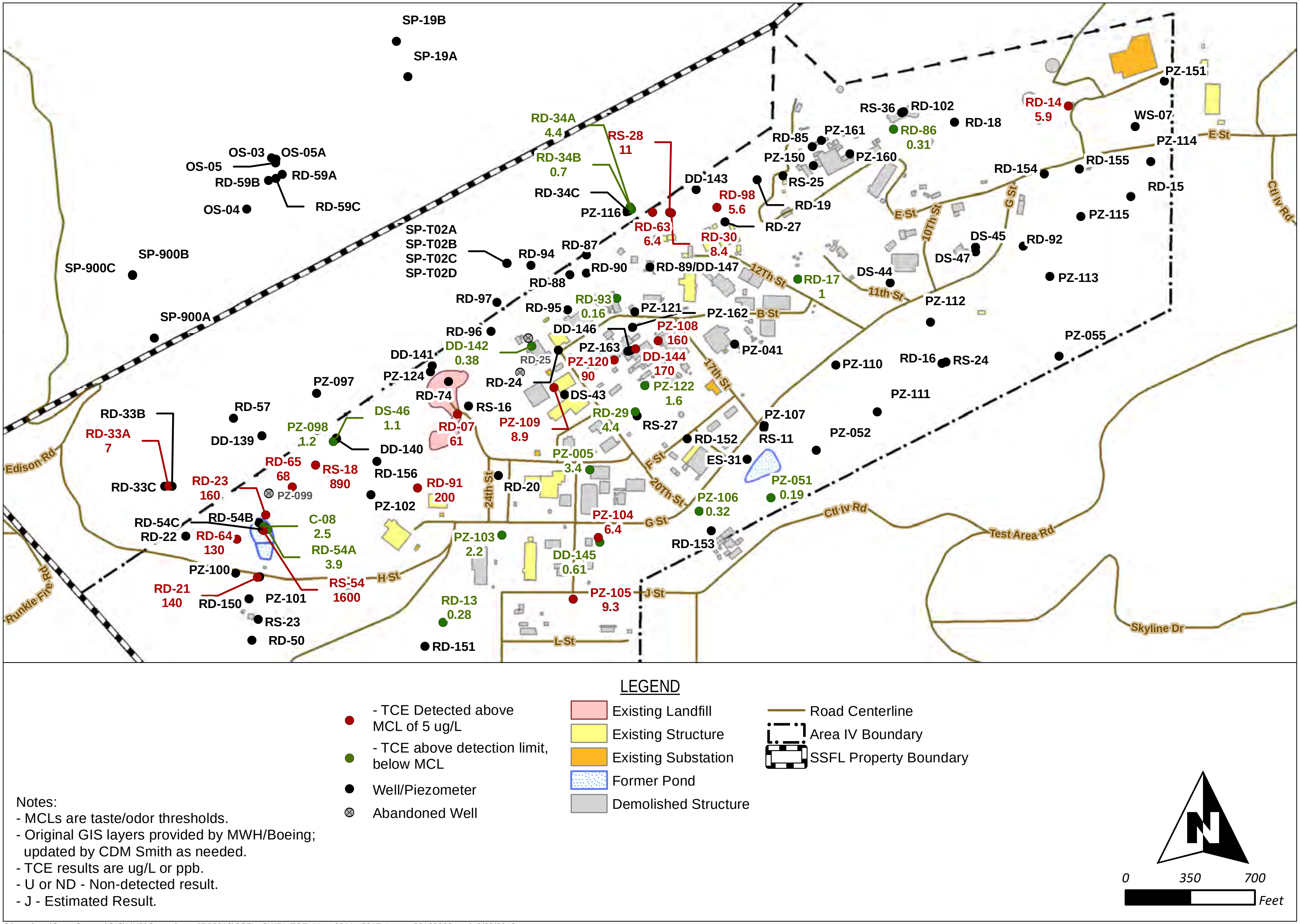
CDM Smith

FIGURE 5.1-1
Area IV Max TCE Results 2000-2010



Notes:
- MCLs are taste/odor thresholds.
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

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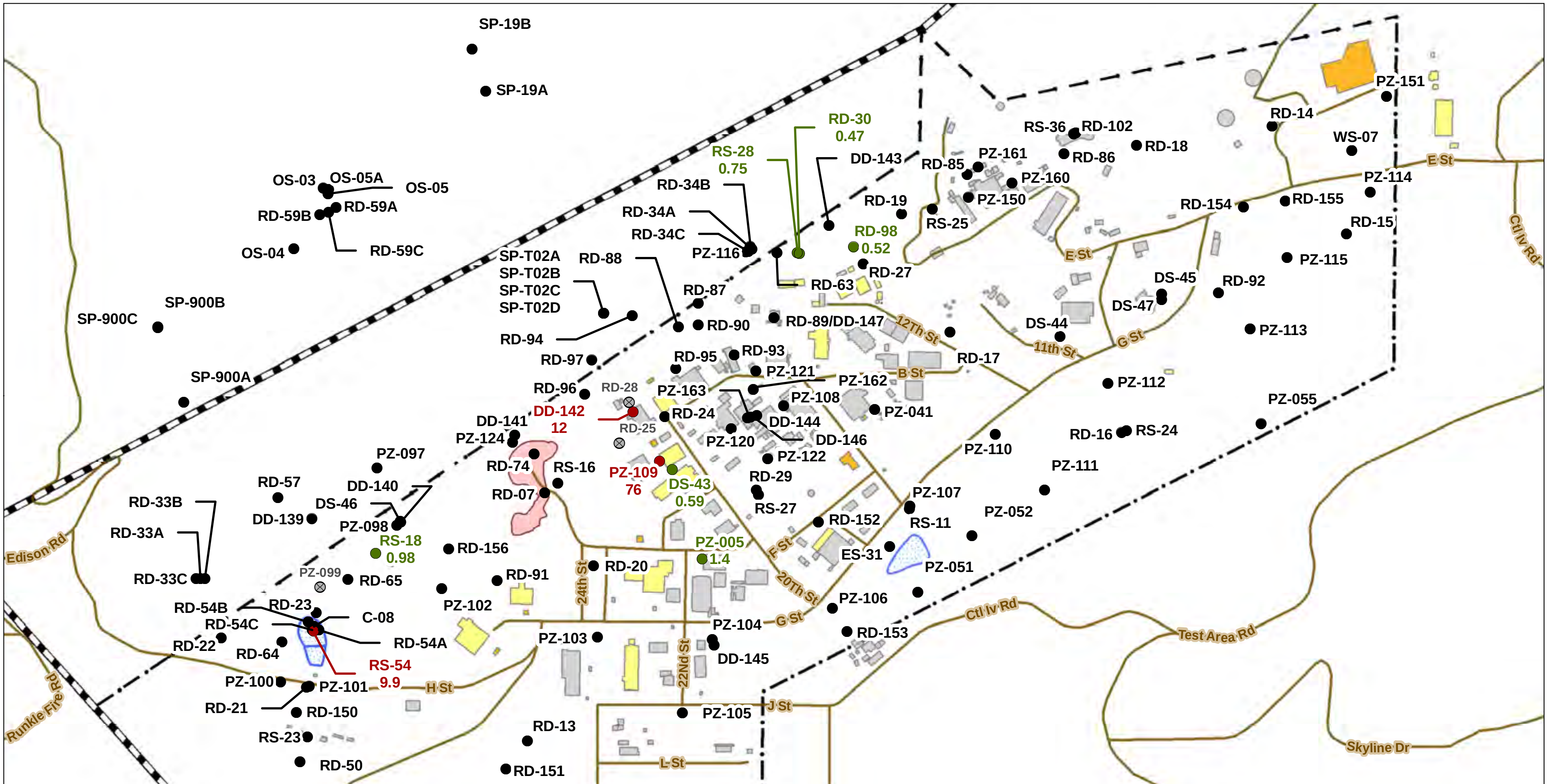
CDM Smith

FIGURE 5.1-2
Area IV Max TCE Results 2011-2017



LEGEND

- PCE Detected above MCL of 5 ug/L
- PCE above detection limit, below MCL
- Well/Piezometer
- Abandoned Well
- Existing Landfill
- Existing Structure
- Existing Substation
- Former Pond
- Demolished Structure
- Road Centerline
- Area IV Boundary
- SSFL Property Boundary

Notes:
- MCLs are taste/odor thresholds.
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- PCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

0 350 700 Feet

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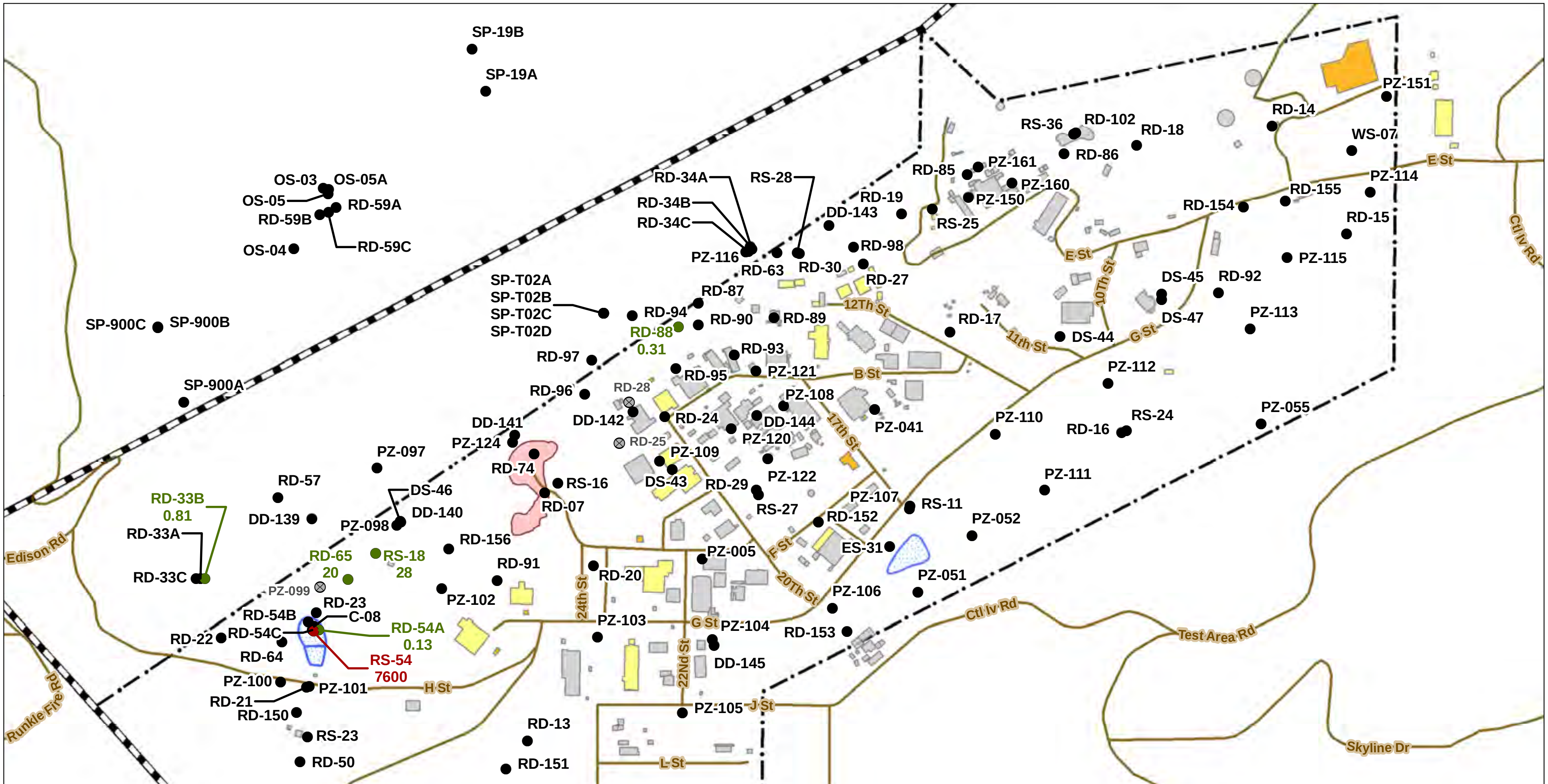
CDM Smith

FIGURE 5.1-3

Area IV Max PCE Results 2011-2017



LEGEND

- 1,1,1-TCA Detected above MCL of 200 ug/L
- 1,1,1-TCA above detection limit, below MCL

Well/Piezometer

Abandoned Well

Existing Landfill

Existing Structure

Existing Substation

Former Pond

Demolished Structure

Road Centerline

Area IV Boundary

SSFL Property Boundary

0 350 700 Feet

Notes:
- MCLs are taste/odor thresholds.
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- 2011 to 2016 1,1,1-TCA results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

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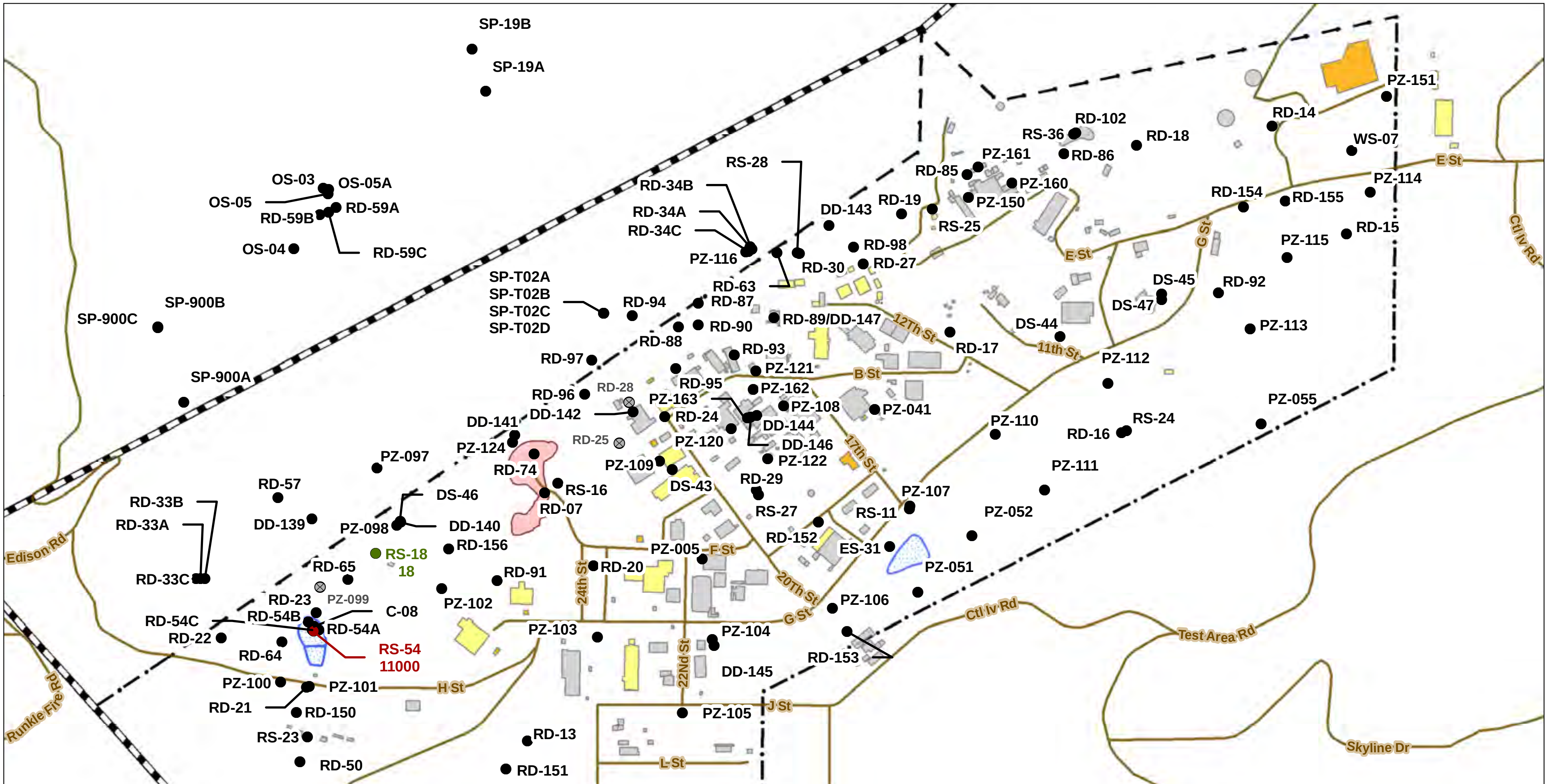
CDM Smith

FIGURE 5.1-4a

Area IV 1,1,1-Trichloroethane 2000 to 2010 Results



LEGEND

- 1,1,1-TCA Detected above MCL of 200 ug/L
- 1,1,1-TCA above detection limit, below MCL
Well/Piezometer
Abandoned Well

Existing Landfill
Existing Structure
Existing Substation
Former Pond
Demolished Structure

Road Centerline
Area IV Boundary
SSFL Property Boundary

0 350 700 Feet

Notes:
- MCLs are taste/odor thresholds.
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- 1,1,1-TCA results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

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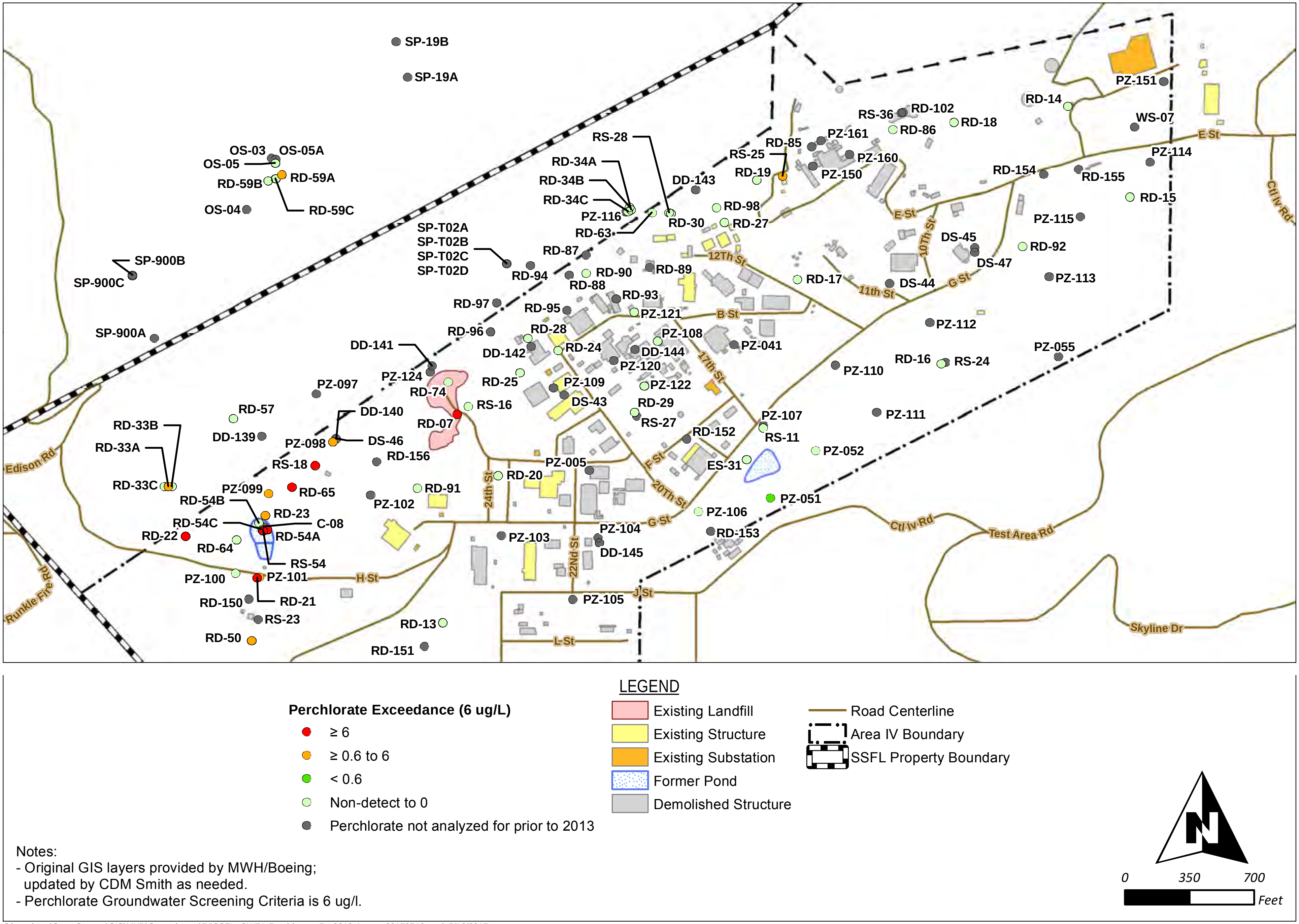
CDM Smith

FIGURE 5.1-4b
Area IV 1,1,1-Trichloroethane 2011 to 2017 Results



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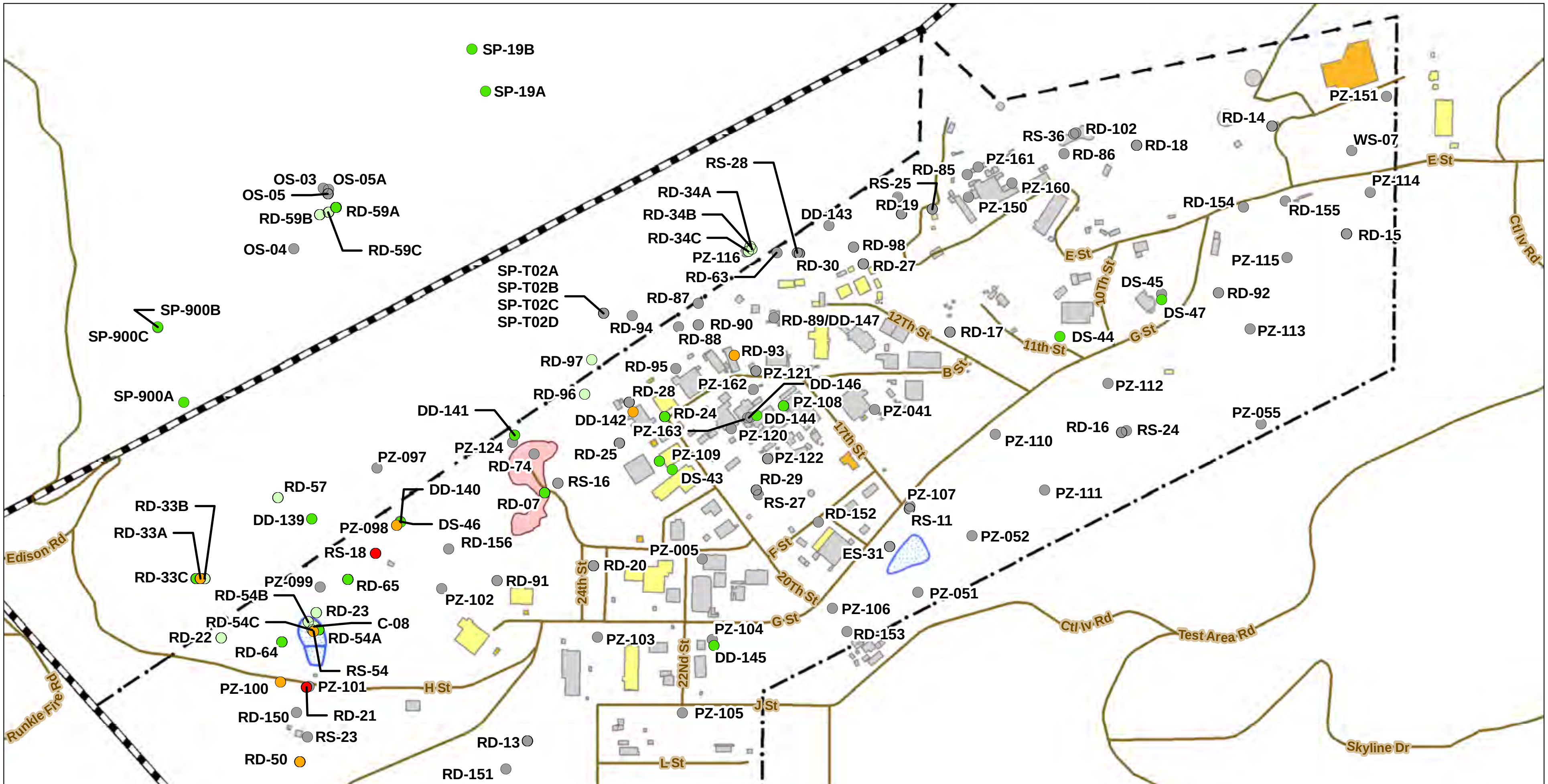
CDM Smith

FIGURE 5.1-5a
Area IV Perchlorate Pre-2013 Results



Perchlorate Exceedance (6 ug/L)

- ≥ 6
- ≥ 0.6 to 6
- < 0.6
- Non-detect to 0
- Perchlorate not analyzed from 2013 to 2017

LEGEND

- Existing Landfill
- Existing Structure
- Existing Substation
- Former Pond
- Demolished Structure
- Road Centerline
- Area IV Boundary
- SSFL Property Boundary

0 350 700 Feet

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- Perchlorate Groundwater Screening Criteria is 6 ug/l.

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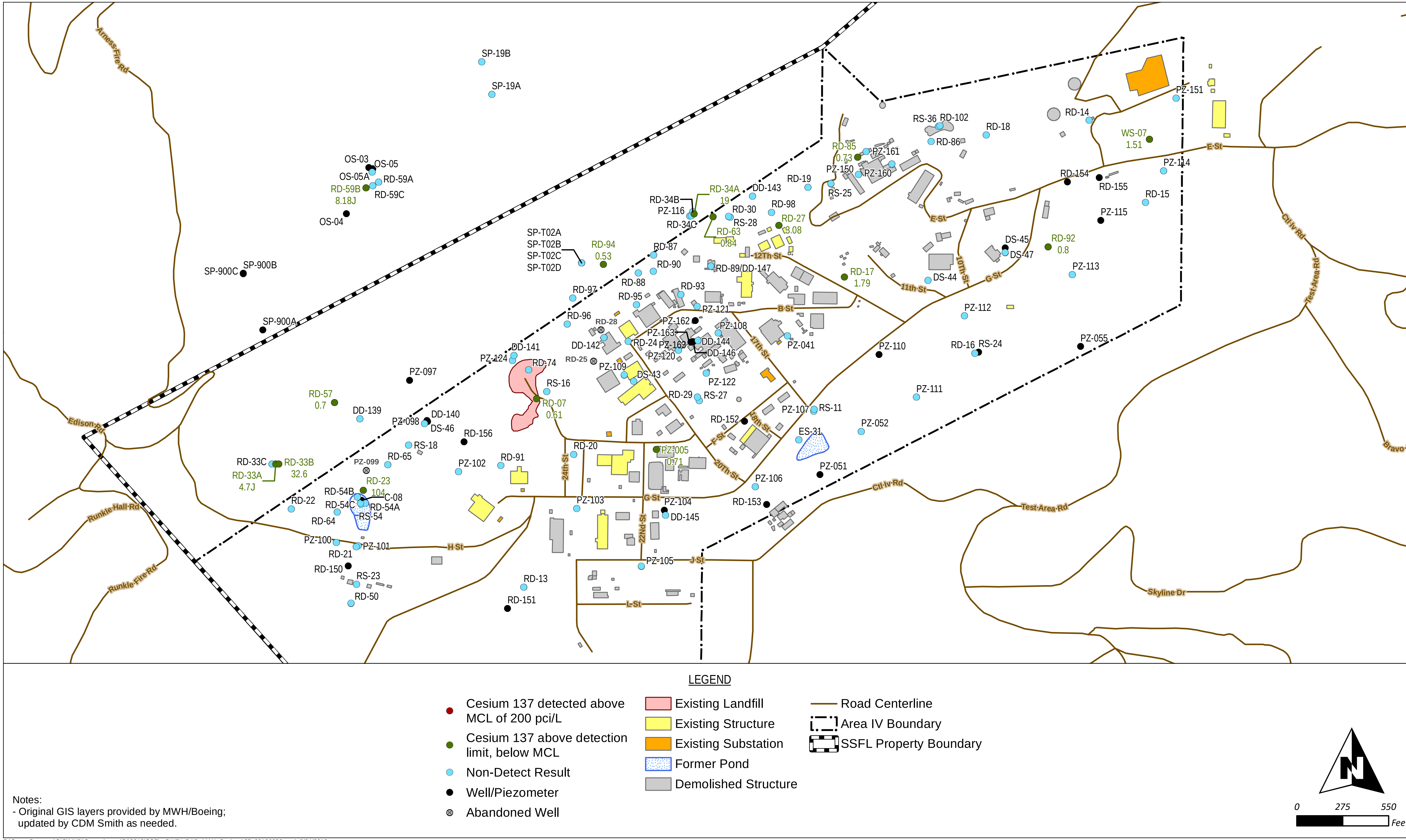
CDM Smith

FIGURE 5.1-5b
Area IV Perchlorate 2013 to 2017 Results



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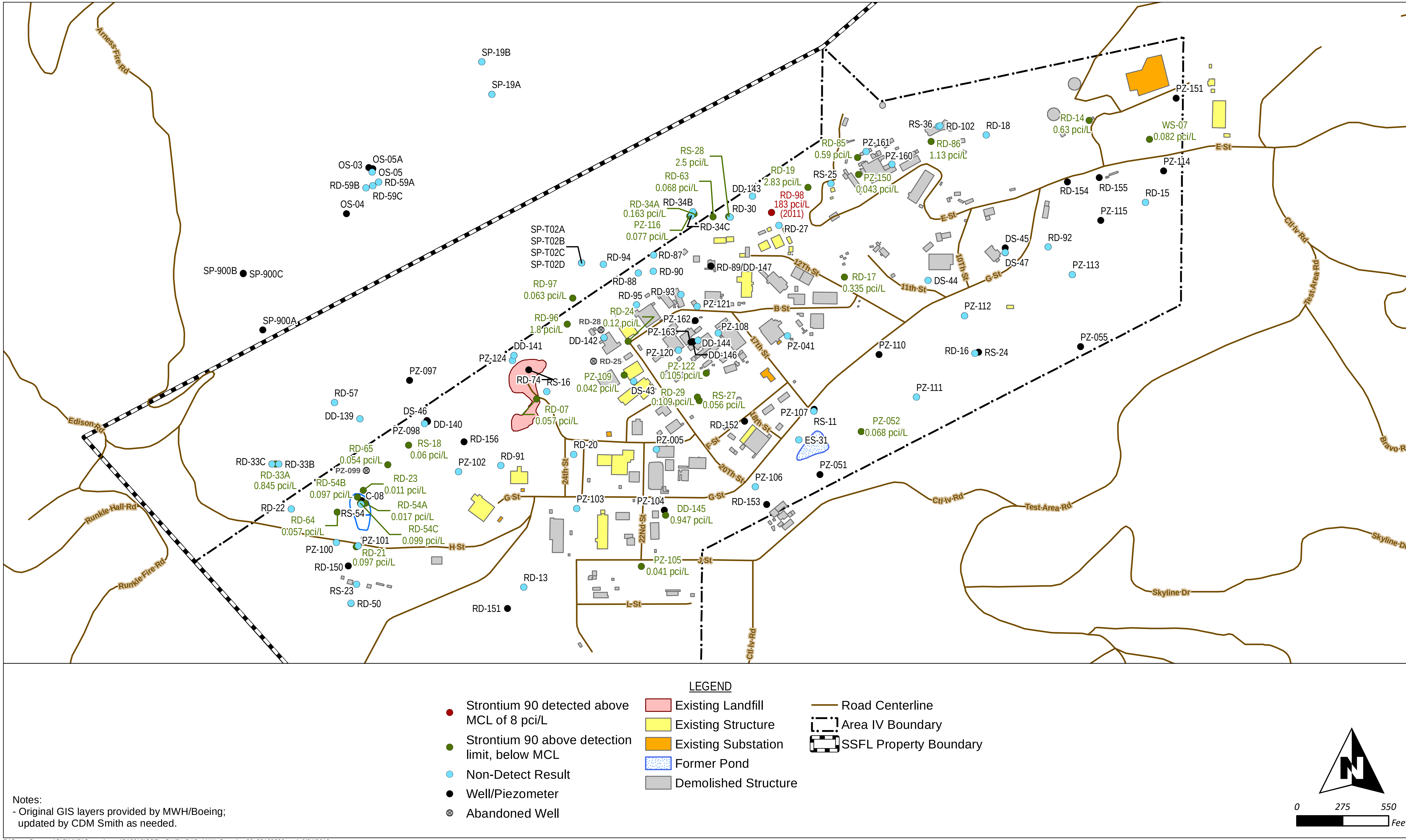
CDM Smith

FIGURE 5.1-6
Area IV Max Cesium 137 Results



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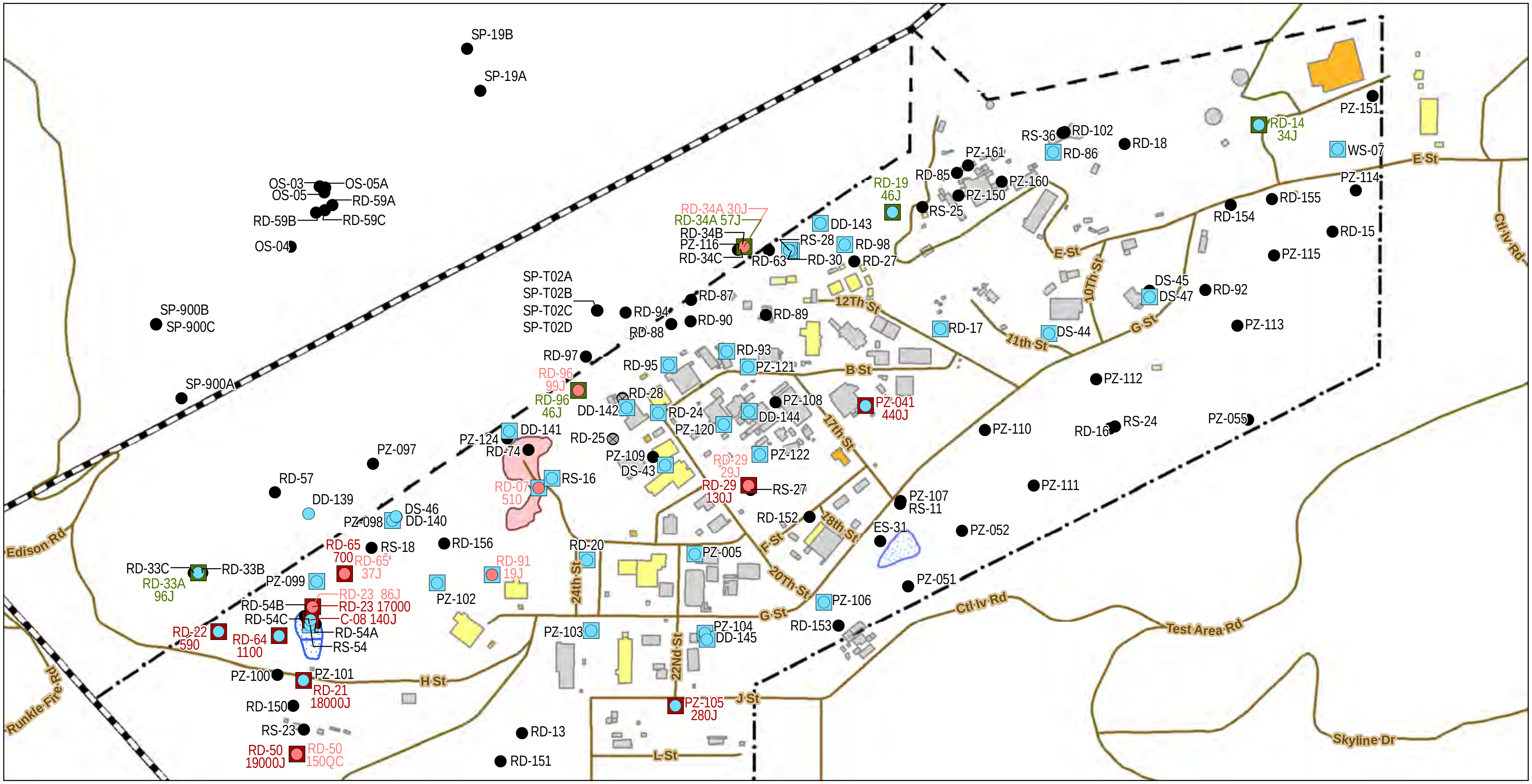
CDM Smith

FIGURE 5.1-7
Area IV Max Strontium 90 Results



LEGEND

Light TPH
- TPH detected above MCL of 5 ug/L
- TPH above detection limit, below MCL
- Light TPH Non-Detect Result

Heavy TPH
- TPH detected above MCL of 100 ug/L
- TPH above detection limit, below MCL
- Heavy TPH Non-Detect Result
- Well/Piezometer
- Abandoned Well

- Existing Landfill
- Existing Structure
- Existing Substation
- Former Pond
- Demolished Structure

- Road Centerline
- Area IV Boundary
- SSFL Property Boundary

0 350 700 Feet

N

Notes:
- MCLs are taste/odor thresholds.
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.

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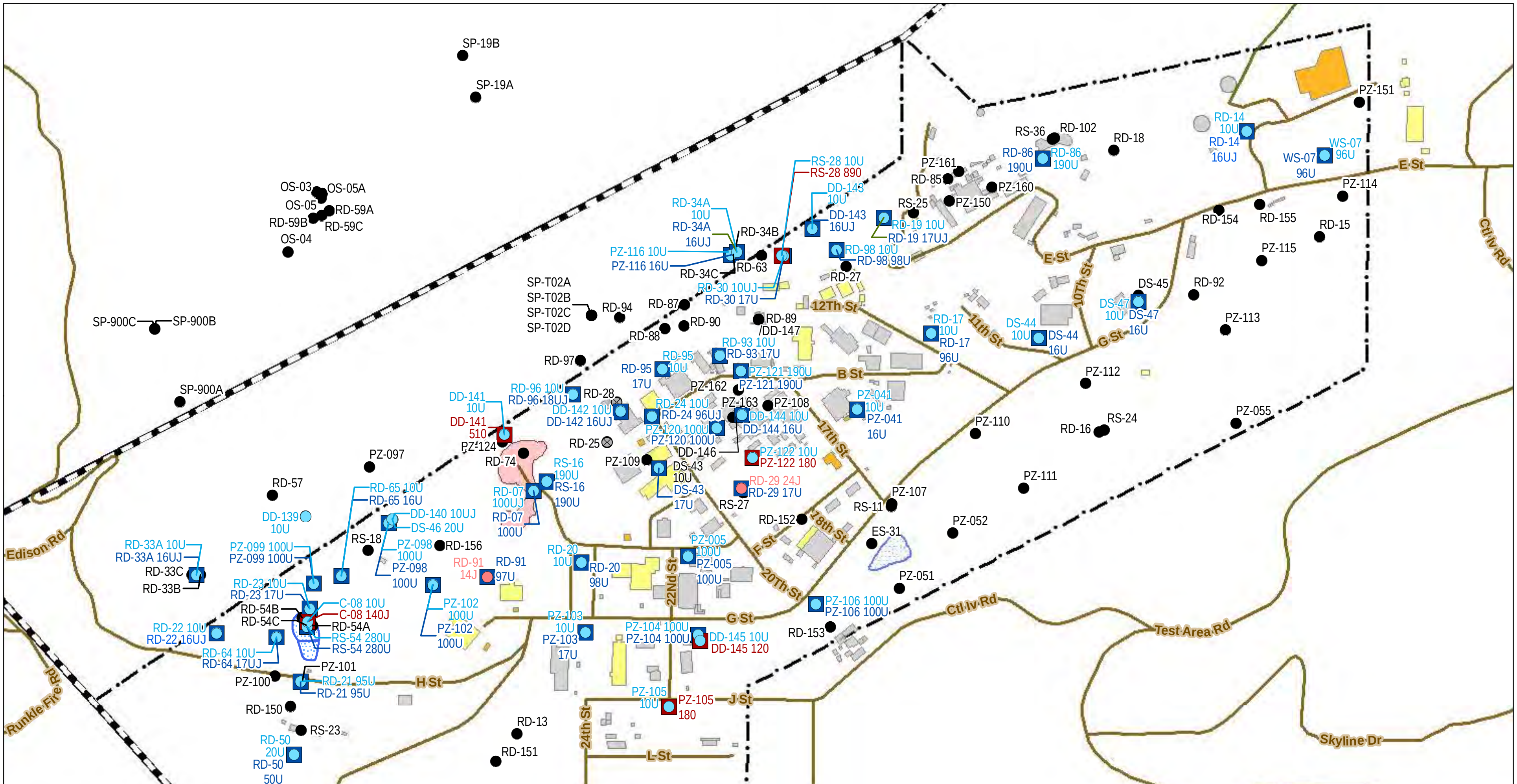
CDM Smith

FIGURE 5.1-8a **Area IV**
Historic Maximum TPH Results



LEGEND

Light TPH

- TPH detected above MCL of 5 ug/L
- TPH above detection limit, below MCL
- Light TPH Non-Detect Result

Heavy TPH

- TPH detected above MCL of 100 ug/L
- TPH above detection limit, below MCL
- Heavy TPH Non-Detect Result
- Well/Piezometer
- Abandoned Well

- Existing Landfill
- Existing Structure
- Existing Substation
- Former Pond
- Demolished Structure

- Road Centerline
- Area IV Boundary
- SSFL Property Boundary

0 350 700 Feet

Notes:
- MCLs are taste/odor thresholds.
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.

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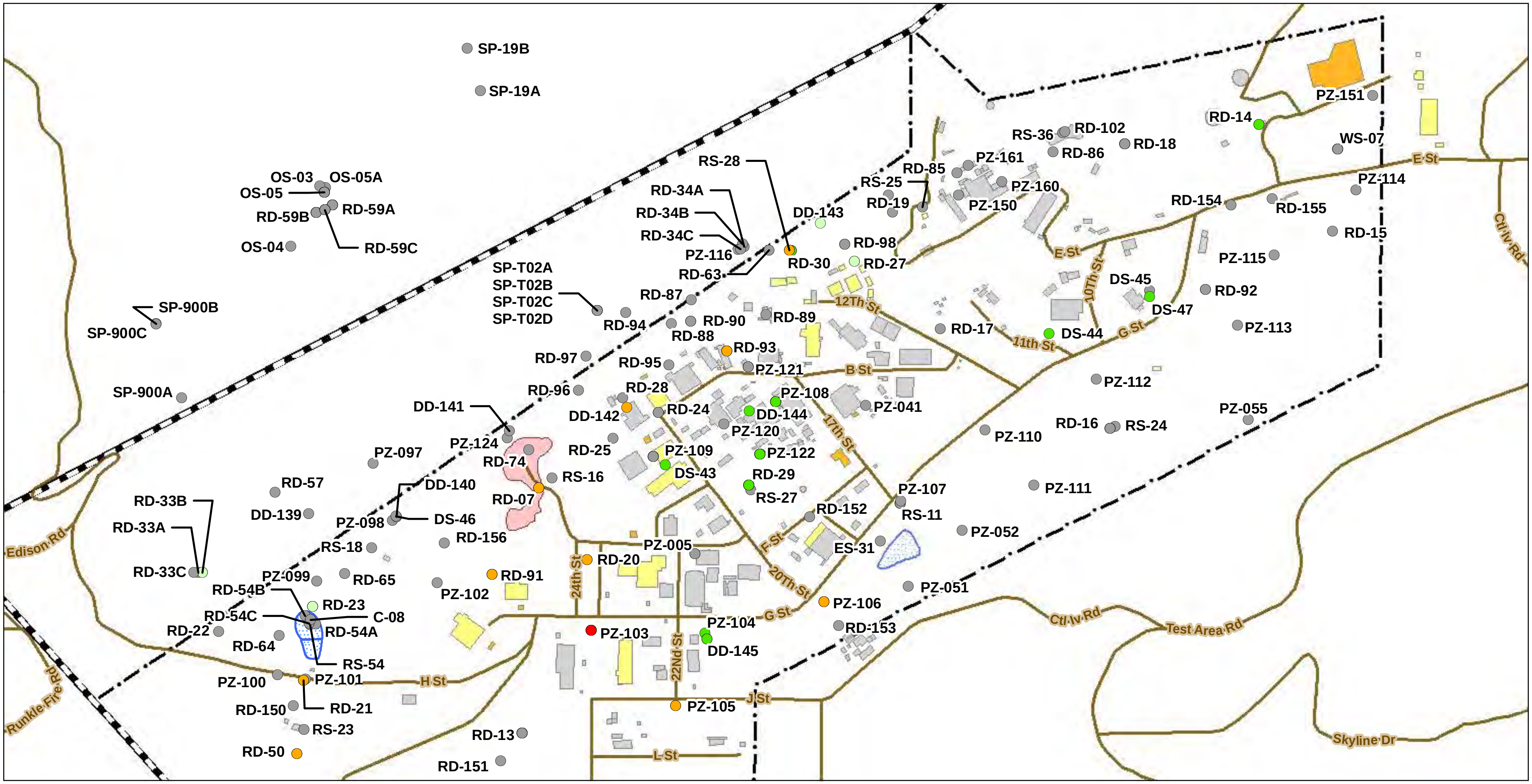
CDM Smith

FIGURE 5.1-8b
Area IV 2017 TPH Results



LEGEND

Nitrate Exceedance (45,000 ug/L)

- ≥ 45,000
- ≥ 4,500 to 45,000
- < 4,500
- Non-detect to 0
- Nitrates not analyzed from 2013 to 2017

- Existing Landfill
- Existing Structure
- Existing Substation
- Former Pond
- Demolished Structure

- Road Centerline
- Area IV Boundary
- SSFL Property Boundary

0 350 700 Feet

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- Nitrates Groundwater Screening Criteria is 45,000 ug/l.

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CDM Smith

FIGURE 5.1-9

Area IV Nitrates 2013 to 2017 Results

Table 5.1-1 - Frequency of Detection - Area IV Groundwater Database - Volatile Organic Compounds

Analyte	GW Screening Level (ug/L)[1]	# of Samples	# of Detects	Frequency of Detection	# of Exceedances of Screening Level	Frequency of Exceedance
Trichloroethene	5	2406	1157	48.1%	704	29.3%
cis-1,2-Dichloroethene	6	2295	768	33.5%	318	13.9%
1,1-Dichloroethene	6	2405	477	19.8%	169	7.0%
1,4-Dioxane	1	493	77	15.6%	56	11.4%
1,1-Dichloroethane	5	2405	364	15.1%	104	4.3%
Toluene	150	2059	208	10.1%	2	0.1%
1,2-Dichloroethane	0.5	2396	158	6.6%	142	5.9%
Tetrachloroethene	5	2405	209	8.7%	66	2.7%
Benzene	1	2059	177	8.6%	54	2.6%
trans-1,2-Dichloroethene	10	2406	195	8.1%	14	0.6%
1,1,1-Trichloroethane	200	2405	122	5.1%	66	2.7%
Carbon Tetrachloride	0.5	2405	64	2.7%	64	2.7%
Vinyl Chloride	0.5	2404	38	1.6%	30	1.2%
1,1,2,2-Tetrachloroethane	1	2033	2	0.1%	1	0.0%
1,1,2-Trichloro-1,2,2-trifluoroethane	1200	1758	154	8.8%	1	0.1%
1,1,2-Trichloroethane	5	2405	30	1.2%	10	0.4%
1,1-Dichlorobutane		1	0	0.0%	0	--
1,1,1,2-Tetrachloroethane		161	0	0%	0	0.0%
1,1-Dichloropropene		120	0	0.0%	0	--
1,1-Dimethylhydrazine		30	0	0.0%	0	--
1,2,3-Trichlorobenzene	2.1	120	2	1.7%	0	0.0%
1,2,3-Trichloropropane	0.005	151	0	0.0%	0	0.0%
1,2,4,5-Tetrchlorobenzene		1	0	0.0%	0	--
1,2,4-Trichlorobenzene	5	209	2	1.0%	0	0.0%
1,2,4-Trimethylbenzene	330	158	1	0.6%	0	0.0%
1,2-Dibromo-3-chloropropane	0.2	166	0	0.0%	0	0.0%
1,2-Dibromoethane	0.05	130	0	0.0%	0	0.0%
1,2-Dichlorobenzene	600	1889	2	0.1%	0	0.0%
1,2-Dichloropropane	5	2015	0	0.0%	0	0.0%
1,3,5-Trimethylbenzene	330	158	1	0.6%	0	0.0%
1,3-Dichlorobenzene	600	1890	2	0.1%	0	0.0%
1,3-Dichloropropane	130	120	1	0.8%	0	0.0%
1,3-Dichloropropylene	0.5	1	0	0.0%	0	0.0%
1,4-Dichlorobenzene	5	1887	4	0.2%	0	0.0%
1-Chlorohexane		54	0	0.0%	0	--
2,2-Dichloropropane		120	0	0.0%	0	--
2-Butanone (MEK)	3800	1842	19	1.0%	0	0.0%
2-Chloro-1,1,1-trifluoroethane		54	0	0.0%	0	--
2-Chloroethyl Vinyl Ether		836	0	0.0%	0	--
2-Chlorotoluene		120	0	0.0%	0	--
2-Hexanone	250	1465	1	0.1%	0	0.0%
2-Methyl-1-Propanol		1	0	0.0%	0	--
2-Phenylbutane		120	0	0.0%	0	--
4-Chlorotoluene	140	120	0	0.0%	0	0.0%

Table 5.1-1 - Frequency of Detection - Area IV Groundwater Database - Volatile Organic Compounds

Analyte	GW Screening Level (ug/L)[1]	# of Samples	# of Detects	Frequency of Detection	# of Exceedances of Screening Level	Frequency of Exceedance
4-Methyl-2-pentanone (MIBK)	120	1466	2	0.1%	0	0.0%
Acetone	20000	1880	180	9.6%	0	0.0%
Acetonitrile	300000	2	0	0.0%	0	0.0%
Acrolein	110	479	0	0.0%	0	0.0%
Acrylonitrile	910	479	1	0.2%	0	0.0%
Allyl Chloride	8.9	1	0	0.0%	0	0.0%
Bis(2-Chloroethyl) Ether		81	1	1.2%	0	--
Bromobenzene		120	0	0.0%	0	--
Bromochloromethane	34000	121	0	0.0%	0	0.0%
Bromodichloromethane	80	2032	7	0.3%	0	0.0%
Bromoform	80	2033	0	0.0%	0	0.0%
Bromomethane	8.8	2032	0	0.0%	0	0.0%
Carbon Disulfide	160	1501	54	3.6%	0	0.0%
Chlorobenzene	70	2036	43	2.1%	0	0.0%
Chloroethane	16	2063	38	1.8%	1	0.0%
Chloroform	80	2405	163	6.8%	0	0.0%
Chloromethane	5.7	2059	30	1.5%	2	0.1%
Chlorotrifluoroethylene		86	0	0.0%	0	--
cis-1,3-Dichloropropene	0.5	2010	0	0.0%	0	0.0%
Cymene		122	0	0.0%	0	--
Di isopropyl Ether		54	0	0.0%	0	--
Dibromochloromethane	80	2012	13	0.6%	0	0.0%
Dibromomethane		122	0	0.0%	0	--
Dichlorobenzenes		91	0	0.0%	0	--
Dichlorodifluoromethane	1000	426	0	0.0%	0	0.0%
DiisopropylL Ether		54	0	0.0%	0	--
Ethyl Ether	750	1	0	0.0%	0	0.0%
Ethyl Methacrylate		1	0	0.0%	0	--
Ethylbenzene	300	2058	9	0.4%	0	0.0%
Hexachlorobutadiene		200	0	0.0%	0	--
Isopropylbenzene	770	131	0	0.0%	0	0.0%
m,p-Xylene		1406	8	0.6%	0	--
m,p-Xylene	1750	97	5	5.2%	0	0.0%
M-Dinitrobenzene		46	0	0.0%	0	--
Methyl Iodide		55	0	0.0%	0	--
Methyl Methacrylate	25	1	0	0.0%	0	0.0%
Methyl Tert-Butyl Ether	5	57	0	0.0%	0	0.0%
Methylacrylonitrile	2100	1	0	0.0%	0	0.0%
Methylene Chloride	5	2405	127	5.3%	45	1.9%
n-Butylbenzene	260	131	0	0.0%	0	0.0%
Nitrobenzene		97	0	0.0%	0	--
n-Propylbenzene	260	120	0	0.0%	0	0.0%
o + p Xylene	1750	9	0	0.0%	0	0.0%
o-Xylene	1750	1494	22	1.5%	0	0.0%

Table 5.1-1 - Frequency of Detection - Area IV Groundwater Database - Volatile Organic Compounds

Analyte	GW Screening Level (ug/L)[1]	# of Samples	# of Detects	Frequency of Detection	# of Exceedances of Screening Level	Frequency of Exceedance
Pentachloroethane		1	0	0.0%	0	--
Propionitrile		1	0	0.0%	0	--
Styrene		739	0	0.0%	0	--
tert-Butyl Ethyl Ether		54	0	0.0%	0	--
tert-Butylbenzene	260	120	0	0.0%	0	0.0%
Tertiary butyl alcohol	12	57	0	0.0%	0	0.0%
Tetrahydrofuran		1	1	100.0%	0	--
trans-1,3-Dichloropropene	0.81	2029	1	0.0%	0	0.0%
trans-1,4-Dichlorobutene		1	0	0.0%	0	--
Trichlorofluoromethane	150	2127	28	1.3%	0	0.0%
Vinyl Acetate	88	606	0	0.0%	0	0.0%
Xylenes (Total)	1750	203	0	0.0%	0	0.0%

1Screening Lvels from Haley & Aldrich (2010)
ug/L = micrograms per liter
Data through 2017 sampling

Table 5.1-2 Frequency of Detection for Metals

Total Fraction							
Analyte	Unit	Screening Level	# of Samples	# of Detects	Frequency of Detects	# of Exceedances	Frequency of Exceedances
Aluminum	ug/l	200	99	59	59.6%	32	32.3%
Antimony	ug/l	2.5	279	65	23.3%	8	2.9%
Arsenic	ug/l	7.7	276	175	63.4%	3	1.1%
Barium	ug/l	150	278	274	98.6%	5	1.8%
Beryllium	ug/l	0.14	277	26	9.4%	8	2.9%
Boron	ug/l	340	97	88	90.7%	17	17.5%
Cadmium	ug/l	0.2	280	64	22.9%	41	14.6%
Calcium	ug/l	--	78	78	100.0%	--	--
Chromium	ug/l	14	278	113	40.6%	6	2.2%
Chromium (Hex)	ug/l	14	22	0	0.0%	0	0.0%
Cobalt	ug/l	1.9	268	207	77.2%	33	12.3%
Copper	ug/l	4.7	278	151	54.3%	55	19.8%
Cyanide	mg/l	--	191	8	4.2%	--	--
Iron	ug/l	4100	109	104	95.4%	13	11.9%
Lead	ug/l	11	279	180	64.5%	11	3.9%
Magnesium	ug/l	77000	102	102	100.0%	0	0.0%
Manganese	ug/l	150	107	104	97.2%	19	17.8%
Mercury	ug/l	0.063	111	6	5.4%	3	2.7%
Molybdenum	ug/l	2.2	108	86	79.6%	42	38.9%
Nickel	ug/l	17	279	216	77.4%	18	6.5%
Potassium	ug/l	9600	115	115	100.0%	8	7.0%
Selenium	ug/l	1.6	279	93	33.3%	48	17.2%
Silver	ug/l	0.17	280	39	13.9%	19	6.8%
Sodium	ug/l	190000	186	185	99.5%	2	1.1%
Strontium	ug/l	800	87	87	100.0%	5	5.7%
Thallium	ug/l	0.13	278	37	13.3%	8	2.9%
Tin	ug/l	2.4	253	8	3.2%	0	0.0%
Vanadium	ug/l	2.6	276	167	60.5%	77	27.9%
Zinc	ug/l	6300	278	230	82.7%	0	0.0%

Table 5.1-2 Frequency of Detection for Metals

Dissolved Fraction							
Analyte	Unit	Screening Level	# of Samples	# of Detects	Frequency of Detects	# of Exceedances	Frequency of Exceedances
Aluminum	ug/l	13000	114	23	20.2%	0	0.0%
Antimony	ug/l	2.5	648	145	22.4%	9	1.4%
Arsenic	ug/l	7.7	761	288	37.8%	14	1.8%
Barium	ug/l	150	762	734	96.3%	7	0.9%
Beryllium	ug/l	0.14	657	25	3.8%	12	1.8%
Boron	ug/l	340	146	124	84.9%	11	7.5%
Cadmium	ug/l	0.2	763	91	11.9%	45	5.9%
Calcium	ug/l	--	123	123	100.0%	--	--
Chromium	ug/l	14	763	105	13.8%	2	0.3%
Chromium (Hex)	ug/l	38	6	0	0.0%	0	0.0%
Cobalt	ug/l	1.9	540	291	53.9%	36	6.7%
Copper	ug/l	4.7	647	337	52.1%	62	9.6%
Iron	ug/l	4100	446	216	48.4%	2	0.4%
Lead	ug/l	11	763	365	47.8%	38	5.0%
Magnesium	ug/l	77000	179	178	99.4%	0	0.0%
Manganese	ug/l	150	445	392	88.1%	50	11.2%
Mercury	ug/l	0.063	595	16	2.7%	12	2.0%
Molybdenum	ug/l	2.2	479	242	50.5%	95	19.8%
Nickel	ug/l	17	649	412	63.5%	26	4.0%
Potassium	ug/l	9600	131	130	99.2%	3	2.3%
Selenium	ug/l	1.6	763	246	32.2%	112	14.7%
Silver	ug/l	0.17	763	22	2.9%	11	1.4%
Sodium	ug/l	190000	234	234	100.0%	2	0.9%
Strontium	ug/l	800	147	147	100.0%	7	4.8%
Thallium	ug/l	0.13	650	59	9.1%	29	4.5%
Tin	ug/l	2.4	281	5	1.8%	0	0.0%
Vanadium	ug/l	2.6	548	201	36.7%	44	8.0%
Zinc	ug/l	6300	651	527	81.0%	0	0.0%

Table 5.1-3 Groundwater Radionuclide Frequency of Detection (Dissolved Fraction)

Analyte	Analyte Unit	GW Screening Level[1]	# of Samples	# of Detects	Frequency of Detection	# of Exceedances	Frequency of Exceedence
Actinium-227	pCi/L		159	9	5.66%		--
Actinium-228	pCi/L		728	124	17.03%		--
Aluminum-26	pCi/L		4	0	0.00%		--
Americium-241	pCi/L		223	10	4.48%		--
Antimony-125	pCi/L	300	602	4	0.66%		--
Barium-133	pCi/L	1520	600	13	2.17%	7	1.17%
Barium-137M	pCi/L	2150000	167	9	5.39%	0	0%
Beryllium-7	pCi/L		10	0	0.00%		--
Bismuth-212	pCi/L		435	20	4.60%		--
Bismuth-214	pCi/L		594	214	36.03%		--
Cadmium-113	pCi/L		161	3	1.86%		--
Californium-249	pCi/L		159	13	8.18%		--
Carbon-14	pCi/L	2000	10	4	40.00%		0%
Cerium-139	pCi/L		4	0	0.00%		--
Cerium-144	pCi/L		4	0	0.00%		--
Cesium-134	pCi/L	80	1182	8	0.68%		--
Cesium-137	pCi/L	200	1436	28	1.95%	2	0.14%
Chromium-51	pCi/L		4	0	0.00%		--
Cobalt-56	pCi/L		4	0	0.00%		--
Cobalt-57	pCi/L	1000	737	0	0.00%		0%
Cobalt-58	pCi/L		4	0	0.00%		--
Cobalt-60	pCi/L	100	1225	9	0.73%	2	0.16%
Curium-243/244	pCi/L		26	1	3.85%		--
Curium-245/246	pCi/L		26	12	46.15%		--
Europium-152	pCi/L	200	781	9	1.15%	2	0.26%
Europium-154	pCi/L		781	8	1.02%		--
Europium-155	pCi/L		602	6	1.00%		--
Gross Alpha	pCi/L	15	1724	1215	70.48%	202	11.72%
Gross Beta	pCi/L	50	1715	1469	85.66%	13	0.76%
Holmium-166	pCi/L		161	5	3.11%		--
Iodine-129	pCi/L	1	19	2	10.53%		0%
Isotopic Uranium Activity	pCi/L		7	7	100.00%		--
Lead-210	pCi/L		275	6	2.18%		--
Lead-212	pCi/L		600	54	9.00%		--
Lead-214	pCi/L		600	192	32.00%		--
Manganese-54	pCi/L	300	621	4	0.64%	2	0.32%
Neptunium-236	pCi/L	5960	162	2	1.23%		0%
Neptunium-237	pCi/L		10	1	10.00%		--
Neptunium-239	pCi/L		159	2	1.26%		--
Niobium-94	pCi/L	707	164	11	6.71%		0%
Plutonium-239	pCi/L		2	0	0.00%		--
Plutonium-238	pCi/L		28	6	21.43%		--
Plutonium-239/240	pCi/L		26	2	7.69%		--
Plutonium-242	pCi/L		25	1	4.00%		--
Potassium-40	pCi/L		1224	89	7.27%		--

Table 5.1-3 Groundwater Radionuclide Frequency of Detection (Dissolved Fraction)

Analyte	Analyte Unit	GW Screening Level[1]	# of Samples	# of Detects	Frequency of Detection	# of Exceedances	Frequency of Exceedence
Protactinium-231	pCi/L		159	3	1.89%		--
Radium-226	pCi/L	5	772	273	35.36%	3	0.39%
Radium-228	pCi/L	5	479	269	56.16%	5	1.04%
Ruthenium-106	pCi/L		6	0	0.00%		--
Silver-108	pCi/L		318	28	8.81%		--
Silver-110	pCi/L		10	0	0.00%		--
Sodium-22	pCi/L	400	773	3	0.39%	2	0.26%
Strontium-90	pCi/L	8	648	52	8.02%	11	1.70%
Technetium-99	pCi/L		19	0	0.00%		--
Tellurium-125	pCi/L		159	1	0.63%		--
Thallium-208	pCi/L		533	56	10.51%		--
Thorium-228	pCi/L		91	11	12.09%		--
Thorium-230	pCi/L		91	15	16.48%		--
Thorium-231	pCi/L		156	146	93.59%		--
Thorium-232	pCi/L		88	6	6.82%		--
Thorium-234	pCi/L		599	48	8.01%		--
Thulium-171	pCi/L	1000	167	17	10.18%	1	0.60%
Tin-126	pCi/L	293	169	19	11.24%		0%
Tritium	pCi/L	20000	1488	304	20.43%	57	3.83%
Uranium	pCi/L	20	617	550	89.14%	12	1.94%
Uranium-233/234	pCi/L	20	485	467	96.29%	15	3.09%
Uranium-234	pCi/L	20	133	96	72.18%	2	1.50%
Uranium-235	pCi/L	20	898	301	33.52%		0%
Uranium-235/236	pCi/L	20	156	146	93.59%		0%

[1]Screening Levels from Haley & Aldrich 2010.

pCi/L = picocuries per liter

5.2 Assessment by Groundwater Investigation Areas

This section presents data and discussions of nature and extent of contamination in the 14 groundwater investigation areas identified in Section 1 that are the responsibility of DOE:

1) Former Sodium Disposal Facility (FSDF)
2) Building 100 Trench
3) Building 56 Landfill
4) Buildings 4057/4059/4626 Area
5) Building 4457 Hazardous Materials Storage Area (HMSA)
6) Tritium Plume
7) Radioactive Materials Handling Facility (RMHF)
8) Old Conservation Yard (OCY)
9) Metals Clarifier/DOE Leach Fields 3
10) Building 4064 Leach Field
11) Buildings 4030 and 4093 Leach Fields
12) Hazardous Waste Management Facility (HWMF) Building 4133/Building 4029
13) Building 4009 Leach Field
14) Rockwell International Hot Lab.

The investigation areas are shown in **Figure 5.2-1**. The following sections of Chapter 5 describe the operations, prior and recent investigation findings, nature and extent of contamination, and numeric modeling results for the areas exhibiting groundwater impacts.

There are five appendices to this GW RI Report that provide supporting information relative to the investigation findings. **Appendix A** provides the boring logs for the wells installed in Area IV. **Appendix B** provides summary tables by well for the key VOC, metals, radionuclide, perchlorate, and nitrate results. **Appendix C** is the report of the numeric modeling performed using Area IV hydrogeologic parameters. **Appendix D** provides an assessment of the attenuation of TCE and PCE based on the Area IV groundwater data. **Appendix E** provides figures illustrating locations of soil gas samples collected in Area IV.

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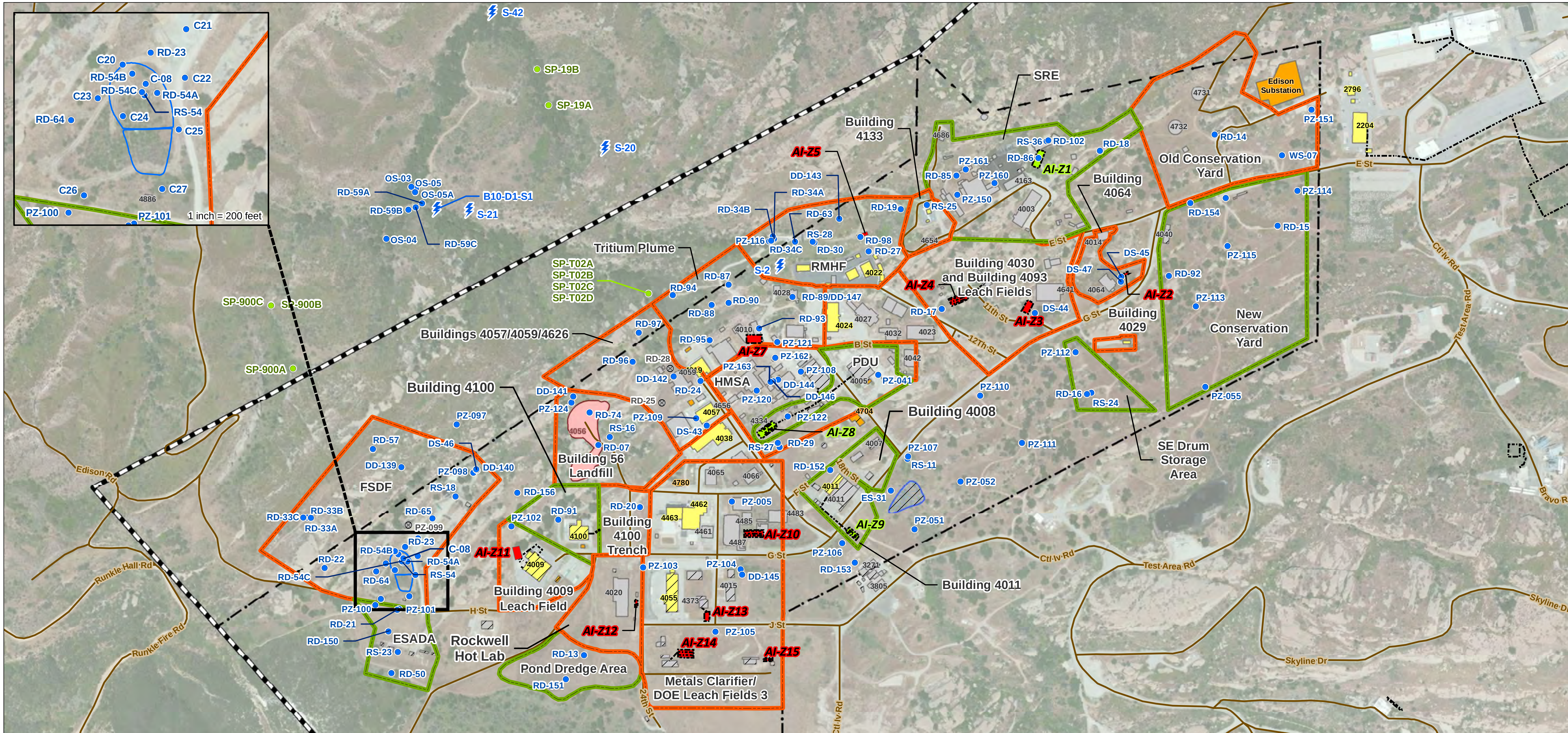

LEGEND

- Abandoned Well
- Well/Piezometer
- Seep Well
- Seep
- Road Centerline

Responsibility*
- Boeing
- DOE

Groundwater Investigation Area
- Boeing
- DOE

- Existing Landfill
- Existing Structure
- Existing Substation
- Former Pond
- Demolished Structure
- Boeing Structure
- Former FSDF Pond
- Area IV Boundary
- SSFL Property Boundary

0 275 550 Feet

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

C:_projects\SantaSusana\GIS\MXD\Groundwater\RI\2018\SSFL_GWRI_Investigation_Areas_Revised_Sect5_20180823.mxd 8/24/2018

CDM Smith

FIGURE 5.2-1
Area IV Groundwater Investigation Areas

5.3 Former Sodium Disposal Facility – Building 4886

Groundwater beneath the FSDF exhibits the highest concentrations of 1,1,1-TCA and TCE of any location within Area IV; and remedial actions for soil and groundwater performed to date have reduced contaminant concentrations over time. Prior to historic pumping, the maximum concentrations observed in Near-surface groundwater were 15,000 µg/L of 1,1,1-TCA in 1996 and 4,500 µg/L of TCE in 1994. During and following the 1997 pumping of RD-21 and RS-54, concentrations of 1,1,1-TCA and TCE decreased. Concentrations in 2013 were measured at 5,600 µg/L 1,1,1-TCA and 1,600 µg/L TCE in well RS-54. In 2017, following a normal rainfall year, concentrations of 1,1,1-TCA and TCE in RS-54 increased to 11,000 and 1,400 µg/L, respectively. Pumping of RS-54 during the source removal groundwater interim action (GWIM) from November 2017 to June 2018 reduced 1,1,1-TCA concentrations to 2,700 µg/L and TCE to 720 µg/L (CDM Smith 2018b). In 2018 RS-54 still exhibited the highest VOC concentrations for any well within Area IV

5.3.1 Source Area Evaluation

Operation History

The FSDF, also known as the Sodium Burn Pit and Building 4886, was used from 1956 to 1978 to clean metallic components and other materials (pipes, valves, tanks, and instruments) of alkali metals (sodium and potassium/sodium mixtures). Treatment was accomplished by reacting the alkali metals with water using either a pressure washer or placement in a pool of water. Operations at the FSDF ceased under the RCRA rules which precluded treatment and disposal in open unlined facilities. In addition to sodium-contaminated materials, the FSDF received chemical wastes including chlorinated solvents (mostly TCE and 1,1,1-TCA), polychlorinated biphenyls (PCBs), metals (such as mercury), and radionuclides (primarily Cs-137. The site was also used for the burning of "Santo-wax," an organic compound used as a heat transfer medium in nuclear reactors.

The FSDF consisted of three facilities – (1) an asphalt and concrete pad used for steam cleaning objects, (2) an adjacent concrete submergence pool, and (3) two earth-lined ponds (see **Figure 5.3-1**). To the immediate north of the pad and pool, was the upper earth-formed pond, with a second lower earth-formed pond at the north edge of the facility. The steam cleaning of sodium-impacted metallic objects occurred on the pad, and then the material was placed in the concrete pool for final reaction of residual sodium with water. Following treatment, the rinseate was either reused or placed into one of the two earthen ponds. As a maintenance activity, material placed in the ponds was periodically removed after dewatering of the ponds. The dried sludge that accumulated on the pond bottom was bulldozed out of the pond and disposed either locally in the western debris area or removed from the site. In addition, the concrete submergence pool adjacent to the steam cleaning pad at the FSDF was connected to a pipe from the ESADA facility (Building 4814; Boeing responsibility per the 2007 CO) that received liquid wastes from sodium metal tests conducted at that facility.

The land west of the FSDF was also reported to be used for drum and waste material storage. However, the specific types of materials stored in this area are not identified in the Group 8 RI Report (MWH 2007). Another feature of the FSDF location is the former shooting range located immediately south of the former ponds.

Soil and Debris Removal Actions

Following cessation of use, the FSDF area was subject to a series of soil and groundwater investigations and removal actions for contaminated surface soil, drums, and debris. The soil within and adjacent to the ponds was found to be contaminated by PCBs, mercury, Cs-137, and solvents. Groundwater was found to be contaminated by TCE, 1,1,1-TCA, metals, and perchlorate.

As soil contamination was discovered, soil removal actions were performed. The first soil cleanup was performed in 1980 when approximately 20 cubic yards of soil containing Cs-137 were excavated from the Lower Pond in June 1993, soil and debris in the two ponds was excavated to the bedrock interface and all debris found within the excavation was removed. This effort also included all drums, impacted soil, and debris within the western debris area. By 1993, over 12,000 cubic yards of contaminated soil and 20,000 pounds of debris were removed from the site. Soil removal also included excavation from two drainages north of the facility that were contaminated.

Per DOE requirements, soil exhibiting radioactivity above background was managed and disposed of separately from soil that was only chemically contaminated. Following removal of radiologically impacted soil and subsequent soil surveys conducted in 1994, no radiation was found above background and the FSDF was no longer considered a radioactive material handling area.

Soil sampling and removal efforts continued for several years. Soil sampling conducted in 1995, in the vicinity of the FSDF, identified contamination by mercury, TPH, PCBs, and dioxins. Some limited excavations of buried objects occurred in August 1996 within previously non-excavated areas based on the results of a geophysical survey. Other soil and debris removals at and in the vicinity of the FSDF ponds continued to the year 2000. In all, 14,000 cubic yards of soil and 20,000 pounds of debris were removed from the site. The soil/debris removal action addressed the original source of groundwater contamination. The excavated ponds were covered with an impermeable liner to capture rainfall that was routinely pumped off. In 2000, the liners were removed and the ponds backfilled with soil from the Area IV borrow pit.

Fill materials primarily consisted of silty, fine-grained sand and sandy silt with sandstone gravel and cobbles. The maximum depth of backfill in the area of the former FSDF pond excavation is about 13 feet below current grade based on topographic surveys performed following the excavation. In December 2000, the site was hydroseeded and oak trees were planted in the cover. In 2016 the oak trees were between 10 and 15 feet in height; however, they showed adverse effects from the ongoing southern California drought.

Groundwater Interim Measures

Interim measures to remove TCE and perchlorate from the groundwater were conducted first from 1997 to 2000, second from 2002 to 2003, and recently during 2017 and 2018. Groundwater upgradient from the FSDF was extracted from bedrock well RD-21 and Near-surface groundwater well RS-54 within the former lower pond area. Extracted water was treated using activated carbon for VOCs and by resin filters for perchlorate. Wells RD-54A, RD-54B, and RD-23 were also subject to pumping tests in 2002 and 2003.

The pumping test using RD-54B was conducted over a 165 day period at a rate of about 173 gallons per day (MWH 2006a). Groundwater elevation responses to RD-54B pumping were measured at 6 of the 16 observation wells, with responses were measured at distances of up to 400 feet away from the extraction well (MWH 2006a).

An interim measure at the FSDF was initiated in November through the pumping of RS-54. The well was pumped dry and allowed to recover prior to subsequent pumping and sampling. From November 6, 2017, to June 20, 2018, RS-54 was pumped dry 25 times. During pumping a sample for chemical characterization was collected. In all, approximately 331 gallons of water was extracted from RS-54. In June 2019 bedrock cores were drilled at the FSDF as part of the investigation of fractures containing VOCs. One core hole (C-21) produced water and was pumped as part of the GWIM (CDM Smith 2018b).

Infiltration of rainwater through the backfill placed in the FSDF ponds was measured using two pan lysimeters installed in 2000. Lysimeter 1 was installed near the Lower Pond and lysimeter 2 installed to the south of the first. The lysimeters were placed about 1 foot above the bedrock interface. The total soil cover above lysimeter 1 is approximately 7 feet and above lysimeter 2 is approximately 11 feet. Four piezometers were also installed to measure water at the backfilled soil-bedrock interface. The piezometers were advanced from the surface to 4 to 6 inches into the bedrock.

5.3.2 Soils, Geology, and Hydrogeology

The former FSDF facility and ponds are on the western edge of the relatively flat terrain of Burro Flats. The land surface drops off approximately 20 feet to the northeast. There are two geologic bedrock units of interest in the FSDF groundwater investigation area – the Chatsworth Formation that underlies the FSDF and the Santa Susana Formation that is immediately to the south of ESADA and the FSDF.

The soils in the FSDF area are derived from weathered Chatsworth bedrock and colluvium. The FSDF area borders the Santa Susana formation that is of a higher elevation and some soil at the FSDF may be derived as colluvium. Backfill material for the FSDF ponds came from the borrow site located in the Santa Susana formation.

The FSDF is underlain by the Upper Burro Flats member of Chatsworth Formation. This sandstone unit includes thin interbeds of fine-grained rock and to the northeast, in the NBZ, the Shale 3 members outcrop. Beds of these units generally strike N63°E and dip 25°NW. **Figure 5.3-2** presents a simple cross section looking along the strike of these fine-grained beds.

The Santa Susana Formation is predominantly composed of micaceous claystone and siltstone, with a few minor sandstone beds (Dibblee 1992). Structurally, the Chatsworth and Santa Susana Formations are separated by the Burro Flats Fault, located immediately south of ESADA. This fault strikes east-west in the study area. This fault is mentioned because it is believed to be a barrier to groundwater flow to the south, but has limited effect on the FSDF hydrogeology. Other structural features in the FSDF include a series of deformation bands north and west of the FSDF.

Two other structures have been historically mapped east of the FSDF site and called the FSDF Structures. Investigations of the Western FSDF Structure Lineament and the Eastern FSDF Lineament Structure by MWH indicate that these structures are not faults (MWH 2013) (Section 3.0 **Figure 3-3**). Although an investigation of these structures has been performed, there remains some uncertainty as to the effect, if any, on groundwater flow in this area.

At the FSDF, Near-surface groundwater is located in bedrock fractures above the Chatsworth Formation groundwater. When present (Near-surface groundwater is not always present), Near-surface groundwater can be as shallow as 6 feet bgs at ESADA and 8 to 21 feet bgs near the FSDF. Because it is located in shallow fractures, there is a downward vertical gradient between the Near-surface and bedrock groundwater. Near-surface groundwater flow, when present, is anticipated to flow the direction of surface topography and shallow bedrock fractures.

Depth to Chatsworth Formation groundwater beneath the FSDF varies greatly from about 100 feet bgs to 310 feet bgs. Within the bedrock there is also a generally downward vertical gradient at locations on Burro Flats, and an upward vertical gradients at locations at the base of the western slopes of the FSDF. The lateral flow gradient is generally to the north and northwest, but is influenced locally by fracture flow (See Section 6.0 for particle track presentation).

Corehole 8 (C-08) was drilled to 400 feet bgs in the FSDF area to obtain data on bedrock properties. C-08 is a 12.25-inch diameter borehole that is cased from ground surface to 65 feet bgs. From 65 feet to 400 feet the corehole is a nominal 5-inch diameter. Nineteen bedrock core samples were collected while drilling C-08 for hydraulic conductivity (K_m) analyses. Laboratory results for K_m ranged between $4.96 x 10^{-8}$ centimeters per second (cm/s) and $9.67 x 10^{-2}$ cm/s, with a geometric mean of $2.61 x 10^{-7}$ cm/s (MWH 2007) indicating that although the formation is fractured it is generally tight with slow groundwater migration rates.

The bulk hydraulic conductivity (K_b) of bedrock at the FSDF was determined by 26 rising head and falling head slug tests in four wells equipped with discrete interval monitoring systems. Approximately 90 percent of the tests indicated K_b values in the range of 10^{-5} to 10^{-6} cm/s, and a geometric mean of $5.4 x 10^{-6}$ cm/s (MWH 2007), again indicating that groundwater migration is generally slow.

A pumping test using RD-54B was conducted to further evaluate bedrock K_b. Groundwater was extracted at a rate of 173 gpd for 165 days, inducing a 160-foot groundwater elevation drawdown. Measurements were made in 16 adjacent wells fitted with pressure transducers. The test resulted in a geometric mean K_b value of $6 x 10^{-7}$ cm/sec. The data indicate that the bedrock fracture network near the FSDF area does not appreciably enhance the K_b (an aquifer property that effects groundwater migration rates) of the Chatsworth Formation (MWH 2007).

Downhole geophysical logging has been conducted in wells RD-22, RD-23, RD-57, and RD-65, and in C-8 following their drilling between 1989 and 2002. Supplemental downhole geophysical logging was performed in C-08, RD-23, RD-54A, and RD-65 during the spring 2016 (CDM Smith 2016b). The additional geophysics were used to evaluate the stratigraphy at depth and the fracture patterns, sizes, and orientation to characterize the three-dimensional geometry of the bedrock. These data and the boring logs were used to evaluate the local connectivity of bedrock fractures and the inter-well relationships in the vicinity of the FSDF. Overall the hydrogeological investigation of the FSDF area indicated that the bedrock sandstone has a lower bulk hydraulic conductivity with fewer fractures and connectivity (COLOG 2016) than other parts of Area IV, resulting in appreciably slower migration of groundwater and associated groundwater contamination than other locations within Area IV and across the SSFL.

5.3.3 Nature and Extent of Impacted Groundwater

To assist in the understanding of the transport of contaminants in groundwater at the FSDF, the following text provides a summary of the CSM. A more detailed discussion of the CSM is provided in Section 5.3.4.1.

During historic operations at the FSDF, wastewater impacted with VOCs was likely discharged into the upper and lower ponds. VOC impacted water infiltrated downward into the alluvium and weathered bedrock sandstone matrix to the interface with competent bedrock. The shallow alluvium VOC source was removed when the ponds and impacted surrounding soil were remediated (1980 to 2000). The current source of VOCs to groundwater is residual contaminants retained in fractures found in the upper competent bedrock. Movement of VOCs in bedrock is controlled by the tight nature of the matrix, which has resulted in the majority of the mass being found in upper bedrock fractures. (See corehole C-08 discussed in Section 5.3.3.1). In wetter rainfall years when the Near-surface groundwater comes in contact with the partially weathered bedrock, TCE in upper bedrock fractures can be mobilized. Alluvial soil (fill) and/or weathered Chatsworth Formation, therefore, act as a water storage reservoir following precipitation events providing hydraulic head to move the underlying residual VOCs. The VOCs then move with the infiltrated groundwater through bedrock fractures, downward and laterally (depending on fracture orientation) from the original source location. In drier rainfall years, the groundwater in the near-surface bedrock fractures dries up and movement of VOC from the source is minimal. As noted above, the vertical migration of groundwater from the Near-surface to the lower bedrock system is hindered by the low bulk hydraulic conductivity (4×10^{-6}) of the Chatsworth Formation and limited interconnected bedrock fracture network near the FSDF. Therefore, the primary mechanism for movement of VOC impacted groundwater in bedrock is controlled by the limited amount of transmissive fractures.

Another critical aspect of contaminant flow and distribution at the FSDF are the extended lengths of open boreholes that are drilled through source areas and fractures that otherwise were not connected to other fractures. This results in the interconnection and transport of contaminants between Near-surface and bedrock groundwater.

5.3.3.1 Groundwater Investigation Analytical Results

The FSDF location has been investigated using eight Near-surface wells and piezometers (RS-18, RS-54, DS-46, PZ-097, PZ-098, PZ-099 [abandoned in 2005], PZ-100, and PZ-101), and fifteen bedrock wells (**Figure 5.3-1**). Corehole C-08 drilled within the lower FSDF pond was also used for hydrogeologic characterization. In 2016, well borings were subject to packer testing, the objective of which was to locate fractures bearing VOCs. During the spring of 2018, eight shallow bedrock cores, drilled to about 60 feet bgs, were used to assess the presence and distribution of VOCs in the near-surface bedrock fractures (CDM Smith 2018c). Bedrock core samples were collected and processed for laboratory analysis for the presence of VOCs. The results of the packer tests and analyses support the conceptual model that VOCs are primarily associated with shallow bedrock fractures.

Shallow Well Analytical Results

When Near-surface groundwater is present, TCE and 1,1,1-TCA have been reported in groundwater samples from piezometers and shallow groundwater monitoring wells. Appendix B provides the historic sample result data tables for the FSDF monitoring wells. In June 2018, eight approximately 60 feet deep bedrock cores were drilled, and bedrock sampled for the presence of VOCs. The sample results identified fractures primarily to the north of RS-54 with VOCs (CDM Smith 2018c). Core samples collected south of RS-54, particularly in the area of the former upper pond, did not contain VOCs. One coring (C-21) located north of RS-54 exhibited the VOC concentrations similar to that observed for RS-54 groundwater samples.

Piezometer PZ-097

Piezometer PZ-097 located topographically downgradient of the FSDF, has always been dry and does not provide water quality data. It is 44.5 feet deep and screened from 33 to 43 feet bgs.

Piezometer PZ-098

Piezometer PZ-098 is 37.5 feet deep and screened from 24 to 34 feet bgs. It is typically dry. It was sampled once in April 2003; the TCE concentration was 29 µg/L and 1,1,1-TCA was non-detect. New wells DS-46 and DD-140 were installed at this location in 2016 to provide water elevation control and monitoring downgradient of the FSDF (see bedrock well discussion).

Piezometer PZ-099 (Abandoned)

Piezometer PZ-099 was installed topographically downgradient from the FSDF. PZ-099 was only sampled one time in April 2003. TCE was reported at a concentration of 140 µg/L and 1,1,1-TCA was non-detect. The well was dry during the RD-54B pumping test and the location has provided no additional aquifer characterization data. Well PZ-099 was abandoned in 2006 during the installation of surface water erosion controls at nearby Outfall 005. New well DD-139 was installed in 2016 north of former PZ-099 to provide additional water elevation control and monitoring point (see bedrock well discussion).

Piezometer PZ-100

Piezometer PZ-100 is 16.5 feet deep and screened from 5.7 to 15.7 feet bgs. It is located, topographically lateral and upgradient of the FSDF and downgradient of ESADA. It was sampled twice prior to 2011; TCE and 1,1,1-TCA were non-detect for both events. PZ-100 has been typically dry and is not a reliable monitoring point.

Piezometer PZ-101

Piezometer PZ-101 is located topographically upgradient of the FSDF. It was drilled to a total depth of 27 feet and screened from 10 to 20 feet bgs. It is typically dry has only been sampled once in 2005 and exhibited 140 µg/L of TCE; 1,1,1-TCA was non-detect. PZ-101 water levels are about 20 feet above those measured in RS-54.

Near-surface Well RS-18

Well RS-18 was installed topographically downgradient from the FSDF. The well is 13 feet deep and screened from 7.5 to 13 feet bgs. Highly dependent on rainfall, TCE concentrations have ranged from 3,200 µg/L in 1994 to 1.2 µg/L in 2016. 1,1,1-TCA concentrations have ranged from 670 µg/L in 1994 to non-detect in 2016.

Near-surface Well RS-54

Well RS-54 has exhibited the highest 1,1,1-TCA and TCE concentrations reported for the FSDF study area. RS-54 is 46 feet deep with an open corehole from 7 to 46 bgs. It was installed within the boundaries of the lower FSDF pond adjacent to deep cluster well RD-54A, RD-54B, and RD-54C. RS-54 monitors groundwater found in near-surface bedrock fractures. RS-54 was dry prior to 2017, but exhibited groundwater following the 2017-2018 rains; when sampled in 2013, a TCE at 1,600 µg/L and 1,1,1-TCA at 5,600 µg/L of were reported; the results for 2017 were 1,200 µg/L for TCE and 11,000 µg/L for 1,1,1-TCA.

In November of 2017, DOE initiated a groundwater interim measure (GWIM) using RS-54 as the pumping well. The well was pumped dry 25 times and allowed to recover. It was last pumped in June 2018 when the recovery rate was about 0.01 inches per day. Approximately 330 gallons of water were removed from the well during the pumping period (CDM Smith 2018b).

Bedrock Well Analytical Results

Sixteen bedrock wells have been used to monitor water quality within the Chatsworth Formation at the FSDF. The bedrock wells are RD-21, RD-22, RD-23, RD-33A, RD-33B, RD-33C, RD-54A, RD-54B, RD-54C, RD-57, RD-64, RD-65, DS-46, DD-139, DD-140, and C-08 (**Figure 5.3-1**). Well cluster RD-33A, RD-33B, and RD-33C, and wells DD-139 and RD-57 are in the NBZ downslope of the FSDF.

Interval sampling (packer testing) of C-08, RD-23, RD-33A, and RD-64 at the FSDF was performed in 2016 to identify fracture zones bearing VOC-impacted groundwater. Prior to packer testing, geophysical logging of several wells was performed to identify fracture zones and stratigraphic breaks, ideally exhibiting infiltration for targeted interval sampling. Interval sampling was performed using a single or straddle packer system to collect groundwater seepage within the vadose and groundwater flowing from fractures within the saturated zone. Interval sampling confirmed that VOCs are present in fractures in the vadose zone (above the water table) and that these fractures contribute VOC impacts in deeper groundwater (**Table 4-1**). Thus, VOCs can and do ‘seep’ into the open boreholes and migrate downward to the water table. Interval samples collected below the water table show that VOC is present within specific fracture and bedding intervals. The ability of these intervals to produce water was also determined during sampling. Interval sampling combined with historical and recent groundwater quality results improve the understanding of the nature, extent, and transport of the VOC in the FSDF area.

A discussion of individual bedrock monitoring wells and associated groundwater impacts within the FSDF follows.

Bedrock Well RD-21

Well RD-21, located upgradient from (or lateral to) the FSDF, is an open corehole from 30 to 175 feet bgs. As shown in **Figure 5.3-2**, RD-21 is open to both the Upper and Lower Burro Flats members with the current water level at the ELV. Well RD-21, also located upgradient of the FSDF and adjacent to PZ-101, exhibits TCE concentrations exceeding 100 µg/L. Historically, 1,1,1-TCA has not been reported in RD-21 samples. It is the only well in Area IV exhibiting carbon tetrachloride. This data indicates that there are two separate TCE sources in this area. Groundwater within RD-21 is about 70 feet above groundwater levels measured at RD-54A (refer to bedrock well discussion and Figure 4-4).

Comparison of groundwater results from the open borehole of RD-21, pre-FLUTe™ conditions, with results from the FLUTe™ ports (**Figure 5.3-3**) suggest that TCE may be entering the well above the shallowest FLUTe™ port. In addition, open borehole samples collected between 1989 through December 2013 contain higher TCE concentrations than most samples collected from the FLUTe™ ports from January 2003 through January 22, 2013. A plausible interpretation of the distinctly different RD-21 data is that the FLUTe™ sealed the borehole between the conductor casing (set from 0 to 30 feet bgs) and the first FLUTe™ port and, in effect, sealed the open borehole, preventing TCE from migrating vertically within the borehole conduit. When the FLUTe™ was removed, the seal was essentially removed, and the vertical pathway re-established. Open borehole sample results collected prior to and following FLUTe™ liner removal are shown on **Figure 5.3-3**.

The use of RD-21 for groundwater pumping had an effect on the TCE concentrations in RD-21 (**Figure 5.3-3**). Groundwater extraction was performed at FSDF between January 1997 and mid-2002 using RD-21. The groundwater extraction rate from RD-21 averaged about 173 gpd. As reported in the September 2007 Group 8 RFI Report, (Appendix D – FSDF RFI Site (SWMU 7.3)), RD-21 does not communicate hydraulically with other wells located at the FSDF.

Observations and conclusions from the groundwater extraction interim measure include:

- Following the groundwater pumping and prior to FLUTe™ installation, TCE was detected at lower concentrations indicating that portions of the mass had been removed from the fractures and bedding planes.
- A slight TCE rebound appeared following pumping. Rebound is common in many wells as higher concentrations of TCE enter the fractures from the bedrock matrix through diffusion, followed by equilibration.
- There was no discernable influence on water levels or TCE concentrations in downgradient monitoring wells at the FSDF as a result of pumping RD-21.

Perchlorate has also been detected in RD-21. Perchlorate is typically related to rocket engine testing wastes and there is no evidence or documentation of DOE using perchlorate in Area IV. Prior to installation of the FLUTe™ in January 2003, perchlorate was reported at concentrations between 3.7 µg/L and 9 µg/L (MCL of 6 µg/L). Results for RD-21 with the FLUTe™ system indicate perchlorate concentrations were between 9.7 µg/L and 12 µg/L. Samples were collected from ports 2 (9.7 µg/L), 3 (9.8 µg/L), 4 (11 µg/L), and 5 (12 µg/L). Groundwater samples collected from the open borehole (30 to 175 feet) in 2013 contained slightly lower perchlorate concentrations – 6.2 µg/L (February 2013), 5.8 µg/L (July 2013), and 4.1 µg/L (February 2014). Perchlorate was reported at 2.5 µg/L in the February 2016 sample. (**Appendix B** provides the chemical sampling results.)

Bedrock Well RD-22

Well RD-22 is 440 feet deep and cased from the ground surface to 30 feet bgs. It is located laterally and downgradient from the FSDF (**Figure 5.3-1**). TCE and 1,1,1-TCA have not been reported in samples collected from RD-22, either prior to installation of the FLUTe™ or during sampling of the FLUTe™ ports. RD-22 does not appear to be affected by releases of VOCs at the FSDF. The FLUTe™ system was removed from this well in June 2016 (CDM Smith 2016c).

Perchlorate, was not detected prior to installation of the FLUTe™ but was detected following FLUTe™ installation (February 2003). Perchlorate concentrations decreased over time and were not detected in open borehole sampling. In addition, exceedance of metals detected above the groundwater screen level are believed to be the result of FLUTe™ cross-contamination (see Appendix B tables).

It is presumed that RD-22 was installed to define the vertical and horizontal extent of TCE contamination emanating from the FSDF[3]. The following observations for RD-22 are used to support the CSM:

- RD-22 is used to define the vertical and western horizontal extent of the FSDF TCE plume
- RD-22 is in communication with other wells at the FSDF as observed during pumping at RD-54B
- Particle track modeling (Section 6.0), the location and depth of RD-22 is appropriate define the vertical and western horizontal extent of the FSDF TCE plume
- TCE and 1,1,1-TCA are not present in the well

Bedrock Well RD-23

Well RD-23 is 440 feet deep and cased from the ground surface to 30 feet bgs. It is a bedrock monitoring well located downgradient of the FSDF. TCE concentrations reported for RD-23 are variable depending on depth of sample. The highest TCE concentration observed was 630 µg/L in port 3 in 2009. Following removal of the FLUTe™ liner in spring of 2016, the TCE concentrations were 19 µg/L (May 2016) and 22 µg/L (October 2016) for the open borehole (**Figure 5.3-4**). It should be noted that FLUTe™ ports 2 and 3 were the only ports sampled after 2004 and generally reflect a scatter of data points collected prior to the installation of the FLUTe™. 1,1,1-TCA has not been detected in samples collected from this well.

There was a marked increase in TCE concentrations in well RD-23 between September 1992 (78 µg/L) and March 1993 (540 µg/L) whereas the highest open borehole TCE detection in the well occurred in February 2000 at a concentration of 610 µg/L (**Figure 5.3-4**). Water elevations remained relatively stable over the TCE sampling period. In review of pre-FLUTE data, TCE concentrations fluctuated, generally mirroring annual precipitation with higher TCE concentrations occurring following the higher annual precipitation. Lower TCE concentrations generally correspond with decreasing annual precipitation (1993, 1994, 1995, 1996, and 1997).

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[3] The historical records are unclear regarding the data quality objective for wells installed in Area IV

This did not occur during the years the FLUTe™ sampling occurred. The water level fluctuations relative to changes in precipitation are minimal and may be explained by the presence of siltstone (9 to 30 feet bgs), but most likely from the presents of the ELV at 210 to 225 feet bgs. Water level measurements from this well reflect the Lower Burro Flats member.

Higher TCE concentrations detected in the open borehole versus the TCE concentrations detected in the FLUTe™ ports immediately after installation is that the FLUTe™ sealed the open borehole between the conductor casing (set from 0 to 30 feet bgs) and the first FLUTe™ port. If TCE is present in this interval, the FLUTe™ prevented TCE from entering the well from this zone.

At this location, TCE detected in groundwater samples was either present prior to drilling the monitoring well (as supported by TCE being detected immediately after well installation) or the open borehole immediately created a conduit through the ELV as supported by stable TCE concentrations from 1989 to 1992 and a substantial increase in TCE in groundwater resulted from above average annual precipitation in 1992 and 1993 (32.21 and 36.23 inches), respectively. This rise in TCE concentration demonstrates the 'flushing' of TCE retained in the upper zones and presence of a preferential pathway between TCE present in the vadose zone and the water table (open borehole). **Figure 5.3-5** presents TCE concentration in RD-23 1982 through 2016.

In July 2016 interval sampling of isolated zones using inflatable packers was performed. **Figure 5.3-5** illustrates a summary of physical and chemical data collected for RD-23 including but not limited to lithology, water levels, and the depths of FLUTe™ sample ports. TCE concentrations for pre-FLUTe™ open borehole, FLUTe™, post-FLUTe™ open borehole, and interval sampling are shown on the figure. During interval sampling, TCE is present in the fracture immediately above the water table at that time. It also shows TCE in fractures below the water table and at concentrations above the open borehole sample concentration (19 µg/L; a composite TCE concentration of the entire borehole).

Perchlorate was analyzed in samples from May 1998, February 2003, and February 2014 and has not been detected in RD-23. Unlike other wells in Area IV, perchlorate was not detected following installation of the FLUTe™ liner which suggests that the FLUTe™ was not previously exposed to contamination or was properly decontaminated following removal from Area I.

The following observations for RD-23 are used to support the CSM:

- RD-23 is in communication with other wells at the FSDF (as observed during the RD-54B pumping test)
- RD-23 water levels do not directly respond to increased annual precipitation
- TCE was present in groundwater prior to installation of the well
- RD-23 intercepts fractures and bedding planes containing elevated TCE concentrations that appear to discharge to the open borehole with increased precipitation
- The open borehole has created a TCE conduit between the vadose zone and water table. The open borehole conduit may be the result of a poor conductor casing seal, the conductor

casing not extending entirely through the weathered Chatsworth Formation, and/or impacted TCE vadose zone fractures intercepting the open borehole

RD-33 Well Cluster

The RD-33 well cluster was installed in the NBZ downgradient of the FSDF (**Figure 5.3-1**). It consists of three wells – RD-33A, RD-33B, and RD-33C installed in the Chatsworth Formation.

Bedrock Well RD-33A – RD-33A is 320 feet deep and cased from the surface to 100 feet bgs. TCE concentrations prior to FLUTe™ installation in 2003 ranged between 2.4 µg/L and 14 µg/L (**Figure 5.3-6**). Following installation of the FLUTe™ on January 9, 2003, the TCE concentrations were reported below 0.9 µg/L. The decrease in TCE concentrations is believed to be a result of not aligning FLUTe™ port sample depths with formation fractures, as the post-2003 results do not appear to characterize TCE concentrations migrating into well RD-33A. TCE concentrations were below the laboratory reporting limit in the February 2014 sample. The FLUTe™ was removed on March 4, 2016 and sampled in June 2016 using standard low-flow methods. The open borehole sample had a TCE concentration of 7 µg/L, which is similar to the average of pre-FLUTe™ concentrations. **Figure 5.3-7** illustrates a summary of physical and chemical data collected for RD-33A including but not limited to lithology, water levels, FLUTe™ sample ports, open borehole sample, and interval samples with their respective range of TCE concentrations. 1,1,1-TCA has not been reported in an RD-33A sample.

Perchlorate was measured at an estimated concentration of 3.8 µg/L in February 2003 and at 1.2 µg/L in February 2012 from port 3.

Based on FEFLOW particle track modeling (see Chapter 6) this well is located downgradient of the FSDF and defines the vertical and horizontal extent of TCE contamination to the west of the FSDF.

The following observations for RD-33A are used to support the CSM:

- Relatively large and rapid water level response indicates that there is a small storage capacity in the bedrock (less response than most wells in Area IV)
- Gradual decline in water levels after recharge event indicates low to moderate bulk permeability of the bedrock (water slowly drains from the bedrock)
- TCE was detected in RD-33A prior to FLUTe™ sampling
- TCE was detected in the open borehole sample following FLUTe™ removal
- RD-33A is in communication with the FSDF TCE plume
- TCE concentrations will remain between 1 and 7 µg/L due to diffusion and dispersion along its flow path

Bedrock Well RD-33B - RD-33B is 415 feet deep and cased from the surface to 360 feet bgs. The original borehole was advanced to a total depth of 678 feet bgs and then cemented back to 415 feet bgs during well completion (**Figure 5.3-2**). It never had a FLUTe™ system. TCE has been reported in RD-33B twice; at a concentration of 0.76 µg/L in December 1991 and at a concentration of 0.18 µg/L in August 2002. Samples have been non-detect since 2011. 1,1,1-TCA has not been reported in an RD-33B sample.

Perchlorate has been sampled for seven times and was not detected.

The following observations for RD-33B are used to support the CSM:

- Relatively large and rapid water level response indicates that there is a small storage capacity in the bedrock (less response than most wells in Area IV)
- Gradual decline in water levels after recharge events indicates low to moderate bulk permeability of the bedrock (water slowly drains from the bedrock)
- TCE is not present at RD-33B
- RD-33B defines the vertical extent of TCE at this location
- TCE migrates in fractures above 360 feet (1,433 feet MSL) based on RD-33A data

Bedrock Well RD-33C – RD-33C is 520 feet deep and cased from the surface to 480 feet bgs. TCE, 1,1,1-TCA, and perchlorate have never been detected in RD-33C.

The following observations for RD-33C are used to support the CSM:

- Relatively large and rapid water level response indicates that there is a small storage capacity in the bedrock (less response than most wells in Area IV)
- Gradual decline in water levels after recharge events indicates low to moderate bulk permeability of the bedrock (water slowly drains from the bedrock)
- TCE has not been detected in RD-33C which corroborates the lack of TCE in the Lower Burro Flats member.

RD-54 Well Cluster

The RD-54 well cluster consists of three wells drilled to different depths – RD-54A, RD-54B, and RD-54C. All three wells were installed in the center of the former FSDF pond area, adjacent to shallow well RS-54 (**Figure 5.3-1**) in the Chatsworth Formation.

Bedrock Well RD-54A – RD-54A, the shallowest well of the cluster, is a 278-foot deep bedrock well. It is cased and sealed from the surface to 119 feet bgs. A FLUTe™ was installed in January 2003 and TCE concentrations exhibited a marked decrease compared to pre-FLUTe™ concentrations; however, the shallowest interval (port) was not sampled (**Figure 5.3-8**). The well has been sampled eight times since the FLUTe™ was removed in January 2011. Since removal, TCE concentrations have ranged from 1.3 µg/L in February 2013 to 3.9 µg/L in March 2017.

The RD-54A TCE time-trend profile supports the belief that TCE was present in the Chatsworth Formation groundwater prior to drilling the well (**Figures 5.3-2 and 5.3-8**). Like RD-23, the borehole intercepted fractures and bedding planes that contained TCE which seeped into borehole and migrated through the vadose and into groundwater. Also, higher precipitation years are believed to increase TCE migrating to the water table from the vadose zone.

1,1,1-TCA was reported in groundwater samples ranging from 14 µg/L in 1994 to non-detect in 2002, prior to FLUTe™ system installation. These 1,1,1-TCA concentrations were an order of magnitude less than the TCE concentrations, which is the opposite of what was observed in adjacent well RS-54. 1,1,1-TCA has not been detected in samples collected from RD-54A since removal of the FLUTe™ liner in 2011.

Perchlorate was detected in the open borehole groundwater samples prior to installation of the FLUTe™ in January 2003. From the perchlorate data it can be concluded that fractures and bedding planes that contain perchlorate are in communication with the well between 190.5 and 260.5 feet. Perchlorate was not detected in the open borehole in groundwater samples collected February 2013, 2014, 2015, and 2016. RD-54A water level fluctuations in response to precipitation events are considered minimal and may be explained by the presence of claystone (12 to 14 feet bgs) and clayey sandstone (75 to 90 feet bgs) resulting in a higher storage capacity for the bedrock in this area but most likely from the presents of the ELV at 153 to 186 feet bgs. Water measurement from this well reflect the Lower Burro Flats member.

The following observations for RD-54A are used to support the CSM:

- RD-54A is in communication with other wells at the FSDF based on observations made during the RD-54B pumping test
- RD-54A groundwater levels do not significantly respond to increased or decreased annual precipitation
- TCE was present in groundwater prior to installation of the well
- TCE increases with increased annual precipitation
- RD-54A intercepts fractures and bedding planes that contained higher TCE concentrations and flow into the well during years of higher precipitation
- TCE concentrations in groundwater have decreased two orders of magnitude between 1993 and 2016

Bedrock Well RD-54B – RD-54B is 437 feet deep and cased from the surface to 379 feet bgs. TCE has been reported four times in RD-54B at concentrations between 1 and 9.9 µg/L (in 1993 and 2002, respectively). TCE and 1,1,1-TCA have not routinely been detected in this well and were not detected in February 2014 or March 2016. Perchlorate has been analyzed for six times and has been non-detect.

RD-54B is located within the area of the former ponds and defines the vertical extent of TCE contamination. RD-54B water level fluctuations in response to precipitation events are considered minimal and may be explained by the presence of the ELV (191 to 224 feet bgs), a higher storage capacity for the bedrock in this area or because water measurement from this well reflect the Lower Burro Flats member exclusively.

A pumping test using RD-54B was conducted over a 165-day period (in 2002 or 2003) at a pumping rate of about 173 gpd (MWH 2006a). Groundwater elevation responses to RD-54B pumping were measured and confirmed in 6 of the 16 observation wells, and responses were measured at distances of up to 400 feet away from the extraction well (MWH 2006a).

The following observations for RD-54B are used to support the CSM:

- TCE has not been detected in RD-54B since 2002
- RD-54B is in communication with six wells at a radius of influence of approximately 400 feet.
- RD-54B supports definition of the vertical extent of TCE at the FSDF

Bedrock Well RD-54C – RD-54C was the first boring of the RD-54 cluster drilled and provided the lithologic description for the location. The available well completion information for RD-54C is conflicting. The RD-54C boring log shows a total depth of the borehole as 620 feet bgs. The schematic diagram of monitoring well RD-54C shows a total depth of 520 feet bgs and the database shows a total depth of 638 feet bgs. It is unknown if the borehole was advanced to 638 feet bgs and then cemented to a shallower depth as was done in other boreholes at SSFL. RD-54C is cased from the surface to 557 feet bgs.

TCE has been reported for RD-54C seven times with a maximum concentration of 1.1 µg/L in a 2006 sample. TCE has not been reported above laboratory detection limits since 2006, including samples collected in February 2014 and March 2016. 1,1,1-TCA has not been detected in any sample, and perchlorate has been analyzed for six times and was non-detect.

RD-54C water level fluctuations in response to precipitation events are considered minimal. This well is open to the lower portions of the Lower Burro Flats member and possibly the SPA and Shale 2 fine-grained units.

The following observations for RD-54C are used to support the CSM:

- TCE has not been reported at low concentrations in 2006, and has not been detected since.
- RD-54C does not appear to be in communication with RD-54A; the early presence of TCE may have resulted in cross-contamination between the upper zones and lower zone during drilling through the shallow contamination zone.
- RD-54C confirms the vertical extent of TCE at this location defined by RD-54B.

Bedrock Well RD-57

Well RD-57 is 419 feet deep and cased from ground surface to 19.5 feet bgs. It is located in the NBZ downgradient of the FSDF. A single TCE detect was reported in RD-57 in 2000, at a concentration of 1.9 µg/L. Otherwise, TCE has not been reported above its detection limit, including the sample collected in February 2014. 1,1,1-TCA has never been detected in this well. A FLUTe™ system was installed in September 2003 and was attempted to be removed in June 2016. The liner tore apart during removal and therefore blocks use of the well for current monitoring purposes. It does not appear that FLUTe™ sampling has biased previously reported TCE concentrations in this well.

Groundwater samples have been analyzed for perchlorate that were collected from the RD-57 open borehole well and from FLUTe™ ports. Perchlorate was not detected in any sample.

RD-57 water levels fluctuations in response to precipitation events are minimal and may be explained by the presence of the Lot Bed (166 to 183 feet bgs), the ELV (376 to 409 feet bgs), a higher storage capacity for the bedrock in this area, or most likely, water level found in the Upper Burro Flats member below the Lot Bed.

The following observations from RD-57 are used to support the CSM:

- RD-57 is the farthest downgradient well at the FSDF
- RD-57 is open to both shallow and deep members of the Chatsworth Formation
- TCE has not been detected in other than one sample at a concentration of 1.9 µg/L
- RD-57 defines the horizontal and vertical extent of TCE northwest of the FSDF

Bedrock Well RD-64

Well RD-64 is 398 feet deep and cased from the surface to 19 feet bgs. It was installed immediately west of the FSDF ponds. TCE is the primary VOC observed in well samples. 1,1,1-TCA has not been detected in samples collected from this well, including those collected while FLUTe™ liner was installed.

Following well installation, only toluene was detected in the first groundwater sample collected from the well in May 1994. The second sample collected in February 1995 exhibited 8.9 µg/L and 61 µg/L of TCE in February 1996. TCE concentrations continued to increase to 680 µg/L over the next seven years (March 1994 to March 2001) strongly suggesting that the open borehole has created a conduit for TCE in the vadose zone to migrate downward to the water table (**Figure 5.3-9).**

Sampling select zones using the FLUTe™ liners between 2003 and 2014 masked TCE concentrations. This masking occurred because the FLUTe™ liners were reused and the depth-specific sampling ports did not always correspond to transmissive fractures in the Area IV open boreholes. Following removal of the FLUTe™ liner in 2016, the open borehole samples were 14 µg/L in May and 32 µg/L in November 2016. However, the selected interval sampling (packer sampling) conducted in July 2016 indicated that higher concentrations of TCE remain within the upper bedrock matrix, 130 µg/L TCE within the ELV member above the water table (see **Figure 5.3-10**). This data supports the CSM indicating that a significant source for TCE remains within the bedrock and above the water table where TCE continues to be moved through the fractures and along bedding planes. Because the upper fractures/bedding planes that transport TCE have been drained of infiltrating surface water during the currently drier rainfall periods, additional sampling during future wetter rainfall periods will be required to determine whether or not saturation and additional flushing the fractures/bedding planes containing TCE will produce higher TCE concentrations at this well.

Cis-1,2-DCE has been detected at concentrations ranging from 1.9 to 440 µg/L indicates that dechlorination may be occurring in this well (see Appendix B tables); potential dechlorination will be further evaluated with future data. Vinyl chloride, another dechlorination by product, was detected at a concentration of 0.6 µg/L (Appendix B).

Perchlorate has not been detected in samples collected from RD-64.

RD-64 groundwater elevations fluctuate in response to precipitation events are less than other Area IV wells and may be explained by the presence of the ELV (182 to 215 feet bgs). The open borehole is exposed to both the Upper and Lower Burro Flats members. Water levels measured in this well are likely the combination of both members.

The following observations for RD-64 are used to support the CSM:

- RD-64 is in communication with other wells at the FSDF based on the RD-54B pumping test results.
- RD-64 water levels do not significantly respond to increased or decreased annual precipitation.
- TCE is present in fractures above the water table. The open borehole is providing a conduit for TCE located in the vadose to impact groundwater. TCE concentrations in groundwater are affected by flushing of TCE from the vadose zone.

Bedrock Well RD-65

RD-65 is 397 feet deep and cased from the ground surface to 19 feet bgs. It is a bedrock well installed downgradient of the FSDF and RD-23. 1,1,1-TCA was reported in groundwater samples collected from 1995 through 2002, but at concentrations (9 to 79 µg/L) that are an order of magnitude less than TCE. 1,1,1-TCA was not detected in the open borehole samples collected 2013 through 2016.

Figure 5.3-11 shows TCE concentrations in RD-65 over time. TCE concentrations generally remain stable from well installation in 1995 through 2002. As was observed for other wells, there was a decrease in TCE concentrations following installation of the FLUTe™ system.   The FLUTe™ system was removed in February 2013 and samples collected from the open borehole contained slightly higher concentrations of TCE. TCE concentrations in samples from the open borehole after 2013 (5 to 68 µg/L) were still lower than TCE concentrations detected when the FLUTe™ liner was installed (Appendix B).

Figure 5.3-12 illustrates a summary of physical and chemical data collected for RD-65, including, but not limited to lithology, water levels, and TCE concentrations from FLUTe™ sample ports, open borehole sample, and interval sampling. As shown on the figure, TCE was detected in fractures located above the water table.

Perchlorate was not initially detected in the May 1998 groundwater sample. However, following FLUTe™ installation in October 2002, perchlorate was detected in five sampling ports in February 2003 with concentrations ranging from 1.6 to 6.2 µg/L. Since removal of the FLUTe™ on February 2013, perchlorate was not detected in either 2014 or 2015, but was detected at an estimated concentration of 0.022 J µg/L in 2016. The "J" data qualifier denotes that the concentration was estimated, meaning that it was positively detected, but was below the laboratory practical quantification limit (PQL).

RD-65 water level fluctuation in response to precipitation events are considered minimal and may be explained by the presence of the ELV (199 to 232 feet bgs) and like RD-64, the long open borehole provides influences from both the Upper and Lower Burro Flats members.

The following observations for RD-65 are used to support the CSM:

- RD-65 is in communication with other wells at the FSDF based on RD-54B pumping test results
- RD-65 water levels do not significantly respond to changes in annual precipitation rates
- There is no apparent trends in TCE concentrations with respect to changes in precipitation rates
- TCE is present in fractures above the water table. However, it does not appear that the open borehole is providing a significant conduit for TCE in the vadose zone to reach the water table. This may be due to RD-65 being located beyond (and cross gradient of) the FSDF ponds source area (i.e., no TCE impacts present in the vadose zone)
- TCE diffusion from the bedrock matrix to groundwater present in the fractures/bedding planes is occurring. Groundwater with higher concentrations of TCE is no longer present in fractures/bedding planes sampled in RD-65

Bedrock Well DS-46

Well DS-46 was drilled to a depth of 206 feet bgs and is cased from the surface to 19 feet bgs. It was installed in February 2016 to serve as an upper bedrock (first encounter of groundwater) monitoring well and addresses a data gap associated with dry piezometer PZ-98. Depth to groundwater in July 2016 was 21.32 feet. DS-46 was sampled in June 2016 and was non-detect for 1,1,1-TCA and TCE.

Bedrock Well DD-139

Well DD-139 was drilled to a depth of 206 feet bgs and cased from the surface to 19 feet bgs. Well DD-139 was installed in February 2016 in the Northern Buffer Zone northwest of the FSDF. This well serves to monitor both local groundwater flow direction and sentinel monitoring for the northerly migration of the FSDF TCE plume (**Figure 5.3-1**). Depth to groundwater was 175.61 feet bgs in July 2016. DD-139 was sampled in March and November 2016 and 1,1,1-TCA and TCE were not detected in samples from both events.

Bedrock Well DD-140

DD-140 was drilled to a depth of 167 feet bgs and is cased from ground surface to 60 feet bgs. DD-140 was installed in February 2016 in the drainage northeast of the FSDF and is co-located with PZ-098 and shallow well DS-46. It serves as a deeper sentinel monitoring well in the upper bedrock located topographic downgradient of the FSDF ponds (**Figure 5.3-1**). Depth to groundwater was 162.26 feet in July 2016. Neither 1,1,1-TCA or TCE were detected in samples collected in March and November 2016.

Corehole C-08

C-08 is a 400-foot deep, 12.25-inch diameter borehole, cased from ground surface to 65 feet bgs. It offers the opportunity to observe shallower bedrock conditions than at adjacent bedrock well RD-54A (**Figure 5.3-1**) that is cased from the surface to 119 feet bgs. Because C-08 was drilled at the FSDF lower pond location, it was evaluated to provide additional understanding the local fracture network where residual TCE may be harbored.

During drilling, vadose zone and saturated bedrock core samples were collected and crushed, followed by porewater extraction and analysis to confirm matrix diffusion processes occurring in the bedrock. The porewater profile for TCE shows that more than 99 percent of the TCE mass is located in the vadose zone (MWH 2006a). The majority of TCE found in porewater in the vadose zone occurs between 19 and 57 feet, at 90 feet, and between 140 to 150 feet bgs (MWH 2006a). This distribution is illustrated in **Figure 5.3-13**. Core-measured VOC concentrations represent contaminants in the rock matrix that have been introduced by molecular diffusion and may be a function of water-level history and contaminant source variations.

Following the drilling and coring of C-08 in April 2002, C-08 was fitted with a blank FLUTe™ system liner; no sampling ports existed. The liner was removed from the hole in June 2016 and then the borehole was sampled as a conventional monitoring well. Depth to groundwater was 197.59 bgs in July 2016. The July 2016 sample was non-detect for 1,1,1-TCA and exhibited 1 µg/L of TCE. The October 2016 sample was non-detect for 1,1,1-TCA and exhibited 1.4 µg/L of TCE.

Selected interval sampling was conducted in C-08 in July 2016 (**Figure 5.3-14**). TCE at 1 µg/L was observed at the water table and at 2 µg/L at an interval immediately below the water table. All deeper interval samples were non-detect for TCE. Currently, the low TCE concentration detected in the open borehole sample shows that groundwater found in the ELV and Lower Burro Flats member has been impacted. It is believed that the blank FLUTe™ prevented TCE from entering the borehole. It is believed that precipitation events may flush TCE from the vadose zone and migrate via the borehole to the water table. It is believed that TCE concentrations will increase over time and will be dependent on flushing events.

5.3.3.2 FSDF Bedrock Coring

In June 2018 eight bedrock cores were drilled to approximately 60 feet bgs and part of a VOC source investigation of the FSDF. Cores that exhibited fractures or staining were collected for off-site analysis for VOCs. The results of the core samples are provided in a technical memorandum (CDM Smith 2018c).

5.3.3.3 FSDF Soil Passive Soil Gas Investigations

In November 2017 and again in June 2018, passive soil gas samples were collected at the FSDF in an effort to identify where near-surface bedrock contained VOCs. Overall results of the studies are provided in technical memoranda (CDM Smith 2018d).

5.3.3.4 COC Identification

The results of soil sampling at the FSDF location following the extensive removal actions show that the surface soils are nearly absent of contaminants. Therefore, this section focuses on current soil vapor and historic groundwater contamination data for the FSDF.

MWH performed a soil vapor investigation across Area IV during the summer 2014 (MWH 2014b). Results for key COCs are documented Appendix E figures. As would be expected, the highest TCE concentration observed for Area IV was 1.6 µg/L for the soil vapor sample collected at the location of the FSDF (8SV_DG-512). Lesser amounts of TCE were observed at locations adjacent to the FSDF (8SV_DG-506, 8SV_DG-515, 8SV_DG-502, 8SV_DG-503, and 8SV_DG-517). These results are consistent with the knowledge that the FSDF was the source for TCE in groundwater at this location.

Groundwater sampling results for the past 25 years show that TCE and its associated breakdown products (cis-1,2-DCE and trans-1,2-DCE), 1,1,1-TCA, 1,1-dichloroethane, 1,1-dichloroethene, and perchlorate are the primary COCs for the FSDF area. Perchlorate has been reported in soil and groundwater samples collected from the FSDF area. The FSDF is the only Area IV location with repeated detections of perchlorate, which is believed to have come from rocket engine testing wastes.

Cadmium, cobalt, copper, molybdenum, nickel, and selenium were consistently reported in RS-54 groundwater samples above screening levels collected between 2000 through 2008. The observation of metals in groundwater samples would be consistent with the practice of cleaning sodium from metal objects and leaving the objects in the pond. Metals results for FS-54 samples collected in 2017 and 2018 confirm that cobalt, copper, molybdenum, and nickel, but not selenium, are present above screening levels. . Molybdenum in RD-23 and RD-64, and copper in RD-54A, and strontium in RD-22 were the metals observed above screening levels in these bedrock wells (**Appendix B**).

Nitrate was reported below its screening level for samples collected from RD-21 and RD-54A. RS-54 and RD-21 are the only two Area IV wells exhibiting perchlorate not associated with FLUTe™ liner results.

5.3.3.5 Vadose Zone Mass Estimate

The presence of VOCs (specifically 1,1,1-TCA and TCE) in groundwater beneath the area of the FSDF is assumed to be the result of discharge into the ponds during former operations. However, there are no records documenting quantities, or how or when the solvents were discharged. The original source of VOCs in the alluvium has been removed through soil removal actions. For these reasons, there is no reliable method of calculating the potential mass of VOCs that remains in shallow bedrock beneath the site. Although the mass of residual VOCs in shallow bedrock could be estimated using available historic information, it was determined that a complete investigation of VOC mass would be more appropriate prior to a potential corrective action. The CMS for the FSDF will address this data requirement. All groundwater data for the FSDF indicates that the majority of the remaining VOCs are harbored in the upper bedrock, probably between 20 feet and 60 feet bgs as exhibited by well RS-54.

5.3.3.6 Horizontal Extent of Contamination

The horizontal extent of the VOC plumes have been presented in a number of documents such as the 2009 Groundwater RI report and previous annual groundwater monitoring reports. However, the extent of all VOC (e.g., TCE, DCE, 1,1,1-TCA) groundwater contamination at the FSDF can be depicted using recent TCE data (**Figure 5.3-1**). A single COC plume map for the FSDF is justified for the following reasons:

(a) TCE was historically disposed at the facility and the source identified is believed to be the same source of other COCs including perchlorate and metals,

(b) TCE is the most prevalent VOC for all wells,

(c) TCE is present in all wells with daughter product screening level exceedances,

(d) Perchlorate is no longer present at the FSDF at concentrations exceeding its screening level in groundwater,

(e) 1,4-Dioxane has been removed from plume map delineation because detections only coincide with FLUTe™ results,

(f) Carbon tetrachloride is not shown because it is only found in RD-21 and is believed to be a separate source from the FSDF TCE plume,

(g) All metal exceedances occur within the TCE plume footprint.

The RD-59 well cluster (RD-59A, RD-59B, and RD-59C) is located downslope from the FSDF area and is used to establish horizontal extent of TCE contamination. All three wells are open bedrock borehole wells with RD-59A open from 21 to 58 feet bgs, RD-59B from 178 to 214 feet bgs, and RD-59C from 345 to 397 feet bgs. Wells RD-59B and RD-59C are artesian, flowing when the well caps are removed. There have been no detections of TCE and no consistent detections of metals above screening levels in samples collected from these wells.

Considering the hydraulic parameters of the local alluvium, and weathered and competent bedrock, the lateral movement of the TCE contaminant plume is very slow. The configuration of this plume has not changed in decades and is confirmed by enhanced definition via samples from new monitoring wells to the north and northeast of the FSDF.

As previously mentioned, two separate groundwater impacted areas exist in the FSDF area. One originating in the former pond area and one associated with well RD-21 (due to the presence of carbon tetrachloride), physically located upgradient of the FSDF. The source for the contamination at RD-21 is not known.

Another source of perchlorate may have been located south of the former concrete pool north of H Street. A 20-foot by 50-foot area of soil was excavated to bedrock to remove perchlorate contamination in a circa 2000 interim remedial measure. The source of perchlorate in well RD-54A is uncertain and may have resulted from disposal of the chemical in the former ponds. In 2014, 2015, and 2016, the only detection of perchlorate in the FSDF area was in RD-21, upgradient of the FSDF and adjacent to an interim action soil excavation.

5.3.3.7 Vertical Extent of Contamination

Cross-section of the geology for the FSDF area have been developed to show the relationship of geologic units, water table elevations, and TCE concentrations. The vertical extent of TCE contamination is illustrated in **Figure 5.3-2**. The results from deep bedrock wells indicate the vertical extent of TCE contamination may extend 200 feet or more into bedrock; however, the vertical extent is more likely limited to groundwater within the Upper Burro Flats and ELV members. And the monitoring well construction may of allowed for the downward migration into this deeper unit or the false indication of deeper groundwater contamination in a well open across multiple unites during sampling. Most groundwater samples collected from wells solely open in the Lower Burro Flats member are non-detect for TCE. This adverse condition of deep open boreholes should be remedied.

Groundwater metals contamination is shallow based on data for RS-54. None of the bedrock wells exhibit metals concentrations indicative of impacted groundwater originating from the former ponds.

5.3.3.8 Seeps Evaluation

Seep cluster SP-900A, SP-900B, and SP-900C is located downgradient of the FSDF (**Figure 5.3-1**). Each probe was sampled in 2014 and the samples were non-detect for VOCs. There was insufficient water in the seep probes to sample during the spring 2016 sampling event.

5.3.4 Fate and Transport

5.3.4.1 Conceptual Site Model

The information and data collected during the many investigations of the hydrogeologic conditions across the FSDF have been used to develop the CSM for the occurrence and migration of VOCs within both the Near-surface and Chatsworth Formation groundwater. The local VOC-impacted groundwater within the FSDF plume most likely originated from discharges to the ground surface (e.g., drum storage) and from the former FSDF treatment ponds. Of note, removal actions have eliminated contaminated soil and sediment to bedrock that comprised the original source of VOC to groundwater. Following historic removals, the area was backfilled with clean local fill soil.

VOC contamination at the FSDF occurs in the Near-surface and Chatsworth Formation groundwater. The Near-surface groundwater is precipitation perched in the partially weathered bedrock and alluvium (fill). The presence of Near-surface groundwater is dependent on the movement of vadose zone moisture toward the lower Chatsworth Formation water table.

The current source of contaminants to groundwater are residual VOCs entrained in the weathered and unweathered bedrock occurring as either water in open fractures or along bedding planes, or as porewater in the bedrock sandstone matrix. VOCs in open and interconnected fractures/bedding planes correspond to solute transport while VOC transfer from impacted porewater to water/groundwater corresponds to diffusion. Both processes are believed to be currently active at the FSDF.

The historical studies performed at the FSDF show that the vertical migration of water from the Near-surface system to the bedrock system is hindered by the low bulk hydraulic conductivity of the Chatsworth Formation as well as a general lack of a bedrock fractures and/or tight or less transmissive fractures within the FSDF, which is different within Area IV compared to Areas I, II, III of SSFL. Local alluvial soil (fill) and/or weathered Chatsworth Formation act as a water storage reservoir following precipitation events. The lateral extent of the VOC-impacted groundwater entrained in the alluvial soil changes as water levels rise (the plume expands outward) and fall (the plume contracts) in this zone. The plume's horizontal extent is controlled by presence if alluvium (thin and occurs as fingers between bedrock outcrops), the contact with low K_b bedrock members, and groundwater elevation.

The Near-surface groundwater is separated from the Chatsworth Formation groundwater by a vadose (unsaturated) zone. Contaminated groundwater migrates vertically and horizontally from the Near-surface system to the bedrock system, through fractures and bedding planes. Migration through the bedrock matrix is constricted by the low bulk conductivity of the bedrock matrix. Because the fractures and bedding planes are not continuous and the hydraulic conductivity is very low, extent of groundwater movement and therefore contaminant plumes movement is limited. The other limiting factor is the small amount of precipitation and associated infiltration that moves into the fractures/bedding planes to facilitates the transport VOCs away from their sources.

5.3.4.2 Numerical Flow Model Results

Chapter 6 provides a summary of the numeric modeling of contaminant transport at the FSDF. **Appendix C** provides the overall modeling report.

Monitoring well RD-23 was used as the modeling point to assess movement of VOCs in the FSDF area. **Figures 6-1 through 6-5** in Chapter 6 illustrate the modeling results. Figure 6-1 illustrates the particle track possibilities for contamination associated with RD-23 assuming there is no restriction on time. This figure shows an initial westerly flow prior to a northwesterly flow. **Figure 6-2** illustrates the relative rate of movement of groundwater based on the calibrated site-scale groundwater flow model for the FSDF area. Further, this figures illustrate the low bulk conductivity of the bedrock matrix that controls groundwater flow. **Figures 6-3, 6-4, and 6-5** illustrate how far from RD-23 VOC-impacted groundwater is expected to move over time when the release occurred over 20 years ago. The modeling results are consistent with groundwater sampling results for this location that show minimal movement of VOCs from its source since the release.

5.3.4.3 Contaminant Fate Analysis

Appendix D provides an assessment of contaminant attenuation at the FSDF. Groundwater sampling data for the FSDF location (see Appendix B) show that expected degradation products of 1,1,1-TCA (e.g., 1,1-dichloroethane) and TCE (e.g., cis-1,2-dichlorethene and trans 1,2-dichlorethene) are present. This indicates that some degree of degradation of 1,1,1-TCA and TCE is occurring. Vinyl chloride, although not observed in most samples over time, was observed in the GWIM sample results. The GWIM data demonstrate that complete dechlorination is likely occurring. In addition, because none of the degradation products are seen to be increasing in concentration (their ratios with the parent chemicals are remaining about the same over time), reduction in daughter product concentrations maybe more strongly influenced by dispersion and dilution factors than degradation.

5.3.4.4 Plume Stability Assessment

All of the hydrogeologic data for the FSDF indicate that the limited plume movement observed at this location of Area IV of SSFL is strongly controlled by bedrock properties. Non-fractured bedrock exhibits low transmissivity and existing fractures that allow for movement of contaminants are few and are not well interconnected. These factors significantly reduce vertical migration, with the primary contaminant source remaining in the upper bedrock. Fractures have allowed for some lateral movement from the primary source, but not a great distance (**Figure 5.3-1**). Based on the hydrogeologic properties, contaminants are not expected to move much further than where they are currently observed.

5.3.5 Uncertainties and Data Gaps

The source to Chatsworth Formation groundwater contamination by VOCs is found in bedrock fractures, primarily those less than 50 feet bgs. Packer testing has identified some deeper fractures with VOCs, but not at the same concentrations at in the near-surface fractures. Coring and soil gas sampling of the FSDF area indicates that the primary locations with fractures harboring VOCs are found to the west and south of well RS-54. As part of remedy design, additional bedrock coring may be necessary to identify the locations and extent of fractures with VOC impacted groundwater. Metals appear to have impacted only the fractures in the area of the lower FSDF pond. Continued sampling for metals will be needed to confirm metals distribution.

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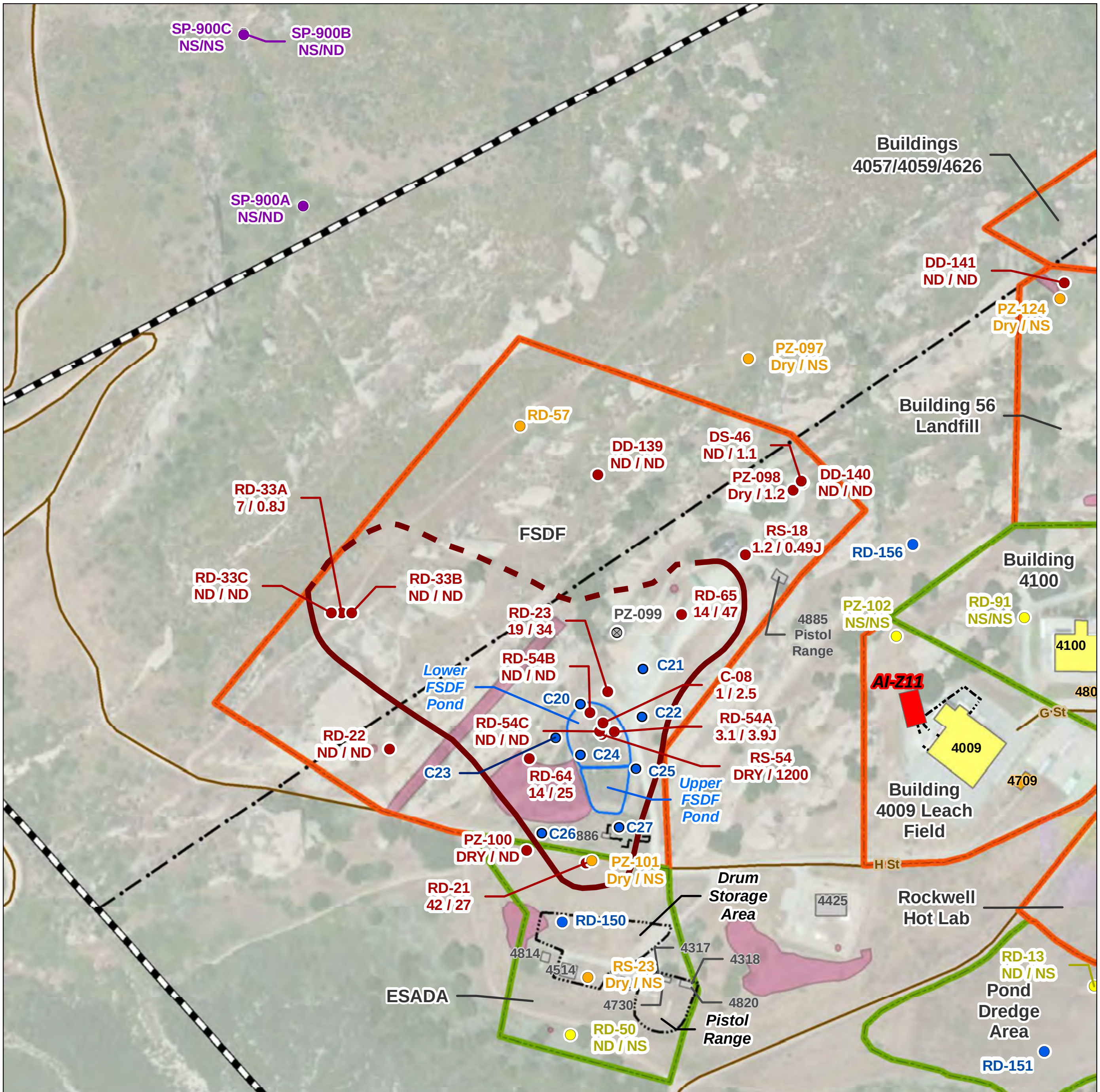


LEGEND

- Sampled Well
- Dry well or insufficient water for purging/sampling (<3 feet of water in well designated for low-flow purging)
- Not Sampled
- Abandoned Well
- Boeing Well
- Seep Well
- TCE at 5 ug/L
- Former Concrete Pool
- Road Centerline
- Former FSDF Pond

Chemical Use Areas
- Debris

Responsibility*
- AI-Zxx Boeing
- AI-Zxx DOE

Groundwater Investigation Area
- Boeing
- DOE
- Existing Structure

- Existing Substation
- Demolished Structure
- SSFL Property Boundary
- Area IV Boundary

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).
- Plume boundary dashed where inferred.
- 2016/2017 TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

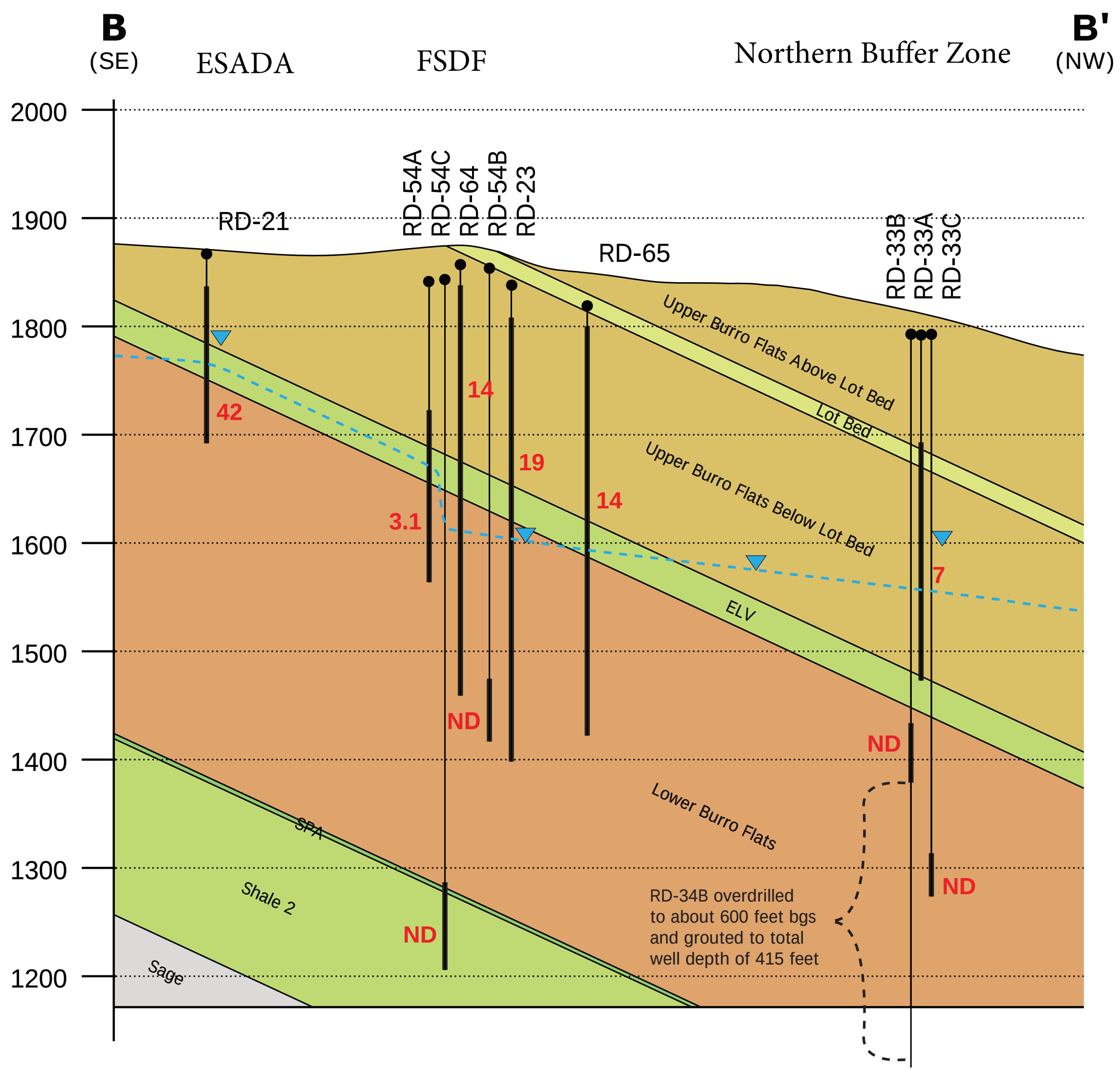
N

0 150 300 Feet

C:_projects\SantaSusana\GIS\MXD\Groundwater\RI\2018\SSFL_GWRI_FSDF_Layout_20180824.mxd 8/24/2018

CDM Smith

FIGURE 5.3-1
Former Sodium Disposal Facility (FSDF) Layout



Cross section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross section shows topographic surface along the cross section line. Monitoring wells may appear above or below the topographic surface depending on relationship of the well to the cross-section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1,800 elevation in feet above mean sea level.

42 Trichloroethene (TCE) reported in micrograms per liter (µg/L) in 2016.

Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 600ft

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CDM Smith

FIGURE 5.3-2
Cross Section of FSDF

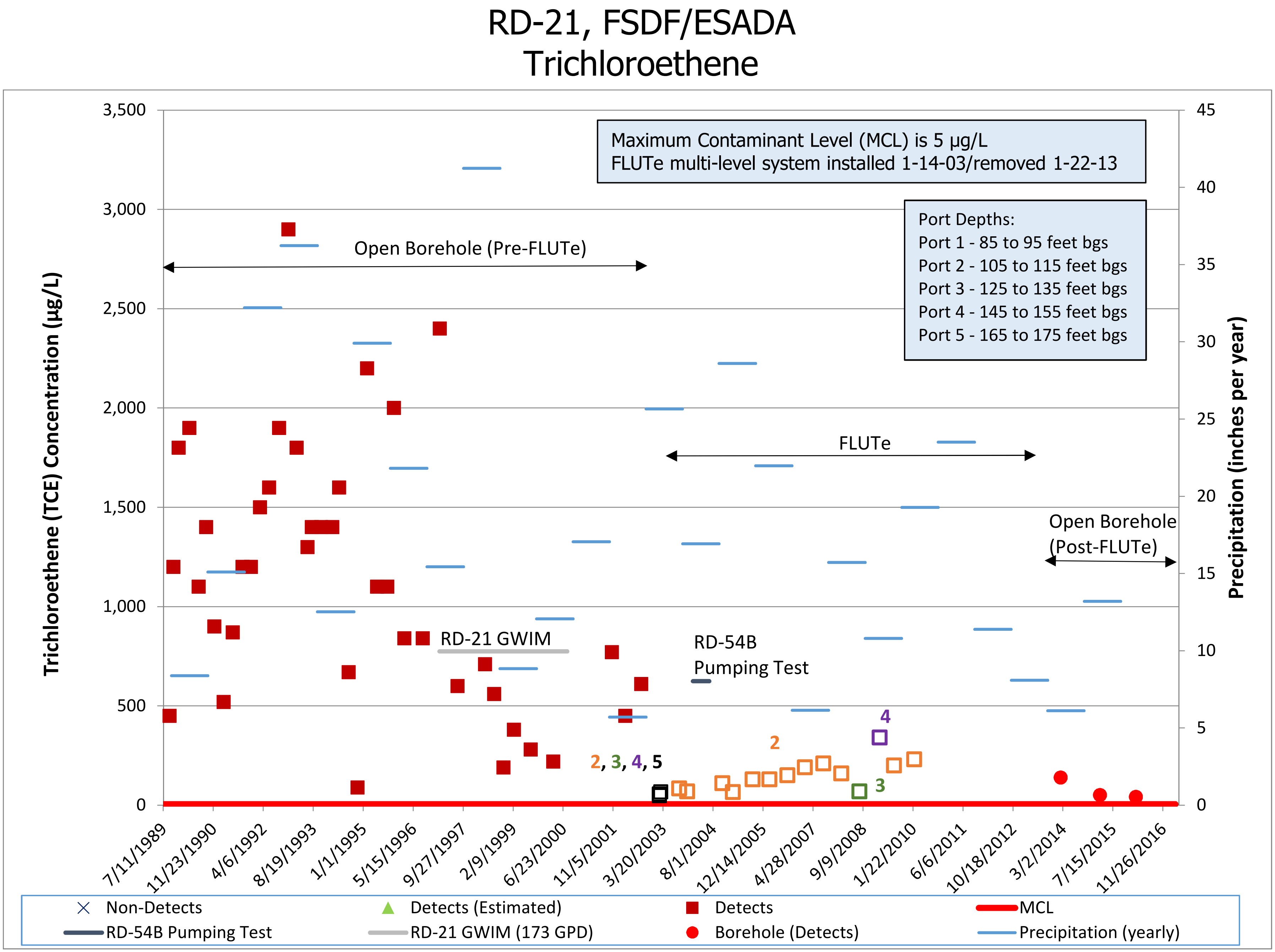


Figure 5.3-3
RD-21, TCE Concentrations in Groundwater

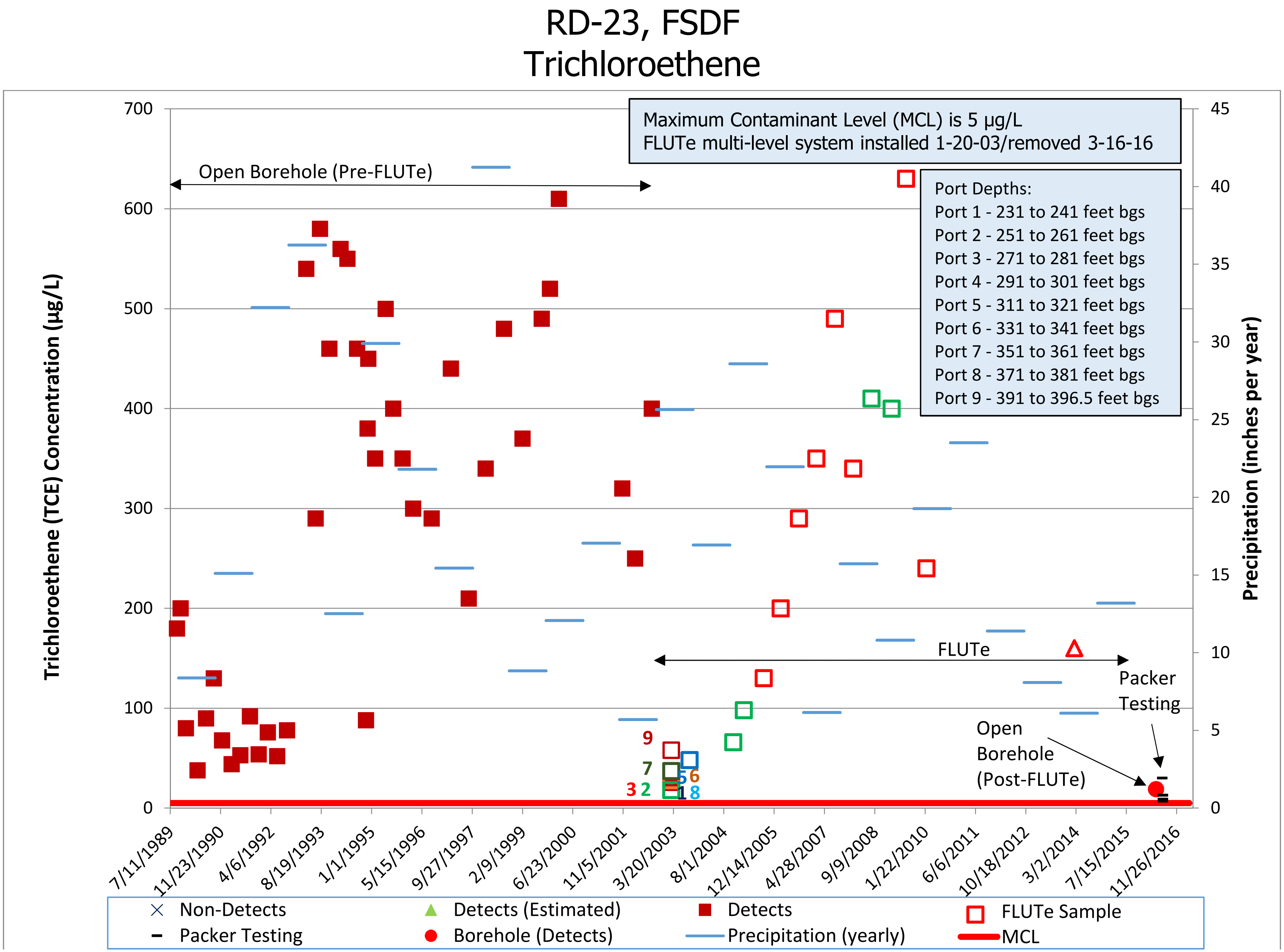
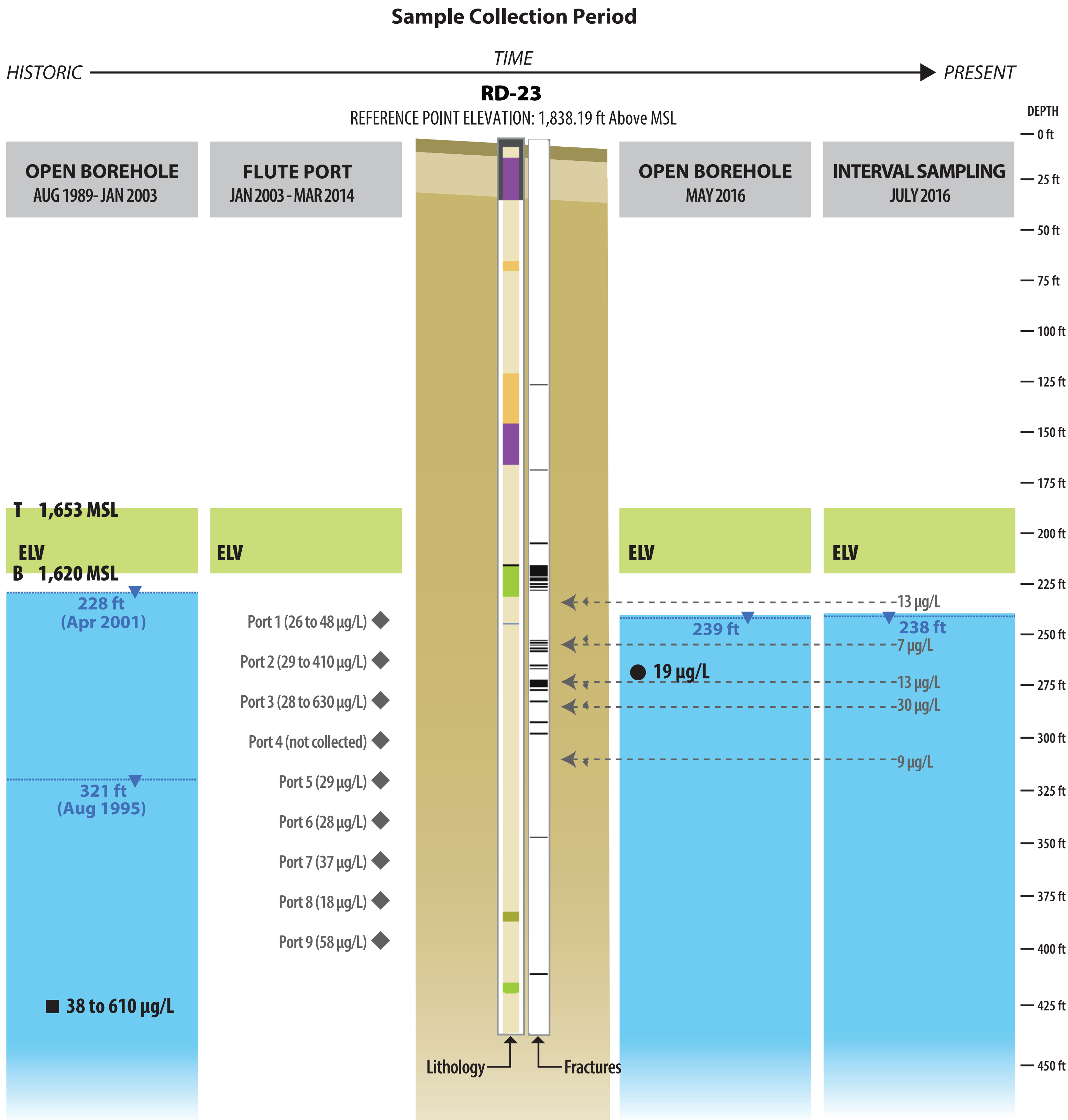


Figure 5.3-4

RD-23, TCE Concentrations in Groundwater



NOTES:

- Water level in FLUTe ports are not presented. Saturated zone **(BLUE)** is the same as Open Borehole minimum depth for illustration purposes.
- Borehole lithologies and fractures are presented in Section 4.
- ELV member **(GREEN)** projected along Area IV strike approximately N63°E and dip 25 degrees to the northwest.
- Elevation in Feet Above Mean Sea Level (MSL) of Projected Contact (T = Top, B = Bottom)

FIGURE 5.3-5

RD-23, TCE in Groundwater Over Time

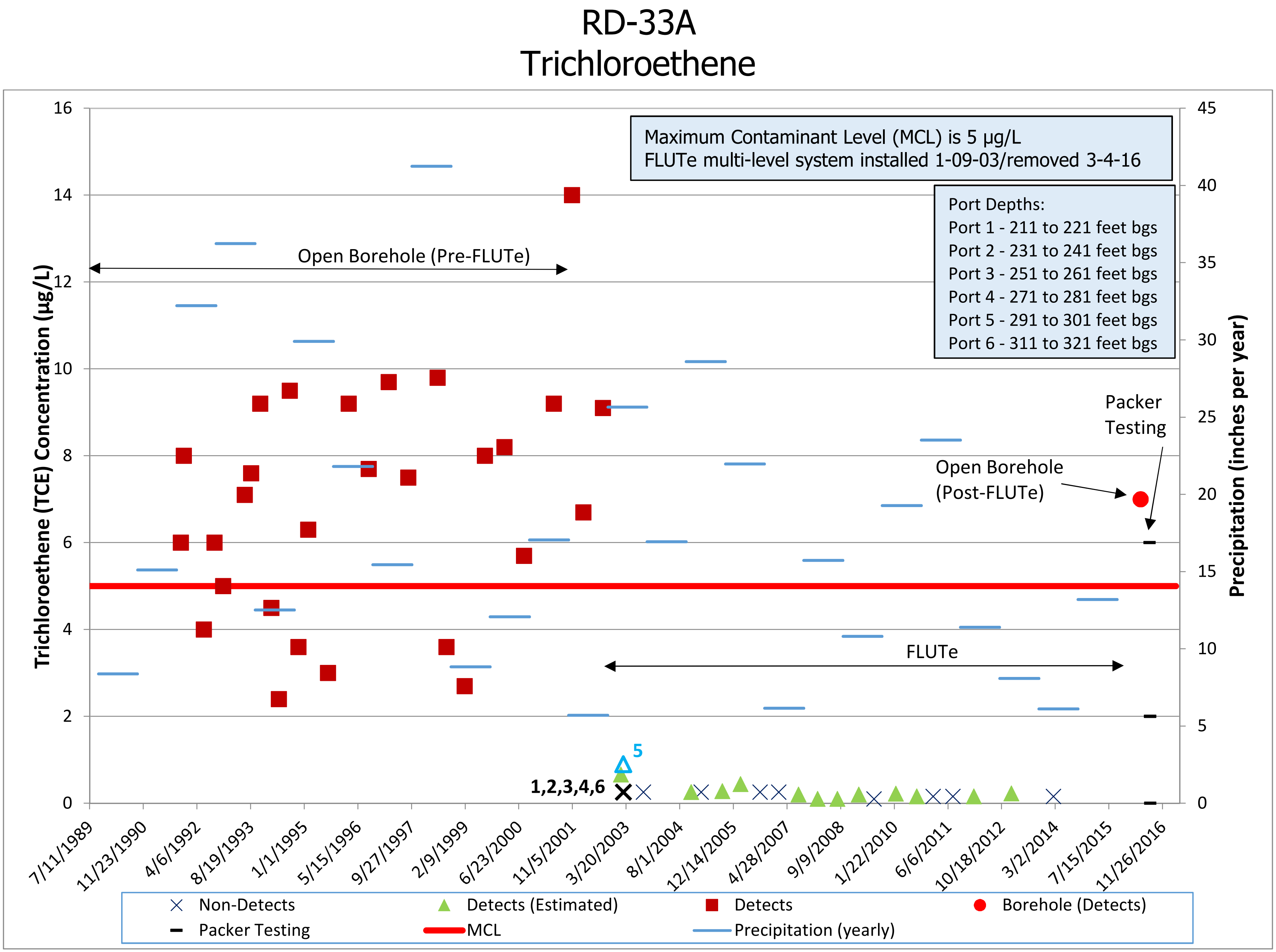
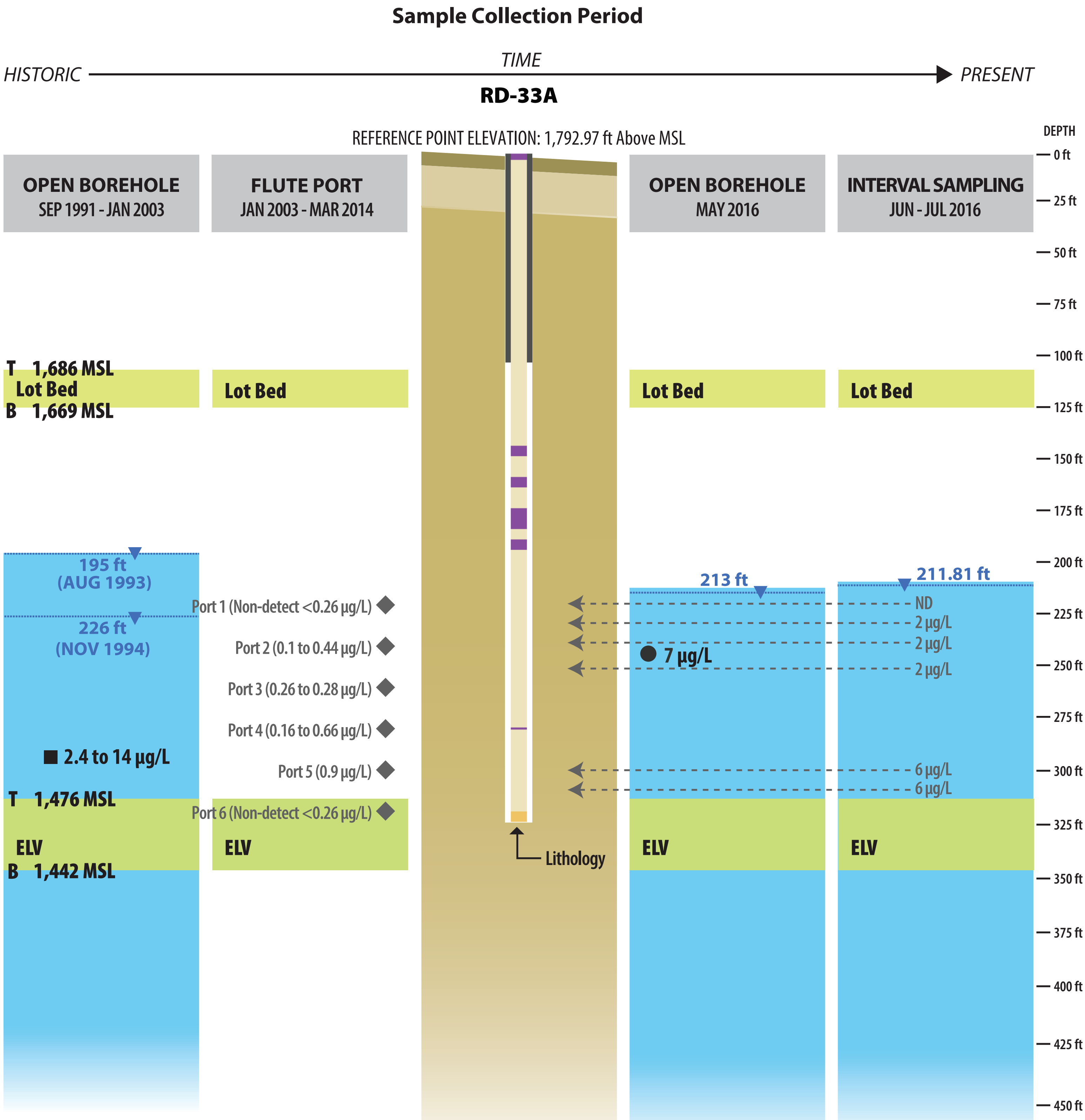


Figure 5.3-6

RD-33A, TCE Concentrations in Groundwater



NOTES:

- Water level in FLUTe ports are not presented. Saturated zone **(BLUE)** is the same as Open Borehole minimum depth for illustration purposes.
- Borehole lithologies and fractures are presented in Section 4.
- ELV member and lot bed **(GREEN)** projected along Area IV strike approximately N63°E and dip 25 degrees to the northwest.
- Elevation in Feet Above Mean Sea Level (MSL) of Projected Contact (T = Top, B = Bottom)

FIGURE 5.3-7

RD-33A, TCE in Groundwater Over Time

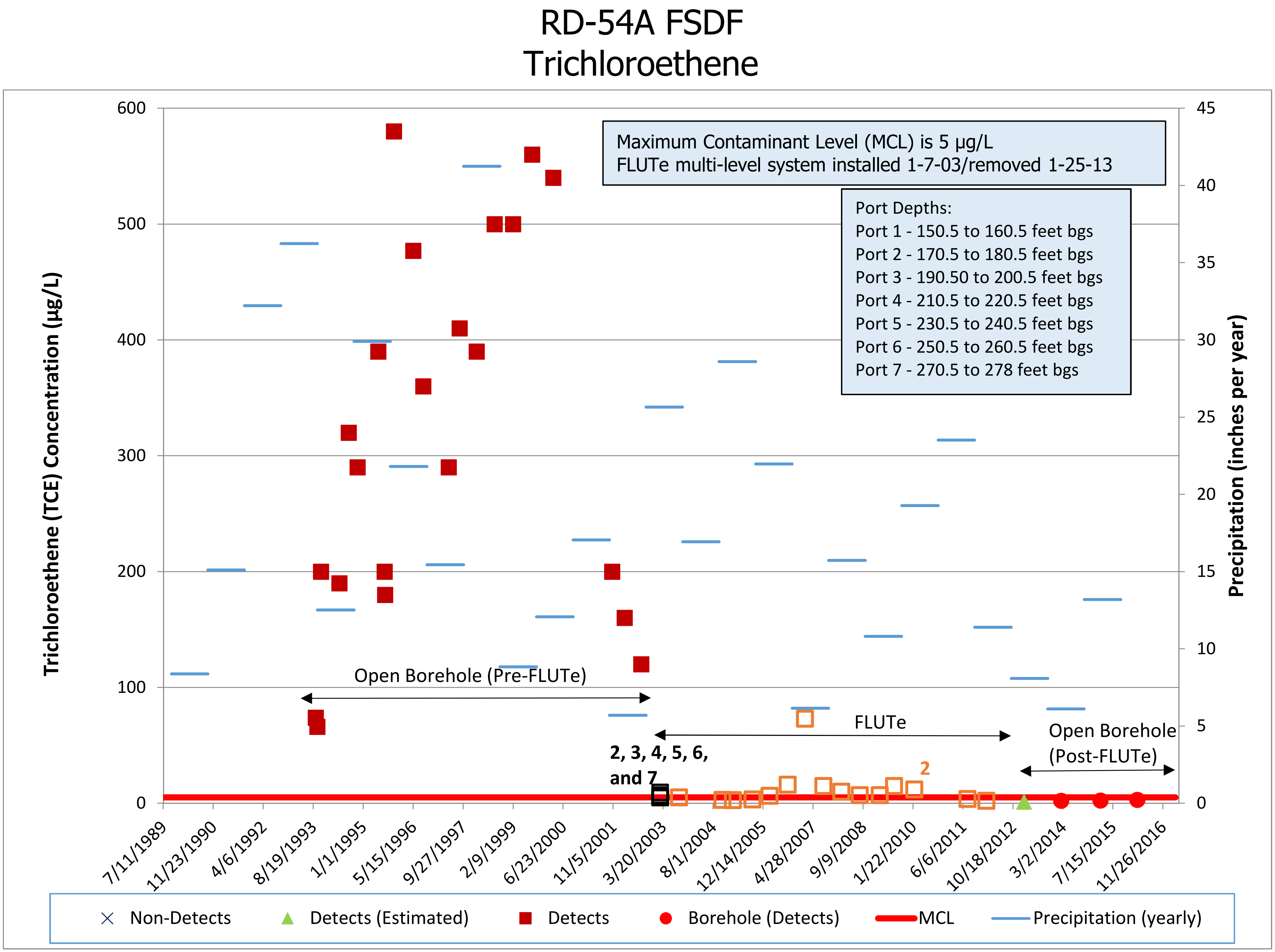


Figure 5.3-8
RD-54A, TCE Concentrations in Groundwater

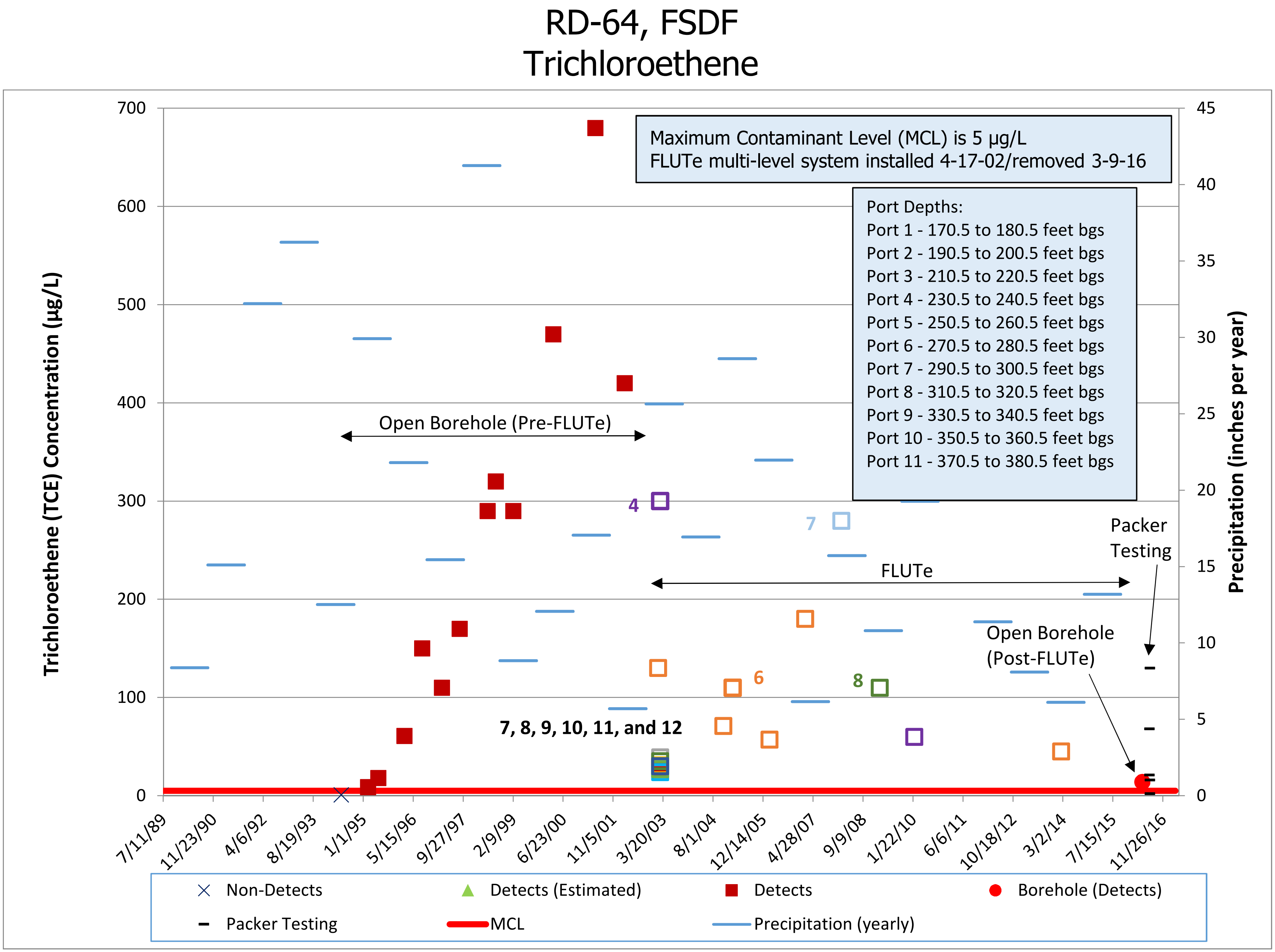
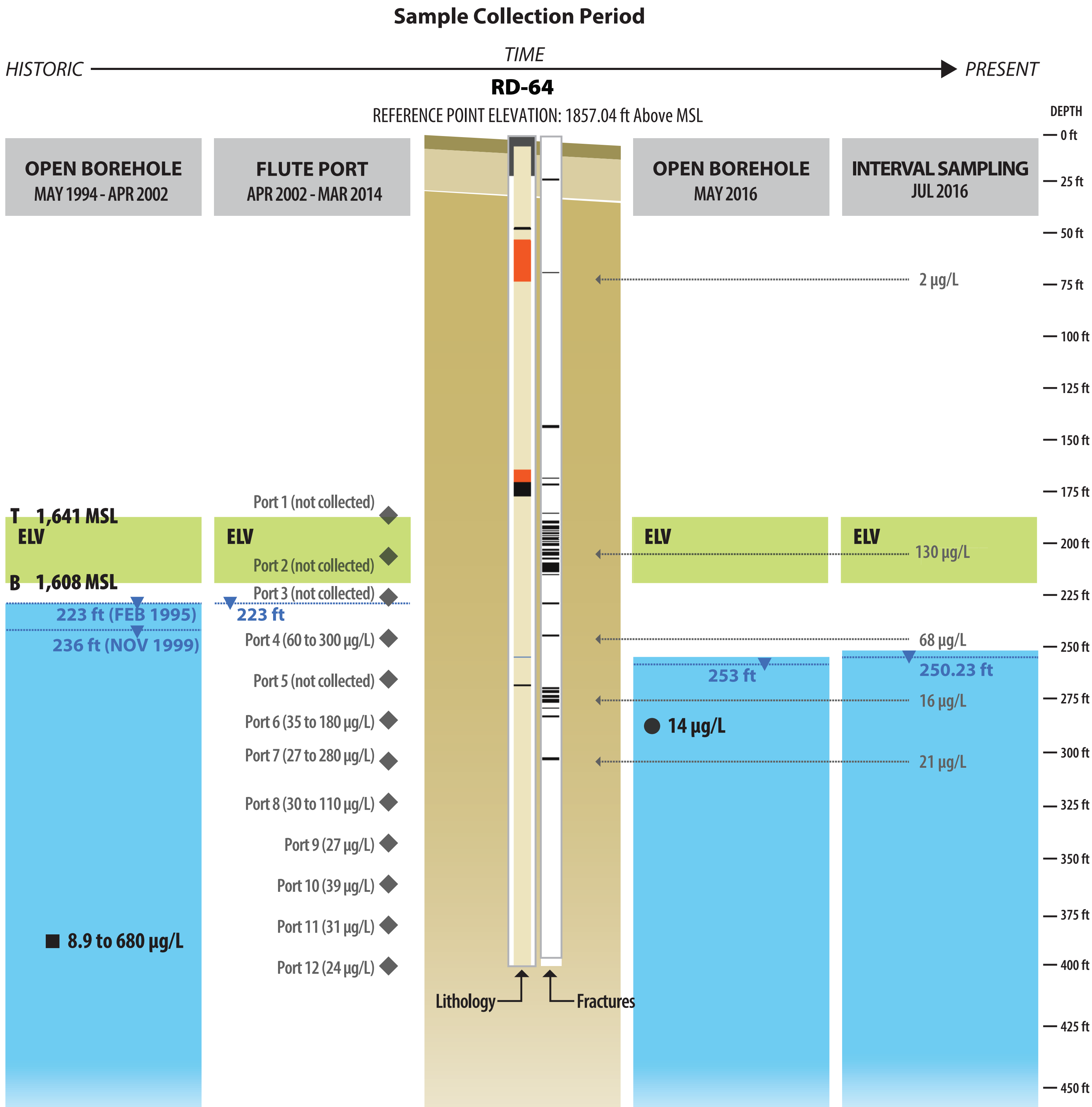


Figure 5.3-9

RD-64, TCE Concentrations in Groundwater



NOTES:

- Water level in FLUTe ports are not presented. Saturated zone **(BLUE)** is the same as Open Borehole minimum depth for illustration purposes.
- Borehole lithologies and fractures are presented in Section 4.
- ELV member **(GREEN)** projected along Area IV strike approximately N63°E and dip 25 degrees to the northwest.
- Elevation in Feet Above Mean Sea Level (MSL) of Projected Contact (T = Top, B = Bottom)

FIGURE 5.3-10

RD-64, TCE in Groundwater Over Time

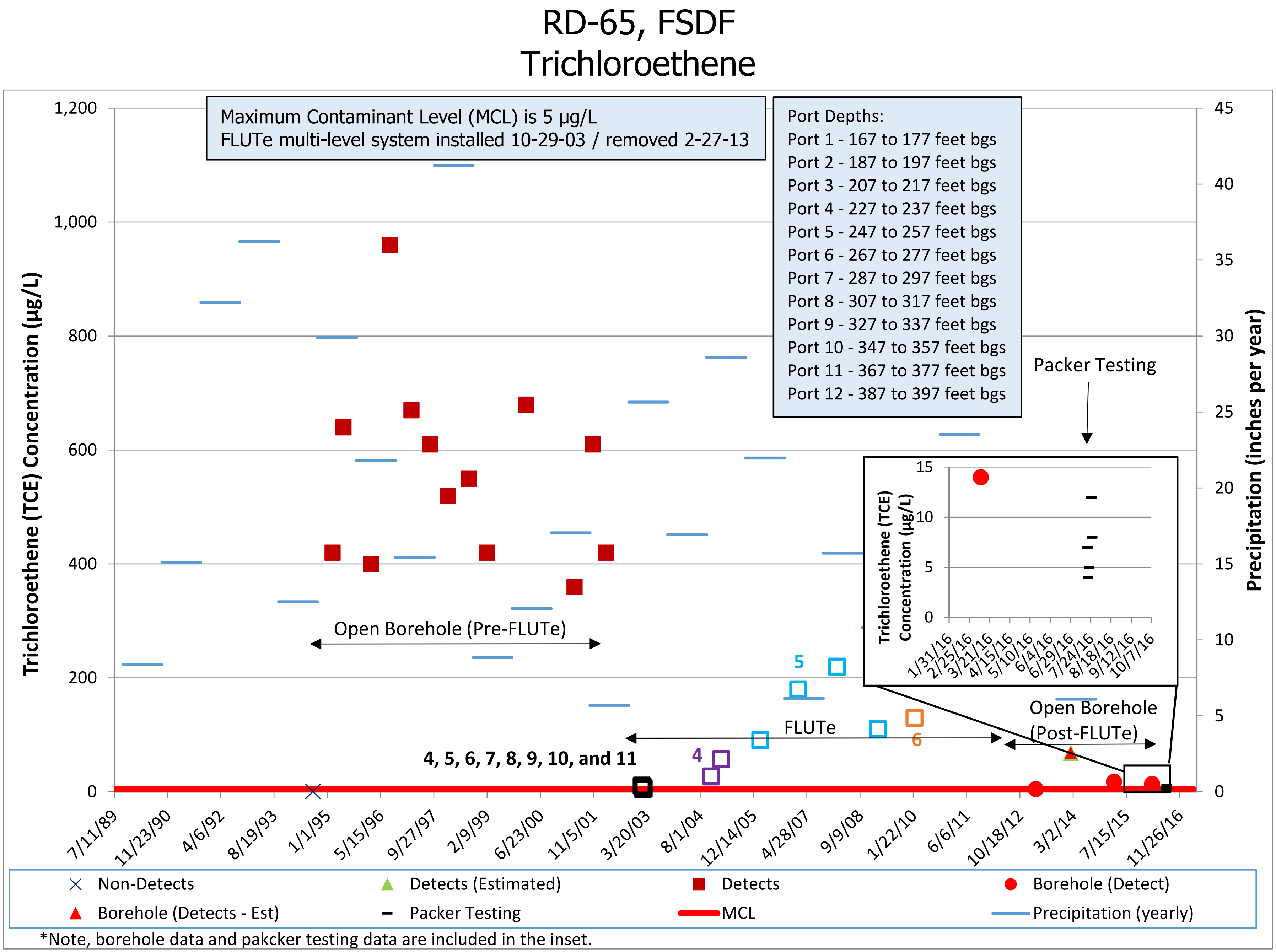
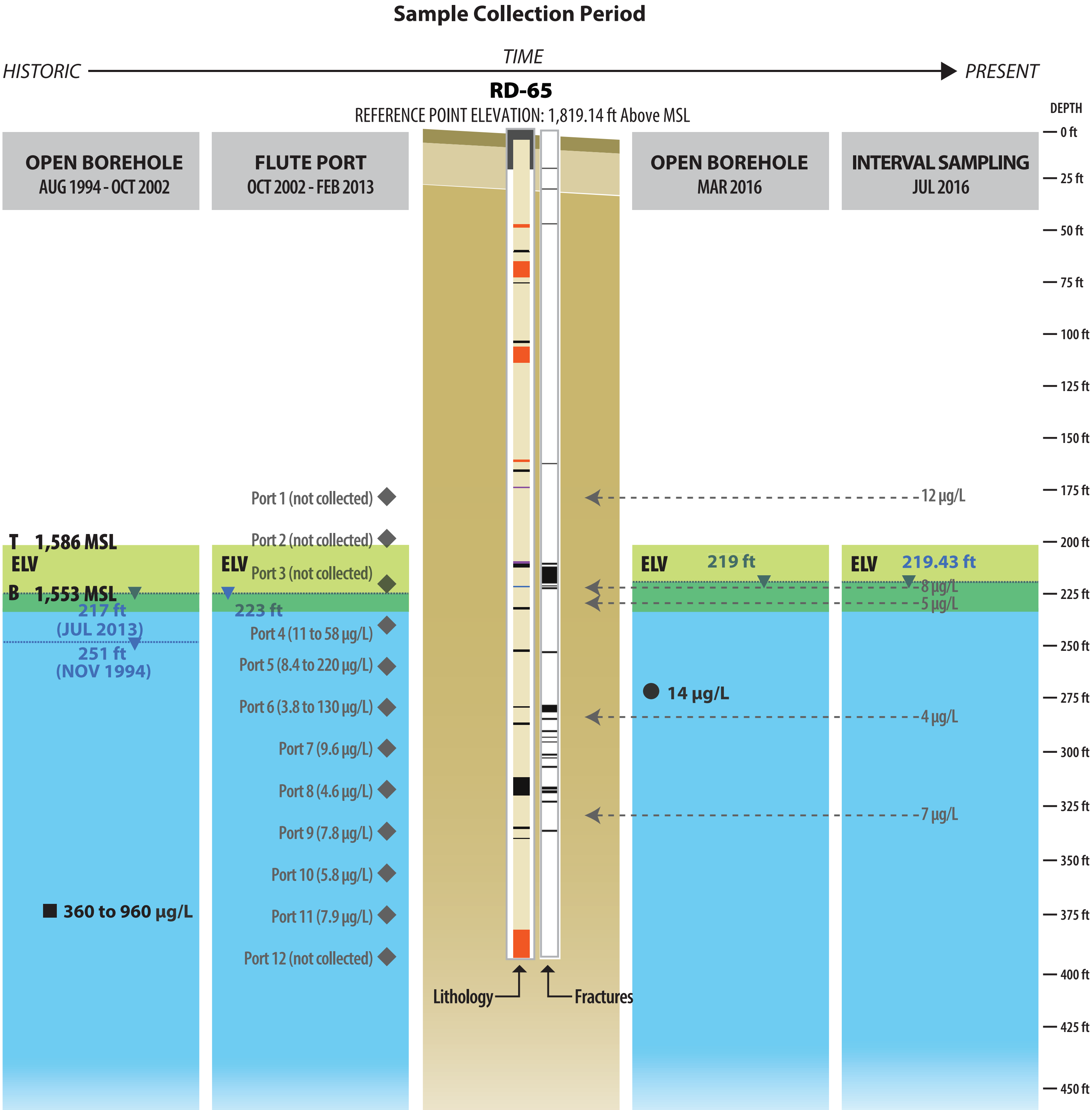


Figure 5.3-11

RD-65, TCE Concentrations in Groundwater



NOTES:

- Water level in FLUTe ports are not presented. Saturated zone **(BLUE)** is the same as Open Borehole minimum depth for illustration purposes.
- Borehole lithologies and fractures are presented in Section 4.
- ELV member **(GREEN)** projected along Area IV strike approximately N63°E and dip 25 degrees to the northwest.
- Elevation in Feet Above Mean Sea Level (MSL) of Projected Contact (T = Top, B = Bottom)

FIGURE 5.3-12

RD-65, TCE in Groundwater Over Time

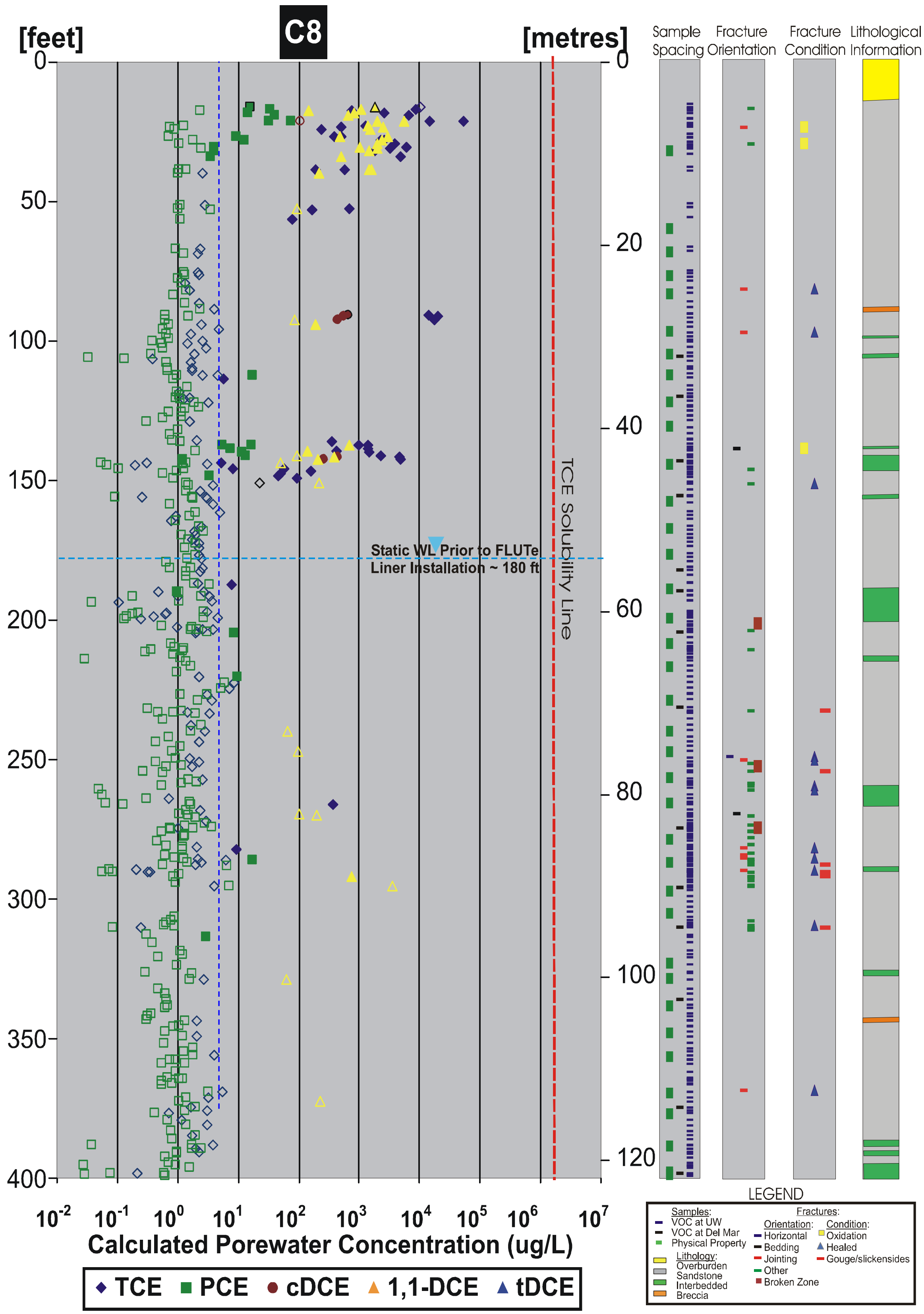


Figure 6. C8 (Former Sodium Disposal Facility) Source Area Profile of Chlorinated Ethene Porewater Concentrations

The dashed blue line represents the maximum TCE concentration in drinking water for the state of California. Open symbols represent values that are estimated (fall between the method detection limit and the method reporting limit) or samples that were qualified or samples that were qualified with a J flag according to the U.S EPA National Functional Guidelines for Organic Data Review (1999). Solid symbols represent quantitative values. Non-detects are not plotted.

Source: Report of Results, Former Sodium Disposal Facility, Groundwater Characterization: Appendix C, Nature and Extent of Chemicals in Environmental Media at the FSDF. (MWH, 2006)

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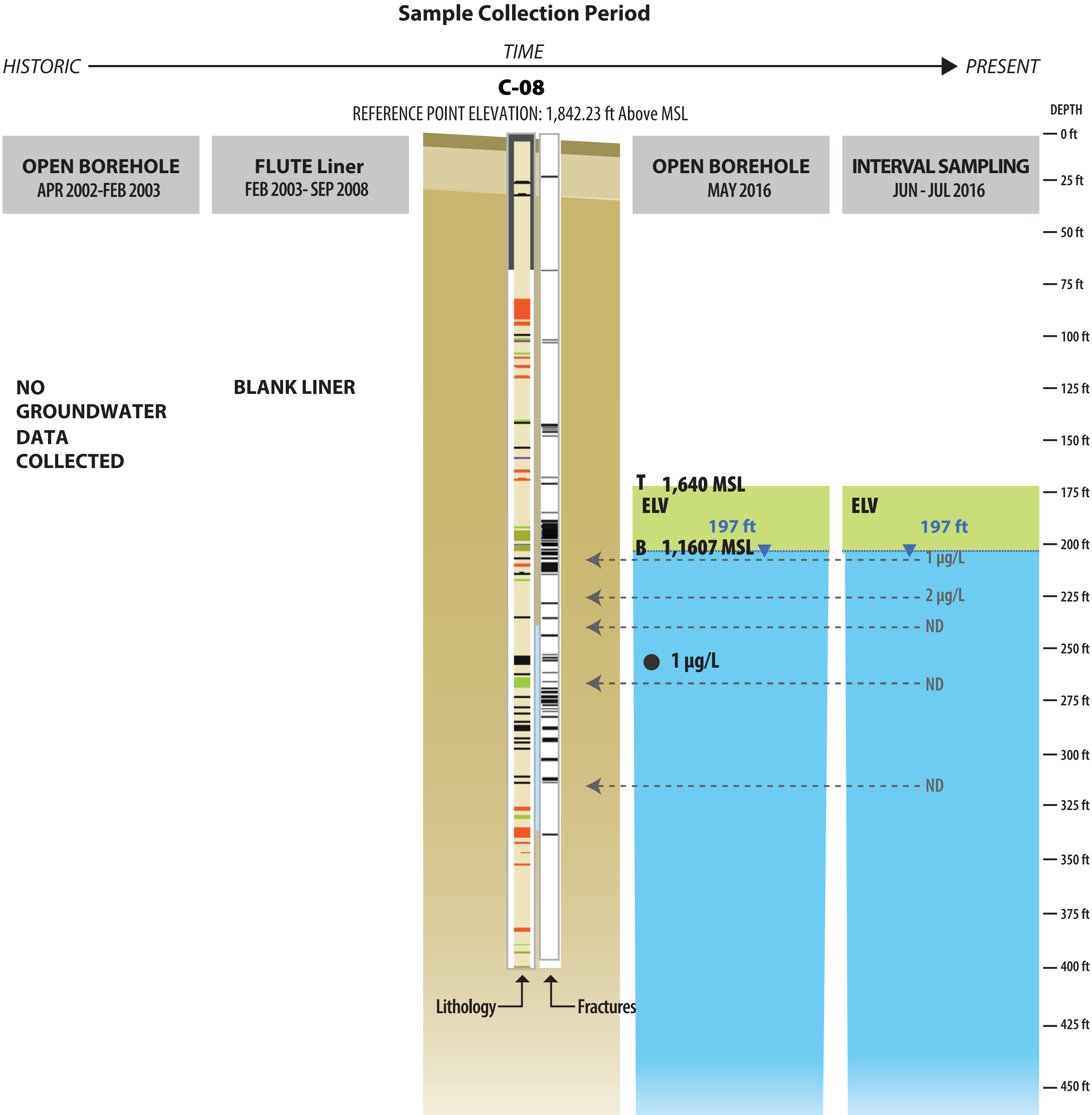
CDM Smith

FIGURE 5.3-13

C-08 Bedrock Core

Chlorinated Ethene Porewater Results



NOTES:

- Water level in FLUTe ports are not presented. Saturated zone **(BLUE)** is the same as Open Borehole minimum depth for illustration purposes.
- Borehole lithologies and fractures are presented in Section 4.
- ELV member **(GREEN)** projected along Area IV strike approximately N63°E and dip 25 degrees to the northwest.
- Elevation in Feet Above Mean Sea Level (MSL) of Projected Contact (T = Top, B = Bottom)

FIGURE 5.3-14

C-08, TCE in Groundwater Over Time

5.4 Building 100 Trench

The Building 100[4] Trench groundwater investigation area (**Figure 5.4-1**) is a small (less than 1-acre) property located about 250 feet east of Building 4100. A much larger (4.4-acre) area was investigated during the RFI (CH2M Hill 2008).

5.4.1 Source Area Evaluation

Operation History

The Building 100 Trench was used from 1960 through 1966 for burning and disposal of building debris. The trench had nothing to do with Building 4100 operations, but was labeled Building 100 Trench due to its close proximity to Building 4100. According to CH2M Hill (2008) there are no site records of the types of materials burned or placed in the trench. The site consisted of three elongated trenches (60 to 100 feet long, 20 to 40 feet wide, and 2 to 6 feet deep). The overall area measured approximately 100 feet by 100 feet. The trenches were filled and partially paved over in 1971. In 1988, Rocketdyne surveyed the trench area for gamma readings. The survey concluded that the gamma readings were sufficiently low that the area complied with unrestricted release criteria. Soil and soil vapor samples were collected in 1999 through 2001.

Soil and Debris Removal Actions

In 2003, 330 cubic yards of material (scrap metal, asbestos, and other debris) were removed from the former trenches and disposed of off-site. Soil samples collected following debris removal demonstrated no residual contamination. The trenches were backfilled with material from the Area IV borrow site (CH2M Hill 2008).

5.4.2 Soil, Geology, and Hydrogeology

Alluvial soils are less than 11 feet thick throughout the groundwater investigation area, and weathered bedrock is estimated to be about 30 feet thick. The ELV fine-grained member of Sandstone 2 subcrops out beneath the trenches and dips to the northwest intersecting RD-20 at a depth of about 26 to 28 feet bgs as indicated by thick "claystone" beds at that depth (Groundwater Resources 1995c). As shown on **Table 3-1**, the ELV is projected to be present from 0 to 22 feet bgs at RD-20.

During the excavation of debris, groundwater was not observed in the trench. The nearest Near-surface well (PZ-103) is located 300 feet south of the Building 4100 Trench area. Historically, Near-surface groundwater occurred at a depth of about 23 feet bgs.

5.4.3 Nature and Extent of Contamination

During the RFI (June 1995 to June 2008), investigators sampled soil and soil vapor. VOCs were not detected in soil or soil vapor samples. Semi-volatile organic compounds (SVOCs) and TPH were reported at concentrations in soils at less than their respective risk-based screening levels (RBSLs) (CH2MHill 2008).

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[4] Through most of the period of operations within Area IV, structures were numbered using a three-digit format (e.g., 123). Towards the end of operations, the number 4 was added to the structure number to differentiate buildings among the four areas of SSFL. The Building 100 Trench was named prior to adding the fourth number.

In 2014, MWH (2014b) collected three soil vapor samples (5CSV_DG-530, 5CSV_DG-531, and 5CSV_DG-572) near the former trench and all results were non-detect for key COCs (**Appendix E**).

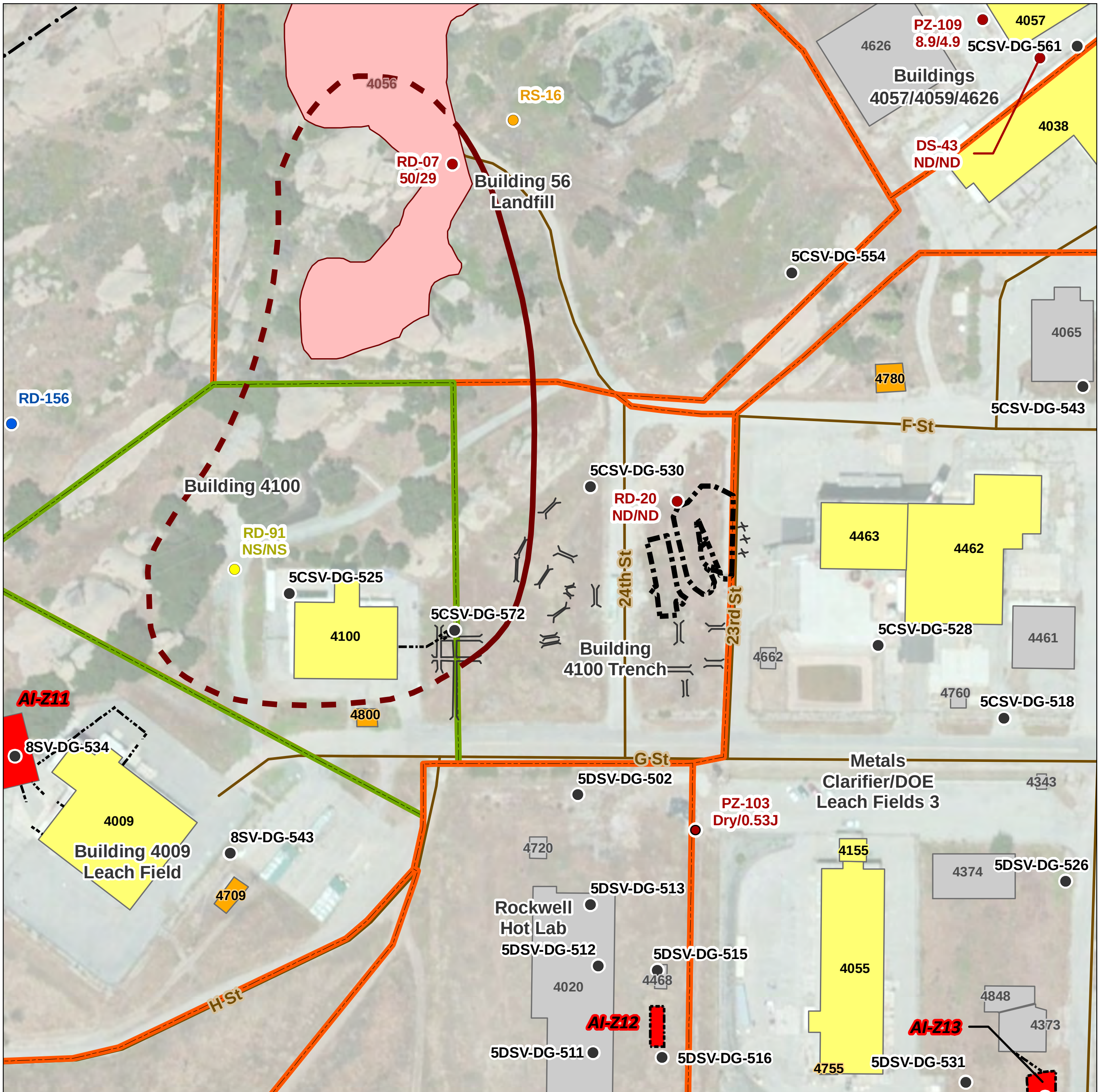
Bedrock well RD-20 was installed in July 1989 at the location of the former trench. RD-20 is a 127-foot deep bedrock corehole, cased from the ground surface to 30 feet bgs. This well has been sampled 26 times (including 2016) since installation. TCE was detected in one sample at 0.21 µg/L (1990) and has been non-detect since (including samples collected in 2016, 2017, and 2018). TCE is the only VOC reported for RD-20 (**Appendix B** data tables).

Metals including lead, barium, selenium, copper and zinc were reported in soil above site background concentrations (CH2MHill 2008). However, selenium was the only metal observed in a groundwater sample from RD-20, at 2.8 µg/L slightly above its screening level of 1.6 µg/L.

Based on these findings, including removal of buried construction debris, no soil contamination, and no evidence of impact to groundwater, there is no further discussion of the Building 100 Trench groundwater investigation area in this report.

5.4.4 Uncertainties and Data Gaps

There are no uncertainties or data gaps associated with the Building 100 trench groundwater investigation area. Sampling for antimony and lead should continue in RD-20 to confirm any metals impact.



LEGEND

- Sampled Well
- Dry well or insufficient water for purging/sampling (<3 feet of water in well designated for low-flow purging)
- Not Sampled
- Abandoned Well
- Boeing Well
- Soil Vapor Location
- TCE at 5 ug/L
- Road Centerline
- RFI Soil Investigation Trench
- B100 Trench Outline

Groundwater Investigation Area
- Boeing
- DOE

Responsibility*
- AI-Zxx Boeing
- AI-Zxx DOE
- Existing Landfill

- Existing Structure
- Existing Substation
- Demolished Structure
- Area IV Boundary
- SSFL Property Boundary

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).
- Soil Vapor Data Gap locations provided by MWH (2014).
- 2016/2017 TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

N

0 75 150 Feet

C:_projects\SantaSusana\GIS\MXD\Groundwater\RI\2018\SSFL_GWRI_B100_Trench_Layout_20180824.mxd 8/24/2018

CDM Smith

FIGURE 5.4-1
Building 4100 Trench Layout

5.5 Building 56 Landfill

The Building 56 Landfill groundwater investigation area includes a 4-acre rock, soil, and construction debris landfill located south and west of the basement excavation at Building 56[5]. The basement excavation is the source of much of the landfilled rock and soil. The groundwater investigation area (**Figure 5.5-1**) includes the landfill area, the Building 56 basement excavation, and associated groundwater monitoring wells RS-16, PZ-124, RD-07, RD-74, and DD-141. RD-07 and DD-141 were the only wells recently sampled within the investigation area. TCE was present in RD-07 at concentrations of 52 µg/L in 2013, 57 µg/L in 2014, 56 µg/L in 2015, and 50 µg/L in 2016, and 29 µg/L in 2017. No VOCs were reported for well DD-141 in 2016, 2017 ,and 2018 groundwater samples.

5.5.1 Source Area Evaluation

Operation History

The Building 56 Landfill site was not used as a typical excavation and fill landfill, but was used to fill surface depressions and drainages with a variety of materials. Use of the site as a landfill originated in the 1960s for the placement of excavated bedrock from construction of the basement of Building 56. Today this excavation is a circular vertical pit extending approximately 65 feet into the bedrock. Within the landfill area proper, a Southern Debris Area had been used for disposal of other materials. Per the Group 8 RFI Report (MWH 2007) use of the landfill for disposal of building debris continued to the late 1970s. Materials deposited included asphalt, concrete, and scrap metal generated during the initial construction phases of Building 56, located east of the landfill.

The landfilled materials, including those in the Southern Debris Area, were placed in topographic lows, filling depressions in the topography resulting in a relatively flat surface. In the mid-1970s drums of waste (including grease, oils, alcohols, sodium, sodium reaction products, phosphoric acid, asbestos rags, and rope) were stored on the flat ground surface in the middle part of the landfill. Drums were also noted at the base of a ravine along the western edge of the Southern Debris Area.

Soil and Debris Removal Actions

The drums of wastes were removed in the early 1980s. Other building materials including asphalt, concrete, and scrap metal remain onsite.

5.5.2 Soils, Geology, and Hydrogeology

Natural alluvial soil is about 8 feet thick throughout the landfill area. Fill soil in the northern landfill area range from less than 1 foot to 25 feet thick. In the Southern Debris Area, fill soil ranges between 1 foot and 14 feet thick. A mound of soil, created for a ramp used during excavation of the Building 56 basement, is located on the east side of the excavation. Some metal debris was observed in the bottom of the excavation when the pit was dewatered in 1999 as part of the effort to lower the groundwater near former Building 4059.

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[5] Building 56 was never constructed. The project it was designated for was cancelled shortly after the basement excavation was completed.

The Building 56 Landfill groundwater investigation area sits on the Upper Burrow Flats member of the Chatsworth Formation (**Figure 5.5-2**). The ELV fine-grained member of Sandstone 2 is projected to intersect RD-07 at a depth of 167 to 200 feet bgs. Harding Lawson Associates (1995) conducted focused geologic mapping in the groundwater investigation area and determined that beds strike at N45˚E and dip 35˚ to the northwest. Two predominant fracture sets were mapped – one striking northeast and dipping to the southwest and the other striking north-northwest and dipping to the northeast. Both of these sets of fractures cut across bedding planes; however, acoustic televiewer logs of well RD-07 indicate that some fractures are parallel and co-incident with bedding planes (Harding Lawson 1995).

Perched Near-surface groundwater was observed prior to 2012 in shallow monitoring well RS-16 (**Figure 4-1**), but the well has been dry since (**Figure 4-2**). RS-16 is located about 60 feet west of the Building 56 excavation and adjacent to bedrock well RD-07. Natural gamma geophysical logs of RD-07 indicate a relatively clay-rich stratigraphic unit at a depth of 15 to 25 feet (Harding Lawson 1995). The Near-surface groundwater is likely perched on this finer-grained material. Historically, water levels in RS-16 have been up to 60 feet higher than in RD-07 (MWH 2009) indicating that the Near-surface groundwater is not hydraulically connected to the underlying Chatsworth Formation groundwater. However, the Near-surface groundwater is hydraulically connected to the surface water in the excavation; RS-16 was dry during the 6-years from 1999 to 2004 that the excavation was actively dewatered (MWH 2007). When the adjacent Building 56 excavation was dewatered in 1999, lowering the water surface elevation in the excavation by 49 feet, RS-16 went dry. Near-surface groundwater has been observed sporadically in PZ-124.

The presence of Chatsworth Formation groundwater in the area of the Building 56 Landfill is shown in cross section on **Figure 5.5-2**. When pumping of RD-25 and RD-28 (located to the northeast of the Building 56 Landfill) began in 1999 to dewater the basement of Building 4059, a response (lowering of water levels) was observed in RD-07, indicating a hydraulic connection between RD-07 and one or both of those wells (Groundwater Resource Consultants [GRC] 1999a). However, dewatering of the Building 56 excavation pit did not impact water levels in RD-07, but did influence water levels in RD-74 (GRC 1999b).

Although there are strong downward vertical gradients between the Near-surface groundwater and the Chatsworth Formation groundwater, there are no data that document vertical gradients within the Chatsworth Formation. Packer testing of individual fracture zones indicates that the fractures are less conductive with depth (Harding Lawson 1995).

Additional packer testing of RD-07 was conducted on July 20, 2016 and is discussed below.

5.5.3 Nature and Extent of Impacted Groundwater

5.5.3.1 Groundwater Investigation Analytical Results

Near-Surface Well RS-16

Well RS-16 is a 20.5 foot deep well installed into the alluvium above bedrock. It is screened between 16.5 and 20.5 feet bgs. RS-16 was sampled in 1997, 1998, 2005, and 2008 for VOCs during years of above-average rainfall. No VOCs were detected in these samples. The well was sampled for metals once in 2008 and mercury was reported at 0.26 μg /L above the screening level (0.063 μg/L). The well has been dry since.

Near-Surface Well PZ-124

Well PZ-124 was drilled in March 2003 to 31 feet into the weathered bedrock. It is screened between 11.3 to 31 feet bgs. It was sampled once following installation in July 2011 and no VOCs were detected. The well has been dry since.

Bedrock Well RD-07

Well RD-07 is 300-foot deep and cased from ground surface to 25 feet bgs. The well was installed in January 1986 in the Chatsworth Formation. As shown in **Figure 5.5-3**, TCE was reported between 16 and 26 µg/L when the well was first sampled in 1986. Concentrations of TCE gradually increased to 77 µg/L in 2002. During this sampling period (pre-2002), low concentrations of TCE breakdown product *cis*-1,2-DCE were also increasing slowly to 5.6 µg/L (see **Appendix B** data tables).

In 2002, a FLUTe™ multi-port sampling system was installed in the open borehole of RD-07. The system had thirteen 10-foot long ports spaced evenly along the length of the borehole starting at a depth of 50 to 60 feet (**Figure 5.5-4**). A 10-foot long "blank" (where the borehole was sealed from sampling) was inserted between each port. The FLUTe™ ports were not set to correspond to fractures and the ports were not consistently sampled to provide useful groundwater data. The system was removed in January of 2013. Since removal, TCE concentrations have ranged 57 µg/L (2014 sample) to 29 µg/L in 2017, indicating a possible decrease in groundwater contamination in recent years.

Perchlorate was reported in this well in a 2003 sample collected after the FLUTe™ system was installed. Perchlorate was not detected in any sample from RD-07 collected after 2004.

Fractures with TCE contamination were identified in well RD-07 during packer testing (CDM Smith 2016b). The fractures are shown on the **Figure 5.5-4**.

Bedrock Well RD-74

Well RD-74 is 101 feet deep, and is cased from the ground surface to 30 feet bgs (**Figure 5.5-2**). It was installed in January 1999 and sampled three times that year for VOCs and metals. TCE was not detected in the three samples. It was not sampled again due to an obstruction (that turned out to be a sampling pump) lodged in the borehole. According to MWH (2007), the well is installed near a surface drainage and water levels may be influenced by surface water infiltration when the drainage has flowing water. With less than average rainfall in recent years, well RD-74 has been dry since October 2011 (including 2018). In 2016, an attempt was made to drill through the obstruction at 70 feet bgs. It was determined obstruction was a sampling pump that had become lodged in the well. The pump was pushed to the bottom of the well where it remains.

Bedrock Well DD-141

Well DD-141 is 133 feet deep, and is cased between ground surface and 19.5 feet bgs. Well DD-141 was installed in June of 2016 in the drainage at the toe of the Building 56 Landfill near piezometer PZ-124. It serves as an upper aquifer monitoring well. TCE was not detected in the groundwater samples collected from the well in July and October 2016, March 2017, and March 2018.

5.5.3.2 COC Identification

Five chemical use areas were identified at the Building 56 Landfill during the RFI (MWH 2007) (**Figure 5.5-1**). From these areas, a total of 205 soil samples and 95 soil vapor samples were collected. Various VOCs and perchlorate were detected in soil. TCE has been detected in groundwater samples, but not soil. Perchlorate has been observed sporadically in groundwater. Metals including lead, mercury, and selenium were reported above background values in the soil samples. Selenium was detected at 1.7 µg/L to 2.9 µg/L above its screening level of 1.6 µg/L in recent (2014-2016) groundwater samples for well RD-07. Nitrate has been reported at less than its screening level of 45,000 µg/L.

The chemical use areas are described below based on information presented in the Group 8 RFI Report (MWH 2007).

Building 56 Landfill (Chemical Use Area 1):

Thirty-seven soil samples were collected at the Building 56 Landfill site. Acetone was reported in three samples ranging from 1,520 to 5,000 µg/kg. Methylene chloride was reported in one sample at 23 µg/kg. The acetone and methylene chloride detections are likely the results of laboratory contamination and not actually present in the soil. VOCs were not reported in the other 33 soil samples collected from the landfill.

Thirty-six soil vapor samples were collected from this area and analyzed for VOCs including methane. Methane was detected in two soil vapor samples at a 7 and 12 feet bgs at a concentration of 10 µg/L. Other VOCs were not detected in any of the soil vapor samples.

Southern Debris Area (Chemical Use Area 2a):

Twenty-three soil samples were collected and analyzed for VOCs from this area. Trichlorofluoromethane (Freon 11) was reported at 900 µg/kg in one soil sample. Besides Freon 11 and four acetone were reported at concentrations ranging between 10 and 41µg/kg; no other VOCs were detected in soil.

A total of 16 soil vapor samples were collected and analyzed for VOCs and methane. Methane was reported in 10 soil vapor samples from 7 locations with concentrations ranging between 10 and 17 µg/L. VOCs were not detected in any of the soil vapor samples from this area.

Roadside Debris Area (Chemical Use Area 2b):

Samples were not collected from the Roadside Debris Area.

Building 56 Excavation (Chemical Use Area 3a):

Seven soil samples were collected and analyzed from this area and VOCs and perchlorate were not detected in any of the samples. Surface water samples from the Building 56 excavation pond collected by USEPA, RFI investigators and DOE did not indicate contamination (HGL 2012c). The pond is believed to be a surface expression of the water table as the excavation extends approximately 50 feet into bedrock.

Building 56 Excavation Debris Area (Chemical Use Area 3b):

Soil samples were not collected from the Building 56 Excavation Debris Area during the RFI.

MWH performed an additional soil vapor investigation during the summer of 2014 within Area IV (MWH 2014b), with one sample being collected near the Building 56 Landfill. VOCs were not reported for MWH soil vapor sample 8SV-DG-545 (**see Appendix E**).

5.5.3.3 Vadose Zone Mass Estimate

Based on soil and soil vapor data, there does not appear to a VOC source associated with the Building 56 Landfill. The source of the TCE in groundwater at RD-07 may be located upgradient of the landfill proper. The nearest possible source being the Building 4100 area.

5.5.3.4 Horizontal Extent of Contamination

The horizontal extent of TCE in groundwater at the Building 56 Landfill area is shown on **Figure 5.5-1**. The horizontal extent is defined by wells DD-141 and RD-96 to the north, DD-140 to the west, and DD-142 and DS-43 to the east of RD-07. Well RD-91 to the south has exhibited higher concentrations of TCE than RD-07 indicating that Building 4100 could be a source of TCE at the Building 56 Landfill area.

5.5.3.5 Vertical Extent of Contamination

Well RD-07 is the only well at the Building 56 Landfill. Well DD-141 at the toe of landfill has not exhibited TCE in samples collected in 2016, 2017, and 2018. Packer testing of the RD-07 in July 2016 indicated that the fractures producing the highest TCE concentrations were at a depth of approximately 120 feet bgs. The deepest fracture sampled in RD-07 at 280 feet bgs showed TCE at 6 µg/L. This sample was collected from below the ELV Member. **Figure 5.5-4** illustrates the depth profile for well RD-07.

5.5.3.6 Seeps Evaluation

Well cluster RD-59 northwest of the Building 56 Landfill produces groundwater under artesian conditions – flowing water at the surface. TCE has not be detected in groundwater samples collected in the RD-59 well cluster or other shallow groundwater monitoring wells further downgradient of the Building 56 Landfill.

5.5.4 Fate and Transport

5.5.4.1 Conceptual Site Model

The TCE has been consistently detected in well RD-07, starting with 16 µg/L in January 1986, a maximum concentration of 130 µg/L in December 1987, and most recently in 2018 at 29 µg/L. The highest concentration observed since 1987 was in March 2000 at 81 µg/L. No source for TCE has been identified at the Building 56 Landfill, including the Building 56 excavation and the Southern Debris Area. Soil and soil vapor samples have been collected and no TCE has been detected in those samples (MWH 2007).

The contaminant profile for TCE in RD-07 is different from other monitoring wells in Area IV. The higher concentrations are not within the upper bedrock but deeper in the well. This indicates that the TCE present in RD-07 may have moved laterally in fractures from an adjacent source location and not vertically downward from the landfill site.

The association of higher concentrations of TCE and bedding features and fractures indicates that the contaminant source is likely upgradient and along geologic strike from well RD-07. Based on the 2013 groundwater elevation data, groundwater flows from well RD-91 (1,740 feet MSL) located at Building 4100, toward RD-07 (1,728 feet MSL). Well RD-91 exhibited TCE at 200 µg/L in 2014 and is located approximately 450 feet to the southwest of well RD-07. Flow along bedding plane fractures from RD-91 to RD-07 may have been accelerated when wells RD-25 and RD-28 were pumped between 1996 and 2004, which temporarily lowered the water level in RD-07.

5.5.4.2 Numerical Flow Model Results

Monitoring well RD-07 was used as the modeling point to assess movement of TCE in the Building 56 Landfill area. Chapter 6 provides a summary of the numerical modeling of contaminant transport at the Building 56 landfill. Appendix C provides the overall modeling report. **Figures 6-6** through **6-10** illustrate the modeling results**. Figure 6-6** illustrates the particle track possibilities for groundwater movement from well RD-07 assuming there is no restriction to the time period. This figure shows a northwesterly flow of groundwater. **Figure 6-7** illustrates the relative rate of movement of groundwater based on the calibrated site-scale groundwater flow model at the Building 56 Landfill area. The figure illustrates the low simulated flow rate and bulk conductivity of the bedrock that controls contaminant transport, particularly within about 100 meters (330 feet) of the assumed source**. Figures 6-8, 6-9, and 6-10** illustrate how far from TCE from well RD-07 TCE is expected to move over time (the release occurred over 20 years ago). The modeling results are consistent with groundwater sampling results for this location showing little movement of TCE from the Building 56 Landfill.

5.5.4.3 Contaminant Fate Analysis

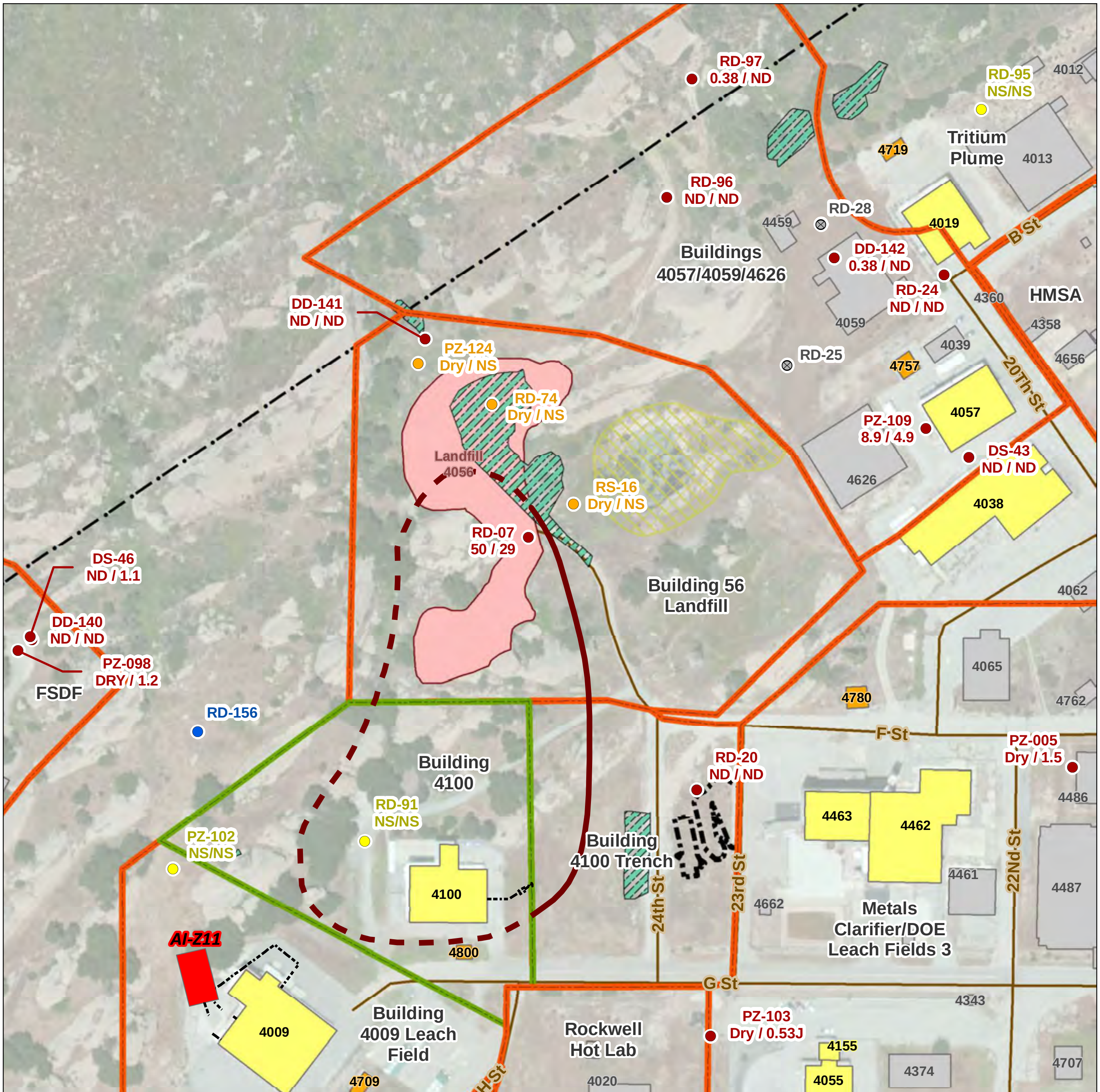
Appendix D provides a brief assessment of attenuation of TCE in RD-07. Cis-1,2-DCE, a common degradation product of TCE, has been consistently observed in samples from RD-07 since 1986. In a closed system, the TCE concentrations in well RD-07 would ultimately be reduced; however, TCE concentrations in well RD-07 have remained constant suggesting TCE continuing to migrate from an upgradient source. Ultimately, addressing TCE in the upgradient source is expected to reduce TCE concentrations at the Building 56 Landfill.

5.5.4.4 Plume Stability Assessment

All data collected for wells surrounding the Building 56 Landfill indicate that the plume front is stable and has not migrated far from the RD-07 location.

5.5.5 Uncertainties and Data Gaps

The source to Chatsworth Formation groundwater contamination observed in well RD-07 does not appear to have originated at the landfill. The closest well with elevated concentrations of TCE is well RD-91 at Building 4100. Soil gas at the Building 4009 leach field was sampled in 2018 with no detections of VOCs. The specific source for the VOCs in RD-07 remains a data gap. Sampling for mercury should continue.



LEGEND

- Sampled Well
- Not Sampled
- Road Centerline
- Building 56 Excavated Area
- Existing Landfill
- Area IV Boundary
- Dry well or insufficient water for purging/sampling (<3 feet of water in well designated for low-flow purging)
- Abandoned Well
- Boeing Well
- TCE at 5 ug/L
- **Responsibility***
  - Boeing
  - DOE
  - B100 Trench Outline
- Debris Area
- **Groundwater Investigation Area**
  - Boeing
  - DOE
- Existing Structure
- Existing Substation
- Demolished Structure
- SSFL Property Boundary

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).
- Plume boundary dashed where inferred.
- 2016/2017 TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

N

0 100 200 Feet

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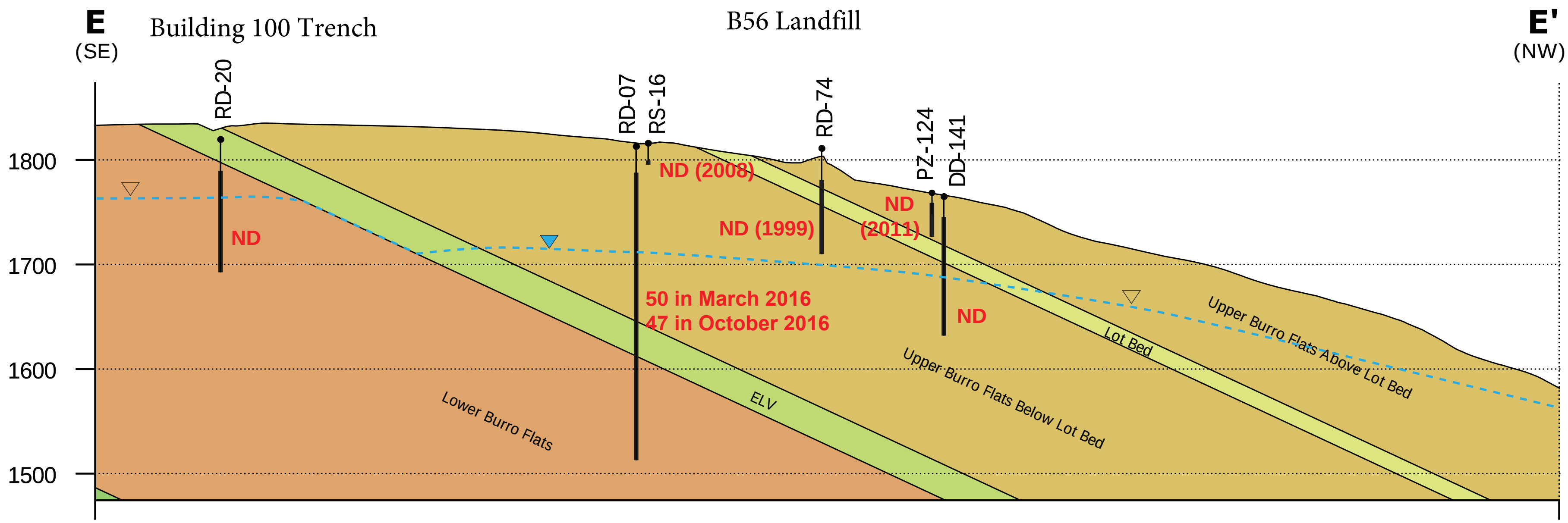
FIGURE 5.5-1
Building 56 Landfill Layout



Cross-section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross-section shows topographic surface along the cross section line.

Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross-section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

50 Trichloroethene (TCE) reported in micrograms per liter (ug/L)

Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 100ft

C:\Users\huseke\Documents\01TEMPforPROJECTS\SSFLtemp\Boreholes\newTemplate\SSFL_GWRI_Template_letter_KH.mxd 12/22/2016

CDM Smith

FIGURE 5.5-2

Vertical Extent of TCE Contamination at Building 56 Landfill

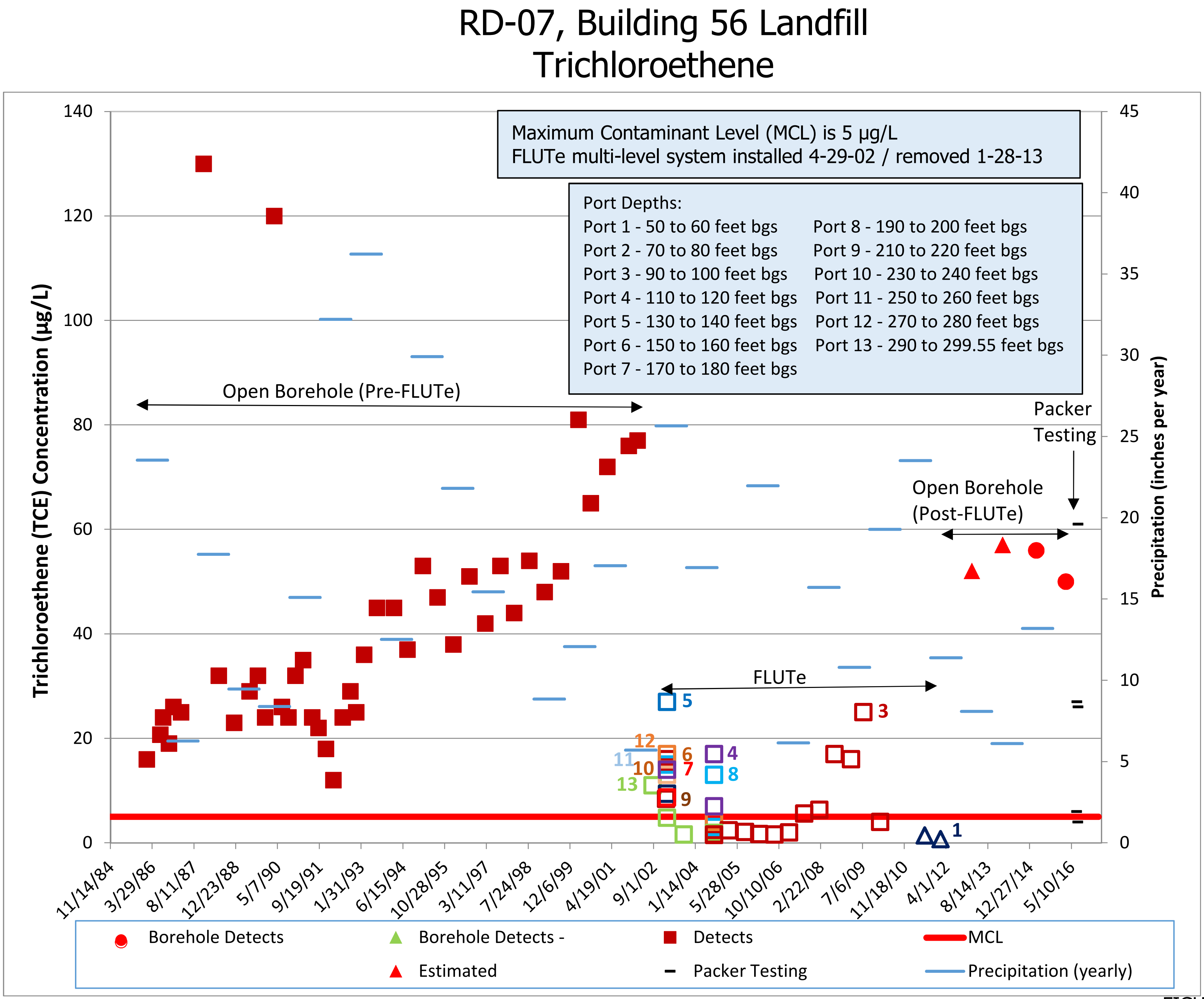
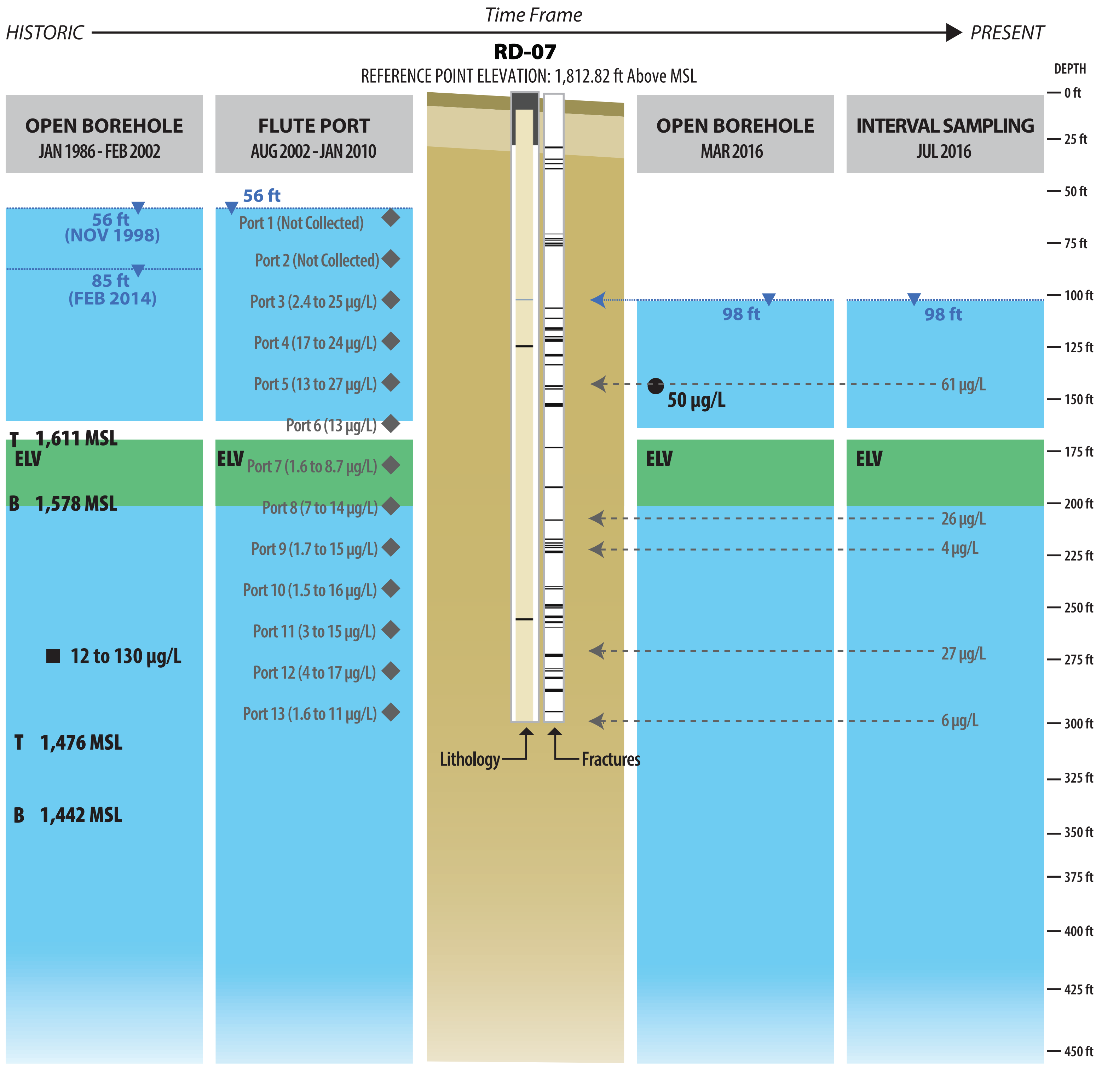


FIGURE 5.5-3

RD-07, TCE Concentrations in Groundwater



NOTES:

- Water level in FLUTe ports are not presented. Saturated zone **(BLUE)** is the same as Open Borehole minimum depth for illustration purposes.
- Borehole lithologies and fractures are presented in Section 4.
- ELV member **(GREEN)** projected along Area IV strike approximately N63°E and dip 25 degrees to the northwest.
- Elevation in Feet Above Mean Sea Level (MSL) of Projected Contact (T = Top, B = Bottom)

FIGURE 5.5-4

RD-07, TCE in Groundwater Over Time

5.6 Buildings 4057/4059/4626

The buildings comprising this study area (4057, 4059, and 4626) were part of DOE former operations. PCE-contaminated groundwater has been identified near former Buildings 4059 and 4626, and existing Building 4057. Building 4059 was part of the Systems Nuclear Auxiliary Power (SNAP) facility in the western part of Area IV. Existing Building 4057 supported the liquid metals testing program, while former Building 4626 was used for equipment storage. The building footprints, monitoring wells, potential source areas for PCE contamination for the Building 4057/4059/4626 groundwater investigation area are depicted on **Figure 5.6-1.**

5.6.1 Source Area Evaluation

Operation History

Building 4059 was constructed between 1961 and 1963. Between 1961 and 1964 and again from 1968 to 1969, Building 4059 was used to test SNAP reactors. The tests were terminated in 1969 when a leak in the reactor core was identified. From 1973 to 1978 the building was used for the Large Leak Test Sodium Test program.

In 1964, a French drain was constructed around three of the external building sides, below the foundation to collect and remove any infiltrating groundwater from the test cells of the reaction vault. Sump (S-2) received water from a French drain and maintained water levels in the sump within 3 feet of its bottom (CH2M Hill 2008). Operational history details of the French drain system are limited. The following information was reported in the *Results of Enhanced Dewatering, Building 059* (GRC 1999b):

- Foundation boring data in 1961 suggests that the water table was below the basement level of Building 4059 when it was initially constructed.
- A review of data and reports achieved in GRC files did not reveal when groundwater seepage into Building 4059 was initially recognized.
- It appears that groundwater impacted by VOCs was initially confirmed in Building 4059 in 1978.

GRC (1999a) reports that groundwater levels near Building 4059 rose in the late 1960s in response to cessation of pumping of on-site production wells when local water supply was replaced by external sources. Releases of imported water, particularly at the rocket engine test stands, resulted in a net historic rise in groundwater levels of approximately 50 feet in eastern portions of Area IV, as observed by the rise in WS-07 (GRC 1999b) located 2,500 feet east Building 4059. It is not clear when sump S-2 pumping began; however, it is reported that during periods of high seasonal precipitation as much 300 gpd was pumped, treated, and released locally (CH2M Hill 2008). Analysis of groundwater samples collected from the basement sump identified a maximum concentration of 540 µg/L PCE (E&E 1989) (**Figure 5.6-2**). This is the highest historic PCE concentration observed in this area.

In 1983, radioactive isotope-contaminated water was detected in seepage found in a below-grade vault of the south test cell in Building 4059. Radioactivity measurements in the water samples were less than maximum concentration permissible (MCP) limits at that time, but countermeasures were established to pump out the water and prevent leaching from impacted building basement concrete. No radioactive contamination was detected in groundwater outside of the building footprint (CH2MHill 2008). Collected water was pumped out of the vault and the vault was sealed.

In 1987, groundwater seepage was present in the north test cell of the reactor vault floor. Two radionuclides (Eu-152 and Na-22) were detected above their respected MCP limits. Following this discovery, Rockwell began a decontamination and decommissioning program to remove the remaining radioactivity.

From 1986 through 1992, water collected in the drainage system was found to be contaminated with tritium and PCE, TCE, and their degradation products (CH2M Hill 2008). Water from the French drain was temporarily stored in a holding tank, screened for radioactivity, and then discharged through carbon treatment vessels to the storm drain. Non-radioactive water from the French drain was transported to an air stripping tower in Area II for treatment prior to disposal. To lower the water table in the Building 4059 area, pumping of nearby monitoring well RD-24 began in early 1995. Wells RD-25 and RD-28 were pumped in mid-1999 to facilitate dewatering of the basement area of Building 4059 in advance of demolition of the building.

The SNAP facilities included 14 aboveground storage tanks (ASTs), four underground storage tanks (USTs), and a reaction products tank (RPT). None of the tanks were reported to have contained PCE or other solvents; however, the contents of two tanks located along the perimeter of Building 4059 were not known (CH2M Hill 2008).

Chemicals were used or stored at the following locations in this area:

- Building 4057 – used as a Liquid Metals Engineering Center (LMEC) Laboratory. A flammable materials storage cabinet was located outside the north wall of the building. The cabinet was used for storing alcohol, paint, TCA, oil, and ethylene glycol monoethyl ether.
- Building 4038 – used for ETEC administration offices. An unknown quantity of acetone was released in 1989 and two gallons of hydraulic oil spilled into an open trench in 2000.
- Building 4358 – used for chemical storage and for Sodium Component Testing Laboratory (SCTL) support. Later it was used for Sodium Component Testing Installation (SCTI) and the Kalina program support. The building was moved from the SNAP area in 1978.
- Building 4360 – used for storage of acids, bases, and combustible liquids used for SCTI.
- Building 4459 – contained a large diesel generator and was used to store non-radiological supplies and flammables. When Building 4059 was demolished, Building 4459 was used to store radioactive waste containers.
- Building 4626 – used for equipment storage. Soil samples collected on the south side of the building during the 2005 RFI were found to be contaminated with VOCs, including PCE at a concentration of 37µg/kg at a depth of 9 feet bgs.

Soil and Debris Removal Actions

Building 4059, the French drain, and storage tanks were removed in 2003 and 2004. The resulting excavation was backfilled with approximately 5,000 to 8,000 cubic yards of material from an Area IV borrow pit (CH2M Hill 2008). Monitoring wells RD-25 and RD-28 were abandoned in April 2004 as part of the building demolition. Other buildings in this area have been removed, including Buildings 4626 (2004), 4459 (2003), 4358 (2003), 4360 (1999), and 4459 (2003). Buildings 4019, 4038 and 4057 remain at this time (2017).

Groundwater Interim Measures

The pumping of wells RD-24, RD-25, RD-28 and the Building 4059 basement between 1999 and 2004 influenced groundwater contamination, particularly PCE at Building 4059. PCE concentrations in wells RD-24 and RD-25 decreased following pumping from 2.9 μg/L to 0.57 μg/L in RD-24 and from 35 μg/L to 0.48 μg/L in RD-25.; while PCE in RD-28 remained less than 1 μg/L.

5.6.2 Soils, Geology, and Hydrogeology

Native soil up to 12 feet thick are present in the Building 4057/4059/4626 area. The basement of Building 4059 was constructed into the top of the Chatsworth Formation sandstone.

Near-surface groundwater is present at Building 4057 at piezometer PZ-109 which is installed into the upper weathered Chatsworth Formation. The Near-surface groundwater monitored at PZ-109 appears to be continuous with the groundwater “mound” observed in central Area IV to the immediate east-northeast (**Figure 4-3**). Near-surface groundwater is absent at well RS-16 so PZ-109 is likely the western edge of the localized groundwater mound. Near-surface groundwater at PZ-109 has been reported to be continuous with the Chatsworth Formation groundwater (CH2M Hill 2008).

Under static (non-pumping) conditions, groundwater flow in the Chatsworth Formation is toward the west-northwest. However, from about 1986 to 2004 pumping from the French drain sump and wells RD-24, RD-25, and RD-28 were used to lower the water table around Building 4059. There are no groundwater elevation data in the Chatsworth Formation prior to 1989, but pumping of the sump in 1986 lowered the groundwater to below the building foundation (approximately 60 feet bgs) and probably caused a localized cone of depression in the potentiometric surface around the building. Similarly, when pumping starting at RD-24, and later at RD-25 and RD-28, the potentiometric level dropped. When pumping of RD-25 and RD-28 started in July 1999, an abrupt drop in groundwater elevations was observed in RD-07, approximately 350 feet southwest of RD-25 indicating hydraulic connectivity between RD-07, RD-25, and RD-28 (GRC 1999a). PCE has never been observed in groundwater samples collected from RD-07 so groundwater flow direction may not be to the west from Building 4059.

5.6.3 Nature and Extent of Impacted Groundwater

5.6.3.1 Groundwater Investigation Analytical Results

Piezometer PZ-109

Piezometer PZ-109 was installed in 2001 and is 36.5 feet deep with a screen interval from 25 to 35 feet bgs. It is installed into weathered bedrock near the Building 4057 dry well. This well is screened in Near-surface groundwater and has typically exhibited the highest PCE groundwater concentrations of wells in this area (300 µg/L in 2002; 55 µg/L in March 2016; 42 µg/L in March 2017; 72 µg/L in March 2018).

Bedrock Well DS-43

Well DS-43 was installed in 2016 adjacent to PZ-109 within the upper Chatsworth Formation groundwater. DS-43 is 84 feet deep with casing from ground surface and 28 feet bgs. It was sampled in the first quarter 2016 with the sample reported with an estimated concentration of PCE at 0.59 J µg/L; the 2017 and 2018 results were 0.57 J µg/L and 0.25 J µg/L.

Bedrock Well RD-24

Well RD-24 was installed in 1989 within the upper Chatsworth Formation groundwater. It is 150 feet deep with casing from ground surface and 30 feet bgs. Well RD-24 monitors groundwater near Building 4019, southeast of former Building 4059. Historically samples from well RD-24 have PCE concentrations between 0.4 µg/L (1996) and 1.4 µg/L (2002). PCE was not detected in the first quarter 2016 sample. The 2017 sample was also non-detect.

Bedrock Well RD-25

RD-25 was installed in 1989 within the upper Chatsworth Formation Groundwater. It was 175 feet deep located southwest of former Building 4059. It was abandoned in 2004 as part of building demolition. PCE was detected in this well at concentrations between 5.4 µg/L (1990) and 27 µg/L (2002).

Bedrock Well RD-28

Well RD-28 was installed in 1989 within the upper Chatsworth Formation groundwater. It was 150 feet deep located immediately north of former Building 4059. It was abandoned in 2004 as part of building demolition. The maximum PCE concentration was 1.5 µg/L (1991) but was typically non-detect above the laboratory reporting limit of 1.0 µg/L.

Bedrock Well RD-96

Well RD-96 was installed in 2006 within the upper Chatsworth Formation groundwater. It is 90 feet deep and located northwest and downgradient of former Building 4059. Well RD-96 has been sampled 10 times since installation and neither PCE nor TCE have been detected.

Bedrock Well DD-142

Well DD-142 was installed in 2016 as a Chatsworth formation groundwater well to replace the monitoring capability once provided by RD-25 and RD-28. Well DD-142 was installed within the footprint of former Building 4059. It is 91 feet deep with casing from ground surface to 34 feet bgs. PCE was detected in this well at 12 µg/L in March 2016 and at 6.4 in October 2016 µg/L. The well was 0.2 µg/L in 2017 and 3.6 µg/L in 2018.

5.6.3.2 COC Identification

The primary groundwater contaminant in the Building 4057/4059/4626 area is PCE. Other VOCs, including of the degradation products of PCE (TCE and cis-1,2-DCE) have been reported at lower concentrations in the same set of wells.

Metals including antimony, cadmium, mercury, selenium, and silver have been observed in soil above background concentrations in this area. Elevated concentrations of molybdenum (not a soil contaminant) and cadmium up to 17 µg/L have been reported for groundwater sampled from PZ-109. Metals observed in soil and exceeding groundwater screening levels include antimony and copper (PZ-109). No metal exceeded screening levels have been detected in RD-24, RD-25, or RD-28. Selenium slightly exceeded screening levels was detected in RD-96 in 2014 and 2015.

During the RFI, soil and soil vapor were sampled and analyzed at eleven locations around Buildings 4059, 4057, and 4626 (CH2MHill 2008). The soil vapor locations are shown on **Figure 5.6-1** and discussed below.

Building 4059

Soil samples were collected from three locations surrounding the previous SNAP excavation area (Building 4059). PCE was the most common VOC detected in the soil samples. Soil vapor samples were collected from three locations, one from the SNAP excavation area, one southwest of former Building 4059, and one from the excavation backfill. PCE, benzene, and toluene were the most common observed soil vapor contaminants (CH2MHill 2008).

Building 4057

Soil samples were collected at two locations near southwest corner of building and northwest corner of building. VOCs were reported at both locations with PCE reported above the Residential Risk Based Screening Level. Soil vapor samples were collected from four locations along the southern perimeter of the building. VOCs were reported above RBSLs for PCE, benzene, and toluene.

Building 4626

Soil samples were collected from five locations, one in the center of the former building and four at the eastern perimeter of the former building. PCE was reported in soil above the Residential RBSL at two locations along the eastern perimeter of the building. Soil vapor was collected at two locations, one in the center of the former building and one at the eastern perimeter of the former building. PCE was reported above the Residential RBSL in the eastern perimeter soil vapor sample. Ten soil vapor samples from this part of Area IV were collected in 2014 and all samples were non-detect for key Area IV COCs (MWH 2014b). The distribution of VOCs is provided in **Appendix E**.

5.6.3.3 Vadose Zone Mass Estimate

The residual mass of contaminants in the vadose zone at Building 4059/4057/4626 is currently being evaluated.

5.6.3.4 Horizontal Extent of Contamination

Figure 5.6-1 illustrates the horizontal extent of PCE contamination identified for the Building 4059/4057/4626 area using 2016 groundwater data. The distribution of PCE using 2001 groundwater data is depicted on **Figure 5.6-2**. In 2001, the northern area of PCE-impacted groundwater (to the MCL of 5 µg/L) extended from PZ-109 (280 µg/L) northwest to RD-25 (12 µg/L). The highest concentration of PCE was collected from the Building 4059 sump was 540 µg/L in the late 1990s. PCE was detected in the newly installed well DD-142 at the former

Building 4059 at 12 µg/L during the first quarter 2016. Concentrations of PCE were detected in PZ-109 at 48 µg/L (2014) and 55 µg/L (2016). Newly installed bedrock well DS-43, adjacent to PZ-109, contained an estimated PCE concentration at 0.59 J µg/L indicating that the PCE does not extend to the Chatsworth Formation groundwater. PCE has not been detected in the downgradient bedrock monitoring well RD-96.

5.6.3.5 Vertical Extent of Contamination

Figure 5.6-3 is a cross section illustrating the vertical depth of PCE contamination identified for the Building 4059/4057/4626 area. The vertical extent near Building 4057 is defined by new well DS-43 to be less than 80 feet bgs. The vertical extent at the former Building 4059 has not been defined.

5.6.3.6 Seeps Evaluation

PCE has not been detected in seep samples collected from cluster SP-T02 down gradient from the Building 4059/4057/4626 area.

5.6.4 Fate and Transport

5.6.4.1 Conceptual Site Model

There are multiple sources for PCE in the Near-surface and Chatsworth Formation groundwater in the Building 4059/4057/4626 area. Piezometer PZ-109 at Building 4057 and the basement sump at former Building 4059 show similar historical elevated PCE concentrations in Near-surface groundwater, while bedrock wells between the two locations do not show the same elevated concentrations. PCE was reported at increasing concentrations with depth in soil on the south side of Building 4626 and in soil vapor on the east side of Building 4057. PCE in the soil is carried by infiltrating precipitation to the Near-surface groundwater. Under a downward vertical hydraulic gradient, PCE-impacted groundwater moves within the fractures of the Chatsworth Formation. In the Chatsworth Formation, the PCE diffuses into the rock matrix, potentially becoming a future source of low-level contamination. The PCE-impacted groundwater also flows downgradient through fractures in the rock. As the hydraulic gradients changed due to dewatering efforts between 1994 and 2004, the flow path of contaminated groundwater could have reversed direction until cessation of pumping.

The change of PCE concentrations over time at PZ-109, RD-24, RD-25, and RD-28 are shown on **Figure 5.6-4** along with the time periods when groundwater pumping occurred at wells RD-24, RD-25 and RD-28. Pumping from the Building 4059 French drain sump started prior to the installation of the Chatsworth Formation wells in 1989 and therefore, the impacts the sump pumping is not shown. Water levels would have dropped first at RD-24, then at RD-25 and RD-28. Conversely, there was an abrupt rise in groundwater elevations at the end of pumping in 2004. The dewatering of the Building 4059 basement drain also ceased in 2004 and the groundwater elevations returned to non-pumping conditions.

With the start of pumping at RD-24, the direction of groundwater flow likely shifted northward. Prior to the start of pumping at well RD-24, concentrations of PCE in RD-25 increased from less than 5 µg/L in 1989 to a high of 43 µg/L in 1995. With the start of pumping at well RD-24 PCE in RD-25 declined to between 6 and 12 µg/L in 2001 and 2002. PCE concentrations increased at RD-

25 to 27 µg/L following the cessation of pumping with the exception of the last sample from RD-25 collected in 2004 which was less than 1 µg/L.

5.6.4.2 Numerical Flow Model Results

Chapter 6 provides a summary of the numerical modeling of contaminant transport for PCE in groundwater near Building 4057. **Appendix C** provides the modeling report.

Piezometer PZ-109 was used as the modeling point to assess movement of TCE from the Building 4057 area. **Figures 6-11 through 6-15** in Chapter 6 illustrate the modeling results. **Figure 6-11** illustrates the particle track possibilities for groundwater movement from PZ-109 assuming there is no restriction on time frame. This figure shows a northeast pathway for groundwater flow. **Figure 6-12** illustrates the relative rate of movement of groundwater based on the calibrated site-scale groundwater flow model at the Building 4057 area. This figure illustrates a greater groundwater velocity than that predicted for the FSDF location. **Figures 6-13, 6-14, and 6-15** illustrate how far from PZ-109 the contaminant plume expected to move over time. These figures illustrate a greater potential for contaminant migration. Well RD-24 in the pathway illustrated by the model exhibited PCE from 1996 through 2005 (2.9 µg/L maximum concentration of PCE) indicating movement of PCE towards RD-24. PCE has been non-detect in the well since 2008.

5.6.4.3 Contaminant Fate Analysis

Since 2004, when wells RD-25 and RD-28 were removed and pumping stopped in RD-24, PCE results for RD-24 have decreased to non-detect. Piezometer PZ-109 has been sampled four times with PCE concentrations of 300 µg/L in 2002, 67 µg/L in 2013, and 48 µg/L in 2014, and 55 µg/L in 2016. The source for the PCE appears to be in the vicinity of Buildings 4057 and 4626. The decrease in PCE concentrations in PZ-109 is likely due to the depletion of any remaining source over the 15-year period, some diffusion of the PCE into the weathered rock matrix, and potentially, some reductive dechlorination of PCE into its breakdown products, TCE and cis-1,2-DCE. Both of these breakdown products have been detected in PZ-109. The groundwater in 2013 was compatible for reductive dechlorination (an ORP value of -246 EV and a DO concentration of 0.88 µg/L) (MWH 2014a). However, the concentrations of the breakdown products (TCE and cis-1,2-DCE) did not increase over the same time that PCE concentrations were decreasing.

5.6.4.4 Plume Stability Assessment

Groundwater data collected for the PCE plume at the Building 4059/4057/4626 area since 2000 demonstrate that the area of impacted groundwater is stable and is not moving appreciably in the direction of predicted groundwater flow.

5.6.5 Uncertainties and Data Gaps

VOCs are present in this groundwater investigation area in both near-surface weathered bedrock and in competent Chatsworth Formation bedrock. The highest concentrations are detected in the near-surface groundwater; the bedrock wells in 2018 exhibited PCE less than its MCL. Characterization of this area is complete for purposes of evaluating remedies in the corrective measures study. Sampling of DS-43 and PZ-109 for metals should continue.

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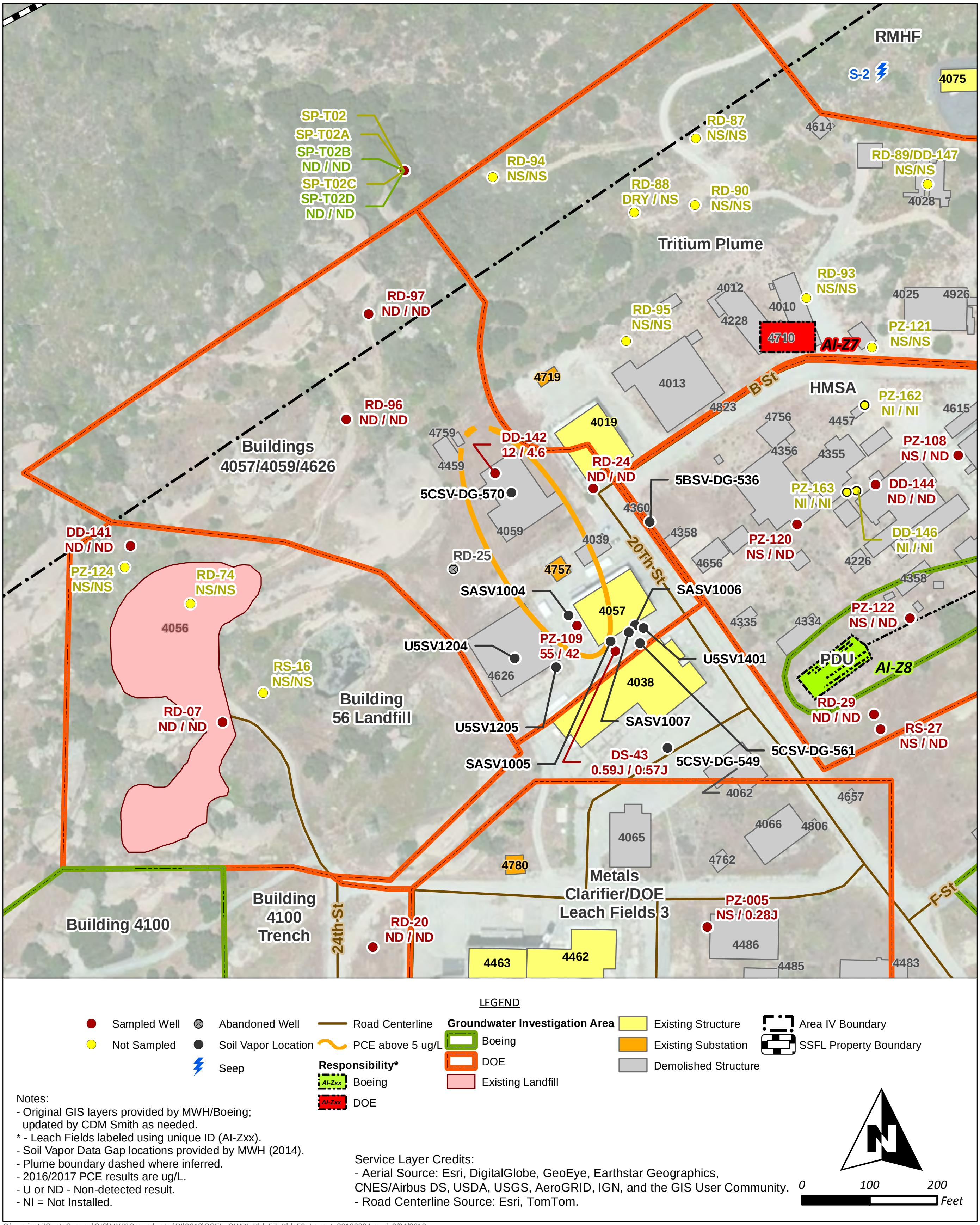

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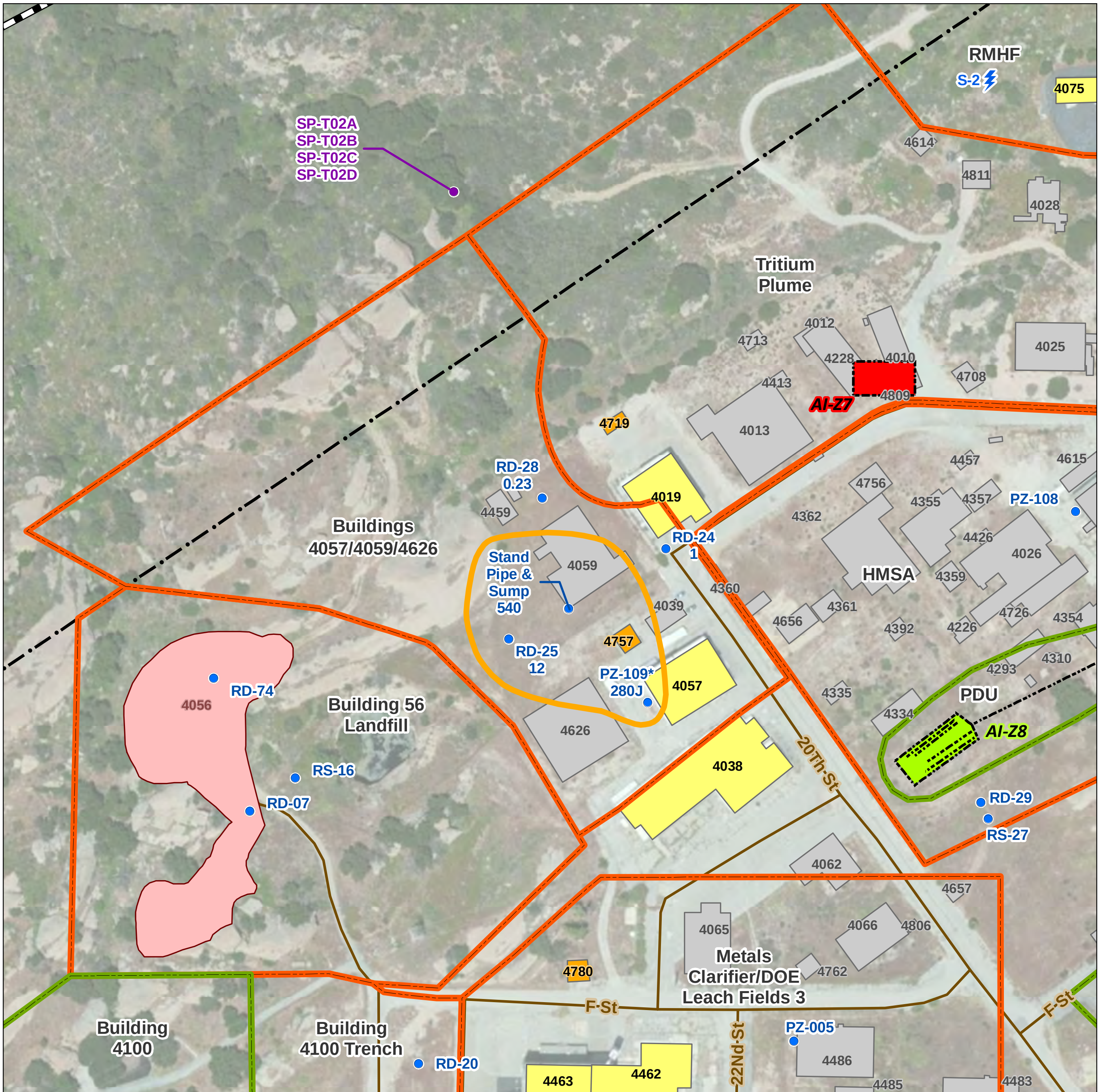
FIGURE 5.6-1

Buildings 4057/4059/4626 PCE Concentrations - 2016 and 2017



LEGEND

- Well/Piezometer
- Seep Well
- Seep
- Road Centerline
- PCE above 5ug/L

Responsibility*
- AI-Zxx Boeing
- AI-Zxx DOE

Groundwater Investigation Area
- Boeing
- DOE
- Existing Landfill

- Existing Structure
- Existing Substation
- Demolished Structure
- Area IV Boundary
- SSFL Property Boundary

0 100 200 Feet

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).
- 2001 PCE results in ug/L.
- J - Estimated Result.
- *PZ-109 PCE result collected in 2002.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

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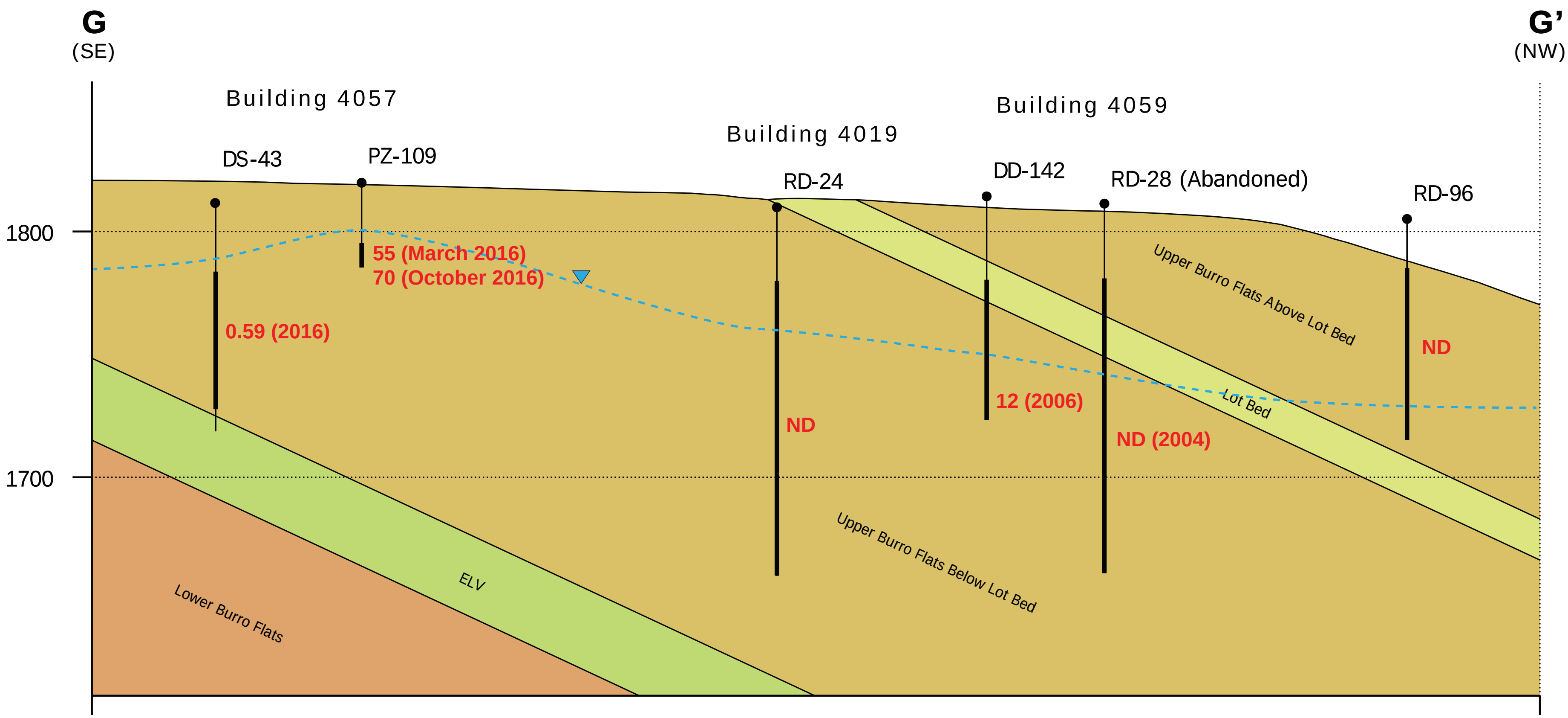
CDM Smith

FIGURE 5.6-2

Buildings 4057/4059/4626 PCE Concentrations - 2001



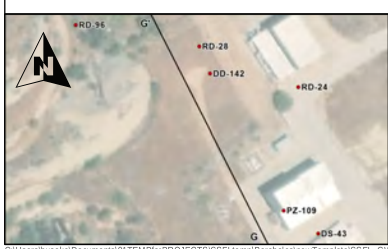
Cross section line is drawn perpendicular to strike of Fine-Grained Units in Area IV. Cross section shows topographic surface along the cross section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

12 Tetrachloroethene (PCE) reported in micrograms per liter (ug/L).



Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
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GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 100ft

C:\Users\huseke\Documents\01TEMPforPROJECTS\SSFLtemp\Boreholes\newTemplate\SSFL_GWRI_Template_letter_KH.mxd 12/22/2016

CDM Smith

FIGURE 5.6-3

Vertical Extent of PCE Contamination at Building 4059/4057/4626

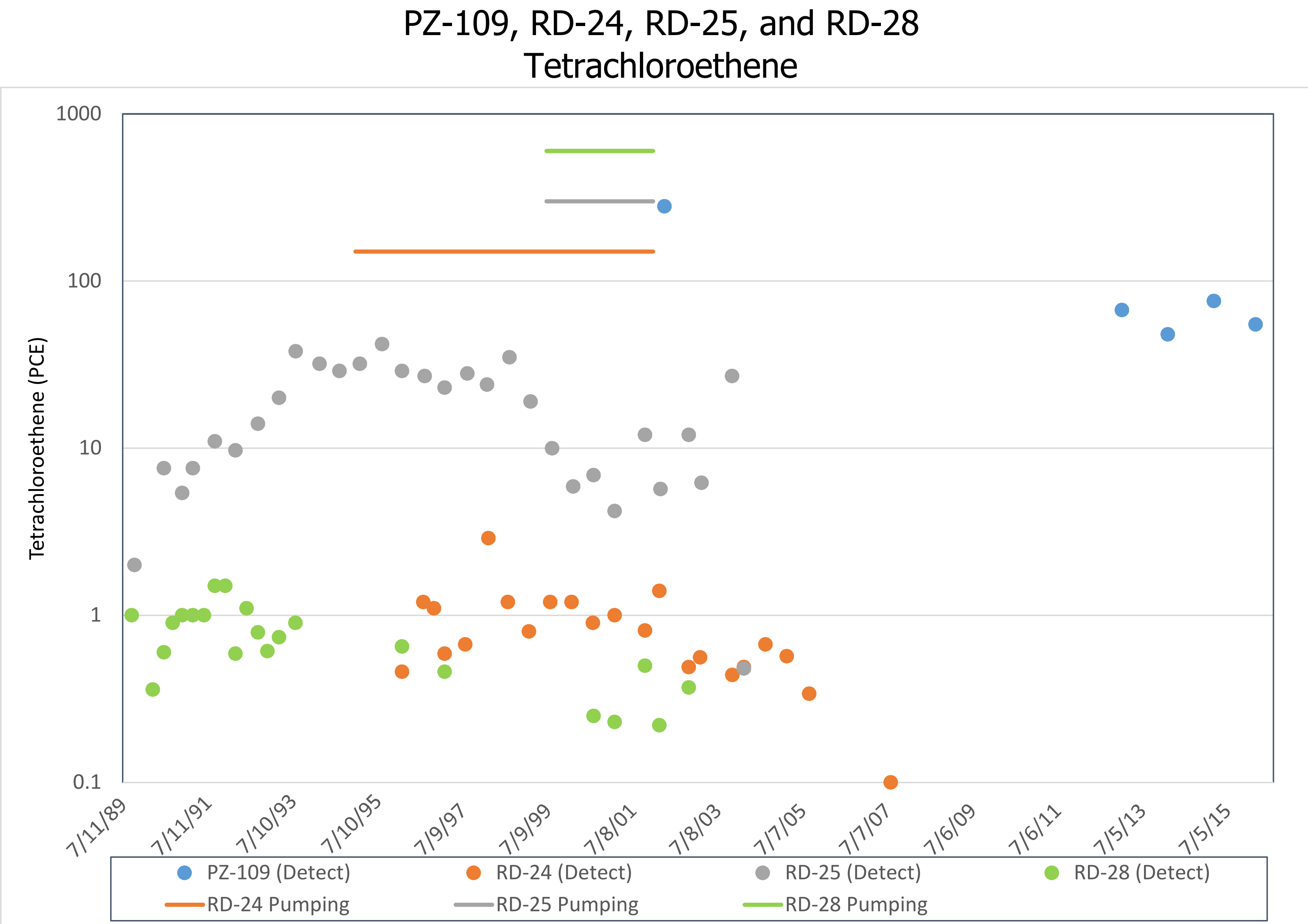

FIGURE 5.6-4

PZ-109, RD-24, RD-25, and RD-28 PCE Concentrations in Groundwater

5.7 Hazardous Materials Storage Area (Building 4457)

A relatively small area (2 to 3 acres) of TCE-contaminated groundwater comprises the HMSA groundwater investigation area (**Figure 5.7-1**). This area spans central Area IV bounded by former Building 4626 on the west, former Building 4005 to the east, 'B' Street to the north, and the Building 4005 leach field to the south. Groundwater quality in this area has historically been monitored using piezometers within the Near-surface groundwater (PZ-041, PZ-108, PZ-109, PZ-120, PZ-121, and PZ-122). Two piezometers, PZ-162 and PZ-163, were installed in May 2018 to further evaluate the Near-surface groundwater. All piezometers are screened in the weathered bedrock. Piezometers PZ-108, PZ-120, PZ-162, and PZ-163 are impacted with TCE and piezometers PZ-041, PZ-109, PZ-121, and PZ-122 define the edge of the plume. TCE detected in PZ-109 may be a degradation product of PCE as PCE is detected at higher concentrations at this location. Shallow well RS-27 at the HMSA is dry and has not been sampled since 1995. Chatsworth Formation monitoring wells DD-140 and DD-143 provide bedrock data for the center of the plume, and wells RD-24 RD-29, and DD-144 provide deeper groundwater data north and south of the shallow groundwater plume. The layout of the HMSA, monitoring well locations, 2016/17 analytical data, and the extent of the TCE plume to MCLs are shown on **Figure 5.7-1**. **Figure 5.7-2** illustrates the concentrations of TCE observed in this area in 2000.

5.7.1 Source Area Evaluation

Operation History

There were multiple historical activities within the HMSA area that may have been the source of groundwater contamination. **Table 5.7-1** provides summary details of buildings within the HMSA, operations and chemical use. The majority of DOE-sponsored activities within Area IV, including the HMSA, ceased by 1982. It is assumed that some chemical storage and use still occurred that was associated with the decommissioning and demolition of buildings.

The operational history of activities within the HMSA is provided in the *Group 5 RFI Report* (CH2M Hill 2008). A total of 25 structures were located in the vicinity of Building 4457 including Nos. 4005, 4024, 4025, 4026, 4226, 4334, 4335, 4355, 4356, 4357, 4358, 4359, 4361, 4392, 4426, 4457, 4478, 4615, 4625, 4656, 4826, 4925, 4926, 4927, and 4928. There were also 51 ASTs, 14 USTs, and 3 sumps. Building 4005 had an associated leach field (AI-Z8). Only Building 4024 remains; all other buildings have been demolished and ASTs and USTs removed.

The RCRA Program identified Building 4457 as an Area of Concern (DTSC 2007). Building 4457 was used for testing of sodium-lubricated bearings for large sodium pumps in the 1960s. Later, the building was used for storage of a variety of chemicals including waste oils, acids, bases, solvents, petroleum hydrocarbon oils, and other lubricants. A 1,000-gallon sulfuric acid storage tank and two sumps were located within the building.

Various SNAP operations, including testing of prototype reactors, were conducted in Buildings 4024 and 4025. Building 4026 housed a facility for testing components of sodium-cooled graphite moderated reactors and later became a sodium component test laboratory. The Sodium Component Testing Installation (SCTI) operations were conducted in Building 4355 (the control room), 4356 (steam generation), and 4457 (testing of lubricated bearings for sodium pumps).

DOE operated the Kalina program, to expand non-nuclear power technologies in Buildings 4334 (the control building) and 4335 (turbine).

Most of the 65 ASTs and USTs were used for storage of various forms of sodium or ammonia, fuels, lubricants, sulfuric acid and acid rinse waters, sodium hydroxide, and caustic rinse waters. None of the tanks were documented to contain solvents, although a "drain tank" located in Building 4361 was noted of "unknown" size and contents.

CH2M Hill (2008) reported five documented spills: two of sulfuric acid (1 gallon in Building 4355 and 25 gallons in the SCTI area), one of sodium hydroxide (3 to 5 gallons in Building 4355), one of sodium hydroxide (15 gallons in the Kalina area), and one of ammonia (3,900 pounds in the Kalina area). No solvent spills were documented.

Table 5.7-1 History of Operations within the HMSA Area

HMSA Building	Operations Conducted	Chemicals Known/Potentially Used or Released
4005	Testing non-nuclear thermodynamic characteristics of coolants for organic moderated reactor experiments and Piqua reactors Fabrication of enriched carbide fuel Pilot plant for molten salt combustion Included change rooms, chemistry labs, storage Building had a leach field	Polyphenols Benzene produced by coal gasification Chlorinated waste Sodium carbonate Chromium was detected in clean salt bin Tar/water mixtures have been released
4024	Testing of prototype reactors	No chemical uses reported
4025	Nuclear reactor remote handling Warehouse storage	No chemical uses reported
4026	Testing components of sodium-cooled graphite moderated reactors Included a below-grade drain tank	Hydraulic line broke releasing fluid to ground (1999) Ammonia and glycol released from pipe (1997) DeWorals sodium, Dowanol sodium, and hydrocarbons were generated and disposed off-site
4226	Housed a motor generator and used for storage of drummed non-radiological hazardous materials	Petroleum spills PCB-containing hydraulic oil used
4334	Control room, general chemical storage	Stored aqueous and anhydrous ammonia, turbine lubrication oil, compressor oil, greases, and other lubricants Leaks of anhydrous ammonia
4335	Housed turbine for Kalina facility	No chemical uses identified
4355	Control room, offices, small chemistry laboratory, and record storage Cooling tower and emergency generator	No chemical uses reported
4356	Sodium tank cleaning, steam generation from sodium heat source, water treatment, X-ray operations Testing small steam engines	Sulfuric acid, sodium hydroxide, hydrazine, and morpholine were used Cadmium and chromium were stored Recorded sodium leak; 200-300 gallons of 20 percent sulfuric acid spilled (1988) Six to eight gallons of sulfuric acid spilled (unknown)
4357	Supply storage for SCTI Pump bearing test facility	Propellants for rockets mixed and processed
4358	Chemical storage and storage for SCTL and Kalina	Igniters containing ammonium, magnesium, potassium perchlorate

Table 5.7-1 History of Operations within the HMSA Area

HMSA Building	Operations Conducted	Chemicals Known/Potentially Used or Released
	Storage of Space Shuttle Main Engine (SSME) stability bombs	Drums of lube oil
4359	SCTI compressor building and storage	Oil staining from a transformer
4361	SCTI hazardous material storage Chemicals stored in underground storage tanks (USTs) with containment pit	Chlorine stored in drums
4392	Electrical equipment building for Kalina and SCTI	No chemical use
4426	Uninterruptible power supply	No chemical uses reported
4457	Proof and performance testing of sodium lubricated bearings	Waste oils stored Sulfuric acid (1,000-gallon tank) Acids, bases, TPH oils, solvents, and lubricants were stored in subsurface sumps
4478	Office support trailer	No known chemical uses
4615	Combustion test facility (non-radiological)	No known chemical uses
4625	Non-nuclear component storage building	No chemical uses reported
4656	Cooling stacks	Cooling tower periodically treated with chlorine Sulfuric acid and sodium hydroxide used to regenerate resins Hydrazine and morpholine to control oxygen and pH
4826	Expansion of Building 4026 Testing components in sodium environment	No chemical uses reported
4925	Mechanical equipment slab	No known chemical uses
4926	Sodium Reactor Mock-up Equipment Area	No known chemical uses
4927	Nitrogen tank storage area	Nitrogen
4928	Cooling Tower for Building 4026	No known chemical uses

Notes:

HMSA – Hazardous Materials Storage Area

SCTI – Sodium Component Testing Installation

SSME – Space Shuttle Main Engine

SCTL – Sodium Component Testing Laboratory

UST – underground storage tank

Soil and Debris Removal Actions

With the exception of Buildings 4024, and nearby buildings 4019, 4038, and 4057, all buildings in this area have been removed. All appurtenances associated with the former buildings, including ASTs, USTs, and sumps, were also removed.

Groundwater Interim Measures

No groundwater interim measures have been performed in this groundwater investigation area.

5.7.2 Soils, Geology, and Hydrogeology

Up to 11 feet of soil derived from the weathering of the Chatsworth Formation underlies the HMSA. The soil consists of fine-grained silty sand, sandy silt, lean clay, and poorly graded sand (MWH 2008b). Bedrock in the HMSA consists predominantly of the Upper Burro Flats member of the Upper Chatsworth Formation. This member consists of fine- and medium-grained sandstone with minor interbeds of shale and siltstone. Immediately east of the HMSA, the ELV fine-grained member of Sandstone 2 that contains at least 50 percent fine-grained rock (shale and siltstone) is found at surface or subcropping beneath the surface alluvial soils. The ELV fine-grained member of Sandstone 2 and Upper Burro Flats Members strike N63˚E and dip 25˚ to the northwest. This structural configuration brings the top of the ELV fine-grained member of Sandstone 2 beneath the HMSA (projected at well DS-43) at a depth of 87 feet bgs on the northwestern edge of the HMSA and about 100 feet bgs at DD-144 in the central portion of the HMSA (**Figure 5.7-3**).

Near-surface groundwater in the HMSA is discontinuous and perched above the Chatsworth Formation groundwater (MWH 2008b). The ELV fine-grained member of Sandstone 2 may be providing a barrier to the downward infiltration of precipitation, causing the water to perch, particularly in the eastern portions of the HMSA. On the southern edge of the HMSA, well RS-27, screened in the weathered ELV fine-grained member of Sandstone 2 at a depth of about 10 feet bgs is frequently dry. The other Near-surface piezometers PZ-108, PZ-109, PZ-120, and PZ-121, are screened at depths between 26 to 36 feet bgs. Piezometer PZ-121, located on the northern side of the HMSA, was dry in 2014. Groundwater flow direction in the Near-surface groundwater varies considerably. Groundwater elevations in PZ-108 have been higher than those in PZ-120 over much of the last 14 years indicating a general southwesterly component to the flow direction. However, at least once during that same period the water levels in PZ-109 (southwest of PZ-120) were also higher than PZ-108 indicating a northeasterly flow direction from PZ-109 to PZ-120.

Until the installation of bedrock well DD-144 in 2016, only perched wells were used to monitor the TCE plume. Well RD-24, open from 30 to 150 feet bgs in the Upper Burro Flats member of the Chatsworth Formation, is located on the western side of the HMSA. Well RD-29, open from 30 to 150 feet bgs in the Lower Burro Flats Member, is located on the southern side of the HMSA. Well RD-93, open from 20 to 60 feet bgs is located about 100 feet northwest of PZ-121; generally north of the HMSA plume. Groundwater elevations in RD-24 are about 20 feet lower than those in the closest Near-surface groundwater piezometer (PZ-109). Similarly, groundwater elevations in well RD-93 are about 20 feet lower than those in PZ-120. Groundwater elevations in RD-29 are less than a foot lower than those in adjacent well RS-27, although there is only a small set of data that can be compared as RS-27 is dry much of the time. Groundwater in the Lower Burrow Flats member may be semi-confined beneath the ELV fine-grained member of Sandstone 2.

The HMSA is also located on a groundwater divide within the Chatsworth Formation, with bedrock groundwater flowing radially outward, predominantly to the east, southeast, southwest, and west (**Figure 4-3**).

5.7.3 Nature and Extent of Impacted Groundwater

5.7.3.1 Groundwater Investigation Analytical Results

The HMSA is monitored by eight piezometers (PZ-041, PZ-108, PZ-109, PZ-120, PZ-121, PZ-122, PZ-162, and PZ-163), one shallow well (RS-27), and six bedrock wells (RD-24, RD-29, RD-93, DD-144, DD-146, and DD-147). Piezometer PZ-109, which also monitors the PCE plume associated with Buildings 4057/4059/4626 is described in Section 5.6.4.4. Data discussed herein are presented in Appendix B.

Piezometer PZ-041

Piezometer PZ-041 located in the PDU east of the HMSA TCE groundwater plume is 29.6 feet deep and screened from 19 to 29 feet bgs. TCE was not detected in samples collected from PZ-041 in 2014, 2015, and 2016. TCE was detected once at an estimated concentration of 2 J µg/L in 2003.

Piezometer PZ-108

Piezometer PZ-108 located within the HMSA TCE groundwater plume is 30 feet deep and screened from 26 to 30 feet bgs. The well was sampled annually from 2011 to 2015. There was insufficient water in 2016 to sample. TCE concentrations ranged between 74 and 160 µg/L between 2012 and 2018.

Piezometer PZ-120

Piezometer PZ-120 also located within the HMSA groundwater plume is 26 feet deep and screened from 15 to 25 feet. The well exhibited TCE at 90 µg/L in 2014 and 21 µg/L in 2018.

Piezometer PZ-121

Piezometer PZ-121 located north of the HMSA groundwater plume is 33 feet deep and is screened from 15 to 25 feet bgs. The well was last sampled in 2003 and TCE was non-detect.

Piezometer PZ-122

Piezometer PZ-122 located south of the HMSA groundwater plume is 27.5 feet deep and is screened from 15.5 to 25.5 feet bgs. The TCE sample results for this well are 0.84 µg/L for 2014, non-detect for 2015, and 1.6 µg/L for 2018.

Piezometer PZ-162

Piezometer PZ-162 was installed within the footprint of former Building 4457 to evaluate the location as a source. The piezometer is 41 feet deep and screened between 31 and 41 feet bgs. The well was sampled in May 2018 and produced a TCE concentration of 11 µg/L.

Piezometer PZ-163

Piezometer PZ-163 was installed within the central portion of the HMSA plume at well DD-144. The piezometer is 40 feet deep and screened between 30 and 40 feet bgs. The well was sampled three times in May 2018 and produced TCE concentration of 150, 170, and 190 µg/L.

Shallow Well RS-27

Shallow well RS-27 is only 9 feet deep and has always been dry.

Bedrock Well RD-24

Well RD-24 is a bedrock monitoring well drilled to 150 feet bgs and cased from ground surface to 30 feet bgs. This well also monitors the former Building 4059 PCE impacted groundwater. It is located north of the HMSA TCE plume, serving as a bedrock groundwater horizontal and vertical plume extent monitoring point. Low levels of TCE, less than 1 µg/L were detected in this well in 2004, 2006, and 2007. The well has been non-detect for TCE (less than 0.5 µg/L) since.

Bedrock Well RD-29

Well RD-29 is a bedrock monitoring well, drilled to 100 feet bgs and cased from ground surface to 30 feet bgs. It is located immediately south of the HMSA TCE plume, serving as a bedrock groundwater vertical and horizontal plume extent monitoring point. Historically TCE was detected between 3 µg/L (1989) to 2.5 µg/L (2008). TCE was detected at 3.3 µg/L in 2014, 2.3 µg/L in 2015, 3.8 µg/L in 2016, and 1.1 µg/L in 2018. This reflects stable groundwater concentrations in the central Area IV.

Bedrock Well RD-93

Well RD-93 is a bedrock monitoring well, drilled to 60 feet bgs and cased from ground surface to 20 feet bgs. It is located north of the HMSA TCE plume, serving as a bedrock vertical and horizontal plume monitoring point. TCE was detected at 0.16 µg/L in 2014 and was non-detect in 2016.

Bedrock Well DD-144

Well DD-144 was drilled into the Upper Burro Flats bedrock in January 2016 in the HMSA TCE plume. It was drilled to 71 feet bgs and cased from ground surface to 38 feet bgs. TCE was detected at 98 µg/L in March 2016, 190 µg/L in October 2016, 170 µg/L in March 2017 and 200 µg/L in March 2018.

Bedrock Well DD-146

Well DD-146 was drilled into the Upper Burro Flats bedrock in July 2018 to be a deeper companion well to DD-144. It was drilled to 140 feet bgs and cased from ground surface to 120 feet bgs. It has not been sampled.

Bedrock Well DD-147

Well DD-147 was drilled through the location of well RD-89. It was determined that RD-89 was too shallow (50 feet bgs) to sample groundwater (well was typically dry). Groundwater transport modeling indicated that a deeper well was needed to monitor TCE emanating from the MHSA. The depth of well RD-89 was extended to 257 feet bgs. It is cased from ground surface to 30 feet bgs. It has not been sampled.

5.7.3.2 COC Identification

Since monitoring began in 2001, TCE has been reported at concentrations greater than the MCL (5 µg/L) in the Near-surface groundwater at piezometers PZ-108 (160 µg/L in 2018), PZ-120 (90 µg/L in 2014), and PZ-163 (190 µg/L in 2018). Piezometer PZ-109 located at Building 4057 is also impacted with PCE at 76 µg/L (2015). TCE observed in this well may be a degradation product of PCE and the well may not be connected with the HMSA impacted area. TCE concentrations reported for PZ-109 over the last four years (2013 to 2016) ranged from 2.8 µg/L to 8.9 µg/L. Concentrations of TCE below the MCL have been detected in PZ-122 (0.84 J µg/L in 2014). Historic TCE results for these wells are shown on **Figure 5.7-2**. Recently installed Chatsworth Formation bedrock well DD-144 also contained TCE at concentrations exceeding the 5 µg/L MCL (98 µg/L in March and 190 µg/L in October 2016). Therefore, both the Near-surface and Chatsworth Formation groundwater are impacted by TCE at the HMSA.

Other VOCs, including 1,2-dichloroethene, acetone, and *cis*-1,2-DCE, have been found in the HMSA groundwater samples; however, all concentrations are below their respective MCLs.

MWH (2014b) collected 21 soil vapor samples from this part of Area IV. TCE was reported in three of the samples, and PCE and benzene in four samples (**Appendix E**).

Metals were detected in Near-surface monitoring wells PZ-108 and PZ-109. Cadmium and vanadium were consistently detected in post-2014 samples collected from PZ-108 at concentrations ranging from 0.26 to 0.93 µg/L (screening level of 0.2 µg/L) and 1.9 to 4.2 µg/L (screening level of 2.6 µg/L), respectively. Antimony, cadmium, and copper were consistently reported in post-2014 samples collected from PZ-109. Antimony was detected at concentrations ranging from 2.4 to 9.8 µg/L (screening level 2.5 µg/L); cadmium was detected at concentrations ranging from 2.7 to 17 µg/L (screening level of 0.2 µg/L), and copper was detected at concentrations ranging from 1.1 to 11 µg/L (screening level 4.7 µg/L). With the exception of vanadium, these metals are also present in soil samples collected at this location of Area IV.

All nitrate results for piezometers PZ-108, PZ-121, PZ-122, and RD-29 were less than the screening level of 10,000 µg/L.

5.7.3.3 Vadose Zone Mass Estimate

The distribution of TCE concentrations at the HMSA indicates that the source may have been in the vicinity of wells DD-144 and PZ-163. This is where the highest concentrations are observed. To evaluation a possible vadose zone source at the HMSA, an investigation of building B4457 was conducted (CDM Smith, 2018e). TCE at 16 J µg/L was reported for the sample collected at Building4457 and was not detect for the sample collected at the center of the HMSA plume. There does not appear to be a significant source in the vadose zone for TCE remaining at the HMSA.

5.7.3.4 Horizontal Extent of Contamination

Figure 5.7-1 illustrates the extent of the TCE-impacted groundwater in 2016. The HMSA GIA is in the center of the groundwater mound of central Area IV. Given that the groundwater elevation has not decreased at the same rate as other locations within Area IV, horizontal and vertical groundwater movement in this area may be much less within the mound.

5.7.3.5 Vertical Extent of Contamination

Figure 5.7-3 provides a cross section illustrating the depth of the TCE-impacted groundwater at the HMSA. The concentrations at the new well DD-144 (98 µg/L in March 2016 and 190 µg/L in October 2017) demonstrates a downward movement of TCE-impacted water from the perched zone. The vertical extent is not identified in DD-144. TCE was reported at concentrations below the MCL in bedrock wells RD-29 (3.3 µg/L in 2014 and 3.8 µg/L in 2016) and RD-93 (0.16 µg/L in 2014, not detected in 2016). TCE was not detected in bedrock well RD-24. Additional investigative work was conducted in the summer of 2018 and will be reported under a separated cover and will be used to inform the CSM.

5.7.3.6 Seeps Evaluation

Seep cluster SP-T02 to the northwest and downgradient of the HMSA has not been impacted by TCE.

5.7.4 Fate and Transport

5.7.4.1 Conceptual Site Model

The source of the TCE found in the HMSA groundwater has not been definitively determined, but based on the history of building usage and features, is most likely the result of spills, discharge, or other leakage associated with operations in one or more of the following buildings:

- Building 4457, where solvents were once stored and where two sumps were located. Spilled solvents in the sumps may have leaked into the surrounding soil through cracks in the concrete. Soil vapor sampling conducted during the RFI identified VOCs, including TCE, in soil near Building 4457 (CH2M Hill 2008). Results of a passive soil gas sample collected in 2018 near the Building 4457 did indicate the presence of VOCs. The 2018 groundwater result for PZ-162 installed within the building footprint was 11 µg/L indicating that the building is on the edge of the TCE plume and a source is not present. Passive soil gas investigation conducted in 2018, demonstrated that Build 4457 no longer is a significant source to underlying groundwater (CDM Smith, 2018e)
- Building 4026 was used for sodium-cooled reactor component testing had a floor drain and tank. Building 4026 is also located between piezometers PZ-108 and PZ-120 where the highest concentrations of TCE have been consistently found. Building 4426, located southwest of piezometer PZ-120, was used for non-radioactive hazardous material storage. Soil vapor samples collected during the RFI had detectable VOCs, but not TCE (CH2M Hill 2008).
- Building 4357, where sodium storage tanks were cleaned. There was no reported use of solvents in this building. Soil vapor sampling during the RFI found that soil vapors contained VOCs; however, TCE was not identified (CH2M Hill 2008). Piezometer PZ-120 is the location with the highest concentrations of TCE detected in 2014 and is located at the southwestern corner of former Building 4356.

VOCs can be present as vapors in soil pore spaces when there is a nearby source in the soil or when groundwater is sufficiently contaminated that VOCs volatilize from the water and migrate upward into the unsaturated soil pore spaces. The presence of VOCs in soil vapor near these three buildings confirms that they are likely initial sources of VOCs to soil and groundwater.

TCE present in soil from leaks or spills at these source areas would be carried downward by precipitation infiltrating the surface soil and migrating to the perched Near-surface groundwater. Once in the groundwater, dissolved TCE will migrate with groundwater flow. There is not a clear direction of groundwater flow in this discontinuous, perched groundwater; however, between April 2004 and February 2014 groundwater levels typically were higher in PZ-108 than in PZ-120 indicating that groundwater flow within the relatively porous media of the perched water table was from northeast to southwest. Concentrations of TCE increased in PZ-120 over that period (from 7 µg/L in April 2004 to 90 µg/L in February 2014). This distribution of the contamination indicates a source area northeast of PZ-120. Though the horizontal extent is bounded, the vertical extent is not.

5.7.4.2 Numerical Flow Model Results

Chapter 6 provides a summary of the numerical modeling of contaminant transport at the HMSA TCE plume location. Appendix C provides the complete modeling report.

Well DD-144 was used as the modeling point to assess movement of TCE in groundwater at the HMSA. **Figures 6-26 through 6-30** in Chapter 6 illustrate the modeling results. **Figure 6-26** illustrates the particle tracking possibilities for groundwater movement from well DD-144 assuming there is no restriction in time. This figure shows a northeast pathway for groundwater flow similar to the adjacent PCE plume area. **Figure 6-27** illustrates the relative rate of groundwater movement based on the calibrated site-scale groundwater flow model at the HMSA. This figure illustrates a greater groundwater velocity than that predicted for the FSDF location. **Figures 6-28, 6-29, and 6-30** illustrate how far the TCE is expected to travel when the release occurred over 20 years ago. These figures illustrate a greater potential for contaminant migration, relative to sources at the FSDF and Building 56 Landfill. Wells RD-89 and RD-93 in the pathway of contaminant movement do not show a presence of TCE. Modeling uncertainties for vertical and horizontal migration, along with predicted depth of TCE at locations of the wells, may affect this observation. In addition, the model does not consider some physicochemical aspects of TCE that would retard its rate of movement in groundwater.

5.7.4.3 Contaminant Fate Analysis

The overall concentration trend in the Near-surface groundwater is a gradual decrease (from 160 µg/L in 2002 to 75 µg/L in 2015 at piezometer PZ-108). TCE concentrations in piezometer PZ-120 have generally increased from 7 µg/L in 2003 to 90 µg/L in February 2014 indicating slow movement or spreading of the impacted groundwater westward. Piezometer PZ-041 located east of PZ-108 has always been less than 5 µg/L for TCE. PZ-108 and PZ-120 show the presence of cis-1,2-DCE indicating some degradation of TCE is occurring.

5.7.4.4 Plume Stability Analysis

The 20-foot potentiometric head difference between the Near-surface groundwater and the Chatsworth Formation groundwater over much of the HMSA indicates a downward vertical gradient. TCE-contaminated perched water leaking through the low-permeability layer will infiltrate through the underlying weathered bedrock rock into the Chatsworth Formation through fractures. The HMSA is located on a groundwater divide for the Chatsworth Formation groundwater with low horizontal groundwater gradients. The Near-surface TCE-impacted groundwater is expected to migrate slowly to the northwest and southeast. However as groundwater moves downward, bedrock flow is to the northeast. TCE will diffuse from the groundwater in the fractures into the rock matrix, decreasing the concentration of TCE in fractures and generally slowing the migration of the plume front.

5.7.5 Uncertainties and Data Gaps

Investigations of the HMSA performed to date show that the highest concentrations of VOCs are found in the weathered bedrock. The horizontal extent of weathered bedrock contamination has been defined by piezometers. The vertical extent of VOC contamination was being investigated in 2018 through the installation of a deeper well in the center of the plume and deepening of well on the downgradient edge of the plume. Data for the 2018 HMSA investigations are not available for this report but will be provided in technical memoranda. Sampling of RD-93 for antimony should continue.

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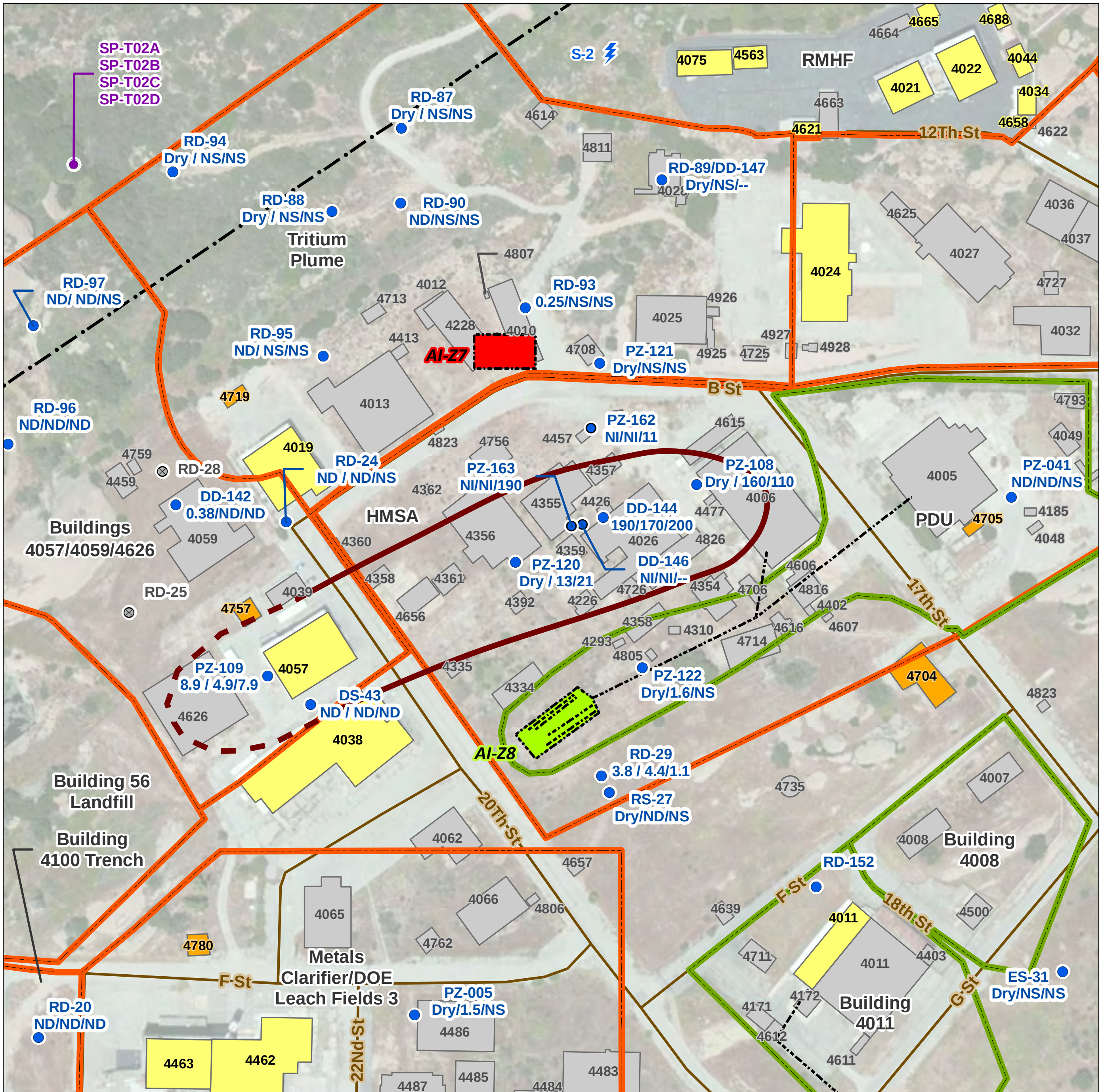

LEGEND

- Sampled Well
- Abandoned Well
- Seep Well
- Seep
- TCE at 5 ug/L
- Road Centerline

Responsibility*
- AI-Zxx Boeing
- AI-Zxx DOE

Groundwater Investigation Area
- Boeing
- DOE
- Existing Structure
- Existing Substation
- Demolished Structure
- Area IV Boundary
- SSFL Property Boundary

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).
- 2016/2017/2018 TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.
- NI = Not Installed.
- NS = Not sampled

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

0 100 200 Feet

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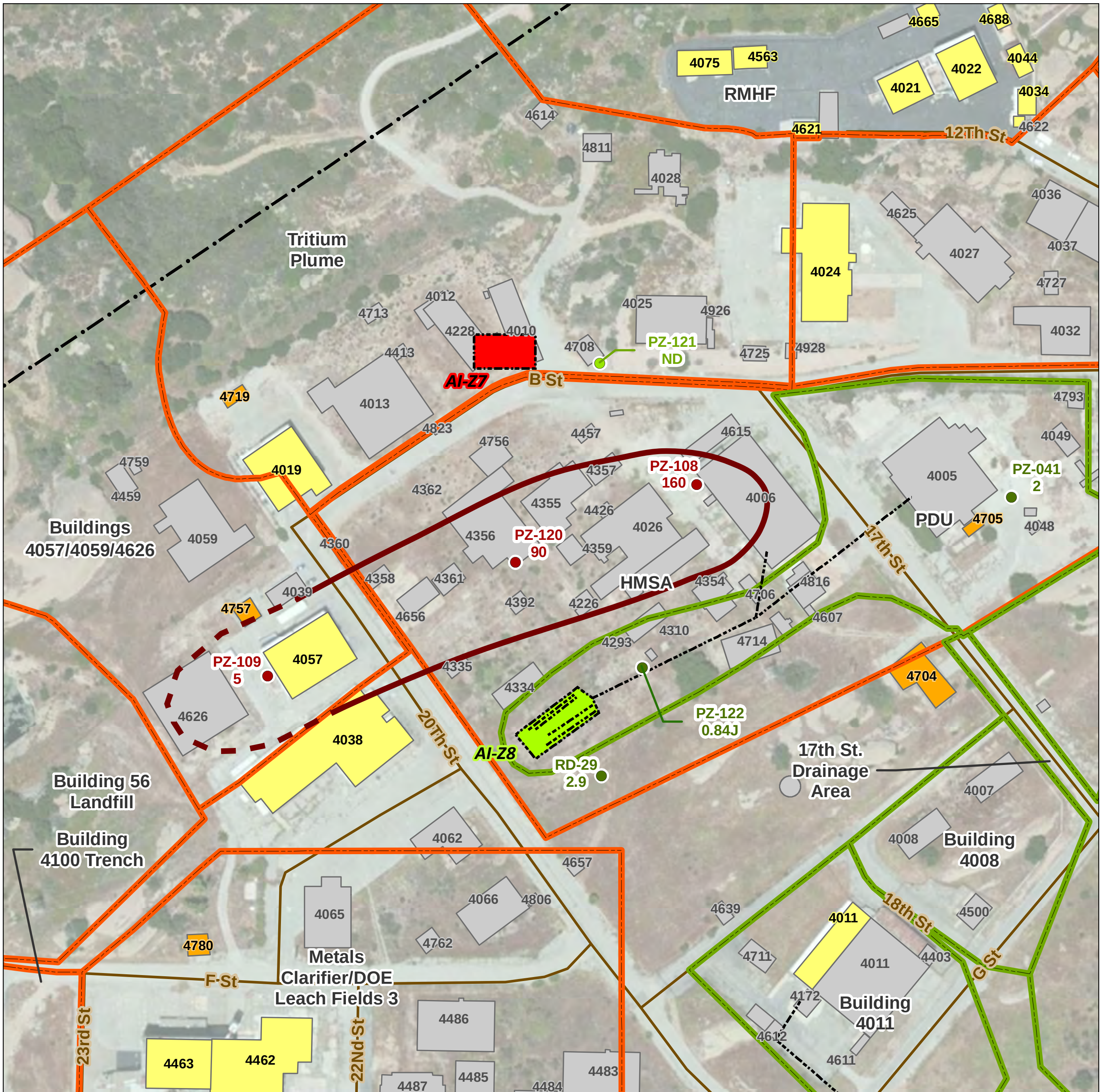
CDM Smith

FIGURE 5.7-1
Hazardous Materials Storage Area Layout



LEGEND

- TCE above MCL of 5 ug/L
- TCE above detection limit, below MCL
- TCE not detected above detection limits (ND)
- TCE at 5 ug/L
- Road Centerline

Responsibility*
- AI-Zxx Boeing
- AI-Zxx DOE

Groundwater Investigation Area
- Boeing
- DOE

- Existing Structure
- Existing Substation
- Demolished Structure
- Area IV Boundary
- SSFL Property Boundary

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).
- TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

N

0 100 200 Feet

C:_projects\SantaSusana\GIS\MXD\Groundwater\RI\SSFL_GWRI_HMSA_Layout_Historic_20170117.mxd 1/17/2017

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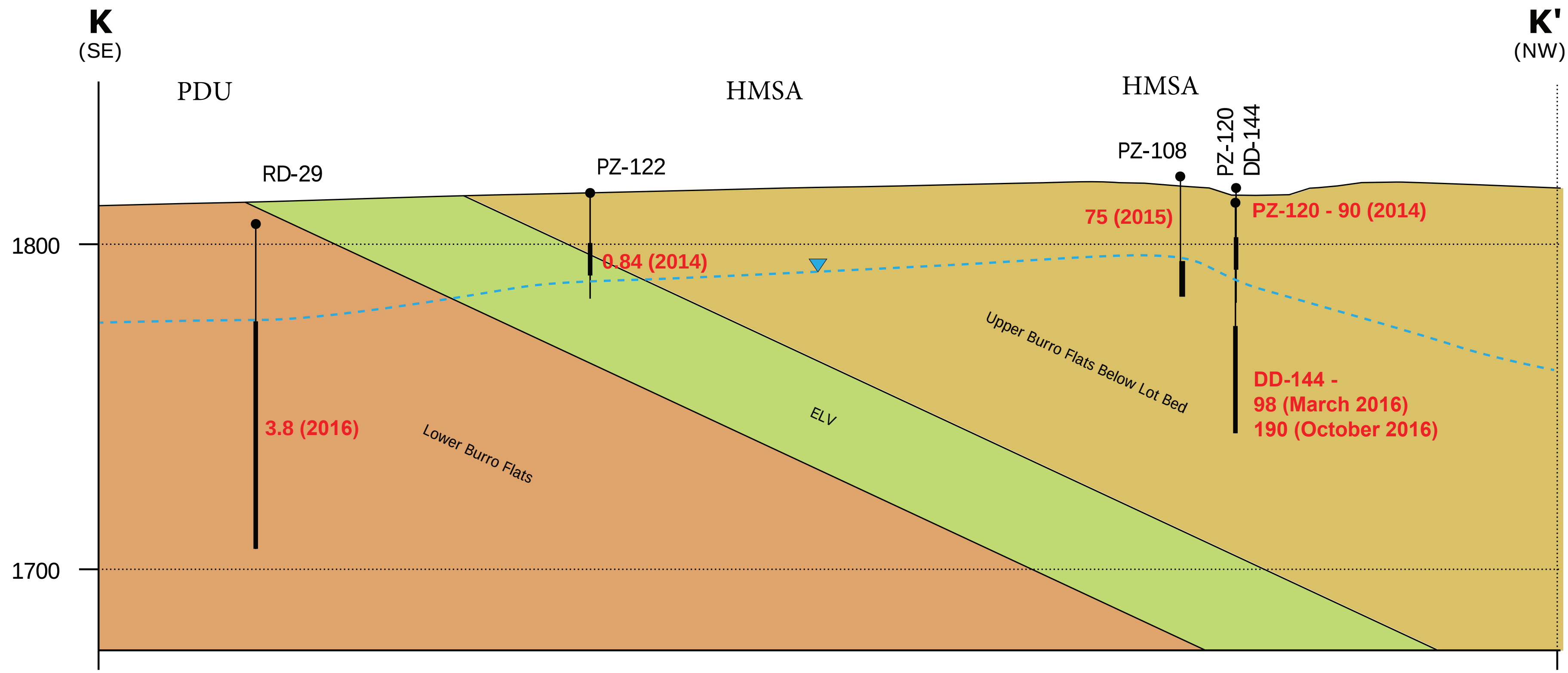
FIGURE 5.7-2
Hazardous Materials Storage Area TCE Concentrations - Circa 2000



Cross-section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross-section shows topographic surface along the cross section line.

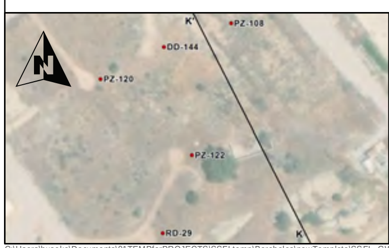
Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross-section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

75 Trichloroethene (TCE) reported in micrograms per liter (ug/L)



Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 100ft

CDM Smith

FIGURE 5.7-3

Vertical Extent of TCE Contamination at HMSA

5.8 Tritium Plume

Tritium, the radioactive isotope of elemental hydrogen, is found in the Chatsworth Formation groundwater in the north central portion of Area IV (**Figure 5.8-1**). This plume, Building 4010 and the B4010 leach field (AI-Z7) are DOE's responsibility as specified in the 2007 CO.

5.8.1 Source Area Evaluation

Operation History

The tritium plume exists in an area where several reactor experiments occurred during the 1960s and early 1970s. Reactors were in the following buildings:

- Building 4059 – SNAP 8 Development Reactor Facility (active between 1968 to 1969 and demolished in 2004);
- Building 4019 - SNAP Flight System Critical Facility (active between 1964 to 1965, building remains);
- Building 4010 - SNAP Reactor Experimental Test Facility (active between 1959 to 1960, and 1963 to 1965, demolished 1978; the associated leach field AI-Z7 was deactivated in 1961);
- Building 4024 - SNAP Environmental Test Facility (active between 1961 to 1962, and 1965 to 1966, building remains); and,
- Building 4028 - Shield Test Irradiation Facility (active between 1964 and1974 and demolished in 1989; the associated leach field IZ-Z6 was deactivated in 1961).

Tritium in Area IV groundwater was discovered by EPA in 1989 when EPA staff sampled groundwater collected from the Building 4059 French drain (see Section 5.2.4 for a discussion of Building 4059). EPA reported a tritium value of 1,890 ± 538 picocuries per liter (pCi/L). Prior to these results, the physicists managing the nuclear program had stated that there was no radioactive contamination in groundwater (1989 ASER) (Rocketdyne 1990a). The suspected source of the tritium was the absorption of neutrons captured in lithium in the concrete containment walls of the reactor building (Rocketdyne 1990b). Tritium was next reported in groundwater in the 1992 ASER in well RD-28 (420 to 1,025 pCi/L) at Building 4059 and well RD-34A (1,800 to 7,069 pCi/L) at the RMHF (Rocketdyne 1993). The ASER authors attributed the presence of tritium in well RD-34A to neutron-activated lithium in the concrete from Building 4010 which was demolished in 1978.

The extent of tritium-impacted groundwater was defined in 2004 and 2005 with the installation of wells RD-87, RD-88, RD-90, RD-93, RD-94, and RD-95.

Soil and Debris Removal Actions

With the exceptions of Buildings 4019 and 4024 and their associated surrounding concrete/asphalt areas, all structures in the area of the tritium plume have been removed. Removal of radiologically impacted bedrock adjacent to reactor vaults was completed as part of the reactor structure removal and the reactor building vaults and basements were backfilled using local borrow soils.

Groundwater Interim Measures

With the exception of the pumping to lower the water table associated with the Building 4059 basement (see Section 5.6 for a description of these activities), no interim actions have been taken in the area of the Tritium Plume.

5.8.2 Soils, Geology, and Hydrogeology

Between 1 and 11 feet of soil derived from the weathered Chatsworth Formation underlies the tritium plume area. These soils consist of fine-grained silty sands, sandy silts, lean clays, and poorly graded sands (MWH, 2008). Bedrock in the vicinity of the tritium plume consists predominantly of the Upper Burro Flats member of the Upper Chatsworth Formation (**Figure 5.8-2**). This member consists of fine- and medium-grained sandstone with minor interbeds of shale and siltstone. Immediately east of the plume, the ELV fine-grained member of Sandstone 2 that contains at least 50 percent fine-grained rock (shale and siltstone) is found at surface or subcropping beneath the surface soils. The ELV fine-grained member of Sandstone 2 and Upper Burro Flats Members strike N70˚E and dip 25˚ to the northwest. This structural configuration to depths ranging from 0 feet on the southeast to about 260 feet bgs on the northwestern edge of the plume.

All wells used to define the tritium plume have been installed within the Chatsworth Formation groundwater. Near-surface groundwater to the south of the tritium plume is described for the HMSA (see Section 5.7).

5.8.3 Nature and Extent of Impacted Groundwater

5.8.3.1 Groundwater Investigation Analytical Results

Eight bedrock monitoring wells (RD-34A, RD-87, RD-88, RD-89, RD-90, RD-93, RD-94, RD-95), and seep cluster well SP-T02, are used to monitor the tritium plume (**Figure 5.8-1**). All wells except RD-34A are adjacent to former reactor buildings. Well RD-34A in the RMHF drainage, also monitors the northern extent of tritium plume. Tritium concentrations in the wells are summarized in **Table 5.8-1**. The MCL for tritium is 20,000 pCi/L.

Table 5.8-1 Tritium Groundwater Data for Tritium Plume Area

Monitoring Well	Boeing 2004/2005	EPA 2010	EPA 2011	Boeing 2014	DOE 2016	DOE 2017	DOE 2018
RD-34A	1,050	966	342	530	391	NS	NS
RD-34B	<180	191	187	NS	NS	NS	NS
RD-87	14,800	7,630	5,600	4,100	Dry	3,240	NS
RD-88	86,800	44,800	4,040	Dry	Dry	1,050	NS
RD-89	Dry	Dry	Dry	Dry	Dry	Dry	Dry
RD-90	83,800	41,000	54,900	40,000	37,200	38,300	31,600
RD-93	28,400	8,200	9,130	5,300	3,740	5,460	NS
RD-94	12,300	9,550	5,000	7,200	Dry	1,740	NS
RD-95	119,000	59,700	49,900	28,000	27,400	19,600	31,000
SP-T02A	Not installed	Not installed	Not installed	2,500	Dry	Dry	Dry
SP-T02B	Not installed	Not installed	Not installed	1,400	802	Dry	972.5
SP-T02C	Not installed	Not installed	Not installed	Not detected	520	Dry	734.5

Table 5.8-1 Tritium Groundwater Data for Tritium Plume Area

Monitoring Well	Boeing 2004/2005	EPA 2010	EPA 2011	Boeing 2014	DOE 2016	DOE 2017	DOE 2018
SP-T02D	Not installed	Not installed	Not installed	1,100	1,272	713	1229.4

Units - Picocuries per liter
NS – not sampled

Bedrock Well RD-87

Well RD-87 is 60 feet deep and cased from the ground surface to 30 feet bgs. It is used to monitor the leading edge of the tritium plume to the northeast. It was dry in 2016 but contained sufficient water to sample in 2017 (see Table 5.8-1).

Bedrock Well RD-88

Well RD-88 is 30 feet deep and cased from the ground surface to 20 feet bgs. It is used to monitor the central portion of the tritium plume. It was dry in 2016 but contained sufficient water to sample in 2017 (see Table 5.8-1).

Bedrock Well RD-89

Well RD-89 is 50 feet deep and cased from the ground surface to 30 feet bgs. It is used to monitor the central portion of the tritium plume. It was dry in 2016 and 2017 (see Table 5.8-1). In July 2018, RD-89 was deepen to a total depth of 257 feet. This extended borehole has subsequently named DD-147. DD-147 will allow collection of groundwater to monitor the plume. The result of that work is provided in (CDM Smith 2018f)

Bedrock Well RD-90

Well RD-90 is 125 feet deep and cased from the ground surface to 20 feet bgs. It is used to monitor the central portion of the tritium plume. In recent years, the highest tritium concentrations have been measured in this well (Table 5.8-1).

Bedrock Well RD-93

Well RD-93 is 60 feet deep and cased from the ground surface to 20 feet bgs. It is used to monitor the southeastern extent of the tritium plume.

Bedrock Well RD-94

Well RD-94 is 35 feet deep and cased from the ground surface to 20.5 feet bgs. It is in the RMHF drainage below the operational areas and is used to monitor the downgradient edge of the tritium plume to the northwest. It contained insufficient water to be sampled in 2016 but was sampled in 2017 (Table 5.8-1).

Bedrock Well RD-95

Well RD-95 is 80 feet deep and cased from the ground surface to 50 feet bgs. It is used to monitor the south-central portion of the tritium plume. This well exhibited the highest tritium concentration of 119,000 pCi/L in 2005, but was at 19,600 pCi/L in 2017.

Bedrock Well RD-34A

Well RD-34A is in the RMHF drainage northeast of the main tritium plume. It is 60 feet deep and cased from the ground surface to 16 feet below the surface. Well RD-34A is noted here due to an historic tritium concentration in 1992 of 7,069 pCi/L. It is not known whether the tritium once observed is a result of pumping at well RD-63 pulling tritium in the direction of the well, a separate tritium source, and/or dispersion of tritium along its flow path. The 2016 sample for RD-34A was 391 pCi/L, well below the MCL of 20,000 pCI/L.

5.8.3.2 COC Identification

Tritium is the only groundwater contaminant for this area. No VOCs have been detected. Cadmium was previously detected in well RD-95 at an estimated concentration of 0.21 J µg/L just above the screening level of 0.2 µg/L and selenium was detected at an estimated concentration of 3.2 J µg/L above the screening level of 1.6 µg/L. Nitrate has been detected in the groundwater but at concentrations less than the screening level of 10,000 µg/L. These concentrations of metals near their respective screening levels are not considered COCs.

5.8.3.3 Vadose Zone Mass Estimate

Rocketdyne (1990b) attempted to identify the potential source(s) of the tritium plume; however, they concluded that the size of reactors and length of operation could not have resulted in the observed mass of tritium observed in groundwater. Although the plume originally was described as the "Building 4010 plume", the source may not be entirely related to Building 4010. It is possible that all the reactor buildings contributed some tritium contamination to groundwater in Area IV.

Bedrock core pore-water was sampled during the installation of wells RD-87, RD-88, RD-89, RD-93, RD-94, and RD-95 in 2004 and 2005. This sampling was performed to identify potential tritium sources in bedrock. **Table 5.8-2** below provides the core pore-water results. It is significant to note that these are not groundwater well samples but are of the interstitial pore water extracted from the bedrock matrix. The half-life of tritium is 12.5 years. Therefore, the majority of the sample results are predicted to be one-half the concentration in 2018. Bedrock core from wells RD-96 and RD-97 was also tested for tritium; however, tritium was non-detect.

Table 5.8-2 Tritium Concentrations in Bedrock Cores

Location	Static Water Level feet bgs	Date	Zone (Core)	No. of Samples (Cores)	No of Detects	Average Conc. (pCi/L)	Minimum Conc. (pCi/L	Maximum Conc. (pCi/L)
RD-87	45.71	8/18/04	Vadose	2	2	1,351.5	74	2,629
			Groundwater	3	3	10,096	8,638	11,925
RD-88	26.55	8/18/04	Vadose	3	3	16,076	9,592	21,149
			Groundwater	1	1	73,764	73,764	73,764
RD-89	18.6	5/20/05	Vadose	0	--	--	--	--
			Groundwater	9	9	32	16	77
RD-93	35.9	5/20/05	Vadose	17	17	98,137	90	246,921
			Groundwater	12	12	47,077	13,120	113,601
RD-94	5.5	5/20/05	Vadose	0	--	--	--	--
			Groundwater	10	10	13,574	5,139	17,102
RD-95	46.9	5/20/05	Vadose	0	--	--	--	--
			Groundwater	6	6	73,342	38,564	133,968
SB-Trit-01	40	3/12/07	Vadose	7	7	11,118	200	66,866
			Groundwater	18	18	244,202	37,656	931,258
SB-Trit-02	47.25	3/22/07	Vadose	4	4	13,198	116	34,691

Table 5.8-2 Tritium Concentrations in Bedrock Cores

Location	Static Water Level feet bgs	Date	Zone (Core)	No. of Samples (Cores)	No of Detects	Average Conc. (pCi/L)	Minimum Conc. (pCi/L	Maximum Conc. (pCi/L)
			Groundwater	36	36	41,845	2,191	90,367
Source: 2009 SSFL GW RI Report (MWH 2009)								

An additional investigation of potential tritium sources was performed in 2007 when two bedrock coreholes were drilled; SB-Trit-01 near RD-93 and SB-Trit-02 near RD-95. Corehole SB-Trit-01 was drilled to 127.5 feet bgs with core retrieved in 5-foot lengths. The cores were sampled and pore water extracted from the core rock matrix was analyzed for tritium. Tritium was observed throughout the corehole, and the highest concentrations were observed between 39.5 and 72.5 feet bgs. This zone is consistent with the water table. SB-Trit-002 was drilled to 219.5 feet bgs. The zone with the highest tritium levels was from 40.5 to 180 feet bgs. The average tritium concentrations in the bedrock coreholes corresponded with the groundwater collected from the adjacent monitoring wells at that time.

For most wells and coreholes, the samples collected from below the water table were higher in tritium concentrations compared to samples collected above the water table. SB-Trit-01 at the former Building 4010 had a rock core pore-water result from above the water table of 66,866 pCi/L and below the water table of 931,258 pCi/L[6]. Well RD-93, also located within the former Building 4010 footprint, had a rock core sample results from the vadose zone ranging from 90 to 246,921 pCi/L and samples collected below the water table at concentrations ranging between 13,120 and 113,601 pCi/L.

5.8.3.4 Horizontal Extent of Contamination

Figure 5.8-1 illustrates the current down gradient extent of the tritium plume. The horizontal extent is defined by monitoring wells RD-97 to the west, RD-34A to the northeast, and seep cluster SP-T02 to the northwest. Well RD-93 bounds the tritium plume to the east and well DD-142 bounds the plume to the southwest. Reduced tritium concentration in bedrock groundwater is most likely the result of half-life decay, percolation and flushing of fractures with atmospheric precipitation (low tritium activity), and dissolution with atmospheric precipitation in both fractures and within the rock matrix.

Further groundwater sampling in the 1990s identified detectable tritium in wells RD-23 (672 pCi/L), RD-21 (560 pCi/L), and RS-54 (1,099 pCi/L) at the FSDF, and repeated detections in RD-28 and RD-34A. Continued sampling of these wells confirmed the presence of tritium at these locations. Recent sampling (2016) showed these wells are now non-detect for tritium.

5.8.3.5 Vertical Extent of Contamination

Figure 5.8-2 is a cross section illustrating the central portion of the tritium plume. Tritium shown at depth is based on the collection depth of groundwater samples. DD-147 was advance from the terminus of RD-89 at 50 ft bgs and advanced to a total depth of 257 ft. bgs. Data from

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[6] These samples were collected 10 years ago. The half-life for tritium is 12.5 years. Therefore today the concentration of tritium is expected to be about one half of that observed in the 2007 pore water samples.

DD-146 will used to evaluate vertical extent of contamination and vertical groundwater gradient in this area.

5.8.3.6 Seeps Evaluation

Seep cluster SP-T02 located in the drainage downgradient of the tritium plume exhibited tritium at 1,272 pCi/L in 2016 and 713 pCi/L in 2017. This location exhibits damp soil, but has been dry in recent years due to drought conditions. Samples collected from other seep sampling locations north of Area IV have not had detectable concentrations of tritium.

5.8.4 Fate and Transport

5.8.4.1 Conceptual Site Model

Tritium is created in the atmosphere via solar energy interacting with water molecules or as part of nuclear reactions by adding a neutron to the nucleus of a hydrogen atom (atomic weight of 3). Like non-radioactive hydrogen, the tritium atom readily reacts with oxygen to form tritiated water (water with one hydrogen atom and one tritium isotope). When released into the environment, the tritiated water will behave in the same manner as un-tritiated water. It will percolate through surficial soils down to the bedrock, move with water into bedrock cracks, and then diffuse into the bedrock matrix due to concentration gradients. The tritium core pore-water data illustrates the diffusion of tritium into bedrock. Tritium will continue to move with the groundwater as it flows in fractures downward and laterally from the location of release.

Several reactors were tested in the location of the tritium plume where activation of water in concrete may have occurred. It is also possible that tritium could have migrated with groundwater from another source area such as Building 4010 during nearby Building 4059 groundwater pumping. The former reactors have all been removed, and the soil tested largely non-detect for tritium indicating that the tritium sources have been removed. The resulting groundwater impacts of tritium will continue to be monitored.

5.8.4.2 Numerical Flow Model Results

Chapter 6 provides a summary of the numerical modeling of contaminant transport for the tritium plume. The modeling report is included as Appendix C.

Well RD-95 was used as the modeling point to assess movement of tritium in groundwater for the tritium plume. Figures 6-16 through 6-20 in Chapter 6 illustrate the modeling results. **Figure 6-16** illustrates the particle tracking possibilities for groundwater movement from well RD-95 assuming there is no restriction of time. This figure shows a northeast pathway for groundwater flow that is similar to the adjacent HMSA plume area. **Figure 6-17** illustrates the relative rate of movement of groundwater based on the calibrated site-scale groundwater flow model in the northern part of Area IV. This figure illustrates a greater groundwater velocity than that predicted for the FSDF location. **Figures 6-18, 6-19, and 6-20** illustrate how far from well RD-95 the tritium plume is expected to move over time. These figures illustrate that the migration potential for tritium is extremely low. The half-life of tritium is a controlling factor and the plume will be below the tritium MCL within the next 10 years. The modeling results are consistent with groundwater sampling results for this location.

5.8.4.3 Contaminant Fate Analysis

A significant characteristic for the evaluation of tritium fate and transport is its half-life of 12.5 years. Every 12.5 years the concentration of tritium is reduced by one-half. Assuming that the last tritium was released in 1974 with the closure of the Shield Test Radiation Facility at Building 4028, any tritium created then would have been reduced by three half-lives thus far.

However, the rate of diminishing tritium concentrations in groundwater is faster than the half-life due to dispersion and dilution factors. **Figure 5.8-3** illustrates the decay rate for tritium at SSFL as demonstrated in well RD-90. The graph illustrates the rate of diminishing concentrations resulting from both its decay rate and diffusion into the bedrock.

5.8.4.4 Plume Stability Assessment

Tritium concentrations in seep cluster SP-T02 have been stable reflecting the slow movement of groundwater in this part of Area IV. The plume front is stable and is not expected to move beyond the SP-T02 location.

5.8.5 Uncertainties and Data Gaps

The extent and properties of the Tritium plume are sufficiently understood for remedy evaluation in the CMS. Data to be collected from the deepening of RD-89 (now DD-147) will aid in assessing the plume tritium levels over time.

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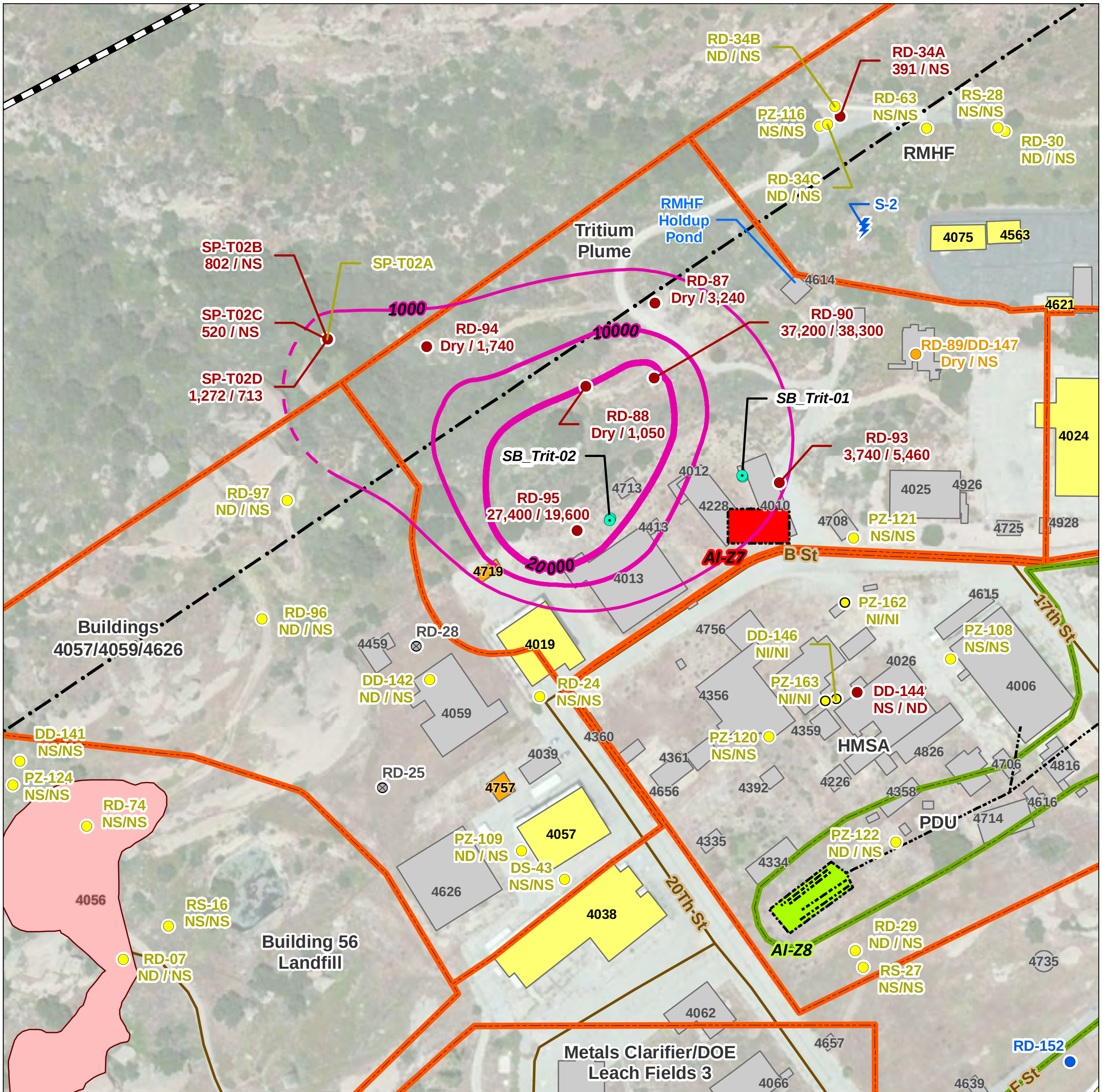

LEGEND

- Sampled Well
- Dry well or insufficient water for purging/sampling (<3 feet of water in wells designated for low-flow purging)
- Not Sampled
- Boeing Well
- Abandoned Well
- Tritium Soil Boring Location
- Seep
- Tritium at 20,000 Picocuries/L
- Road Centerline

Responsibility* Groundwater Investigation Area
- AI-Zxx Boeing
- AI-Zxx DOE
- Boeing
- DOE

- Existing Landfill
- Existing Structure
- Existing Substation
- Demolished Structure
- Area IV Boundary
- SSFL Property Boundary

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).
- Plume boundary dashed where inferred.
- 2016/2017 Tritium results are picocuries/L.
- U or ND - Non-detected result.
- J - Estimated Result.
- NI = Not Installed.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

0 100 200 Feet

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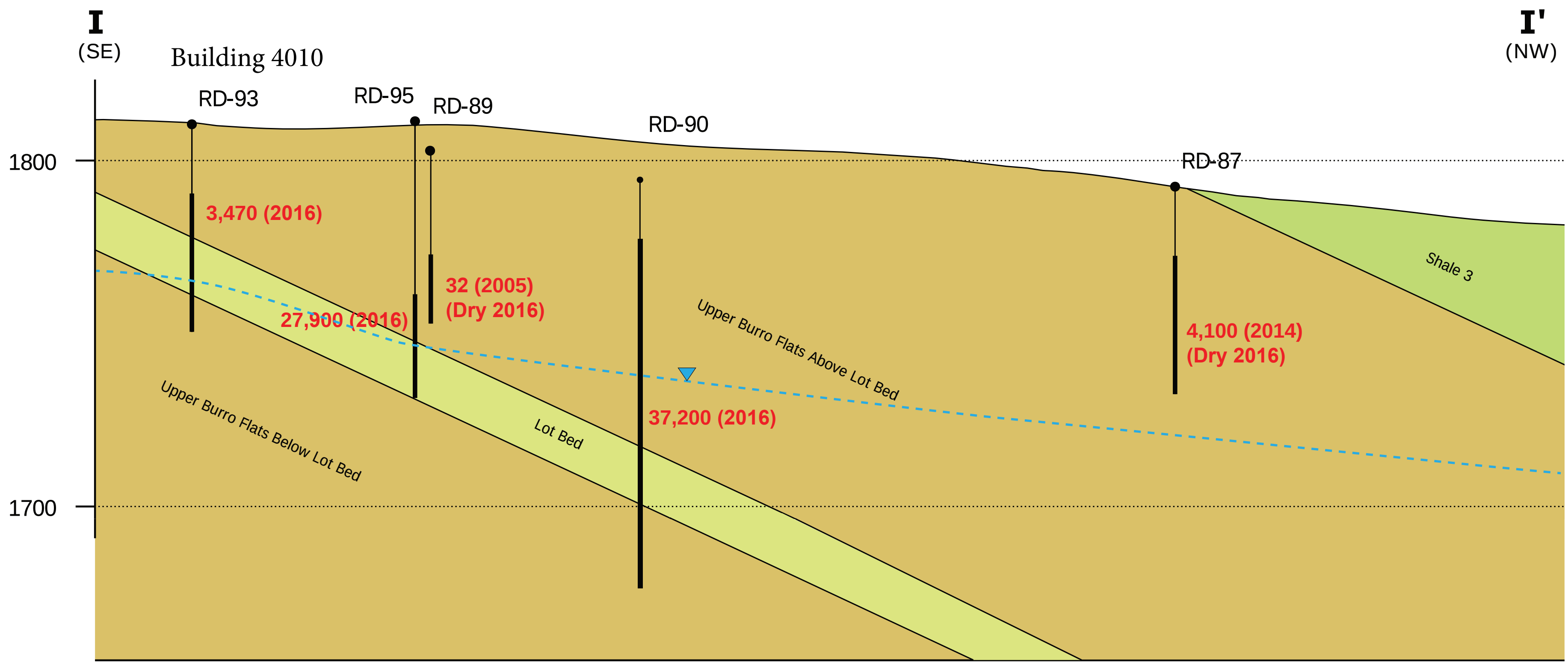
FIGURE 5.8-1
Tritium Plume Layout



Cross-section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross-section shows topographic surface along the cross-section line.

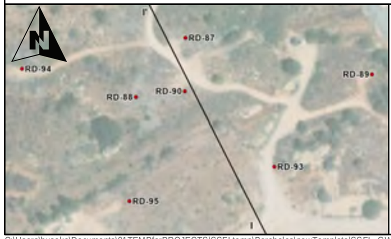
Monitoring wells may appear above or below the topographic surface depending on relationship of the well to the cross-section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

4,100 Tritium (H3) reported in picocuries per liter (pCi/L).



Notes:
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Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS
- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND
- Groundwater Level
- Water Table

0ft 100ft

C:\Users\huseke\Documents\01TEMPforPROJECTS\SSFLtemp\Boreholes\newTemplate\SSFL_GWRI_Template_letter_KH.mxd 12/22/2016

CDM Smith

FIGURE 5.8-2
Vertical Extent of Tritium in Bedrock at Tritium Plume

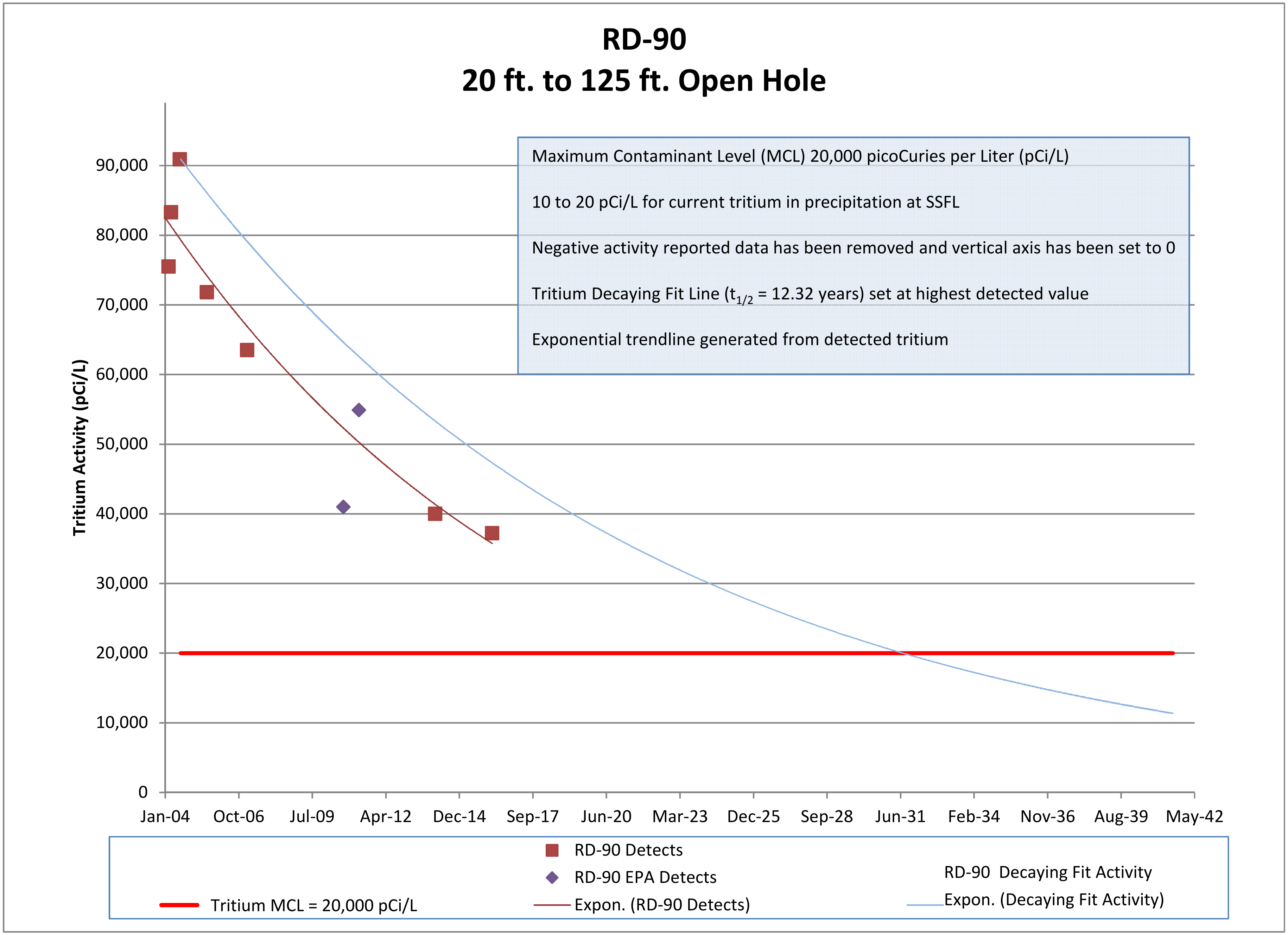

Figure 5.8-3

Tritium Decay Curve for Well RD-90

5.9 Radioactive Materials Handling Facility

The RMHF was used for the processing, packaging, and shipping of radioactive materials (solids and liquids) produced in the various nuclear testing facilities within Area IV. Well RD-27 was installed within the fenced area of the RMHF. Groundwater at this well is not impacted. The former leach field (AI-Z5) is north of the RMHF has been the focus of RMHF groundwater investigation (**Figure 5.9-1**).

5.9.1 Source Area Evaluation

Operation History

Figure 5.9-1 illustrates existing features of the RMHF. There are several structures within the fenced area of the RMHF where treatment and packaging of radioactive waste materials occurred. The leach field was constructed in 1959 for disposal of sanitary wastewater. The leach field was taken out of service for sanitary purposes in late 1961 when the central wastewater treatment facility was constructed in Area III; however, there may have been unauthorized disposal of other liquid wastes from the RMHF into the leach field after 1961.

A pipeline directed effluent from RMHF Buildings 4021 and 4022 to the leach field. This pipeline was also connected to a liquid waste holding tank in the yard of the RMHF (Rockwell 1982a). The intention of the tank was to hold radioactive liquids until their decay met discharge standards. The tank apparently received liquid containing TCE and Sr-90 wastes with a 28.8-year half-life. The liquid waste containing Sr-90 in the holding tank was speculated to have been released into the leach field in 1963 (Rockwell 1982b). The period during which the release of liquid wastes with TCE into the leach field is unknown.

Soil and Debris Removal Actions

Sr-90 contamination at the leach field was discovered in 1975 during routine monitoring in the vicinity of the RMHF when monitoring instruments indicated vegetation was contaminated by radioactivity. In 1978, contaminated soil from the leach field was excavated to bedrock. Radioactive materials observed in the upper portion of the bedrock were removed by hydraulic hammering excavation. Concentrations of up to 115,000 picocuries per gram (pCi/g)[7] of Sr-90 were observed in the excavated materials. After excavation, an average of 300 pCi/g of Sr-90 and traces of Cs-137 remained in bedrock cracks (Rockwell 1982b). The site was left with a minor amount of radioactive material in three cracks in the sandstone rock. The cracks are more than 10 ft below the surface and have been sealed with a bituminous asphalt mastic to prevent the percolation of water through the cracks and the excavation backfilled with 10 feet of soil (ESG-DOE-13385).

Three bedrock cracks exhibiting radioactive contamination were mapped prior to sealing. The cracks averaged 1.5 inches wide and were 7, 12, and 19 feet in length (Rockwell 1982b). They were estimated to be 10 feet deep, which was the depth to which hydraulic hammering was completed.

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[7] This is approximately one-half life ago (28.8 years). Concentration today would be expected to be nearly half the concentrations in 1978.

Groundwater Interim Measures

TCE was found in wells RD-30 and RD-34A, both located in the drainage below the RMHF, following their installation in 1989 and 1991, respectively. Well RD-63 was installed in 1994 for groundwater extraction. Well RD-63 was pumped intermittently for nearly 10 years and approximately 4.3 million gallons of groundwater extracted. The specific objectives of the groundwater extraction at RD-63 were not documented but it is assumed that it was in response to the TCE concentrations between 47 to 85 μg/L in RS-28, 34 to 44 μg/L in RD-30, and 42 to 91 μg/L in RD-34A. As a result of pumping, TCE concentrations in well RS-28 decreased from 59 to 15 μg/L until the well went dry in 2015. TCE concentrations in well RD-30 decreased from 34 μg/L to 5.4 μg/L. Recent concentrations in well RD-30 are between 8.4 μg/L (2013) and 4.8 μg/L (2016). TCE concentrations in well RD-34A decreased from 91 μg/L in 1993 to less than 1 μg/L and was recently reported at 0.44 μg/L (2016). During the pumping years, the maximum TCE concentration reported was 20 μg/L in 1998. Recently TCE concentrations in well RD-63 were reported at 6.1 μg/L (2014), 4.6 μg/L (2015), 4.9 μg/L (2016), and 6.2 μg/L (2017).

5.9.2 Soils, Geology, and Hydrogeology

Soil in the vicinity of the RMHF Leach Field AI-Z5 is typically less than 1 foot in depth. Numerous bedrock outcrops are present. Surface water retained in the thin soil veneer above bedrock is controlled by the bedrock topography (drainage) and is expected to flow westward (down drainage) away from the leach field. The east to west trending fractures observed in the weathered bedrock during the removal of the leach field (Carroll et al. 1982) also direct Near-surface groundwater to the west. In addition, Near-surface groundwater flow is more east to west than the typical northwesterly trend in this area, possibly following structure more than other areas. Chatsworth Formation groundwater (below the Near-surface groundwater) is predicted to flow to the northeast.

Well RD-63 was pumped for 10 years between 1994 and 2005. Drawdown of up to 30 feet was observed in well RD-30 100 feet upgradient of RD-63, and 6 to 9 feet in well RD-19 600 feet upgradient of RD-63. Pumping of well RD-63 may have had a significant impact on hydraulic gradients and groundwater flow direction near the RMHF Leach Field and may have resulted in preferential migration of TCE contamination in the direction of RD-63 during pumping.

The wells shown in **Figure 5.9-1** and the shallow groundwater flow system in this area are located in the Upper Burro Flats member of the Chatsworth Formation. Groundwater flow occurs primarily in fractures within the relatively low-permeability sandstone. Finer-grained beds within the Upper Burro Flats member likely increase the horizontal anisotropy and reduce vertical groundwater flow (**Figure 5.9-2**). The ELV fine-grained member of Sandstone 2 at the base of the Upper Burro Flats member constitutes an aquitard that isolates the Upper Burro Flats member from the underlying Lower Burro Flats member.

Groundwater elevation differences in the RD-34 well cluster suggest a small downward vertical hydraulic gradient in the shallower part of the Upper Burro Flats member and a moderate upward hydraulic gradient between the lower and upper strata of the Upper Burro Flats member.

Groundwater elevations vary significantly in wells near the RMHF Leach Field, with Near-surface groundwater wells showing greater variability than bedrock wells. Near-surface groundwater elevations correlates with monthly precipitation totals, particularly in the wettest months in which a precipitation event exceeds about 6 inches. Between 2008 and 2014, groundwater elevations in bedrock well RD-98 varied 23 feet which was somewhat less variable than groundwater elevations in well RD-34A with 28 feet in elevation change. These patterns indicate that recharge to the Chatsworth Formation groundwater is occurring in response to precipitation.

Recharge to Near-surface groundwater occurs by infiltration into overlying unconsolidated soil and bedrock. During use of the RMHF Leach Field, percolation of discharged water occurred on a more frequently than just rain events. Following excavation of the leach field, recharge to the major bedrock fractures at the leach field site would have been reduced because of the emulsified asphalt.

5.9.3 Nature and Extent of Impacted Groundwater

5.9.3.1 Groundwater Investigation Analytical Results

Shallow Well RS-28

Well RS-28 is 19 feet deep installed into weathered bedrock. It was sampled for TCE and Sr-90 periodically until 2008 when it was capped by Boeing. Sr-90 was not detected at that time. The well was not accessible for EPA's groundwater sampling in 2010 and 2011. DOE directed Boeing to reopen the well for the first quarter 2014 sampling event. Sr-90 concentrations were detected at 2.5 pCi/L in the dissolved phase in 2014. Sr-90 was non-detect in the 2015 sample, the well was dry in 2016, and the 2017 sample showed 2.62 pCi/L.

Bedrock Well RD-27

Well RD-27 is the only well within the RMHF boundaries. It is 150 feet deep and is cased from the surface to 30 feet bgs. It has been sampled nearly annually since 1989 and has not exhibited contamination. The other wells associated with the RMHF are in the drainage below the RMHF site.

Bedrock Well RD-98

Well RD-98 is a bedrock well drilled to 65 feet bgs and cased from the ground surface to 20 feet bgs. Well RD-98 was drilled in June 2008 (Cabrerra 2008). Investigative-derived waste from the drilling fluids showed 80 pCi/L of Sr-90. When first sampled (2008 and 2009), Sr-90 was below the MCL of 8 pCi/L. Groundwater elevations were low at that time. As groundwater elevations rose in subsequent years, Sr-90 was detected at higher concentrations. **Figure 5.9-3** displays a plot of Sr-90 concentration and groundwater elevation at well RD-98 over time. The highest concentration of Sr-90 (Hydrogeologic, Inc. [HGL] 2012a), was reported in 2011 at 183 pCi/L which corresponds with the highest groundwater elevation. The drier rainfall during the years 2012 to 2016 resulted in decreasing concentrations. In 2017, following a more normal winter rain period, the well exhibited Sr-90 at 114 pCi/L. This indicates that remaining Sr-90 at the leach field is shallow and has not migrated deep into the bedrock.

Bedrock Well RD-19

Well RD-19 is 135 feet deep and cased from ground surface to 30 feet bgs. It is upgradient of RD-93 and responded to pumping of RD-63 indicating it is hydraulically connected. This well has not exhibited groundwater contamination (Appendix B).

Bedrock Well RD-30

Well RD-30 is a 75-foot deep bedrock well cased from ground surface to 30 feet bgs. It was sampled for TCE and Sr-90 periodically until 2008 when it was capped by Boeing. The well was not accessible for EPA's groundwater sampling in 2010 and 2011. DOE directed Boeing to reopen the well for the first quarter 2014 sampling event. Sr-90 concentrations have either been below the MCL or non-detect during all sampling events (including 2017). The maximum TCE concentration at well RD-30 was 50 µg/L in 1989. In 2016, TCE was reported at 4.8 µg/L; 3.2 µg/L in 2017.

Bedrock Well RD-34A

Well RD-34A is the shallowest well in the RD-34 cluster. It is 60 feet deep and cased from ground surface to 16 feet bgs. TCE has been consistently detected in RD-34A. Historically TCE has been above its MCL of 5 µg/L (91 µg/L for a 1993 sample). However, the concentrations of TCE decreased following pumping of RD-63 and have remained low since. The first quarter 2014 TCE result was 0.98 µg/L, 0.18 µg/L in 2015, and 0.44 µg/L in 2016, and 2.3 µg/L in 2017

Bedrock Well RD-34B

Well RD-34B is the middle well in the RD-34 cluster. It is 415 feet deep and cased from ground surface to 360 feet bgs. In 2011, well RD-34B had a reported TCE concentration of 0.7 µg/L. In 2016 and 2017, TCE was non-detect. An obstruction is present in this well at 167 feet bgs preventing access to the open bedrock interval (360 to 415 feet bgs). Currently the well is sampled above the obstruction.

Bedrock Well RD-34C

Well RD-34C is the deepest well in the RD-34 cluster. It is 520 feet deep and cased from ground surface to 480 feet bgs. TCE has never been detected in RD-34C.

Bedrock Well RD-63

Well RD-63, installed in 1994 to extract TCE[8]-impacted groundwater, is 230 feet deep and cased from ground surface to 20 feet bgs. The well was pumped periodically for about 10 years between 1995 and 2005. TCE concentrations dropped from 20 µg/L and have remained near the MCL (4.9 µg/L in 2016 and 6.2 µg/L in 2017).

Bedrock Well DD-143

Well DD-143 was installed in June 2016 across the drainage swale northwest of well RD-98 and the leach field. It is 100 feet deep and cased from the ground surface to 19.7 feet bgs. This well was installed to provide data to determine the groundwater flow direction from the leach field. Neither TCE nor Sr-90 were detected in this well during the 2016 and 2017 sampling events.

5.9.3.2 COC Identification

Sr-90 and TCE are the two contaminants of concern at the RMHF leach field. The RMHF leach field appears to be the source for Sr-90. The presence of TCE in RD-98 indicates that the leach field was also a source for TCE. However, the continued decline in TCE concentrations in the well

[8] According to 1995 ASER

since 2008 indicated that the leach field is no longer a source. The extent of Sr-90-impacted groundwater is limited to the immediate vicinity of the former leach field.

Beryllium at 0.17 µg/L and thallium at 0.19 µg/L are the only metals detected recently in well RD-34A. Both concentrations are just above their screening levels of 0.14 µg/L and 0.13 µg/L, respectively. Based on the sample results at well RD-98, metals have not been observed consistently above their screening levels in the former leach field. Cadmium was detected at its screening level, and selenium slightly above its screening level in well RS-28. Metals have not been consistently detected in wells RD-30 and RD-63. Nitrate has been detected at concentrations less than its screening level of 10,000 µg/L.

5.9.3.3 Vadose Zone Mass Estimate

Site investigation data for the RMHF leach field show bedrock contamination extends approximately 35 feet bgs (CDM Smith 2015a). The anticipated excavation depth to remove impacted bedrock would be 40 feet. The area of the former leach field is 20 feet wide by 40 feet deep. The volume of impacted bedrock at the leach field is estimated at 415 cubic yards with an average Sr-90 concentration of 300 pCi/g.

The amount of residual TCE in bedrock is not known. The results for wells RS-28 and RD-30 indicate that TCE is primarily in the alluvium and weathered upper bedrock. TCE concentrations in RS-28 have steadily decreased from as high as 87 µg/L (1990) to 11 µg/L (2014), the last time well RS-28 exhibited water. TCE concentrations in well RD-30 have also decreased from a maximum concentration of 50 µg/L in 1989 to 4.8 µg/L in 2016. TCE concentrations in RD-98, at the leach field site, have decreased from 10 µg/L in 2008 to 2.1 µg/L in 2016. These results indicate an insignificant residual mass.

5.9.3.4 Horizontal Extent of Contamination

Figure 5.9-1 illustrates the historical extent of TCE-impacted groundwater. In 2016, TCE was not detected in any of the site wells greater than its MCL of 5 µg/L. Near-surface groundwater contamination migration appears to be westward from RD-98 following the RMHF drainage; while groundwater contours developed using bedrock groundwater elevations indicate flow direction to the northwest (**Figure 4-3**).

Groundwater monitoring for TCE and Sr-90 has been conducted at the RD-34 well cluster (since about 1994) and more recently in wells RS-28 and RD-30. Near-surface groundwater flow appears to be downgradient from RD-98 towards these wells. Concentrations of Sr-90 have been below the MCL (8 pCi/L) in all the wells except RD-98. Well RD-98 is located at the former RMHF leach field.

5.9.3.5 Vertical Extent of Contamination

Figure 5.9-2 is a cross-section parallel to the RMHF drainage illustrating the depth of Sr-90 and TCE contamination associated with the RMHF leach field. The vertical extent of TCE and Sr-90 are adequately defined by the existing well network.

5.9.3.6 Seeps Evaluation

Neither TCE nor Sr-90 have been detected in samples collected from seep probes located downgradient of the RMHF.

5.9.4 Fate and Transport

5.9.4.1 Conceptual Site Model

Sr-90 in groundwater originated with discharge of water to the RMHF former leach field. Characterization of the leach field by borings prior to remediation indicated that the highest concentrations in the leach field gravel and soil exist within 10 feet of the surface (Carroll et al. 1982). Weathered bedrock contaminated with Sr-90 that could be practically excavated were removed during remediation and the excavation backfilled with clean soil.

Based on the observations made during the excavation, the Sr-90 source is shallow bedrock between 10 and 40 feet bgs. When groundwater elevations are low during dry rainfall periods, the top of the groundwater is not in contact with the impacted bedrock and Sr-90 concentrations are at their lowest. When groundwater elevations rise in response to increased rainfall, they contact the impacted bedrock and Sr-90 concentrations rise. This cycle is expected to reoccur seasonally. The half-life of Sr-90 is 30 years, so Sr-90 concentrations could remain for over 100 years.

TCE is also present in the upper bedrock. TCE travels in bedrock fractures away from its source (assumed to be the RMHF leach field). The upper bedrock fractures are oriented east to west in the RMHF drainage consistent with the east to west migration of the TCE plume. The historical pumping of groundwater from the fractures greatly reduced the TCE concentrations in the impacted area consistent with the site conceptual model. TCE concentrations did not rebound after pumping and residual TCE observed in groundwater samples appears to be from TCE diffusing from the bedrock matrix. The concentrations of TCE that have diffused back into the fractures show a continued decline over time since most the TCE mass was removed during pumping at RD-63.

Several cracks or fractures were identified during remediation as containing Sr-90 contamination extending to greater depths. The Sr-90 concentrations remaining below the excavated zone were estimated at approximately 0.05 Curies, although there is significant uncertainty in this calculated estimate (Tuttle 1978). Elevated Sr-90 concentrations were observed in the cracks and the adjoining rock estimated to be between 200 to 1,000 pCi/g. The vadose zone below the RMHF former leach field is the principal remaining source of Sr-90 at this location, with contamination existing in the fracture zones and the sandstone matrix of the Upper Burro Flats member. Sr-90 is released to groundwater by recharge from downward percolating infiltration or by direct contact with contaminated rock when the water table rises (**Figure 5.9-3**).

5.9.4.2 Numerical Flow Model Results

Chapter 6 provides a summary of the numerical modeling of contaminant transport at the RMHF leach field. Appendix C is the modeling report.

Well RD-98 was used as the modeling point to assess movement of Sr-90 in groundwater from the RMHF leach field. **Figures 6-21 through 6-25** in Chapter 6 illustrate the modeling results.

Figure 6-21 illustrates the particle tracking possibilities for groundwater movement from well RD-98 assuming there is no restriction on time. This figure shows a north trending pathway for groundwater for more than 100 feet into the bedrock. Site data for groundwater less than 50 feet bgs indicate a more westerly flow at this location. **Figure 6-22** illustrates the relative rate of movement of groundwater based on the calibrated sit-scale groundwater flow model in the northern part of Area IV and a greater groundwater velocity than that predicted for the FSDF location. Figures **6-23, 6-24, and 6-25** illustrate how far from well RD-98 the Sr-90 is predicted to move. The release of Sr-90 occurred over 50 years ago, most likely in the early 1960s. These figures illustrate that the migration potential for Sr-90 is extremely low and is mitigated by sorption and radioactive decay.

5.9.4.3 Contaminant Fate Analysis

Sr-90 is moderately soluble in groundwater relative to many other radionuclides and its transport is governed by several processes, including advection, dispersion, radioactive decay, diffusion, sorption, and potentially colloid-facilitated transport. Advective transport in the saturated zone of the Upper Burro Flats member is primarily in the fracture network of the sandstone. Sr-90-impacted groundwater has migrated in the longitudinal and transverse directions by hydrodynamic dispersion within fractures and at fracture intersections. Radioactive decay reduces the activity and mass of Sr-90 in the groundwater with a half-life of 28.8 years.

Diffusion of dissolved Sr-90 from the groundwater in fractures into the sandstone rock matrix retards transport relative to advective transport. Diffusive mass transfer between the fractures and the rock matrix is a function of groundwater specific discharge, fracture aperture, fracture spacing, matrix diffusion coefficient, matrix porosity, and sorption coefficient in the matrix. In general, the effectiveness of matrix diffusion as a retardation mechanism in groundwater transport increases with transport distance and time from the source. Sorption onto the rock matrix also enhances diffusive mass transfer into the matrix and increases effective retardation for Sr-90 in the groundwater system.

Sr-90 is a moderately sorbing solute in most geologic media and achieves an equilibrium distribution between aqueous and solid phases. A compilation of measurements of sorption coefficient for 63 soils indicates a median value of 15 milliliters per gram (mL/g) and a highly skewed distribution that extends to very large values for some samples (EPA 1999). Sr-90 is subject to sorption via mineral surface complexation and ion exchange with some clay minerals; both of these reversible processes likely contribute to sorption and retardation of Sr-90 in sandstone of the Upper Burro Flats member. Even moderate sorption of Sr-90 in the rock matrix results in significant retardation in transport in the groundwater system, assuming matrix diffusion provides access to the sorptive capacity of the sandstone matrix.

Colloid-facilitated transport occurs when a contaminant is carried by colloids at a rate faster than it would be by groundwater alone. Such enhanced groundwater migration has been observed in natural systems for highly sorbing radionuclides, such as plutonium (Kersting et al. 1999). Groundwater colloids are particles smaller than 10 microns and may consist of various minerals or organic macromolecules. Potentially important processes for colloid-facilitated transport include sorption of Sr-90 onto colloids, advective transport of colloids, sorption and cation exchange on the sandstone matrix, filtration of colloids, and retardation of colloids. The concentration of natural colloids in groundwater can be readily measured and would provide one measure of the potential for colloid-facilitated transport. However, evaluating sorption of Sr-90 onto colloids and filtration/retardation of colloids in the groundwater flow system are more difficult and costly measurements. The sorption coefficient for colloids may be large relative to aquifer material due to the large surface area to mass ratio of colloidal particles. In equilibrium, sorption onto colloids is in balance with sorption (or cation exchange) onto the aquifer medium. Slow desorption kinetics from colloids may lead to non-equilibrium chemical conditions and enhanced colloid-facilitated contaminant transport, particularly over short transport distances and time scales (Turner et al. 2006). Colloids are subject to mechanical filtration, which may permanently remove them from groundwater, and to retardation by electrostatic attachment to mineral surfaces in the sandstone.

The potential for significant colloid-facilitated transport of Sr-90 is related to the concentration of groundwater colloids, the sorption coefficient onto colloids, desorption kinetic rates, colloid velocities, and colloid retardation. Although extensive research on colloid-facilitated transport processes has been conducted, predicting such transport at the field scale remains uncertain because of the complex interaction among these factors. However, the general conclusion is that the greatest potential for colloid-facilitated transport of radionuclides is for highly sorbing elements, such as plutonium, americium, and cesium. Sr-90 has a low potential for significant colloid-facilitated transport relative to these more highly sorbing species. For example, the groundwater transport modeling for the safety assessment of Yucca Mountain included colloid-facilitated transport of plutonium, americium, thorium, protactinium, and cesium, but not strontium (Zyvoloski et al. 2003).

Future groundwater migration of Sr-90 in the area of the RMHF former leach field will be limited by the location of the primary source in the vadose zone, diffusion into the sandstone rock matrix, sorption of Sr-90 in the matrix, and radioactive decay. Rise in the water table associated with high precipitation appears to leach Sr-90 from the vadose zone, but subsequent fall in the water table reduces the rate of release to the groundwater system resulting in lower Sr-90 concentrations in well RD-98. Sr-90 that is released to groundwater is subject to retardation by matrix diffusion and sorption along transport pathways in fractures downgradient of the RMHF former leach field. The apparent retention of Sr-90 in the vadose zone below the former leach field demonstrates the effectiveness of these processes in retarding Sr-90 migration. Radioactive decay of Sr-90 in the source zone and in the groundwater system reduces activity concentrations with a 28.8-year half-life. Colloid-facilitated transport of Sr-90 is unlikely to have a significant impact on migration in groundwater. Overall, Sr-90 contamination in the groundwater is projected to present limited risk beyond a local area near the RMHF former leach field, but will be present for periods beyond several half-lives of Sr-90 (i.e., greater than about 100 years).

Monitoring for Sr-90 concentrations is already conducted at wells RS-28, RD-30, RD-63, and the RD-34 cluster to the west of RD-98 and the RMHF former leach field. These monitoring locations are consistent with the conceptual model that groundwater flow occurs preferentially in a westerly direction due to fractures oriented in that direction.

TCE concentrations in all monitoring wells have been decreasing since the cessation of the pumping of RD-63 in 2005. The source for the TCE is no longer present and the presence of TCE in bedrock fractures and matrix continues to decline with time. Degradation products of TCE including 1,1-DCE and 1,2-DCE are present in samples collected from RD-63 demonstrating that some degradation of TCE is occurring. The 2016 groundwater sampling results showed all wells to be below the 5 µg/L MCL for TCE.

5.9.4.4 Plume Stability Assessment

Analytical results show that the TCE plume is shallow and stable. TCE concentrations in at the downgradient well cluster RD-34 show decreasing concentrations over time. The horizontal extent of Sr-90 impact is limited to the area between well RD-98 and RD-30 (**Figure 5.9-1)**.

5.9.5 Uncertainties and Data Gaps

The VOC impacted groundwater associated with the RMHF leach field is either at or below the MCL for TCE. VOCs require no further investigation. The vertical depth of the strontium-90 impacted bedrock is interpolated from Sr-90 concentration responses to rising/falling groundwater elevations. The specific depth and horizontal spread (if any) of the Sr-90 in bedrock fractures can only be determined through additional boreholes and physical extraction of the impacted bedrock.

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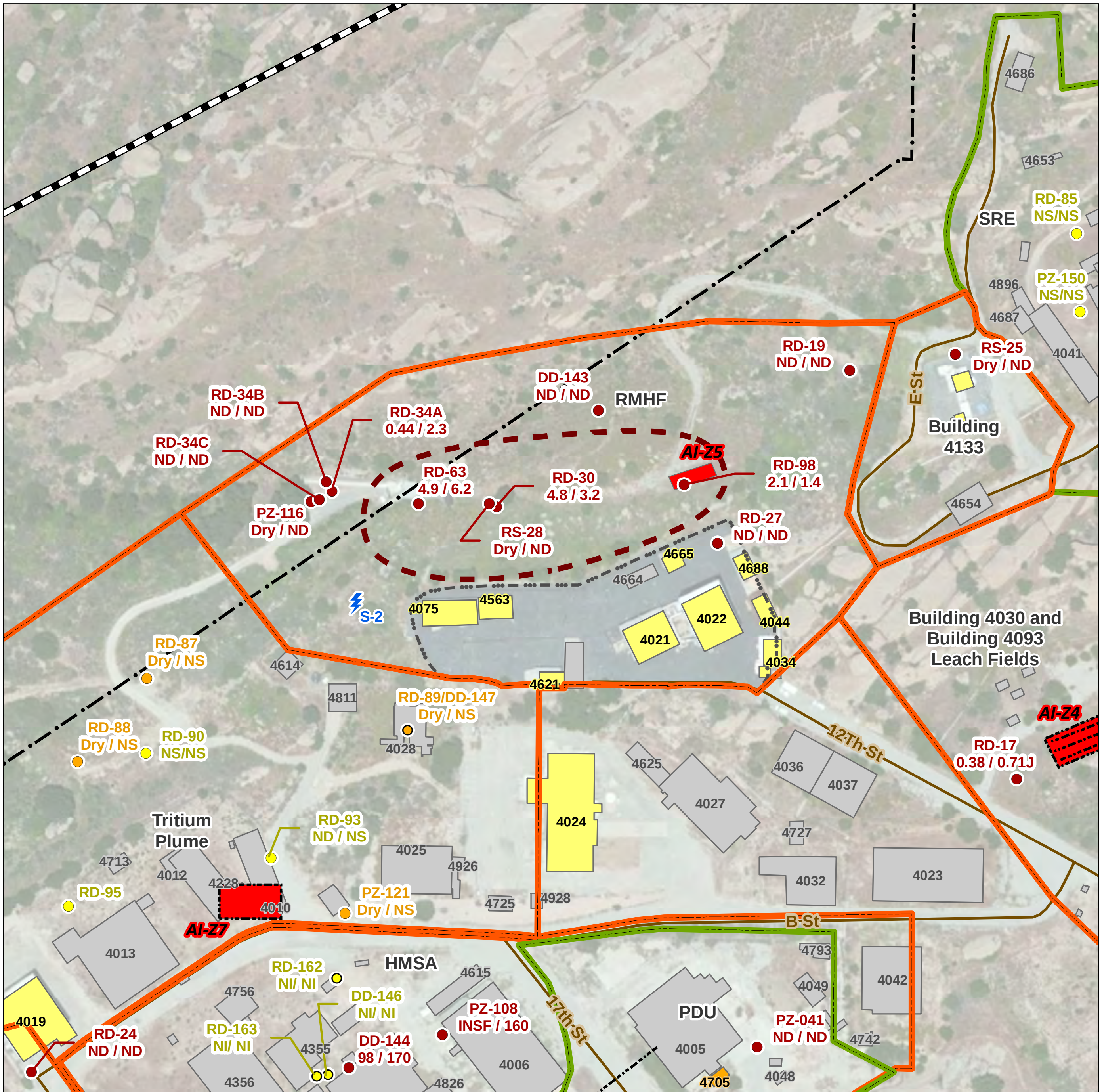


LEGEND

- Sampled Well
  - Dry well or insufficient water for purging/sampling (<3 feet of water in well designated for low-flow purging)
- Not Sampled
- Abandoned Well
- Boeing Well
- Seep
- TCE at 5 ug/L
- Road Centerline

Responsibility*
- AI-Zxx Boeing
- AI-Zxx DOE

Groundwater Investigation Area
- Boeing
- DOE
- RMHF Boundary

- Existing Structure
- Existing Substation
- Demolished Structure
- Area IV Boundary
- SSFL Property Boundary

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).
- Plume boundary dashed where inferred.
- 2016/2017 TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.
- NI = Not Installed.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

N

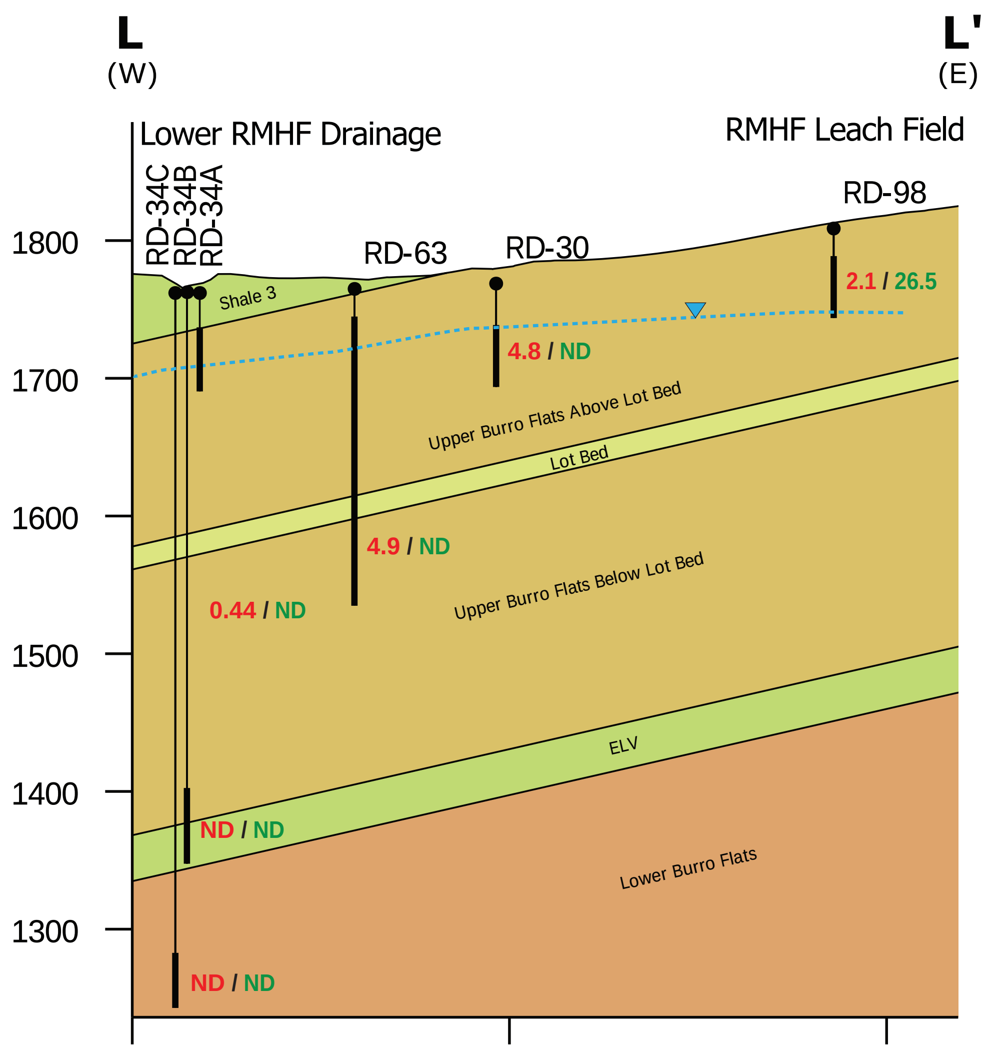
0 100 200 Feet

C:_projects\SantaSusana\GIS\MXD\Groundwater\RI\2018\SSFL_GWRI_RMHF_Layout_20180824.mxd 8/24/2018

CDM Smith

FIGURE 5.9-1

Radioactive Materials Handling Facility Layout



Cross section line is NOT drawn perpendicular to strike of Fine-Grained Units in Area IV. Instead, cross section drawn West to East. Cross section shows topographic surface along the cross section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross section line.

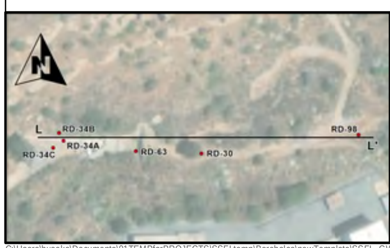
Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

21 Trichloroethene (TCE) reported in micrograms per liter (ug/L)

26.5 Strontium 90 (Sr-90) reported in picocurie per gram (pCi/L) Non-Detected (ND)



Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 300ft

C:\Users\huseke\Documents\01TEMPforPROJECTS\SSFLtemp\Boreholes\newTemplate\SSFL_GWRI_Template_letter_KH.mxd 12/22/2016

CDM Smith

FIGURE 5.9-2

Vertical Extent of TCE and Sr-90 Contamination at RMHF

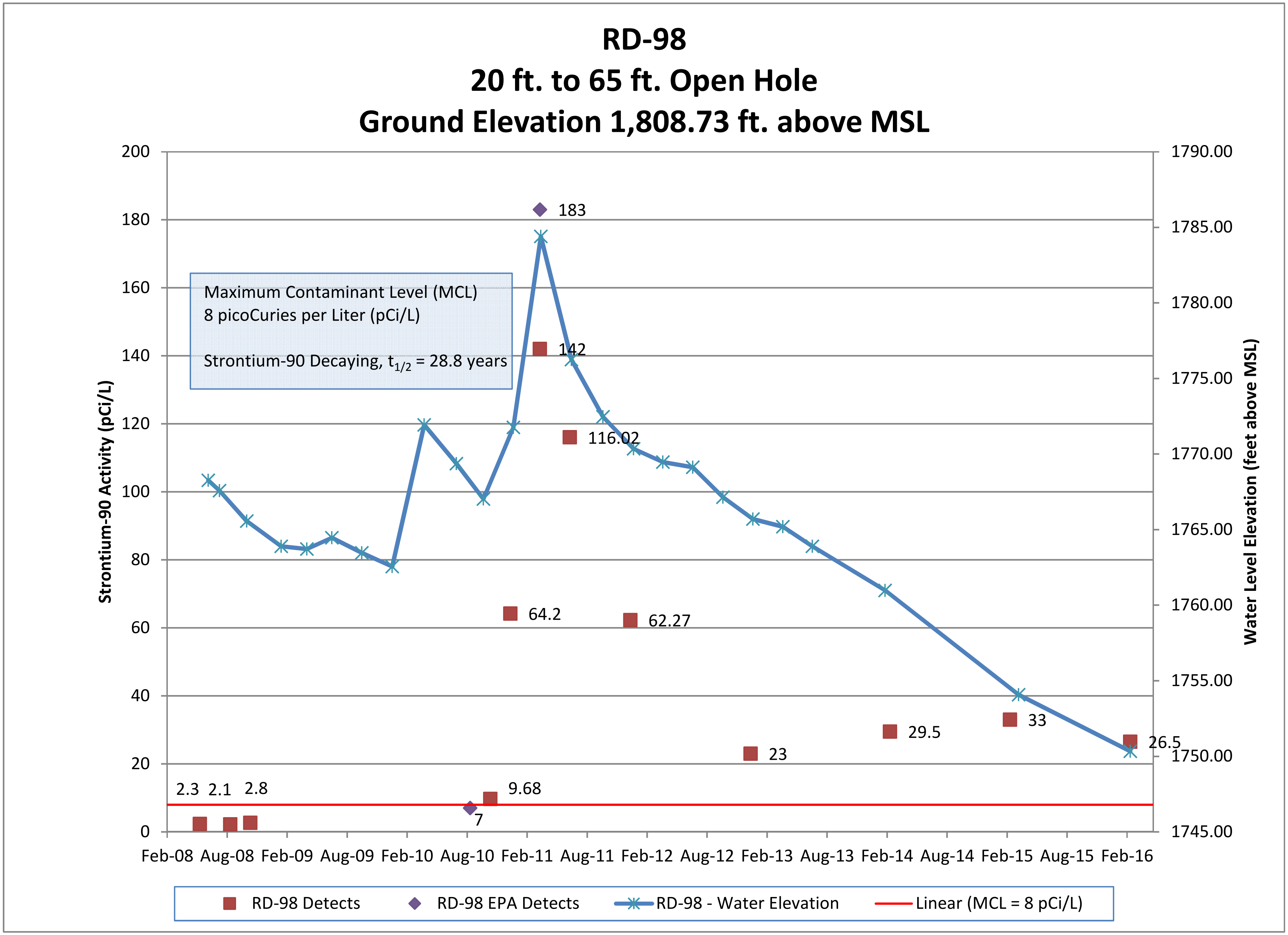


Figure 5.9-3

Relationship of Strontium-90 in RD-98 with Groundwater Elevation

5.10 Old Conservation Yard

The OCY groundwater investigation area is approximately 10 acres located along a topographic ridge in the northeastern part of Area IV. Several former storage and debris disposal areas are included in the OCY (**Figure 5.10-1**). Groundwater is monitored by one Chatsworth Formation groundwater well RD-14. Piezometer PZ-151, located outside of the OCY on the easternmost edge of Area IV about 450 feet from well RD-14 was installed to monitor a TCE plume originating in the NASA-administered Area II.

5.10.1 Source Area Evaluation

Operation History

The OCY was used from 1952 to 1977 to store salvageable materials (metal parts and equipment) used during Area IV operations. Typically, the materials were stored in drums (MWH 2006b). In 1977, the stored materials were moved to the NCY and the OCY was converted for storage by the Plant Services (Rockwell 1990). From 1986 to the late 1990s the OCY was used by the SSFL transportation department as a storage area for trailers and containers. All buildings and most other features have been removed from the OCY.

The former storage areas and other features that could have been sources of contamination are shown on **Figure 5.10-1** and include:

- Former Rocketdyne Conservation Yard – used for storage of salvageable materials and drums of unknown contents. Chlorinated VOCs were detected in soil vapor in 1997, but have not been detected in soil. Some SVOCs were detected in the surface soil of the southwest corner of the yard. No metals were detected in the soil above background (MWH 2006b). Cesium 137 (Cs-137) contaminated soil was found in a 400-square-foot area in the southwest corner of the Rocketdyne Conservation Yard in 1988 and was subsequently removed (Rockwell 1990). Benzo(a)pyrene, TPH, PCBs, and the metals boron, cadmium, lead, mercury silver, thallium, zinc were detected in soil at multiple locations of the OCY listed below.

- Former AI Conservation Yard – used for storage of salvageable materials and drums of unknown contents. Most of the yard was covered with asphalt-aggregate material. 2-Butanone (11 µg/kg) was the only VOC detected in shallow soil (MWH 2006b).

- Former North Slope Storage Area – used for storage of equipment and materials; some storage was likely in drums (MWH 2006b). No VOCs were detected in soil or soil vapor.

- Former Container Storage Area – Containers were stored on an asphalt road after the fuel farm was constructed in 1977. The area is divided by a north-south trending drainage ditch. The area is also located near the former SRE Pond drainage pipeline. No VOCs were detected in this area.

- Former ASTs 732 and 731 and Earthen Berms – Between 1952 and 1977 the area was used for storage of drums of unknown contents. In 1981, two 1.5-million gallon ASTs were constructed for storage of diesel fuel. The ASTs were removed in 1999 and the berm was leveled over the area in 2002. Due to spillage of diesel during fuel transfers, elevated TPH has been detected in soil (MWH, 2006b).

- SRE Pond Pipeline Discharge Area– the pipeline and discharge ditch diverted water from the SRE Pond to Silvernale Reservoir. During the RFI, only acetone was detected in soil beneath the pipeline although it was not considered site-related contaminant (MWH 2006b). Mercury was detected in sediment samples.
- Former Telephone Pole Storage Area – used for wooden telephone pole storage. During the RFI, some poles were observed to have been charred; all poles were removed in 2000. Soil samples were not analyzed for VOCs during the RFI (MWH 2006b). PCBs and PAHs were detected in surface soil samples.
- Northern Debris Area – used as a construction debris (metal, wood roofing material, and asbestos-containing material) disposal area. The debris was burned prior to disposal. No VOCs were detected in soil (MWH 2006b).
- Southern Debris Area – used for disposal of construction debris similar to the Northern Disposal Area. One 55-gallon drum of unknown contents was found. No VOCs were detected in the soil (MWH 2006b).
- North Slope Debris Areas A and B – used for miscellaneous material disposal. These debris areas were found after the 2005 Topanga Fire. The debris, located in a steep natural drainage, included metal, crushed drums, 5-gallon drums, and graphite cylinders. 4-Isoproyltoluene at a concentration of 1.9 µg/kg was detected in soil during the RFI (MWH 2006b). No other VOCs were detected.
- Several transformer storage areas – Soil samples collected from these areas during the RFI identified PCB contamination.
- Topographic Low Spot and Downslope Discharge Area – the area collects surface run-off from other debris and storage areas in OCY. Soil samples were not collected from this area during the RFI.

Soil and Debris Removal Actions

All debris and waste materials have been removed from the OCY. Impacted soil was addressed in the multiple removal actions taken for this area as described in the bullets in the previous section above.

Groundwater Interim Measures

No groundwater interim measures have been conducted for the OCY area.

5.10.2 Soils, Geology, and Hydrogeology

Unconsolidated materials in the OCY area include native soil and fill placed following soil and structure removal actions. Native soils are thin in some locations and are estimated to be up to 10 feet thick in other locations. Bedrock in the OCY consists of the Upper Burro Flats member of the Upper Chatsworth Formation. This member consists of fine- and medium-grained sandstone with minor interbeds of shale and siltstone. Generally, the OCY lies between the Lot Bed and the ELV fine-grained members of Sandstone 2 that contains at least 50 percent fine-grained rock (shale and siltstone).

As shown on **Figure 5.10-2**, well RD-14 is completed in Upper Burro Flats member and does not extend into the ELV. The ELV outcrops at the surface south of RD-14. The ELV fine-grained member of Sandstone 2 and Upper Burro Flats members strike N63˚E and dip 25 degrees to the northwest.

Near-surface groundwater is discontinuous and perched above the Chatsworth Formation groundwater when present.

5.10.3 Nature and Extent of Impacted Groundwater

5.10.3.1 Groundwater Investigation Analytical Results

There are no Near-surface or perched groundwater wells in the OCY. The nearest Near-surface well is piezometer PZ-151, located at the eastern edge of Area IV about 450 feet east of well RD-14. Piezometer PZ-151 was drilled to 82 feet bgs and is typically dry. It is more representative of groundwater conditions beneath Areas II and III, than the OCY.

Bedrock Well RD-14

Well RD-14 is 125 feet deep and cased from the ground surface to 30 feet bgs. It is open in the Upper Burro Flats member of the Chatsworth Formation. TCE was detected in well RD-14 when the well was first sampled in 1989 and the highest TCE concentration was 13 µg /L in 1990. From 1992 to 2010, the concentrations of TCE were below the MCL of 5 µg/L. In 2011, TCE was detected at 5.9 µg/L. Since 2011, concentrations were non-detect in 2014, 0.29 µg/L in 2015, 0.76 µg /L in 2016, and 0.43 J in 2017. The concentration of *cis*-1,2-DCE, the anaerobic degradation product of TCE, peaked at a concentration of 2.6 µg/L in early 1992, shortly after the highest TCE concentration.

Water Supply Well 07

Water supply well 07 (WS-07) was installed in 1954 to serve as an industrial water source for SSFL. It is 700 feet deep and cased from the surface to 200 feet bgs. WS-07 does not serve as a representative monitoring well due to its construction details (casing depth and lengthy open borehole). Due to its proximity to impacted groundwater originating in Area II, NASA has been sampling the well. NASA sampled WS-07 in May 2016 and TCE was not detected (CH2M Hill 2017).

5.10.3.2 COC Identification

MWH (2014b) collected three soil vapor samples in the southern part of the OCY. Benzene was the only VOC detected at 0.00871 µg /L. Relatively low concentrations of TCE have been detected in groundwater as described above. Well RD-14 has been sampled five times for metals with no consistent detections above screening levels (Appendix B).Nitrate has not been detected above its screening level in groundwater.

5.10.3.3 Vadose Zone Mass Estimate

The amount of TCE remaining in shallow bedrock is unknown, but the amount would be minimal as current groundwater concentrations are at the analytical detection limit.

5.10.3.4 Horizontal Extent of Contamination

Concentrations of TCE in groundwater are below the MCL thus there are no horizontal limits to be defined.

5.10.3.5 Vertical Extent of Contamination

Concentrations of TCE in groundwater are below the MCL thus there are no vertical limits to be defined.

5.10.3.6 Seeps Evaluation

There are no seeps in the vicinity of this groundwater investigation area.

5.10.4 Fate and Transport

5.10.4.1 Conceptual Site Model

Very low levels of some VOCs have been detected in the soil and soil vapor samples collected in portions of the OCY. The low concentrations found in soil vapor and soil measured prior to 2014 are not indicative of a continuing source of groundwater contamination. This lack of a source is supported by the fact that TCE concentrations have decreased through time. The presence of *cis*-1,2-DCE indicates the anaerobic dechlorination of the TCE.

The TCE found in groundwater was likely the result of a spill or leak to the surface soil at the OCY. The TCE would have dissolved in, and migrated through, the soil and weathered bedrock, with infiltrating precipitation until it reached the water table.

5.10.4.2 Numerical Flow Model Results

Numerical modeling was not performed at this location as there is no significant contaminant mass to model.

5.10.4.3 Contaminant Fate Analysis

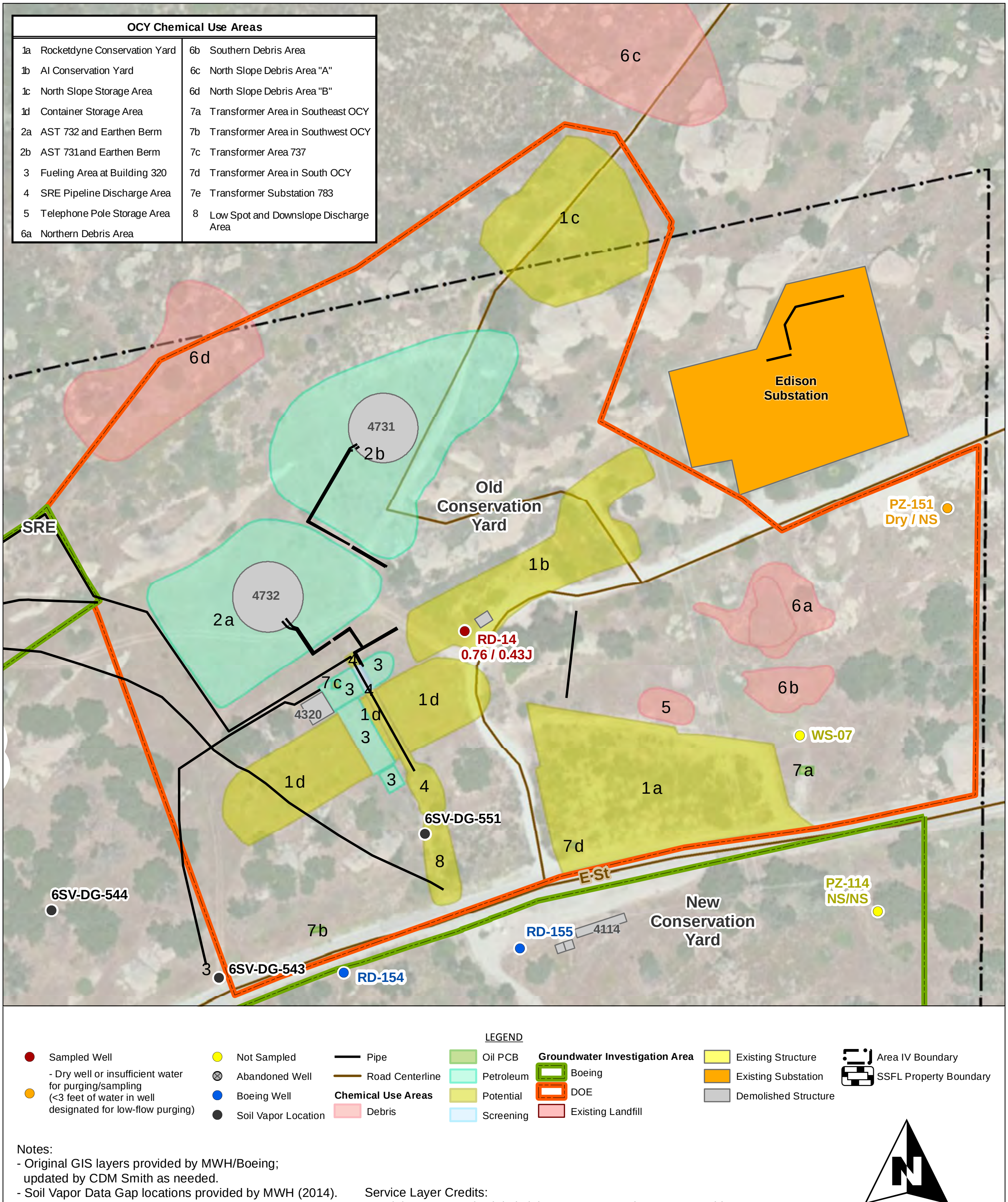
The decreasing concentrations of TCE over time along with the occasional detection of *cis*-1,2-DCE indicate that dispersion, dilution, and TCE degradation is ongoing at this location.

5.10.4.4 Plume Stability Assessment

There is no remaining VOC plume to be assessed.

5.10.5 Uncertainties and Data Gaps

The presence of metals hot spots in soils and having only one well in thes OCY area indicates a data gap. Whether or not groundwater at the hot spots has been impacted by metals is not known. Additional monitoring in this area may be necessary, should soil cleanup be delayed.



Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- Soil Vapor Data Gap locations provided by MWH (2014).
- 2016/2017 TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

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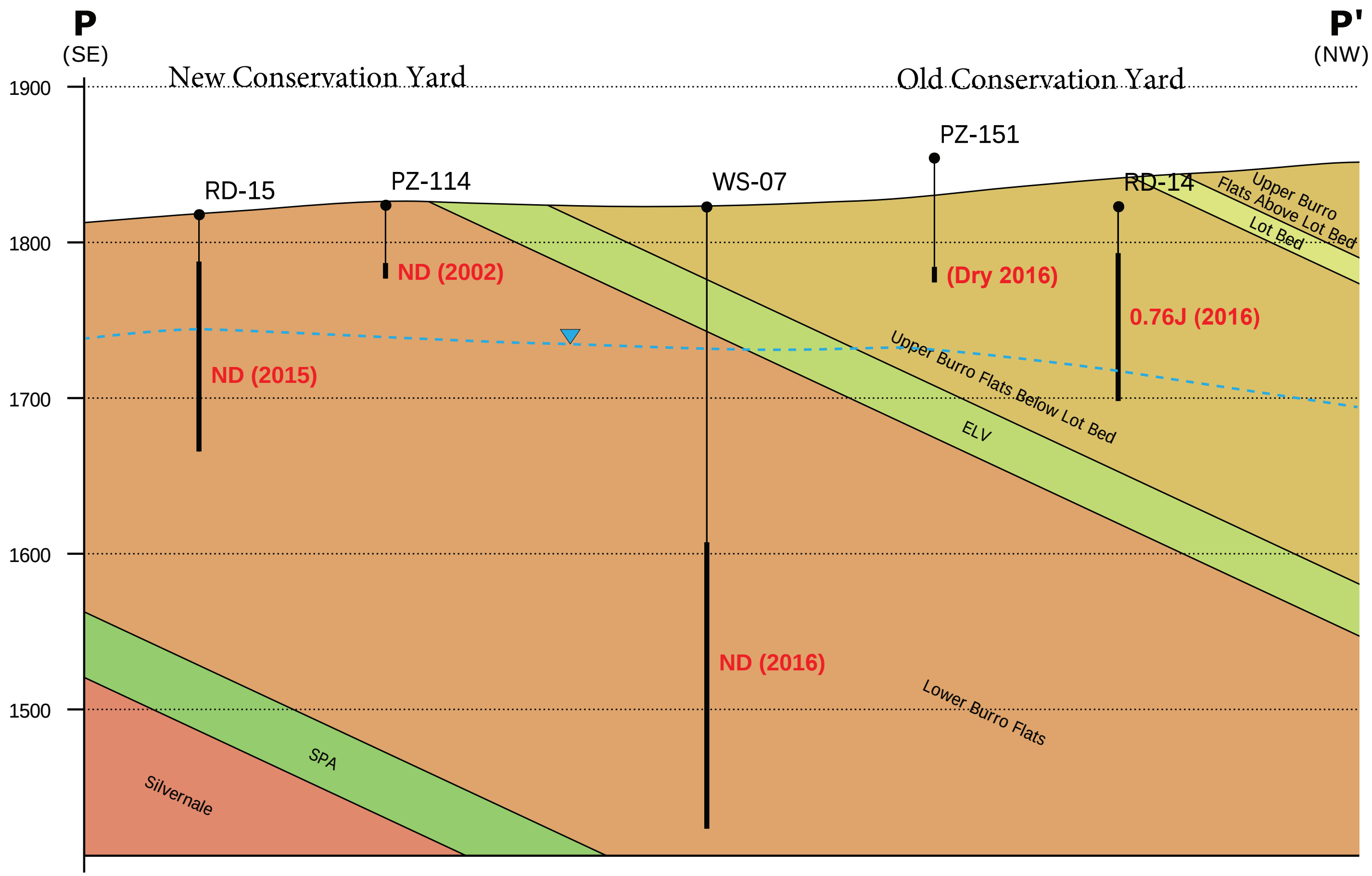
CDM Smith

FIGURE 5.10-1
Old Conservation Yard Layout



Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

0.76J Trichloroethene (TCE) reported in micrograms per liter (ug/L).

Cross-section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross-section shows topographic surface along the cross-section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross-section line.

Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 100ft

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CDM Smith

FIGURE 5.10-2

Vertical Extent of TCE Contamination at OCY

5.11 Metals Clarifier Laboratory Building 4065/ DOE Leach Fields 3

This groundwater investigation area is approximately 20 acres in the south-central part of Area IV. The DOE Leach Fields 3 RFI site includes four leach fields associated with Buildings 4353 (AI-Z15), 4363 (AI-Z14), 4373 (AI-Z13), and 4383 (AI-Z10) (**Figure 5.11-1**). Building 4065 did not have a leach field but is included in this groundwater investigation area because it proximity and overlap with the DOE Leach Fields 3 area, and because Building 4065 is a potential source of TCE to groundwater. The Metals Clarifier Laboratory Building 4065 and several former structures are where TCE may have been used and released to the environment.

There are four piezometers in the groundwater investigation area: PZ-005, PZ-103, PZ-104, and PZ-105 screened in the weathered bedrock. Piezometer PZ-005 is located immediately downgradient of Building 4065 and the PZ-104 and PZ105 are near the former leach fields (**Figure 5.11-1**). Bedrock well DD-145 was installed into the consolidated Chatsworth Formation in 2016 to monitor bedrock groundwater water quality conditions.

5.11.1 Source Area Evaluation

Operation History

Constructed in 1963, Building 4065 was used as a vacuum test facility until 1972. From 1973 until it was demolished in 1999, the building was used as the Chemical and Metallographic Analysis Laboratory. During the RFI, Building 4065 was identified as an Area of Concern. Chemicals reported to have been used include compressed gases, solvents (acetone, 1,1,1-TCA, and TCE), acids, bases and metals, and kerosene. Metals preparations were conducted under large fume hoods. The fume hoods channeled condensed gasses to a 3-stage clarifier located on the south side of the building via below-grade pipes contained in a concrete trench. The clarifier was approximately 4 wide by 12 feet long and 6 feet deep; discharge was piped underground to a sewage treatment plant in Area III. The clarifier was removed in 2000 (CH2M Hill 2008).

In addition to the four leach fields, the DOE Leach Fields 3 RFI site included 31 former and existing buildings, 12 ASTs, and 9 USTs. The facilities located in the site supported the SNAP and SRE programs from the 1950s through the 1970s. Development and testing of large sodium pumps occurred from the mid-1970s through 2001. Two of the USTs (UT-12 and UT-55; not shown) were used for fuel oil and were removed in 1986 and 1999. Evidence of a fuel oil leak was found in soil during the removal of the tanks, and metals contamination was found in soil at UT-12. A third fuel oil tank (UT-75; not shown) was removed in 2001; no contamination was found associated with this tank during removal. No spills of TCE were identified in the historical RFI documents, although spills of ethanol (1995) and isopropanol or denatured ethanol (1982) occurred at Building 4462.

The buildings associated with potential contamination impacts within this groundwater investigation area include the following:

- Building 4055 – Used 1967 to 1982 as the Nuclear Materials Development Facility and included chemistry laboratories. Solvents were used in this building and benzene and toluene were detected in soil vapor. Although no TCE was detected in soil samples, the detection limits for TCE were high in the soil samples and could have masked the presence of TCE and other VOCs. Fuel oil tank UT-55 was located at this building.

- Building 4062 - Used from 1963 to 1982 for non-nuclear reactor qualification testing, storage, and instrument calibration. Soil investigations did not identify contamination at this location.

- Building 4066 - Used from 1963 to 1982 for instrument repair and calibration and testing of non-nuclear material. Soil investigations did not identify contamination at this location.

- Building 4353 – Used in the 1960s for sodium mass transfer studies, and later as a research and development laboratory and general storage. No VOCs were reported to have been used in the building. The leach field (AI-Z15), located east of the building, received sanitary wastes (CH2M Hill 2008). No VOCs were found in soil vapor samples collected in 1993 or in soil samples collected in 2001.

- Building 4363 – Used between 1957 and1963 as a metallurgical research and development laboratory for post-test examination of SRE components. The building was the Mechanical Component Development and Counting Building, also used for sodium systems in support of the SRE. From 1963 until it was demolished in 2001, the building was primarily used for storage. No VOCs were detected in the two soil vapor samples and no soil samples were collected as part of the RFI (CH2M Hill 2008). The building was connected to a leach field (AI-Z14) that received sanitary wastes from a 1,500-gallon septic tank.

- Building 4373 – Used from 1954 to 1965 for the manufacture of high-energy rocket fuels. From 1957 to 1963 it was used for conducting SNAP reactor criticality tests. In 1964, the building was used for a sodium heat transfer facility. After 1964, the building was used for storage of heat transfer equipment. Solvents were used in the building; however, no VOCs were detected in soil vapor and no soil samples were collected as part of the RFI (CH2M Hill 2008). The building 4373 leach field (AI-Z13), located south of the building, received sanitary wastes from a septic tank (CH2M Hill 2008).

- Building 4374 – Used from 1956 to 1999 for testing non-nuclear liquid metal in heat transfer loops. Solvents were used, but no VOCs were detected in the soil vapor and soil samples collected as part of the RFI (CH2M Hill 2008).

- Building 4383 – Used between 1963 to the early 1980s, as "Instrumentation Building" and "Assembly and Testing Building." It was the liquid metal engineering center assembly and testing and construction staging building connected to leach field (AI-Z10). Solvents were used but no VOCs were detected in soil vapor. No soil samples were collected as part of the RFI (CH2M Hill 2008).

- Building 4462 – Used from 1974 to 2000 as the Sodium Pump Test Facility. No solvents were reported to have been used in Building 4462. VOCs were detected in one soil sample collected as part of the RFI, but concentrations were below the RFI screening criteria (CH2M Hill 2008).

- Building 4463 – Used from 1974 to 2000 as a sodium cleaning and handling facility. The building is attached to Building 4462. These facilities (Buildings 4462 and 4463) included one AST used for liquid nitrogen, two ASTs used for water, and two USTs for generator petroleum fuel storage. Soil sampling and analyses conducted during the RFI did not identify any impacted soils associated with these fuel tanks (CH2M Hill 2008). All ASTs and USTs have been removed.

Soil and Debris Removal Actions

All buildings except Buildings 4055 (Nuclear Materials Development Facility), and 4462 and 4463 (the sodium pump test facilities) have been removed. The leach fields associated with the buildings were removed between 2000 and 2002. The normal practice at the time of building removal was to address any soil contamination encountered during facility removals. Records are not available on the types and amount of soil removal actions that may have accompanied building and leach field removal.

Groundwater Interim Measures

There have been no groundwater interim actions in this groundwater investigation area.

5.11.2 Soils, Geology, and Hydrogeology

Soil thickness in this groundwater investigation area is estimated to be up to 20 feet in depth. The majority of the area is within the Lower Burro Flats member of the Chatsworth Formation, although the far southeast corner of the investigation area is underlain by the fine-grained SPA member of Sandstone 2 and Silvernale Member of the Chatsworth Formation. The strata in this area strike about N63˚E and dip about 25˚ northwest. The fine-grained SPA member of Sandstone 2 dips beneath the site, at a depth of about 20 feet at piezometer PZ-105.

All four piezometers (PZ-005, PZ-103, PZ-104, and PZ-105) in the groundwater investigation area are screened in the Near-surface groundwater within the weathered bedrock. The potentiometric surfaces shown on **Figure 4-1** and **Figure 4-2** are developed from above average precipitation and below precipitation years, respectively. The Near-surface groundwater contours show in **Figure 4-3** illustrate that the groundwater investigation straddles the southwestern portion of the groundwater mound present in Area IV.

5.11.3 Nature and Extent of Impacted Groundwater

5.11.3.1 Groundwater Investigation Analytical Results

The Metals Clarifier Laboratory Building 4065/DOE Leach Fields 3 area is monitored by four piezometers (PZ-005, PZ-103, PZ-104, and PZ-105) and one Chatsworth Formation well (DD-145; Figure 5.11-2.

Piezometer PZ-005

Piezometer PZ-005 was drilled to 45 feet bgs and is screened between 25 to 45 feet bgs. PZ-005 is the closest monitoring well to Building 4065. TCE and PCE were detected at 8 µg/L and 4 µg/L, respectively in 2002, 3.4 µg/L and 1.4 µg/L respectively in 2013, and 1.5 and 0.28 J µg /L, respectively in 2017.

Piezometer PZ-103

Piezometer PZ-103 was drilled to 39 feet bgs and is screened between 36 to 39 feet bgs. TCE was detected at 3 µg/L in 2003 and 2.2 µg/L in 2014. It had insufficient water to sample in 2014, 2015, and 2016, but showed 0.53 J µg /L TCE in 2017. PCE has not been detected in samples collected from this well.

Piezometer PZ-104

Piezometer PZ-104 was drilled to 38.5 feet bgs and is screened between 17 to 27 feet bgs. It is downgradient of PZ-005 has exhibited decreasing TCE concentrations over time with concentrations of 9 µg/L in 2003, 6.4 µg/L in 2013, and 3.4 µg/L in 2014. The well was dry in 2016, but showed 1.8 µg /L TCE in 2017/. PCE has not been detected in samples collected from this well.

Piezometer PZ-105

Piezometer PZ-105 was drilled to 28 feet bgs and is screened between 17 to 27 feet bgs. It has exhibited the highest TCE concentration in Near-surface groundwater in this area with concentrations at 10 µg/L in 2009. TCE was detected at 8.7 µg/L in 2014 and was not detected above the laboratory reporting limit of 5.9 µg/L in 2015. The well was dry in 2016, but showed 7.9 µg /L TCE in 2017.

Bedrock Well DD-145

Well DD-145 was drilled in February 2016 to 82 feet bgs and is cased from the ground surface to 27 feet bgs. This well is used to monitor the upper Chatsworth formation groundwater adjacent to piezometer PZ-104. The well was sampled in March and October 2016 and TCE was detected at 0.31 µg/L and 0.35 µg/L, respectively. The 2017 sampled showed 0.92 J µg /L of TCE. This indicates that the TCE in the Near-surface groundwater has not migrated appreciably into the Chatsworth Formation groundwater.

5.11.3.2 COC Identification

TCE and its associated breakdown products are the primary COCs at the Metals Clarifier Laboratory Building 4065/DOE Leach Fields 3 area. The PCE detected at piezometer PZ-005 may indicate a separate contaminant source near the metals clarifier.

MWH (2014b) collected 24 soil vapor samples within this groundwater investigation area (see Appendix E). The soil vapor sample collected at former Building 4065 (5CSV_DG-543) contained TCE at 0.19 µg/L. At former leach field AI-Z10 (5CSV_DG-516) PCE was detected at 0.021 µg/L and TCE at 0.034 µg/L in the soil vapor sample. PCE was detected at an estimated concentration of 0.0098 J µg/L in soil vapor sample near the Boeing Area III EEL facility (5CSV_DG-511). There were no VOCs detected in soil vapor samples collected at former leach fields AI-Z13 (5DSV_DG-530), AI-Z14, and AI-Z15 (5DSV_DG-532) (**Appendix E**).

Metals including barium, beryllium, cadmium, chromium, cobalt, copper, manganese, nickel, selenium, silver, thallium and vanadium were detected in piezometer samples above their respective screening levels. These metals were also detected in well DD-145 but below screening levels. Cadmium, selenium, and silver have been identified as soil contaminants for Area IV. The source for the other metals observed in groundwater samples probably reflects background variability for these elements. Nitrate was detected in piezometer PZ-005 in 2008 at 64,000 µg/L and 71,000 µg/L exceeding the screening level of 45,000 µg/L.

5.11.3.3 Vadose Zone Mass Estimate

With a trend of decreasing TCE concentrations in groundwater, particularly in the Building 4065 area, it is likely that the source has dissipated and no appreciable mass of TCE remains in the vadose zone.

5.11.3.4 Horizontal Extent of Contamination

Concentrations less than 10 µg/L of TCE have been detected in piezometers PZ-005, PZ-104, and PZ-105 since 2013. The analytical results for TCE are plotted spatially on **Figure 5.11-1**. TCE has decreased in the years since sampling first started, specifically concentrations at piezometers PZ-005 and PZ-104 that were below the MCL of 5 µg/L and the concentration in well PZ-105 that was 8.7 µg/L in 2014.

5.11.3.5 Vertical Extent of Contamination

Bedrock well DD-145 contained TCE at a concentration of less than 1 µg/L indicating that depth of impacted groundwater is approximately 30 feet bgs (**Figure 5.11-2**).

5.11.3.6 Seeps Evaluation

There are no seeps in the vicinity of this groundwater investigation area.

5.11.4 Fate and Transport

5.11.4.1 Conceptual Site Model

The source of TCE contamination in the Near-surface groundwater this groundwater investigation area is uncertain, although the source of contamination in piezometer PZ-005 is likely the metals clarifier. As shown on **Figure 5.11-1**, there were multiple potential sources of TCE located upgradient of well PZ-104 and PZ-105, including several buildings and leach fields. However, TCE was not detected in the soil in these areas. The metals clarifier and leach fields were removed between 2000 and 2002 which is believed to have removed those potential sources.

TCE present in soil would enter the Near-surface groundwater by infiltrating precipitation. The concentrations detected in the Near-surface groundwater indicate an insignificant release.

Once in the Near-surface groundwater, TCE would migrate with groundwater flow, diffusing into the weathered rock matrix and potentially undergoing dechlorination. The oxygen reduction potential (ORP) measured during the 2013 groundwater sampling event indicated that groundwater is reducing. Although there are downward vertical gradients migration of TCE to the unweathered Chatsworth Formation groundwater would be expected to be minimal due to the low initial concentrations, the diffusion of TCE into the weathered rock matrix, and the presence of the underlying fine-grained SPA member of Sandstone 2 of the Chatsworth Formation.

5.11.4.2 Numerical Flow Model Results

Chapter 6 provides a summary of the numerical modeling of contaminant transport at the Metals Clarifier Laboratory Building 4065/DOE Leach Fields 3. Appendix C provides the modeling report.

Piezometer PZ-105 was used as the modeling point to assess movement of groundwater from this groundwater area. **Figures 6-31 through 6-35** in Chapter 6 illustrate the modeling results. **Figure 6-31** illustrates the particle tracking possibilities for groundwater movement from piezometer PZ-105 assuming there is no restriction on time frame. This figure shows a westward trending groundwater pathway. **Figure 6-32** illustrates the relative rate of movement of groundwater based on the results of the model using hydrogeologic properties for the central part of Area IV. This figure illustrates a greater groundwater velocity than that predicted for the FSDF location. **Figures 6-33, 6-34, and 6-35** illustrate how far from the PZ-105 location the TCE is predicted to move, which reflects the current extent of TCE-impacted groundwater. Because TCE in this area is already at the MCL, advective and dispersion properties are expected to continue to degrade this plume.

5.11.4.3 Contamination Fate Analysis

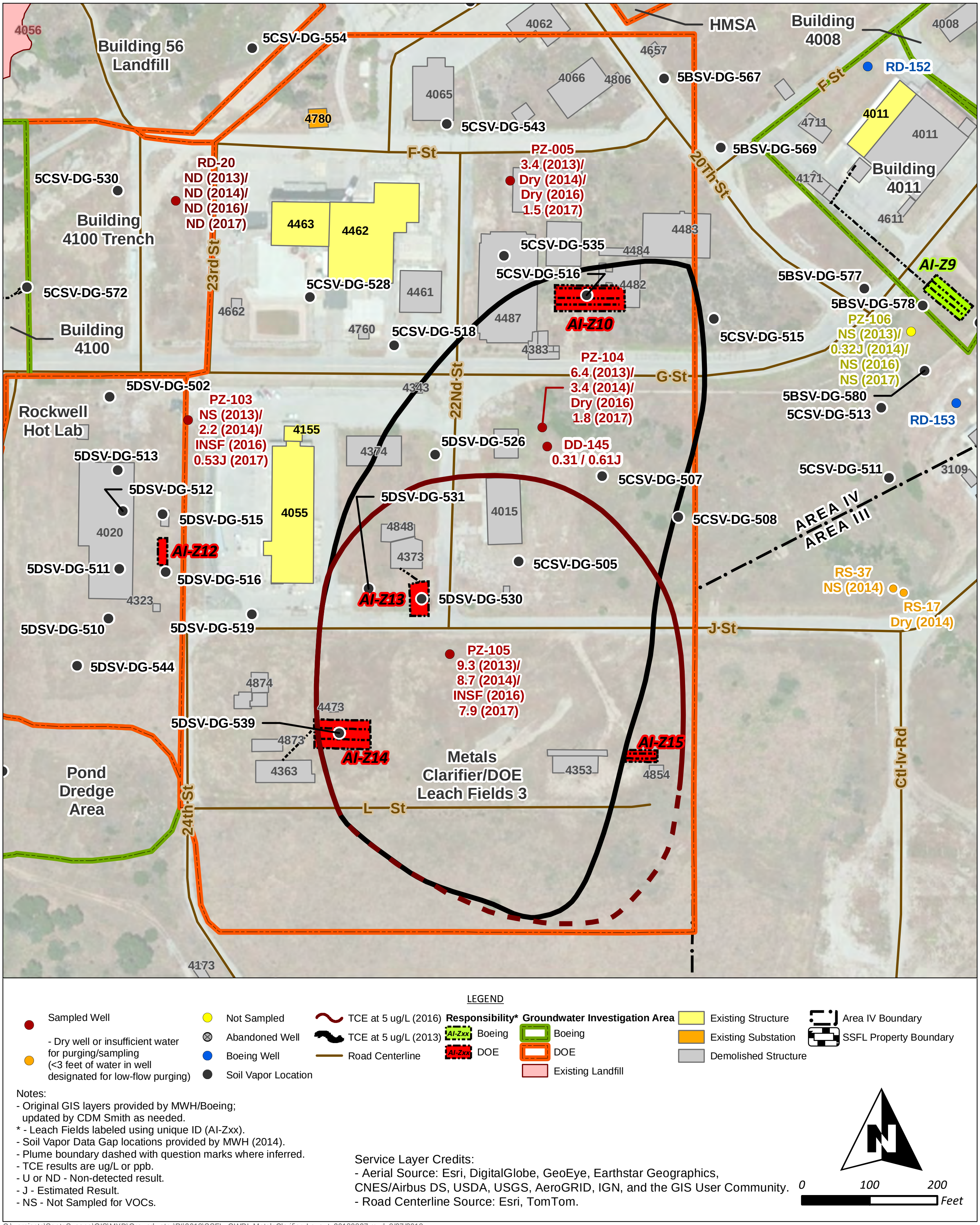
The historical and recent data illustrate decreasing TCE concentrations resulting from degradation, dispersion and dilution of the plume. There is no remaining source to contribute to groundwater contamination.

5.11.4.4 Plume Stability Analysis

Figure 5.11-1 illustrates the size of the groundwater plume in 2016. The plume is stable.

5.11.5 Uncertainties and Data Gaps

There are no data gaps or uncertainties with this groundwater investigation area for VOCs. Further evaluation of metals hotspots may be warranted.



Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
* - Leach Fields labeled using unique ID (AI-Zxx).
- Soil Vapor Data Gap locations provided by MWH (2014).
- Plume boundary dashed with question marks where inferred.
- TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.
- NS - Not Sampled for VOCs.

Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

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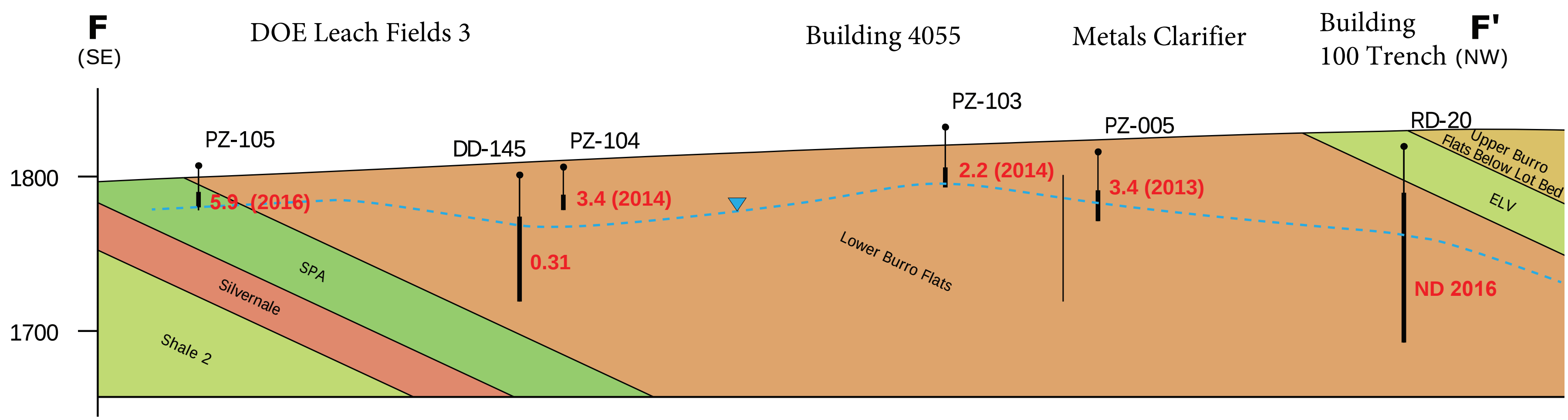
CDM Smith

FIGURE 5.11-1
Metals Clarifier/DOE Leach Fields 3 Layout



Cross-section line is drawn perpendicular to strike of fine-grained units in Area IV. Cross-section shows topographic surface along the cross-section line.

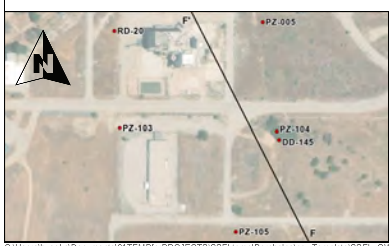
Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross section line.

Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

2.2 Trichloroethene (TCE) reported in micrograms per liter (ug/L)



Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 100ft

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CDM Smith

FIGURE 5.11-2

Vertical Extent of TCE Contamination at Metals Clarifier/DOE Leach Fields 3

5.12 Building 4064 Leach Field

The Building 4064 Leach Field (AI-Z2) is located about 20 feet northeast of former Building 4064 in the northeastern part of Area IV. Chatsworth Formation groundwater in the vicinity of the leach field had been monitored solely by well RD-92 shown on **Figure 3-7**. Wells DS-45 and DS-47 were installed at the former leach field in 2016. The buildings, leach fields, and wells are shown on **Figure 5.12-1**.

5.12.1 Source Area Evaluation

Operation History

Building 4064 was constructed in 1958 and was used as the former Nuclear Materials Storage Facility. Packaged source material including depleted uranium and thorium and enriched uranium-233 were stored in the building. There were no process tanks or sinks. There was no reported chemical use in Building 4064 (MWH 2006b). There were three documented releases of radiological materials at Building 4064 (MWH 2006b):

- In 1963, a leaking drum containing irradiated fuel pins was discovered to have contaminated soil and concrete with Cs-137 and Cs-134.
- In 1964, a can of uranium carbide oxidized and spilled on the concrete dock, resulting in increased alpha radiation levels.
- In 1967, a drum of uranium oxide (U_3O_8) was opened outside on plastic sheeting and some of the waste fell onto the plastic. Wind dispersed the U_3O_8 resulting in increased alpha radiation on surrounding vegetation.

Soil and Debris Removal Actions

As part of investigation of the building site, an area of Cs-137 impacted soil was excavated from the Building 4064 side yard . The soil was also found to be contaminated with methylene chloride (40 µg/kg) and acetone (130 µg/kg).

The leach field was constructed of 120 linear feet of leach lines branching out from a 750-gallon septic tank. The leach field and septic tank were not used after 1961 but remained in place until they were removed in 1997. No elevated metals were found in waste characterization samples. The demolition of Building 4064 was completed in 1999 (MWH 2006b).

Groundwater Interim Measures

No groundwater contamination has been reported for the Building 4064 Leach Field so no GWIM actions have occurred.

5.12.2 Soils, Geology, and Hydrogeology

Soil in the area is approximately 1-foot deep as indicated by the boring logs from the RFI (MWH 2008b). When the leach field was removed, the excavation was not backfilled; instead it was re-graded. The leach field was located above the subcropping ELV fine-grained member of Sandstone 2, which dips beneath the Building 4064. A trench between the former building and the leach field was within weathered siltstone at a depth of about 1.5 feet. Other borings encountered siltstone and shale gravel (MWH 2006b).

Well DS-45 was drilled in 2016 into the top of the ELV at depth of 75 feet bgs. Near-surface groundwater was not observed in the shallow soil and weathered bedrock. **Figure 5.12-2** is a geologic cross-section encompassing the groundwater investigation area.

5.12.3 Nature and Extent of Impacted Groundwater

5.12.3.1 Groundwater Investigation Analytical Results

Prior to 2016, bedrock well RD-92 served as the closest monitoring well to Building 4064. RD-92 also monitors the New Conservation Yard area. This well has not exhibited VOC contamination in recent years. In 2016, two Chatsworth Formation bedrock wells (DS-45 and DS-47) were installed at the Building 4064 leach field (**Figure 5.12-1**).

Bedrock Well DS-45

Well DS-45 was drilled to 75 feet bgs and is cased from the ground surface to 18 feet bgs. The well was dry after installation in 2016 and did not exhibit water in 2017.

Bedrock Well DS-47

Well DS-47 was drilled to 145 feet bgs and is cased from the ground surface to 18 feet bgs. The well was sampled in March 2016 and 2017 and was non-detect for VOCs and was below screening levels for metals.

5.12.3.2 COC identification

No groundwater COCs have been identified at Building 4064. Metals have been detected in the groundwater samples from well RD-92 but with no consistent exceedances of screening levels.

5.12.3.3 Vadose Zone Mass Estimate

No contamination was identified in soil or groundwater.

5.12.3.4 Horizontal Extent of Contamination

No contamination was identified in groundwater.

5.12.3.5 Vertical Extent of Contamination

No contamination was identified in groundwater.

5.12.3.6 Seeps Evaluation

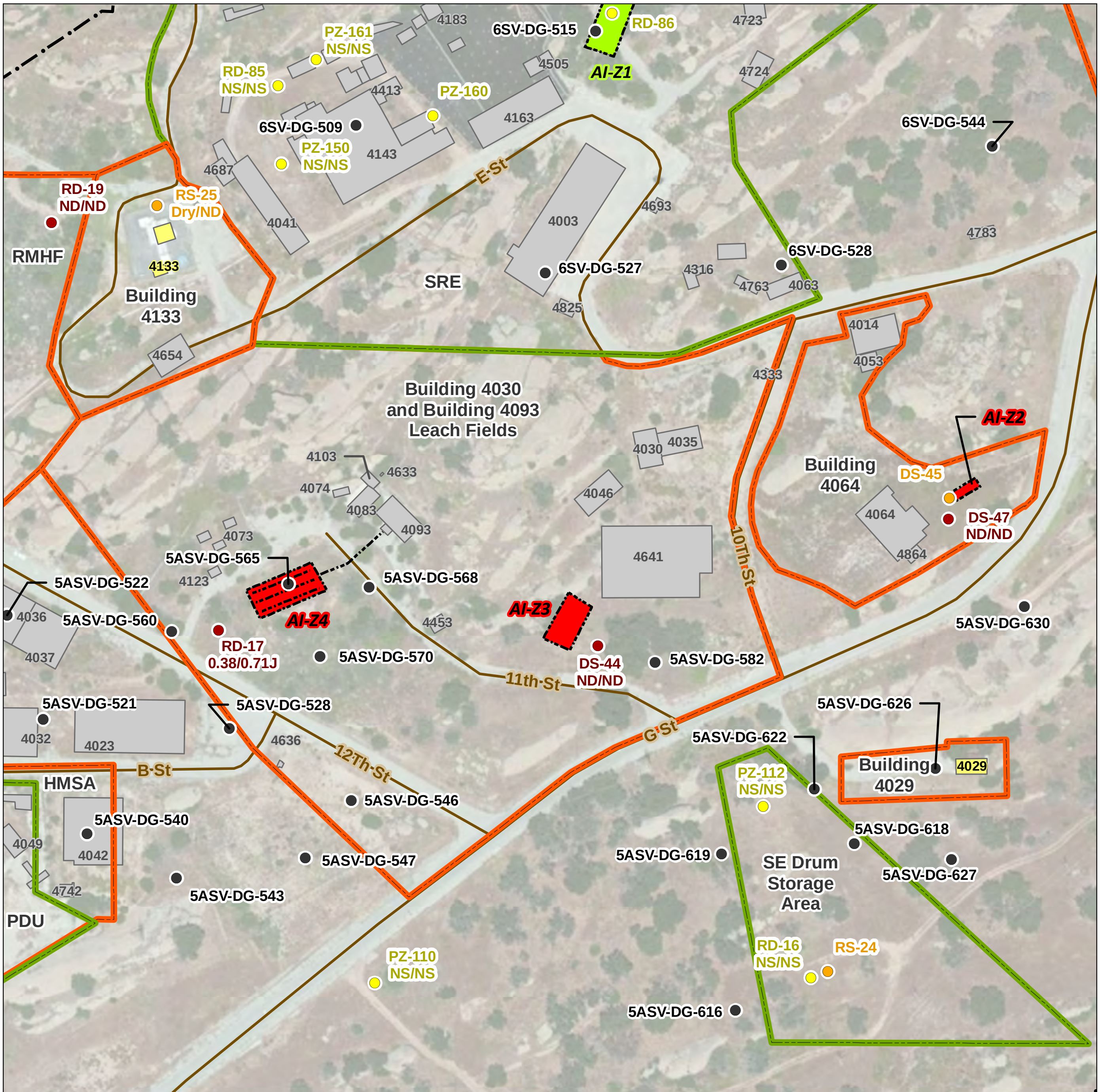
There are no seeps in the vicinity of this groundwater investigation area.

5.12.4 Fate and Transport

No contamination was identified in groundwater.

5.12.5 Uncertainties and Data Gaps

There are no data gaps or uncertainties with this groundwater investigation area for VOCs or metals.



LEGEND

- Sampled Well
- Dry well or insufficient water for purging/sampling (<3 feet of water in well designated for low-flow purging)
- Not Sampled
- Abandoned Well
- Boeing Well
- Soil Vapor Location
- Road Centerline
- **Responsibility***
  - Boeing
  - DOE
- **Groundwater Investigation Area**
  - Boeing
  - DOE
  - Existing Structure
- Existing Substation
- Demolished Structure
- Area IV Boundary
- SSFL Property Boundary

Notes:
- Original GIS layers provided by MWH/Boeing; updated by CDM Smith as needed.
- * - Leach Fields labeled using unique ID (AI-Zxx).
- Soil Vapor Data Gap locations provided by MWH (2014).
- 2016/2017 TCE results are ug/L or ppb.
- U or ND - Non-detected result.
- J - Estimated Result.

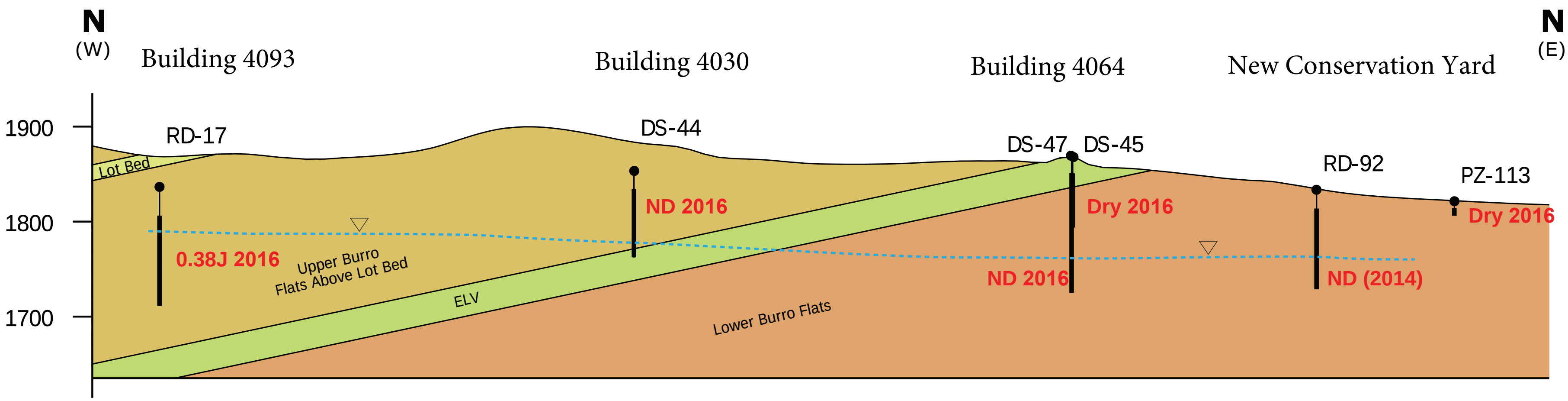
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
- Road Centerline Source: Esri, TomTom.

0 100 200 Feet

C:_projects\SantaSusana\GIS\MXD\Groundwater\RI\2018\SSFL_GWRI_4029_4030_4064_4093_SEDrum_Layout_20180824.mxd 8/28/2018

CDM Smith

FIGURE 5.12-1
Buildings 4030/4064/4093 Leach Fields Layout



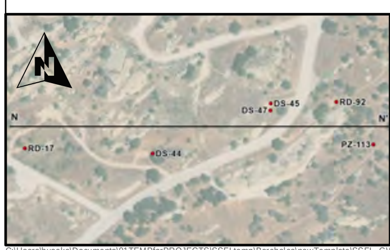
Thin black line represents casing in borehole.

Thick black line represents open borehole.

1800 elevation in feet above mean sea level.

0.38J Trichloroethene (TCE) reported in micrograms per liter (ug/L).

Cross-section line is not drawn perpendicular to strike of fine-grained units in Area IV. Cross-section shows topographic surface along the cross-section line. Monitoring well may appear above or below the topographic surface depending on relationship of the well to the cross section line.



Notes:
- GIS Layers provided by MWH/Boeing.
Service Layer Credits:
- Aerial Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

GEOLOGIC LAYERS

- Shale 3
- ELV
- Lower Burro Flats
- SPA
- Sage
- Shale 2
- Silvernale
- Simi Formation
- Upper Burro Flats Above Lot Bed
- Upper Burro Flats Below Lot Bed
- Lot Bed

LEGEND

- Groundwater Level
- Water Table

0ft 400ft

C:\Users\huseke\Documents\01TEMPforPROJECTS\SSFLtemp\Boreholes\newTemplate\SSFL_GWRI_Template_letter_KH.mxd 12/22/2016

CDM Smith

FIGURE 5.12-2

Vertical Extent of TCE Contamination at Building 4064 Leach Field

5.13 Building 4030 and Building 4093 Leach Fields (DOE Leach Field 1)

The Building 4030 and Building 4093 leach field groundwater investigation area corresponds to the DOE Leach Field 1 RFI site. Several buildings in the area around Building 4030 and Building 4093 were used in support of the Kinetics Experiment Water Boiler (KEWB) reactors and the Water Boiler Neutron Source (WBNS) reactor. Both reactors used uranyl sulfate as fuel. The RFI identified potential chemical use in several buildings included in the Building 4030 and Building 4093 leach field groundwater investigation area (CH2M Hill 2008). TCE has been consistently detected in bedrock well RD-17, but always at concentrations below the MCL. VOC contamination was not observed in bedrock well DS-44. TCE has not been detected in piezometer PZ-112 (to the southeast), although it is frequently dry. The buildings, leach fields, and wells used to monitor groundwater are shown on **Figure 5.12-1**.

5.13.1 Source Area Evaluation

Operation History

The Building 4030 leach field (AI-Z3), located southwest of the building, was used from 1958 to 1961 and received sanitary waste from a 1,000-gallon septic tank. The system included 90 linear feet of pipe. Building 4030 and adjacent Building 4035 were used as a counting room and work shop from 1960 to 1964 for the Van de Graff accelerator experiments. Beginning in 1972, the buildings were used for purchasing, shipping, receiving, and warehousing. In 1991, there was a release of less than 10 gallons of diesel fuel. The chemical storage yard at Building 4035 was the site of two releases in 1987 including 1,000 pounds of nickel chloride flake and 1 pint of Turco 3878 (sodium chromate).

The Building 4093 leach field (AI-Z4) was used from 1958 to 1961. Although, not confirmed, the construction is likely to have been 4-inch terracotta clay pipe surrounded by gravel and buried 2 to 6 feet bgs. Three leach lines, a total length of 234 feet, received waste from a 750-gallon septic tank. The leach field and tank were removed in 1999 (CH2M Hill 2008). Building 4093 was used for the WBNS reactor from 1958 to 1980. In 1985, the building was decommissioned and all uranyl sulfate fuel was removed. The building was released for unrestricted use in 1987 and was used for storage beginning in 1987.

Three releases were documented to have occurred in this building. In 1959, there was a fission gas release to air. In 1982, there was a release of uranium-235 (U-235) water to the floor and concrete shield. In 1995, a radioactive High Efficiency Particulate Air (HEPA) filter was found in a pile of debris. Only the liquid waste could have threatened groundwater.

Other reactor and support buildings with documented chemical use (CH2M Hill 2008) within this groundwater investigation area include:

- Building 4073 was used for the KEWB reactors from 1956 to 1966. The building was decontaminated in 1968 and removed in 1975.
- Building 4023 was used as a liquid metals and analytical lab in support of SNAP from 1962 until the late 1970s. It was used to conduct studies of radioactive contamination transport

of Manganese-54 (Mn-54) and Cobalt-60 (Co-60). The building was used until 1958 to remove radioactive isotopes from nuclear fuel. Lithium chloride, potassium chloride, and cadmium were used. Possible releases of Mn-54 occurred in 1980 and 1981 and 0.1 gallon of mercury was released in 1997.

- Building 4074 was a storage and x-ray film processing facility which was demolished in 1995.
- Building 4083 was a reactor kinetics control building.
- Building 4103 was a reactor kinetics lab also used for storage.
- Building 4123 was used for temporary storage of radiological waste material.
- Building 4453 was used for neutron radiography and uranyl sulfate handling.
- Building 4641 was used for shipping and receiving from 1964 to 1985. Materials handled in the building included radiological material. The parking lot (north of the building) was used for storage of materials and equipment. Releases of mercury (both less than 0.1 gallon) were reported in 1996 and 1997 (CH2M Hill 2008).
- Building 4893 was a reactor pad.

The support infrastructure also included two 550-gallon ASTs used to store diesel fuel and two radioactive water "vaulted tanks." Radioactive water was also stored in a 220-gallon UST from 1976 to 1993 (CH2M Hill 2008).

Soil and Debris Removal Actions

All buildings and supporting infrastructure have been removed along with any identified soil contamination.

Groundwater Interim Measures

There has been no groundwater contamination at the Building 4030 and Building 4093 leach field warranting interim measures.

5.13.2 Soils, Geology, and Hydrogeology

Soil in the Building 4030 and Building 4093 leach field groundwater investigation area is 1 to 10 feet thick and is comprised of weathered material from the Upper Burro Flats and ELV fine-grained member of Sandstone 2 of the Chatsworth Formation. **Figure 5.12-2** is a geologic cross-section encompassing the groundwater investigation area.

The presence of Near-surface groundwater in the area is uncertain. Near-surface groundwater has been observed infrequently in piezometer PZ-112, located approximately 350 feet southeast of the investigation area. Piezometer PZ-112 is screened from 24 to 34 feet bgs and was last sampled in 2002. The well has been dry since 2014. Approximately 50 feet west of the Building 4093 leach field, moisture was noted from 16 to 30 feet bgs during the installation of Chatsworth Formation well RD-17 in January 1986. Near-surface groundwater may have been present at that time.

Groundwater elevation was measured in the uppermost part of well RD-17 at approximately 32 feet bgs in 2013. Well RD-17 is up- or cross-gradient of many former buildings and other features in this area. The groundwater investigation area is located on a groundwater divide. When groundwater is present at piezometer PZ-112, southeast of the AI-Z3 leach field, the Near-surface groundwater would to flow to the southeast. Chatsworth Formation groundwater would flow to the southeast, south-southwest, and west.

5.13.3 Nature and Extent of Impacted Groundwater

During the RFI (CH2M Hill 2008), VOCs in soil vapor were reported in one sample collected at the southeast corner of Building 4631, directly upgradient of piezometer PZ-112. Acetone (10 µg/kg) was reported in a soil sample collected from the former location of the Building 4093 leach field, and low levels of styrene were detected at Buildings 4023, 4103/4083, and 4453. TCE was not detected in soil samples. No VOCs were detected above soil screening levels from the two leach fields.

VOC use, specifically TCE was not documented in this groundwater investigation area. TCE was not detected in the soil during the RFI (CH2M Hill 2008). Only acetone was found in the soil of the former Building 4093.

5.13.3.1 Groundwater Investigation Analytical Results

Two wells are located within the groundwater investigation area that are used to monitor Chatsworth Formation groundwater. These are bedrock wells RD-17 at the former Building 4093 leach field and DS-44 at the former Building 4030 leach field (**Figure 5.12-1**).

Bedrock Well RD-17

Well RD-17 is 125 feet deep and cased from ground surface and 30 feet bgs. Low concentrations of TCE (2.9 µg/L maximum in 1994, 0.38 µg/L in 2016, and 0.71 µg /L in 2017) have been reported over its history of sampling.

Bedrock Well DS-44

Well DS-44 is 91 feet deep cased from the ground surface to 18 feet bgs. It has been sampled three times, March and November 2016 and March 2017, and was non-detect for VOCs in all samples.

5.13.3.2 COC identification

Historically, low concentrations of TCE have been observed in well RD-17. The highest concentration of TCE was detected at 2.9 µg/L in 1994. Since 2008 concentrations have been less than or equal to 1 µg/L. It is likely that the TCE detected in well RD-17 reflects the eastern boundary of the HMSA TCE plume, and not derived from the Building 4093 leach field. Well RD-17 has been sampled twice for metals, once in 1989 and again in 2014. All detected metals were below their respective groundwater screening levels. It was sampled once for nitrate in 1989 and concentrations were less than the screening level.

5.13.3.3 Vadose Zone Mass Estimate

No contamination identified in soil and only low levels of TCE (less than 1 µg/L) in groundwater.

5.13.3.4 Horizontal Extent of Contamination

There is no significant groundwater contamination in this groundwater investigation area.

5.13.3.5 Vertical Extent of Contamination

There is no significant groundwater contamination in this groundwater investigation area.

5.13.3.6 Seeps Evaluation

There is no seeps in the vicinity of this groundwater investigation area.

5.13.4 Fate and Transport

There is no significant groundwater contamination in this groundwater investigation area. It is likely that the TCE observed in well RD-17 is the eastern boundary of the HMSA TCE plume.

5.13.5 Uncertainties and Data Gaps

There are no data gaps or uncertainties with this groundwater investigation area for VOCs or metals.

5.14 Building 4133/Building 4029 Hazardous Waste Management Facility

Building 4133 and Building 4029 Hazardous Waste Management Facility are RCRA-regulated facilities that have been combined under the same RCRA permit. Together, they comprise the Hazardous Waste Management Facility (HWMF). The Building 4133 area is actually located adjacent to the RMHF area and northwest of the Buildings 4030/4093 leach fields. Building 4029 is located 0.25 mile southeast of Building 4133 (see **Figure 5.12-1**). The buildings and building areas are not physically connected.

Building 4133 was actively used from 1978 to 1997. Reactive metals such as sodium and potassium were treated in Building 4133 by heating them in a pan for subsequent reaction with air. The result of the process was sodium hydroxide and potassium hydroxide solutions that were then neutralized in a tank. The HWMF was permitted under RCRA in 1983 and a RCRA closure plan was developed following cessation of operations in 1997.

One Near-surface groundwater monitoring well (RS-25) is located at Building 4133. RS-25 is 13.5-feet deep installed in 1988 (**Figure 5.12-1**). The well is generally dry. EPA sampled purge water from the well in 2010/2011 because it did not recover following purging. One bedrock monitoring well (RD-19) is located downgradient of Building 4133. Installed in 1989, well RD-19 is 135 feet deep and cased from ground surface to 30 feet bgs. It is located near the top of the RMHF drainage, upgradient of RMHF well RD-98. Well RD-19 has been sampled annually since 1994 with TCE detected only once at 5.1 µg/L in 2006. This result is considered an anomaly, either a sampling or analytical error because TCE has not been detected in this well before or since.

Building 4029 was originally used from 1959 to 1974 for the storage of radioactive materials. In 1974, all radioactive materials and the below grade storage sumps were removed. In 1978, Building 4029 became part of the HWMF. The facility was permitted under RCRA in 1983. Building 4029 was used for storage of reactive metals prior to their treatment at Building 4133. A RCRA closure plan was developed for the HWMF (MWH 2003a) but never implemented because of the 2007 moratorium on demolition of DOE structures in Area IV. There are no monitoring wells associated with Building 4029.

As part of the RCRA closure action for Buildings 4133 and 4029, the potential for groundwater contamination will be evaluated through the installation of new wells once the buildings and their foundations are removed. Any detected contamination will be addressed as part of the closure action. Therefore, these buildings are not evaluated further as part of this Area IV GW RFI Report.

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5.15 Building 4020 Rockwell International Hot Lab

Building 4020 also known as the Rockwell International Hot Lab (RIHL) was used from 1959 through 1987 for the examination and preparation of irradiated nuclear reactor fuel and for decladding, cleaning, and packaging of nuclear fuel for reprocessing. This work was performed for DOE and Rockwell private industry customers.

5.15.1 Source Area Evaluation

Operation History

The RIHL contained four large radioactive-material handling "hot cells." There was a machine shop that stored chemicals in drums on a concrete pad located on the eastern side of the building. Chemical uses within the hot lab included solvents, SVOCs, PCBs, and metals. Building 4020 also had a leach field (AI-Z12) (**Figure 5.15-1**)). Piezometer PZ-103 is situated between Buildings 4020 and 4055; it has exhibited low concentrations (<5 μg/L) of TCE (**Appendix B**).

The leach field was used from 1959 to 1961 for disposal of sanitary wastewater. It was removed from service in 1961 when Area IV was connected to the central wastewater treatment facility. The leach field site was excavated during the demolition of Building 4020 between 1992 and 1996.

Soil and Debris Removal Actions

Decommissioning of Building 4020 started in 1986 and building demolition was completed between 1992 and 1996. Decontamination and decommissioning of the entire RIHL was completed in 1998.

Three 5,000-gallon steel USTs (UT-8, UT-9, UT-64; not shown), one 5,000 gallon fuel UST (UT-10; not shown), and one 500 gallon fuel UST (UT-11; not shown) were removed. UT-8, UT-9, and UT-64 were designed to store fission gases, but were not used for that purpose (CH2M Hill 2008). There was no evidence of leakage from UT-10, but 42 cubic yards of petroleum-impacted soil were excavated upon removal of UT-11 (CH2M Hill 2008).

During the removal of Building 4020, soil was excavated in its general footprint (CH2M Hill 2008). The maximum depth of excavation was 70 feet bgs. The excavation was backfilled with soil from the Area IV borrow site.

Groundwater Interim Measures

There has been no groundwater contamination at the RIHL warranting interim measures.

5.15.2 Soils, Geology, and Hydrogeology

Soil beneath at the RIHL is at least 6 feet thick and at some locations can be as much as 14 feet thick. The soil consists of weathered Chatsworth Formation materials which are primarily fine-grained silty sands, sandy lean clays, lean clays, and silts.

The RIHL is underlain by the Lower Burro Flats member of the Upper Chatsworth Formation. Beds of the Lower Burro Flats member generally strike N70˚E and dip 25˚NW. The Lower Burro Flats member is predominantly fine- and medium-grained sandstone with significant interbeds of siltstone and shale.

5.15.3 Nature and Extent of Impacted Groundwater

5.15.3.1 Groundwater Investigation Analytical Results

Piezometer PZ-103 is the only monitoring well at the Building 4020 site. PZ-103 also serves as a monitoring well downgradient of the Metals Clarifier Laboratory Building 4065/DOE Leach Fields 3 (see Section 5.11). Piezometer PZ-103 is 39 feet deep installed within the weathered bedrock with a screened interval from 36 to 39 feet bgs. The well has been sampled three times (2002, 2003, and 2014) with TCE reported at 3J µg/L in 2003 and 2.2 µg/L for 2014.

5.15.3.2 COC Identification

Piezometer PZ-103 has been sampled four times for VOCs. TCE was non-detect above a reporting limit of 5 µg/L in 2002, but was detected at estimated concentrations of 3 J µg/L in 2003, 2.2 µg/L in 2014, and 0.53 J µg /L in 2017. . The low concentrations of TCE may reflect the edge of the perched groundwater plume from the Metals Clarifier Laboratory Building 4065/DOE Leach Fields 3 investigation area (Section 5.11).

Piezometer PZ-103 was sampled for metals in 2014. Barium, beryllium, cadmium, chromium, cobalt nickel, selenium, silver, thallium, and vanadium were reported at concentrations exceeding their respective groundwater screening levels. Aluminum, barium, cadmium, mercury, nickel, selenium, vanadium, zinc, and TPH were identified in soil during the RFI (CH2M Hill 2008). Piezometer PZ-103 was sampled for nitrate eight times between 2008 and 2014. Five of the eight samples exceeded the screening level for nitrate.

5.15.3.3 Vadose Zone Mass Estimate

The TCE in groundwater may be associated with the edge of the plume from the Metals Clarifier Laboratory Building 4065/DOE Leach Fields 3 investigation area to the east. The source for metals, if one exists, is not known.

5.15.3.4 Horizontal Extent of Contamination

There is no significant groundwater contamination below the RIHL.

5.15.3.5 Vertical Extent of Contamination

There is no significant groundwater contamination below the RIHL.

5.15.3.6 Seeps Evaluation

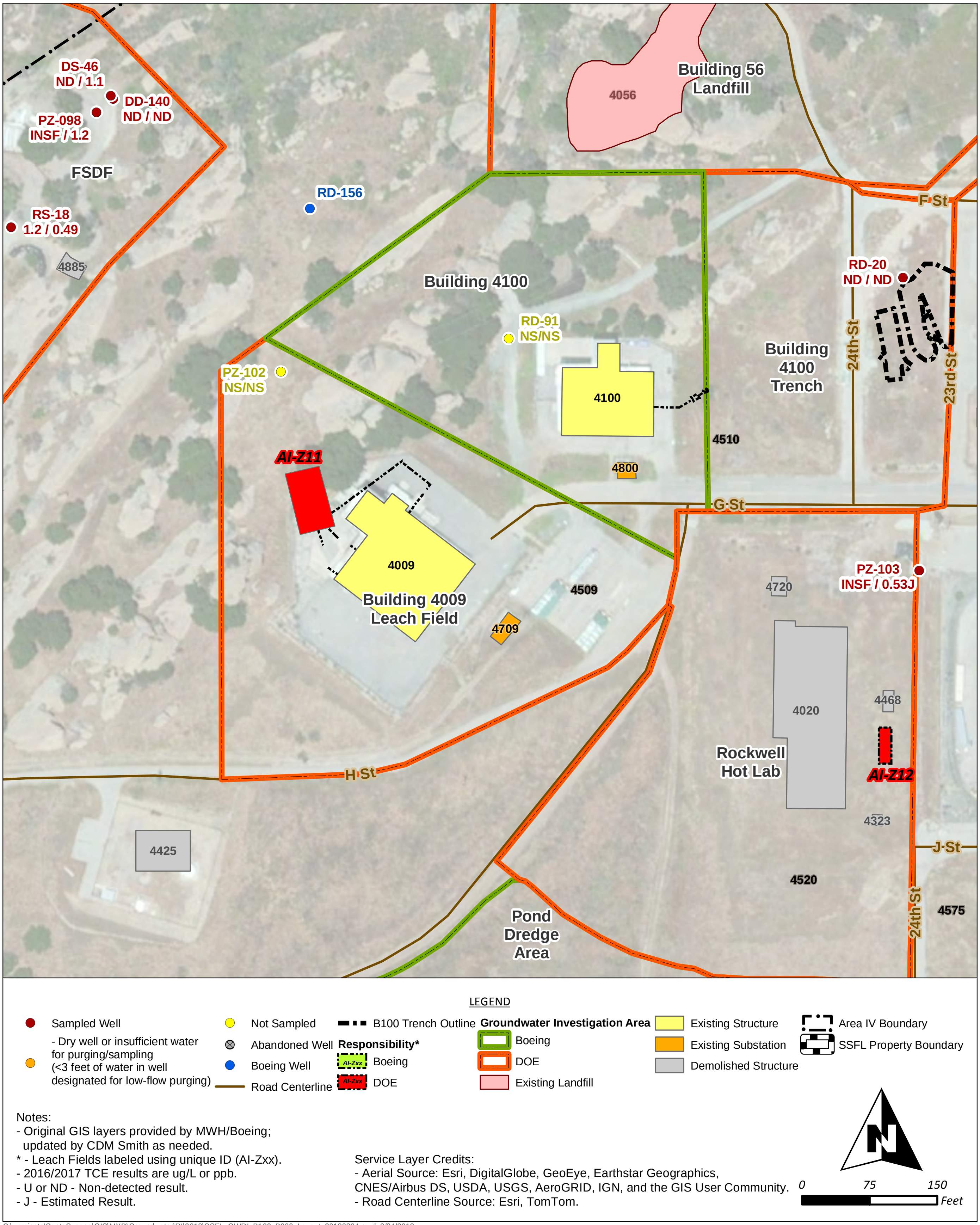
There are no seeps in the vicinity of the RIHL.

5.15.4 Fate and Transport

There is no significant groundwater contamination below the RIHL.

5.15.5 Uncertainties and Data Gaps

There are no data gaps or uncertainties with this groundwater investigation area for VOCs or metals.



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CDM Smith

FIGURE 5.15-1
Building 4100 and Building 4009 Leach Field Layout

5.16 Building 4009 Leach Field

Building 4009 (**Figure 5.15-1**) was used as a nuclear test facility, an in-service inspection facility, for high-energy rate forging, and for non-nuclear research. The building was constructed in 1957 and remains, but is unoccupied. The building is owned by Boeing who will be responsible for its demolition.

5.16.1 Source Area Evaluation

Operation History

Two 1,000-gallon waste holding tanks (UT-4 and UT-5; not shown) were used to store liquid and gaseous wastes generated by the Organic Moderated Reactor and Sodium Graphite Reactor tests conducted in this building. A 1,200-gallon tank was also used to store a terphenyl coolant mixture. A diesel fuel tank (UT-3; not shown) was used to provide fuel for a back-up electrical generator.

Building 4009 was connected to a sanitary leach field (AI-Z11) from 1957 to 1961 then to the central wastewater treatment plant in 1961. The leach field may have received liquid process wastes after 1961 (MWH 2007).

Soil and Debris Removal Actions

The Organic Moderator Reactor liquid waste tank (UT-5) was removed in 1986. The Sodium Graphite Reactor liquid waste holding tank (UT-4) was removed 1989 to 1990. Concrete supporting the tank's sump was removed between 1995 and 1996. Fuel tank UT-3 was removed in 1995. Soil beneath this tank was found to be impacted with TPH.

The leach field and septic tank at Building 4009 was removed in 2002. Along with the tanks and piping, 50 tons of soil, debris and 18-inch leach lines were removed and disposed of off-site (MWH 2007).

Groundwater Interim Measures

There has been no groundwater contamination at the Building 4009 Leach Field warranting interim measures.

5.16.2 Soils, Geology, and Hydrogeology

Soil at the Building 4009 Leach Field ranges from 1 to 5 feet deep, and are surrounded by bedrock outcrops. Soil in the drainage channels leading from the area may be thicker in some places.

The Building 4009 Leach Field is underlain by the Upper and Lower Burro Flats members of the Upper Chatsworth Formation. Beds of the Upper Burro Flats member generally strike N70˚E and dip 25˚NW. The Lower Burro Flats member is predominantly composed of fine- and medium-grained sandstone with significant interbeds of siltstone and shale.

Two northeast trending deformation bands are present to the west of Building 4009. These bands do not appear to control groundwater flow. However, bedrock between the bands appears to be more closely spaced with fewer fractures than other locations in Area IV and may serve to deflect groundwater flow to the northeast.

5.16.3 Nature and Extent of Impacted Groundwater

5.16.3.1 Groundwater Investigation Analytical Results

Piezometer PZ-102 is the only monitoring well near the Building 4009 Leach Field. PZ-102 was drilled to 59.2 feet bgs and has a screened interval from 48.5 to 59.2 feet bgs. PZ-102 has only been sampled once (2003) and TCE was detected at 6 µg/L. The well has been dry since 2014.

5.16.3.2 COC Identification

TCE is the primary contaminant reported at the Building 4009 Leach Field based on the data from PZ-102. PZ-102 was sampled once for metals. Copper, molybdenum, silver, and vanadium were reported at concentrations slightly above their respective groundwater screening values.

In April 2018, six passive soil gas samples were collected from the vicinity of the leach field and analyzed for VOCs. There were not VOCs detected in any of the samples (CDM Smith 2018e)

5.16.3.3 Vadose Zone Mass Estimate

The source of TCE at piezometer PZ-102 is not known, but it is proximate to Building 4100. A soil gas investigation conducted in 2018 demonstrated that the B4009 leach field is not source area for underlying groundwater. All passive soil gas results were non-detect for VOCs. (CDM Smith, 2018a) Chatsworth Formation well RD-91 near Building 4100 had a reported concentration of 200 µg/L TCE in 2014. Therefore, the TCE detected in piezometer PZ-102 is more likely from the Building 4100 source than from former operations in Building 4009.

5.16.3.4 Horizontal Extent of Contamination

There is no significant groundwater contamination in this groundwater investigation area.

5.16.3.5 Vertical Extent of Contamination

There is no significant groundwater contamination in this groundwater investigation area.

5.16.3.6 Seeps Evaluation

There are no seeps in the vicinity of the Building 4009 Leach Field.

5.16.4 Fate and Transport

5.16.4.1 Conceptual Site Model

The 6 µg/L TCE concentration observed in one sample from PZ-102 is indicative of minor contamination, and possibly the associated with the edge of contamination from an adjacent investigation area. Building 4100 is a possible source for TCE observed in PZ-102. Passive soil gas results confirm that B4009 leach field is not a source to underlying groundwater.

5.16.4.2 Numerical Flow Model Results

Numerical modeling was not performed at this area.

5.16.4.3 Contaminant Fate Analysis

Based on data collected from nearby wells, concentrations of TCE in piezometer PZ-102 are expected to decline with time.

5.16.4.4 Plume Stability Assessment

There is no plume at PZ-102 to be assessed.

5.16.5 Uncertainties and Data Gaps

There are no data gaps or uncertainties with this groundwater investigation area for VOCs or metals.

Section 6

Contaminant Transport Numerical Model

This section describes the results of numerical modeling of contaminant transport. The transport numerical model is based on the Mountain Scale Groundwater Flow Model (MSGFM) that was developed for the SSFL hydrogeologic conditions to understand site-specific groundwater flow. To sufficiently represent site-specific three-dimensional groundwater flow in the MSGFM, a preliminary regional scale model was developed to determine (1) the boundaries to the groundwater flow system originating at the SSFL, (2) the features that need to be represented in the model to provide a reasonable representation of site-specific groundwater flow, and (3) the field observations available to assess the reasonableness of the simulated groundwater system. The finite-element groundwater modeling code FEFLOW (*DHI-WASY* 2012)] was used to develop the MSGFM for the SSFL. Because of the complex the geologic setting, the stratigraphy and structure are the dominant influences on groundwater flow at the SSFL. FEFLOW's enhanced capabilities facilitate an accurate representation of the system. The MSGFM domain encompasses the entire SSFL and extends to the surrounding alluvial valleys, an area of approximately 52 km^2 (20 sq. miles). The finite element mesh comprises 52 layers, more than 13.2 million elements and 9.7 million nodes. A total of 716 distinct hydraulic conductivity zones are used to represent the complex geology and structure.

In its current form, the MSGFM provides a reasonable representation of three-dimensional groundwater flow as assessed by comparing simulated groundwater levels and groundwater discharges to field observations. The MSGFM is to be used at the SSFL to evaluate site-specific three-dimensional groundwater flow from key locations and to provide representative input conditions for additional contaminant transport simulations. These flow and transport models provide insight into the migration of contaminants and help evaluate the utility of existing and potential future well locations for monitoring contaminant transport.

Recognizing that groundwater models are simplifications of reality and that input parameters and boundary condition values are always based on incomplete data sets, model results always contain uncertainty. Understanding the uncertainty in simulating the groundwater flow system is addressed through a set of Null Space Monte Carlo simulations that yield equally probably calibrated hydraulic conductivities and hence equally probable flow paths that can be used for contaminant transport simulations.

The model can be useful for estimating and predicting the flow direction at any point of interest. It can also be used to interrogate the effects on the flow field due to hypothetical management scenarios such as pumping or injection or to changes in climate (e.g., increased or decreased rainfall infiltration).

6.1 Introduction

DOE elected to update and recalibrate the 2009 MSGFM for two primary reasons. First, re-interpretations of Area IV geology fault and geological structure presence (e.g., FSDF structures) dictated some revisions to the model. Second, differences in Area IV geology discussed in Section 3 (e.g., tighter bedrock conditions, less dense fracture networks) also dictated the need to update the model. These updates do not mean that the 2009 MSGFM is not applicable for characterizing groundwater flow elsewhere at SFFL. However, DOE wanted a numeric model more representative of Area IV.

The updated and recalibrated mountain-scale groundwater flow model simulates groundwater flow paths from sources of groundwater contamination using particle tracking and the specific discharge along those flow paths. In addition, the null-space Monte Carlo analysis quantifies the uncertainty in those flow paths and groundwater flow rates, as described previously. However, the particle tracking algorithm in FEFLOW does not provide simulated contaminant concentrations or some important transport processes, such as matrix diffusion.

A separate one-dimensional (1-D) contaminant transport model was developed and linked to the particle tracking results from the mountain-scale groundwater flow model to simulate contaminant migration from selected locations of observed groundwater contamination. The objectives of the transport model are to give reasonable estimates of the extent of contaminant migration and the maximum contaminant concentrations in groundwater for various times after release. The transport model was constructed to include important features and processes relevant to the fate and transport of contaminants in groundwater. However, the model is subject to simplifications, limitations, and uncertainties, such as the 1-D nature of the model and the assumption of groundwater flow in parallel, evenly spaced fractures. Consequently, the transport model is not intended to make precise predictions of contaminant migration, but does provide reasonable guidance for remedial investigations at the site.

6.2 Conceptual Model of Contaminant Transport

The conceptual model of contaminant transport via groundwater includes release of contaminants at the surface or in the shallow subsurface, generally vertical migration in the vadose zone, and lateral transport in groundwater below the water table. Some contaminants, such as TCE, may have been released as dense non-aqueous phase liquids (DNAPLs), but the generally low groundwater concentrations of TCE and the lack of very deep contamination in Area IV suggest that vertical migration of TCE as a DNAPL was limited. Physical and chemical processes potentially important to groundwater contaminant transport include advection in bedrock fractures, hydrodynamic dispersion, diffusion in the rock matrix, sorption in the matrix, radioactive decay of radionuclides, and possible chemical degradation of organic compounds.

The 1-D conceptualization of advective transport is steady-state flow along a single groundwater flow line or stream tube with groundwater movement confined to the fracture network. The steady-state conditions established in the calibrated mountain-scale groundwater flow model are considered to be representative of average flow conditions in the past and future in Area IV, which has been affected less by historical groundwater pumping than some other areas at the SSFL. Groundwater specific discharge is variable along the flow path as the groundwater flows through hydrogeologic units of varying hydraulic conductivity. The cross-sectional area of a groundwater stream tube varies accordingly, with a smaller cross-sectional area in zones of high conductivity and a larger area in zones of low conductivity. Hydrodynamic dispersion occurs in the longitudinal and transverse directions, but the 1-D conceptual model includes only longitudinal dispersion. Neglecting transverse dispersion results in overestimates of contaminant concentrations in numerical simulations. The simplified conceptual model of matrix diffusion is a system of parallel, evenly spaced fractures with diffusive mass transfer between the fractures and matrix occurring perpendicular to the fractures. An equilibrium, linear isotherm model for sorption of relevant aqueous species is included in the conceptual model. Radionuclide mass and activity reduction occurs by first-order decay. Several lines of evidence indicate that chemical degradation of TCE has occurred in groundwater at the site. Several potential conceptual models of degradation are available; however, this process is conservatively not included in the contaminant transport model, resulting in potential overestimates of contaminant concentrations.

The exact timing, duration, and location of contaminant releases that have affected groundwater quality in Area IV are uncertain for some locations. The conceptual model of contaminant sources in the 1-D transport model is assumed to be a continuous release of a specified concentration with a duration of 10 years, beginning approximately 50 years ago. Contaminant sources at seven locations were included in transport model simulations. These locations were specified as wells with observed groundwater contamination. The locations, associated presumed source, and contaminants of concern are listed in **Table 6-1**.

Table 6-1. Contaminant source locations for the 1-D transport model

Well	Associated Facility	Contaminant of Concern
RD-23	FSDF	TCE
RD-07	Building 56 Landfill	TCE
PZ-109	Building 4057/4059/4626	PCE
RD-95	Uncertain	Tritium
RD-98	RMHF Leachfield	Sr-90
DD-144	HMSA	TCE
PZ-105	Metals Clarifier/DOE Leachfields	TCE

6.3 Numerical Model Implementation

The 1-D transport model was implemented using the FEHM software code with the finite-element method (Zyvoloski 2007). The model domain consists of a series of quasi-3D elements connected along the stream line derived from the particle tracking with the mountain-scale groundwater flow model. Each element in the model is 1 m in length. The streamtube defined by the 1-D transport model has a nominal cross-sectional area of 1 m^2 that varies in thickness transverse to flow to account for variations in specific discharge along the stream path. The groundwater flow rate simulated by the mountain-scale model is specified at the upstream end of the 1-D transport model and the downstream end is specified hydraulic head.

Each element volume is subdivided into a groundwater flow domain corresponding to fractures in the bedrock and a rock matrix domain using the generalized dual-porosity module in FEHM. Flow occurs only in the fracture domain, diffusive mass transfer of contaminants occurs between the fracture domain and the rock matrix, and diffusion occurs within the rock matrix. Radioactive decay or chemical degradation occurs in the fractures and matrix, and sorption may occur in the rock matrix. The rock matrix is discretized into ten elements that increase exponentially in thickness perpendicular to the fracture to obtain a more accurate numerical solution for the matrix diffusion process. The generalized dual-porosity algorithm implemented in the 1-D transport model is equivalent to a system of parallel, evenly-spaced fractures in the porous bedrock.

Parameter values representative of the average hydrogeologic conditions in Area IV and of the contaminants of concern were used in the 1-D transport model. The relevant parameters specified in the model are listed in **Table 6-2**.

Table 6-2. Parameter values used in the 1-D transport model.

Parameter	Value
Fracture porosity (-)	0.01
Rock matrix porosity (-)	0.13
Longitudinal dispersivity (m)	10.
Bulk density (kg/m^3)	2750.
Effective diffusion coefficient (m^2/s) (TCE, PCE, Sr-90)	1.8×10^{-11}
Effective diffusion coefficient (m^2/s) (Tritium)	5.5×10^{-11}
Sorption coefficient of Sr-90 (mL/g)	15.
Half-life of Tritium (years)	12.3
Half-life of Sr-90 (years)	28.8

Parameter values used in the 1-D contaminant transport model are taken primarily from MWH (2009). The sorption coefficient for strontium is based on a review of data on sorption, as related to groundwater pH and clay content of the aquifer medium (EPA 1999). The value of 15 mL/g is the minimum of the range given for near neutral pH and 10 to 20 weight% clay content.

A continuous source of contaminated groundwater at a specified concentration was applied at the upstream end of the 1-D transport model for the first ten years of the simulation. Conceptually, this source could correspond to infiltration from the vadose zone, a leachfield, leaking surface impoundment, or dissolution of a DNAPL source. Because the original source concentrations at the site are unknown the value of the specified concentration at the beginning of the simulation was determined by a trial-and-error method in which the specified concentration was adjusted so that the maximum simulated contaminant concentration near the source after 50 years was approximately equal to the average current observed concentration. This process of calibrating the contaminant source concentration was conducted separately for each of the source locations investigated.

6.4 Transport Model Results

The results of the 1-D contaminant transport model are presented as a series of figures for the seven source locations listed in **Table 6-1**. **Figures 6-1 to 6-35** show a series of figures that are repeated for each source location, so that Figures **6-1 to 6-5** are a set for a TCE source at the location of well RD-23, **Figures 6-6 to 6-10** are a set for a TCE source at RD-07, etc.

The first figure in each set is a map showing the simulated particle path from the calibrated mountain-scale flow model (shown in color) superimposed on the multiple, equally likely particle paths from the null-space Monte Carlo analysis (shown in gray). The color scale indicates the depth below ground surface of the particle path along its entire length from the source to either a groundwater discharge point or the boundary of the mountain-scale model.

The second figure in each set has a plot of groundwater flux versus distance along the stream line particle path and plots of simulated contaminant concentration versus distance along the stream line for 20 years, 50 years, and 100 years after release at the contaminant source. The first plot is calculated from the particle tracking results of the mountain-scale flow model and is an input to the 1-D transport model. The second plot is output from the 1-D contaminant transport model.

The third, fourth, and fifth figures in each set are maps that illustrate the results of the 1-D transport model regarding the estimated migration distance of contaminated groundwater for 20 years, 50 years, and 100 years after release at the contaminant source, respectively. The simulated contaminant concentrations along the particle path are indicated by the colors plotted and represent a snapshot of the distance contamination has traveled at that time. The simulated particle paths have been truncated for values of simulated concentration that are less than one tenth of the MCL (e.g., at a value of 0.5 mg/L for TCE).

The results indicate significant variation in the extent of simulated contaminant migration from the different source locations. The TCE plumes from the locations of wells RD-23 and RD-07, and the Sr-90 plume from RD-98 are simulated to migrate a few tens of meters 100 years after release. The limited contaminant migration from the locations of RD-23 and RD-07 is attributable to the low simulated groundwater flux on the order of 0.01 to 0.03 m/year in the region immediately downgradient of the source. The limited migration of Sr-90 from the location of RD-98 is associated with the sorption of strontium in the sandstone matrix. The more extensive simulated migration of TCE, PCE, and tritium of up to several 100 meters from the locations of the other wells is related to the higher values of simulated groundwater flux downgradient of the wells, generally on the order of 0.1 to 1 m/year and the absence of assumed sorption of the contaminants.

The maximum simulated contaminant concentrations decrease with time for all contaminants because of the processes of longitudinal dispersion and matrix diffusion, as shown in **Figures 6-2, 6-7, 6-12, 6-17, 6-22, 6-27, and 6-32**. In addition, radioactive decay results in decreases in maximum simulated concentrations for tritium by orders of magnitude and for Sr-90 by several times over the period of 100 years following the contaminant releases. The 1-D transport model results indicate that the maximum concentrations for tritium from the location of well RD-95 and for TCE from well PZ-105 would decrease below the MCL for those contaminants within 100 years of contaminant release.

The variability and uncertainty in potential groundwater flow paths from the source locations are indicated by the results of the null-space Monte Carlo particle tracking analyses shown in **Figures 6-1, 6-6, 6-11, 6-16, 6-21, 6-26, and 6-31**. However, neither these particle tracking results nor the 1-D contaminant transport model results include the effects of transverse dispersion, which spreads groundwater contamination in the direction perpendicular to the flow path. Consequently, the complete envelope of uncertainty in groundwater flow paths from the source locations would be somewhat wider than indicated by the null-space Monte Carlo results.

6.5 Discussion of Contaminant Transport

The 1-D contaminant transport model was developed and linked to the mountain-scale groundwater flow model to provide reasonable estimates of the extent and direction of contaminant migration along flow paths from key source locations in Area IV. The contaminant transport simulations account for important physical and chemical processes relevant to contaminant nature and extent, including advection, dispersion, matrix diffusion, potential sorption, and decay. Limitations and simplifications in the mountain-scale flow model and the 1-D transport model place some restrictions on the spatial resolution and precision of modeling results. Modeling results are also based on the assumption that relevant hydrogeological features have been identified and implemented in the mountain-scale flow model. However, the modeling results are appropriate for use in the general interpretation of the groundwater system and planning of potential remedial actions and monitoring.

The 1-D contaminant transport model results indicate that groundwater contamination in Area IV has migrated on the scale of tens of meters to hundreds of meters in the approximately 50 years since most contaminant releases occurred, depending on the location and contaminant. This conclusion is broadly consistent with observations from well sampling and the spatial distribution of groundwater contamination. Furthermore, the model results suggest that further migration of groundwater contamination exceeding MCLs over the next 50 years would be limited to a maximum of several hundred meters, even in the absence of intervention. Further migration from some locations could be significantly less than hundreds of meters.

The transport modeling results show that maximum contaminant concentrations would be expected to decline with time in the groundwater, assuming no additional inputs of contaminant mass from the vadose zone. The simulated maximum concentrations in the tritium plume are projected to fall below the MCL within 50 years. The transport model results indicate that the maximum TCE concentrations would fall below the MCL for some locations such as PZ-105 that currently have relatively low contaminant concentrations. In the absence of chemical degradation or sorption of TCE and PCE, as assumed in the 1-D contaminant transport model, contaminant concentrations in groundwater are not simulated to fall below the MCL within 50 years at any of the locations modeled, assuming no further remedial actions.

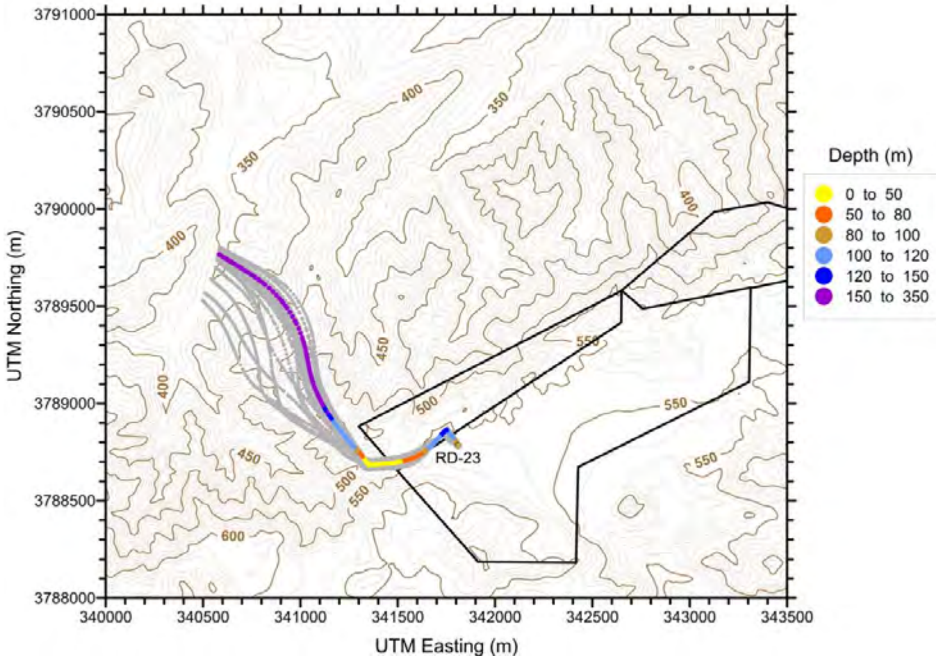

Figure 6-1.
Simulated groundwater flow path from the location of well RD-23. Alternative flow paths from the null-space Monte Carlo analysis shown in gray.

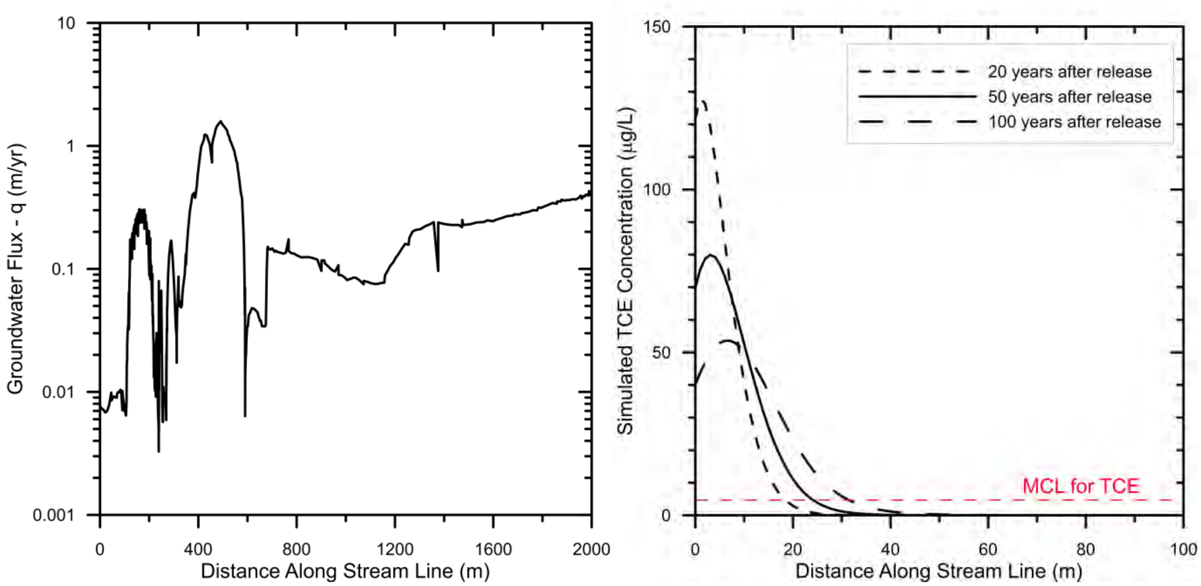

Figure 6-2.
Simulated groundwater flux profile and TCE concentration profiles for three times following release along the flow path from the location of well RD-23.

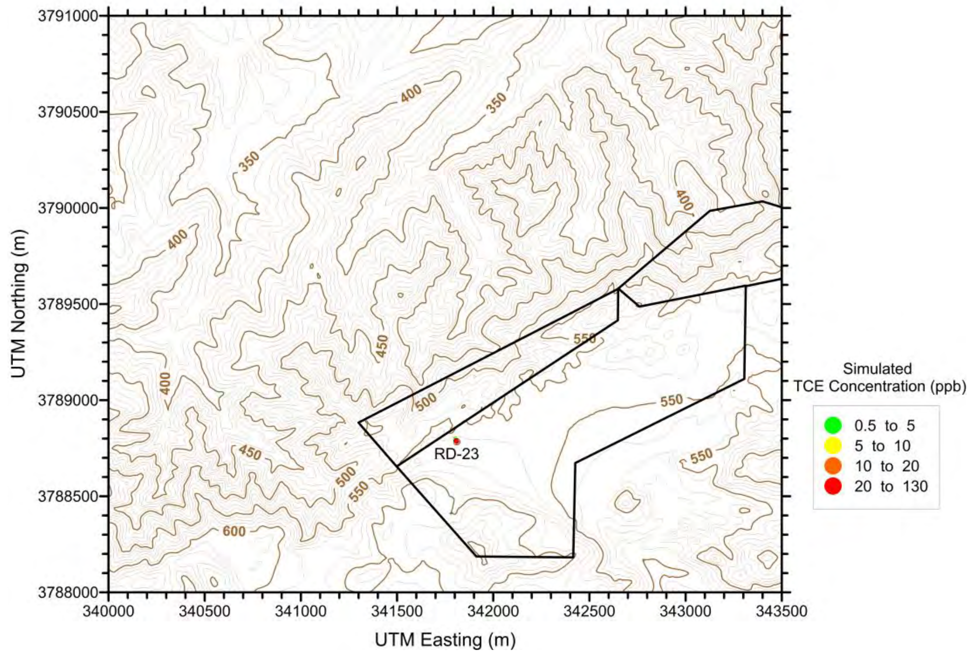

Figure 6-3.
Simulated TCE concentrations at 20 years following release from a source at the location of well RD-23. Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

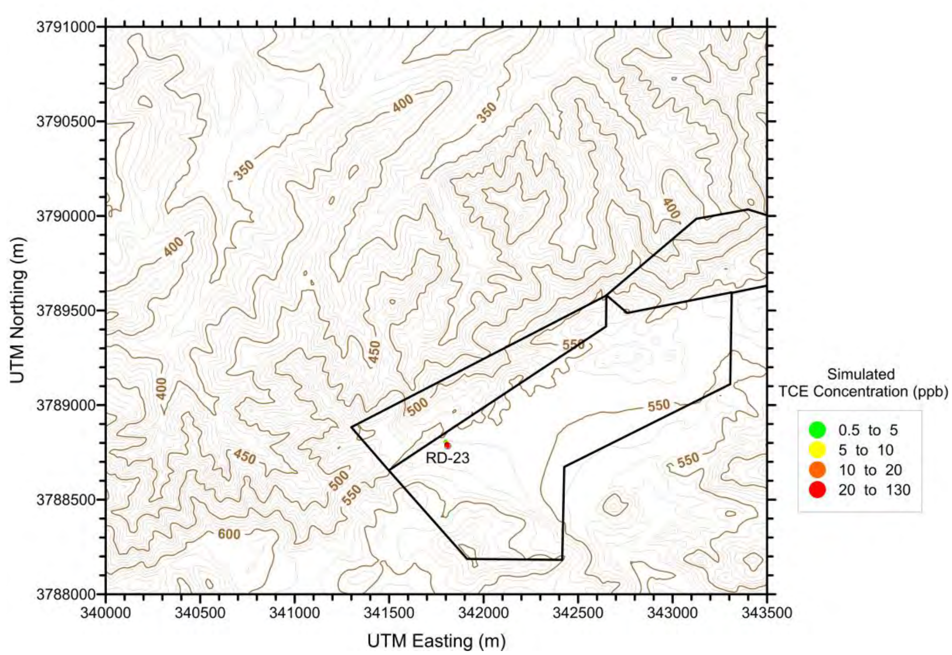

Figure 6-4.
Simulated TCE concentrations at 50 years following release from a source at the location of well RD-23. Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

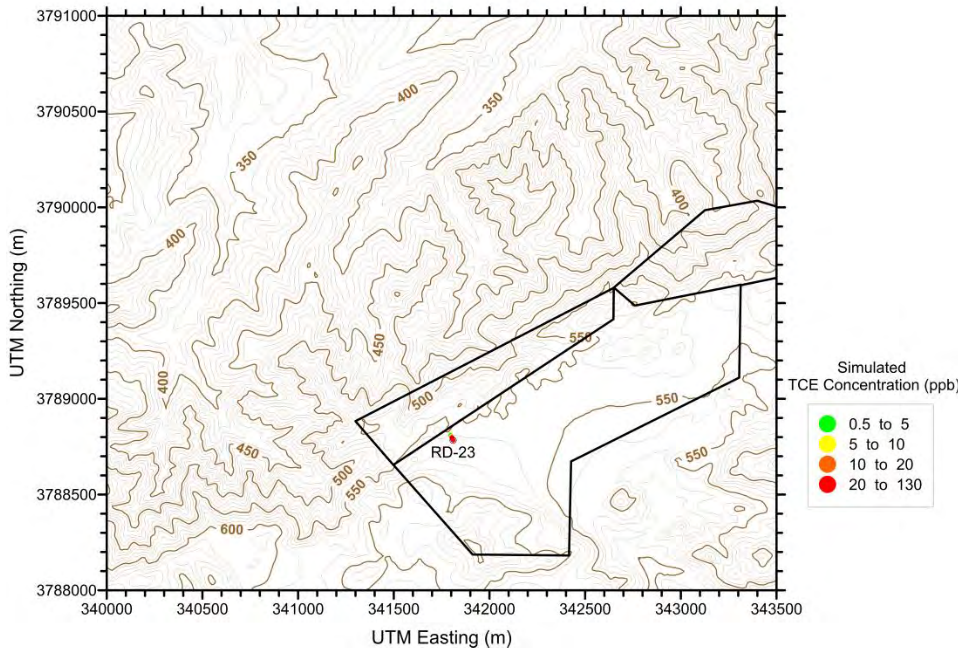

Figure 6-5.
Simulated TCE concentrations at 100 years following release from a source at the location of well RD-23. Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

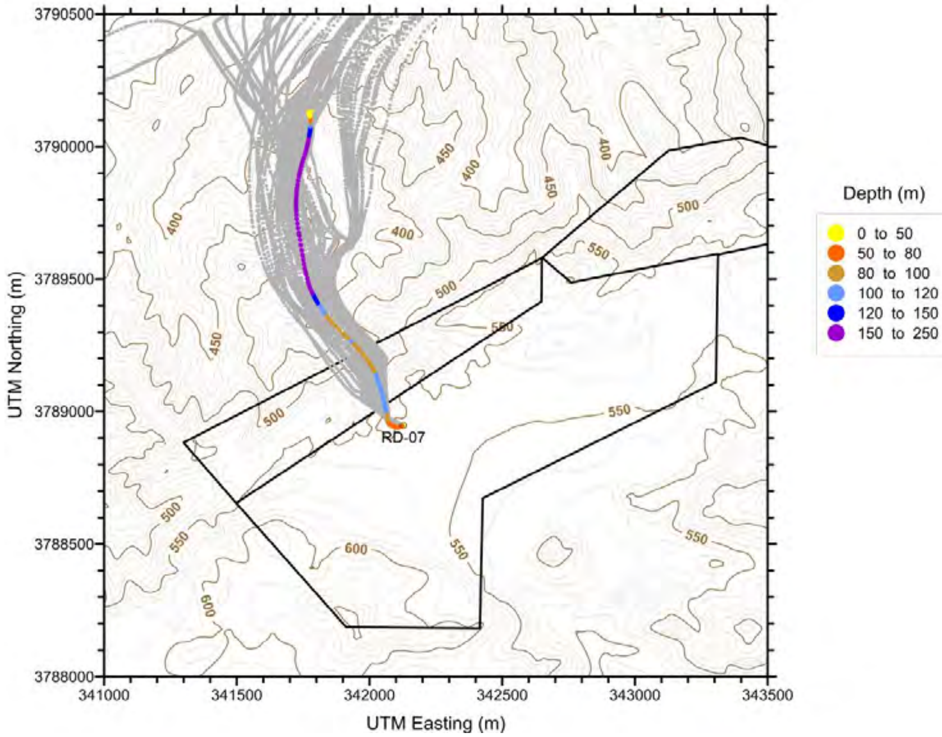

Figure 6-6.
Simulated groundwater flow path from the location of well RD-07. Alternative flow paths from the null-space Monte Carlo analysis shown in gray.

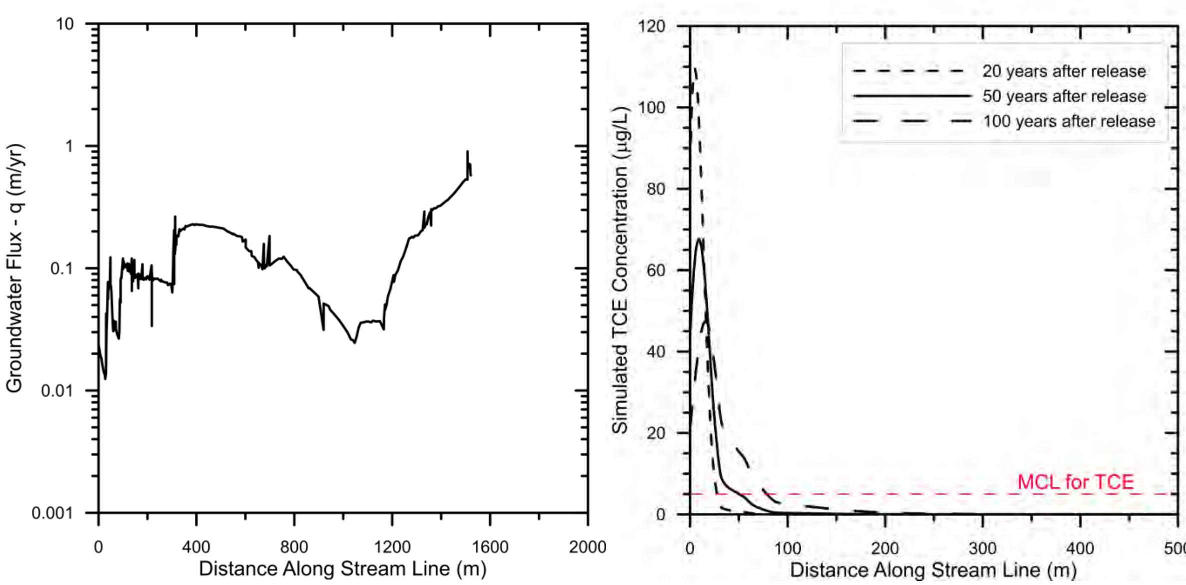

Figure 6-7.
Simulated groundwater flux profile and TCE concentration profiles for three times following release along the flow path from the location of well RD-07.

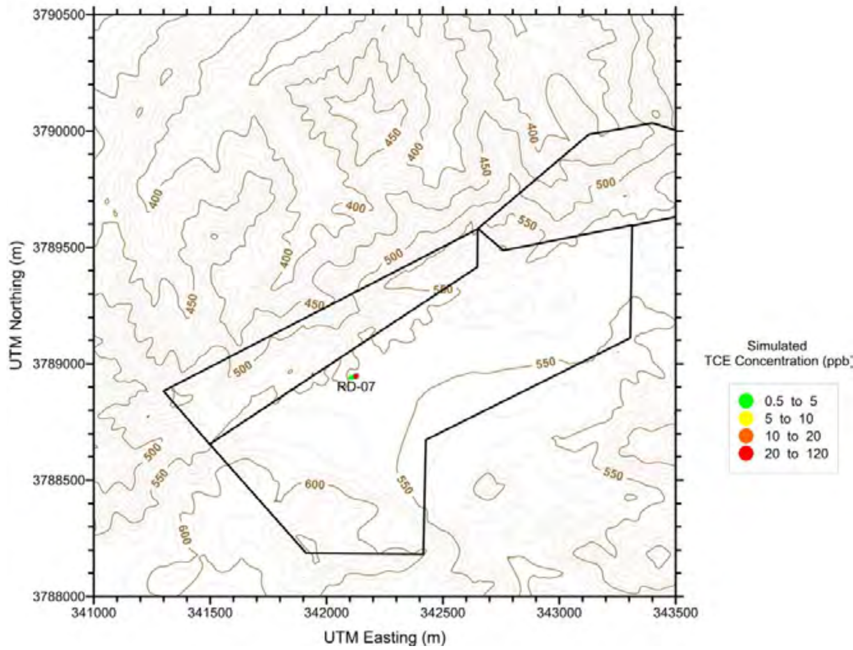

Figure 6-8.
Simulated TCE concentrations at 20 years following release from a source at the location of well RD-07.
Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

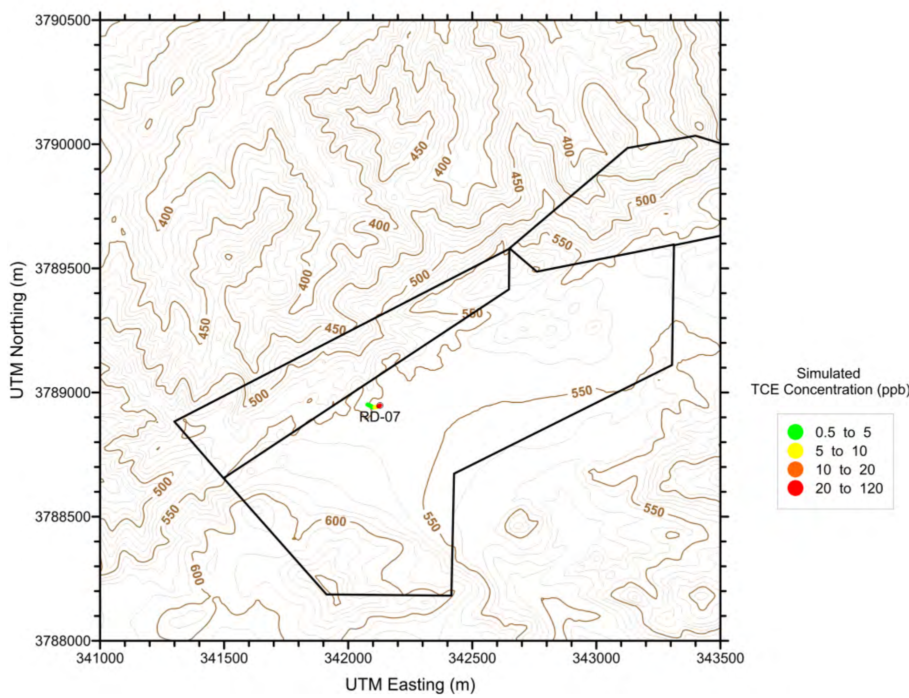

Figure 6-9.
Simulated TCE concentrations at 50 years following release from a source at the location of well RD-07.
Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

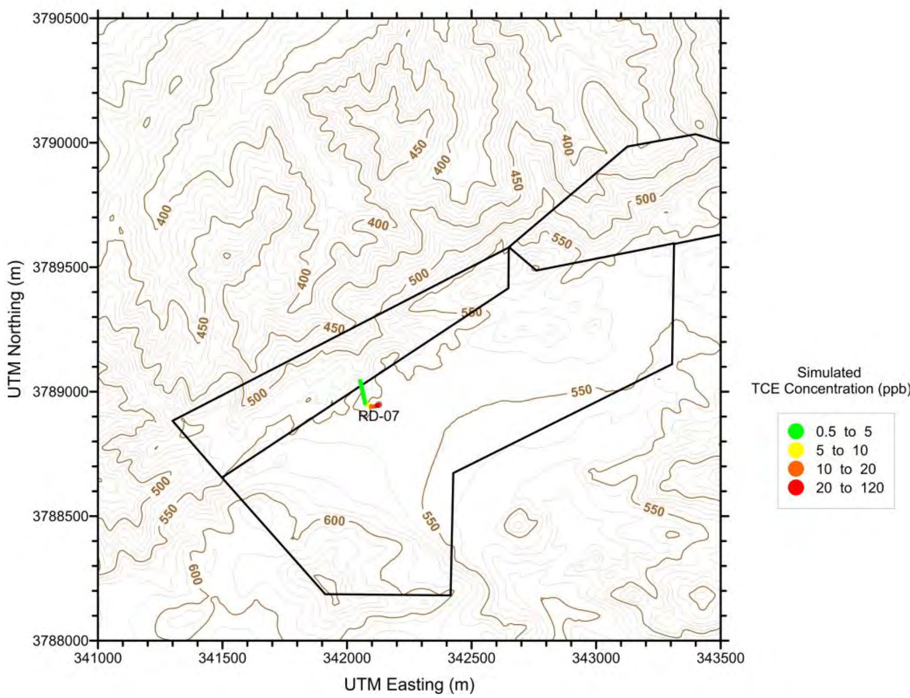

Figure 6-10.
Simulated TCE concentrations at 100 years following release from a source at the location of well RD-07.
Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

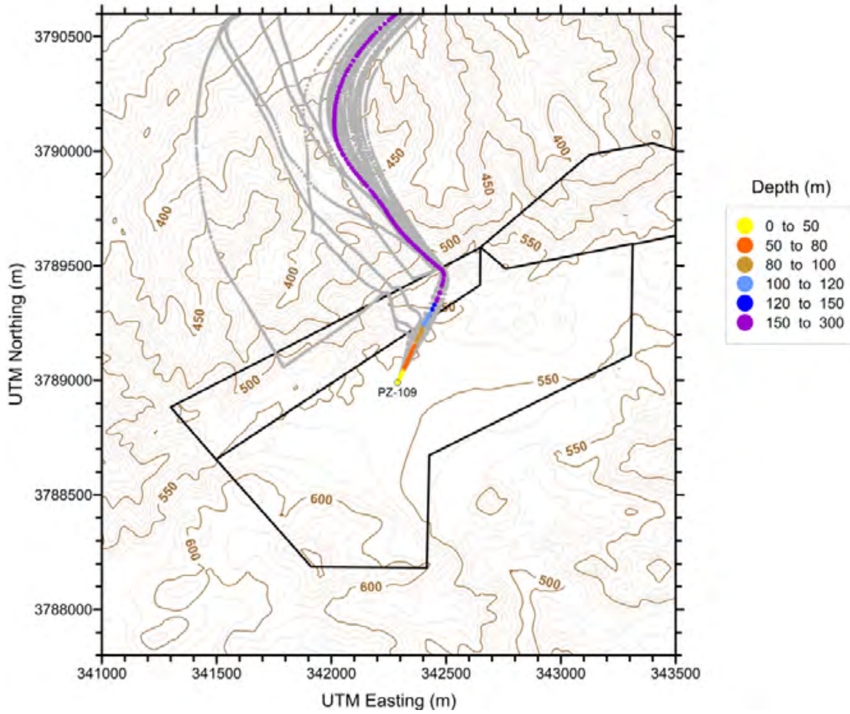

Figure 6-11.
Simulated groundwater flow path from the location of well PZ-109. Alternative flow paths from the null-space Monte Carlo analysis shown in gray.

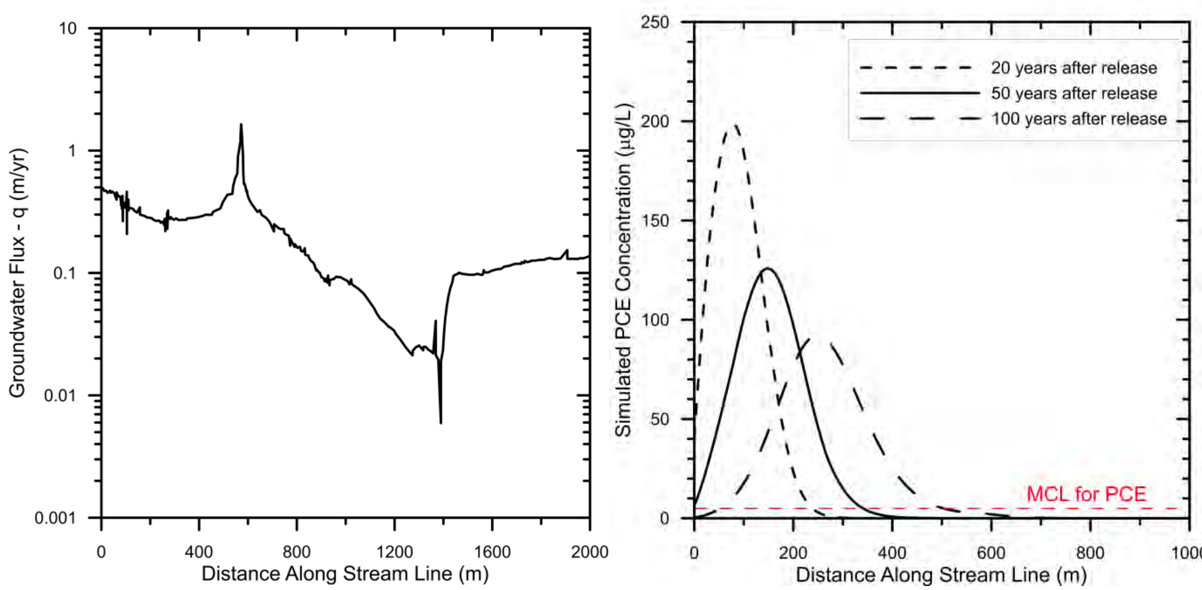

Figure 6-12.
Simulated groundwater flux profile and PCE concentration profiles for three times following release along the flow path from the location of well PZ-109.

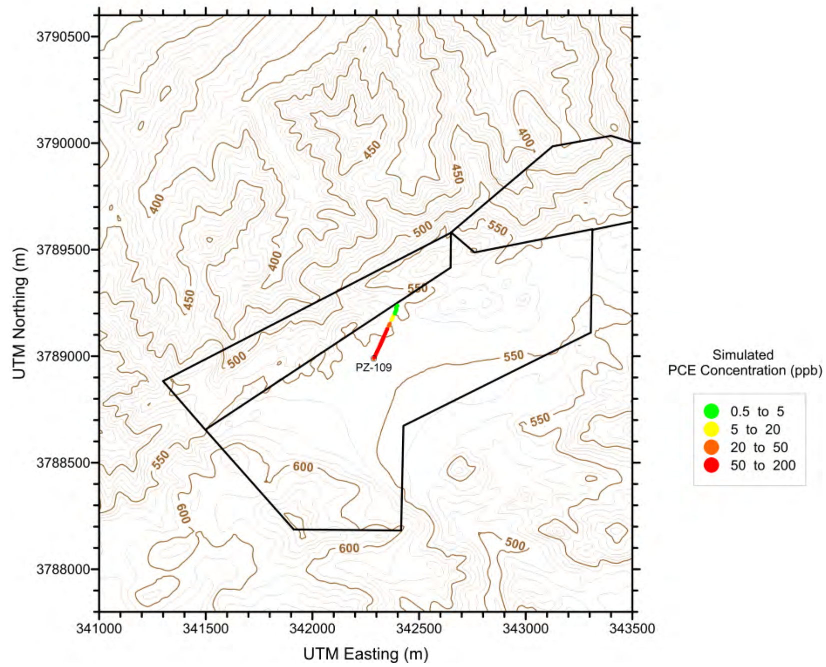

Figure 6-13.
Simulated PCE concentrations at 20 years following release from a source at the location of well PZ-109. Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

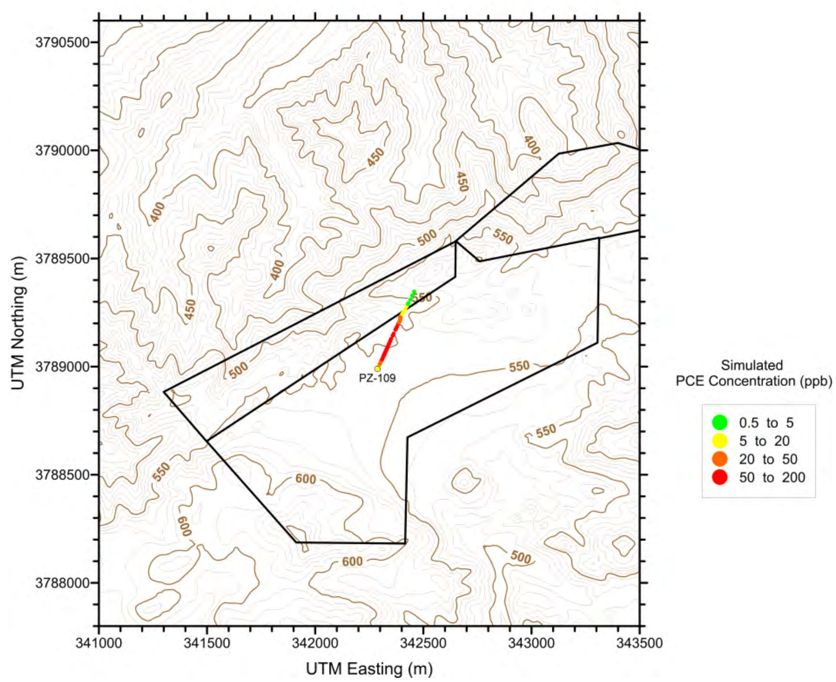

Figure 6-14.
Simulated PCE concentrations at 50 years following release from a source at the location of well PZ-109. Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

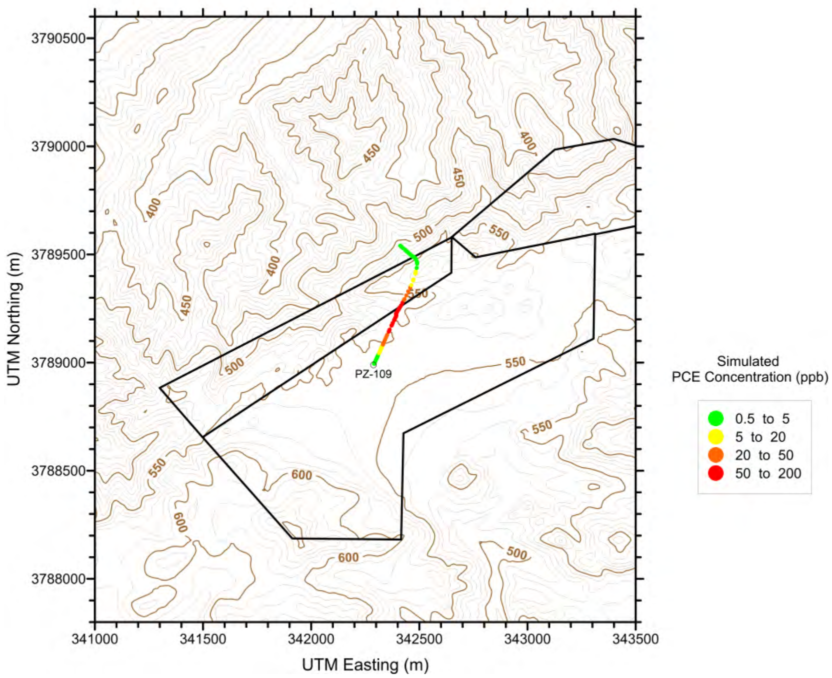

Figure 6-15.
Simulated PCE concentrations at 100 years following release from a source at the location of well PZ-109. Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

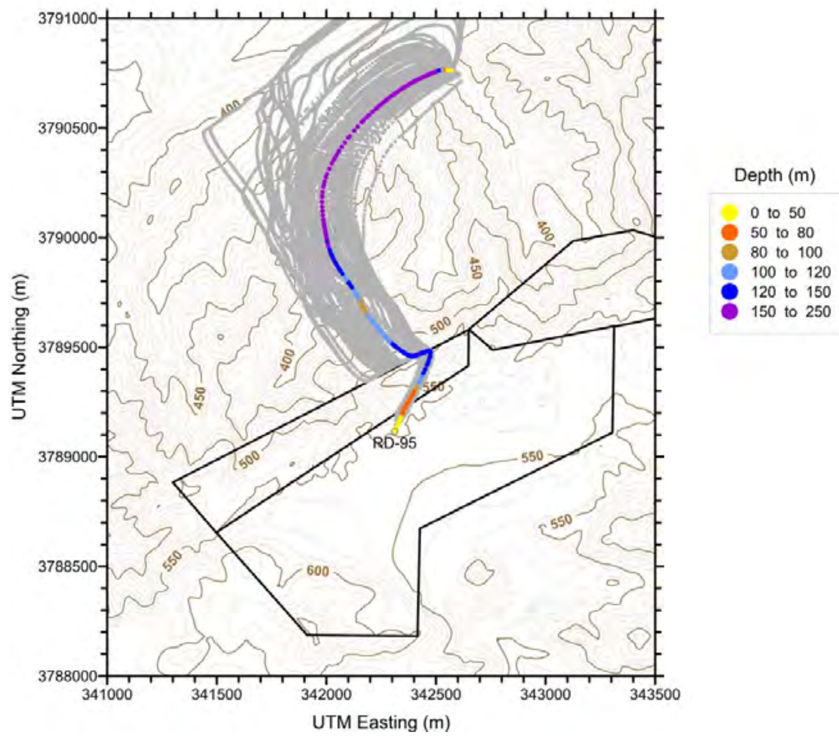

Figure 6-16.
Simulated groundwater flow path from the location of well RD-95. Alternative flow paths from the null-space Monte Carlo analysis shown in gray.

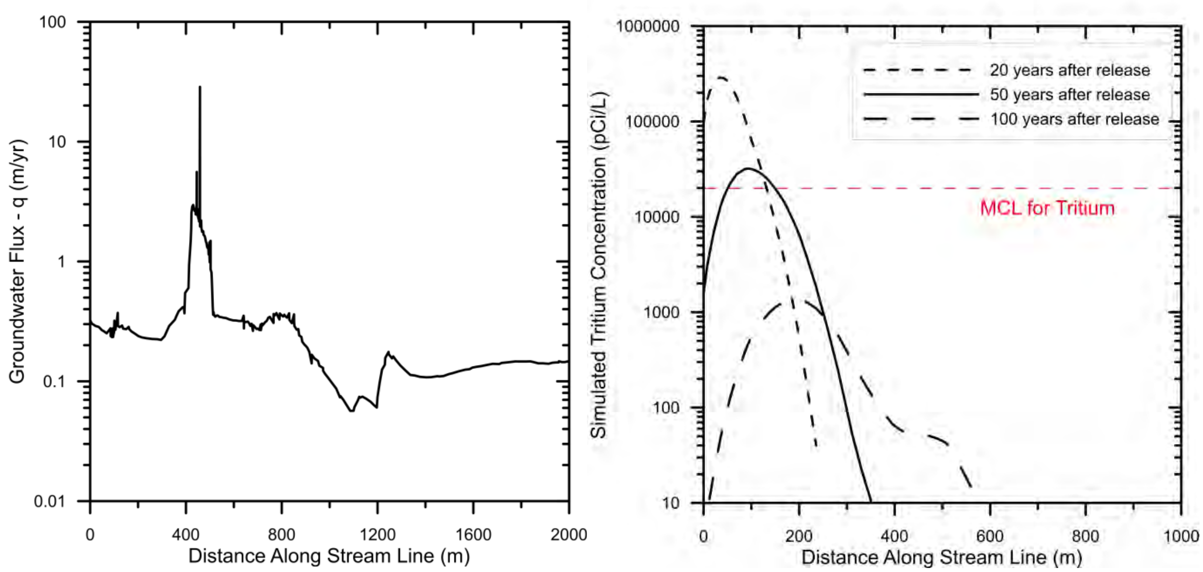

Figure 6-17.
Simulated groundwater flux profile and tritium concentration profiles for three times following release along the flow path from the location of well RD-95.

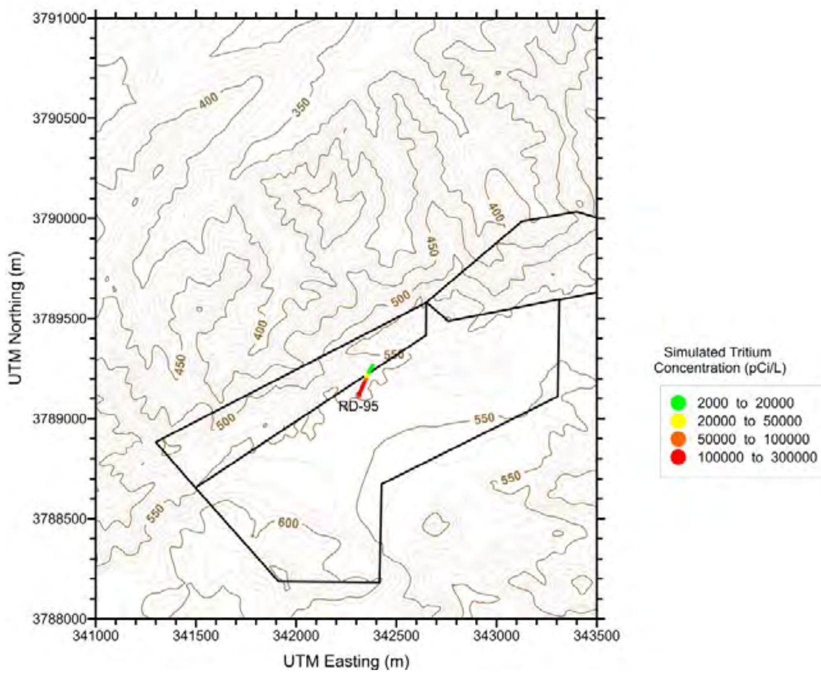

Figure 6-18.
Simulated tritium concentrations at 20 years following release from a source at the location of well RD-95. Particle tracking plot truncated at simulated concentrations of less than 2000 pCi/L.

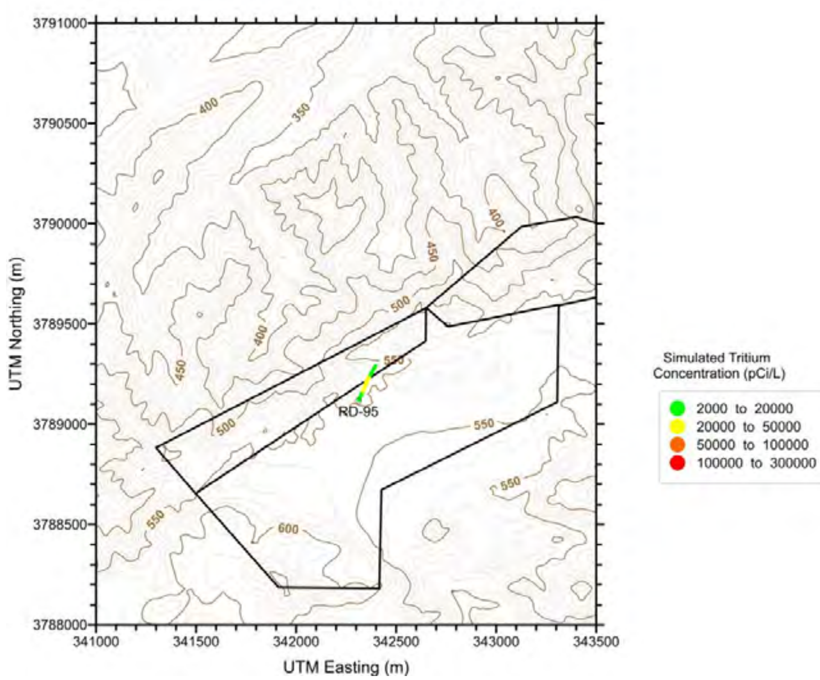

Figure 6-19.
Simulated tritium concentrations at 50 years following release from a source at the location of well RD-95. Particle tracking plot truncated at simulated concentrations of less than 2000 pCi/L.

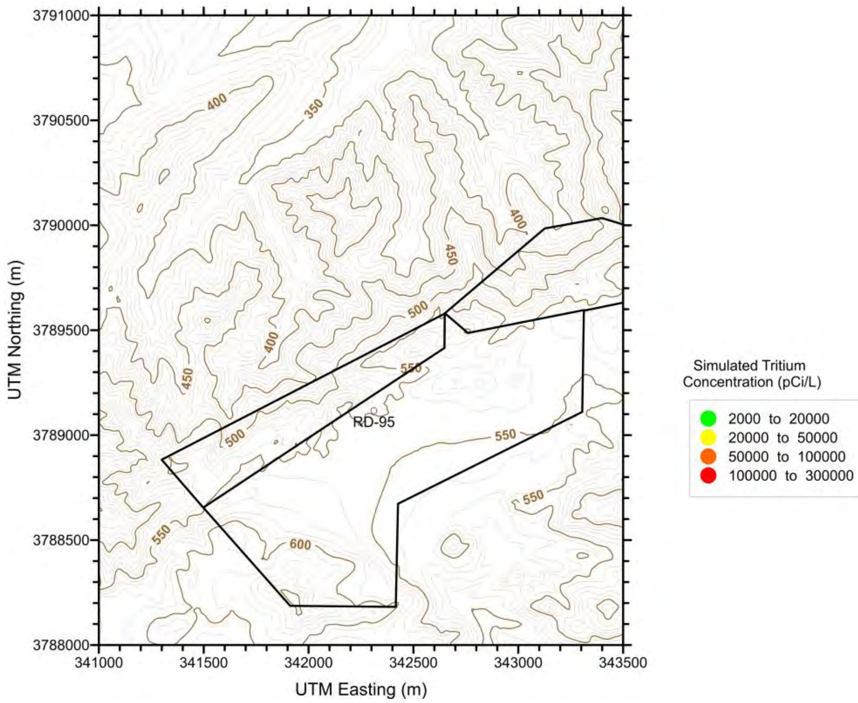

Figure 6-20.
Simulated tritium concentrations at 100 years following release from a source at the location of well RD-95. Particle tracking plot truncated at simulated concentrations of less than 2000 pCi/L.

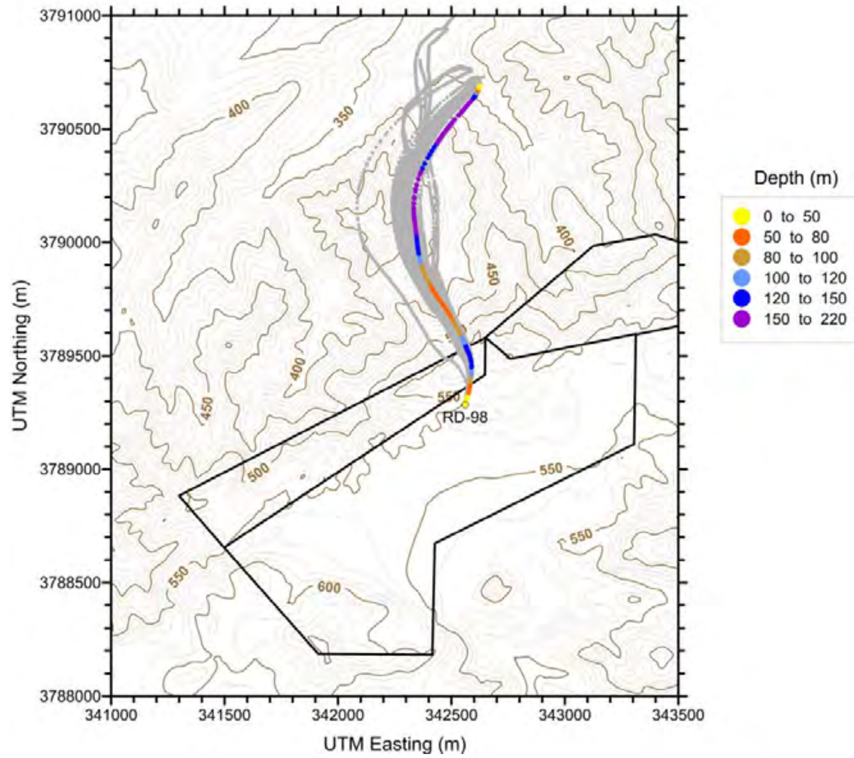

Figure 6-21.
Simulated groundwater flow path from the location of well RD-98. Alternative flow paths from the null-space Monte Carlo analysis shown in gray.

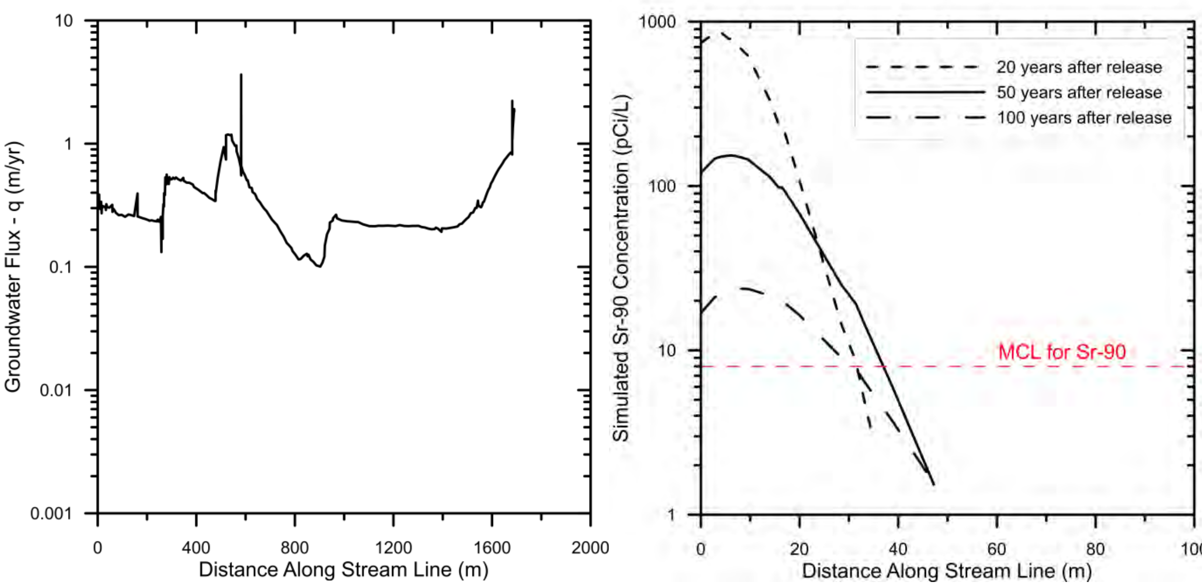

Figure 6-22.
Simulated groundwater flux profile and Sr-90 concentration profiles for three times following release along the flow path from the location of well RD-98.

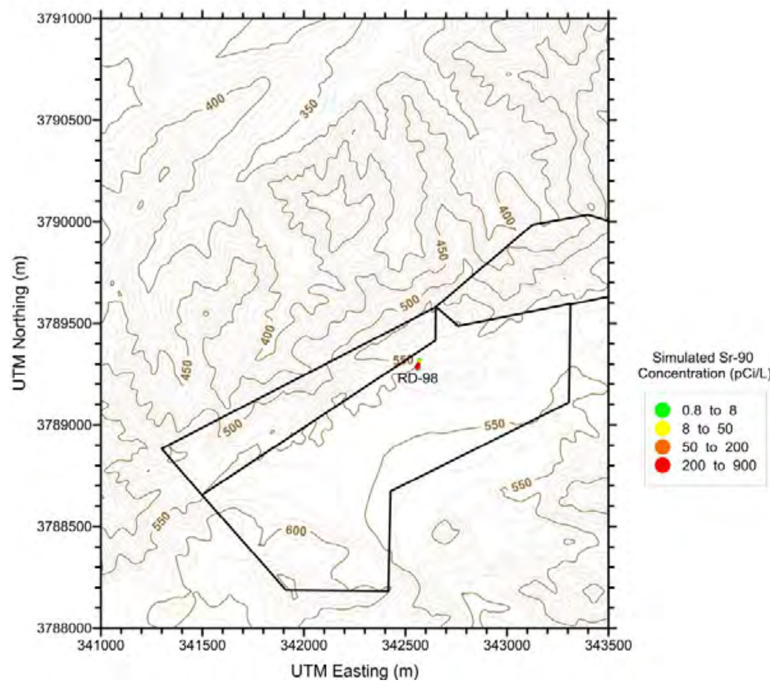

Figure 6-23.
Simulated Sr-90 concentrations at 20 years following release from a source at the location of well RD-98. Particle tracking plot truncated at simulated concentrations of less than 0.8 pCi/L.

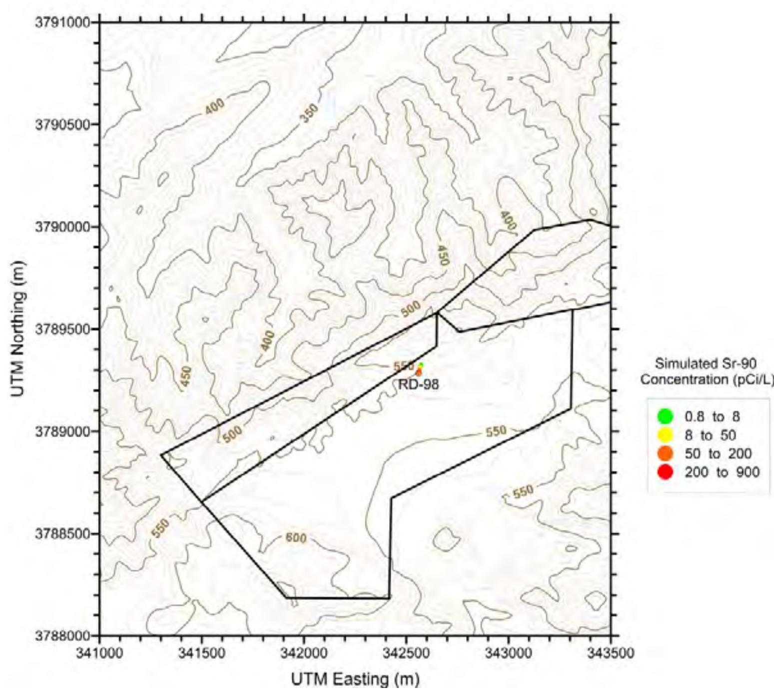

Figure 6-24.
Simulated Sr-90 concentrations at 50 years following release from a source at the location of well RD-98. Particle tracking plot truncated at simulated concentrations of less than 0.8 pCi/L.

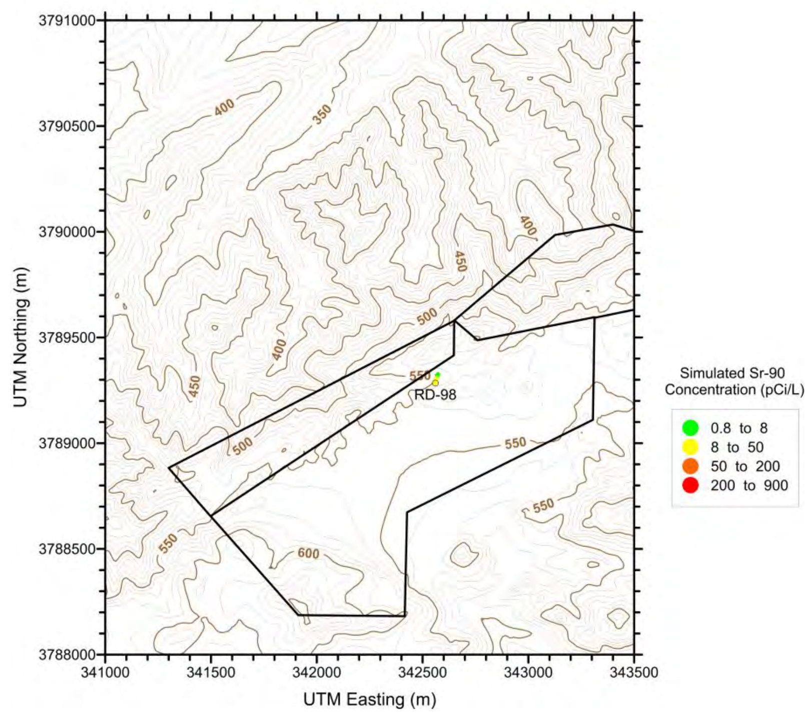

Figure 6-25.
Simulated Sr-90 concentrations at 100 years following release from a source at the location of well RD-98. Particle tracking plot truncated at simulated concentrations of less than 0.8 pCi/L.

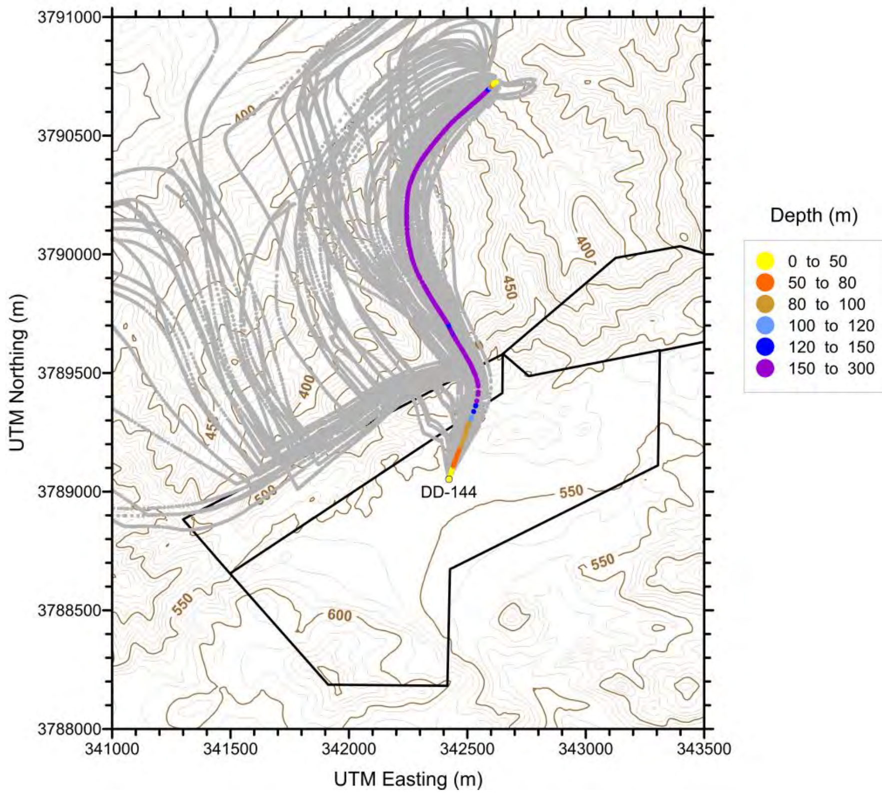

Figure 6-26.
Simulated groundwater flow path from the location of well DD-144. Alternative flow paths from the null-space Monte Carlo analysis shown in gray.

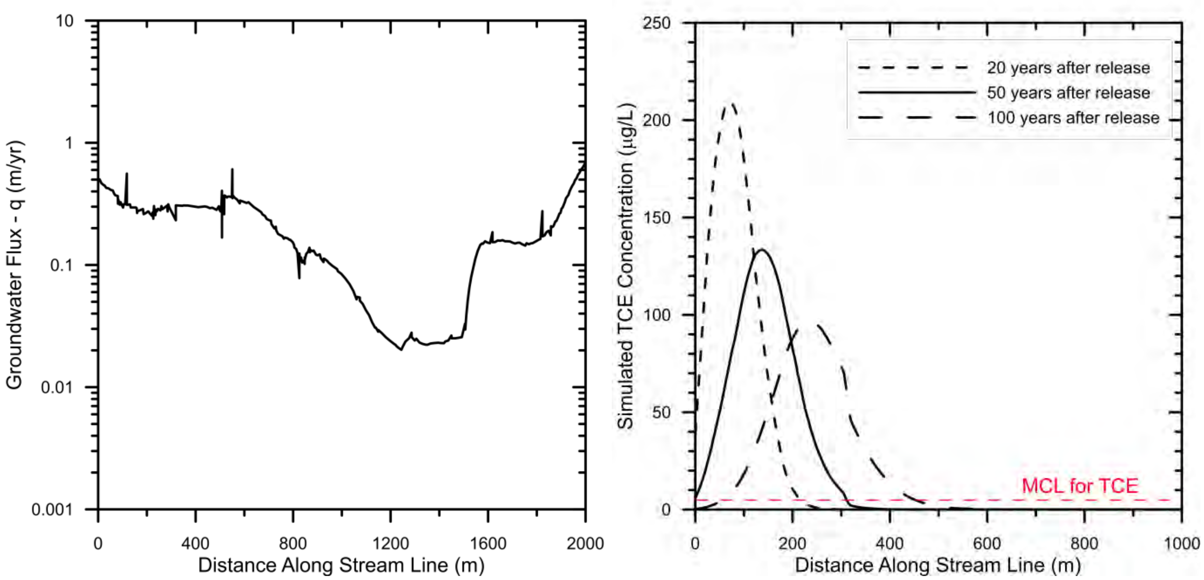

Figure 6-27.
Simulated groundwater flux profile and TCE concentration profiles for three times following release along the flow path from the location of well DD-144.

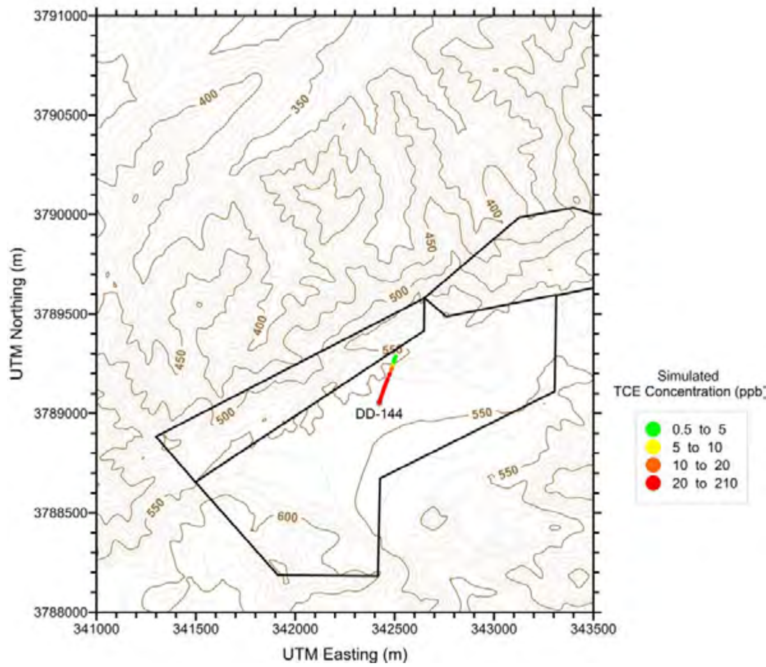

Figure 6-28.
Simulated TCE concentrations at 20 years following release from a source at the location of well DD-144. Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

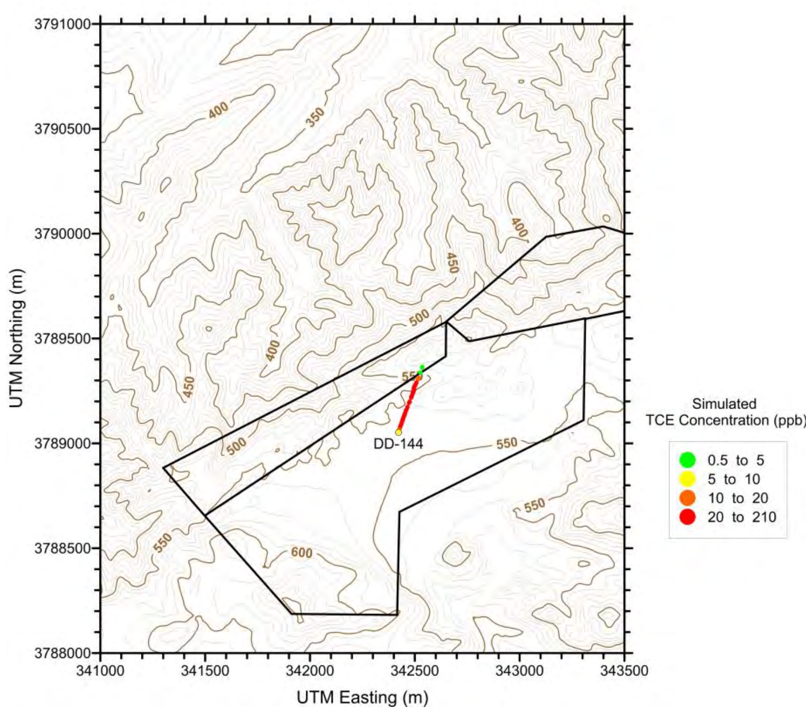

Figure 6-29.
Simulated TCE concentrations at 50 years following release from a source at the location of well DD-144. Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

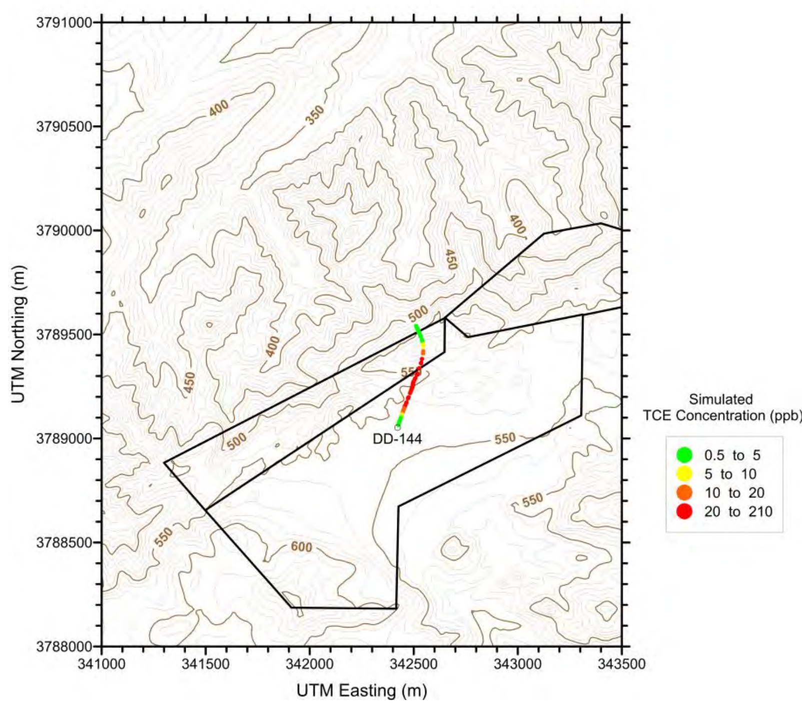

Figure 6-30.
Simulated TCE concentrations at 100 years following release from a source at the location of well DD-144. Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

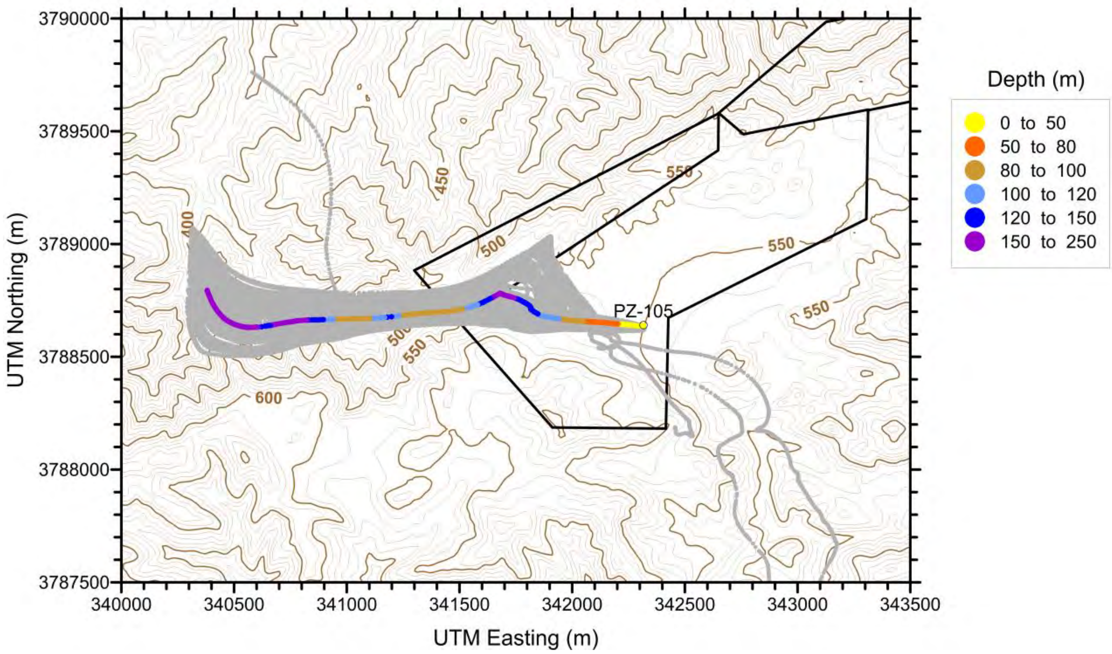

Figure 6-31.
Simulated groundwater flow path from the location of well PZ-105. Alternative flow paths from the null-space Monte Carlo analysis shown in gray.

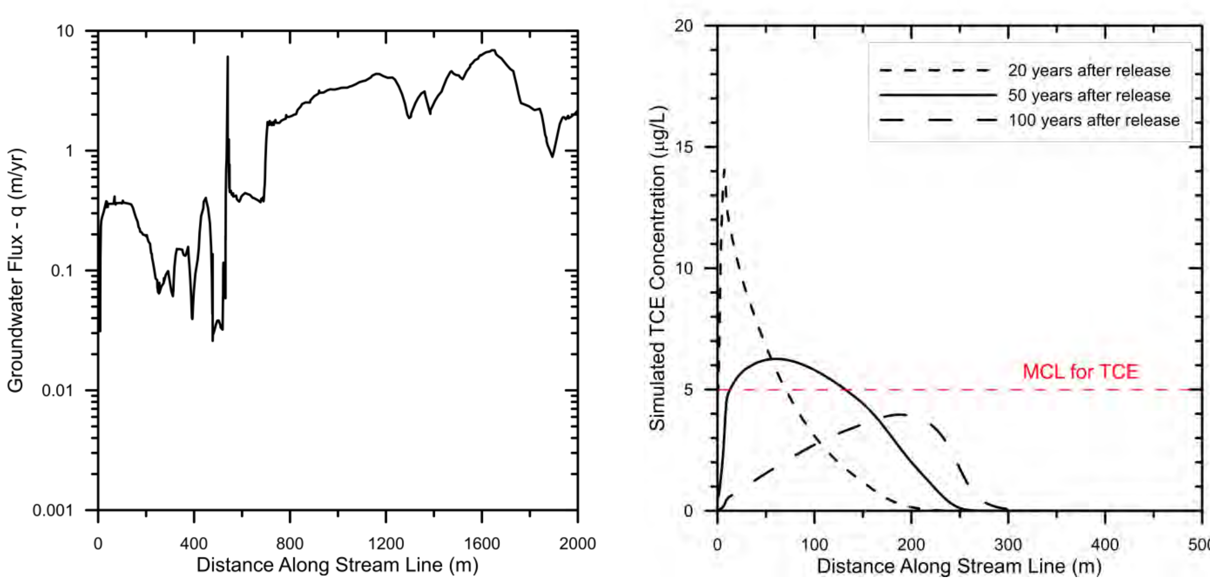

Figure 6-32.
Simulated groundwater flux profile and TCE concentration profiles for three times following release along the flow path from the location of well PZ-105.

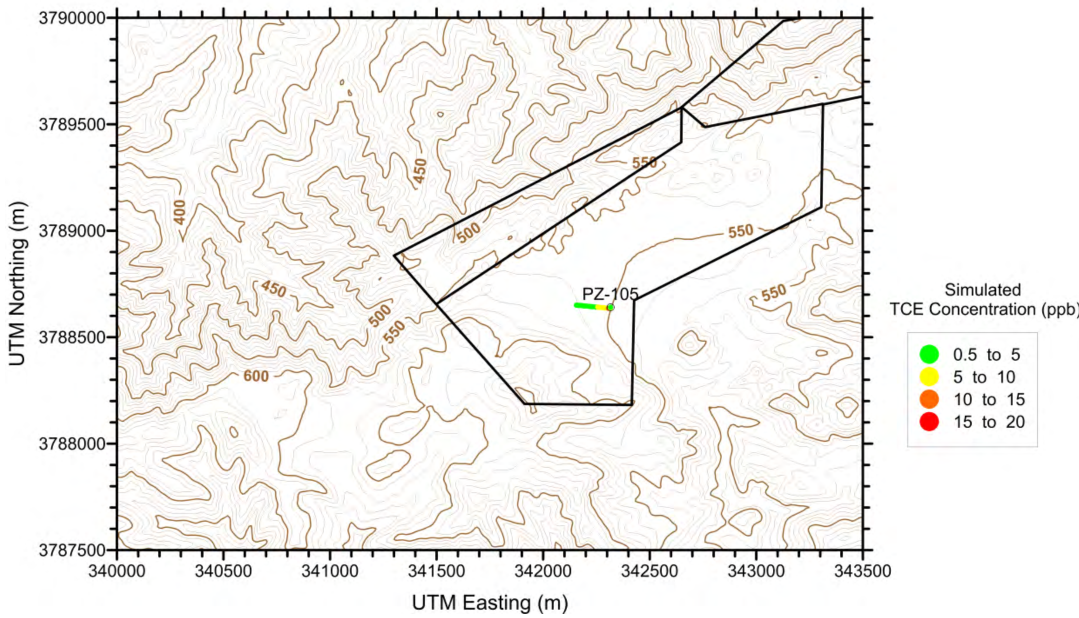

Figure 6-33.
Simulated TCE concentrations at 20 years following release from a source at the location of well PZ-105.
Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

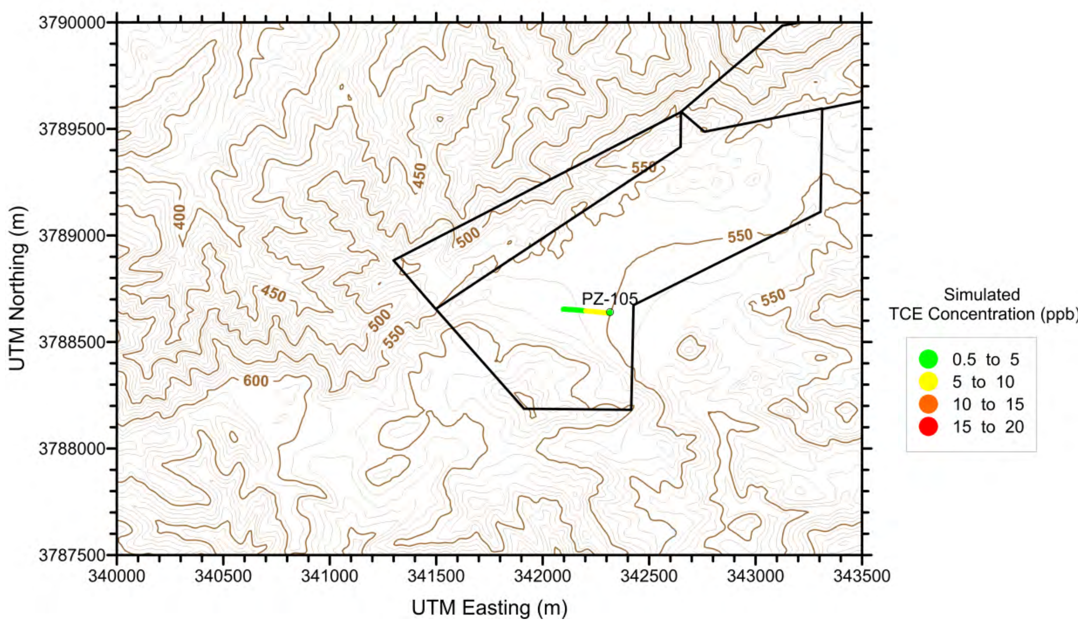

Figure 6-34.
Simulated TCE concentrations at 50 years following release from a source at the location of well PZ-105.
Particle tracking plot truncated at simulated concentrations of less than 0.5 µg/L.

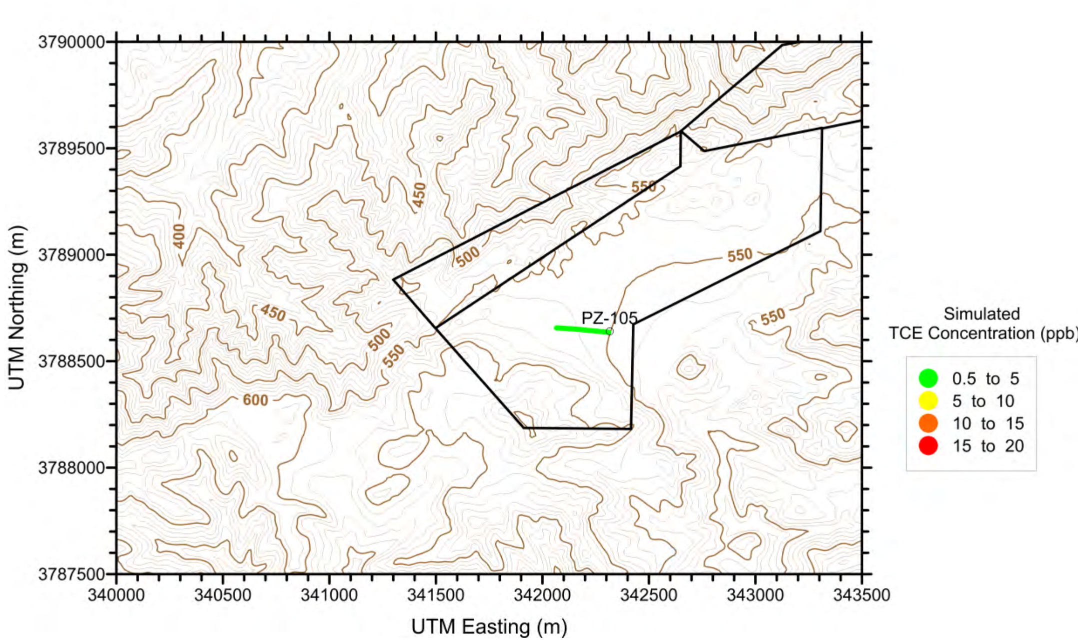

Figure 6-35.
Simulated TCE concentrations at 100 years following release from a source at the location of well PZ-105.
Particle tracking plot truncated at simulated concentrations of less than 0. 5 µg/L.

Section 7

Summary and Conclusions

Section 7 presents a summary of the findings of the hydrogeologic studies and investigations of sources and extent of groundwater contamination. This section also introduces initial recommendations for the subsequent groundwater corrective measures studies.

7.1 Major Conclusions of Area IV Groundwater Investigation Areas

7.1.1 Former Sodium Disposal Facility

The FSDF, which primarily consisted of two unlined ponds, was used from 1956 to 1978 for the removal of alkali metals from metallic objects. Although not part of the FSDF operations, the land adjacent to the FSDF was also used for placement of drums containing wastes. The ponds and drums have all been removed.

Following are conclusions of FSDF source areas:

- The lower FSDF pond is presumed to be the primary source of contaminants to groundwater, based on past waste disposal practices, and passive soil gas and rock core results for the vicinity of the FSDF. Past removals remediated surficial contamination; however, residual contamination remains in underlying weathered and fractured bedrock matrix and contributes as secondary source to groundwater contamination.
- Rock core indicate that the primary VOC mass is located within near-surface bedrock to approximately 60 feet bgs. Some lateral migration of TCE in bedrock fractures has occurred that has resulted in downward migration of TCE in open boreholes. Recently completed soil gas and bedrock coring indicates that the primary area of impacted bedrock starts near RS-54 and extends to the north.
- Historical records of drum storage near the ponds indicate that there may have been additional sources of contamination near the FSDF, but the impacted soil and drums were removed over 20 years ago.

Conclusions regarding the current nature and extent of groundwater contamination at the FSDF are presented below.

- Groundwater contaminants include the following:
  - VOCs including 1,1,1-TCA and TCE and associated chemical breakdown products. The highest reported concentrations of 1,1,1-TCA and TCE (15,000 µg/L in 1996 and 4,500 µg/L in 1994, respectively) were detected in Near-surface groundwater within the footprint of the former lower pond (well RS-54).
  - Metals including cadmium, cobalt, copper, molybdenum, nickel, and selenium have exceeded screening levels in RS-54 from 2000 to 2018.

- Perchlorate is an historic groundwater contaminant, but recent sample results show it at groundwater screening levels for the FSDF location.

- Results from Chatsworth Formation bedrock wells at the FSDF indicate that TCE has impacted bedrock groundwater, but at concentrations less than that observed at RS-54. TCE concentrations in adjacent bedrock well RD-64 have decreased from 680 µg/L in a 2001 sample to 32 µg/L for a 2016 sample. The 2014-2017 drought is one possible cause of the reduction as vadose zone contamination has not been transported via fractures to the underlying aquifer.
- The vertical and lateral extent of groundwater contamination has been defined.
- Sampling data show that metals groundwater contamination is restricted to the location of the former ponds.

7.1.2 Building 100 Trench

- The following are concluded from historic and current data at the Building 100 trench:
- The Building 100 Trench was used 1960 through 1966 for burning and disposal of building materials. In 2003 all materials were removed.
- No groundwater contamination is identified for this area.
- Metals in adjacent soils remains a concern.

7.1.3 Building 56 Landfill

Conclusions for source areas and the current nature and extent of contamination at the Building 56 Landfill are presented below.

- Material initially placed at the landfill consisted of bedrock excavated from the Building 56 basement. The material was placed on the surface and in drainages. The site was subsequently used for placement on the surface drums and building debris. All drums and debris were removed in the early 1980s.
- Chatsworth formation groundwater beneath the landfill is impacted with TCE; the highest concentration of 130 µg/L was reported for a RD-07 sample collected in 1987. Since 2013, TCE concentrations in RD-07 samples have ranged from 47 to 57 µg/L.
- The source of TCE in groundwater is not known, since soil vapor results did not indicate the presence of TCE within the landfill. The source may have originated closer to Building 4100 and migrated along bedrock fractures in the Near surface groundwater.
- Monitoring of downgradient wells indicates that TCE-impacted groundwater has not migrated beyond the boundary of the landfill.

7.1.4 Buildings 4057/4059/4626

Conclusions for source areas and the current nature and extent of contamination at Buildings 4057/4059/4626 are presented below.

- Buildings 4057/4059/4626 area is the only location in Area IV impacted by PCE. PCE was discovered in the 1980s while dewatering the basement in Building 4059
- PCE concentrations in monitoring wells have ranged from a high of 300 µg

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- /L for a 2002 sample to 55 µg/L for a March 2016 sample collected from PZ-109.
- Historic records suggest two possible PCE sources in this area. One at former Building 4059 and the second in the area between Buildings 4057 and 4626.
- Soil gas and soil sample results indicate that there are no remaining PCE sources in the soil; however, residual contamination remaining in underlying weathered and fractured bedrock matrix may provide a secondary source to groundwater contamination.
- The lateral and extent of groundwater contamination has been defined using monitoring wells that surround the investigation area.

7.1.5 Building 4457 Hazardous Materials Storage Area

Conclusions for source areas and the current nature and extent of contamination at the HMSA are presented below.

- The Near-surface groundwater beneath and adjacent to the HMSA is impacted by TCE; the source has not been identified although the highest groundwater concentrations are closer to former Building 4026 than former Building 4457. Chemicals were used at multiple locations at the HMSA, and historically there may have been multiple sources.
- The highest near-surface groundwater TCE concentration for the HMSA were reported in piezometer PZ-108 at 160 µg/L in a 2000 sample. PZ-108 is located in the eastern portion of the HMSA, south of former Building 4457.
- The highest current (2018) TCE concentration was reported for bedrock well DD-144 (at 200 µg/L) and piezometer 163 µg/L at 190 both located near the center of the HMSA groundwater impact area near former Building 4026.
- The HMSA straddles the top of the groundwater mound in the center of Area IV, where perched zone groundwater occurs more often.
- The horizontal extent of TCE contamination is defined within the borders of the HMSA; however, the vertical extent is not defined. In June 2018 well DD-146 was installed adjacent to DD-144 to assess the vertical migration of the TCE.

7.1.6 Tritium Plume

Conclusions for source areas and the current nature and extent of contamination for the Tritium Plume are presented below.

- An area of tritium-impacted groundwater exists in northern Area IV near former test reactors including Buildings 4010, 4019, 4024, 4028, and 4059.
- The remaining source is harbored in upper bedrock fractures.
- The horizontal extent of contamination has been defined and is monitored by wells within the Chatsworth Formation groundwater
- The vertical extent is not defined in the central portion of the plume.
- Groundwater tritium concentrations have decreased by over 50 percent in the last 10 years (the half-life of tritium is 12.5 years), and overall concentrations are expected to be below the 20,000 pCi/L MCL in the next 10 years.
- The plume front is stable (tritium concentrations in seep well SP-T02D remain around 1,200 picocuries) and is not expected to migrate further downgradient.

7.1.7 Radioactive Materials Handling Facility

Conclusions for source areas and the current nature and extent of contamination for the RMHF are presented below.

- Groundwater to the immediate north of the RMHF is impacted by both TCE and Sr-90.
- Both contaminants are assumed to have been released at the former leach field north of the RMHF.
- Ten years of groundwater extraction occurred between 1994 and 2005 at Chatsworth Formation well RD-63 reducing TCE concentrations to the MCL at 5 µg/L MCL.
- The leach field location remains impacted by Sr-90 in near-surface bedrock between 30 and about 50 feet below ground surface.
- Concentrations of Sr-90 have been below the MCL (8 pCi/L) in all the wells except RD-98 at the western end of the former RMHF leach field.
- The approximate location of the Sr-90 in near surface is estimated by groundwater elevation responses, but the mass of remaining Sr-90 is unknown.

7.1.8 Old Conservation Yard

Conclusions for source areas and the current nature and extent of contamination for the OCY are presented below.

- Groundwater at the OCY is monitored by Chatsworth Formation bedrock well RD-14.
- Near-surface groundwater is discontinuous and perched above the Chatsworth Formation groundwater when present.
- TCE and its breakdown product cis-1,2-DCE are the only contaminants detected above screening levels. The highest concentration of TCE observed in the last 25 years of sampling was 5.9 µg/L in 2011. TCE has been detected since 2011 at concentrations less than 3 µg/L.
- No source for TCE has been identified at the OCY.
- The OCY contains hot spots of metals in soils that may warrant further investigation.

7.1.9 Building 4065 Metals Clarifier/DOE Leach Field 3

Building 4065 has been combined with DOE Leach Field 3 as a single groundwater investigation area due to the proximity of the Metals Clarifier with four former leach fields.

Conclusions for source areas and the current nature and extent of contamination for the Building 4065/DOE Leach Field 3 are presented below.

- Near-surface perched groundwater beneath the Metals Clarifier Laboratory Building 4065 and DOE Leach Fields 3 area is impacted with TCE with a recent maximum of 8.7 µg/L in 2014 for piezometer PZ-105 (maximum of 12 µg/L detected in a 2002 sample).
- The PCE detected at piezometer PZ-005 may indicate a separate contaminant source near the metals clarifier.
- No source for TCE or PCE has been identified for this area, but based on groundwater results, no significant source remains.
- TCE in the near-surface groundwater has not migrated appreciably into the Chatsworth formation groundwater as indicated by the sampling results from bedrock well DD-145 (TCE estimated in 2016 at 0.31 µg/L).

7.1.10 Buildings 4030/4093 Leach Fields

This combined groundwater investigation area consists of two former leach field sites (AI-Z3 and AI-Z4) associated with former buildings 4030 and 4093 located in the eastern portion of Area IV.

Conclusions for source areas and the current nature and extent of contamination for the Building 4030/4093 DOE Leach Fields are presented below.

- With the exception of bedrock well RD-17 located up- or cross-gradient from the Building 4093 leach field (TCE at 0.38 µg/L in 2016), none of the monitoring wells in these two areas exhibit groundwater contamination.
- It is likely that the TCE observed in well RD-17 is the eastern boundary of the HMSA TCE plume.
- No contaminant source or groundwater impact related to the former leachfields is present.

7.1.11 Building 4064 Leach Field

Conclusions for source areas and the current nature and extent of contamination for the Building 4064 Leach Field are presented below.

- No source for groundwater contamination has been identified at this site.
- The leach field once associated with Building 4064 (AI-Z2) is monitored by well DS-47 installed in late winter of 2016.
- Well DS-45 installed to the top of the Lot Bed adjacent to DS-47 has been dry since installation in 2016.
- Well DS-47 has been non-detect for TCE for both samples collected in 2016.

7.1.12 Hazardous Waste Management Facility

The HWMF consists of two remaining structures, Building 4133 and Building 4029. The HWMF is a RCRA-permitted facility being closed under RCRA procedures. There are two wells near Building 4133. The Near-surface groundwater monitoring well is generally dry and the bedrock well has been sampled annually since 1994 with TCE detected only once in 2006 which was considered anomalous as the results have not been repeated. The requirements for groundwater monitoring at both buildings will be addressed as part of the RCRA closure action. Following structure removal, soils will be sampled. Based on the soil results, the need for groundwater related studies will be defined.

7.1.13 Rockwell International Hot Lab

Conclusions for source areas and the current nature and extent of contamination for the RIHL are presented below.

- Piezometer PZ-103 is the only monitoring well in this area installed within the weathered bedrock with a screened interval between 36 and 39 feet bgs.
- When last sampled in 2017 this well exhibited 0.53 J µg/L of TCE.
- No source for TCE has been identified for this site.

7.1.14 Building 4009 Leach Field

Conclusions for source areas and the current nature and extent of contamination for the Building 4009 Leach Field are presented below.

- Piezometer PZ-102 is the only monitoring well near the Building 4009 Leach Field. This well is normally dry, but was sampled once in 2003 and TCE was detected at 6 µg/L.
- There were no VOCs detected in passive soil gas samples collected in the leach field area in May 2018.
- Adjacent to the Building 4009 leach field site is monitoring well RD-98 at Building 4100 which exhibited 200 µg/L in 2104. The source for the TCE is not known, but does not appear to be associated with Building 4009.

7.2 Conclusions on Area IV Hydrogeology in Relation to Overall SSFL Hydrogeology

The basic concept for contaminant transport mechanisms established for SSFL at the mountain-scale applies to Area IV. That is, solvents and other contaminants released at the surface, migrate downward through the soils, carried by precipitation where the infiltrating water encounters the alluvium-bedrock interface. At the bedrock interface, the impacted water can either become perched at the interface (spreading laterally), or migrate further downward depending on bedrock tightness and fracture network. This transport mechanism is observed at the FSDF, HMSA, and RMHF Leach Field areas. When bedrock fractures are present, or the perched water encounters fractures, the impacted groundwater then follows the pathways of the fractures. Contaminants in fractures can also migrate into the bedrock matrix through matrix diffusion principles.

Unlike other areas of the SSFL Site, the data indicate that the majority of contaminant mass in Area IV remains in near-surface bedrock, particularly within the upper bedrock fractures. When well RD-63 at the RMHF was pumped for 10 years, TCE concentrations in adjacent wells RS-28, RD-30 and RD-34A decreased without rebounding following pumping. TCE concentrations in well RS-28 decreased from 59 µg/L to 15 µg/L during pumping and have not exceeded 16 µg/L since cessation of pumping. TCE concentrations in well RD-30 decreased from 44 µg/L to 11 µg/L and have remained less than 12 µg/L since. TCE concentrations in well RD-34A dropped from 91 µg/L to 1 µg/L during pumping and after pumping TCE concentrations have not been greater than 5.3 µg/L since (0.38 J in 2018). Concentrations in all RMHF wells are currently at or below the 5 µg/L MCL for TCE. This demonstrates that the pumping of RD-63 was effective at removing mass of TCE from the fracture network, and the residual TCE observed following pumping reflects reverse diffusion from the bedrock.

Another difference for Area IV hydrogeology compared with other parts of SSFL is that bedrock is tighter and less fractured. The pumping of well RD-21 upgradient of the FSDF had no influence on groundwater surface elevations in multiple wells less than 50 feet away. The presence of elevated TCE concentrations in perched well RS-54, without similar concentrations in deeper wells 10 to 30 feet away, illustrates retarded contamination migration. And the presence of the groundwater mound in the central Area IV during a time of drought illustrates the tightness of the upper bedrock. This conclusion is also supported by other Area IV well data that demonstrates that contaminants have not moved far (vertically and horizontally) from their sources.

7.3 Conclusions on Area IV Faults

There are two bedrock faults associated with Area IV – Burro Flats fault and North fault – and an area with lineaments/deformation bands, that have been assessed for their influence on groundwater flow and control.

The Burro Flats fault is located along the southern boundary of Area IV. It marks the abutment of the Santa Susan Formation and the Chatsworth Formation. Hydrogeologically, the fault area is upgradient of the FSDF. However, groundwater flow in this part of Area IV is limited by tight bedrock. When well RD-21 upgradient of the FSDF was pumped, there was no response in well RD-50, located immediately south of the fault. When well RD-54A at the FSDF was pumped, there was no response in wells RD-21 and RD-50. This strongly indicates that groundwater flow is controlled by bedrock porosity/transmissivity (or lack thereof) and not the Burro Flats fault.

The North fault has been depicted several different ways, but today the geologists studying SSFL faults believe that it does not exist north of Area IV. There are a series of lineaments/deformation bands trending southwest to northeast near the western and northern Area IV boundary. The hydrogeologic evidence shows a limited influence of the lineaments/deformation bands on groundwater flow. Groundwater flow is controlled by the bedrock porosity and the fracture network.

7.4 Conclusions on Contaminant Fate and Transport

The evaluation of the hydrogeology and well sampling data demonstrate that groundwater contaminants have not moved far from their sources. The tritium plume may be an exception, because it cannot be retarded by elements comprising the site geochemistry. However, the main core of the tritium plume remains within the Area IV boundaries and is within 10 years of being below its MCL.

Regarding the chlorinated solvents PCE, and 1,1,1-TCA, and specifically TCE, there is evidence of degradation of the parent chemical into first stage daughter products (e.g., cis-1,2-DCE) to vinyl chloride. Vinyl chloride is not observed in all wells, but one reason could be that the starting concentrations of the parent and resulting daughter chemicals are too low to see succeeding chemicals. Another reason could be that the groundwater in open boreholes that is being sampled is open to the air allowing volatilization of vinyl chloride before it can be measured. When the FLUTe liners were installed at the FSDF wells, the liners effectively blocked oxygen movement, and vinyl chloride was occasionally observed in FLUTe samples. Vinyl chloride has been consistently observed in in the GWIM samples collected at the FSDF.

Groundwater flows in different directions depending on location in Area IV, affecting contaminant transport. In the western portion of Area IV flow is to the west/northwest, in the northern part of Area IV flow is to the north, and in the eastern part of Area IV flow is to the southeast. Contaminant transport is highly controlled by bedrock rock properties, including tightness and fracture density. Fracture density and network probably is the greatest controlling factor in distance of contaminant movement. Bedrock in the western part of Area IV is the least fractured/tightest and groundwater flow (contaminant transport) is slow. At the FSDF sampling data show that TCE has not moved more than 300 feet from the FSDF source. The contaminant distribution at the HMSA (groundwater mound area) has shown no appreciable movement since sampling started. The Tritium Plume is in an area of greater bedrock fracture density, but laterally the plume has only migrated about 500 feet.

Vertical migration is also controlled by the fracture network. Data for the FSDF location show migration via fractures to about 150 feet bgs. But concentrations at depth are significantly less that what is observed in shallow bedrock. Vertical migration is less prevalent elsewhere in Area IV, but the starting source concentrations are not at the same levels as observed at the FSDF.

7.5 Corrective Measures Study Recommendations

Based on the findings discussed in this this GW RFI Report, the text in section introduces concepts to be considered for the development of the Corrective Measures Study.

7.5.1 Former Sodium Disposal Facility

Current understanding:

- Corehole data and packer testing data illustrate that VOCs are harbored in bedrock fracture groundwater that can be extracted for surface treatment.
- Contaminant mass has been shown remain in upper bedrock zone.
- With limited surface water infiltration, contaminant mass is not moving appreciably away from RS-54.
- The source area appears to be the lower pond.

CMS characterization considerations:

- Evaluate the 2017-2018 GWIM results to determine the effectiveness of bedrock fracture dewatering in removing VOC mass.
- Assess current bedrock core results to determine whether additional coring is needed north of RS-54.

CMS recommendations:

- Evaluate for a full range of source control, removal and groundwater cleanup actions.

7.5.2 Building 100 Trench

Current understanding:

- There is no groundwater contamination at this location.

CMS characterization considerations:

- This area is adequately characterized.
- Assess threat to groundwater of metals.

CMS recommendations:

- No further action.

7.5.3 Building 56 Landfill

Current understanding:

- One well, RD-07, is impacted by TCE at this location.
- Groundwater contamination by TCE has been between 29 and 57 µg/L for the past five years, indicating that concentrations are not controlled by groundwater elevation level or surface infiltration.
- Soil vapor data indicates that the landfill is not the source.
- Sampling data provide clear evidence of degradation of TCE.

CMS characterization considerations:

- Continue investigation for a VOC source near the landfill.

CMS recommendations:

- Evaluate for a full range of source control, removal and groundwater cleanup actions.

7.5.4 Buildings 4057/4059/4626

Current understanding:

- The horizontal and vertical extent of contamination by PCE is defined.
- There may be multiple historic sources for the PCE, but decreasing PCE groundwater concentrations and lack of evidence of an existing source from soil vapor data indicate that the source has diffused.
- Sampling data provides clear evidence of the degradation of PCE.

CMS characterization considerations:

- Continue evaluation of the trend data.

CMS recommendations:

- Evaluate for a full range of source control, removal and groundwater cleanup actions.

7.5.5 Hazardous Materials Storage Area

Current understanding:

- The groundwater impact area straddles the groundwater mound characteristic of central Area IV. Groundwater at this location appears to be “stagnant” meaning it is not appreciably moving in any direction.
- The horizontal extent of contamination by TCE is defined, the vertical extent remains under investigation.

- There may be multiple historic sources for the TCE, but the lack of strong evidence of a source from soil vapor data indicate that the source has diffused. Remaining source of TCE to groundwater is from that retained in the bedrock matrix and fractures.
- Sampling data provide clear evidence of the degradation of TCE.

CMS characterization considerations:

- Assess the residual mass of TCE in the vadose zone by collection of additional soil gas data.
- Analyze data from deeper well to assess vertical extent of contamination.

CMS recommendations:

- Evaluate for a full range of source control, removal, and groundwater cleanup actions.

7.5.6 Tritium Plume

Current understanding:

- Groundwater trends for the two most contaminated wells show decreasing concentrations of tritium consistent with its 12.5-year half-life. The impacted groundwater may be below the tritium MCL in the next 10 years.
- Bedrock cores drilled 10 years ago show that highest concentrations of tritium to be present in the vadose zone and upper portion of the aquifer, consistent to that observed for solvent contamination.
- The horizontal extent of contamination is defined.

CMS characterization considerations:

- Continue the monitoring of tritium decay trends.

CMS recommendations:

- Monitored natural attenuation.

7.5.7 Radioactive Materials Handling Facility

Current understanding:

- The extent of TCE-impacted groundwater is shallow and continues to decrease with time.
- The Sr-90 source appears to remain in shallow bedrock, and groundwater concentrations are highly influenced by groundwater surface elevation.
- Impacted groundwater by Sr-90 appears to remain in the vicinity of the former leach field.

CMS characterization considerations:

- Evaluation of extent of Sr-90 impacted bedrock through drilling of bedrock cores.

CMS recommendations:

- Continued groundwater monitoring for TCE.
- Evaluate for a full range of source control, removal, and groundwater cleanup actions for the Sr-90 impact.

7.5.8 Old Conservation Yard

Current understanding:

- All debris, waste materials and impacted soil was removed from the area during decommissioning.
- Groundwater impacted by TCE remains below the MCL.
- Detection of cis-1,2-DCE indicate that dispersion, dilution, and TCE degradation is ongoing at this location.

CMS characterization considerations:

- Assess the potential for metals in soil to impact groundwater

CMS recommendations:

- Continued groundwater monitoring.

7.5.9 Metals Clarifier Laboratory Building 4065/DOE Leach Field 3

Current understanding:

- Perched-zone groundwater impacted by TCE, but historic data trends show diminishing TCE concentrations.
- Source is dissipated and thus no appreciable mass of TCE remains in the vadose zone.
- The vertical extent of the TCE-impacted groundwater is defined. Horizontal extent is generally defined to MCLs for all wells.

CMS characterization considerations:

- This area is adequately characterized.

CMS recommendations:

- Continued groundwater monitoring.

7.5.10 Buildings 4030/4093 Leach Fields (DOE Leach Field 1)

Current understanding:

- Minimal TCE groundwater impact at edge of the Building 4030/4093 groundwater investigation areas.
- No identified groundwater impact near the former leach fields.

CMS characterization considerations:

- This area is adequately characterized.

CMS recommendations:

- Continued groundwater monitoring.

7.5.11 Building 4064 Leach Field

Current understanding:

- No observed groundwater contamination.

CMS characterization considerations:

- This area is adequately characterized.

CMS recommendations:

- Continued groundwater monitoring.

7.5.12 Building 4133/Building 4029 Hazardous Waste Management Facility

Current understanding:

- The two buildings associated with the HWMF (Building 4133 and Building 4029) are being closed (removed and contamination removed) under a RCRA facility permit.
- Wells at Building 4133 exhibit no appreciable groundwater contamination.
- There is no groundwater monitoring at the Building 4029 location.

CMS characterization considerations:

- Future soil and groundwater characterization requirements will be addressed through the RCRA closure process. Soil cannot be sampled until the facilities are removed.

CMS recommendations:

- Future monitoring requirements will be addressed through the RCRA closure process following soil characterization.

7.5.13 Building 4020 Rockwell International Hot Lab

Current understanding:

- Well screened within the weathered bedrock has only contained low concentrations of TCE (0.53 J µg/L for PZ-103 in 2018). TCE concentrations may reflect the edge of the perched groundwater plume from the Metals Clarifier area and is not likely from the RIHL.
- Well has also contained metals and nitrate exceeding their respective groundwater screening levels.
- The perched zone in this area was dry in 2016.

CMS characterization considerations:

- This area is adequately characterized.

CMS recommendations:

- Continued groundwater monitoring.

7.5.14 Building 4009 Leach Field

Current understanding:

- No source of VOC contamination identified for the leach field site. This was confirmed during a 2018 passive soil gas investigation of the leach field site.
- A perched well PZ-102 contained 6 µg/L of TCE during a single sampling event in 2003. This well is also adjacent to Building 4100 where TCE-impacted groundwater is present (in 2014) at concentrations up to 200 µg/L.

CMS characterization considerations:

- Investigation of TCE sources near Building 4100 will be used to confirm no additional assessment of the B4009 area is required.

CMS recommendations:

- Continued groundwater monitoring.

Section 8

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