ASSESSMENT OF POTENTIAL IMPACT OF CONTAMINATED GROUNDWATER PLUMES ON WATER SUPPLY WELLS IN THE LOS ANGELES COUNTY AREA



MOHAMMAD M. ZAIDI, PG, CHG
SITE INVESTIGATIONS CLEANUP OVERSIGHT REVIEW LLC

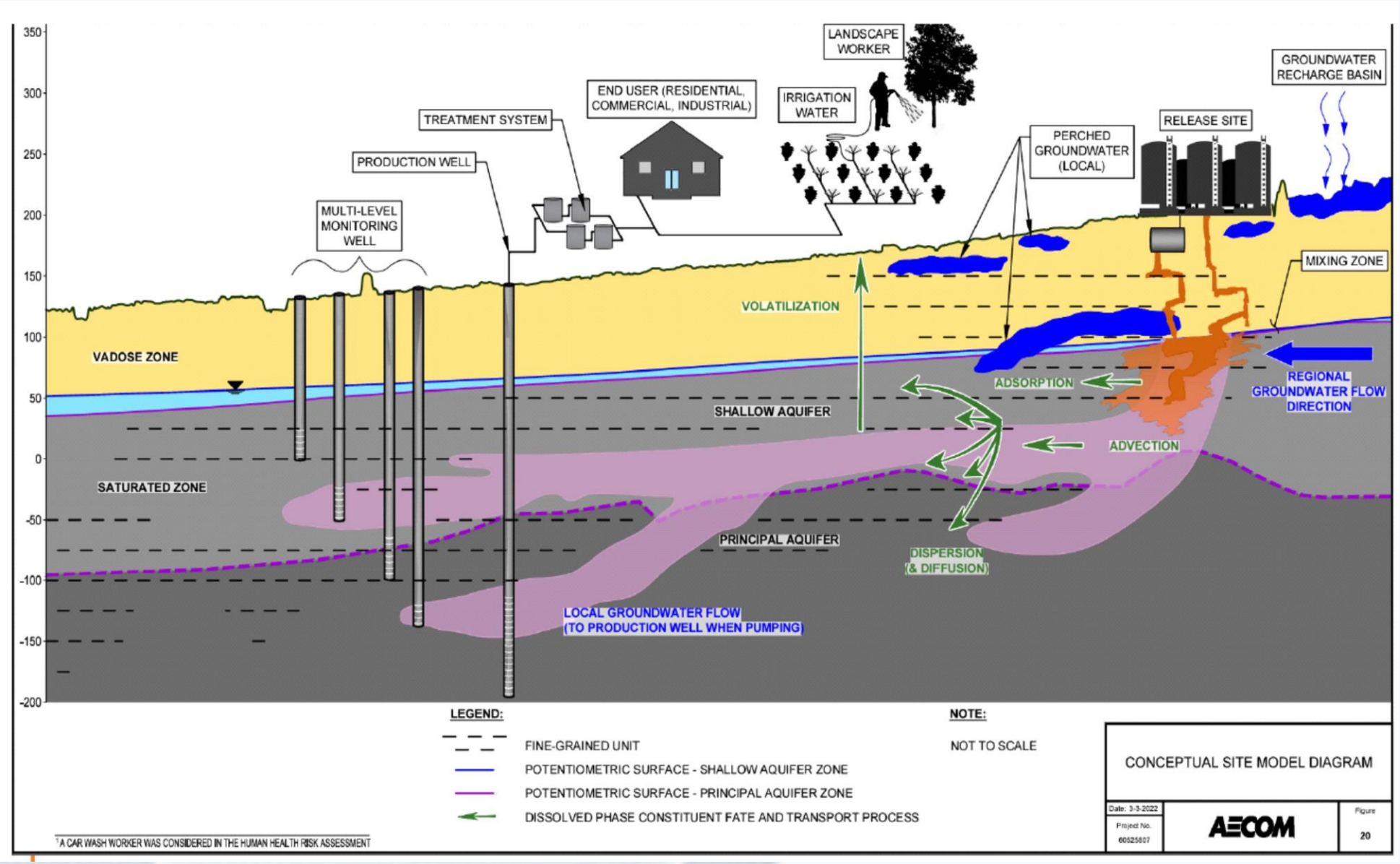
SICR

ASSESSMENT OF CONTAMINATED GROUNDWATER PLUME IMPACT

- Conduct onsite and offsite investigation of a site to determine the lateral and vertical extent of contamination in soil, soil gas, and groundwater from the source areas to the required cleanup goals / maximum contaminant level (MCL) boundary of the groundwater plume(s) migrating toward a Water Supply Well (WSW).

- Have the contaminants from the onsite source area(s) of a site migrated vertically through the vadose zone to form a groundwater plume in the underlying unconfined and confined aquifer(s)?

- If yes, then, delineate the migration pathways along which the plume(s) has been migrating toward a WSW generally located hydraulically downgradient.


350
300
250
200
150
100
50
0
-50
-100
-150
-200
LANDSCAPE WORKER
GROUNDWATER RECHARGE BASIN
END USER (RESIDENTIAL, COMMERCIAL, INDUSTRIAL)
IRRIGATION WATER
TREATMENT SYSTEM
PERCHED GROUNDWATER (LOCAL)
RELEASE SITE
PRODUCTION WELL
MULTI-LEVEL MONITORING WELL
MIXING ZONE
VOLATILIZATION
VADOSE ZONE
ADSORPTION
REGIONAL GROUNDWATER FLOW DIRECTION
SHALLOW AQUIFER
ADVECTION
SATURATED ZONE
PRINCIPAL AQUIFER
DISPERSION (& DIFFUSION)
LOCAL GROUNDWATER FLOW (TO PRODUCTION WELL WHEN PUMPING)
LEGEND:
FINE-GRAINED UNIT
POTENTIOMETRIC SURFACE - SHALLOW AQUIFER ZONE
POTENTIOMETRIC SURFACE - PRINCIPAL AQUIFER ZONE
DISSOLVED PHASE CONSTITUENT FATE AND TRANSPORT PROCESS
NOTE:
NOT TO SCALE
CONCEPTUAL SITE MODEL DIAGRAM
Date: 3-3-2022
Project No. 60625607
AECOM
Figure 20
[1] A CAR WASH WORKER WAS CONSIDERED IN THE HUMAN HEALTH RISK ASSESSMENT

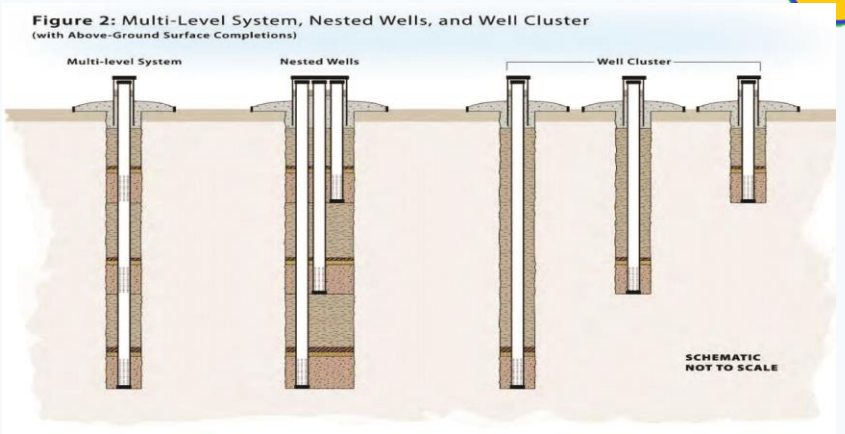
DETERMINE VERTICAL AND LATERAL EXTENT OF CONTAMINATION ONSITE AND OFFSITE

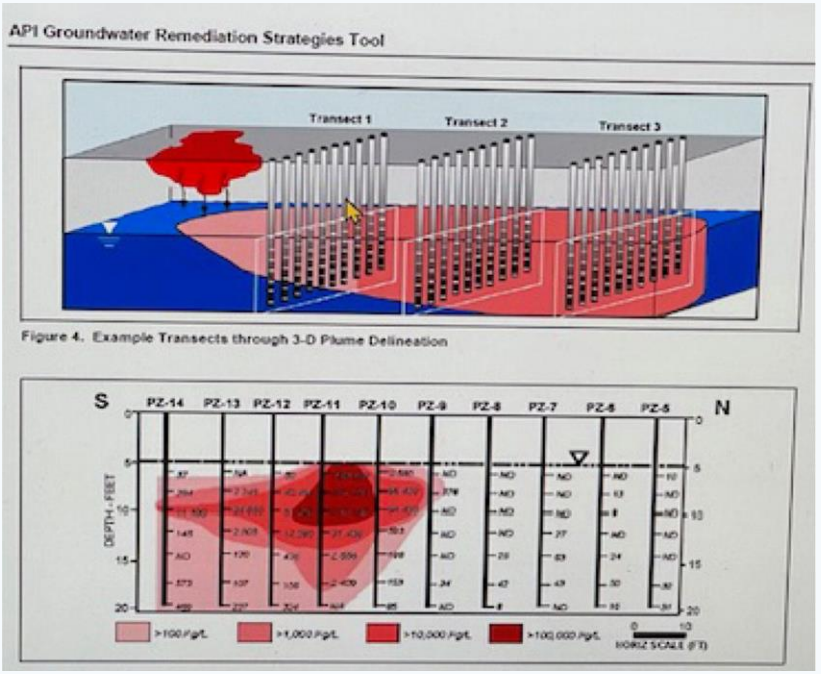
- Drilling, soil, soil gas, and groundwater sampling to depths of background / required cleanup levels, starting at the source area(s) and expanding outwards.

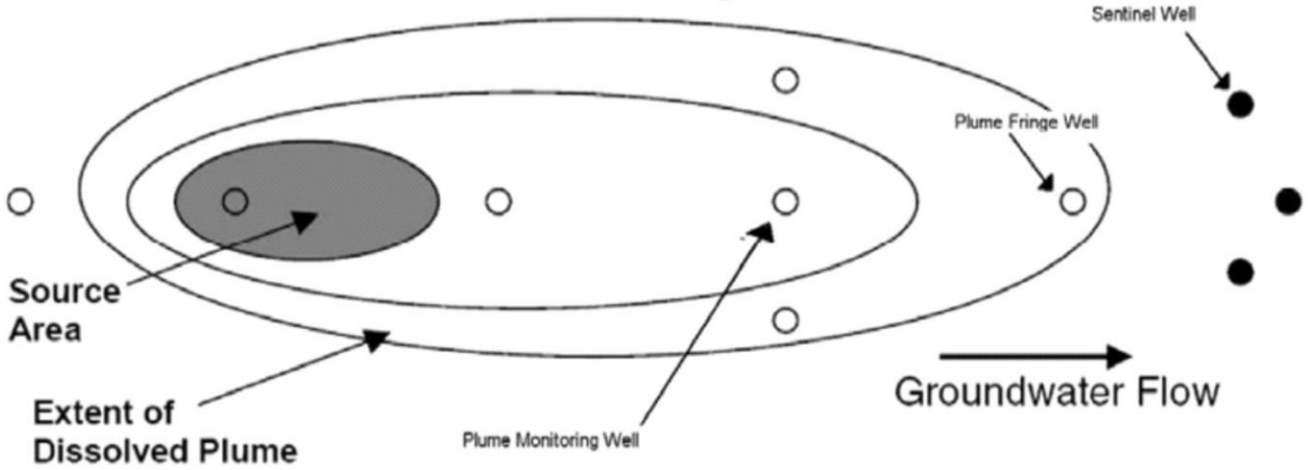
- Lab analyses of samples chemicals of concern (CoC), and QA/QC and tabulate analytical results.

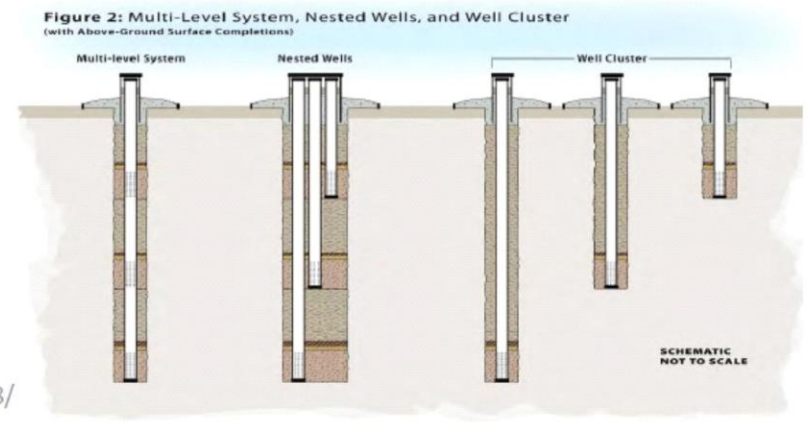
- Install cluster, nested, or multi-level system (Transects) groundwater monitoring wells (MWs) screened laterally in the same soil formation(s) as the aquifer zone(s) in the WSWs, to depths below the MCL iso-concentration contour. These wells determine horizontal and vertical hydraulic gradients in the plume(s), plume flow pathways and locations and extent of plume hot spots along plume-preferred migration pathways. This helps concentrating remediation at the hot spots. Vertical downward gradients indicate plume migration to deeper zones.

- Install and monitor sentinel MWs between the MCL boundary and the WSW screened in the same stratigraphic unit(s) to proactively protect WSWs and expedite plume remediation and containment before it impacts the WSWs.



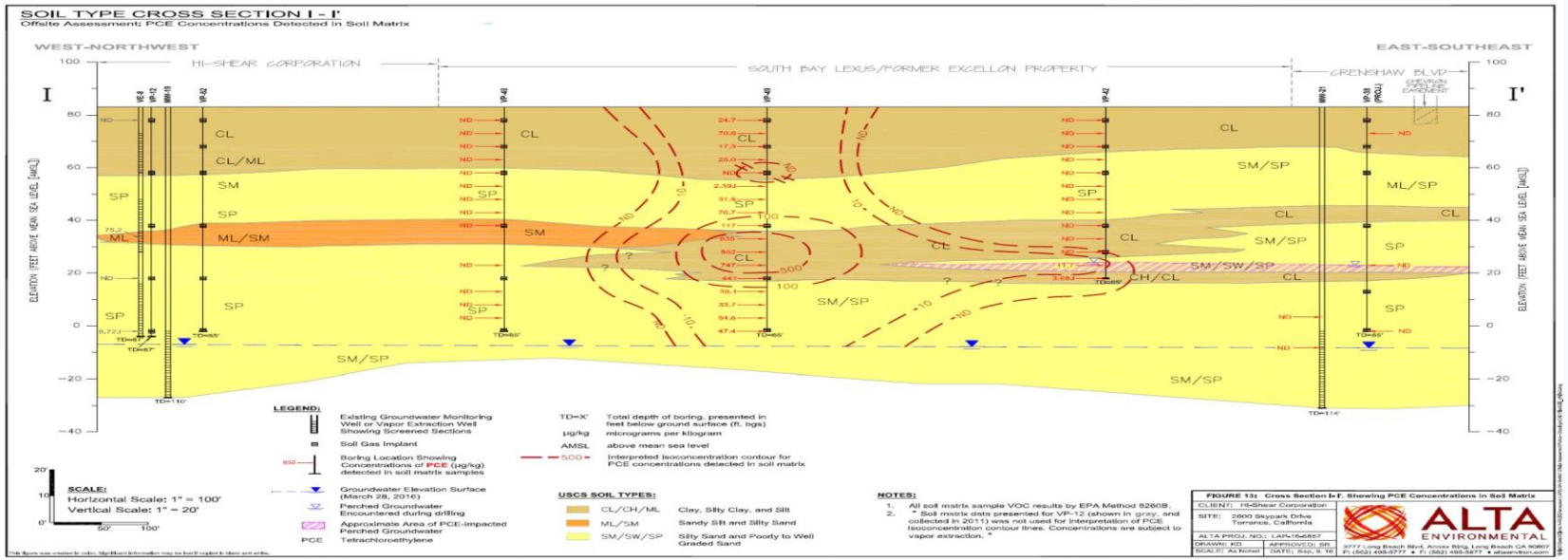




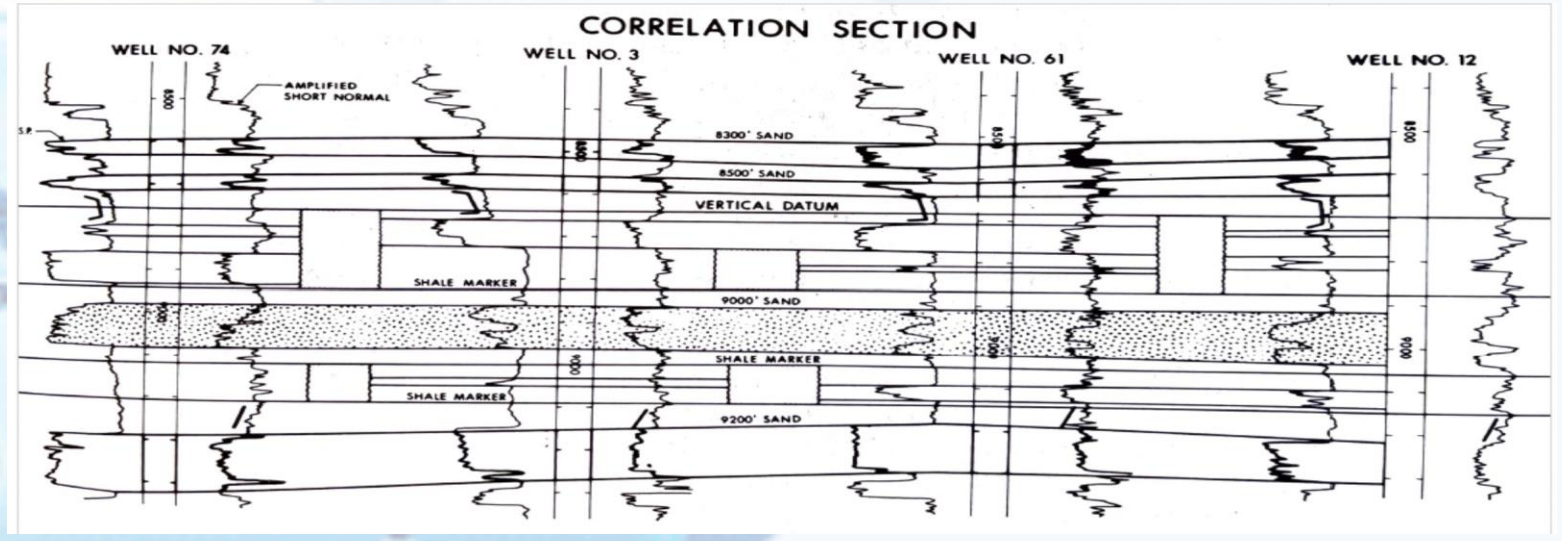


Well No	Depth Int feet	Phase 1 PCE	Phase 1 TCE	Phase 1 PCE/TCE	Phase 2 PCE	Phase 2 TCE	Phase 2 PCE/TCE	Phase 3 PCE	Phase 3 TCE
B-1-MW2	100-140	500	90	5.56	4300	1500	2.87	--	--
	150-170	990	250	3.96	4900	2100	2.33	9578	2880
	229-249	610	120	5.08	2100	140	15.00	7726	2100
	318-338	49	14	3.50	2700	580	4.66	6933	1896
	380-400	66	6	11.00	2300	480	4.79	7944	2146
	421-441	110	30	3.67	2700	620	4.35	9500	2832

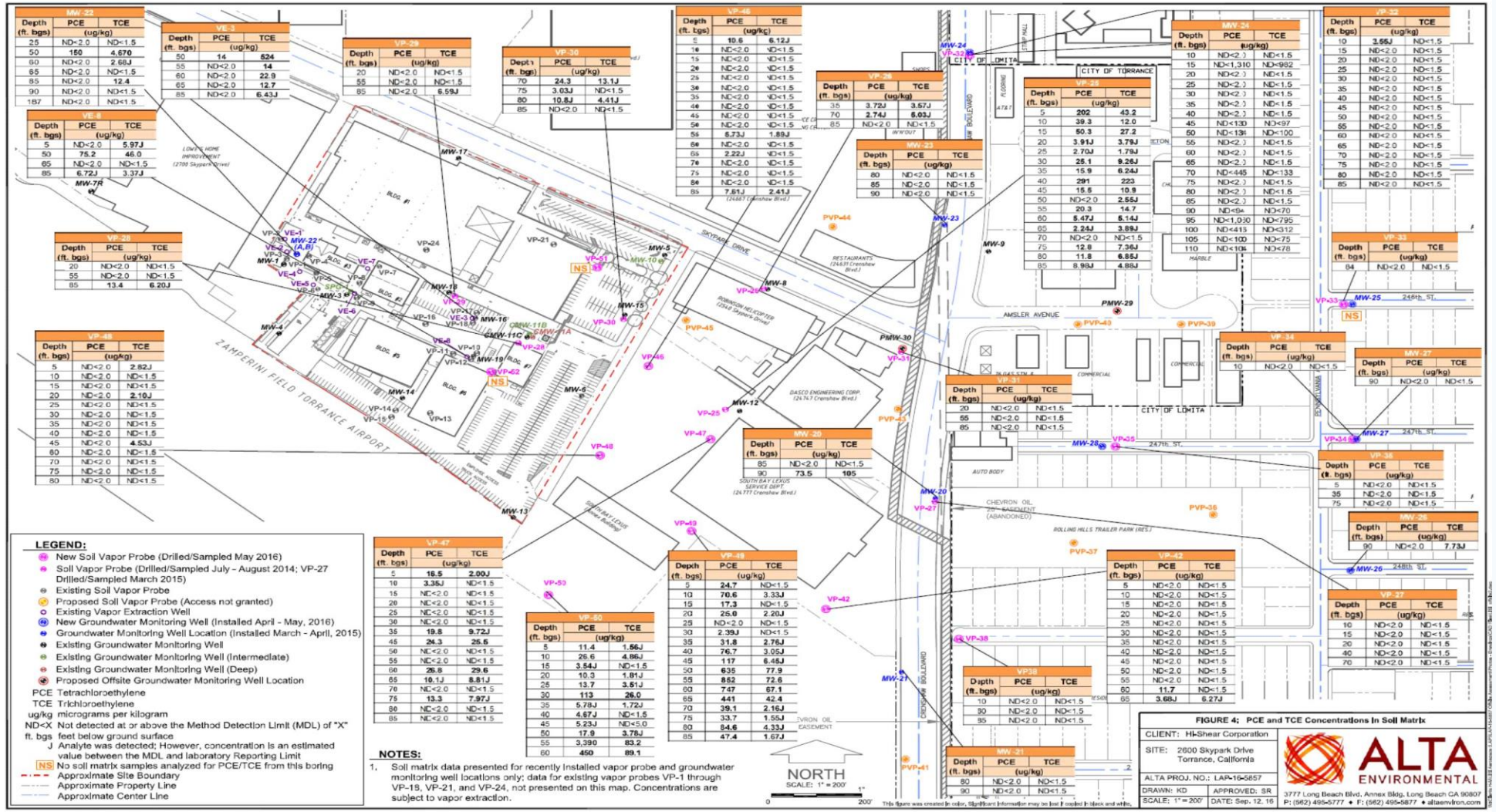
Construct lithologic cross-sections along and across the plume axis. plot significant CoC concentrations at each sampling depth to show lateral and vertical distribution of contaminants in soil and soil gas in the Vadose Zone.



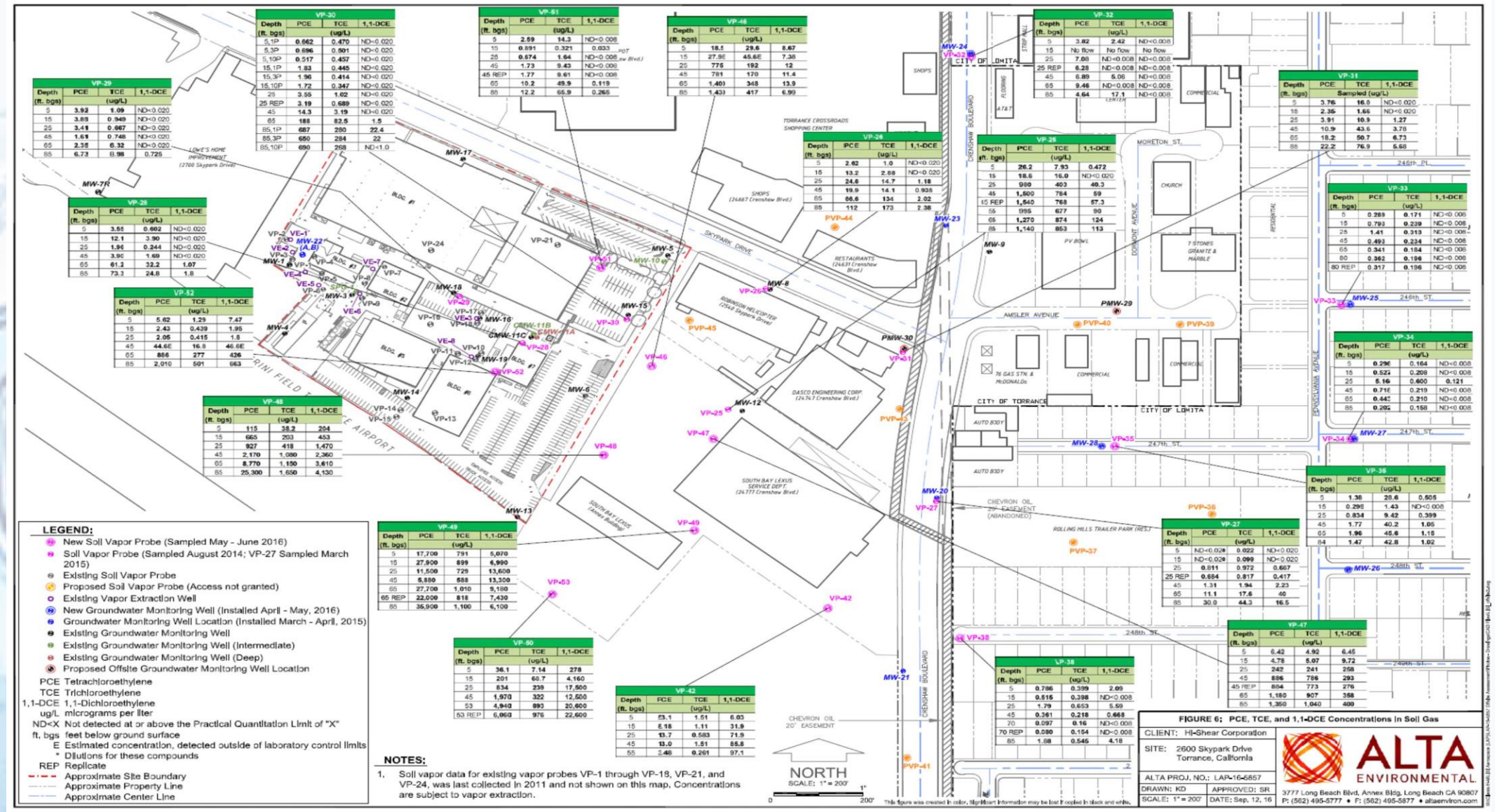
Boring logs, and SP, Resistivity logs



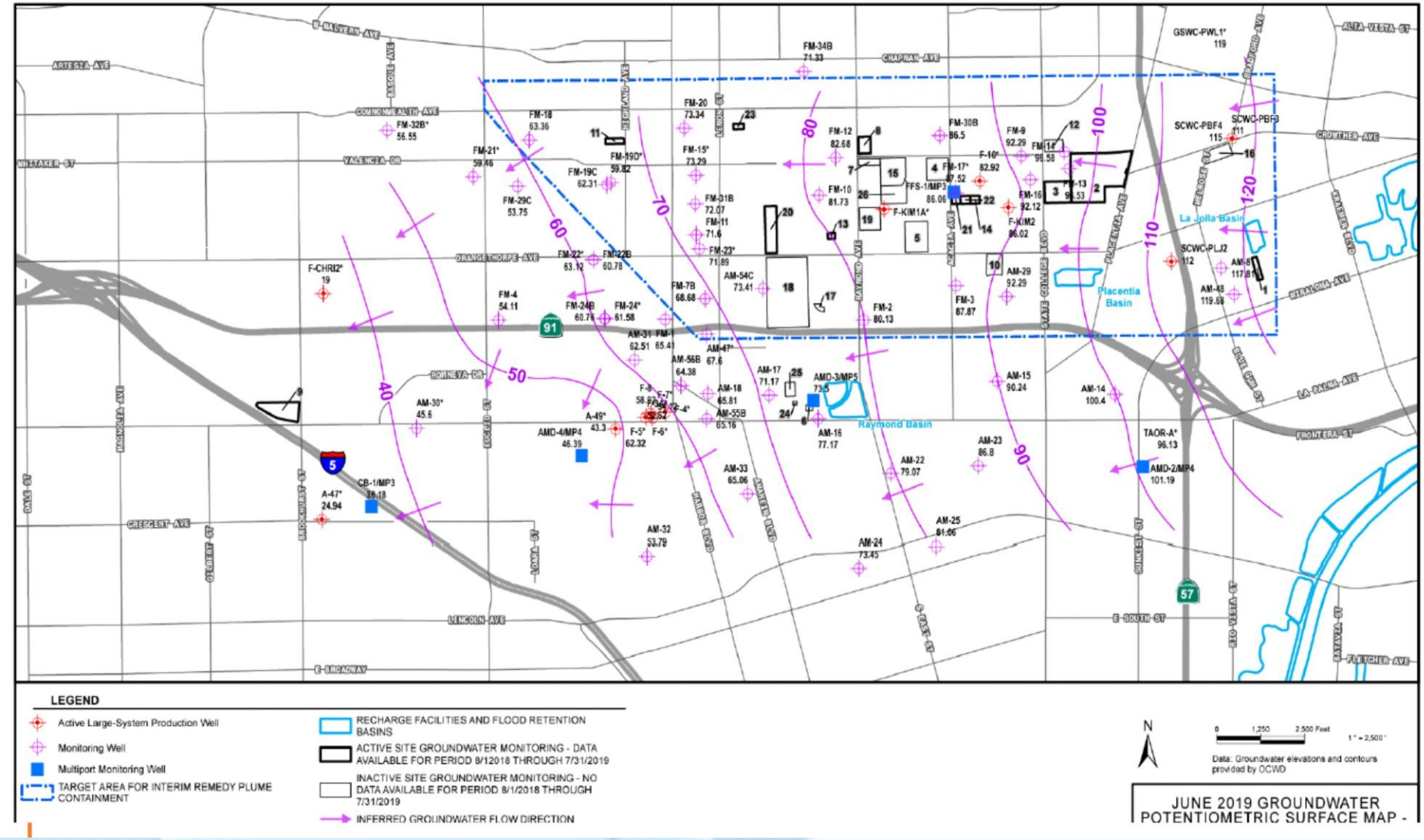
ISO-CONCENTRATION MAPS OF CoCs IN SOIL MATRIX SAMPLES COLLECTED FROM SHALLOW INTERMEDIATE, AND DEEP PORTIONS OF VADOSE ZONE

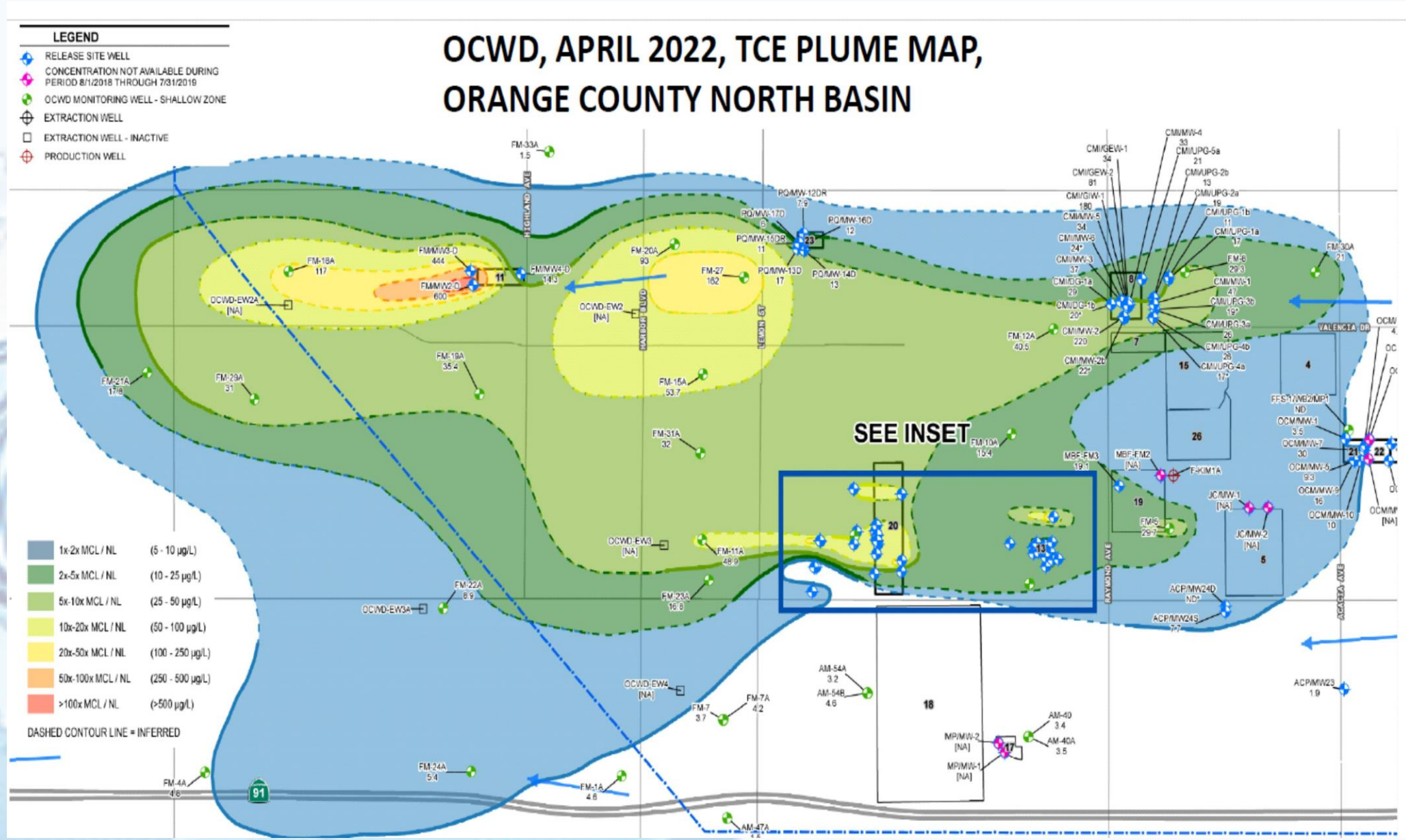


PLOT CoC SOIL VAPOR SAMPLE CONCENTRATIONS FROM MULTIPLE VADOSE ZONE DEPTHS ZONES AT BORING LOCATIONS



Adapted from: June 2022, RI/FS STUDY, RI Report, ORANGE COUNTY NORTH BASIN, OCWD




OCWD, APRIL 2022, TCE PLUME MAP,
ORANGE COUNTY NORTH BASIN
LEGEND
RELEASE SITE WELL
CONCENTRATION NOT AVAILABLE DURING PERIOD 8/1/2018 THROUGH 7/31/2019
OCWD MONITORING WELL - SHALLOW ZONE
EXTRACTION WELL
EXTRACTION WELL - INACTIVE
PRODUCTION WELL
1x-2x MCL / NL (5 - 10 µg/L)
2x-5x MCL / NL (10 - 25 µg/L)
5x-10x MCL / NL (25 - 50 µg/L)
10x-20x MCL / NL (50 - 100 µg/L)
20x-50x MCL / NL (100 - 250 µg/L)
50x-100x MCL / NL (250 - 500 µg/L)
>100x MCL / NL (>500 µg/L)
DASHED CONTOUR LINE = INFERRED
SEE INSET
HIGHLAND AVE
HARBOR BLVD
LEMON ST
RAYMOND AVE
ACACIA AVE
VALENCIA DR
91

GROUNDWATER MONITORING AND REPORTING

- Perform monthly, quarterly, annual Groundwater Monitoring (GWM) and submit reports as required by the state/federal environmental regulatory agencies. Continue GWM of required compliance and sentinel wells until required remedial cleanup goals are achieved.

- Construct, include, and periodically update groundwater elevation contour maps (do not include elevation(s) caused by pumping well inefficiency and losses that are lower than those representative elevations from surrounding MWs), determine flow direction and plot horizontal and vertical hydraulic gradient vectors, and iso-concentration plume maps . Downward vertical gradients indicate plume migration to deeper aquifer zones.

AQUIFER PUMPING TESTING TO DETERMINE AQUIFER CHARACTERISTICS BEFORE EXTRACTION/INJECTION / REMEDIATION WELL INSTALLATIONS

- **Use pumping well and observation wells/piezometers** (same and deep screen depth aquifer intervals). Use surveyed top of the casing elevations, pressure transducers, data logger, and Data analysis software.
- **Step-drawdown test** – for **specific capacity, aquifer loss and well loss, and well inefficiency** – Hantush-Bierschenk method.
- **Constant discharge test** – 8, 24, or 72 hours; **optimum Q and drawdown, K, T, S, extent of cone of depression, optimum spacing for extraction and injection wells and capture zone extent**.
- **Recovery test** – Theis.
- **Use appropriate methods for pumping test data analysis**, some are:Theis, Jacob time/distance drawdown (Confined Aquifer Steady/Non-Steady state); Hantush-Jacob (Steady state); Hantush Inflection-point, Neuman-Witherspoon (Leaky Confined); Neuman curve-fitting (Unconfined Unsteady state).
- **Install GW extraction well(s) / remedial injection well(s) at aquifer test-based well spacing within the Source area/CoC hot spots area(s) for Pump & Treat (P&T) and Ex-situ treatment, in-situ injection of chemicals, bioremediation, if warranted. Start soil, soil gas, and groundwater remediation at source area(s), and expand outward.**
- **Perform remedial system(s) progress monitoring and required periodic reporting.**

THEIS

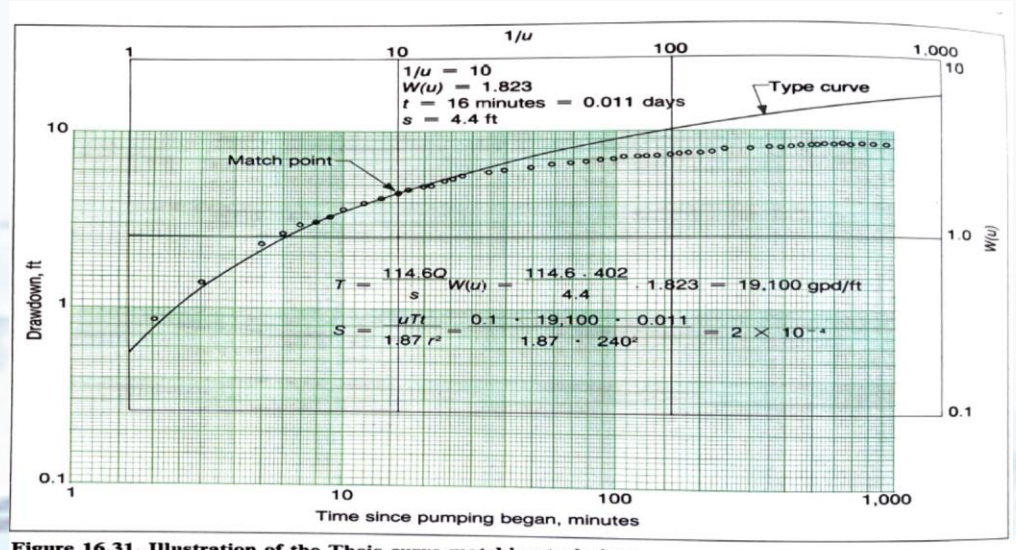
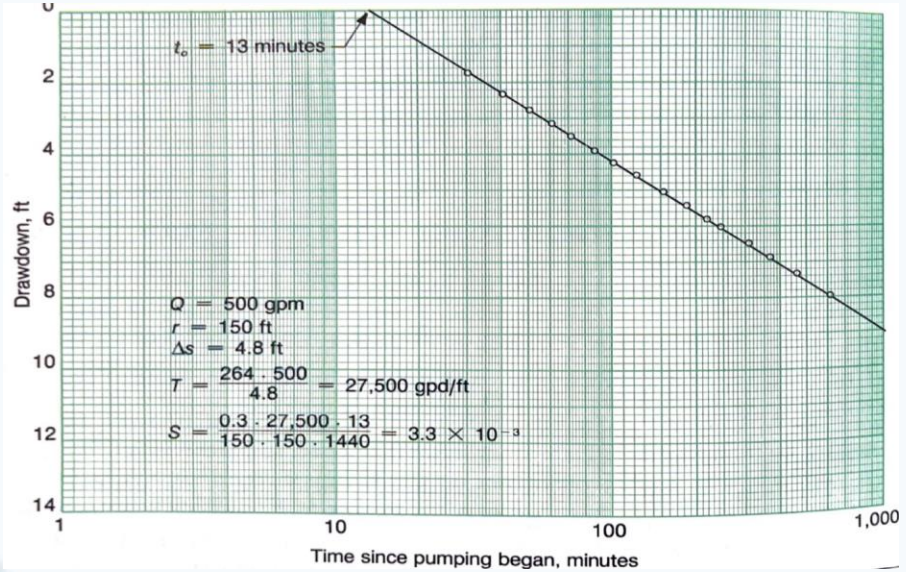


Figure 16.31. Illustration of the Theis curve-matching technique.

COOPER JACOB



NEUMAN DELAYED YIELD

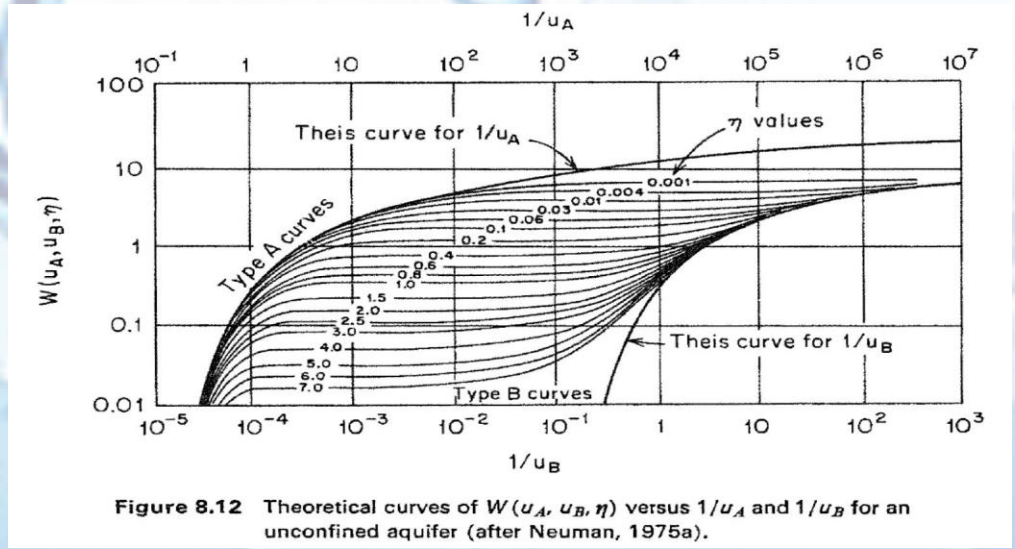


Figure 8.12 Theoretical curves of $W(u_A, u_B, \eta)$ versus $1/u_A$ and $1/u_B$ for an unconfined aquifer (after Neuman, 1975a).

HANTUSH-JACOB – LEAKY AQUIFER

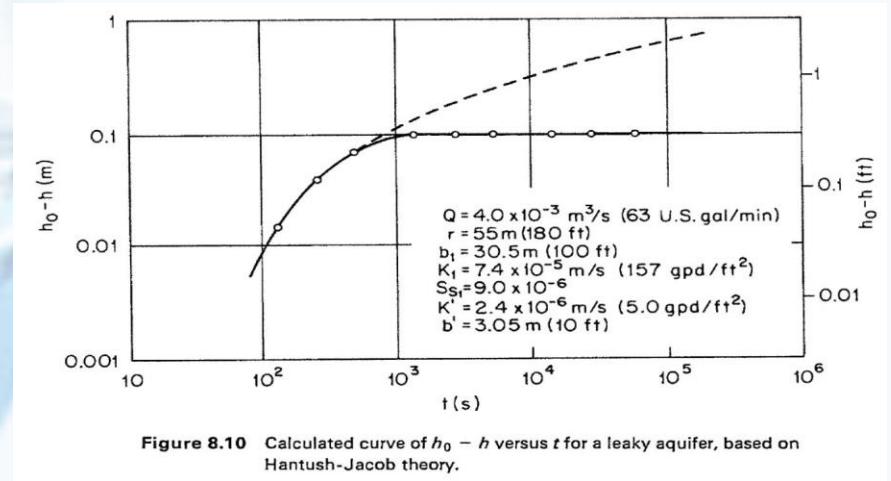


Figure 8.10 Calculated curve of $h_0 - h$ versus t for a leaky aquifer, based on Hantush-Jacob theory.

CAPTURE ZONE ANALYSIS

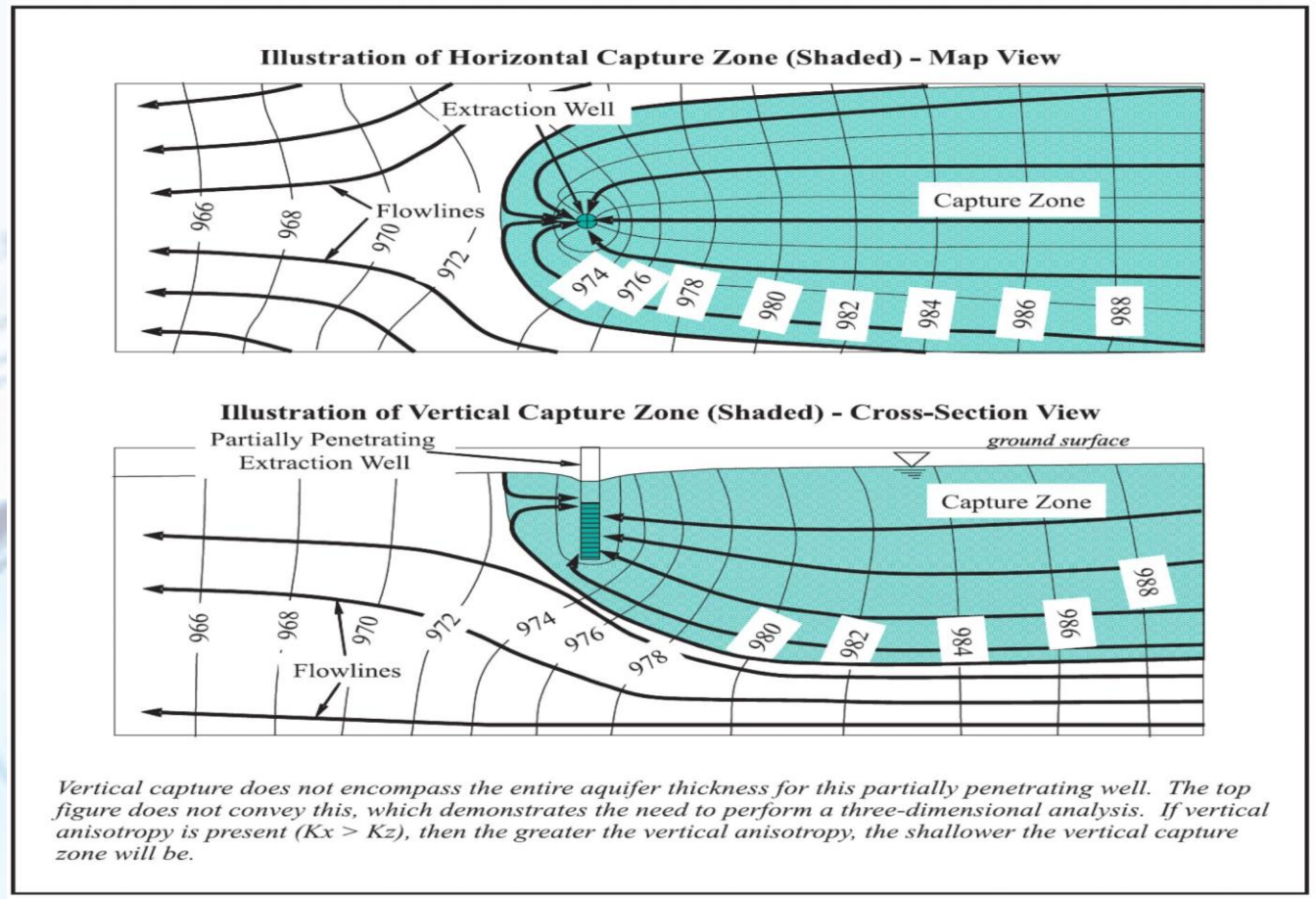


Figure 1. Illustration of horizontal and vertical capture zones.

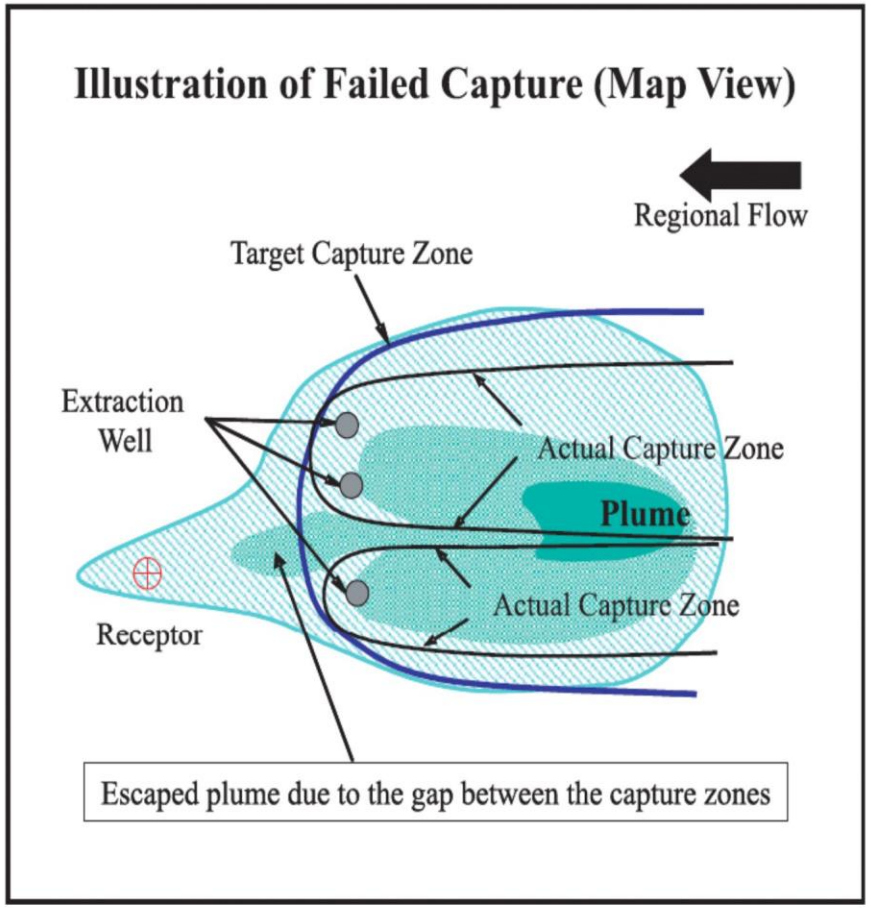
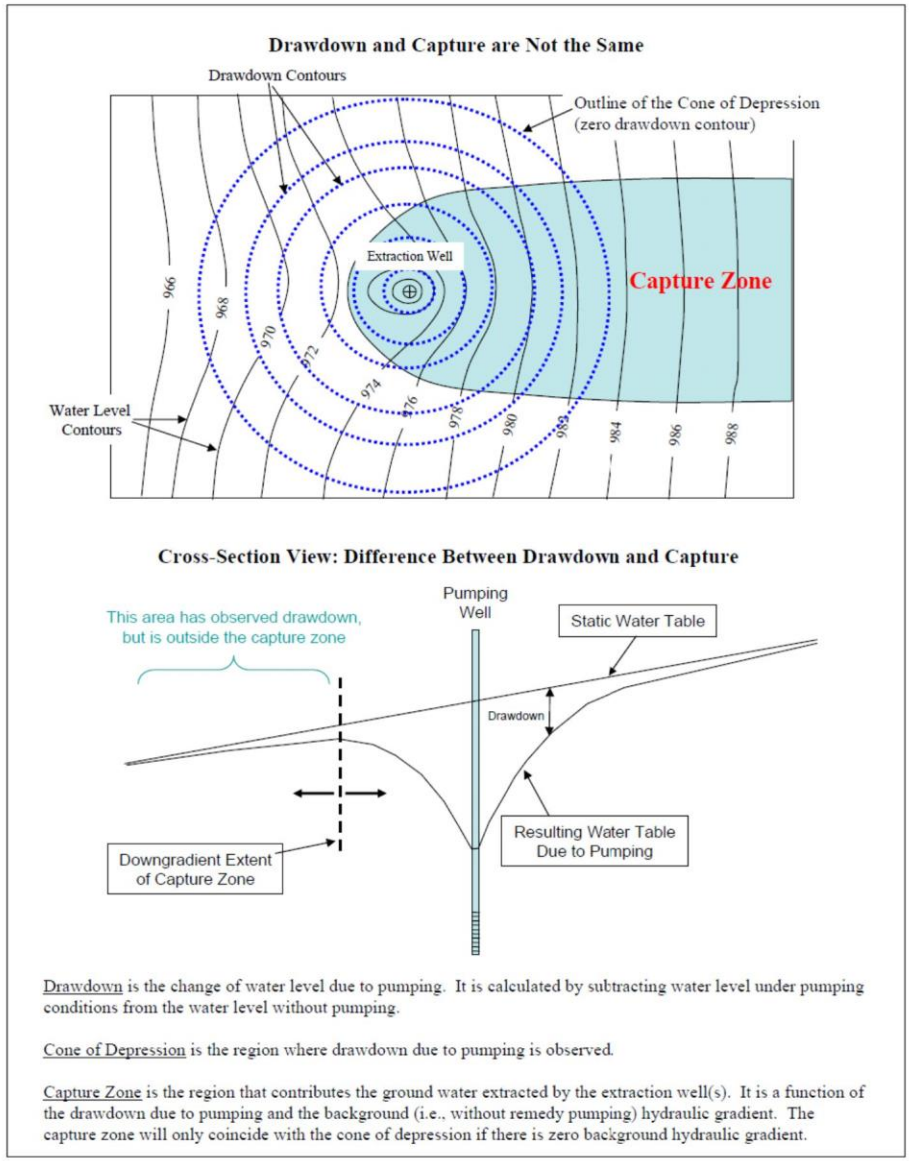


Figure 2. Illustration of failed capture.

MCL iso-concentration contour envelops around the capture zone.

Plume escaped through gaps between adjacent capture zones impacts water well.



Drawdown is the change of water level due to pumping. It is calculated by subtracting water level under pumping conditions from the water level without pumping.

Cone of Depression is the region where drawdown due to pumping is observed.

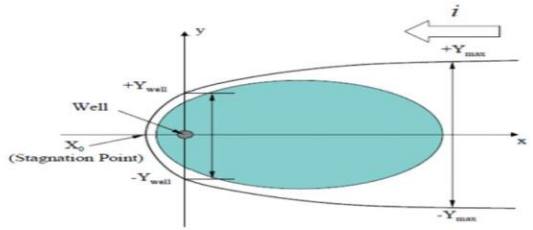
Capture Zone is the region that contributes the ground water extracted by the extraction well(s). It is a function of the drawdown due to pumping and the background (i.e., without remedy pumping) hydraulic gradient. The capture zone will only coincide with the cone of depression if there is zero background hydraulic gradient.

Figure 6. Drawdown and capture are not the same.

Capture Zone Width Calculation, One Extraction Well

Assumptions:

- homogeneous, isotropic, confined aquifer of infinite extent
- uniform aquifer thickness
- fully penetrating extraction well(s)
- uniform regional horizontal hydraulic gradient
- steady-state flow
- negligible vertical gradient
- no net recharge, or net recharge is accounted for in regional hydraulic gradient
- no other sources of water introduced to aquifer due to extraction (e.g., from rivers or leakage from above or below)



$$x = \frac{-y}{\tan\left(\frac{2\pi T i}{Q} y\right)} \quad -or- \quad y = \pm\left(\frac{Q}{2Ti}\right) - \left(\frac{Q}{2\pi Ti}\right)\tan^{-1}\left(\frac{y}{x}\right)$$

$$X_o = -Q/2\pi Ti \quad ; \quad Y_{max} = \pm Q/2Ti \quad ; \quad Y_{well} = \pm Q/4Ti$$

(must use consistent units, such as "ft" for distance and "day" for time)

Where:

Q	=	extraction rate
T	=	transmissivity, $K \cdot b$
K	=	hydraulic conductivity
b	=	saturated thickness
i	=	regional (i.e., pre-remedy-pumping) hydraulic gradient
X_o	=	distance from the well to the downgradient end of the capture zone along the central line of the flow direction
Y_{max}	=	maximum capture zone width from the central line of the plume
Y_{well}	=	capture zone width at the location of well from the central line of the plume

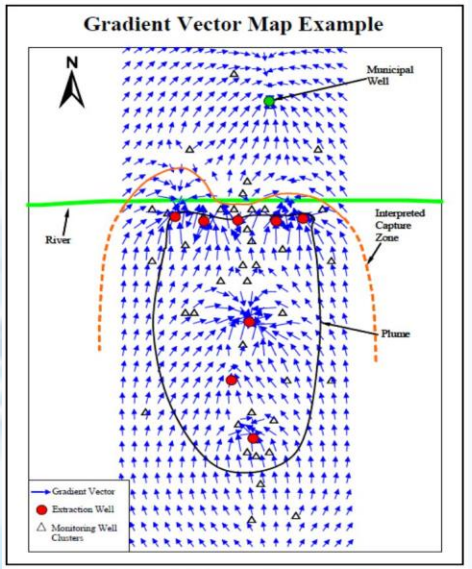


Figure 7. Gradient vector map example.

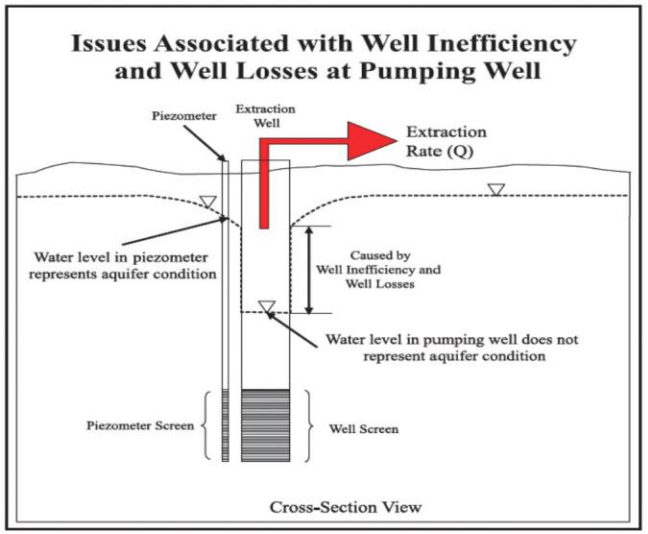


Figure 8. Issues associated with well inefficiency and well losses at pumping well.

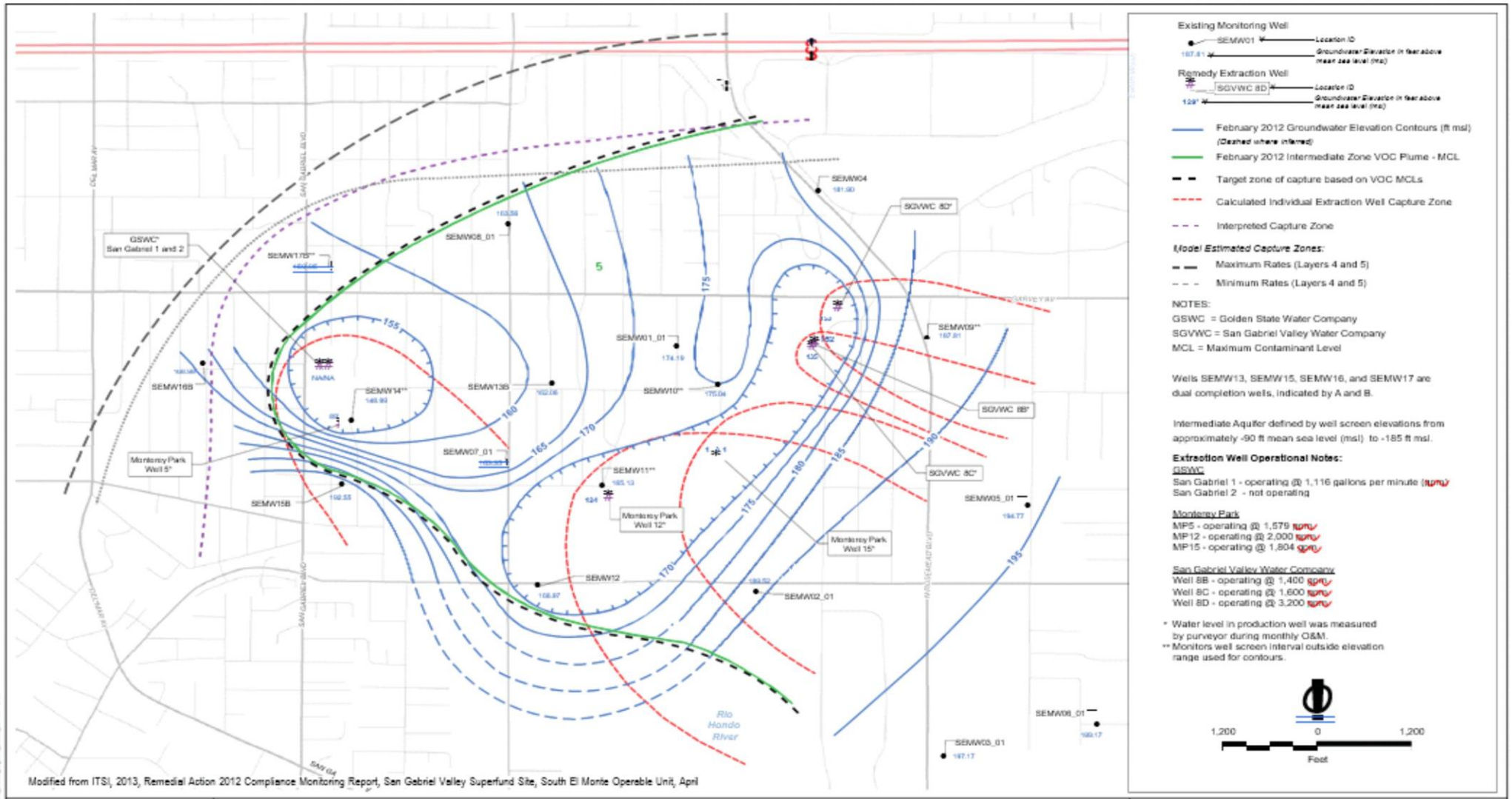


Figure 6-8: Capture Zones for the South El Monte OU Remedy

GROUNDWATER FLOW MODELING WITH PARTICLE TRACKING PLUME MIGRATION PATHWAYS

- Run a numerical model such as MODFLOW to simulate hydraulic heads and flow, and calibrate the model by varying boundary conditions, aquifer properties, and drawdowns in response to various actual pumping rates of the P&T system, until an acceptable match with field–measured heads, attained at either average pumping rates or a range of pumping rates, and observed drawdowns is achieved.
- Follow the calibrated MODFLOW model with MODPATH to evaluate capture zones based on particle tracking. Release the particles in the source area at several starting points horizontally and vertically. The particles move forward (by advection only) so that they are ultimately captured at specific extraction well locations.

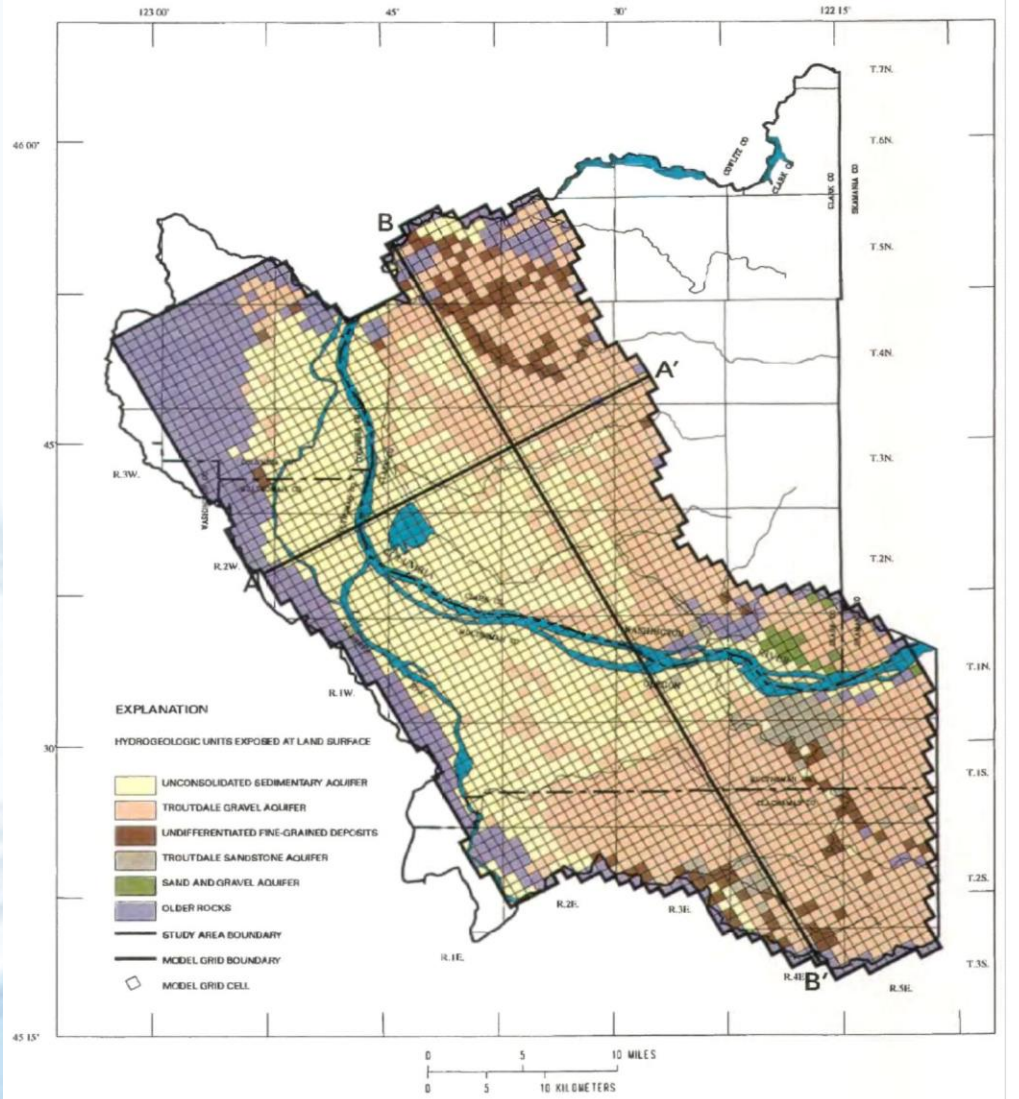


Figure 3. Ground-water flow model grid and modeled hydrogeology

- Particle path line is a function of groundwater velocity (in turn depends on pumping/injection rates), time, and location of initial release of the particle.
- To ensure plume capture, forward particle tracking requires that the minimum simulated distance between initial location of a particle within a plume and all candidate extraction wells must equal zero; all particles must terminate at a well. The minimum distance between the path line and the well decreases with increased extraction rate which when sufficient captures the particle.
- Accurate capture delineation by reverse tracking requires the minimum distance between all particle path lines and specified locations on the plume. To ensure capture, at least one particle from extraction well must travel back ward along its path line through specified locations on the plume.

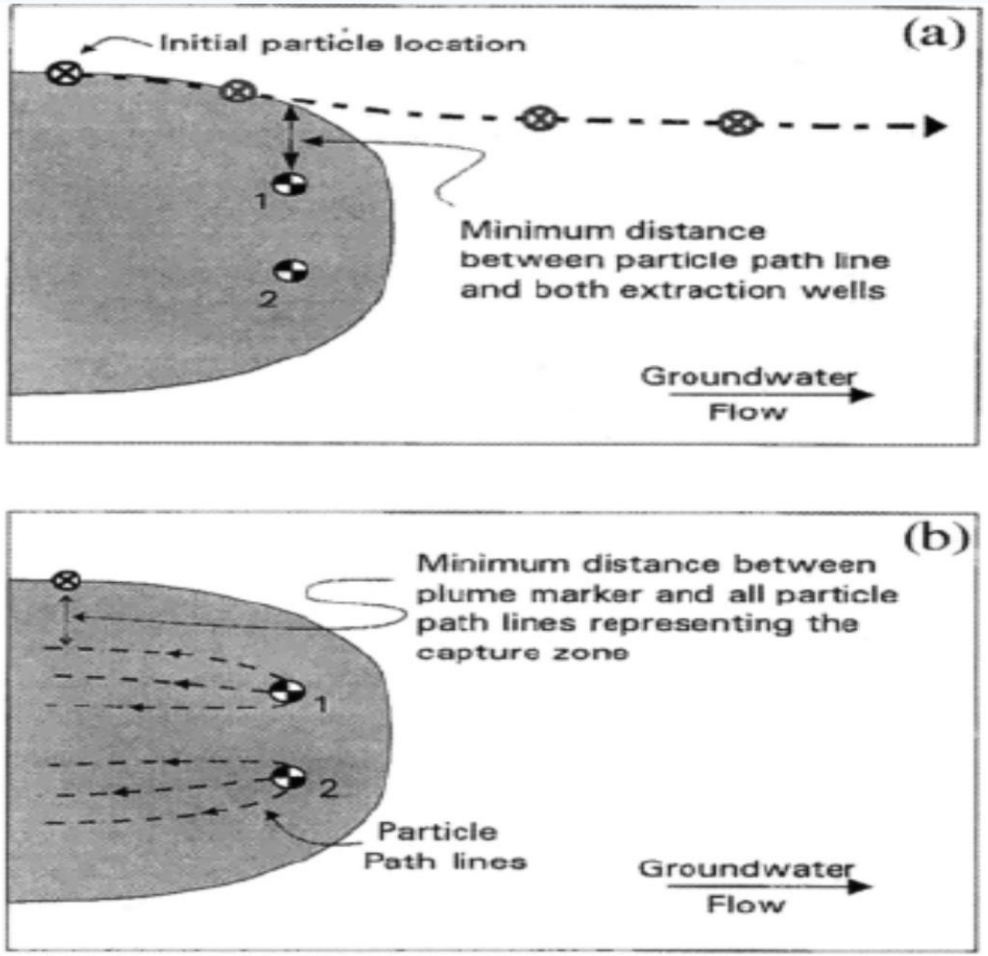


Figure 1. Particle path lines and constraint functions for (a) forward tracking and (b) reverse tracking. Path lines are shown as dashed lines in Figures 1a and 1b. The shaded area represents the contaminant plume to be contained.

From: Ann E. Mulligan, David P. Ahlfeld: Advective control of groundwater contaminant plumes: Model development and comparison to hydraulic control, Water Resources Research. Vol.35, No. 8, Pages 2285-2294, August 1999

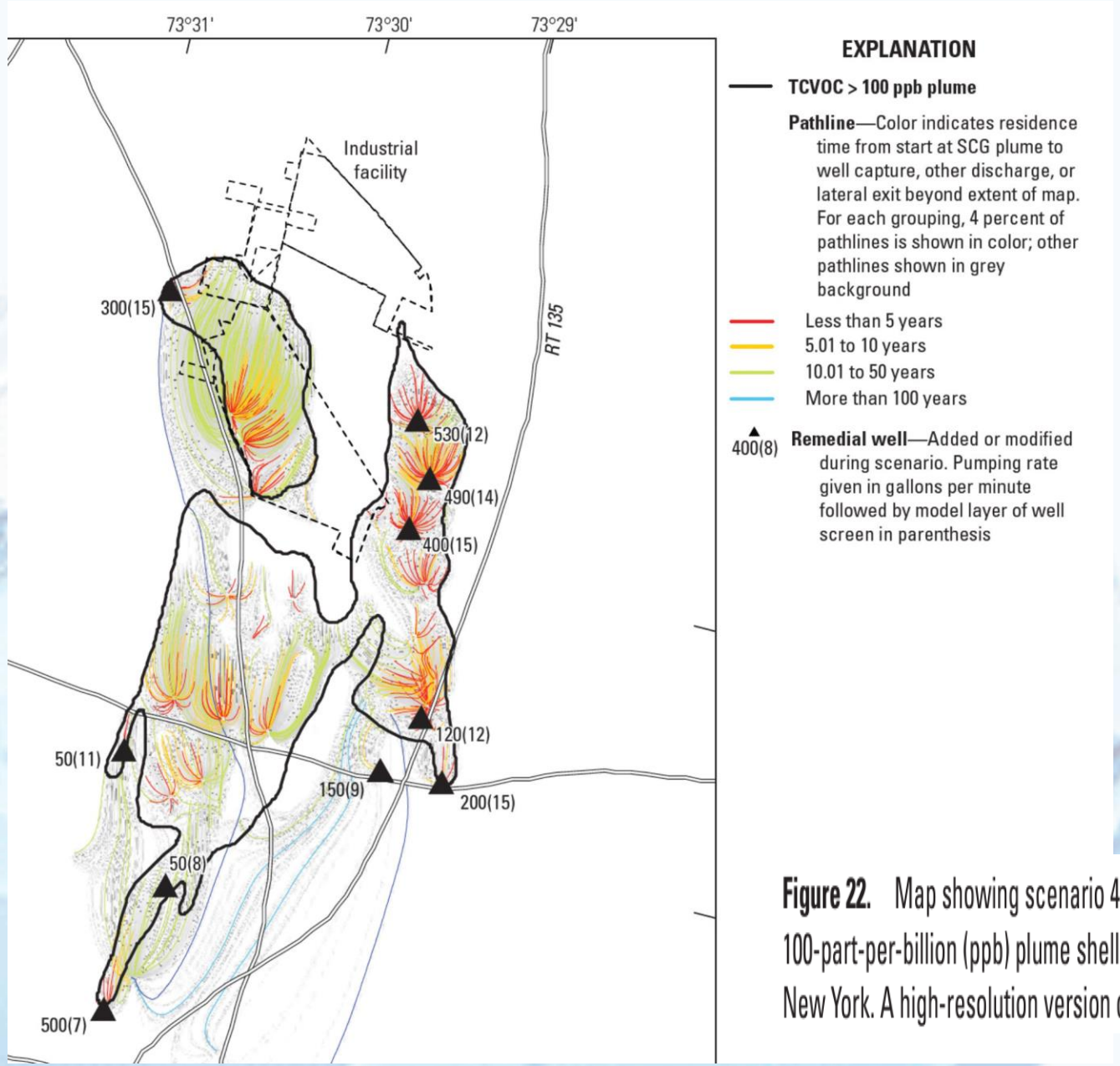
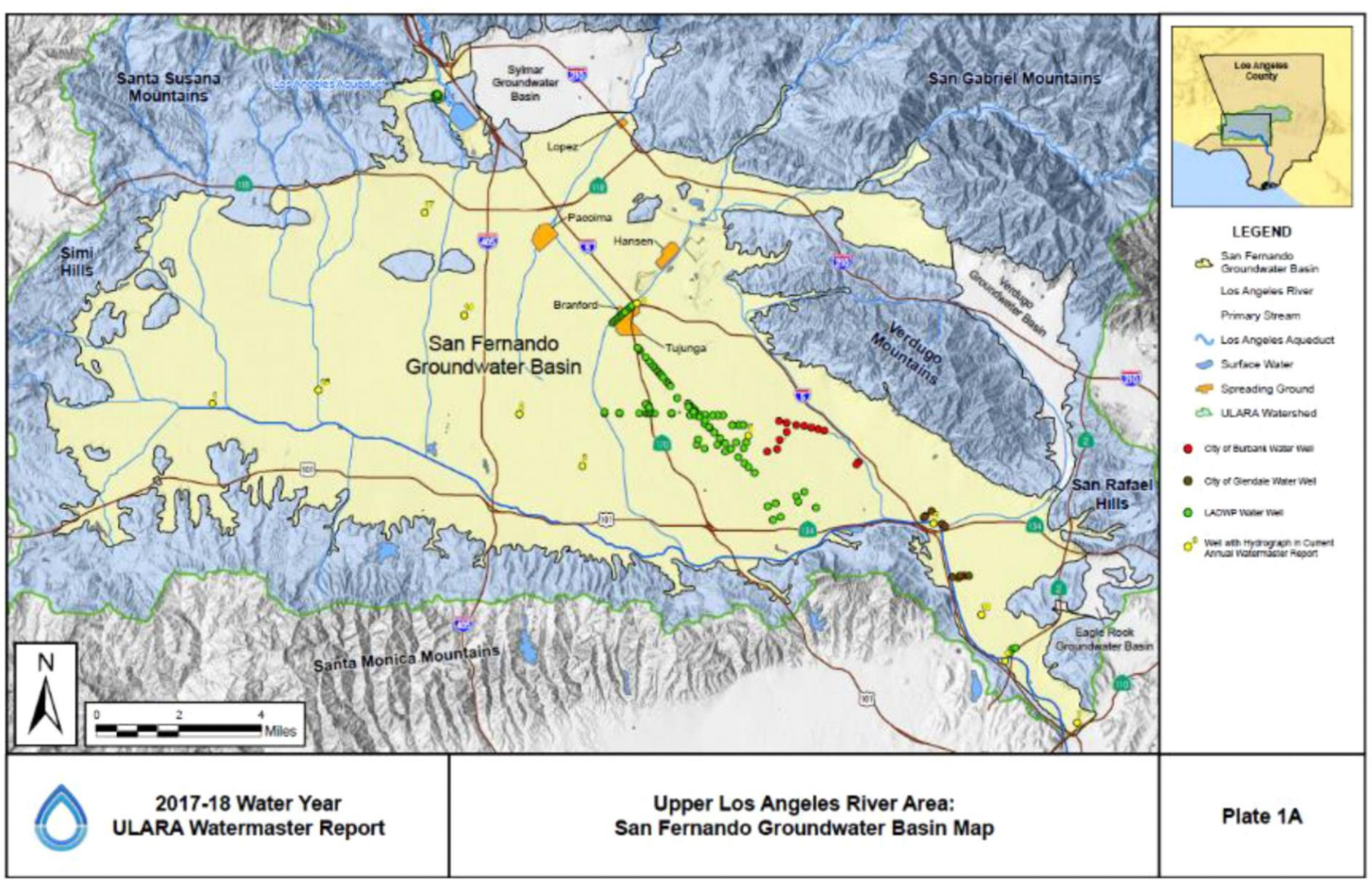


Figure 22. Map showing scenario 4 pumping wells, the total chlorinated volatile organic compound (TCVOC) greater than (> 100-part-per-billion (ppb) plume shell (HDR, 2019), and particle pathlines starting at the plume shell, southeastern Nassau Cou New York. A high-resolution version of this figure is available for download at https://doi.org/10.3133/sir20205090.



Source: 2017-18 Annual Watermaster Report, (ULARA 2019)

Figure 3. San Fernando Groundwater Basin, Part of the Upper Los Angeles River Adjudicated Area

SFV GW Superfund Basin

North Hollywood Area-1: North Hollywood OU (NHOU), Burbank OU (BOU)

Crystal Springs Area 2: Glendale OU (GOU)

NHOU: LADWP (1989)

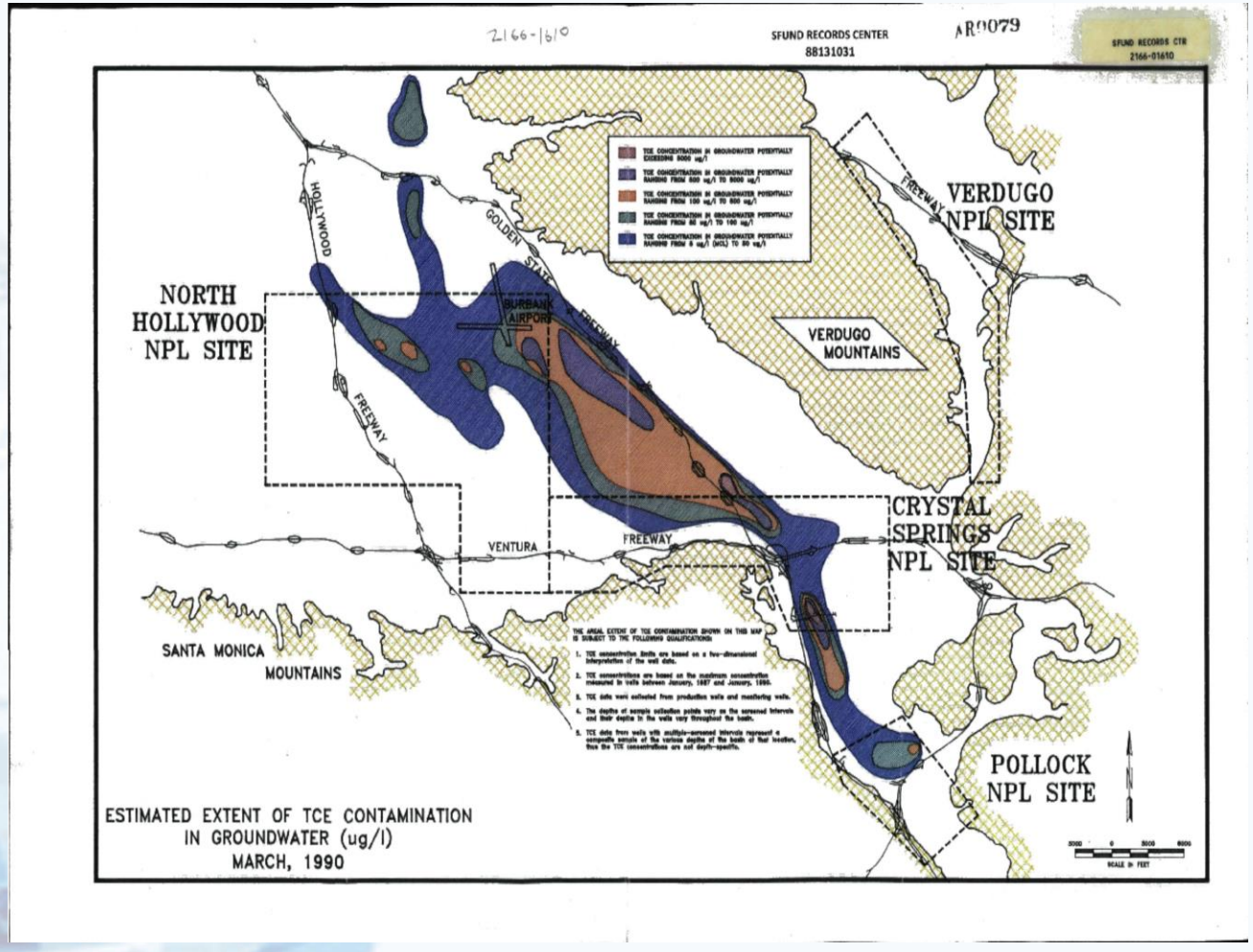
P&T, Air Stripping, VPGAC & LPGAC (VOCS),

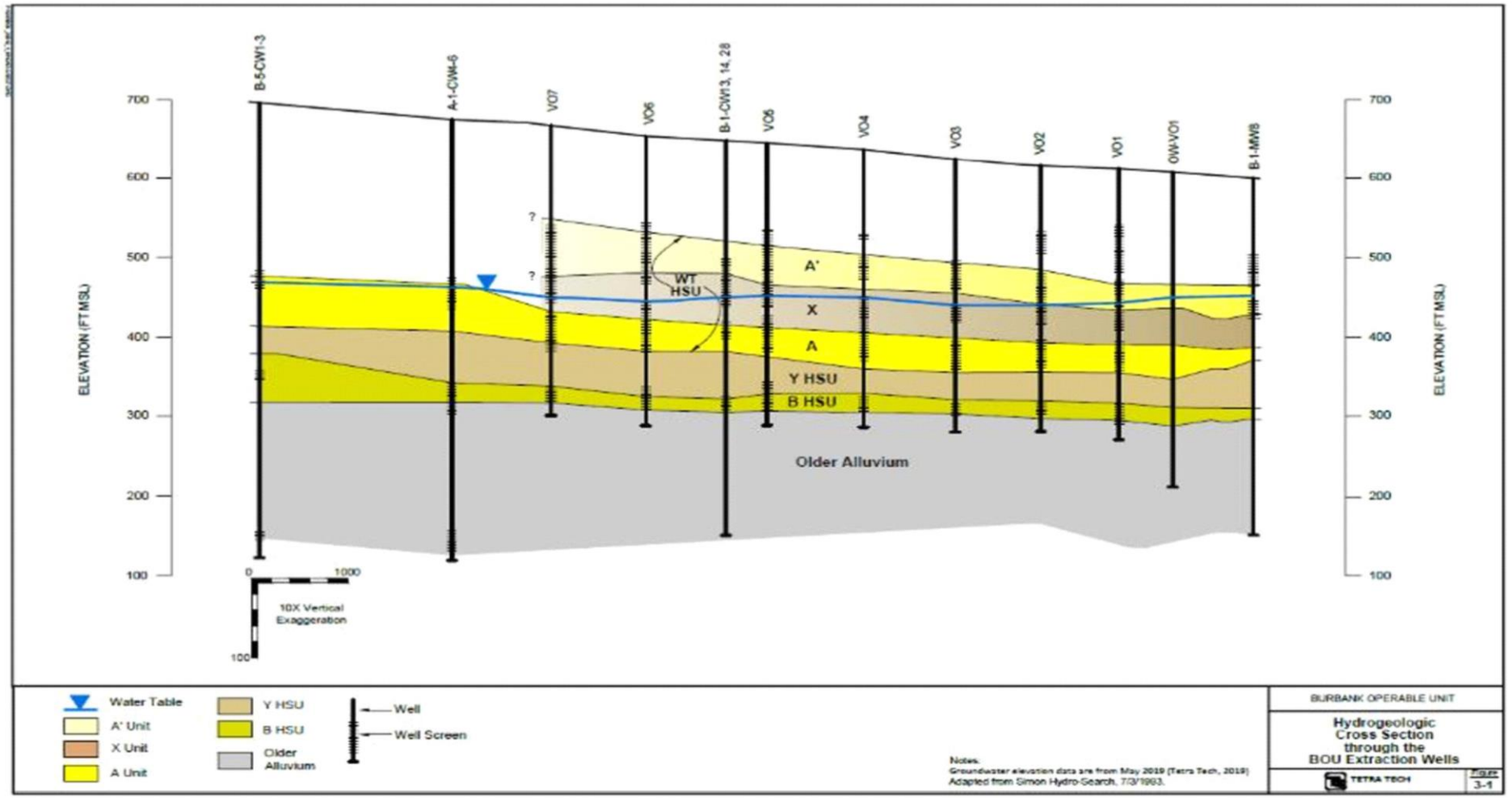
Cr+6: Fe2O2 reduction w/microfilteration

BOU: Lockheed Martin (1997), Burbank (2000) – P&T

GOU: Glendale (VOCs 2000, Cr+6 2007)

SFV Groundwater Monitoring Program (1992): Primarily TCE, PCE, Cr+6

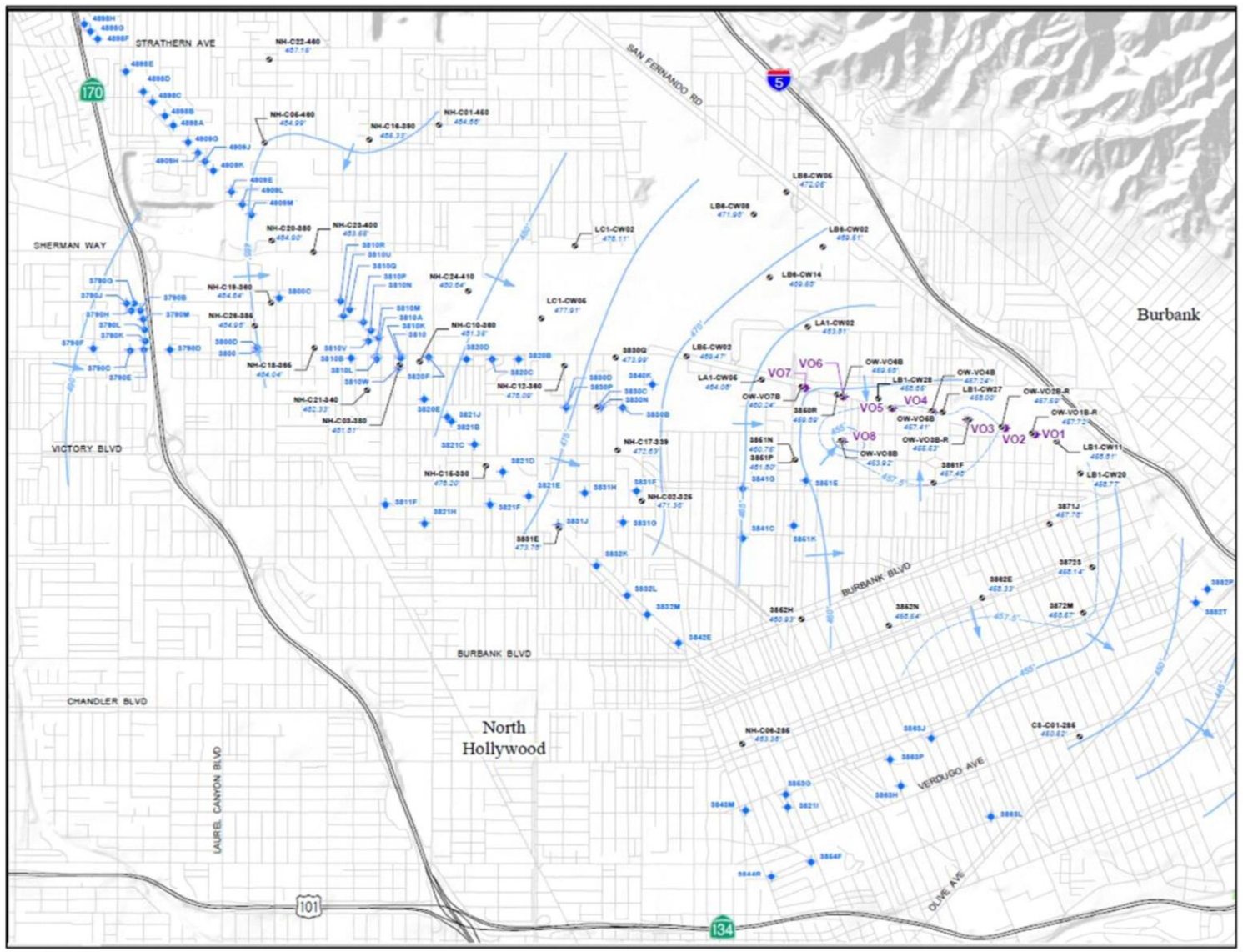




Source: Focused Feasibility Study, Burbank Operable Unit, Burbank, California (Tetra Tech, 2021)

Figure 4. Generalized Hydrogeologic Cross Section for San Fernando Valley Superfund Site

GROUNDWATER ELEVATION CONTOUR MAP, 2021



Source: Focused Feasibility Study, Burbank Operable Unit, Burbank, California (Tetra Tech, 2021)

SAN FERNANDO VALLEY BASIN, TCE CONCENTRATION IN SHALLOW GW ZONE 2007

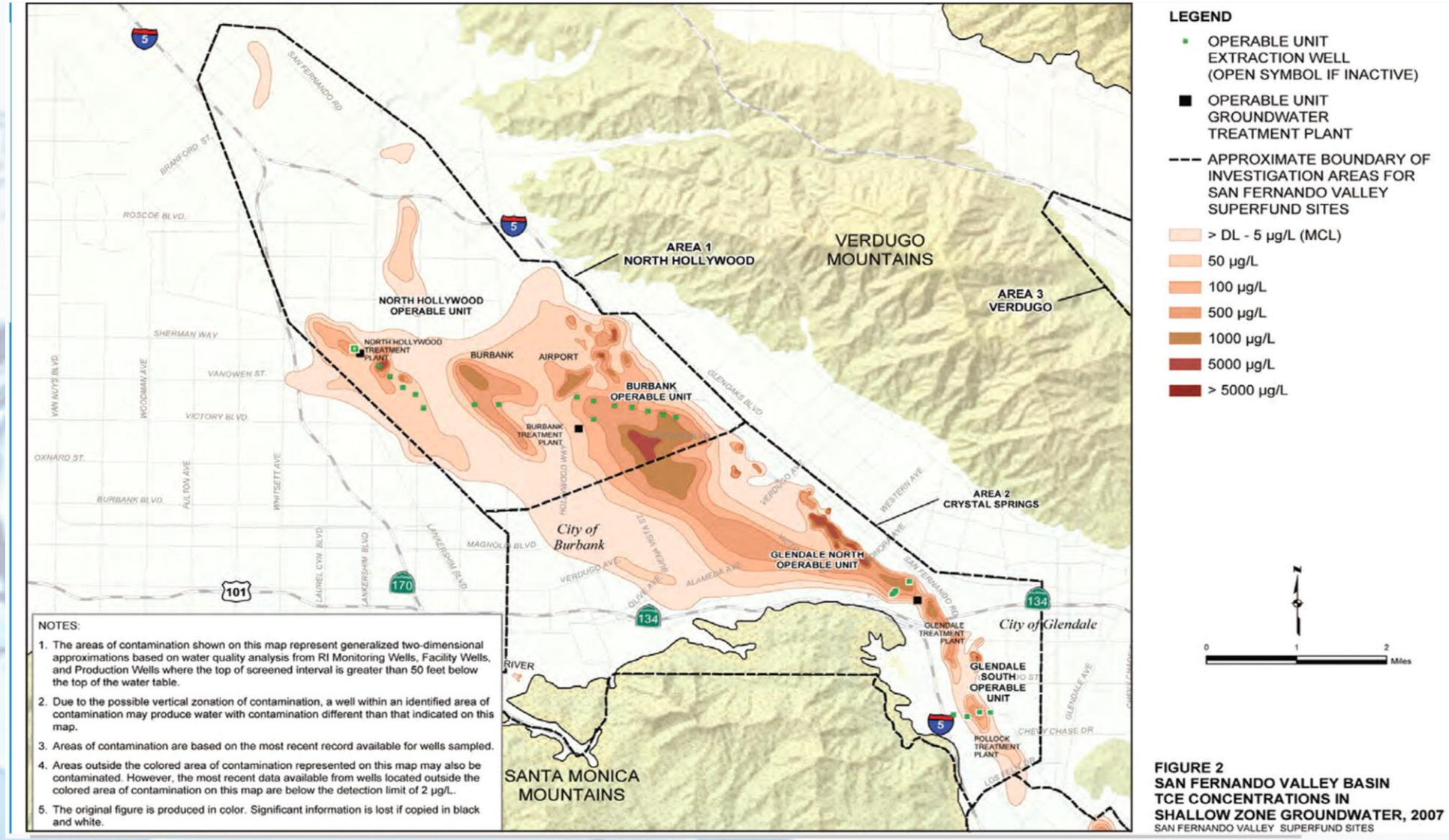
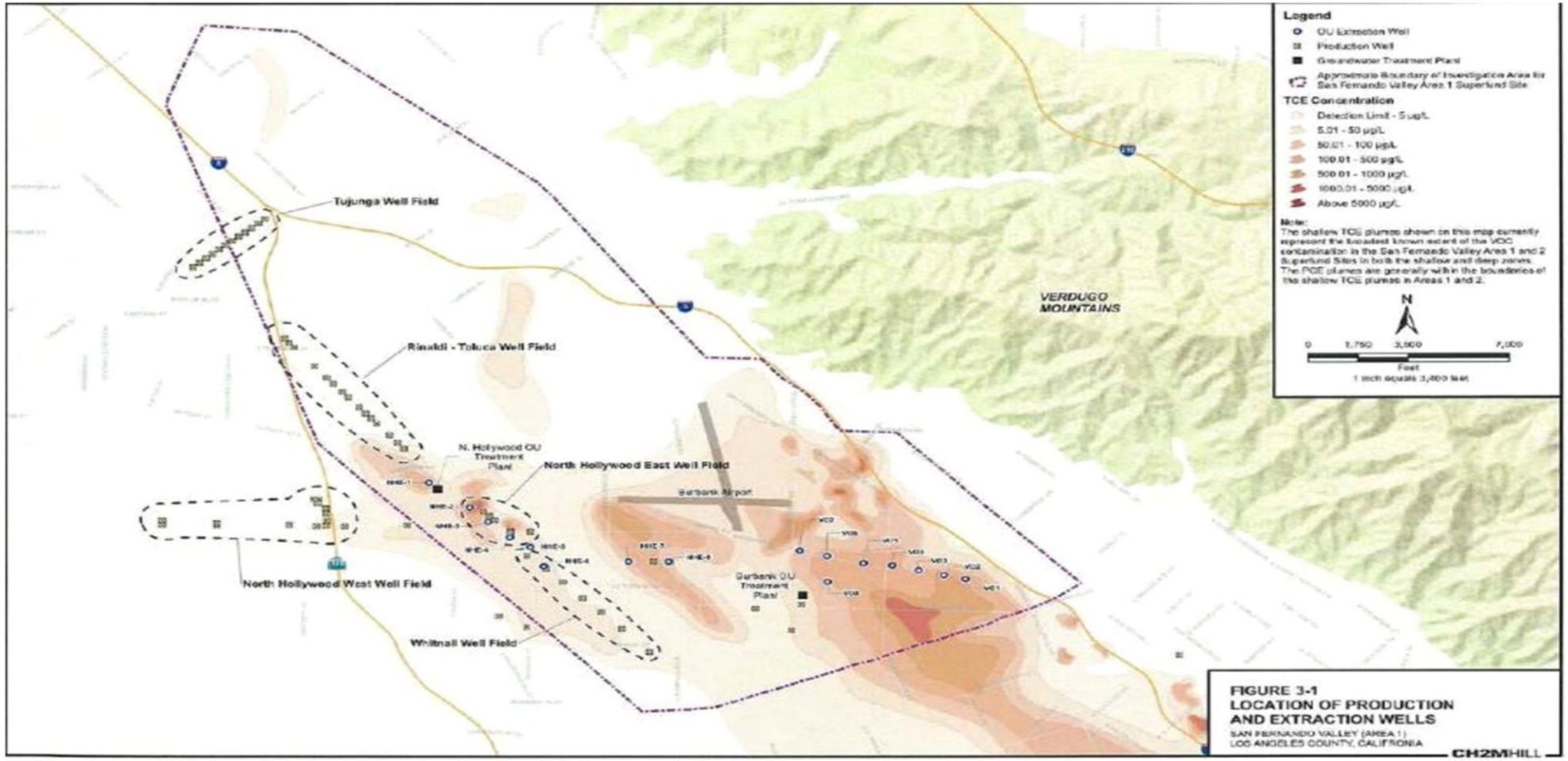


FIGURE 2
SAN FERNANDO VALLEY BASIN TCE CONCENTRATIONS IN SHALLOW ZONE GROUNDWATER, 2007
SAN FERNANDO VALLEY SUPERFUND SITES



Source: Focused Feasibility Study, Burbank Operable Unit, Burbank, California (Tetra Tech, 2021)

Figure 7. Location of Production and Extraction Wells and Treatment Plants

Air Stripper Towers BOU



Ion Exchange Vessels



Vapor Phase GAC Vessels



Liquid Phase GAC



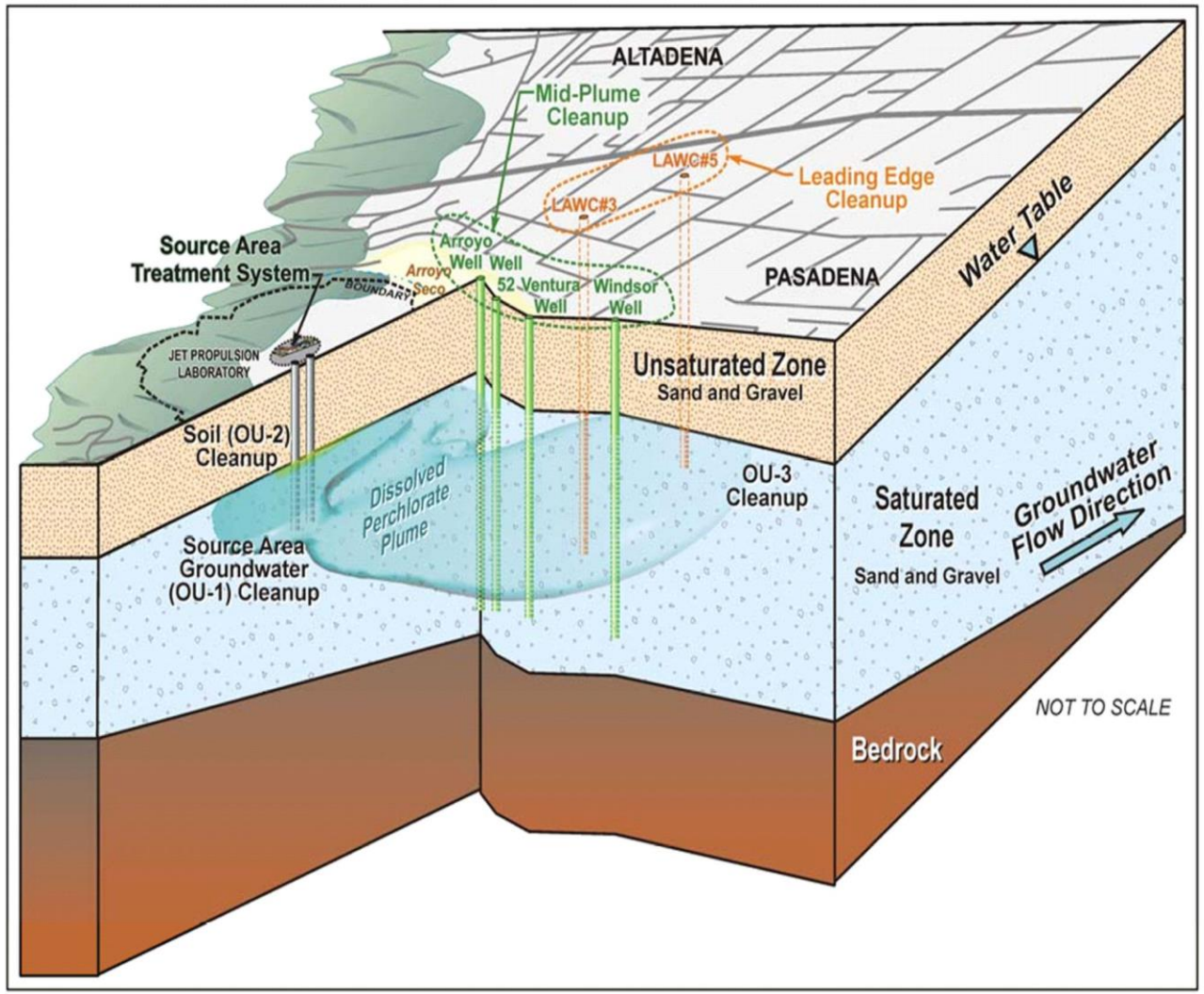


Figure 4-1. Conceptual Representation of the Comprehensive Groundwater Cleanup Program at JPL

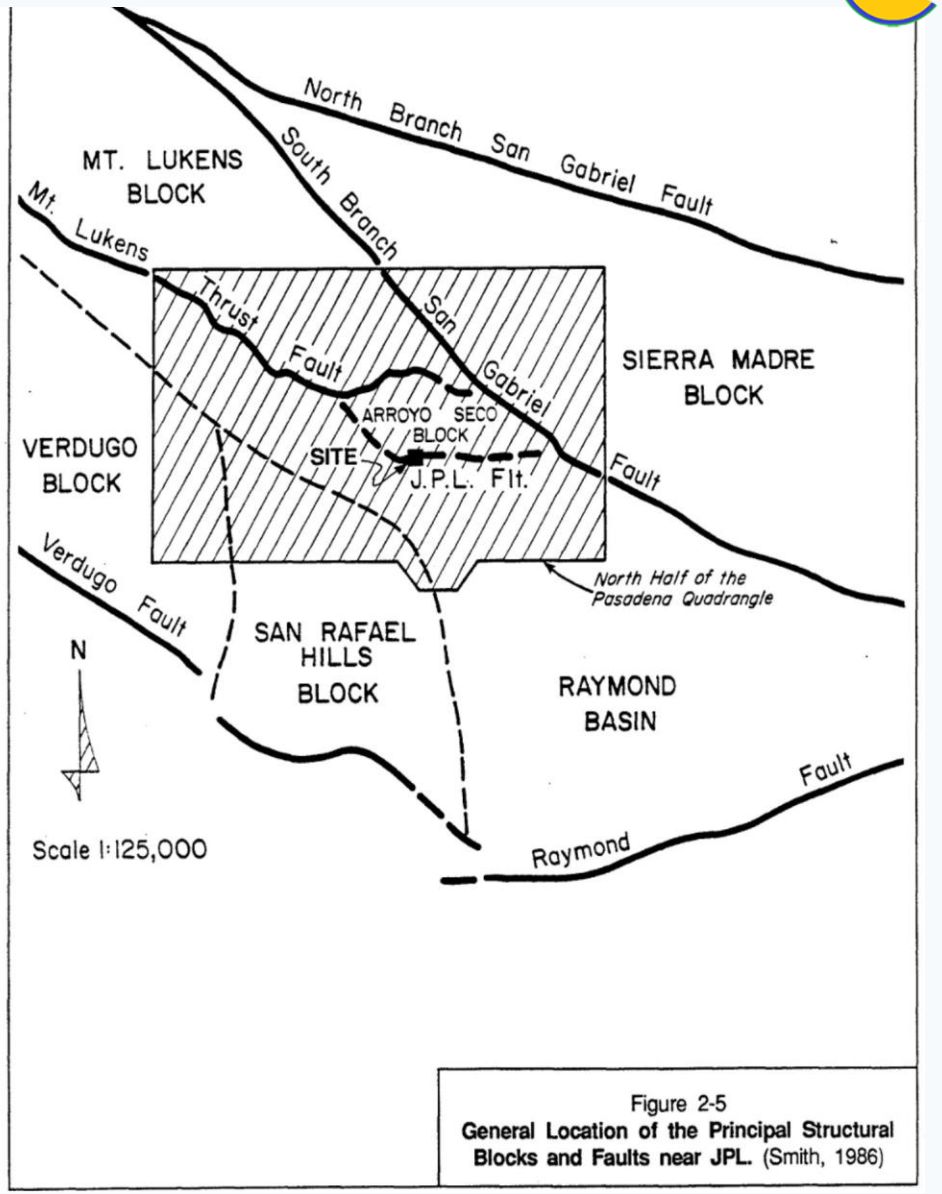
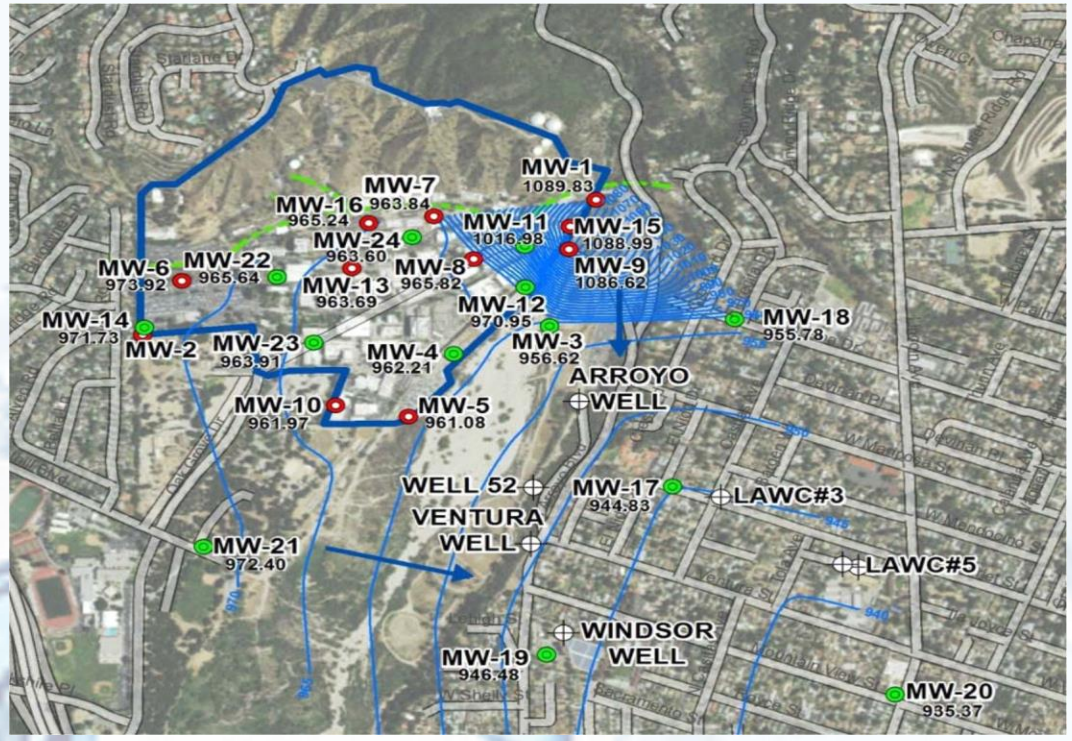


Figure 2-5
General Location of the Principal Structural Blocks and Faults near JPL. (Smith, 1986)



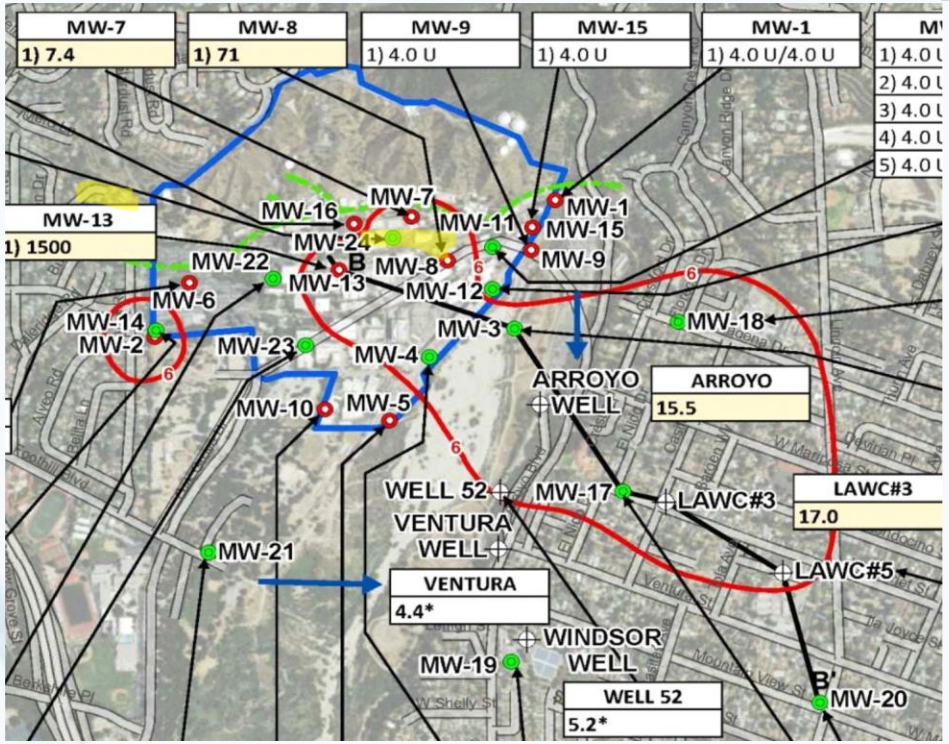


Table 5-3. OU1 Source Area Monitoring Well Concentrations

Source Area Monitoring Well Concentrations		MW-7	MW-13	MW-16	MW-24	Upgradient (1)
		µg/L				
Current Levels (Apr-May 2015)	Perchlorate	7.4	1,500	*2.5*	66.0	5.0
	Carbon Tetrachloride	<0.5	<0.5	<0.5	<0.5	<0.5
	TCE	<0.5	<0.5	<0.5	<0.5	2.0
Prior to OU1 Startup	Perchlorate	4,810	51.5	322	4,880	4.2
	Carbon Tetrachloride	51.4	*0.4*	<0.5	7.8	<0.5
	TCE	8.7	1.4	<0.5	1.6	0.7
Historic Highs	Perchlorate	13,300	2,100	13,100	4,880	7.4
	Carbon Tetrachloride	310	70	200	58	<0.5
	TCE	48	73	43	15	4.8

(1) Upgradient concentrations identified as maximum concentrations from Valley Water Company Wells 1, 2 and
Italicized values were below detection limits and reported as "J" values.

NASA JPL SUPERFUND SITE, PASADENA

P&T, LGAC, Fluidized Bed Reactor

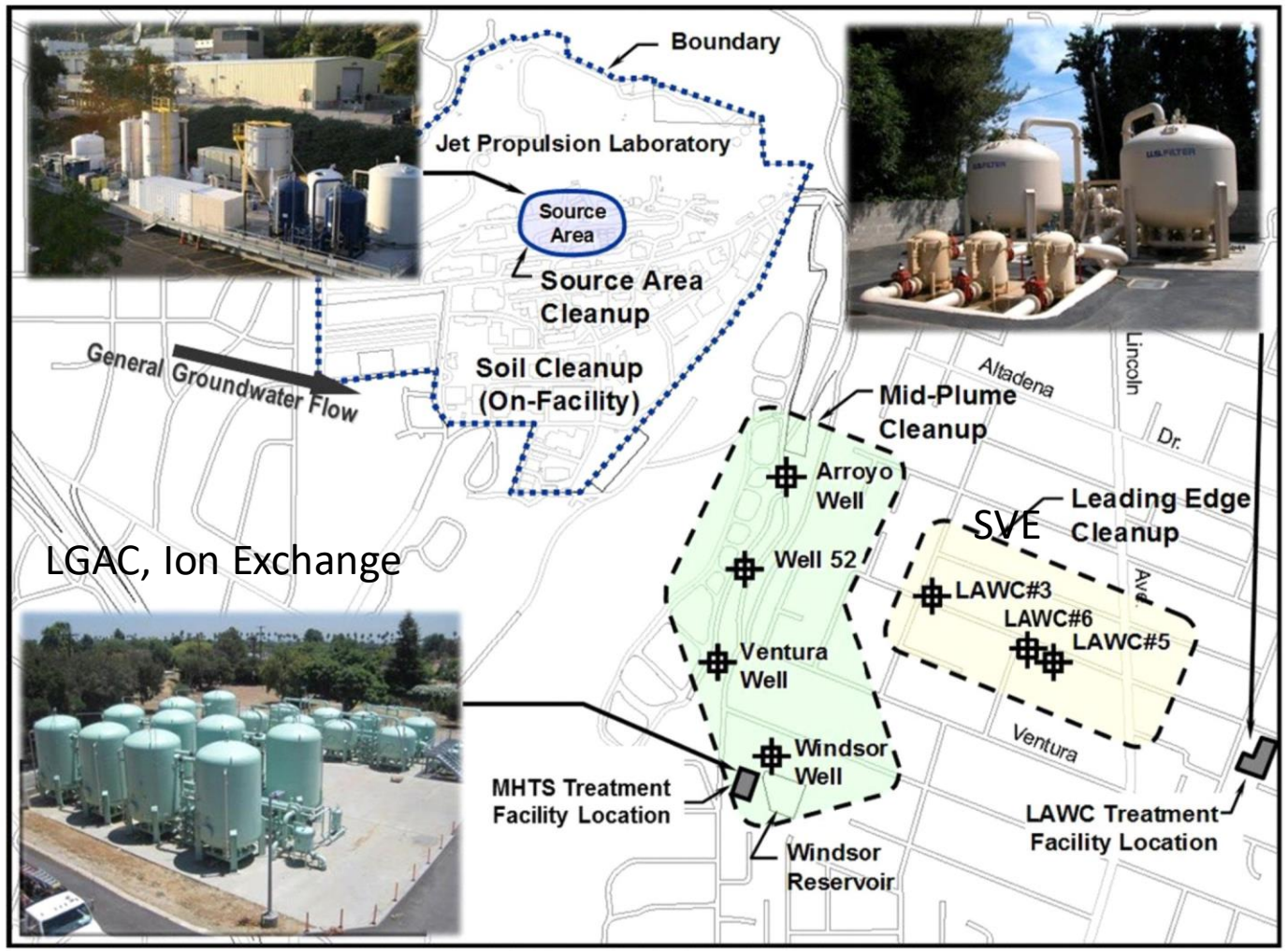
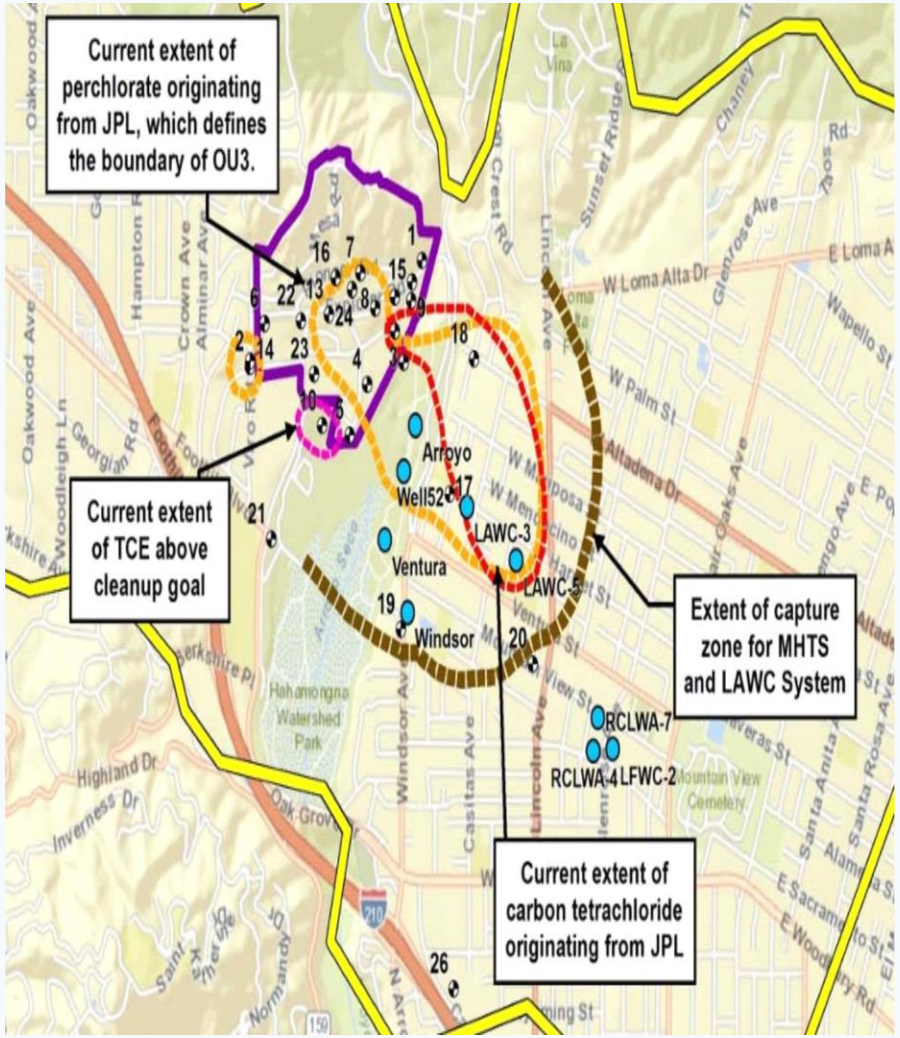


Figure 1-1. Location of Treatment Systems

LGAC, Ion Exchange



CONCLUSIONS

- Thoroughly determine lateral and vertical extent of contamination, first onsite source areas, then offsite.
- Cross-sections, groundwater elevation contour maps, flow directions, horizontal, and vertical gradients.
- Iso-concentration maps of CoCs in soil matrix, soil vapor, and groundwater (plume maps).
- Aquifer testing and analysis, groundwater monitoring wells, extraction wells, injection wells.
- Capture zone analysis.
- Groundwater flow modeling and particle tracking.
- First remediate onsite source areas using the most effective remedial technologies to reduce CoC concentrations to required cleanup goals, contain and prevent plume offsite migration. Then proceed offsite. If WSWs at risk, conduct concurrent remediation.