Numerical Modeling of a Permeable Reactive Barrier for a PCE WQARF Site in Arizona

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Objective

- Design a passive in-situ groundwater remediation system (PIGRS) using a numerical model

Themes

- Funnel & Gate's may not meet containment goals
- Carefully design PRBs to contain/capture plumes

PRESENTATION OUTLINE

- **Site Characterization:**
  1) *ADEQ 2001. Updated Site Conceptual Model 2001 For Park-Euclid Water Quality Assurance Revolving Fund Site.*

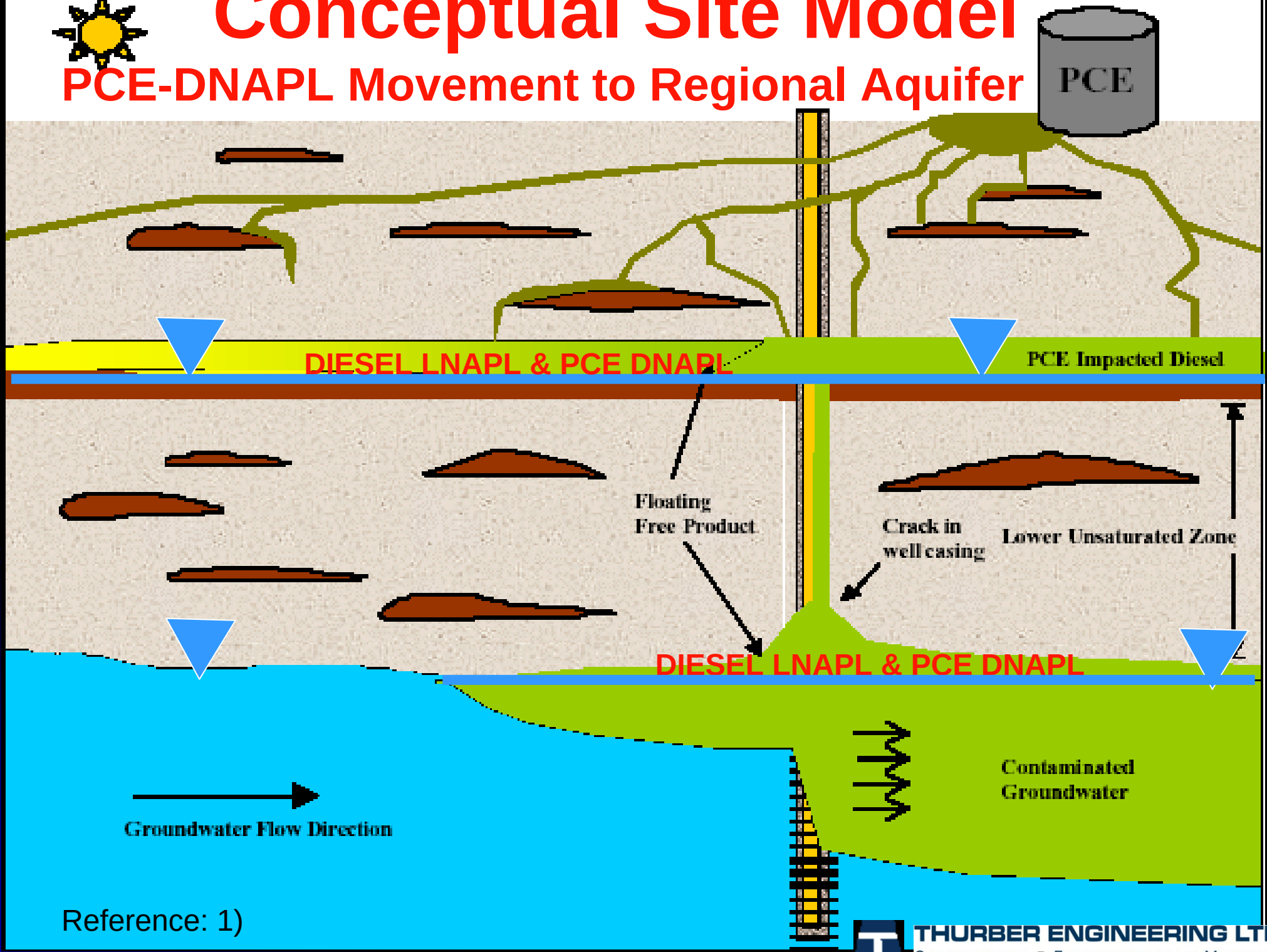
- **Remedial Design Options:**
  2) *Puls 2001. Permeable Reactive Barriers for Groundwater Remediation. EPA –ADA, Oklahoma.*

- **Published Examples:**
  3) Gavaskar et.al 2000. Design Guidance for Application of Permeable Reactive Barriers for Groundwater Remediation. SERDP.
  4) Monticello Utah, U.S. Department of Energy – Grand Junction Office *http://www.gjo.doe.gov/perm-barr/index.htm*

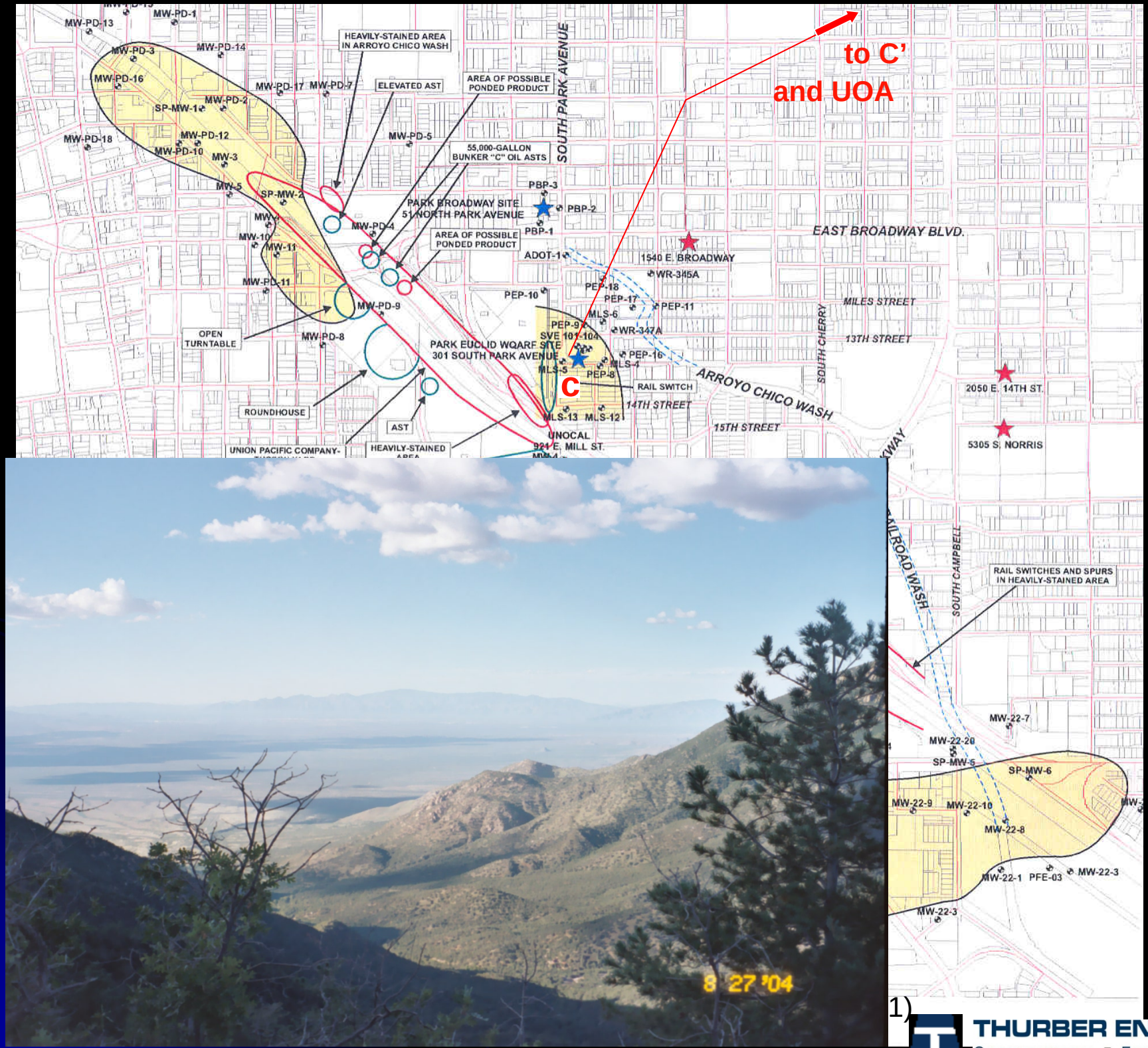
- **Time-lapsed numerical simulations:**
  1) no-action scenario
  2) funnel & gate
  3) short reactive wall
  4) long reactive wall

Conceptual Site Model

PCE-DNAPL Movement to Regional Aquifer

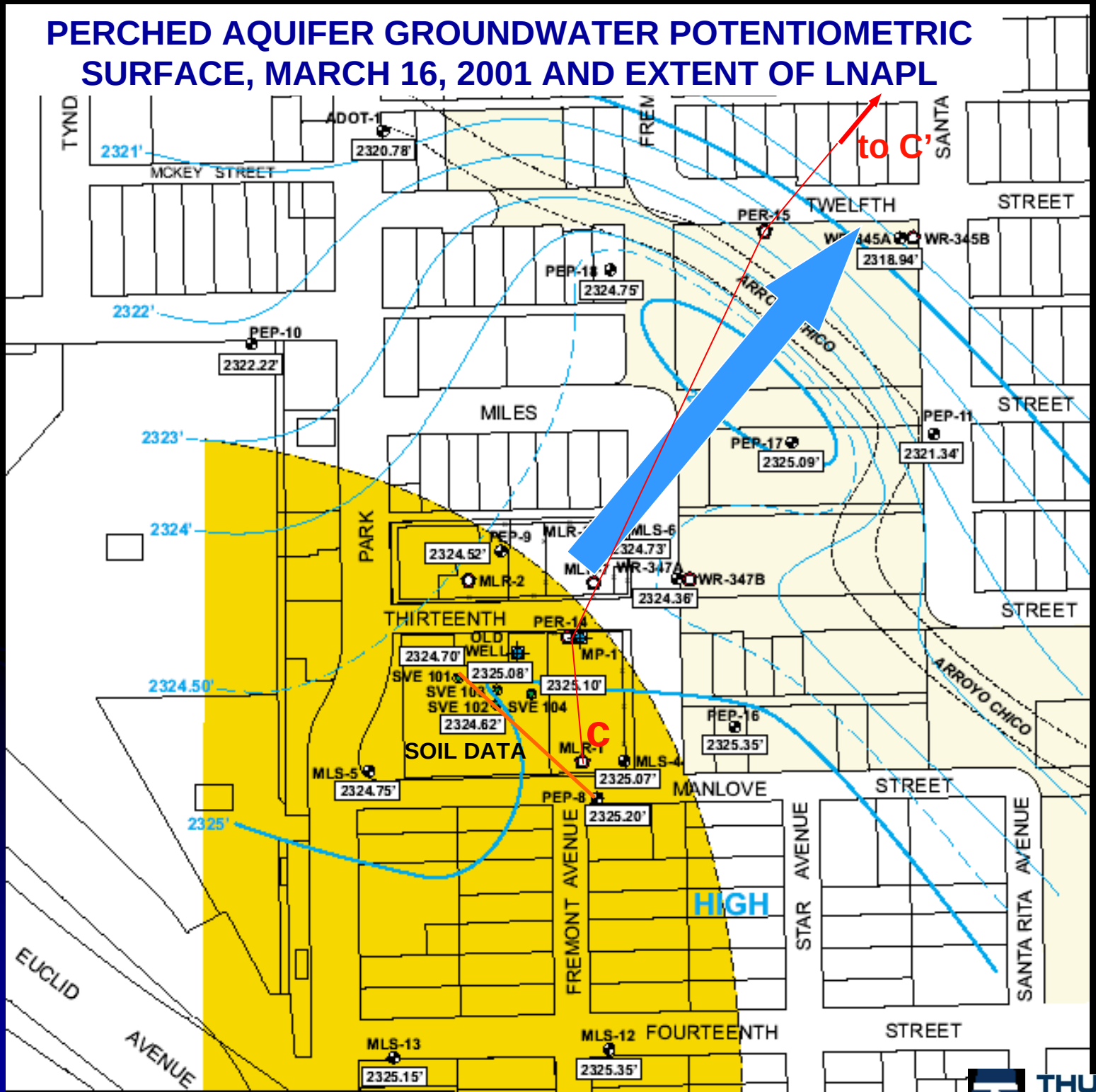


Reference: 1)

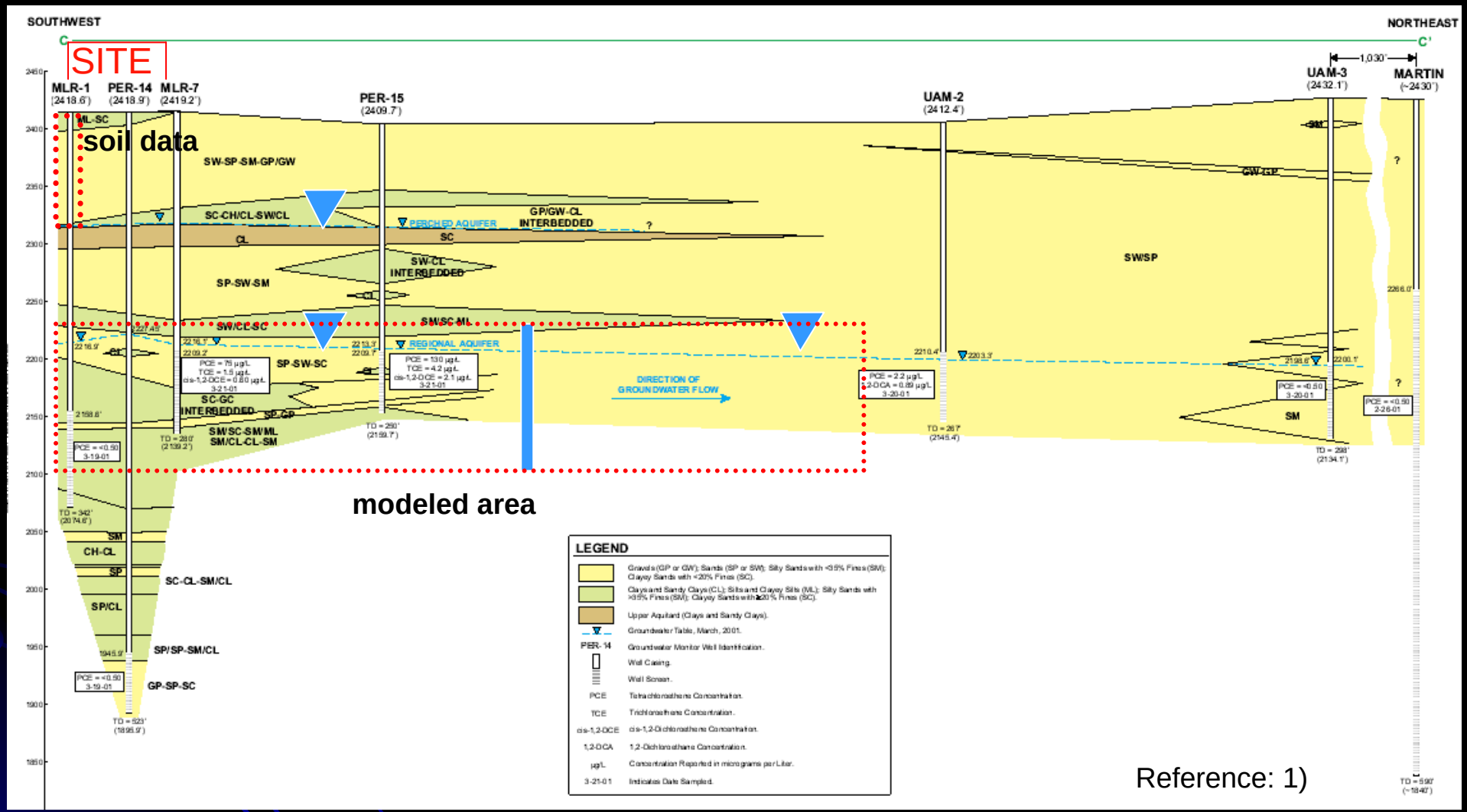

to C'
and UOA
HEAVILY-STAINED AREA IN ARROYO CHICO WASH
AREA OF POSSIBLE PONDED PRODUCT
ELEVATED AST
SOUTH PARK AVENUE
55,000-GALLON BUNKER "C" OIL ASTS
PARK BROADWAY SITE
51 NORTH PARK AVENUE
EAST BROADWAY BLVD.
1540 E. BROADWAY
OPEN TURNTABLE
PARK EUCLID WQARF SITE
301 SOUTH PARK AVENUE
C
ROUNDHOUSE
AST
UNION PACIFIC COMPANY-
HEAVILY-STAINED
UNOCAL
921 E. MILL ST.
RAIL SWITCH
ARROYO CHICO WASH
14TH STREET
15TH STREET
MILES STREET
13TH STREET
SOUTH CHERRY
2050 E. 14TH ST.
5305 S. NORRIS
RAIL SWITCHES AND SPURS IN HEAVILY-STAINED AREA
SOUTH CAMPBELL
RAILROAD WASH
8 27 '04

1)

PERCHED AQUIFER GROUNDWATER POTENTIOMETRIC SURFACE, MARCH 16, 2001 AND EXTENT OF LNAPL



Reference: 1)


SOUTHWEST
NORTHEAST
C
C'
SITE
soil data
modeled area
MLR-1
(2418.6')
PER-14
(2418.9')
MLR-7
(2419.2')
PER-15
(2409.7')
UAM-2
(2412.4')
UAM-3
(2432.1')
MARTIN
(~2430')
1,030'
ML-SC
SW-SP-SM-GP/GW
SC-CH/CL-SW/CL
CL
PERCHED AQUIFER
GP/GW-CL
INTERBEDDED
SC
SW-CL
INTERBEDDED
SP-SW-SM
SW/SP
GW-GP
SW/CL-SC
SM/SC-ML
REGIONAL AQUIFER
SP-SW-SC
SC-GC
INTERBEDDED
SP-GP
SM/SC-SM/ML
SM/CL-CL-SM
DIRECTION OF
GROUNDWATER FLOW
SM
CH-CL
SP
SC-CL-SM/CL
SP/CL
SP/SP-SM/CL
GP-SP-SC
SM
LEGEND
Gravels (GP or GW); Sands (SP or SW); Silty Sands with <35% Fines (SM); Clayey Sands with <20% Fines (SC).
Clays and Sandy Clays (CL); Silts and Clayey Silts (ML); Silty Sands with >35% Fines (SM); Clayey Sands with ≥20% Fines (SC).
Upper Aquitard (Clays and Sandy Clays).
Groundwater Table, March, 2001.
PER-14
Groundwater Monitor Well Identification.
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Well Screen.
PCE
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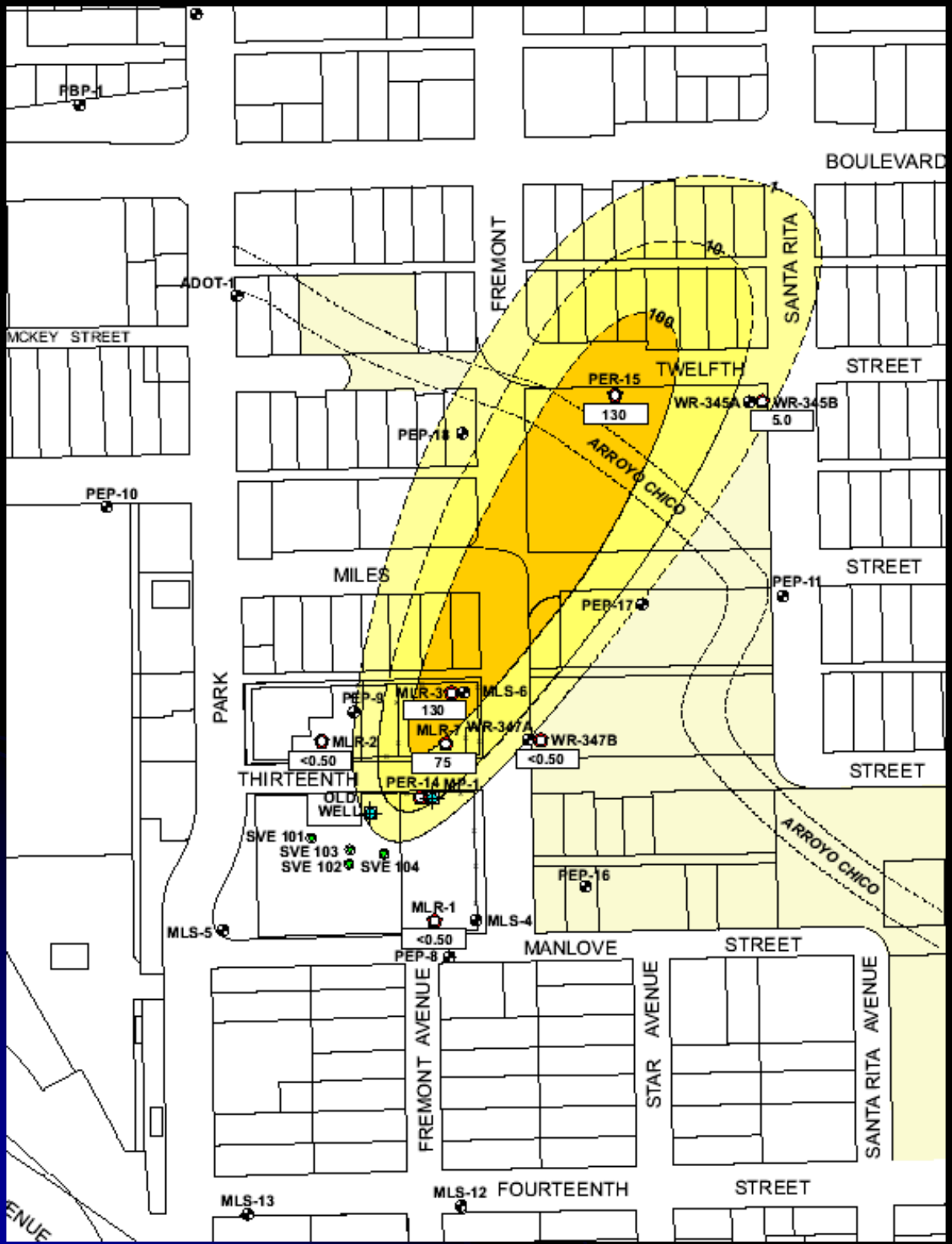
TCE
Trichloroethene Concentration.
cis-1,2-DCE
cis-1,2-Dichloroethene Concentration.
1,2-DCA
1,2-Dichloroethane Concentration.
µg/L
Concentration Reported in micrograms per Liter.
3-21-01
Indicates Date Sampled.

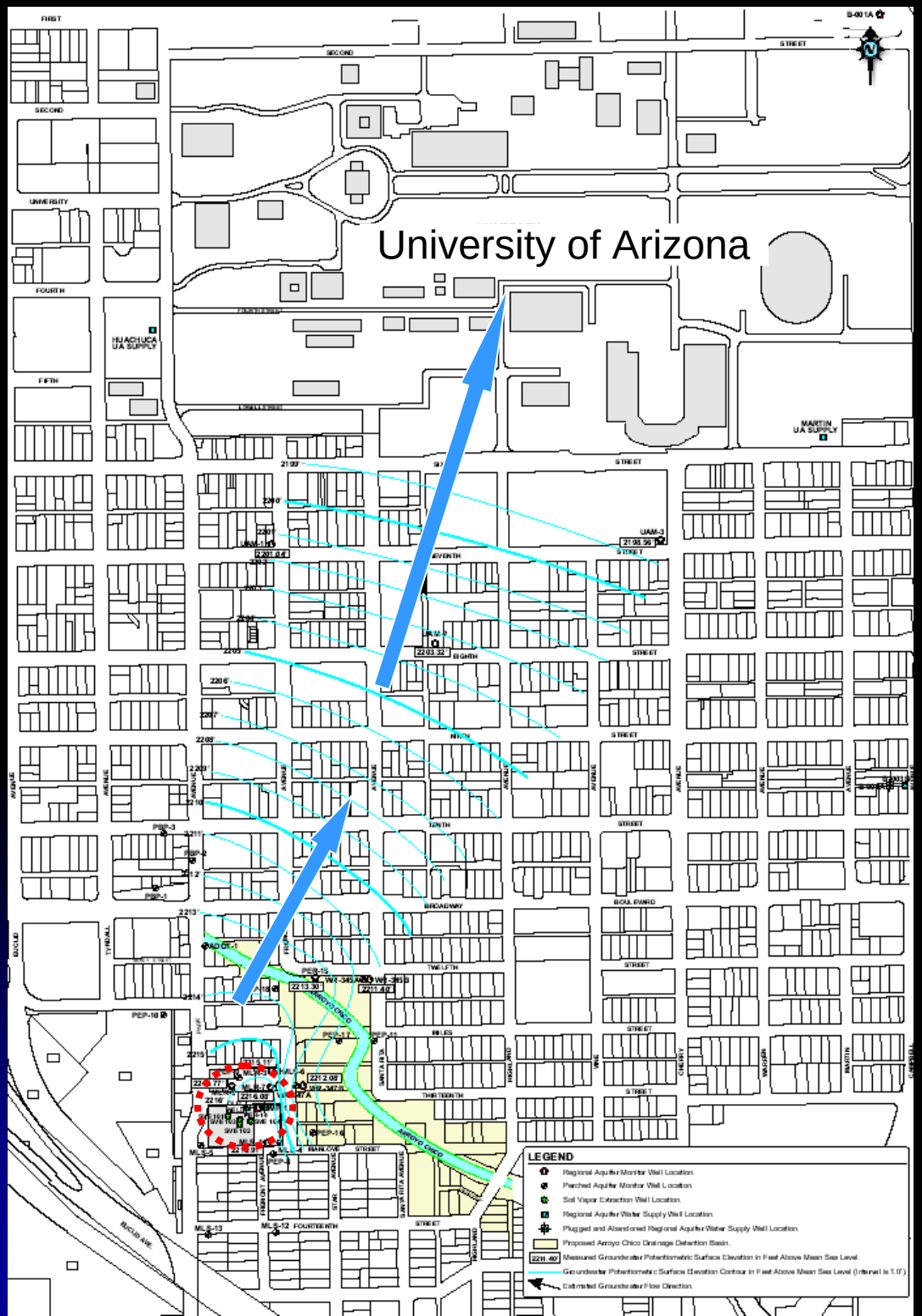
Reference: 1)

UNCONFINED REGIONAL AQUIFER
DISTRIBUTION OF PCE
MARCH 2001



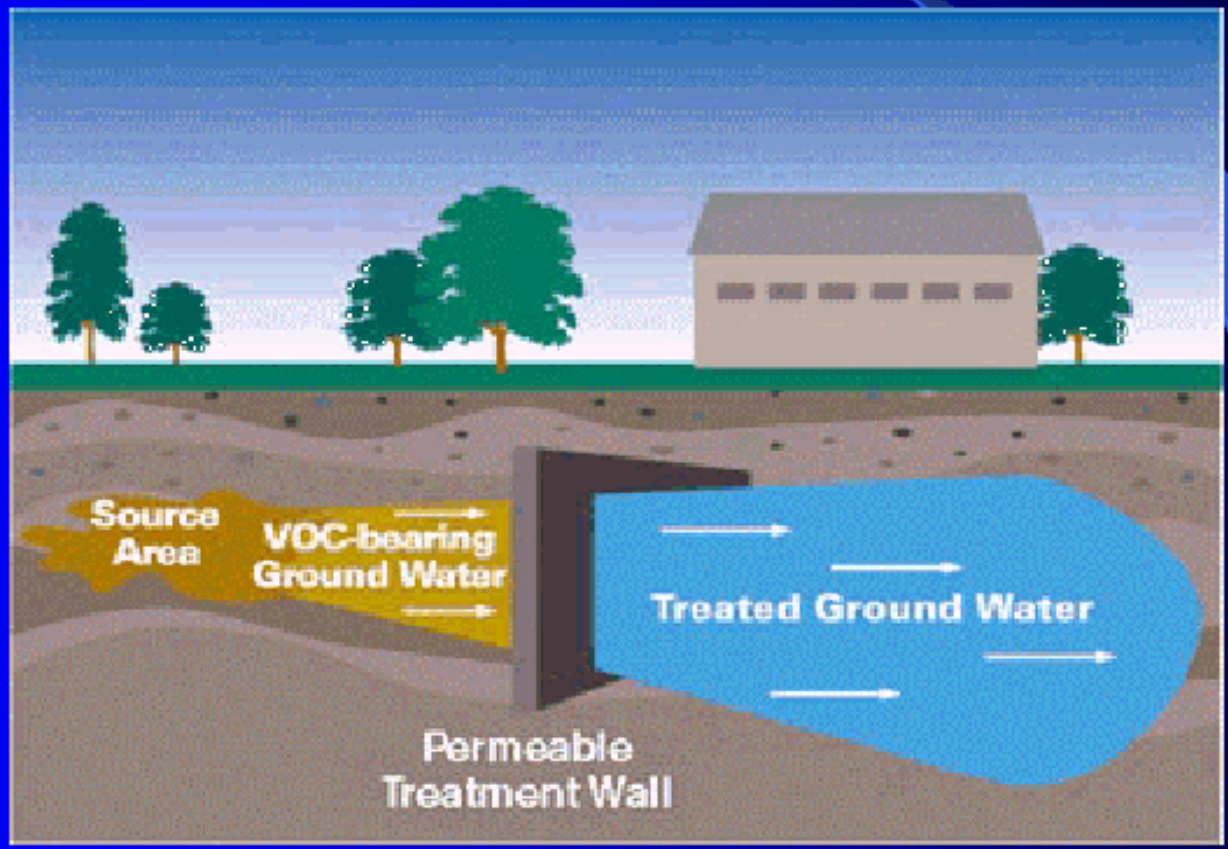
Reference: 1)

UNCONFINED REGIONAL AQUIFER GROUNDWATER POTENTIOMETRIC SURFACE MARCH 2001



Reference: 1)

A PRB for VOC Remediation



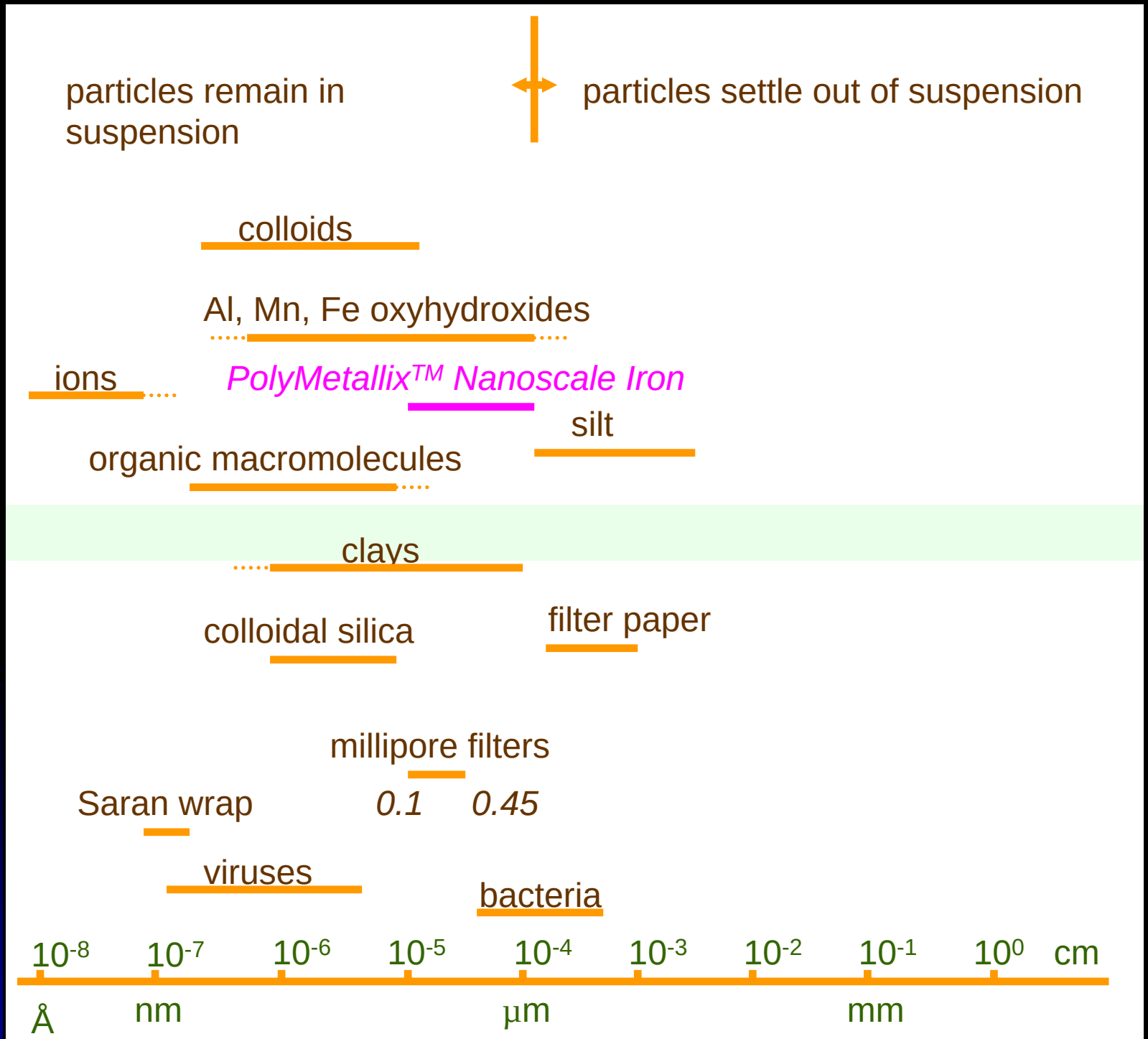
Source: General Electric Company

Reference: 2)

Treatment Matrix

- Zone or material that promotes treatment
- Focus on zero-valent iron [Fe^0]
  - to treat groundwater affected by
    - chlorinated ethenes
    - chlorinated ethanes
    - chlorinated methanes (some)
    - dissolved metals

reference 2)


particles remain in suspension
particles settle out of suspension
colloids
Al, Mn, Fe oxyhydroxides
ions
PolyMetallix™ Nanoscale Iron
silt
organic macromolecules
clays
colloidal silica
filter paper
millipore filters
Saran wrap
0.1
0.45
viruses
bacteria
10-8
10-7
10-6
10-5
10-4
10-3
10-2
10-1
100
cm
Å
nm
µm
mm

reference 2) go to utube geosierra & erm

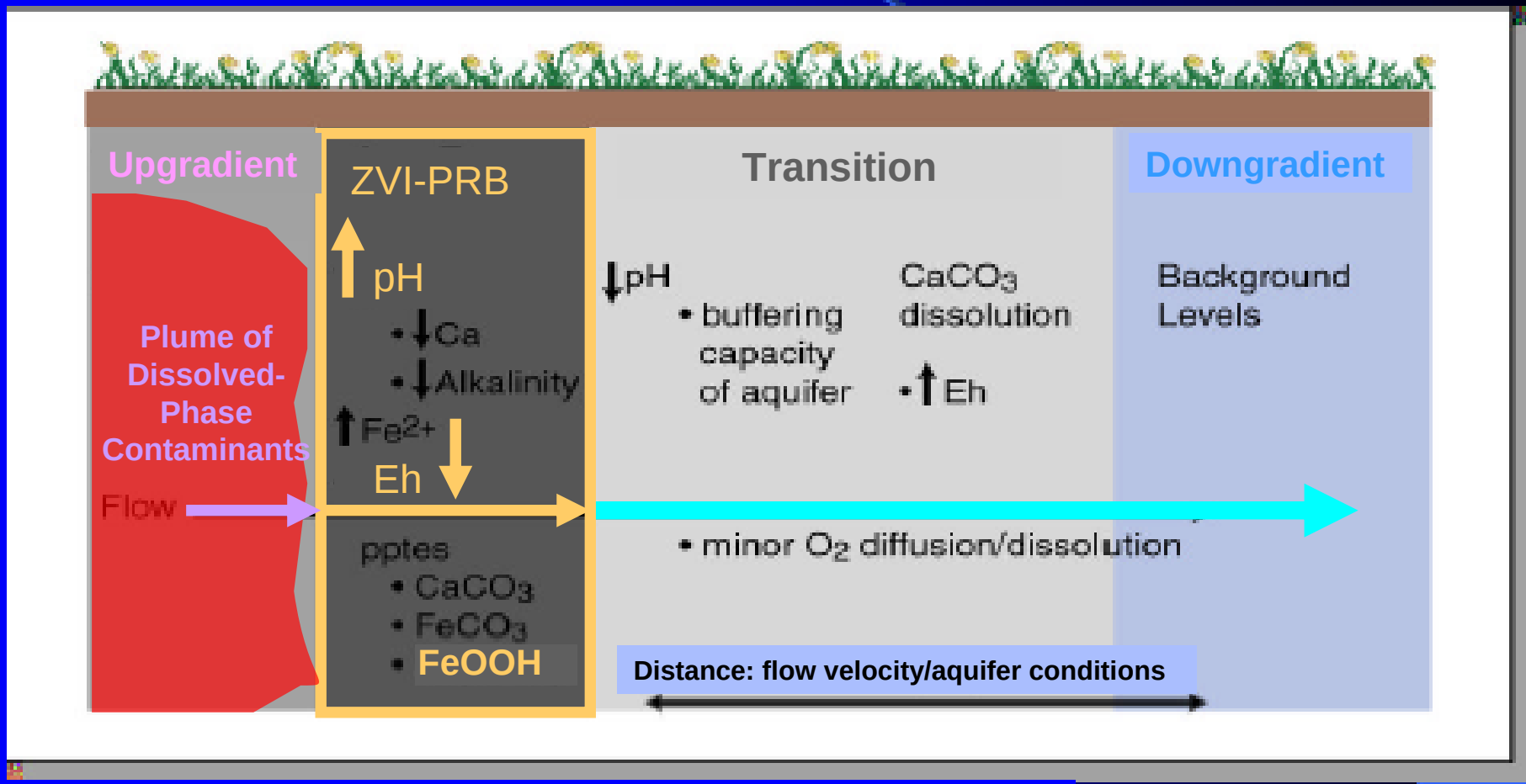
Zero-valent iron (Fe) reduces water to hydrogen gas via:

$Fe^0 + 2H^+ \leftrightarrows Fe^{2+} + H_2$

$Fe^0 + 2H_2O \rightarrow 2FE^{2+} + H_2 + 2OH^-$

$Fe^0 + O_2 + 2H_2O \rightarrow 2FE^{2+} + 4OH^-$

pH ↑ Fe^{2+} ↓ Eh



Fe(III) oxyhydroxides akageneite, goethite: $4Fe^{2+} + O_2 + 6H_2O \leftrightarrows 4FeOOH^0 + 8H^+$

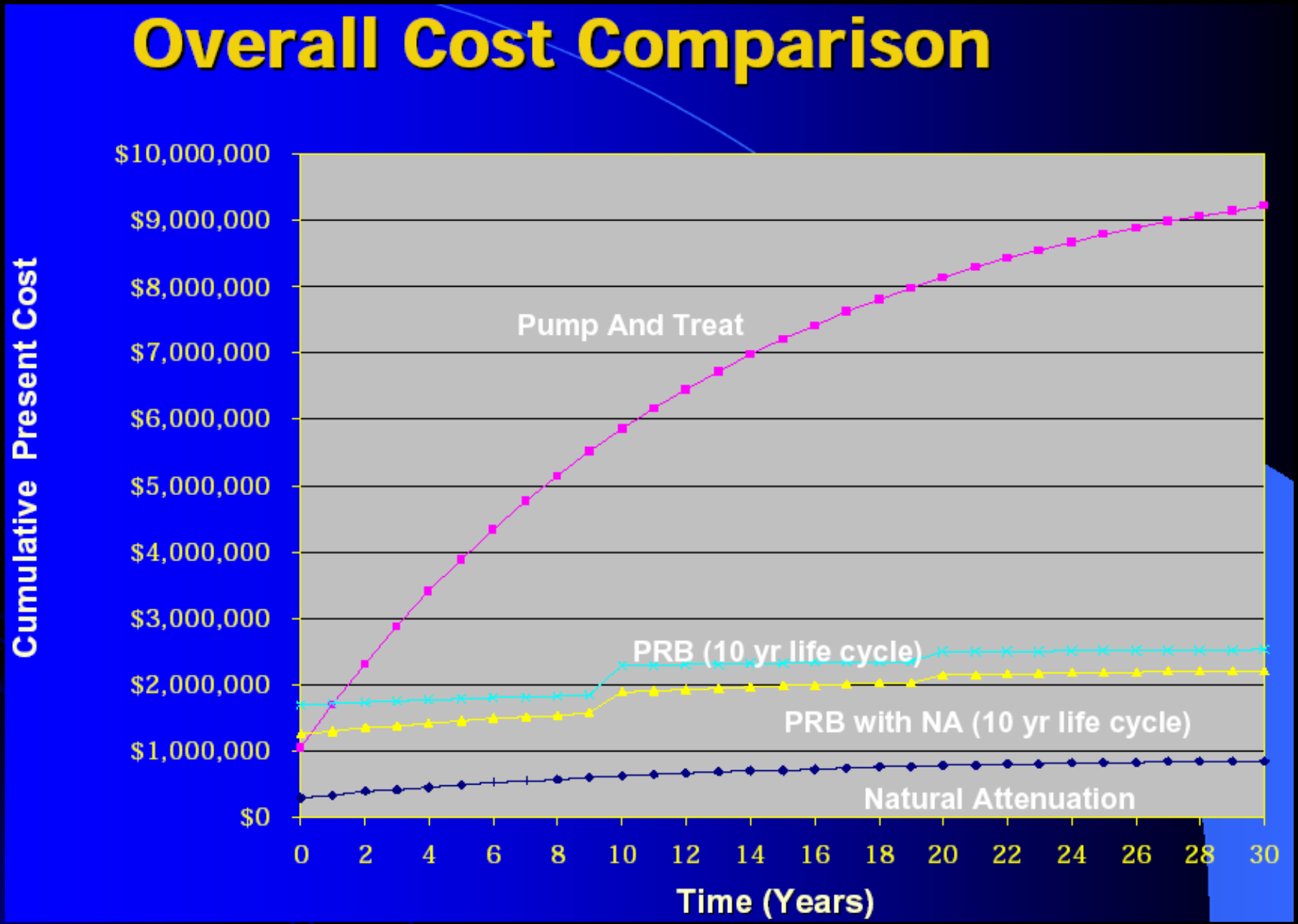
magnetite: $Fe(II)Fe(III)_2O_4$ as Fe_3O_4

green rust: $Fe(II)_4Fe(III)_2(OH)_{12}SO_4$ as $Fe_6(OH)_{12}SO_4$

Fe(II) sulfide/hydroxide, and carbonate minerals

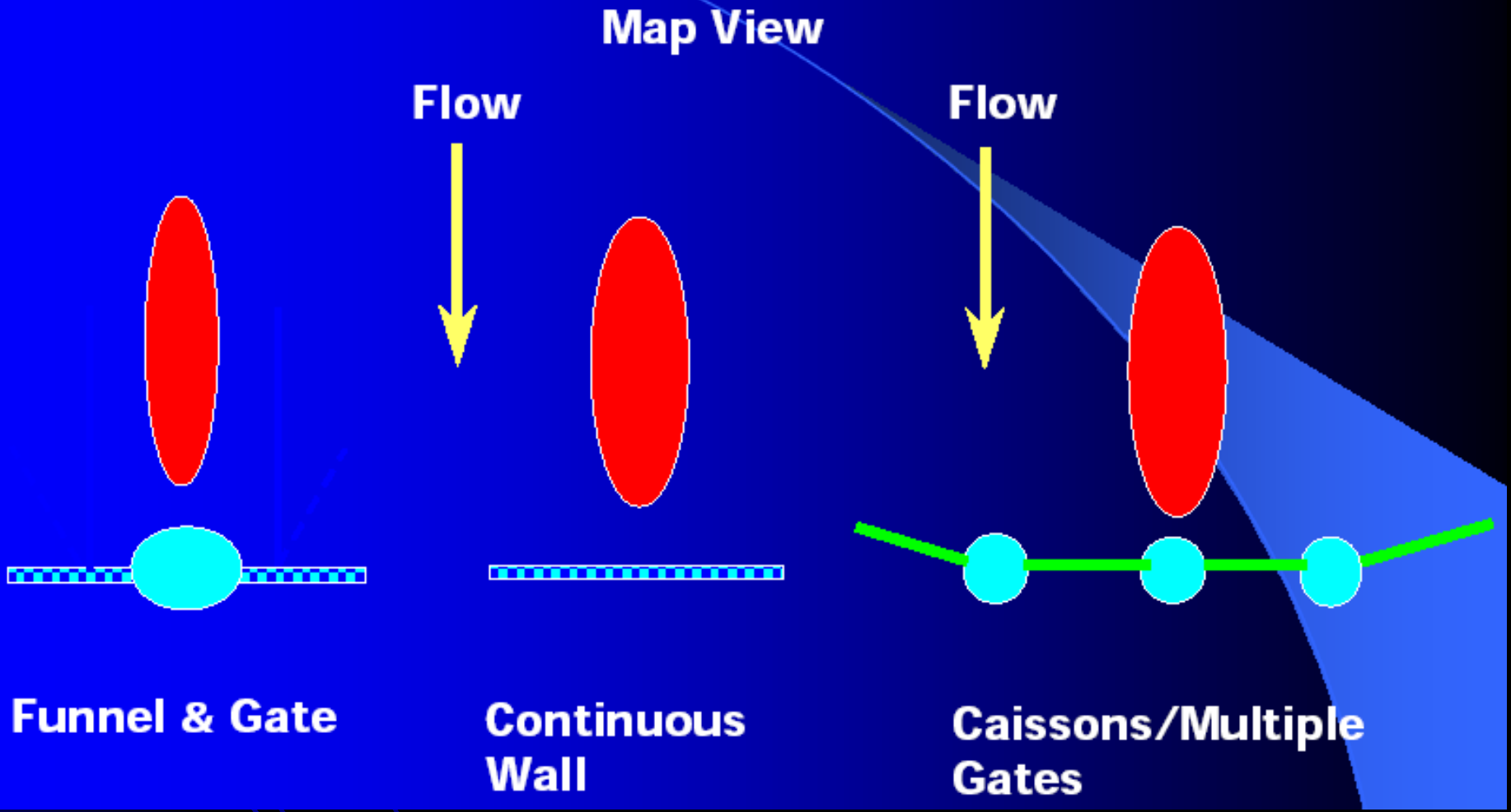
adapted from reference 4)

Overall Cost Comparison



Reference: 2)

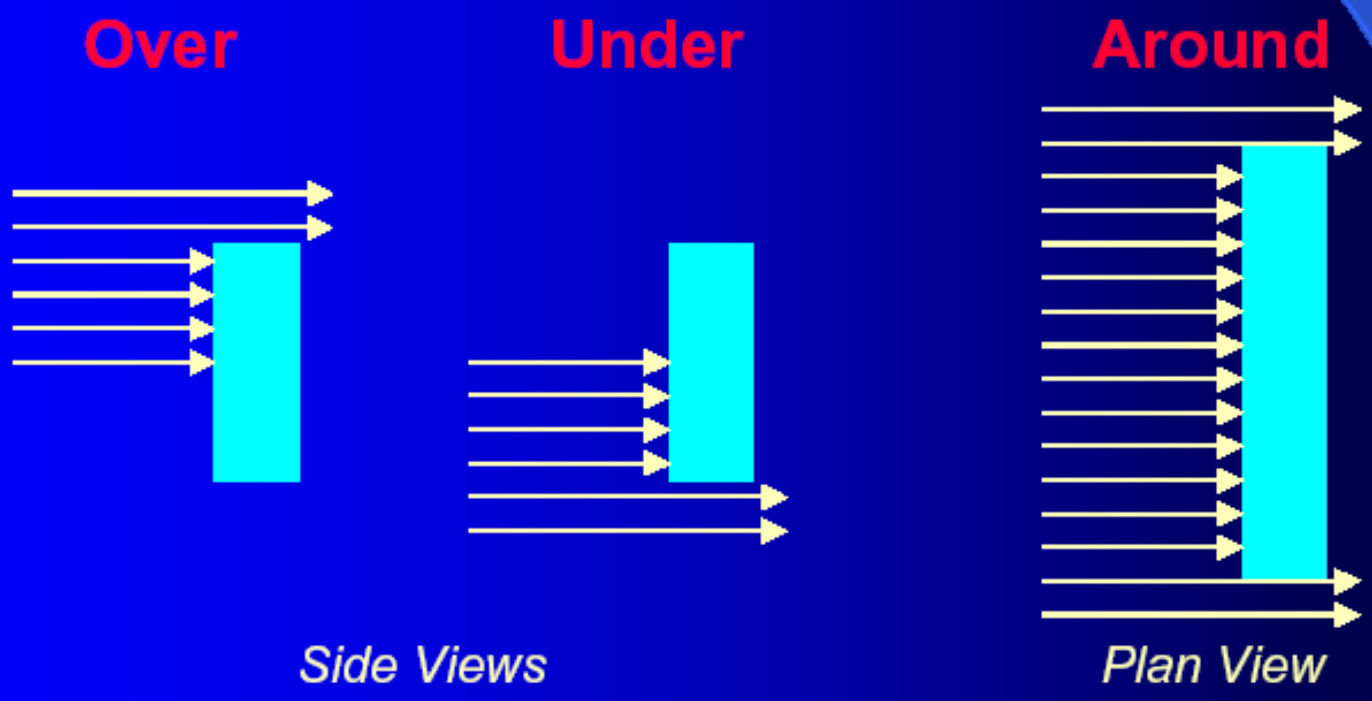
Hydraulic Control Systems



Reference: 2)

Potential Problems

- The plume could pass over, under, or around the barrier
- The groundwater flow direction or velocity might change
- Incomplete remediation as higher concentrations reach the barrier
- Loss of surface reactivity—precipitate coatings, etc.
- Barrier plugging, decreased permeability



Reference: 2)

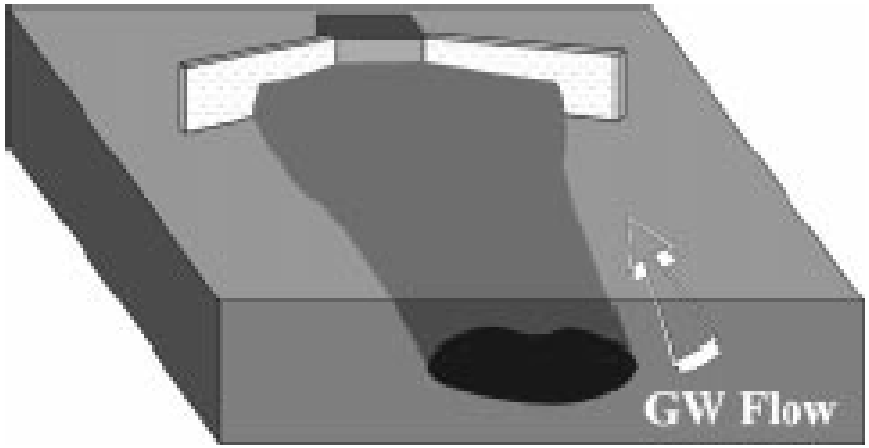


Figure 3a. *Plume capture by a funnel & gate system. Sheet piling funnels direct the plume through the reactive gate.*

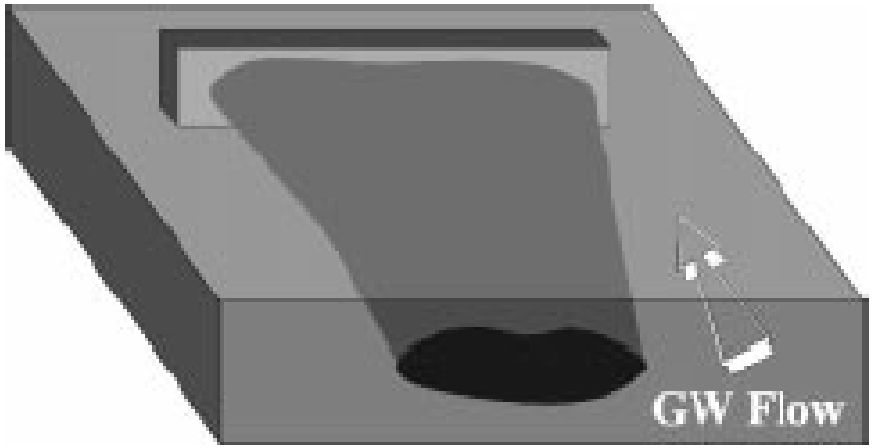


Figure 3b. *Plume capture by a continuous trench system. The plume moves unimpeded through the reactive gate.*

A simplified schematic plan view and a cross section of a continuous permeable wall are shown in

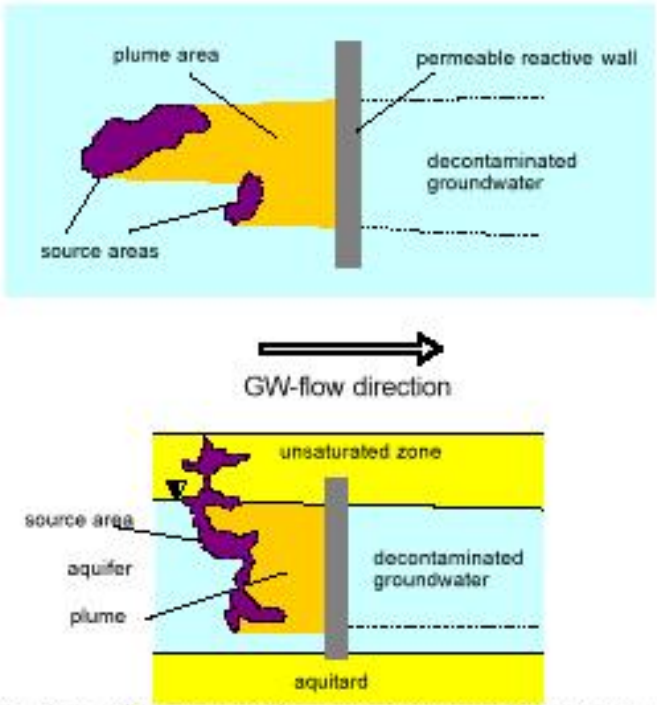


Figure 1: Plan view and schematic cross section through a continuous permeable in-situ wall

Reference:
EPA/600/F-97/008

Final

Design Guidance for Application of Permeable Reactive Barriers for Groundwater Remediation

Prepared for

Project Officer: Alison Lightner
Air Force Research Laboratory
Tyndall Air Force Base, Florida

Contract No. F08637-95-D-6004
Delivery Order No. 5503

By

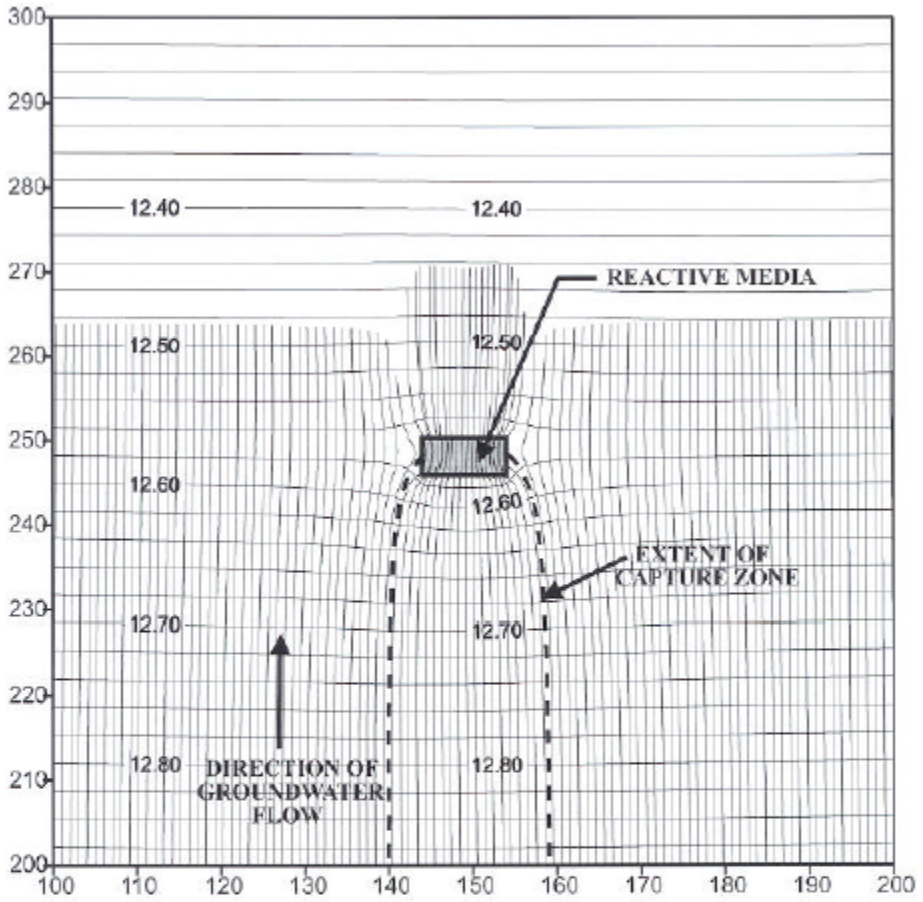
Arun Gavaskar, Neeraj Gupta, Bruce Sass,
Robert Janosy, and James Hicks

BATTELLE
Columbus, Ohio

March 31, 2000

Study sponsored by

SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness through Environmental Research



Media: 10 feet long, 6 feet wide (parallel to flow)
K_{media} = 283 feet/day
$K_{aquifer}$ = 10 feet/day
Gradient = 0.005

Figure 6-1. Simulated Capture Zone for a Continuous Reactive Barrier Showing Flowpaths for 180 Days

Reference: 3)

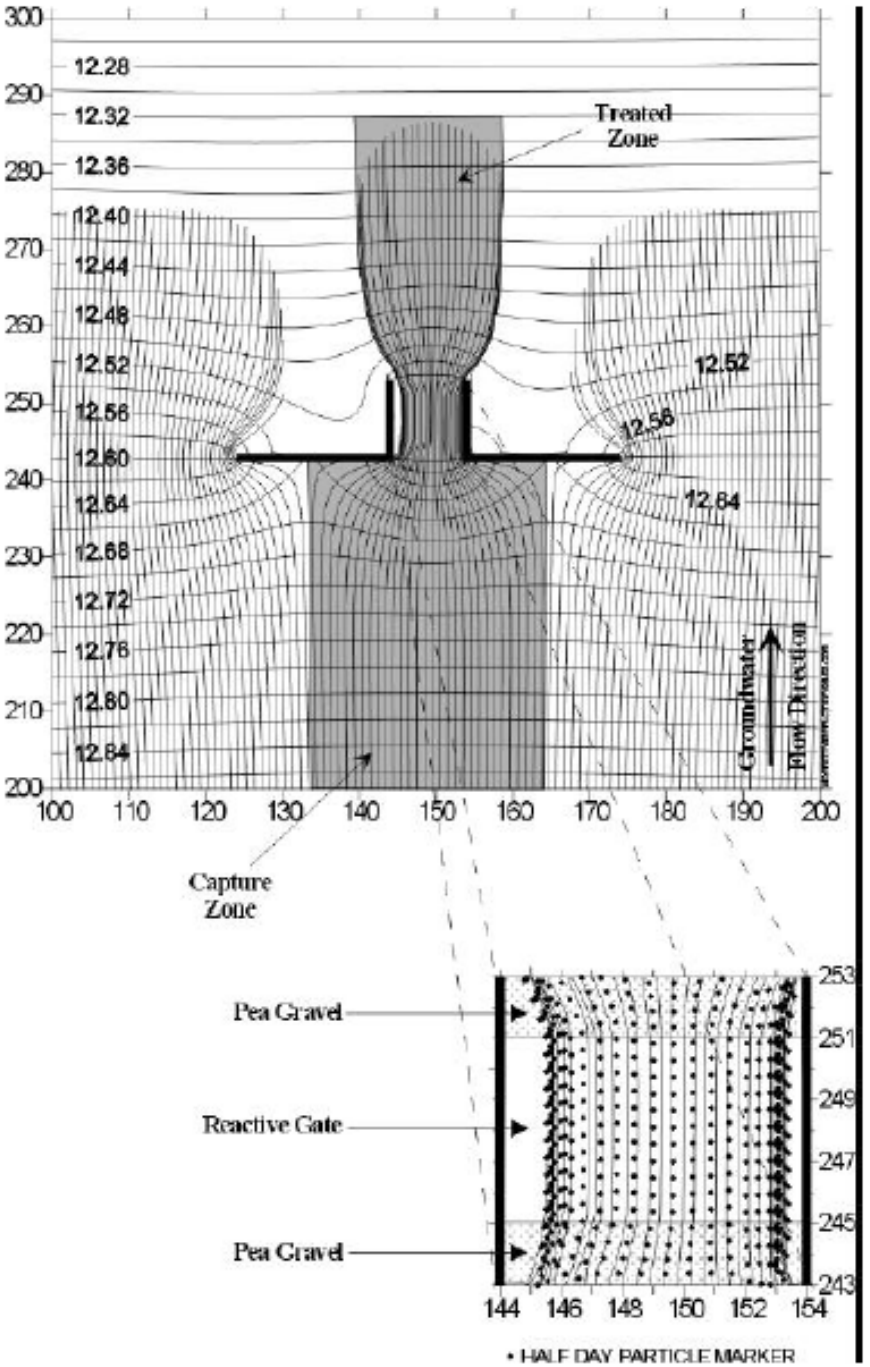


Figure 6-2. Simulated Particle Pathlines Showing Capture Zone for a Funnel-and-Gate System in a Homogeneous Aquifer

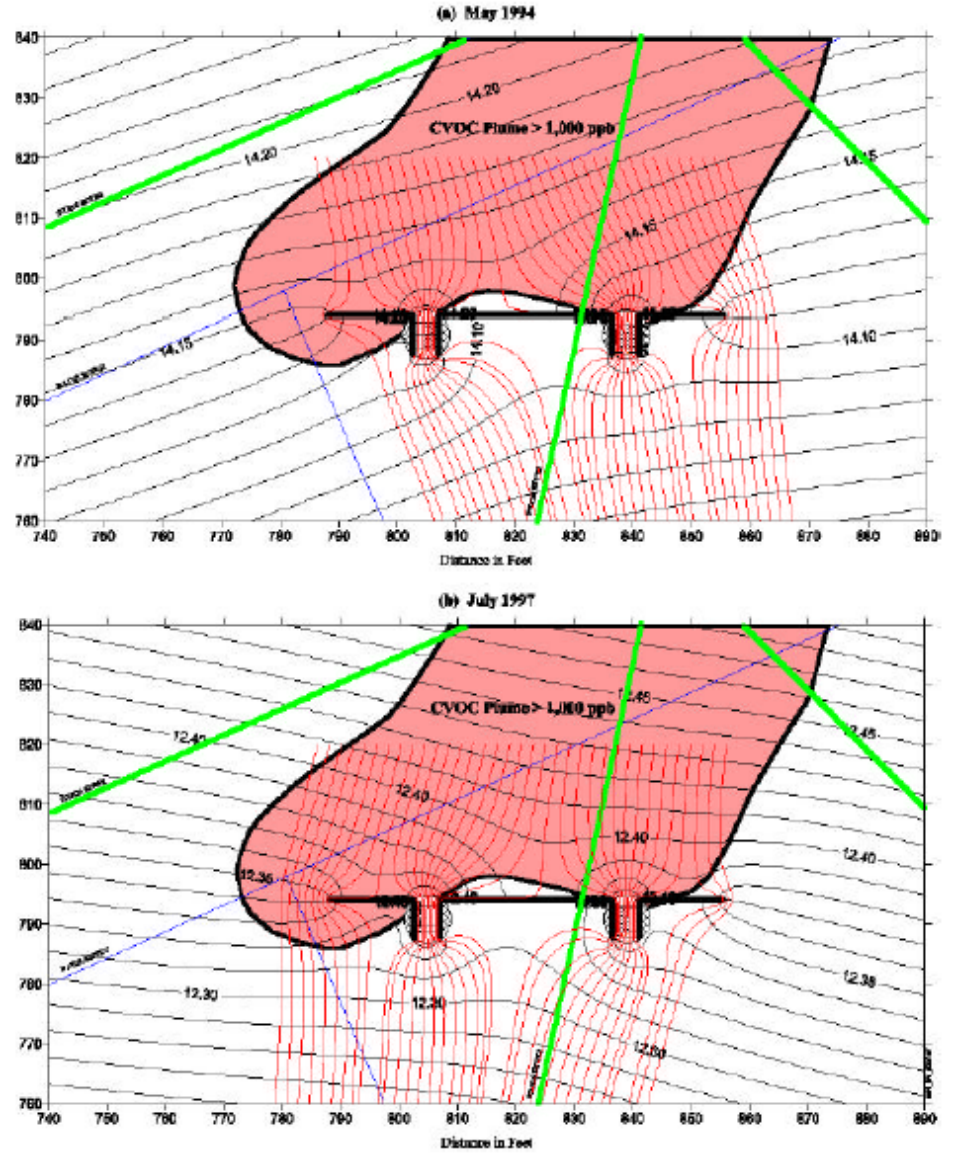


Figure 6-4. Capture Zones for the PRB at Dover AFB Showing the Effect of Fluctuating Flow Directions

Reference: 3)

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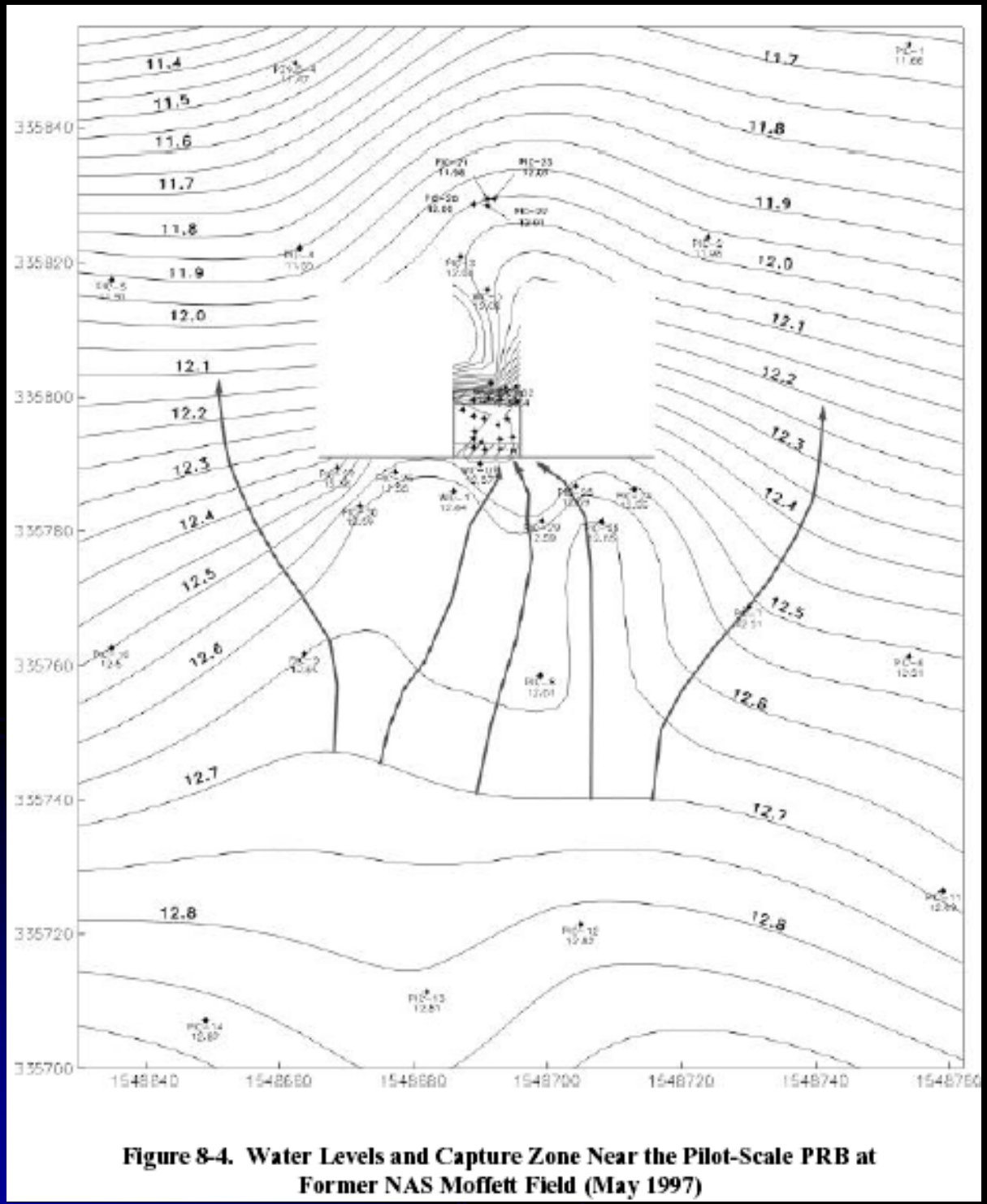


Figure 8-4. Water Levels and Capture Zone Near the Pilot-Scale PRB at Former NAS Moffett Field (May 1997)

Reference: 3)

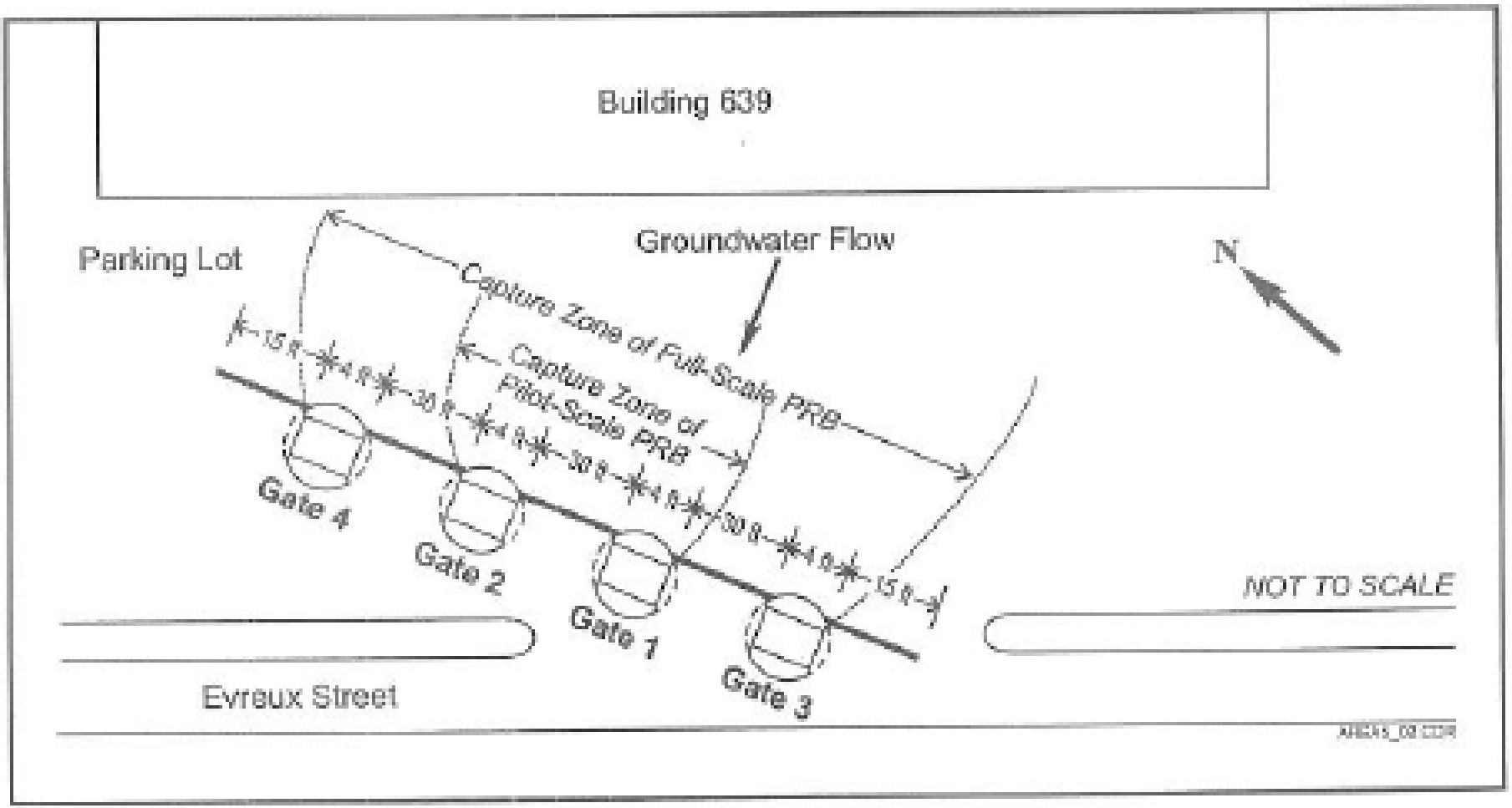
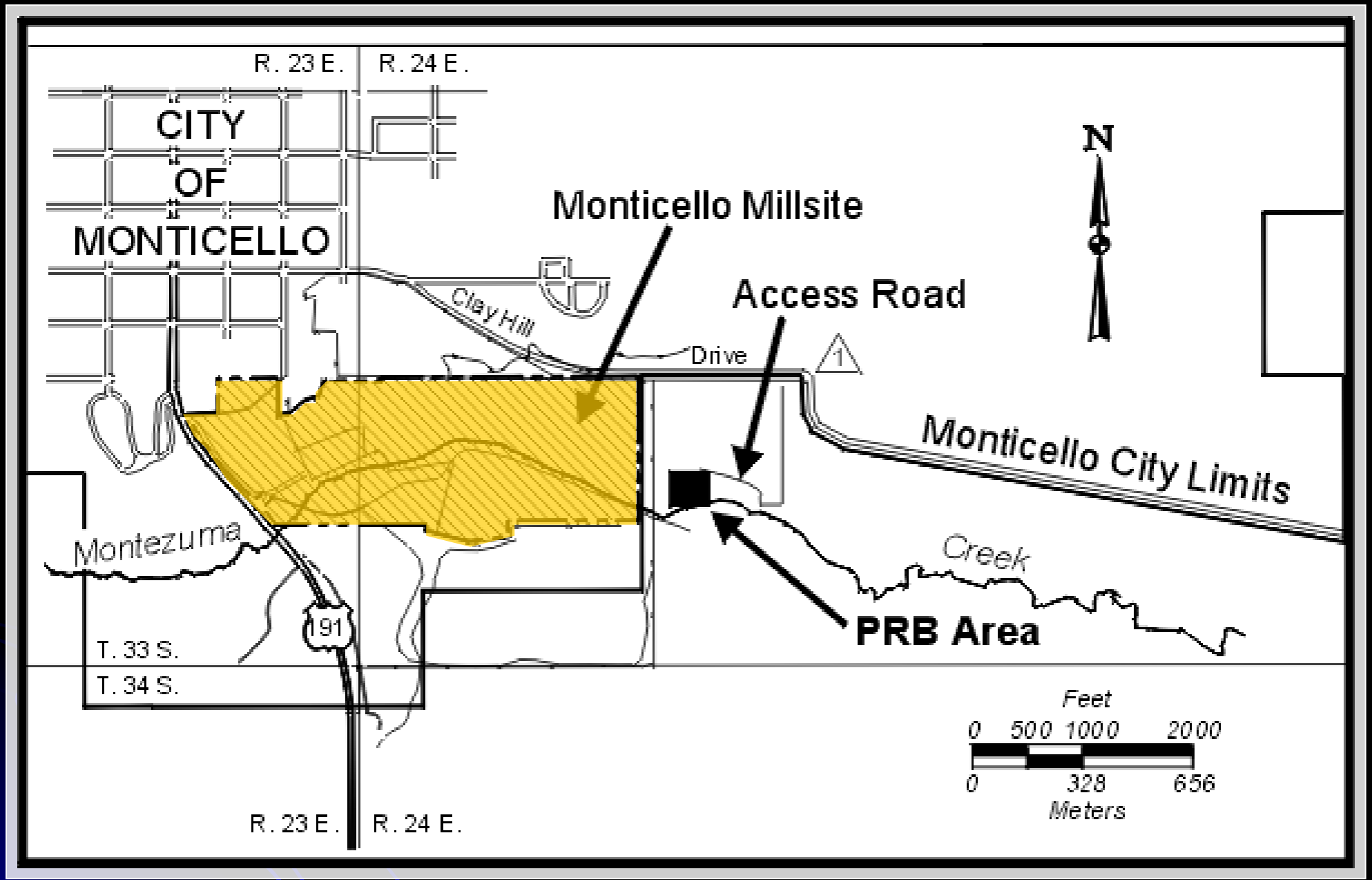


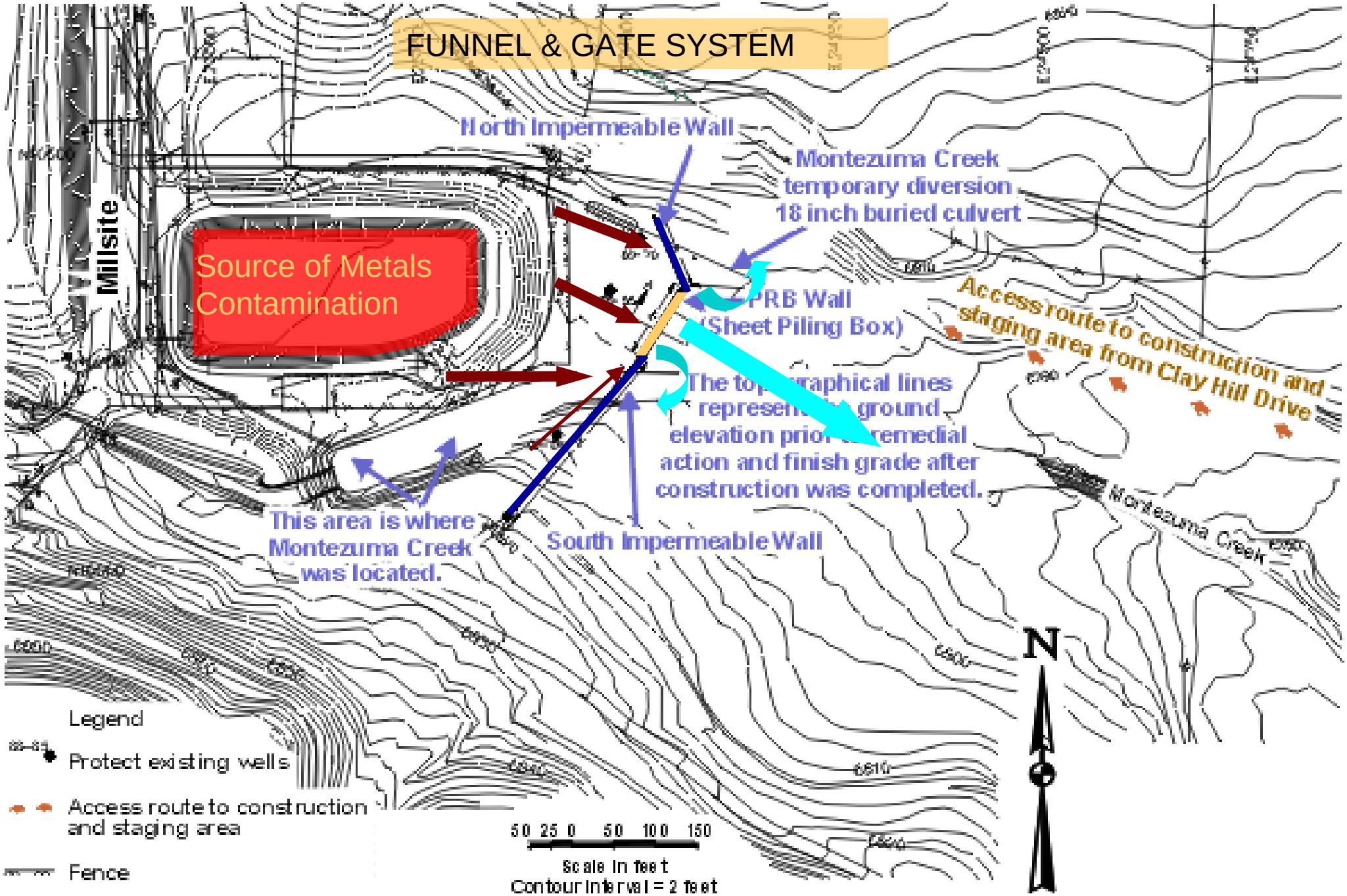
Figure B-2. Schematic of the Scaleup of the PRB

Reference: 3)


R. 23 E.
R. 24 E.
CITY
OF
MONTICELLO
Monticello Millsite
Access Road
N
Clay Hill
Drive
1
Monticello City Limits
Montezuma
Creek
191
PRB Area
T. 33 S.
T. 34 S.
Feet
0 500 1000 2000
0 328 656
Meters
R. 23 E.
R. 24 E.

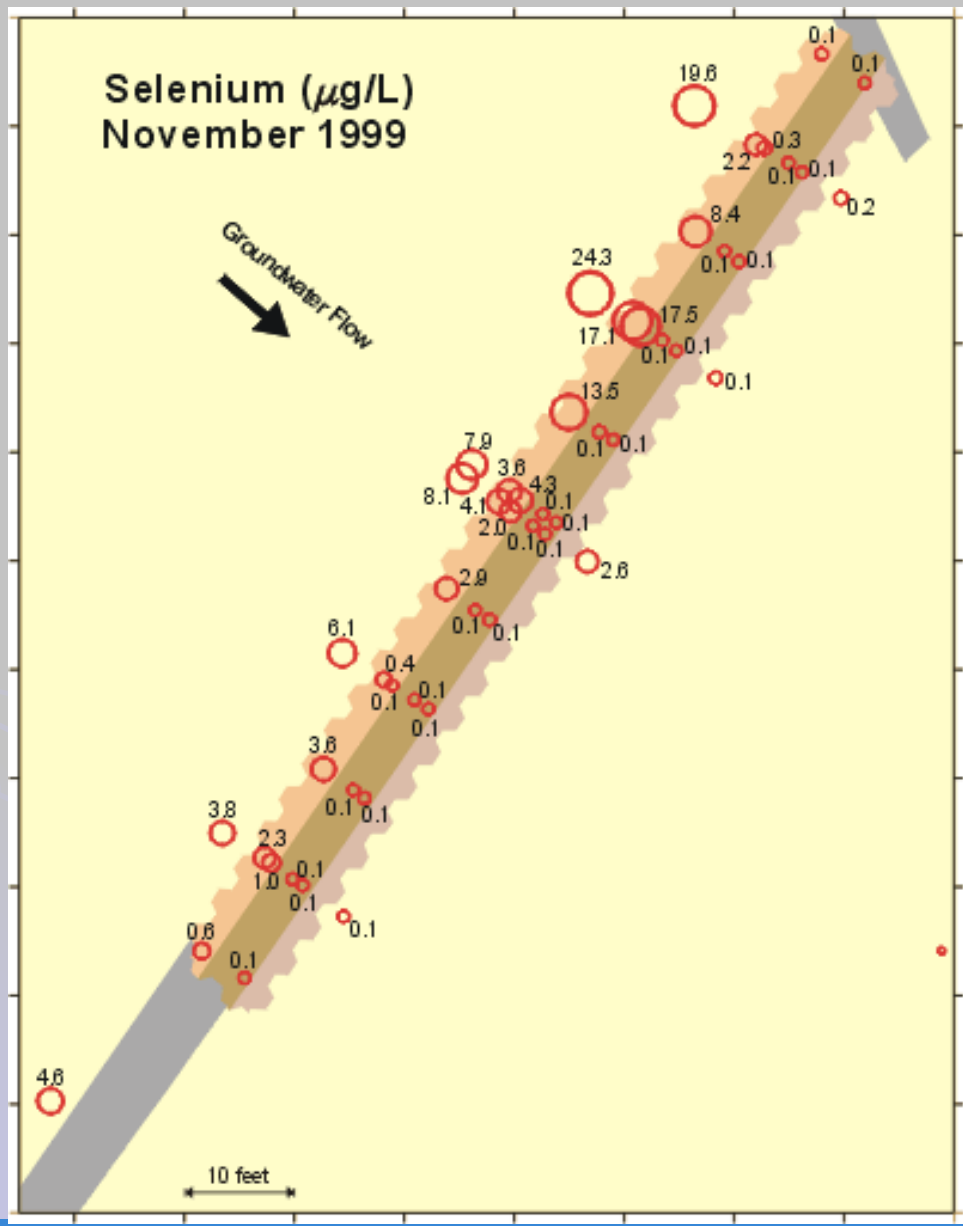
Reference: 4)

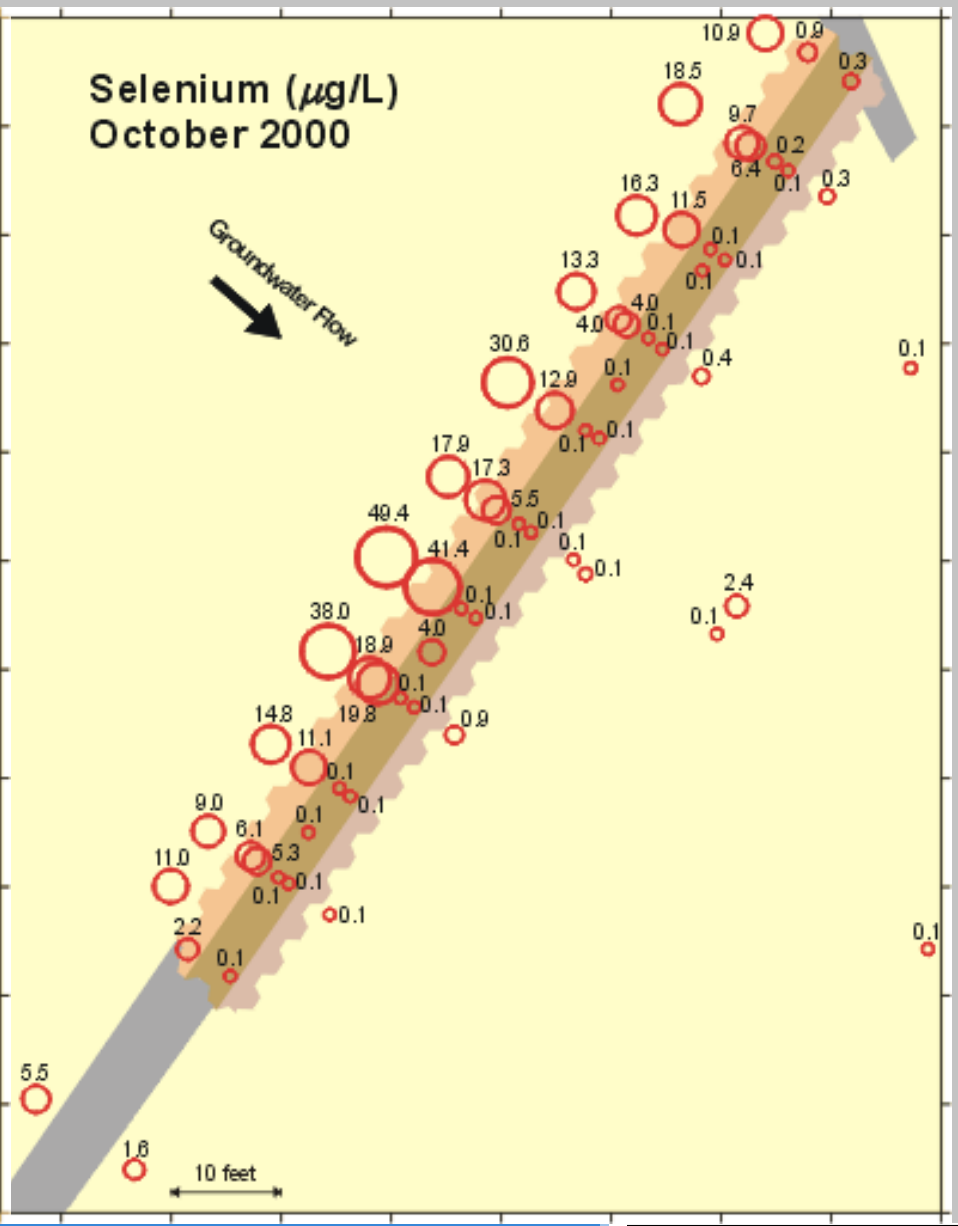
FUNNEL & GATE SYSTEM



Reference: 4)

Permeable Reactive Barriers





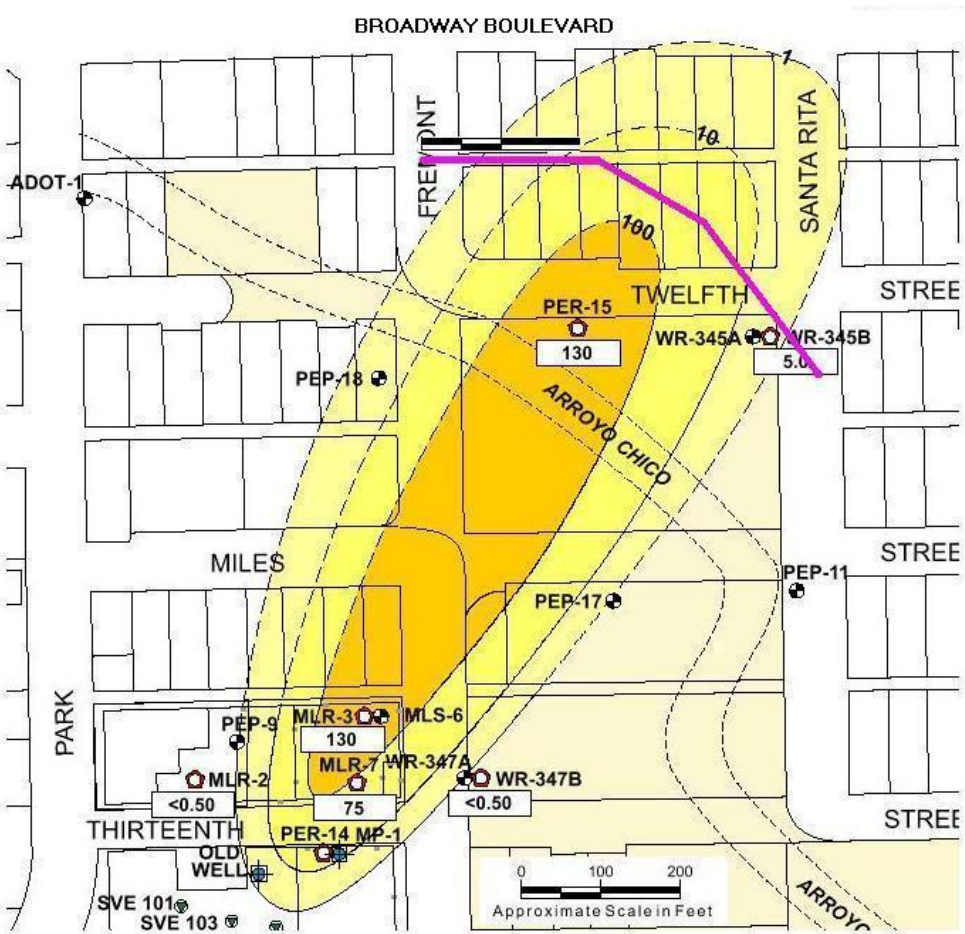


Figure 22A from Conceptual Model

PCE Concentrations (ppb)
in the Regional Aquifer

Legend: Relatively Impermeable Vertical Hanging Wall (RIVHW)

Note: K~ 30 ft/d = 1E-4 m/s (conceptual model p22)
gw vel~ 1.16 ft/d =423 ft/y (p39)
total length RIVHW ~ 650 ft

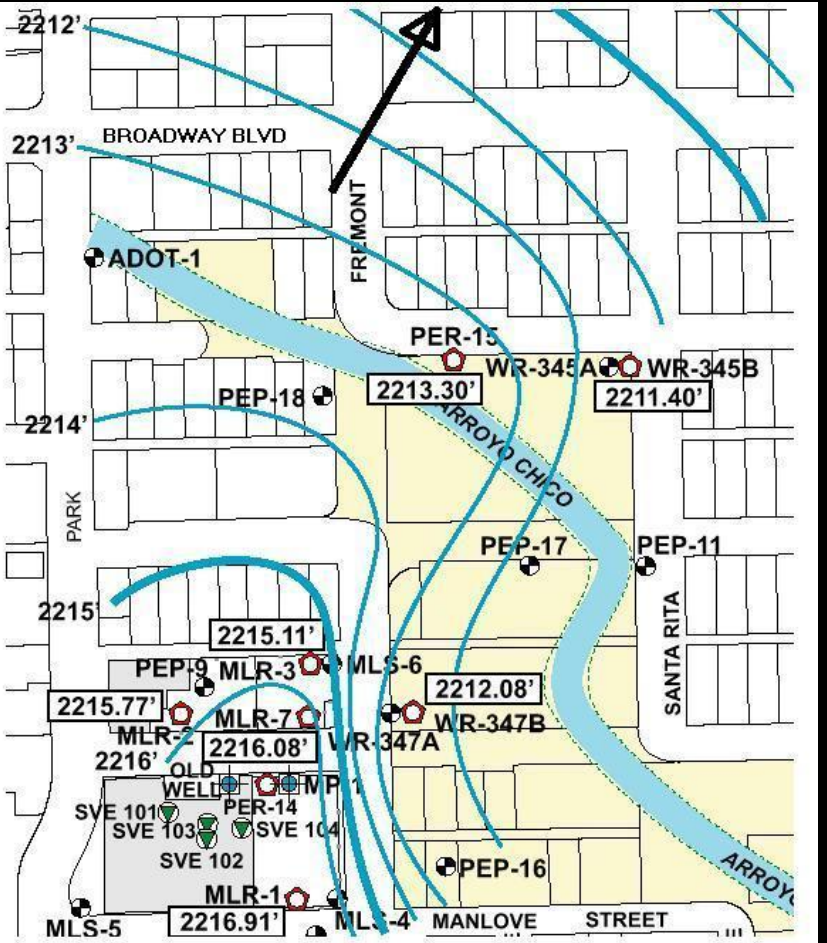
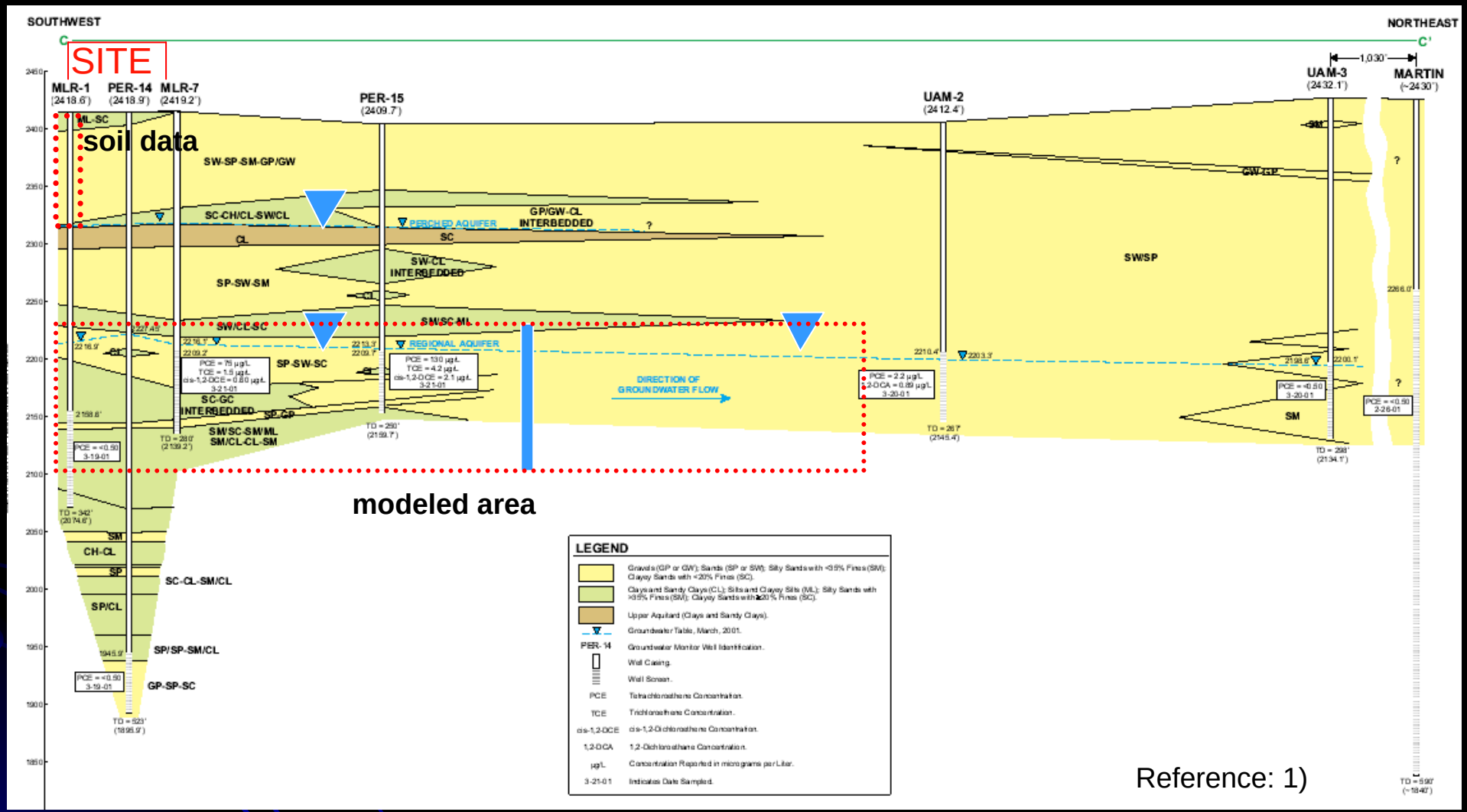


Figure 35 from Conceptual Model

Water Level Elevations (feet NGVD)
and direction of Groundwater Flow
in the Regional Aquifer

Reference: 1)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INTERBEDDED
SP-SW-SM
SW/SP
GW-GP
SW/CL-SC
SM/SC-ML
REGIONAL AQUIFER
SP-SW-SC
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SM/SC-SM/ML
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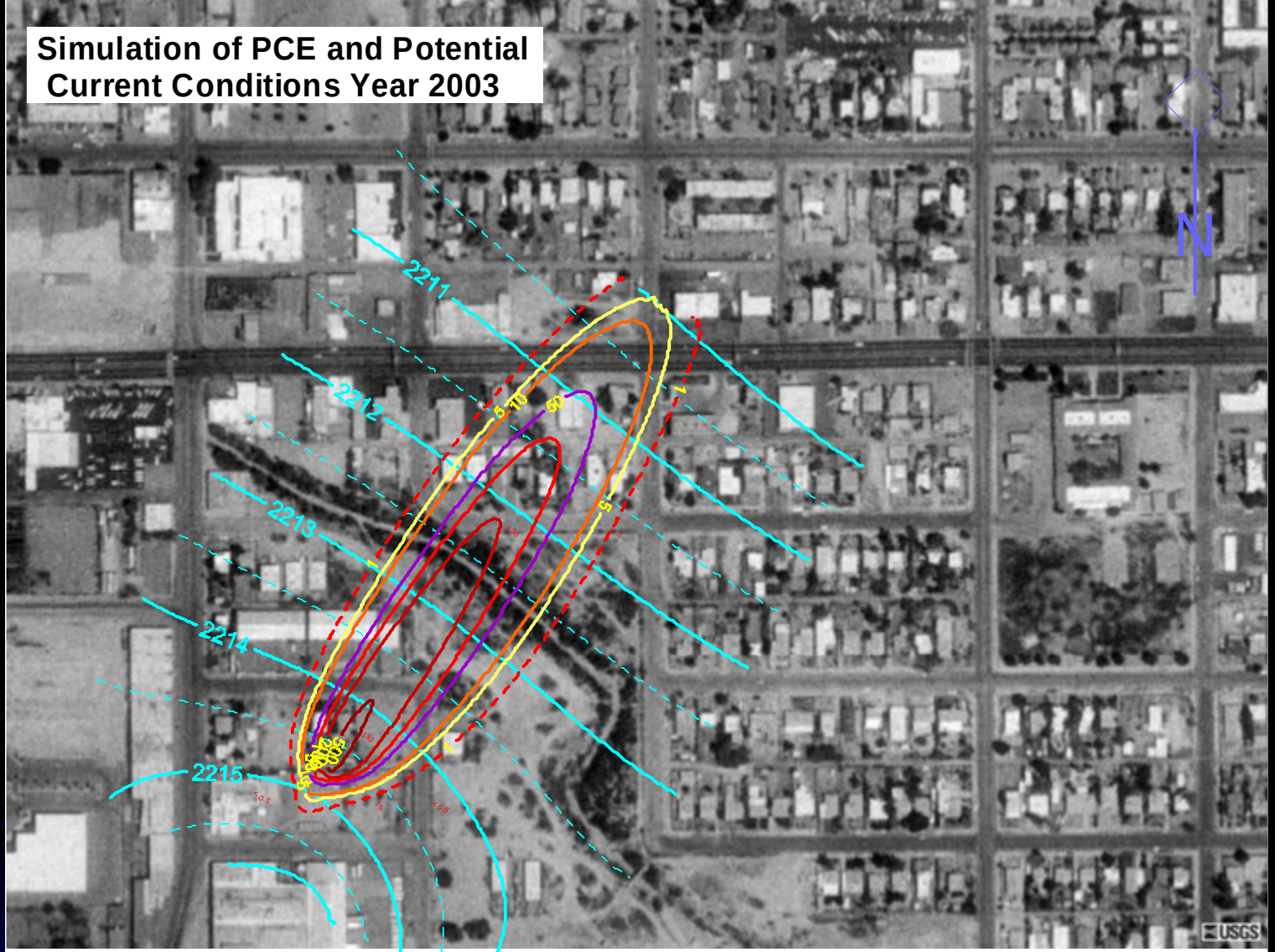
cis-1,2-Dichloroethene Concentration.
1,2-DCA
1,2-Dichloroethane Concentration.
µg/L
Concentration Reported in micrograms per Liter.
3-21-01
Indicates Date Sampled.

Reference: 1)

Tucson, Arizona, United States 16 May 1992

Simulation of PCE and Potential Current Conditions Year 2003

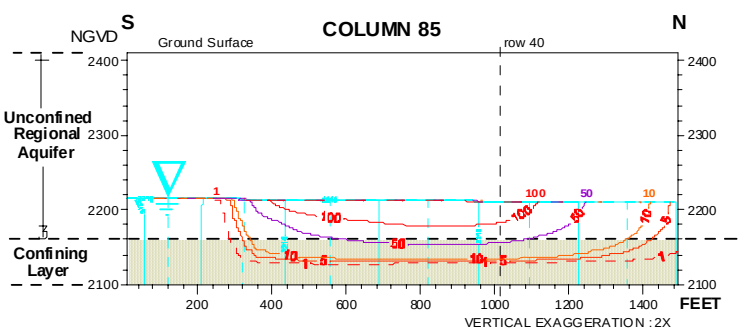


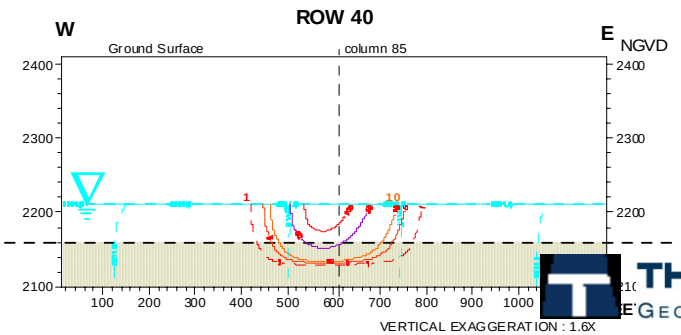
0 100 M

0 100 yd

Tucson, Arizona, United States 16 May 1992

Image courtesy of the U.S. Geological Survey





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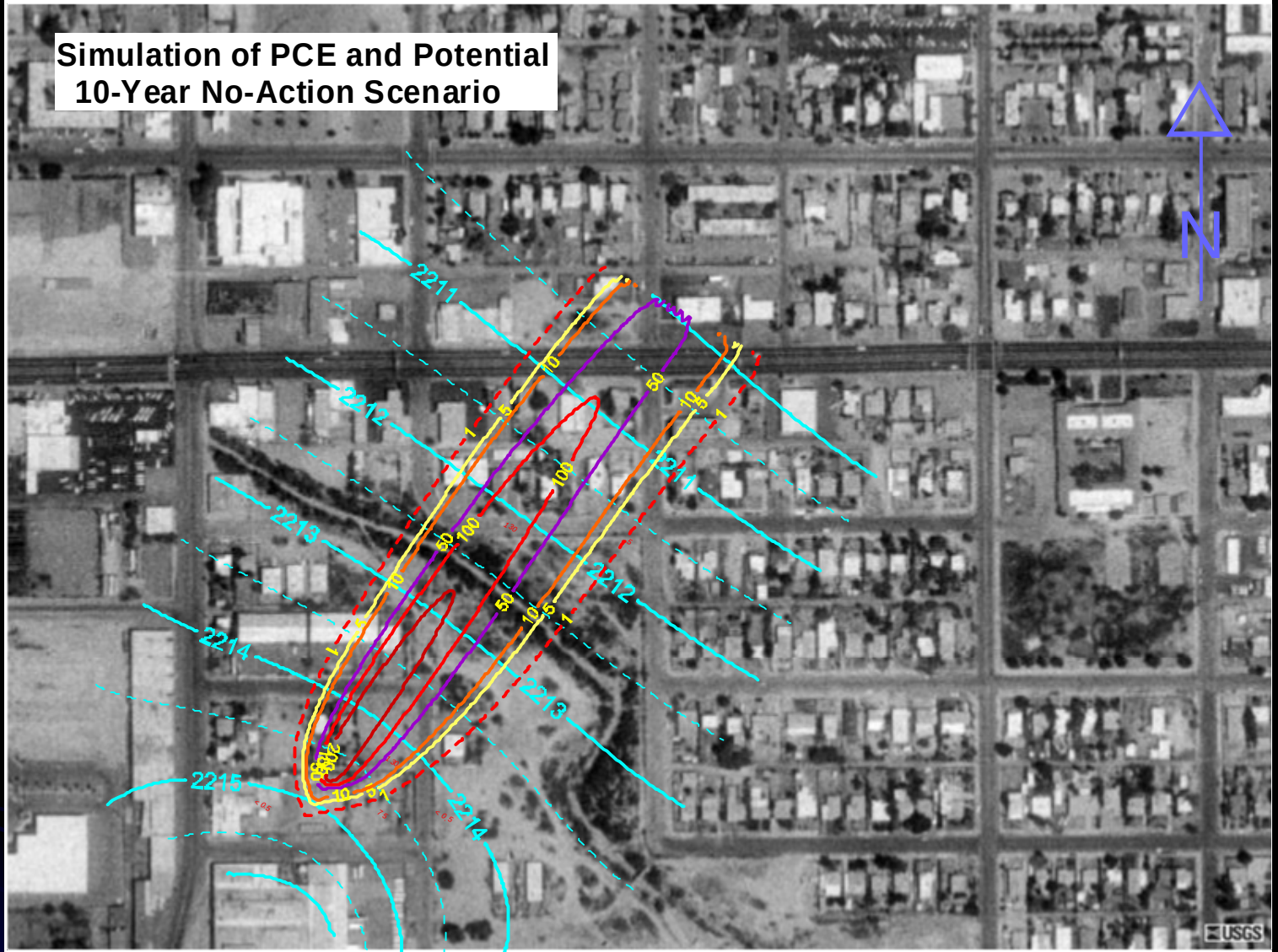
Simulation of PCE and Potential 10-Year No-Action Scenario

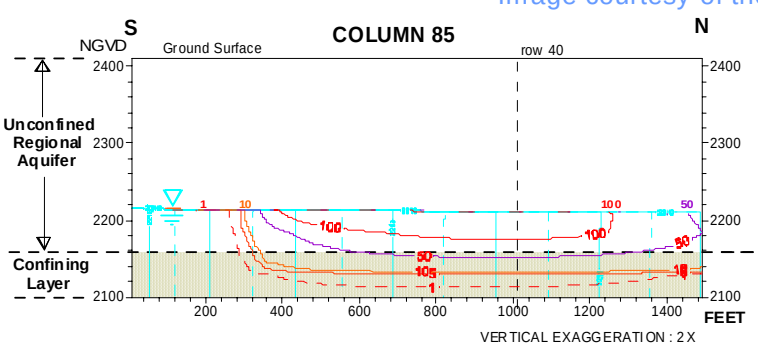


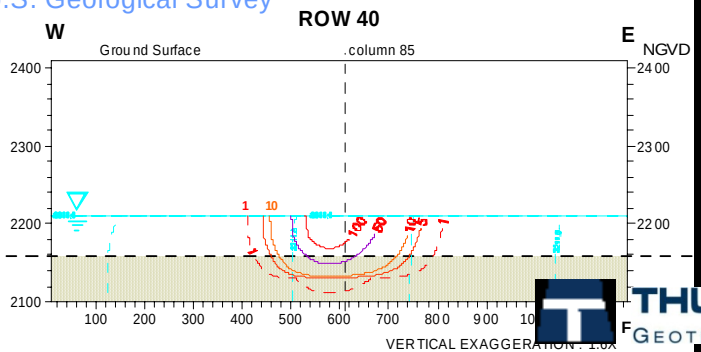
0 100 M

0 100 yd

Tucson, Arizona, United States 16 May 1992

Image courtesy of the U.S. Geological Survey





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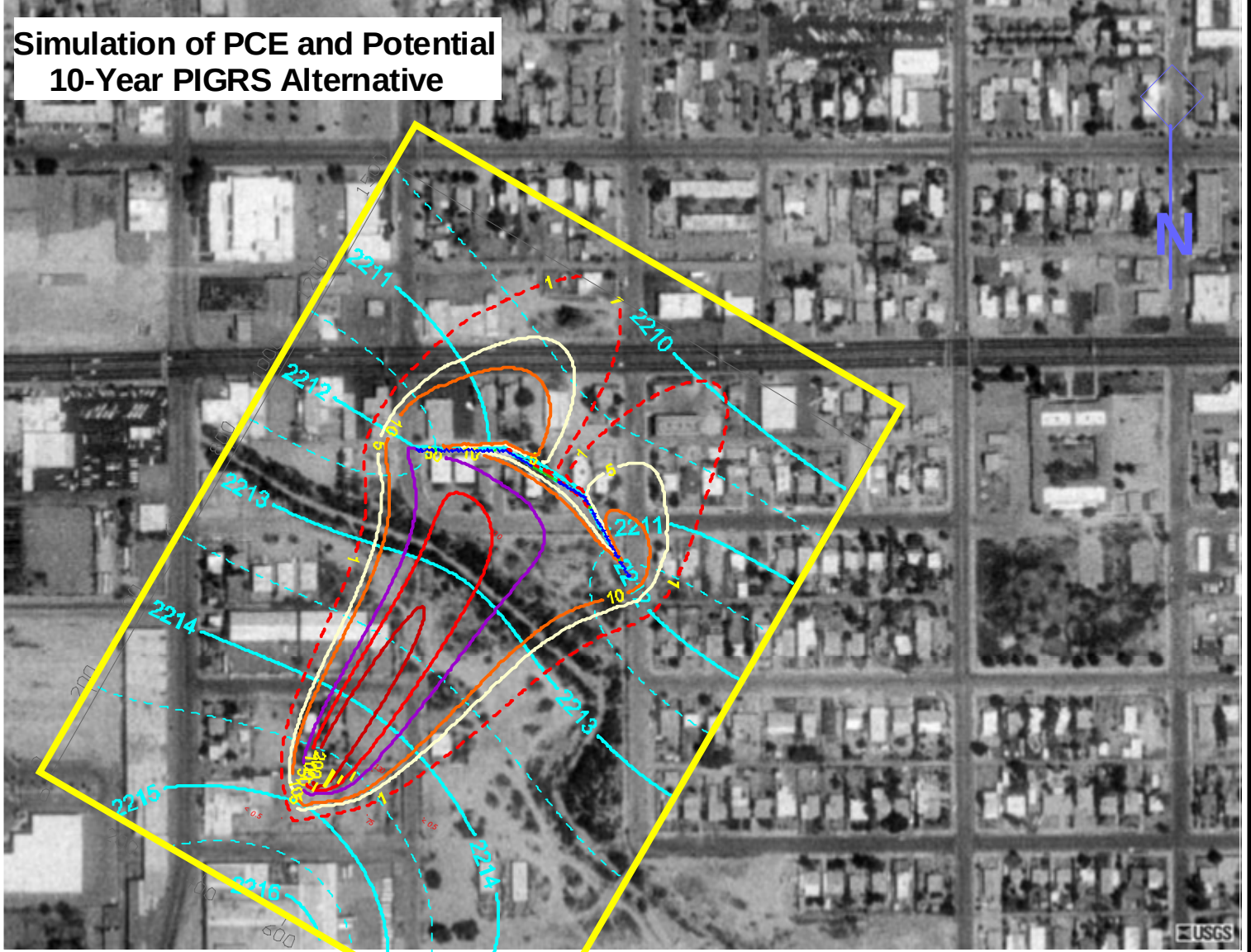
Simulation of PCE and Potential 10-Year PIGRS Alternative

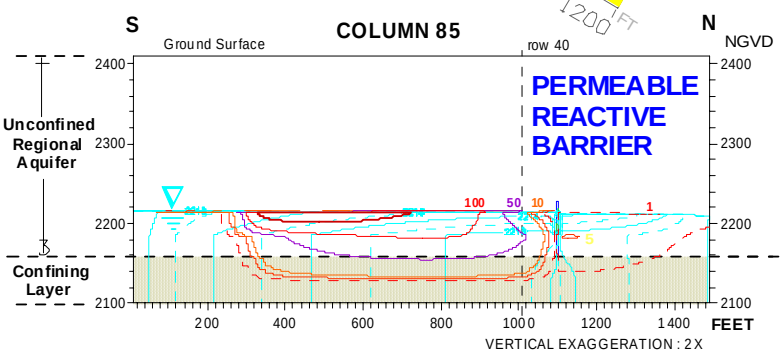


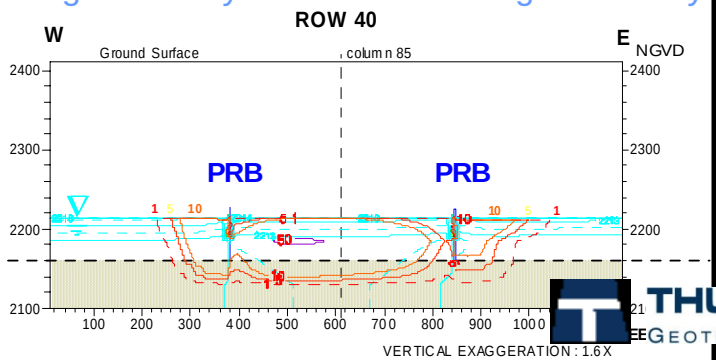
0 100 M

0 100 yd

Tucson, Arizona, United States 16 May 1992

Image courtesy of the U.S. Geological Survey





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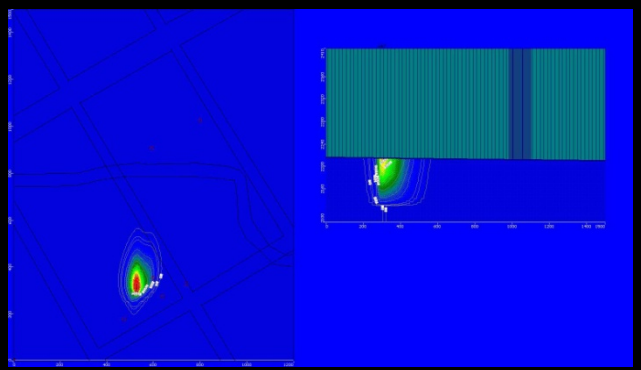
Time-lapsed simulations of groundwater flow and transport:

1) no-action scenario
2) funnel & gate
3) short ZVI-PRB wall
4) long reactive wall



CONCLUSIONS

1) ZVI-PRBs can be utilized to reduce dissolved-phase contaminant concentrations in groundwater flow systems *iff* they are designed properly.

2) Characterize the groundwater flow system sufficiently to allow successful design of the ZVI-PRB.

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