Recognizing Critical Processes and Scales in Conceptual Site Models for Decision Support at Sites of Groundwater Contamination

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Management Decisions at Sites of Groundwater Contamination

What motivates the development of a Conceptual Site Model (CSM)?

**Absolute Objectives:** Higher order community and societal (stakeholder) requirements (e.g., mitigate human and ecological adverse health effects, minimize disturbances to community, adherence to drinking water standards, etc.)

**Functional Objectives:** Operational goals that lead to successful achievement of absolute objectives (e.g., prevent off-site migration, source zone reduction/removal, reduction of concentrations to MCLs, etc.)

Functional objectives are the driving force for establishing & refining a Conceptual Site Model (CSM) and data collection to implement functional objectives.

.data requirements and detail in the CSM will vary depending on the defintion of the functional objectives.

Six-Step Process for Source Remediation

SCM = Site Conceptual Model
**Functional objectives** are like an elephant . . . they can appear to be large and cumbersome . . .

. . . require conceptualizing operational, physical, hydrogeologic, and biogeochemical processes over multiple spatial and temporal scales. . .

For example:  **Functional objective:** Mitigating off-site contaminant migration

- **Source zone characterization.** . . . source zone architecture and fluxes, chemical phases, solid-phase reactions, biogeochemical process, etc. . . .
- **Local and regional groundwater flow and contaminant transport.** . . . local and regional geologic controls, hydrologic & topographic controls, surface water drainages, chemical attenuation processes, etc. . . .
It helps to “compartmentalize” our thinking about Conceptual Site Models.

- Conceptualize processes that affect contaminant “storage” and contaminant fluxes
- Define site characterization, monitoring, and modeling to quantify contaminant “reservoirs” and contaminant fluxes (relevant to functional objectives)

(modified from Sale et al., 2008; Sale and Newell, 2011; ITRC 2011)
**Functional objectives** are like an elephant . . . they can appear to be large and cumbersome . . .

. . . how do you eat an elephant?

. . . one bite at a time!

- Identify contaminant “reservoirs” and fluxes that dominate process outcomes . . .
- Identify spatial and temporal scales that dominate processes outcomes . . .

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**Organic Contaminants:**

14 - Compartment Model and Contaminant Fluxes between Compartments

- Identify contaminant “reservoirs” and fluxes that dominate process outcomes.
- Identify spatial and temporal scales that dominate processes outcomes.

(modified from Sale et al., 2008; Sale and Newell, 2011; ITRC 2011)
An Example of Applying Functional Objectives

- **Mitigating off-site contaminant migration in fractured rock**

Discussions of the complexity of fractured rock aquifers (Site Characterization, Modeling, and Applications to Waste Isolation and Remediation)


An Example of Applying Functional Objectives

- **Mitigating off-site contaminant migration in fractured rock**

Fractures control groundwater flow...

...but, there are numerous fractures...

...over dimensions from centimeters to kilometers.

Do we need to characterize “all” fractures to achieve the objective of mitigating off-site contaminant migration?
What do we know about fractures and their capacity to transmit groundwater?

Fractures and Fracture Transmissivity in a Single Borehole

Granite and schist
Mirror Lake, NH

Straddle packers isolate a section of borehole to conduct hydraulic tests.
Few fractures control majority of groundwater flow. Results of hydraulic tests conducted in boreholes over the Mirror Lake watershed, New Hampshire.
An Example of Applying Functional Objectives

- **Mitigating off-site contaminant migration in fractured rock**

**Critical Process and Scales:**

- Narrowed from looking at all fractures...to only the most transmissive fractures & their connectivity
- Narrowed data collection and monitoring efforts
- Information critical to design of mitigation (e.g., hydraulic containment, constructed barriers, etc.)
Identifying Transmissive Fractures and Their Connectivity

**Advances over 25+ years**

- Local and regional tectonic and lithologic controls on fracturing
- Surface and borehole geophysical methods
- Multilevel monitoring equipment
- Design and interpretation of hydraulic and tracer tests
- Modeling groundwater flow and parameter estimation methods
Identifying Transmissive Fractures and Their Connectivity

Granite and Schist, Mirror Lake Watershed, New Hampshire

FSE Well Field Plan View

FSE Well Field Cross Section

USGS
Identifying Transmissive Fractures and Their Connectivity

Clustering of drawdown records from different monitoring intervals during hydraulic tests provides evidence of transmissive fractures & fracture connectivity. . .
Mitigating off-site contaminant migration in fractured rock

- Identify the most transmissive fractures & their connectivity
  
  . . . identify pathways of contaminated groundwater from source zone to compliance boundaries. . .

  . . . additional information needed to characterize the potential for off-site migration. . . e.g., source zone inputs, attenuation processes, sources/sinks from rock matrix, etc. . . .
An Example of Applying Functional Objectives

- **Mitigating off-site contaminant migration in fractured rock**
  - Identify contaminant fate and transport along groundwater flow paths. . .

**One approach** -> incorporating biogeochemical processes into groundwater flow path models. . .

TCE, DCE, VC are electron acceptors which compete with other electron accepting processes
An Example of Applying Functional Objectives

- **Mitigating off-site contaminant migration in fractured rock**
- Identify contaminant fate and transport along groundwater flow paths.

*Modeling chemical transport in fracture networks is conceptually complex & computationally intensive to account for mobile and immobile groundwater... parameterization is highly uncertain.*

Flow paths in fractures are highly convoluted.
An Example of Applying Functional Objectives

- Mitigating off-site contaminant migration in fractured rock
- Identify contaminant fate and transport along groundwater flow paths
  
  Alternatively -> conceptualize biogeochemical processes along representative flow paths and identify conditions that bound process responses...

Natural Attenuation Software
An Example of Applying Functional Objectives

- Mitigating off-site contaminant migration in fractured rock

Conceptual Site Model:

- **Critical process:** Chemical advection by most transmissive fractures

- **Bounding process outcomes:**
  - Source zone and attenuation processes along representative groundwater flow paths
  - Account for uncertainty in groundwater flow paths
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Summarizing...

• Beneficial to have understanding of all processes and scales that affect contaminant fate and transport...

• To address specific functional objectives...all processes and scales do not need to translate into a decision support tool...

• Recognize critical processes and fluxes — constrains and focuses data collection efforts...couple less complex models to bound process outcomes...

• Recognize critical processes and fluxes — address spatial and temporal scales consistent with limitations of complexity and data availability...
Selected References


