# GW/SW Interactions: Developing Conceptual Site Models of Organism Exposures

*Robert Ford*

**Office of Research and Development**
**National Risk Management Research Laboratory, Cincinnati, OH**
**USEPA Region 10 GW-SW Workshop, November 16, 2018**

# Disclaimer

The findings and conclusions in this presentation have not been formally disseminated by the U.S. EPA and should not be construed to represent any agency determination or policy.

# Developing Effective Conceptual Site Models

# Developing Effective Conceptual Site Models

## Common Scenarios at Contaminated Sites

- There is a GW plume at a site that is near a surface water body.
  - *Is the GW plume impacting the SW body or does the potential exist?*
- There is an observed impact within a surface water body adjacent to a contaminated site.
  - *Is the impact related to GW plume discharge?*

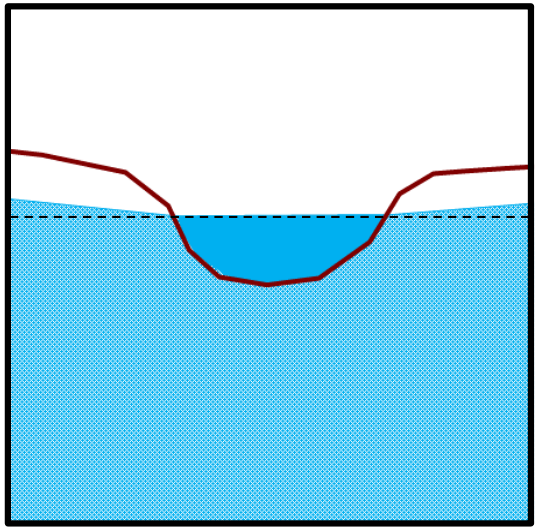
# Developing Effective Conceptual Site Models

- CSM needs to be informed by knowledge of several components
  - Site hydrology
  - Contaminant transport characteristics
  - Ecological exposure endpoints
- Interaction of these factors dictates location and magnitude of exposure

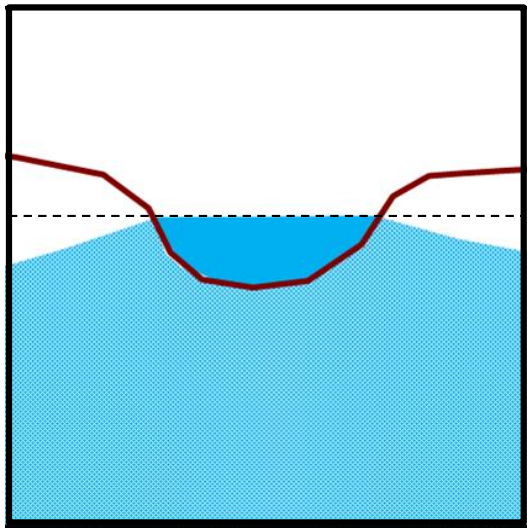
## Effective CSMs - Site Hydrology Issues

- Hydraulic connection between GW plume and surface water body
  - Does it exist?
  - If so, is it continual or episodic?
  - When connected, does the direction of water exchange vary?
- Questions need to be addressed to understand timing and location of exposure

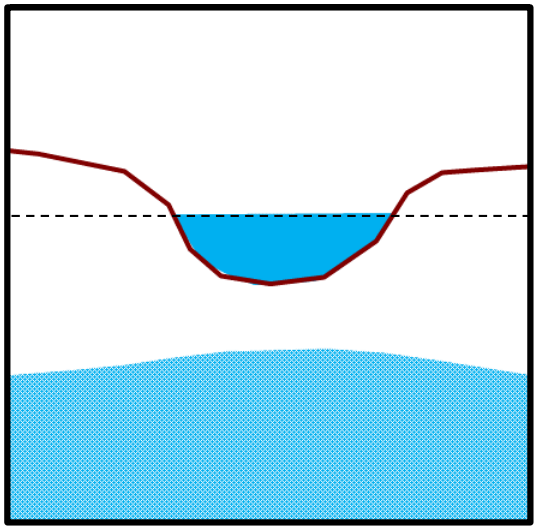
# Developing Effective Conceptual Site Models



Connected Gaining

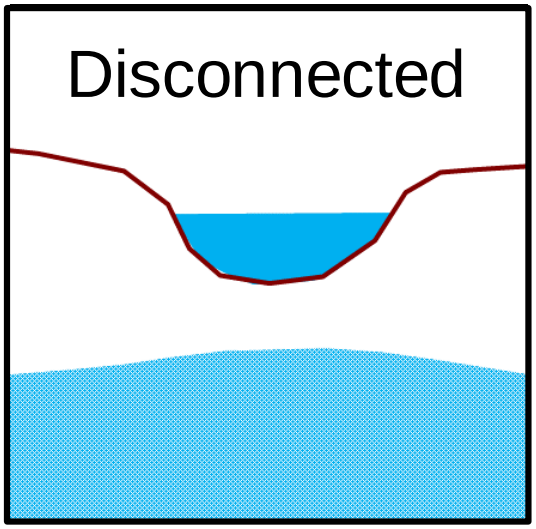


Connected Losing



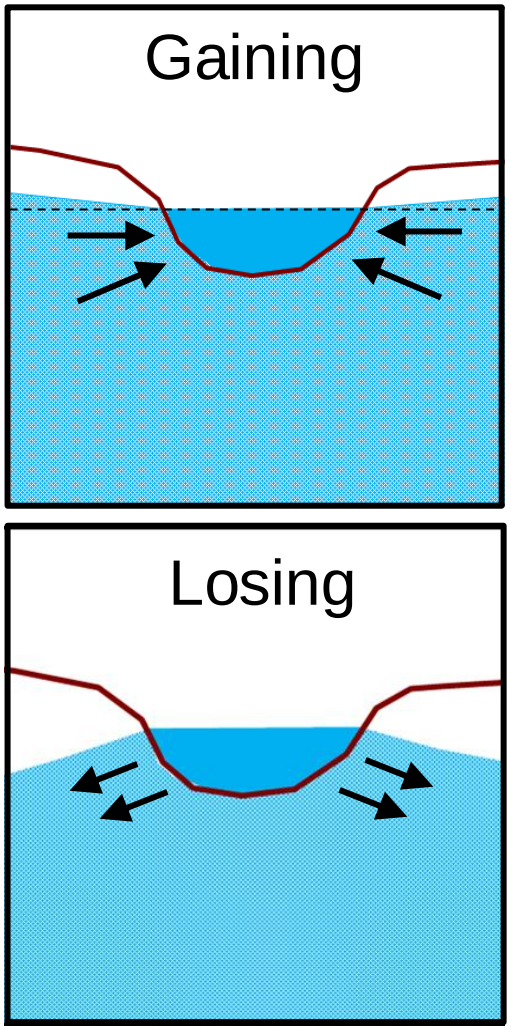
Disconnected

# Developing Effective Conceptual Site Models



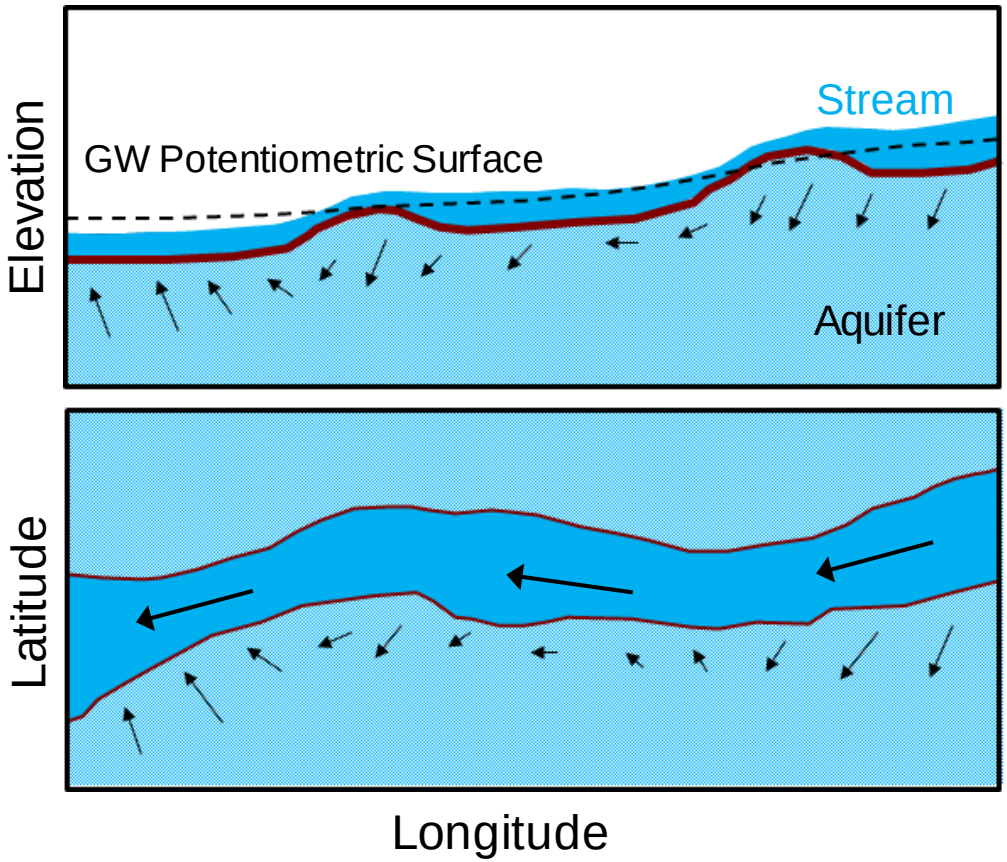

- Not uncommon to have deep unsaturated zone
- May be an episodic situation for semi-arid climates with extended dry-wet periods
- Need to develop good understanding of local GW table elevation and seasonal variation
  - Episodic (e.g., quarterly) manual measurements of GW table insufficient to assess situation

# Developing Effective Conceptual Site Models




- GW contribution to SW flow may vary seasonally or due to external forces
  - Flow management in SW body
  - GW extraction system operations
- Need to define gaining period & location in relation to GW plume
- May also vary along reach of SW body

# Developing Effective Conceptual Site Models




- Site topography and stream morphology influence GW flow direction and magnitude
- May need to characterize this spatial variability relative to GW plume dimension
- GW is not a static system, but may respond more slowly to changes in water budget (continuous logging)

# Developing Effective Conceptual Site Models

- An effective CSM depends on understanding contaminant transport
- Typically attempt to combine some level of knowledge of GW flow with measurements of contaminant concentrations in GW and SW
- Contaminant non-detects that occur along some assumed flow path could mean two things:
  - Plume edge does not reach SW
  - ***Monitoring location is not in the flow path***
- Hydrologic measurements within the GW/SW transition zone bridge upland GW-to-SW pathway

# Developing Effective Conceptual Site Models

## Freely Available Resources - Hydrology

- Ground Water and Surface Water, A Single Resource

  U.S. Geological Survey Circular 1139
  https://pubs.usgs.gov/circ/circ1139/

- Field Techniques for Estimating Water Fluxes Between Surface Water and Ground Water

  U.S. Geological Survey Techniques and Methods 4-D2
  https://pubs.usgs.gov/tm/04d02/

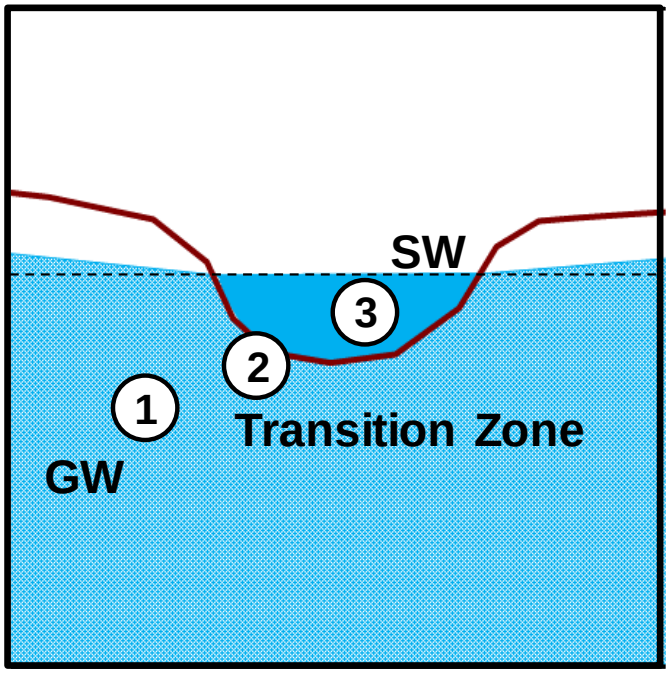
# Factors Affecting Contaminant Transport and Exposure Route

# Factors Affecting Contaminant Transport and Exposure Route

## Contaminant Transport Issues

- Contaminant properties dictate whether it will remain mobile in water, attached to sediment, and/or change chemical form
  - Does contaminant partition to aquifer/sediment solids?
  - Does it biodegrade? Product non-toxic and/or immobile?
  - Does chemical form change due to shifts in water chemistry?
- This will govern locations and types of media to sample for exposure assessment

# Factors Affecting Contaminant Transport and Exposure Route




1) Contaminant may attenuate in aquifer and stop moving with GW flow
2) Contaminant may attenuate in sediment before entering SW
   - Benthic community may dictate transfer through food chain
   - Biodegradation, bioavailability
3) Changes in porewater or SW chemistry may cause change in contaminant form in sediment and mobility

# Factors Affecting Contaminant Transport and Exposure Route

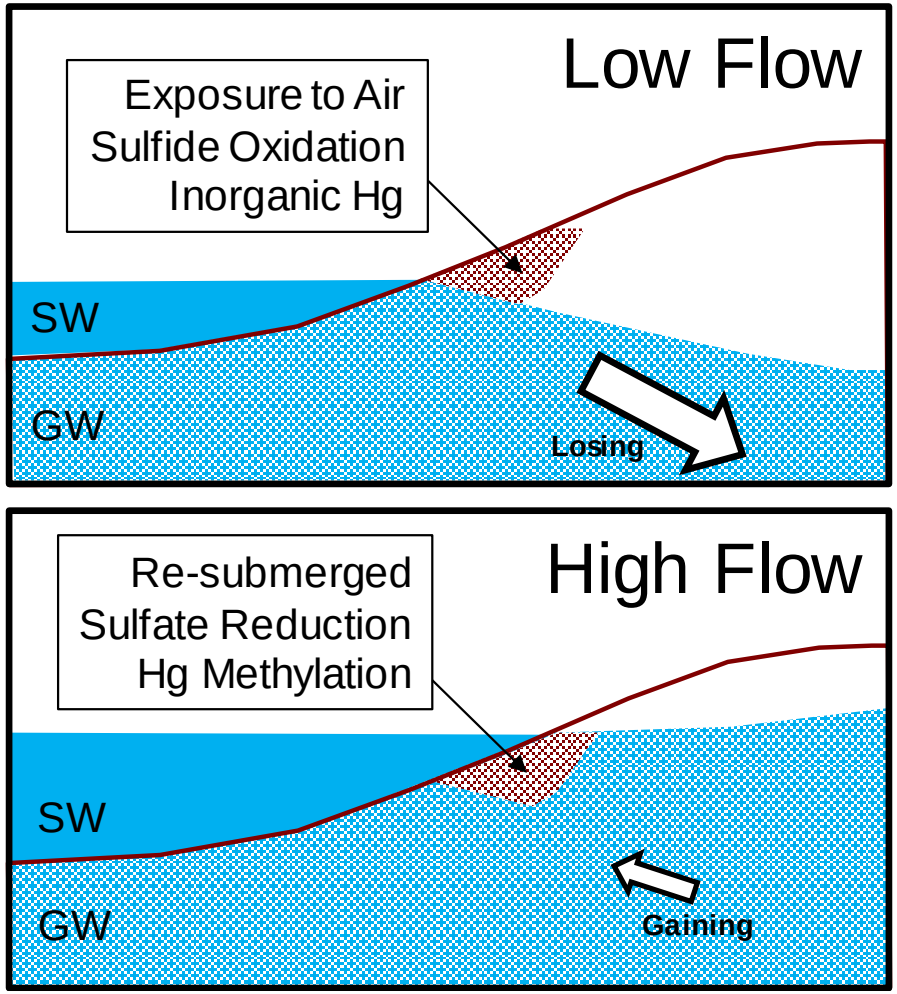
**Factors that influence contaminant mobility or toxicity**

- Other chemicals alter contaminant mobility
  - Hydrophobic Organic Compounds (HOCs) + Solvents
  - Metals (copper) + High TDS (salts)
- Microbial processes in sediment
  - Conversion of mercuric ions to methylmercury
  - Conversion of PCE to vinyl chloride
- Oxic-anoxic transitions (redox)
  - Reduction of arsenate (immobile) to arsenite (mobile)
  - Driven by biology or oxygen mass-transfer dynamics

# Factors Affecting Contaminant Transport and Exposure Route

## Hydrologic Fluctuations

- Contaminated sediment exposure to air during baseflow can affect Hg chemistry
- Hg-methylation linked to microbial conversion of sulfur and organic carbon
- Patterns in Methyl-Hg production during gaining periods may be misinterpreted as GW flux





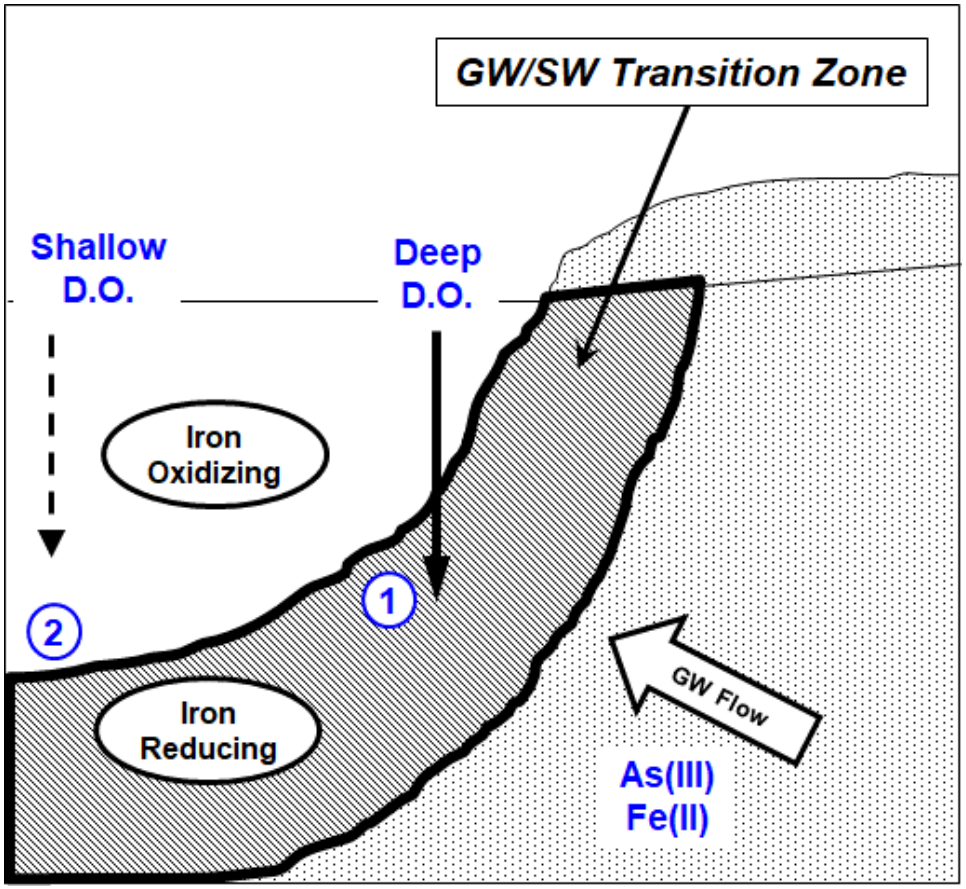



Chris Eckley (Region 10), Todd Luxton (ORD)

# Factors Affecting Contaminant Transport and Exposure Route

## Reduced GW Plume

- SW body with varying water depth in which oxygen reaches sediments in shallow locations but not deep
- Oxidation & attenuation of Fe and As in sediments for shallow depths
- Unhindered transport of As into SW for deeper depths



# Factors Affecting Contaminant Transport and Exposure Route

## Freely Available Resources - Contaminant Transport

- Evaluating Potential Exposures to Ecological Receptors Due to Transport of Hydrophobic Organic Contaminants in Subsurface Systems

  EPA/600/R-10/015
  https://clu-in.org/download/contaminantfocus/sediments/EPA-600-R-10-015.pdf

- The Impact of Ground-Water/Surface-Water Interactions on Contaminant Transport with Application to an Arsenic Contaminated Site

  EPA/600/S-05/002
  https://nepis.epa.gov/

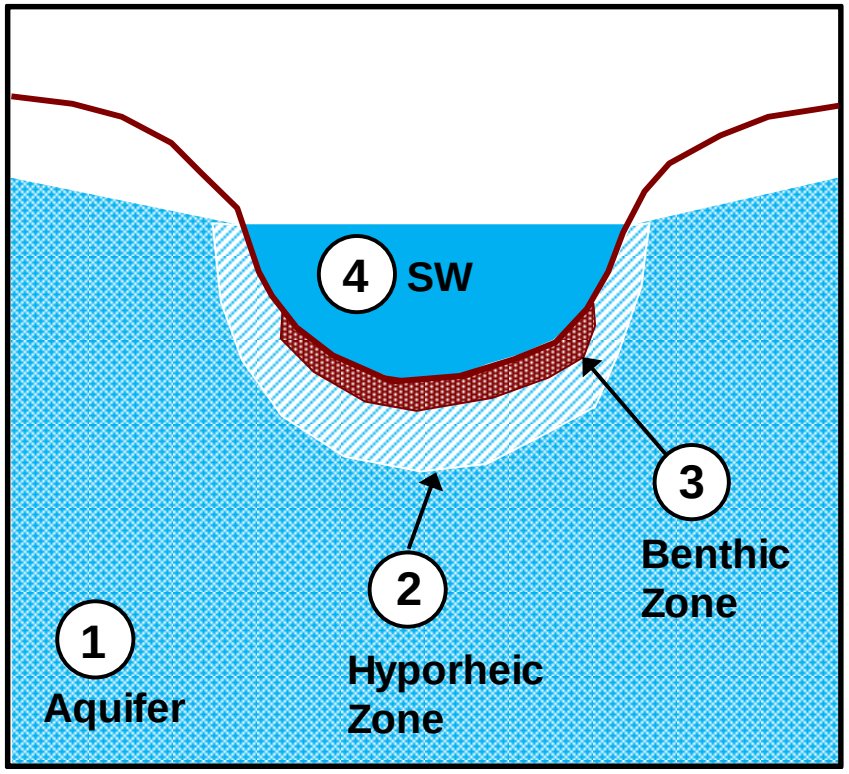
# Importance of Characterizing the GW/SW Transition Zone

# Importance of Characterizing the GW/SW Transition Zone

## Why monitor the GW/SW Transition Zone?

- Transition from aquifer to surface water body is typically characterized by dramatic compositional gradients
  - Aquifer solids (local geology) transition to aquatic sediments (contributions from deposition and biological productivity)
  - Water chemistry (abiotic and biotic reactions)
  - GW-SW mixing (variable in space and time)

# Importance of Characterizing the GW/SW Transition Zone




## Potential for Exposure

1) Contaminant attenuates in aquifer prior to discharge (No)
2) Contaminant attenuates in hyporheic zone below benthic zone (No / Not Likely)
3) Contaminant attenuates in benthic zone (Likely / Bioaccumulation-Biotransfer-Biomagnification)
4) Contaminant transports into SW with GW discharge (Yes)

# Importance of Characterizing the GW/SW Transition Zone

## Exposure Route(s) and Endpoint(s)

- Need to understand contaminant transport relative to organism(s) of concern and exposure route
  - Direct exposure to higher trophic levels in water column may be important, but not only route
  - Predation of exposed benthic organisms, with transfer along food chain, may also be important
  - GW-SW transition zone data may provide critical knowledge for projecting or understanding ecological impacts

# Importance of Characterizing the GW/SW Transition Zone

## Why monitor the GW/SW Transition Zone?

- Significant changes in contaminant transport may occur that can limit ability to rely solely on upland GW & SW data
  - GW discharge occurring with contaminant attenuation in transition zone…
    *At a depth in sediment that is biologically accessible?*
    *Could conditions supporting attenuation change during different hydrologic periods?*
  - GW discharge not occurring…
    *Are your measurements at right location?*
    *Different location or time of year?*

# Importance of Characterizing the GW/SW Transition Zone

## Freely Available Resources – Transition Zone

- Evaluating Ground-Water/Surface-Water Transition Zones in Ecological Risk Assessments

  EPA/540/R-06/072
  https://www.epa.gov/sites/production/files/2015-09/documents/eco_update_08.pdf

- Proceedings of the Ground-Water/Surface-Water Interactions Workshop (Part 1, 2, 3)

  EPA/542/R-00/007
  https://www.epa.gov/remedytech/proceedings-ground-watersurface-water-interactions-workshop-0

# Importance of Characterizing the GW/SW Transition Zone

## Freely Available Resource – Ecosystem Services

- Ecosystem Services at Contaminated Site Cleanups

  EPA/542/R-17/004
  https://www.epa.gov/remedytech/ecosystem-services-contaminated-site-cleanups

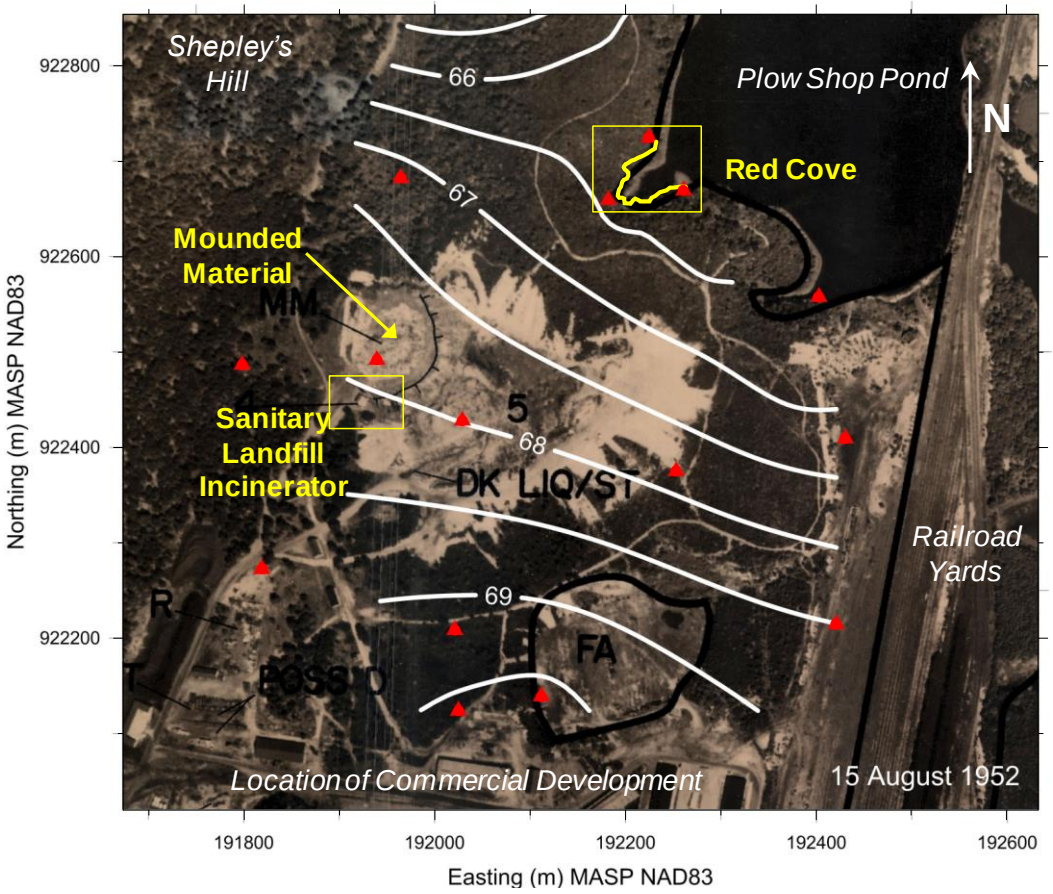
  – Facilitate communication of why certain endpoints are selected: Direct Benthic Impact = Indirect Food Chain Impact (Fish)

  – Envisions considering impacts that may be outside of current “routine” scenarios: Altered Behavior (migration) vs. Health Impact

# Real Examples of Conceptual Site Models

# Real Examples of Conceptual Site Models

## (Former) Fort Devens Superfund Site



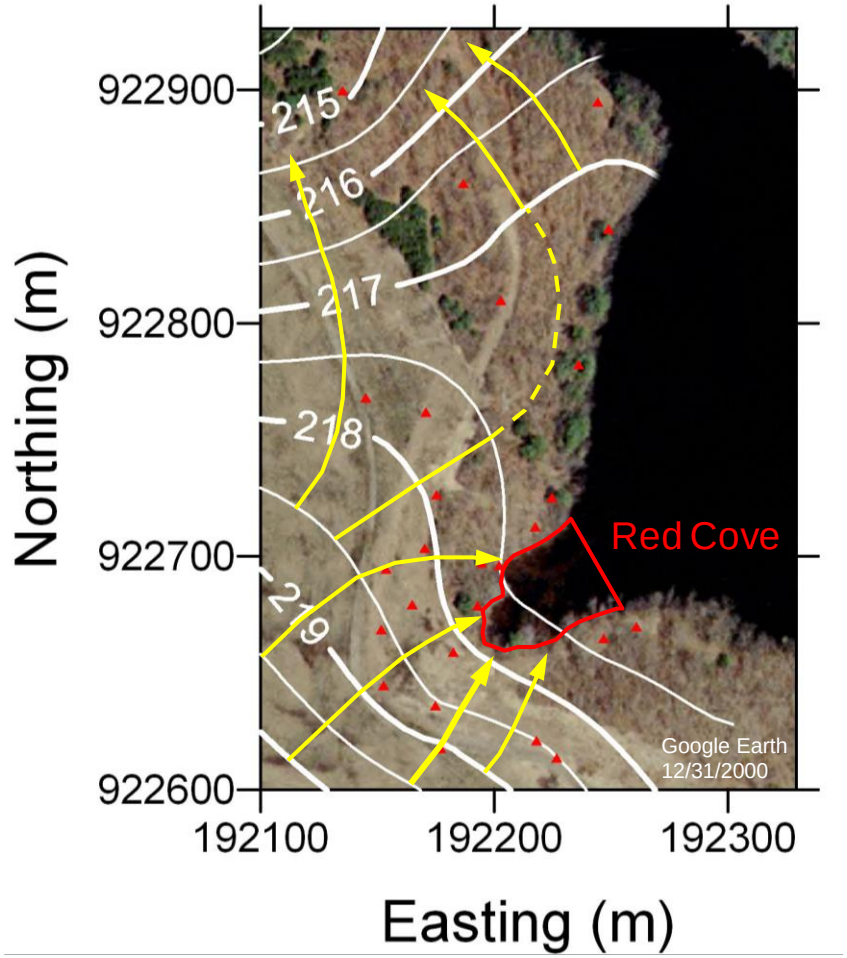

- Historic, un-lined landfill
- Arsenic contamination in GW derived from waste and natural sources
- Flow-through, recreational lake influenced by storms & beaver dams
- Contaminated GW discharging to part of adjacent lake





Ford et al (2011) Chemosphere, 85: 1525-1537

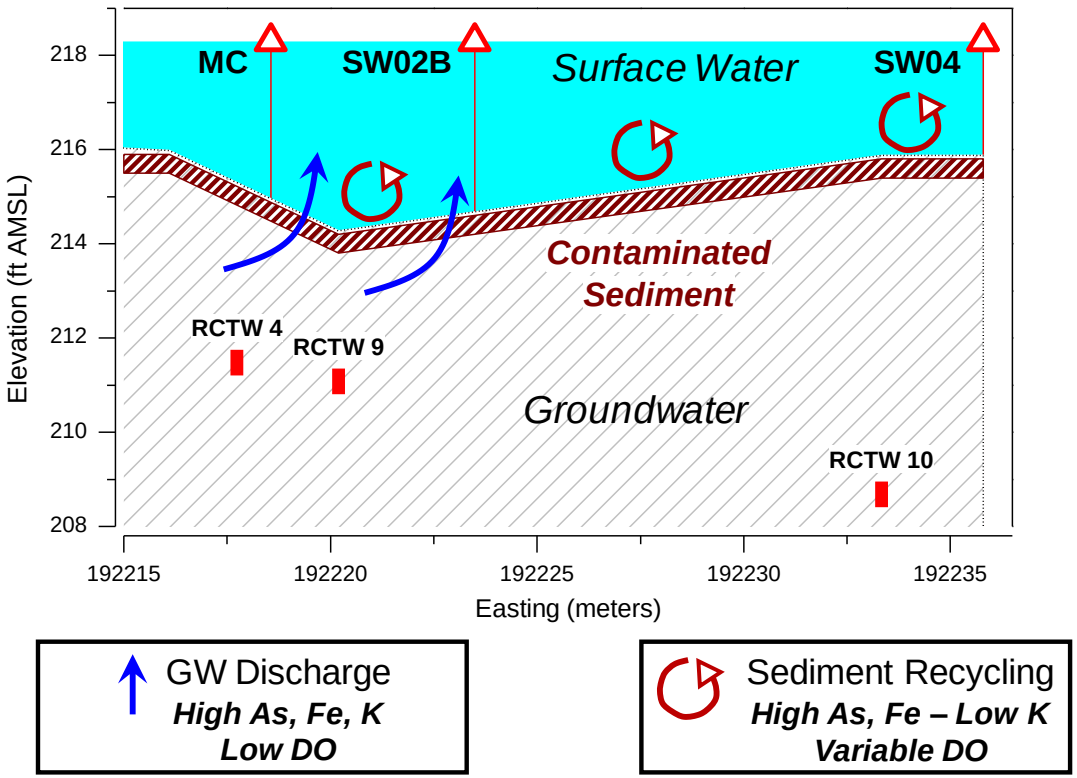
# Real Examples of Conceptual Site Models




## Initial CSM

- GW plume discharge to “Red Cove” source of contaminated sediment
- Sediment impacts to survival and growth of benthic test organisms due to accumulated metals from plume
- Characterization in cove to examine flow pattern & contaminant concentrations in GW, pore water, sediment, and SW

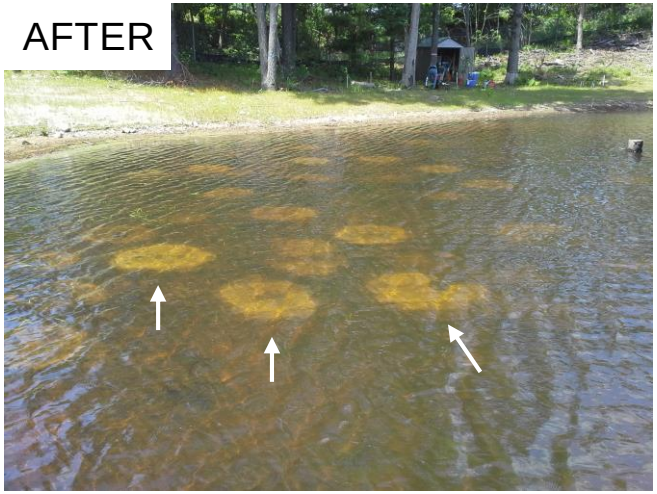
# Real Examples of Conceptual Site Models




## Refined CSM

- GW flux measurements indicated discharge not spatially uniform
- Vertical chemical profiles through SW column & shallow GW revealed areas of As flux from plume discharge
- Sustained AWQC exceedances at plume discharge locations
- Episodic high As in SW in other locations primarily due to sediment release

# Real Examples of Conceptual Site Models

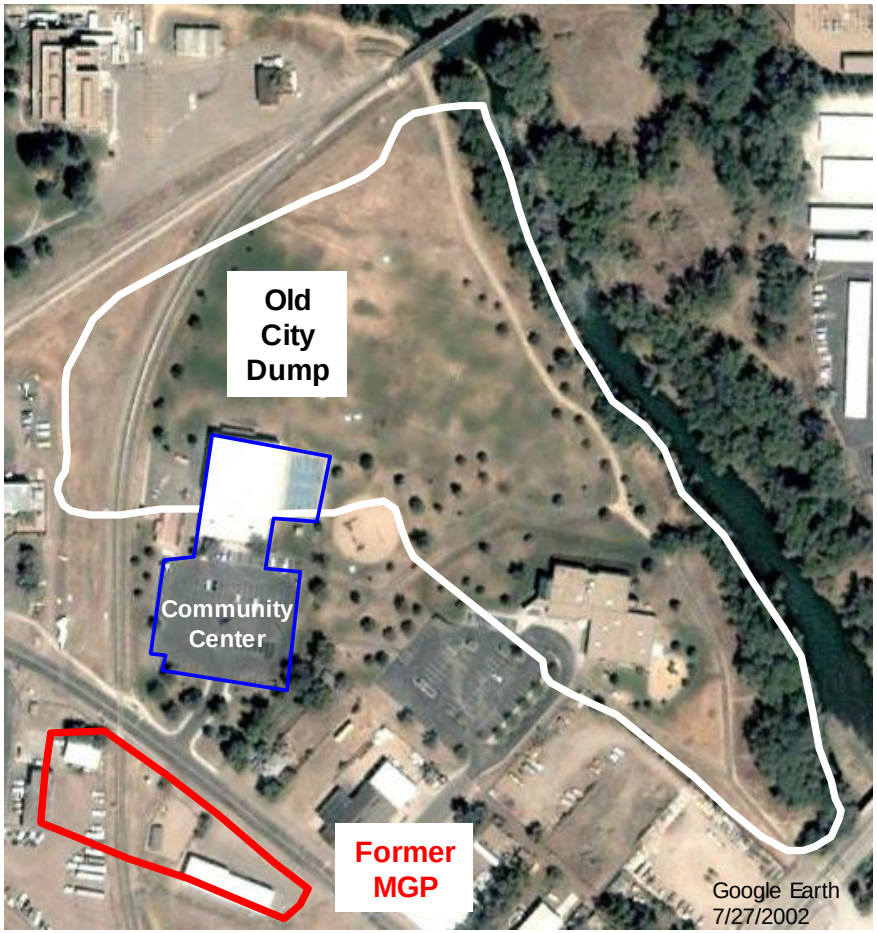




## Outcome

- GW plume diverted by hydraulic barrier & removal of existing contaminated sediment
- Fish nest building observed immediately after and continues (2014-2018)
- Performance metric is GW contaminant flux reduction – no explicit ecosystem metrics
- Occasional exceedances of AWQC for As primarily from re-accumulated sediment

# Real Examples of Conceptual Site Models

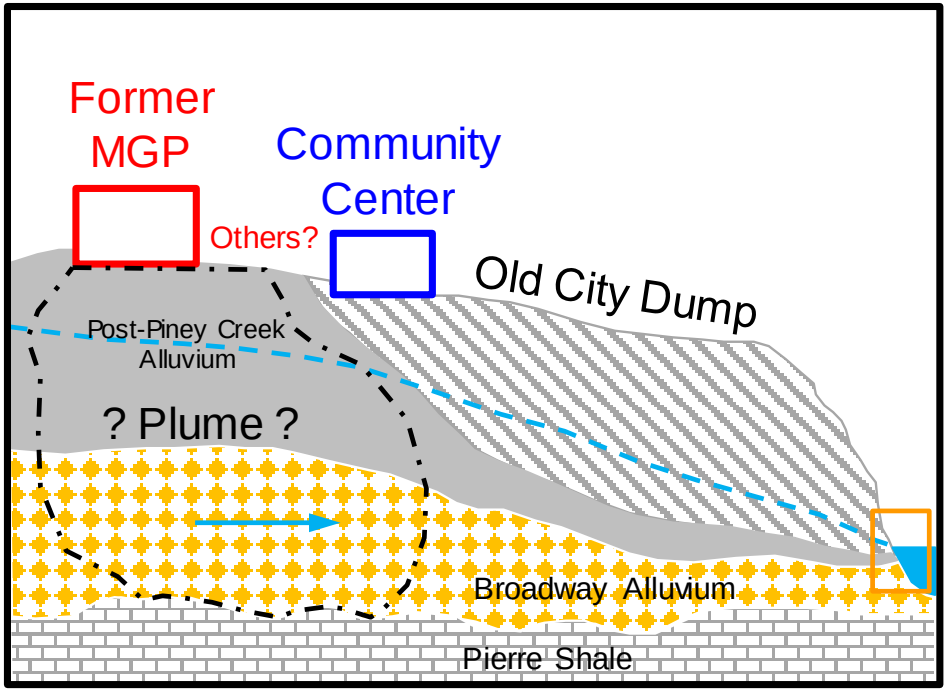
## Poudre River Site (Fort Collins)




- Historic location of Manufactured Gas Plant (red) and “Old City Dump” (white)
- Former “Dump” had been capped
- Desire to rebuild and expand community center triggered additional assessment
- Brownfield redevelopment grant and PRP funding

# Real Examples of Conceptual Site Models

Poudre River Site (Fort Collins)

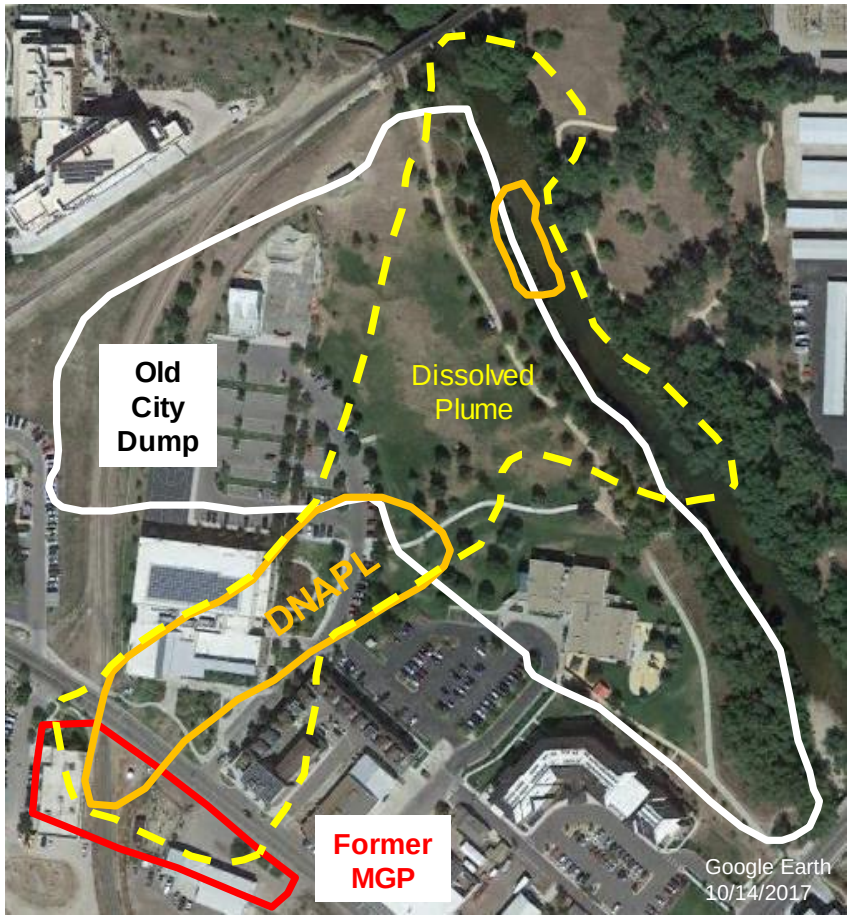



## Initial CSM

- "Gooey stuff" and "burbling" observed in Poudre River at low flow period (orange outline)
- Contaminant transport from former MGP property or other non-landfill sources presumed
- Dissolved versus NAPL transport unknown
- Subsurface location of plume largely unknown

# Real Examples of Conceptual Site Models

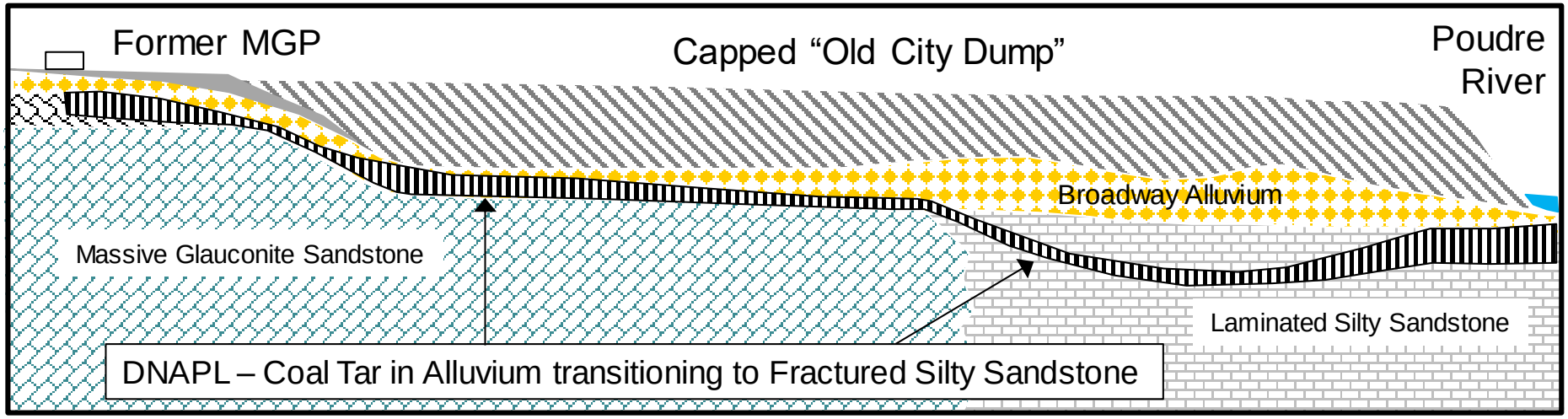
## Poudre River Site (Fort Collins)




- Surface geophysics and Hollow-Stem Auger borings used to determine alluvium-bedrock contact and bedrock quality
- Temporary sampling locations with in-field analytical used to assess contaminant distribution
- Passive samplers used to map shoreline contamination in transition zone

# Real Examples of Conceptual Site Models

## Final CSM - Poudre River Site, Fort Collins, Colorado




- Other volatile-semivolatile sources identified (including landfill)
- DNAPL traced back to Former MGP
- Barrier wall, control wells, sump pumps and on-site treatment constructed to block alluvial and minimize gradient from bedrock

# Real Examples of Conceptual Site Models

## Outcome

- More detailed mapping of subsurface geology critical for tracing DNAPL transport path
- Identification of fractured bedrock influenced design of hydraulic barrier adjacent to river shoreline
- Management approach for site characterization (Triad), including data types and field analysis, accelerated schedule to remedy selection
- Ecological endpoints were not explicitly assessed, but the City of Fort Collins continuously assesses Cache la Poudre River health – includes water quality metrics (DO)

# Real Examples of Conceptual Site Models

## Freely Available Resources – Real CSM Examples

### (Former) Fort Devens Superfund Site

Remedial Oversight of Activities at Fort Devens Plow Shop Pond and Grove Pond
www3.epa.gov/region1/superfund/sites/devens/253822.pdf

Final Report: Arsenic Fate, Transport and Stability Study [EPA/600/R-09/063]

Devens 2008 Monitoring Update [EPA/600/R-09/064]
nepis.epa.gov/

### Poudre River Brownfield Site

The Role of a Conceptual Site Model for Expedited Site Characterization Using the Triad Approach
clu-in.org/download/char/poudre_river_case_study.pdf

EPA Region 8 Brownfields Program and Triad Approach
www.epa.gov/sites/production/files/2016-01/documents/r8_ft_collins_co_ss_051509.pdf

The Poudre River Site (PowerPoint Presentation)
brownfieldstsc.org/pdfs/poudre.pdf

State of the Poudre River Assessment (Reach 10)
www.fcgov.com/poudrereportcard/