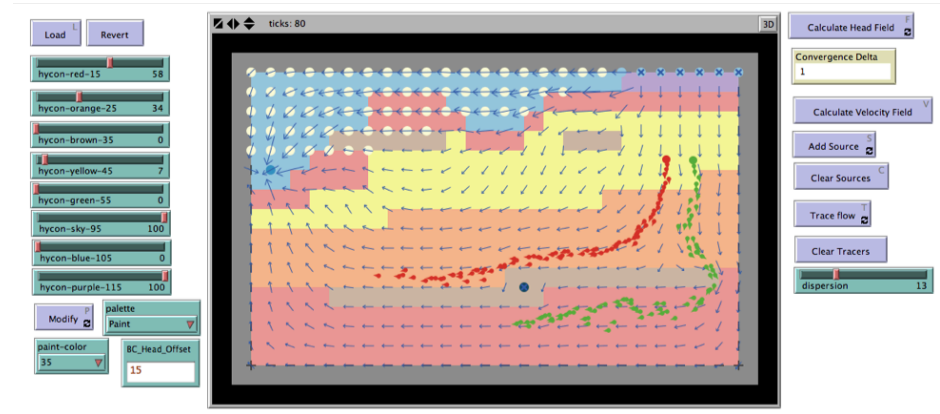
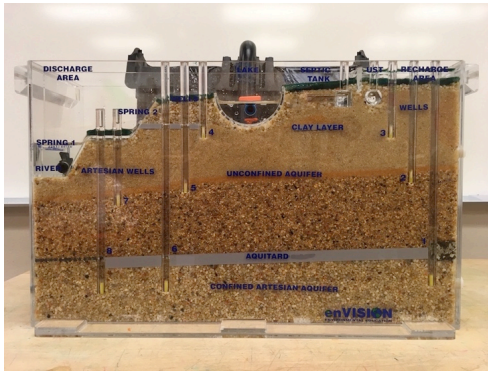




# Water Science Through Physical, Conceptual, and Computational Modeling



Beth Covitt

Agatha Podrasky

University of Montana

NAAEE – Spokane, WA – October 11, 2018

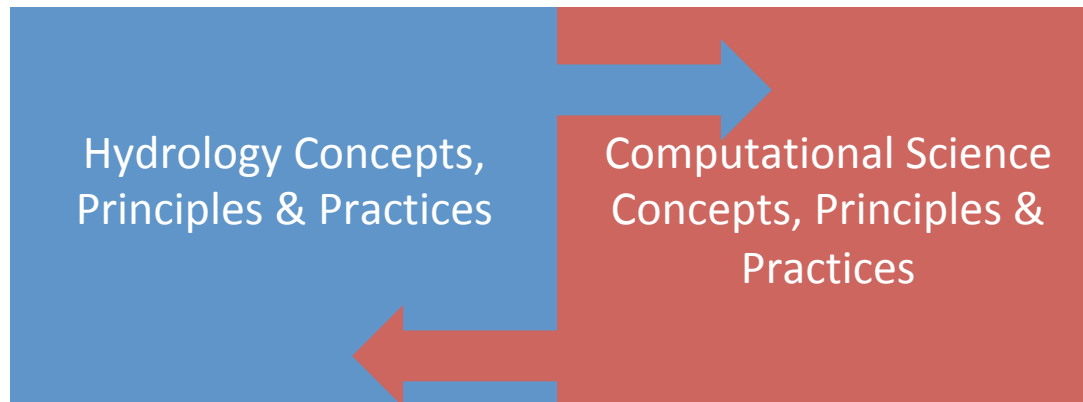


# Agenda

- Project Introduction
- Groundwater Contamination Unit
- Try It Out
  - What determines how GW moves? (Head Tube Lab & Permeameter Lab)
  - Investigating with GW system models (Physical & NetLogo)
- Questions, Discussion

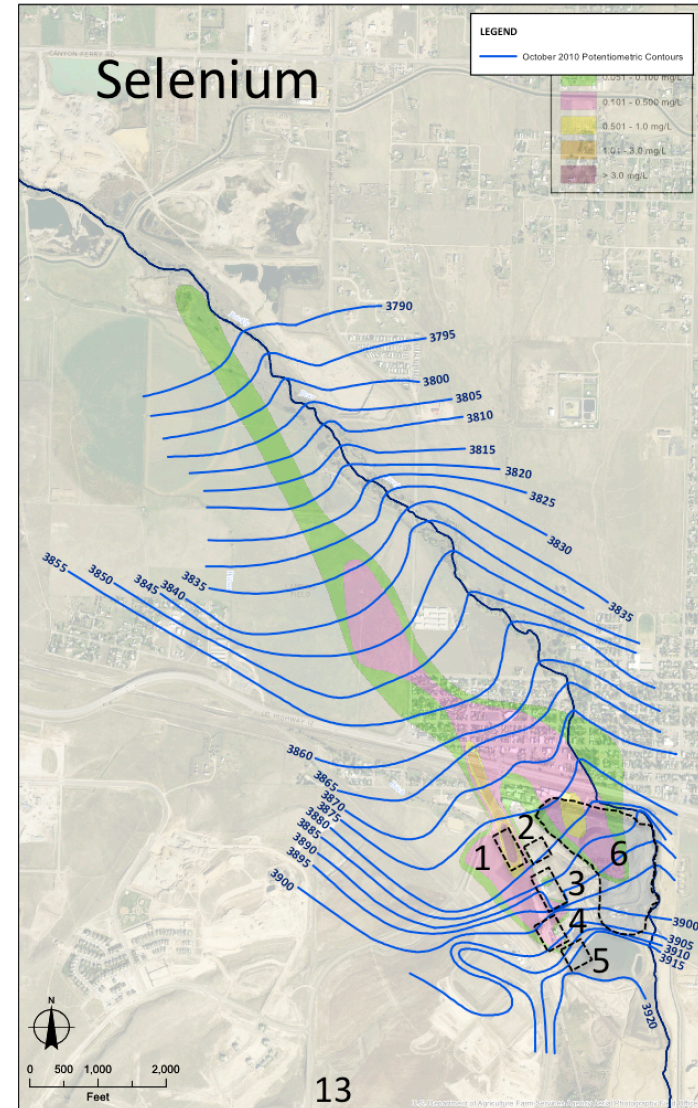
# Project Goal

Integrate teaching & learning of environmental science w/computational modeling in authentic & innovative ways.



# Hydrologic Problems Context

What knowledge and practice are needed to make sense of and make or evaluate decisions about hydrologic problems such as groundwater contamination?



# Partners



Colorado  
State  
University®



ARIZONA



NATIONAL COMPUTATIONAL  
SCIENCE INSTITUTE

BEAR  CENTER



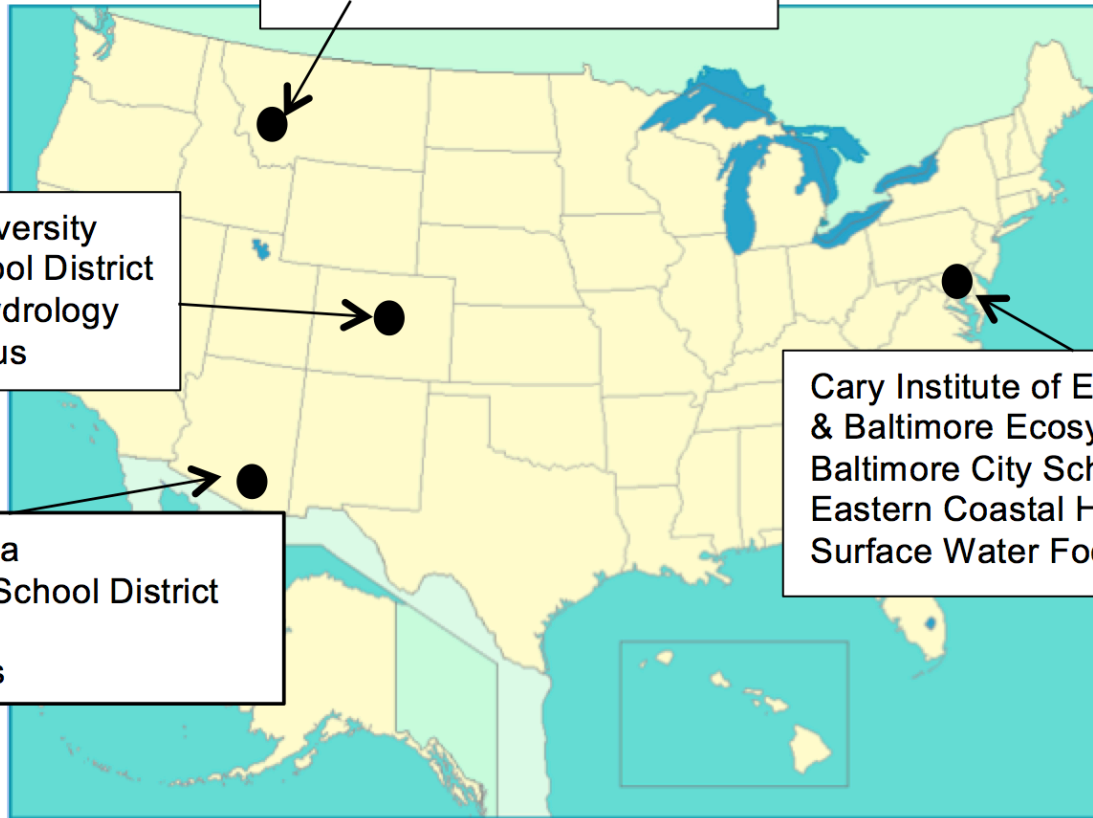
# Comp Hydro

**University of Montana  
3 School Districts  
Rocky Mountain Hydrology  
Groundwater Focus**

**Colorado State University  
Poudre Valley School District  
Rocky Mountain Hydrology  
Surface Water Focus**

**University of Arizona  
Sunnyside Unified School District  
Desert Hydrology  
Groundwater Focus**

**Cary Institute of Ecosystem Studies  
& Baltimore Ecosystem Study  
Baltimore City School District  
Eastern Coastal Hydrology  
Surface Water Focus**



# Environmental Science Literacy

Capacity to understand & participate in evidence-based discussions and decision-making about socio-environmental issues.

Environmental science literate individuals can...

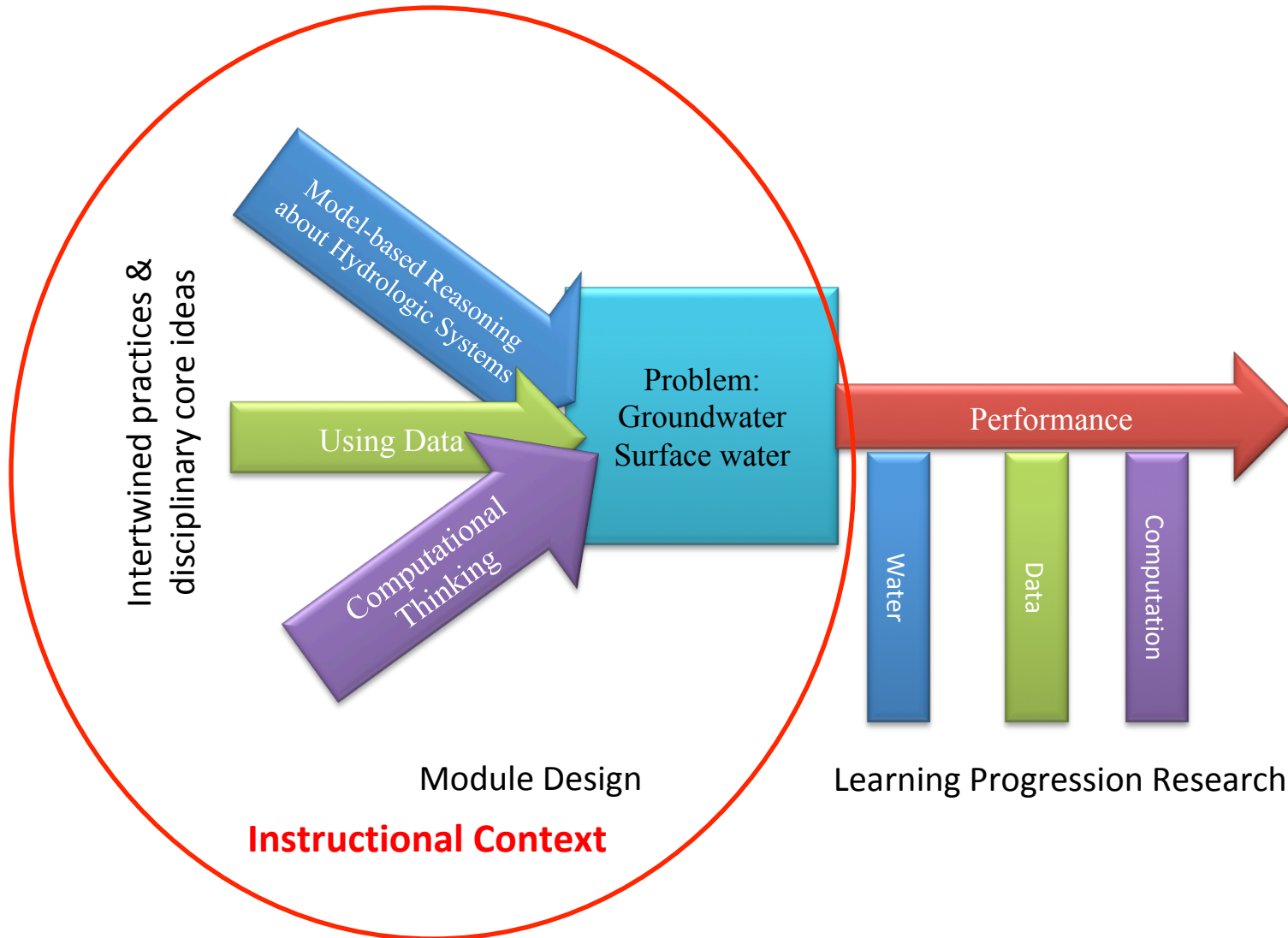
- Understand & evaluate arguments of experts
- Choose actions consistent with their values

# Project Objectives

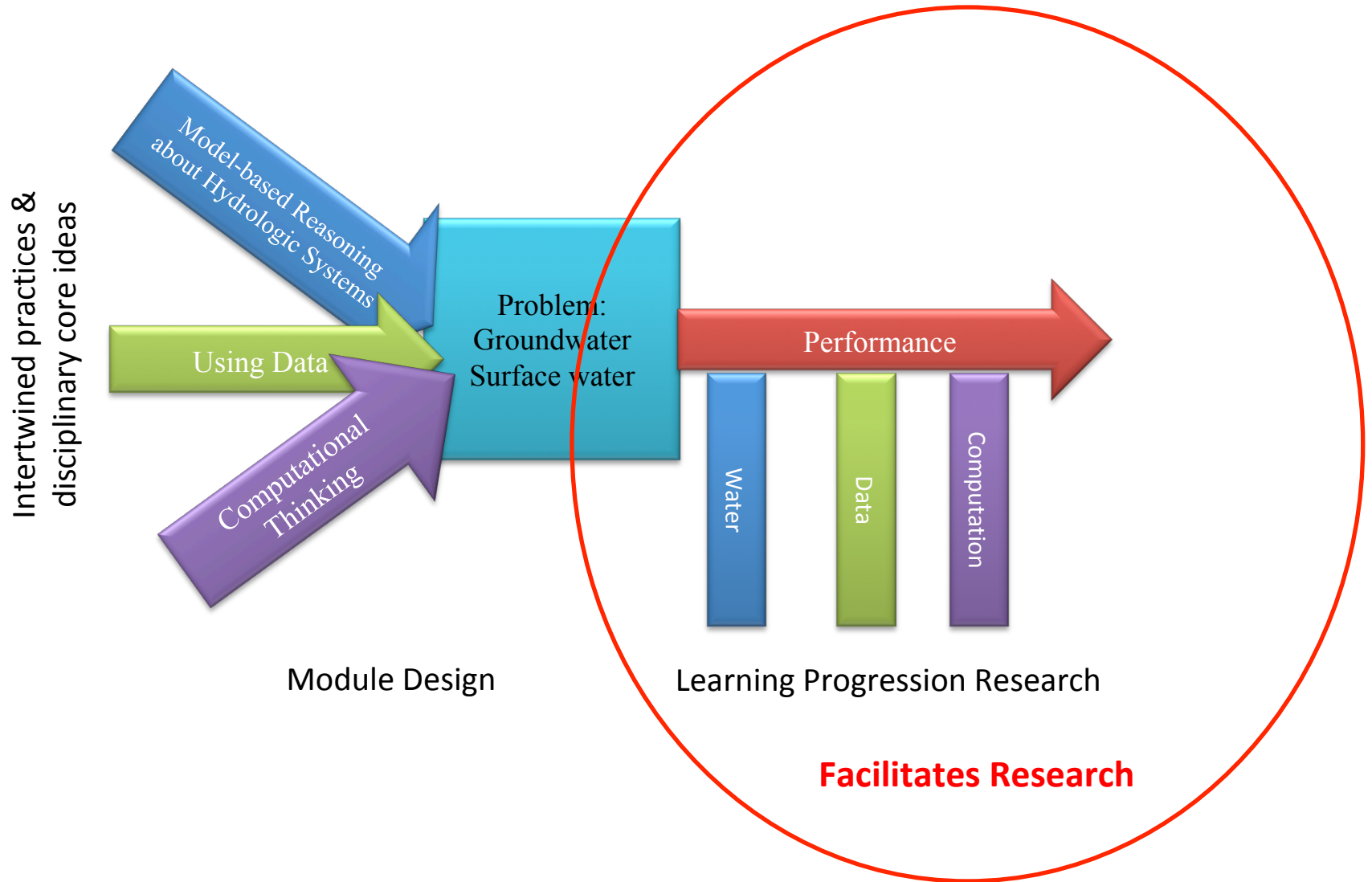
1. Develop modules
2. Develop/conduct teacher PD
3. Develop learning progressions
4. Investigate how to support use in classrooms
5. Develop digital platform for above objectives



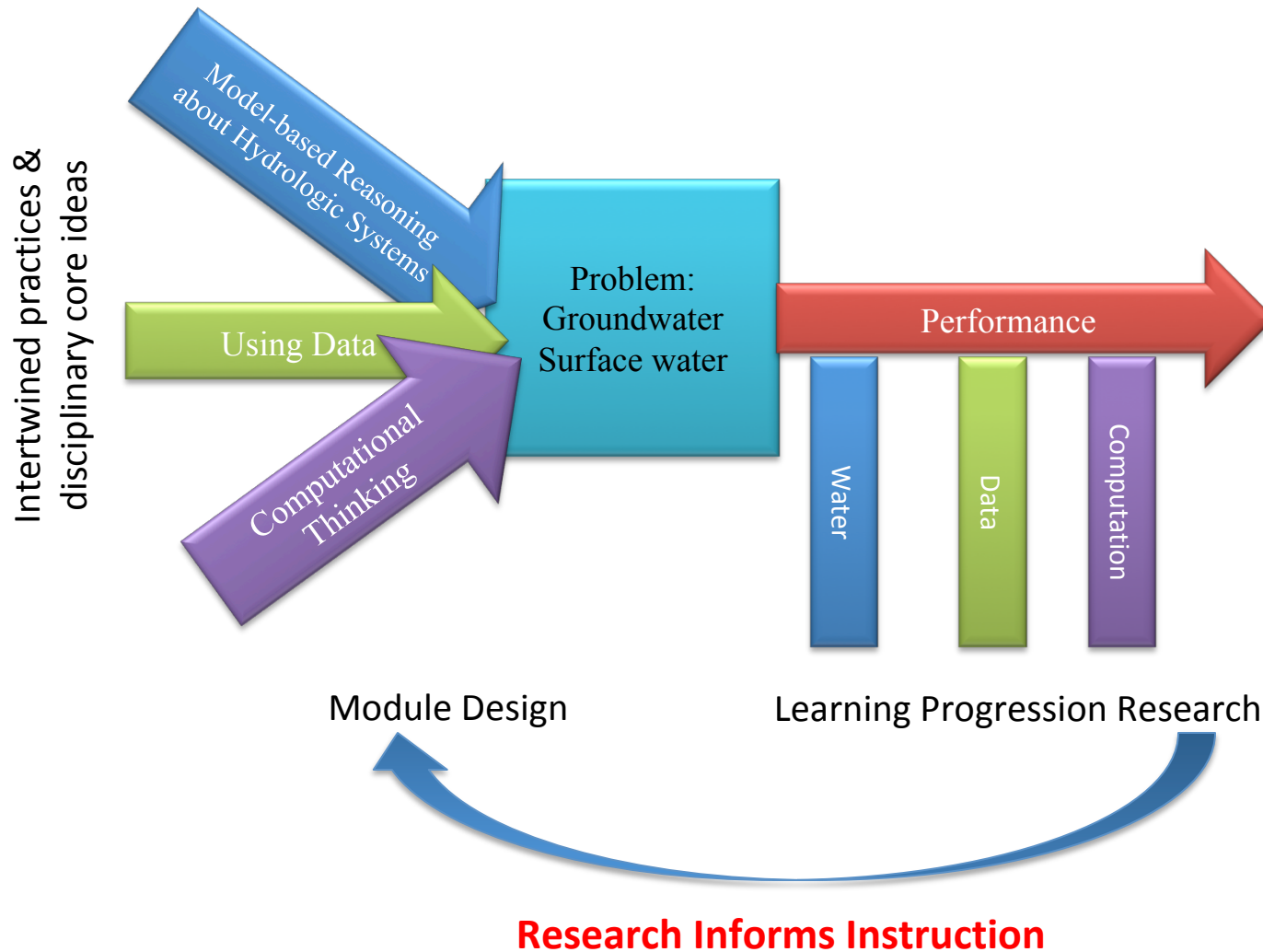
# Integrated Instruction & Research



# Integrated Instruction & Research

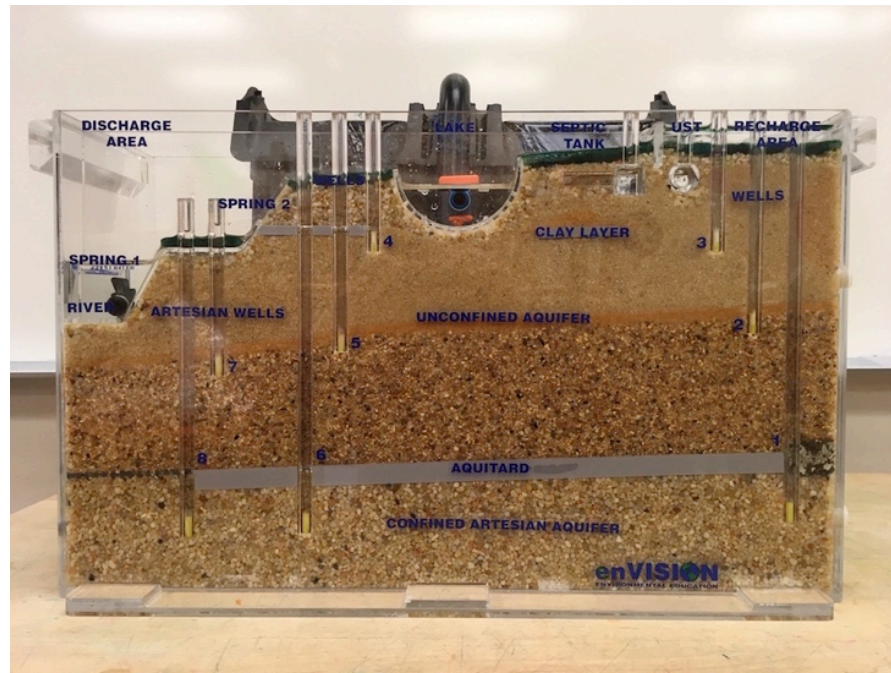


# Integrated Instruction & Research



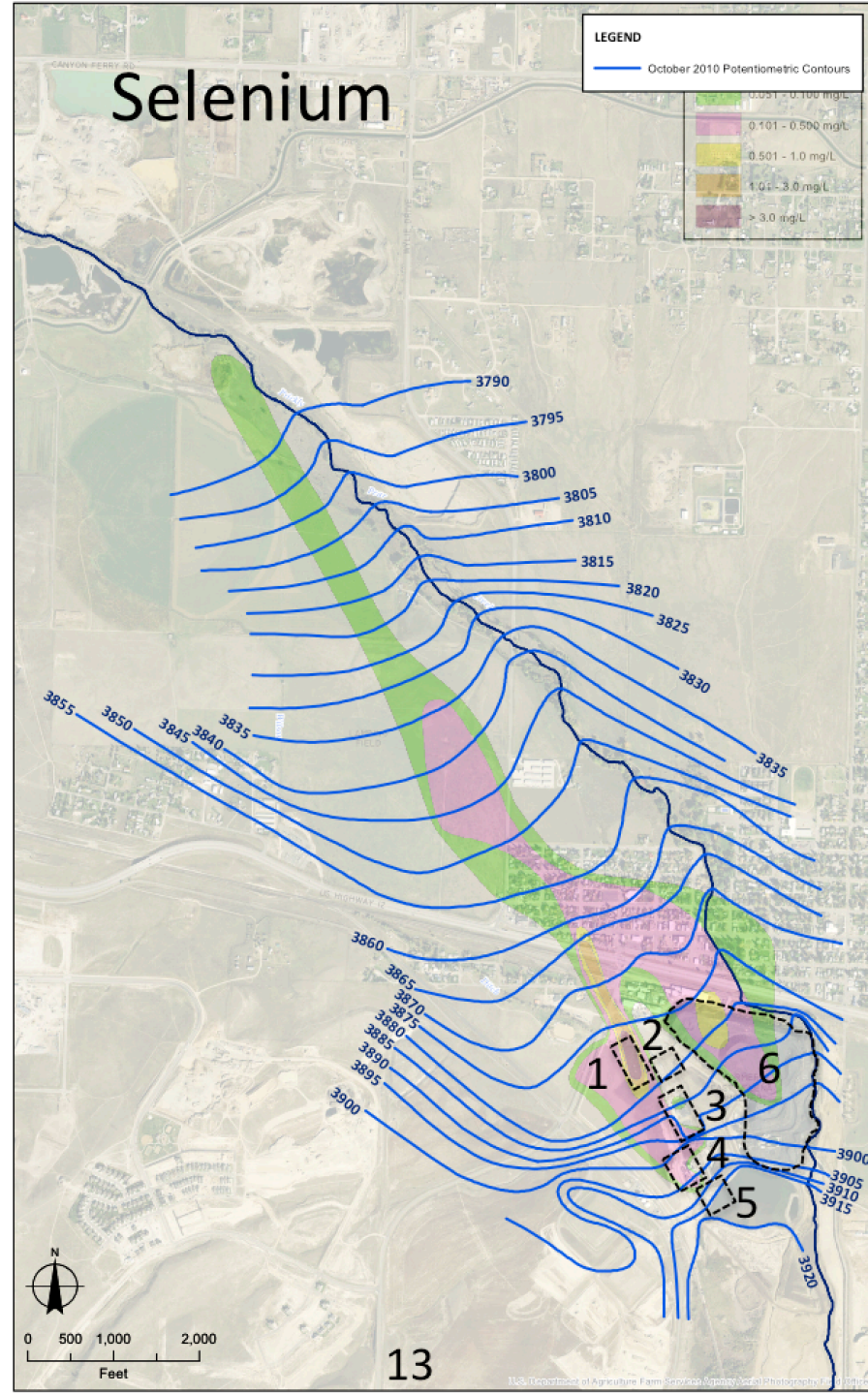
# Hydrologic Concepts

- Groundwater (GW) system structure
  - Unsaturated & saturated zone, water table, aquifer
- GW system function
  - Potential energy & hydraulic conductivity govern flow of GW & contaminants



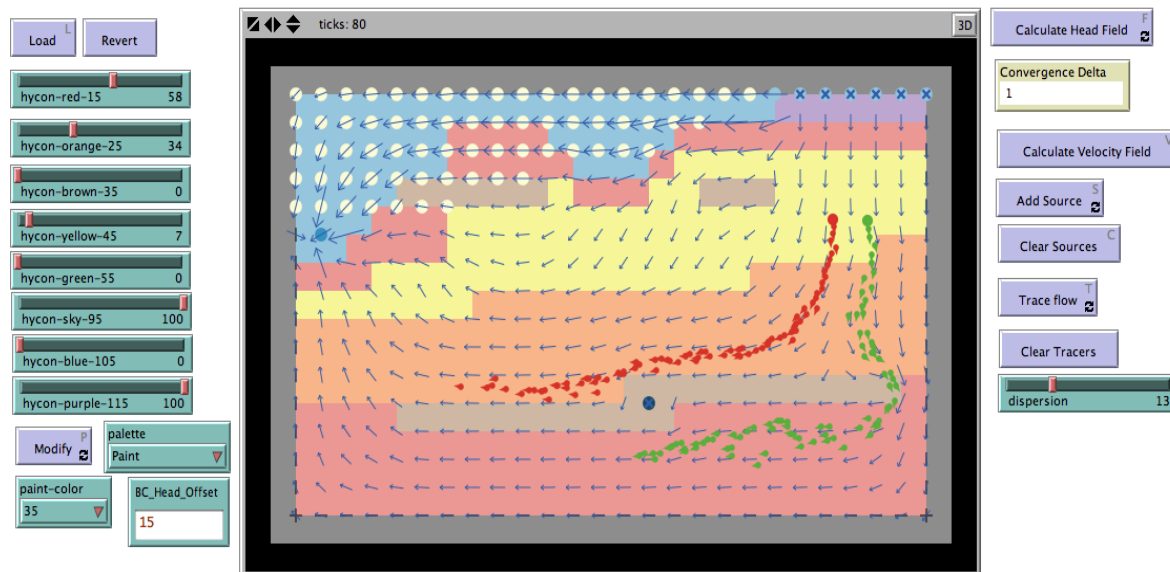
# Interpreting & Using Data

- Connect levels of abstraction across multiple scales
- Make inferences about 3D systems from 2D representations & vice versa
- Manage uncertainty
- Bringing scientific principles to bear



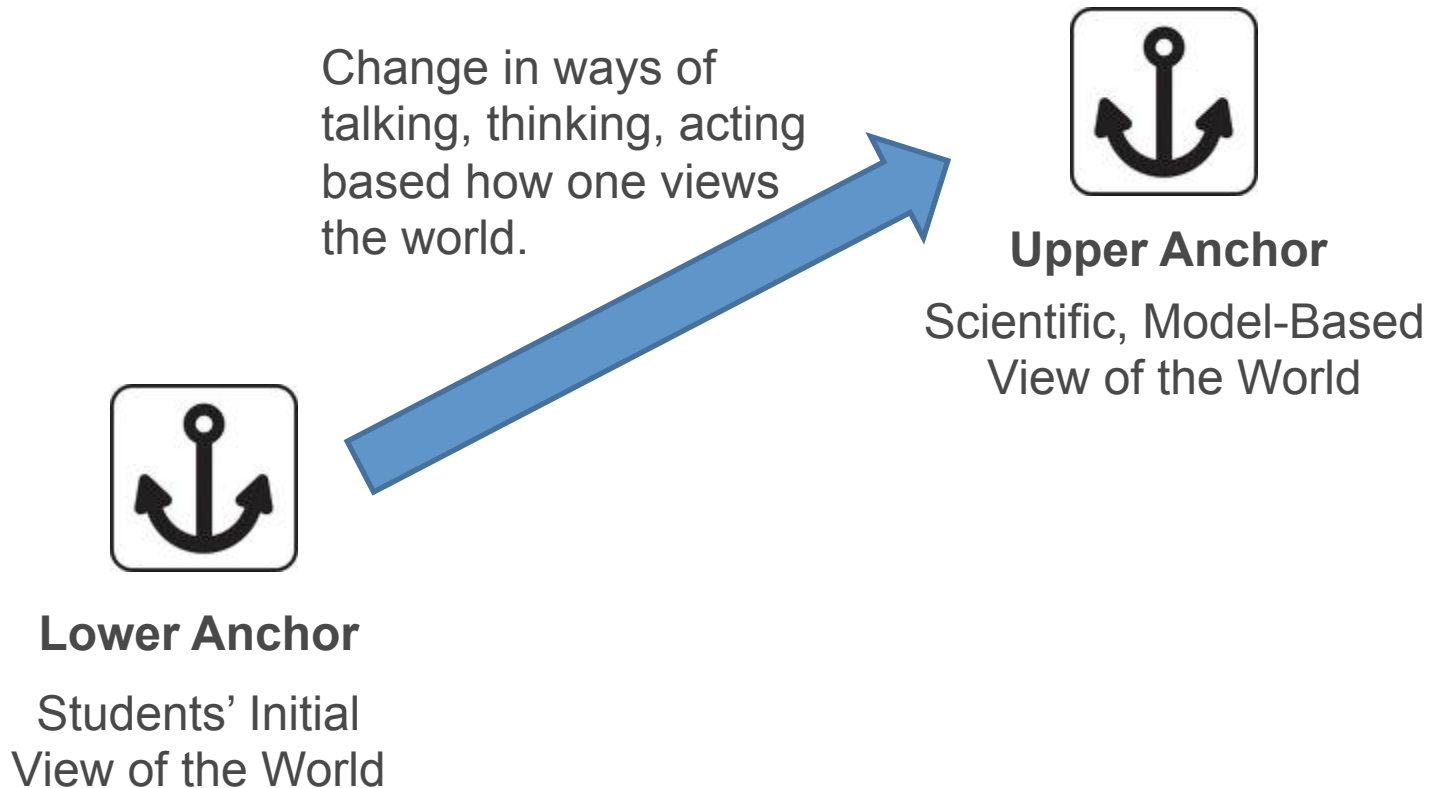
# Computational Thinking

- Advantages & limitations of computer modeling
- Parameterization
- Discretization
- Boundary conditions
- Testing & falsifying models with observations



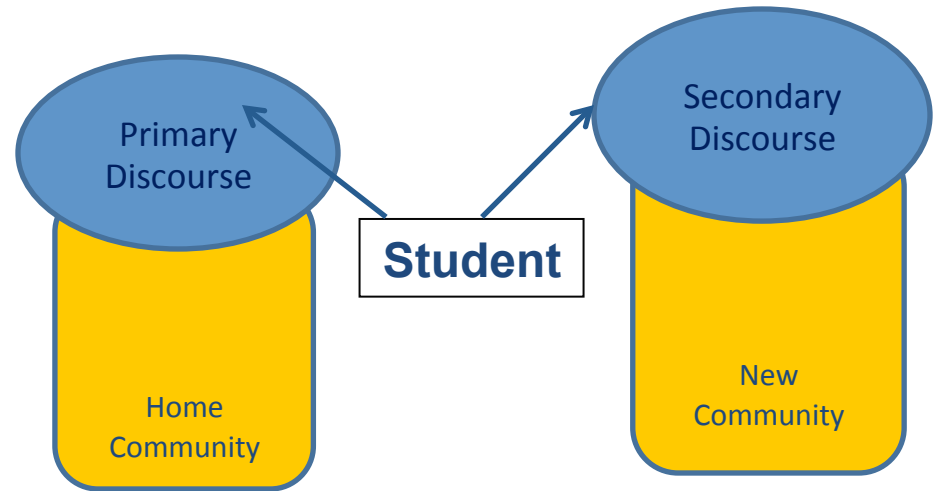
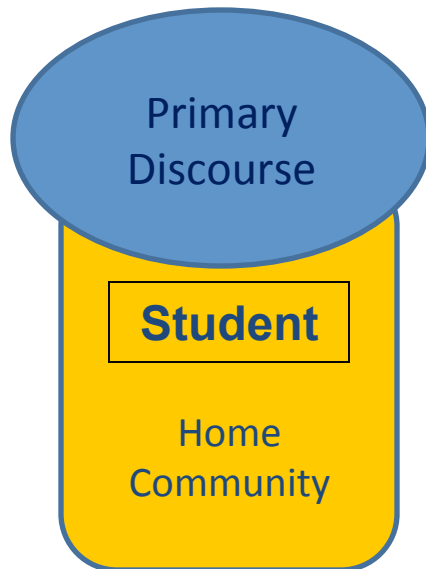
# Learning Progressions

Descriptions of successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time. (National Research Council, 2007)

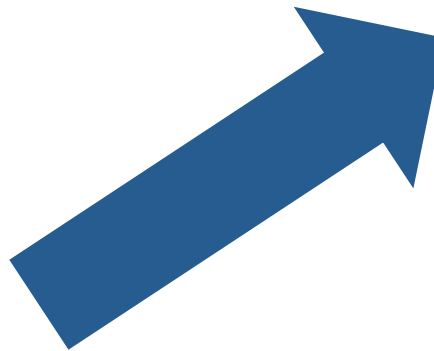


# What Progresses

**Discourse** is a way of thinking, talking, acting that a group has in common.



Can participate in multiple Discourses



- Learning**
- New knowledge
  - New practices
  - New Discourse



# Water Systems Learning Progression

## **Level 4 – Qualitative Model-Based Reasoning**

System events follow mechanistic, model-based principles  
Atomic-Molecular to Landscape Scales

## **Level 3 – School Science Accounts**

Events in order, Names processes  
Microscopic to landscape scales

## **Level 2 – Force Dynamic with Mechanisms**

Actors, enablers, antagonists  
Macroscopic only

## **Level 1 – Simple Force Dynamic Accounts**

Water in isolated locations  
Human-centric

# Septic Tank Assessment Example

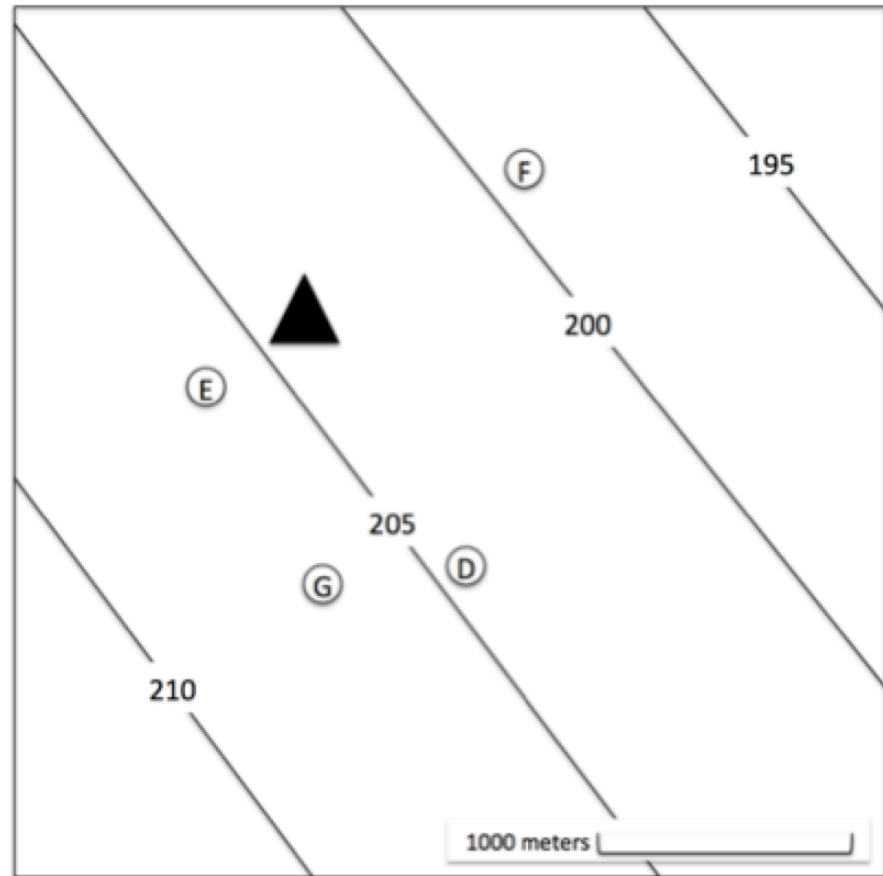
The contour lines on the map to the right show the groundwater elevation above sea level (in meters).

The triangle represents a septic tank and drain field, and the circles show the locations of different wells.

If someone installed the septic tank incorrectly and septic wastes percolated into the groundwater, in which well would contaminated groundwater most likely be detected first?

Select one:

- D
- E
- F
- G



Why would contaminated water be detected first in the well you chose?

# Septic Tank Assessment Example

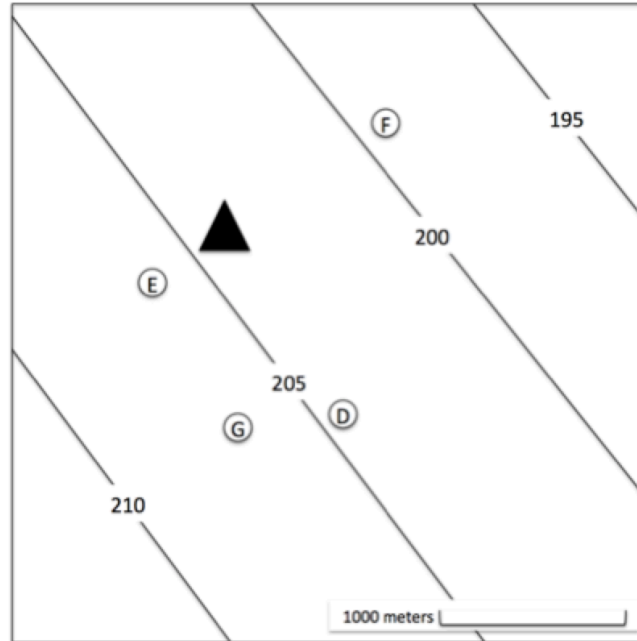
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Select one:

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- E
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- G



Why would contaminated water be detected first in the well you chose?

**L4:** Indicates GW moves from high to low potential energy and/or addresses hydraulic head

*“F. Because groundwater moves from high elevation to low.”*

**L3:** Indicates down hill or down elevation but does not specify GW not surface water  
*“F. It is down hill from the septic tank.”*

**L2:** Strong proximity  
*“E. It’s the closest to the septic tank.”*

**L1:** Literal map reading  
*“D. because it would go down.”*

# Implications of Learning Progressions (LPs) for Research & Instruction

## Research

- Develop integrated LPs for hydro reasoning, computational thinking, and data sense-making to inform...

## Instruction

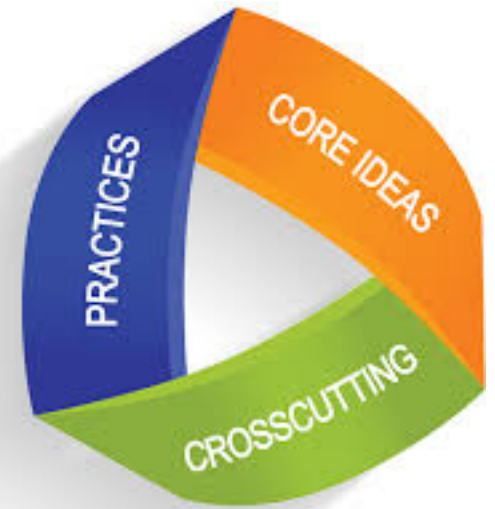
- (Unit) Provide students opportunities to engage in and develop sophisticated hydro reasoning, computational thinking, and data sense-making
- (PD) Provide teachers with tools and supports

# NGSS Alignment

- **HS-ESS2-2:** Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
- **HS-ESS3-4:** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- **HS-ESS3-6:** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activities.
- **HS-ETS1-2:** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- **HS-ETS1-3:** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints including cost ... as well as possible social, cultural and environmental impacts.
- **HS-ETS1-4:** Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems.

# NGSS Alignment

- **Science Practices**
  - Developing and using models
  - Analyzing and interpreting data
  - Using mathematics and computational thinking
  - Constructing explanations and designing solutions
- **Crosscutting Concepts**
  - Cause and effect
  - Scale, proportion, and quantity
  - Systems and systems models
  - Energy and matter
  - Structure and function



# Building Connected Models

- Knowledge & practice through experiences w/ multiple models & representations
- Models & representations:
  - Physical models (table top GW flow model, 3D PVC pipe water table model)
  - 2D representations on paper (contour maps, cross-sections)
  - Conceptual scientific models (principled explanations of how systems work)
  - Computer models (NetLogo models)
  - Do not delve deeply into mathematical models

# Montana GW Unit

## Module 1: Establishing the Problem

Intro to E. Helena Smelter Site Case

## Module 2: Intro to GW System & Flow

L1: What is a system? & intro to GW

L2: What determines how GW moves?

L3: Cross section of East Helena Site

L4: Intro to computer models of GW systems

L5: NetLogo GW Flow Model

## Module 3: Landscape Scale Water Table & Flow Direction of Water & Contaminants

L1: Intro to investigation of East Helena with 3D modeling

L2: Virtual investigation of East Helena using Google Earth

L3: NetLogo contour map modeling of East Helena Plume

L4: Computer modeling of GW & contaminant dispersion in East Helena

**Module 4: Addressing the Problem** Teams review & evaluate cleanup options, develop remediation plans, present, & review what's being done in E. Helena



# Montana GW Unit

**Module 1: Establishing the Problem** ← (Need for hydrogeology training)

Intro to E. Helena Smelter Site Case

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(2D system)



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**(3D, Large Scale)**



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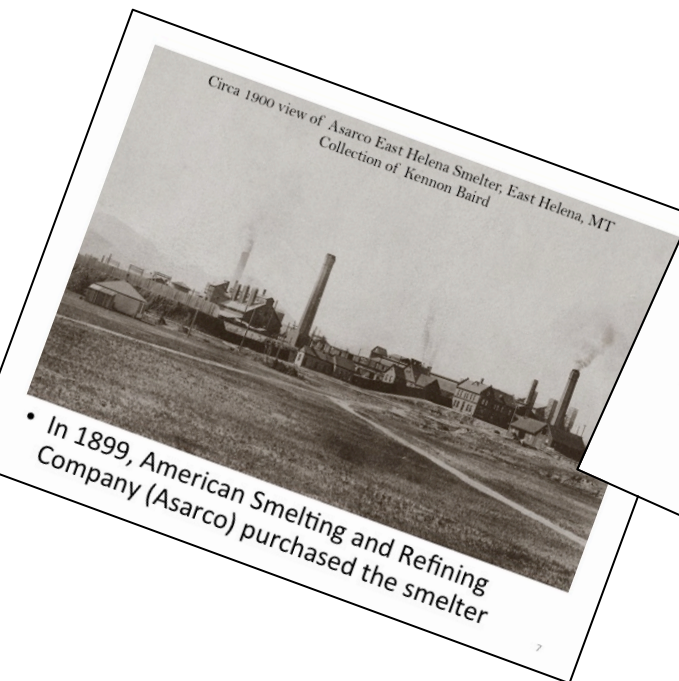
**Module 4: Addressing the Problem** Teams review & evaluate cleanup options, develop remediation plans, present, & review what's being done in E. Helena



**(Application)**

# Module 1: Establishing the Problem

- **Activity 1: There's a problem in East Helena**
  - History of E. Helena Smelter site & contamination
- **Activity 2: Who cares?**
  - Discuss stakeholders & their concerns
- **Activity 3: What do we need to know?**
  - Go back to 2009 & take on role of scientists to figure out what happened & what to do. Share ideas about what we need to know.



### Asarco Timeline

- Smelter closed in 2001
- Asarco declared bankruptcy in 2005
- In 2009, Asarco turned over land and almost \$2 billion for cleanup of sites across the country

East Helena Smelter, 2001

FOR USE AS A MOTOR FUEL ONLY  
CONTAINS LEAD  
(Pb/BAHTHPL)

### Contamination history

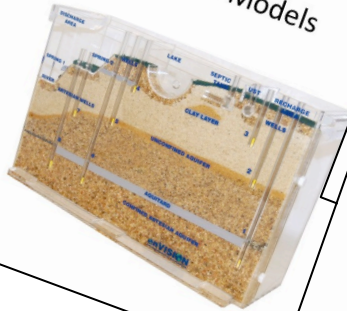
- Environmental investigations began at site in 1969
  - Smelting had impacted air, soil, surface water, groundwater, vegetation, livestock, wildlife and humans
- In 1984, Environmental Protection Agency (EPA) designated site as a Superfund Site
- Cleanup began in 1987

19

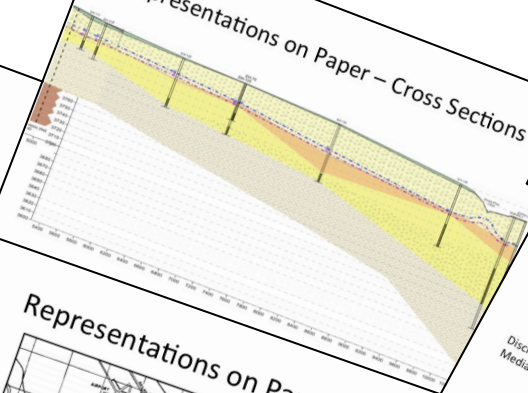
# M2L1: What is a system?

- What is a system? (Formative Assessment)
- Define systems & preview types of system models & representations

Physical Models



Representations on Paper – Cross Sections

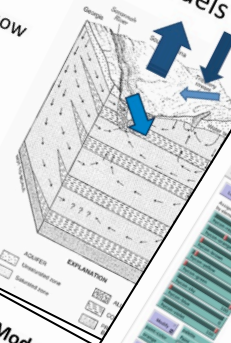


Representations on Paper - Maps



Conceptual Models

- A conceptual model is a scientific explanation of how a system works
- It relies on data, scientific principles, and expert knowledge

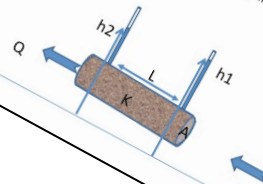


Mathematical Models

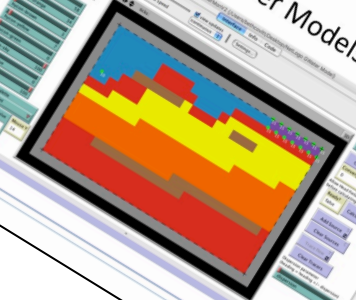
**Darcy's Law**  
governing the flow of fluids through porous sediment

$$Q = KiA$$

Discharge of groundwater (Q) is equal to the hydraulic conductivity of the porous Media (K) times the hydraulic gradient (i = (h1-h2)/L) times the cross sectional area (A)



Computer Models

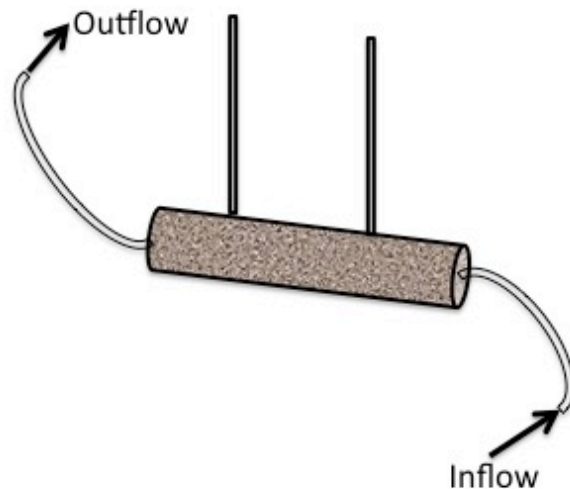


# M2L2: What determines how GW moves?

## Investigation Stations

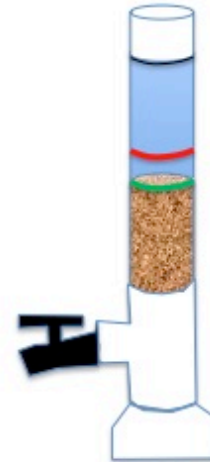
### HEAD TUBE STATION

How can water underground flow uphill?



### PERMEAMETER STATION

What affects how easily water can flow through different materials?



# M2L2: What determines how GW moves?

## Scientific Explanation of Hydraulic Head

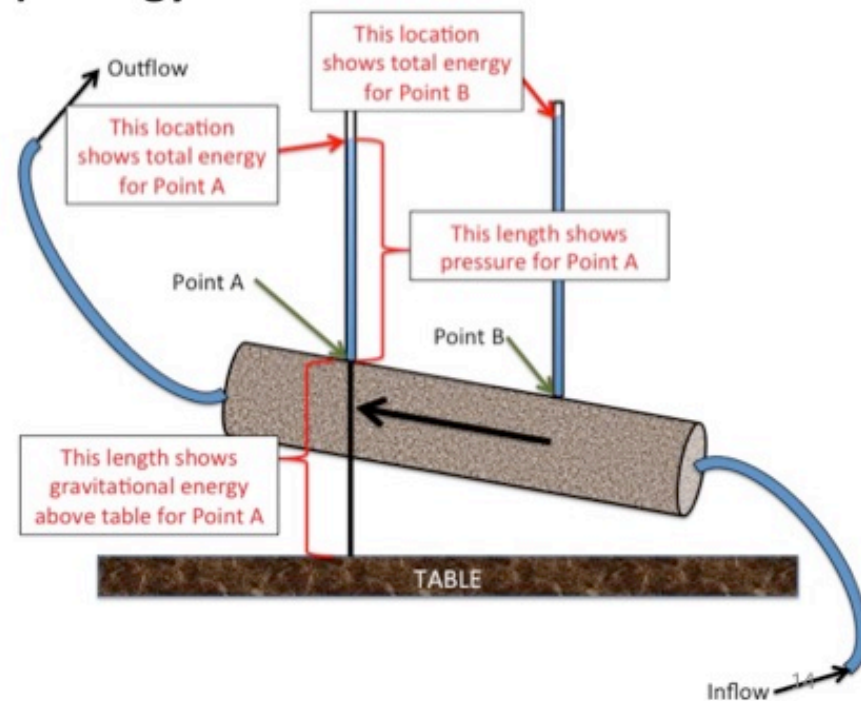
Height of the water in tubes shows...

**Hydraulic head** or **total potential energy**, which equals the amount of energy at a place in space that is a combination of...

**Gravitational (positional) Energy**

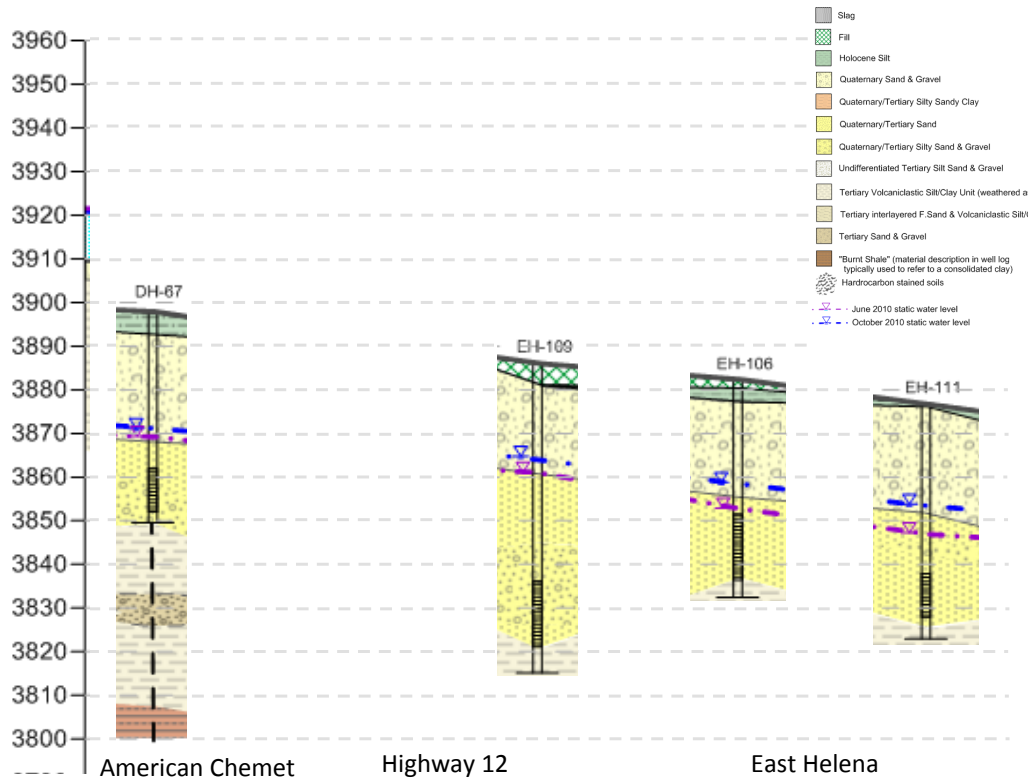
**And Pressure Energy**

Groundwater always moves in direction from higher hydraulic head (total potential energy) to lower hydraulic head.

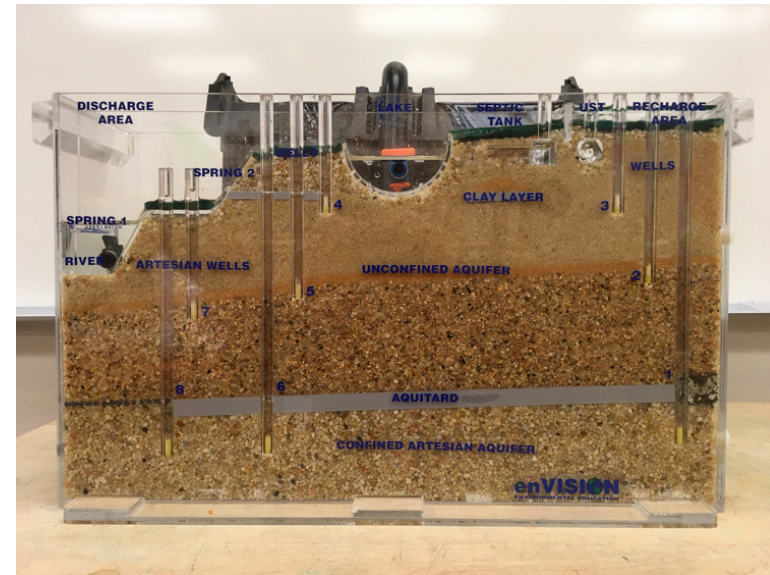




# M2L3: Cross Section of East Helena & GW Flow Model Experiments



Data



Qualitative  
Physical Model

# M2L4: Intro to Computer Models

The screenshot shows the NetLogo interface for a model named "Grid\_Flow\_Energy". The window title is "NetLogo — Grid\_Flow\_Energy {/Users/bethcovitt/Dropbox (CarbonTIME)/MT Comp Hydro/Octo...". The interface includes a menu bar with "Interface", "Info", and "Code". Below the menu bar are controls for "Edit", "Delete", "Add", a "Button" dropdown, a speed slider set to "normal speed", a "view updates" checkbox, a "continuous" dropdown, and a "Settings..." button.

On the left side, there are several control panels:

- A "Setup" button.
- "Go" and "Step" buttons.
- A panel for "Place-water-randomly?" with "On" and "Off" radio buttons.
- A panel for "Water-from-top-only?" with "On" and "Off" radio buttons.
- A panel for "Record-pathways?" with "On" and "Off" radio buttons.

The main display area shows a 10x10 grid of potential energy values. The grid is titled "ticks: 0" and has a "3D" button in the top right corner. The values in the grid are as follows:

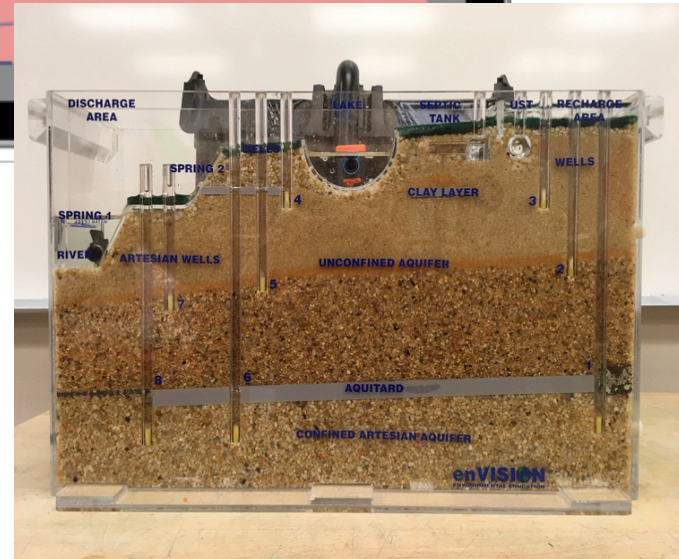
100	98	100	100	100	97	98	99	100	100
95	92	97	99	97	94	91	92	90	93
91	89	93	96	91	90	88	84	87	86
85	83	89	88	84	85	82	80	82	83
79	77	83	82	81	79	77	76	78	80
72	73	75	77	75	71	72	73	74	75
68	69	68	70	71	67	65	66	69	70
63	64	65	66	63	64	62	61	66	67
60	61	60	59	58	60	57	58	63	63
53	58	57	56	53	56	53	54	59	60

Below the grid, the text "Potential Energies shown" is displayed. At the bottom of the interface is a "Command Center" with a "Clear" button and a text input field containing "observer>".

# M2L5: NetLogo GW Flow Model

The screenshot displays the NetLogo GW Flow Model interface. The central window shows a 2D flow field simulation with a grid of blue arrows indicating flow direction and magnitude. The flow is generally from left to right, with some local variations. The simulation area is divided into several colored regions representing different geological layers or zones. The interface includes several control panels:

- Left Panel:** Contains sliders for color-coded parameters: hycon-red-15 (58), hycon-orange-25 (34), hycon-brown-35 (0), hycon-yellow-45 (7), hycon-green-55 (0), hycon-sky-95 (100), hycon-blue-105 (0), and hycon-purple-115 (100). Below these are buttons for 'Load', 'Revert', 'Modify', and 'palette Paint'. A 'paint-color' dropdown is set to 35, and a 'BC\_Head\_Offset' input field is set to 15.
- Top Panel:** Shows 'ticks: 80' and a '3D' button.
- Right Panel:** Contains buttons for 'Calculate Head Field', 'Calculate Velocity Field', 'Add Source', 'Clear Sources', 'Trace flow', and 'Clear Tracers'. A 'Convergence Delta' input field is set to 1, and a 'dispersion' slider is set to 13.



# M3L1: Intro to E. Helena Investigation & 3D Model



# M3L2: Virtual Investigation w/Google Earth

**Search**

Search

ex: Computer repair near Boston

[Get Directions](#) [History](#)

**Places**

- My Places
  - Sightseeing Tour
    - Make sure 3D Buildings layer is checked
  - EHwells
    - EH\_60wells
      - EH\_60wells
      - EH\_30wells
      - EH\_15wells
  - Temporary Places
    - EHwells
      - EH\_60wells
      - EH\_30wells
      - EH\_15wells

**Layers**

- Primary Database
  - The new Google Earth
  - Borders and Labels
  - Places
  - Photos
  - Roads
  - 3D Buildings
  - Ocean
  - Weather
  - Gallery
  - Global Awareness
  - More
  - Terrain

**EH-102**

EH-102	
FID	1
SiteID	EH-102
MP_Elevati	3880
SWL	8
Northing	862174.5306
Easting	1360751.101
Se	5

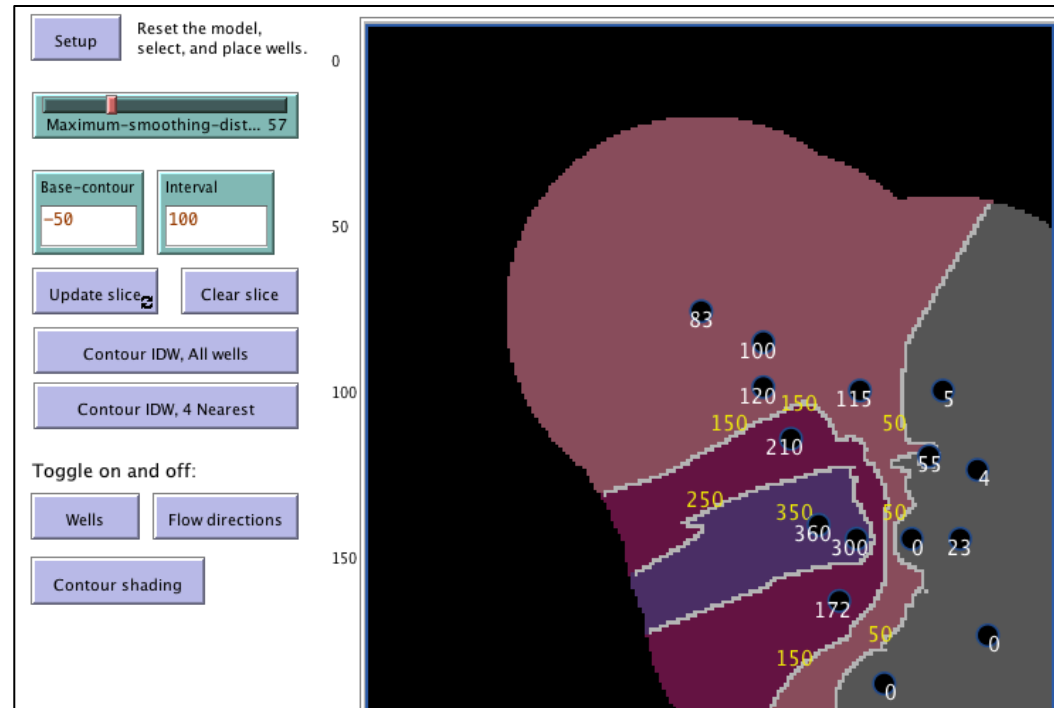
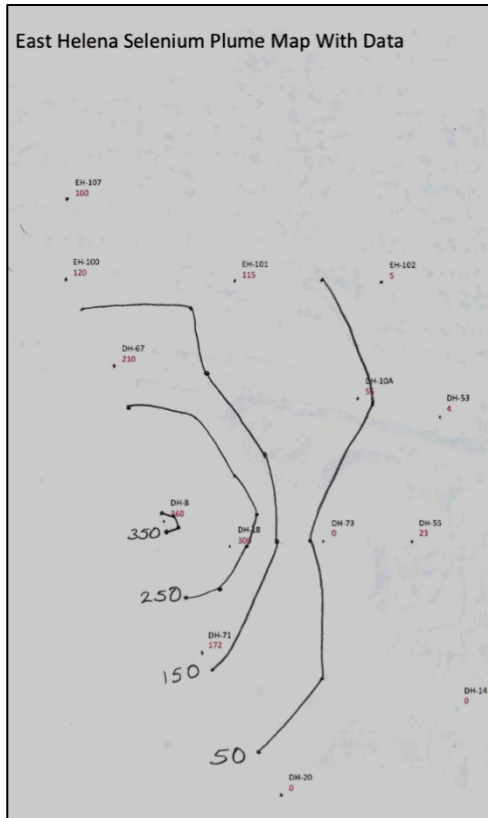
Directions: [To here](#) [From here](#)

© 2013 Google

Google earth

Imagery Date: 7/25/2014 46°35'02.55" N 111°54'24.43" W elev 0 ft eye alt 8817 ft

# M3L2/L3: Contour mapping by Hand & Computer




# M3L4: Computer Modeling of E. Helena

- Explore how computational modeling was used to develop remediation plan at site
- Jigsaw using videos of scientist who developed the model

**Meet Joel**

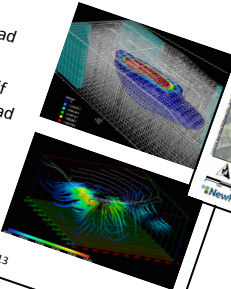
- Joel Jacobson, hydrogeologist at NewFields
- Created the computational model of East Helena Superfund site



2:15

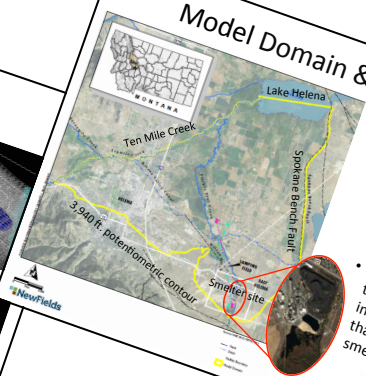
**MODFLOW**

- MODFLOW discretizes space into cells and calculates hydraulic head for each cell
- What can we determine if we know the hydraulic head in each cell?
- Why was MODFLOW the right tool for modeling groundwater flow in E. Helena?



01:13

**Model Domain & Boundaries**



- Model boundaries correspond with natural hydraulic and geologic boundaries
- Why do you think the model domain includes much more than just the smelter site?

02:47

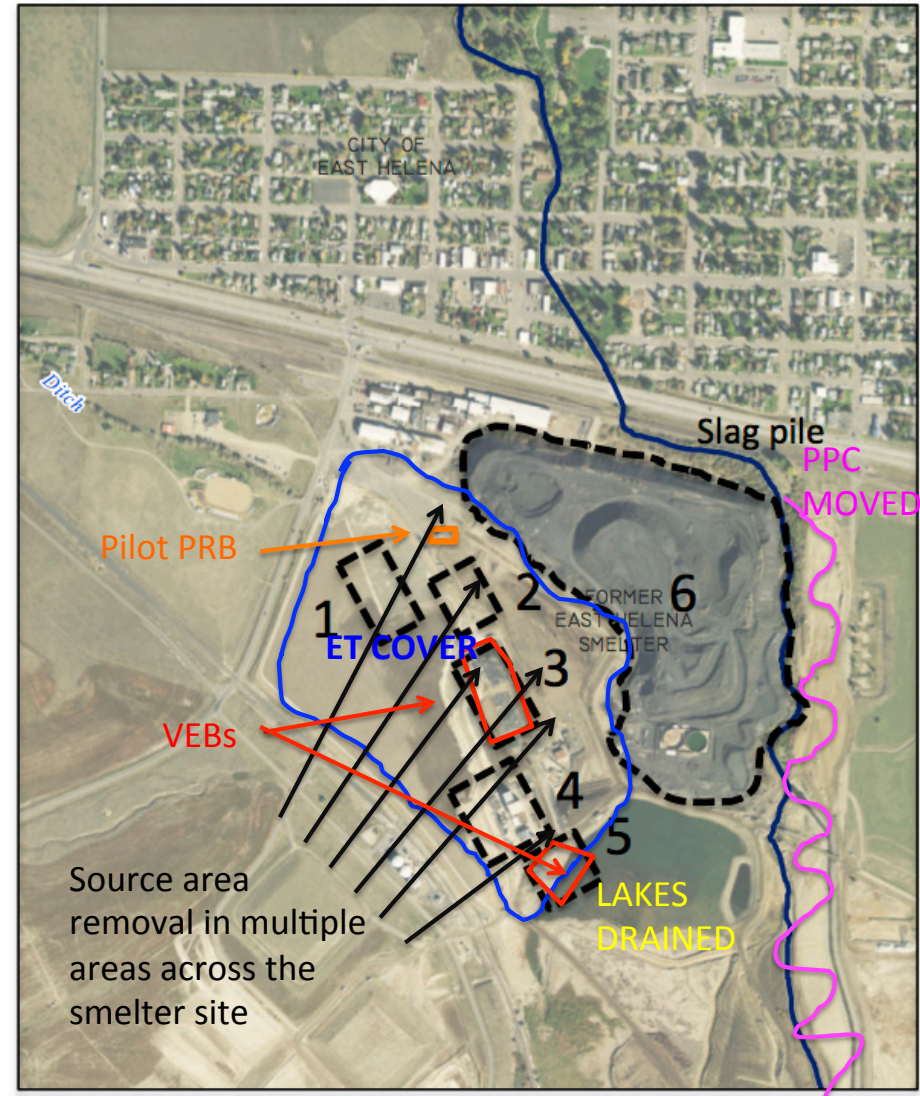
**Calibration Process**

```
graph TD
    A[Decide how similar modeled and field observed results need to be to be considered acceptable] --> B[Set Targets]
    B --> C[Run Model to simulate a dependent variable e.g., head or contaminant concentration]
    C --> D[Compare Model Results to observations targets]
    D --> E[Acceptable results with uncertainty]
    D --> F[Not OK]
    F --> G[Model parameters, boundaries, inputs and outputs of water and re-run model]
    G --> C
```

00:49

# M4: Addressing the Problem

- Teams evaluate cleanup options
- Explore NetLogo remediation strategy models
- Develop remediation plans
- Present plans
- Review what's being done in E. Helena





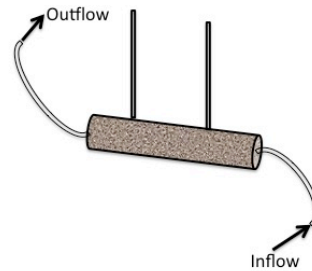
# Try it out

- What determines how GW moves? (Head Tube Lab & Permeameter Lab)

## Investigation Stations

### HEAD TUBE STATION

How can water underground flow uphill?

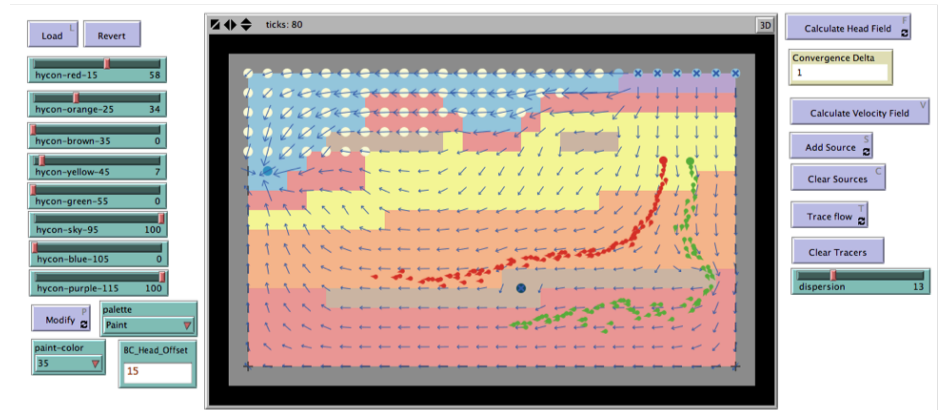
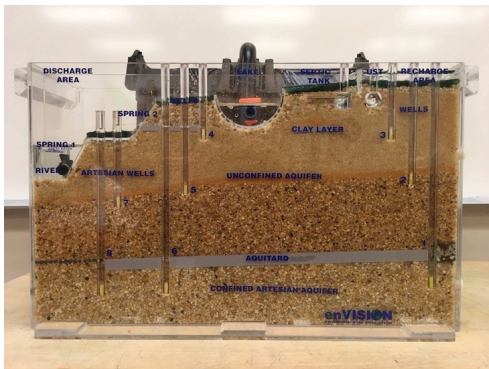


### PERMEAMETER STATION

What affects how easily water can flow through different materials?



- Investigating with GW system models (Physical & NetLogo)





# Questions / Discussion / Thank you

## Contact

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Unit materials available upon request

To learn more about Comp Hydro, visit:  
<http://ibis.colostate.edu/comphydro/>

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# Generalized Environmental Science Learning Progression

Level of Achievement	Type of Account	Elements of Accounts		
		Structure & Systems	Scale	Principles
Level 4: Model-based accounts	Scientific, model-based explanations of how & why	Multiple, detailed & connected systems	Connected across atomic-molecular through large scales	Invoke scientific principles (e.g., driving forces, constraining factors)
Level 3: Phenomenological (school science) accounts	Descriptions of what happens	Connected systems; visible & some hidden components	Spans micro to macro scale, some challenges linking scales	Address ordered events, named processes, & make use of “school rules”
Levels 1 & 2: Force-dynamic accounts	Force-dynamic descriptions - actors fulfill purposes	Visible, familiar components of systems	Visible, macroscopic scale	Invoke actors’ capacities & purposes as explanation

# Developing LPs for Comp Hydro

Table 1: Preliminary Construct Maps and Progress Variables		
	<b>Lower Anchor (Informal Reasoning)</b>	<b>Upper Anchor (Model-Based Reasoning)</b>
<b>Water in Environmental Systems (Gunckel et al., 2012)</b>		
Structure & Systems	Water in isolated, visible systems only	Traces water through connected systems
Scientific Principles	Invokes agents to move water	Identifies driving forces and constraints
Scale	Macroscopic only	Atomic-molecular through large scale
Representation	Disconnected from the physical world	Maps and cross-sections used as models
Dependency & Agency	Water serves human needs only	Humans part of environmental systems
<b>Bringing Scientific Principles and Models to Bear in Making Sense of Data (Covitt, Dauer, &amp; Anderson, In press)</b>		
Answering Questions	Substitutes an easier question	Asks relevant scientific questions
Patterns in data	Uses stories not statistics	Weds computational thinking with knowledge of scientific models
Validating Models	Uses confirmation bias	Falsifies and test models
Explaining Events	Simple cause and effect	Recognizes mechanistic relationships
Recognizing Uncertainty	False certainty	Uncertainty is reduced and managed
<b>Computational Modeling &amp; Data Representation (based on preliminary explorations)</b>		
Quantitative Reasoning	Qualitative descriptions of change; variability is human error	Identifies trends quantitatively; distinguishes variability & error
Design and Modeling	Unconstrained brainstorming	Identifies relevant constraints; parameterizes variables
Problem-solving	One & done	Iterative & recursive approaches
Simulation	Simulations disconnected from systems they model	Compares generated & empirical data
Data Visualization	Concrete and physical models only	Uses different levels of abstraction