Geology Best Practices: Conceptual Site Model Development for Site Characterization and Remediation

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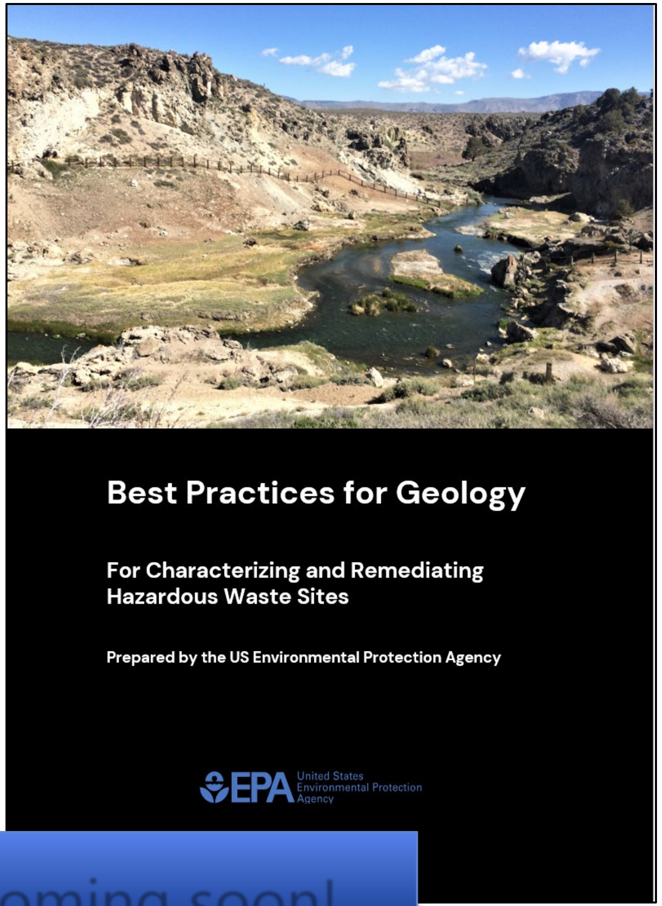
Agency

Overview

- **Why is EPA creating this document?**
  - Geologic principles are underrepresented in remedial technologies
  - Historical use of geotechnical approach (rather than mining or O&G/ESS)
  - Observation of lagging/ineffective remedies due to incomplete understanding of GW flow pathways
  - Improve site team's knowledge and ability to speak to the working CSM
  - "Geological Renaissance"



Best Practices for Geology

For Characterizing and Remediating Hazardous Waste Sites

Prepared by the US Environmental Protection Agency

EPA United States Environmental Protection Agency

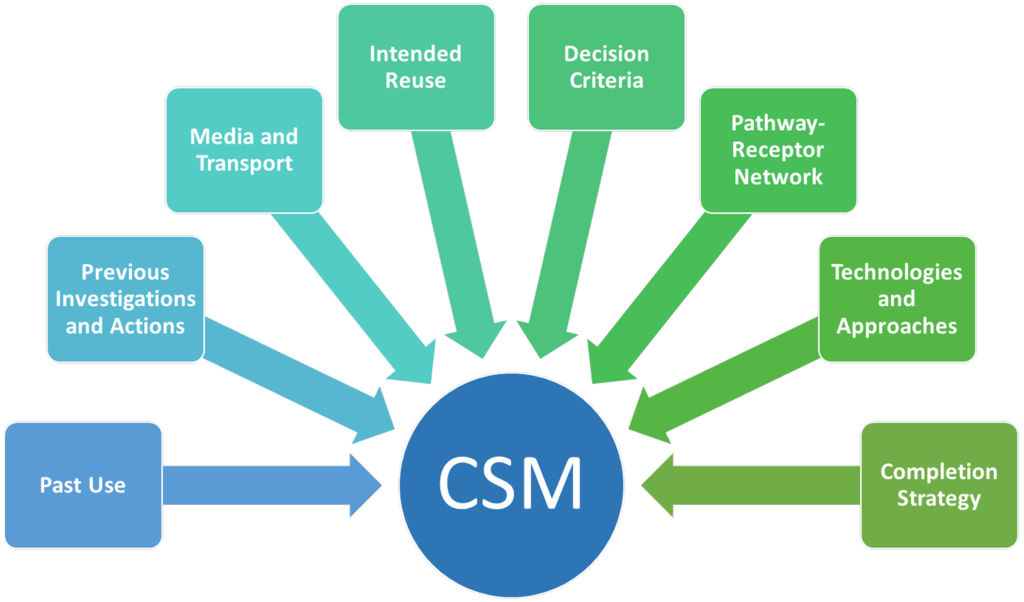
Coming soon!

Topics

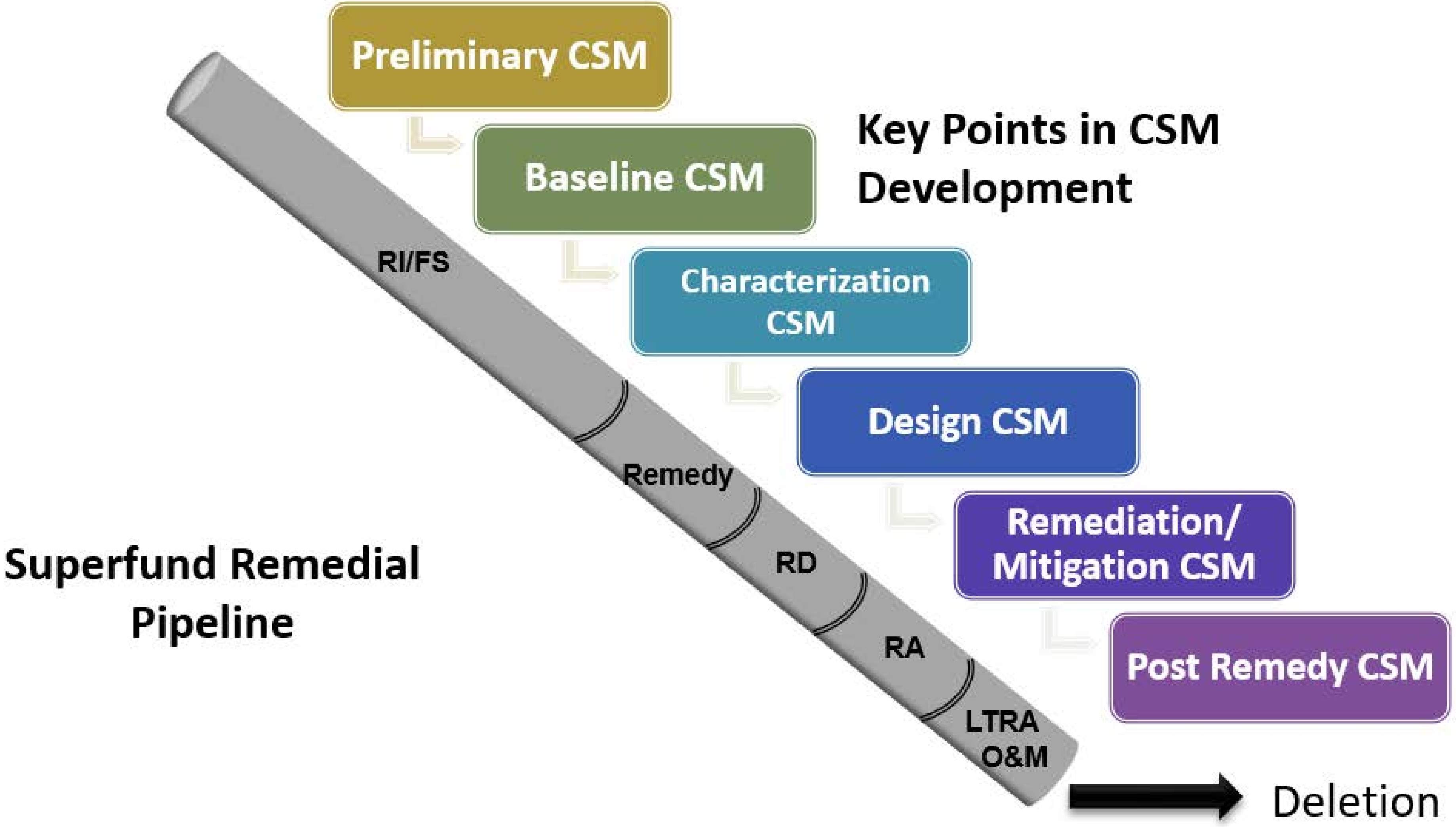
- ♦ Building the conceptual site model (CSM)
- ♦ Understanding geological environments for site remediation
- ♦ Testing/validating a CSM with 3D exploration
- ♦ Developing a 3D CSM
- ♦ Applying the CSM

Building a Conceptual Site Model (CSM)

- Applicable to any stage of a project lifecycle
- Remedial decision-making drives CSM needs
- Work from large scale to small scale
- Sources of data (What remedial processes are possible & what data is needed to support the CSM?)
- What are typical depths of water supply wells in the area? Which unit(s) are they screened in?



Six Stages of the Project Life Cycle CSM



Key Points in CSM Development

- Preliminary CSM
- Baseline CSM
- Characterization CSM
- Design CSM
- Remediation/ Mitigation CSM
- Post Remedy CSM

Superfund Remedial Pipeline

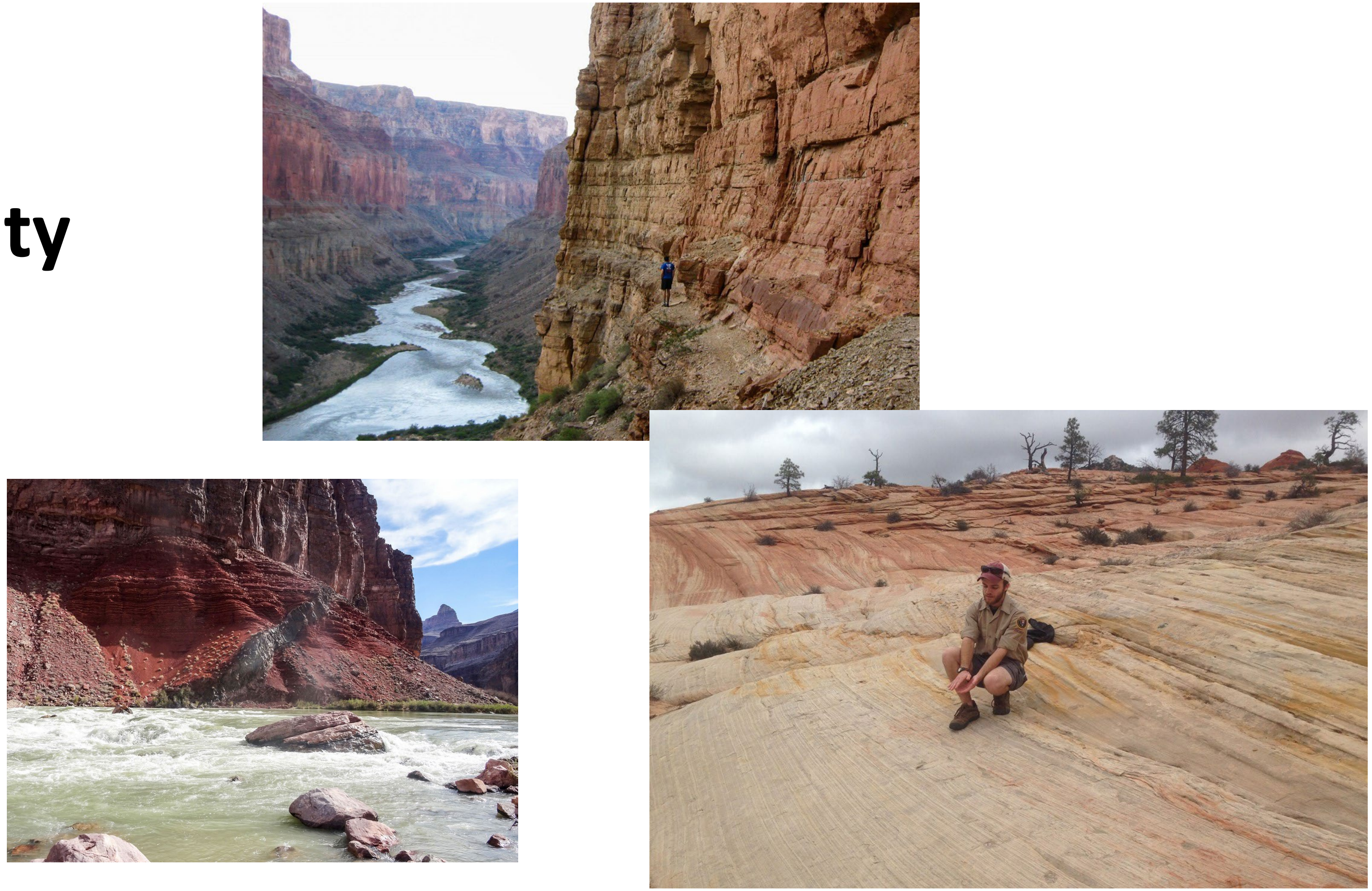
Role of the Project Geologist

- **Designs data collection activities**
- **Assists with development of the CSM**
- **Understands the regional and local geologic setting**
- **Uses geologic principles to analyze data in three or four dimensions to support decision making throughout the project lifecycle**

BP: Use an experienced project geologist to design data collection plan and to interpret data

Basic Principles of Geology

- Uniformitarianism
- Superposition and original horizontality
- Cross-cutting relationships
- Lateral continuity
- Heterogeneity



https://www.nps.gov/subjects/geology/fundamental-geologic-principles.htm

Understanding geological environments for site remediation

Overburden

Pathways, storage compartments

- Depositional environments (apply ESS)
- Variability/Thickness
- **Heterogeneity**

Scale issues - work from large to small scale (key theme)

Fractured Rock

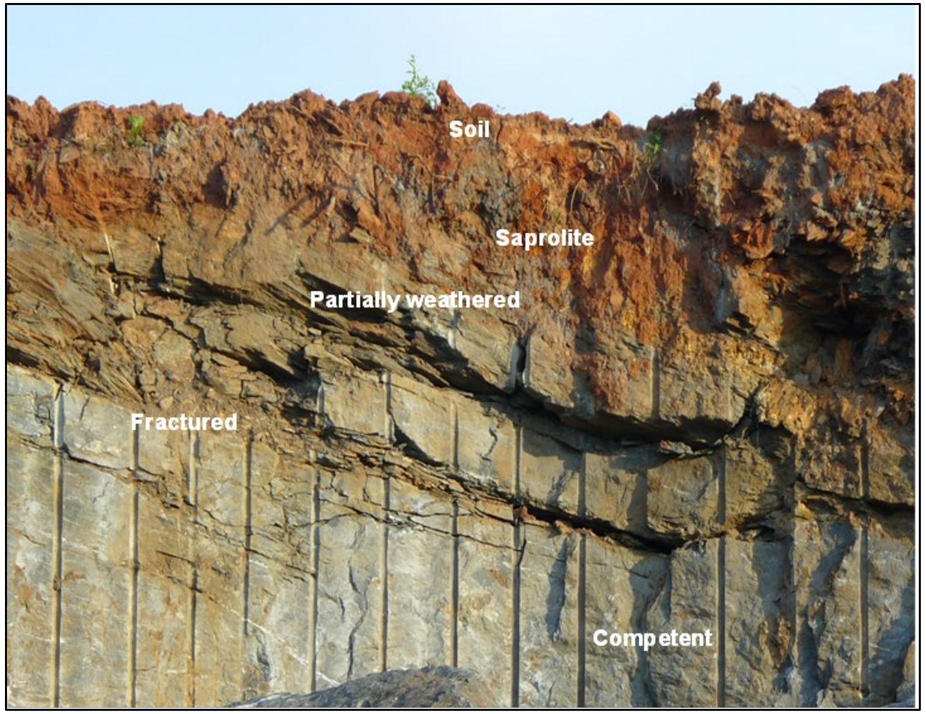
Characteristics of fractured and host rock

- Rock types
- Structural Style
- Fracture Variability

Presents unique challenges for CSMs and remedy selection/design

Transitional Environment (top of bedrock)

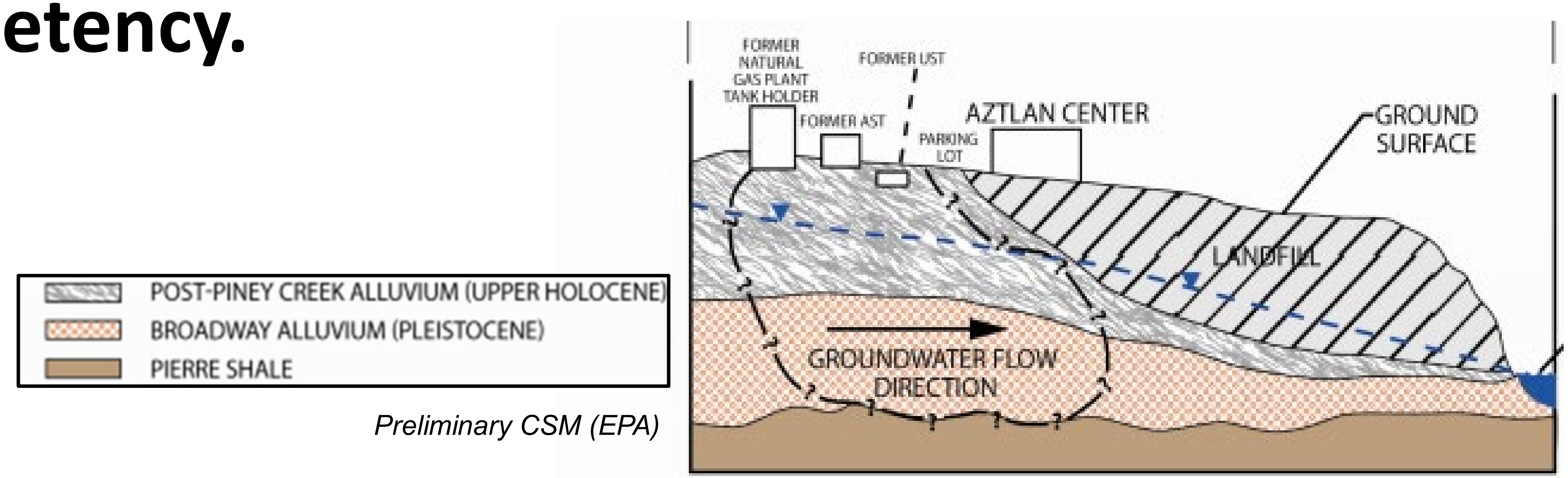
Shape, variability, weathering



Road cut showing the transition between competent bedrock (bottom) to fractured bedrock, saprolite and soil (EPA)

Where to Start?

- Regional and local geologic setting including topography, major lithologic units, and structures
- Site-specific geology and lithology including the vertical and spatial extent of units and subunits, the soil texture (grain size, sorting, layering) or bedrock type and competency.

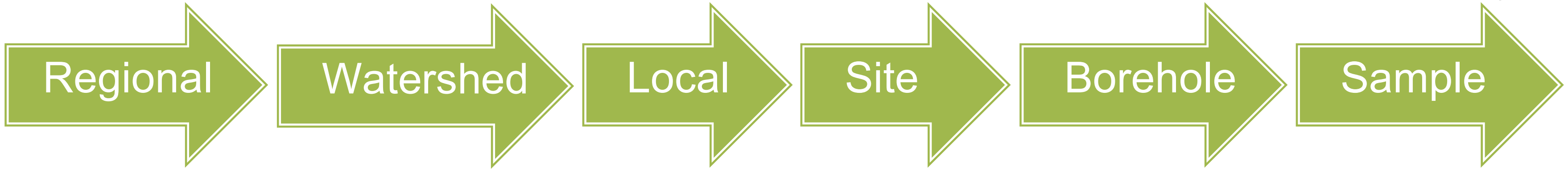


Preliminary CSM (EPA)

Zoom in to Site Scale

- **Site scale geologic mapping**
  - Work within the regional framework
  - Reconnaissance of the greater site area
  - What geological characteristics or features are important at the site (e.g., overburden, frac rock, deep plume, etc)?
  - Develop a mapping strategy that emphasizes ID & mapping of appropriate features

Measuring fractures with a Brunton (Bill Brandon, EPA)



Regional → Watershed → Local → Site → Borehole → Sample

Scales of Heterogeneity

Location	Setting	Horizontal K correlation length (m)	Vertical K correlation length (m)	Investigator
Chalk River Ontario	Aeolian/fluvial medium to fine sand	1.5	0.47	Indelman et al. (1999)
Borden CFB Ontario, Canada	Beach sand	2.8	0.12	Sudicky (1986)
Otis ANG Base Cape Cod Massachusetts	Glacial sand and gravel	2.9 – 8	0.18 – 0.38	Hess et al. (1992)
Columbus AFB, Mississippi	Fluvial gravel	12.7	1.6	Rehfeldt et al. (1992)
Aefligen Hydrothermal Site Switzerland	Glacial gravel	15 – 20	0.05 – 0.06	Hufschmied (1986)

- ♦ **Like geologic features, heterogeneity occurs at all spatial scales**
- ♦ **The scale of the study and CSM should be considered to inform the investigation strategies**
- ♦ **Minor variations in hydraulic conductivity in the horizontal or vertical direction (table on left) can have significant implications on groundwater flow and contaminant transport**

Publicly Available Geologic Data Sources

- ♦ **National Geological Survey**
  - » Geologic maps; publications
- ♦ **State or Local Agencies**
  - » Geological survey; mining agencies; water resources
- ♦ **Universities**
  - » Theses & dissertations
- ♦ **Professional Societies**
  - » e.g. GSA, AAPG, AIPG
- ♦ **Environmental Agencies**
  - » Cleanup site documents
- ♦ **Other: Roadside Geology; field trip guides**

經濟部中央地質調查所
Central Geological Survey, MOEA

中華民國地質學會
Geological Society Located in Taipei

臺灣地質知識服務網
Taiwan Geoscience Portal

Tips for Choosing Data Sources

- **Use peer-reviewed published technical sources**
- **Use and cite primary data source**
  - » If not available, reference appropriately (e.g. "Jones, 1967, cited in EPA 2019")
- **Use quality control checks for boring logs**

- **Best Practice: Apply quality control procedures <u>before</u> using and interpreting boring logs.**

How to Express a Geologic CSM

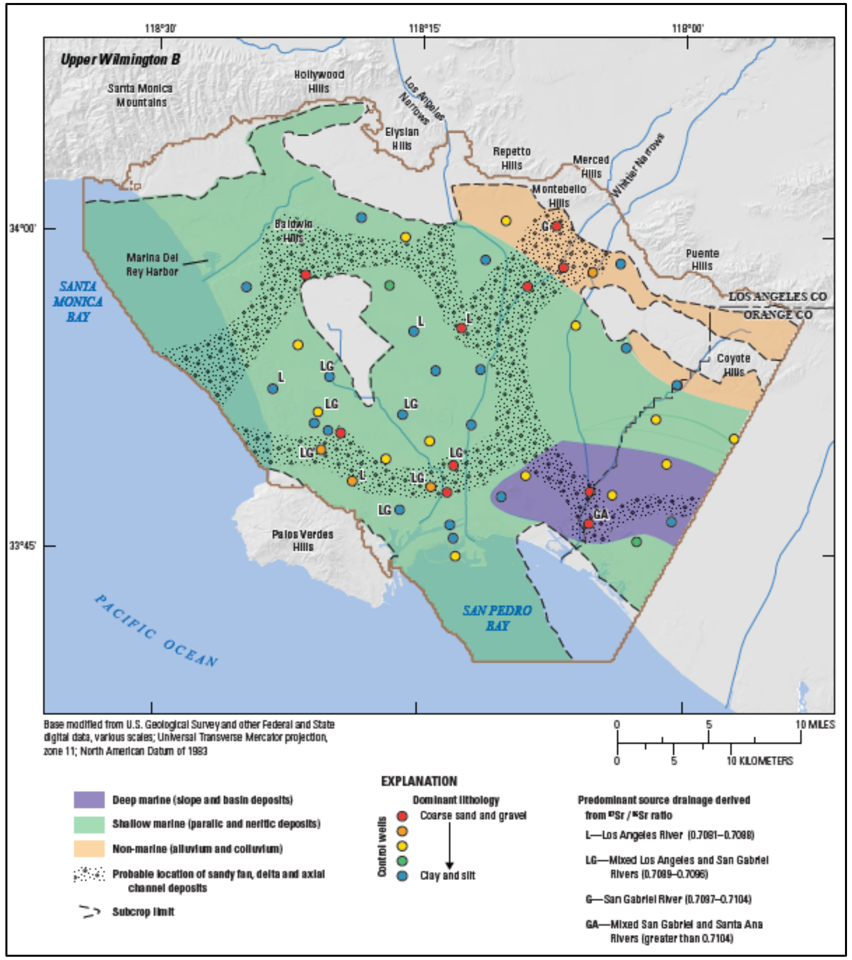
Your chosen CSM depends on:

- What do you want to show?
- How complicated is your site?
  - As site knowledge increases, the CSM can become more detailed

Common Expressions of the Geologic CSM	
Category	**Subcategories**
Geologic Feature Plan Map	Soil, Bedrock, Structural, Geophysical, or Depositional Environment
2D Profiles	Cross Sections; Fence Diagrams
Stratigraphic Column	Overburden, Rock, Combined
Block Diagram	General Site Features; Geologic Environment
Visualization	Geostatistical – 3DVA; Environmental Sequence Stratigraphy
Tables, Charts, Figures	Geologic Units; Fracture Data; Grain Size and Permeability Data
Other Supporting Data	Images; Conceptual Diagrams

2D CSM: Plan View Maps

- **Initial data collection activities can focus on the larger scale geologic components such as:**
  - Faults
  - Fracture traces
  - Depositional environments
  - Surficial geologic materials
- **At the site scale, plan view maps are also useful in showing more details like:**
  - Lithology
  - Thickness/topography of permeable and non-permeable zones
  - Bedrock topography
  - Other geologic characteristics



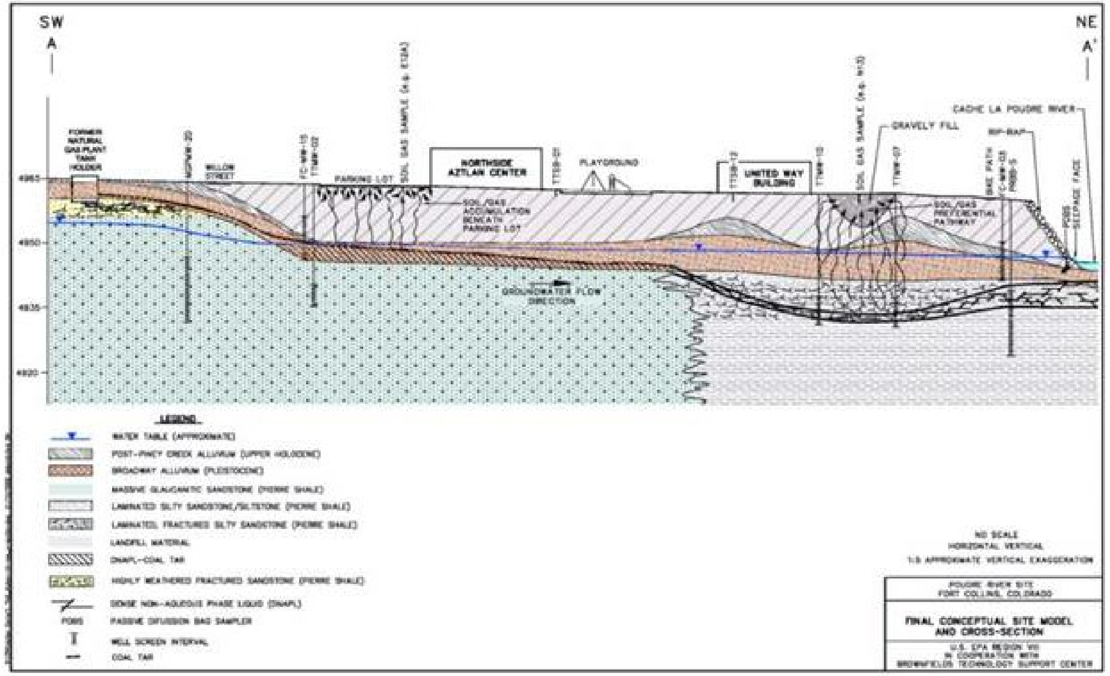
Base modified from U.S. Geological Survey and other Federal and State digital data, various scales; Universal Transverse Mercator projection, zone 11; North American Datum of 1983

Geologic plan view map showing depositional environments during one depositional cycle

2D CSM Profiles: Cross Sections and Fence Diagrams

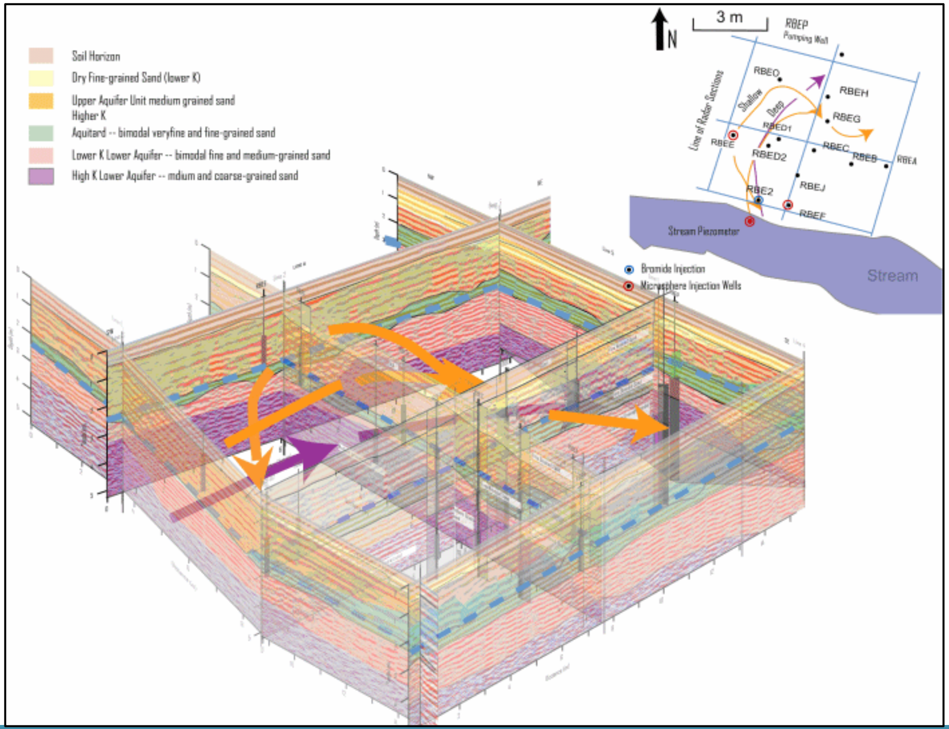
Cross sections:

- Provide interpretation of the sequence of geologic layers vertically and horizontally
- Boring logs are commonly used to produce cross sections, along with geophysical, test pit and other subsurface information

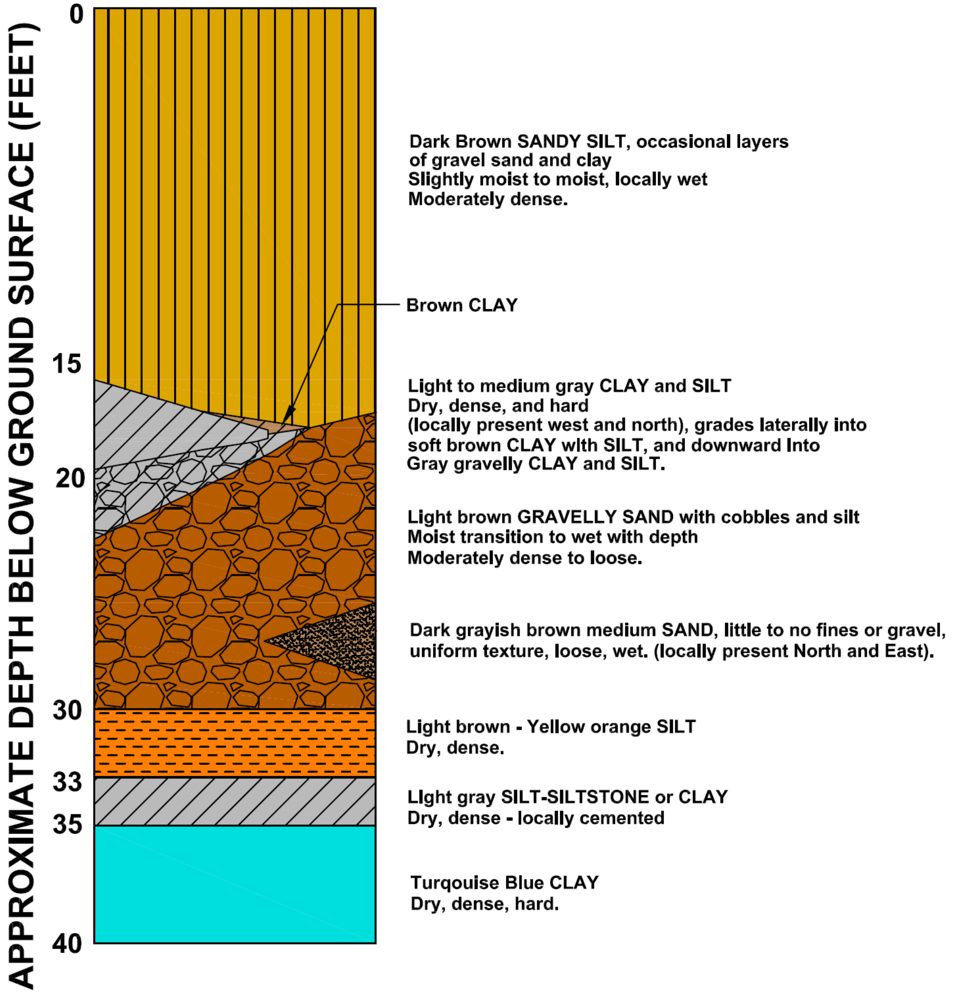


Fence Diagrams:

- When 3 or more intersecting cross sections are presented in perspective, a fence diagram allows the viewer to infer 3D relationships from the 2D cross sections



2D CSM: Stratigraphic Columns

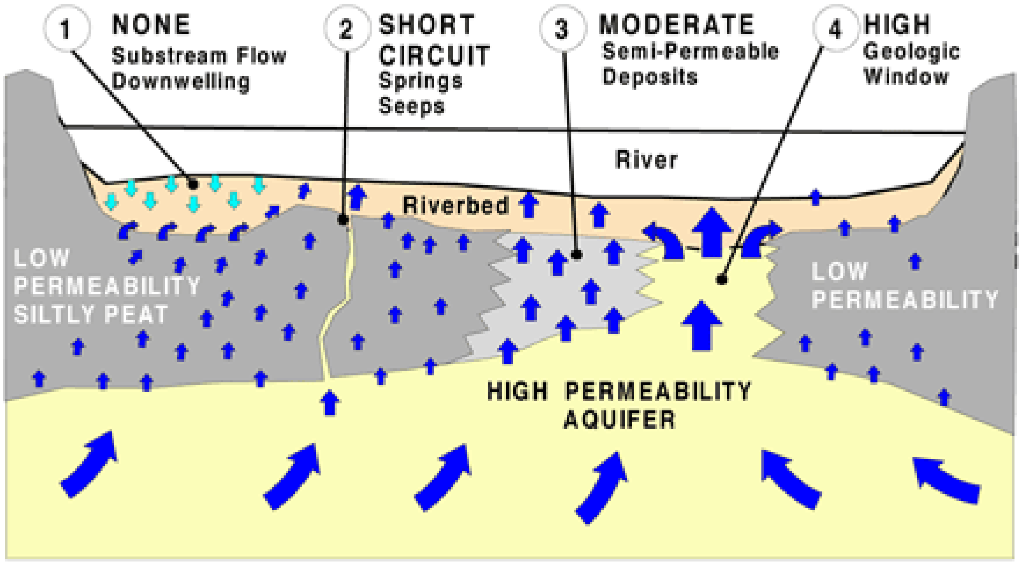


- **Provides the sequence of geologic materials at the site**
- **Helpful in planning field work as it provides an understanding of the anticipated geology**
- **Best Practices:**
  - Planning: Consider the objective
  - Constructing: Use consistent terminology, colors and patterns. Provide depth scale or ranges
  - Content: Keep the descriptions general and describe how the units vary geographically
  - Interpretation: Include detailed descriptions of the units and sitewide variability in the text

Other 2D Geologic Data Representations

- **Any useful geologic or data representation can become part of the CSM**
  - Tables, graphs, photographs, and figures

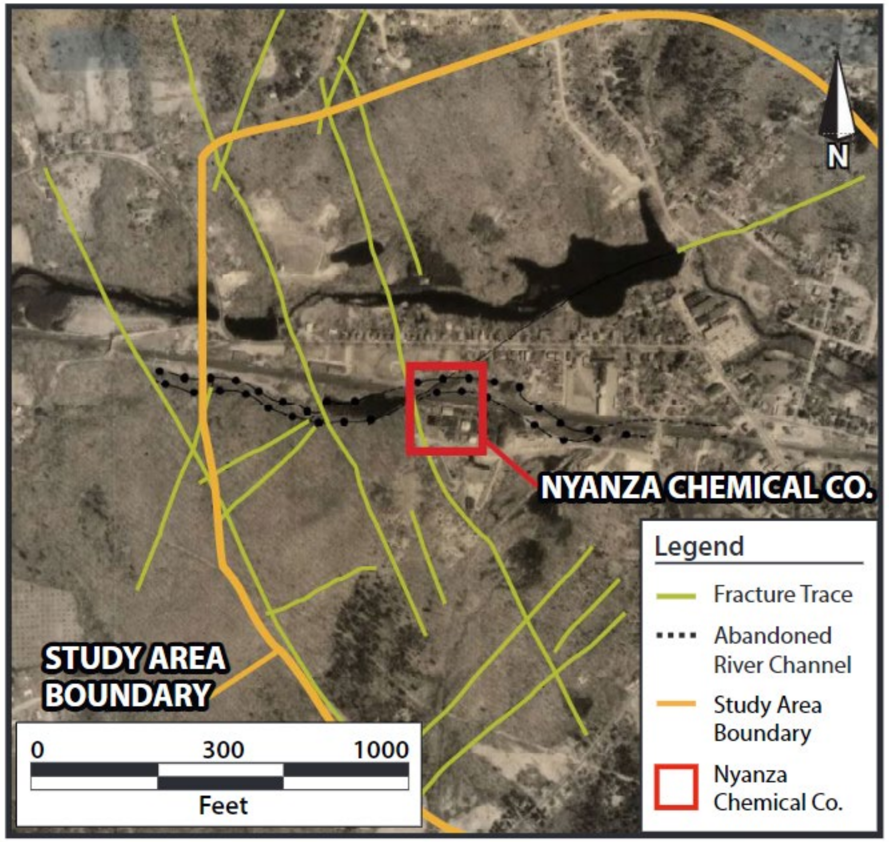
- **Best Practices:**
  - Planning: Use supplemental representations to show site condition details
  - Constructing: Cite the origin of diagrams, data sets, and photographs. Identify scales, graph axes, and orientation of photographs.
  - Content: Identify the key features of interest using highlights, circles, lines, and arrows.
  - Interpretation: Explain how the data supports the CSM.



Conceptual Diagrams in CSMs. Left - Conceptual diagram of heterogeneous geologic conditions in a stream. From EPA Clu-In Sediments, Conceptual Site Models

Developing an initial 2D CSM – Fractured Rock Example

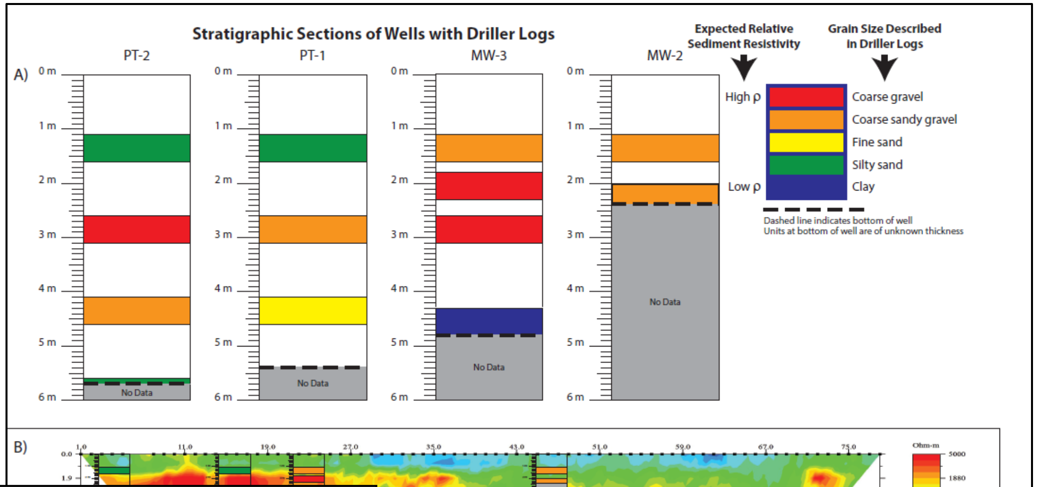
- **Compile & evaluate existing information**
  - Map the site to identify key geologic features
  - Identify general fracture styles & characteristics mapped at larger scale
  - Identify key fractures at site scale--orientation, lateral & vertical extents, aperture, hydraulic conductivity
  - Evaluate: If possible, develop a working model of the fracture network integrating mapping and subsurface data
  - Evaluate and identify additional data needs if necessary
  - Iterate as needed and update CSM



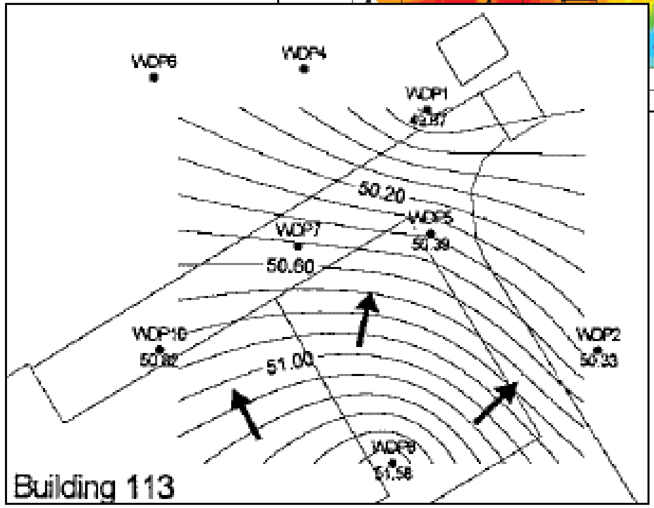
Fracture trace map (EPA)

Testing the CSM

- **Test/validate conceptual model with 3D exploration**
  - Use drilling, test pitting, geophysics to assess vertical dimension
  - Assess lateral & vertical connectivity using hydraulic or tracer testing
  - Assess hydraulic gradients in conjunction with geologic information
  - Revise and update the CSM



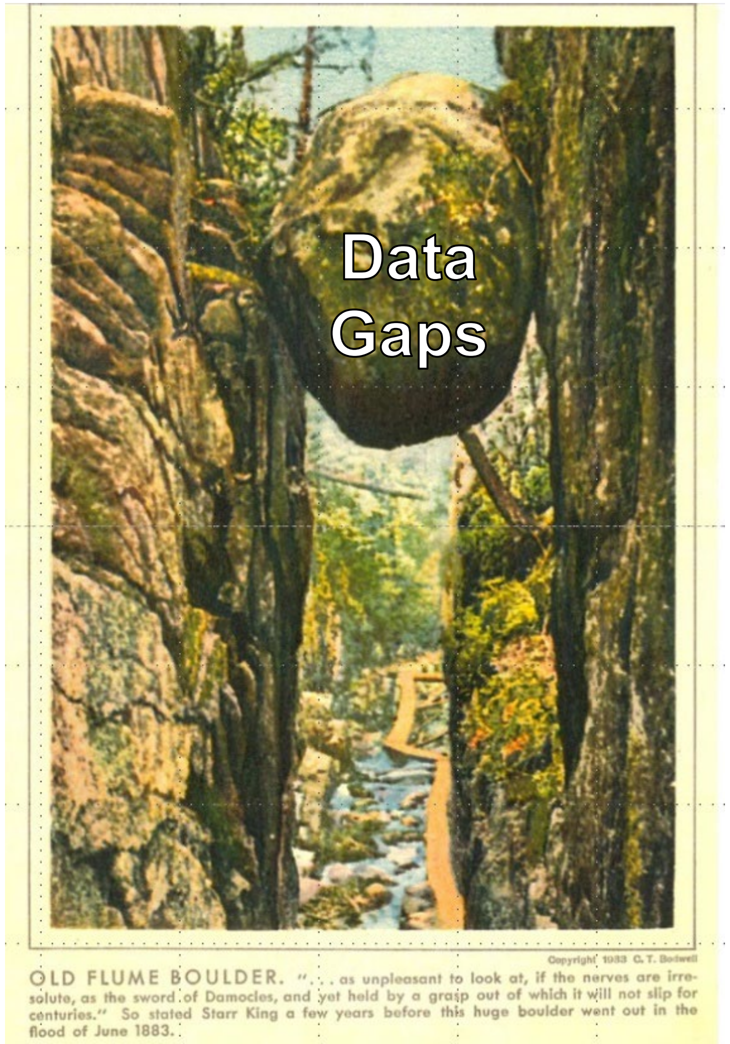
Correlation between boreholes and resistivity survey (Appalachian State University)



Hydraulic Gradient at Pease AFB

Develop 3D CSM

- **Are additional phases of work needed to fill data gaps?**
  - » Surface geophysics
  - » Borehole geophysics
  - » Hydrological testing
  - » Emerging techniques
  - » HRSC
  - » Targeted drilling & monitoring well installations



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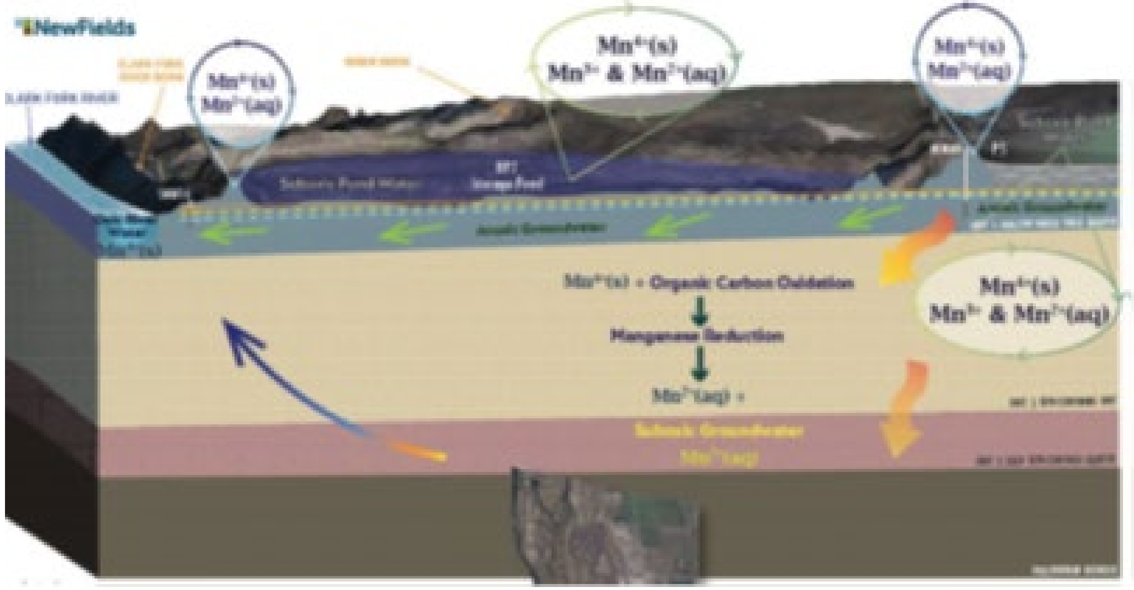
OLD FLUME BOULDER. "... as unpleasant to look at, if the nerves are irresolute, as the sword of Damocles, and yet held by a grasp out of which it will not slip for centuries." So stated Starr King a few years before this huge boulder went out in the flood of June 1883.

Conceptual Block Diagrams

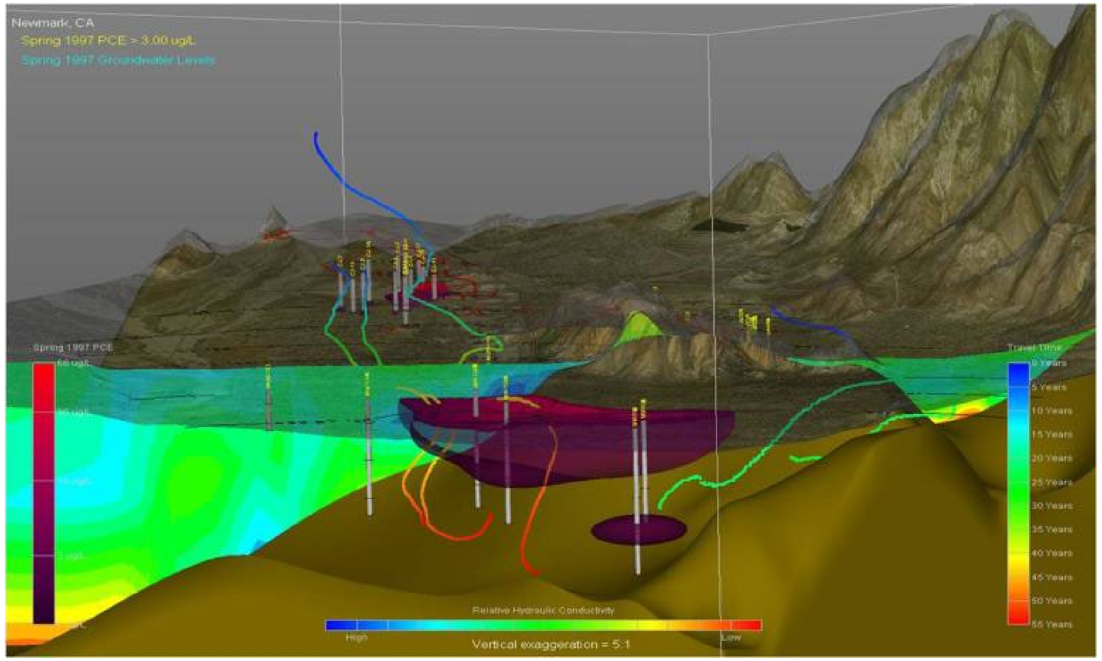
- ♦ **Used to express the relationship of geologic features in 3D**
- ♦ **Advantageous in focusing on key features and using images familiar to the reader such as houses, wells, streams, and lakes**
- ♦ **Best Practices for conceptual block diagrams:**
  - » Planning: Consider the objective. Decide on the level of detail and the key features
  - » Construction: State the scale and vertical exaggeration. Mark the diagram with compass directions. Use a viewing angle that maximizes the 3D content
  - » Content: Identify the most important geologic features with labels
  - » Interpretation: Do not overinterpret the content



Example of a block diagrams at a complex site showing geologic features that support the interpretation of manganese speciation

3D Visualization & Analysis (3DVA)

- **Data-based geospatial representation of surface and subsurface conditions**
- **Uses geostatistical interpolation to provide estimated values where data are sparse**



3DVA diagram example (EPA)

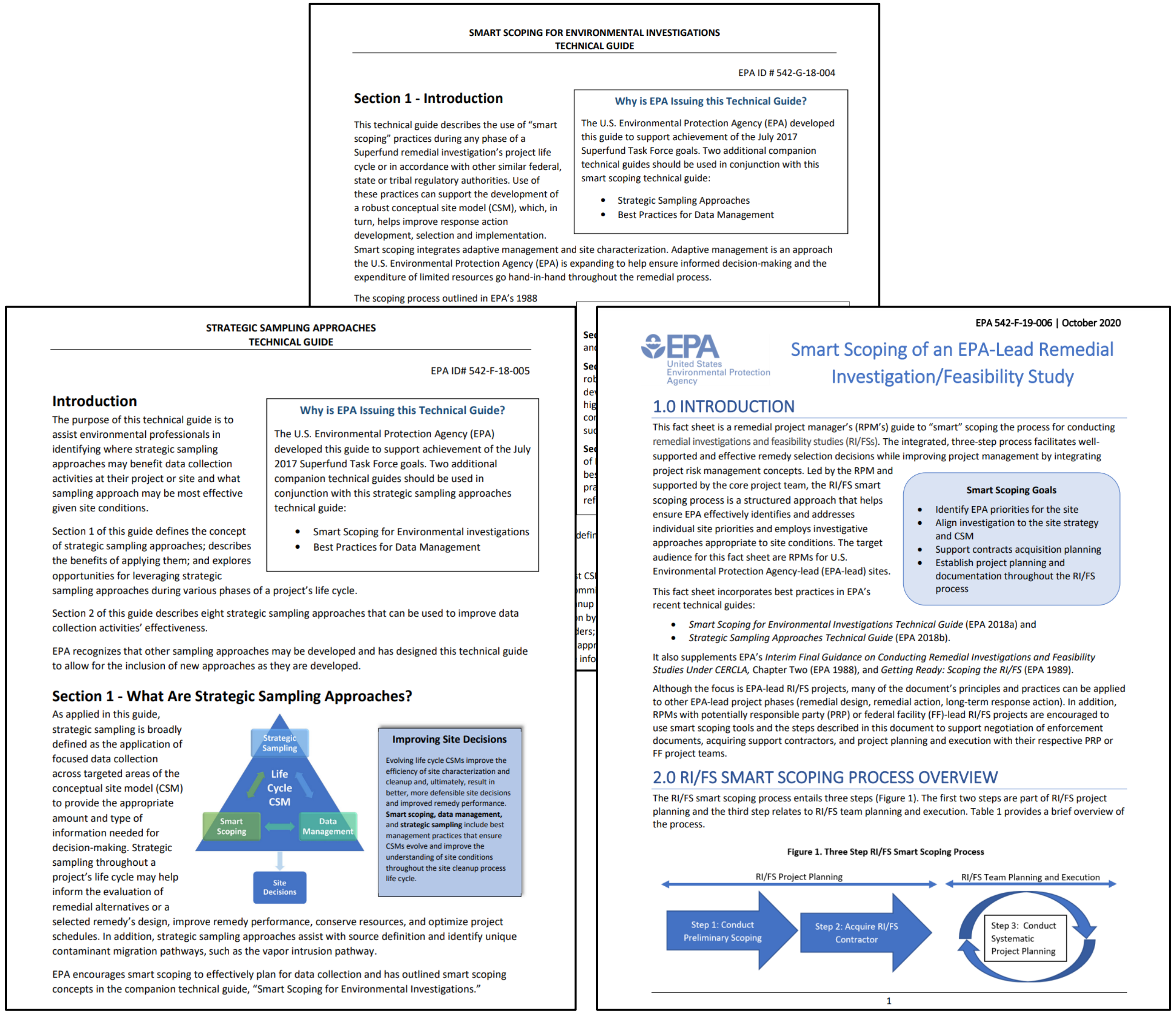
- **Common frameworks include:**
  - Lithology-based – Organizing geologic layers based on predominant grain size (gravel, sand, gravelly sand, silty sand, silt/clay)
  - Formation-based – Formation names are useful in correlating units over long distances
  - Depositional environments or facies-based – When enough geologic information is available to interpret the depositional environments

Considerations When Preparing and Interpreting 3DVAs

Issue	Consideration
Data Density	Interpolation between widely spaced data points (either spatial or depth) has less certainty than closely spaced points. Extrapolation beyond outside data points has high uncertainty and can be misleading.
Boring Log Quality	Drilling methods may affect the logged intervals and quality of the samples. Boring logs prepared by different loggers may not be consistent or may have different level of detail and accuracy in descriptions.
Boundary Effects	Data is often sparse at the boundaries of the site or model domain. Interpolations at the edge of the model domain tend to have more uncertainty because there is no bounding data.
Grouping versus Splitting Layers	Geologic descriptions can be grouped together to simplify the development of 3DVA. High resolution data is more helpful in understanding fate and transport of contaminants but may not always be practical.
Outputs	The final product of most 3DVAs are renderings of the data components. They are viewed using 3D PDFs, online tools, or software-specific data viewers. Data sets used in the visualization are generally available as spreadsheet files, but the final files are not easily transferred between platforms or contractors.

Scoping your Geologic CSM

- **Planning for scoping**
  - Uncertainty in the CSM is addressed and decreased throughout the project life cycle by implementing a strong scope
  - Planning activities that precede scoping include assembling a team and conducting **Systematic Project Planning** (SPP), which includes developing/revising the CSM
  - Several tools and technical guides are available at EPA to help the project team balance the cost and benefit of geologic data collection and develop a strong scope, such as the **Smart Scoping** guides at right



SMART SCOPING FOR ENVIRONMENTAL INVESTIGATIONS
TECHNICAL GUIDE

EPA ID # 542-G-18-004

Section 1 - Introduction

Why is EPA Issuing this Technical Guide?

The U.S. Environmental Protection Agency (EPA) developed this guide to support achievement of the July 2017 Superfund Task Force goals. Two additional companion technical guides should be used in conjunction with this smart scoping technical guide:

- Strategic Sampling Approaches
- Best Practices for Data Management

This technical guide describes the use of "smart scoping" practices during any phase of a Superfund remedial investigation's project life cycle or in accordance with other similar federal, state or tribal regulatory authorities. Use of these practices can support the development of a robust conceptual site model (CSM), which, in turn, helps improve response action development, selection and implementation.
Smart scoping integrates adaptive management and site characterization. Adaptive management is an approach the U.S. Environmental Protection Agency (EPA) is expanding to help ensure informed decision-making and the expenditure of limited resources go hand-in-hand throughout the remedial process.

The scoping process outlined in EPA's 1988

STRATEGIC SAMPLING APPROACHES
TECHNICAL GUIDE

EPA ID# 542-F-18-005

Introduction

Why is EPA Issuing this Technical Guide?

The U.S. Environmental Protection Agency (EPA) developed this guide to support achievement of the July 2017 Superfund Task Force goals. Two additional companion technical guides should be used in conjunction with this strategic sampling approaches technical guide:

- Smart Scoping for Environmental investigations
- Best Practices for Data Management

The purpose of this technical guide is to assist environmental professionals in identifying where strategic sampling approaches may benefit data collection activities at their project or site and what sampling approach may be most effective given site conditions.

Section 1 of this guide defines the concept of strategic sampling approaches; describes the benefits of applying them; and explores opportunities for leveraging strategic sampling approaches during various phases of a project's life cycle.

Section 2 of this guide describes eight strategic sampling approaches that can be used to improve data collection activities' effectiveness.

EPA recognizes that other sampling approaches may be developed and has designed this technical guide to allow for the inclusion of new approaches as they are developed.

Section 1 - What Are Strategic Sampling Approaches?

Improving Site Decisions

Evolving life cycle CSMs improve the efficiency of site characterization and cleanup and, ultimately, result in better, more defensible site decisions and improved remedy performance. **Smart scoping, data management,** and **strategic sampling** include best management practices that ensure CSMs evolve and improve the understanding of site conditions throughout the site cleanup process life cycle.

As applied in this guide, strategic sampling is broadly defined as the application of focused data collection across targeted areas of the conceptual site model (CSM) to provide the appropriate amount and type of information needed for decision-making. Strategic sampling throughout a project's life cycle may help inform the evaluation of remedial alternatives or a selected remedy's design, improve remedy performance, conserve resources, and optimize project schedules. In addition, strategic sampling approaches assist with source definition and identify unique contaminant migration pathways, such as the vapor intrusion pathway.

EPA encourages smart scoping to effectively plan for data collection and has outlined smart scoping concepts in the companion technical guide, "Smart Scoping for Environmental Investigations."

EPA 542-F-19-006 | October 2020

EPA United States Environmental Protection Agency

Smart Scoping of an EPA-Lead Remedial Investigation/Feasibility Study

1.0 INTRODUCTION

This fact sheet is a remedial project manager's (RPM's) guide to "smart" scoping the process for conducting remedial investigations and feasibility studies (RI/FSs). The integrated, three-step process facilitates well-supported and effective remedy selection decisions while improving project management by integrating project risk management concepts. Led by the RPM and supported by the core project team, the RI/FS smart scoping process is a structured approach that helps ensure EPA effectively identifies and addresses individual site priorities and employs investigative approaches appropriate to site conditions. The target audience for this fact sheet are RPMs for U.S. Environmental Protection Agency-lead (EPA-lead) sites.

Smart Scoping Goals

- Identify EPA priorities for the site
- Align investigation to the site strategy and CSM
- Support contracts acquisition planning
- Establish project planning and documentation throughout the RI/FS process

This fact sheet incorporates best practices in EPA's recent technical guides:

- *Smart Scoping for Environmental Investigations Technical Guide* (EPA 2018a) and
- *Strategic Sampling Approaches Technical Guide* (EPA 2018b).

It also supplements EPA's *Interim Final Guidance on Conducting Remedial Investigations and Feasibility Studies Under CERCLA,* Chapter Two (EPA 1988), and *Getting Ready: Scoping the RI/FS* (EPA 1989).

Although the focus is EPA-lead RI/FS projects, many of the document's principles and practices can be applied to other EPA-lead project phases (remedial design, remedial action, long-term response action). In addition, RPMs with potentially responsible party (PRP) or federal facility (FF)-lead RI/FS projects are encouraged to use smart scoping tools and the steps described in this document to support negotiation of enforcement documents, acquiring support contractors, and project planning and execution with their respective PRP or FF project teams.

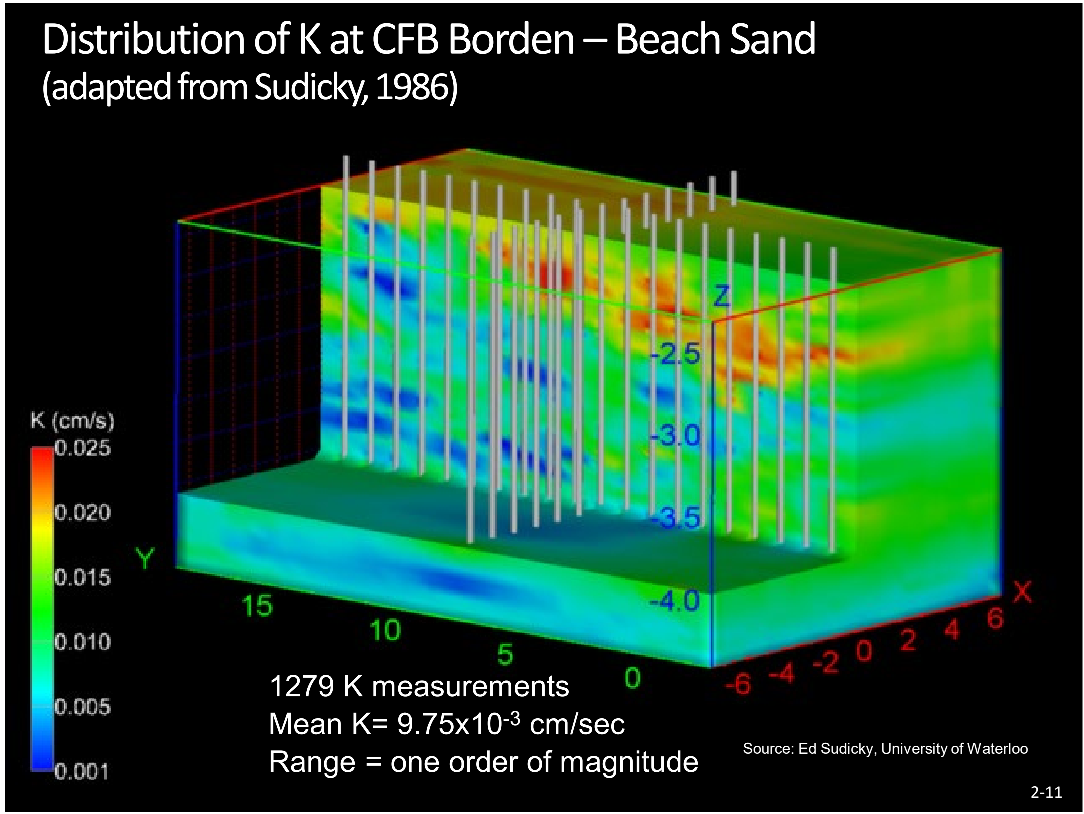
2.0 RI/FS SMART SCOPING PROCESS OVERVIEW

The RI/FS smart scoping process entails three steps (Figure 1). The first two steps are part of RI/FS project planning and the third step relates to RI/FS team planning and execution. Table 1 provides a brief overview of the process.

Figure 1. Three Step RI/FS Smart Scoping Process

1

Estimating Data Density Needs



Distribution of K at CFB Borden – Beach Sand
(adapted from Sudicky, 1986)

1279 K measurements
Mean K= 9.75×10^{-3} cm/sec
Range = one order of magnitude

Source: Ed Sudicky, University of Waterloo

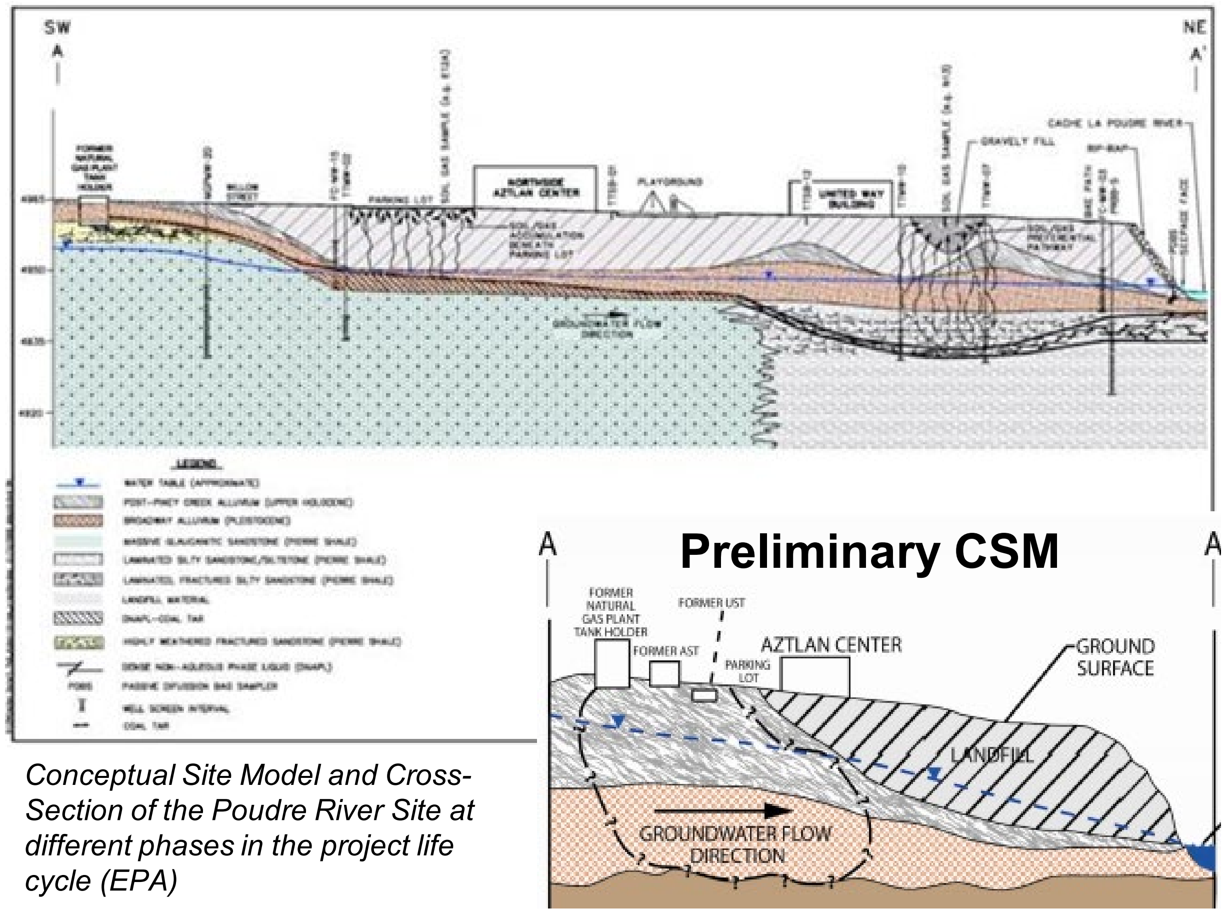
- ♦ **Each CSM has different data density needs, which is determined by the underlying geology**
- ♦ **Reviewing existing geologic data can give an understanding of how consistent the geologic features are and the depositional environments**
- ♦ **There is no agreed-upon rule of thumb for determining the number of borings needed, but the scale of heterogeneity and the acceptable level of uncertainty in the CSM will provide guidance**
  - » In general, source areas need more closely spaced data than downgradient areas

Scoping Best Practices

- **Scope from large scale to small scale data needs**
  - Review and assimilate the regional scale data before refining the data needs and approach for collecting the site scale data
- **Scope by project objectives and decision points**
  - When developing the scope, the team should clearly identify the objectives of the geologic data collection and how the data will be used for response actions
- **Use a Dynamic Work Strategy**
  - The dynamic approach may include iterative investigation phases or contingent investigations to address new data
- **Utilize all available resources**
  - EPA resource documents
  - EPA regional hydrogeologists, mining engineers and other experts
  - State geologic agencies
  - Colleges and universities

Applying the CSM

Design CSM



Conceptual Site Model and Cross-Section of the Poudre River Site at different phases in the project life cycle (EPA)

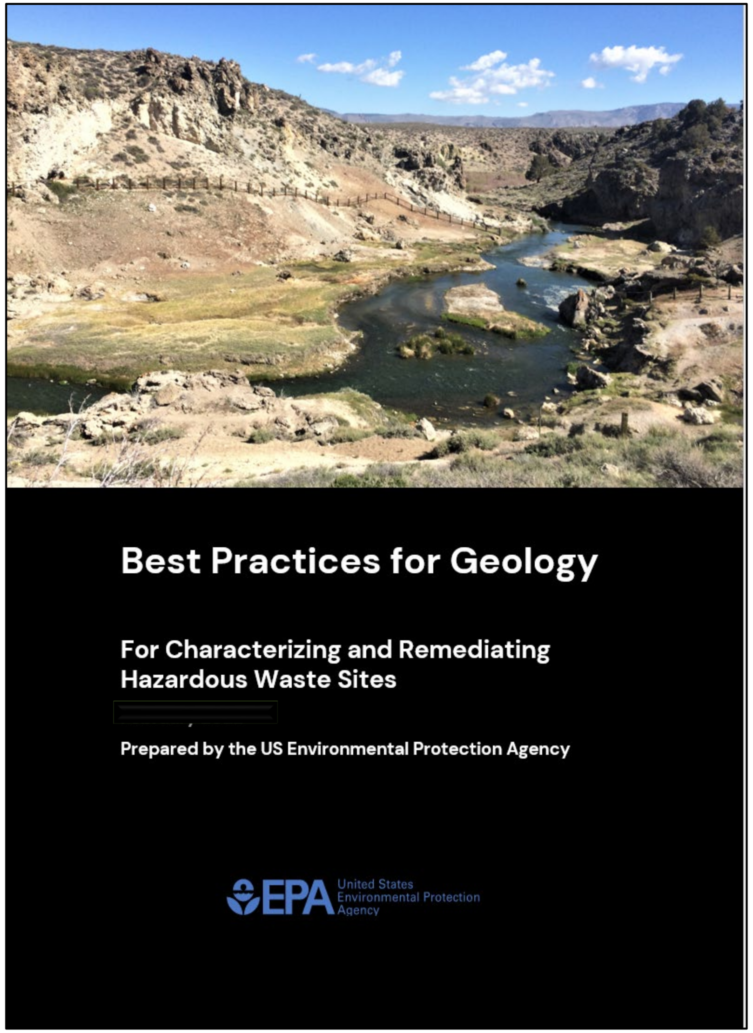
- ♦ **Use the CSM to guide remediation**
  - » Cache La Poudre River in CO
  - » ***Understanding geology helps in selecting more effective remedies***
- ♦ **Validate or update CSM periodically (Lifecycle CSM)**
  - » LTM and subsequent remedies are commonly needed
  - » Remedial performance monitoring
  - » Documents the most up to date CSM

More Geology Best Practices Coming Soon…

Geology Best Practices - coming in 2023!

Meanwhile, these documents are available…

- Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model
- Smart Scoping for Environmental Investigations Technical Guide
- Smart Scoping of an EPA-Lead Remedial Investigation/Feasibility Study
- Strategic Sampling Approaches Technical Guide



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