

Session 6: Contaminant Fate and Transport at the SSFL



Dr. John Cherry
May 19, 2011



Transport and Fate of Contaminants in Groundwater

Transport:

- *The movement of chemicals under the influence of physical processes (e.g. advection, diffusion)*

Fate:

- *Contaminant change into other chemical species*
- *Contaminant transfer to subsurface solids or surface environments*



Today's Lecture

- 1. The Scientific Method Applied at SSFL**
- 2. Chlorinated Solvents Degradation**
- 3. The Former Sodium Disposal Facility (FSDF) Area**
- 4. WS9A- Southwest Drainage Study Area**
- 5. Tritium at SSFL**
- 6. TCE Fate Summary**
- 7. Implications for Remediation**
- 8. Plume Monitorability**

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The RI and SCM are Based on the Scientific Method

RI

SCM

DRAFT
SITE-WIDE GROUNDWATER
REMEDIAL INVESTIGATION REPORT
SANTA SUSANA FIELD LABORATORY
VENTURA COUNTY, CALIFORNIA

VOLUME 1
TEXT, TABLES AND FIGURES

Prepared For:

THE BOEING COMPANY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
UNITED STATES DEPARTMENT OF ENERGY

Prepared by:

MWH Americas, Inc.
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Walnut Creek, CA 94593

December 2009



SITE CONCEPTUAL MODEL FOR THE MIGRATION AND FATE OF
CONTAMINANTS IN GROUNDWATER AT THE SANTA SUSANA
FIELD LABORATORY, SIMI, CALIFORNIA

OVERVIEW AND 20 SITE CONCEPTUAL MODEL ELEMENTS

VOLUME 1 OF 4

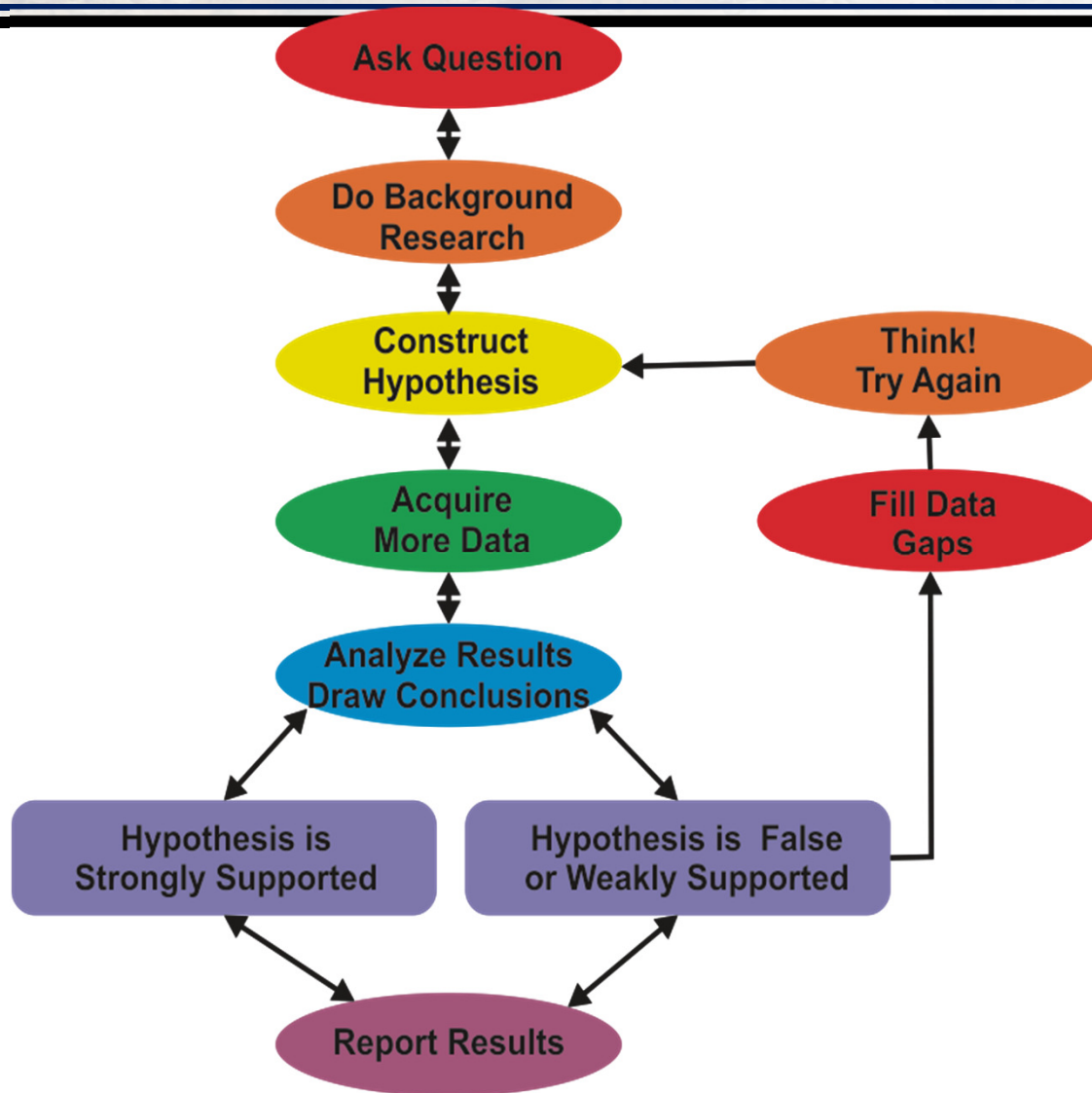
Prepared for:
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Prepared by:
THE SSFL GROUNDWATER ADVISORY PANEL, in association with
THE UNIVERSITY OF GUELPH
MONTGOMERY WATSON HARZA
HALEY & ALDRICH
AQUARESOURCE INC.



The Scientific Method



Examination of multiple working hypotheses and continual skepticism are the essential elements of the scientific method.

Two Complimentary Approaches for Evaluating SSFL Groundwater

I

Remedial Investigation Report

Inductive Approach

Observe and Conclude

Structured compilation of relevant data and observations

reviewed by DTSC

leads to:

Concluding hypothesis

II

Site Conceptual Model Report

Deductive Approach

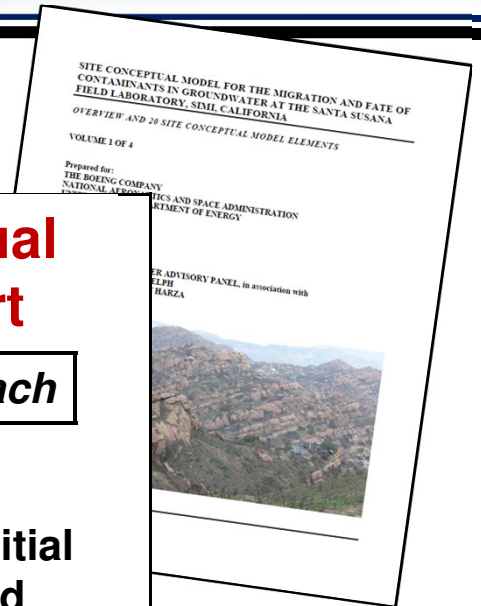
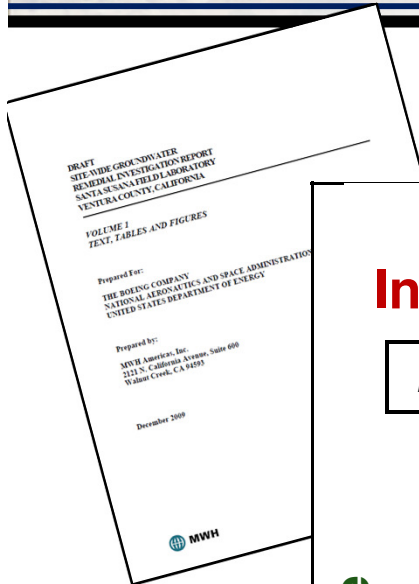
Hypothesize and Test

Hypothesis formulated from initial observations and scientific theory

created in peer-reviewable modules

Tested, modified, and confirmed by:

Supporting observations and data



A background image showing a rocky, arid landscape under a clear blue sky. The title text is overlaid on the right side of this image.

Site Conceptual Model (SCM) Definition

- *The SCM organizes information in a clear and transparent structure and facilitates the identification of data gaps*
- *The SCM is one of the primary planning tools used to support the decision making process managing contaminated land and groundwater on a large scale*

SCM Approach U.S. EPA (1993)

Figure 4. Elements of Site Conceptual Model

The data and analysis required for TI evaluations will be determined by EPA on a site-specific basis. This information should be presented in formats conducive to analysis and in sufficient detail to define the key site conditions and mechanisms that limit restoration potential. Types of information and analysis that may be needed for conceptual model development are illustrated below.

Background Information

Contaminant Distribution, Transport, and Fate Parameters

- Phase distribution of each contaminant (gaseous, aqueous, sorbed, free-phase NAPL, or residual NAPL) in the unsaturated and saturated zones.
- Spatial distribution of subsurface contaminants in each phase in the unsaturated and saturated zones.
- Estimates of subsurface contaminant mass.
- Temporal trends in contaminant concentrations in each phase.
- Sorption information, including contaminant retardation factors.
- Contaminant transformation processes and rate estimates.
- Contaminant migration rates.
- Assessment of facilitated transport mechanisms (e.g., colloidal transport).
- Properties of NAPLs that affect transport (e.g., composition, effective constituent solubilities, density, viscosity).
- Geochemical characteristics of subsurface media that affect contaminant transport and fate.
- Other characteristics that affect distribution, transport, and fate (e.g., vapor transport properties).

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USEPA
Publication 9234.2-25
EPA/540-R-93-080
PB93-963507
September 1993



SCM Approach in the DTSC Process

The California DTSC also requires the SCM approach as follows:

Define where the chemicals are, understand how they are moving, identify applicable physical parameters for each contaminant, assess how contaminant may migrate within existing site conditions, and describe phase and location where contaminants are found.

The RI and SCM are Based on the Scientific Method

RI

SCM

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Data Quality Objectives Process

“DQO Process”



United States
Environmental Protection
Agency

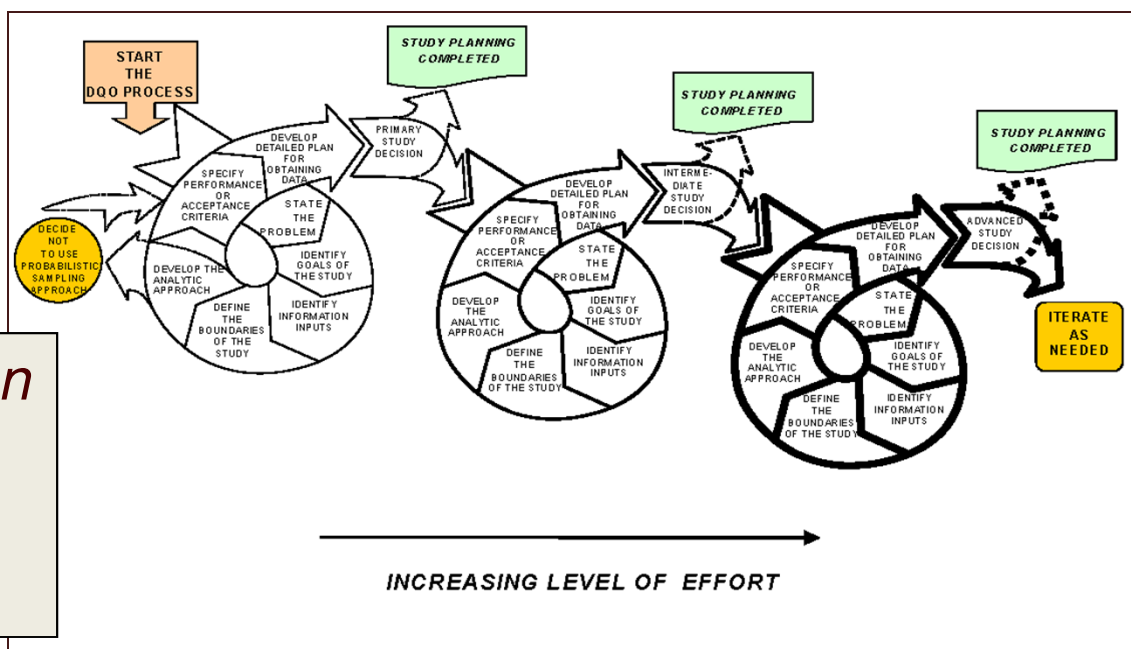
Office of Environmental
Information
Washington, DC 20460

EPA/240/B-06/001
February 2006

Guidance on Systematic Planning Using the Data Quality Objectives Process

EPA QA/G-4

The DQO Process has been applied at the SSFL systematically to characterize groundwater.



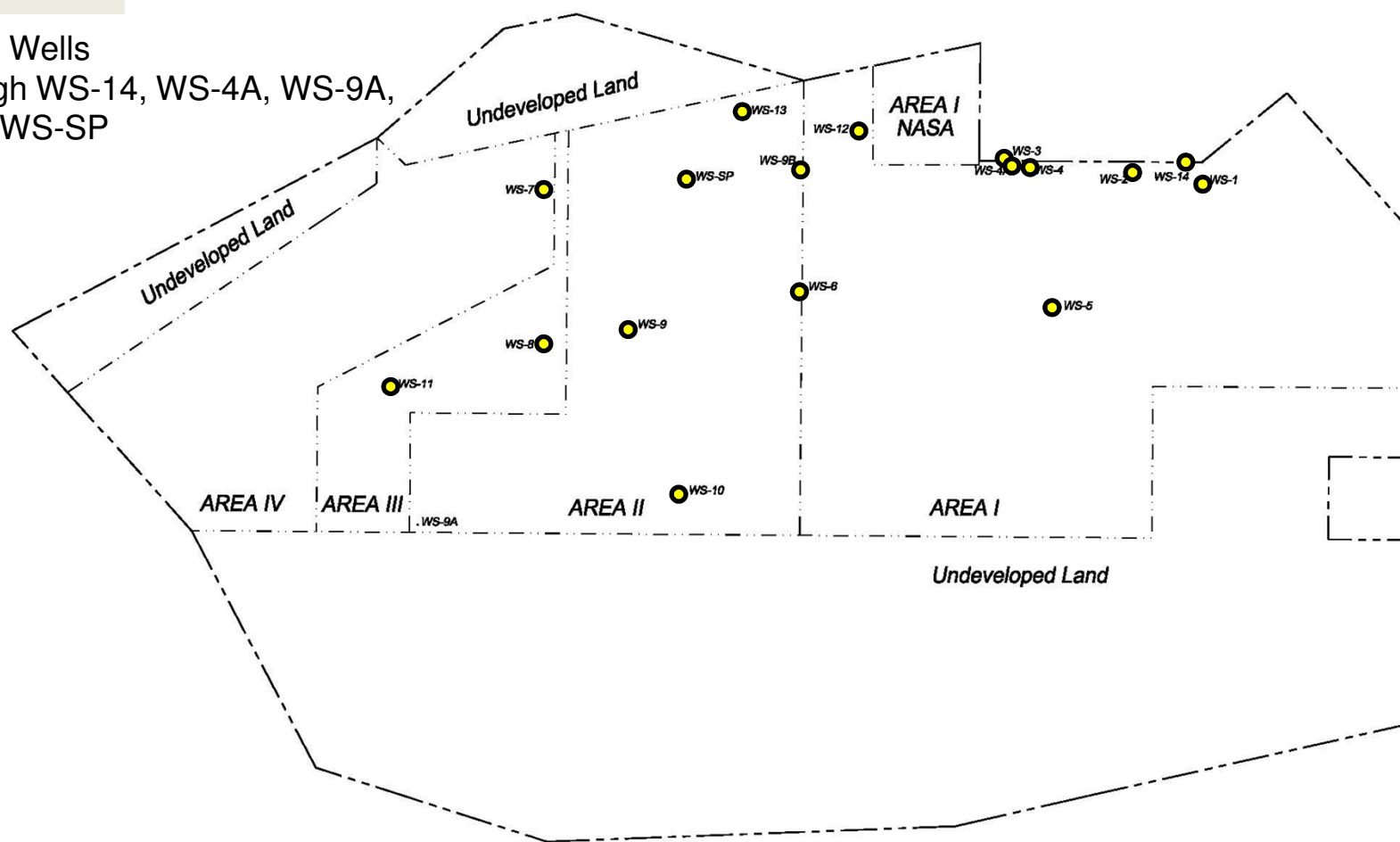
In this process, data gaps are identified at each new investigation phase.

Phases of Monitoring Well Installation

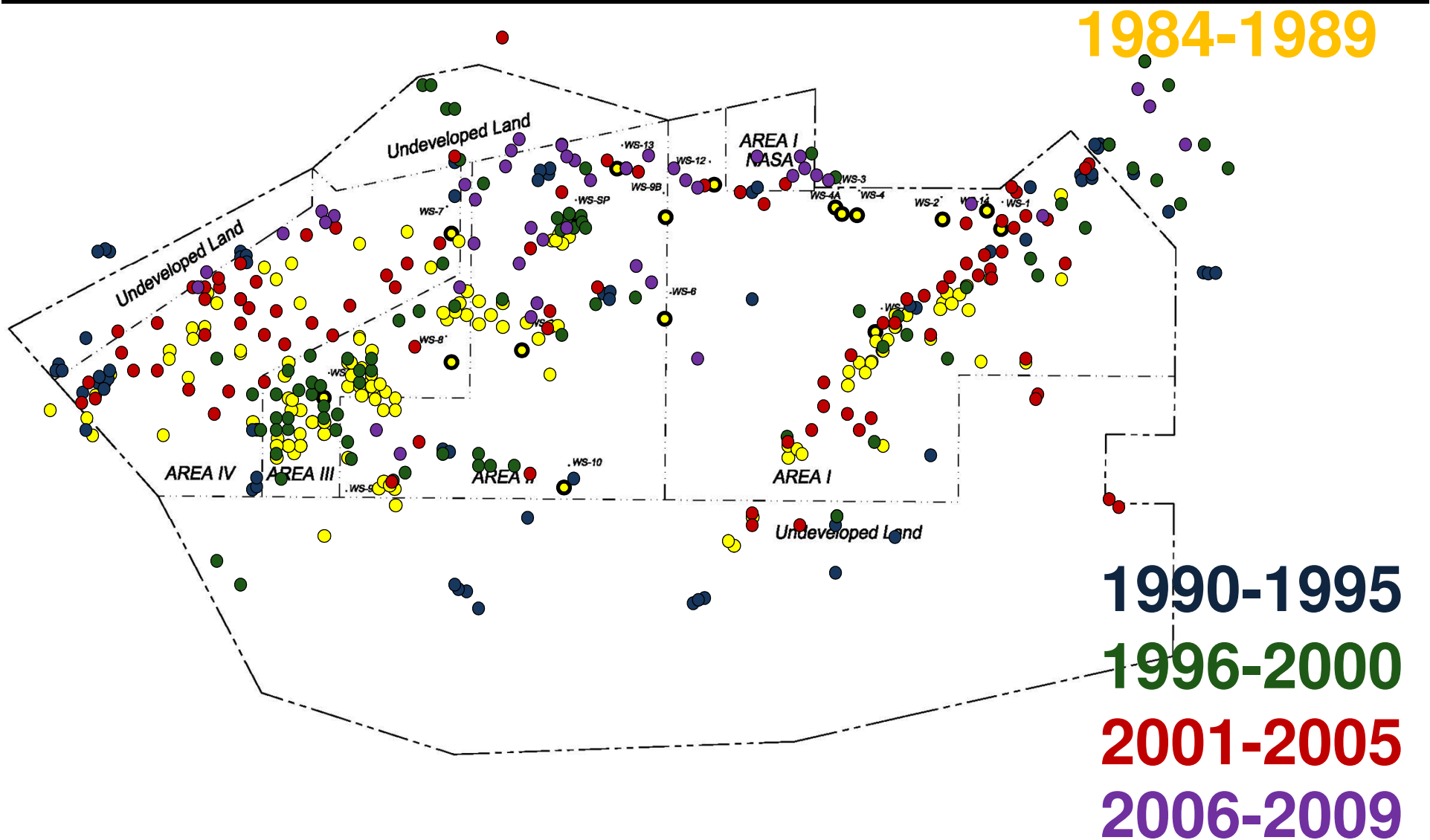
Pre-1984

Water Supply Wells

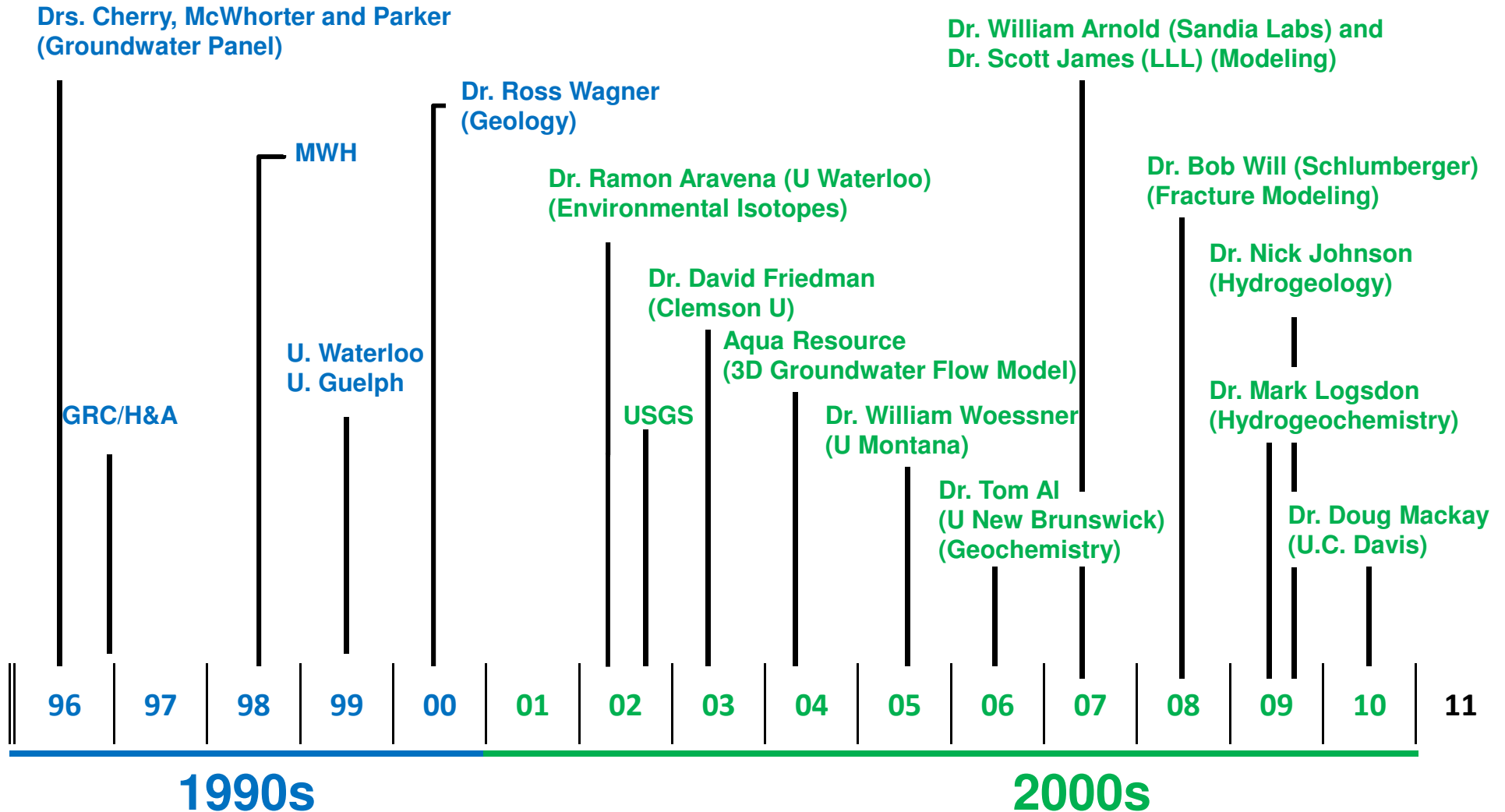
- WS-1 through WS-14, WS-4A, WS-9A, WS-9B and WS-SP



**Wells Installed at SSFL Through Time
1984 -2009**



Additions of Scientific Expertise



Module 1: Summary and Implications

- *The understanding of the distribution, transport and fate of SSFL groundwater contaminants has advanced strongly through the scientific method and this has been reported in the Groundwater RI and SCM documents*
- *There is sufficient knowledge now to design remedial treatability studies*
- *Confirmatory studies in progress for data gaps*



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Processes Influencing Transport and Fate

How Contaminants Move

Transport Processes

- Advection (Flow)
 - Groundwater
 - DNAPL
- Molecular Diffusion

How Contaminants Change

Reaction Processes

- Sorption
 - Adsorption
 - Absorption
- Chemical Reactions
- Biological Reactions
- Radioactive Decay

A horizontal banner image showing a rocky, arid landscape under a clear blue sky. The title text is overlaid on this image.

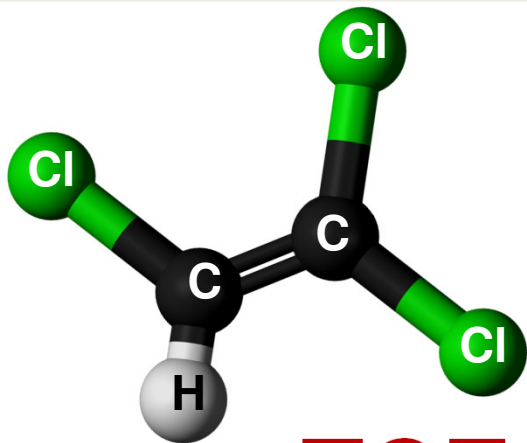
Degradation of Chlorinated Solvents

The compound changes into another compound that may be more or less hazardous

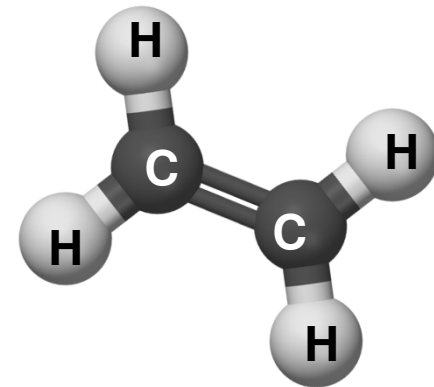
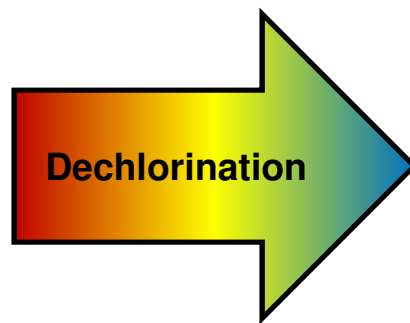


Key Question

*Is complete dechlorination
occurring in SSFL groundwater?*

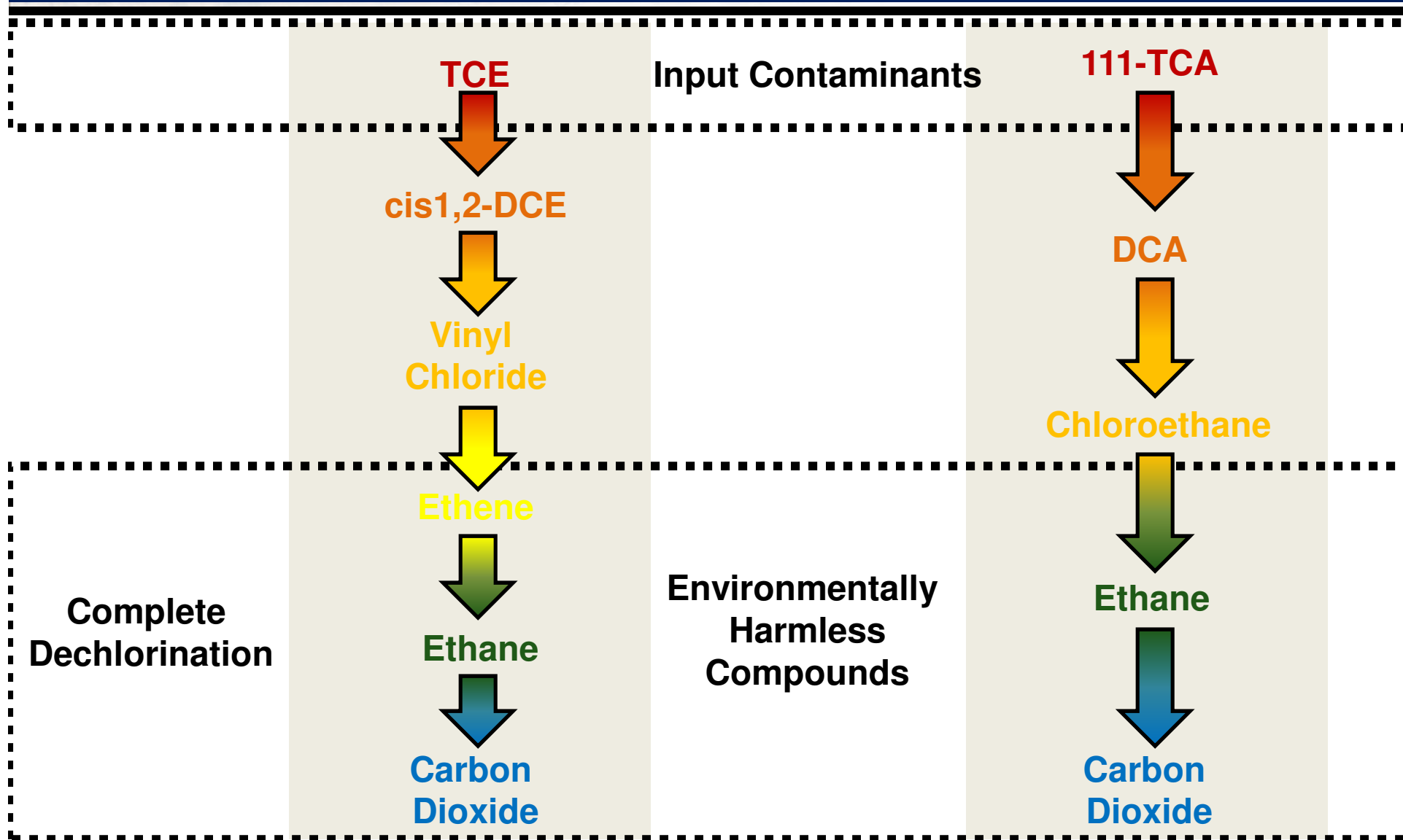


TCE
111-TCA

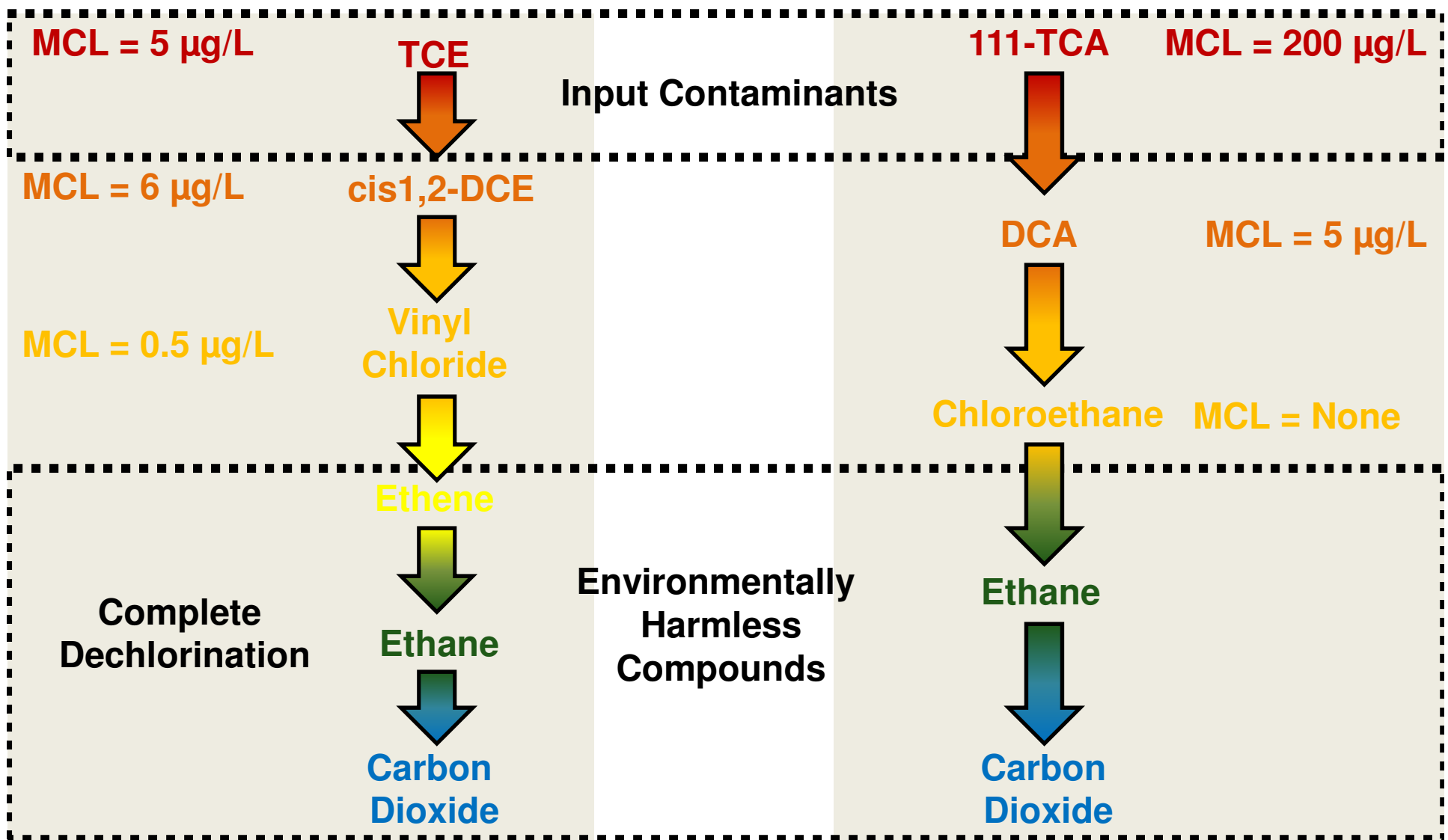


**Harmless
Compounds?**

Degradation and Dechlorination Processes for TCE and TCA

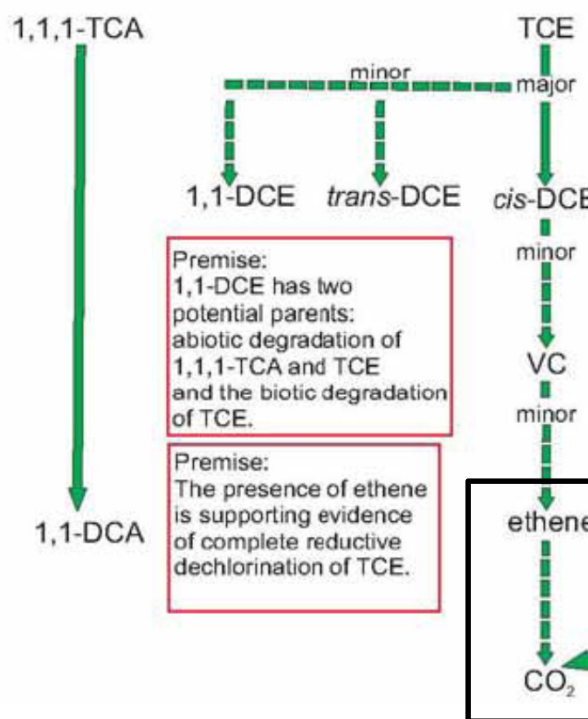


Degradation and Dechlorination Processes for TCE and TCA

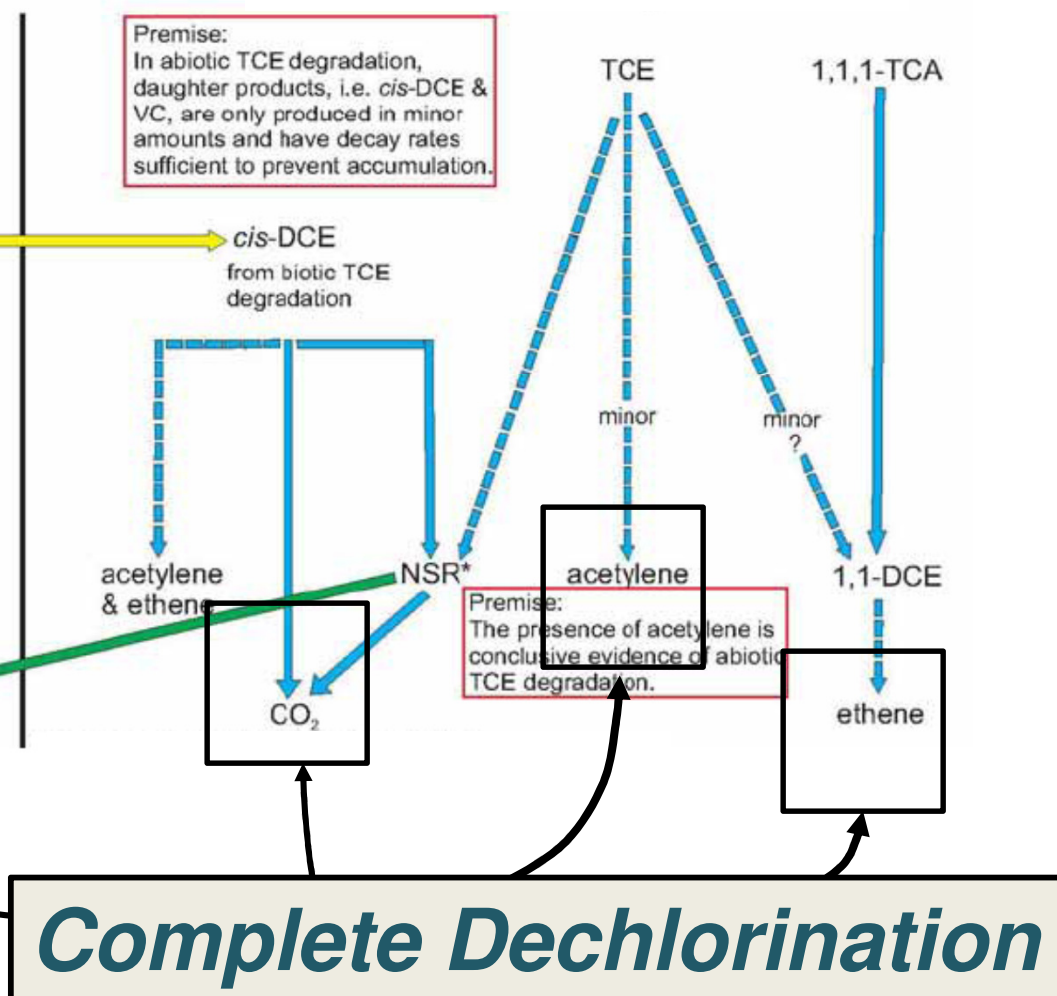


Degradation and Dechlorination Pathways for TCE and TCA

Biotic Pathways



Abiotic Pathways



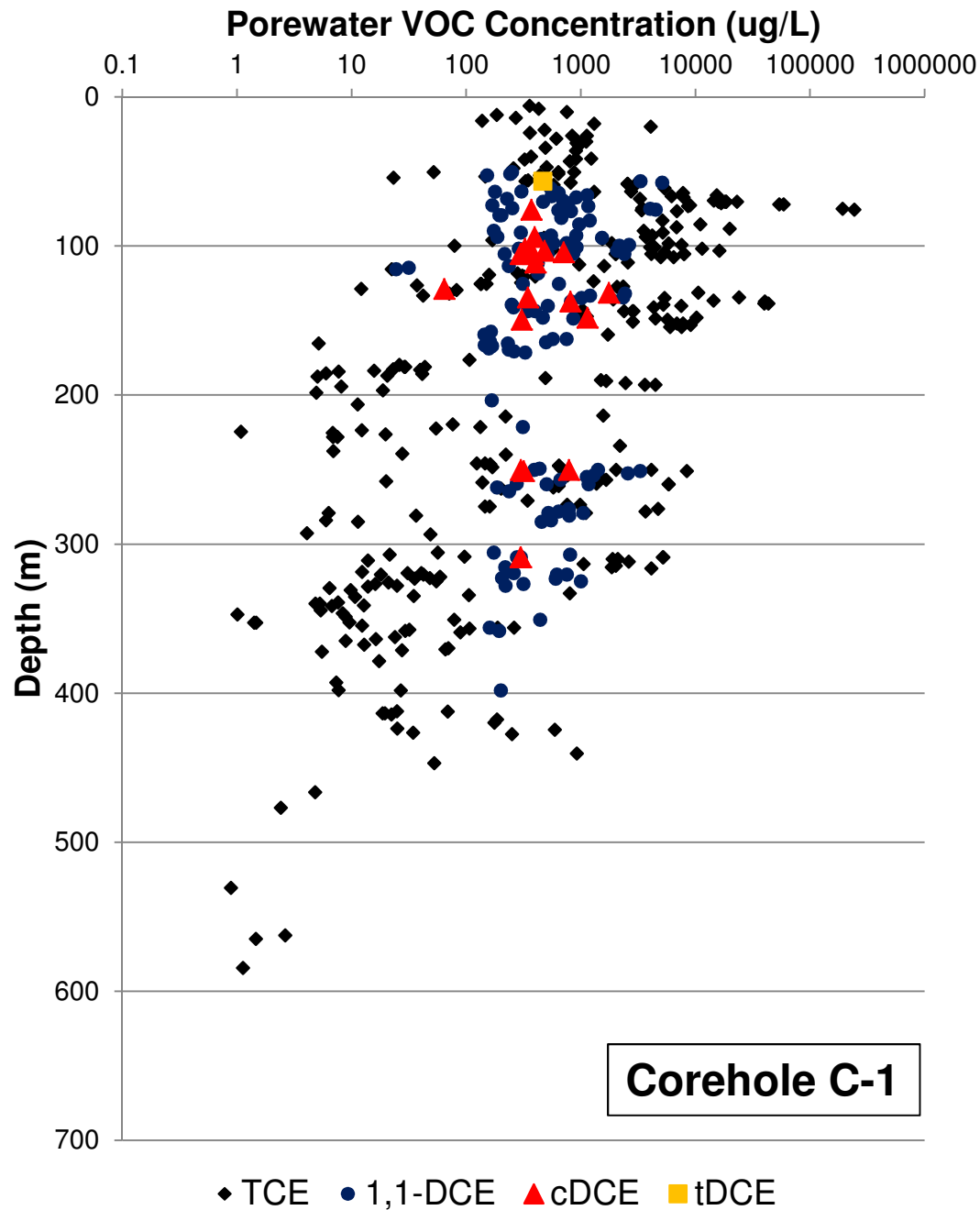


- Degradation is transformation of a compound without specification of dechlorination
- Dechlorination is the process that breaks these compounds down into harmless chemicals
- Dechlorination causes plumes be smaller than they would otherwise be

Types of Studies Conducted Concerning Degradation

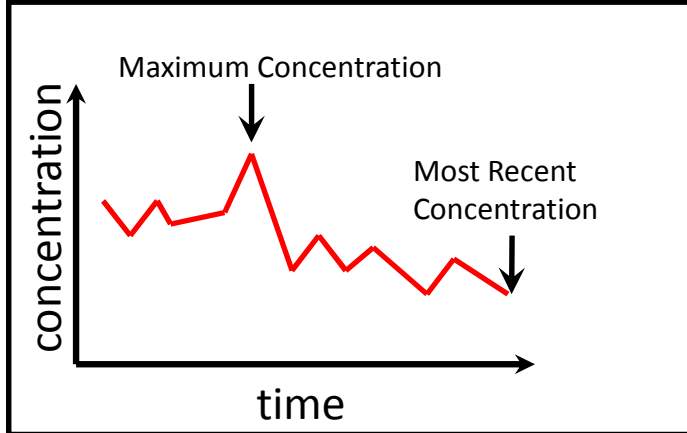
TOPIC	UNIVERSITY
Specific sampling and analysis for diagnostic degradation products	
Compound Specific isotope Analysis	
Laboratory microcosm studies	
Identification of microbes in rock core (in Progress)	
Application of Bio Traps (in progress)	

Results from Rock Core

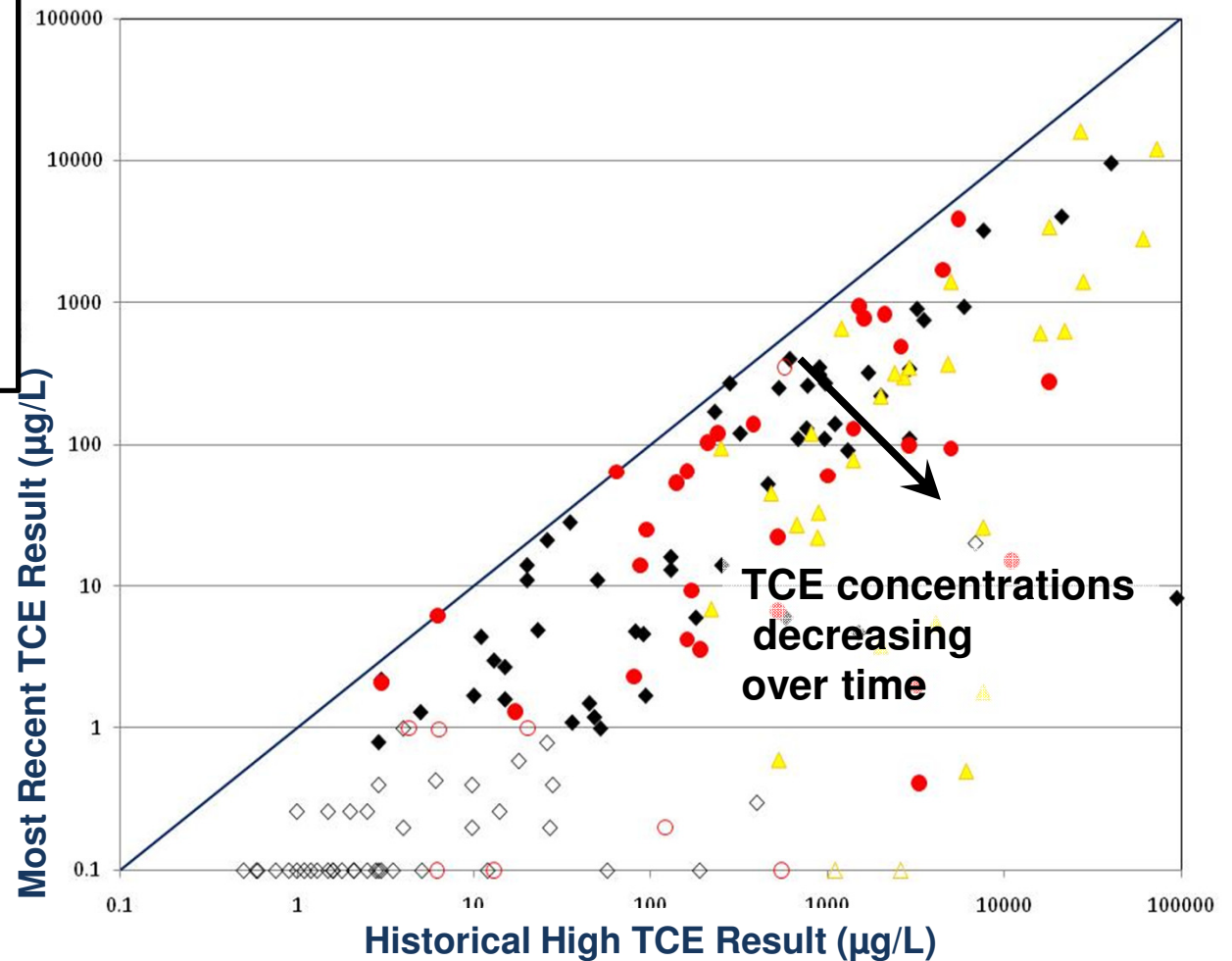


Rock core results show abundant TCE degradation products

Groundwater TCE Concentrations are Decreasing



Comparison of most recent results to maximum historical values



- ◇ Chatsworth Formation Wells (Recent Results Estimated or <MDLs)
- △ Extraction Wells (Recent Results <MDL)
- Shallow Wells (Recent Results Estimated or <MDLs)
- One to One Comparison Line
- ◆ Chatsworth Formation Wells
- ▲ Extraction Wells
- Shallow Wells

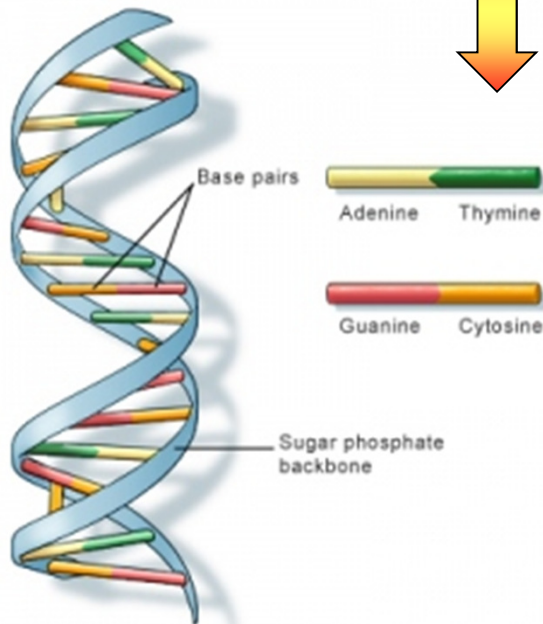
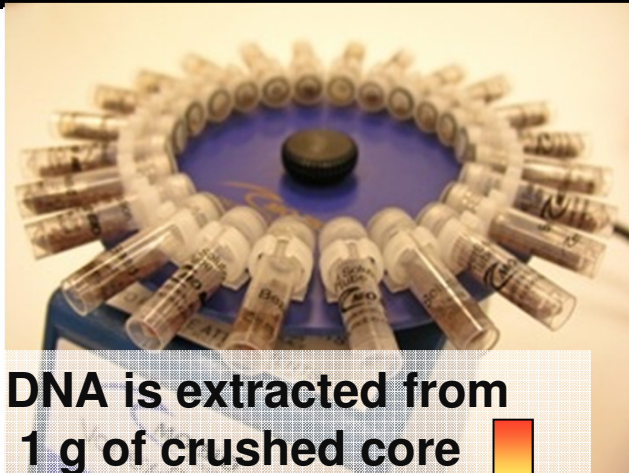
Snap Sampler Used at SSFL



Bottles sealed in-situ to capture volatile compounds **indicating dechlorination**



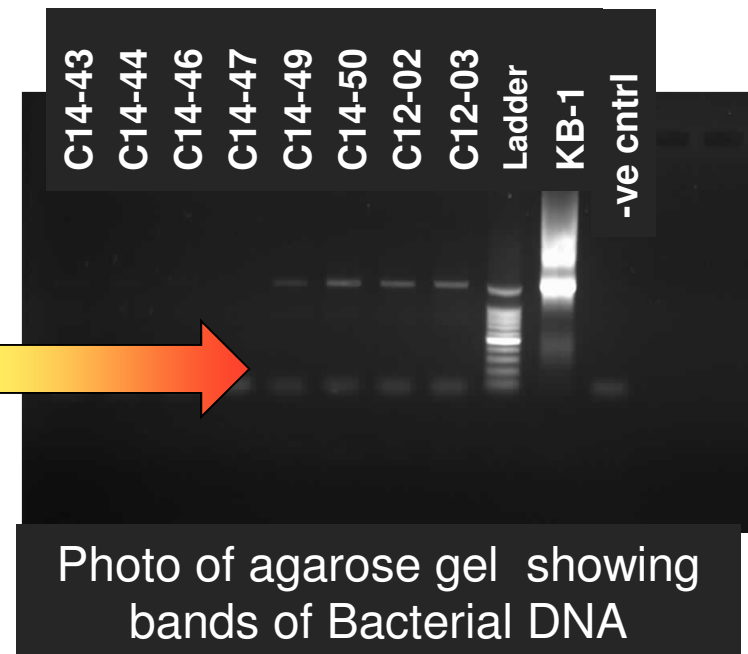
SSFL Rock Core Examined for Bacteria Causing Dechlorination



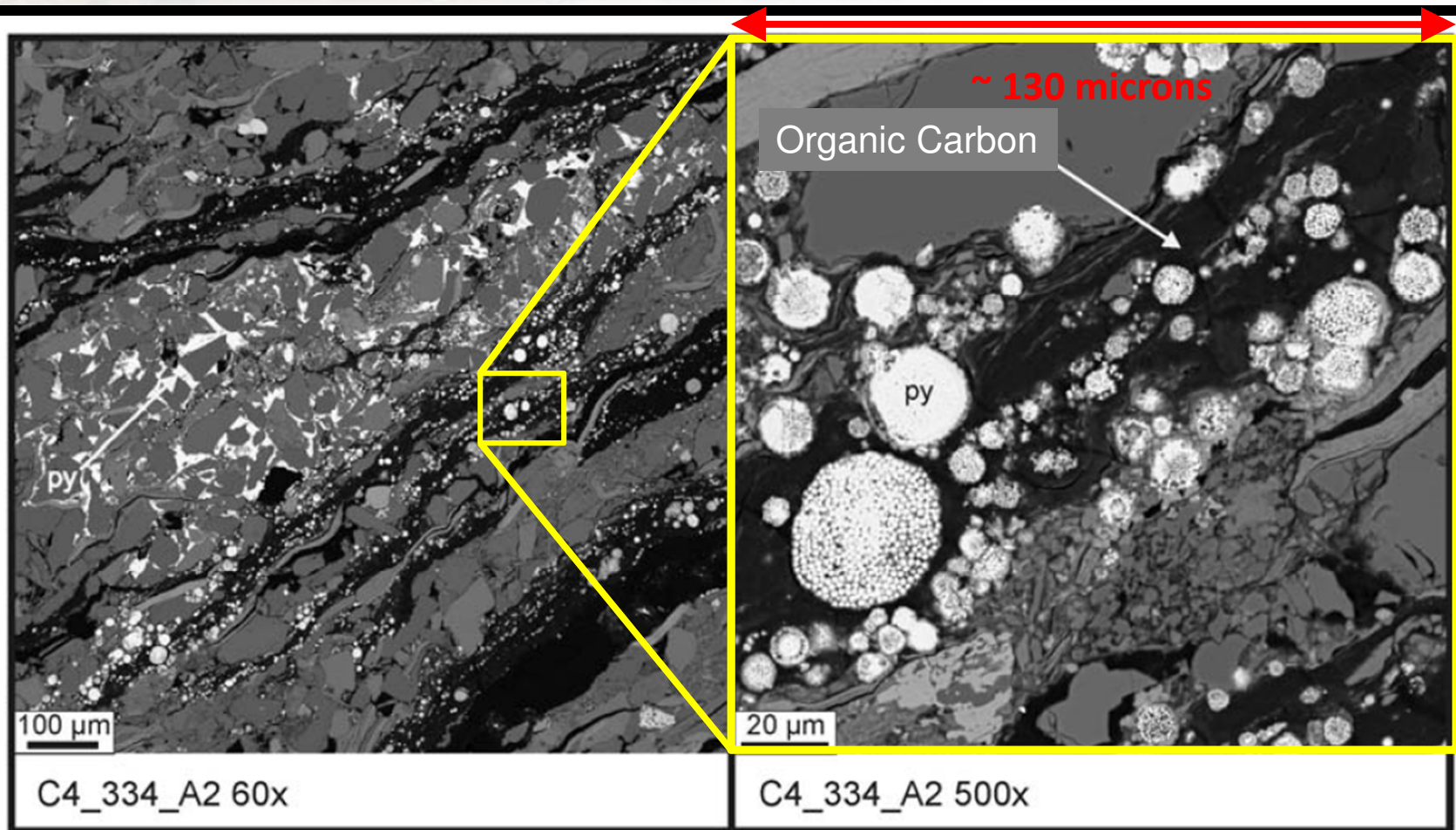
Microbial DNA from Coreholes C12, C13 and C14:

Looking for bacteria that contribute to TCE biodegradation.

DNA is amplified by PCR and visualized in a gel

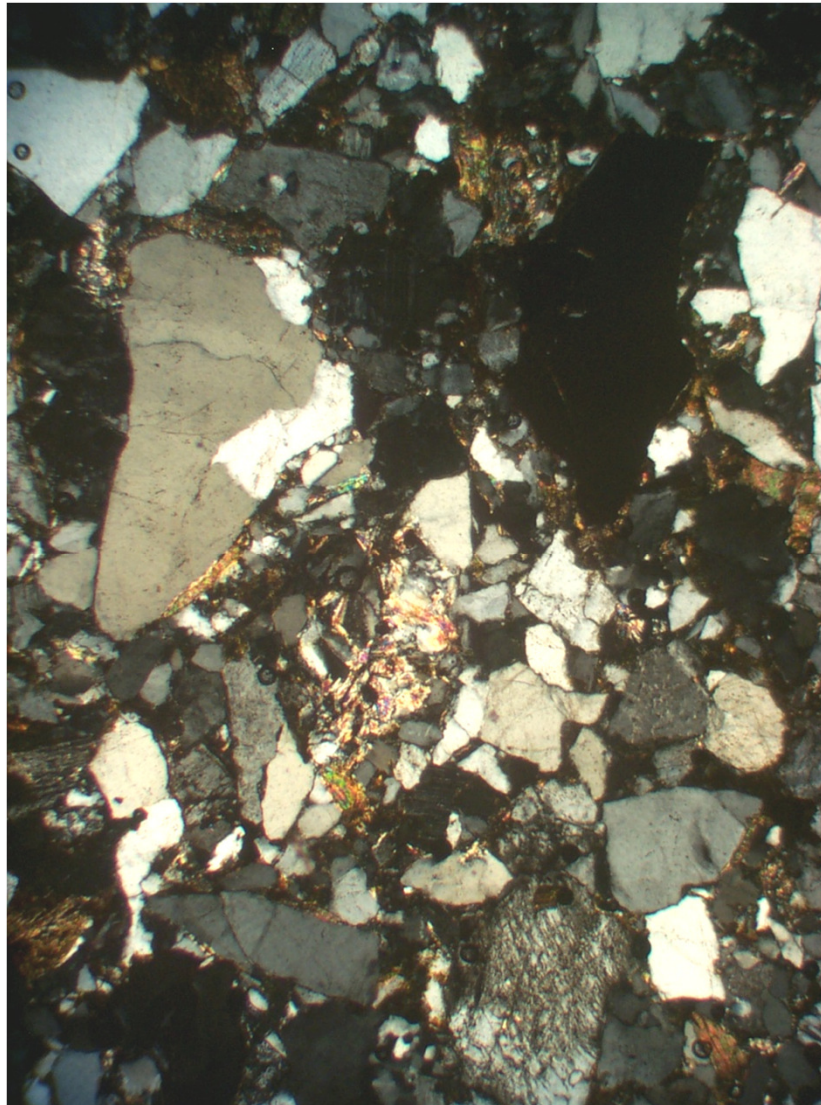


Substantial Organic Matter SSFL Rock Fosters Microbial Activity



SEM BSE Images of Thin Slices of SSFL Rock Core
Solid Organic Carbon (*foc*) in Rock Matrix

Contains Reactive Minerals in SSFL Rock Fosters Abiotic Dechlorination



***The Chatsworth Formation
contains :***

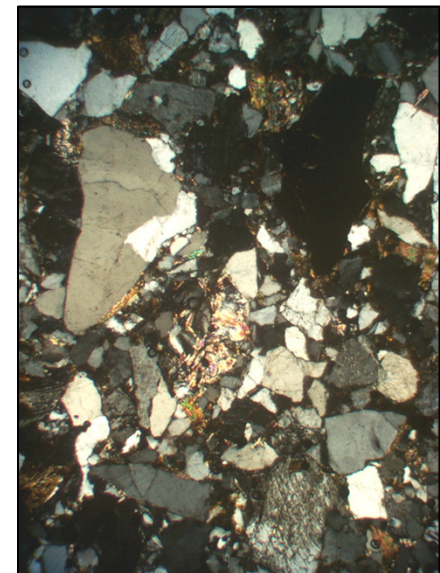
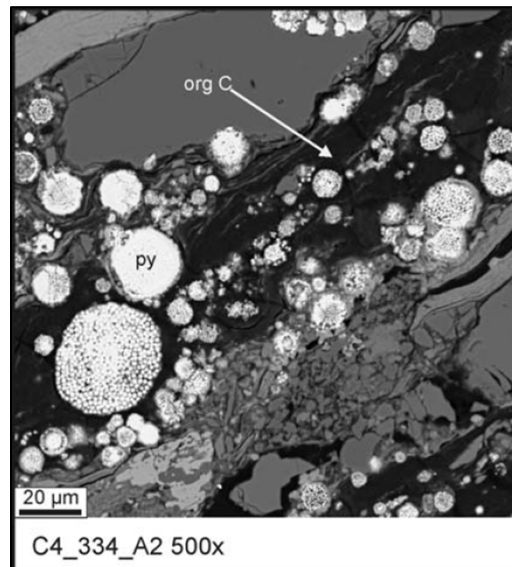
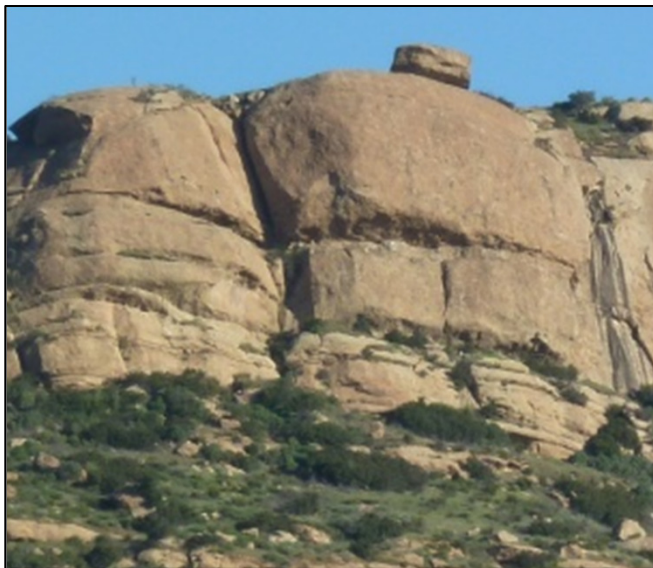
Reactive Minerals:

- pyrite
- biotite
- hornblende
- iron minerals

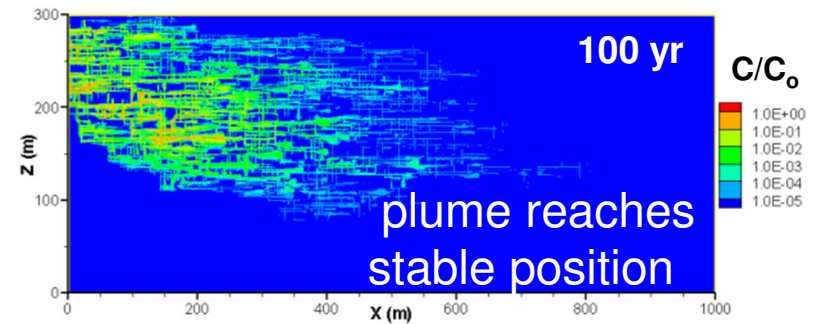
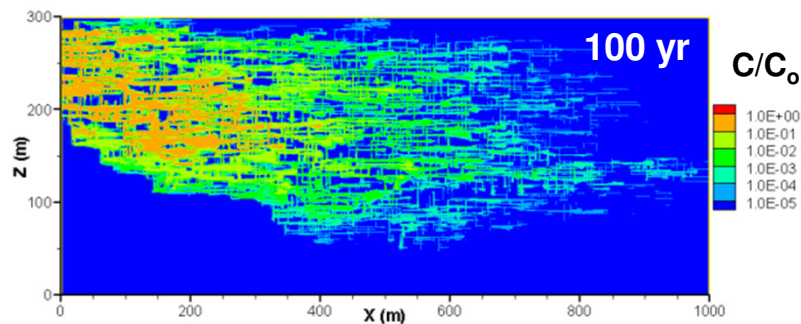
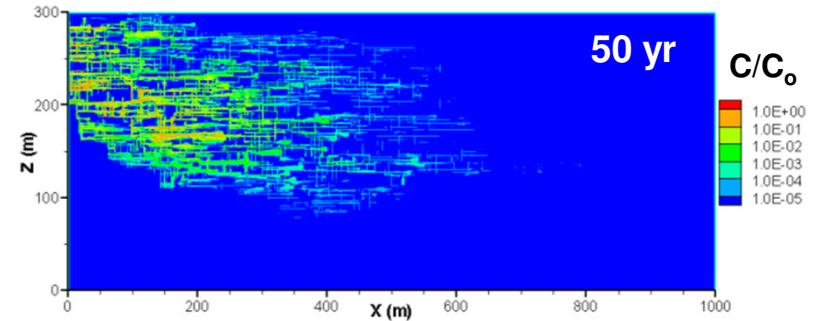
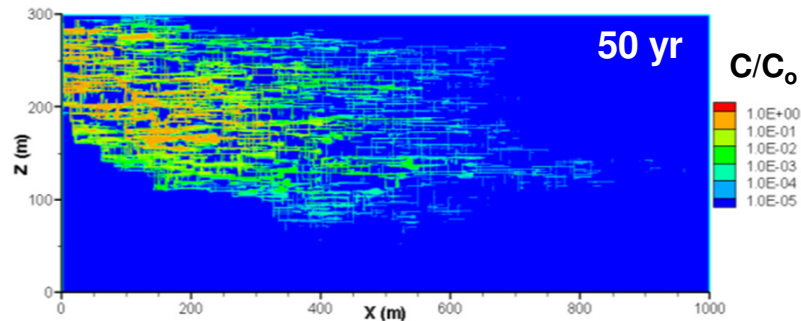
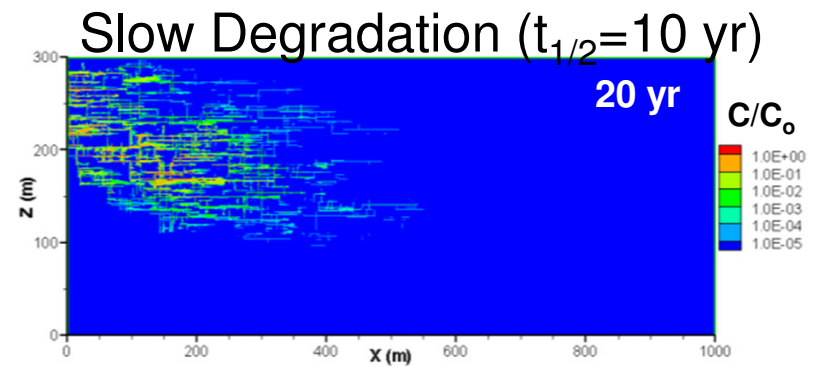
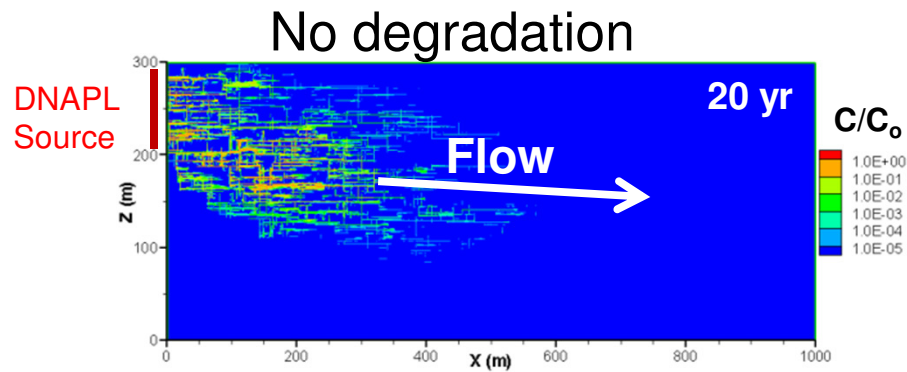
***Thin section of rock using
microscopic***

Chatsworth Formation Summary

The turbidite origin gives the Chatsworth Formation compositions favorable for TCE and TCA Dechlorination



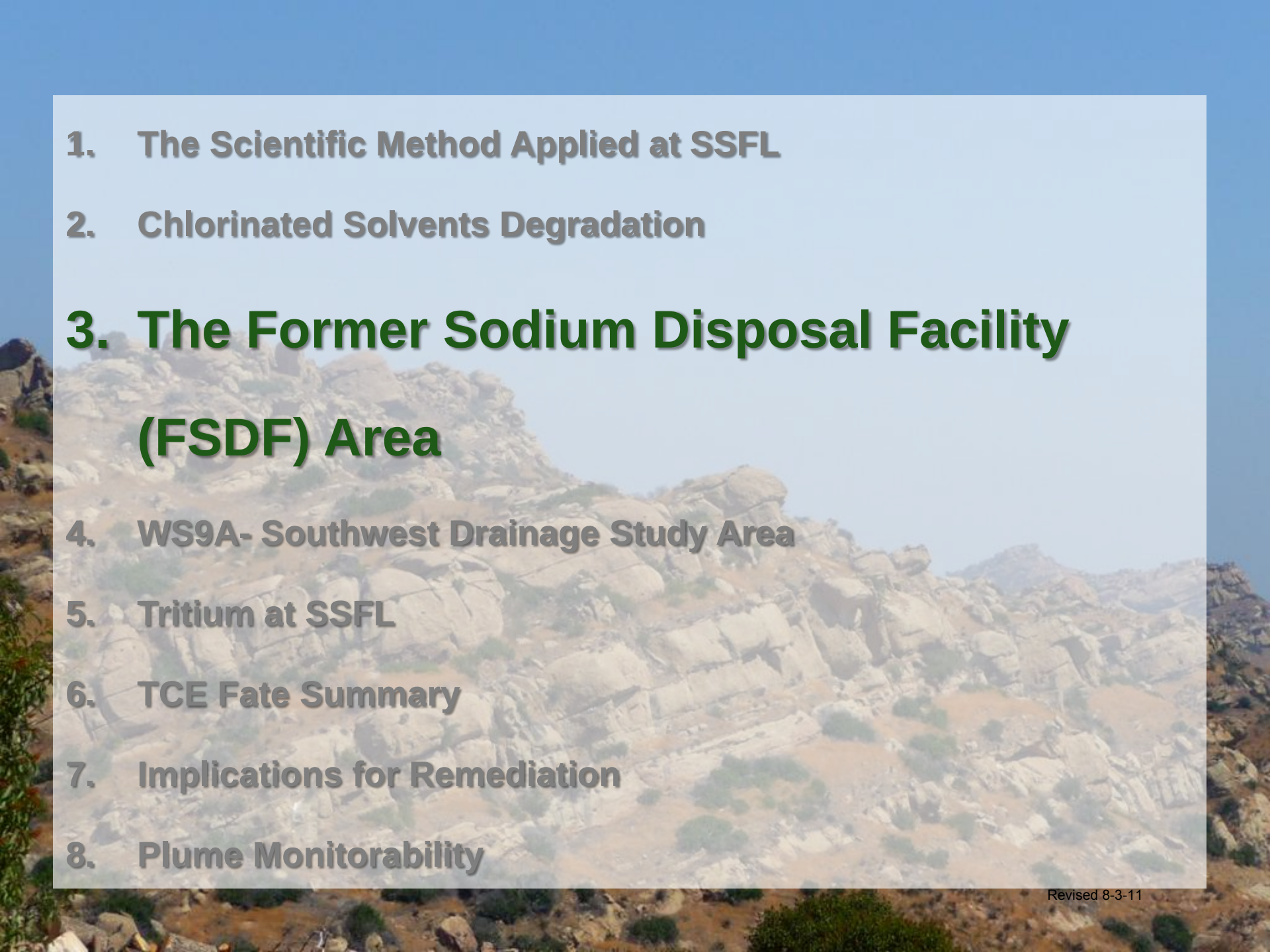
FRACTRAN - Continual Source Degradation Causes TCE Plume Shrinkage



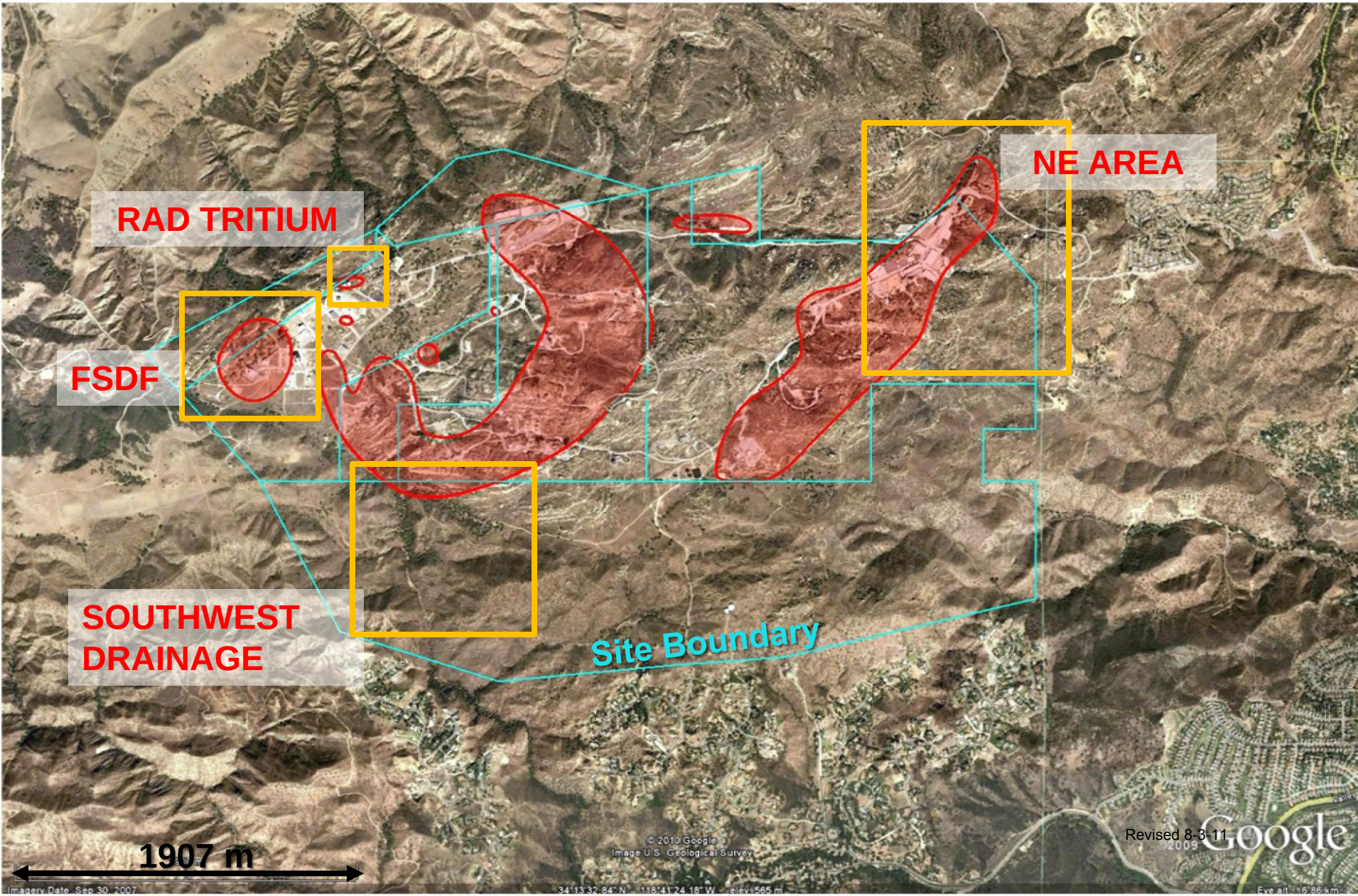


Module 2: Summary and Implications

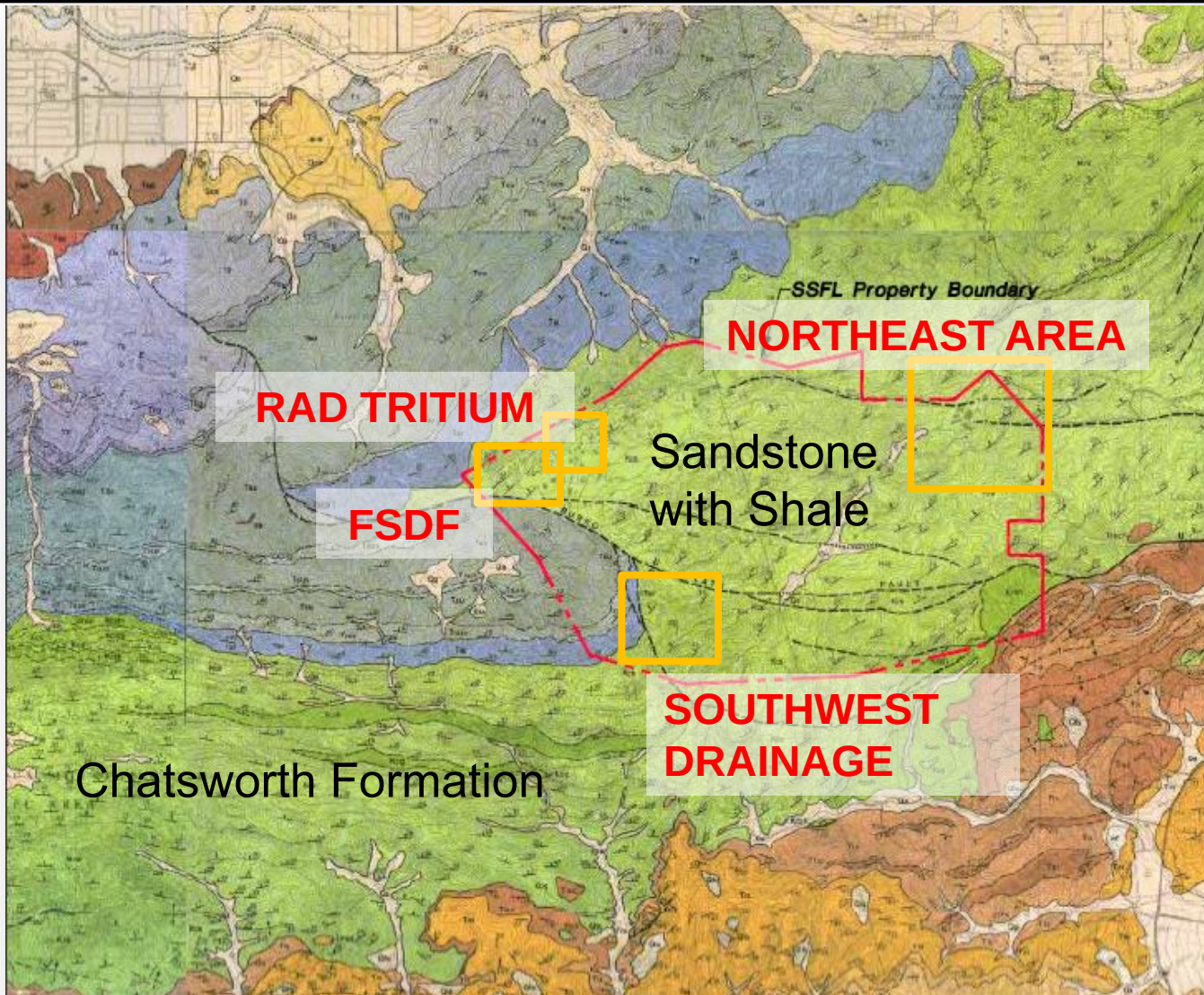
- *Various lines of evidence show complete TCE and TCA dechlorination is occurring*
- *Even extremely slow degradation rates can be effective at retarding plumes*
- *Studies are in progress to determine the extensiveness of dechlorination*
- *Ability to monitor dechlorination over time*

- 
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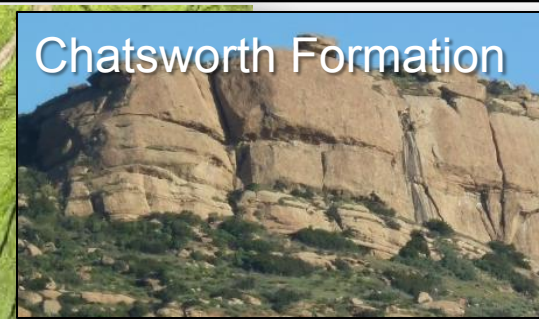
SSFL Groundwater Contamination



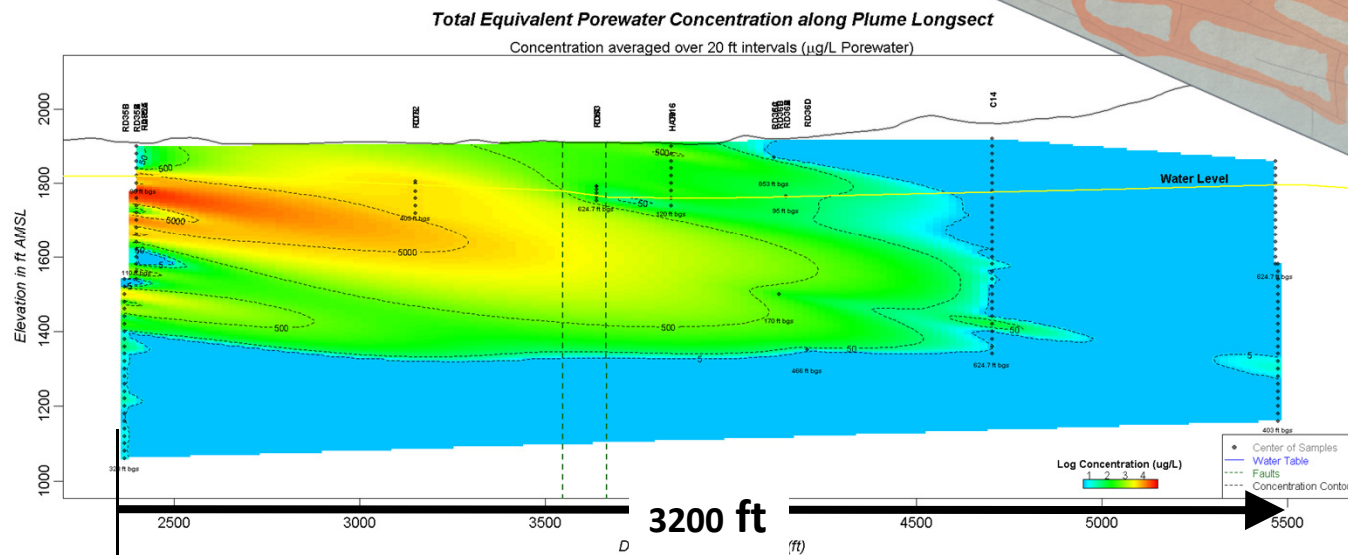
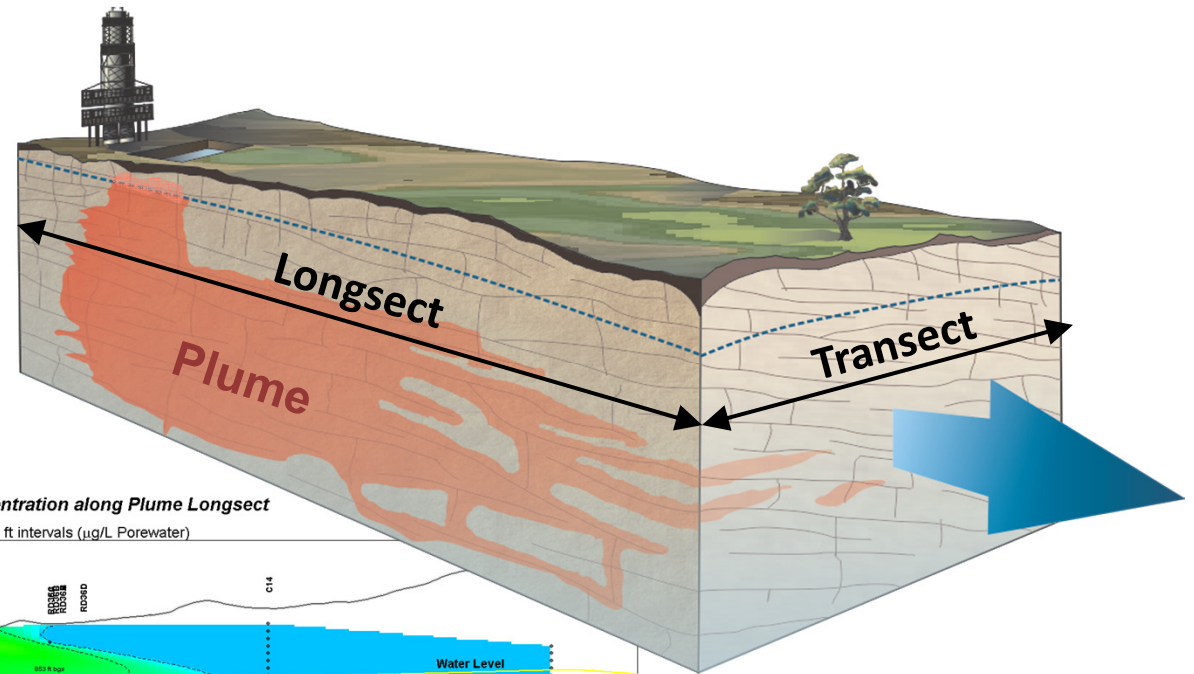
Chatsworth Formation Beneath All Study Areas



Chatsworth Formation

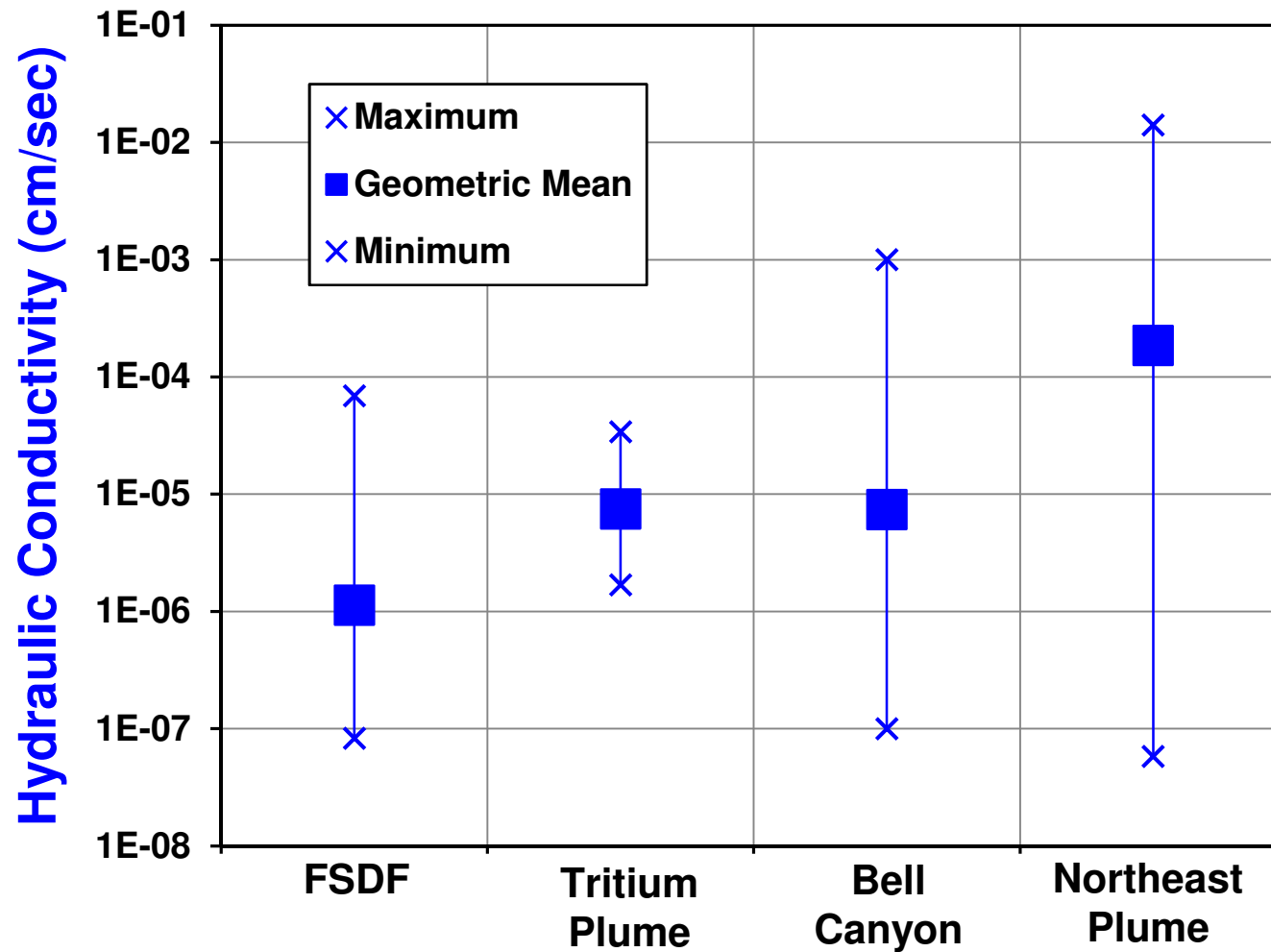


NE Plume Has Not Migrated Far in 60 Years



Groundwater Flow

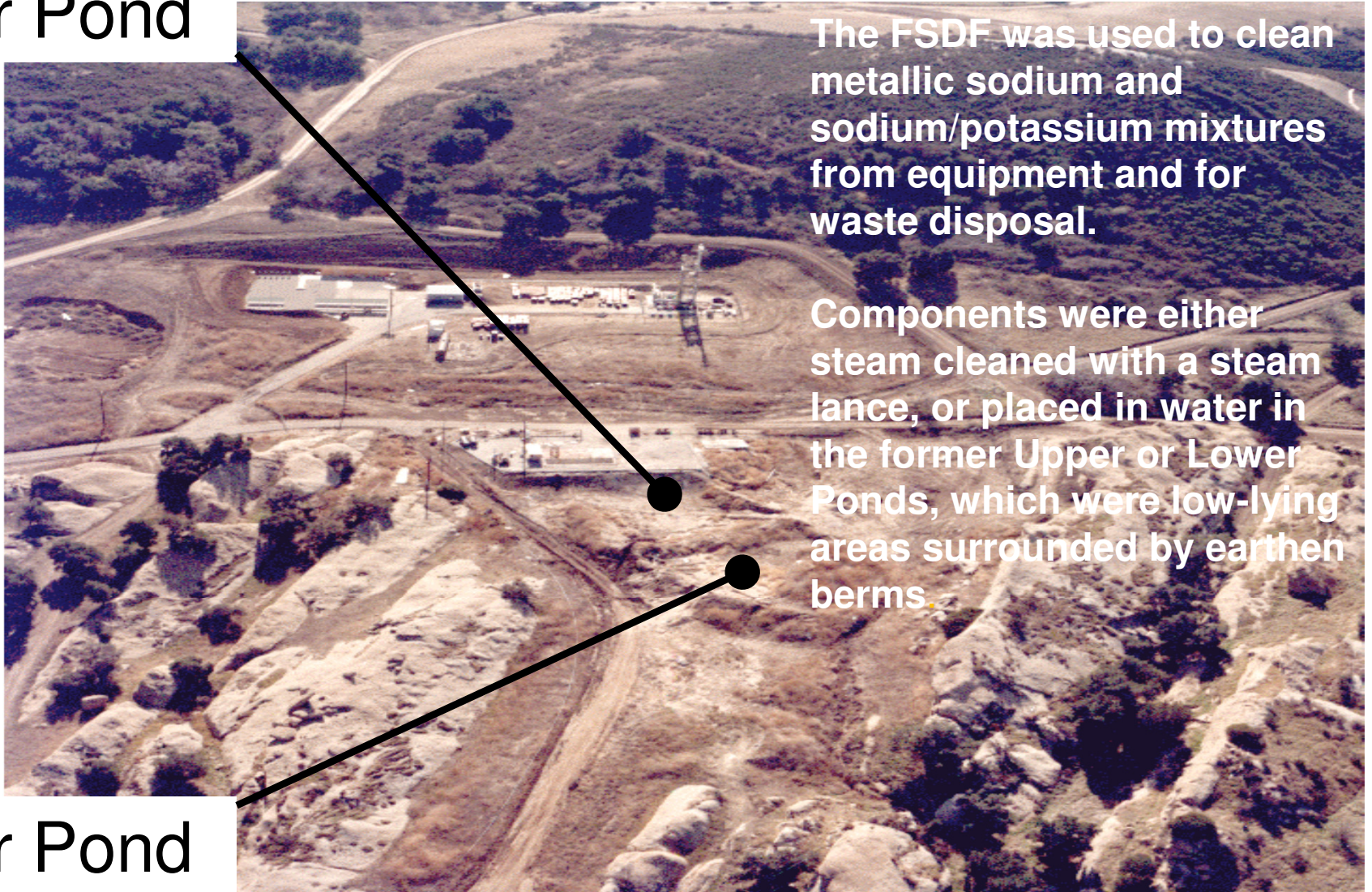
Hydraulic Conductivity Varies Greatly Across Site



These 4 areas span a large range of site hydrogeologic conditions

FSDF Ponds Used for Wastewater Disposal

Upper Pond



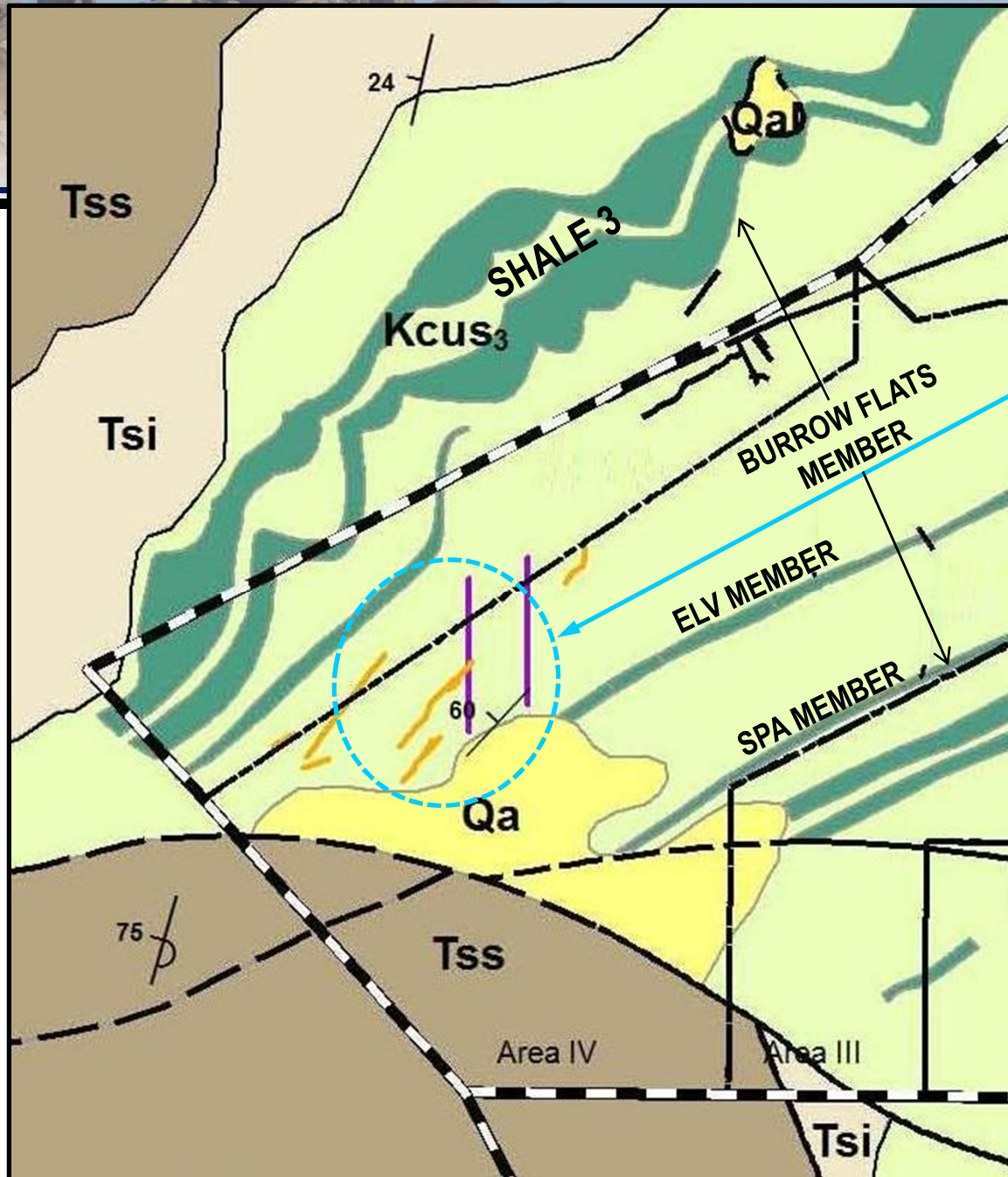
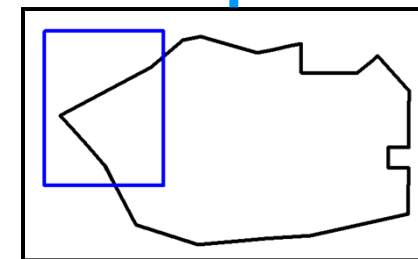
The FSDF was used to clean metallic sodium and sodium/potassium mixtures from equipment and for waste disposal.

Components were either steam cleaned with a steam lance, or placed in water in the former Upper or Lower Ponds, which were low-lying areas surrounded by earthen berms.

Lower Pond

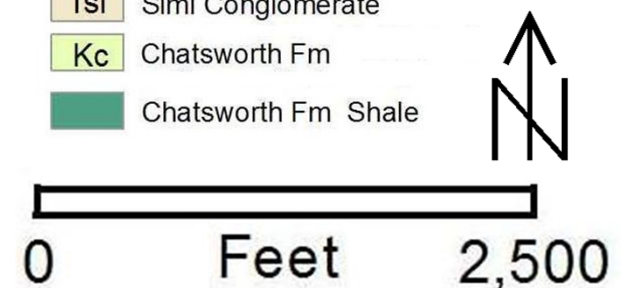
FSDF Geologic Map

FSDF area of
groundwater
impacted by TCE and
other compounds



Geologic Units

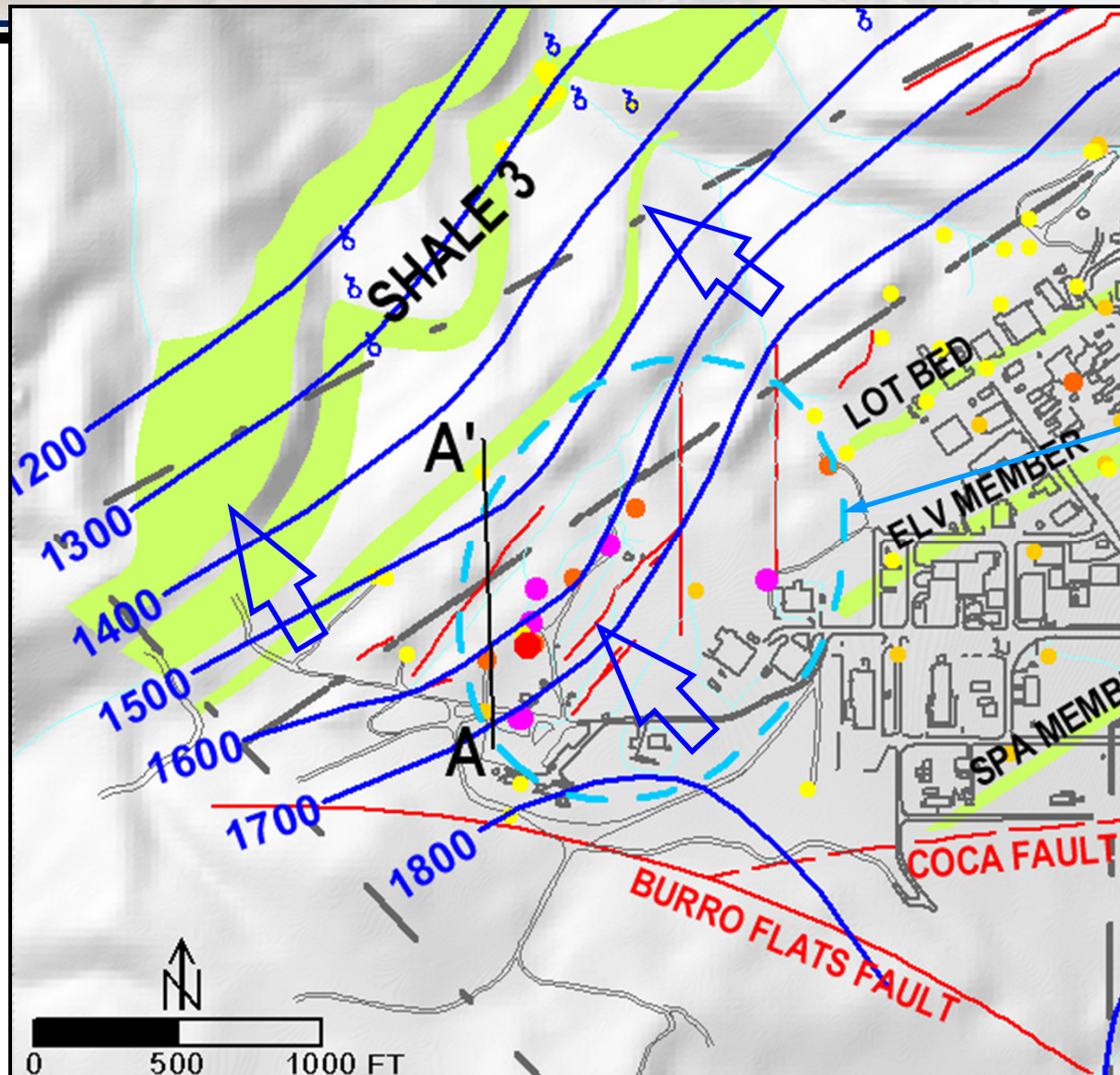
- Qa Alluvium
- Tss Santa Susana Fm
- Tsi Simi Conglomerate
- Kc Chatsworth Fm
- Chatsworth Fm Shale



Exposed Bedrock at FSDF After Excavation of Overburden



FSDF TCE and Groundwater Elevation Contours



Direction of groundwater flow aligned with stratigraphic dip

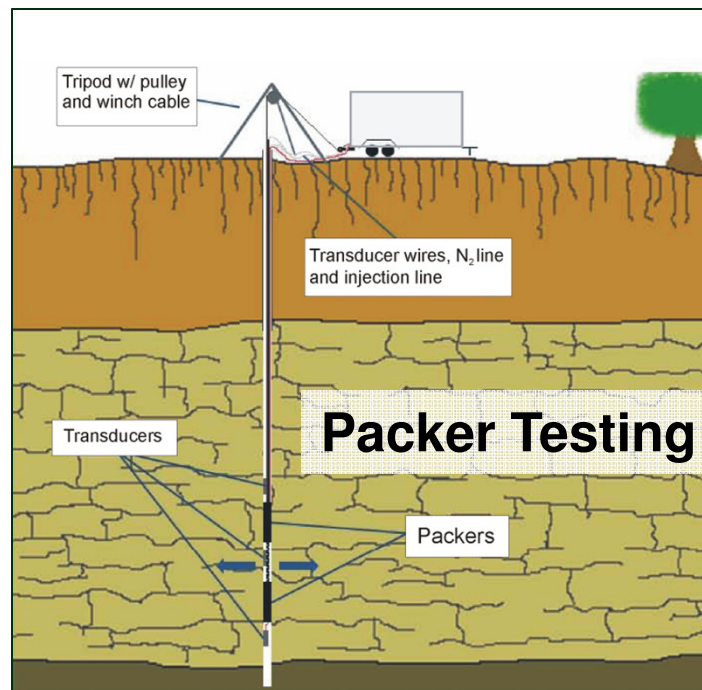
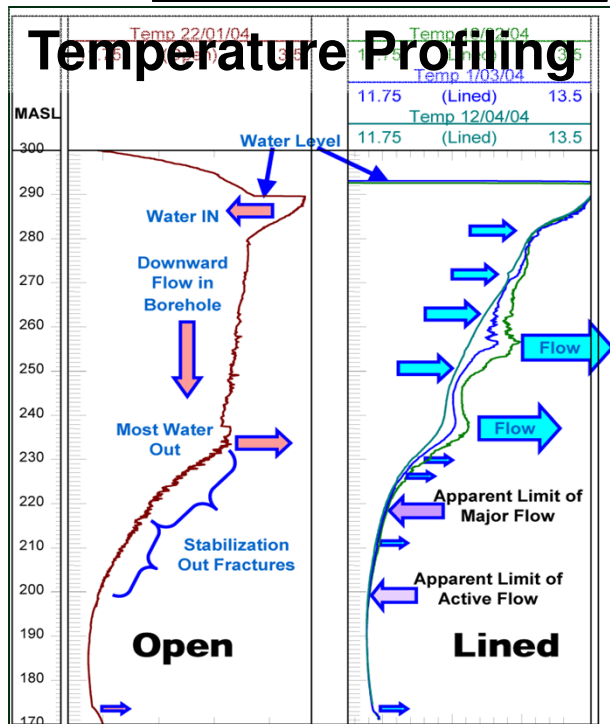
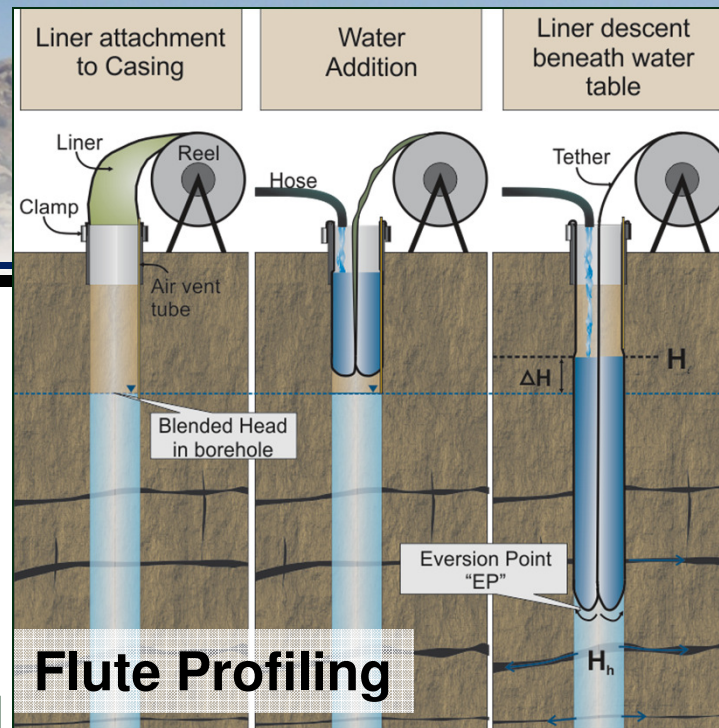
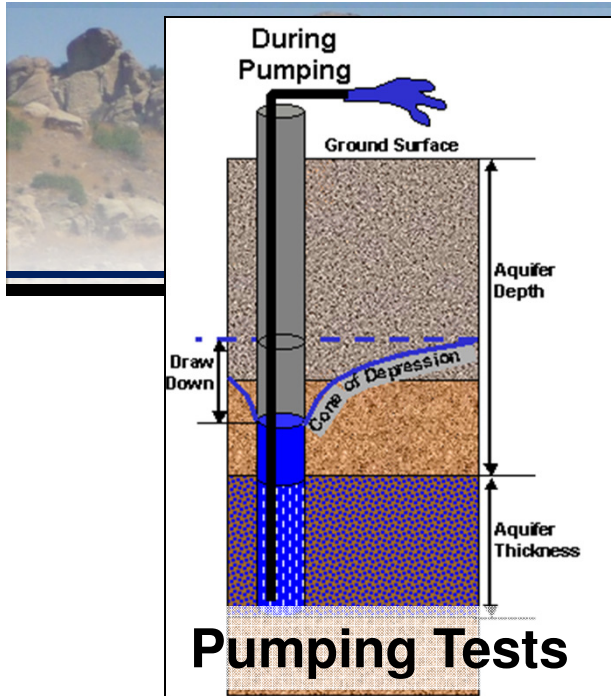
FSD area of TCE-impacted groundwater

A----A' Line of section

TCE* (ug/L)

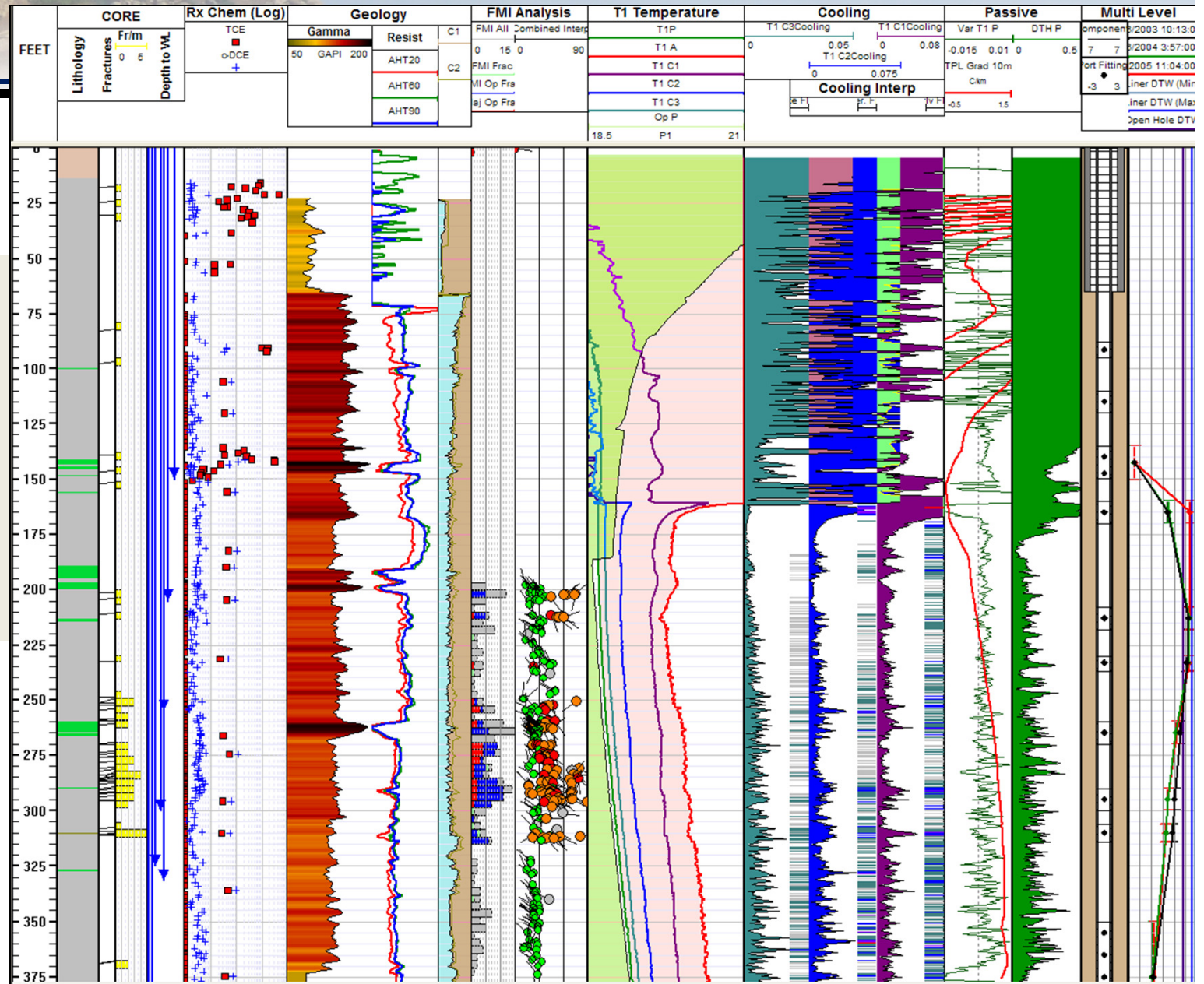
- 0 to 1
- 1 to 10
- 10 to 100
- 100 to 1000
- 1000 to 10000

*Geometric mean of all samples



Methods to Seek Evidence for Permeable Fractures and Groundwater Flow

FSDF Area Corehole C8:



Temperature Profiling shows active groundwater flow in numerous fractures

TCE in FSDF Groundwater

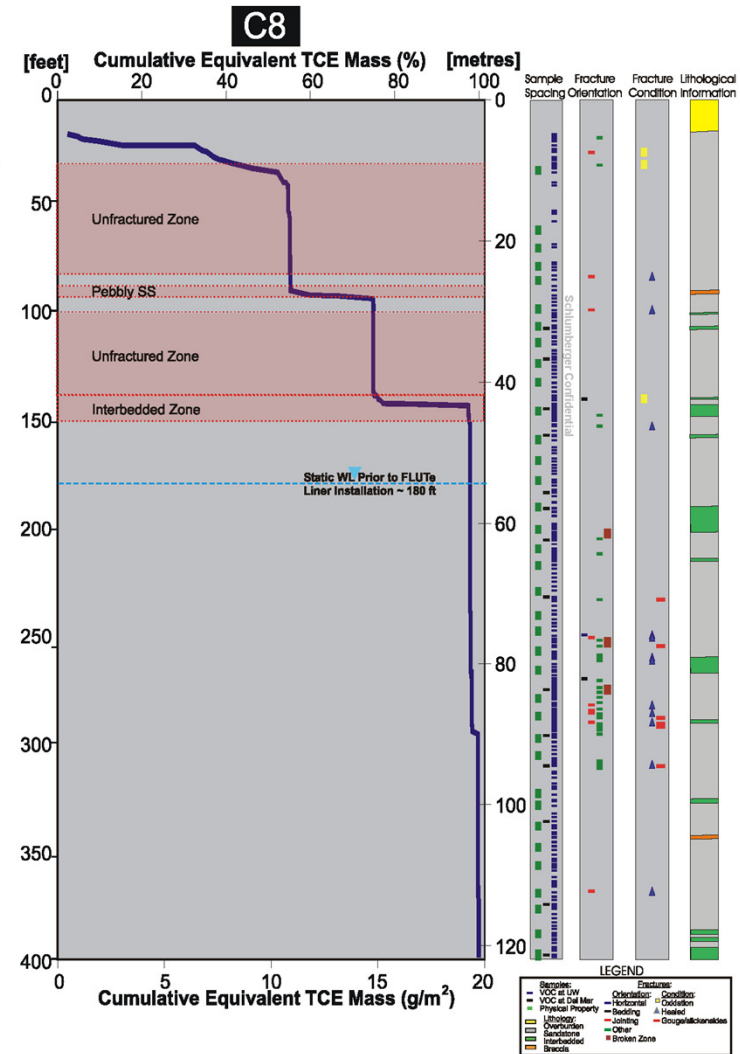
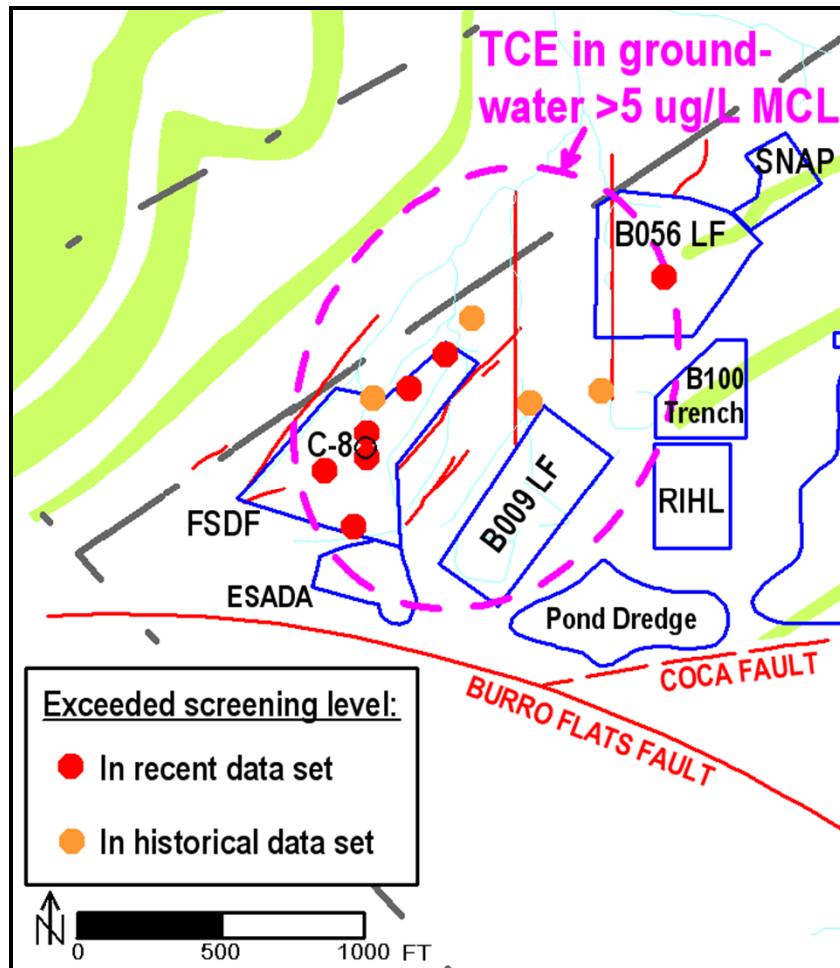


Figure 12. C8 (Former Sodium Disposal Facility) Source Area Cumulative Equivalent TCE Concentration Profile



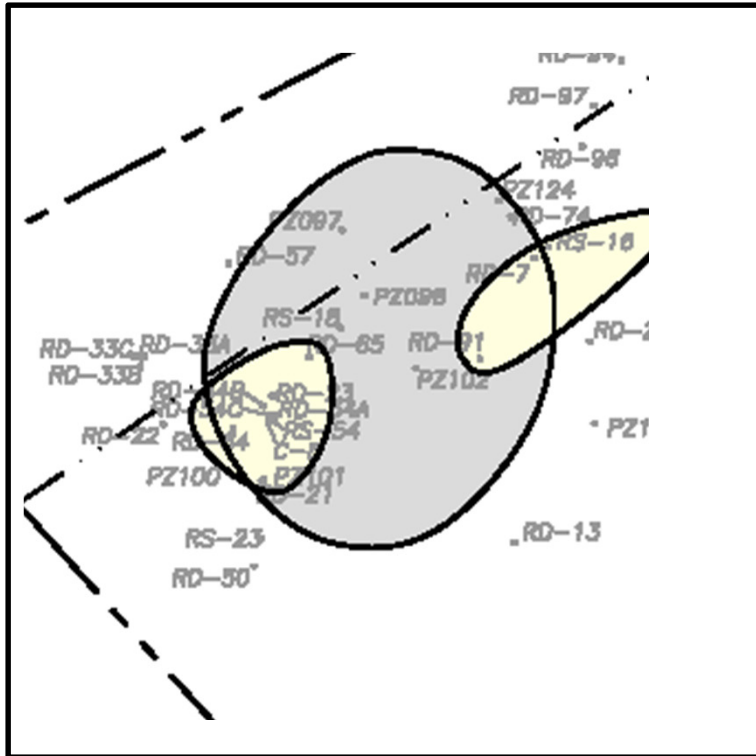
Transport Summary

- FSDF contaminated area is small; consistent with the low bulk hydraulic conductivity and small fractures
- Contaminants are found in the low permeability rock matrix at shallow depth
- The same processes that control the FSDF plume are controlling the NE plume



TCE and its Degradation Products at FSDF

TCE & cDCE

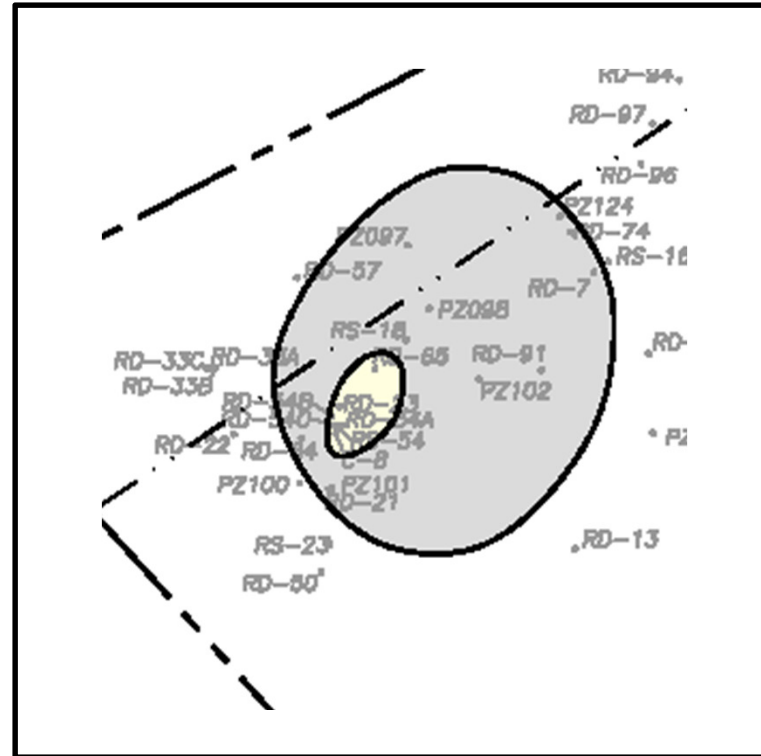


Legend

-  Property Boundary
 Administrative Area Boundary
 Location of Monitoring Well/Piezometer
 cis-1,2-DCE in Groundwater >6ug/L
 TCE in Groundwater >5ug/L

From RI Report

TCE & 1,1-DCE

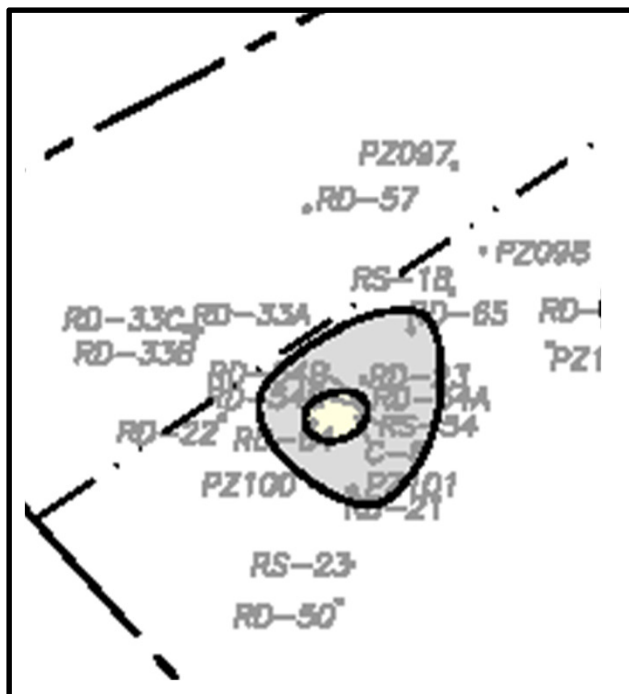


Legend

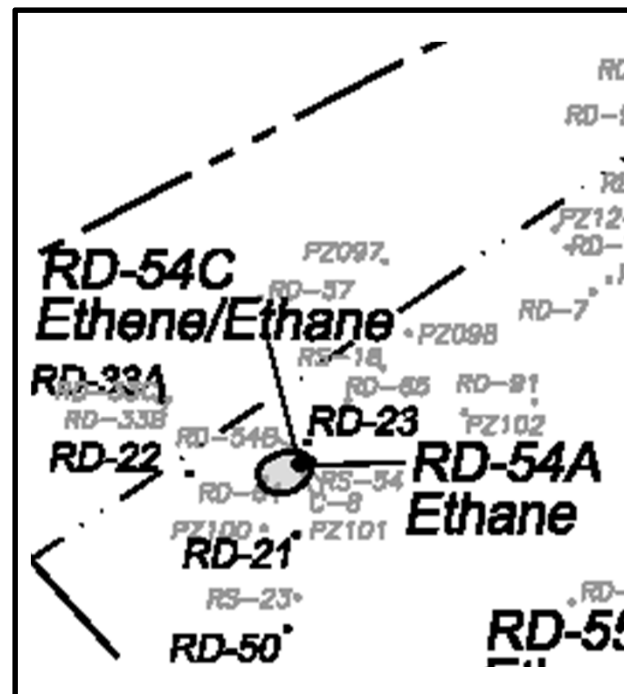
- - - - - Property Boundary
 - - Administrative Area Boundary
 • Location of Well Sampled for VOCs and Dissolved Gases
 ○ 1,1-DCE in Groundwater >6ug/L
 ○ TCE in Groundwater >5ug/L

TCE and Degradation/Dechlorination Products at FSDF

cDCE & VC



VC & Ethene/Ethane



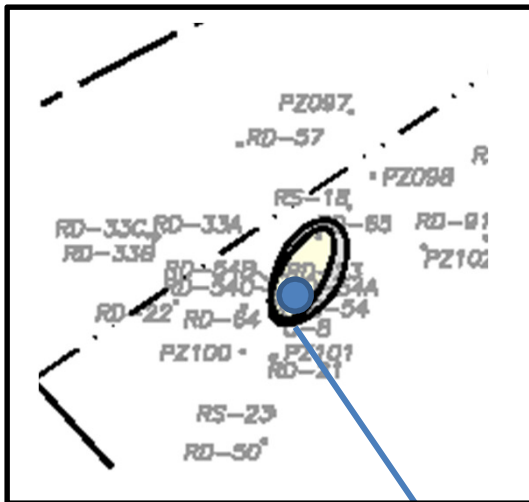
Legend

- Property Boundary
- - - - Administrative Area Boundary
- RD-24, Location of Monitoring Well/Piezometer
- Vinyl Chloride in Groundwater >0.5ug/L
- cis-1,2-DCE in Groundwater >6ug/L

Bold indicates well sample analyzed for ethene/ethane

1,1,1 TCA and 1,4 Dioxane at FSDF

1,1-DCA &
1,1-DCE

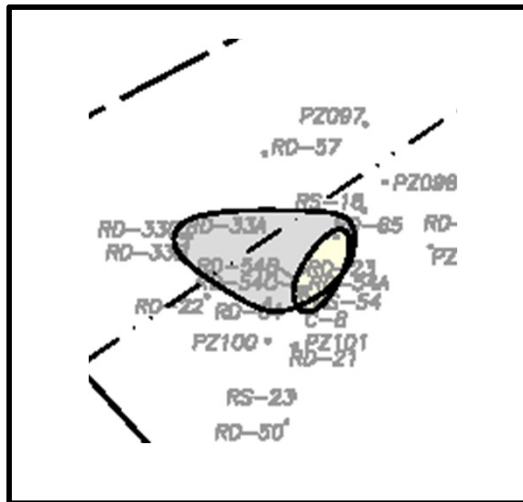


1,1,1-TCA

Legend

- Property Boundary
- ... Administrative Area Boundary
- RD-94 Location of Monitoring Well/Piezometer
- Yellow circle 1,1-DCA in Groundwater >5ug/L
- Grey circle 1,1-DCE in Groundwater >6ug/L

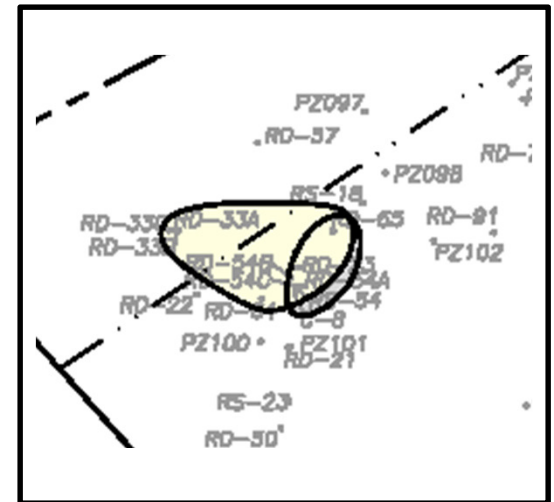
1,1-DCA &
1,4-Dioxane



Legend

- Property Boundary
- ... Administrative Area Boundary
- RD-94 Location of Monitoring Well/Piezometer
- Yellow circle 1,1-DCA in Groundwater >5ug/L
- Grey circle 1,4-Dioxane in Groundwater >3ug/L

1,1-DCE &
1,4-Dioxane



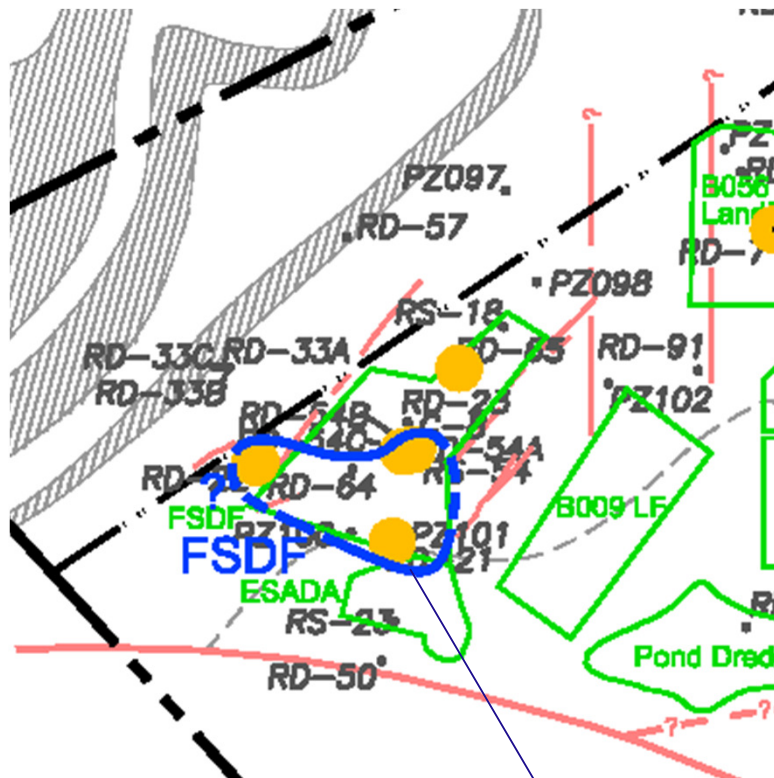
Legend

- Property Boundary
- ... Administrative Area Boundary
- RD-94 Location of Monitoring Well/Piezometer
- Yellow circle 1,4-Dioxane in Groundwater >3ug/L
- Grey circle 1,1-DCE in Groundwater >6ug/L

1,4 Dioxane "MCL" = 1 ug/L

Perchlorate and Other Chemicals in FSDF Groundwater

Perchlorate



Perchlorate

RS-54
1,1,1-TCA
Benzene
Methylene Chloride
Boron
Cadmium
Cobalt
Copper
Molybdenum
Nickel
Chloride

RD-33A
Chloride

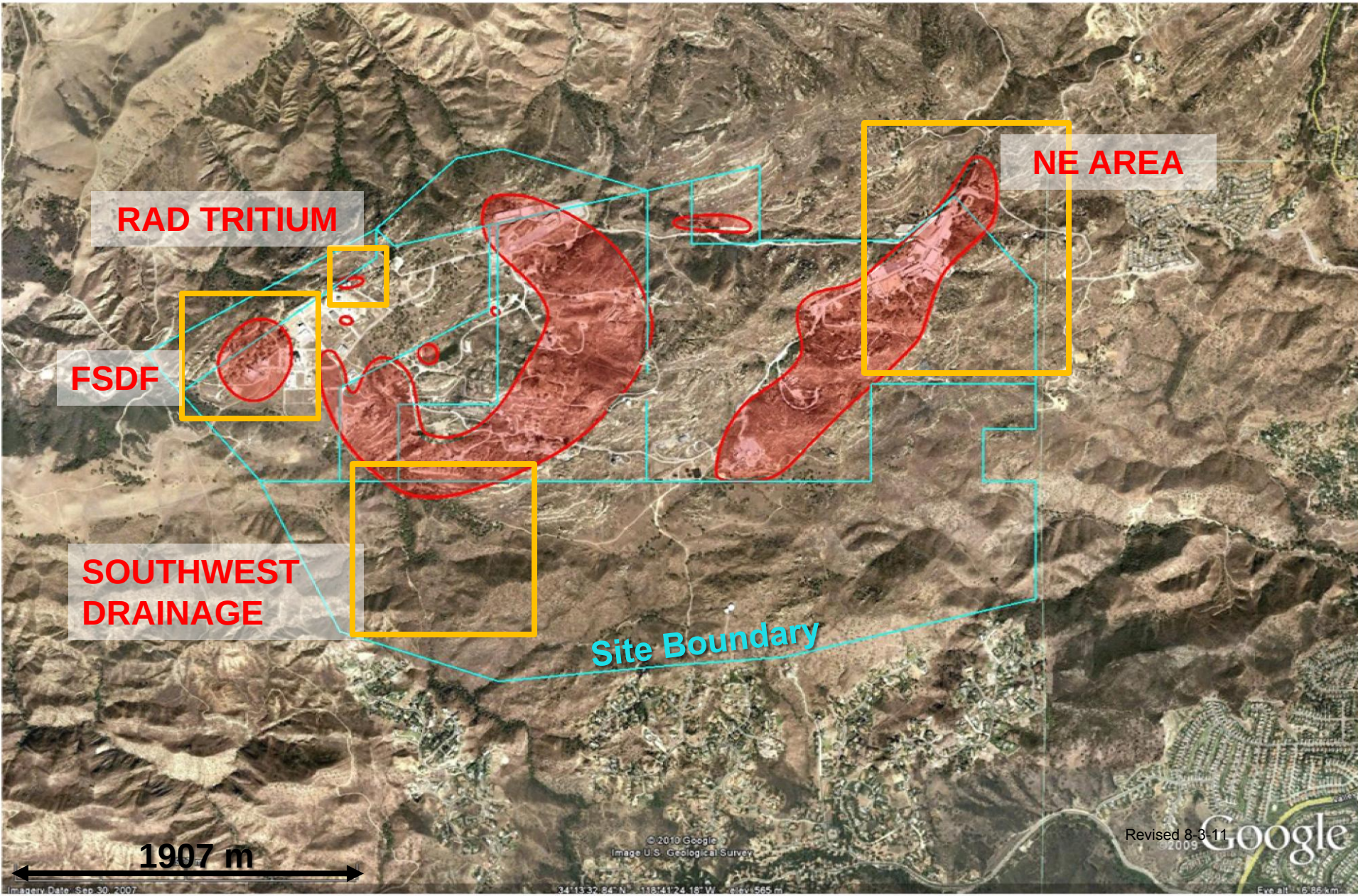


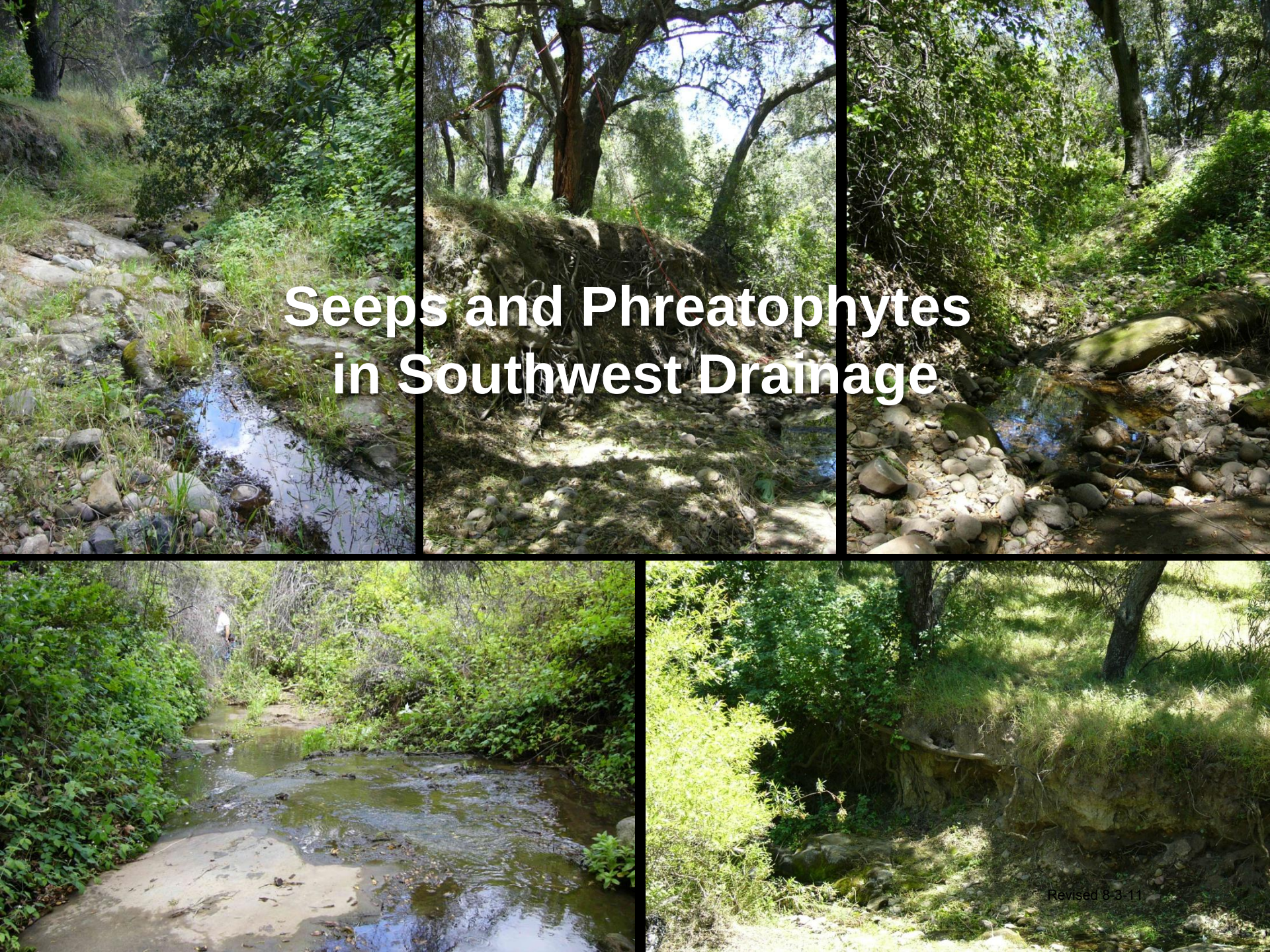
Module 3: Summary and Implications

- *FSDf contamination is very localized, consistent with the low hydraulic conductivity (K)*
- *Even though the bulk K is low, fractures are the main pathways for contaminant migration*
- *Matrix diffusion limits plume migration*
- *TCE and TCA dechlorination is likely occurring*

- 
1. The Scientific Method Applied at SSFL
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SSFL Groundwater Contamination





Seeps and Phreatophytes in Southwest Drainage

Aerial Perspective of TCE (and transformation product) detections in on-site seeps

Systems Test Laboratory (STL)-IV

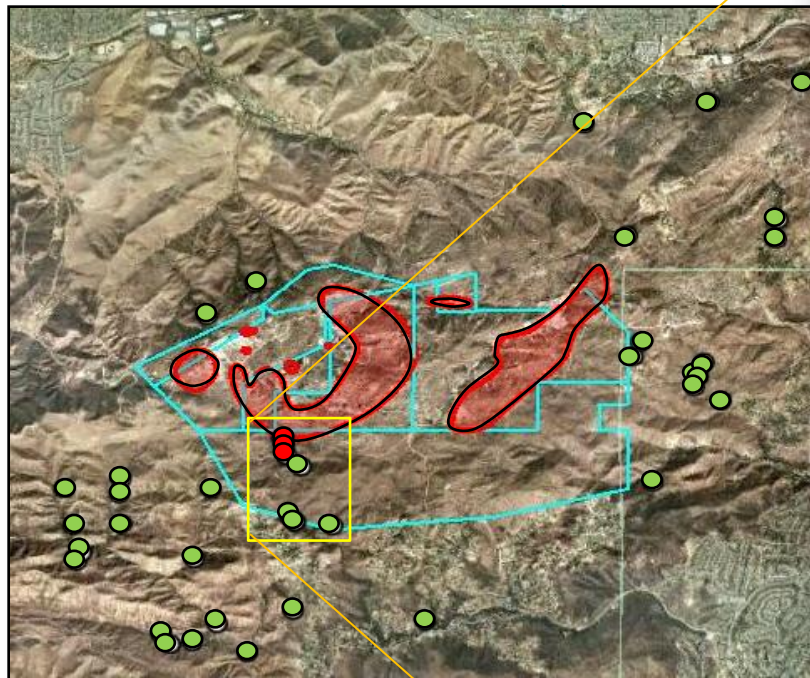
Delta Test Area



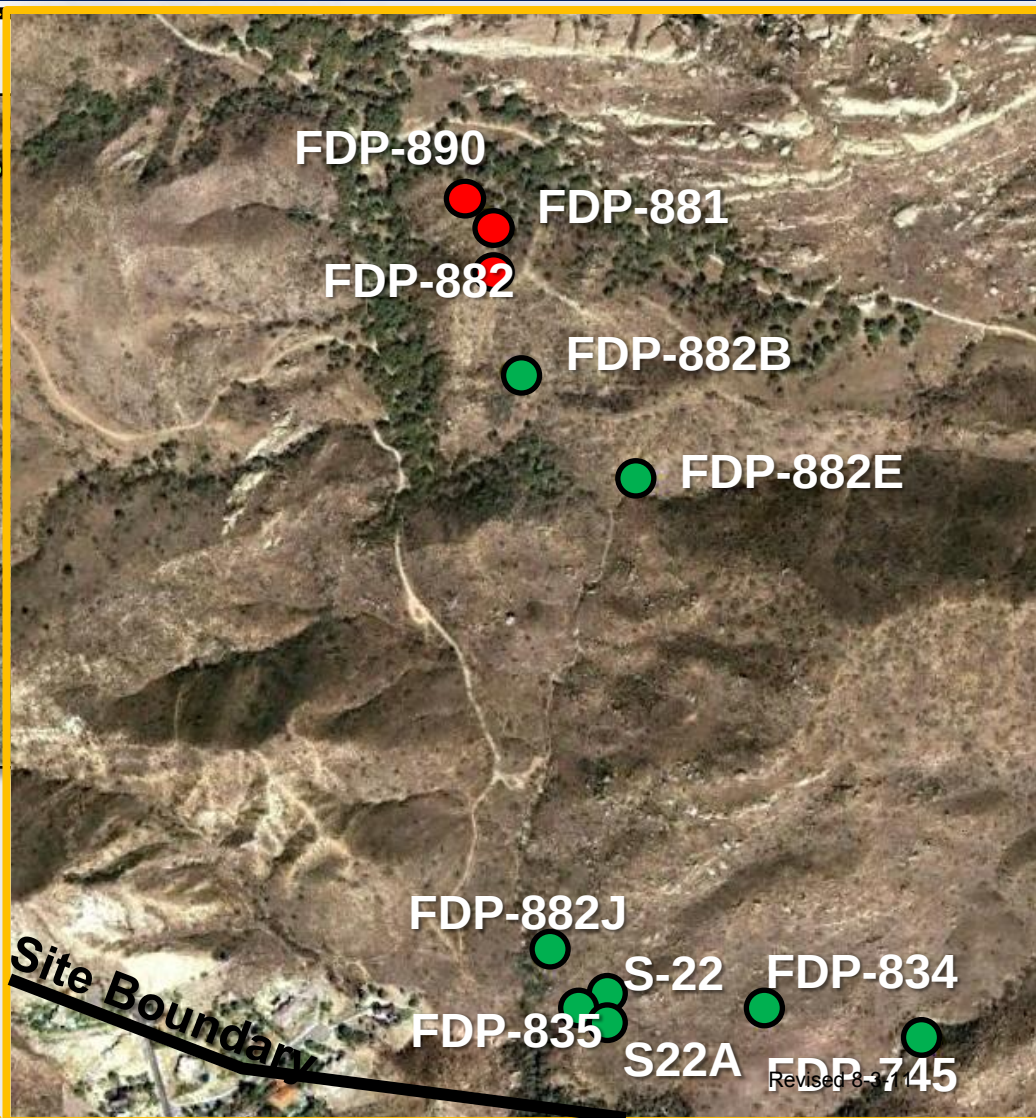
**Perspective view looking north-northeast
(blued shading TCE above drinking water)**

**On-site seeps with TCE
detections**

On-Site Contaminated Seeps in Southwest Drainage

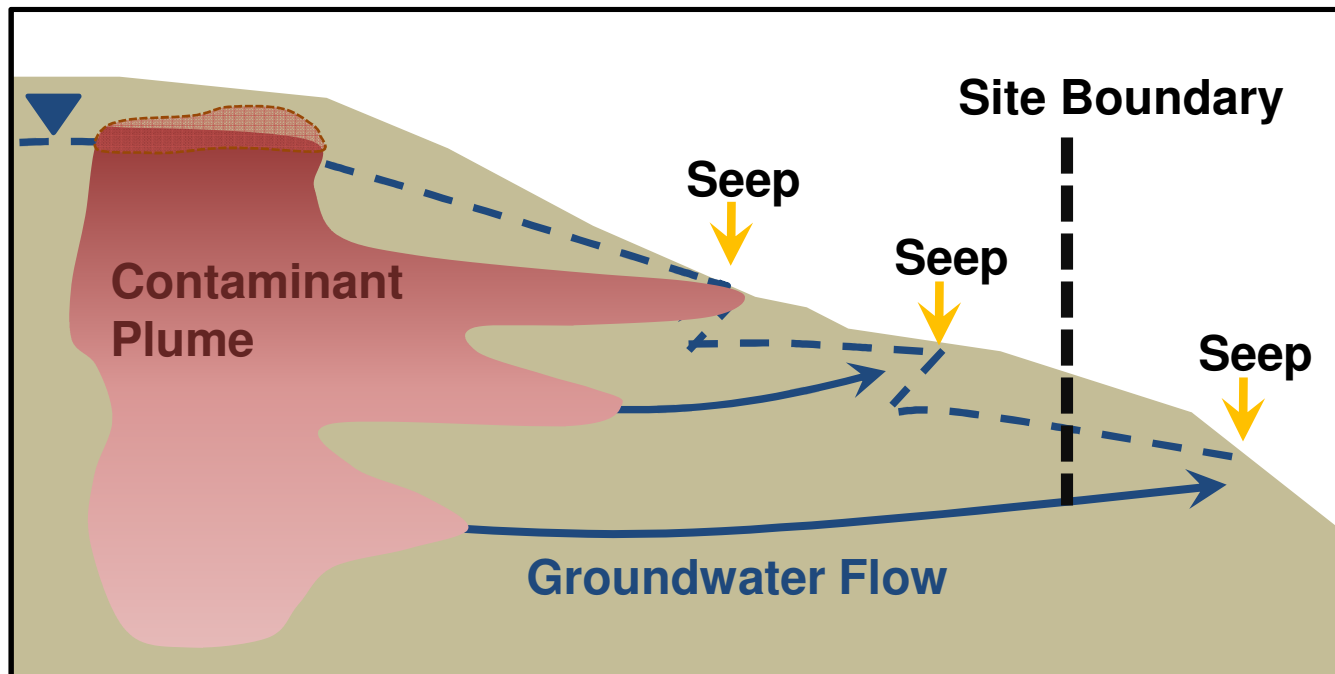


Low-level detections of TCE and degradation products at 3 on-site seeps (all below drinking water standards)

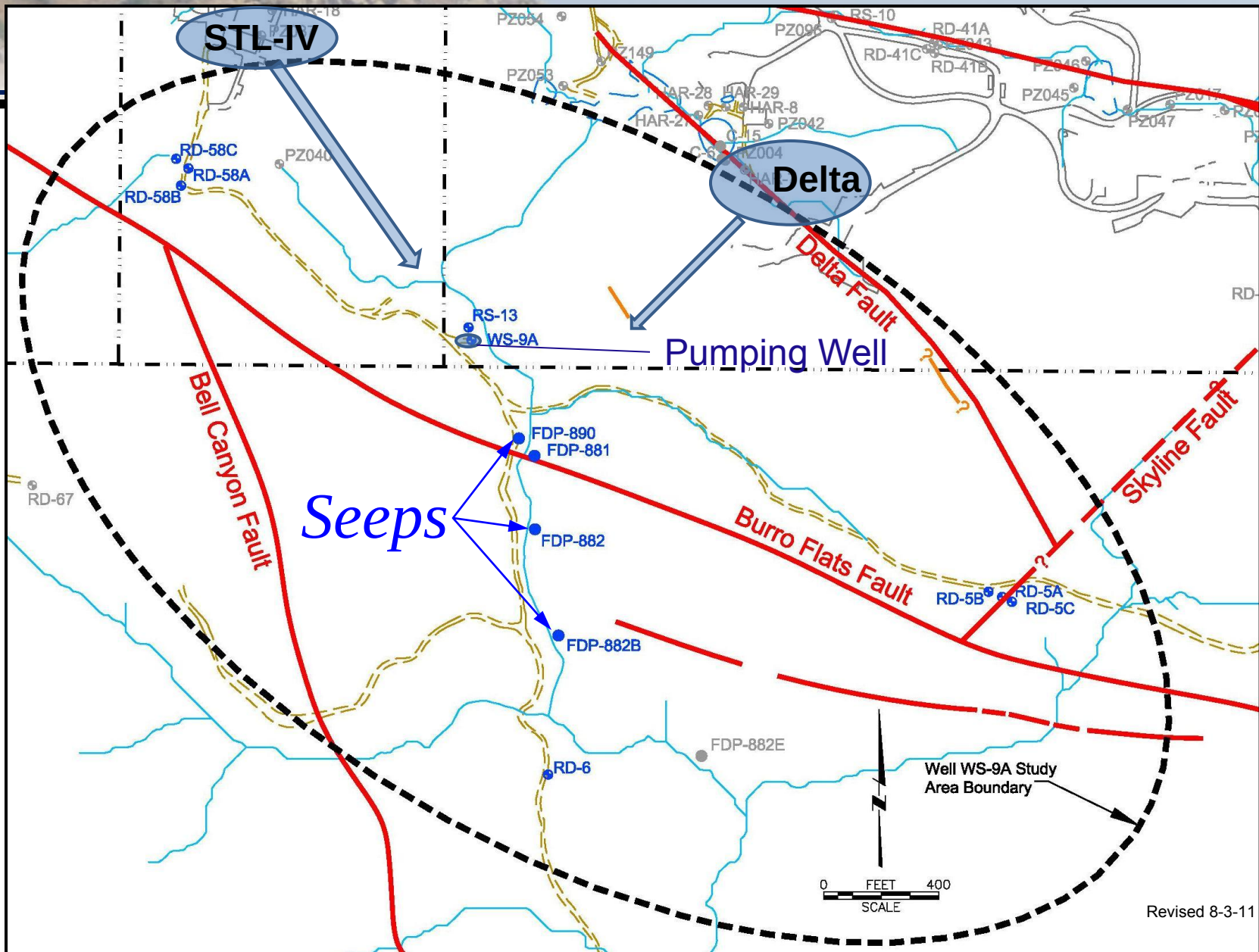


Plumes in Relation to Seeps

Seeps sampling indicates plumes have reached onsite seeps but not offsite



Southwest Drainage: Sources and Seeps



No Contaminants Detected at Off-Site Seeps

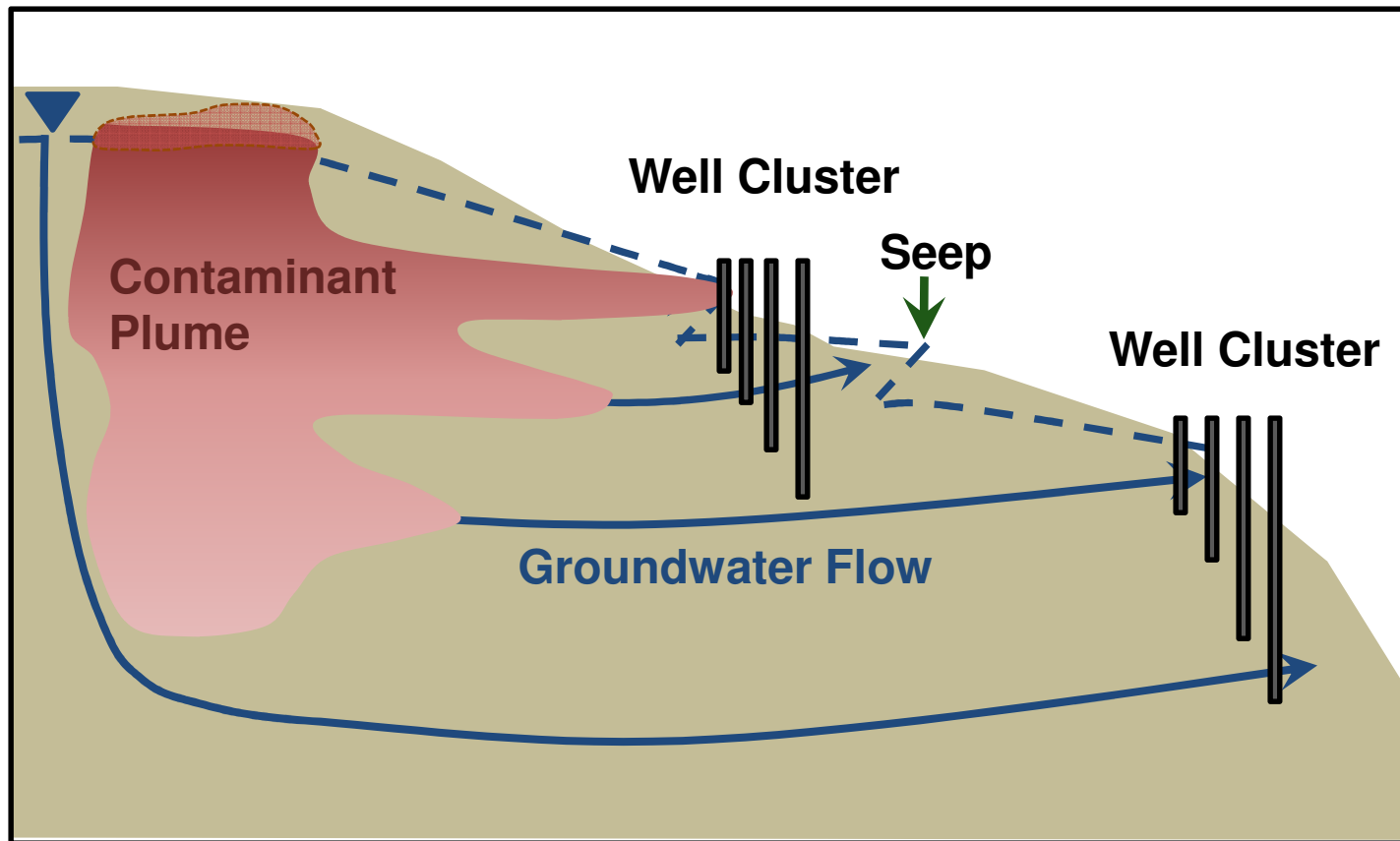
Possibilities why:

- Contaminants are not at the seep because;
 - Seep not on plume flow line
 - On plume flow line but not arrived
- Contaminants are actually at the seep but;
 - Loss due to surface volatilization at seep
 - Trapped in the mud around the seep



Have Plumes Reached Offsite Seeps?

Monitoring well clusters to sample groundwater beneath seeps



2011 Drilling at Seeps May 10, 2011





Module 4: Summary and Implications

- *No TCE in more distant seeps is expected due to plume retardation-degradation*
- *Monitoring wells being installed to confirm absence of plumes at more distant seeps*
- *Pump and treat controls the onsite contaminated seeps*

- 
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 - 4. WS9A- Southwest Drainage Study Area**
 - 5. Tritium at SSFL**
 - 6. TCE Fate Summary**
 - 7. Implications for Remediation**
 - 8. Plume Monitorability**

Tritium (^3H)

Radioactive isotope of hydrogen with a decay half-life of 12 years.

^1H is normal Hydrogen

^2H is heavy hydrogen

^3H is radioactive hydrogen

Three Nuclides of the Hydrogen Isotopes:

Protium



1 proton

Deuterium



1 proton
1 neutron

Tritium



1 proton
2 neutrons

Two Primary Functions at SSFL



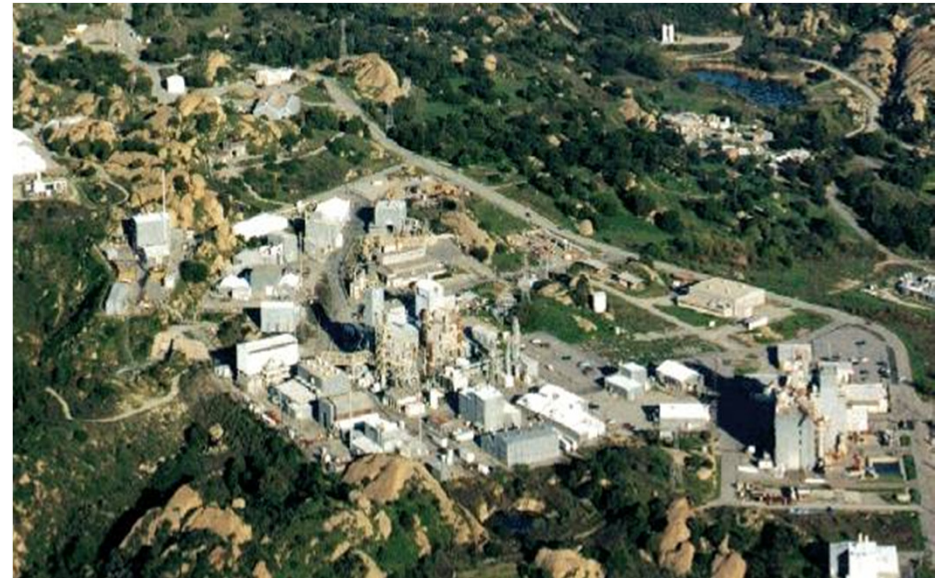
Rocket Engine Testing for NASA

- 1949-2006
- Six Test Stands – 17,000 Rocket Engine & Component Tests
- Last test March 3, 2006

Nuclear Research & Liquid Metal Research for DOE

- Nuclear Power Research: 1956-1983
- Ten reactors
- Sodium component test facilities
- DOE Program ends 1988

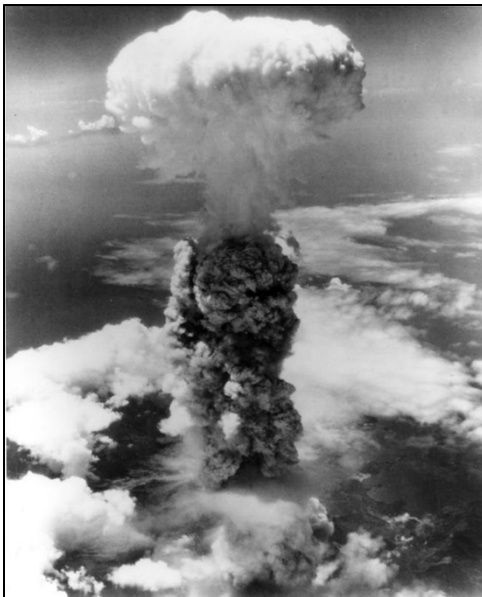
Sources of Tritium



Two Sources of Tritium in SSFL Groundwater

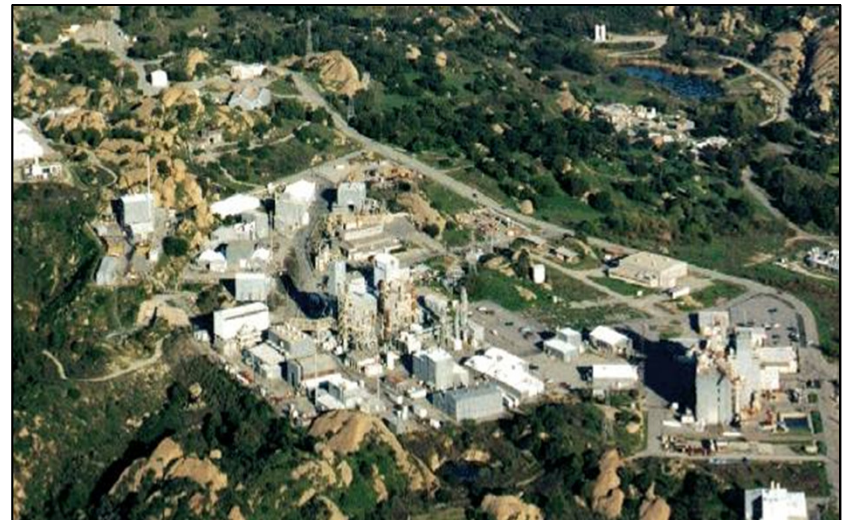
- *Rainfall*

fallout from nuclear
atmospheric tests
1950-1963



- *Nuclear Research Operations*

- Experimental nuclear reactors
- Radioactive materials used in research





Units for Radioactive Elements

Picocuries (pCi) – 2 disintegrations per minute

Tritium Unit (TU) – 1 Tritium atom in 10^{18} H atoms

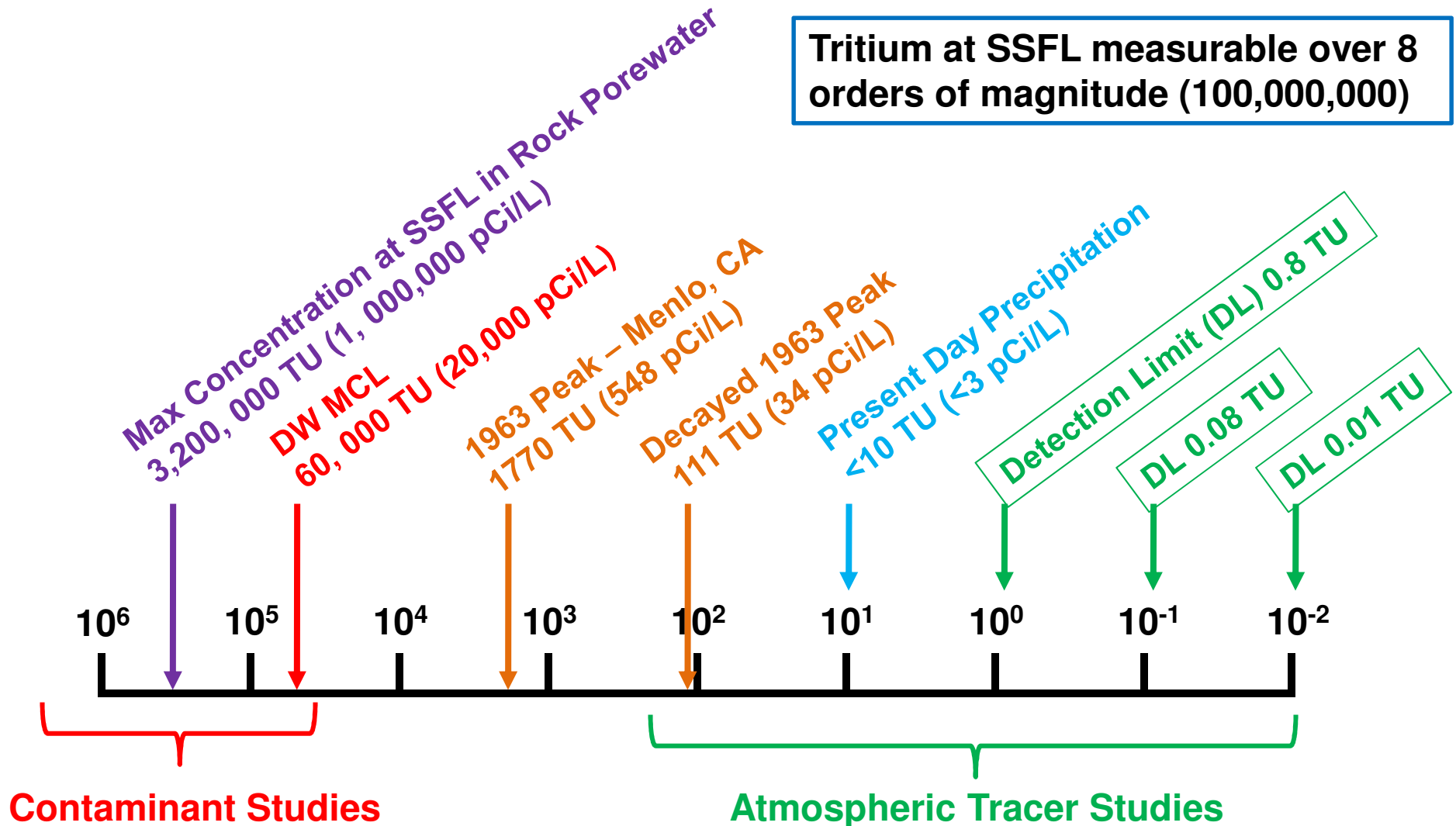
Picocuries per liter = 1 pCi/L ~ 3 TU

Maximum Concentration for
Drinking Water = 20,000 pCi/L

Lowest Detection Limit ~ 0.02 TU

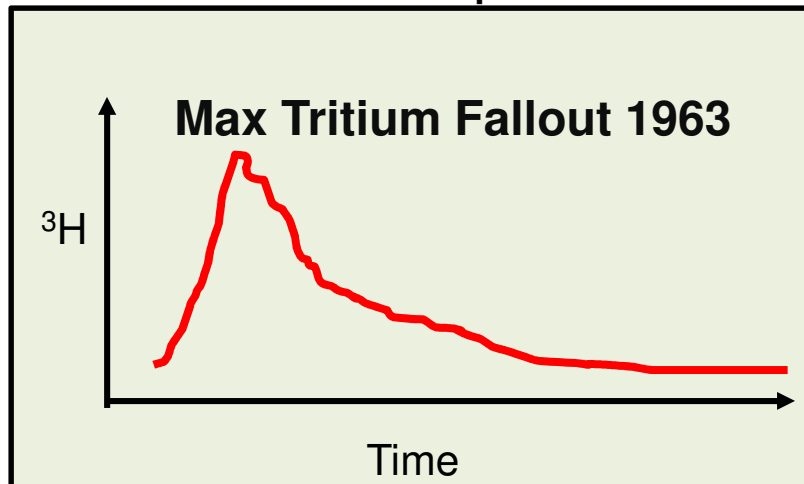
Tritium is a Sensitive Tracer of the Groundwater Flow System

Tritium at SSFL measurable over 8 orders of magnitude (100,000,000)

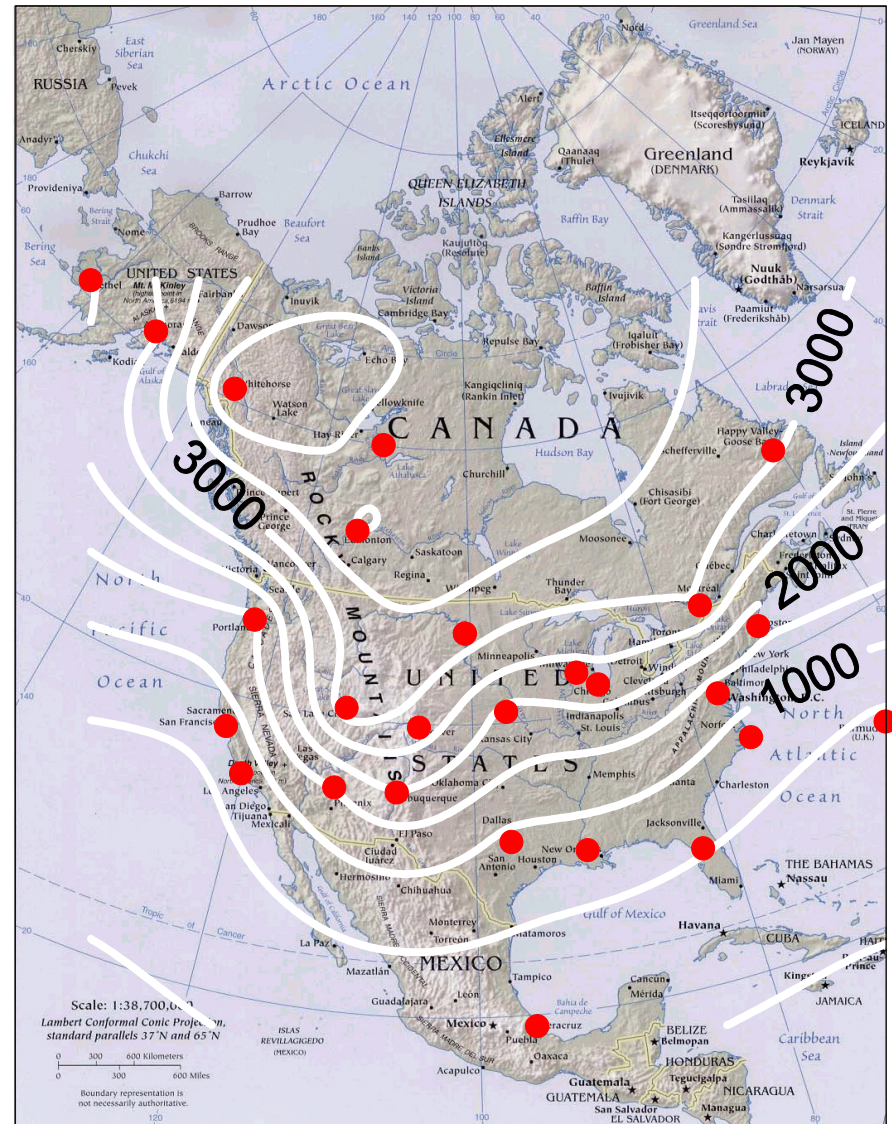


Peak tritium in Precipitation 1963:

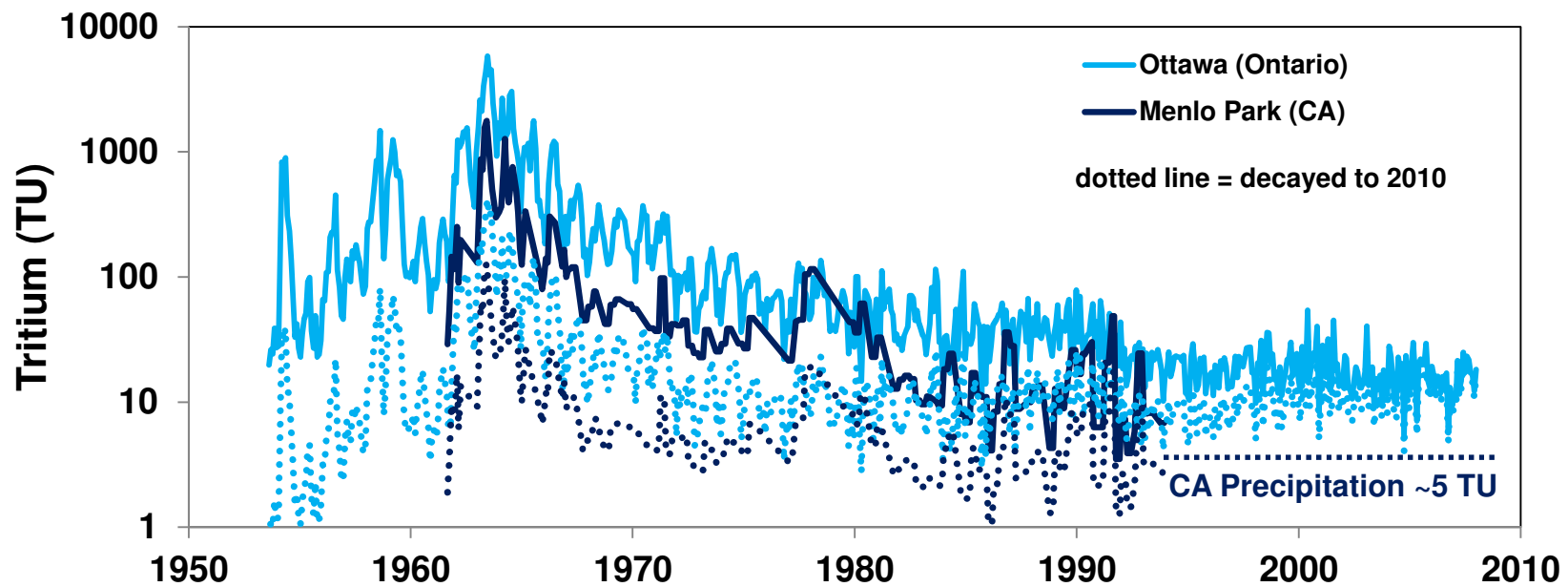
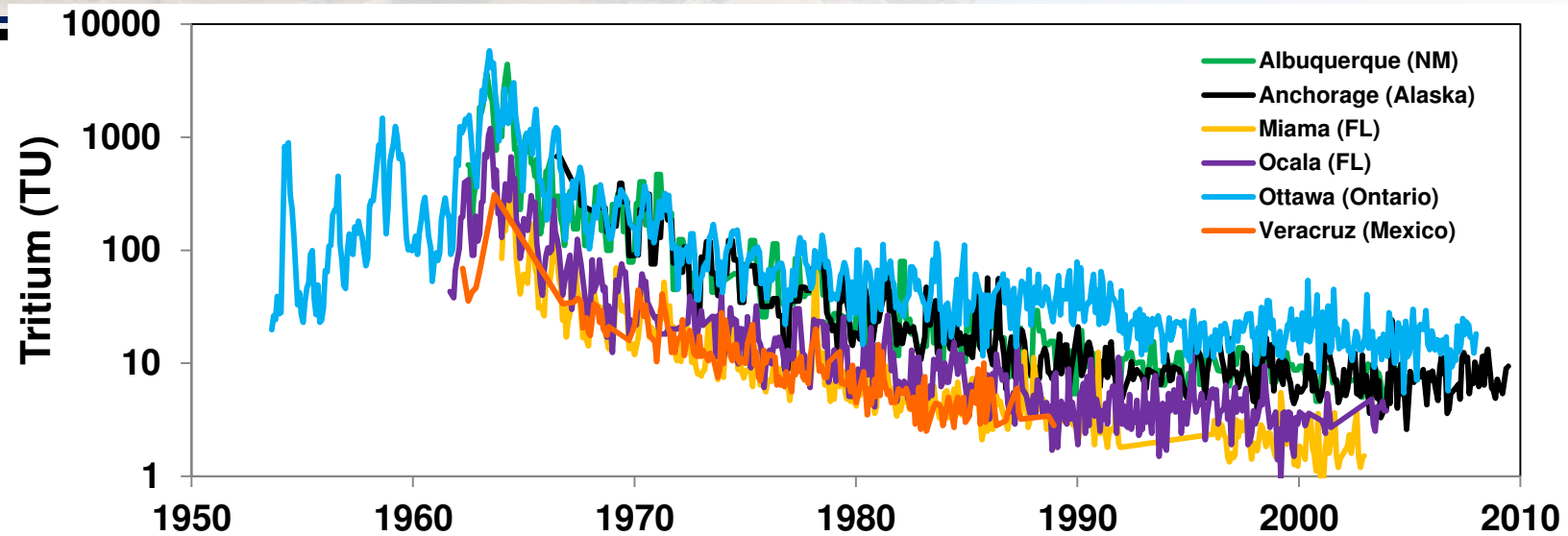
Tritium in Rain from Atmospheric Nuclear Tests



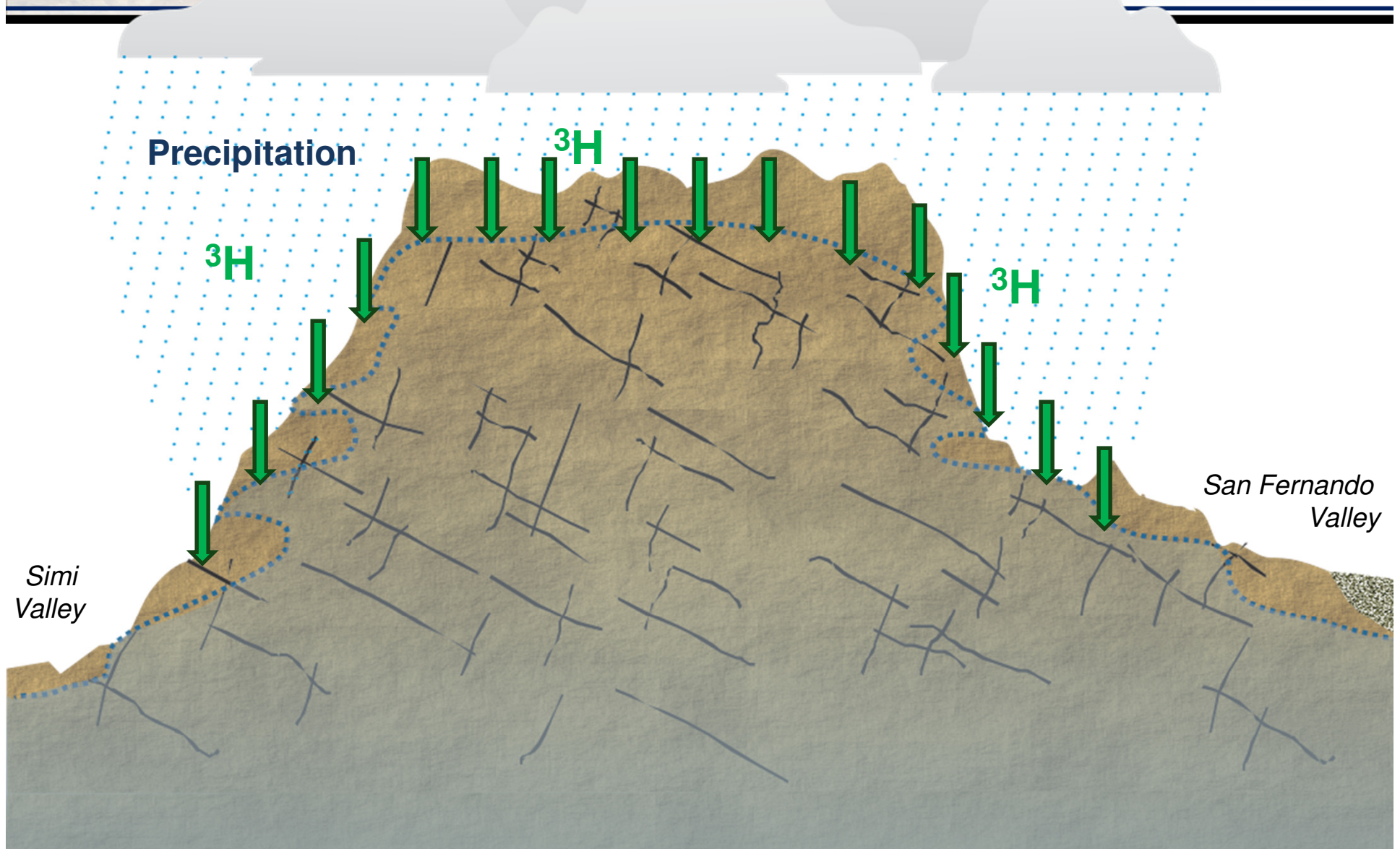
Since 1952, Tritium in rain is from atmospheric bomb tests



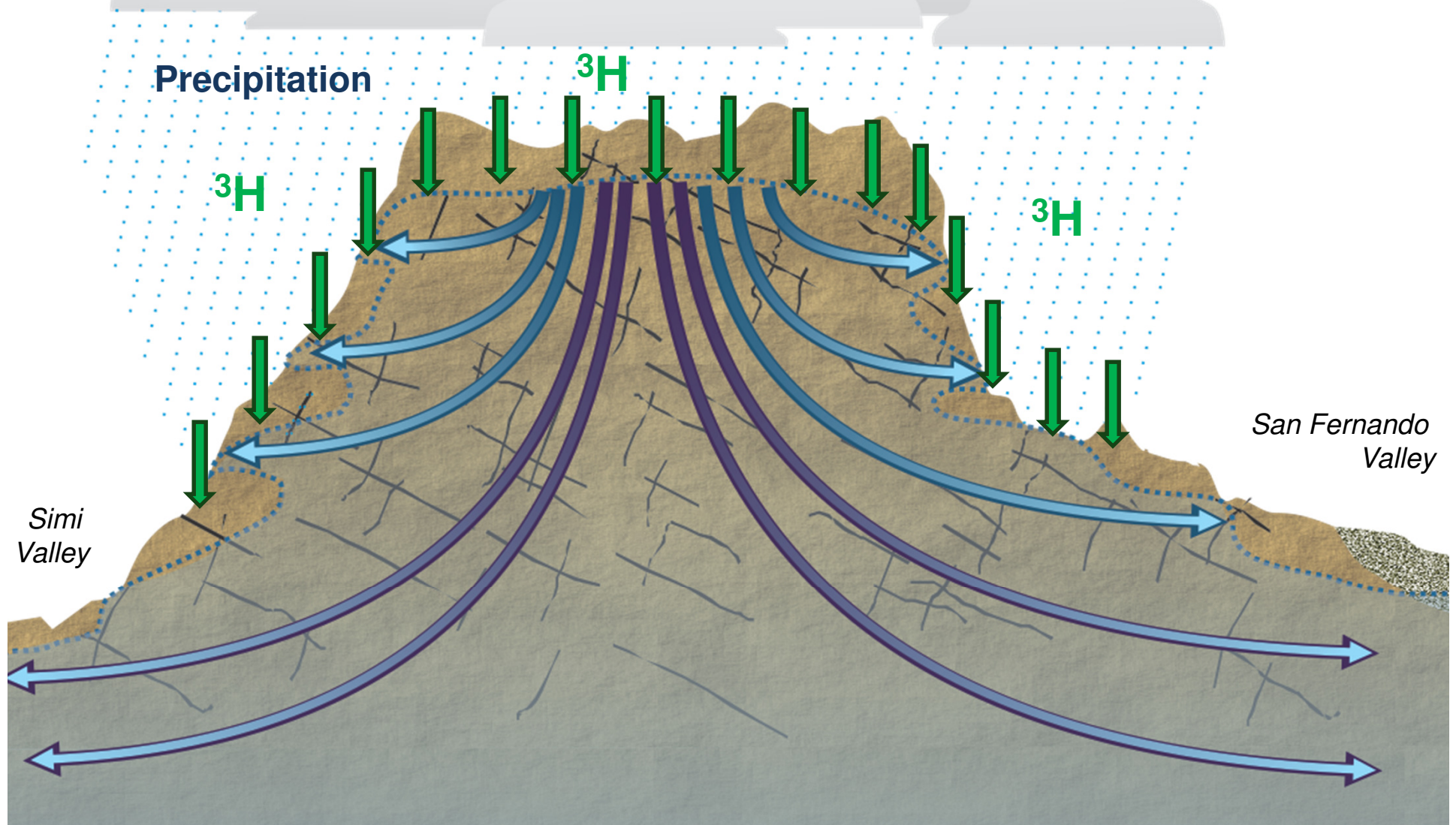
Tritium (^3H) in Precipitation



Groundwater Recharge Everywhere Contains Tritium



Tritium is Carried Along Groundwater Flowpaths



Use of Atmospheric Tritium in Groundwater Studies

- **Porous Medium**

- Provides groundwater age (up to 50 years)

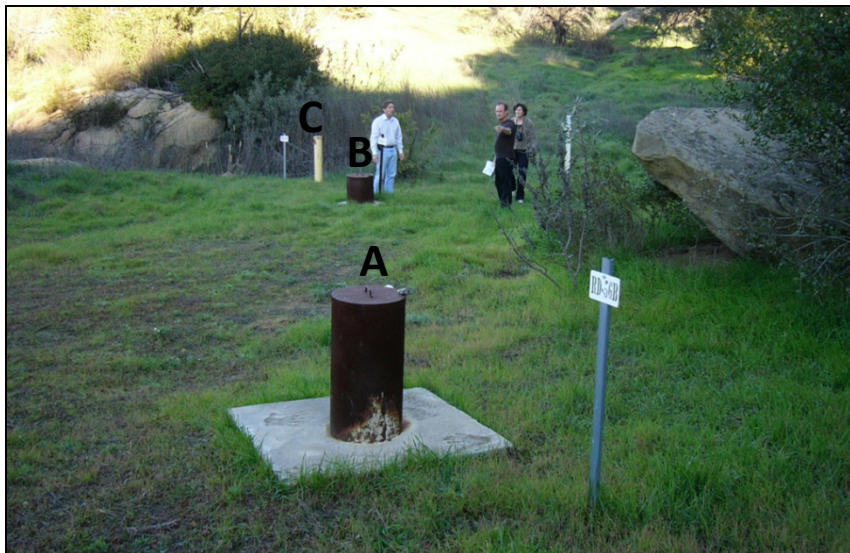
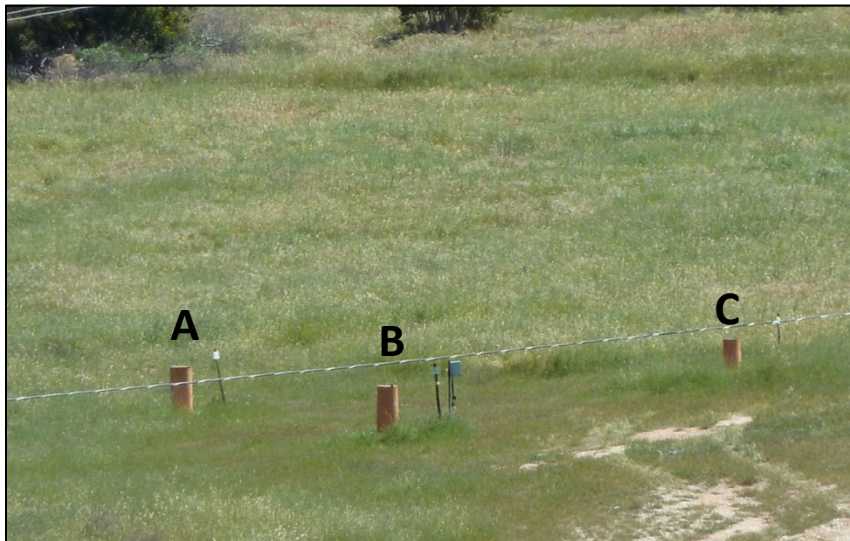


- **Fractured Rock**

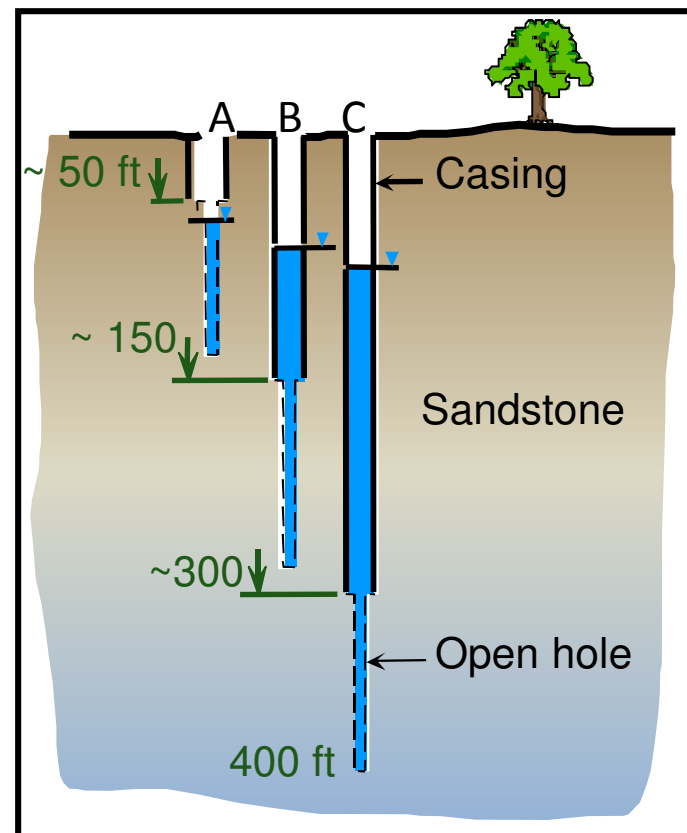
- Indicator of flow directions and matrix diffusion effects



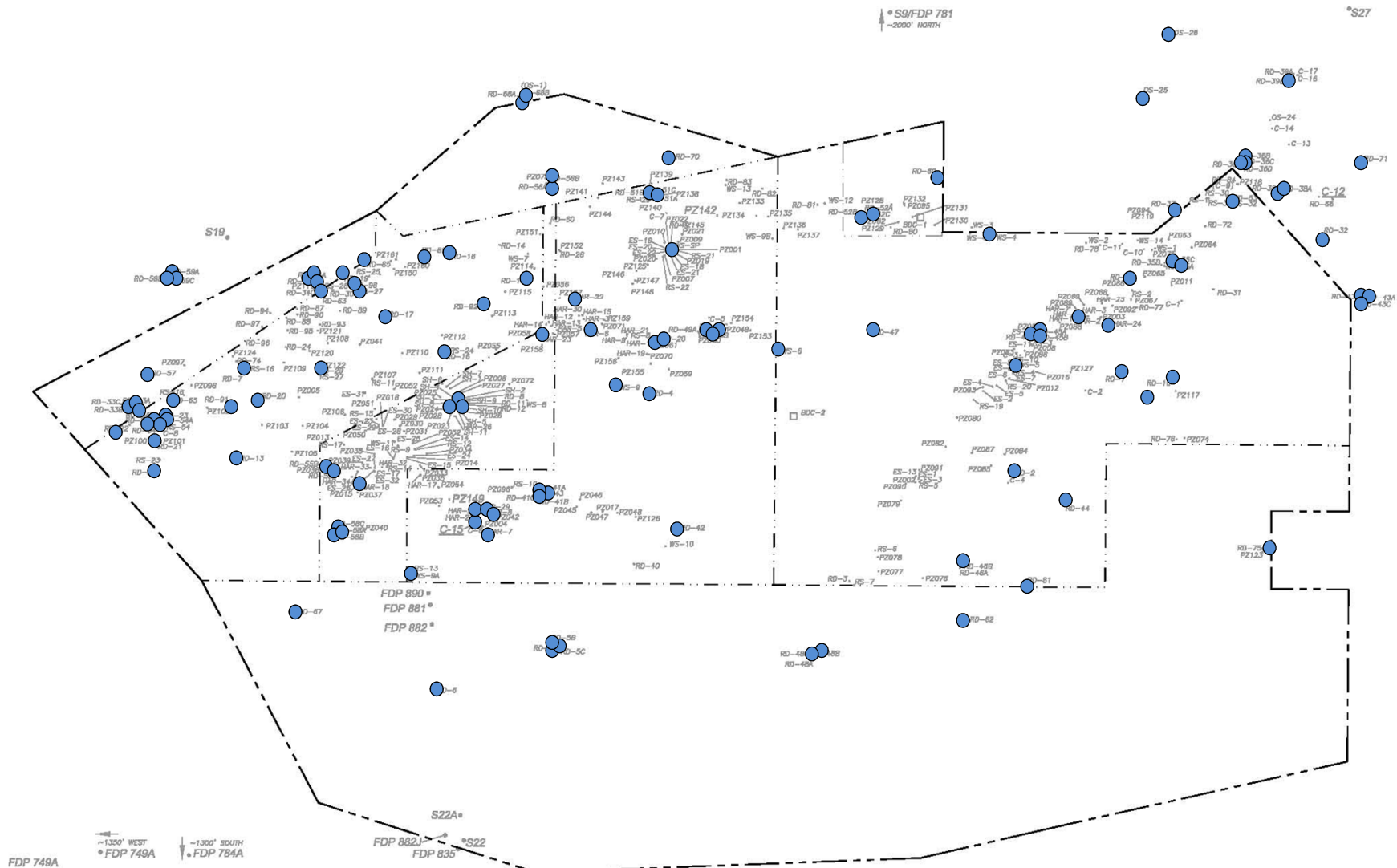
Conventional Monitoring Wells Sampled for Tritium



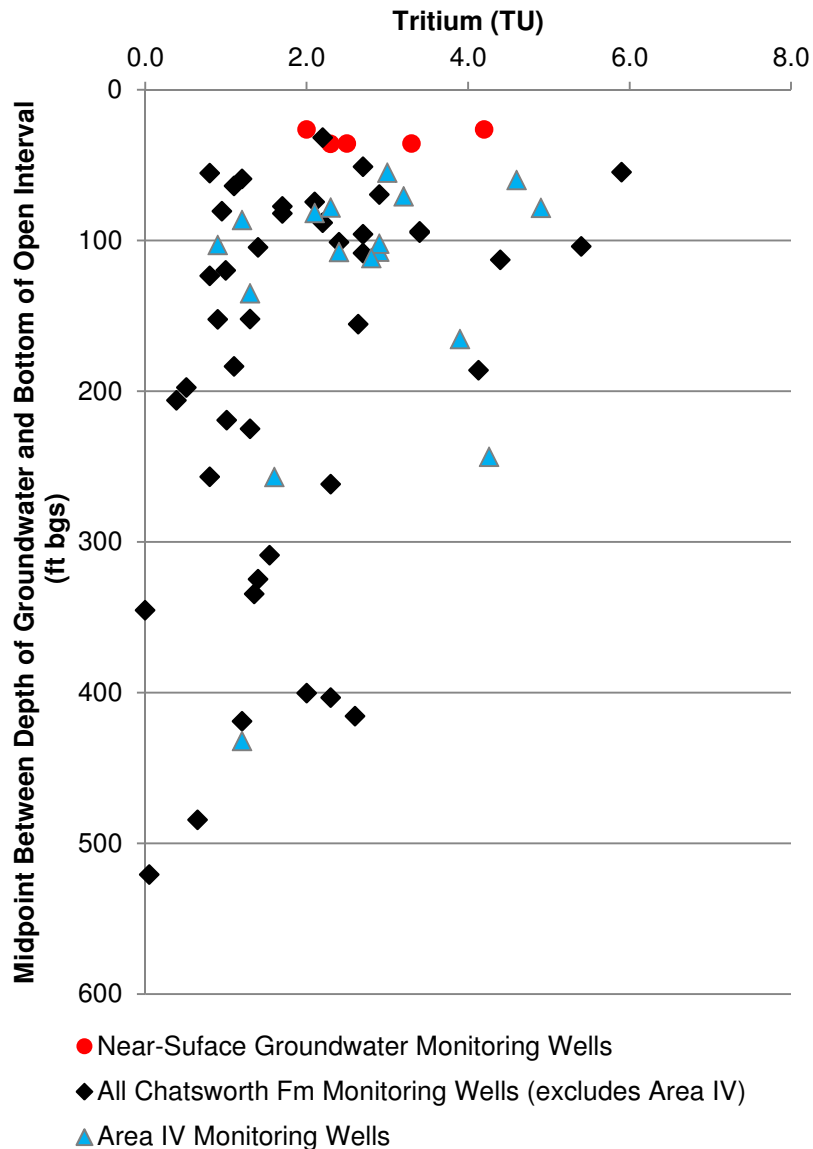
Conventional Monitoring well nest



Many Wells Sampled for Atmospheric Tritium Across the Site



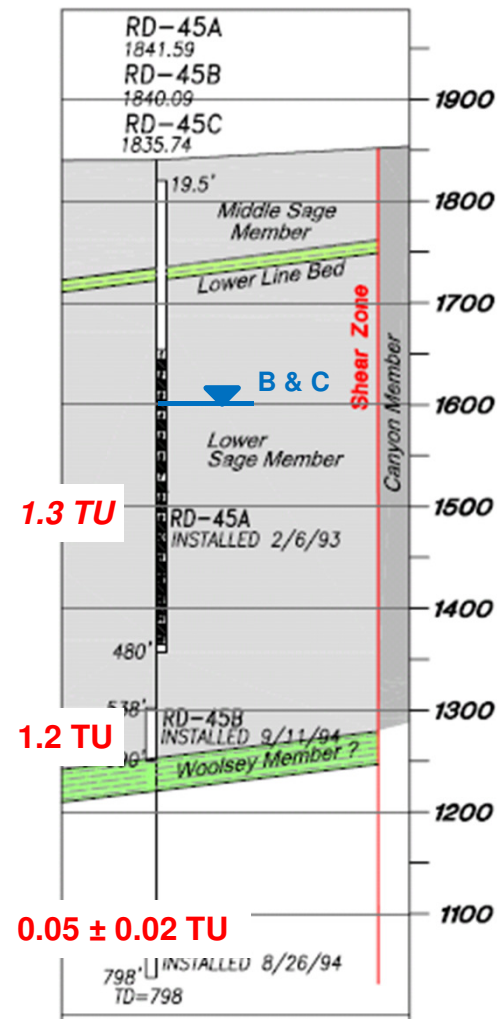
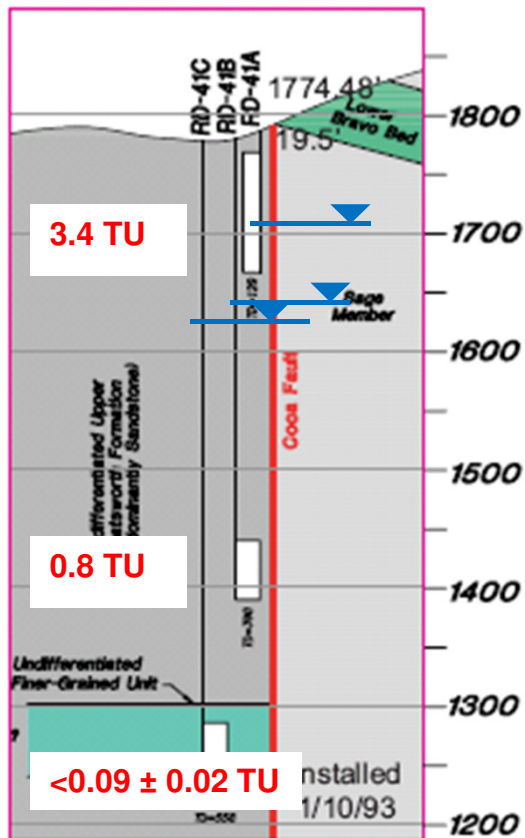
Atmospheric Tritium in Monitoring Wells Decreases with Depth



- Present day tritium in CA ~ 5-10 TU
- Samples collected in 2007 through 2009 and historical values (1987 – 1998), adjusted for radioactive decay

Tritium Decreases with Depth

Example from two cluster well locations

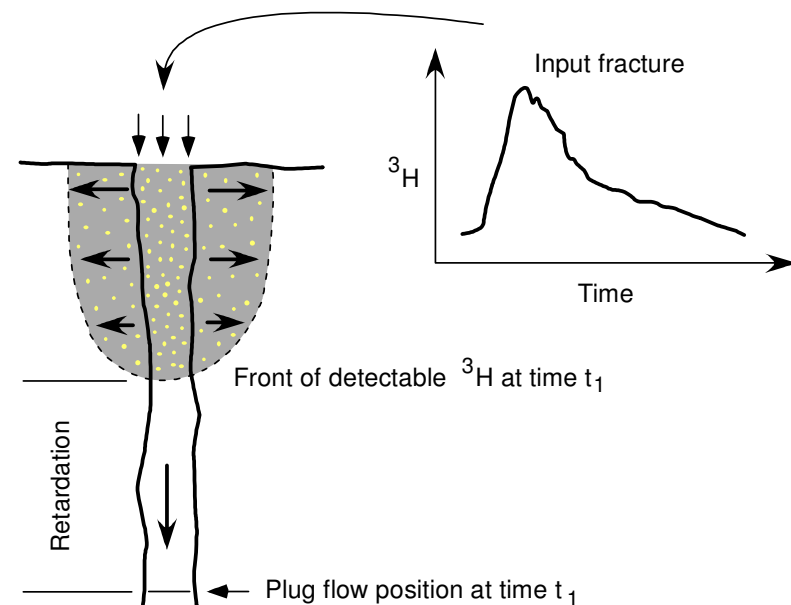


Atmospheric Tritium Summary

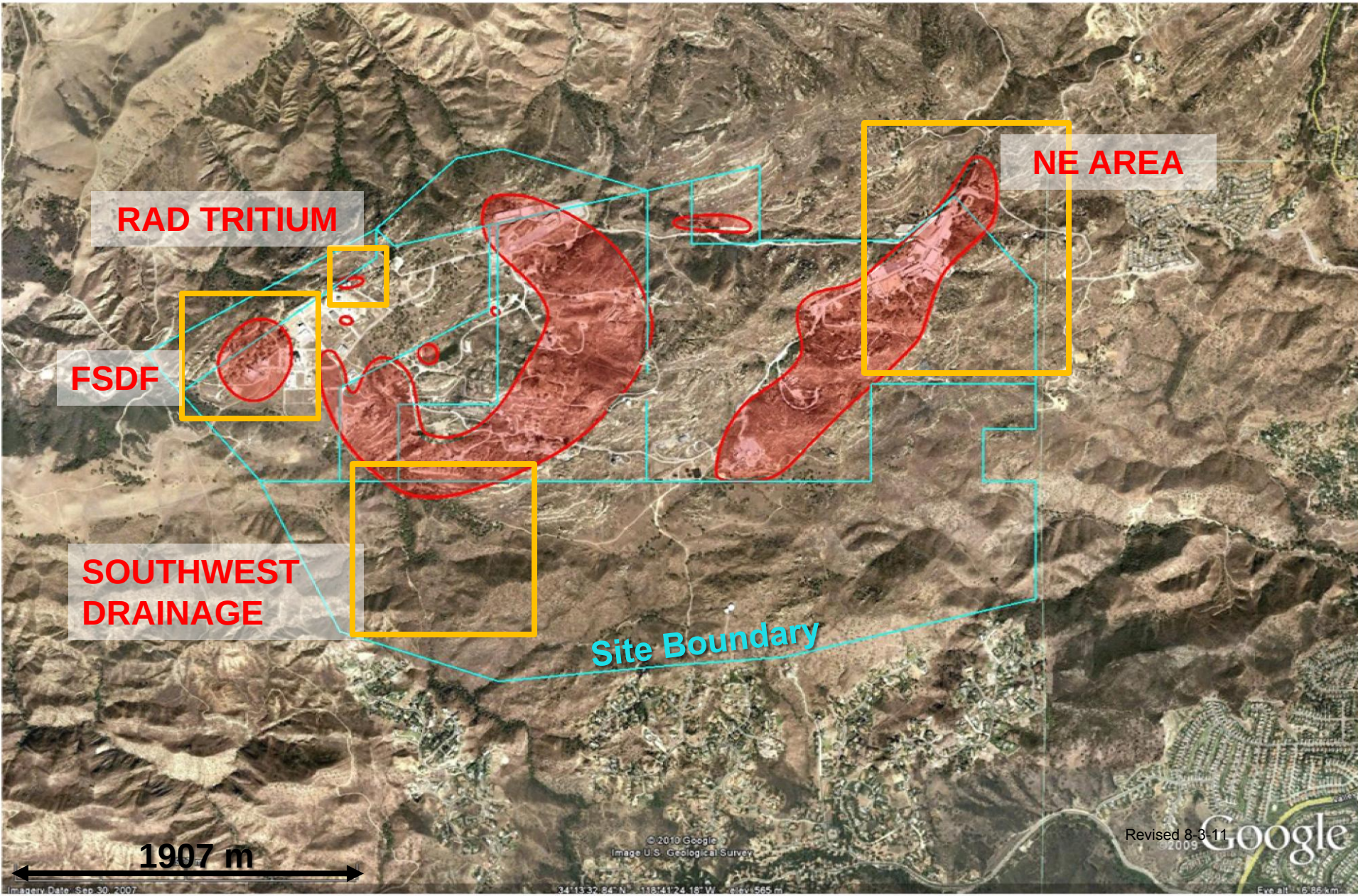
Atmospheric tritium is used as a tracer to tell us how far dissolved contaminants can travel in 50 years

Atmospheric tritium has not migrated far due to matrix diffusion

^3H transport down a simple fracture

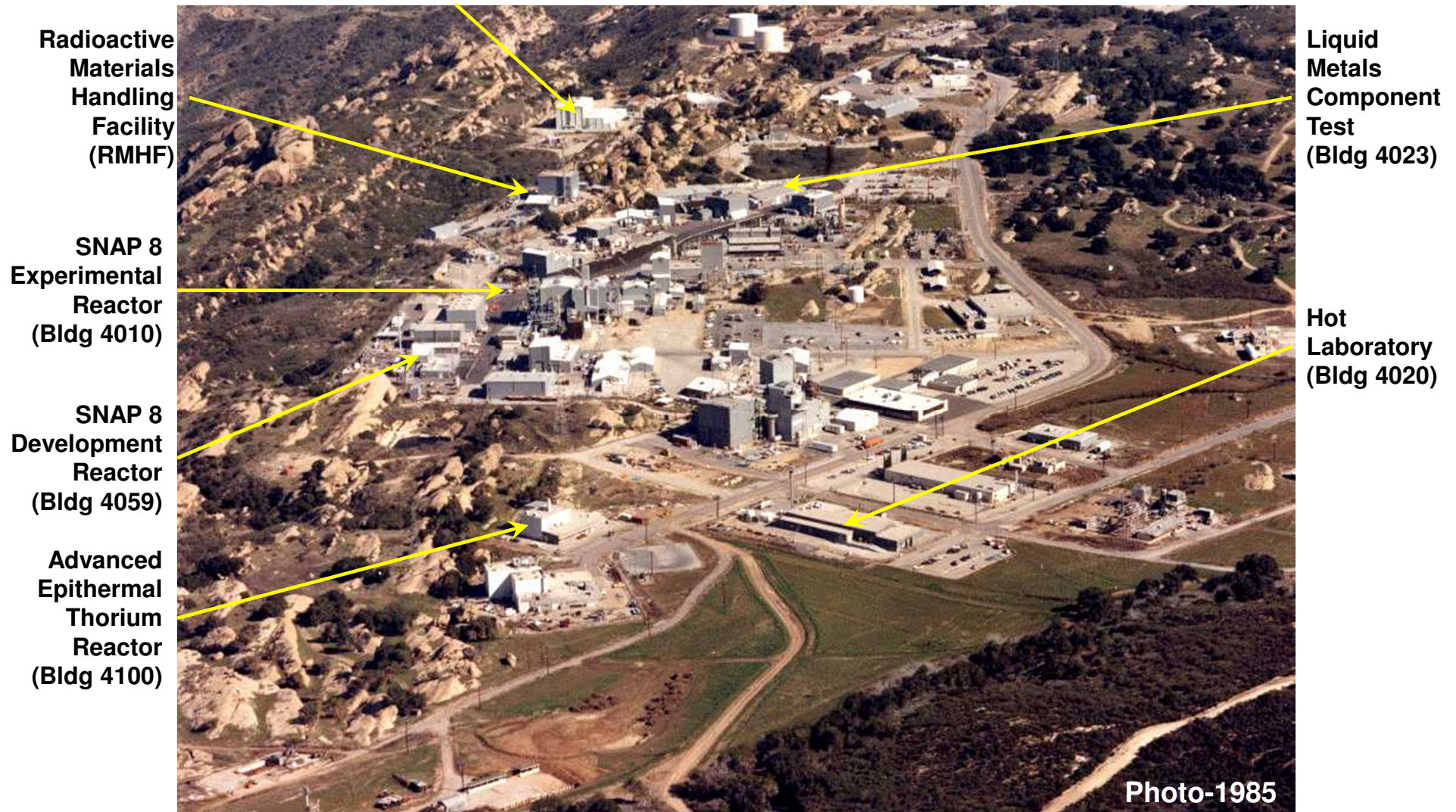


SSFL Groundwater Contamination

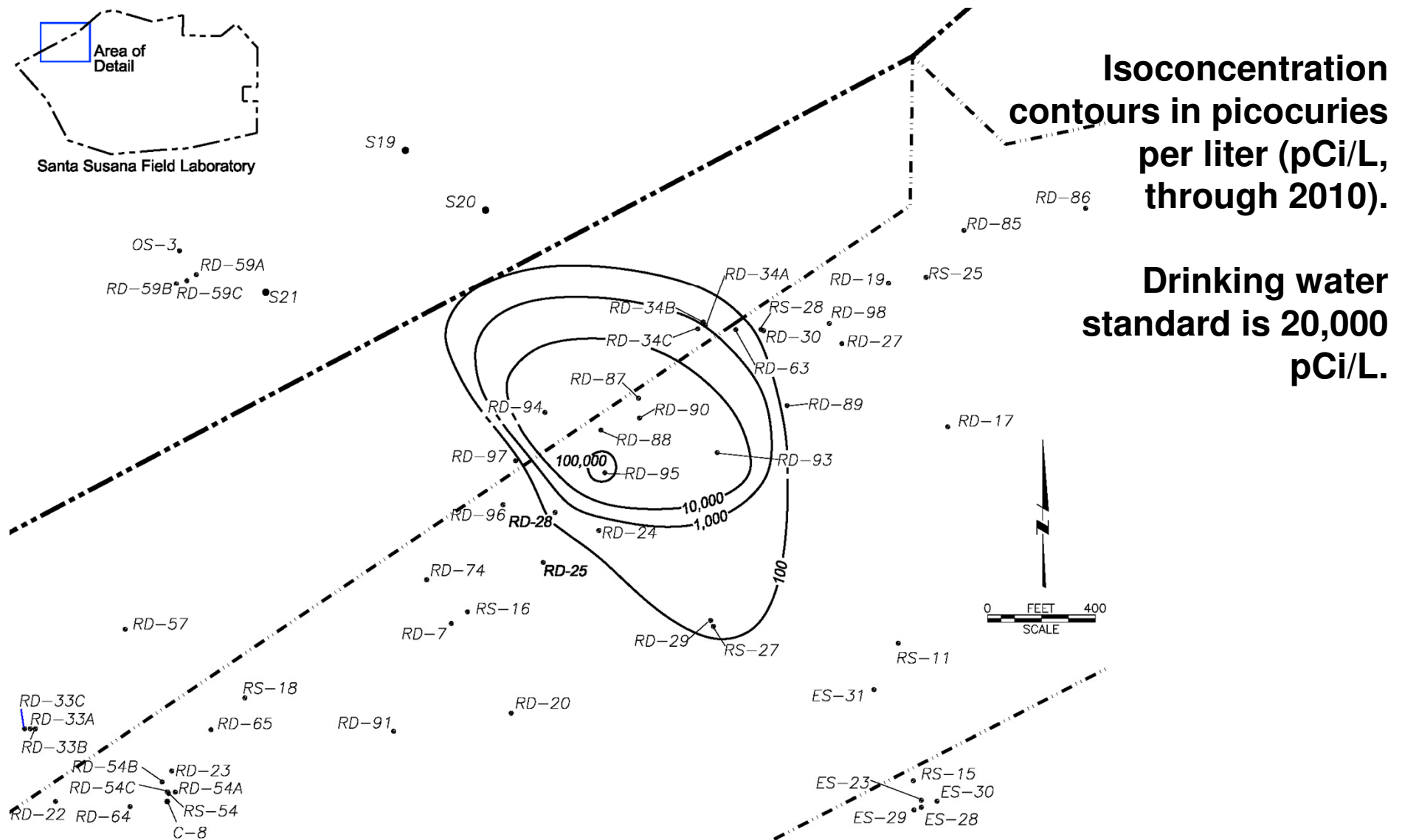


Former Nuclear-related Facilities in Area IV

Sodium Reactor Experiment

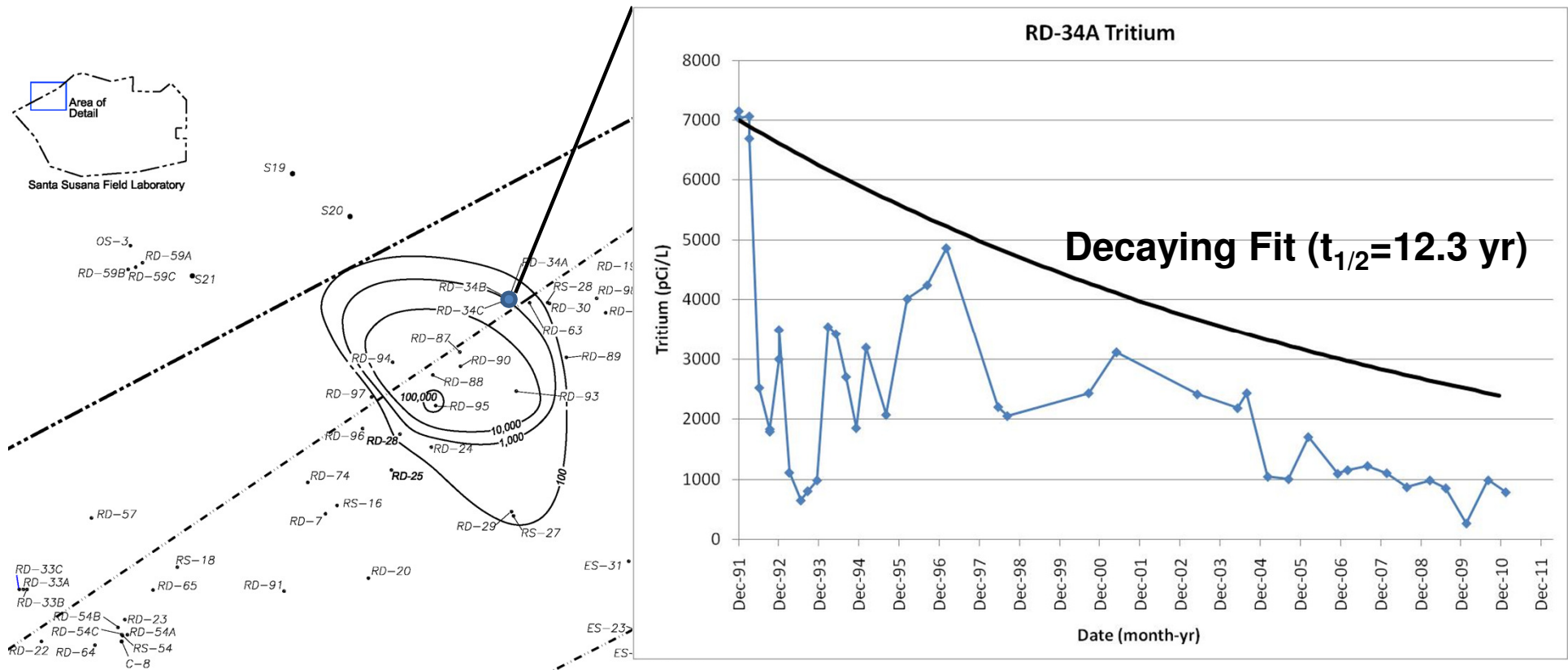


Site-Related Tritium in Groundwater Well Samples

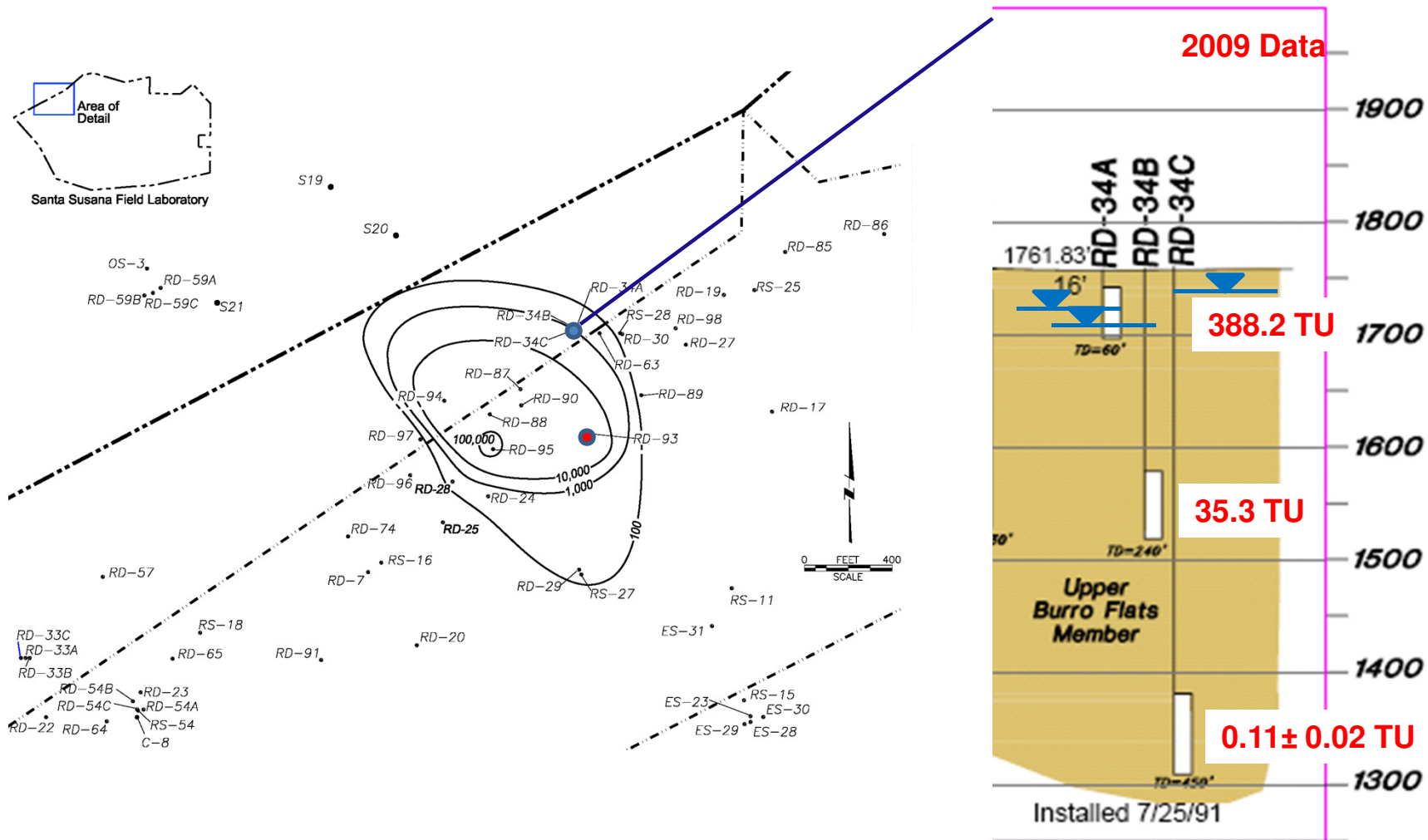


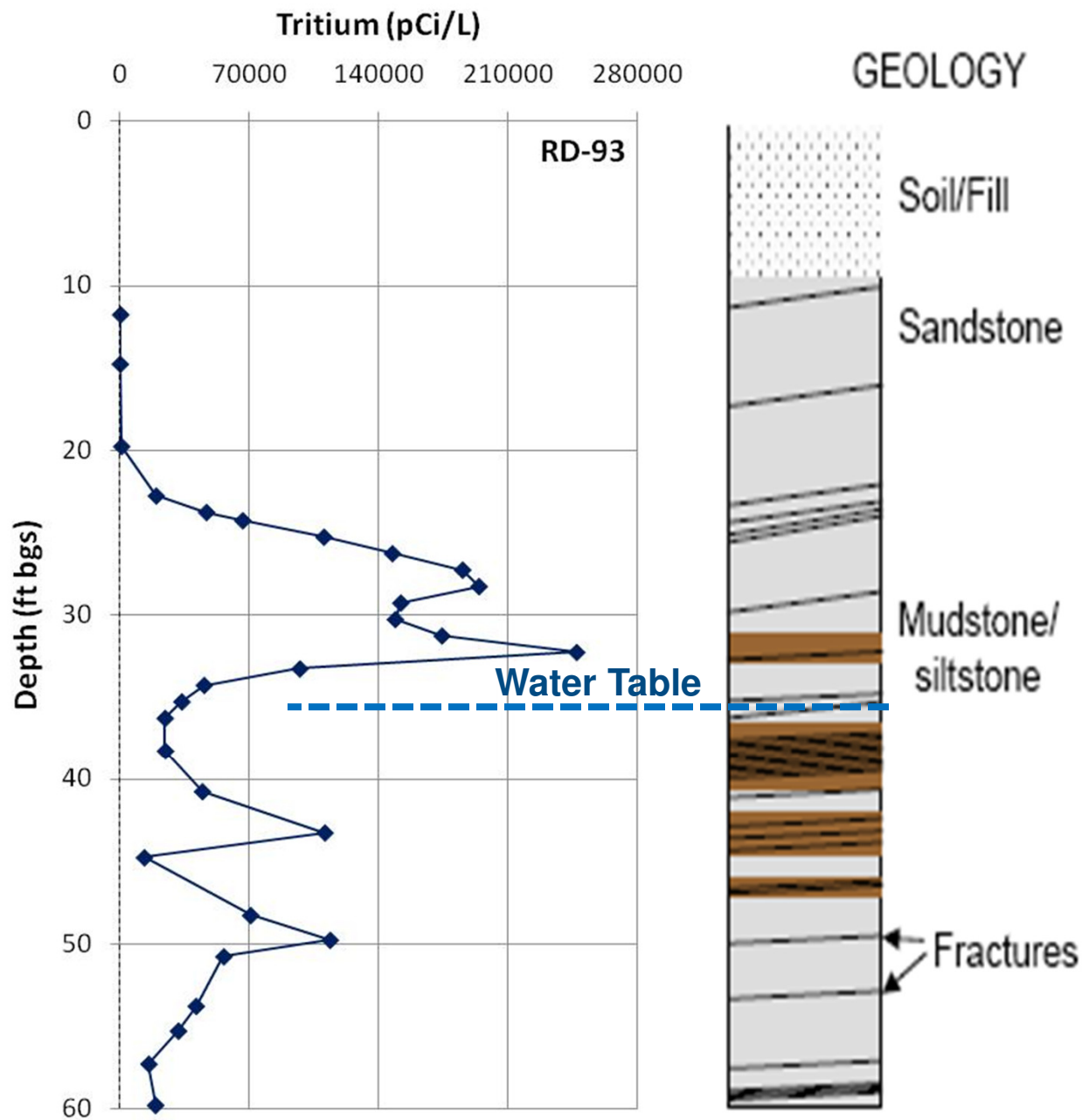
Tritium Concentrations Over Time

Impacted Monitoring Well Long-Term Tritium

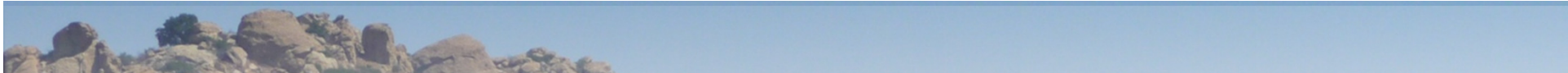


Example of SSFL Tritium in Monitoring Well Cluster

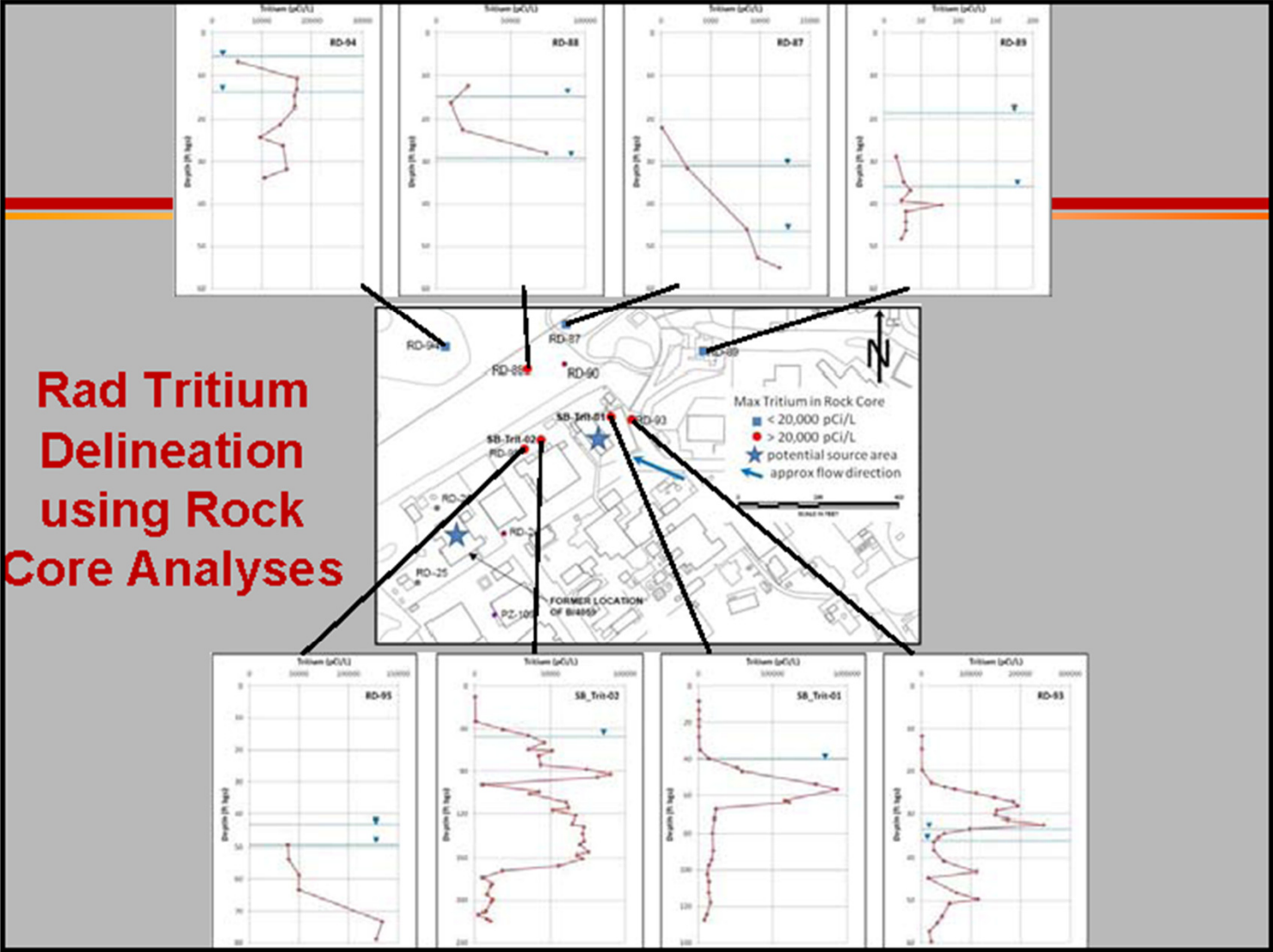




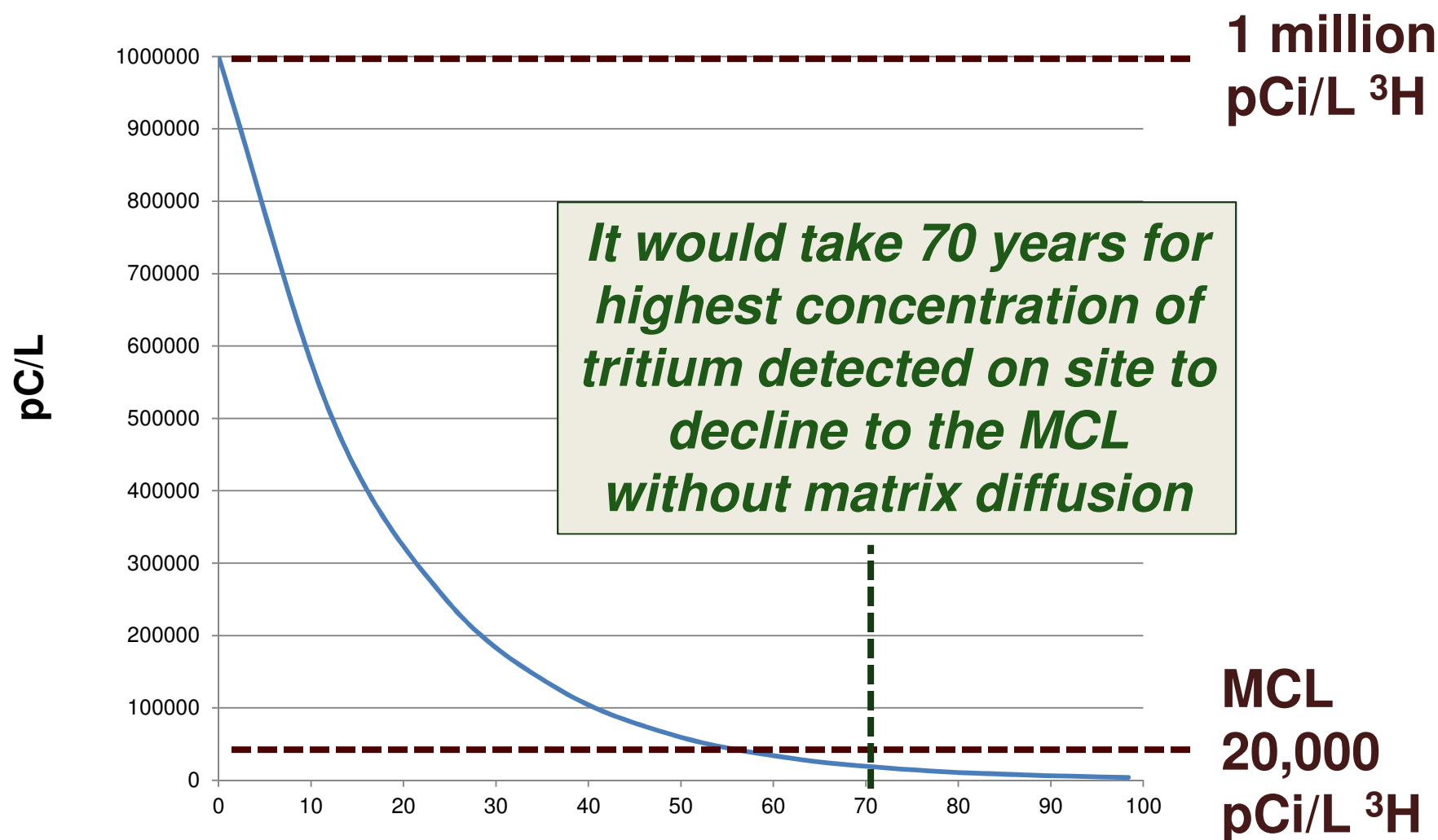
Tritium Diffused into Rock Matrix



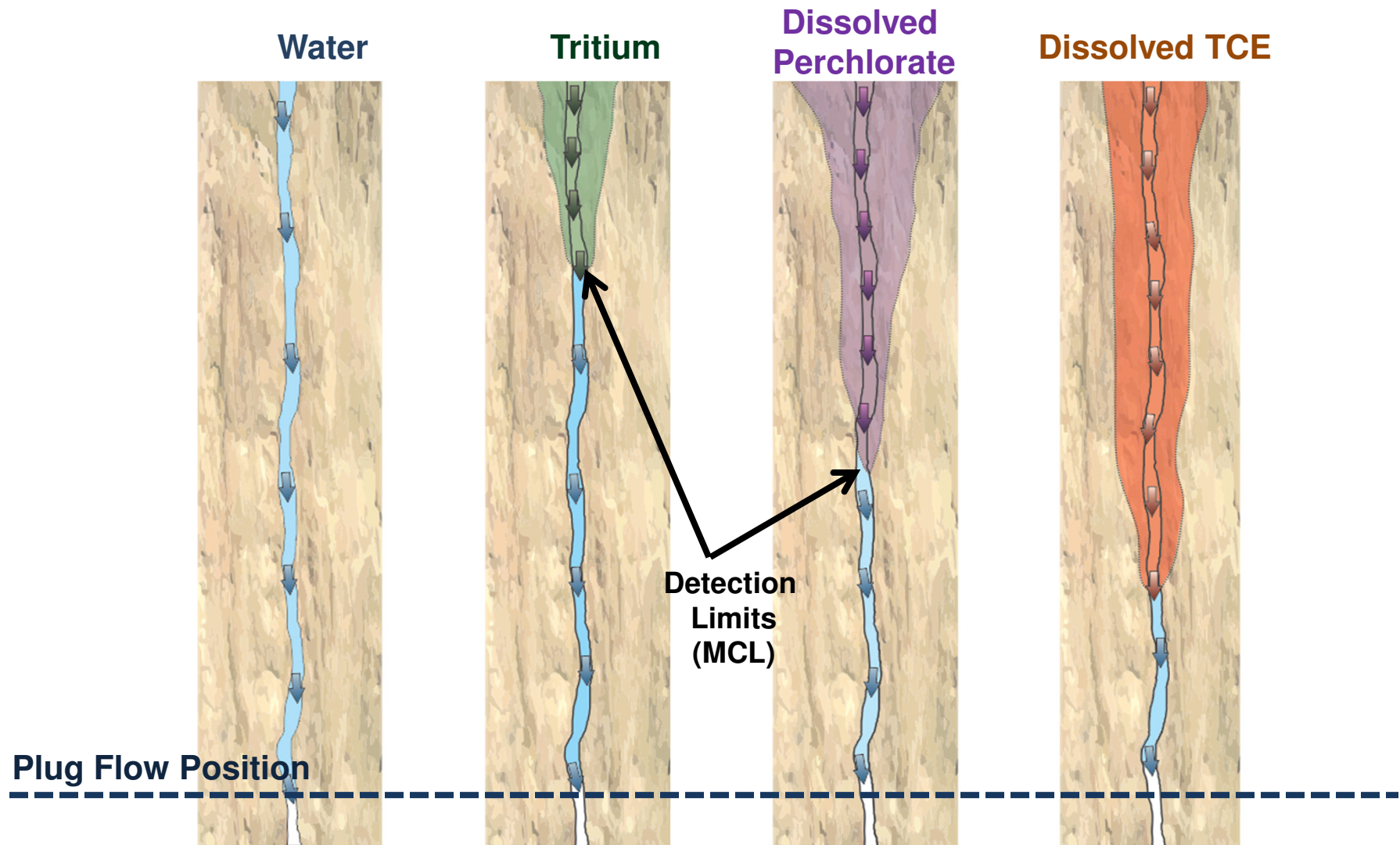
Tritium Rock Core Profiles



Radioactive Decay is a Strong Process



Aqueous Contaminant Movement in Fractures



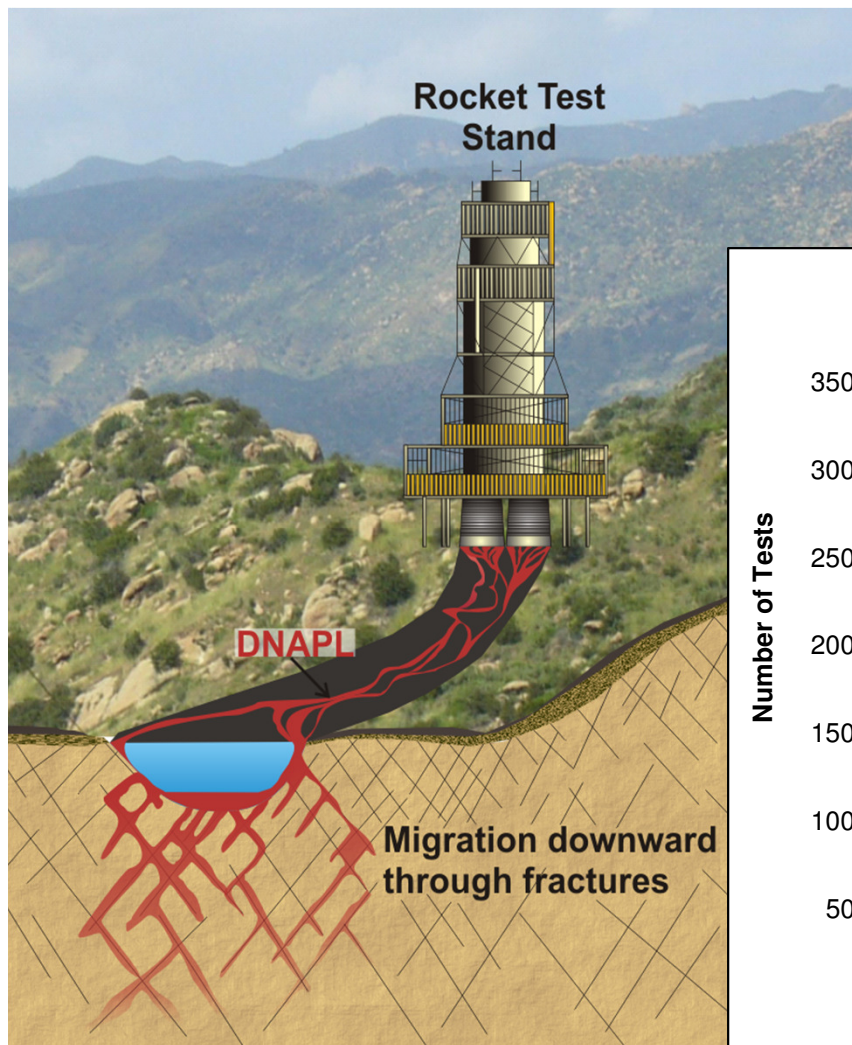


Module 5: Summary and Implications

- *Atmospheric tritium is an excellent tracer for dissolved contaminant transport by SSFL groundwater*
- *SSFL tritium contamination from nuclear operations shows a small plume consistent with lower permeability and strong matrix diffusion*

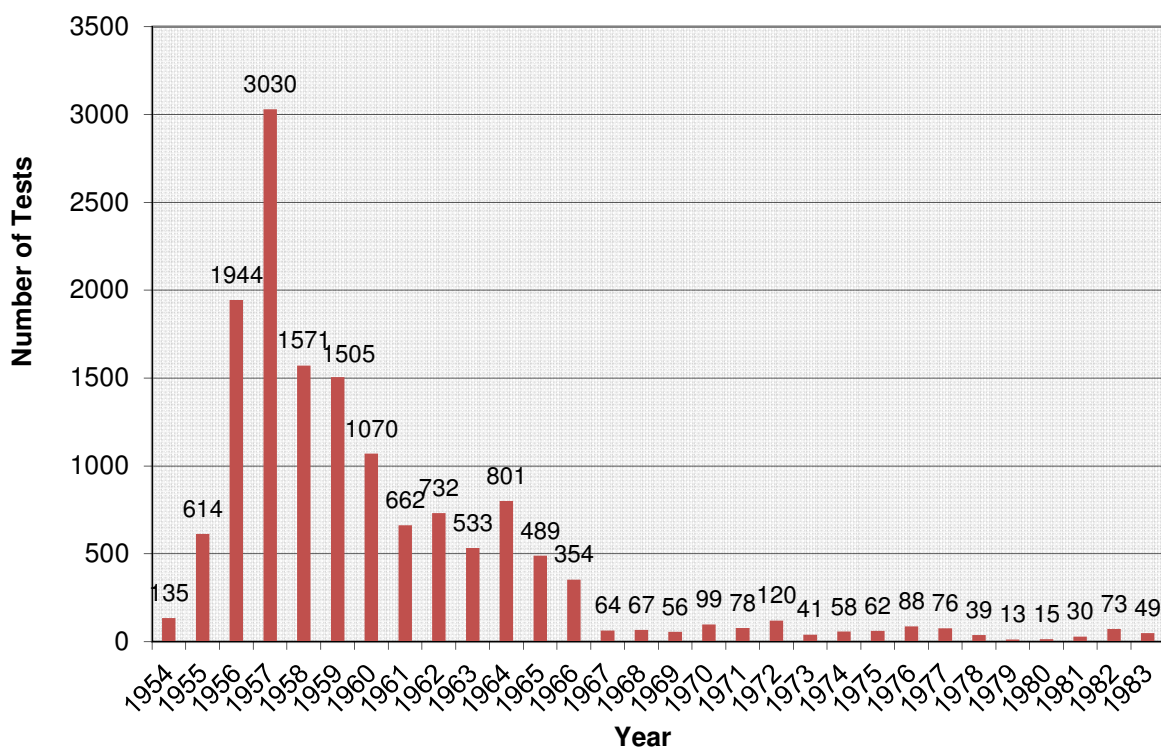
- 
- 1. The Scientific Method Applied at SSFL**
 - 2. Chlorinated Solvents Degradation**
 - 3. The Former Sodium Disposal Facility (FSDF) Area**
 - 4. WS9A- Southwest Drainage Study Area**
 - 5. Tritium at SSFL**
 - 6. TCE Fate Summary**
 - 7. Implications for Remediation**
 - 8. Plume Monitorability**

Much TCE DNAPL Went into the Ground – What Happened to it?



CH2M Hill Estimate (1993) ~ 500,000 gallons

**Rocket Engine Tests at Stands
1954 - 1983**



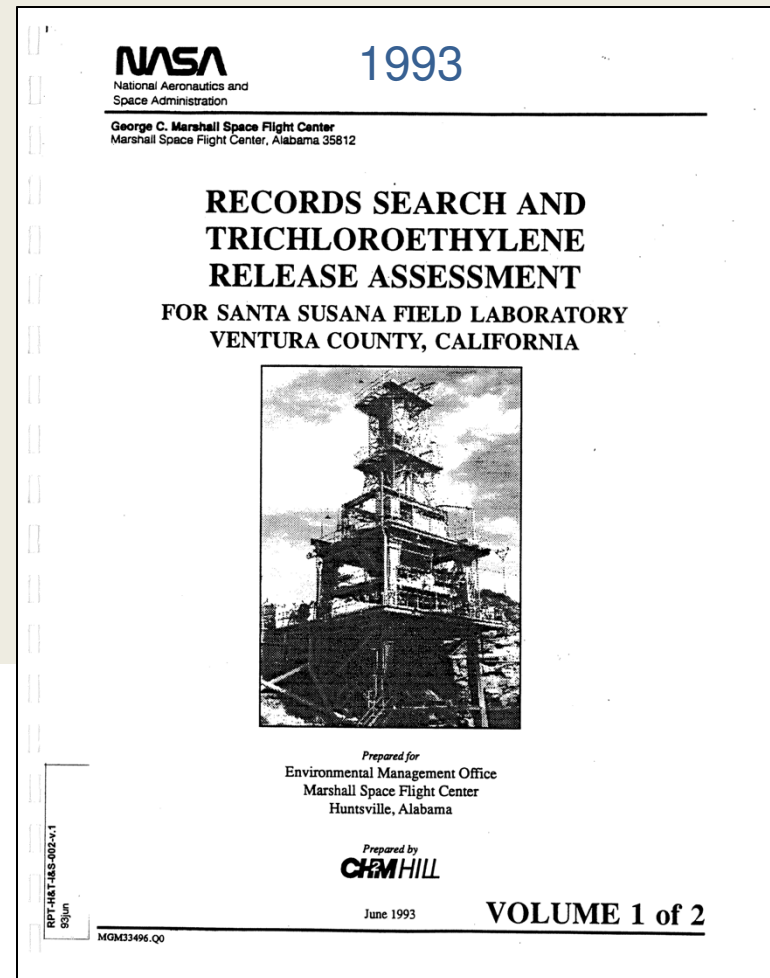
Estimates of TCE Released to Ground (1955-1984)

530,400 Gallons

9,643 drums



~ 95% used between 1955 to 1966





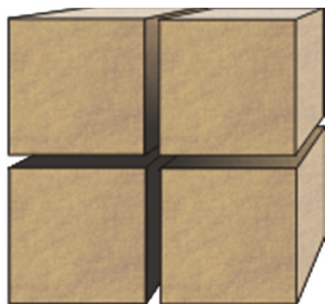
Can the Sandstone Beneath SSFL Accommodate this DNAPL?

Two Calculations:

1. Assume that DNAPL goes into the fractures without dissolving
2. Assume that the DNAPL dissolves completely and then resides as dissolved and sorbed mass in the rock matrix

How Much Chatsworth Rock Is Required To Accommodate 500,000 gal of TCE DNAPL

Cubic Matrix Blocks



Fracture Porosity = $3\epsilon/L$

Fracture Spacing : 1 meter
Fracture Aperture: 100 microns
Footprint of DNAPL Release : 10 acres

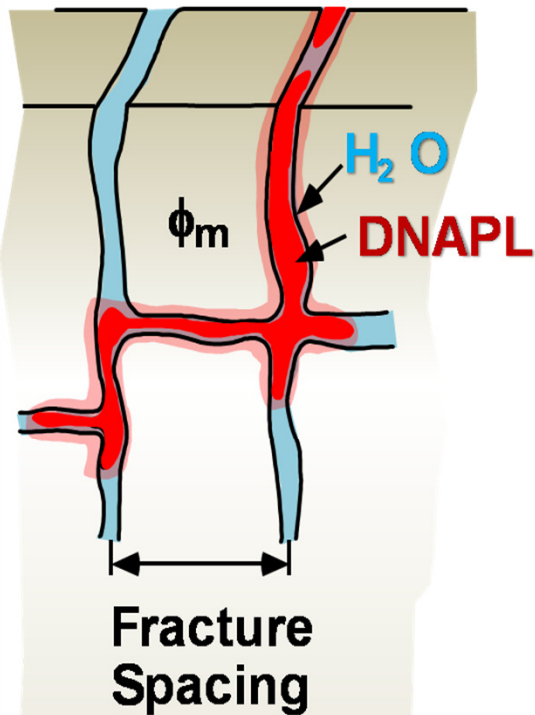
Resulting Depth of
DNAPL Penetration = 150 meters

500,000 gal can be accounted for in the fractures beneath only 10 acres to depth of about 150 meters.

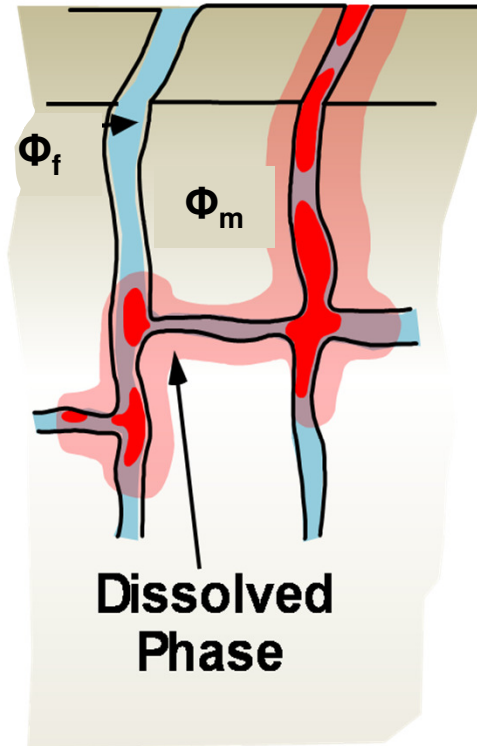
Thus, the total DNAPL input volume can be accounted for by fracture porosity near the input locations.

Second Calculation: TCE is Entirely Dissolved and Sorbed in the Matrix

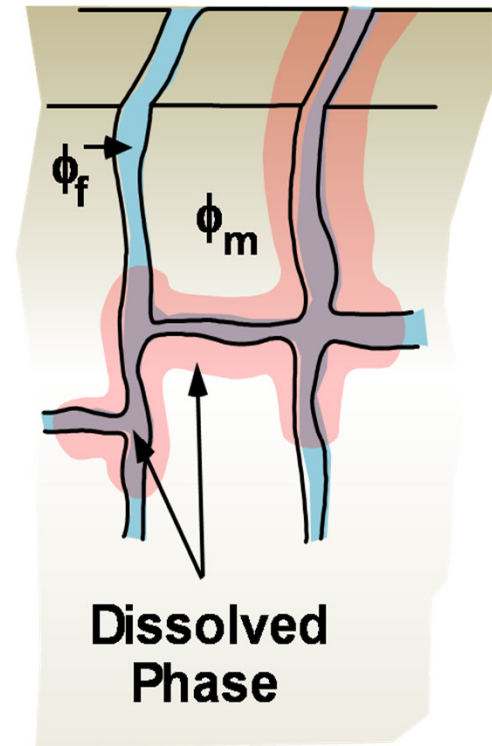
Decades Ago



Intermediate

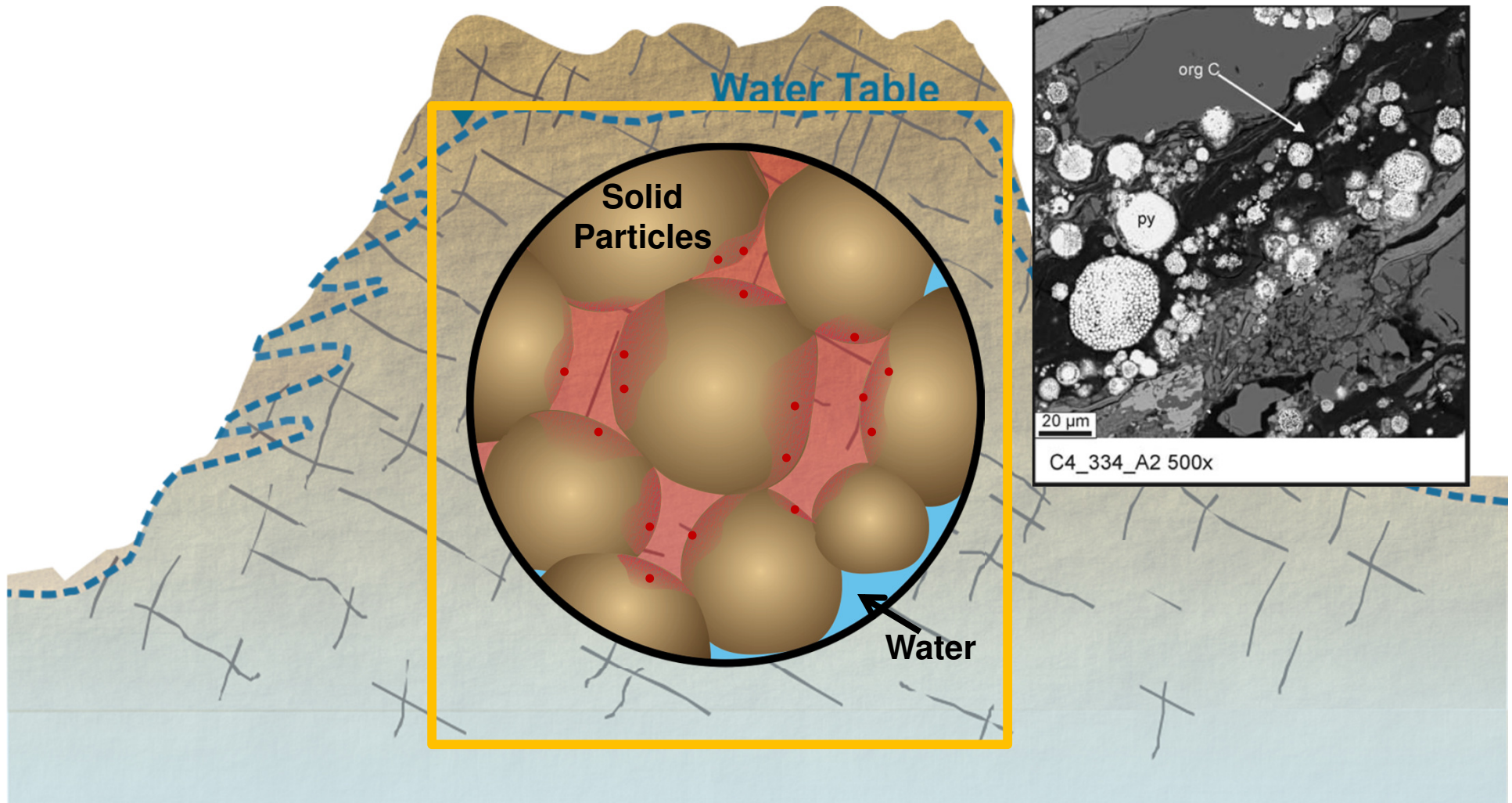


Now

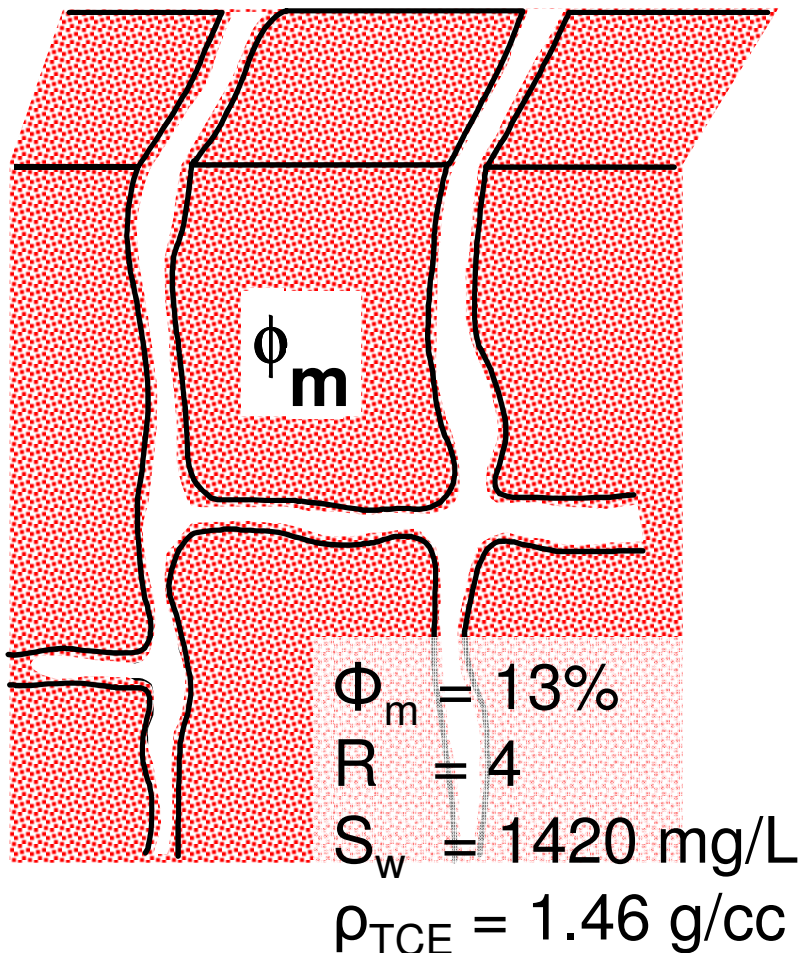


Mountain TCE Retention Capacities for Dissolved and Sorbed TCE

Storage capacity for dissolved TCE = Dissolved and sorbed in the rock matrix



SSFL Chatsworth TCE Mass Storage Capacity in Matrix



$$M_m = \Phi_m S_w R$$

Dissolved and sorbed
mass in matrix

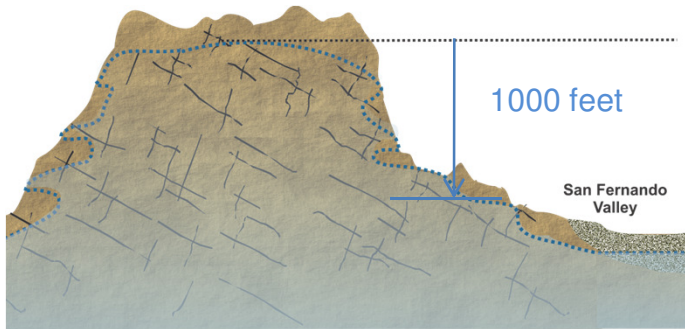
$$M_m = 0.73 \text{ kg/m}^3$$



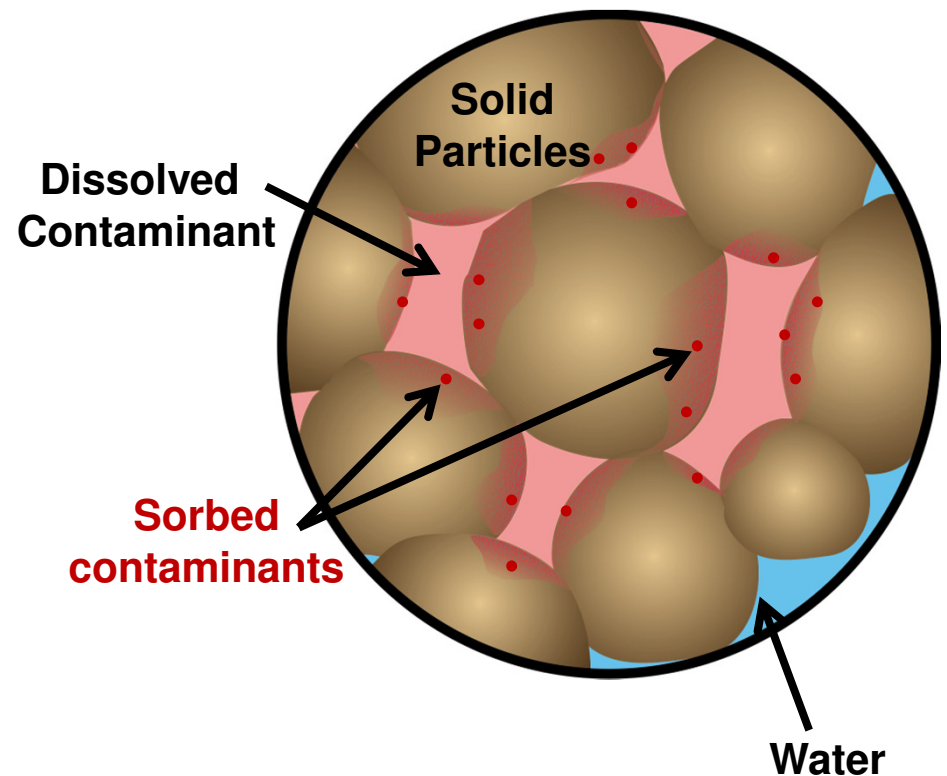
0.5 liters TCE/m³

How Much Dissolved TCE can the Mountain “Store” in the Rock Matrix?

Storage Capacity = Dissolved + Sorbed Capacity in the Rock Matrix

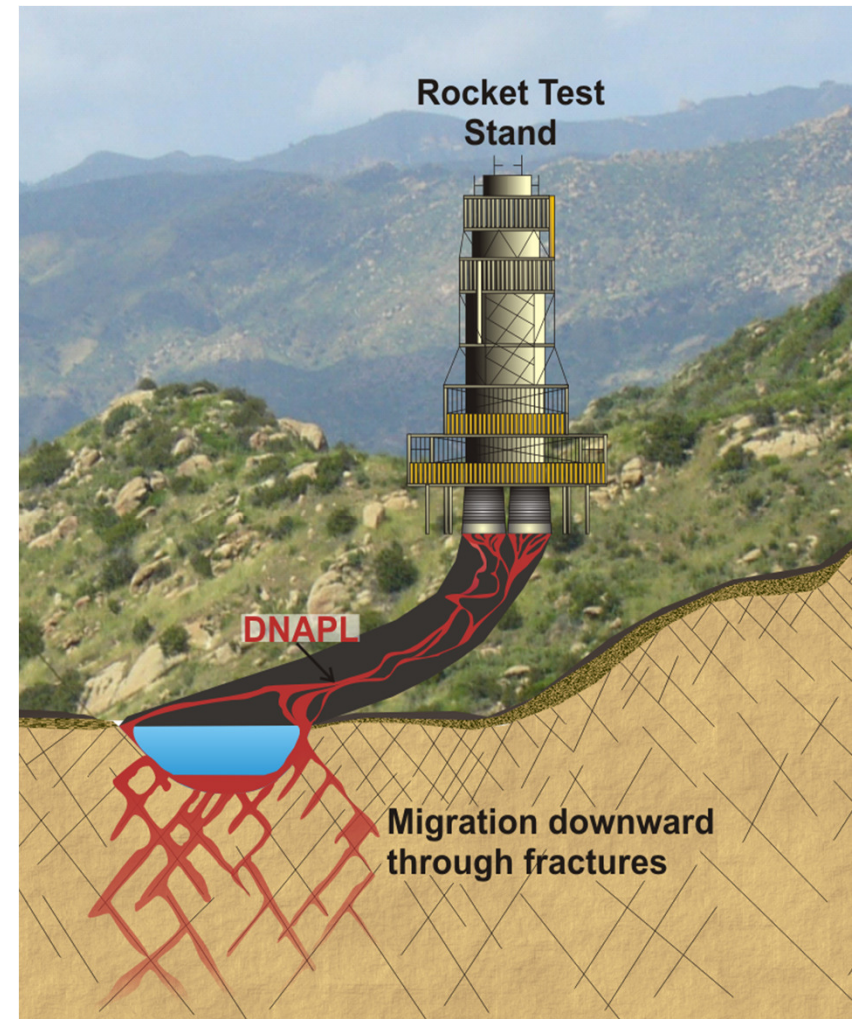


*500,000 gallons
TCE DNAPL
represents less than
0.5 % of the
mountain's TCE
storage capacity*





These calculations show that it is reasonable that the amount of contaminants released can be stored within the footprint of the site



- 
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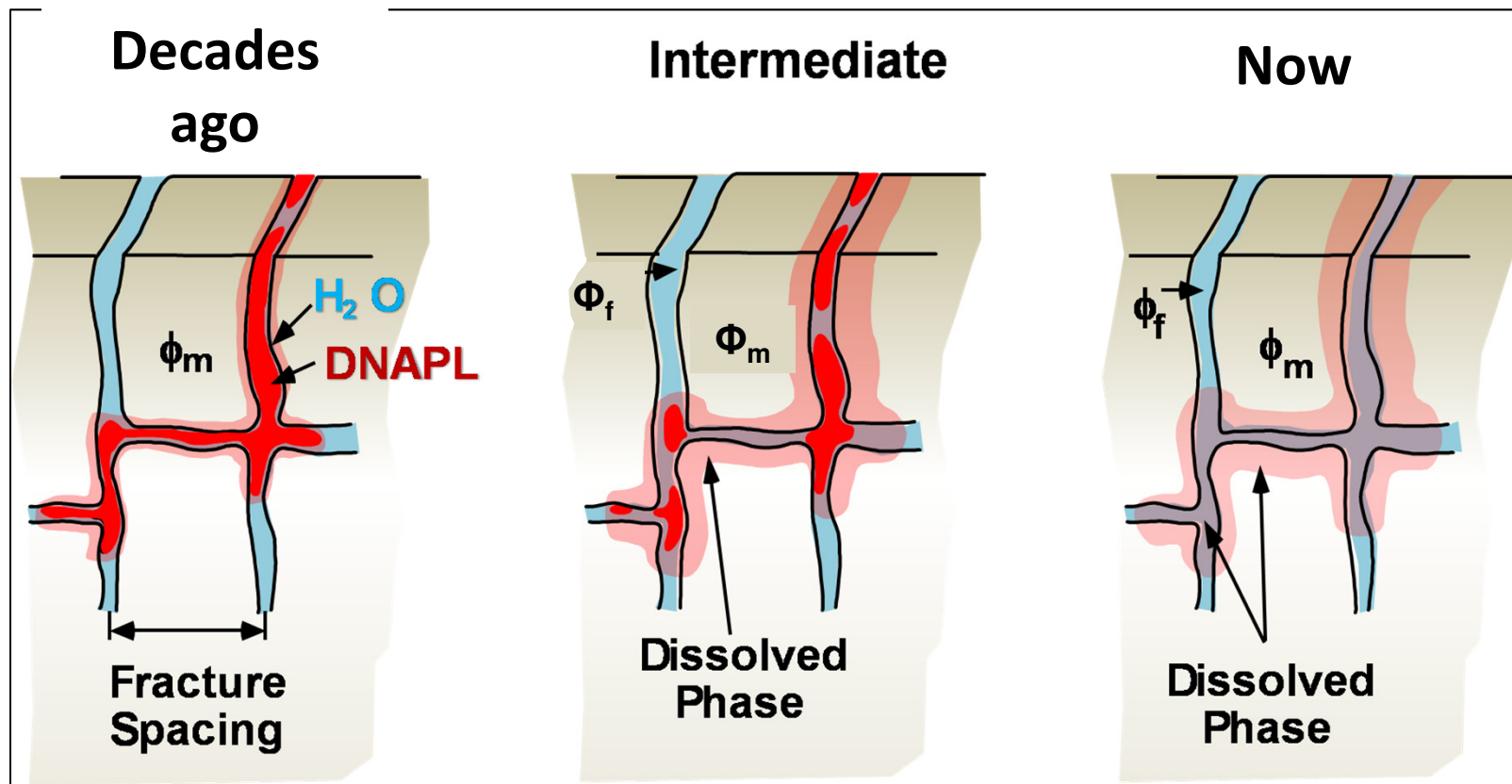
General Remediation Goals

To protect human health and the environment

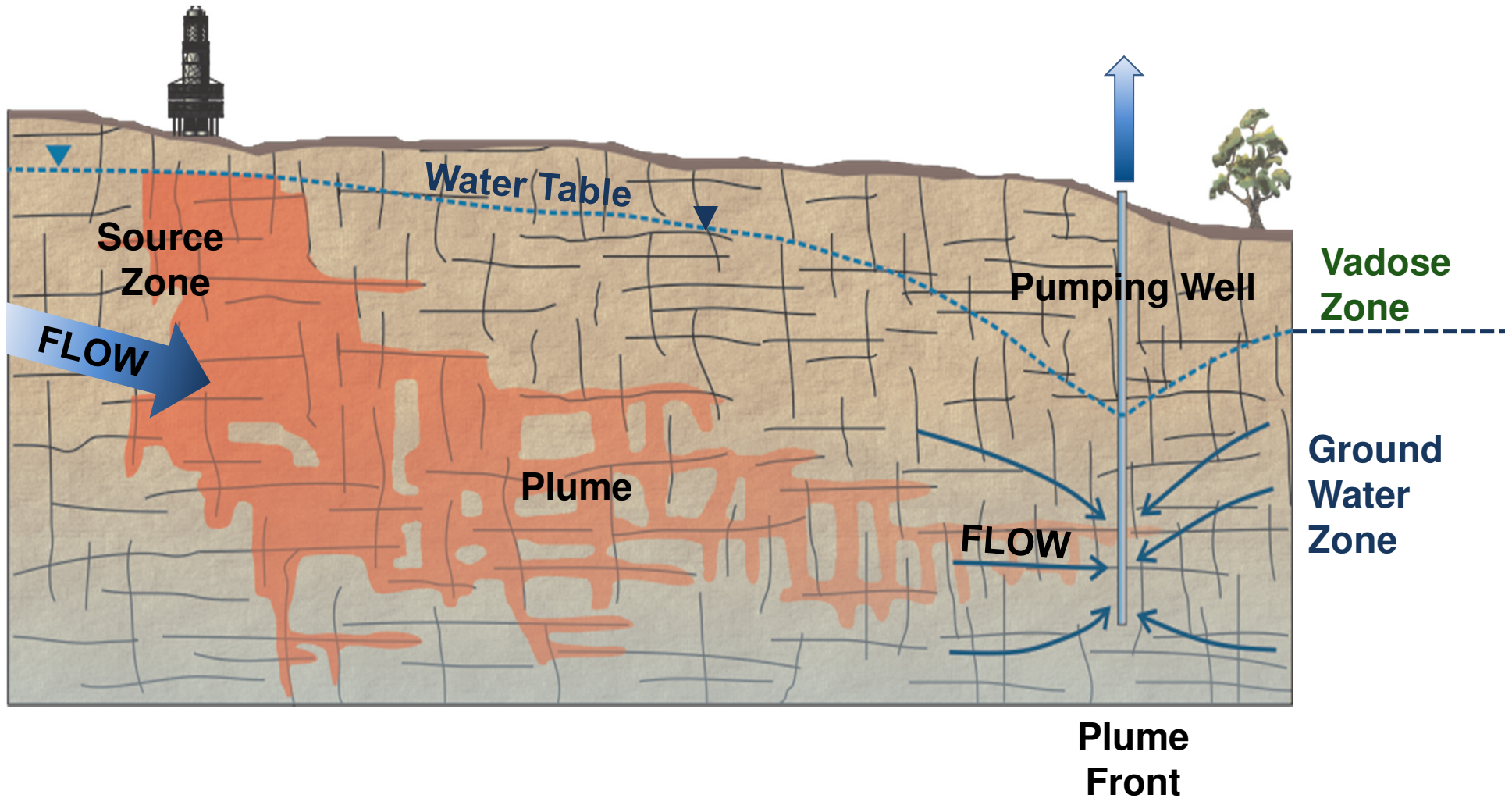
- *Prevent contaminants from reaching off site receptors*
- *Restore the groundwater to drinking water conditions*
- *Reduce risk where appropriate*

Decades of Diffusion

Nearly all the contaminant mass is in the rock matrix between the fractures.



Pump and Treat Can Control Plumes





Pump and Treat Remediation

Useful for control of plume fronts but not for
contaminant mass reduction

*Therefore **mass reduction**
technologies must be considered*

A horizontal banner image showing a rocky, arid landscape under a clear blue sky. The title text is overlaid on the right side of this banner.

Technologies for TCE Mass Reduction

- **Remove Mass**

- Bring the contaminants from the rock to the surface for destruction
- *Requires injection and pumping*

- **Mass Destruction In Situ**

- Inject substances to destroy mass in the rock
- *Requires injection and diffusion*

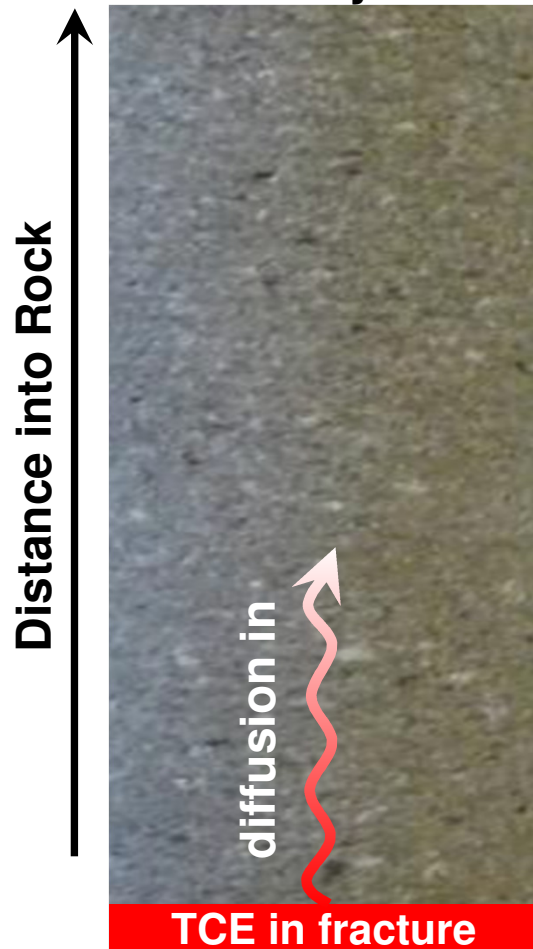
A horizontal banner image showing a rocky, arid landscape under a clear blue sky. The title text is overlaid on the right side of this banner.

Mass Reduction Technologies for TCE

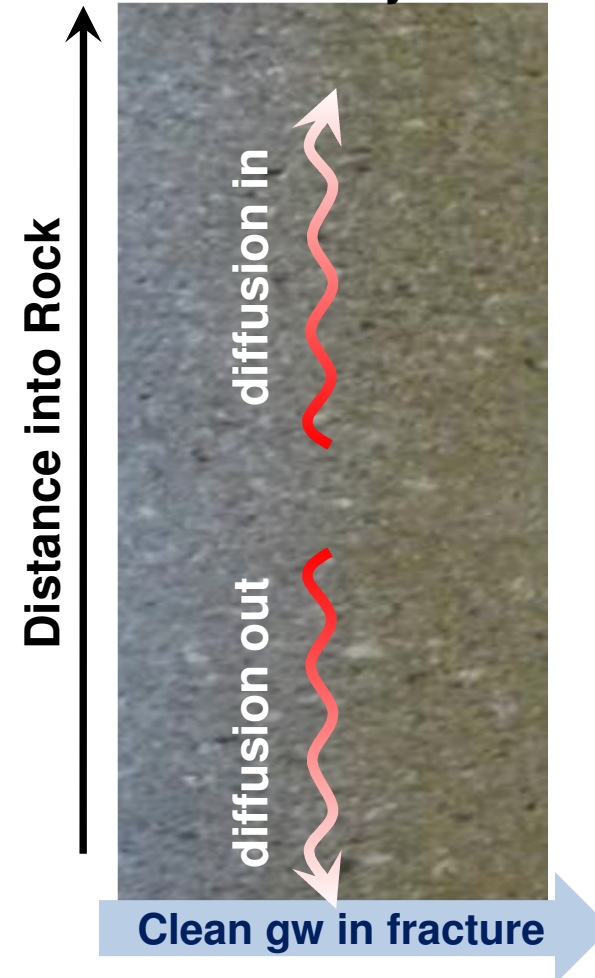
- **Remove Mass**
 - Surfactant flush
 - Air sparging
 - Vacuum
 - Heat
- **In-Situ Destruction**
 - Chemical oxidation
 - Iron particle injection
 - Enhanced microbiological

TCE Removal from Rock Matrix Controlled by Diffusion

Time Period 1: TCE in Fracture
0 to 50 years



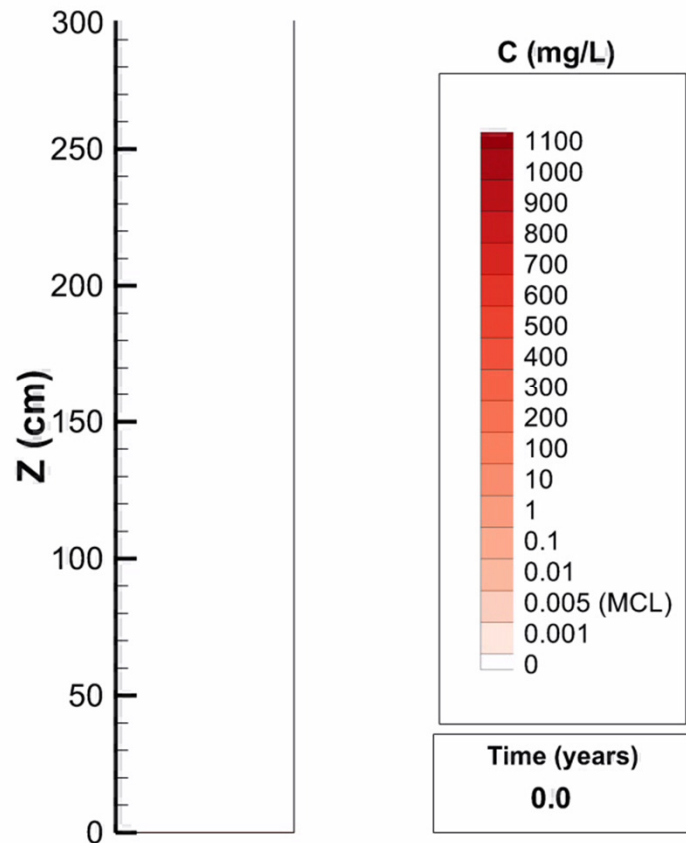
Time Period 2: Remediation Stage
50 to 150 years



Mass Removal Computer Simulation

TCE Diffusion in Sandstone at the SSFL (150 years)

Remediation (source C = 0) from 50 to 150 years



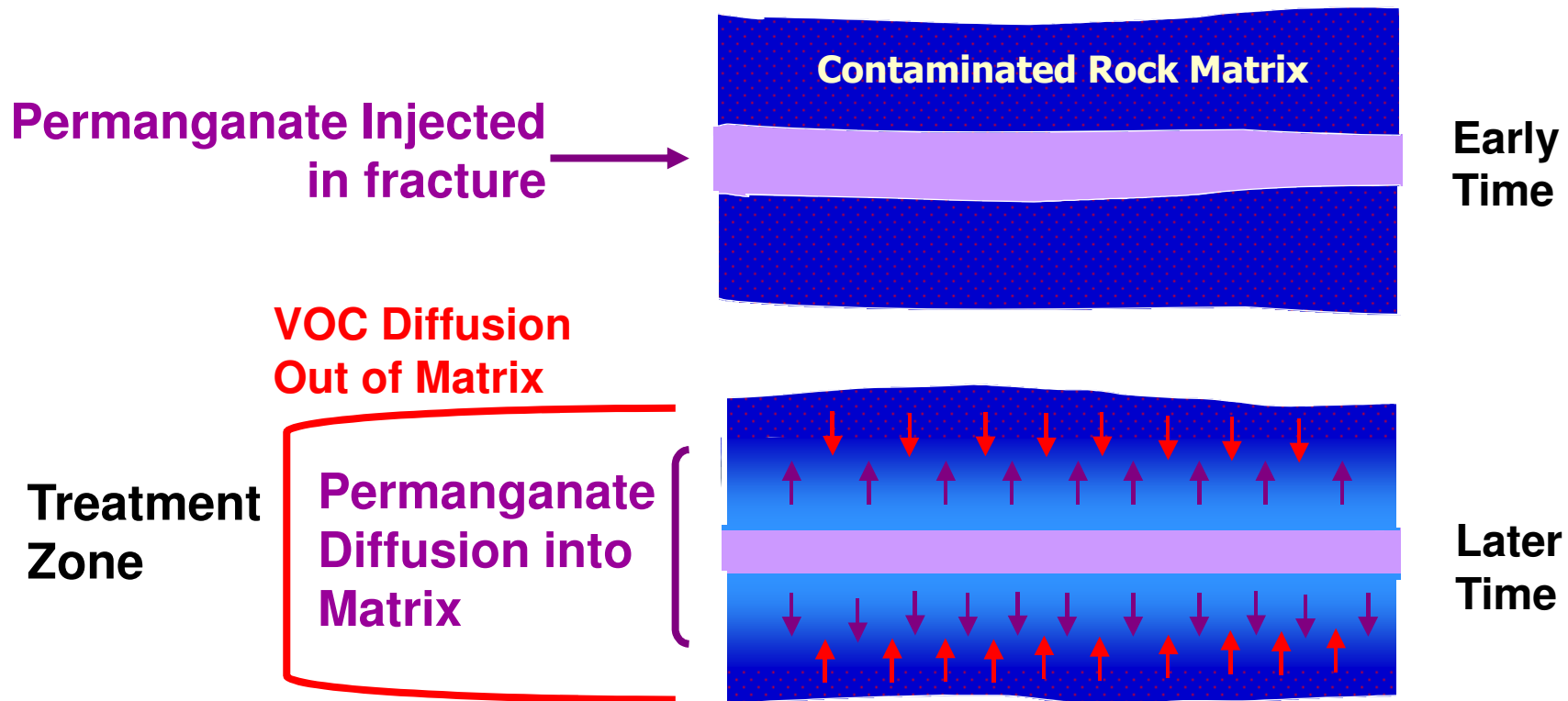
This video shows TCE diffusion in and out of a column of SSFL sandstone

Source in fracture is removed after 50 years

Example of Permanganate Remediation: Watervliet, NY



Permanganate Application in Fractured Rock

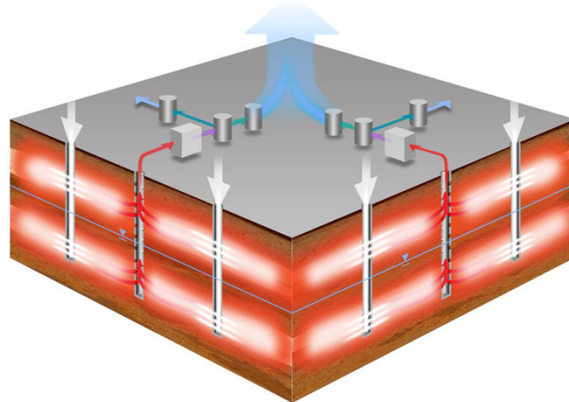


Diffuses into porous matrix to destroy aqueous and sorbed mass

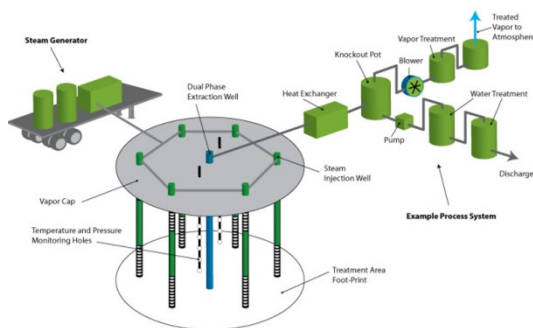
In Situ Thermal Schematics



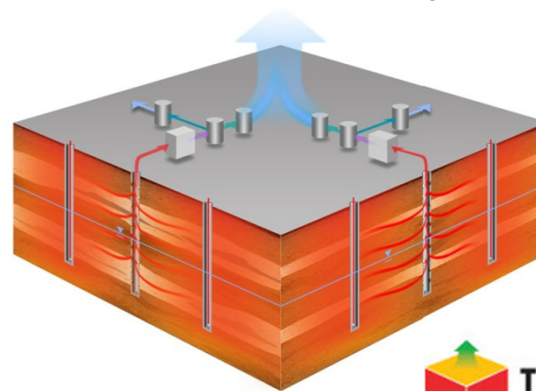
Steam-enhanced extraction



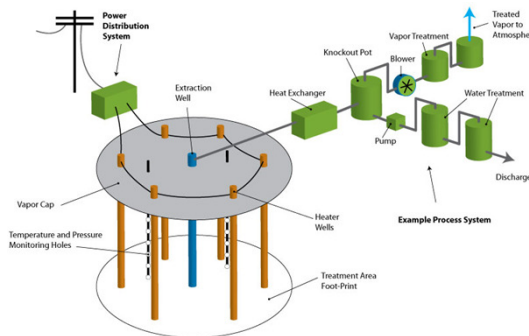
SEE
Steam Enhanced Extraction



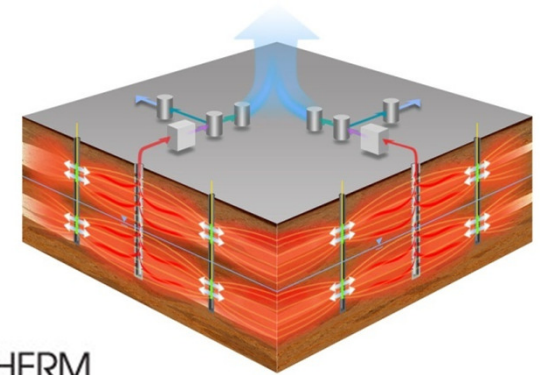
In-situ thermal desorption



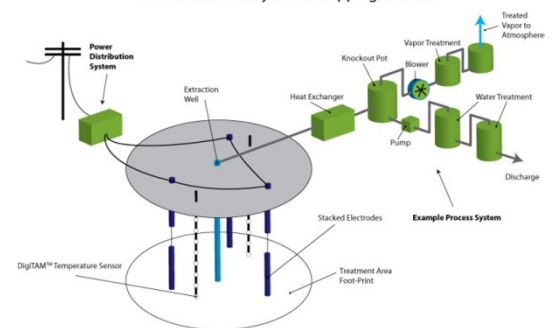
ISTD
In Situ Thermal Desorption - Utilizing Thermal Conduction Heating



Electro-thermal dynamic stripping



ET-DSP™
Electro-Thermal Dynamic Stripping Process





Treatability Studies for Investigation and Remedy Design

1992

United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

Office of Solid Waste and
Emergency Response
Washington, DC 20460

Superfund

EPA/540/R-92/071a

October 1992



Guidance for Conducting Treatability Studies under CERCLA

Final





Treatability Studies Soon to Begin at SSFL

Laboratory Studies

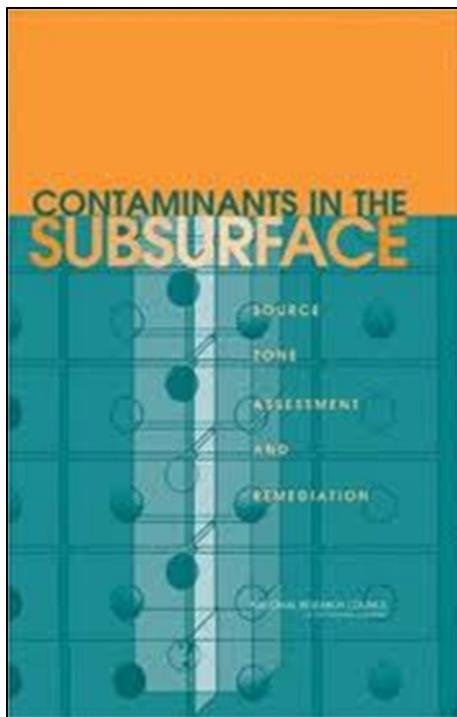
- **Permanganate**
- **Thermal**
- **Enhanced biological**

Field Trials

- **Bedrock Vapor
Extraction (at Bowl)**
- **In Situ Chemical
Oxidation (in Northeast)**

Five General Hydrogeologic Settings

US National Resource Council
(2004). Contaminants in the
Subsurface: Source Zone
Assessment and Remediation.



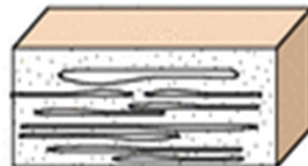
(I) Granular Media with Mild Heterogeneity and Moderate to High Permeability
(e.g.,olian sands)



(II) Granular Media with Mild Heterogeneity and Low Permeability
(e.g., lacustrine clay)



(III) Granular Media With Moderate to High Heterogeneity
(e.g., deltaic deposition)



(IV) Fracture Media with Low Matrix Porosity
(e.g., crystalline rock)



(V) Fracture Media with High Matrix Porosity
(e.g., limestone, sandstone or fractured clays)



SSFL



Quotes from NRC (2004)

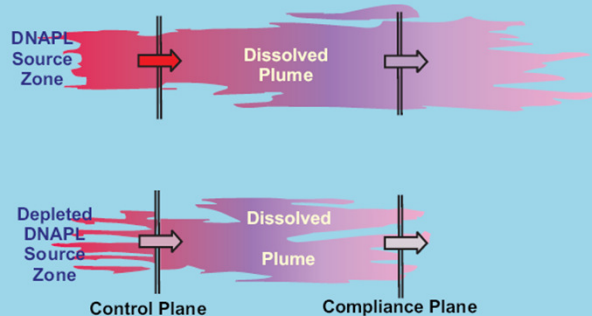
- *The challenges of managing contamination in this hydrogeologic setting include describing the extent of the source zone, characterizing the fracture network, delivering remedial solutions to the targeted areas in some cases, and understanding the potential for reverse diffusion to sustain contaminant concentrations in the transmissive fractures after depletion of DNAPL.*
- *“Reverse diffusion of contaminants from these areas can sustain elevated contaminant concentrations in groundwater for long periods of time.”*

EPA Expert Panel on DNAPL Remediation



2003

The DNAPL Remediation Challenge: Is There a Case for Source Depletion?



“Molecular diffusion initially retards contaminant migration via advection, as the rock-matrix porosity serves as a sink. However, once the source is removed and the contaminant concentrations in the fracture network decrease, diffusion out of these stagnant intra-matrix regions can sustain contaminant concentration in the advective flow paths within the fracture network. “



Module 7: Summary and Implications

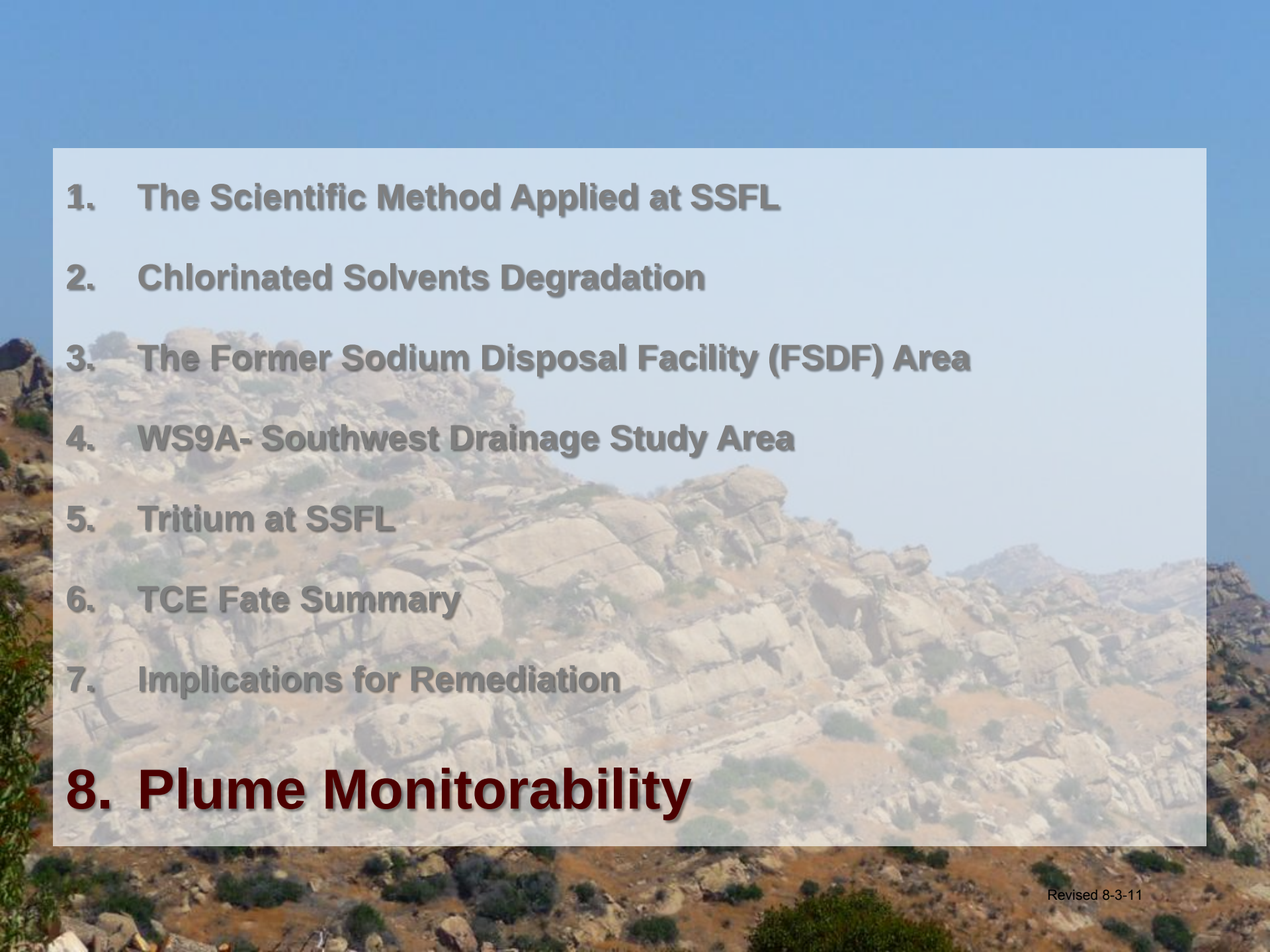
- *The options for contaminant mass reduction are limited because nearly all mass is in the low permeability matrix*
- *Appropriate treatability studies will begin soon*



Natural Attenuation Became an EPA Focus in the mid-1990's

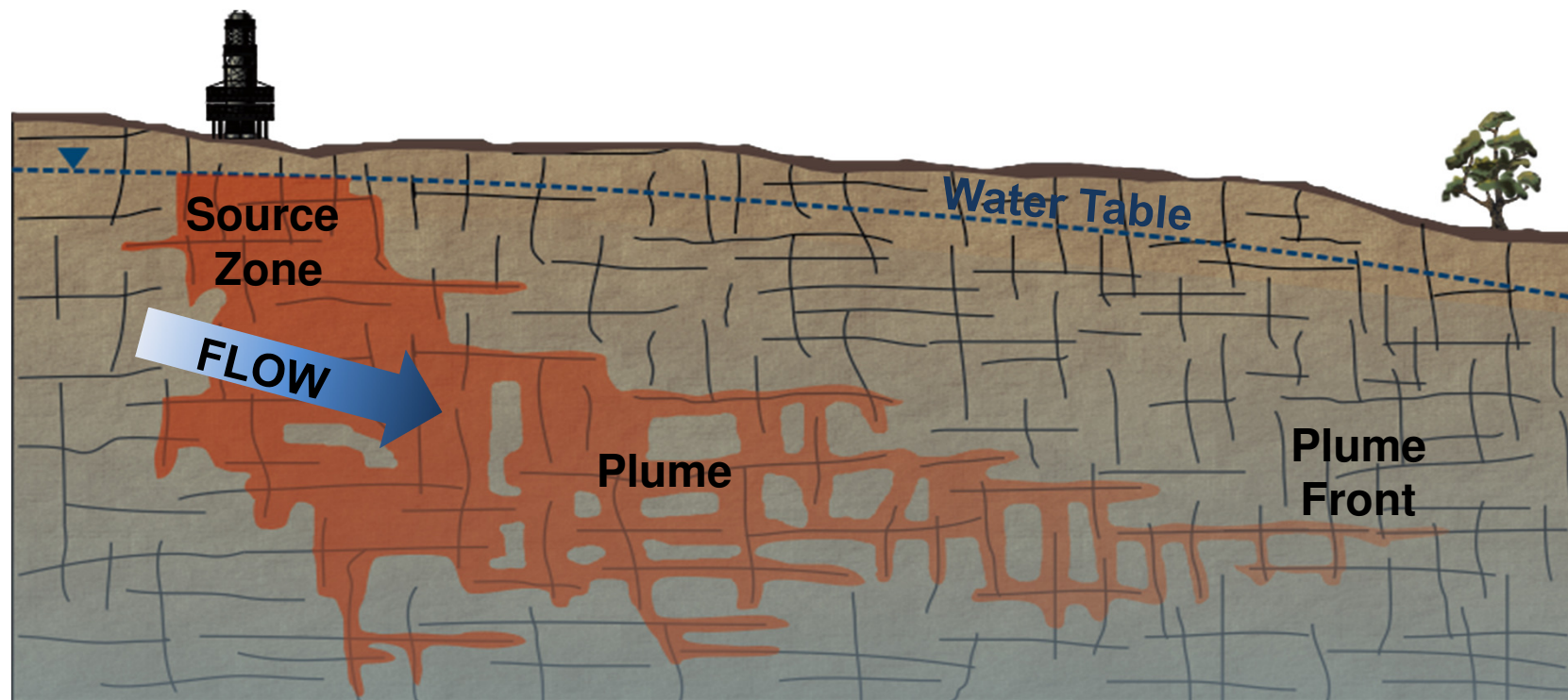
“The natural reduction in concentration by physical, chemical and biological processes that occur without human intervention ...makes use of natural processes to contain, attenuate and control contaminants at sites.”

USEPA, 1999

- 
- 1. The Scientific Method Applied at SSFL**
 - 2. Chlorinated Solvents Degradation**
 - 3. The Former Sodium Disposal Facility (FSDF) Area**
 - 4. WS9A- Southwest Drainage Study Area**
 - 5. Tritium at SSFL**
 - 6. TCE Fate Summary**
 - 7. Implications for Remediation**
 - 8. Plume Monitorability**

What do we Mean by 'Groundwater Monitorability'?

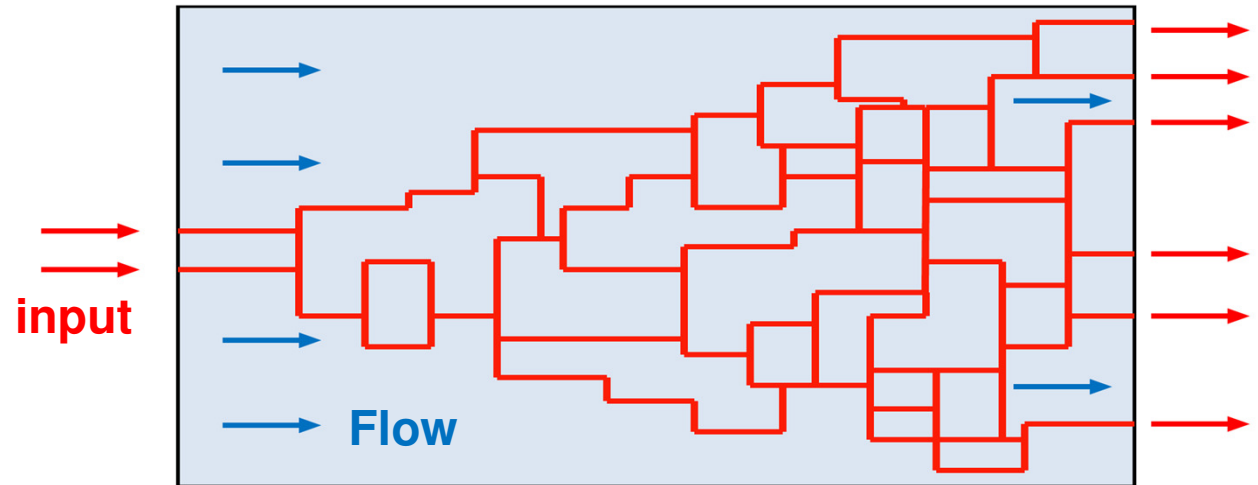
Feasibility of finding and delineating the contaminants so that the nature and extent is reliably established



Good and Poor Monitorability

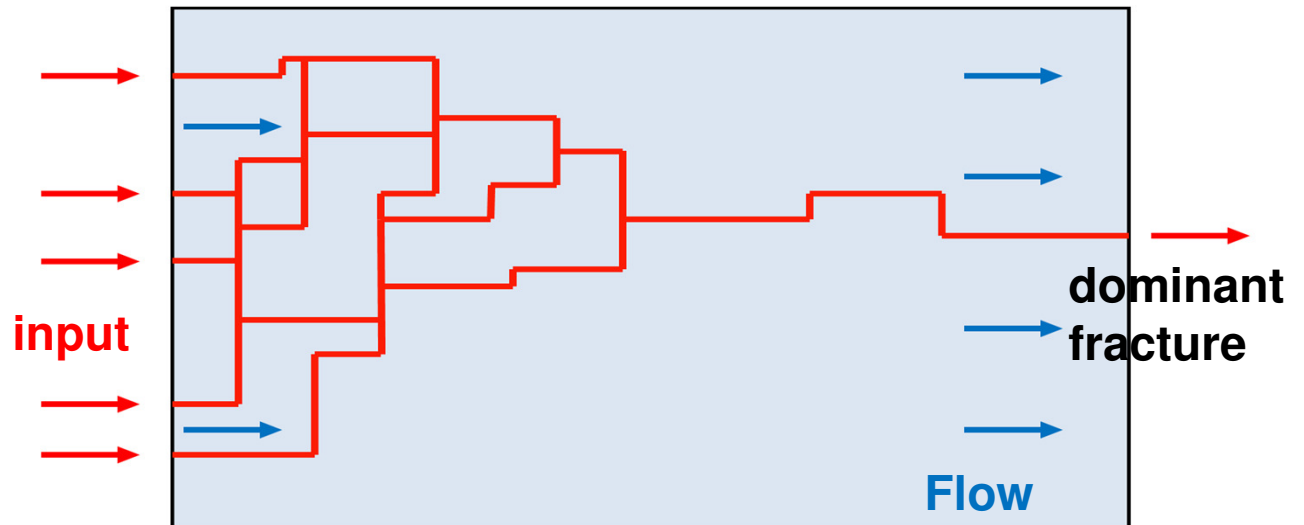
Good Monitorability:

Interconnected fracture network causes plume to spread laterally

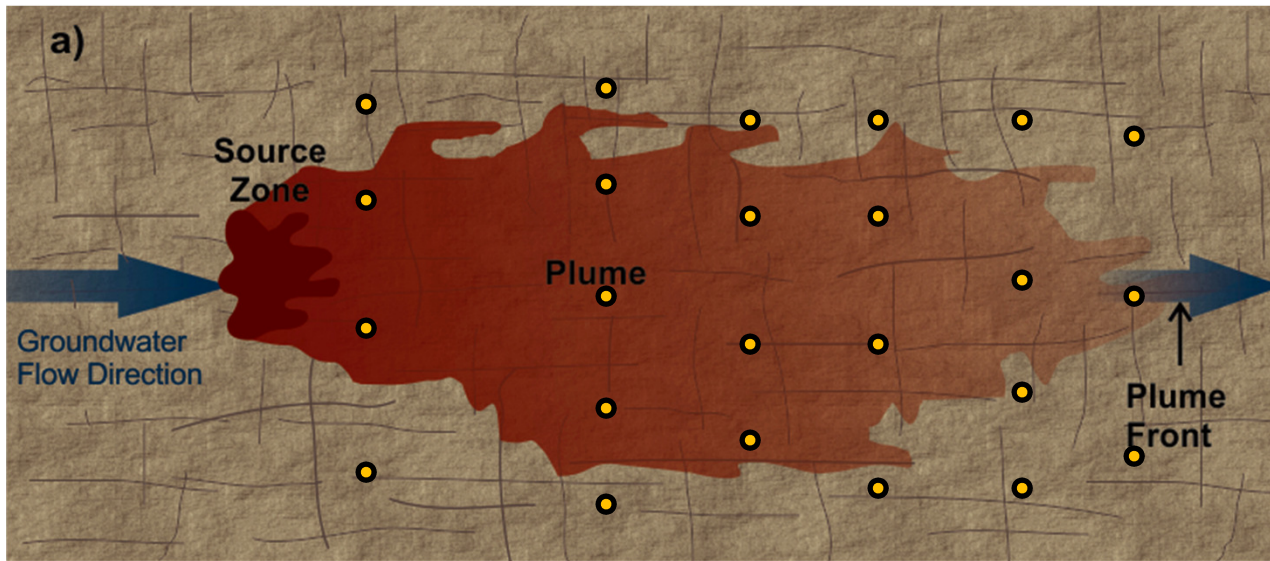


Poor Monitorability:

Paths converge to dominant fracture – “Superhighway” concept

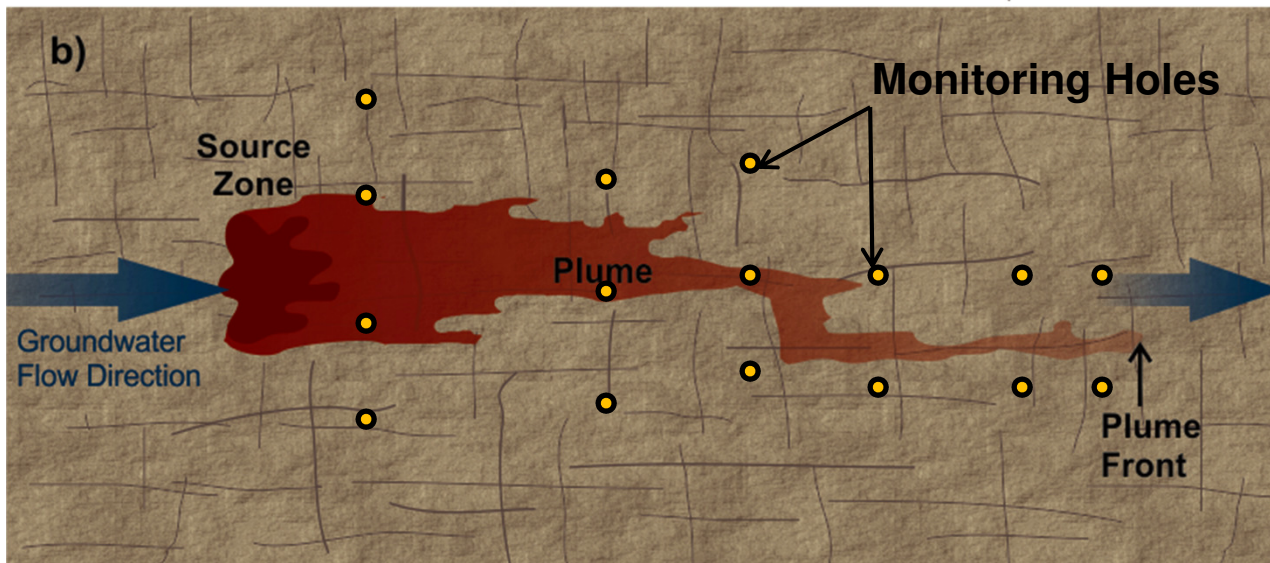


Good and Poor Monitorability



a. Fan Shaped Plume

Relatively easy to locate



b. Funnel Shaped Plume

More Difficult to Locate

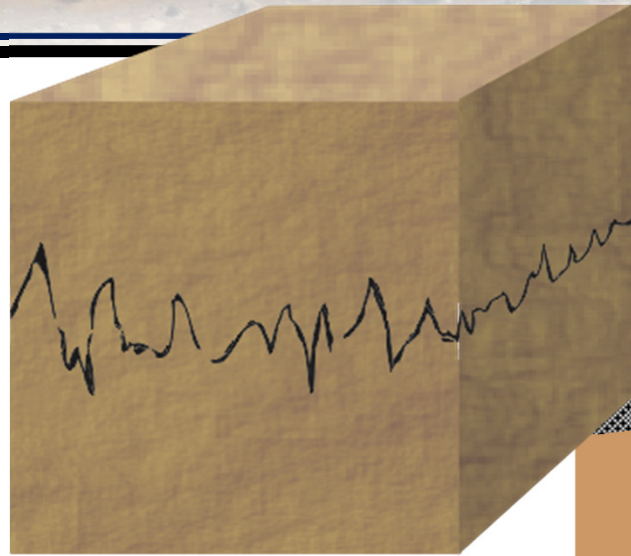
Factors Influencing Monitorability

- Channeling in individual fractures
- Mixing at fracture junctions
- Diffusion to rock matrix
- Relative size of contaminant inputs
- Time since contamination began
- Monitoring well samples capture water from a large volume of fractured sedimentary rock

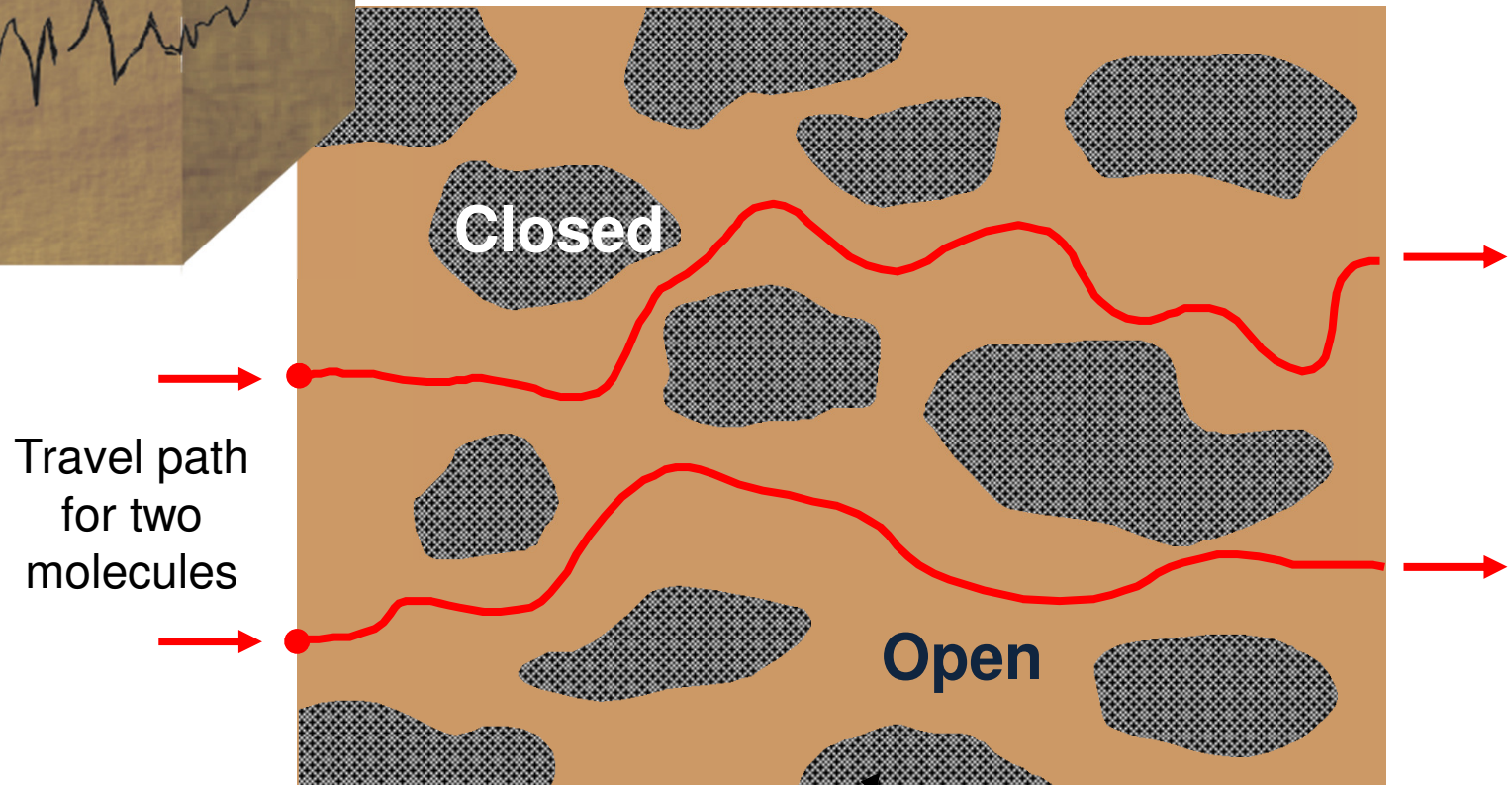
Groundwater in fractures:
0.001 – 0.1 % of rock vol.



Plan View of Fracture Surface



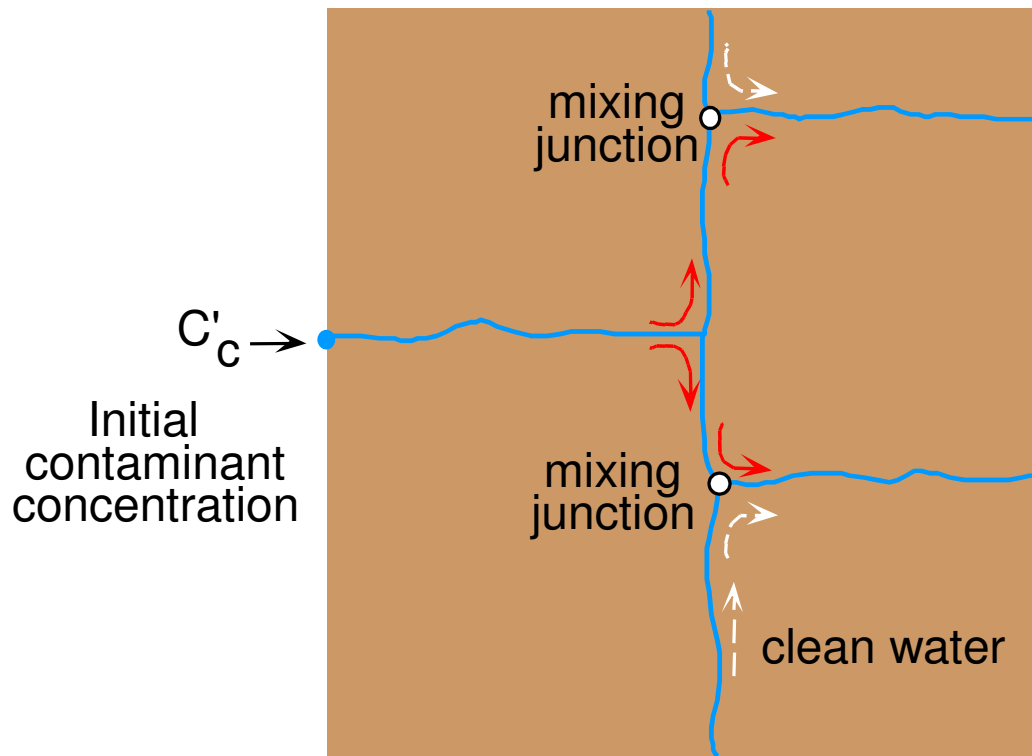
Channeled paths



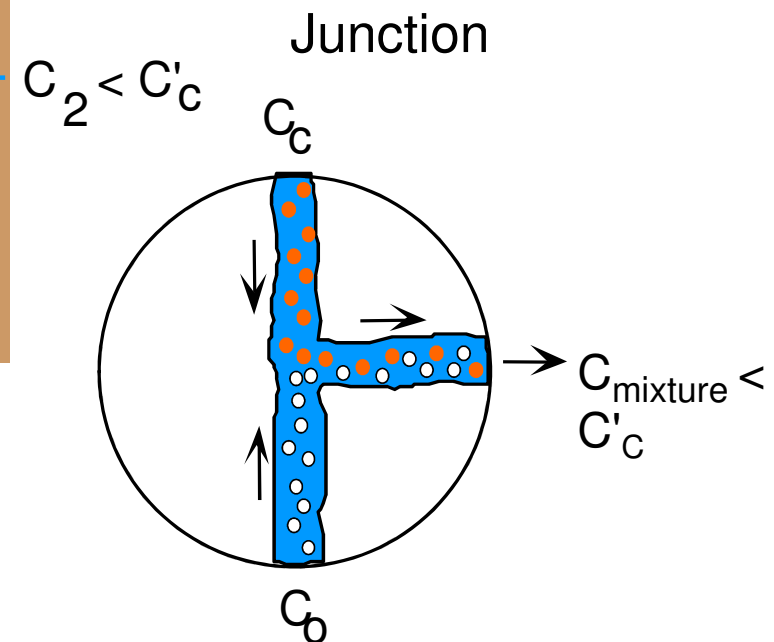
Travel path
for two
molecules

area of closed fracture

Mixing at Fracture Junctions

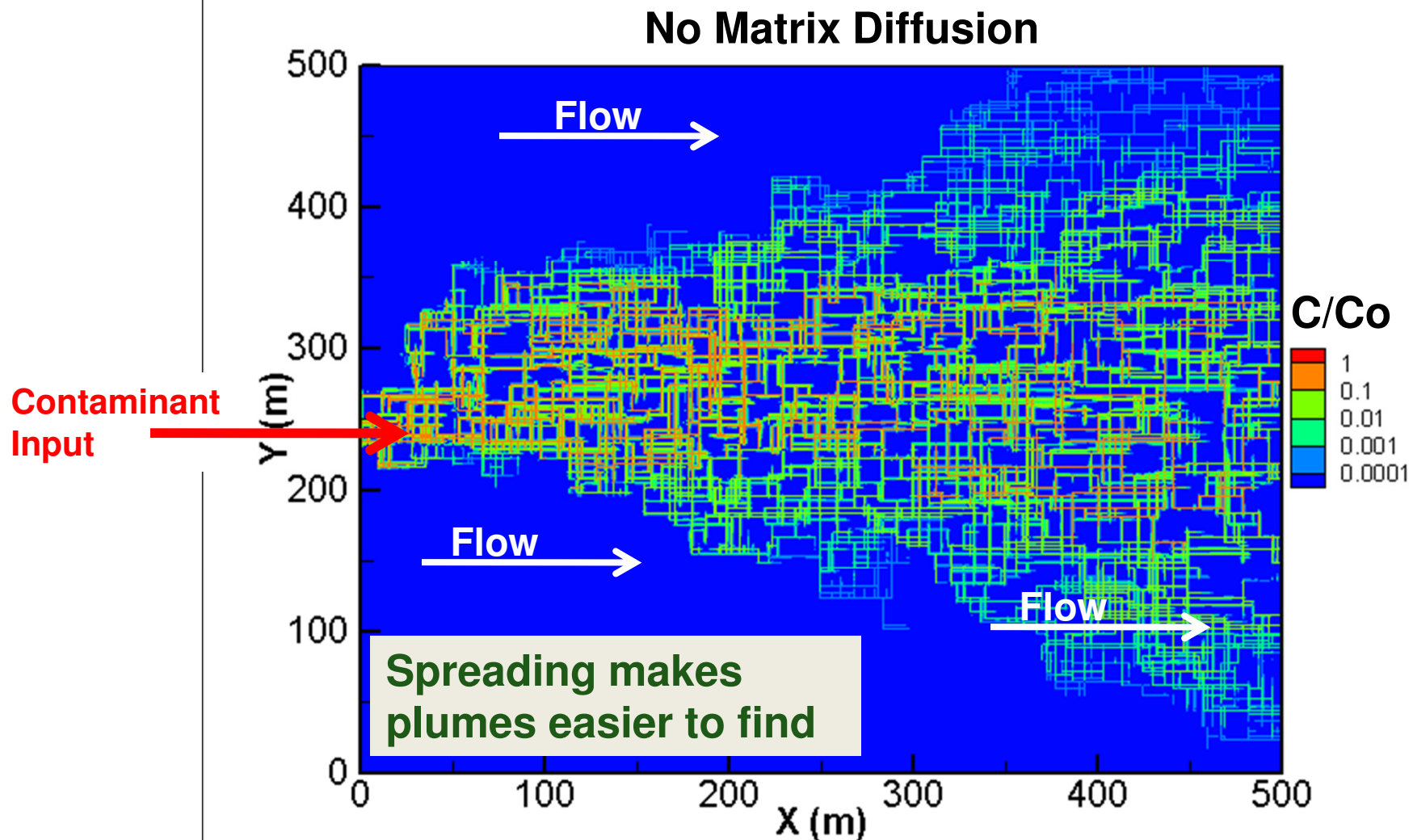


*Causes
Dilution and
Spreading*

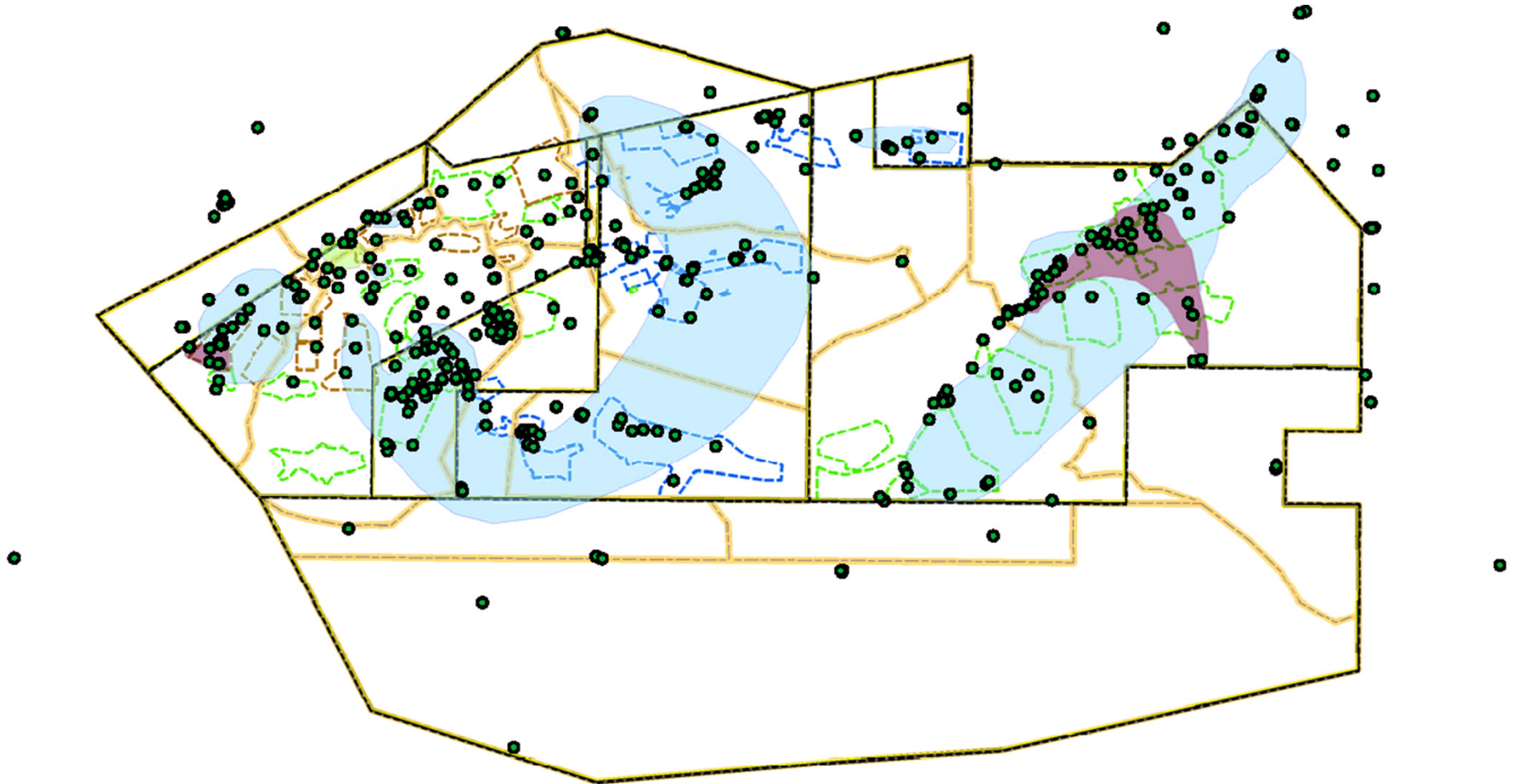


Applies to lateral and vertical

Fracture Junctions Cause Plume Spreading



Lots of Wells Show Contamination and Lots of Wells Do Not



428 monitoring wells used to define extent of contamination



Site Characterization vs. Long Term Monitoring

- **Site Characterization**

- Determine nature and extent
- Understand the nature and extent
- Predict future plume behavior

Using rock core analysis, monitoring wells and multilevel systems

- **Long Term Monitoring**

- Confirm predictions of plume behavior
- Protect potential receptors
- Observe remediation performance

Using monitoring wells



Module 8: Summary and Implications

SSFL groundwater plumes are monitorable because:

- *Orderly, dense fracture networks cause strong spreading*
- *Strong matrix diffusion leaves trails*
- *Contaminant inputs are large enough*
- *Sufficient time has passed for diffusion and spreading*
- *Well capture volume is large due to small fracture porosity*
- *Processes governing the plumes are understood*

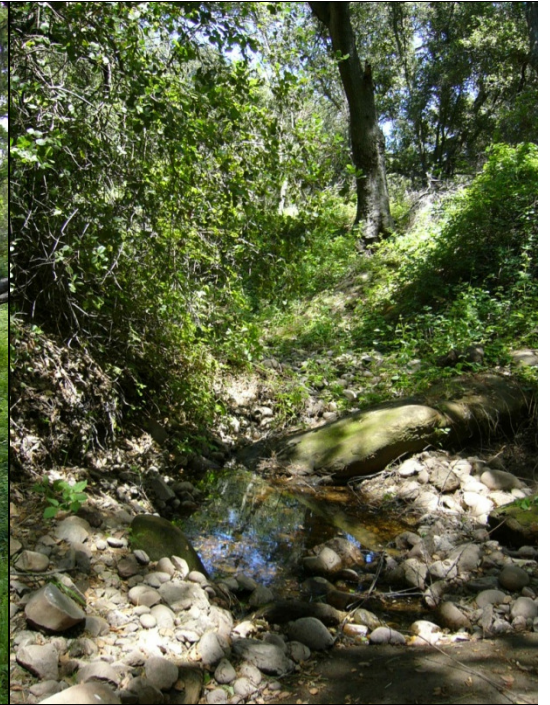


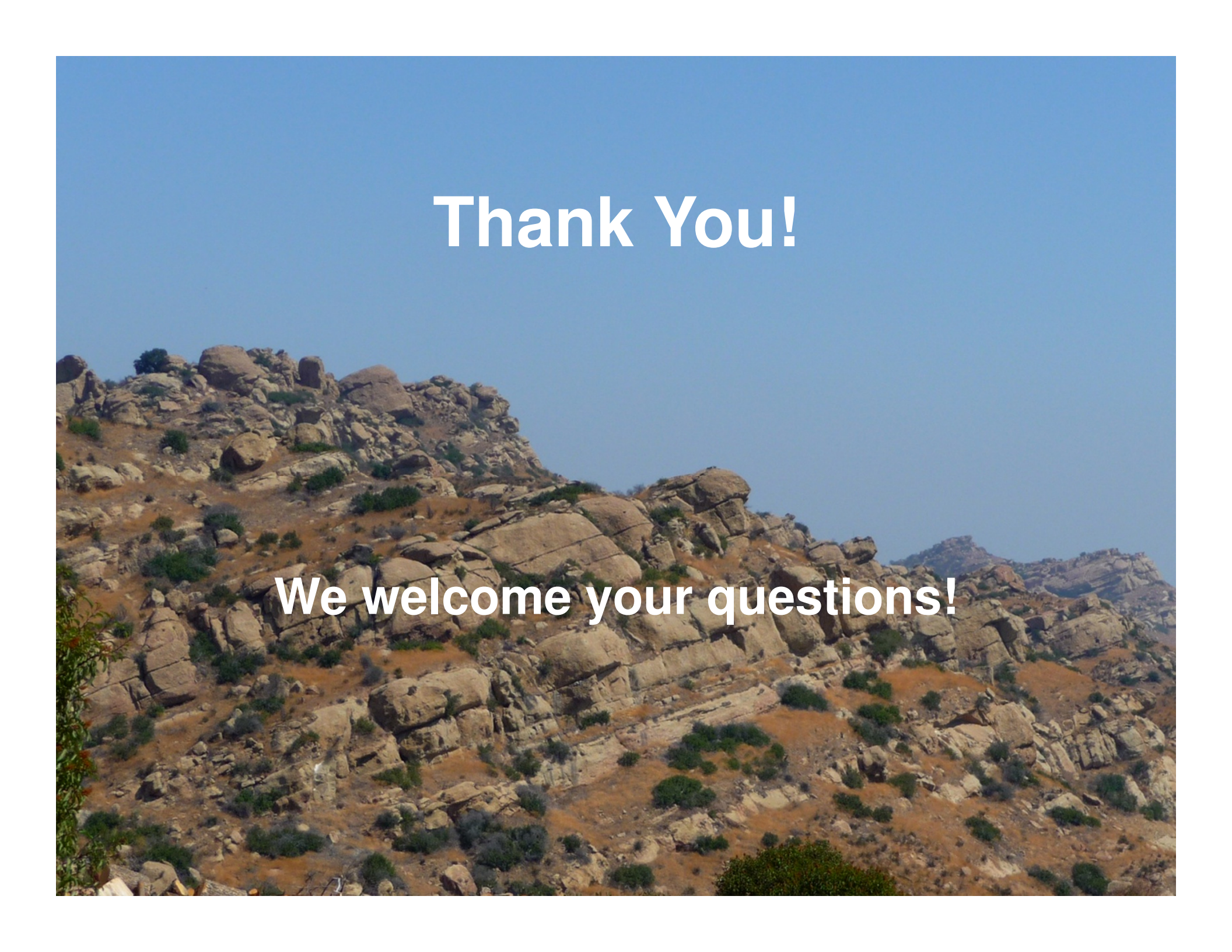
Summary

1. *Natural Processes of degradation and decay are occurring and are decreasing contaminant levels*
2. *Groundwater flows in the fractures but mass is in the matrix where these degradation processes occur*
3. *Long term monitoring of groundwater conditions and contaminant concentrations is important to verify the plume stability and continued attenuation*
4. *Remediation strategies must be based on the fact that nearly all contaminant mass resides in the low permeability matrix blocks between fractures*







A photograph of a rocky, arid hillside under a clear blue sky. The hillside is covered with large, light-colored boulders and sparse, low-lying green and brown shrubs. The sky is a uniform, clear blue.

Thank You!

We welcome your questions!