Appendix D
Cost Evaluation

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APPENDIX D

Cost Evaluation

D.1 Introduction

This appendix evaluates the estimated net present value (NPV) costs associated with the groundwater remedial alternatives for the former West-Cap project area focused feasibility study (FFS). The cost evaluations are based on engineering judgment, are order-of-magnitude estimates, and are expected to be accurate within +50 to -30 percent. The following sections provide brief descriptions of the components and costs associated with each alternative.

D.2 Assumptions for Estimating Costs for Components of Remedial Alternatives

Assumptions were made in developing capital and operations and maintenance (O&M) cost estimates for the following components of the alternatives analyzed (1) groundwater monitoring; (2) groundwater extraction and/or treatment; (3) administration, permitting, and legal; and (4) NPV analysis. These assumptions for components of the alternatives are described in the following subsections. Detailed cost summaries and NPV analyses for potential remedial actions included in the alternatives are developed as follows.

D.1.1 Groundwater Monitoring

In addition to the O&M costs associated with construction, all the alternatives will require annual monitoring and reporting. Cost estimates for the groundwater monitoring program were developed on the basis of the following assumptions:

- Future costs associated with water quality sampling include costs for sampling existing wells and costs for sampling the new wells proposed in the remedial alternatives.
- Projected monitoring timeframe is unknown. An NPV cost was done for 30 years for Alternative 1 and 13 years for Alternative 2.
- The monitoring will consist of collecting samples for volatile organic compounds (VOCs) from approximately 26 groundwater wells on a semiannual basis. For natural attenuation, additional monitoring is required from approximately five wells for sulfate, manganese, hardness, nitrate/nitrite, alkalinity, total dissolved solids, ferric/ferrous iron, methane, ethane, ethene, total organic compounds (TOCs), oxidation/reduction potential (redox), and dissolved oxygen on an annual basis. Costs for developing the annual reports will include writing, word processing, editing, graphics, and reprographics.
- Future water level measurements will be collected on a semiannual basis. Costs associated with obtaining water levels are included in the quarterly well sampling cost.

- The suite of contaminants being analyzed will not change in the future.
- Analytical costs will remain fixed over the duration of the monitoring program.
- Quality control costs will be 20 percent of the analytical fees.
- Progress reports will occur semiannually and plume maps will be created semiannually.
- Technical support, provided under the O&M cost, includes services to monitor, evaluate, and report progress of remedial action. *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (United States Environmental Protection Agency [EPA], 2000[1]) was used to determine the percentage for estimating technical support needs. Technical support is assumed to be 10 percent of total O&M costs for the alternatives presented in this FFS.
- Overhead is assumed to be 10 percent of the total O&M costs. Indirect cost includes field office overhead and general and administrative costs (EPA, 2000).
- Monitoring wells will be rehabilitated every 15 years.
- Pump refurbishment or replacement will be every 10 years.

D.1.2 Groundwater Extraction, Treatment, and Injection

A cost estimate for this alternative was developed on the basis of the alternative description in **Section 3.1** of the main text and the following assumptions:

- Projected operational time frame is unknown. An NPV cost was done for 4 years at 160 gallons per minute (gpm) and then another 26 years at 40 gpm.
- Costs for installation of a new liquid-phase granular activated carbon (LGAC) adsorbent unit at the former West-Cap project area are included in this cost evaluation. The costs reflect installation of a new treatment system to accommodate for the total flow coming from the extraction well system.
- The feasibility of obtaining the land needed to accommodate the treatment facility was not performed for these costs presented in this appendix.
- Extraction wells and injection wells will be rehabilitated every 15 years.
- Extraction well pumps will be refurbished every 10 years.
- Electrical power rates—the rate is $0.10 per kilowatt-hour (kWh). The location of the project facilities is entirely within the Tucson Electric Power service area. The power rate used reflects an average cost based on information provided by commercial representatives of Tucson Electric Power.

[1] U.S. Environmental Protection Agency (EPA). 2000. *A Guide to Developing and Documenting Cost Estimates during the Feasibility Study*. July.

D.1.3 In Situ Chemical Oxidation (ISCO)

A cost estimate for this alternative was developed on the basis of the alternative description in **Section 3.2** of the main text and the following assumptions:

- The time to complete the remediation is estimated to be 13 years.
- Only one injection of permanganate will be necessary.
- The feasibility of obtaining the land needed to accommodate the injection system was not performed for the costs presented in this appendix.

D.1.4 Administration, Permitting, and Legal

Along with the direct capital costs for equipment and construction in the previous sections, remedial design, project administration, construction management, contingencies and permitting are also included in the total capital costs for each alternative. The following definitions and percentages were used for this FS:

Project Management: Project management includes services that are not specific to remedial design, construction management, or technical support of O&M activities. Project management includes planning and reporting, community relations support during construction or O&M, bid or contract administration, and legal services (EPA, 2000).

Remedial Design: Remedial design includes services to design the remedial action. Activities that are part of remedial design include pre-design collection and analysis of field data, engineering survey for design, and the various design components, such as design analysis, plans, specifications, cost estimates, and schedule at the preliminary, intermediate, and final design phases (EPA, 2000).

Construction Management: Construction management includes services to manage construction or installation of the remedial action. Activities include review of submittals, design modifications, construction observation or oversight, engineering survey of construction, preparation of O&M manual, documentation of quality control/quality assurance, and record drawings (EPA, 2000).

Permitting: Permitting and legal costs are incremental estimates for the legal fees and fees of technical personnel needed to obtain licenses and permits required from federal, state, and local jurisdictions.

Contingencies: The contingencies included in this FFS are for bid and scope events. The bid contingency is an incremental estimate that covers unknown costs associated with construction, such as technological or geotechnical unknowns. The scope contingency is an incremental estimate that covers scope changes that invariably occur during final design and implementation.

A Guide to Developing and Documenting Cost Estimates During the Feasibility Study (EPA, 2000) was used to determine the percentages for remedial design, project administration, construction management, contingencies, and permitting costs. The percentages are based on the subtotal of the alternative so the ranges follow:

- **Project Management**—5 to 10 percent
- **Remedial Design**—6 to 20 percent
- **Construction Management**—6 to 15 percent
- **Permitting**—2 percent (fixed)
- **Bid Contingency**—10 to 20 percent
- **Scope Contingency**—10 to 25 percent

The detailed capital and O&M costs for the alternatives are presented in **Tables D-1** and D**-2**.

D.1.5 Net Present Value Analysis

For cost comparison, an NPV cost has to be calculated. The PW is the present value of the alternative at some defined period in the future. The PW calculations were performed using a discount rate of 4 percent, and time periods of 30 years for Alternative 1 and 13 years for Alternative 2.

The calculation of NPV costs for the two alternatives are presented in **Tables D-3** and **D-4**

TABLE D-1

Cost Estimate for Alternative 1 - Groundwater Extraction, LGAC Treatment and Injection

TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Description	Quantity	Unit	Unit Cost	Amount	Assumptions/Basis
CAPITAL COSTS					
Wells and Conveyance System - Install Two Extraction Wells, Four Injection Wells, and Underground Piping and Conduit					
Construction Costs					Based on WDC invoice from previous work at site; quotes for other sites
Mobilization/Demobilization - General Contractor	1	LS	20,000	20,000	Assumes project trailer setup and rental for approximately 6 months. Rate based on recent work for project site in Palmdale, CA.
Mobilization/Demobilization - Driller	1	LS	20,000	20,000	Mob/demob for drill rigs
Geophysical Survey - Utility Clearance	1	LS	3,600	3,600	Assumes 3 days at $1200/day for extraction wells, injection wells, trench lines, and treatment system location
Professional Land Survey - Coordinates	1	LS	2,500	2,500	For extraction wells, injection wells, trench lines, and treatment system location.
Extraction Wells - Drilling - 14-inch borehole	240	LF	205	49,200	Assumes 120 feet for two extraction wells
Injection Wells - Drilling - 18-inch borehole	600	LF	205	123,000	Assumes 150 feet for four injection wells
Extraction Wells - Furnish and Install 8-inch diameter SCH80 PVC Casing	240	LF	30	7,200	Assumes 120 feet for two extraction wells
Injection Wells - Furnish and Install 12-inch diameter SCH80 PVC Casing	600	LF	45	27,000	Assumes 150 feet for four injection wells
Extraction Wells - Furnish and Install 8-inch diameter SS Well Screen	100	LF	195	19,500	Assumes 50 feet screened area for two extraction wells
Injection Wells - Furnish and Install 12-inch diameter SS Well Screen	200	LF	315	63,000	Assumes 50 feet screened area for four injection wells
Extraction Wells - Furnish and Install 8-inch diameter 5-ft long sump, type 304 SS blank casing with baseplate	10	LF	370	3,700	Assumes 5 feet for two extraction wells
Injection Wells - Furnish and Install 12-inch diameter 5-ft long sump, type 304 SS blank casing with baseplate	20	LF	790	15,800	Assumes 5 feet for four injection wells
Extraction Wells - Furnish and Install 2-inch diameter SS Drop Pipe	240	LF	40	9,600	Assumes 120 feet for two extraction wells
Injection Wells - Furnish and Install 2-inch diameter Certa-Lok Drop Pipe (SCH80 PVC)	600	LF	20	12,000	Assumes 150 feet for four injection wells
Well Vault Completion	6	EA	5,000	30,000	Install well vault and well head connections
Furnish and Install Submersible Pumps	2	EA	5,000	10,000	Grundfos Model 40S; 10 HP; 4-inch submersible pump and installation
Furnish and Install Pressure Transducers	6	EA	2,000	12,000	In-Situ TROLL 500 and cable
Well Development (Extraction and Injection)	6	EA	5,000	30,000	Assumes 25 hours per well at $200 per hour; based on various drill quotes
Roll-off Bin Rental (10 CY capacity)	12	WK	75	900	Assumes six roll-off bins for one week each
Roll-off Bin Delivery and Removal	6	EA	650	3,900	Assumes delivery and cleaning one time for each bin
Soil Characterization	18	EA	250	4,500	Assumes 3 samples per roll-off bin load
Soil Transport and Disposal (nonhazardous)	75	TON	135	10,125	Assume 5 CY per extraction well (14-in dia, 120 ft) and 10 CY per injection well (18-in dia, 150 ft); one CY equals 1.5 ton
Wastewater Tank Delivery and Cleaning	2	EA	2,100	4,200	Assumes delivery and cleaning one time for each tank
Wastewater Tank Move	5	EA	500	2,500	Assumes tanks will be moved to well locations as needed
Wastewater Tank Rental (21,000 gal capacity)	12	WK	420	5,040	Assumes two 21,000-gal tanks to be moved to wells as needed; one week per well so 6 weeks total for each tank ($30/day/tank)
Wastewater Characterization	12	EA	250	3,000	Assumes 1 sample per load
Wastewater Delivery and Disposal (nonhazardous)	120,000	GAL	0.50	60,000	Assumes 20,000 gallons per well (~75 gpm for 4 hours); 6 wells total
Subsurface Trenching/Piping/Conduit (Extraction Wells)	1,675	LF	100.00	167,500	Assumes in dirt area (no paving); 2-inch SCH40 PVC pipe and conduit
Subsurface Trenching/Piping (Injection Wells)	1,320	LF	90.00	118,800	Assumes in dirt area (no paving); 2-inch SCH40 PVC pipe and conduit
Subtotal A				$ 838,565	
Contractor Overhead and Profit	838,565	15% overhead; 10% profit	25%	$ 209,641	Based on EPA July 2000 Guidance Page 5-8

TABLE D-1

Cost Estimate for Alternative 1 - Groundwater Extraction, LGAC Treatment and Injection

TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Description	Quantity	Unit	Unit Cost	Amount	Assumptions/Basis
Subtotal B				$ 1,048,206	
Contingency - Scope and Bid	1,048,206	15% scope; 10% bid	25%	262,052	Based on EPA July 2000 Guidance Page 5-12
Construction Costs - Subtotal				**1,310,258**	
Non-Construction Costs					
Permitting	1,310,258		2%	26,205	Based on the construction cost subtotal; Engineer's Estimate
Project Management	1,310,258		6%	78,615	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Remedial Design	1,310,258		12%	157,231	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Contractor Management	1,310,258		8%	104,821	Based on the construction cost subtotal, contractor overhead, and contractor profit; EPA July 2000 Guidance Page 5-10, 5-11
Non-Construction Costs - Subtotal				**$ 366,872**	
Well and Conveyance System - TOTAL				**$ 1,677,130**	
Groundwater Treatment System - Install Containment Pad and Treatment Equipment					
Construction Costs					Equipment costs below are based on recent work for other projects, vendor quotes, and engineer's estimates
Mobilization/Demobilization	0	LS	20,000	-	Included in the well and conveyance estimate
Geophysical Survey - Utility Clearance	0	LS	3,600	-	Included in the well and conveyance estimate
Professional Land Survey - Coordinates	0	LS	2,500	-	Included in the well and conveyance estimate
Containment Pad - Concrete with Rebar	1	LS	60,000	60,000	Assumes 50 feet by 35 feet by 1 foot with berm (2 feet tall by 8-inch wide) and ramp. Rate based on recent work for project site in Palmdale, CA.
Security Fencing	200	FT	50	10,000	Chain Link with Privacy Slats; Engineer's estimate
Transformer with Breaker	1	EA	10,000	10,000	Assume needed to connect to power at site, 150kva
Canopy for Control Panel and Operator Area	1	EA	2,500	2,500	Engineer's estimate
Control Panel with PLC and OIT	1	EA	20,000	20,000	NEMA 4X rated with air conditioner, cabinet ~ $10,000 and PLC with OIT ~$10,000
Power Meter	1	EA	500	500	Meter to monitor power usage
Polyethylene Water Tank - 5000 gallons	3	EA	10,000	30,000	Equalization tank, treated water tank, and carbon backwash tank; with ladders
Liquid-phase Granular Activated Carbon Skid	1	EA	60,000	60,000	Includes two 5000-pound LGAC vessels with pipe nest to allow for lead-lag reversal
Initial Carbon Fill	10,000	LB	1	10,000	Initial carbon fill of 10,000 lbs
Transfer Pump	1	EA	2,000	2,000	5 HP; centrifugal, rated for 200 gpm at 70 ft head
Discharge Pump	2	EA	2,000	4,000	7.5 HP; centrifugal rated from 200 gpm at 100 ft head; one pump for each injection pipe branch (two branches)
Sump Pump	1	EA	300	300	3/4 HP with built in on/off switch
Bag Filter Dual Housing	4	EA	3,500	14,000	SS rated at 150 psi for 200 gpm; two before LGAC and two before injection
pH Adjustment Skid	1	EA	7,500	7,500	Includes small tank with metering pump for acid/base and pH probe (for pH adjustment prior to injection)
Flow Sensor and Transmitter	10	EA	3,000	30,000	One at each extraction well (four total), each injection well (four total), equalization tank influent, and treated water tank effluent
Ultrasonic Tank Level Sensor	2	EA	1,000	2,000	One in equalization tank and one in treated water tank to control pump speed
Float Level Switch	5	EA	200	1,000	Two in equalization tank (LSH, LSL), two in treated water tank (LSH, LSL), one in sump (LSHH)
Variable Frequency Drives	5	EA	6,500	32,500	One for each new extraction well (two total), one for transfer pump, two for discharge pumps
Automated Ball Valve	2	EA	2,000	4,000	To control flow to injection well branches (two wells on each branch)
Equipment Installation	1	LS	50,000	50,000	Includes labor and crane rental for equipment placement; approximately 30% of equipment costs
Piping - PVC SCH80	1	LS	10,000	10,000	Aboveground in Treatment Compound
Valves/Gauges	1	LS	4,000	4,000	PVC SCH 80 ball valves and SS pressure gauges; assume 20 items at $200 each
Piping Insulation	1	LS	5,000	5,000	1/2-inch foam with aluminum covering to protect from UV damage and prevent freezing
Programming	1	LS	30,000	30,000	Assumes design, one week of onsite programming and includes travel expenses
Electrical Installation	1	LS	100,000	100,000	Includes all electrical work for connecting extraction well pumps, running conductor to wells, all electrical work in treatment system compound
System Performance Verification	1	LS	15,000	15,000	Assumes one week of testing and includes travel expenses
Subtotal A				$ 514,300	

TABLE D-1
Cost Estimate for Alternative 1 - Groundwater Extraction, LGAC Treatment and Injection
TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Description	Quantity	Unit	Unit Cost		Amount	Assumptions/Basis
Contractor Overhead and Profit	514,300	15% overhead; 10% profit	25%	$	128,575	Based on EPA July 2000 Guidance Page 5-8
Subtotal B				$	642,875	
Contingency - Scope and Bid	642,875	15% scope; 10% bid	25%		160,719	Based on EPA July 2000 Guidance Page 5-12
Construction Costs - Subtotal					**803,594**	
Non-Construction Costs						
Permitting	803,594		2%		16,072	Based on the construction cost subtotal; Engineer's Estimate
Project Management	803,594		6%		48,216	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Remedial Design	803,594		12%		96,431	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Contractor Management	803,594		8%		64,288	Based on the construction cost subtotal, contractor overhead, and contractor profit; EPA July 2000 Guidance Page 5-13
Non-Construction Costs - Subtotal				**$**	**225,006**	
Groundwater Treatment System - TOTAL				**$**	**1,028,600**	
CAPITAL COSTS - TOTAL				**$**	**2,706,000**	
O&M COSTS - 160 gpm						
Groundwater Treatment System						
Labor	416	HR	110	$	45,760	Assumes 8 hours/week; assumes half hours for technician and half hours for jr level engineer
Engineering and Management	208	HR	155	$	32,240	Assumes 4 hours/week for mid level engineer
O&M Reporting	4	EA	10,000	$	40,000	Quarterly; Based on estimated report preparation costs, including data management and validation
LGAC Carbon Replacement	2,555	LB	1.50	$	3,833	Estimated usage 7 pounds per day (based on 160 gpm at 50 ug/L TCE), includes disposal, labor, and carbon testing; engineer's estimate
Waste Disposal	1	LS	1,000	$	1,000	Bag filters, etc, excludes spent carbon
Groundwater O&M Laboratory Analysis	144	EA	160	$	23,040	Semi-monthly influent, effluent, between carbon vessels, and three QA/QC samples for VOC analysis; excludes well sampling
Electrical Power	424,772	KWH	0.10	$	42,477	65 horsepower based on extraction well pumps (4 x 10 HP), transfer pump (5 HP), discharge pumps (2 x 7.5 HP), and air conditioner for control panel (5 HP)
Replacement Parts	514,300	2% capital costs	2%		10,286	Based on the construction cost subtotal for groundwater treatment system (subtotal A); Engineer's Estimate
Subtotal - Direct Groundwater Treatment System Costs				**$**	**198,636**	
Contingency - Scope and Bid	198,636	15% scope; 10% bid	25%		49,659	Based on EPA July 2000 Guidance Page 5-12
Project Management	198,636		5%		9,932	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Technical Support	198,636		10%		19,864	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-14
Overhead, General and Administrative Costs	198,636		10%		19,864	
Subtotal - Indirect Groundwater Treatment System Costs				**$**	**99,318**	
Monitoring and Natural Attenuation						
Labor	120	HR	110	$	13,200	
Equipment	2	LS	2,000	$	4,000	
Engineering and Management	20	HR	155	$	3,100	
Reporting	60	EA	155	$	9,300	

TABLE D-1
Cost Estimate for Alternative 1 - Groundwater Extraction, LGAC Treatment and Injection
TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Description	Quantity	Unit	Unit Cost		Amount	Assumptions/Basis
Laboratory Analysis - VOCs	26	EA	130	$	3,380	
Laboratory Analysis - MNA	5	EA	300	$	1,500	
Quality Control	4,880		20%	$	976	
Waste Disposal	4,000	GAL	0.14	$	560	
Subtotal - Direct Monitoring and Natural Attenuation Costs				**$**	**36,016**	
Contingency - Scope and Bid	36,016	15% scope; 10% bid	25%		9,004	Based on EPA July 2000 Guidance Page 5-12
Project Management	36,016		5%		1,801	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Technical Support	36,016		10%		3,602	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-14
Overhead, General and Administrative Costs	36,016		10%		3,602	
Subtotal - Indirect Monitoring and Natural Attenuation Costs				**$**	**18,008**	
ANNUAL O&M COST - TOTAL				**$**	**352,000**	
O&M COSTS - 40 gpm						
Groundwater Treatment System						
Labor	416	HR	110	$	45,760	Assumes 8 hours/week; assumes half hours for technician and half hours for jr level engineer
Engineering and Management	208	HR	155	$	32,240	Assumes 4 hours/week for mid level engineer
O&M Reporting	4	EA	10,000	$	40,000	Quarterly; Based on estimated report preparation costs, including data management and validation
LGAC Carbon Replacement	730	LB	1.50	$	1,095	Estimated usage 2 pounds per day (based on 40 gpm at 50 ug/L TCE), includes disposal, labor, and carbon testing; engineer's estimate
Waste Disposal	1	LS	1,000	$	1,000	Bag filters, etc, excludes spent carbon
Groundwater O&M Laboratory Analysis	144	EA	160	$	23,040	Semi-monthly influent, effluent, between carbon vessels, and three QA/QC samples for VOC analysis; excludes well sampling
Electrical Power	228,724	KWH	0.10	$	22,872	35 horsepower based on extraction well pumps (1 x 10 HP), transfer pump (5 HP), discharge pumps (2 x 7.5 HP), and air conditioner for control panel (5 HP)
Replacement Parts	514,300	2% capital costs	2%		10,286	Based on the construction cost subtotal for groundwater treatment system (subtotal A); Engineer's Estimate
Subtotal - Direct Groundwater Treatment System Costs				**$**	**176,293**	
Contingency - Scope and Bid	176,293	15% scope; 10% bid	25%		44,073	Based on EPA July 2000 Guidance Page 5-12
Project Management	176,293		5%		8,815	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Technical Support	176,293		10%		17,629	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-14
Overhead, General and Administrative Costs	176,293		10%		17,629	
Subtotal - Indirect Groundwater Treatment System Costs				**$**	**88,147**	
Monitoring and Natural Attenuation						
Labor	120	HR	110	$	13,200	
Equipment	2	LS	2,000	$	4,000	
Engineering and Management	20	HR	155	$	3,100	
Reporting	60	EA	155	$	9,300	
Laboratory Analysis - VOCs	26	EA	130	$	3,380	
Laboratory Analysis - MNA	5	EA	300	$	1,500	
Quality Control	4,880		20%	$	976	
Waste Disposal	4,000	GAL	0.14	$	560	

TABLE D-1
Cost Estimate for Alternative 1 - Groundwater Extraction, LGAC Treatment and Injection
TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Description	Quantity	Unit	Unit Cost	Amount	Assumptions/Basis
Subtotal - Direct Monitoring and Natural Attenuation Costs				**$ 36,016**	
Contingency - Scope and Bid	36,016	15% scope; 10% bid	25%	9,004	Based on EPA July 2000 Guidance Page 5-12
Project Management	36,016		5%	1,801	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Technical Support	36,016		10%	3,602	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-14
Overhead, General and Administrative Costs	36,016		10%	3,602	
Subtotal - Indirect Monitoring and Natural Attenuation Costs				**$ 18,008**	
ANNUAL O&M COST - TOTAL				**$ 318,500**	
PERIODIC COSTS					
5-Year Review Report	1	EA	50,000	$ 50,000	
Subtotal - Year 5				**$ 50,000**	
Pump Replacement (every 10 yrs)	1	EA	7,500	$ 7,500	For WC-13B only; other three wells will only operate the first 10 years
5-Year Review Report	1	EA	50,000	$ 50,000	
Subtotal - Year 10				**$ 57,500**	
Well Rehabilitation (every 15 yrs)	2	EA	7,500	$ 15,000	For WC-13B and one injection well
5-Year Review Report	1	EA	50,000	$ 50,000	
Subtotal - Year 15				**$ 65,000**	
Pump Replacement (every 10 yrs)	1	EA	7,500	$ 7,500	For WC-13B only; other three wells will only operate the first 10 years
5-Year Review Report	1	EA	50,000	$ 50,000	
Subtotal - Year 20				**$ 57,500**	
5-Year Review Report	1	EA	50,000	$ 50,000	
Subtotal - Year 25				**$ 50,000**	
Demobilization of Treatment System	1	EA	25,000	$ 25,000	
Well Abandonment	37	EA	2,000	$ 74,000	7 extraction wells, 4 injection wells, 26 monitoring wells
Remediation Action Report	1	EA	75,000	$ 75,000	
Subtotal - Year 30				**$ 174,000**	

TABLE D-2
Cost Estimate for Alternative 2 - In-Situ Chemical Oxidation
TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Description	Quanity	Unit	Unit Cost	Amount	Assumptions/Basis
CAPITAL COSTS					
Installation Of Monitoring & Injection Wells					Install 7 USU injection wells and 3 nested downgradient monitoring wells (2 ports each)
Construction Costs					
Mobilization/demobilization of drilling subcontractor and equipment to Site	1	LS	20,000	20,000	Previous work at the site
Staging area decontamination pad	1	LS	500	500	Previous work at the site
Geophysical survey – utility clearance	1	LS	3,600	3,600	
Sawcut asphalt/concrete	10	EA	250	2,500	Saw cutting a 2-foot square area through the existing 4-inch concrete or asphalt street pavement at 6 locations; Previous work at the site (WDC Proposal 11/04/08)
Injection Wells, Drilling - 9 inch borehole	1172	LF	109	127,748	Sonic Drilling 4 boreholes to 102 ft bgs; 3 boreholes to 120 feet bgs; 2 boreholes to 132 ft bgs; 1 borehole to 140 feet bgs
Injection Wells, Furnish and Install 2-inch diameter SCH40 PVC Casing	768	LF	18	13,824	Assume 100 feet for four injection wells and 120 feet for three injection wells
Monitoring Well, Furnish and Install 2-inch diameter SCH40 PVC Casing	404	LF	18	7,272	Assumes 130 feet for two monitoring wells and 140 feet for one monitoring well
Well Development	26	EA	400	10,400	Assume 2 hr per well port, a total of 13 ports;
Well Vault Completion	10	EA	200	2,000	Flush-mounted 18-inch diameter well pad, manhole casing/well caps
Roll-off Bin Rental 8 Wk (10 CY capacity)	12	WK	75	900	Assumes three roll-off bins for four weeks each
Roll-off Bin Delivery and Removal	3	EA	650	1,950	Assumes delivery and cleaning one time for each bin
Soil Characterization	3	EA	250	750	Assumes 3 samples per roll-off bin load
Soil Transport and Disposal (Non-Hazardous)	30	TON	135	4,050	Assumes 2 cy per well; one cy equals 1.5 tons
Professional Land Survey	1	EA	1,600	1,600	Well locations and elevations
Subtotal A				$ 197,094	
Contractor Overhead and Profit	197,094	15% Overhead, 10% Profit	25%	49,274	
Subtotal B				$ 246,368	
Contingency – Scope Bid	246,368	15% scope; 10% bid	25%	61,592	
Construction Costs - Subtotal				**$ 307,959**	
Non-Construction Costs					
Permitting	307,959		2%	6,159	Based on the construction cost subtotal; Engineer's Estimate
Project Management	307,959		6%	18,478	Based on the construction cost subtotal; EPA July2000 Guidance Page 5-13
Remedial Design	307,959		12%	36,955	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Contractor Management	307,959		8%	24,637	Based on the construction cost subtotal, contractor overhead, and contractor profit; EPA July 2000 Guidance Page 5-10, 5-11
Non-Construction Costs - Subtotal				**$ 86,229**	
Installation of Monitoring and Injection Wells - TOTAL				**$ 394,188**	
CAPITAL COSTS - TOTAL				**$ 394,188**	

TABLE D-2
Cost Estimate for Alternative 2 - In-Situ Chemical Oxidation
TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Description	Quanity	Unit	Unit Cost	Amount	Assumptions/Basis
OPERATIONAL COSTS					
Permanganate Injection					
Secondary Containment	2	MO	3,150	6,300	Spillguard (12' x 16' x 1', one) and (12' x 50' x 1', two)
Injection and Storage Tank	2	MO	1,020	2,040	2 Poly Tank (2450-gallon injection tank and storage tank)
Transfer Pumps with Control Panel	2	MO	3,700	7,400	$1850/EA (2 sets)
Generator to power extraction, mixing and injection pumps	2	MO	1,300	2,600	25 kW generator
Bag Filters	2	MO	1,700	3,400	Two particulate filters
Flow Meters, Valves, and Fittings	2	MO	1,000	2,000	
Transducers	2	MO	1,500	3,000	Solinst Level Logger 3001 or equal
Eductor BPES-5 plus Configuration	2	MO	1,300	2,600	2009 vendor quote
1,600-gallon Mixing Tank plus Configuration	2	MO	1,300	2,600	2009 vendor quote
Equipment Shipping	1	EA	440	440	2009 vendor quote
Equipment Shipping - Return	1	EA	440	440	2009 vendor quote
Submersible Pumps for Extraction Wells	1	MO	1,800	1,800	2" Grundfos submersible pumps and controller rental ($600 per month per set; 3 extraction wells) for source zone
Temporary Above-Ground Piping	500	LF	10	5,000	2" PVC connection piping; RSMeans
Security Fencing, Traffic Control, and Utility Location	1	LS	10,000	10,000	
Injection System Installation and Setup	80	HR	110	8,800	4 days 2 person
Injection System Move to Second Location	80	HR	110	8,800	4 days 2 person
Potassium Permanganate	35,003	LB	2.16	75,606	Unit cost of $2/lb escalated by 4%
Sodium Thiosulfate - Oxidant Neutralizer	550	GAL	7.25	3,988	Aqueous 6% Concentration
Site Trailer/Temporary Office/Misc	2	MO	3,000	6,000	Includes chemical storage
Injection Labor	840	HR	110	92,400	42 days to inject 1,200,000 gallon 0.35% KP solution at 15 gpm per well ; 4 wells per location; assuming 2 person team
Per Diem	84	EA	200	16,800	2 persons
Car rental and fuel	9	Week	500	4,500	
Subtotal A				$ 266,514	
Contingency – Scope and Bid	266,514	15% Scope, 10% bid	25%	66,628	Based on EPA July 2000 Guidance Page 5-12
Operational Costs – Subtotal				**$ 333,142**	
Non-Construction Costs					
Permitting	333,142		2%	6,663	Based on the operational cost subtotal; Engineer's Estimate
Project Management	333,142		6%	19,989	Based on the operational engineer estimate cost subtotal, EPA July 2000 Guidance Page 5-13
Remedial Design	333,142		12%	39,977	Based on the operational engineer estimate cost subtotal; EPA July 2000 Guidance Page 5-13
Non-Construction Costs Subtotal				**$ 66,628**	
OPERATIONAL COSTS - TOTAL				**$ 399,771**	
ANNUAL O&M COST					
Monitoring and Natural Attenuation					
ISCO performance groundwater sampling and gauging (labor)	140	HR	110	15,400	Semi-annual sampling of 23 monitoring well points
Equipment	2	LS	2,000	4,000	Equipment rental (pump, generator, YSI Multiparameter probe and disposables)
Engineering and Management	20	HR	155	3,100	
Reporting	60	HR	155	9,300	
Laboratory Analysis - VOCs	18	EA	130	2,340	
Laboratory Analysis - MNA	5	EA	300	1,500	
Quality Control	3,840		20%	768	

TABLE D-2
Cost Estimate for Alternative 2 - In-Situ Chemical Oxidation
TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Description	Quanity	Unit	Unit Cost	Amount	Assumptions/Basis
Waste Disposal	4,000	GAL	0.14	560	
Subtotal - Direct O&M Costs				**$ 36,968**	
Contingency	36,968		25%	9,242	Based on EPA July 2000 Guidance Page 5-12
Project Management	36,968		5%	1,848	Based on the construction cost subtotal; EPA July 2000 Guidance Page 5-13
Technical Support	36,968		10%	3,697	Based on the operational engineer estimate cost subtotal, EPA July 2000 Guidance Page 5-14
Overhead	36,968		10%	3,697	Based on EPA July 2000 Guidance Page 5-8
Subtotal - Indirect O&M Costs				**$ 18,484**	
ANNUAL O&M COSTS - TOTAL				**$ 55,452**	
PERIODIC COSTS					
First 5-Year Review Report	1	EA	50,000	50,000	
Subtotal - Year 5				**$ 50,000**	
Second 5-Year Review Repor	1	EA	50,000	50,000	
Subtotal - Year 10				**$ 50,000**	
Well Abandonment	41	EA	2,000	$ 82,000	5 extraction wells, 7 injection wells, 29 monitoring wells
Remediation Action Report	1	EA	75,000	75,000	
Subtotal - Year 13				**$ 157,000**	

TABLE D-3

Net Present Value of Alternative 1 - Groundwater Extraction, LGAC Treatment and Injection

TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Year	Capital cost	O&M Cost	Periodic Cost	Total cost	NPV Factor	Net Present Value
1	$ 2,706,000	$ 352,000		$ 3,058,000	0.9615	$ 2,940,385
2		$ 352,000		$ 352,000	0.9246	$ 325,444
3		$ 352,000		$ 352,000	0.8890	$ 312,927
4		$ 352,000		$ 352,000	0.8548	$ 300,891
5		$ 318,500	$ 50,000	$ 368,500	0.8219	$ 302,880
6		$ 318,500		$ 318,500	0.7903	$ 251,715
7		$ 318,500		$ 318,500	0.7599	$ 242,034
8		$ 318,500		$ 318,500	0.7307	$ 232,725
9		$ 318,500		$ 318,500	0.7026	$ 223,774
10		$ 318,500	$ 57,500	$ 376,000	0.6756	$ 254,012
11		$ 318,500		$ 318,500	0.6496	$ 206,892
12		$ 318,500		$ 318,500	0.6246	$ 198,934
13		$ 318,500		$ 318,500	0.6006	$ 191,283
14		$ 318,500		$ 318,500	0.5775	$ 183,926
15		$ 318,500	$ 65,000	$ 383,500	0.5553	$ 212,944
16		$ 318,500		$ 318,500	0.5339	$ 170,050
17		$ 318,500		$ 318,500	0.5134	$ 163,509
18		$ 318,500		$ 318,500	0.4936	$ 157,221
19		$ 318,500		$ 318,500	0.4746	$ 151,174
20		$ 318,500	$ 57,500	$ 376,000	0.4564	$ 171,601
21		$ 318,500		$ 318,500	0.4388	$ 139,769
22		$ 318,500		$ 318,500	0.4220	$ 134,393
23		$ 318,500		$ 318,500	0.4057	$ 129,224
24		$ 318,500		$ 318,500	0.3901	$ 124,254
25		$ 318,500	$ 50,000	$ 368,500	0.3751	$ 138,231
26		$ 318,500		$ 318,500	0.3607	$ 114,880
27		$ 318,500		$ 318,500	0.3468	$ 110,461
28		$ 318,500		$ 318,500	0.3335	$ 106,213
29		$ 318,500		$ 318,500	0.3207	$ 102,127
30		$ 318,500	$ 174,000	$ 492,500	0.3083	$ 151,847

Total Net Present Value: $ 8,445,716

Notes:
NPV = Net Present Value

NPV Factor is equal to $(1+i)^{-n}$, where i is the discount rate of 4% and n is the number of years from the start of the project

TABLE D-4

Net Present Value of Alternative 2 - In-Situ Chemical Oxidation

TIAA Superfund Site, West-Cap Project Area, Focused Feasibility Report, Tucson, Arizona

Year	Capital cost	O&M Cost	Periodic Cost	Total cost	NPV Factor	Net Present Value
1	$ 394,188	$ 455,223		$ 849,411	0.9615	$ 816,741
2		$ 55,452		$ 55,452	0.9246	$ 51,268
3		$ 55,452		$ 55,452	0.8890	$ 49,297
4		$ 55,452		$ 55,452	0.8548	$ 47,401
5		$ 55,452	$ 50,000	$ 105,452	0.8219	$ 86,674
6		$ 55,452		$ 55,452	0.7903	$ 43,825
7		$ 55,452		$ 55,452	0.7599	$ 42,139
8		$ 55,452		$ 55,452	0.7307	$ 40,518
9		$ 55,452		$ 55,452	0.7026	$ 38,960
10		$ 55,452	$ 50,000	$ 105,452	0.6756	$ 71,240
11		$ 55,452		$ 55,452	0.6496	$ 36,021
12		$ 55,452		$ 55,452	0.6246	$ 34,635
13		$ 55,452	$ 157,000	$ 212,452	0.6006	$ 127,593

Total Net Present Value: $ 1,486,311

Notes:

NPV = Net Present Value

NPV Factor is equal to $(1+i)^{-n}$, where i is the discount rate of 4% and n is the number of years from the start of the project

Appendix E
Focused Feasibility Study for Texas Instruments Project Area

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Imagine the result

Tucson International Airport Area Superfund Site

Texas Instruments Incorporated Project Area

Focused Feasibility Study

June 2011

Signature 1 Name
Title

Signature 2 Name
Title

Signature 3 Name
Title

Focused Feasibility Study

Texas Instruments Incorporated
Project Area

Prepared for:
Texas Instruments Incorporated

Prepared by:
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Our Ref.:
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Date:
June 2011

ARCADIS

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Abbreviations and Acronyms

µg/L	microgram(s) per liter
µg/kg	microgram(s) per kilogram
$\mu g/m^3$	microgram(s) per cubic meter
ADHS	Arizona Department of Health Services
AF	attenuation factor
ARAR	applicable or relevant and appropriate requirements
AWR	air to water ratio
bgs	below ground surface
BHHRA	Baseline Human Health Risk Assessment for the Tucson International Airport Area Site
Cal/EPA	California Environmental Protection Agency
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CHHSL	California Human Health Screening Levels
COI	contaminant(s) of interest
COPC	contaminant(s) of potential concern
ELCR	excess life cancer risk
EPC	exposure point concentration
ESL	Environmental Screening Levels
gpm	gallon(s) per minute
GRA	general response action
HI	hazard index
HQ	hazard quotient
ISCO	in situ chemical oxidation
MCL	maximum contaminant level
MNA	monitored natural attenuation
NPL	National Priorities List
O&M	operations and maintenance
PCE	tetrachloroethene
PCRWRD	Pima County Regional Wastewater Reclamation Department
POTW	Publicly Owned Treatment Works
PVC	polyvinyl chloride
RAO	remedial action objective
ROD	Record of Decision
RSL	regional screening level
RWQCB	Regional Water Quality Control Board
SDWA	Safe Drinking Water Act

Abbreviations and Acronyms

Site	Texas Instruments-Tucson manufacturing facility
TARP	Tucson International Airport Area Groundwater Remediation Project
TCE	trichloroethene
TI	Texas Instruments Incorporated
TIAA	Tucson International Airport Area Superfund Site
U.S. EPA	United States Environmental Protection Agency
VOC	volatile organic compound

Executive Summary

The purpose of this focused feasibility study for the former Texas Instruments-Tucson manufacturing facility (Site), which is part of the Tucson International Airport Area Superfund Site (TIAA), in Tucson, Arizona, is to evaluate alternatives for the remediation of volatile organic compound (VOC) contaminated groundwater. Major factors that contributed to this evaluation include:

1. Texas Instruments Incorporated (TI) is no longer performing manufacturing activities on the Site. The Site has been decommissioned, and therefore cannot accept the treated groundwater from the current groundwater extraction and treatment system for use in plant processes and cooling towers.

2. The current groundwater extraction and treatment system, while reliable in containing and remediating the contaminated groundwater, is anticipated to operate for an additional 30 years.

3. In situ chemical oxidation (ISCO) has been pilot tested at the Site and other Project Areas within the TIAA Superfund Site. The results of which have demonstrated that ISCO is an effective treatment option for the remediation of contaminated groundwater and potential source areas.

Five remedial alternatives were identified in the focused feasibility study: no action, groundwater extraction and treatment with water reuse, groundwater extraction and treatment with discharge to the Publicly Owned Treatment Works (POTW), groundwater extraction and treatment with injection, and ISCO with monitored natural attenuation (MNA). The alternatives were screened with consideration of the Site's current conditions, and three alternatives were retained and developed for analysis. The alternatives are described below.

Alternative 1 - Groundwater extraction and treatment with discharge to POTW

Alternative 1 includes groundwater extraction and treatment to remove VOCs from the groundwater, with discharge of treated water to the POTW. One new groundwater extraction well would be installed to replace the existing extraction well. The existing treatment system, packed column air stripper, would be moved to a more accessible location on the Site and a connection would be established to the POTW.

Alternative 2 - Groundwater extraction and treatment with injection

Alternative 2 includes groundwater extraction and treatment to remove VOCs from the groundwater, with injection of treated water at the Site. A new groundwater extraction well and two new injection wells would be installed as part of this alternative. The existing treatment system, packed column air stripper, would be moved to a more accessible location on the Site.

Alternative 3 – ISCO with MNA

Alternative 3 includes a full-scale ISCO injection of potassium permanganate into the source area and groundwater, coupled with a monitored natural attenuation (MNA) program to evaluate the remedy. ISCO will reduce concentrations of VOCs in the source area and mass flux out of the source area into the downgradient groundwater plume.

Cost estimates and net present value calculations were completed for each alternative. A comparative analysis was conducted to consider the alternatives in relation to one another and the evaluation criteria. The purpose of the comparative analysis was to identify the advantages and disadvantages of each alternative relative to each other. Each of the alternatives is protective of human health and the environment and reduces VOC concentrations in the source area. Due to diffusion rates of VOCs from the fine-grained media, Alternatives 1 and 2 are considered less effective and would possibly not be completed within a reasonable time. After the groundwater extraction and treatment system is turned off, it is possible that the VOC concentrations would rebound as residual VOCs diffuse from the fine-grained media into the groundwater. Indefinite operation of groundwater extraction and treatment will meet the applicable or relevant and appropriate requirements (ARARs), but is not efficient or cost effective. Alternatives 1 and 2 have an estimated project life of 30 years with a net present value of $1.9 million and $2.0 million, respectively, while Alternative 3 has an estimated project life of 13 years and a net present value of $971,700.

1. INTRODUCTION

The United States Environmental Protection Agency (U.S. EPA) has requested Texas Instruments Incorporated (TI) to prepare a focused feasibility study for the former Texas Instruments-Tucson manufacturing facility (Site). The Site is located within Eastern Plume Area B of the Tucson International Airport Area (TIAA) Superfund Site, in Tucson, Arizona. The focused feasibility study was commissioned by TI and was conducted by ARCADIS U.S., Inc, in general accordance with *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (U.S. EPA, 1988). The purpose of the focused feasibility study is to evaluate alternatives for the remediation of contaminated groundwater at the Site. Major factors that contributed to this evaluation include:

1. TI is no longer performing manufacturing activities on the Site. The Site has been decommissioned, and therefore cannot accept the treated groundwater from the current groundwater extraction and treatment system for beneficial use in plant processes and cooling towers.

2. The current groundwater extraction and treatment system, while reliable in containing and remediating the contaminated groundwater, is anticipated to operate for an additional 30 years.

3. In situ chemical oxidation (ISCO) has been pilot tested at the site and other Project Areas within the TIAA Superfund Site. The results of which have demonstrated that ISCO is an effective treatment option for the remediation of contaminated groundwater and source areas.

The alternatives were screened with consideration of the Site's current conditions, as discussed in Section 3. In addition, the Tucson Basin groundwater system is designated as a Sole Source Aquifer under the Safe Drinking Water Act. In accordance with the *Third Management Plan for the Tucson Active Management Area (2000-2010, Arizona Department of Water Resources, 1999)*, extracted groundwater must be put to the highest beneficial use, therefore the alternatives were also screened with this criteria. The alternatives selected for detailed analysis are presented in Sections 3.1 – 3.3, while a comparative analysis is presented in Section 3.4. The selection of a remedy for the Site will be documented in an amendment to the *Tucson International Airport Area Record of Decision for Groundwater Remediation* (ROD; U.S. EPA, 1988).

1.1 Organization of Feasibility Study

The organization of the focused feasibility study is as follows:

Section 1 describes the purpose of the focused feasibility study and presents the background information, site description, site history, nature and extent of contamination, contaminant fate and transport, and the risk summary.

Section 2 provides an overview of the remedial action objectives (RAOs), general response actions (GRAs), and identification of technologies evaluated.

Section 3 describes the development and screening of alternatives.

Section 4 provides references used in the focused feasibility study.

1.2 Background Information

The following sections describe the site description, site history, nature and extent of contamination, contaminant fate and transport, and the risk summary.

1.2.1 Site Description

The Site is located at 6730 South Tucson Boulevard, in Tucson, Arizona, northeast of the Tucson International Airport (Figure 1). The Site is bounded by Tucson Boulevard on the east, Plumer Avenue on the west, Aragon Road on the south, and Medina Road on the north. The property comprises approximately 17 acres and is occupied by manufacturing buildings and parking lots, as shown on Figure 2. The Site was originally occupied by Burr-Brown Corporation, who operated a microchip manufacturing facility beginning in 1969. The Site is currently owned by TI, which operated as an engineering/design and wafer manufacturing facility up until 2009, at which time the facility underwent decommissioning activities.

The Site is a Project Area within the TIAA Superfund Site. A description of the history of the TIAA Superfund Site and the Site is provided below.

1.2.2 History

1.2.2.1 TIAA Superfund Site History

The TIAA Superfund Site is generally bounded by Hughes Access Road to the south, the Santa Cruz River to the west, Ajo Way to the north, and Alvernon Way to the east, and is currently occupied by heavy industrial facilities, residential developments, and the Tucson International Airport.

Groundwater contamination was first discovered at what is now the TIAA Superfund Site in 1952 when elevated levels of chromium were discovered in a municipal supply well in the area. During that time period, local residents also complained of foul smelling water from private supply wells. The groundwater contamination was believed to be connected to airplane refitting operations that were conducted in the area during the early 1940s. Continued industrial use and large-scale waste disposal, including aircraft manufacturing facilities, electronics facilities, fire drill training areas and landfills are believed to have contributed to the contamination that occurred over the next several decades.

The U.S. EPA listed the TIAA Superfund Site on the National Priorities List (NPL) in September 1983. The TIAA Superfund Site was broken up into seven project areas: Burr-Brown (the Site), the Tucson International Airport Area Groundwater Remediation Project (TARP), Air Force Plant 44, Airport Property, Arizona Air National Guard, West-Cap, and West Plume B.

1.2.2.2 Site History

Initial groundwater investigations conducted in the vicinity of the Burr-Brown facility in 1984 indicated the average concentration of trichloroethene (TCE) in groundwater was 41.6 micrograms per liter (μg/L). The remedial investigation listed Burr-Brown as a "highly-probable" source of local TCE contamination of groundwater. In 1987, three monitor wells, designated BB-1, BB-2, and BB-3, were installed and sampled on the Burr-Brown facility (Figure 2). TCE was reported at concentrations of 4.6 µg/L in BB-1 and 11.4 µg/L in BB-2. TCE was not detected above the reporting limit at BB-3. Also in 1987, a site-wide shallow soil gas survey of the Burr-Brown property was conducted and identified TCE in soil gas samples at concentrations of up to 15.7 µg/L in the vicinity of the former chemical storage facilities (Figure 2).

The Burr-Brown Project Area TCE plume was characterized during site investigation activities conducted between 1988 and 1991. In 1988, two 100-foot deep soil borings, designated B-1 and B-2, were drilled at the location where the highest TCE concentrations were detected in shallow soil gas, near the former chemical storage facilities. TCE concentrations detected in soils at depth in the borings were considered insignificant, so underlying groundwater contamination became the focus of subsequent remediation at the Site. Four additional groundwater monitor wells, designated CMW-1, CMW-2, AW-1, and AW-2R, were installed on the adjacent property north of the Site in 1990 and 1991. TCE was initially reported in AW-1 at a concentration of 10 µg/L. TCE was not detected above the reporting limit in groundwater samples obtained from CMW-1, CMW-2, and AW-2R.

Burr-Brown activated a groundwater remediation system in 1992 in response to the ROD and Consent Decree executed in 1988 and 1989, respectively. The remediation system consisted of two extraction wells and packed column air stripping. Treated groundwater was used for plant process water and cooling towers. Groundwater extraction well EW-1A was installed along the north property boundary of the Site. TCE was initially reported at concentrations of up to 26 µg/L in well EW-1A.

Two additional soil borings, designated B-3 and B-4, were installed east and west of extraction well BB-2, respectively, in February 1996. The highest concentrations of TCE detected in soil vapor at the time (38 to 44 µg/L) were reported in a medium to coarse sand lens at a depth of approximately 80 feet below ground surface (bgs).

In May 1996, BB-2 was incorporated into the extraction and treatment system and was pumped at a rate of approximately 20 gallons per minute (gpm). Extraction well EW-1A was shut down in October 1996 in response to increasing TCE and tetrachloroethene (PCE) concentrations observed in monitor well SF-3, located immediately south and upgradient of the Site. There was concern that extraction from EW-1A was inducing migration of groundwater contamination attributed to the West-Cap Project Area located immediately southwest of the Site (Figure 1). Pumping at BB-2 continued until March 1997, when the Burr-Brown treatment system was shut down at the request of the U.S. EPA for installation and start-up testing of an extraction well network at the West-Cap Project Area. The West-Cap groundwater extraction system was initiated in October 1998, with extracted groundwater being conveyed to the Burr-Brown treatment system at a rate of approximately 50 gpm. Pumping at BB-2 at the Site resumed in November 1999. Historical concentration trends for Site monitoring and extraction wells beginning at treatment startup is provided in Appendix A.

Groundwater extraction at the West-Cap Project Area was discontinued in August 2006 in an effort to modify and reconfigure the extraction system.

TI extraction well BB-2 was shut down on September 30, 2009 to prepare for ISCO pilot testing at the Site. The scope of the ISCO project was presented in the work plan, *Pilot Test of In Situ Chemical Oxidation Using Potassium Permanganate Eastern Plume Area B* (Montgomery and Associates, 2009), which was submitted to the U.S. EPA on August 19, 2009 and received "conditional approval" from the U.S. EPA on August 20, 2009. A summary of the pilot testing is provided in Section 3.3.1.2.

Approximately 16.3 pounds of TCE were removed from groundwater at the Site between 1992 and 2009 using the groundwater extraction and treatment system.

1.2.3 Nature and Extent of Contamination

1.2.3.1 Hydrogeology

Figure 3 shows schematic hydrogeologic cross sections representing the generalized stratigraphy at the Site, including the occurrence and thickness of coarser- and finer-grained intervals, completions for vadose zone, and groundwater wells. The sections were prepared to evaluate subsurface conditions along lines that are generally oblique to (A-A') and coincident with (B-B') the principal axis of the TCE plume. Locations for lines of section are shown on Figure 2.

Review of Figure 3 indicates that there are three principal coarser-grained layers that are interpreted to be reasonably well-connected across the Site. The shallowest of these coarser-grained layers will not be discussed here, as site characterization has demonstrated that this layer has not been impacted and it is, therefore, not being targeted for treatment. The intermediate coarser-grained layer that occurs in the vadose zone in the approximate interval from 75 to 85 feet bgs is referred to as the upper sand unit. The upper sand unit is correlative with the upper subunit at the West-Cap Project Area. This unit is of interest because it overlies the roughly 40-foot thick fine-grained layer that is interpreted, based on soil data, to be the principal remaining source of VOC mass at the Site. The lower coarser-grained layer that occurs below the water table in the approximate depth interval from 130 to 140 feet bgs is referred to as the lower sand unit. The lower sand unit is correlative with the lower subunit at the West-Cap Project Area.

1.2.3.2 Distribution of VOCs in Vadose Zone

Based on site characterization efforts conducted over time, the VOC mass in the lower vadose zone that represents a potential contributing source occurs below the historic chemical storage facilities in the roughly 40-foot thick fine-grained layer that directly overlies the water table, occupying the interval from approximately 85 to 126 feet bgs across the Site (Figures 2 and 3).

In May 2008, a multi-completion soil vapor and groundwater monitor well, designated SVMW-1, and a pilot soil vapor extraction well, designated SVE-1, were installed in the vicinity of the former chemical storage area to further investigate what was identified as the only source area at the Site. The borings for wells SVMW-1 and SVE-1 were designated B-5 and B-6, respectively. In borings B-5 and B-6, TCE was reported in soil samples collected in the depth interval from 90 to 125 feet bgs at concentrations ranging from 6.6 to 44 micrograms per kilogram (µg/kg). The highest TCE concentrations in soil were observed at depths of 110 to 120 feet bgs in a clay layer just above the water table. Following installation of the multi-completion monitor well, a discrete groundwater sample was collected from the upper part of the saturated zone at SVMW-1. The TCE concentration from this sampled was reported to be 58 µg/L.

Soil vapor sampling was conducted at SVMW-1 and SVE-1 in 2008 and 2009. In July and September 2008, micro-purge soil vapor samples were obtained at SVMW-1 from each of the three discretely-screened intervals. The highest TCE concentrations were reported at SVMW-1 during the September 2008 event; TCE was reported at concentrations of 0.27, 10, and 23 µg/L in vapor samples obtained at depths of approximately 45, 65, and 83 feet bgs, respectively. In April 2009, a 24-hour soil vapor extraction and testing program was conducted at SVE-1 to provide updated baseline data for design of the ISCO pilot test. Soil vapor samples were obtained at periodic intervals throughout the 24-hour extraction period. TCE concentrations in vapor were fairly consistent during much of the extraction period, ranging from 36 to 56 µg/L; however, late in the test, TCE concentrations were observed to decrease somewhat over time, suggesting that the source area is limited in aerial extent.

1.2.3.3 Patterns of Groundwater Movement

Apparent direction of groundwater movement is generally to the north and northwest (Figure 4). The hydraulic gradient under non-pumping conditions is relatively small, approximately 0.0023.

1.2.3.4 VOC Concentrations in Groundwater

Figure 5 shows TCE concentrations for the Site from a groundwater monitoring event conducted in July 2009. The maximum TCE concentration detected in groundwater at this time was 16 µg/L at extraction well BB-2. The area where TCE concentrations exceed the drinking water maximum contaminant level (MCL) and site remediation goal of 5 µg/L is interpreted to be attributable to a small on-going source beneath the former chemical storage facilities (Figure 5). MCLs are standards that EPA has determined to be safe for drinking water and are applicable for groundwater that is or has the potential to be used as a drinking water source. No other VOCs were detected above the laboratory reporting limit during this sampling event.

Results of previous investigations at the Site indicate that the current distribution of TCE in the groundwater system is attributable to historical releases from the chemical storage facilities that have attenuated over time. Although vadose zone soil matrix and vapor concentrations are relatively small and consistent with the small concentrations currently detected in groundwater at the Site, TCE concentrations in groundwater remain slightly above the drinking water MCL of 5 µg/L, which provided the impetus for implementing an ISCO remedial pilot test.

1.2.4 Contaminant Fate and Transport

Previous work indicates that VOC mass in the subsurface at the Site is a result of historical releases that appear to have largely dissipated and attenuated through natural processes, along with the mass removal that has occurred in conjunction with on-going extraction and treatment operations. The majority of the remaining VOC mass is interpreted to occur in a fine-grained layer, comprising silty clays and clayey silts, with minor sandy and gravelly interbeds, that occur in the interval from approximately 85 to 126 feet bgs underlying the historical chemical storage facilities. This approximately 40-foot thick fine-grained layer was encountered in borings BB-2, B-3, B-4, B-5 and B-6, installed in the vicinity of the former chemical storage area (Figure 3). Groundwater monitoring indicates that the water table occurs in the lower portion of this fine-grained layer at a depth of approximately 110 feet bgs. Physical properties analyses for soil samples obtained from borings B-5 and B-6 show that moisture content in the fine-grained layer immediately above the water table is high, indicating this interval is part of the capillary fringe.

The largest TCE concentrations reported in soil samples were from the lower portion of the fine-grained layer at borings B-5 and B-6, at depths of 120 and 110 feet bgs, respectively (Figure 3). Conversely, TCE was not reported above the laboratory reporting limit in soil samples obtained from these borings in the interval from land surface to the top of the fine-grained layer (0 to 85 feet bgs). Based on soil analytical results, TCE mass in vadose zone sediments from land surface to 85 feet bgs is interpreted to be negligible and to not warrant remediation. Soil vapor samples obtained from soil borings B-3 and B-4 in 1996 and from SVMW-1 (boring B-5) in 2008 confirm results of soil sampling. In borings B-3 and B-4, the largest TCE concentrations in soil vapor were observed at a depth of approximately 80 feet bgs in a medium to coarse sand lens overlying the fine-grained layer (Figure 3). TCE concentrations in vapor samples obtained at shallower depths were reported at significantly lower levels. Similarly, in SVMW-1, TCE concentrations in soil vapor samples obtained from intervals screened between 45 and 55 feet bgs and between 65 and 75 feet bgs were substantially smaller than those reported in samples obtained from the lower interval screened from 83 to 93 feet bgs (Figure 3).

Groundwater concentrations at BB-2 and SVMW-1 demonstrate the current impact of downward diffusion of mass from the fine-grained zone into the water table in the vicinity of the historical chemical storage facilities. Recent maximum TCE concentrations in groundwater of 15 µg/L in a pumped sample from BB-2 and 58 µg/L in a grab sample from SVMW-1 are evidence of the diffusion of mass that is occurring from the fine-grained layer into the underlying coarser sediments of the regional aquifer.

1.2.5 Risk Summary

Current and potential future human health risks and hazards related to exposure to contaminated groundwater and soil gas at the Site are evaluated in this section. Exposure to contaminated soil or dust was addressed in a U.S. EPA ROD for soils (U.S. EPA, 1997a) and, therefore, is not addressed in this analysis. This analysis is similar to the *Baseline Human Health Risk Assessment for the Tucson International Airport Area Site* (BHHRA; Arizona Department of Health Services [ADHS], 1996) and also the *Tucson International Airport Area Superfund Site – West-Cap Project Area Focused Feasibility Study* (CH2MHill, 2011), which includes recent contaminant concentration data for the West-Cap area. This risk assessment uses data from recent investigations at the Site to evaluate health risks from potential exposure to contaminants in groundwater and soil gas.

1.2.5.1 TI Risk Summary in the BHHRA

In the BHHRA (ADHS 1996), the results from the risk evaluation for surface soil showed excess lifetime cancer risk (ELCR) less than U.S. EPA's risk management range of 1×10^{-6} to 1×10^{-4} for residents. Exposure to soil gas was evaluated for potential current and future occupational exposure through vapor intrusion and the results showed an ELCR less than the U.S. EPA's risk management range of $1x10^{-6}$ to $1x10^{-4}$. Exposure to groundwater was evaluated for potential future residential exposure and the ELCR was within U.S. EPA's risk management range of $1x10^{-6}$ to $1x10^{-4}$. PCE and TCE were identified as contaminants of potential concern (COPC) in the groundwater.

1.2.5.2 Current/Future Exposure Pathways

Currently there is no residential area at the Site. However, there is still a potential risk, based on a future residential drinking water scenario (i.e., drilling new private wells in the area for drinking water use). Currently there are no local ordinances or state laws that prevent the drilling of private drinking water wells in contaminated areas, or for converting an irrigation well into a drinking water well (ADHS, 2000). If these potential pathways become complete, then ingestion of drinking water and/or using the contaminated water for cooking would be a concern, as would exposure to contaminants via bathing and showering (direct contact and inhalation of volatiles). Therefore, updated risk calculations are presented in this section to supplement the previous risk assessment results with recent groundwater data.

Worker exposures to soil vapors, contaminated soil, or dust were the only current complete exposure pathways identified in the BHHRA (ADHS, 1996). There are a number of buildings at the Site, and the area is zoned as an industrial area. These pathways were addressed in the U.S. EPA ROD for soils (U.S. EPA, 1997a). More recent soil gas data has been collected since the 1990s; therefore, an occupational worker was evaluated for the vapor intrusion pathway using available soil gas data to update the previous risk assessment results.

1.2.5.3 Updated Risk Evaluation

The groundwater concentrations for the COPCs are based on data from 11 monitoring wells (see Figure 2) at the Site and in the adjacent and downgradient wells between 1992 and 2011 and are summarized in Appendix A. For soil gas, data collected from one location (deep soil gas sampling ports in well SVMW-1 [B-5]) in September 2008 was used in this evaluation. In addition, soil gas data collected from B-3 and B-4 in February 1996 were used for comparative purposes because these two locations were not sampled in 2008. Table B-1 in Appendix B presents the soil gas data used in the risk evaluation and Figure 3 shows cross sections for not only SVMW-1, but also B-3 and B-4.

1.2.5.4 Methodology

Each of the chemicals detected in the groundwater and soil gas were selected as COPCs in this risk evaluation. For groundwater, the maximum detected concentrations and tap water regional screening levels (RSL) (U.S. EPA, 2010) were used as exposure point concentrations (EPC) in the calculations. The groundwater risk evaluation follows the methodology used in the BHHRA, essentially a risk ratio method to calculate risks. To calculate cancer risk estimates for individual COPCs, the EPC was divided by the U.S. EPA's RSL (based on carcinogenic effects and a target cancer risk of $1x10^{06}$) and the resulting ratio was multiplied by $1x10^{-06}$. Cancer risk estimates for individual COPCs were then summed to provide a cumulative cancer risk estimate. To obtain the hazard quotient for individual COPCs, the EPC was divided by the U.S. EPA's RSL (based on non-cancer effects and a hazard quotient [HQ] of 1). HQs for the individual COPCs were summed to derive the hazard index (HI). The cumulative risk is compared against a risk management range of $1x10^{-6}$ to $1x10^{-4}$ (U.S. EPA, 1989) for carcinogens and the HI is compared against a threshold HI of 1 for non-carcinogens.

For the soil gas evaluation, detected concentrations from the most recent sampling (SVMW-1 or B-5) and shallowest depth were used as EPCs. Two approaches were used to evaluate indoor air and both corroborate each other and make the evaluation complete for each COPCs. First, indoor air RSLs were adjusted for the soil gas evaluation by multiplying the indoor air RSL by 100 to account for attenuation from deep soil gas to indoor air (U.S. EPA, 2002). The concentration in soil gas was compared to the adjusted RSL and the same procedure used to calculate risks and hazards as for groundwater with carcinogenic and non-carcinogenic ratios was calculated and summed for soil gas COPCs. As an alternative approach, detected concentrations were compared directly with California Human Health Screening Levels (CHHSLs) developed in 2005 by the California Environmental Protection Agency (Cal/EPA). In addition, detected concentration were compared to Environmental Screening Levels (ESLs) developed in 2007 by the California Regional Water Quality Control Board (RWQCB). No adjustments for attenuation were needed in this alternative soil gas evaluation.

1.2.5.5 Current/Future Pathway Risk Summary

Based on the results from recent groundwater data collected in the 11 wells in the vicinity of the Site, the potential future ELCR associated with using groundwater from the Site for drinking water is approximately $9x10^{-5}$ (see Table B-2 in Appendix B), which is less than U.S. EPA's point of departure for taking action ($1x10^{-4}$) but is within

U.S. EPA's risk management range ($1x10^{-6}$ to $1x10^{-4}$). The contributors to the risk are PCE ($5x10^{-5}$), and TCE ($4x10^{-5}$). The overall HI for drinking water is $3x10^{-2}$, which is well below the non-cancer threshold of 1.

In order to reflect current conditions at the Site, maximum concentrations of TCE and PCE were identified in groundwater samples collected in the past several years. The highest TCE (76 µg/L) concentration was found in extraction well BB-2 in December 2008. The highest PCE (5.8 µg/L) concentration was found in monitoring well SF-3 in January 2010. However, concentrations of PCE in monitoring wells SF-3 and SF-1 likely originated from an up-gradient site, the Former West Cap Facility. To be conservative, the maximum concentration from the SF-3 well was used in the analysis even though the source of the PCE may be off-site. The next highest concentration of PCE in the past several years from monitoring well CF-1 (0.87 µg/L) was also used in the analysis (see Table B-2 in Appendix B). Using the alternative concentration of PCE, the potential future ELCR associated with using groundwater from the Site for drinking water is approximately $5x10^{-5}$ (see Table B-2 in Appendix B), which is lower and also within U.S. EPA's risk management range ($1x10^{-6}$ to $1x10^{-4}$). The contributors to the risk are PCE ($8x10^{-6}$) and TCE ($4x10^{-5}$). The overall HI for drinking water is $4x10^{-3}$, which is well below the non-cancer threshold of 1.

The potential future excess lifetime cancer risks associated with indoor air pathway is $2x10^{-6}$ (see Table B-3 in Appendix B) which is at the lower end of U.S. EPA's risk management range ($1x10^{-6}$ to$1x10^{-4}$). The primary contributor to maximum risk ($2x10^{-6}$) was TCE ($9x10^{-7}$) and chloroform ($1x10^{-6}$). TCE was detected at a concentration of 550 micrograms per cubic meter (µg/m^3) and chloroform was detected at a concentration of 74 µg/m^3 in a soil gas sample collected from SVMW1 at a sample interval of 45-55 ft bgs in July 2008. TCE is also a primary contributor to the risk in groundwater; however, the risk from a soil gas sample collected in just one sample might not be representative of current conditions. The overall HI for the indoor air pathway is well below 1.

In order to further evaluate the data with more recent criteria as well as include those COPCs without RSLs, detected concentrations were compared with CHHSLs and ESLs (see Table B-4 in Appendix B). Comparisons or ratios using this direct approach were less than 1 including chloroform and TCE; therefore, no analyte detected in soil gas is of concern for commercial/industrial workers in this analysis. A comparison with nearby borings that were sampled for TCE soil gas in 1996 show that concentrations of TCE soil gas remain fairly constant over the past 10 years with slightly higher concentrations recorded at depth in three sample locations (see Figure 3).

1.2.5.6 Uncertainties

The maximum detected concentration in the groundwater was used to estimate risk, which is conservative and likely overestimates the risks and hazards. Tap water RSLs include the ingestion of water and inhalation of volatiles from water exposure pathways. The dermal exposure route is not included in these RSLs. Therefore, risks and hazards might be slightly underestimated.

Indoor air RSLs were adjusted with a generic attenuation factor (AF) of 0.01 to account for attenuation from deep soil gas to indoor air. Use of this generic AF could underestimate or overestimate the risks and hazards, if the site-specific attenuation is different and is not accounted for with this AF.

Two soil gas samples, B-3 and B-4, both collected in 1996, were included in the risk evaluation for comparative purposes; however, these concentrations might not be representative of current conditions at these two locations and could overestimate or underestimate the risks and hazards.

2. IDENTIFICATION OF TECHNOGOLIES

2.1 Introduction

Treatment technologies were originally evaluated in the *Feasibility Study for Ground Water Remediation in the Tucson Airport Area* (Malcolm Pirnie, 1988). These technologies included:

- Packed column aeration,
- Packed column aeration with vapor phase granular activated carbon, and
- Liquid phase granular activated carbon.

Due to operational changes at the Site, reevaluation of the remedy at the Site is warranted. This reevaluation included a review of treatment technologies, as well as end use options for treated groundwater. This evaluation follows.

2.2 Remedial Action Objectives

The RAOs provide the foundation from which to develop and evaluate remedial actions for the Site. The original RAOs for the Site are identified in the 1988 ROD and are still considered valid:

- Manage migration of contaminants,
- Achieve public acceptance of the remedy,
- Protect public health and the environment,
- Attain consistency with established applicable or relevant and appropriate requirements (ARARs), and
- Determine the most environmentally sound, technically feasible, and cost-effective remedy, which can be implemented in a timely manner.

2.2.1 Contaminants of Interest

Although over 20 VOCs were identified in the 1988 ROD as being detected at elevated concentrations in groundwater within the TIAA Superfund site, only TCE and PCE were detected above MCLs at the Site. Therefore, TCE and PCE are the contaminants of interest (COIs) for the Site.

2.2.2 Allowable Exposure/ARAR Analysis

These criteria address whether the remedial alternatives comply with applicable or relevant and appropriate federal, state, and municipal chemical-specific, action-specific, and location-specific requirements. The ARAR analysis is included as Appendix C.

2.2.3 Remediation Goals

The primary remediation goal for the contaminated groundwater at the Site was developed from chemical-specific ARARs and are defined as the MCL for the contaminants of interest. The MCLs for the contaminants of interest are shown in Table 2-1. The standard applies to in situ groundwater and treated groundwater that is to be injected or otherwise reused.

Table 2-1 Maximum Contaminant Levels for the Contaminants of Interest

Parameter	***Primary MCL (µg/L)***
PCE	5
TCE	5

2.3 General Response Actions

GRAs are actions that could be implemented to remediate the Site. The GRAs identified for this Site are:

- Institutional Action
- Monitoring
- Containment
- Extraction and Treatment
- In situ Treatment

2.3.1 Institutional Actions

Institutional actions are non-engineered instruments, such as administrative and legal controls, that help minimize the potential for human exposure to contamination. Examples of institutional controls include site access limitations and property use restrictions.

2.3.2 Monitoring

Monitoring activities include collection and analysis of groundwater samples, collection of groundwater elevation data to evaluate groundwater flow gradient and direction, and collection of treatment system performance and operation data. Monitoring data will be collected as part of the Site remediation activities to demonstrate compliance with obligations for the remedial action.

2.3.3 Containment

The containment method prevents or reduces the migration of contaminant plumes. This approach may include engineered physical or reactive barriers or hydraulic gradient capture utilizing groundwater extraction wells.

2.3.4 Extraction and Treatment

Groundwater extraction and treatment allows the contaminated groundwater to be extracted and treated ex situ through various treatment methods to achieve the remediation goals. A groundwater extraction and treatment system, consisting of one groundwater extraction well and packed column air stripping treatment is in place at the Site.

2.3.5 In Situ Treatment

In situ treatment of contaminated groundwater allows the groundwater to be treated in place, without having to extract it from the aquifer. Specifically, ISCO will be evaluated. ISCO involves injecting chemical oxidants into the vadose zone or groundwater to oxidize VOC contaminants. ISCO would be used in conjunction with monitored natural attenuation (MNA) outside the treatment area in downgradient areas containing lower VOC concentrations. MNA is the use of natural attenuation processes to achieve, site-specific remedial objectives (EPA, 1997b.)

2.4 Identification of Technologies Evaluated

An evaluation of each GRA, as well as identified technologies associated with the GRAs, is discussed below.

2.4.1 Institutional Actions

As the Site is an active remedial Project Area within the TIAA Superfund Site, and TI (formerly Burr Brown) is considered a Settling Party, it is anticipated that institutional actions will be implemented as a portion of the remedy.

2.4.2 Monitoring

Monitoring activities, including sample collection and groundwater level measurements, will continue and be coupled with the selected alternative to demonstrate compliance with obligations for the remedial action.

2.4.3 Containment

Given the Site conditions the use of physical and reactive barriers is not practical, and therefore will not be evaluated.

While operating, the current extraction and treatment system at the Site was maintaining hydraulic capture of the TCE plume within the Site boundaries. This capture was demonstrated by mapping of the groundwater elevations around the extraction well, mapping of the TCE plume concentrations at the monitoring wells around the extraction well, and TCE concentration trends at downgradient monitor wells. While containment was being maintained by the extraction and treatment system, containment alone will not remediate the site, therefore, hydraulic capture will not be evaluated.

2.4.4 Extraction and Treatment

Groundwater extraction and treatment allows the contaminated groundwater to be extracted and treated ex-situ through various treatment methods to achieve the remediation goals. The treatment method for Alternatives 1 and 2 would be packed column air stripping. For Alternative 1, treated groundwater would be discharged to the Publicly Owned Treatment Works (POTW). For Alternative 2, the treated groundwater would be injected into the aquifer through two new injection wells.

2.4.5 In Situ Treatment

In situ treatment of contaminated groundwater allows the groundwater to be treated in place, without having to extract it from the aquifer. A full-scale ISCO injection will be evaluated as Alternative 3. The chemical oxidant for ISCO treatment would be potassium permanganate, which is suitable for the oxidation of TCE and is stable and persistent. Furthermore, potassium permanganate was successfully utilized in ISCO pilot studies at the site and other Project Areas within the TIAA Superfund Site and, the Site geology appears to be conducive to accept the injections. MNA would be used in conjunction with ISCO to monitor the down gradient areas containing lower VOC concentrations.

3. DEVELOPMENT AND SCREENING OF ALTERNATIVES

Five remedial alternatives were identified for the focused feasibility study, which are summarized in Table 3-1.

Table 3-1 Development and Screening of Alternatives

Alternative	*Screening Result*
No action	Removed from consideration because the alternative is not protective of the environment
Groundwater extraction and treatment with water reuse	Removed from consideration because a reliable end user for beneficial use could not be readily identified.
Groundwater extraction and treatment with discharge to POTW	Retained for analysis
Groundwater extraction and treatment with injection	Retained for analysis
ISCO with MNA	Retained for analysis

Since manufacturing is no longer conducted at the Site, there is no beneficial use for the treated water from the groundwater extraction and treatment system. Thus, operational changes prompted the reconsideration of the remedy at the Site. "No action" was not considered because the alternative is not protective of the environment and human health. Groundwater extraction and treatment with water reuse was removed from consideration because a reliable end user for beneficial use could not be readily identified. Groundwater extraction and treatment with discharge to POTW and groundwater extraction and treatment with injection were retained for analysis as the groundwater extraction and treatment system infrastructure is in place and reliably contained and remediated the groundwater contamination for 17 years. ISCO with MNA was retained for analysis because results from the pilot study at the Site and other areas of TIAA indicate that the alternative could be a short-term and cost effective remedy.

In the sections below, the three identified alternatives are evaluated based on the evaluation criteria outlined in the U.S. EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (U.S. EPA, 1988).

The evaluation criteria include:

1. Overall protection of human health and the environment
2. Compliance with ARARs
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, or volume through treatment
5. Short-term effectiveness
6. Implementability
7. Cost
8. State acceptance
9. Community acceptance

A detailed analysis of each alternative is presented in Sections 3.1, 3.2, and 3.3. The evaluation and comparative analysis of the three alternatives is provided in Section 3.4.

3.1 Alternative 1 – Groundwater extraction and treatment with discharge to POTW

Alternative 1 includes on-site groundwater extraction and treatment to remove VOCs from the groundwater, and discharge of treated water to the POTW. The existing groundwater extraction and treatment system was reviewed and recommended modifications were provided as part of Alternative 1. In addition, a new groundwater extraction well would be installed to replace the existing extraction well. Furthermore, the existing treatment system would be moved to a more accessible location on the Site and a connection would be established to the POTW.

3.1.1 Description

Alternative 1 will involve installation of one new extraction well, improvements and modifications to the existing treatment system, connection to POTW for discharge of treated water, and conveyance piping.

3.1.1.1 Extraction Wells and Piping

The VOC contaminated groundwater plume at the Site would be contained and treated by one new extraction well and the existing treatment system with improvements and modifications. The treatment system is comprised of a packed column air stripper to remove the COIs to below their respective MCLs. Treated groundwater would be discharged to the POTW.

As described in Section 1.2.2, the current groundwater extraction and treatment system was utilized at the Site from 1992 to 2009. In preparation for the ISCO pilot study in 2009, the treatment system was shutdown and pumping equipment was removed from wells EW-1A and BB-2 to facilitate groundwater monitoring conducted by hand bailer. After evaluating the condition of the existing extraction well, it was determined that BB-2 is not a viable extraction well due to damage to the well casing in 2008. Thus, a new extraction well would be necessary for groundwater extraction and treatment. The new extraction well would be placed near BB-2 (see Figure 6), and would have an anticipated production rate of 40 gpm.

It was assumed that new conveyance piping would be necessary to connect the new extraction well to the treatment system and to connect the treatment system to the discharge to POTW. The criteria for the conveyance piping are shown in Table 3-2. Piping would be buried in 2 ft wide by 4 ft deep trenches. The location of the new extraction well and the treatment system are shown on Figure 6.

Table 3-2 Conveyance Piping Criteria

Parameter	*Description*
Connect new extraction well to treatment system	Approximately 500 ft of 2-inch PVC class 160 pipe
Connect treatment system to discharge to POTW	Approximately 200 ft of 2-inch PVC class 160 pipe

3.1.1.2 Treatment System

The existing air stripper was installed in June 1992 and is located on the south side of the Site, which was an optimal location for reuse of the treated water in the Site's high purity treatment process. The high purity water was previously used in manufacturing processes and cooling towers at the Site. However, manufacturing operations at the Site ended in 2009 and the manufacturing facility has been decommissioned. For Alternative 1, the existing air stripper would be moved to the location specified in Figure 6, which would make the air stripper more accessible for maintenance and discharge to the POTW.

The groundwater would be fed through the top of the column through a spray nozzle and flow downward from the base of the packed column through the packing, which would provide a counter-current air flow. The treated water would be pumped to the POTW for discharge. Table 3-3 shows the existing packed column air stripper design parameters.

Table 3-3 Existing Packed Column Air Stripper Design Parameters

Packed Column	***Design Parameters***
Water flow	75-150 gpm
Air flow	300-600 scfm
Air-to-water ratio	25:1
Tower height	27 feet
Tower diameter	30 inches
Material of construction	FRP
Bottom residence time	2 minutes
Packing height	15 feet
Packing type	3.5 inch LanPac
Removal efficiency	>95%

The following system upgrades are recommended for the air stripper for Alternative 1:

- Move the existing air stripping tower to the location specified on Figure 6, which would improve accessibility for maintenance and discharge to the POTW.
- Re-pack the existing air stripping tower with new 3.5-inch LanPac. Packing replacement is recommended to ensure the differential pressure within the column will be at or near design specification.
- Replace the existing blower with a new blower of the same capacity. The existing blower has been in operation since 1992, and after many years of continuous operation, it is near the end of the anticipated life for rotating machinery.
- Install differential air pressure, airflow, and water flow measurement and monitoring equipment. Continual measurement of air flow and water flow can be used to automatically monitor treatment performance parameters such as air to water ratio (AWR) and air pressure drop across the packing.
- Provide controls that calculate AWR and monitor ratios using data to set automatic alarm and shut-down responses based on operational targets.
- A pumping system to convey water from the treatment system to the POTW.

3.1.1.3 *Influent Water Quality*

The new extraction well would pump water from the lower sand unit aquifer (Figure 3). Data from samples collected in July 2009 before the ISCO pilot test, indicated a TCE concentration of 16 µg/L for BB-2 (Figure 5). No other VOCs were detected above the laboratory reporting limit at this well.

3.1.1.4 *Monitoring*

Groundwater monitoring, including collection of groundwater samples and water level elevation data would be conducted on a semi-annual basis to evaluate the effectiveness of the remedy. Groundwater samples would be analyzed for VOCs.

3.1.2 Assessment

The analysis of Alternative 1 will contribute to the comparative analysis of the alternatives in Section 3.4. The next sections provide an analysis of Alternative 1 based on the evaluation criteria described in Section 3.

3.1.2.1 *Overall Protection of Human Health and the Environment*

Alternative 1 can protect human health and the environment from risks caused by the VOC groundwater contamination. In addition, the groundwater contamination would be contained by groundwater extraction.

3.1.2.2 *Compliance with ARARs*

The end use, discharge to the POTW does not comply with one location-specific ARAR. Discharge to the POTW is not considered a high level of beneficial use of the extracted water, in accordance with the Third Management Plan for the Tucson Active Management Area (2000-2010, Arizona Department of Water Resources, 1999) and the designation of the Tucson Basin as a Sole Source Aquifer under the Safe Drinking Water Act.

Alternative 1 is projected to comply with the other chemical-, location-, and action-specific ARARs identified in Appendix C. Alternative 1 includes extracting, treating, and discharge to the POTW to meet remediation goals. There is some uncertainty regarding the length of time required for achieving TCE concentrations below the MCL.

3.1.2.3 Long-Term Reliability and Effectiveness

Extraction and treatment for remediation of VOC groundwater contamination has been reliable and is effective in achieving the RAOs. However, when the COIs are mainly present in fine-grained media, the rate of removal is diffusion dependent, which reduces the effectiveness of the treatment process. Extraction and treatment was used at the Site for 17 years (1992 and 2009), and approximately 16.3 pounds of TCE were removed from groundwater at the Site using groundwater extraction and treatment during that time period.

3.1.2.4 Reduction of Toxicity, Mobility, or Volumes of Wastes

Alternative 1 will use air stripping to remove the VOCs from the groundwater, which will reduce the mobility and volume of VOCs in the groundwater plume. Based on manufacturer information and the groundwater treatment system evaluation, the estimated removal efficiency of the air stripping system is greater than 95%. Although the time necessary to meet remediation goals by groundwater extraction and treatment is unclear, it is assumed that the goals would be reached within 30 years.

3.1.2.5 Short-Term Effectiveness

For Alternative 1, risks to human health and the environment during construction and operation can be minimized through proper decontamination and use of secondary containment. Potential exposure pathways for workers include inhalation and dermal contact during installation of the new groundwater extraction well and piping. The potential exposure pathways can be effectively managed through proper health and safety procedures and the use of personal protective equipment.

3.1.2.6 Implementability

Alternative 1 is not projected to be readily implemented due to constraints with industrial wastewater discharge requirements from Pima County Regional Wastewater Reclamation Department (PCRWRD). Based on discussions with PCRWRC staff, discharge of water treated to drinking water standards would be considered a hydraulic overload to the system, and at this time, would be denied. In addition, discharge to the POTW is not considered a beneficial use of the extracted water, in accordance with the Groundwater Management Plans for the Tucson Active Management Area and the Sole Source Aquifer designation by the Safe Drinking Water Act.

3.1.2.7 Cost

A summary of the cost opinion for Alternative 1 is shown in Table 3-4, while a detailed cost estimate is provided in Appendix D. The cost opinions include total capital costs, the annual operations and maintenance (O&M) requirement, and the net present value for a 30-year period at a discount rate of 4 percent. The cost estimates have been developed based on ARCADIS U.S., Inc. previous experience, RS Means, and vendor's quotes. The cost estimates have an accuracy range of +50 to -30 percent. The cost opinion applies only to Alternative 1 under the assumptions defined in Section 3.1.1 and Appendix D and does not account for changes to the scope of the remedy.

Table 3-4 Summary of Alternative 1 Cost Opinion

Total Capital Costs	Annual O&M	Net Present Value
$288,300	$91,100	$1,863,100

3.2 Alternative 2 – Groundwater extraction and treatment with injection

Similar to Alternative 1, Alternative 2 includes groundwater extraction and treatment to remove VOCs from the groundwater, but with injection of treated water as the end use. The existing treatment system would be modified as part of Alternative 2. Additionally, a new groundwater extraction well and two new injection wells would be installed. Furthermore, the existing treatment system would be moved to a more accessible location.

3.2.1 Description

Alternative 2 will involve installation of an extraction well, improvements and modifications to the existing treatment system, installation of two new injection wells for treated water, and conveyance piping.

3.2.1.1 Extraction Wells, Injection Wells, and Piping

The VOC contaminated groundwater plume at the Site would be contained and treated by one new extraction well, the existing treatment system with improvements and modifications, and two new injection wells for the treated water. The treatment system is comprised of a packed column air stripper to reduce the COIs to below their respective MCLs.

As described in Section 1.2.2, the current groundwater extraction and treatment system was utilized at the Site from 1992 to 2009. In preparation for the ISCO pilot study in 2009, the treatment system was shutdown and pumping equipment was removed from wells EW-1A and BB-2 to facilitate groundwater monitoring conducted by hand bailer. After evaluating the condition of the existing extraction well, it was determined that BB-2 is not a viable extraction well due to damage to the well casing in 2008. Thus, a new extraction well would be necessary for groundwater extraction and treatment. The new extraction well would be placed near BB-2 (see Figure 7), and has an anticipated production rate of 40 gpm.

It is assumed that the two new injection wells would be installed on the north and west sides of the source area (see Figure 7). Each injection well would receive approximately 20 gpm. The location of the injection wells was established to control plume migration and to assist with flushing of the source area. The criteria for the new injection wells are shown in Table 3-5.

Table 3-5 New Injection Well Criteria

Parameter	***Description***
Depth	140 feet
Borehole diameter	10-inch
Casing material	5-inch Schedule 40 PVC blank and stainless steel, wire-wrap screen

It was assumed that new conveyance piping would be necessary to connect the new extraction well to the treatment system and to connect the treatment system to the new injection wells. The criteria for the conveyance piping are shown in Table 3-6. Piping would be buried in 2 ft wide by 4 ft deep trenches. The location of the new extraction well, the treatment system, and the new injection wells are shown on Figure 7.

Table 3-6 Conveyance Piping Criteria

Parameter	***Description***
Connect new extraction well to treatment system	Approximately 500 ft of 2-inch PVC class 160 pipe
Connect treatment system to new injection wells	Approximately 400 ft of 2-inch PVC class 160 pipe

3.2.1.2 Treatment System

The existing air stripper was installed in June 1992 and is located on the south side of the Site, which was an optimal location for reuse of the treated water in the Site's high purity treatment process. The high purity water was previously used in manufacturing processes and cooling towers at the Site. However, manufacturing operations at the Site ended in 2009 and the manufacturing facility has been decommissioned. For Alternative 2, the existing air stripper would be moved to the location specified in Figure 7, which would make the air stripper more accessible for maintenance.

The groundwater would be fed through the top of the column through a spray nozzle and flow downward from the base of the packed column through the packing, which would provide a counter-current air flow. The treated water would then been reinjected. Table 3-7 shows the existing packed column air stripper design parameters.

Table 3-7 Existing Packed Column Air Stripper Design Parameters

Packed Column	***Design Parameters***
Water flow	75-150 gpm
Air flow	300-600 scfm
Air-to-water ratio	25:1
Tower height	27 feet
Tower diameter	30 inches
Material of construction	FRP
Bottom residence time	2 minutes
Packing height	15 feet
Packing type	3.5 inch LanPac
Removal efficiency	>95%

The following system upgrades are recommended for the air stripper for Alternative 2:

- Move the existing air stripping tower to the location specified on Figure 7, which would improve accessibility for maintenance.
- Re-pack the existing air stripping tower with new 3.5-inch LanPac. Packing replacement is recommended to ensure the differential pressure within the tower will be at or near design specification.
- Replace the existing blower with a new blower of the same capacity. The existing blower has been in operation since 1992, and after many years of

continuous operation, it is near the end of the anticipated life for rotating machinery.

- Install differential air pressure, airflow, and water flow measurement and monitoring equipment. Continual measurement of air flow and water flow can be used to automatically monitor treatment performance parameters such as AWR and air pressure drop across the packing.
- Provide controls that calculate AWR and monitor ratios using data to set automatic alarm and shut-down responses based on operational targets.
- A pumping system to convey water for injection.

3.2.1.3 Influent Water Quality

The new extraction well would pump water from the lower sand unit aquifer (Figure 3). Data from samples collected in July 2009 before the ISCO pilot test, indicated a TCE concentration of 16 µg/L for BB-2 (Figure 5). No other VOCs were detected above the laboratory reporting limit at this well.

3.2.1.4 Monitoring

Groundwater monitoring, including collection of groundwater samples and water level elevation data would be conducted on a semi-annual basis to evaluate the effectiveness of the remedy. Groundwater samples would be analyzed for VOCs.

3.2.2 Assessment

The analysis of Alternative 2 will contribute to the comparative analysis of the alternatives in Section 3.4. The next sections provide an analysis of Alternative 2 based on the evaluation criteria described in Section 3.

3.2.2.1 Overall Protection of Human Health and the Environment

Alternative 2 can protect human health and the environment from risks caused by the VOC groundwater contamination. In addition, groundwater contamination would be contained by groundwater extraction.

3.2.2.2 Compliance with ARARs

Alternative 2 is projected to comply with chemical-, location-, and action-specific ARARs. Alternative 2 includes extraction and treatment coupled with reinjection to meet remediation goals. There is some uncertainty regarding the length of time required for achieving TCE concentrations below the MCL.

3.2.2.3 Long-Term Reliability and Effectiveness

Extraction and treatment for remediation of VOC groundwater contamination has been reliable and effective in achieving the RAOs. However, when the COIs are mainly present in fine-grained media, the rate of removal is diffusion dependent, which reduces the effectiveness of the treatment process. Extraction and treatment was used at the Site for 17 years (1992 and 2009), and approximately 16.3 pounds of TCE were removed from groundwater at the Site using groundwater extraction and treatment during that time period.

3.2.2.4 Reduction of Toxicity, Mobility, or Volumes of Wastes

Alternative 2 will use packed column air stripping to remove the VOCs from the groundwater, which will reduce the mobility and volume of VOCs in the groundwater plume. Based on manufacturer information and the treatment system evaluation, the estimated removal efficiency of the air stripping system is greater than 95%. Although the time necessary to meet remediation goals by groundwater extraction and treatment is unclear, it is assumed that the goals would be reached within 30 years.

3.2.2.5 Short-Term Effectiveness

For Alternative 2, risks to human health and the environment during construction and operation can be minimized through proper decontamination and use of secondary containment. Potential exposure pathways for workers include inhalation and dermal contact during installation of the new groundwater extraction well and piping. The potential exposure pathways can be effectively managed through proper health and safety procedures and the use of personal protective equipment.

3.2.2.6 Implementability

Alternative 2 is projected to be readily implemented since the facility is currently equipped with the air stripper and other equipment necessary for treatment. Alternative 2 includes the installation of a new extraction well and two new injection wells, below ground conveyance piping, and relocation of the air stripper.

3.2.2.7 Cost

A summary of the cost opinion for Alternative 2 is shown in Table 3-8, while a detailed cost estimate is provided in Appendix D. The cost opinions include total capital costs, the annual O&M requirement, and the net present value for a 30-year period at a discount rate of 4 percent. The cost estimates have been developed based on ARCADIS U.S., Inc. previous experience, RS Means, and vendor's quotes. The cost estimates have an accuracy range of +50 to -30 percent. The cost opinion applies only to Alternative 2 under the assumptions defined in Section 3.1.1 and Appendix D and does not account for changes to the scope of the remedy.

Table 3-8 Summary of Alternative 2 Cost Opinion

Total Capital Costs	Annual O&M	Net Present Value
$522,300	$85,100	$1,993,400

3.3 Alternative 3 – In Situ Chemical Oxidation with Monitored Natural Attenuation

Alternative 3 includes a full-scale ISCO injection of potassium permanganate into the source area and a MNA program to evaluate the remedy.

A pilot study was conducted in 2009 to evaluate the efficacy of ISCO using potassium permanganate to reduce concentrations of TCE and other VOCs in the lower portion of the vadose zone and the upper portion of the groundwater system to expedite site clean-up and closure (Montgomery and Associates, 2009). Specifically, the pilot study tested the efficacy of ISCO above and below a fine-grained unit located between approximately 85 and 126 feet bgs. This low permeability unit contains elevated concentrations of TCE and appears to act as an ongoing source of contamination to the underlying groundwater. The following sections describe Alternative 3, including a summary of the pilot study results and conceptual design.

3.3.1 Description

Alternative 3 would involve a full-scale ISCO injection of potassium permanganate at the source area followed by a MNA program to monitor the remedy. The following sections describe the target treatment zone, a summary of the pilot study results, and the full-scale ISCO conceptual design.

3.3.1.1 Target Treatment Zone

The source area at the Site was determined based on the distribution of VOCs in soils, soil vapor, and groundwater identified during previous investigation at the site. The majority of the VOC mass is interpreted to occur in a fine-grained layer, comprised of silty clays and clayey silts with minor sandy and gravelly interbeds, that occurs in the interval from approximately 85 to 126 feet bgs. Groundwater monitoring indicates that the water table occurs in the lower portion of this fine-grained layer at a depth of approximately 110 feet bgs. The target treatment area corresponds to the footprint of the historical chemical storage facilities, shown on Figure 2. In the vertical direction, the vadose zone target treatment interval includes the thickness of the fine-grained layer shown on Figure 3, extending from a depth of about 85 feet to a depth of about 110 feet bgs. The vertical extent of the groundwater treatment zone comprises the interval from approximately 110 feet bgs to the base of perforations in groundwater monitoring wells at a depth of approximately 140 feet bgs.

Based on Site conditions, it is assumed that the oxidant would be distributed through the target treatment zone within 1 year of injection, and two additional years of monitoring would confirm the effectiveness of the remedy or identify whether additional injections would be necessary.

3.3.1.2 Summary of ISCO Pilot Study Results

Potassium permanganate injections at SVMW-1 commenced on October 21, 2009 and ran through October 24, 2009. A total of 687.5 pounds of potassium permanganate were injected in to the vadose zone at this location using approximately 31,500 gallons of potable water. The general procedure for the injections was to inject the mixture of potable water and potassium permanganate throughout the day followed by injections of potable water during the night to push the potassium permanganate out in to the target treatment area.

Potassium permanganate injections at SVE-1 were conducted on October 27, 2009, and between November 10 and 11, 2009. A total of 632.5 pounds of potassium permanganate were injected in to the vadose zone at this location using approximately 12,000 gallons of potable water. The general procedure for the injections was to inject the mixture of potable water and potassium permanganate throughout the day followed by injections of potable water during the night to push the potassium permanganate out in to the target treatment area.

Potassium permanganate injections at IW-1 commenced on November 2, 2009 and ran for seven continuous days through November 9, 2009. The general procedure for the injections was to inject the mixture of potassium permanganate throughout the day followed by injections of potable water during the night to push the potassium permanganate out in to the target treatment area. A total 1,209 pounds of potassium permanganate were injected into groundwater and lower sand unit using approximately 91,400 gallons of potable water.

The presence of potassium permanganate was visually observed (coloration) in monitor well BB-2 approximately one month following groundwater injections at IW-1. Within 12 months, potassium permanganate was visual observed monitor well AW-1, located approximately 450 feet down gradient of the target treatment area and approximately 500 feet down gradient of IW-1. Potassium permanganate has not been detected downgradient monitoring wells EW-1A and BB-1, however the concentrations of TCE in groundwater collected from these wells has only increased slightly and appears to be stabilizing over the past 18 months since the initial ISCO injections. This may be evidence that the initial ISCO injections have had a positive effect in reducing TCE concentration in the target treatment area.

3.3.1.3 Full-Scale ISCO Conceptual Design

The full-scale ISCO implementation would be conducted between two and three years following the initial pilot test of ISCO injections. If necessary, a follow-up maintenance dose may be required. An assessment of the efficacy of the pilot test of ISCO will be conducted following the first quarter 2012. The assessment will focus on TCE trends in groundwater in monitoring wells, AW-1, BB-1, EW-1A and BB-2, located immediately downgradient of the target treatment area. The full-scale design will consist of a similar approach to the initial pilot test of ISCO, including both vadose zone and groundwater injections. The location of potential new injection wells are shown on Figure 8. It is assumed that the ISCO and MNA operations will take approximately 13 years to complete. During the first year following injection, oxidation reduction potential (ORP) and coloration will be monitored. Groundwater monitoring, including collection of groundwater samples and water level elevation data will be conducted semi-annually for two years following the ORP and coloration monitoring. The MNA program will then be implemented for approximately the next 10 years.

3.3.1.4 Assumptions

As a conservative assumption, up to two new vadose zone injection wells and one new groundwater injection well may be necessary to implement the full scale injections. Approximately the same mass of potassium permanganate, 2,500 pounds, was also assumed.

3.3.2 Assessment

The analysis of Alternative 3 will contribute to the comparative analysis of the alternatives in Section 3.4. The next sections provide an analysis of Alternative 3 based on the evaluation criteria described in Section 3.

3.3.2.1 Overall Protection of Human Health and the Environment

Alternative 3 can protect human health and the environment from risks caused by TCE groundwater contamination. In addition, Alternative 3 provides treatment of the source area.

3.3.2.2 Compliance with ARARs

Alternative 3 is projected to comply with chemical-, location-, and action-specific ARARs. Alternative 3 includes ISCO with potassium permanganate to meet remediation goals.

3.3.2.3 Long-Term Reliability and Effectiveness

ISCO with potassium permanganate for remediation of VOC groundwater contamination has been demonstrated as efficient and reliable. Furthermore, ISCO with potassium permanganate was pilot tested at the Site to evaluate the efficacy of the remedy to reduce TCE concentrations. Preliminary results from the pilot test indicate that ISCO injections are being accepted by the site geology, and are anticipated to have a positive effect in reducing TCE concentrations in the target treatment area.

3.3.2.4 Reduction of Toxicity, Mobility, or Volumes of Wastes

Alternative 3 will utilize ISCO to oxidize VOCs from the groundwater, which will reduce the concentration and volume of VOCs in the groundwater plume.

3.3.2.5 Short-Term Effectiveness

For Alternative 3, risks to human health and the environment during construction and operation can be minimized through proper decontamination and use of secondary containment. Potential exposure pathways for workers include inhalation and dermal contact during installation of the injection wells for ISCO and during injection activities. The potential exposure pathways can be effectively managed through proper health and safety procedures and the use of personal protective equipment.

3.3.2.6 Implementability

Alternative 2 is projected to be readily implemented. Alternative 3 includes the installation of three new injection wells and the preparation of ISCO injection system.

3.3.2.7 Cost

A summary of the cost opinion for Alternative 3 is shown in Table 3-9, while a detailed cost estimate is provided in Appendix D. The cost opinions include total capital costs, the annual O&M requirement, and the net present value for a 13-year period at a discount rate of 4 percent. The cost estimates have been developed based on ARCADIS U.S., Inc. previous experience, RS Means, and vendor's quotes. The cost estimates have an accuracy range of +50 to -30 percent. The cost opinion applies only to Alternative 3 under the assumptions defined in Section 3.1.1 and Appendix D and does not account for changes to the scope of the remedy.

Table 3-9 Summary of Alternative 3 Cost Opinion

Total Capital Costs	Annual O&M	Net Present Value
$422,500	$55,000	$971,700

3.4 Comparative Analysis

In the following comparative analysis, the alternatives are considered in relation to one another and the evaluation criteria. The purpose of the comparative analysis is to identify the advantages and disadvantages of each alternative relative to each other. State and community acceptance will be addressed in an amendment to the 1988 ROD following comments on the focused feasibility study report and the proposed plan.

3.4.1 Overall Protection of Human Health and the Environment

Each of the alternatives is protective of human health and the environment and reduces VOC contamination in the source area. Alternatives 1 and 2 prevent further migration of the contaminated groundwater plume by containing, extracting, and treating the groundwater to the remediation goals. Alternative 2 also prevents migration of the plume by injection of treated groundwater downgradient of the source area. Alternative 3 directly reduces VOCs in the source area and in the groundwater downgradient from the source area.

3.4.2 Compliance with ARARs

Each of the alternatives complies with ARARs, with the exception of the end use identified for Alternative 1. Discharge to the POTW does not comply with one location-specific ARAR. Discharge to the POTW is not considered a high level of beneficial use of the extracted water, in accordance with the *Third* Management Plan for the Tucson Active Management Area (2000-2010, Arizona Department of Water Resources, 1999), and the designation of the Tucson Basin groundwater system as a Sole Source Aquifer under the Safe Drinking Water Act.

There is some uncertainty regarding the necessary time to meet remediation goals. Extended groundwater extraction and treatment or additional injections of potassium permanganate may be necessary to reach remediation goals at the Site. Alternative 3 is projected to meet ARARs in a shorter time than Alternatives 1 and 2.

3.4.3 Long-Term Reliability and Effectiveness

Groundwater extraction and treatment and ISCO have both been proven reliable and implementable at the Site. Long-term effectiveness relies on the ability of groundwater extraction and treatment or ISCO to fully treat the VOCs present in fine-grained media. The rate of removal from the fine-grained media is diffusion dependent, which reduces the effectiveness of the groundwater extraction and treatment processes. Thus, continued groundwater extraction and treatment may be required in excess of the 30 years estimated for Alternatives 1 and 2. After the groundwater extraction and treatment system is turned off, it is possible that the VOC concentrations would rebound as residual VOCs diffuse from the fine-grained media into the groundwater. Indefinite operation of groundwater extraction and treatment will provide protectiveness in the form of containment and treatment, but is not cost effective or sustainable. Likewise, diffusion rates of potassium permanganate into the fine-grained media are slow, and more than one injection of the oxidant may be necessary to meet the ARARs. The estimated time for Alternative 3 to reach the remediation goals is shorter than both Alternatives 1 and 2 (approximately 13 years for Alternative 3 and 30 years for Alternatives 1 and 2). However, it should be noted that there is considerable uncertainty regarding the time estimates to reach remediation goals for each alternative.

3.4.4 Reduction of Toxicity, Mobility, or Volume of Waste

Alternatives 1 and 2 use packed column air stripping to remove the contaminants of interest at an efficiency greater than 95%. Alternative 3 treats the contaminants of interest by irreversible chemical oxidation with potassium permanganate. Alternative 3 has the potential to treat the source area quicker than Alternatives 1 and 2.

3.4.5 Short-term Effectiveness

Risks to human health and the environment during construction and operation can be minimized through proper decontamination and use of secondary containment. Potential exposure pathways for workers include inhalation and dermal contact during installation of the new wells (extraction and/or injection) and during ISCO injection activities. The potential exposure pathways can be effectively managed through proper health and safety procedures and the use of personal protective equipment.

3.4.6 Implementability

Both groundwater extraction and treatment and ISCO have been implemented at the Site and other Project Areas within the TIAA Superfund Site as either a remedy or pilot test. Each of the alternatives is projected to be readily constructed and operated. Alternative 3 has the potential to be implemented quicker than Alternatives 1 and 2, as these alternatives would require design of the upgrades to the treatment system and conveyance piping. Alternative 3 would require minor design calculations, preparation of the ISCO injection system, and would utilize rented equipment for the injection of potassium permanganate.

3.4.7 Cost

Alternative 3 has a lower net present value and O&M cost than Alternatives 1 and 2 (Table 3-10). Furthermore, Alterative 3 has a project life of 13 years, while Alternatives 1 and 2 have a project life of 30 years. The cost estimates have been developed based on ARCADIS U.S., Inc. previous experience, RS Means, and vendor's quotes. The cost estimates have an accuracy range of +50 to -30 percent. The cost details of the alternatives are included in Appendix D.

Table 3-10 Cost Comparison

Description	Alternative 1 Groundwater Extraction, Treatment, and Discharge to POTW	Alternative 2 Groundwater Extraction, Treatment, and Injection	Alternative 3 In Situ Chemical Oxidation with MNA
Total Project Duration (Years)	30	30	13
Total Capital Cost	$288,300	$522,300	$422,500
Annual O&M Cost	$91,100	$85,100	$55,000
Net Present Value	$1,863,100	$1,993,400	$971,700

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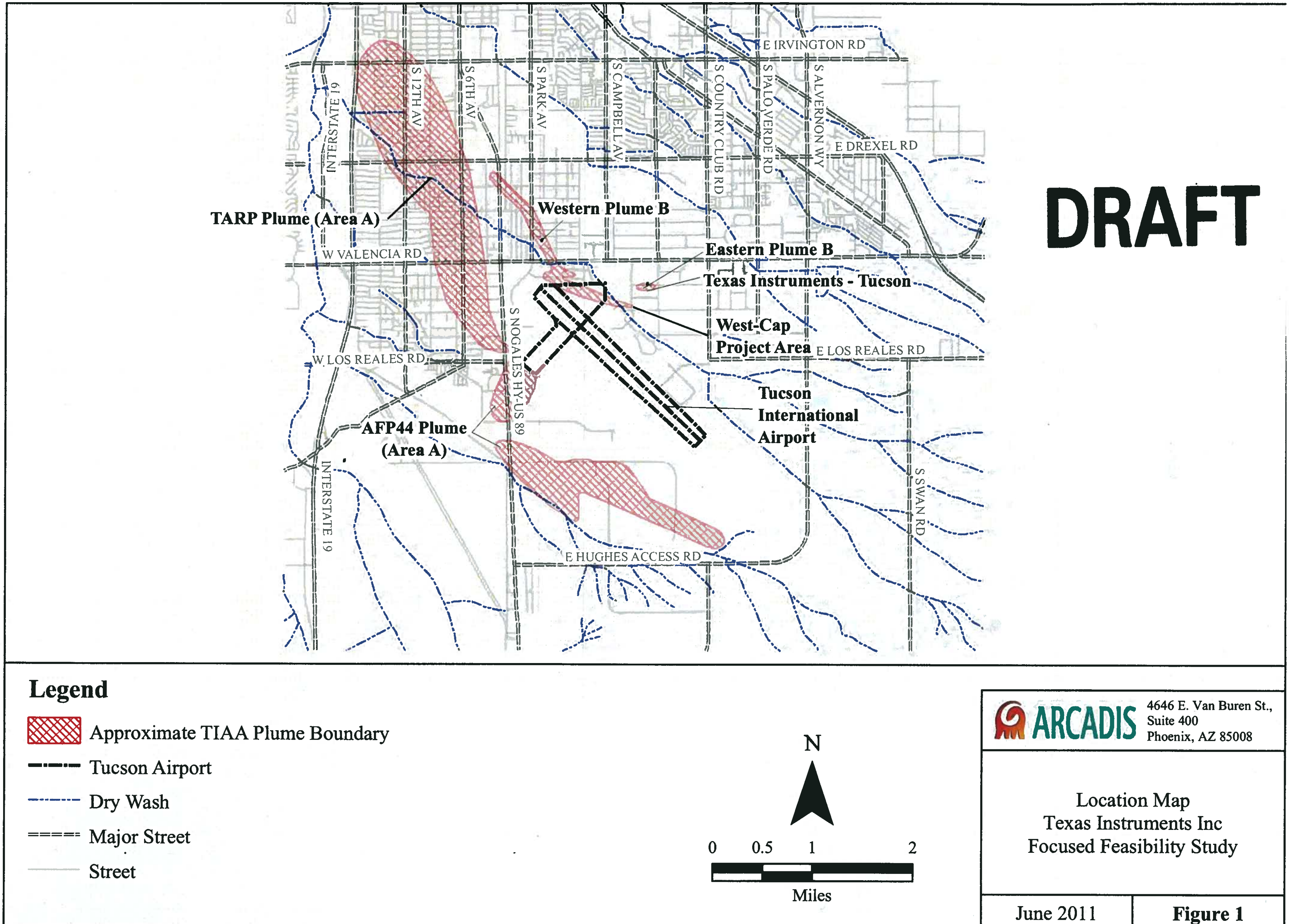
FIGURES



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Location Map
Texas Instruments Inc
Focused Feasibility Study

June 2011 | Figure 1

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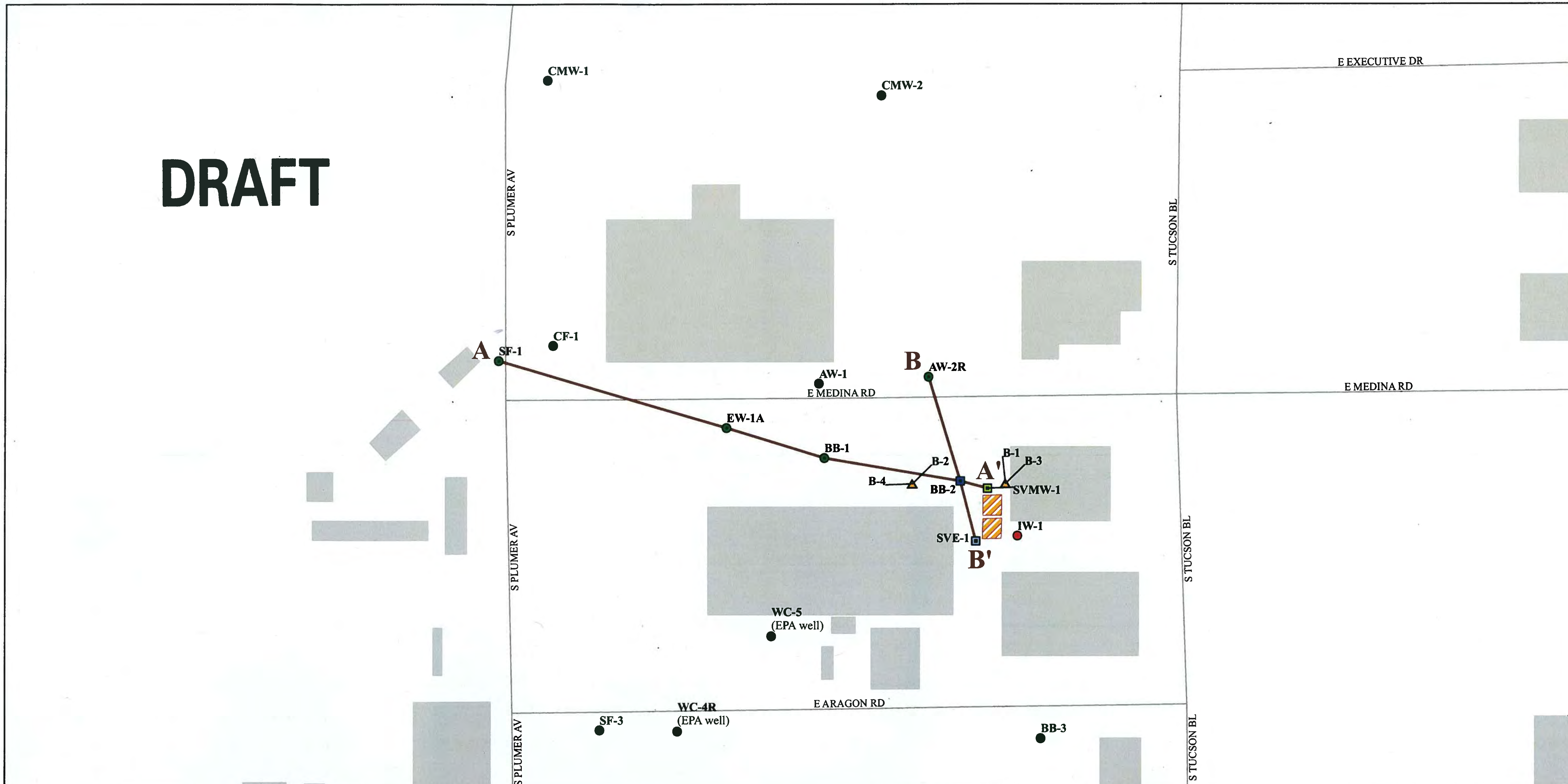

Legend

- ■ Extraction Well
- ● Monitor Well
- ● Injection Well
- ▲ Boring
- Multi-Completion Monitor Well (SVMW)
- Soil Vapor Extraction Well (SVE)
- Geologic Cross Sections
- Street
- Building
- Former Chemical Storage Facility

N

0 100 200 400

Feet

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Monitoring Well Network
Texas Instruments Inc
Focused Feasibility Study

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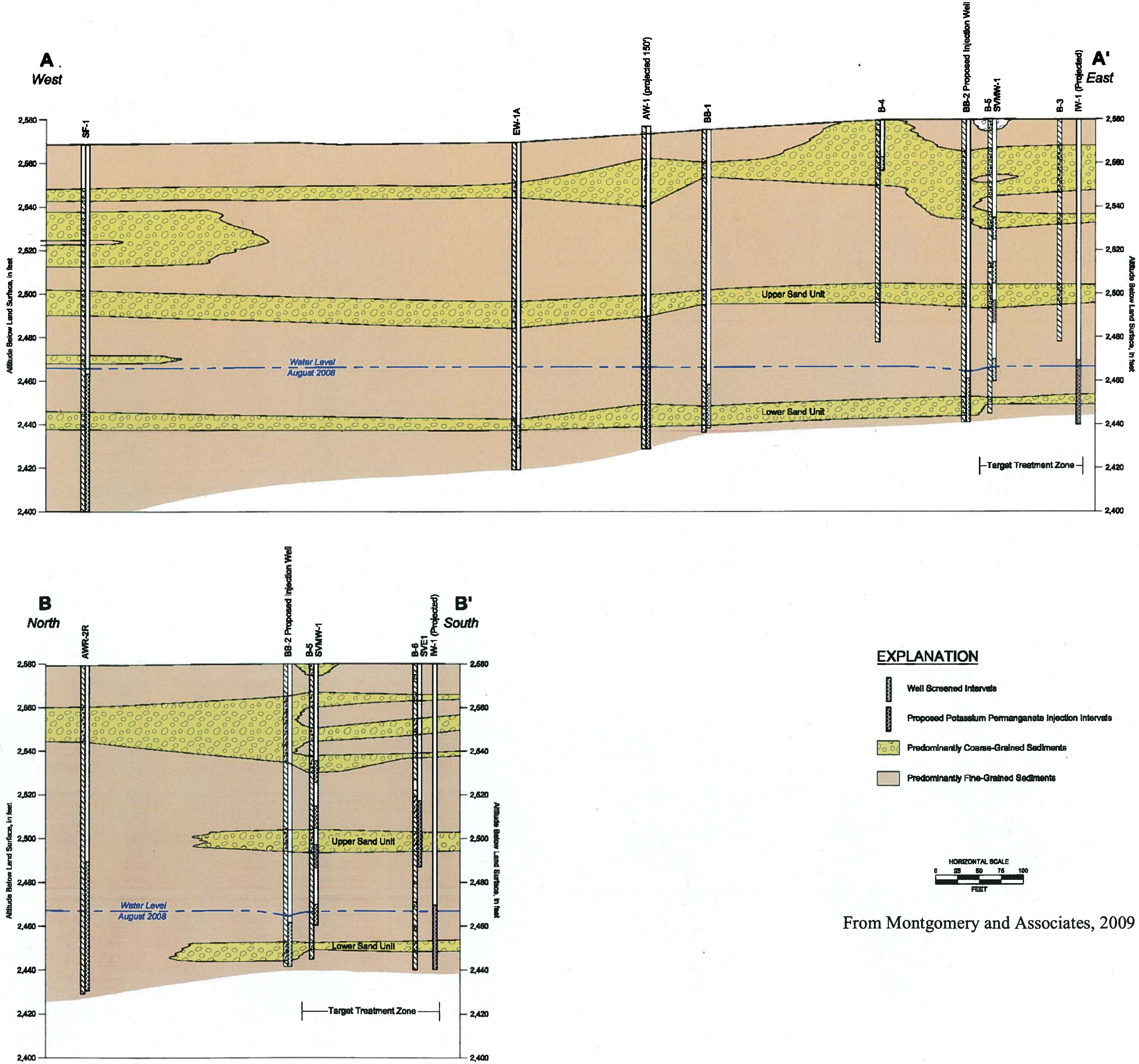

From Montgomery and Associates, 2009

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Geologic Cross Section
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Focused Feasibility Study

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Figure 3

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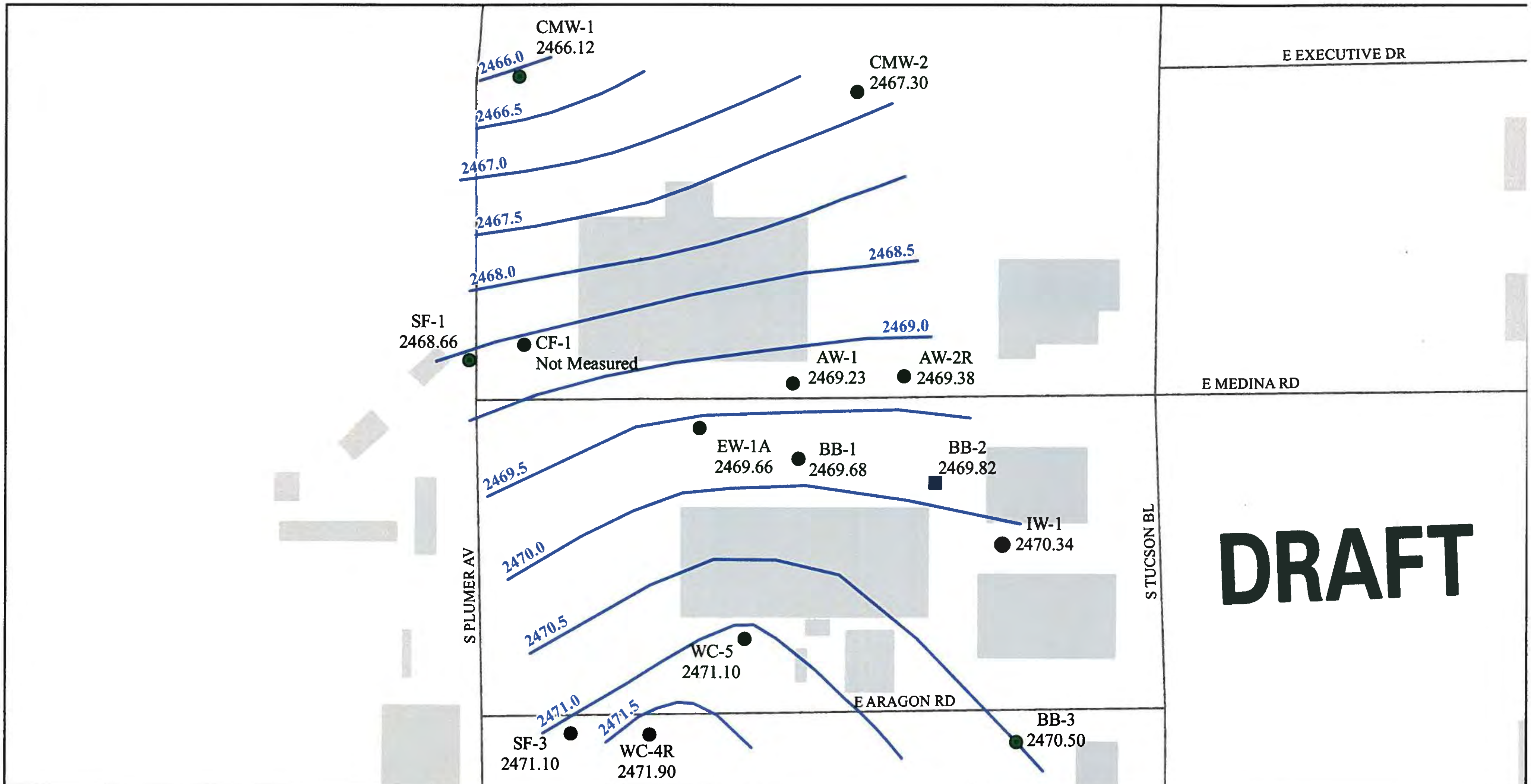

Legend

- Groundwater Elevation
- Monitor Well
- Injection Well for ISCO Pilot Study
- Extraction Well
- Street
- Buildings

2469.37 Groundwater Elevation (feet above mean sea level)

N

0 150 300 600

Feet

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Water Level Elevations (January 27, 2011)
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Focused Feasibility Study

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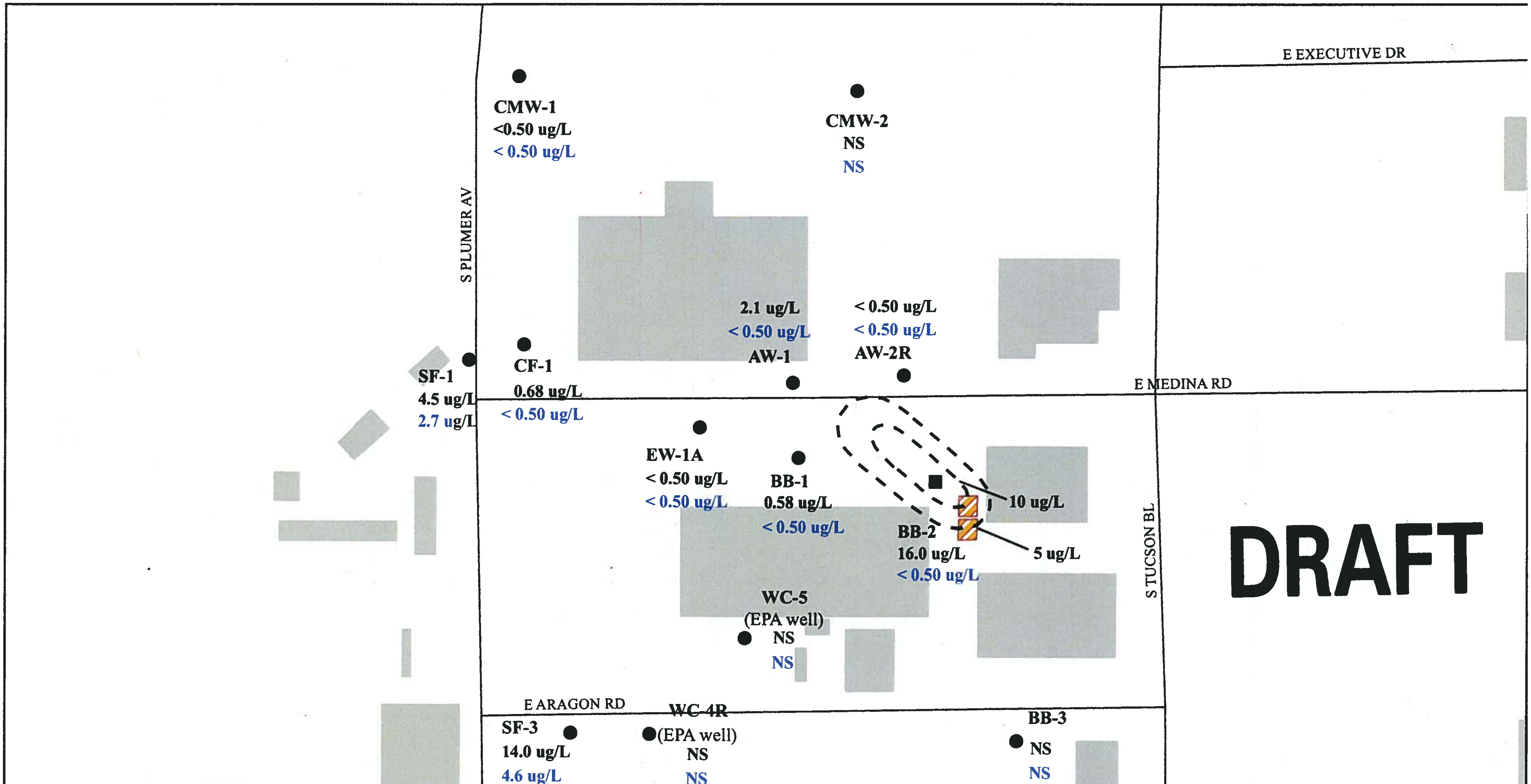

Legend

- - TCE Concentration Contours (ug/L)
—— Streets
Buildings
Extraction Well
Monitor Well
Former Chemical Storage Facility
NS Not sampled this quarter

SF-3	Well ID
14 ug/L	TCE Concentration
4.6 ug/L	PCE Concentration

N

0 150 300 600
Feet

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Detected TCE Concentrations
(July 2009)
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Focused Feasibility Study

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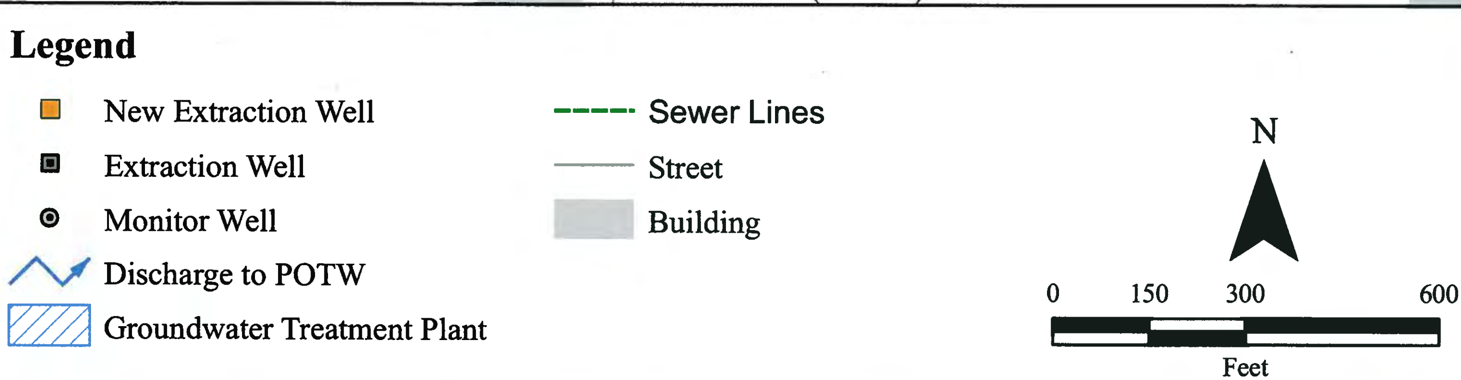

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Conceptual Design for Groundwater Extraction and Treatment with Discharge to POTW
Texas Instruments Inc
Focused Feasibility Study
Alternative 1

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Legend

- New Extraction Well
- New Injection Well
- Extraction Well
- Monitor Well
- Groundwater Treatment Plant
- Sewer Lines
- Street
- Building

N

0 150 300 600

Feet

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Conceptual Design for Groundwater Extraction and Treatment with Reinjection
Texas Instruments Inc
Focused Feasibility Study
Alternative 2

June 2011	**Figure 7**

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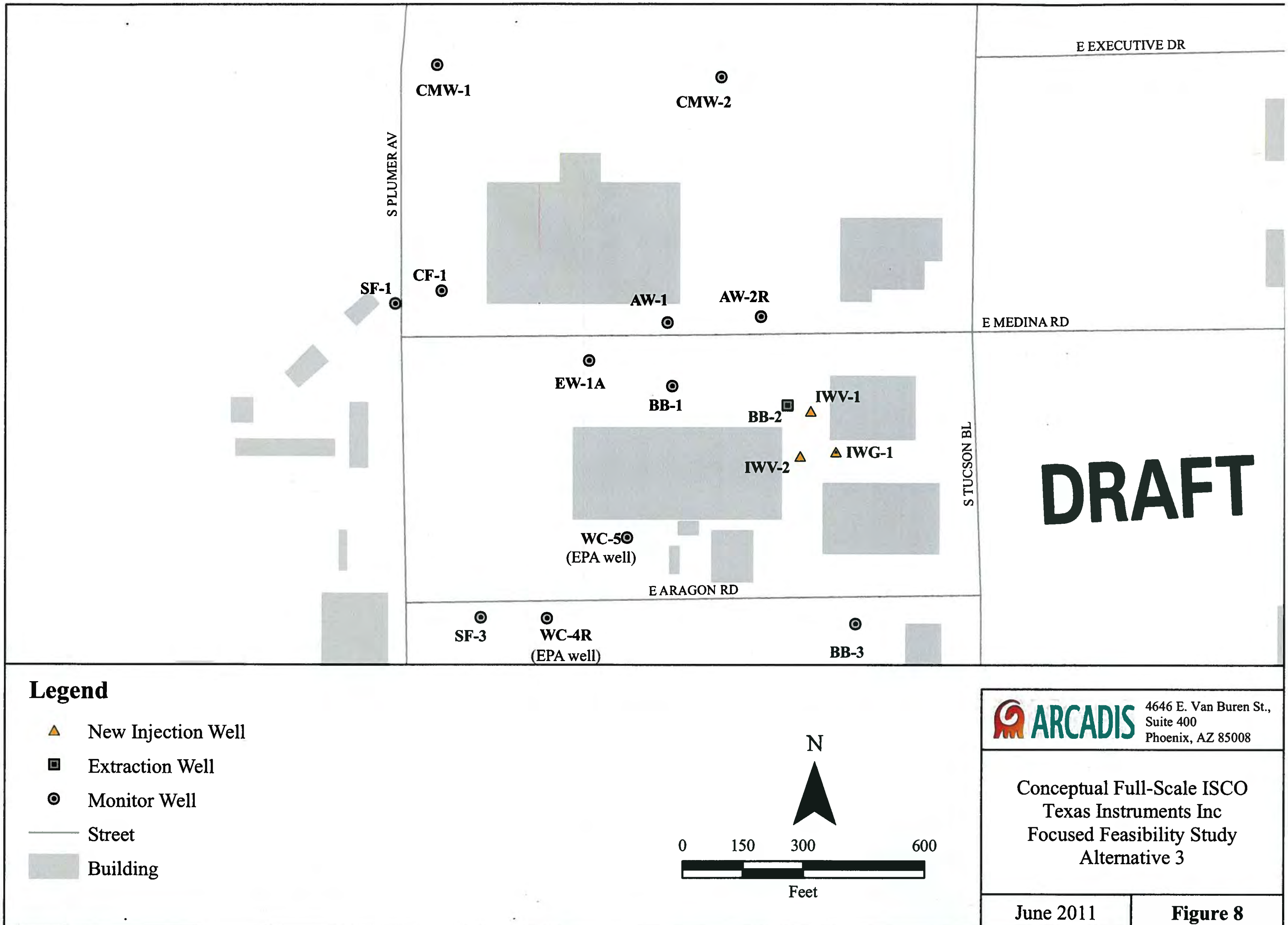

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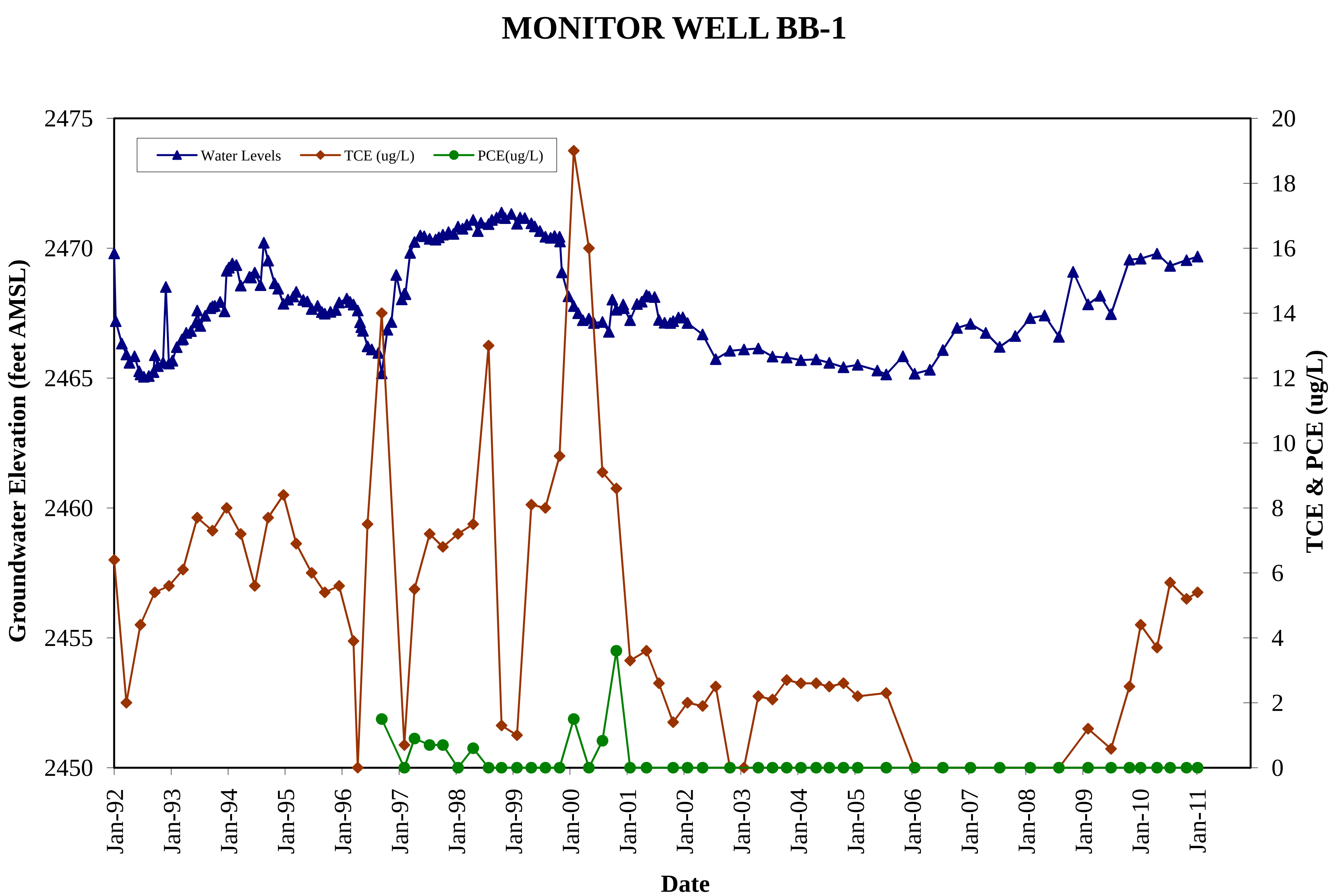
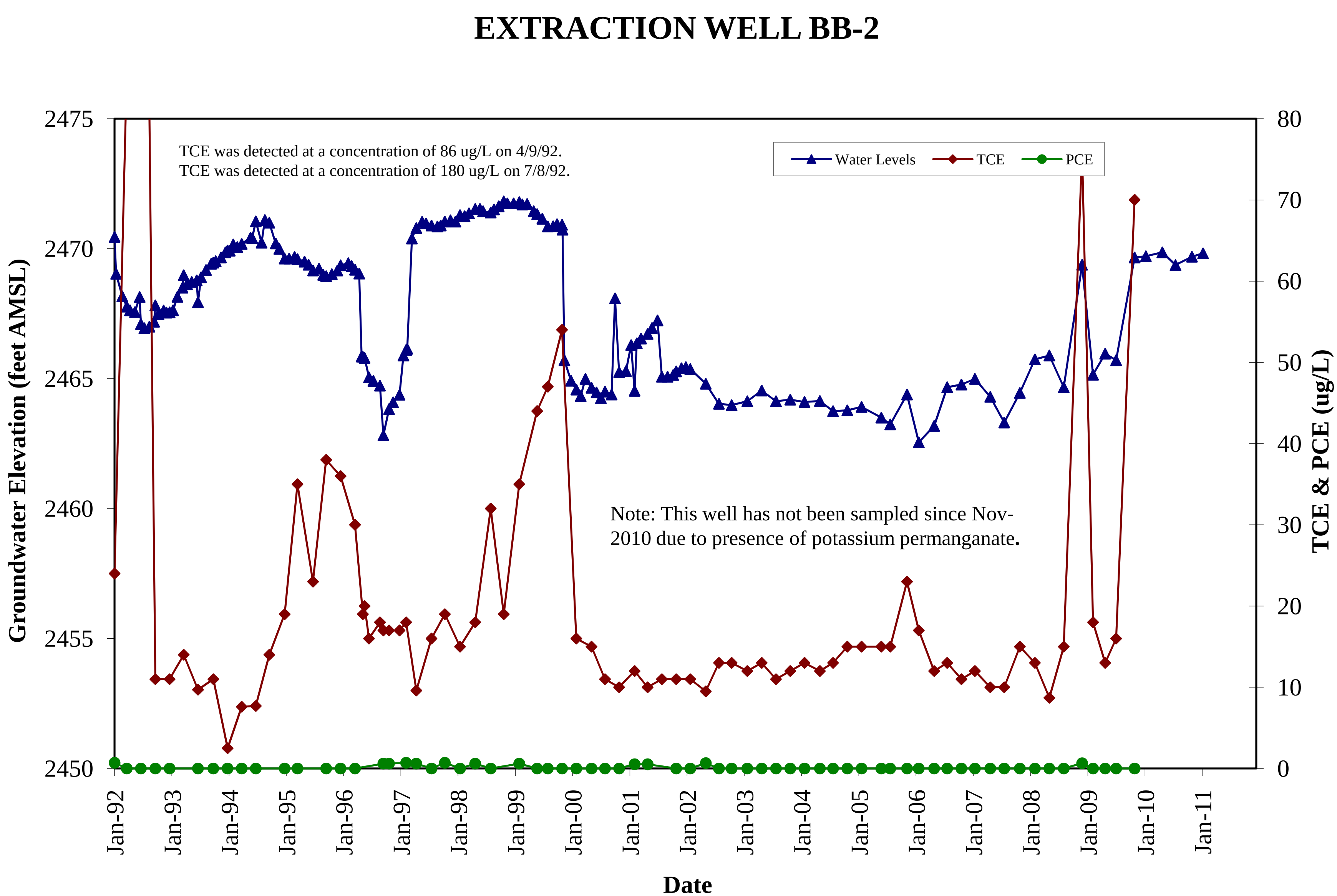
Appendix **A**

Historic Concentrations and Water Level Elevation Trends for Site Monitoring and Extraction Wells



ARCADIS	Historical Groundwater Elevation, TCE and PCE Concentrations in Monitor Well BB-1 Texas Instruments Incorporated	**DRAFT**	June 2011 **Figure A1**



ARCADIS

Historical Groundwater Elevation,
TCE and PCE Concentrations in Monitor Well BB-2
Texas Instruments Incorporated

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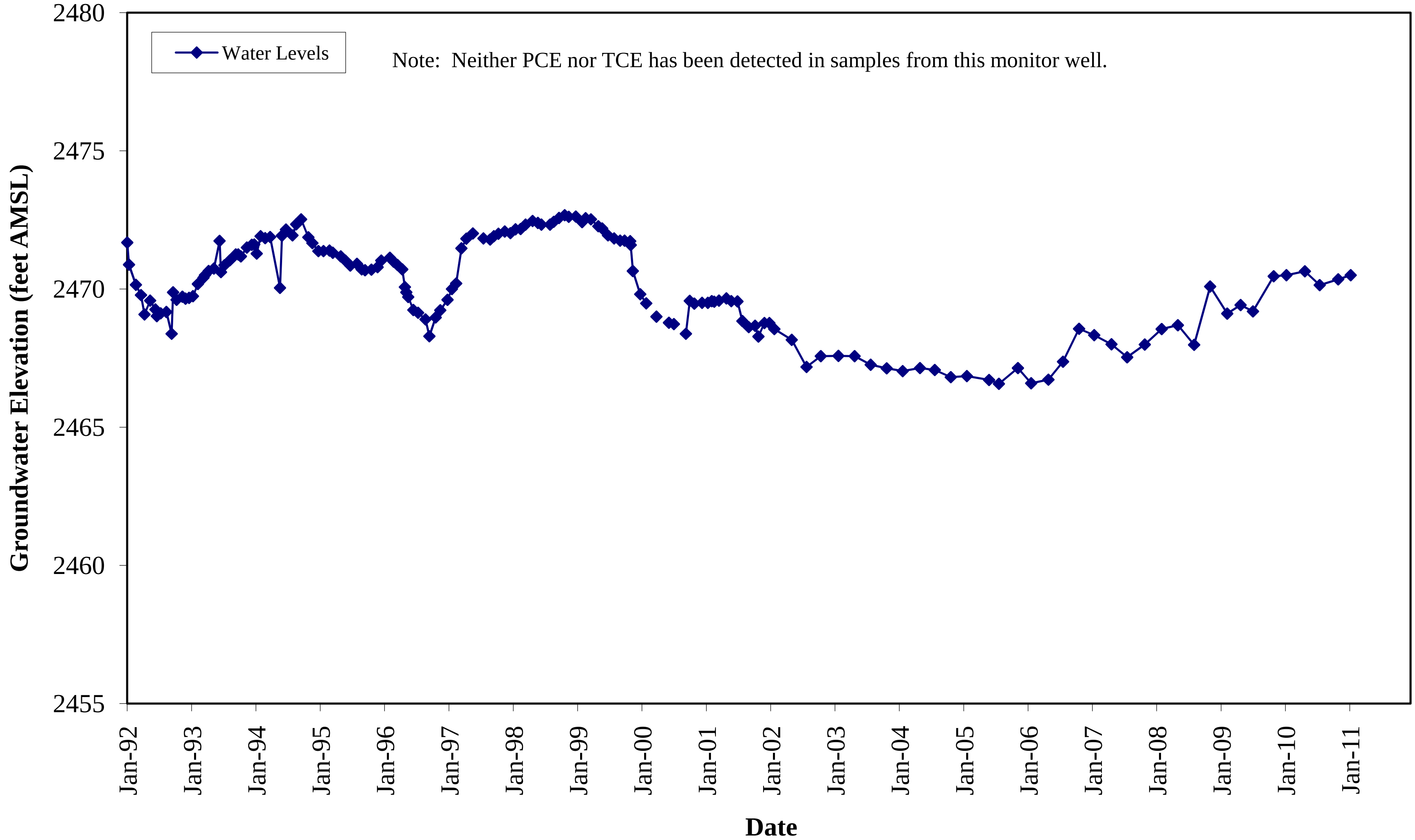
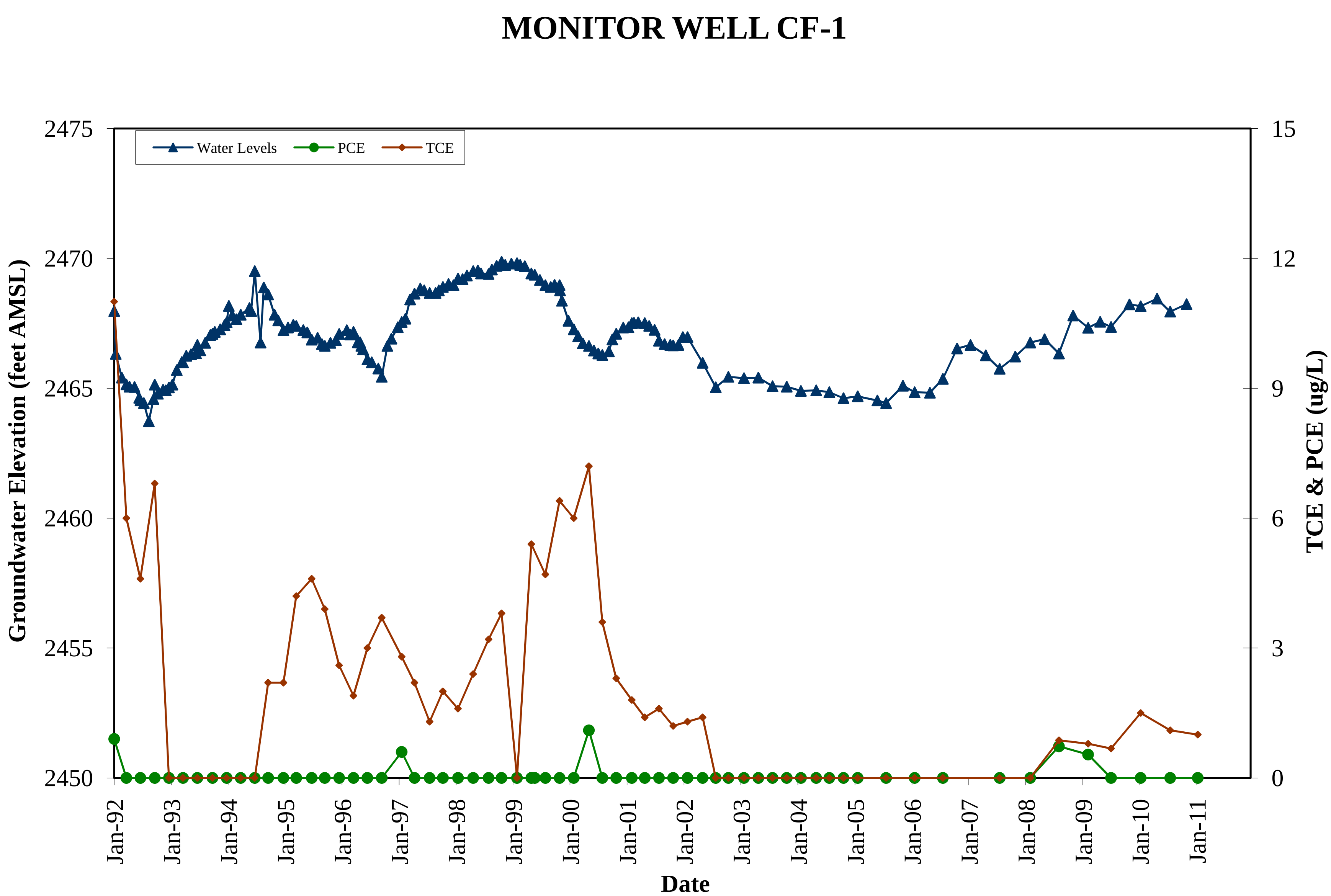
June 2011

Figure A2

MONITOR WELL BB-3

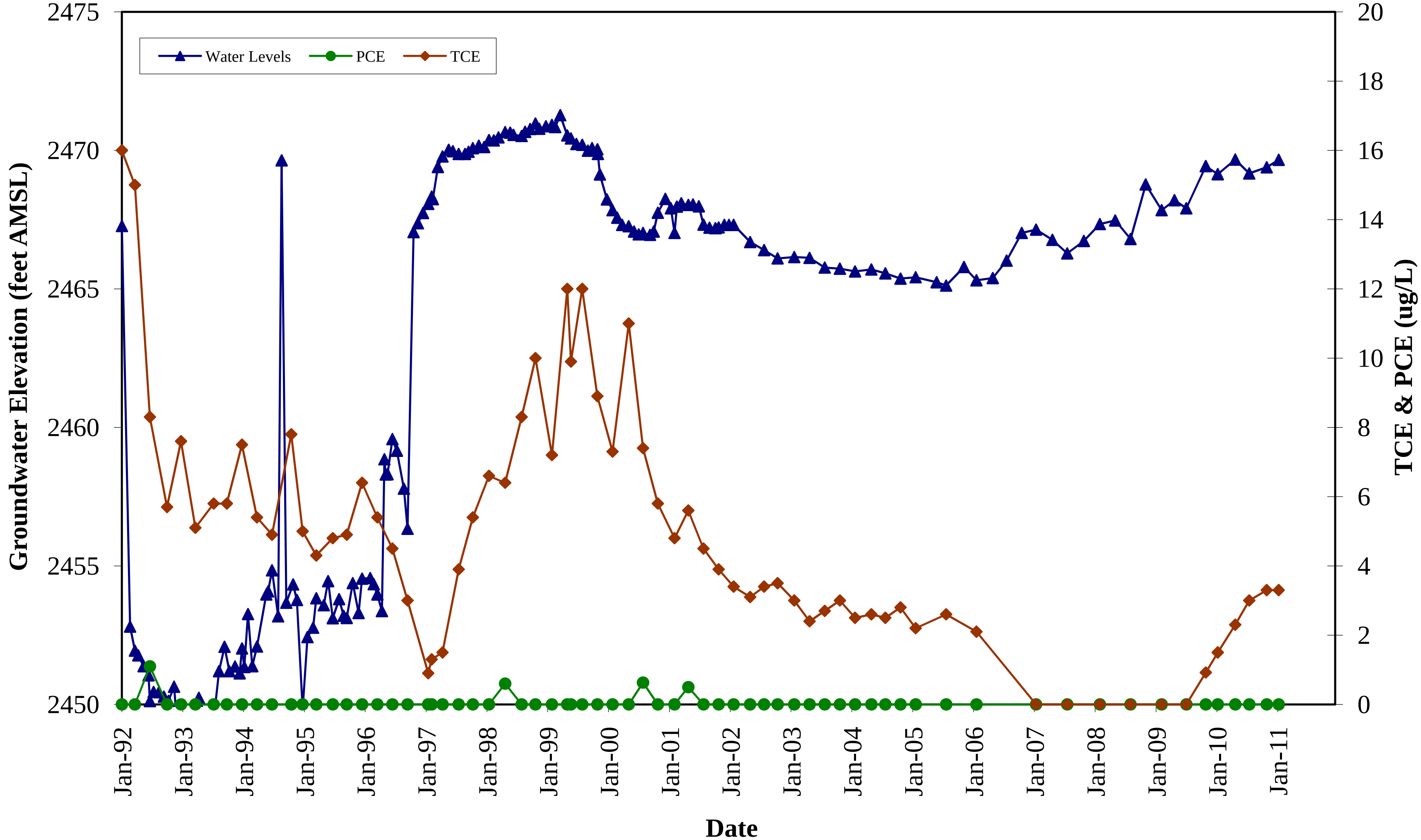


ARCADIS	Historical Groundwater Elevation, TCE and PCE Concentrations in Monitor Well BB-3 Texas Instruments Incorporated	DRAFT	June 2011 **Figure A3**

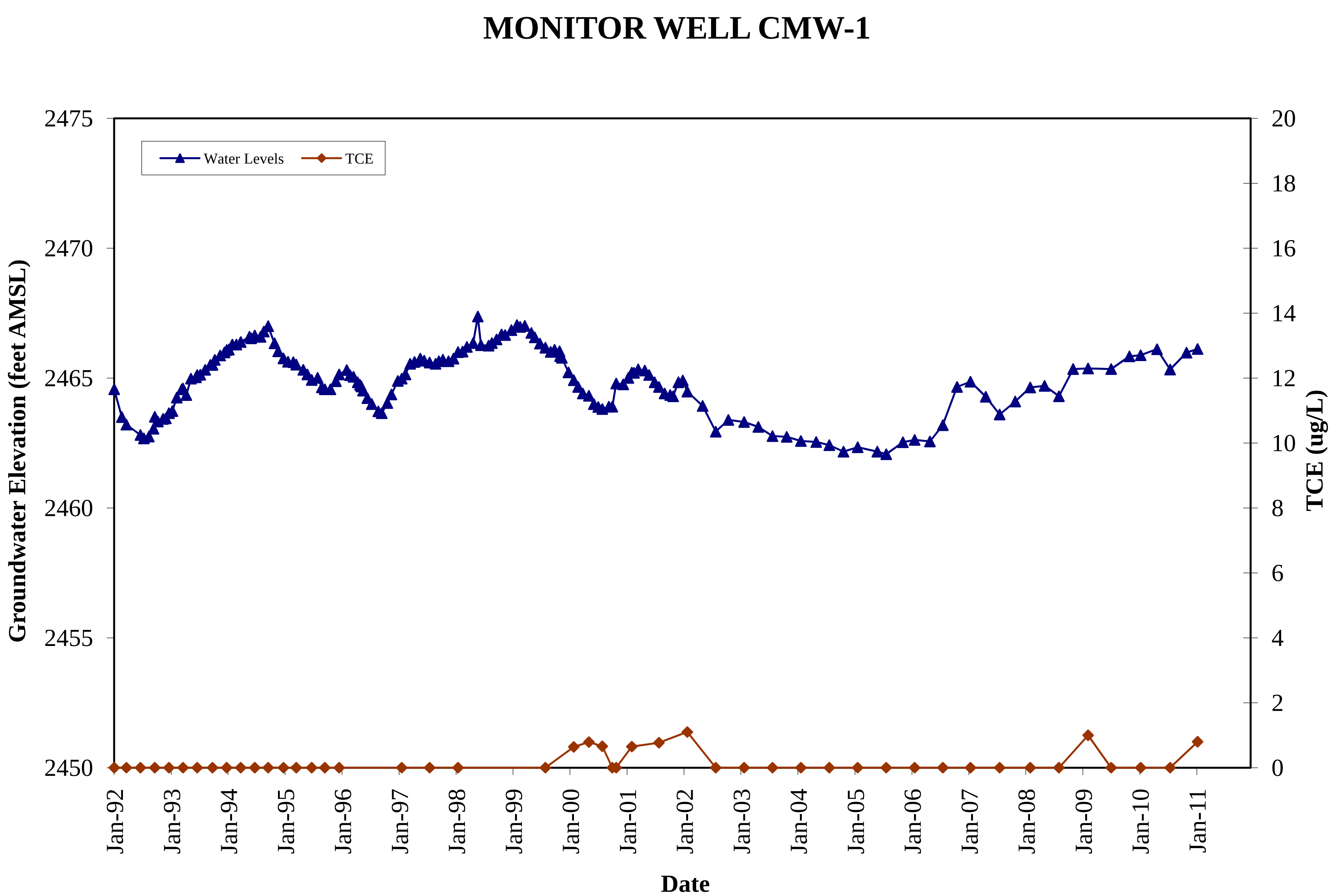


ARCADIS	Historical Groundwater Elevation, TCE and PCE Concentrations in Monitor Well CF-1 Texas Instruments Incorporated	**DRAFT**	June 2011 **Figure A4**

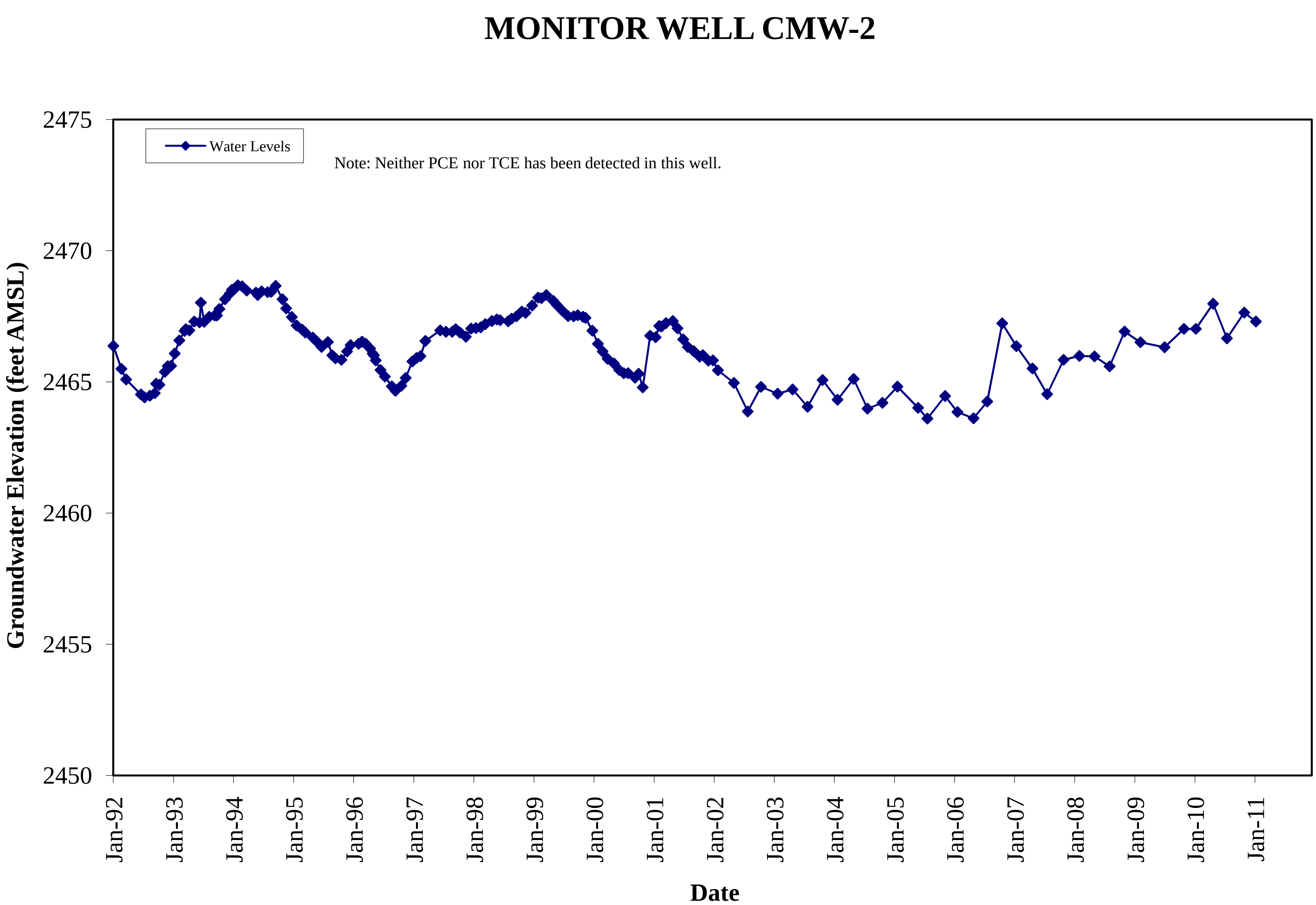
EXTRACTION WELL EW-1A



ARCADIS	Historical Groundwater Elevation, TCE and PCE Concentrations in Monitor Well EW-1A Texas Instruments Incorporated	**DRAFT**	June 2011 **Figure A5**

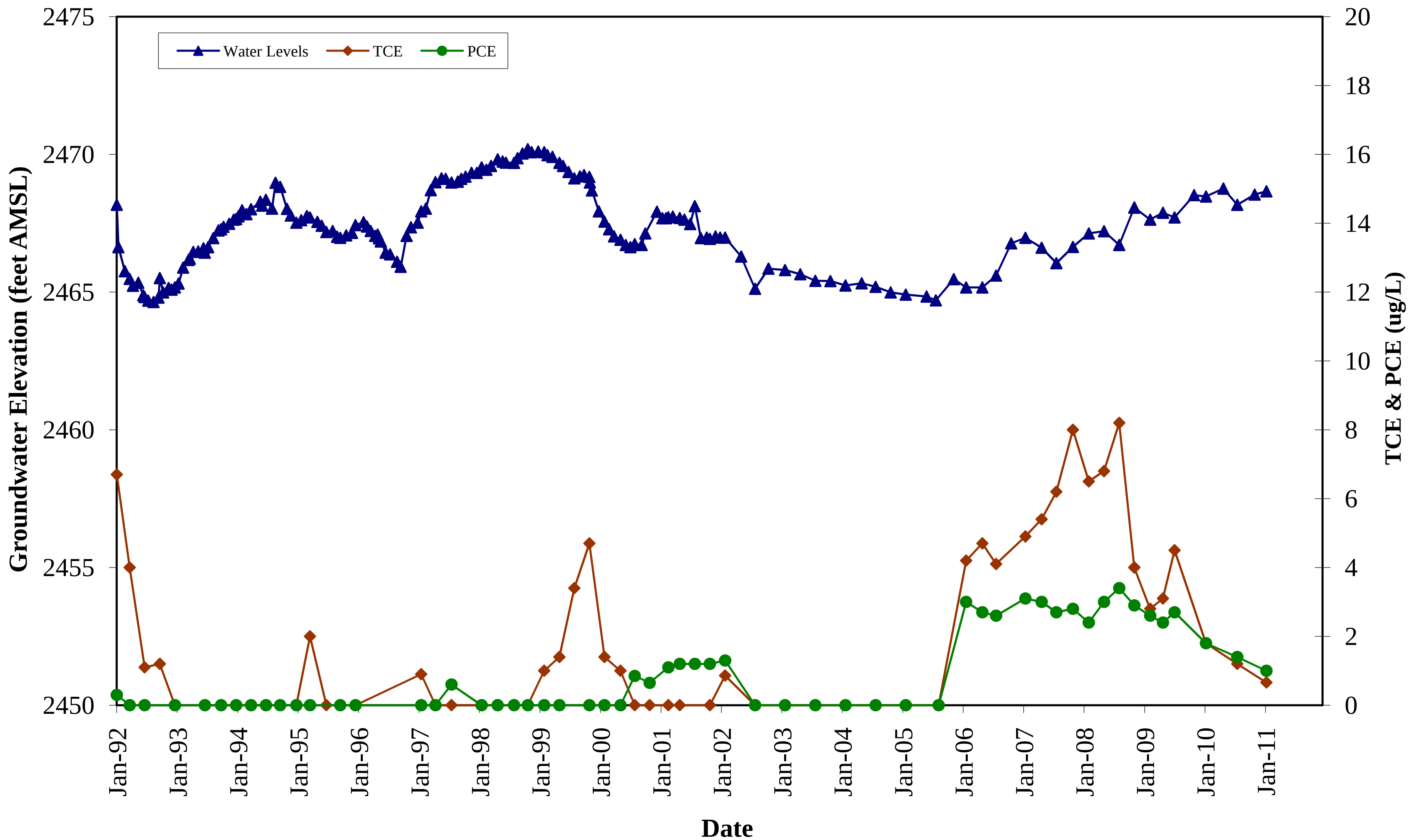


ARCADIS	Historical Groundwater Elevation, TCE Concentrations in Monitor Well CMW-1 Texas Instruments Incorporated	**DRAFT**	June 2011 **Figure A6**



ARCADIS	Historical Groundwater Elevation, TCE and PCE Concentrations in Monitor Well CMW-2 Texas Instruments Incorporated	**DRAFT**	June 2011 **Figure A7**

MONITOR WELL SF-1



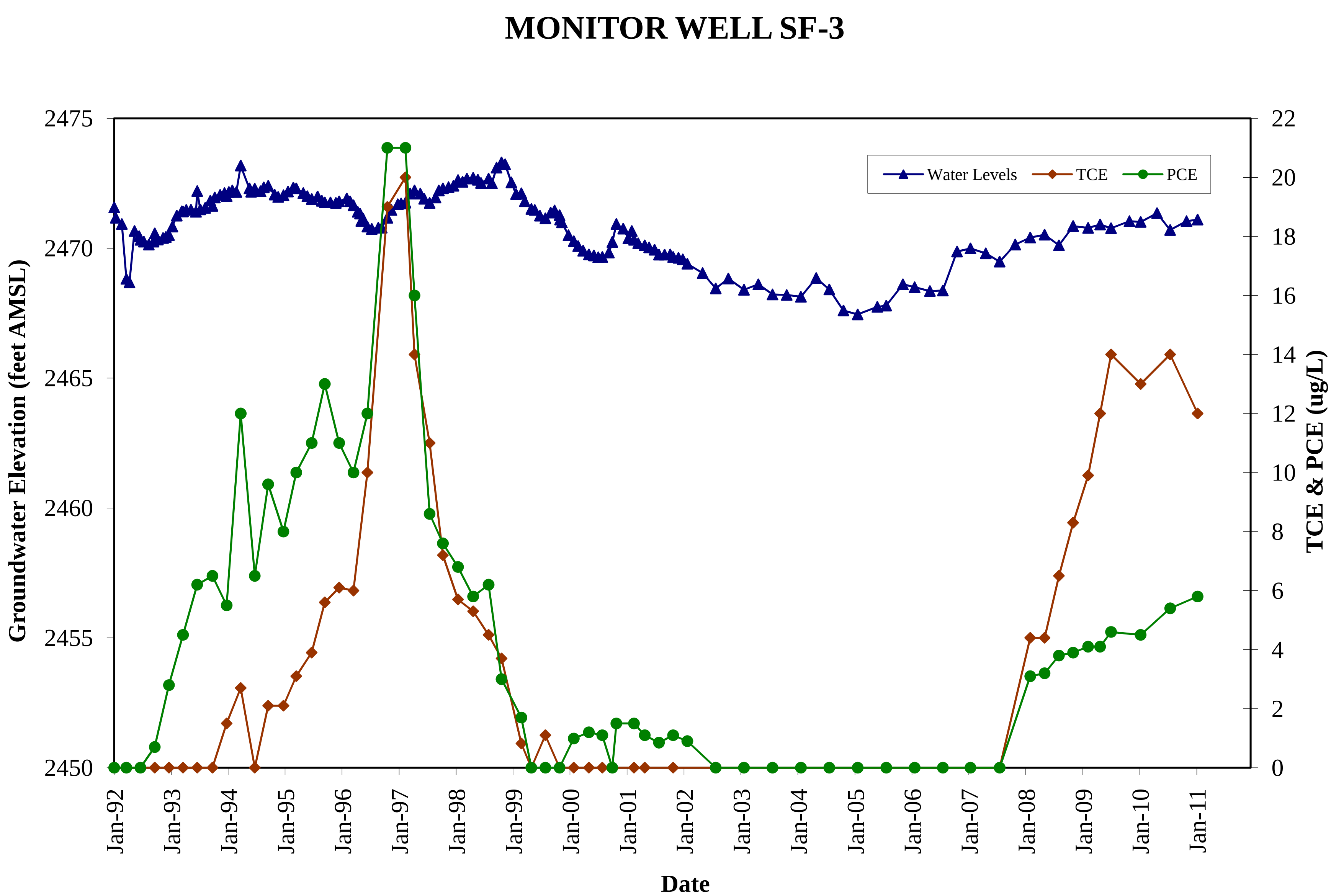
ARCADIS

Historical Groundwater Elevation,
TCE and PCE Concentrations in Monitor Well SF-1
Texas Instruments Incorporated

DRAFT

June 2011

Figure A8



ARCADIS

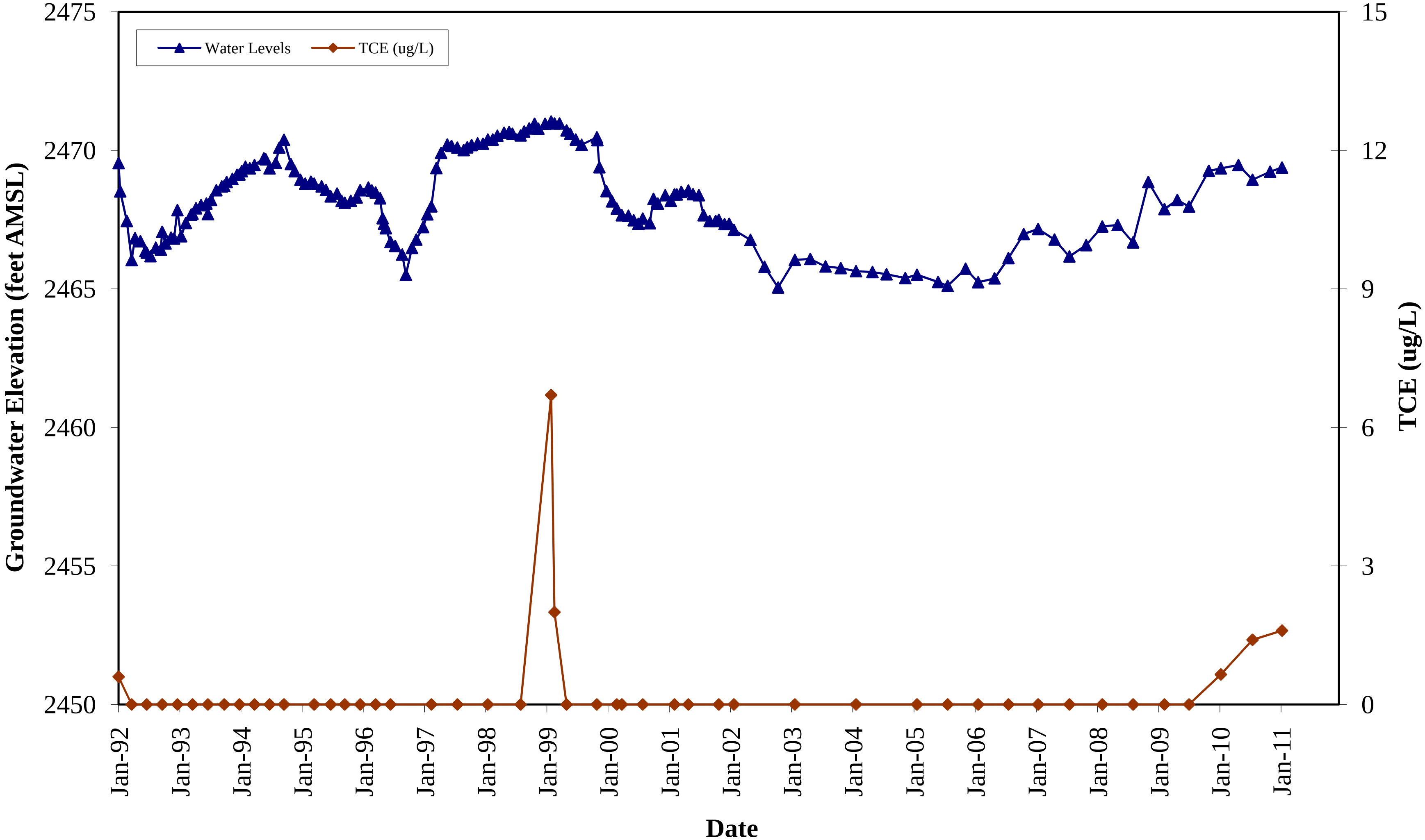
Historical Groundwater Elevation,
TCE and PCE Concentrations in Monitor Well SF-3
Texas Instruments Incorporated

DRAFT

June 2011

Figure A9

MONITOR WELL AW-2R



ARCADIS

Historical Groundwater Elevation,
TCE and PCE Concentrations in Monitor Well AW-2R
Texas Instruments Incorporated

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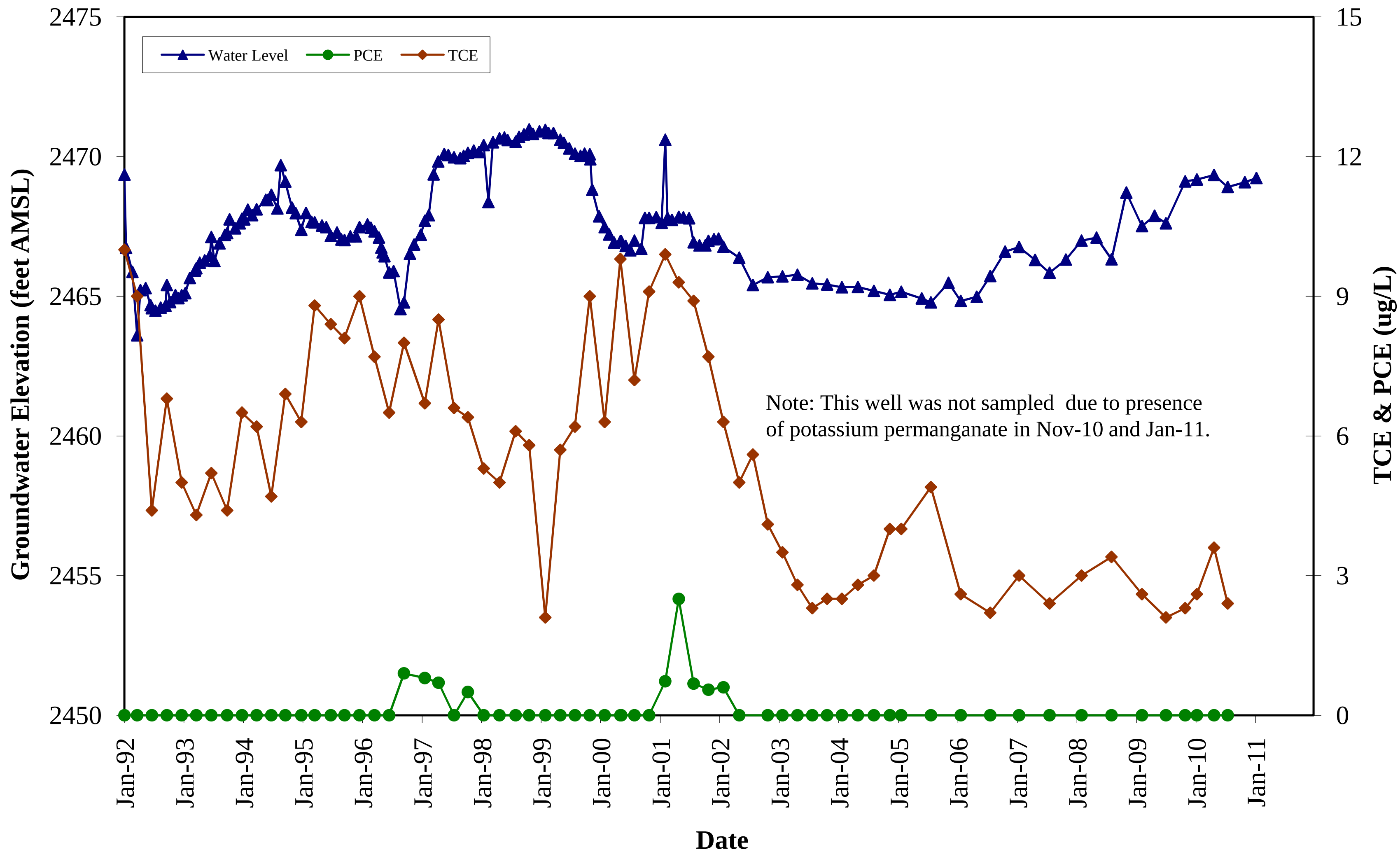
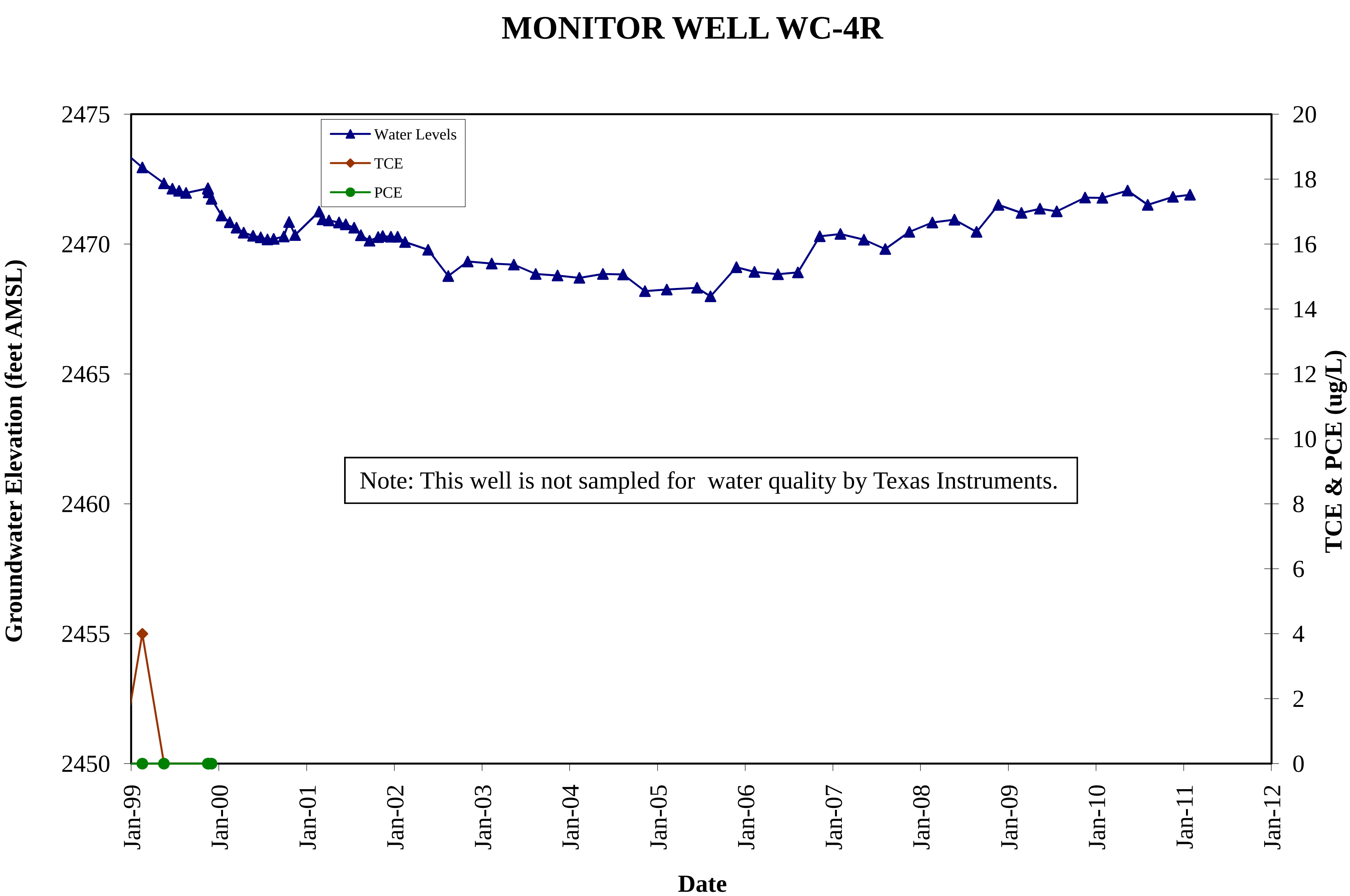
Figure A10

MONITOR WELL AW-1

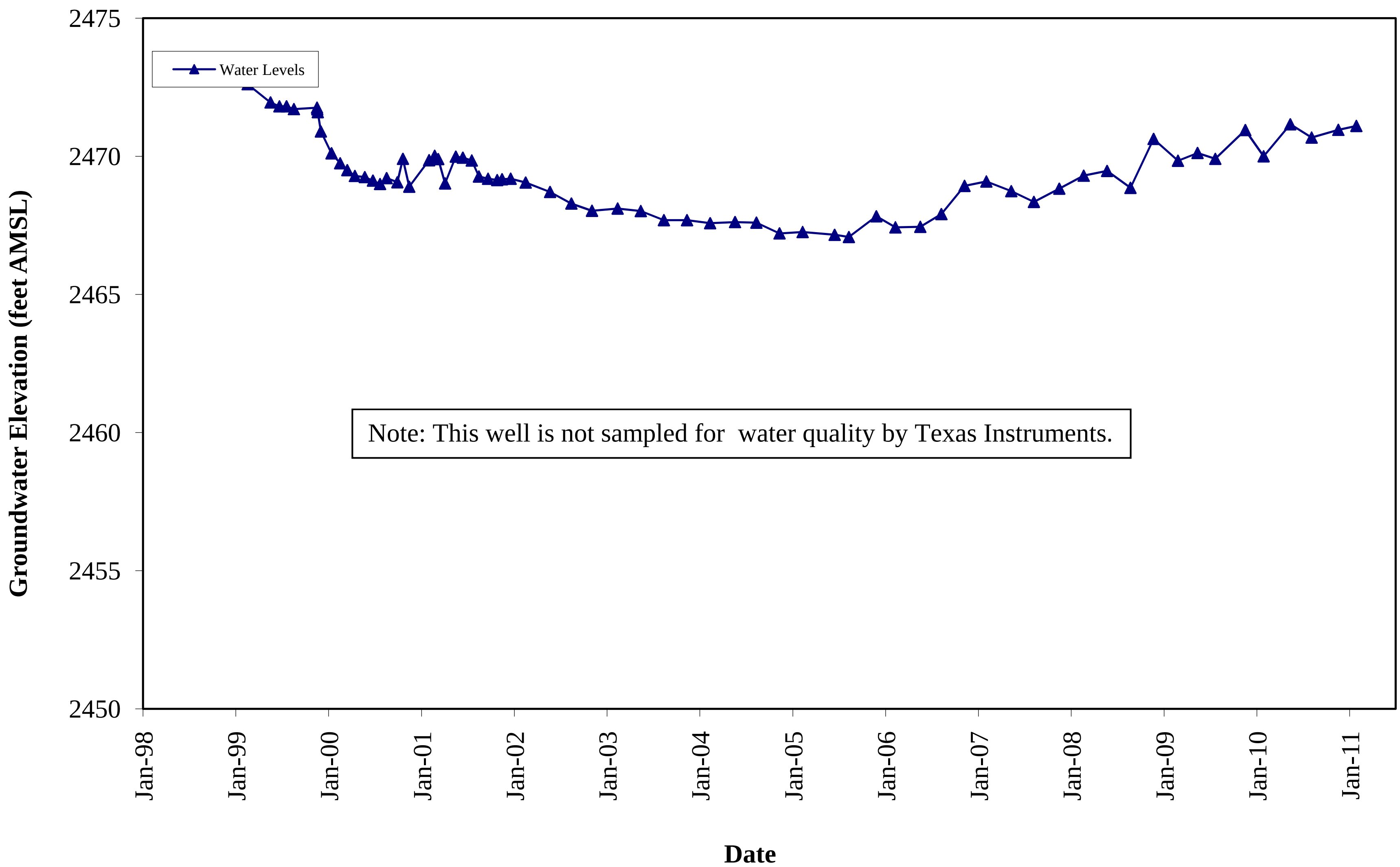


ARCADIS	Historical Groundwater Elevation, TCE and PCE Concentrations in Monitor Well AW-1 Texas Instruments Incorporated	**DRAFT**	June 2011 **Figure A11**



ARCADIS	Historical Groundwater Elevation, TCE Concentrations in Monitor Well WC-4R Texas Instruments Incorporated	DRAFT	June 2011 **Figure A12**

MONITOR WELL WC-5



ARCADIS

Historical Groundwater Elevation,
in Monitor Well WC-5
Texas Instruments Incorporated

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Figure A13

Appendix **B**

Risk Summary Tables

TABLE B-1

Soil Gas Detection Summary

Sample ID	Sample Interval (ft bgs)	Date Collected	Compound	Result	Reporting Limit (ppbv)	Result (μg/m³)	Reporting Limit (μg/m³)
SVMW1-45-55	45-55	7/16/2008	1,1-Dichloroethene	4.3	2.5	17	10
			1,2,4-Trimethylbenzene	5	2.5	25	12
			Benzene	3	2.5	9.8	8.1
			Carbon disulfide	4.2	2.5	13	7.9
			Chloroform	15	2.5	74	12
			Ethylbenzene	3.2	2.5	14	11
			m&p-Xylene	11	5	48	22
			o-Xylene	3.5	2.5	15	11
			Toluene	16	2.5	61	9.6
			Trichloethene	99	2.5	550	14
			Trichlorotrifluoroethane	96	2.5	750	19
SVMW1-65-75	65-75	7/16/2008	1,1-Dichloroethene	61	10	250	40
			Carbon disulfide	24	10	76	32
			Toluene	17	10	65	38
			Trichloethene	580	10	3,200	55
			Trichlorotrifluoroethane	1,100	25	8,500	190
SVMW1-DUP	83-93	7/16/2008	1,1-Dichloroethene	110	10	440	40
			Carbon disulfide	13	10	41	32
			Tetracloroethene	10	10	69	69
			Trichloroethene	1,200	50	6,600	280
			Trichlorotrifluoroethane	1,200	50	9,300	390
SVMW1-83-93	83-93	7/16/2008	1,1-Dichloroethene	68	50	270	200
			Trichloroethene	1,200	50	6,600	280
			Trichlorotrifluoroethane	1,200	50	9,300	390

Notes:
ft bgs = feet below ground surface
ppbv = parts per billion by vapor
ug/m³ = micro gram per cubic meter

TABLE B-2

Groundwater Risk Evaluation

Analyte	Tapwater Regional Screening Levels (μg/L)		Maximum Groundwater Concentration (μg/L)	Cancer Risk	Noncancer Hazard
	Cancer	Noncancer			
Trichloethylene (TCE)	2.00E+00	NA	7.60E+01	3.80E-05	NA
Tetrachloroethylene (PCE)	1.10E-01	2.20E+02	5.80E+00	5.27E-05	2.64E-02
PCE (excluding SF-3 and SF-1)	1.10E-01	2.20E+02	8.70E-01	7.91E-06	3.95E-03
Total Risk/Total Hazard Index				**9.07E-05**	**2.64E-02**
Alternative Total Risk/Total Hazard Index (excluding wells SF-3 and SF-1)				**4.59E-05**	**3.95E-03**

Notes:

The maximum concentration of TCE was from the extraction well BB-2 in December 2008.

The maximum concentration of PCE was from monitor well SF-3 in January 2011.

The alternative maximum concentration of PCE was from monitor well CF-1 in August 2008.

EPA - U.S. Environmental Protection Agency

NA - RSL not available

RSL - Regional Screening Level (EPA, 2010)

μg/L - micrograms per liter

Table B-3

Soil Gas Risk Evaluation Using RSLs

Analyte	**Industrial Regional Screening Levels (µg/m³)**		**Soil Gas Concentration (µg//m³)**	**Industrial Cancer Risk**	**Industrial Noncancer Hazard**
	Cancer	**Noncancer**			
1,1-Dichloroethene	NA	8.76E+04	1.70E+01	NA	1.94E-04
1,2,4-Trimethylbenzene	NA	3.10E+03	2.50E+01	NA	8.06E-03
Benzene	1.60E+02	1.30E+04	9.80E+00	6.13E-08	7.54E-04
Carbon disulfide	NA	3.10E+05	1.30E+01	NA	4.19E-05
Chloroform	5.30E+01	4.30E+04	7.40E+01	1.40E-06	1.72E-03
Ethylbenzene	4.90E+02	4.40E+05	1.40E+01	2.86E-08	3.18E-05
m&p-Xylene	NA	3.10E+05	4.80E+01	NA	1.55E-04
o-Xylene	NA	3.10E+05	1.50E+01	NA	4.84E-05
Toluene	NA	2.20E+06	6.10E+01	NA	2.77E-05
Trichloethene	6.10E+02	NA	5.50E+02	9.02E-07	NA
Trichlorotrifluoroethane	NA	3.10E+05	7.50E+02	NA	2.42E-03
Total Risk/Total Hazard Index				**2.39E-06**	**1.35E-02**

Notes:

All data is from boring SVMW1 (B-5) at the shallowest sample interval (45-55 ft bgs) collected on 7/16/2008.

Screening levels are calculated by multipling EPA indoor air RSLs by 100 to adjust for attenuation from deep soil gas to indoor air.

EPA - U.S. Environmental Protection Agency

ft bgs - feet below ground surface

NA - Screening level not available

RSL - Regional Screening Levels (EPA, 2010)

µg/m³ - micrograms per cubic meter

Table B-4

Alternative Soil Gas Risk Evaluation Using CHHSL and ESLs

Analyte	Commercial/Industrial Shallow Soil Gas (μg/m³)		Soil Gas Concentration (μg/m³)	Ratio > 1
	CHHSLs	ESLs		
1,1-Dichloroethene	NA	1.20E+05	1.70E+01	No
1,2,4-Trimethylbenzene	NA	NA	2.50E+01	NA
Benzene	1.22E+02	2.80E+02	9.80E+00	No
Carbon disulfide	NA	NA	1.30E+01	NA
Chloroform	NA	1.50E+03	7.40E+01	No
Ethylbenzene	NA	3.30E+03	1.40E+01	No
m&p-Xylene	8.87E+05	5.80E+04	4.80E+01	No
o-Xylene	8.79E+05	5.80E+04	1.50E+01	No
Toluene	3.78E+05	1.80E+05	6.10E+01	No
Trichloethene	1.77E+03	4.10E+03	5.50E+02	No
Trichlorotrifluoroethane	NA	NA	7.50E+02	NA

Notes:

All data is from boring SVMW1 (B-5) at the shallowest sample interval (45-55 ft bgs) collected on 7/16/2008.

CHHSLs: California Human Health Screening Levels in Evaluation of Contaminated Properties (Cal/EPA 2005).

ESLs: Screening for Environmental Concerns at Sites With Contaminated Soil and Groundwater (RWQCB 2007).

Cal/EPA - California Environmental Protection Agency

CHHSL - California Human Health Screening Level

ESL - Environmental Screening Levels

ft bgs - feet below ground surface

NA - Screening level not available

RWQCB - California Regional Water Quality Control Board

$\mu g/m^3$ - micrograms per cubic meter

Appendix **C**

ARAR Evaluation

APPENDIX C – ARAR ANALYSIS

1.1 Introduction

Federal and state statutes were considered as potential applicable or relevant and appropriate requirements (ARARs) for the former Texas Instruments-Tucson manufacturing facility (Site), which is part of the Tucson International Airport Area Superfund Site (TIAA), in Tucson, Arizona. The ARARs for the volatile organic compound (VOC)-contaminated groundwater remediation alternatives are presented in Tables C-1 (chemical-specific ARARs for groundwater), Table C-2 (location-specific ARARs for groundwater), and C-3 (action-specific ARARs for groundwater).

TABLE C-1 Chemical-Specific ARARs for VOC-Contaminated Groundwater

Standard, Requirement, Criteria, or Limitation	Applicable or Relevant and Appropriate	Description of Standard, Requirement, Criteria, or Limitation	Manner in Which ARAR Applies to Alternative
Safe Drinking Water Act (42 U.S.C. Sec 300g-1) 40 CFR Part 141 Subpart B, Maximum Contaminant Levels; Subpart G, National Primary Drinking Water Regulations: MCLs	Applicable	Establishes Maximum Contaminant Levels (MCLs). MCLs are standards that EPA has determined to be safe for drinking water and are applicable for groundwater that is or has the potential to be used as a drinking water source.	The remediation levels established in the 1988 ROD are consistent with the MCLs. The selected alternative will comply with these standards.
Clean Water Act (33 U.S.C. Secs 1311-1387)	Relevant and Appropriate	Regulates discharges of pollutants into waters of the United States and establishes water quality discharge standards for surface waters.	These standards would be applicable if the selected alternative includes discharge to the POTW, as the POTW discharges to a water of the United States.
Aquifer Water Quality Standards Arizona Administrative Code R18-11-405 and 406	Applicable	Establishes narrative and numeric aquifer water quality standards.	These standards would be applicable to extraction and treatment alternatives, but not the in situ alternative.

TABLE C-2 Location-Specific ARARs for VOC-Contaminated Groundwater

Standard, Requirement, Criteria, or Limitation	Applicable or Relevant and Appropriate	Description of Standard, Requirement, Criteria, or Limitation	Manner in Which ARAR Applies to Alternative
Endangered Species Act (6 U.S.C. Sec 1531) 50 CFR 200 and 402	Applicable	Determines procedures for evaluating the presence of endangered and threatened species and their habitats, and for mitigating adverse impacts.	No endangered species have been found at the site. If plants or species are identified as endangered or threatened, construction or other activities will be mitigated to avoid adverse impacts for the species or habitat.
Archaeological Discoveries, Arizona Revised Statutes, Title 41, Chapter 4.1, Article 4	Applicable	Preserves archaeological artifacts.	If archaeological artifacts are found during excavation, construction or other activities, the activity must temporarily stop to allow for investigation and preservation of artifacts.
Historic Preservation Arizona Revised Statutes, Title 41, Chapter 4.2 (865)	Applicable	Preserves remains.	If human remains or funerary objects are found during excavation, construction or other activities, the activity must temporarily stop to allow for investigation and preservation of remains or objects.

TABLE C-3 Action-Specific ARARs for VOC-Contaminated Groundwater

Standard, Requirement, Criteria, or Limitation	Applicable or Relevant and Appropriate	Description of Standard, Requirement, Criteria, or Limitation	Manner in Which ARAR Applies to Alternative
Arizona Remedial Action Requirements ARS § 49-282.06 (A)(2)	Applicable	Remedial actions must allow for the maximum beneficial use of the waters of the state.	Drinking water use is the maximum beneficial use of the regional aquifer.
Arizona Groundwater Management Act, ARS Title 45 ARS 45-454.01, 45-494, 45-496, 45-600	Applicable	Regulation exempts new well construction and withdrawal, treatment, and reinjection of groundwater into the aquifer that occur as a part of and on the site of a remedial action undertaken pursuant to CERCLA from obtaining ADWR approval to extract groundwater. Required to comply with certain provisions.	The intent of the provisions outlined in these sections will be met during construction and installation of new wells.
40 CFR Section 262.11 and AAC § R18-8-262	Applicable	Establishes procedures to determine if wastes are hazardous wastes. Waste generators from construction and operation of remedial actions are required to follow procedures to determine if wastes are hazardous wastes.	Applicable to management of waste materials generated from construction or operation of groundwater treatment system.
Clean Air Act 42 U.S.C. §§ 7401-7671q 40 CFR Part 61, Subparts A and V	Applicable	Regulates emissions of VOCs and air pollutants and requires leak detection and repair programs. Applies if the equipment treats a liquid that contains at least 10% volatile hazardous air pollutant.	VOC emissions reduction, leak detection, and repair programs for product accumulator vessels.

A.R.S. § 49-221: AAC § R18-11-101 *et seq*.	Applicable	Water quality standards for discharges to surface water.	Arizona State Water Quality Standards for Surface Waters apply to treatment systems when treated water is discharged to surface water.
A.R.S. § 49-224	Relevant and Appropriate	Aquifers in the state identified and defined under A.R.S. § 49-224 and other aquifers subsequently discovered, identified, and defined shall be classified for drinking water protected use.	The Remedial Objectives for groundwater will be the Federal drinking water standards.
40 CFR Part 122 and Part 125	Applicable	Implements treatment and monitoring requirements for discharges to surface water under the National Pollutant Discharge Elimination System (NPDES) Program	Requirements under the NPDES program apply to treatment systems when treated water is discharged to surface water.
40 CFR § 144.12 - 144.16	Applicable	Underground Injection Control (UIC) program criteria and standards, including current and future use, yield, and water quality characteristics. Regulates the reinjection of groundwater.	Injection wells must comply with the design, construction, operation, and maintenance requirements.
AAC § R12-15-818	Relevant and Appropriate	Prohibits new well construction within 100 feet of any hazardous waste facility.	The location of potential new wells relative to potential hazardous waste facilities will be considered.
Safe Drinking Water Act, 42 U.S.C. §300f *et seq*. 40 CFR 144.24(a), 146	Applicable	Regulates current and future use, yield, and water quality characteristics.	If treatment system returns treated water to the aquifer, regulations apply to design, construction, operation, and maintenance of Class V injection wells.

Federal Clean Water Act, 40 CFR 403 Pima County Code, Title 13 Public Services, 13.36.070, Discharge Limits	Applicable	Standards for the allowable discharge of industrial wastewaters to the POTW.	These standards would be applicable if the selected remedy includes discharge to the POTW.

Appendix **D**

Cost Evaluation

APPENDIX D – COST EVALUATION

1.1 Introduction

Appendix D presents the estimated net present value (NPV) costs for the remedial alternatives for the Texas Instruments-Tucson manufacturing facility (Site) focused feasibility study. The cost estimates have been developed based on ARCADIS U.S., Inc. previous experience, RS Means, and vendor's quotes. The cost estimates have an accuracy range of +50 to -30 percent.

1.2 Assumptions

Assumptions were made during the development of capital costs and operation and maintenance (O&M) costs for the remedial alternatives for the Site. The following sections include groundwater monitoring, groundwater extraction and treatment, and in situ chemical oxidation (ISCO) with monitored natural attenuation.

1.2.1 Groundwater monitoring

Each alternative requires groundwater monitoring in addition to other O&M costs. Cost estimates for groundwater monitoring were developed on the basis of the following assumptions:

- For all alternatives, water quality and water level elevations would be collected on an annual basis.
- The NPV cost was done for 30 years for Alternatives 1 and 2 and 13 years for Alternative 3.
- The VOCs analyzed will not change in the future.

1.2.2 Groundwater extraction and treatment

Cost estimates for Alternatives 1 and 2 were developed on the basis of the following assumptions:

- The time to complete the remediation by groundwater extraction and treatment is 30 years.
- The electrical power rate is $0.09 per kilowatt-hour (kWh).
- Tax and delivery was estimated based for materials at a rate of 11%.
- A factor of 20% was applied to the subtotaled packed column air stripper estimate to account for installation.
- A factor of 4% was applied to the subtotaled mechanical equipment estimate for manufacturer services, and 11% was applied for tax and delivery.
- A factor of 20% was applied to the subtotaled mechanical equipment estimate for each electrical and instrumentation.
- 15% was applied to the subtotaled estimate to account for contractor overhead and profit.
- An estimating contingency of 30% was applied to the subtotaled estimate.

1.2.3 ISCO with monitored natural attenuation

Cost estimates for Alternative 3 were developed on the basis of the following assumptions:

- The time to complete the remediation by ISCO with monitored natural attenuation is 13 years.

- The design and installation of 3 new injection wells includes two vadose zone wells and one well at the groundwater level.
- The cost estimate assumes one maintenance dose.
- An estimating contingency of 30% was applied to the subtotaled estimate.

TABLE D-1
Cost Estimate for Alternative 1 - Groundwater extraction and treatment with discharge to POTW

Description	Total Cost
Packed Column Air Stripper	
Mobilization, preparatory work, and demobilization	$11,200
Relocation and placement of packed column air stripper	$3,900
Repack existing packed column air stripper	$2,800
Packed column inspection	$600
Installation of piping from extraction well to stripper and from stripper to POTW	$11,800
Connection to POTW	$15,000
Subtotal Packed Column Air Stripper	**$45,300**
Mechanical Equipment	
Pump - 100 gpm, 7.5 hp	$3,100
Packed column air and water flow measurement equipment	$5,700
Packed column alarm/shut down controls	$5,700
Antiscalant feed system	$1,100
Subtotal Mechanical Equipment	**$89,300**
Electrical	$17,900
Instrumentation	$17,900
Installation	$9,100
Tax and Delivery	$9,800
Manufacturer Services	$3,600
SUBTOTAL	**$192,800**
Contractor OH & Profit	$28,900
SUBTOTAL	**$221,800**
Contingency	$66,500
TOTAL CAPITAL COST	**$288,300**

O&M	Total Cost
Annual groundwater monitoring and reporting costs	$65,000
Power	
Blower	$300
Heater	$4,700
Pump	$3,500
Carbon changeouts	$1,000
Chemical feed system - H_2SO_4	$3,000
Routine maintenance on air stripper	$1,300
Routine facility maintenance	$6,200
Permit and annual fees for discharge to POTW	$6,000
Subtotal O&M	**$91,100**
NET PRESENT VALUE	**$1,863,100**

TABLE D-2
Cost Estimate for Alternative 2 - Groundwater extraction and treatment with injection

Description	Total Cost
Packed Column Air Stripper	
Mobilization, preparatory work, and demobilization	$11,200
Relocation and placement of packed column air stripper	$3,900
Repack existing packed column air stripper	$2,800
Packed column inspection	$600
Installation of piping from extraction well to stripper and from stripper to injection wells	$15,200
Subtotal Packed Column Air Stripper	**$33,700**
Mechanical Equipment	
Pump - 100 gpm, 7.5 hp	$3,100
Packed column air and water flow measurement equipment	$5,700
Packed column alarm/shut down controls	$5,700
Antiscalant feed system	$1,100
Design and installation of 1 extraction well and 24 hr aquifer test	$70,000
Subtotal Mechanical Equipment	**$199,300**
Electrical	$39,900
Instrumentation	$39,900
Installation	$6,700
Tax and Delivery	$21,900
Manufacturer Services	$8,000
SUBTOTAL	**$349,400**
Contractor OH & Profit	$52,400
SUBTOTAL	**$401,800**
Contingency	$120,500
TOTAL CAPITAL COST	**$522,300**

O&M	Total Cost
Annual groundwater monitoring and reporting costs	$65,000
Power	
Blower	$300
Heater	$4,700
Pump	$3,500
Carbon changeouts	$1,000
Chemical feed system - H_2SO_4	$3,000
Routine maintenance on air stripper	$1,300
Routine facility maintenance	$6,200
Subtotal O&M	**$85,100**
NET PRESENT VALUE	**$1,993,400**

TABLE D-3
Cost Estimate for Alternative 3 - ISCO with Monitored Natural Attenuation

Description	Total Cost
Workplan development	$30,000
Design and installation of 3 injection wells	$120,000
ISCO injections	$100,000
Maintenance dose	$75,000
Subtotal	**$325,000**
Contingency	$97,500
TOTAL CAPITAL COST	**$422,500**

O&M	Total Cost
Annual groundwater monitoring and reporting	$55,000
NET PRESENT VALUE	**$971,700**

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Appendix F
Alternative Analysis for the Arizona Air National Guard Project Area

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Environmental Restoration Program
Final Remedial Alternatives Analysis
Technical Memorandum

162nd Fighter Wing
Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

June 2011

NGB/A7OR
Joint Base Andrews, Maryland

Environmental Restoration Program
Final Remedial Alternatives Analysis
Technical Memorandum

162nd Fighter Wing
Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

June 2011

Prepared For:
Air National Guard
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Joint Base Andrews, Maryland 20762

Contract Number:
DAHA92-01-D-0005/0148

Project Number:
XHEA20117143

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LIST OF ACRONYMS

Acronym	Definition
$\mu g/L$	Micrograms per liter
ADEQ	Arizona Department of Environmental Quality
ANG	Air National Guard
ARAR	Applicable or relevant and appropriate requirement
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Contaminant of concern
EPA	United States Environmental Protection Agency
ERM	ERM-West, Inc.
ESD	Explanation of Significant Differences
FW	Fighter Wing
GWETRS	Groundwater extraction, treatment, and recharge system
ISCO	In situ chemical oxidation
$KMnO_4$	Potassium permanganate
MCL	Maximum contaminant level
MNA	Monitored natural attenuation
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NGB	National Guard Bureau
NPV	Net present value
O&M	Operation and maintenance
ORNL/ETS	Oak Ridge National Laboratory/Environmental Technology Section
PRB	Permeable reactive barrier
RA	Remedial action
RAO	Remedial action objective
RI	Remedial Investigation
ROD	Record of Decision
SVE	Soil vapor extraction
TCE	Trichloroethene
TIAA	Tucson International Airport Area
TM	Technical Memorandum
VOC	Volatile organic compound
WPB	West Plume B

EXECUTIVE SUMMARY

This *Remedial Alternatives Analysis Technical Memorandum* (TM) has been prepared for the 162nd Fighter Wing (FW) of the Arizona Air National Guard, Tucson International Airport Area Superfund Site (TIAA) in Tucson, Arizona. This TM was developed in accordance with the *Air National Guard Installation Restoration Program Investigation Protocol* (Air National Guard 2009); the Comprehensive Environmental Response, Compensation, and Liability Act; and the Superfund Amendments and Reauthorization Act.

The purpose of this TM is to assess potential remedial alternatives to augment the existing remedial action (RA) that has been implemented at the 162nd FW as described in the 1988 United States Environmental Protection Agency (EPA) *Record of Decision* (ROD) for the TIAA, and the 1997 EPA *Explanation of Significant Differences* for the 162nd FW. This TM focuses on treatment of volatile organic compound-impacted groundwater at the 162nd FW at concentrations greater than the applicable maximum contaminant levels.

The remedial alternatives evaluated for volatile organic compound-impacted groundwater at the 162nd FW were:

- Alternative 1 – Continued Extraction and Treatment;
- Alternative 2 – Monitored Natural Attenuation;
- Alternative 3 – In Situ Chemical Oxidation (ISCO); and
- Alternative 4 – Permeable Reactive Barrier.

The remedial alternatives were evaluated using the National Oil and Hazardous Substances Pollution Contingency Plan evaluation criteria provided in the 1988 EPA *Guidance for Conducting Remedial Investigations and Feasibility Studies*. The alternatives also were evaluated against the remedial action objectives for the 162nd FW provided in the 2004 EPA ROD Amendment for TIAA, which are as follows:

- Maintain protection of human health and the environment by reducing the risk of potential exposure to contaminants;
- Expedite site cleanup and restoration;

- Use permanent solutions to the maximum extent practicable;
- Restore contaminated groundwater to the extent practicable to support existing and future land uses;
- Achieve compliance with applicable or relevant and appropriate requirements;
- Minimize untreated waste;
- Cost-effectively reduce contamination in groundwater to concentrations that meet the cleanup goals;
- Return groundwater to its beneficial uses to the extent practicable within a timeframe that is reasonable, given the particular circumstances of the site; and
- Protect groundwater resources by preventing or reducing migration of groundwater contamination above Maximum Contaminant Levels.

Based on the RA analysis, the preferred remedial alternative for groundwater at the 162nd FW is ISCO (Alternative 3). The ISCO alternative effectively or moderately satisfies the evaluation criteria, and is anticipated to achieve the Remedial Action Objectives in a timely manner.

The results of this TM will be included with the forthcoming *Final TIAA-West Cap Project Area Focused Feasibility Study* and used to support the RA selection presented in the forthcoming Proposed Plan for Area B of the TIAA. The final selection of the RAs for Area B will be included in a forthcoming ROD Amendment prepared by the EPA following agency and public responses to the Proposed Plan.

SECTION 1.0

INTRODUCTION

This *Remedial Alternatives Analysis Technical Memorandum* (TM) has been prepared for the 162nd Fighter Wing (FW) of the Arizona Air National Guard (ANG), Tucson International Airport Area Superfund Site (TIAA) in Tucson, Arizona. This Alternatives Analysis was developed in accordance with the *Air National Guard Installation Restoration Program Investigation Protocol* (ANG 2009); the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); and the Superfund Amendments and Reauthorization Act.

This TM was completed under National Guard Bureau (NGB) contract DAHA92-01-D-0005, Delivery Order 0148, between ERM-West, Inc. (ERM) and the NGB, Departments of the Army and Air Force.

1.1 Purpose and Organization of Report

The purpose of this TM is to assess potential remedial alternatives to augment the existing remedial actions (RAs) that have been selected for the 162nd FW in the 1988 United States Environmental Protection Agency (EPA) *Record of Decision* (ROD) for the TIAA, and the 1997 EPA *Explanation of Significant Differences* for the 162nd FW. This TM focuses on treatment of groundwater at the 162nd FW that is impacted with trichloroethene (TCE) at concentrations exceeding the maximum contaminant level (MCL) specified in the Federal Safe Drinking Water Act.

The following four remedial alternatives were included in the TM to address TCE-impacted groundwater at the 162nd FW:

- Alternative 1 – Continued Extraction and Treatment;
- Alternative 2 – Monitored Natural Attenuation (MNA);
- Alternative 3 – ISCO; and
- Alternative 4 – Permeable Reactive Barrier (PRB).

The results of this TM will be included with the forthcoming *Final TIAA-West Cap Project Area Focused Feasibility Study* and used to support the selection of preferred RAs proposed in a forthcoming Proposed Plan for Area B of the TIAA. The final selection of the RAs for Area B will be included in a forthcoming ROD Amendment prepared by the EPA following agency and public responses to the Proposed Plan.

1.2 Site Description and Historical Background

The 162nd FW is located at 1500 East Valencia Road, in the City of Tucson in Pima County, Arizona (Figure 1-1). The 162nd FW occupies approximately 108 acres in the northwest corner of the Tucson International Airport, and is surrounded by industrial, commercial, residential, and vacant properties. The property is currently used as the base of operations of the 162nd FW, which has a mission to provide F-16 aircraft training to fighter pilots from around the world. Operations at the 162nd FW include aircraft and ground vehicle maintenance, and petroleum, oil, and lubricants distribution and management.

The NGB began conducting investigation activities at the 162nd FW in April 1987 (Oak Ridge National Laboratory [ORNL]/Environmental Technology Section [ETS] 1995). A preliminary assessment completed in October 1987 identified eight potentially contaminated former spill and disposal sites at the 162nd FW: Old Fire-Training Area (Site 1), East Fence Line (Site 2), Gatehouse (Site 3), West Base Parking Lot (Site 4), Old Wash Rack Area (Site 5), Solvent Dumping Area (Site 6), Edges of the Aircraft Parking Apron (Site 7), and Petroleum, Oil, and Lubricants Area (Site 8) (Hazardous Materials Technical Center 1987).

In 1988, the EPA issued a ROD for the TIAA that addressed groundwater impacted with volatile organic compounds (VOCs) at Areas A and B (EPA 1988). Groundwater extraction and treatment of VOCs (specifically TCE) to an overall excess cancer risk level of 10^{-6} was selected as the RA for Area B. The ROD selected packed-column aeration strippers as the treatment technology, unless an alternative treatment method was found to be more cost-effective.

In response to the 1988 ROD, the ANG conducted a Remedial Investigation (RI) that was completed in 1995, and designed a groundwater extraction, treatment, and recharge system (GWETRS) at the downgradient 162nd FW property boundary. Results of the RI identified TCE-impacted groundwater at Sites 4, 5, and 7 and a minor VOC source at Site 5 (ORNL/ETS 1995). The RI determined that Site 5 was the only vadose zone source of VOCs at the 162nd FW, and indicated that sitewide groundwater was impacted by an upgradient source of VOCs. The RI recommended the treatment of Site 5 soils by soil vapor extraction (SVE), construction of the GWETRS to treat sitewide groundwater impacted with VOCs, and investigation of upgradient sources of VOCs. No action was recommended for the remaining sites.

An extended SVE pilot test was conducted at Site 5 between April and November 1997 (ERM 1998). A total of approximately 64 pounds of TCE was removed from Site 5 soils. Rebound soil gas monitoring at Site 5 was conducted 14 days and 90 days after the SVE pilot test was completed. Results confirmed that residual TCE in soil gas was reduced to concentrations below the target cleanup goal, and closure for Site 5 was recommended in October 1998. The EPA and the Arizona Department of Environmental Quality (ADEQ) concurred with this recommendation in 1998 (EPA 1998a, ADEQ 1998).

The EPA issued an Explanation of Significant Differences (ESD) to document significant changes to the RA for the 162nd FW only (EPA 1997). The purpose of the 1997 ESD was to incorporate new information and minor changes to the RA since the 1988 ROD was issued. The 1997 ESD modified the RA at the 162nd FW to include the following:

- The use of cascade-tray air strippers, rather than packed-column aeration strippers, to treat TCE in groundwater;
- The re-injection of treated groundwater into the upper zone regional aquifer, rather than being treated for drinking water supply;
- The voluntary use of granular-activated carbon to control vapor-phase VOC emissions to the atmosphere; and
- The adoption of the Federal Safe Drinking Water Act MCLs as the standards for groundwater re-injected into the regional aquifer.

The GWETRS began operation at the 162nd FW in May 1997 to capture and treat TCE in groundwater to its MCL of 5 micrograms per liter (μg/L) and to prevent off-site migration by maintaining hydraulic control of the TCE plume. The GWETRS removes groundwater from up to 11 extraction wells screened in the upper and lower subunits of the upper zone regional aquifer, treats it with cascade-tray air strippers, and re-injects the treated groundwater into the vadose zone. The vapor stream is treated with a vapor-phase carbon adsorption vessel before discharge into the atmosphere. The GWETRS is currently in operation, and through August 2010, a total of approximately 725 million gallons of impacted groundwater has been treated, and 37.2 pounds of TCE have been removed. Details regarding the GWETRS treatment through August 2010 are provided in the *Final Groundwater Monitoring and Remedial Progress Report for April through September 2010* (ERM 2010a).

An in situ chemical oxidation (ISCO) pilot test was conducted in 2010 to evaluate the effectiveness of potassium permanganate ($KMnO_4$) in oxidizing TCE in groundwater (ERM 2010b). A total of 15,600 pounds of $KMnO_4$ was mixed with 195,600 gallons of water to create a 1 percent (%) by weight $KMnO_4$ solution. Approximately 56% of the $KMnO_4$ solution was injected into the upper subunit and 44% was injected into the lower subunit of the upper zone regional aquifer. Groundwater monitoring of the ISCO pilot test began in February 2009 and is currently ongoing. The results of the ISCO pilot test indicate that $KMnO_4$ is effectively oxidizing TCE in groundwater. The TCE plume has decreased by over 60% in areal extent in both the upper and lower subunits of the pilot test area.

1.3 Nature and Extent of Contamination

Monitoring wells, piezometers, and extraction wells that have been installed at the 162nd FW during past investigations are illustrated on Figure 1-2. These wells are generally screened in either the upper or lower subunits of the upper zone regional aquifer. A description of the upper and lower subunits is provided in the *Final Conceptual Site Model Report* (ERM 2010d). TCE has been detected in groundwater samples collected from the wells since June 1989 at concentrations ranging from non-detect to 46 µg/L (ORNL/ETS 1995). The results of the groundwater samples indicate the presence of a persistent TCE plume exceeding the MCL of 5 µg/L in the upper and lower subunits at the 162nd FW. The upper and lower subunit TCE plumes at Area B, based on third quarter 2010 data, are provided on Figures 1-3 through 1-5.

1.4 Applicable or Relevant and Appropriate Requirements

Section 121(d) of CERCLA states that RAs on CERCLA sites must attain (or justify the waiver of) any Federal or more stringent State environmental standards, criteria, or limitations that are determined to be legally applicable or relevant and appropriate requirements (ARARs). Applicable requirements are those cleanup standards, criteria, or limitations promulgated under Federal or State law that specifically address the situation at a CERCLA site. A requirement is applicable if the jurisdictional prerequisites of the environmental standard show a direct correspondence when objectively compared with the conditions at the site.

An evaluation of ARARs for the 162nd FW is provided in Appendix A. Federal and State statutes examined as potential ARARs for the 162nd FW alternatives analysis are listed in Table A-1. The chemical-, location-, and action-specific ARARS are presented in Tables A-2 through A-4. ARARs are identified on a site-specific basis and, therefore, as additional information is developed regarding the 162nd FW — including special features of the site location, the specific chemicals at the site, and the actions being considered as remedies — more ARARs may be progressively identified, and the list of potential ARARs further refined.

1.5 Remedial Action Objectives

Remedial action objectives (RAOs) are narrative statements that define the extent to which sites require cleanup to meet the underlying objectives of protecting human health and the environment. RAOs reflect contaminants of concern (COCs), exposure routes and receptors, and acceptable contaminant levels (or a range of acceptable contaminant levels) for each medium. Once developed, RAOs can be expressed numerically as preliminary cleanup goals. Preliminary cleanup goals are chemical concentrations in environmental media that achieve the levels of protection specified by the RAOs. The preliminary cleanup goals considered the exposure pathways and scenarios that are pertinent to the project areas (Arizona Department of Health Services 1996).

In the 1988 ROD developed for the regional aquifer contamination, the sole end use option for the treated water was direct drinking water use; thus, the analysis of response actions was limited by that end use. Accordingly, when the remedy was selected, a "target TCE concentration" of 1.5 μg/L was established to reduce the levels of TCE to below applicable MCLs, State action levels, and the 10^{-6} excess cancer lifetime risk. The 1998 ESD considered the appropriate cleanup goals where the treated water would not be used as drinking water supply, but would be re-injected into the aquifer; in that instance, the treatment standard was modified to the MCL of 5 μg/L for TCE.

The 1988 ROD did not state the RAOs for the TIAA. However, the RAOs included in the 2004 ROD Amendment for Area B of the TIAA are as follows (EPA 2004):

1) Maintain protection of human health and the environment by reducing the risk of potential exposure to contaminants;
2) Expedite site cleanup and restoration;
3) Use permanent solutions to the maximum extent practicable;
4) Restore contaminated groundwater to the extent practicable to support existing and future land uses;
5) Achieve compliance with ARARs;
6) Minimize untreated waste;
7) Cost-effectively reduce contamination in groundwater to concentrations that meet the cleanup goals;
8) Return groundwater to its beneficial uses to the extent practicable within a timeframe that is reasonable, given the particular circumstances of the site; and
9) Protect groundwater resources by preventing or reducing migration of groundwater contamination exceeding MCLs.

These RAOs are based on the present use of the TIAA, the anticipated potential for future use of the TIAA, and the potential for groundwater in the area to be used as a drinking water supply. These RAOs will be used to evaluate potential RAs for the 162nd FW.

SECTION 2.0

SCREENING AND DEVELOPMENT OF ALTERNATIVES

2.1 Assessment Criteria

The following four remedial alternatives were included in the Remedial Alternatives Analysis to address TCE-impacted groundwater at the 162nd FW:

- Alternative 1 – Continued Extraction and Treatment;
- Alternative 2 – Monitored Natural Attenuation (MNA);
- Alternative 3 – ISCO; and
- Alternative 4 – Permeable Reactive Barrier (PRB).

Each alternative was assessed using the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) evaluation criteria provided in the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1998b). Evaluation of the RA alternatives also considers the effectiveness of achieving Plume B RAOs listed in Section 1.5.

Descriptions of seven of the nine NCP evaluation criteria are provided in the following subsections. Regulatory and community acceptance criteria will be evaluated as part of the approval process in the forthcoming Proposed Plan.

2.1.1 Overall Protection of Human Health and the Environment

This evaluation criterion provides a final check to assess whether each alternative provides adequate protection of human health and the environment. The overall assessment of protection considers the assessments conducted under other evaluation criteria, particularly long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs. This evaluation also allows for consideration of whether an alternative poses any unacceptable short-term or cross-media impacts.

2.1.2 Compliance with ARARs

This evaluation criterion is used to determine whether each alternative will meet all of their identified Federal and State ARARs (i.e., chemical-specific, location-specific, and action-specific ARARs).

2.1.3 Long-Term Effectiveness and Permanence

The long-term effectiveness and permanence criterion evaluates the long-term effectiveness of an RA after response objectives have been achieved. This criterion evaluates the magnitude of residual risk posed by the presence of untreated waste or treatment residuals and the adequacy of institutional actions or containment measures needed to manage residual risk.

2.1.4 Reduction of Toxicity, Mobility, or Volume

This criterion addresses the statutory preference for selecting RAs that employ treatment to permanently reduce toxicity, mobility, or volume. It evaluates the degree to which the treatment is irreversible, as well as the residual compounds that will remain following treatment. This criterion favors alternatives that utilize treatment to the maximum extent possible and generate little or no residual wastes.

2.1.5 Short-Term Effectiveness

The short-term effectiveness criterion evaluates the impact on the community, site workers, and the environment during the construction and implementation phase of a given alternative, until the RAOs are achieved. This phase lasts through the construction phase of the RA. In addition to the impacts on human health, the potential adverse environmental impacts during the construction are evaluated.

2.1.6 Implementability

The implementability criterion addresses the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during its implementation. Technical, administrative, and environmental factors are considered during the evaluation.

2.1.7 Cost

The cost criterion assesses the financial burden associated with implementing the alternative. The factors that are addressed include capital costs — both direct and indirect — and operation and maintenance (O&M) costs. Direct capital costs include construction costs or expenditures for labor, materials, equipment, and subcontractors associated with the RA. Indirect capital costs include expenditures for engineering, permitting, construction management, and other services necessary to carry out the RA. O&M costs include operational labor and maintenance materials associated with the extended O&M and reporting for each alternative. Costs are provided as net present value (NPV) costs. A discount rate of 5 percent is used to evaluate the annual costs for each remedial alternative.

Costs for each alternative were developed independently as standalone remedies. If a combination of alternatives is selected as the preferred remedy, the combined cost should not be considered to be strictly additive, as some components are duplicated (e.g., monitoring).

2.2 Assumptions

Groundwater at the 162nd FW is impacted by TCE located within the property boundaries, as well as a continuing source of TCE that is migrating onto the 162nd FW from the source area at the upgradient West Cap property. The RA that will be selected for West Cap property in the forthcoming ROD Amendment for the TIAA, Area B is anticipated to remediate the high concentration source area (including TCE concentrations greater than 100 μg/L) at West Cap. If the VOC source area at West Cap is remediated, the VOC plume located between West Cap and the 162nd FW is anticipated to attenuate to below 5 μg/L in an estimated 15 to 20 years. Therefore, the alternative RAs in this TM were evaluated using the assumptions that the source area at West Cap has been remediated, and that the mass-flux of TCE onto the 162nd FW at levels exceeding the MCL will continue for 20 years following source area treatment.

2.3 Alternative 1 – Continued Extraction and Treatment

2.3.1 Description

Alternative 1 consists of the continued operation of the GWETRS currently in place at the 162nd FW. A description of the GWETRS is provided in the *Final O&M Manual Update* (ERM 2010c). Implementation of Alternative 1 would consist of the following:

- Preparation of an updated O&M manual and groundwater monitoring work plan;
- Replacement and/or upgrade of GWETRS equipment. A significant portion of the GWETRS consists of original equipment that has not been replaced since the GWETRS began operation in May 1997. Continuous operation of the GWETRS has resulted in the general deterioration of system components, and, as a result, much of the equipment no longer operates at optimal capacity. Replacement of system components — such as the programmable logic controller, the effluent air heater, and the transfer pumps, etc. — is necessary for continued operation of the GWETRS for an additional 20 years;
- O&M of the GWETRS for 20 years, including monthly influent/effluent sampling and weekly maintenance of GWETRS equipment;
- Completion of associated reporting and meetings; and
- Semi-annual groundwater monitoring for 22 years.

2.3.2 Assessment

In this subsection, Alternative 1 is evaluated against the criteria and RAOs provided in Section 2.1. The evaluation was conducted using the assumptions provided in Section 2.2.

Overall Protection of Human Health and the Environment

Alternative 1 is currently in operation at the 162nd FW. The GWETRS is removing and treating TCE from the aquifer, and providing hydraulic control along the northern 162nd FW property boundary. Assuming the source area at West Cap is remediated, the mass-flux of mass-flux of TCE onto the 162nd FW at levels exceeding the MCL will stop after 20 years, which is considered to be a reasonable timeframe. Alternative 1 therefore effectively satisfies this criterion.

Compliance with ARARs

Alternative 1 is currently in operation and is achieving chemical-specific ARARs at the downgradient 162nd FW boundary property boundary near Valencia Road. However, Alternative 1 does not address TCE-impacted groundwater that migrates onto the 162nd FW from the upgradient source area at West Cap. Alternative 1 would not achieve RAO 5 within the entire 162nd FW property boundary; therefore, it only moderately satisfies this criterion.

Long-Term Effectiveness and Permanence

Assuming the source area at West Cap is remediated, the mass-flux of TCE onto the 162nd FW at levels exceeding the MCL will stop after 20 years. Thus, continued operation of Alternative 1 is expected to permanently reduce TCE in both the upper and lower subunits of the 162nd FW. Residual TCE above the MCL will not remain at the 162nd FW after the RAOs are achieved. Short-term monitoring (i.e., 2 years) may be necessary after the GWETRS is shut down to verify that TCE does not rebound to concentrations greater than the MCL. Alternative 1 effectively satisfies this criterion.

Reduction of Toxicity, Mobility, or Volume

TCE concentrations at the 162nd FW have been steadily decreasing since the GWETRS began operation in May 1997 (ERM 2010a). In addition, the GWETRS has maintained hydraulic control of the TCE plume, preventing off-site migration downgradient of the 162nd FW property. It is likely that the injection of groundwater treated by the GWETRS has also promoted the flushing of TCE within the northeastern portion of the 162nd FW, resulting in a reduced TCE plume footprint. Alternative 1 effectively satisfies this criterion.

Short-Term Effectiveness

The GWETRS is currently in operation at the 162nd FW. Therefore, no short-term impacts to site workers or the environment are expected during the implementation phase of this RA. Alternative 1 effectively satisfies this criterion.

Implementability

The GWETRS is currently in operation at the 162nd FW, and all necessary equipment and personnel for continued operation is readily available. Alternative 1 effectively satisfies this criterion.

Cost

The cost associated with Alternative 1 includes an updated groundwater monitoring work plan and O&M manual, upgrades to the GWETRS, O&M, groundwater monitoring, reporting, and associated meetings. Costs assume that the upgradient source at West Cap will be remediated, and that the GWETRS will reduce the residual TCE to below the MCL in 20 years. Because this RA is expected to achieve RAOs in approximately 20 years, costs for groundwater monitoring, reporting, and associated meetings are included for a 22-year period to allow for two years of rebound monitoring. The total estimated cost (NPV) of this alternative is $9,312,209. Of this total, $350,350 is direct and indirect capital cost, and $8,961,859 is O&M cost (NPV). Costs associated with Alternative 2, which are provided in Table 2-1, indicate that RAO 7 is not achieved by the continued operation of the GWETRS. Alternative 1 poorly satisfies this criterion.

2.4 Alternative 2 – Monitored Natural Attenuation

2.4.1 Description

Alternative 2 involves MNA of the TCE plume in the upper and lower subunits at the 162nd FW for a total of 22 years. MNA is a groundwater remediation approach that relies on natural attenuation processes (i.e., biodegradation, dispersion, sorption, diffusion, mixing, and volatilization) to reduce contaminant concentration within a timeframe that is reasonable compared to other remediation methods (EPA 1998c).

MNA would be conducted to monitor the reduction of TCE in sitewide groundwater to concentrations below the MCL. Implementation of this alternative would involve the following:

- Preparation of an MNA work plan;
- Installation of monitoring wells along the upgradient 162nd FW property boundary to better monitor migration of TCE from upgradient sources;

- Collection of soil and groundwater samples for biological and geochemical analysis;
- Semi-annual groundwater monitoring from the existing well network for TCE for 22 years; and
- Completion of associated reporting and meetings.

2.4.2 Assessment

In this subsection, Alternative 2 is evaluated against the NCP criteria provided in Section 2.1. The evaluation was conducted using the assumptions provided in Section 2.2.

Overall Protection of Human Health and the Environment

Alternative 2 is expected to eventually reduce TCE to concentrations below the MCL. Assuming the source area at West Cap is remediated, the mass-flux of TCE onto the 162nd FW at levels exceeding the MCL will stop after 20 years, which is considered to be a reasonable timeframe.

RAOs 6 and 9 are not achieved by Alternative 2, because it does not provide hydraulic control along the northern 162nd FW property boundary, which permits TCE to potentially migrate downgradient into the West Plume B (WPB) area. In addition, there are currently no short-term institutional controls restricting private well use at WPB to prevent exposure to TCE-impacted groundwater by the community.

Based on the evaluation of overall protection and human health, Alternative 2 moderately satisfies this criterion.

Compliance with ARARs

Alternative 2 is expected to achieve chemical-specific ARARs within the 162nd FW property boundaries within a 20-year timeframe. However, it does not prevent the TCE plume from potentially migrating downgradient into the WPB area. To date, there are currently no institutional controls restricting private well use at WPB to prevent exposure to TCE-impacted groundwater by the community. Therefore, RAO 9 is not achieved at the downgradient 162nd FW property boundary. Alternative 2 poorly satisfies this criterion.

Long-Term Effectiveness and Permanence

Alternative 2 is expected to reduce TCE at the 162nd FW to concentrations below the MCL. Historical data collected from the 162nd FW was evaluated to determine whether MNA is a viable remedial alternative for treating TCE at the 162nd FW. The results of the evaluation indicated that natural attenuation of TCE at the 162nd FW is likely the result of physical and geochemical processes (i.e., dispersion, sorption, diffusion, mixing, and volatilization), with reductive dechlorination limited to localized areas. Details of the MNA evaluation are included in the *Conceptual Site Model Report* (ERM 2010d).

Residual TCE is not expected to remain at the 162nd FW after the RAOs are achieved. Short-term monitoring (i.e., 2 years) may be necessary to verify that TCE does not rebound to concentrations exceeding the MCL. Assuming the source area at West Cap is remediated, the mass-flux of TCE onto the 162nd FW at levels exceeding the MCL will stop after 20 years, which is considered to be a reasonable timeframe. Alternative 2 effectively satisfies this criterion.

Reduction of Toxicity, Mobility, or Volume

Alternative 2 is expected to reduce TCE at the 162nd FW to concentrations below the MCL via physical and geochemical processes (i.e., dispersion, sorption, diffusion, mixing, and volatilization), with reductive dechlorination limited to localized areas. Attenuation by physical and geochemical processes would reduce the overall toxicity, but would not reduce the mobility or volume of the plume as a whole. The downgradient migration of TCE into the WPB area also would not be prevented by MNA, which may result in re-contamination of groundwater not currently impacted with TCE at concentrations exceeding the MCL. In addition, there are currently no institutional controls restricting private well use at WPB to prevent exposure to TCE-impacted groundwater by the community. Consequently, RAO 9 would not be achieved. Alternative 2 moderately satisfies this criterion.

Short-Term Effectiveness

This alternative would not effectively treat TCE at the 162nd FW in the short-term, because reduction by MNA is expected to take a very long time. In addition, Alternative 2 would not prevent the migration of TCE into the downgradient WPB area, which currently does not have institutional controls restricting private well use to prevent exposure to TCE-impacted groundwater by the community. Alternative 2 poorly satisfies this criterion.

Implementability

Construction associated with MNA would involve the installation of several monitoring wells on or near the 162nd FW flight line. Although difficulties associated with the well installation would not limit the implementability of Alternative 2, coordination with 162nd FW personnel would be required to ensure that the installation of the wells did not hamper the mission of the 162nd FW, which is to train fighter jet pilots.

MNA analysis procedures for groundwater samples are well developed and widely available; therefore, technical problems will not limit the implementability of Alternative 2. Alternative 2 effectively satisfies this criterion.

Cost

The cost associated with Alternative 2 includes preparation of an MNA work plan, installation of monitoring wells, collection of soil and groundwater samples for geochemical analysis, groundwater monitoring, reporting, and associated meetings. The total estimated cost (NPV) of this alternative is $3,778,578. Of this total, $310,310 is direct and indirect capital cost, and $3,468,268 is O&M cost (NPV). Costs associated with Alternative 2 are provided in Table 2-2. Alternative 2 effectively satisfies this criterion.

2.5 Alternative 3 – In Situ Chemical Oxidation

2.5.1 Description

Alternative 3 involves the full-scale application of ISCO to treat TCE in the upper and lower subunits at the 162nd FW. ISCO is a relatively established technology that uses $KMnO_4$ — an oxidant commonly used in water treatment plants as a disinfectant — to degrade VOCs to inert by-products such as carbon dioxide and water. The potential benefits of ISCO include in situ contaminant destruction, relatively low cost, reliability, simplicity, and rapid treatment. However, site-specific constraints also must be considered. Efficient oxidation is dependent on the contact between oxidant and contaminant. Subsurface heterogeneities, preferential flow paths, and poor mixing in the subsurface may result in inefficient treatment. Facility structures within a contaminant footprint may limit the location of ISCO injections, thus reducing the overall distribution efficiency. In addition, high levels of other oxidizable substances in the treated zone, such as other organic material and reduced-state metals, can significantly impact treatment efficiency and effectiveness.

Implementation of Alternative 3 would consist of the following:

- Preparation of a full-scale ISCO work plan;
- Installation of approximately 30 upper subunit and 20 lower subunit injection wells spaced approximately 50 feet apart. The injection wells will be installed in several rows, or "fences," that span the width of the TCE plume and are located perpendicular to the direction of groundwater flow (Figures 2-1 and 2-2);
- Injection of approximately 140,000 pounds of $KMnO_4$ into the upper and lower subunit injection wells to treat the TCE plume at the 162nd FW. The estimate includes the reapplication of $KMnO_4$ to treat TCE that persists up to 2.5 years after an initial injection. Estimates for the amount of $KMnO_4$ required to treat TCE at the 162nd FW are provided in Appendix B. The $KMnO_4$ would be injected as a slurry through the injection well screens to increase the longevity of $KMnO_4$ at the 162nd FW;
- Installation of approximately five monitoring well pairs across the 162nd FW to assist in monitoring the sitewide effectiveness of ISCO at the 162nd FW;
- Groundwater monitoring of existing and newly installed wells for five years after the injections are complete, which is the approximate timeframe estimated for the $KMnO_4$ to completely oxidize the TCE plume at the 162nd FW (Figures 2-3 and 2-4); and
- Completion of associated reporting and meetings.

2.5.2 Assessment

In this subsection, Alternative 3 is evaluated against the NCP criteria provided in Section 2.1. The evaluation was conducted using the assumptions provided in Section 2.2. In addition, the contribution of TCE from upgradient sources to the 162nd FW TCE plume was assumed to terminate 5 years after the injections are complete, because the proposed ISCO design includes the application of $KMnO_4$ along the upgradient 162nd FW property boundary to treat TCE entering the property from upgradient sources (Figures 2-1 and 2-2).

Overall Protection of Human Health and the Environment

Alternative 3 is expected to permanently reduce TCE at the 162nd FW to concentrations below the MCL within a relatively short timeframe. Groundwater modeling indicates that $KMnO_4$ will completely oxidize the TCE plume at the 162nd FW approximately 5 years after injection (Figure 2-3 and 2-4).

Due to the lack of controls restricting private well use at WPB, there is a potential for the WPB community to be exposed to un-oxidized $KMnO_4$ that may migrate into the WPB area. However, the $KMnO_4$ is anticipated to completely degrade and/or dilute before it reaches residential properties within the WPB area. Conservative $KMnO_4$ concentrations will be used when dosing the TCE plume to mitigate potential off-site migration of $KMnO_4$ that has not been reduced.

Based on the evaluation of overall protection and human health, Alternative 3 effectively satisfies this criterion.

Compliance with ARARs

Implementation of the ISCO alternative would achieve the chemical-specific ARARs at the 162nd FW. Alternative 3 effectively satisfies this criterion.

Long-Term Effectiveness and Permanence

This alternative is expected to permanently reduce TCE at the 162nd FW to concentrations below the MCL. Groundwater modeling indicates that $KMnO_4$ will completely oxidize the TCE plume at the 162nd FW approximately 5 years after injection (Figure 2-3 and 2-4). Residual TCE is not expected to remain at the 162nd FW after the RAOs are achieved; however, short-term monitoring (i.e., 2 years) may be necessary after full-scale ISCO treatment is complete to verify that TCE does not rebound to concentrations greater than the MCL. Alternative 3 effectively satisfies this criterion.

Reduction of Toxicity, Mobility, or Volume

ISCO using $KMnO_4$ is known to react with TCE to form the inert by-products of carbon dioxide and water. Based on the results of the 2009 ISCO pilot test conducted at the 162nd FW, ISCO will effectively reduce toxicity, mobility, and volume of TCE at the 162nd FW. A comparison of the areal distribution of TCE in February 2009 (pre-ISCO pilot test), August 2010, and February 2011 illustrates the reduction of TCE in both the upper and lower subunits of the ISCO pilot test area (Figures 2-5 through 2-6). Off-site migration of TCE into the downgradient WPB area will be prevented by the injection of $KMnO_4$ at the leading edge of the plume. Alternative 3 effectively satisfies this criterion.

Short-Term Effectiveness

There is low to moderate exposure for the community and workers to construction-related risks. Protective equipment should be worn by workers during the construction activities. Alternative 3 effectively satisfies this criterion.

Implementability

Materials and services needed for this alternative are readily available, and technologies are reliable and proven. However, the installation of injection and monitoring wells necessary for full-scale application of ISCO may be impeded by the limited availability of space, as well as access issues at the 162nd FW. The majority of the 162nd FW property is developed with operational buildings and mission-critical infrastructure. Therefore, it may be difficult to access areas required to install the injection well fences. In addition, to effectively treat TCE-impacted groundwater, several injection well fences and monitoring wells would be installed on or near the 162nd FW flight line. Although difficulties associated with well installation would not limit the implementability of Alternative 3, coordination with 162nd FW personnel would be required to ensure that the installation of the injection/monitoring wells did not interfere with the mission of the 162nd FW, which is to train fighter jet pilots. Alternative 3 moderately satisfies this criterion.

Cost

The cost associated with this alternative includes a work plan for full-scale application of ISCO, installation of $KMnO_4$ injection wells and groundwater monitoring wells, and injection of $KMnO_4$ slurry into the upper and lower subunits. Because this RA is expected to achieve RAOs in approximately 5 years, costs for groundwater monitoring, reporting, and associated meetings are included for a 7-year period to allow for sufficient rebound monitoring. The total estimated cost (NPV) of this alternative is $5,071,026. Of this total, $2,074,800 is direct and indirect capital cost, and $2,996,226 is O&M cost (NPV). Costs associated with this alternative are provided in Table 2-3. Alternative 3 effectively satisfies this criterion.

2.6 Alternative 4 – Permeable Reactive Barrier

2.6.1 Description

PRBs involve the installation of a porous treatment media across the flow path of a groundwater plume. As contaminated groundwater moves through the treatment zone, contaminants are removed or treated by physical, chemical, or biological processes. Removal mechanisms may include precipitation, sorption, oxidation/reduction, fixation, and degradation. PRBs may be constructed with nutrients and oxygen, chelating agents, metal-based catalysts, or other agents. PRBs may be installed immediately downgradient of a source area to prevent plume migration.

Application of a PRB at the 162nd FW would involve the installation of two zero-valent iron PRBs (one each in the upper and lower subunits) along the northern (downgradient) property boundary of the 162nd FW. The proposed location for the upper and lower subunit PRB is illustrated on Figures 2-7 and 2-8, respectively. The PRBs would treat TCE-impacted groundwater as it flows off-site and into the downgradient WPB area. The treatment provided by the PRB would be designed to reduce TCE to concentrations below the MCL. Assuming that the source area at West Cap is remediated and that the mass-flux of TCE onto the 162nd FW will conclude after 20 years, the total time for a PRB to reduce on-site TCE to concentrations below the MCL is an estimated 20 years.

Implementation of this alternative generally would involve:

- Preparation of a work plan for PRB installation;
- Installation of groundwater monitoring wells to evaluate the performance of the PRBs;
- Installation of two approximately 1,200-foot long zero-valent iron PRBs (one each in the upper and lower subunits) along the northern 162nd FW property;
- Preparation of a PRB construction completion report;
- Groundwater monitoring and reporting for 20 years; and
- Completion of associated reporting and meetings.

2.6.2 Assessment

In this subsection, Alternative 4 is evaluated against the NCP criteria provided in Section 2.1. The evaluation was conducted using the assumptions provided in Section 2.2.

Overall Protection of Human Health and the Environment

Alternative 4 is expected to reduce TCE to concentrations below the MCL at the downgradient 162nd FW property boundary near Valencia Road, but it would not treat TCE within the upgradient portion of the property. The PRBs would treat TCE-impacted groundwater before it migrates into the downgradient WPB area. Assuming the source area at West Cap is remediated, the mass-flux of TCE onto the 162nd FW at levels exceeding the MCL will stop after 20 years, which is considered to be a reasonable timeframe. Based on the evaluation of overall protection and human health, Alternative 4 moderately satisfies this criterion.

Compliance with ARARs

Alternative 4 would achieve chemical-specific ARARs along the northern 162nd FW property boundary. However, Alternative 4 does not address TCE-impacted groundwater that migrates onto the 162nd FW from the upgradient source area at West Cap. Alternative 4 would not achieve RAO 5 within the entire 162nd FW property boundary; therefore, it only moderately satisfies this criterion.

Long-Term Effectiveness and Permanence

Alternative 4 is expected to permanently reduce TCE at the 162nd FW to concentrations below the MCL. Residual TCE is not expected to remain at the 162nd FW. Short-term monitoring (i.e., 2 years) may be necessary to verify that TCE does not rebound to concentrations exceeding the MCL. Assuming that the source area at West Cap is remediated and that the mass-flux of TCE onto the 162nd FW at levels exceeding the MCL will stop after 20 years, the total time for PRBs to reduce on-site TCE to concentrations below the MCL is an estimated 20 years. Alternative 4 effectively satisfies this criterion.

Reduction of Toxicity, Mobility, or Volume

Alternative 4 is expected to reduce the toxicity, mobility, and volume of contaminants as groundwater flows through the PRBs. Off-site migration of TCE will be prevented by treatment of impacted groundwater by the

PRBs before it migrates into the downgradient WPB area. Alternative 4 effectively satisfies this criterion.

Short-Term Effectiveness

There is low to moderate exposure for the community and workers to construction-related risks associated with Alternative 4. Protective equipment should be worn by workers during the construction activities. Alternative 4 would not, during construction of the PRBs, prevent the migration of TCE into the downgradient WPB area, which currently does not have institutional controls restricting private well use to prevent exposure to TCE-impacted groundwater by the community. Alternative 4 moderately satisfies this criterion.

Implementability

Materials and services needed for this alternative are readily available, and technologies are reliable and proven. However, the installation of the PRBs may be impeded by the limited availability of space, as well as access issues at the 162nd FW. The majority of the 162nd FW property is developed with operational buildings and mission-critical infrastructure, and it may be difficult to access areas capable of accommodating the PRBs. Although difficulties associated with PRB and well installation would not limit the implementability of Alternative 4, coordination with 162nd FW personnel would be required to ensure that the installation of the PRBs did not hamper the mission of the 162nd FW, which is to train fighter jet pilots. Alternative 4 moderately satisfies this criterion.

Cost

The cost associated with this alternative includes an updated groundwater monitoring work plan, groundwater monitoring, reporting, and associated meetings. The total estimated cost (NPV) of this alternative is $17,771,757. Of this total, $11,861,850 is direct and indirect capital cost, and $5,909,907 is O&M cost (NPV). Costs associated with this alternative, which are provided in Table 2-4, indicate that RAO 7 is poorly achieved by PRBs. Alternative 4 poorly satisfies this criterion.

2.7 Comparative Analysis

The comparative analysis evaluates the relative performance of each alternative using the criteria upon which the detailed analysis of alternatives was based. The purpose of the comparative analysis is to identify the advantages and disadvantages of the alternatives relative to one another to aid in the selection of remedy options for each site. This section highlights differences between the alternatives for each criterion.

A summary of the comparative analysis for each alternative is provided in Table 2-5. A discussion of the comparative analysis for the 162nd FW is as follows:

- <u>Overall Protection of Human Health and the Environment:</u> Alternative 1 (continued extraction and treatment), Alternative 3 (ISCO), and Alternative 4 (PRBs) effectively satisfy this criterion. Alternative 2 (MNA) moderately satisfies this criterion.

- <u>Compliance with ARARs:</u> Alternative 3 (ISCO) effectively satisfies this criterion. Alternative 1 (continued extraction and treatment) and Alternative 4 (PRBs) moderately satisfy this criterion. Alternative 2 (MNA) poorly satisfies this criterion.

- <u>Long-Term Effectiveness and Permanence:</u> Alternative 1 (continued extraction and treatment), Alternative 2 (MNA), Alternative 3 (ISCO), and Alternative 4 (PRBs) effectively satisfy this criterion.

- <u>Reduction of Toxicity, Mobility, or Volume:</u> Alternative 1 (continued extraction and treatment), Alternative 3 (ISCO), and Alternative 4 (PRBs) effectively satisfy this criterion. Alternative 2 (MNA) moderately satisfies this criterion.

- <u>Short-Term Effectiveness:</u> Alternative 1 (continued extraction and treatment) and Alternative 3 (ISCO) effectively satisfy this criterion. Alternative 4 (PRBs) moderately satisfies this criterion. Alternative 2 (MNA) poorly satisfies this criterion.

- <u>Implementability:</u> Alternative 1 (continued extraction and treatment) and Alternative 2 (MNA) effectively satisfy this criterion. Alternative 3 (ISCO) and Alternative 4 (PRBs) moderately satisfy this criterion.

- <u>Cost:</u> Alternative 2 (MNA) and Alternative 3 (ISCO) effectively satisfy this criterion, with respective costs of $3,778,578 and $5,071,026. Alternative 1 (continued extraction and treatment) and Alternative 4 (PRBs) poorly satisfy this criterion, with respective costs of $9,312,209 and $17,771,757.

SECTION 3.0

RECOMMENDATIONS

The recommendation of a preferred remedial alternative as part of the evaluation process is consistent with the ANG guidance for conducting investigations and remedy selection (ANG 2009). The preferred remedy for groundwater at the 162^{nd} FW is Alternative 3 (ISCO). The ISCO alternative effectively or moderately satisfied seven of the nine NCP evaluation criteria, and will achieve the RAOs in a timely manner. The final two NCP evaluation criteria, which are regulatory and community acceptance, will be evaluated as part of the approval process of the Proposed Plan. The final selection of a preferred alternative will be determined following agency and public responses to the Proposed Plan.

SECTION 4.0

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FIGURES

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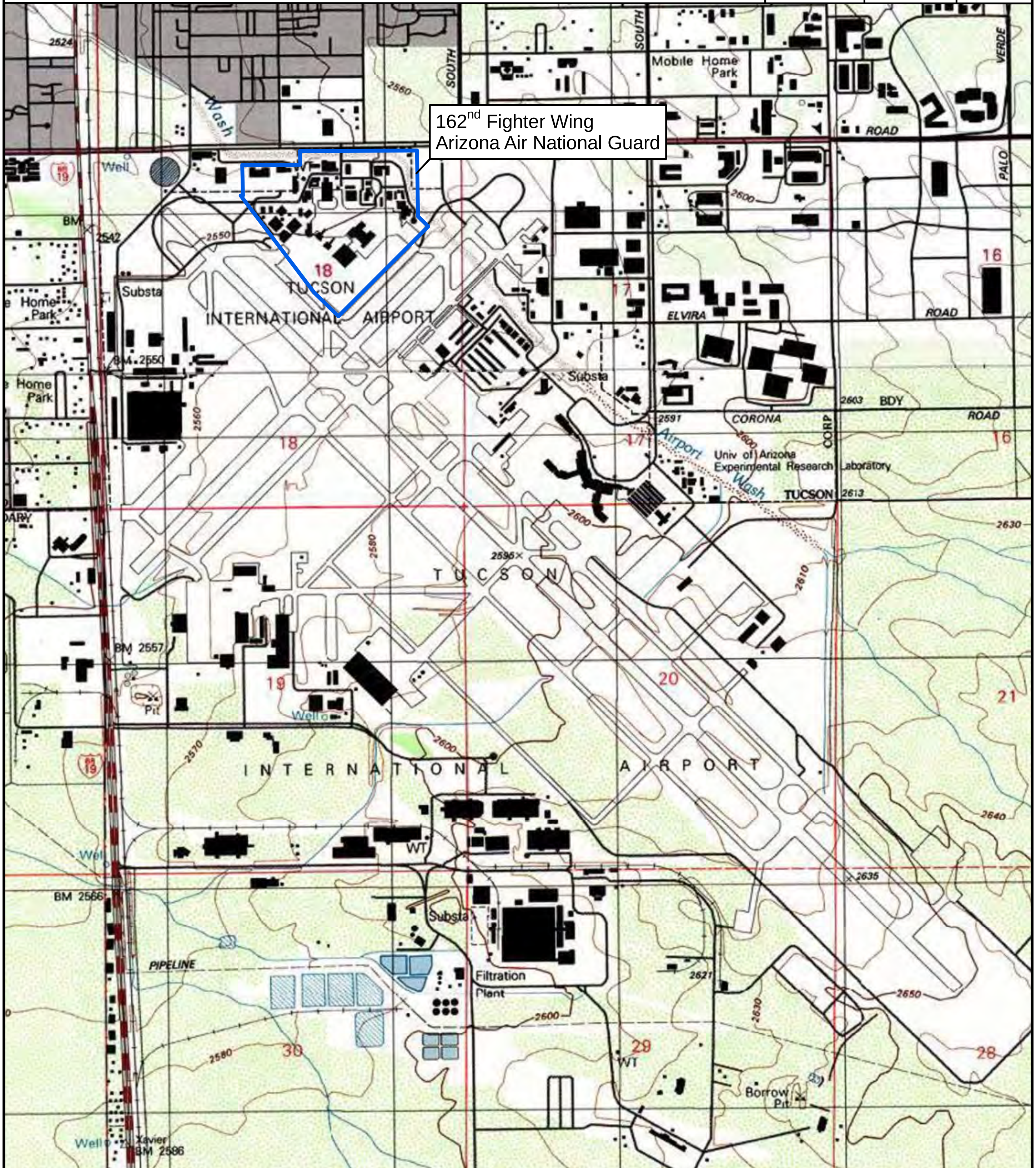

N

1 0.5 0 1 Miles

1,000 0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 Feet

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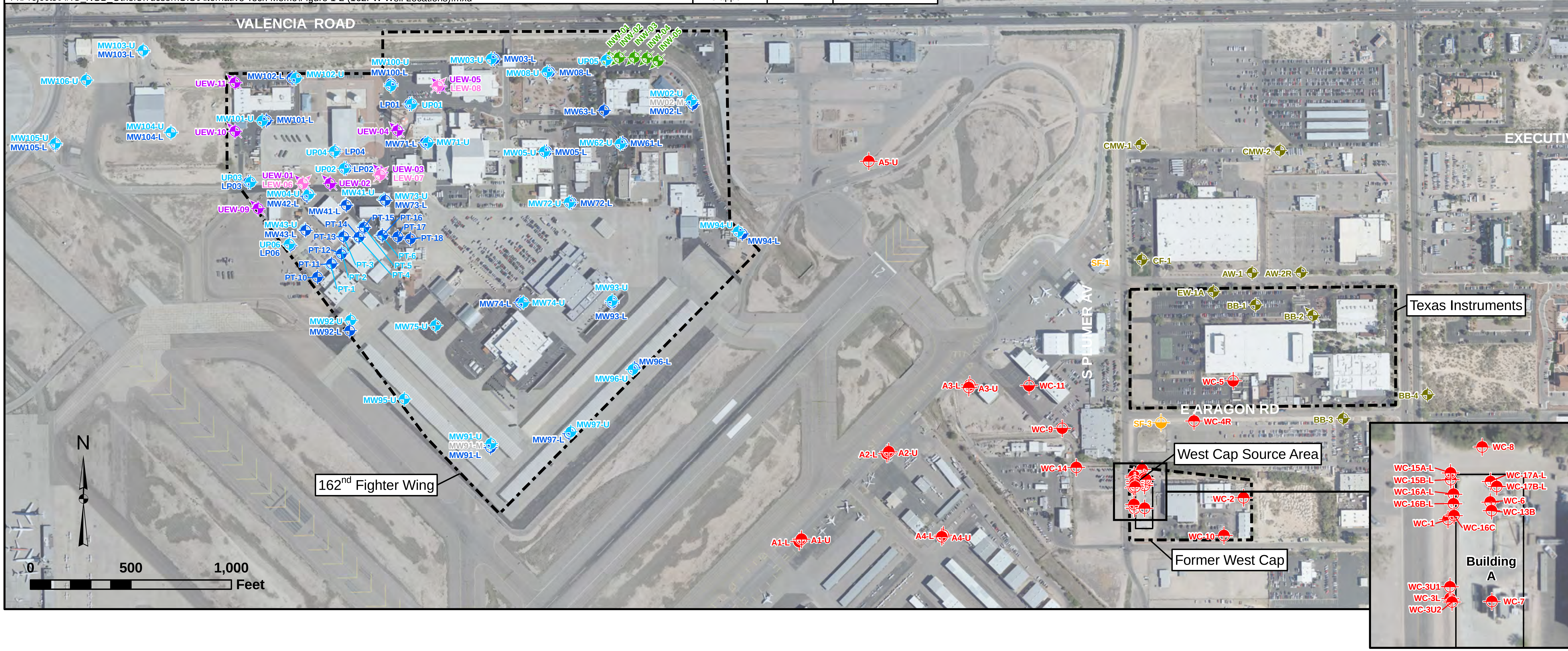
Figure 1-1
Site Location Map
162nd Fighter Wing
Arizona Air National Guard
Tucson, Arizona

03/11

File: F:\Projects\ANG_NGB_Others\Tucson\GIS\Alternative Tech Memo\Figure 1-2 (162FW Well Locations).mxd	Created By: mike.appel	Date: 06/22/2011	Project: 0084559.XX



Legend

- 162nd Fighter Wing (FW) Upper Subunit Monitoring Well, Piezometer, or Pilot Test Well
- 162nd FW Middle Subunit Monitoring Well
- 162nd FW Lower Subunit Monitoring Well, Piezometer, or Pilot Test Well
- 162nd FW Upper Subunit Extraction Well
- 162nd FW Lower Subunit Extraction Well
- 162nd FW Recharge Well
- West Cap Upper Subunit Monitoring Well
- West Cap Lower Subunit Monitoring Well
- Texas Instruments Property Monitoring Well
- Texas Instruments Property Extraction Well
- City of Tucson Lower Subunit Monitoring Well
- Facility Boundary

Figure 1-2
Well Location Map
162nd Fighter Wing, West Cap, and Texas Instruments
Tucson International Airport Area Superfund Site
Tucson, Arizona

File:
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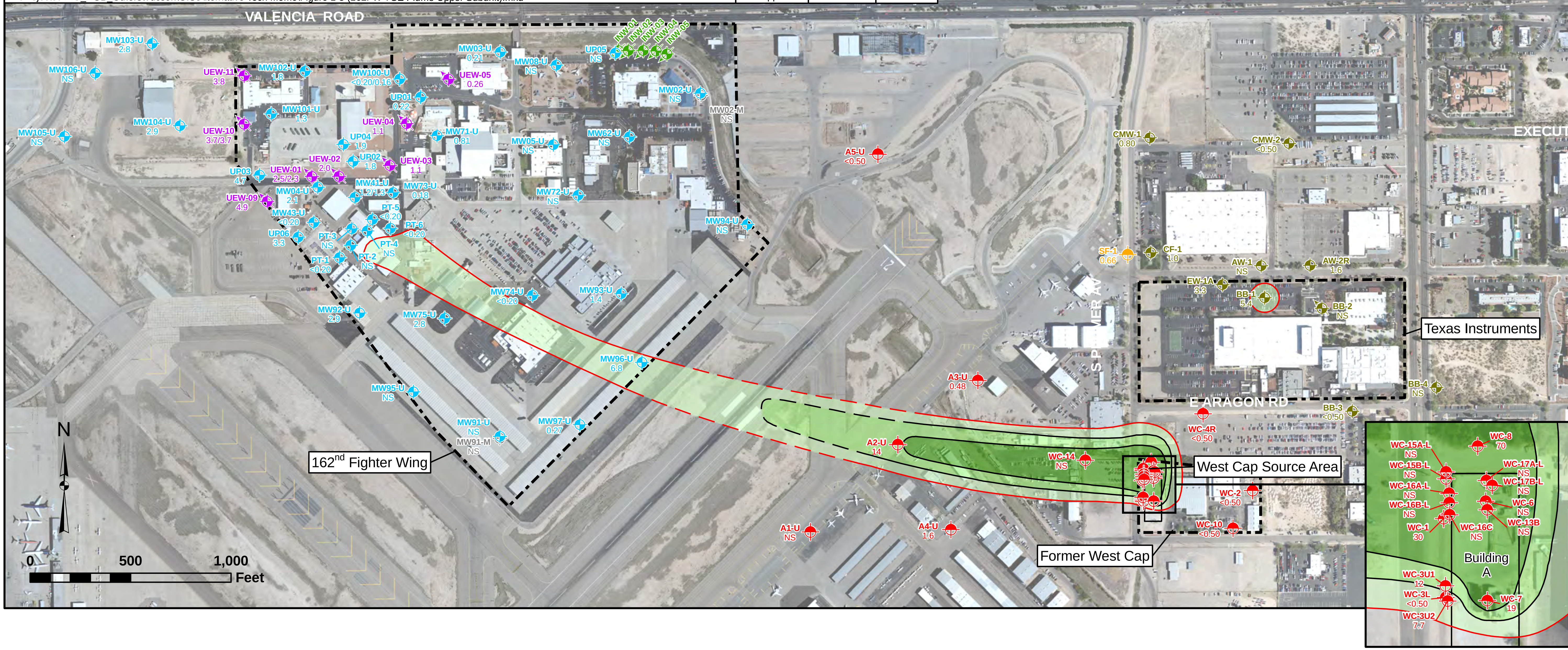


Legend

- 162nd Fighter Wing (FW) Upper Subunit Monitoring Well, Piezometer, or Pilot Test Well
- 162nd FW Middle Subunit Monitoring Well
- 162nd FW Upper Subunit Extraction Well
- 162nd FW Recharge Well
- Texas Instruments Property Monitoring Well
- Texas Instruments Property Extraction Well
- West Cap Upper Subunit Monitoring Well
- City of Tucson Upper Subunit Monitoring Well
- Facility Boundary

TCE Concentrations

- 5-10 µg/L
- 10-15 µg/L
- 15-100 µg/L
- Isoconcentration Contour
- Isoconcentration Contour - Inferred
- MCL Contour (5.0 µg/L)
- MCL Contour (5.0 µg/L) - Inferred

TCE- Trichloroethene

NS- Not Sampled

MCL- Maximum Contaminant Level (5 µg/L)

<0.50- TCE not detected at or above the listed laboratory detection limit

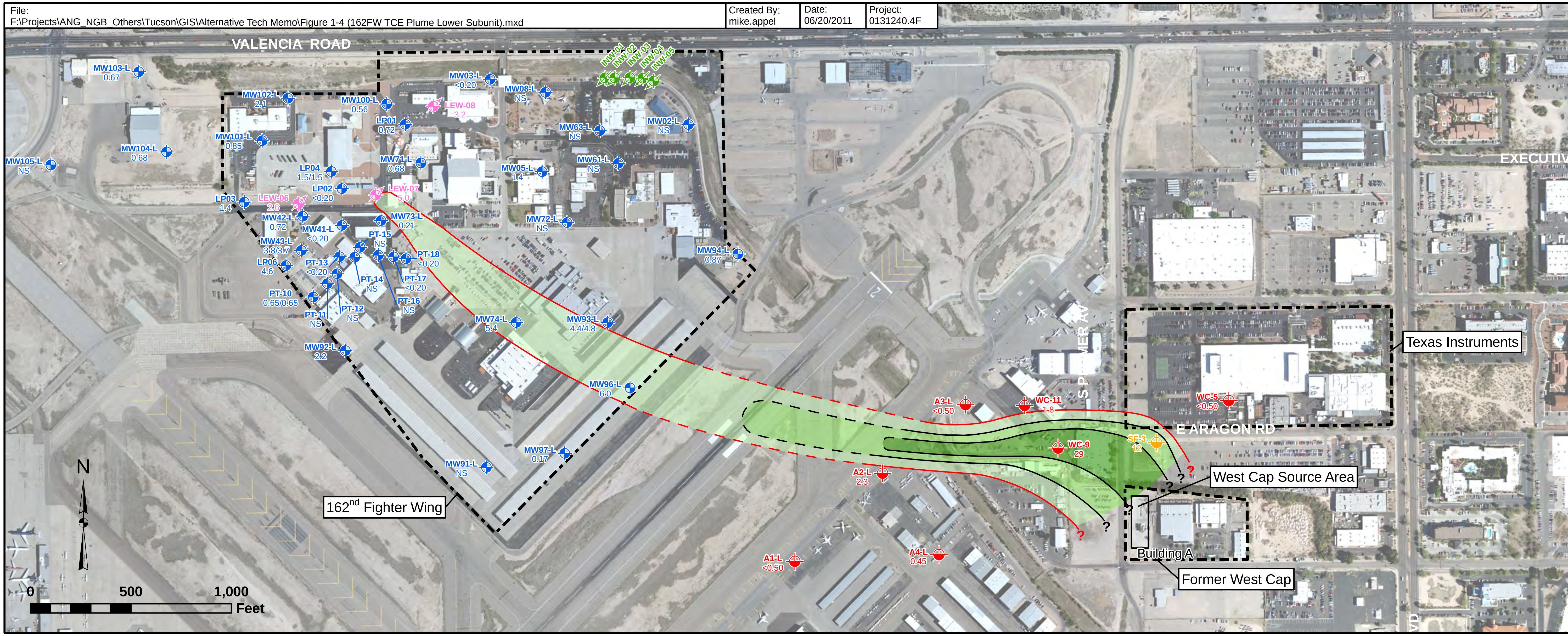
5.8/6.1- Primary Sample Result/Duplicate Result

All results in micrograms per liter (µg/L)

Data collected during first quarter 2011

Figure 1-3

Upper Subunit TCE Plume Map
(First Quarter 2011)
162nd Fighter Wing, West Cap,
and Texas Instruments
Tucson International Airport
Area Superfund Site
Tucson, Arizona



Legend

- 162nd Fighter Wing (FW) Lower Subunit Monitoring Well, Piezometer, or Pilot Test Well
- 162nd FW Lower Subunit Extraction Well
- 162nd FW Recharge Well
- Former West Cap Property Lower Subunit Monitoring Well
- City of Tucson Lower Subunit Monitoring Well
- Facility Boundary

TCE Concentrations

- 5-10 µg/L
- 10-15 µg/L
- 15-100 µg/L
- Isoconcentration Contour
- Isoconcentration Contour - Inferred
- MCL Contour (5.0 µg/L)
- MCL Contour (5.0 µg/L) - Inferred

TCE- Trichloroethene

NS- Not Sampled

MCL- Maximum Contaminant Level (5 µg/L)

<0.50- TCE not detected at or above the listed laboratory detection limit

5.8/6.1- Primary Sample Result/Duplicate Result

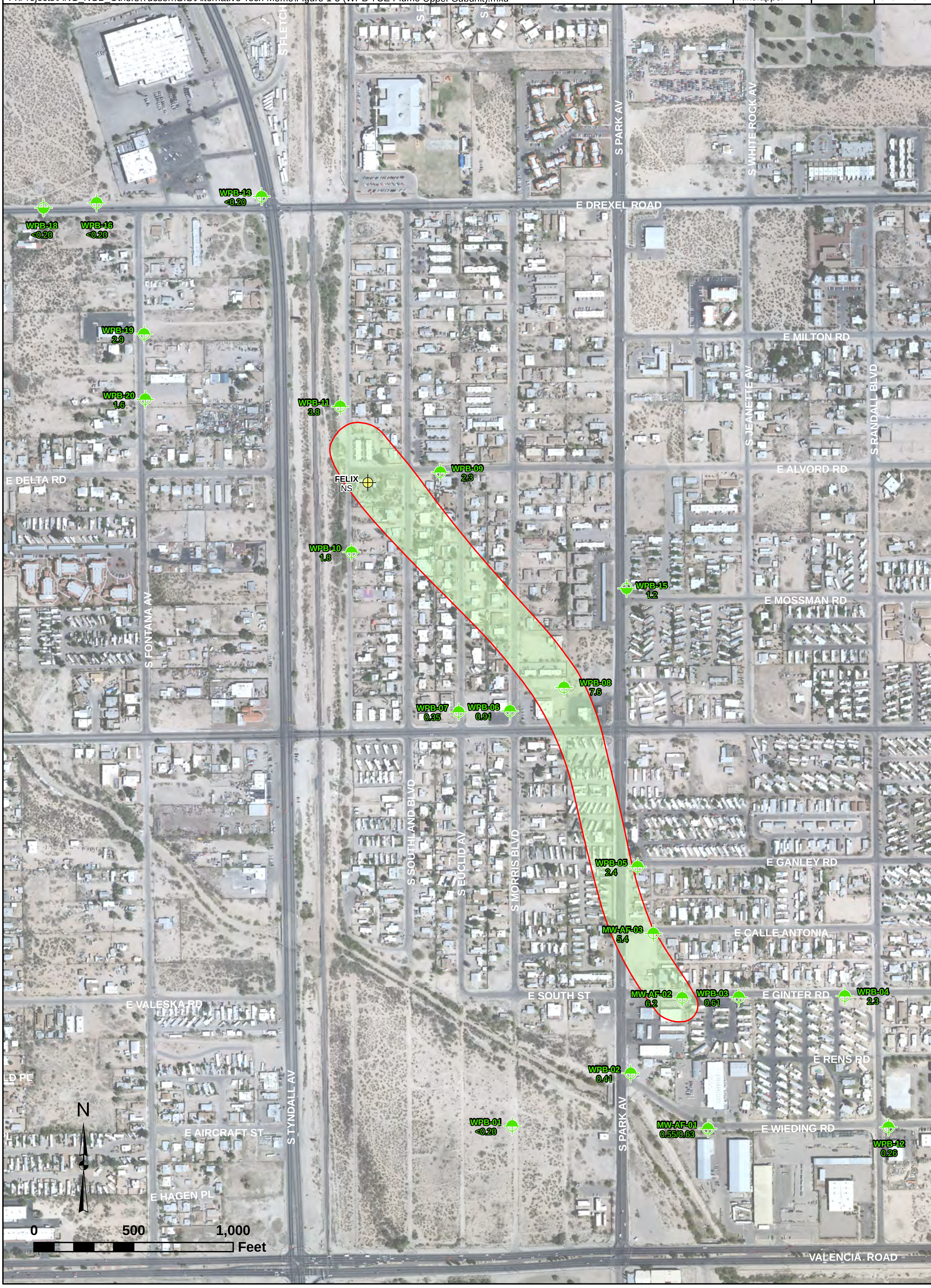
All results in micrograms per liter (µg/L)

Data collected during first quarter 2011

Figure 1-4

Lower Subunit TCE Plume Map
(First Quarter 2011)
162nd Fighter Wing, West Cap,
and Texas Instruments
Tucson International Airport
Area Superfund Site
Tucson, Arizona

File: F:\Projects\ANG_NGB_Others\Tucson\GIS\Alternative Tech Memo\Figure 1-5 (WPB TCE Plume Upper Subunit).mxd	Created By: mike.appel	Date: 06/20/2011	Project: 0131240.4F



Legend

- West Plume B Upper Subunit Monitoring Well
- West Plume B Lower Subunit Monitoring Well
- Private Property Monitoring Well
- MCL Contour (5.0 µg/L)

TCE Concentrations

- 5-10 µg/L

TCE- Trichloroethene

NS- Not Sampled

MCL- Maximum Contaminant Level (5 µg/L)

<0.50- TCE not detected at or above the listed laboratory detection limit

5.8/6.1- Primary Sample Result/Duplicate Result

All results in micrograms per liter (µg/L)

Data collected during first quarter 2011

Figure 1-5

Upper Subunit TCE Plume Map
(First Quarter 2011)
West Plume B
Tucson International Airport
Area Superfund Site
Tucson, Arizona

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Upper Subunit Monitoring/PT Well or Piezometer

Upper Subunit Extraction Well

Recharge Well

Upper Subunit Permanganate Injection Location

Initial Permanganate Concentrations

- 1 ug/L
- 5 ug/L
- 10 ug/L
- 20 ug/L
- 25 ug/L

February 2011 Upper Subunit TCE Plume

- 5-10 ug/L
- 10-15 ug/L
- >15 ug/L

Installation Boundary

Aerial Photo: April 2008

Figure 2-1

Proposed In Situ Chemical Oxidation Design
Upper Subunit
162nd Fighter Wing
Arizona Air National Guard
Tucson, Arizona

06/11

File:
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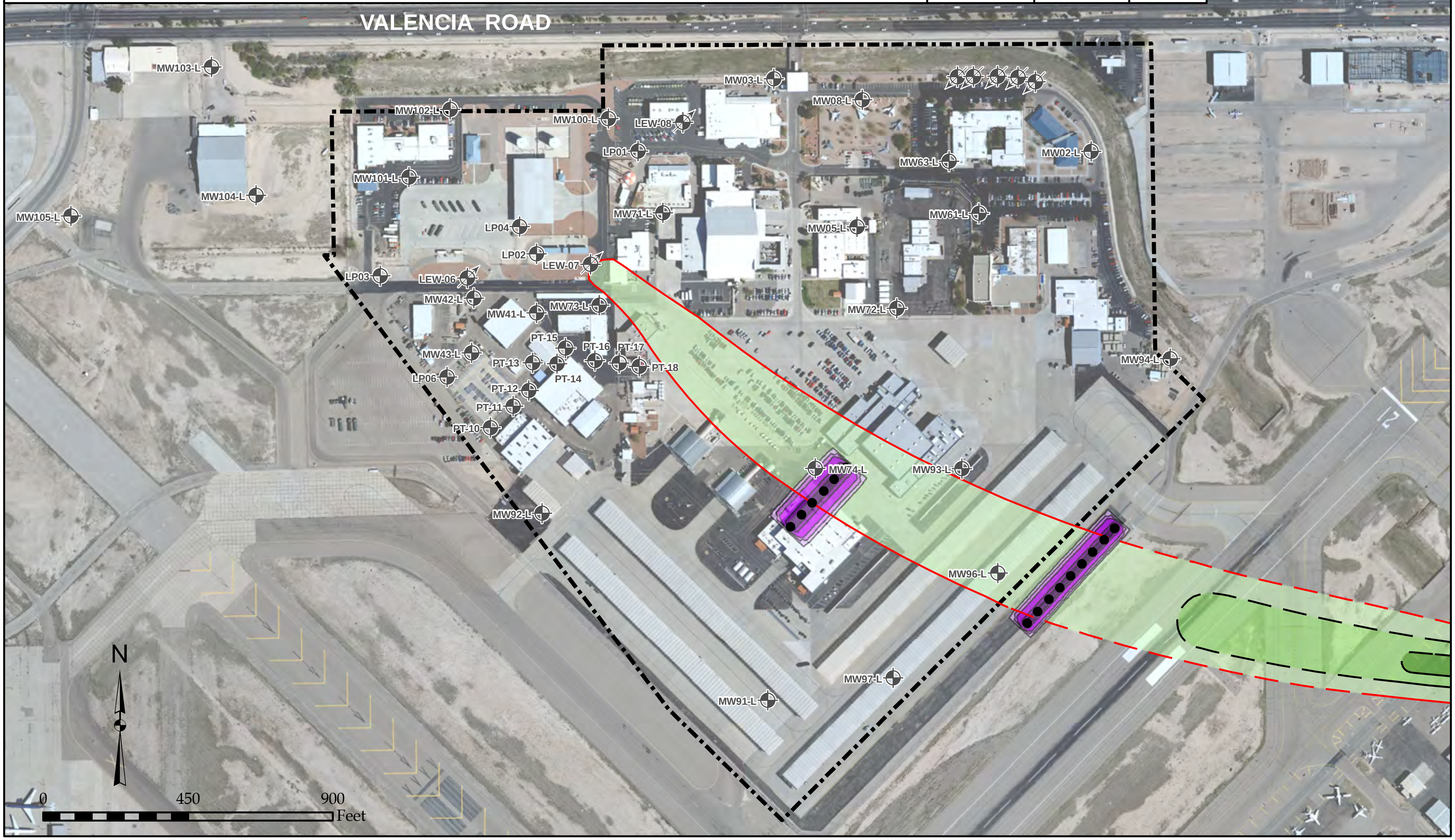


Lower Subunit Monitoring/PT Well or Piezometer
Lower Subunit Extraction Well
Recharge Well
Lower Subunit Permanganate Injection Location

Initial Permanganate Concentrations
- 1 ug/L
- 5 ug/L
- 10 ug/L
- 20 ug/L
- 25 ug/L

February 2011 Lower Subunit TCE Plume
- 5-10 ug/L
- 10-15 ug/L
- > 15 ug/L
- Installation Boundary

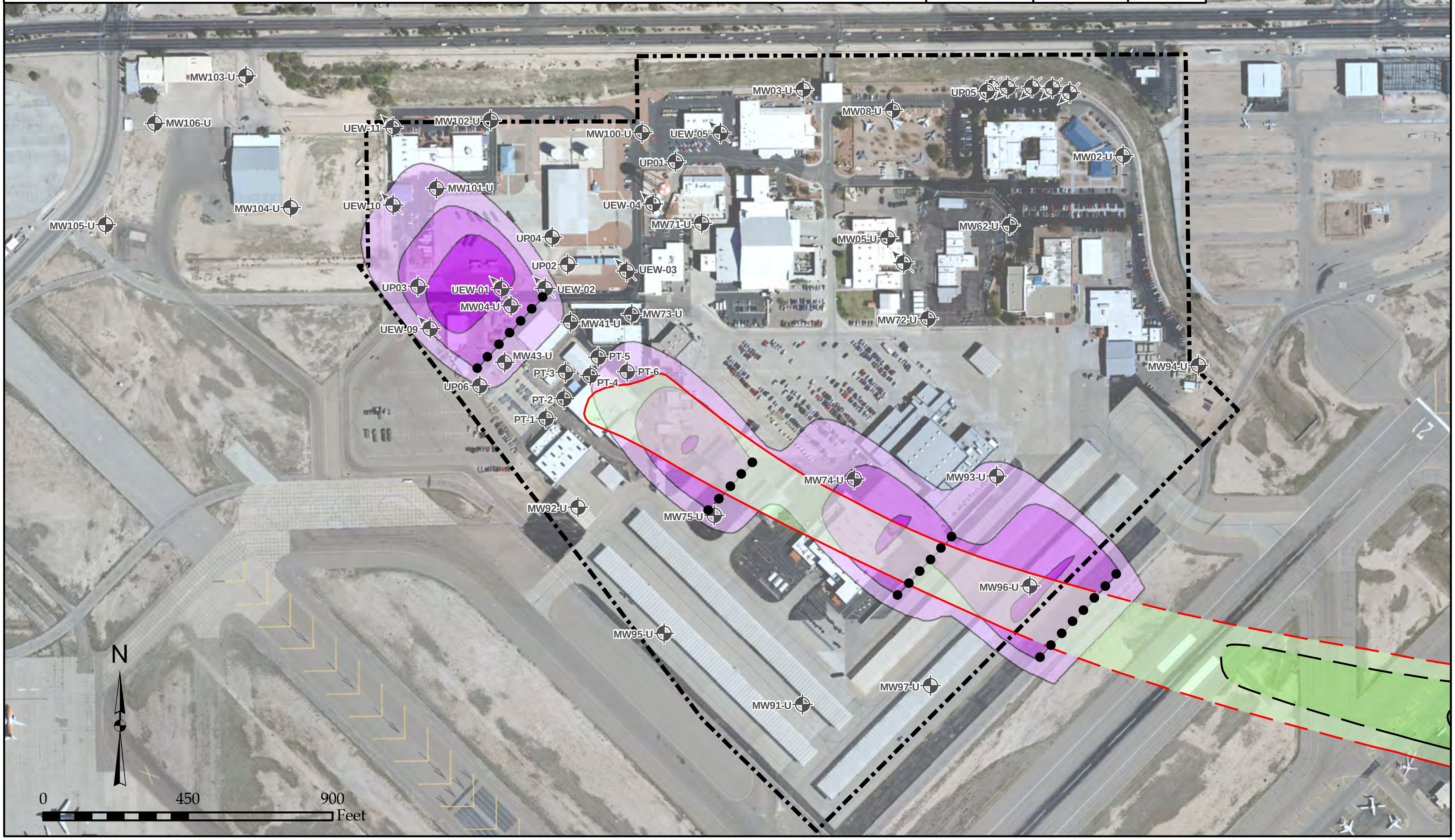
Aerial Photo: April 2008

Figure 2-2

Proposed In Situ Chemical Oxidation Design
Lower Subunit
162nd Fighter Wing
Arizona Air National Guard
Tucson, Arizona

06/11

File: F:\Projects\ANG_NGB_Others\Tucson\GIS\Alternative Tech Memo\Figure 2-3 (Permg5YearUpperRev).mxd	Created By: mike.appel	Date: 06/20/2011	Project: 0131240.4F



Upper Subunit Monitoring/PT Well or Piezometer

Upper Subunit Extraction Well

Recharge Well

Upper Subunit Permanganate Injection Location

Permanganate Concentrations after 5 Years

- 1 ug/L
- 5 ug/L
- 10 ug/L

February 2011 Upper Subunit TCE Plume

- 5-10 ug/L
- 10-15 ug/L
- >15 ug/L
- Installation Boundary

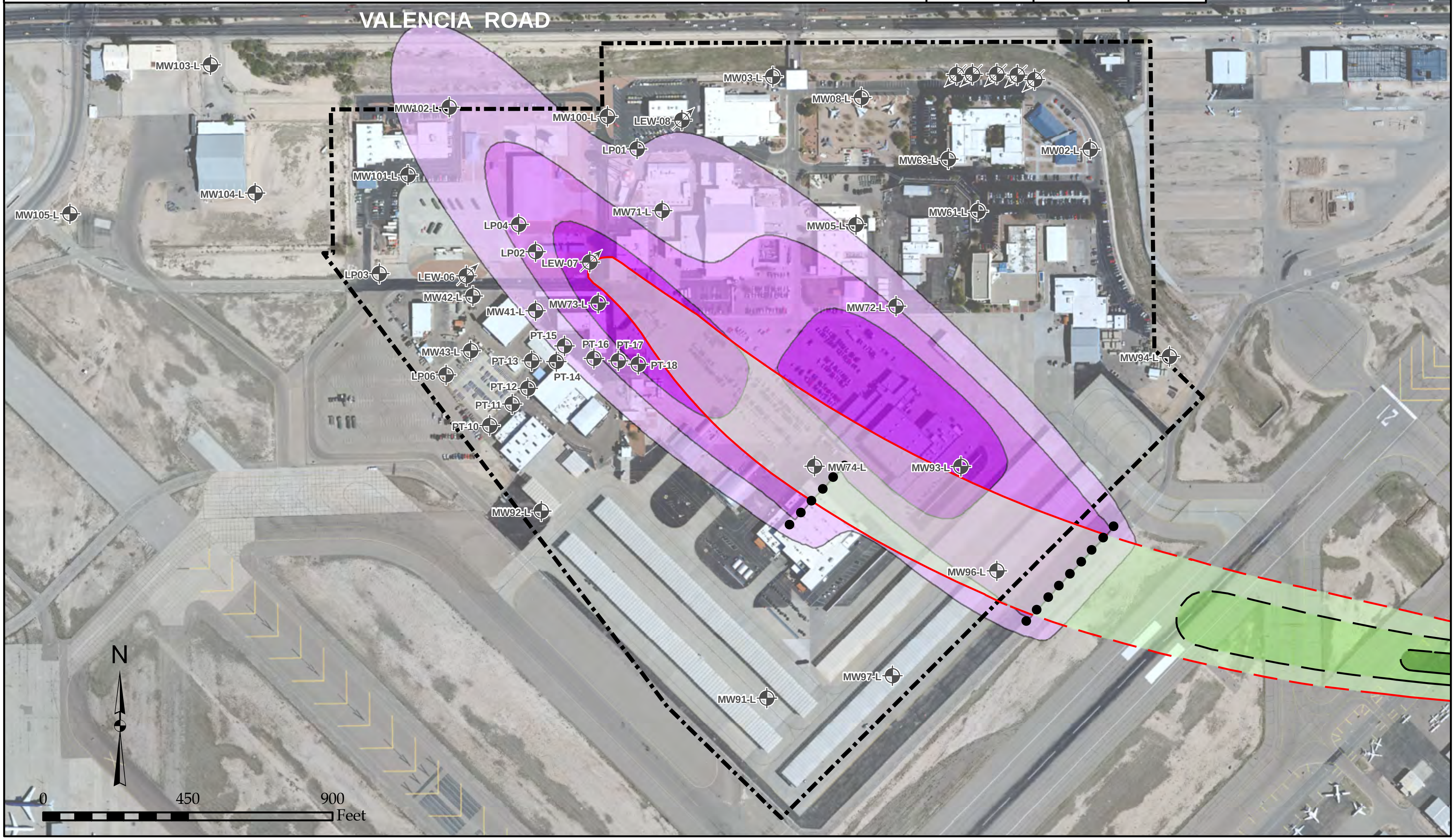
Aerial Photo: April 2008

Figure 2-3

Predicted Potassium Permanganate Distribution
Upper Subunit
5 Years Post-Injection
162nd Fighter Wing
Arizona Air National Guard
Tucson, Arizona

06/11

File: F:\Projects\ANG_NGB_Others\Tucson\GIS\Alternative Tech Memo\Figure 2-4 (Permg5YearLowerRev).mxd	Created By: mike.appel	Date: 06/20/2011	Project: 0131240.4F



Lower Subunit Monitoring/PT Well or Piezometer

Lower Subunit Extraction Well

Recharge Well

Lower Subunit Permanganate Injection Location

Permanganate Concentrations After 5 Years

- 1 ug/L
- 5 ug/L
- 10 ug/L

February 2011 Lower Subunit TCE Plume

- 5-10 ug/L
- 10-15 ug/L
- >15 ug/L

Installation Boundary

Aerial Photo: April 2008

Figure 2-4

Predicted Potassium Permanganate Distribution
Lower Subunit
5 Years Post-Injection
162nd Fighter Wing
Arizona Air National Guard
Tucson, Arizona

06/11

File:
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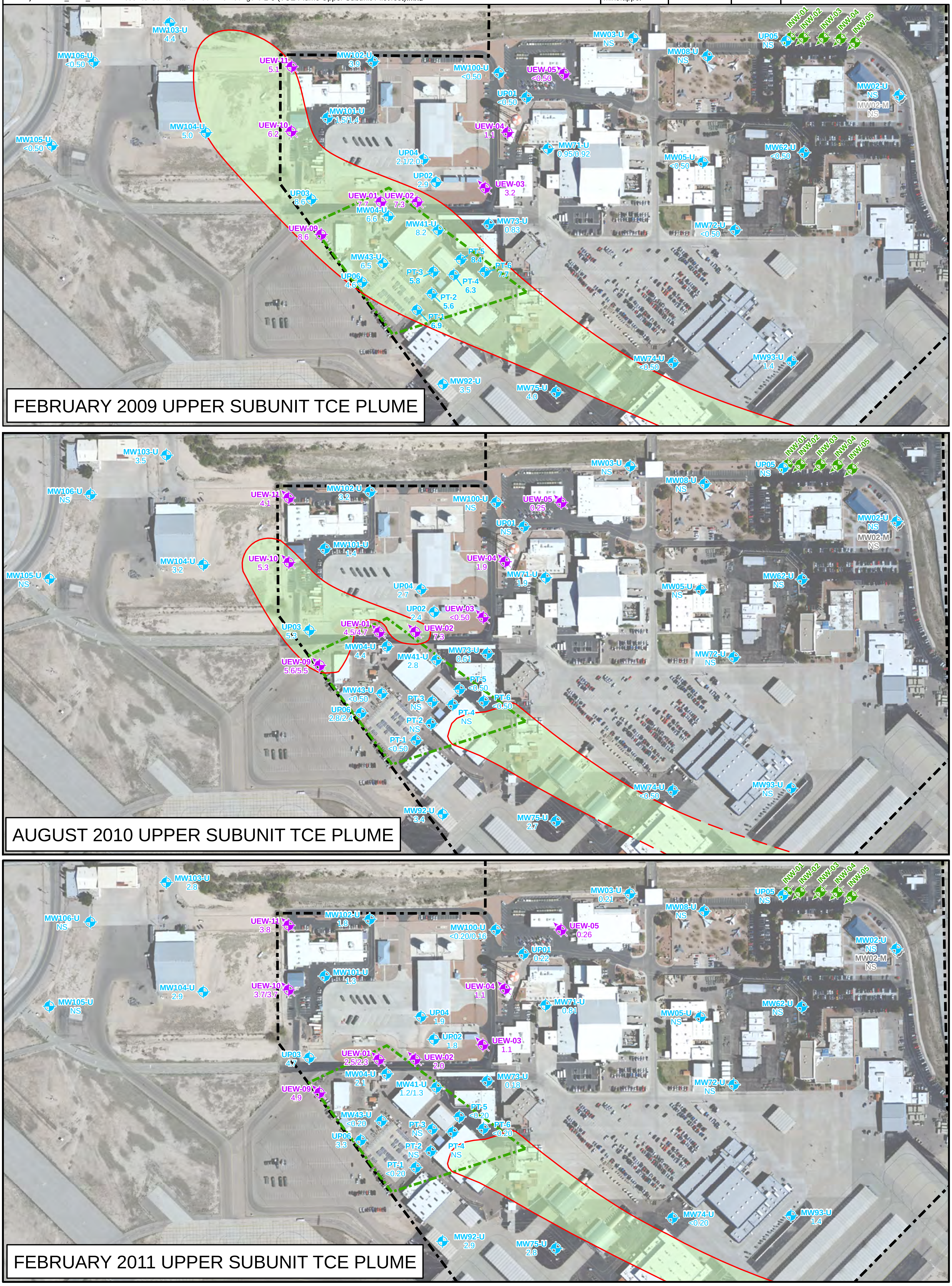

Legend

- 162nd Fighter Wing (FW) Upper Subunit Monitoring Well, Piezometer, or Pilot Test Well
- 162nd FW Middle Subunit Monitoring Well
- 162nd FW Upper Subunit Extraction Well
- 162nd FW Recharge Well
- Pilot Test Area
- Facility Boundary

TCE Concentrations
- 5-10 µg/L
- 10-15 µg/L
- 15-100 µg/L
- MCL Contour (5.0 ug/l)
- MCL Contour (5.0 ug/l) - Inferred

N

0 350 700 Feet

Figure 2-5
Upper Subunit TCE Plume
162nd Fighter Wing Pilot Test Area
Tucson International Airport
Area Superfund Site
Tucson, Arizona

06/11

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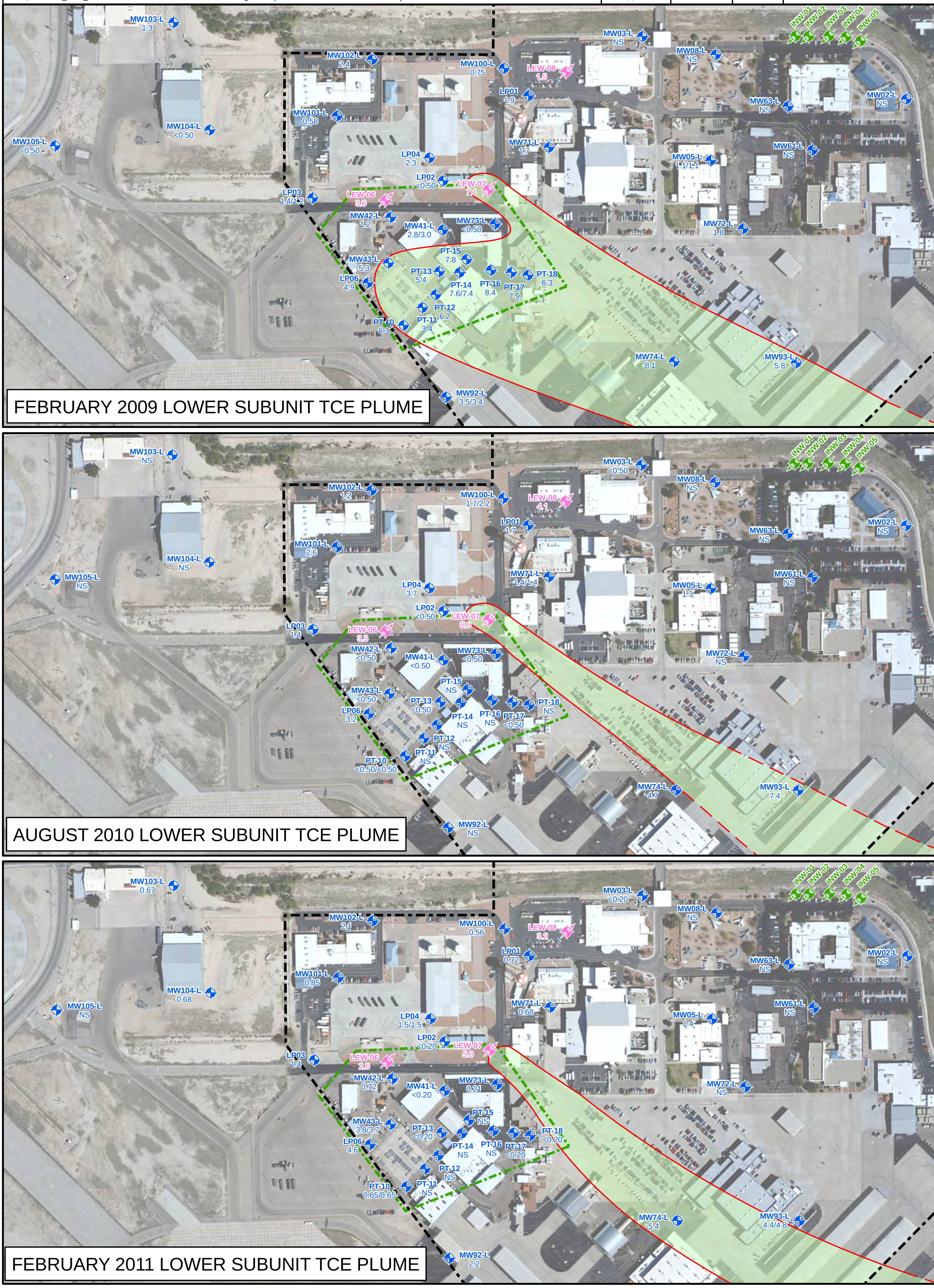

Legend

- 162nd Fighter Wing (FW) Lower Subunit Monitoring Well, Piezometer, or Pilot Test Well
- 162nd FW Lower Subunit Extraction Well
- 162nd FW Recharge Well
- Pilot Test Area
- Facility Boundary

TCE Concentrations
- 5-10 µg/L
- 10-15 µg/L
- 15-100 µg/L
- MCL Contour (5.0 µg/L)
- MCL Contour (5.0 µg/L) - Inferred

0 350 700 Feet

N

Figure 2-6
Lower Subunit TCE Plume
162nd Fighter Wing Pilot Test Area
Tucson International Airport
Area Superfund Site
Tucson, Arizona

06/11

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- PRB Injection Points
- Upper Subunit Monitoring/PT Well or Piezometer
- Upper Subunit Extraction Well
- Recharge Well

February 2011 Upper Subunit TCE Plume

- 5-10 ug/L
- 10-15 ug/L
- >15 ug/L
- Installation Boundary

Aerial Photo: April 2008

Figure 2-7

Proposed Permeable Reactive Barrier Design
Upper Subunit
162nd Fighter Wing
Arizona Air National Guard
Tucson, Arizona

06/11

File:
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- PRB Injection Points
- Lower Subunit Monitoring/PT Well or Piezometer
- Lower Subunit Extraction Well
- Recharge Well
- Base Well

February 2011 Lower Subunit TCE Plume

- 5-10 ug/L
- 10-15 ug/L
- >15 ug/L
- Installation Boundary

Aerial Photo: April 2008

Figure 2-8

Proposed Permeable Reactive Barrier Design
Lower Subunit
162[nd] Fighter Wing
Arizona Air National Guard
Tucson, Arizona

06/11

TABLES

TABLE 2-1

Estimated Costs for Alternative 1
Extraction and Treatment
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Category	Total Cost
Direct Capital Costs	
Updated Groundwater Monitoring Work Plan	$30,000
Updated Operations and Maintenance Manual	$15,000
Groundwater Extraction, Treatment and Recharge System Upgrades[1]	$200,000
Direct Capital Costs	**$245,000**
Indirect Capital Costs	
Contractor Overhead and Profit (15% of Total Direct Costs)	$36,750
Engineering and Oversight (15% of Total Direct Costs)	$36,750
H&S Costs (3% of Total Direct Costs)	$7,350
Project Management and Administration Costs (10% of Total Direct Costs)	$24,500
Indirect Capital Cost	**$105,350**
Annual Costs	
Operations and Maintenance	$213,000
Groundwater Monitoring	$150,000
Reporting[2]	$100,000
Meetings[3]	$75,000
Groundwater Modeling	$45,000
Arizona Department of Environmental Quality Annual Database Update	$20,000
Replacement Cost (7% of Total Direct Costs)	$17,150
Annual Costs (22 years)	**$620,150**
Total Undiscounted Operations and Maintenance Costs (22 years)	**$13,643,300**
NPV Annual Costs (22 years at 4% discount rate)	**$8,961,859**
Total Costs for Alternative 1 (Net Present Value)	**$9,312,209**

Assumptions:

[1]Groundwater Extraction, Treatment, and Recharge System Upgrades includes replacement of the programmable logic controller, the effluent air heater, transfer pumps, etc.

[2]Annual costs for reporting includes semi-annual groundwater monitoring and remedial progress reports; operations and maintenance manual update reports; monthly progress reports; and updated Work Plans

[3]Annual costs for meetings includes Unified Community Advisory Board meetings, project meetings, and Annual Technical Exchange meetings

TABLE 2-2
Estimated Costs for Alternative 2
Monitored Natural Attenuation
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Category	Total Cost
Direct Capital Costs	
Monitored Natural Attenuation Work Plan	$30,000
Sampling Equipment Costs	$5,000
Monitoring Well Installation and Development (3 upper, 3 lower)	$180,000
Laboratory Analysis (geochemical soil and groundwater samples)	$2,000
Direct Capital Costs	**$217,000**
Indirect Capital Costs	
Contractor Overhead and Profit (15% of Total Direct Costs)	$32,550
Engineering and Oversight (15% of Total Direct Costs)	$32,550
H&S Costs (3% of Total Direct Costs)	$6,510
Project Management and Administration Costs (10% of Total Direct Costs)	$21,700
Indirect Capital Cost	**$93,310**
Annual Costs	
Groundwater Monitoring	$150,000
Reporting[1]	$100,000
Meetings[2]	$75,000
Groundwater Modeling	$45,000
Arizona Department of Environmental Quality Annual Database Update	$20,000
Annual Costs (22 years)	**$240,000**
Total Undiscounted Operations and Maintenance Costs (22 years)	**$5,280,000**
NPV Annual Costs (22 years at 4% discount rate)	**$3,468,268**
Total Costs for Alternative 2 (Net Present Value)	**$3,778,578**

Assumptions:

[1]Annual costs for reporting includes semi-annual groundwater monitoring and remedial progress reports; operations and maintenance manual update reports; monthly progress reports; and updated Work Plans

[2]Annual costs for meetings includes Unified Community Advisory Board meetings, project meetings, and Annual Technical Exchange meetings

TABLE 2-3

Estimated Costs for Alternative 3
In Situ Chemical Oxidation
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Category	Total Cost
Direct Capital Costs	
Design/Work Plan	$30,000
Installation and fracturing of injection wells	$1,530,000
Direct Capital Costs	**$1,560,000**
Indirect Capital Costs	
Contractor Overhead and Profit (15% of Total Direct Costs)	$234,000
Engineering and Oversight (15% of Total Direct Costs)	$234,000
H&S Costs (3% of Total Direct Costs)	$46,800
Project Management and Administration Costs (10% of Total Direct Costs)	$156,000
Indirect Capital Cost	**$514,800**
Annual Costs	
Groundwater Monitoring	$150,000
Reporting[1]	$100,000
Meetings[2]	$75,000
Groundwater Modeling	$45,000
Arizona Department of Environmental Quality Annual Database Update	$20,000
Replacement Cost (7% of Total Direct Costs)	$109,200
Annual Costs (7 years)	**$499,200**
Total Undiscounted Operations and Maintenance Costs (7 years)	**$3,494,400**
NPV Annual Costs (20 years at 4% discount rate)	**$2,996,226**
Total Costs for Alternative 3 (Net Present Value)	**$5,071,026**

Assumptions:

[1]Annual costs for reporting includes semi-annual groundwater monitoring and remedial progress reports, operations and maintenance manual update reports; monthly progress reports; and updated Work Plans

[2]Annual costs for meetings includes Unified Community Advisory Board meetings, project meetings, and Annual Technical Exchange meetings

FINAL

TABLE 2-4

Estimated Costs for Alternative 4
Permeable Reactive Barrier
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Category	Total Cost
Direct Capital Costs	
Permeable Reactive Barrier (PRB) Design/Work Plan	$100,000
PRB Installation	$8,000,000
Monitoring Well Installation and Development (6 upper, 6 lower)	$180,000
PRB Construction Completion Report	$15,000
Direct Capital Costs	**$8,295,000**
Indirect Capital Costs	
Contractor Overhead and Profit (15% of Total Direct Costs)	$1,244,250
Engineering and Oversight (15% of Total Direct Costs)	$1,244,250
H&S Costs (3% of Total Direct Costs)	$248,850
Project Management and Administration Costs (10% of Total Direct Costs)	$829,500
Indirect Capital Cost	**$3,566,850**
Annual Costs	
Groundwater Monitoring	$150,000
Reporting[1]	$100,000
Meetings[2]	$75,000
Groundwater Modeling	$45,000
Arizona Department of Environmental Quality Annual Database Update	$20,000
5% Maintenance of PRB (Years 11-20)	$50,000
Annual Costs (Years 1-10)	**$390,000**
Annual Costs (Years 11-20)	**$440,000**
Annual Costs (Years 21-22)	**$390,000**
Total Undiscounted Operations and Maintenance Costs (22 years)	**$9,080,000**
NPV Annual Costs (22 years at 4% discount rate)	**$5,909,907**
Total Costs for Alternative 4 (Net Present Value)	**$17,771,757**

Assumptions:

[1]Annual costs for reporting includes semi-annual groundwater monitoring and remedial progress reports; monthly progress reports; and updated Work Plans

[2]Annual costs for meetings includes Unified Community Advisory Board meetings, project meetings, and Annual Technical Exchange meetings

TABLE 2-5
Comparative Analyses Summary
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

NCP Evaluation Criteria	*A1*	*A2*	*A3*	*A4*
Overall Protection of Human Health and the Environment	*	**	*	**
Compliance with ARARs	**	***	*	**
Long-Term Effectiveness and Permanence	*	*	*	*
Reduction of Mobility, Toxicity, or Volume	*	**	*	*
Short-Term Effectiveness	*	***	*	**
Implementability	*	*	**	**
Cost	***	*	*	***

Notes:
ARARs = Applicable or Relevant and Appropriate Requirements
NCP = National Oil and Hazardous Substances Pollution Contingency Plan
A1 = Alternative 1 – Extraction and Treatment
A2 = Alternative 2 – Monitored Natural Attenuation
A3 = Alternative 3 – In Situ Chemical Oxidation
A4 = Alternative 4 - Permeable Reactive Barrier

Relative performance of remedy:
- * = alternative effectively satisfies criterion
- ** = alternative moderately satisfies criterion
- *** = alternative poorly satisfies criterion

APPENDIX A

EVALUATION OF APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

APPENDIX A

APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

Section 121(d) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) states that remedial actions on CERCLA sites must attain (or justify the waiver of) any Federal or more stringent State environmental standards, criteria, or limitations that are determined to be legally applicable or relevant and appropriate requirements (ARARs). Applicable requirements are those cleanup standards, criteria, or limitations promulgated under Federal or State law that specifically address the situation at a CERCLA site. A requirement is applicable if the jurisdictional prerequisites of the environmental standard show a direct correspondence when objectively compared with the conditions at the site.

If a requirement is not legally applicable, the requirement is evaluated to determine whether it is relevant and appropriate. Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or State law that, while not applicable, address problems or situations sufficiently similar to the circumstances of the proposed response action and are well suited to the conditions of the site. The criteria for determining relevance and appropriateness are listed in Title 40, Code of Federal Regulations (CFR), Section 300.400(g)(2) (40 CFR 300.400[g][2]).

ARARs are concerned only with substantive, not administrative, requirements of a statute or regulation. The substantive portions of the regulation are those requirements that pertain directly to actions or conditions in the environment. Examples of substantive requirements include quantitative health- or risk-based restrictions upon exposure to types of hazardous substances. Administrative requirements are the mechanisms that facilitate implementation of the substantive requirements. Administrative requirements include issuance of permits, documentation, reporting, record-keeping, and enforcement. Thus, in determining the extent to which on-site CERCLA response actions must comply with environmental laws, a distinction should be made between substantive requirements — which may be ARARs — and administrative requirements — which are not.

Furthermore, the ARARs provision in CERCLA applies to on-site actions. "On-site" is defined as the areal extent of contamination and includes the groundwater plumes to be remediated. According to CERCLA §121(e), a remedial response action that takes place entirely on-site may proceed without obtaining permits. This permit exemption applies to all administrative requirements, as well as to permits. Actions taken off-site will need to comply with the substantive, as well as the administrative, requirements of all applicable regulations.

Pursuant to the United States Environmental Protection Agency (EPA) guidance, ARARs generally are classified into three categories: chemical-specific, location-specific, and action-specific requirements. This classification was developed to help identify ARARs, some of which do not fall precisely into one group or another.

Definitions for these categories of ARARs are listed below:

- Chemical-Specific ARARs: laws and requirements that regulate the release to the environment of materials possessing certain chemical or physical characteristics or containing specified chemical compounds. These requirements generally set health- or risk-based concentration limits or discharge limitations for specific hazardous substances. If, in a specific situation, a chemical is subject to more than one discharge or exposure limit, the more stringent of the requirements generally should be applied;

- Location-Specific ARARs: requirements that relate to the geographical or physical position of the site, rather than the nature of the contaminants or the proposed site remedial actions. These requirements may limit the placement of remedial action facilities, and may impose additional constraints on the cleanup action; and

- Action-Specific ARARs: requirements that define acceptable handling, treatment, and disposal procedures for hazardous substances. These ARARs generally set performance, design, or other similar action-specific controls or restrictions on particular kinds of activities related to management of hazardous substances or pollutants. These requirements are triggered by the particular remedial activities that are selected to accomplish a remedy. Because site remediation usually involves several alternative actions, very different action-specific requirements can apply.

A requirement might not meet the definition of an ARAR as defined above, but could still be useful in determining whether to take action at a site and/or to what degree action is necessary. This can be particularly true when there are no ARARs for a site or a particular contaminant. Such requirements are called to-be-considered (TBC) requirements. TBC materials are non-promulgated advisories or guidance documents issued by Federal or State government that are not legally binding, but that may provide useful information or recommended procedures for remedial action. Although TBCs do not have the status of ARARs, they may be considered together with ARARs as part of the site risk assessment to establish the required level of cleanup for protection of human health and the environment.

The following list summarizes the remedial alternatives retained from the initial screening of alternatives that are considered in this ARARs analysis:

- Alternative 1 – Continued Extraction and Treatment;
- Alternative 2 – Monitored Natural Attenuation;
- Alternative 3 – In Situ Chemical Oxidation; and
- Alternative 4 – Permeable Reactive Barrier.

A.1 Statutes Evaluation

Federal and State statutes examined as potential ARARs for the 162nd Fighter Wing (FW), Arizona Air National Guard, Tucson International Airport Area Superfund Site (TIAA) in Tucson, Arizona are listed in Table A-1. ARARs and TBCs are identified at various points throughout the Superfund process.

These criteria are identified on a site-specific basis and, therefore, as additional information is developed regarding the site — including special features of the site location, the specific chemicals at the site, and the actions being considered as remedies — more ARARs may be progressively identified, and the list of potential ARARs further refined.

A.2 Chemical-Specific ARARs

Chemical-specific ARARs for commonly-detected organic compounds at the 162nd FW are summarized in Table A-2. Inorganic compounds are not considered contaminants of concern for the 162nd FW. The major statutes and regulations that contribute to the list of potential chemical-specific ARARs are the Safe Drinking Water Act (SDWA), the Arizona Water Quality Standards (A.A.C Title 18, Chapter 11), and the Arizona Soil Remediation Levels (A.A.C, Title 18, Chapter 7). If an Arizona Water Quality Standard (AWQS) does not exist for a specific compound, the Arizona Department of Environmental Quality (ADEQ) Human Health-Based Guidance Levels for Contaminants in Drinking Water (HBGL) are TBCs. The chemical-specific ARARs that have been evaluated are those that 1) affect groundwater and vadose zone remedial goals, and 2) determine to what degree groundwater and the vadose zone should be treated prior to discharge.

The SDWA maximum contaminant level (MCL) standards are formulated to protect water for human consumption (i.e., drinking, cooking, bathing, and other water contact activities). Economic issues and technical feasibility of treatment processes are considered in the establishment of these levels. MCLs are applicable to the quality of drinking water at the tap pursuant to the SDWA, and are ARARs for treated groundwater when the end use is human consumption. Pursuant to 40 CFR Section 300.430(e)(2)(i)(B), MCLs and non-zero maximum contaminant level goals (MCLGs) are relevant and appropriate as in situ aquifer standards for groundwater that are or may be used for drinking water. The MCLs and non-zero MCLGs are presented in Table A-3. The State of Arizona has adopted the Federal MCLGs and MCLs by reference, as stated in §R18-4-108 and 109. The MCL for TCE is 5 micrograms per liter (μg/L).

The AWQSs (AAC §R18-11-401 et seq.) are standards developed to protect groundwater by preventing discharges of pollutants above certain concentrations to aquifers that endanger human health, or that impair the uses of the aquifer. The AWQSs applied to aquifers classified as sources of drinking water for the primary contaminants of concern are currently identical to the Federal SDWA MCLs. In Arizona, all aquifers are identified as drinking water aquifers unless specifically exempt. As is the case with MCLs, the AWQSs are relevant and appropriate as in situ aquifer cleanup standards for groundwater that may be used for drinking water at the 162nd FW.

TBCs that may be considered at the 162nd FW include the ADEQ HBGLs. These levels, although set forth in Arizona regulations, are not "promulgated" in the sense of being legally enforceable and generally applicable. They might be useful TBCs for determining potential cleanup levels for groundwater at the 162nd FW primarily for compounds that do not have MCLs. Final cleanup standards will be presented in the Record of Decision. The HBGLs for water are included in Table A-3.

Other Chemical-Specific ARARs

Groundwater from CERCLA actions may be treated as non-Resource Conservation and Recovery Act (RCRA) hazardous waste if the waste contains chemicals in concentrations below health-based levels (MCLs) selected by the EPA Region IX as set forth in Table A-3. Treatment-derived water may be subject to certain action-specific ARARs if the wastewater contains contaminants in concentrations above the levels set forth in Table A-3. Although not an ARAR, classification of waste will determine whether wastes are subject to certain action-specific ARARs. As the wastes at the 162nd FW are generally characteristic wastes, most RCRA requirements will be relevant and appropriate (EPA 1971).

A.3 Location-Specific ARARs

Potential location-specific ARARs for the 162nd FW are listed in Table A-4. Location-specific ARARs differ from chemical-specific or action-specific ARARs in that they are not closely related to the characteristics of the wastes at the 162nd FW or to the specific remedial alternative under consideration. Location-specific ARARs are concerned with the area in which the 162nd FW is located. Actions may be required to preserve or protect aspects of the environment or cultural resources of the area that could be threatened by the existence of the 162nd FW or by the remedial actions to be undertaken at the 162nd FW. Final location-specific ARARs will be presented in the Record of Decision.

Construction or remediation activities performed on any lands owned or controlled by the State of Arizona, by any public agency or institution of the state, or by any county or municipal corporation within the state, shall comply with State of Arizona ARARs (41 A.R.S. 841-847.865) establishing procedures for protecting artifacts.

A.4 Action-Specific ARARs

Potential action-specific ARARs considered for the 162nd FW are presented in Table A-5. For each action, a number of potential action-specific ARARs has been identified. A description of the requirements associated with some of the significant potential ARARs, and a discussion of the conditions under which the ARAR would be considered, are included below.

Hazardous Waste Management ARARs Under RCRA

The RCRA is a Federal statute passed in 1976 to meet three goals: the protection of human health and the environment, the reduction of waste and the conservation of energy and natural resources, and the elimination of hazardous waste generation as expeditiously as possible. The Hazardous and Solid Waste Amendments of 1984 significantly expanded the scope of RCRA by adding new corrective action requirements, land disposal restrictions, and technical requirements. Substantive RCRA requirements are applicable to response actions at CERCLA sites if contaminants are characterized as hazardous waste.

Contaminated groundwater at the 162nd FW is not a listed waste. The groundwater is not a characteristic waste because its contaminants are below the levels established for the characteristic of toxicity. Consequently, the RCRA requirements triggered by the hazardous nature of waste are not applicable or relevant and appropriate with respect to the groundwater. For these reasons and because of the EPA's exception for contaminated media, the groundwater that has been treated to health-based standard (i.e., MCLs) would not be an RCRA hazardous waste, and no RCRA requirements would be triggered.

Specific RCRA requirements may be considered relevant and appropriate and may be considered during remedial design. The RCRA requirements may be applicable to residues generated as a result of groundwater treatment (e.g., contaminated carbon) and are classified as hazardous waste. The RCRA program is a delegable program: the states may manage the program in lieu of the EPA if State statutes and regulations are equivalent to or more stringent than Federal statutes and regulations. In some cases, the applicable or relevant and appropriate RCRA requirement will be cited as State law and, in other cases, as Federal law. Some of the RCRA requirements that may be considered applicable or relevant and appropriate are:

- Storage - The substantive storage requirements of RCRA's regulations found in 40 CFR 264, as incorporated into or modified by AAC R18-8-264, may be relevant and appropriate to the storage of hazardous wastes generated on-site, such as contaminated carbon. This includes requirements for container storage, secondary containment, and leak detection. Any off-site storage of hazardous wastes would be subject to administrative requirements, as well; and

- Disposal - The substantive disposal requirements of RCRA's regulations found in 40 CFR 264, as incorporated into or modified by AAC R18-8-264, may be relevant and appropriate to the disposal of hazardous wastes generated on-site, such as contaminated carbon. This includes requirements for notification, disposal methods, and transport.

A.5 Groundwater Extraction and Injection ARARs

Federal regulations that govern underground injection programs are found in 40 CFR 144.12 and 144.13. According to these regulations, the injection of treated groundwater cannot allow movement of contaminants into underground sources of drinking water, which may result in violations of MCLs or adversely affect health. Re-injection of treated groundwater into the same formation from which it was drawn is allowed as part of a CERCLA corrective action.

If treated groundwater is re-injected into an aquifer, substantive permit requirements will need to be issued by the Arizona Department of Water Resources and ADEQ concerning recharge, poor quality groundwater withdrawal, and well installation. The substantive requirements of the Arizona Aquifer Protection Permits (ARS §49-241, et seq. and AAC §R18-9-101 et seq.) will be relevant and appropriate to alternatives requiring recharge or re-injection at the 162^{nd} FW. The Arizona Aquifer Protection Permits program requires that any discharges to the aquifer must not cause or contribute to a violation of AWQSs. ARS §49-241Arizona's state

Superfund program, known as the Water Quality Assurance Revolving Fund (WQARF), provides for cleanup of hazardous substances in groundwater. (ARS § 49-281 et seq.) Section 49-282.06 of the WQARF requires groundwater remedial actions to ensure the protection of public health, welfare, and the environment; to manage and cleanup hazardous substances, to the extent practicable, so as to allow for the maximum beneficial uses of the waters of the state; and to be reasonable, necessary, cost-effective, and technically feasible. These criteria are very similar to criteria applicable to response actions under CERCLA and the National Contingency Plan (NCP). Those authorities require that remediations be protective of human health and the environment, meet ARARs, and consider advancing numerous other factors, including long-term permanence; the reduction of toxicity, mobility, or volume; implementability; and cost-effectiveness. In addition, the NCP requires that groundwater remedial actions generally attain Federal MCLs and non-zero MCLGs, where relevant and appropriate, and that developed remedial alternatives take into account the expectation that the remedial action will return groundwater to its beneficial uses wherever practicable within a reasonable timeframe for the site circumstances.

The WQARF provisions do not appear to be more stringent than those in the NCP and, therefore, are not ARARs. Nonetheless, any remedy the EPA selects will meet the WQARF statutory criteria by meeting the NCP requirements.

A.6 Air Emissions Requirements

The Federal Clean Air Act, 40 CFR 7401, et seq., implemented through its regulations at 40 CFR Parts 50-99, establish National Ambient Air Quality Standards (NAAQS), New Source Performance Standards, and Hazardous Air Pollutant Standards. The NSPs and Hazardous Air Pollutant Standards are not ARARs for the 162nd FW because neither of the standards applies to the types of treatment being evaluated at the 162nd FW. The Clean Air Act's NAAQS are not ARARs because they are not enforceable as applied to individual sources. Rather, the NAAQS are implemented through State Implementation Plans. The alternative for extraction and treatment evaluates the pump-and-treat system currently in operation at the 162nd FW, which generates emissions via air stripper treatment. Some requirements of the Pima County Implementation Plan may be potential ARARs, which are as follows:

- Permits and Permit Revisions — Specifies general requirements for major sources of air emissions. Major sources are defined as those sources capable of emitting 100 tons per year or more of any regulated air pollutant. The proposed groundwater treatment sites are not expected to be a major source of VOC emissions; however, if this limitation is exceeded, emission of VOCs to the atmosphere must be reduced by specified methods, including incineration, adsorption, or other processes not less effective than incineration or adsorption. Title 17 also includes efficiency requirements for the reduction process, and monitoring and testing requirements for VOC emissions;

- Performance Tests — Establishes performance testing requirements for owners and operators of stationary sources to determine compliance with emission standards; and

- Open Fugitive Dust Emissions — This regulation may apply to construction of the treatment system. It imposes limits on the emission of particulate matter for any action, including construction activities that can cause open fugitive dust emissions. This regulation is applicable only for the treatment alternatives that require construction of conveyance pipelines associated with the end use options.

TABLE A-1

Evaluation of Federal, State, and Local Statutes
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Federal Requirements
Clean Water Act
Safe Drinking Water Act
Clean Air Act
Comprehensive Environmental Response, Compensation, and Liability Act
Resource Conservation and Recovery Act
Superfund Amendments and Reauthorization Act
National Archaeological and Historic Preservation Act
Endangered Species Act
Fish and Wildlife Coordination Act
Executive Order on the Protection of Wetlands
Executive Order on the Protection of Flood Plains
Federal Aviation Administration
National Historic Preservation Act
Migratory Bird Treaty Act

State and Local Requirements
Pima County Code (Titles 7, 13, and 17)
Arizona Revised Statutes (Title 49, The Environment)
Arizona Administrative Code (Title 18, Environmental Quality)
Arizona Human Health-Based Guidance Levels for Contaminants in Drinking Water

Note:

Only Federal, State, and local statues applicable to the Alternatives Analysis for the 162nd Fighter Wing (FW) were evaluated for potential Applicable or Relevant and Appropriate Requirements (ARARs). Final ARARs and To-Be-Considered Requirements (TBCs) for the selected remedial actions for groundwater at the 162nd FW will be identified in the forthcoming Record of Decision Amendment.

TABLE A-2

Chemical-Specific ARARs
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Source	*Standard, Requirement, Criteria, or Limitation*	*Applicable or Relevant and Appropriate Requirements*	*Description of Standard, Requirement, Criteria, or Limitation*	*Manner in Which ARAR Applies to Alternative*
Federal Safe Drinking Water Act, 42 U.S.C. Sec. 300g-1, 40 CFR 141.161	40 CFR Part 141 (Subparts B, C, G), Federal Primary Drinking Water Standards-MCLs	Applicable	MCLs are health-based drinking water standards to protect public health from contamination that may be found in drinking water from public water systems. The NCP, 40 CFR §300.430(e)(2)(i)(B), provides that remedial actions generally must attain MCLs and non-zero MCLGs where groundwater is a source or potential source of drinking water.	The cleanup levels for the VOCs in the aquifer are set at Federal MCLs. The selected remedy will comply with these requirements.
Arizona Clean Water Act	Arizona Aquifer Water Quality Standards, R18-11-405, R18-11-406	Applicable	Sets chemical-specific narrative and numeric groundwater standards.	Narrative standard prohibits discharges to groundwater (as would result from injection) that would cause a pollutant to be present above a numeric standard in an aquifer classified for drinking water. The numeric standards are ARARs with respect to any discharges, but are not in situ standards.

TABLE A-2

Chemical-Specific ARARs
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Source	*Standard, Requirement, Criteria, or Limitation*	*Applicable or Relevant and Appropriate Requirements*	*Description of Standard, Requirement, Criteria, or Limitation*	*Manner in Which ARAR Applies to Alternative*
Arizona Soil Remediation Standards	A.A.C Title 18-7-205	Relevant and Appropriate	Provides residential and non-residential soil remediation standards for remedial actions.	Soil affected by the groundwater must meet the non-residential SRLs.

Notes:

ARAR = Applicable or Relevant and Appropriate Requirement

CFR = Code of Federal Regulations

MCL = Maximum Contaminant Level

MCLG = Maximum Contaminant Level Goal

NCP = National Contingency Plan

SRL = Soil Remediation Level

VOC = Volatile Organic Compound

TABLE A-3

Potential Chemical-Specific Groundwater ARARs and TBCs
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Parameter	ARAR		TBC
	Primary MCL[a]	MCLG[b]	HBGL[c] for Water
Organics			
1,1-Dichloroethene	7	7	0.06
cis-1,2-Dichloroethene	70	70	
Tetrachloroethene (PCE)	5	-	0.7
Trichloroethene (TCE)	5	-	3.2

Notes:
ARAR = Applicable or Relevant and Appropriate Requirement
[a] MCL = Maximum Contaminant Level
[b] MCLG = Maximum Contaminant Level Goal
[c] HBGL = Human Health-Based Guidance Levels are only applicable in the absence of an MCL or Arizona Water Quality Standard (AWQS) (March 1991 Update)
The Arizona AWQSs for 1,1-dichloroethene, cis-1,2-dichloroethene, PCE and TCE, are identical to the Federal MCLs.
TBC = To-Be-Considered Requirement

TABLE A-4

Location-Specific ARARs
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Source	*Standard, Requirement, Criteria, or Limitation*	*Applicable or Relevant and Appropriate Requirements*	*Description of Standard, Requirement, Criteria, or Limitation*	*Manner in Which ARAR Applies to Alternative*
Endangered Species Act, 6 U.S.C. § 1531	50 CFR 200 and 402	Applicable	Establishes procedures for determining presence of endangered and threatened species and their habitats, and for mitigating adverse impacts.	No endangered species have been identified at the site. If any native plants or species are identified as endangered or threatened, impacts of construction or other remedial activities will be mitigated to avoid affecting such species or its habitat.
FAA Rules	AC 150/5300-13	Applicable	Restricts structure heights near airports.	Applies to using a drill rig on-site to drill and construct a monitoring or extraction well.
FAA Rules	AC 150/5370-2C	Applicable	Restricts construction, operation, and emissions that may cause a navigational hazard near airports.	Applicable to emissions from excavation and construction or any operational emissions.
FAA Rules	AC 70/7460-1K, 150/5345-43E	Applicable	Establishes marking and lighting requirements for construction equipment or permanent structures near airports.	Applies to construction of extraction wells on airport property.
FAA Rules	AC 150/5380-5B	Applicable	Sets procedures for debris containment and cleanup during construction and operation on airport property.	Applicable to construction and ongoing operations on airport property.

TABLE A-4

Location-Specific ARARs
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Source	*Standard, Requirement, Criteria, or Limitation*	*Applicable or Relevant and Appropriate Requirements*	*Description of Standard, Requirement, Criteria, or Limitation*	*Manner in Which ARAR Applies to Alternative*
Archaeological Discoveries, Historic Preservation	41 Arizona Revised Statutes ("A.R.S.") §§ 841-847, 865	Applicable	Preserves archaeological artifacts and remains.	If any archaeological artifacts, human remains, or funerary objects are discovered during construction, excavation or other on-site activities, the activity must cease temporarily to allow for investigation and preservation of such artifacts, remains, or objects in accordance with these procedures.

Notes:
ARAR = Applicable or Relevant and Appropriate Requirement
CFR = Code of Federal Regulations
FAA = Federal Aviation Administration

TABLE A-5

Action-Specific ARARs
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Source	*Standard, Requirement, Criteria, or Limitation*	*Applicable or Relevant and Appropriate Requirements*	*Description of Standard, Requirement, Criteria, or Limitation*	*Manner in Which ARAR Applies to Alternative*
Arizona Remedial Action Requirements	ARS § 49-282.06 (A)(2)	Applicable	Treatment of groundwater must be conducted in a way to provide for the maximum beneficial use of the waters of the state.	Maximum beneficial use of the regional aquifer is for drinking water use.
Arizona Groundwater Management Act, ARS Title 45	ARS 45-454.01; 45-494 45-495, 45-496, 45-600	Applicable	The regulation exempts new well construction withdrawal, treatment, and injection wells at CERCLA sites from obtaining ADWR approval to extract groundwater, subject to compliance with certain substantive provisions.	The substantive standards set forth in these sections will be compiled within construction and logging of new wells.
40 CFR Section 262.11; AAC § R18-8-262	40 CFR Section 262.11 and AAC § R18-8-262	Applicable	Regulation of waste from construction & operation of remedial action requires waste generators to determine whether wastes are hazardous and establishes procedures for such determinations.	These requirements are applicable to management of waste materials generated as a result of construction of the selected remedial action or operation of any groundwater treatment units.
Clean Air Act 42 U.S.C. §§ 7401-7671q	40 CFR Part 61, Subparts A and V	Applicable	Controls air emissions of VOCs and gaseous contaminants and requires leak detection and repair programs. Only applies if the equipment is in service of a liquid that contains at least 10% volatile hazardous air pollutant, such as TCE.	Requires reduction in, leak detection, and repair programs for VOC emissions from product accumulator vessels.
RCRA Subtitle C; ARS §49-921 *et seq*.	40 CFR Part 264, Subpart I and R18-8-264.170 *et seq.*	Relevant and Appropriate	Establishes requirements for containers holding RCRA hazardous waste for treatment, storage or disposal including condition, management, and inspection of containers, container compatibility with wastes and design and operation of container storage areas.	Containers storing treatment system waste (e.g. GACs or other RCRA waste) must comply with substantive provisions.

TABLE A-5

Action-Specific ARARs
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Source	*Standard, Requirement, Criteria, or Limitation*	*Applicable or Relevant and Appropriate Requirements*	*Description of Standard, Requirement, Criteria, or Limitation*	*Manner in Which ARAR Applies to Alternative*
RCRA Subtitle C; ARS §49-921 et seq.	40 CFR Part 264, Subpart J and R18-8-264.190 et seq.	Relevant and Appropriate	Establishes requirements for tank systems used to store or treat hazardous waste, including design and installation, containment and detection of releases, operating requirements, inspections, responses to leaks or spills and closure and post-closure.	Tanks used for treatment or storage (e.g. VGAC vessels for off-gas treatment) must comply with substantive provisions.
RCRA Subtitle C; ARS §49-921 et seq .	40 CFR Part 268 and R18-8-268	Relevant and Appropriate	Storage of more than 1 year requires demonstration that such storage is solely for the purpose of accumulation to allow for proper recovery, treatment, and disposal.	Storage of land-banned waste must comply with these requirements.
40 CFR § 270	40 CFR § 270	Relevant and Appropriate	Requires that environmental media containing RCRA-listed hazardous waste must be managed as a RCRA hazardous waste.	On-site treatment of the groundwater is subject to substantive requirements of RCRA permits. To the extent, if at all, that purge water associated with groundwater monitoring activities contains RCRA-listed hazardous waste, then purge water must be managed as an RCRA hazardous waste. The groundwater itself must be managed as a RCRA hazardous waste because it contains an RCRA-listed waste. On-site treatment of the groundwater is subject to substantive requirements of RCRA permits.
40 CFR § 262.34	40 CFR § 262.34	Relevant and Appropriate	Regulates temporary accumulation of hazardous waste on-site. Specifies procedure for accumulation of hazardous waste on-site for certain amounts of hazardous wastes and for certain time periods under generator status.	These requirements are applicable to management of waste materials generated as a result of construction of the remedial action and operation of any of the groundwater treatment plants if the waste materials generated are hazardous wastes.

TABLE A-5

Action-Specific ARARs
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Source	*Standard, Requirement, Criteria, or Limitation*	*Applicable or Relevant and Appropriate Requirements*	*Description of Standard, Requirement, Criteria, or Limitation*	*Manner in Which ARAR Applies to Alternative*
A.R.S. § 49-224	A.R.S. § 49-224	Relevant and Appropriate	All aquifers in the state identified under § 49-222(A) and any other aquifers subsequently discovered are classified for drinking water protected use.	
40 CFR § 144.12 – 144.16	40 CFR § 144.12 - 144.16	Applicable	Criteria and standards for the UIC Program. These criteria include current and future use, yield, and water quality characteristics and regulate the re-injection of groundwater.	These criteria are applicable for determining exempt aquifers. Injection wells will comply with these design, construction, operation, and maintenance requirements.
AAC § R18-4-501-502	AAC § R18-4-502	Applicable	Identifies minimum siting and design criteria for treatment units associated with public water systems.	In the event that it is necessary to construct a replacement drinking water treatment plant, compliance with the criteria identified in these regulations is expected.
Federal Clean Air Act, 42 U.S.C §§7401 *et seq.*	Pima County Bureau of Air Pollution Control Rules and Regulation, Title 17 Pima County Air Quality Air Quality Code, 17.16.430, Subparagraph F	Applicable	Limits pollution emissions from unclassified sources and requires reasonably available control equipment from a stationary source that emits VOCs.	If the final remedy resulted in emissions of air pollutants, these rules will apply.

TABLE A-5

Action-Specific ARARs
Applicable or Relevant and Appropriate Requirements
162nd Fighter Wing, Arizona Air National Guard
Tucson International Airport Area Superfund Site
Tucson, Arizona

Source	*Standard, Requirement, Criteria, or Limitation*	*Applicable or Relevant and Appropriate Requirements*	*Description of Standard, Requirement, Criteria, or Limitation*	*Manner in Which ARAR Applies to Alternative*
AAC § R12-15-818		Relevant and Appropriate	Prohibits new well construction within 100 feet of any hazardous waste facility.	
Safe Drinking Water Act, 42 U.S.C. §300f *et seq.*	40 CFR 144.24(a), 146	Applicable	Establishes criteria for determining exempt aquifers, including current and future use, yield, and water quality.	Applies to design, construction, operation, and maintenance of Class V injection wells, if selected to return treated groundwater to the aquifer.
	EPA Office of Solid Waste, RCRA Groundwater Monitoring: Draft Technical Guidance, Nov., 1992 (EPA/530-R93\-001	Performance Standard	Sets forth requirements for the development and implementation of a groundwater monitoring program.	Applies to the development of a comprehensive groundwater monitoring program for the site.

Notes:
AAC = Arizona Administrative Code
ADWR = Arizona Department of Water Resources
ARAR = Applicable or Relevant and Appropriate Requirement
ARS = Arizona Revised Statute
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CFR = Code of Federal Regulations
EPA = United States Environmental Protection Agency
GAC = Granular Activated Carbon
NPDES = National Pollutant Discharge Elimination System
RCRA = Resource Conservation and Recovery Act
SWPCB = State Water Pollution Control Board
TCE = Trichloroethene
U.S.C. = United States Code
UIC = Underground Injection Control
VGAC = Vapor-Phase Granular Activated Carbon
VOC = Volatile Organic Compound

APPENDIX B

POTASSIUM PERMANGANATE CALCULATIONS

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POTASSIUM PERMANGANATE CALCULATIONS

The following calculations were used to determine the amount of potassium permanganate ($KMnO_4$) necessary to treat trichloroethene (TCE) at the 162nd Fighter Wing (FW).

The treatment zones are defined as the total volume to be treated with $KMnO_4$ in the upper and lower subunits at the 162nd FW. TCE data used to estimate the treatment zones is presented in Table 1-1 of the *Draft Alternative Analysis Technical Memo*. The upper subunit treatment zone was calculated as:

$$V_U = A_U * T_U$$

Where:

V_U = Upper subunit treatment zone, cubic feet (ft^3)
A_U = Surface area of the upper subunit TCE plume at the 162nd FW, square feet (ft^2)
T_U = Thickness of upper subunit, feet (ft)

Assuming A_U is based on August 2010 TCE data, and T_U = 10 ft, then:

$$A_U = ½ (390 +195) * 590 + 275 \text{ ft} * 1470 \text{ ft}$$
$$A_U = 577{,}000 \text{ ft}^2$$

$$V_U = 577{,}000 \text{ ft}^2 * 10 \text{ ft}$$
$$V_U = 5.77 \text{ Mft}^3$$

The treatment zone in the lower subunit was calculated as:

$$V_L = A_L * T_L$$

Where:

V_L = Lower subunit treatment zone, ft^3
A_L = Surface area of the lower subunit TCE plume at the 162nd FW, ft^2
T_L = Thickness of lower subunit, ft

Assuming A_L is based on August 2010 TCE data, and T_L = 20 ft, then:

A_L = ½ (400 ft + 100 ft) * 1725 ft
A_U = 431,300 ft^2

V_L = 431,300 ft^2 * 20 ft
V_L = 8.63 Mft^3

The permanganate soil oxygen demand (PSOD) is defined as the mass of permanganate necessary to oxidize a kilogram of saturated soil. Oxidizable compounds include organic carbon, reduced metals species, and volatile organic compounds (such as TCE). Based on laboratory data, the average PSOD for each subunit is:

$PSOD_U$ = average PSOD of upper subunit, milligrams of $KMnO_4$ per kilogram of soil (mg/kg)
$PSOD_U$ = 27 mg/kg

$PSOD_L$ = average PSOD of lower subunit, mg/kg
$PSOD_L$ = 39 mg/kg

PSOD data is provided in the *Final In-Situ Chemical Oxidation Pilot Test Work Plan* (ERM 2009).

To calculate the amount of $KMnO_4$ required for each treatment zone, assume:

ρ = Bulk density of soil = 1.5 grams per cubic centimeter (g/cm^3)

In the upper subunit:

$M_U = V_U * \rho * PSOD_U$

Where:

M_U = Mass of $KMnO_4$ required to dose upper subunit treatment zone, pounds (lbs)

Then:

M_U = 5.77 Mft^3 * 1.5 g/cm^3 * 27 mg/kg
M_U = 14,600 lbs

In the lower subunit:

$$M_L = V_L * \rho * PSOD_L$$

Where:

M_L = Mass of $KMnO_4$ required to dose the lower subunit treatment zone, lbs

Then:

$M_L = 8.62\ Mft^3 * 1.5\ g/cm^3 * 39\ mg/kg$

$\mathbf{M_L = 31{,}500\ lbs}$

To ensure the $KMnO_4$ persists at the injection locations for the estimated 5 years it will take for the treatment zone to encompass the TCE plume, it may be necessary to reapply the $KMnO_4$ treatment after 2.5 years. With a safety factor of 1.5 to ensure full coverage of the treatment zone, the total mass of $KMnO_4$ required is:

$$M_T = (M_U + M_L) * F_S * N$$

Where:

M_T = Mass of $KMnO_4$ required to dose the entire 162nd FW treatment zone, lbs

F_S = Safety Factor = 1.5

N = Number of applications = 2

Then:

$M_T = (14{,}600\ lbs + 31{,}500\ lbs) * 1.5 * 2$

$\mathbf{M_T = 138{,}300\ lbs}$