Definitions for Words Contained in the Educational Session, "*Hydrogeologic Concepts Related to Contaminant Transport*"

Alluvium: loose soil or sediments, which has been eroded, reshaped by water in some form, and redeposited in a non-marine setting; typically made up of a variety of materials such as sand, silt, and gravel

Anisotropy: the property of being anisotropic; having a different value when measured in different directions

Aquifer: a saturated geologic unit capable of transmitting significant quantities of water under ordinary conditions

Aquitard: a saturated geologic unit capable of transmitting water in limited amounts under ordinary conditions

Average Linear Velocity: ($\bar{v}$) calculation for how fast water is moving through the pores of the rock

Carbonate Rock: sedimentary rocks composed primarily of carbonate materials

Confining Unit: a hydrogeologic unit of relatively impermeable material, bounding one or more aquifers

Contaminant Boundary: a boundary developed based on modeling studies of groundwater flow and radionuclide transport; groundwater within this boundary may exceed the safety standards at some time within 1,000 years; safety standard for tritium is 20,000 picocuries per liter

Curie (Ci): a unit of radioactivity equal to 3.7×10^{10} disintegrations per second

Darcy's Law: fundamental law upon which all Nevada National Security Site (NNSS) flow models are based

Desorption: a process whereby a substance is released from or through a surface

Diffusion (Brownian Motion): random motion of particles suspended in a fluid resulting from their collision with the quick atoms or molecules in the gas or liquid

Dissolution: a process by which matter in an original state become dissolved components, forming a solution of the gas, liquid, or solid in the original solvent

Finnegan Inventory: a complete listing of radionuclides on the NNSS originating from underground nuclear tests

Heterogeneity: the state of being heterogeneous (i.e., made up of parts that are different)

Hydraulic Conductivity (k): ease with which water passes through geologic material

Hydraulic Gradient (dh/dl): the difference in available energy (pressure and elevation) from one point to another, it is a measure of the amount of energy available for moving water from one point to another

Hydraulic Head (h): the available energy at one point for moving groundwater; the sum of elevation and pressure

Hydrosphere: the combined mass of water found on, under, and over the surface of a plant

Matrix Diffusion: movement of molecules or atoms from a region of high to low concentration

Maximum Contaminant Level (MCL): the legal threshold limit on the amount of a substance that is allowed in public water systems under the Safe Drinking Water Act; standards set by the U.S. Environmental Protection Agency

Mechanical Dispersion: the process whereby fluids are mechanically mixed during transport caused by velocity variations at a microscopic level

Permeability: the measure of the ease with which a fluid can move through a porous rock

Porosity: measure of how much of a rock is open space; this space can be between grains or within cracks or cavities of the rock

Precipitation: the process by which a solid is created from a solution

Radioactive Decay: process by which the nucleus of an unstable atom loses energy by emitting radiation, including alpha particles, beta particles, and gamma rays

Sorption: physical and chemical process by which one substance becomes attached to another

Specific discharge: (v) volume of water moving through a unit volume of rock per time (a rate)

Tuff: a light, porous rock formed by consolidation of volcanic ash

Welded Tuff: a tuff deposit sufficiently thick and hot at the time of emplacement that the fragments soften and come together to form a rock

Zeolites: a mineral composed primarily of aluminum, silica, and water. It forms as a weathering product of volcanic tuff. It is highly porous and often called a molecular sieve for its ability to trap and hold various molecules.

Zeolitized Tuffs: a tuff that contains a high-percentage of zeolites.

Hydrogeologic Concepts Related to Contaminant Transport

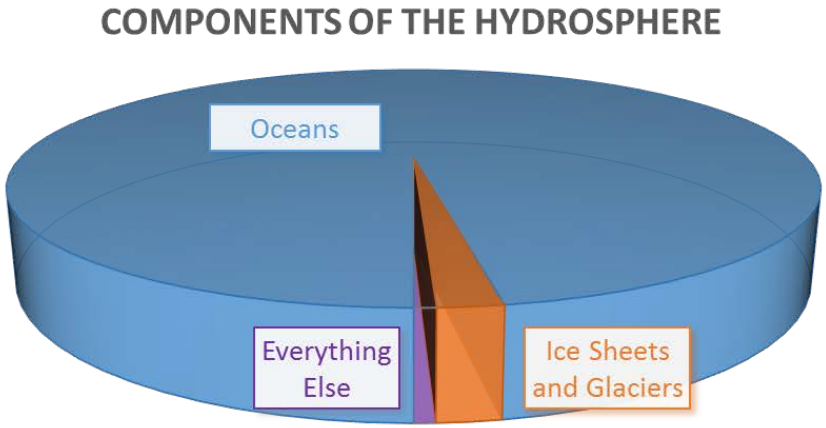
C.E. Russell
Science Advisor, DRI

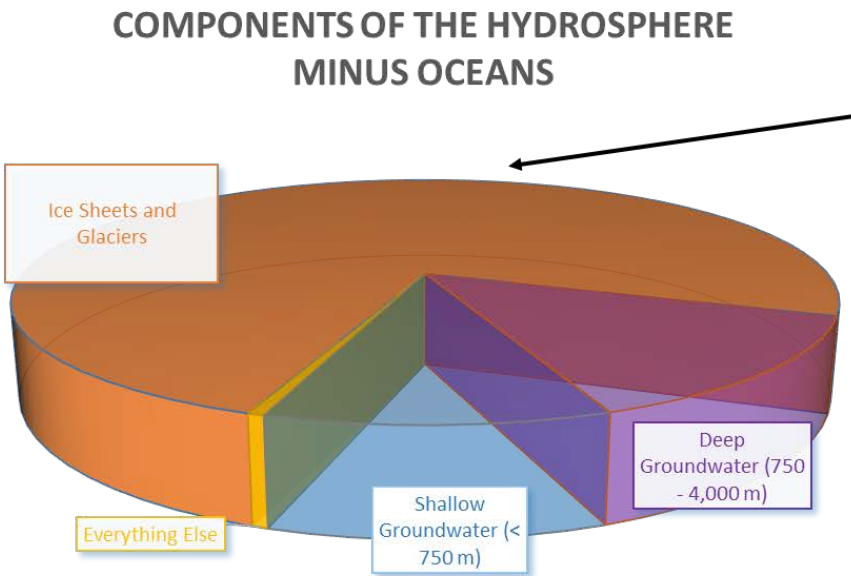
Educational Session for
Nevada Site Specific Advisory Board (NSSAB)
July 20, 2016

Objectives

- Impart a greater understanding of basic hydrologic concepts to members of the NSSAB
- Use a case study to demonstrate how basic hydrologic concepts can be combined to predict key aspects of contaminant transport
- Demonstrate how conceptual models can be revised using new data

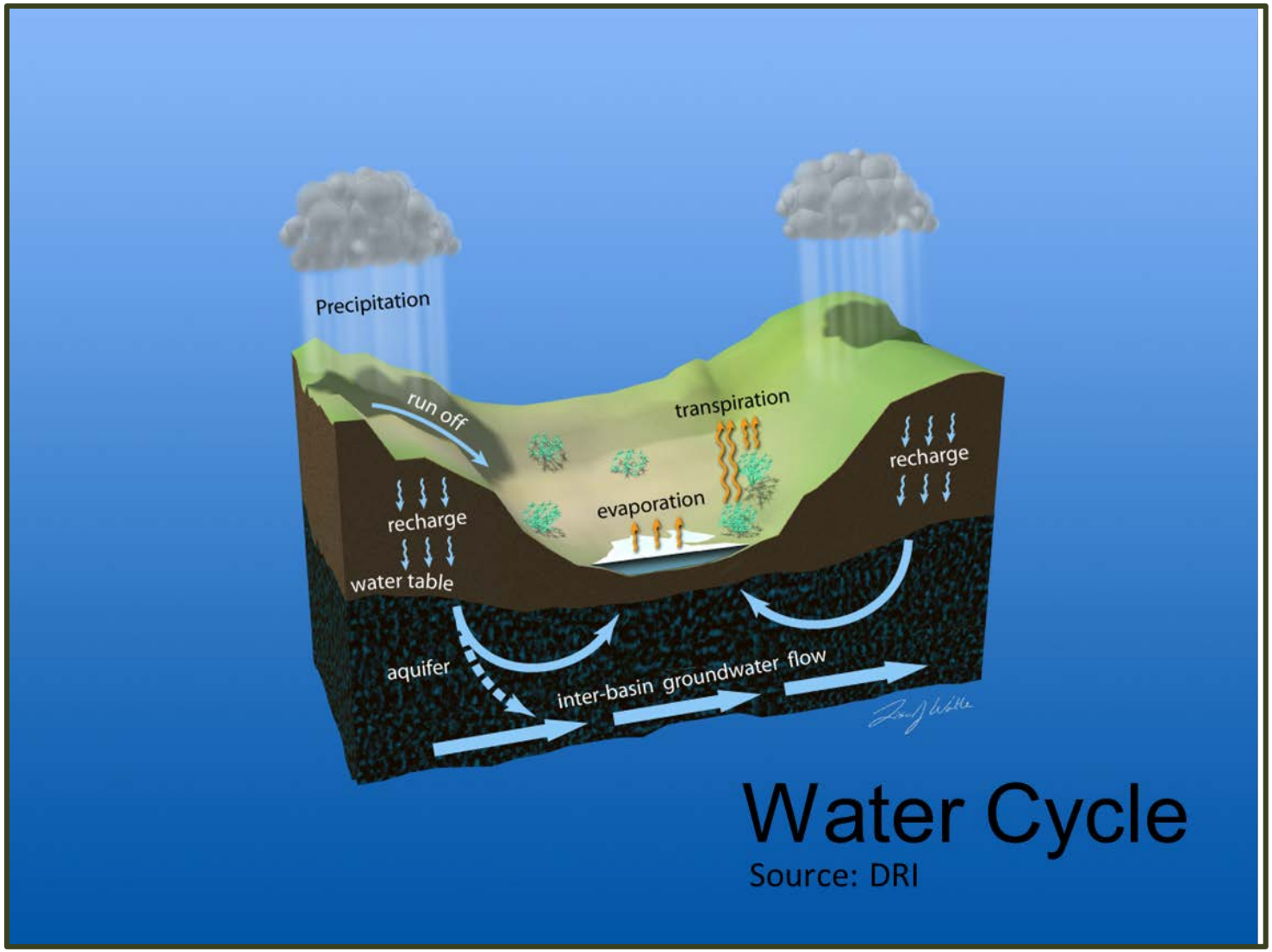
Hydrosphere



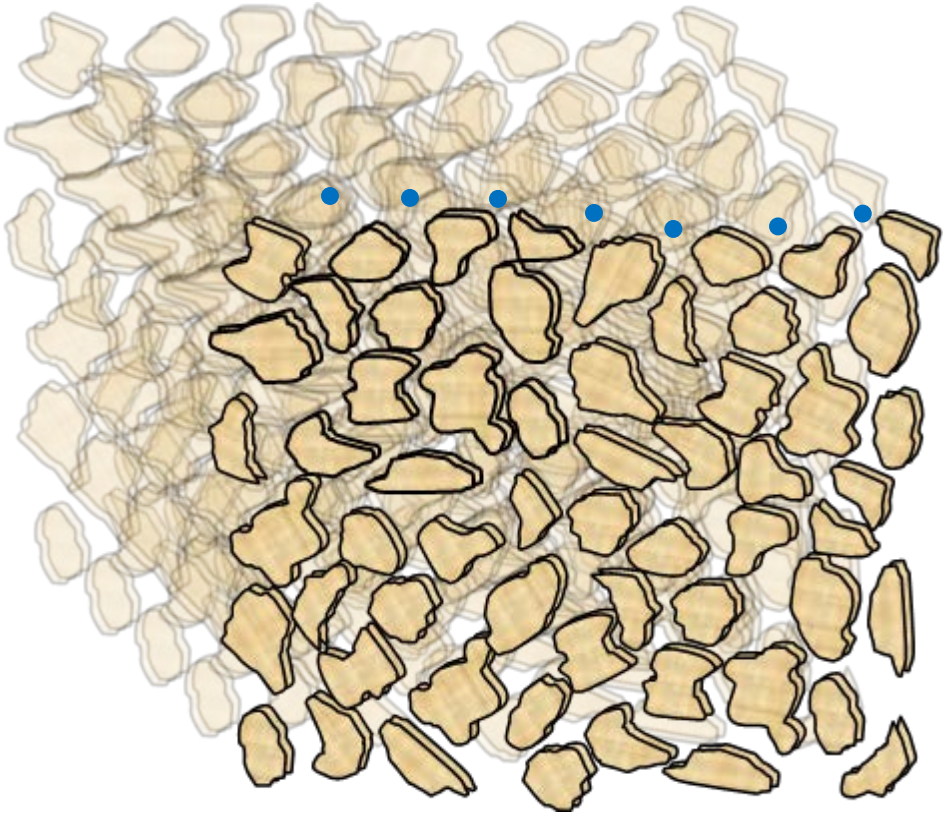


Total volume of hydrosphere is 1.4 billion cubic kilometers. Groundwater constitutes 0.7% of that.

(Retrieved from http://www.britannica.com/science/hydrosphere)

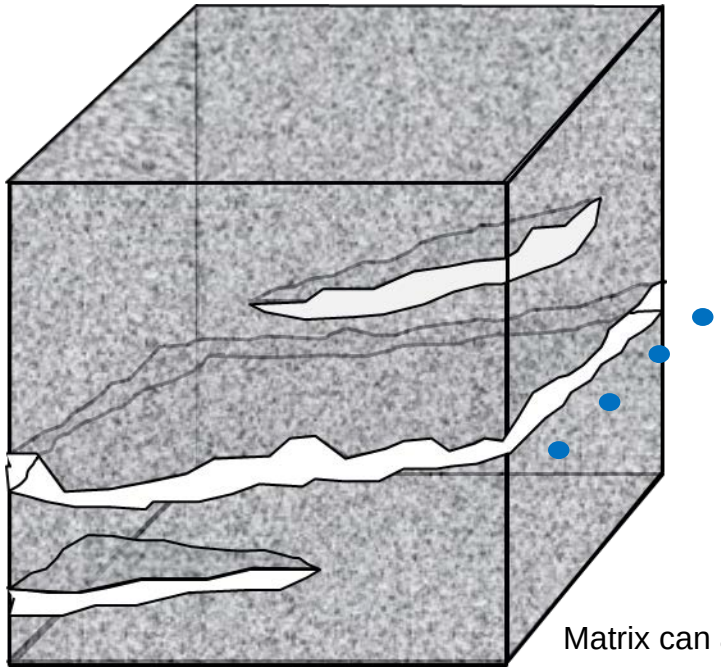

Precipitation
run off
transpiration
recharge
evaporation
recharge
water table
aquifer
inter-basin groundwater flow
Water Cycle
Source: DRI

Primary Porosity



Examples from Nevada National Security Site (NNSS): Alluvium, Zeolitized Tuffs (10 – 55% Porosity)

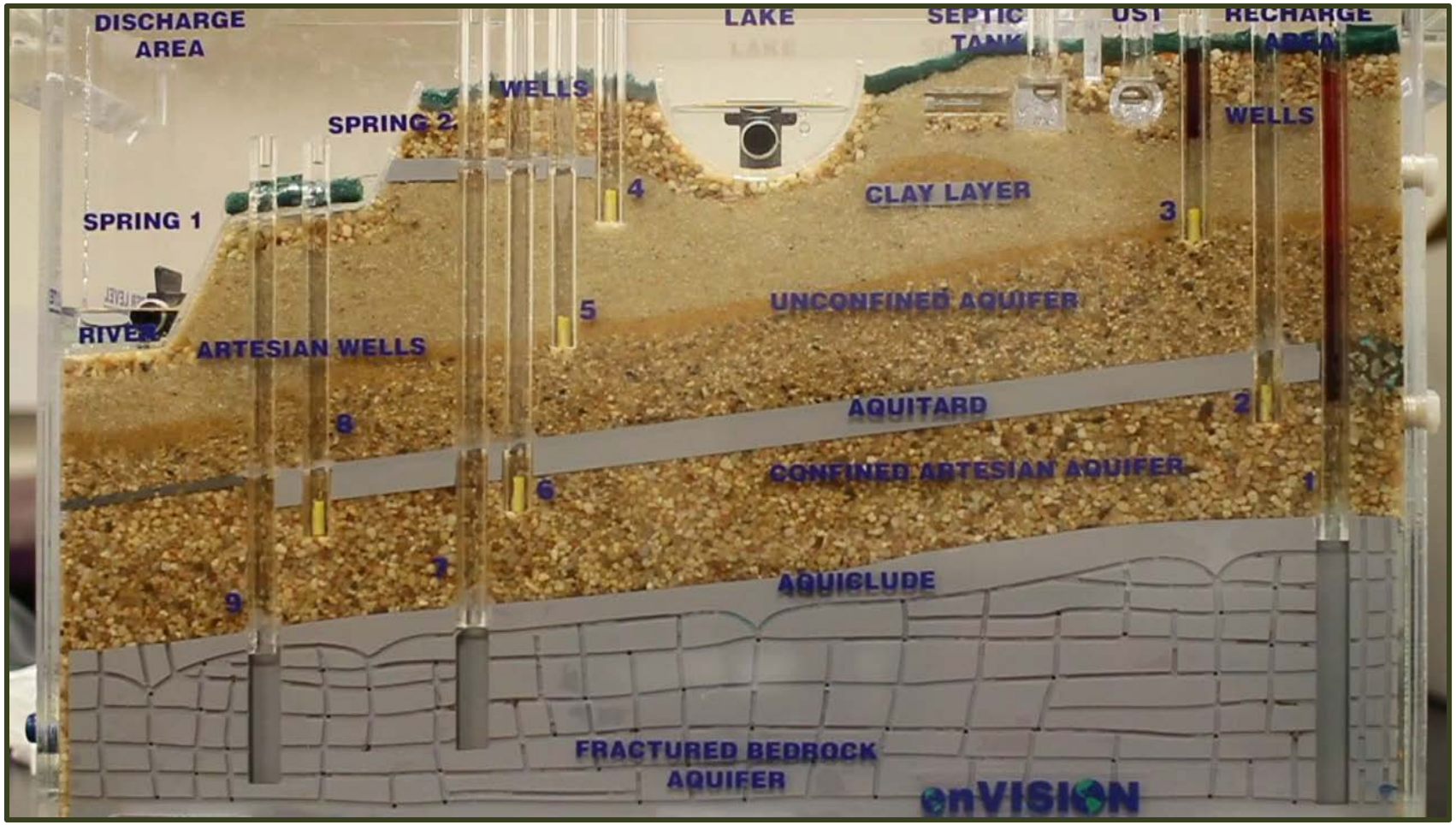
Secondary Porosity (such as fractures and faults)



Matrix can also be porous

Examples NNSS: Granite, Carbonate Aquifer, Lava Flow (<<0.1% – 10% Porosity)

Impact of Porosity: Velocity



Impact of Porosity: Storage

Hydraulic Conductivity

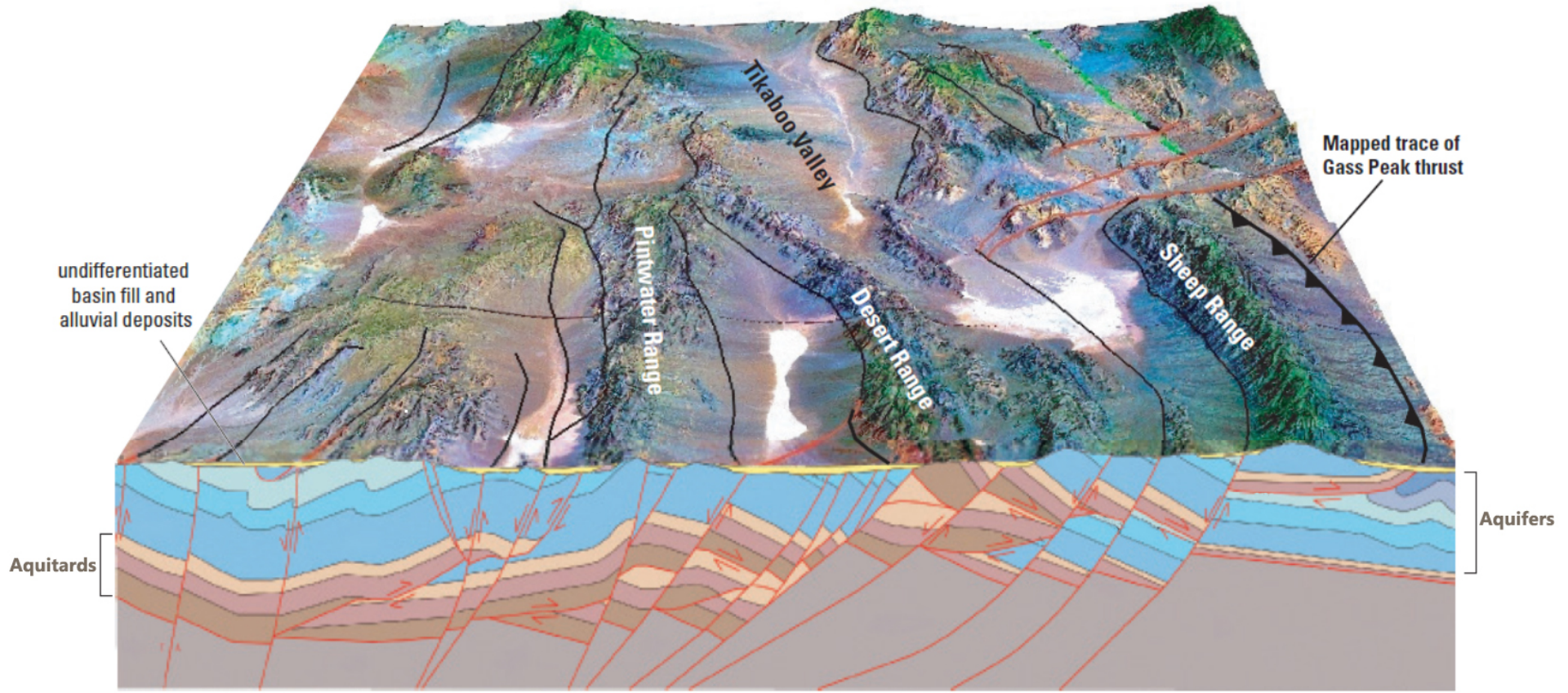
- Ease with which water passes through geologic material
- Many orders of magnitude
- Typical values for NNSS geologic material
  - Alluvium: 5* meters/day (m/d)
  - Welded Tuff: 0.2 m/d
  - Tuff Confining Unit: 0.00006 m/d

*1 meter equals 3.3 feet and
5 meters equals 16.4 feet

0.000001 m/d (est.)

8000 m/d (est.)

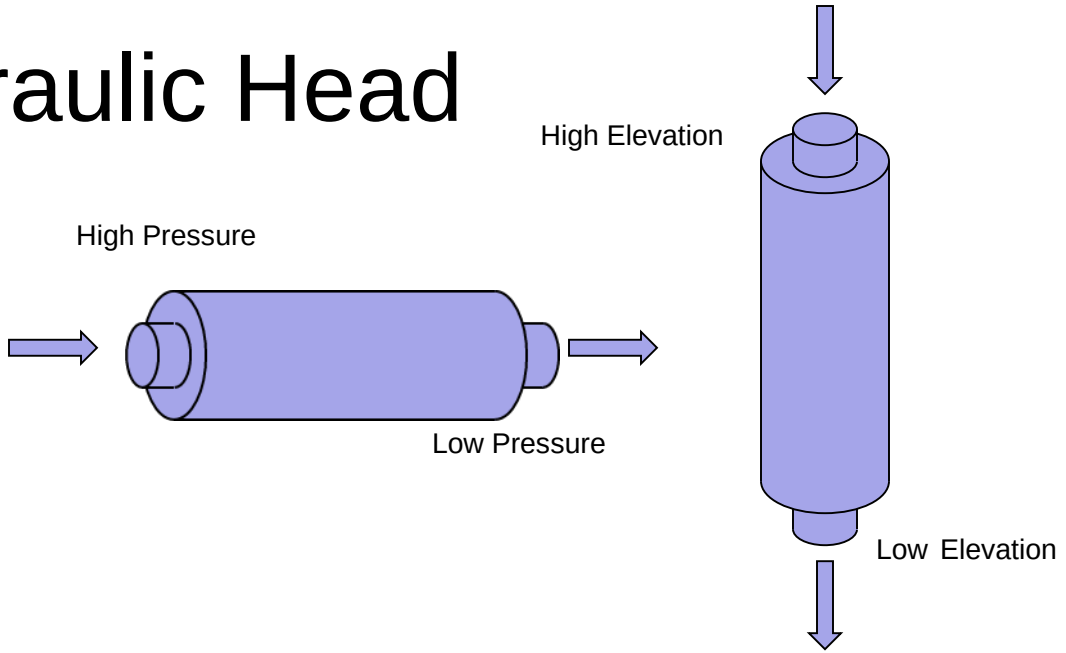
Aquifers Versus Aquitards



Source: U.S. Geological Survey SIR: 2004-5205

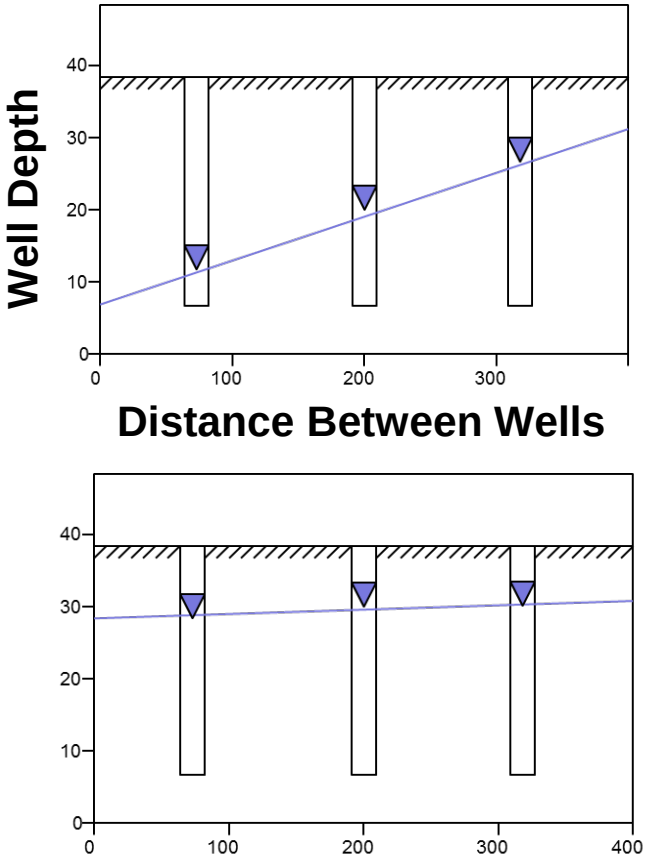
Hydraulic Head

- Heat flows from high temperature to low temperature
- Electrical current flows from high voltage to low voltage
- Water flows from high hydraulic head to low hydraulic head

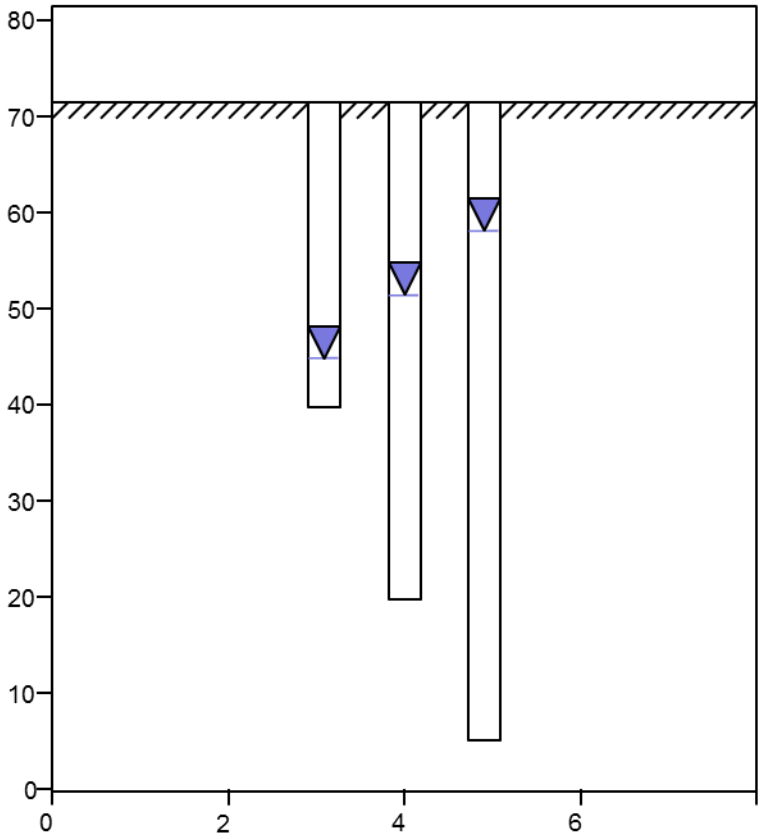


- **Hydraulic head is the sum of elevation and pressure**
  - **Available energy for moving groundwater**

Hydraulic Gradient



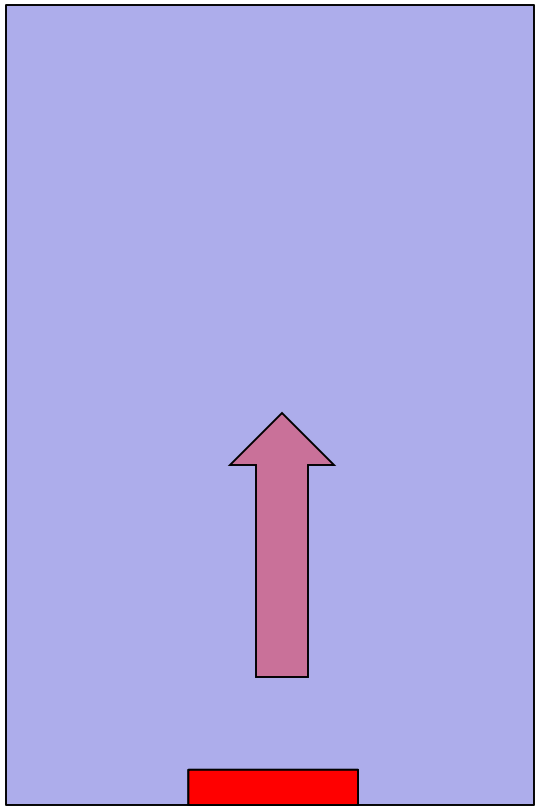
▽= water level



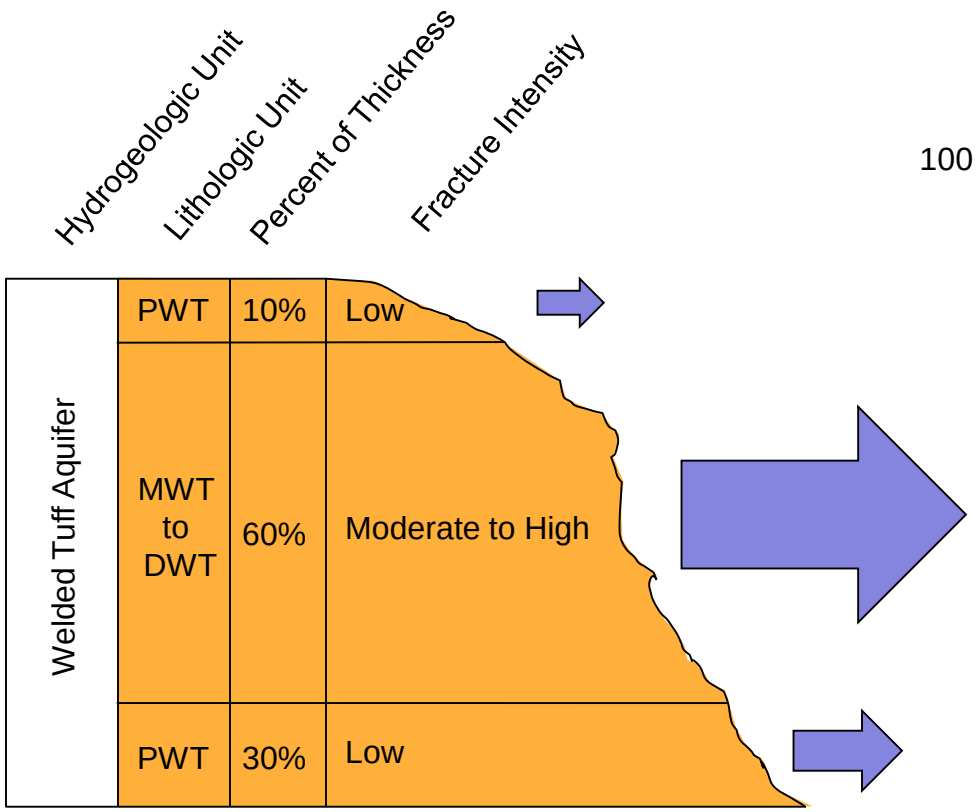
Water can flow uphill when the pressure difference is greater than elevation difference (pressure dominates)

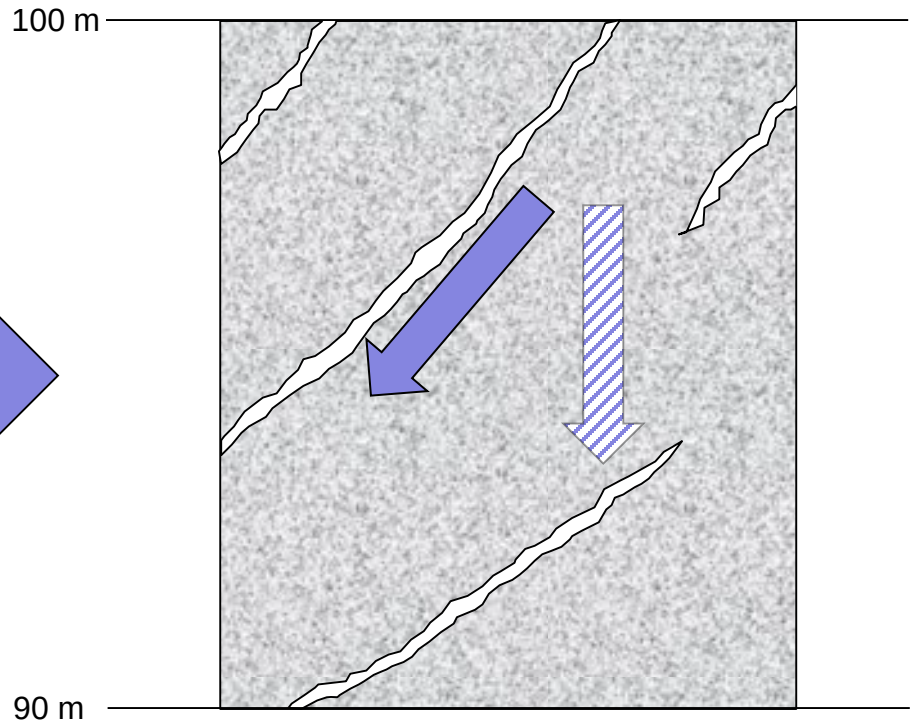
Density Driven Flow

- A helium balloon rises due to the balloon being less dense than the surrounding air
- Similarly, warm water is less dense than cool water and will rise in an otherwise still column of fluid



Geologic Composition Affects Flow Direction





PWT – Partially Welded Tuff
MWT – Moderately Welded Tuff
DWT – Densely Welded Tuff

Darcy's Law

- **Fundamental law upon which all NNSS flow models are based**
- Calculates the amount of water moving through the rock ***(Q)***
- Depends on
  - Permeability of the rock ***(K)***
  - Amount of energy available to push the water through the rock ***(dh/dl)***
  - Size of area the water is flowing through ***(A)***

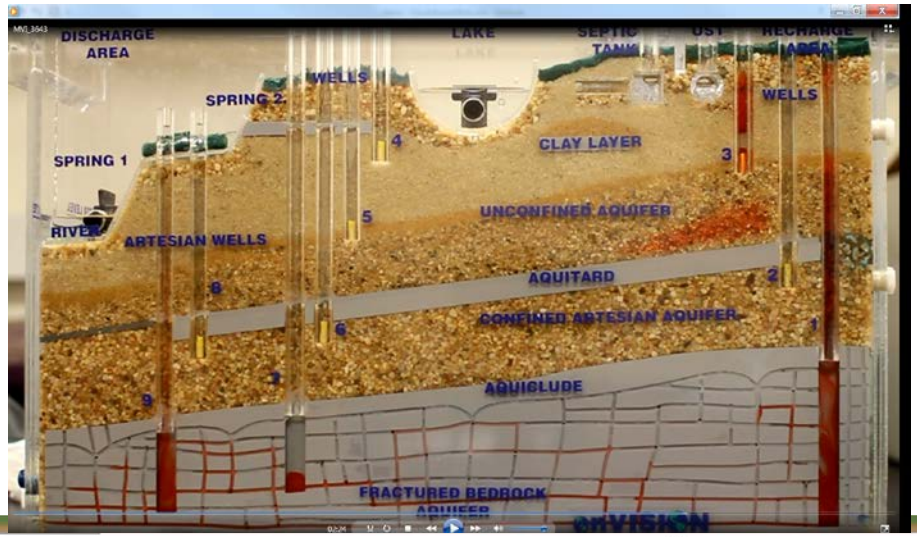
$$Q = K \frac{dh}{dl} A$$

Average Linear Velocity

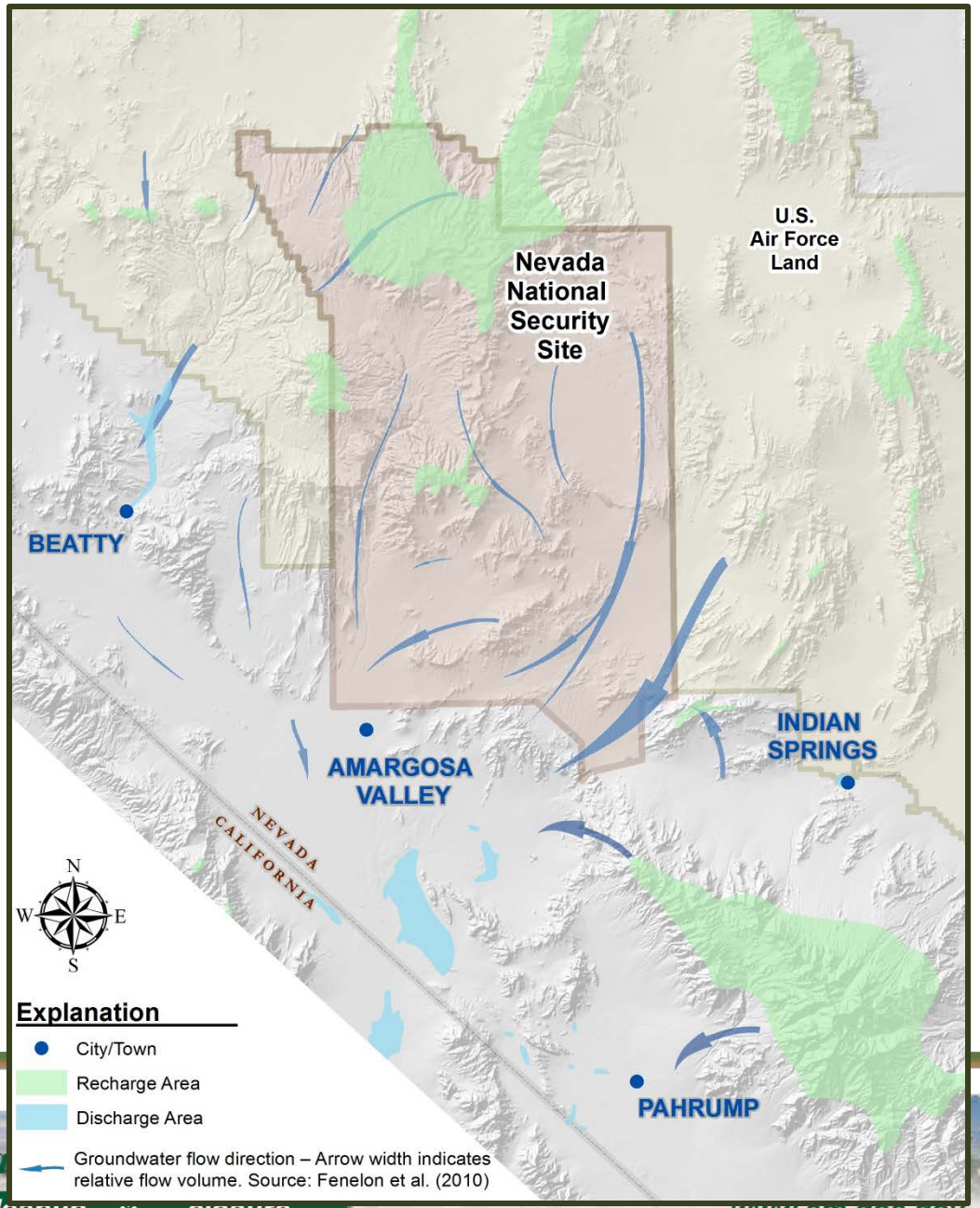
- **Velocity of water in rock is fundamentally related to Darcy's equation**
- Calculates how fast water is moving through the rock
- Identical to Darcy's equation, parameters just moved around and porosity added
  - High porosity ***(n)*** gives us low velocity ***(v)***
  - Low porosity gives us high velocity

$$v = \frac{Q}{A} = K\frac{dh}{dl}$$

$$\bar{v} = \frac{1}{n}\frac{Q}{A} = K\frac{dh}{dl}\frac{1}{n}$$

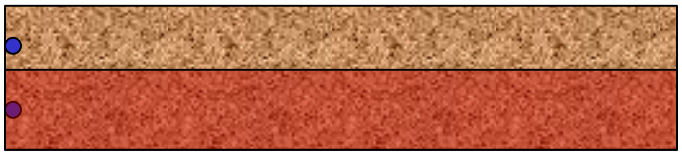


Recharge and Discharge

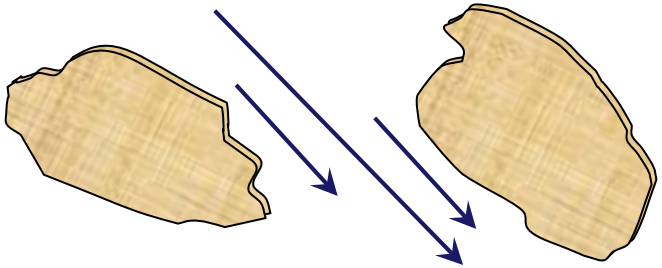


Groundwater Processes that Affect Contaminant Transport

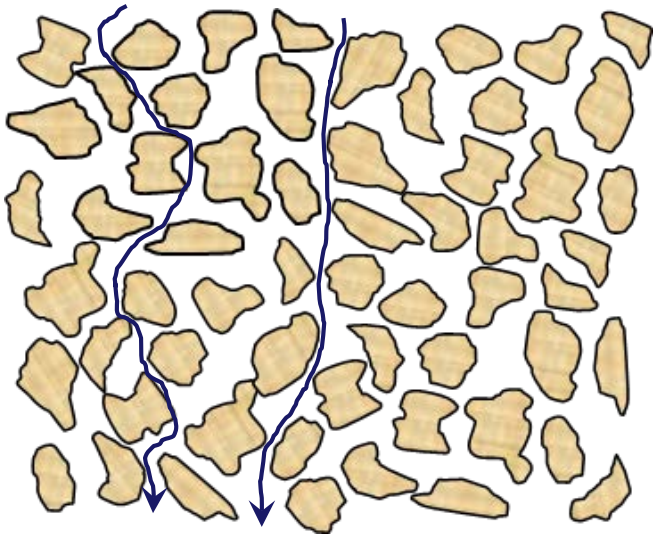
Differing speeds of groundwater



Friction

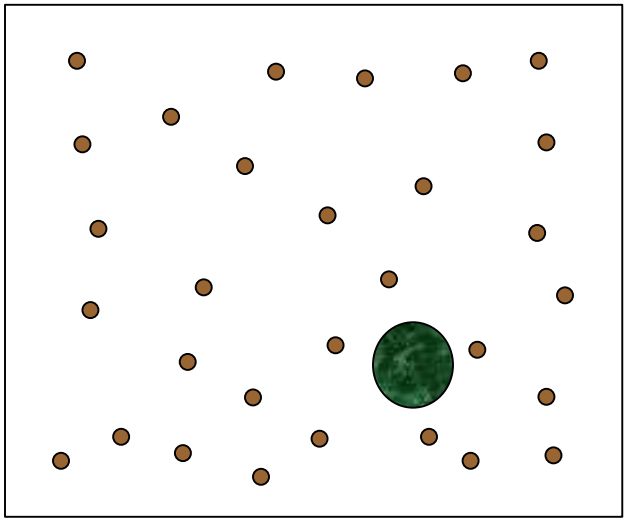


Longer vs shorter paths

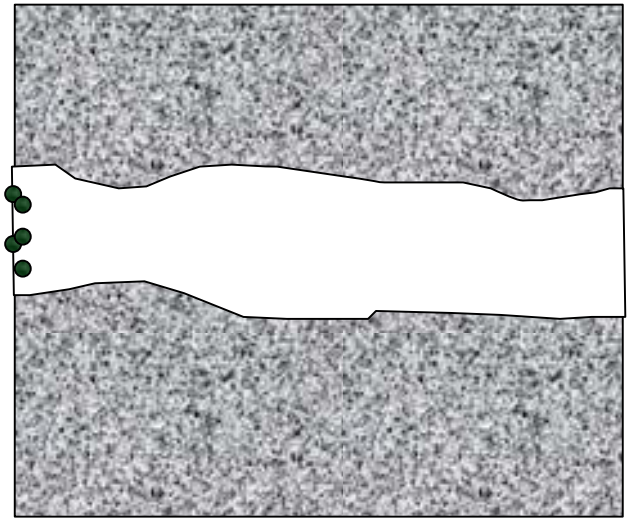


Groundwater Processes that Affect Contaminant Transport (continued)

Diffusion (Brownian Motion)



Matrix Diffusion

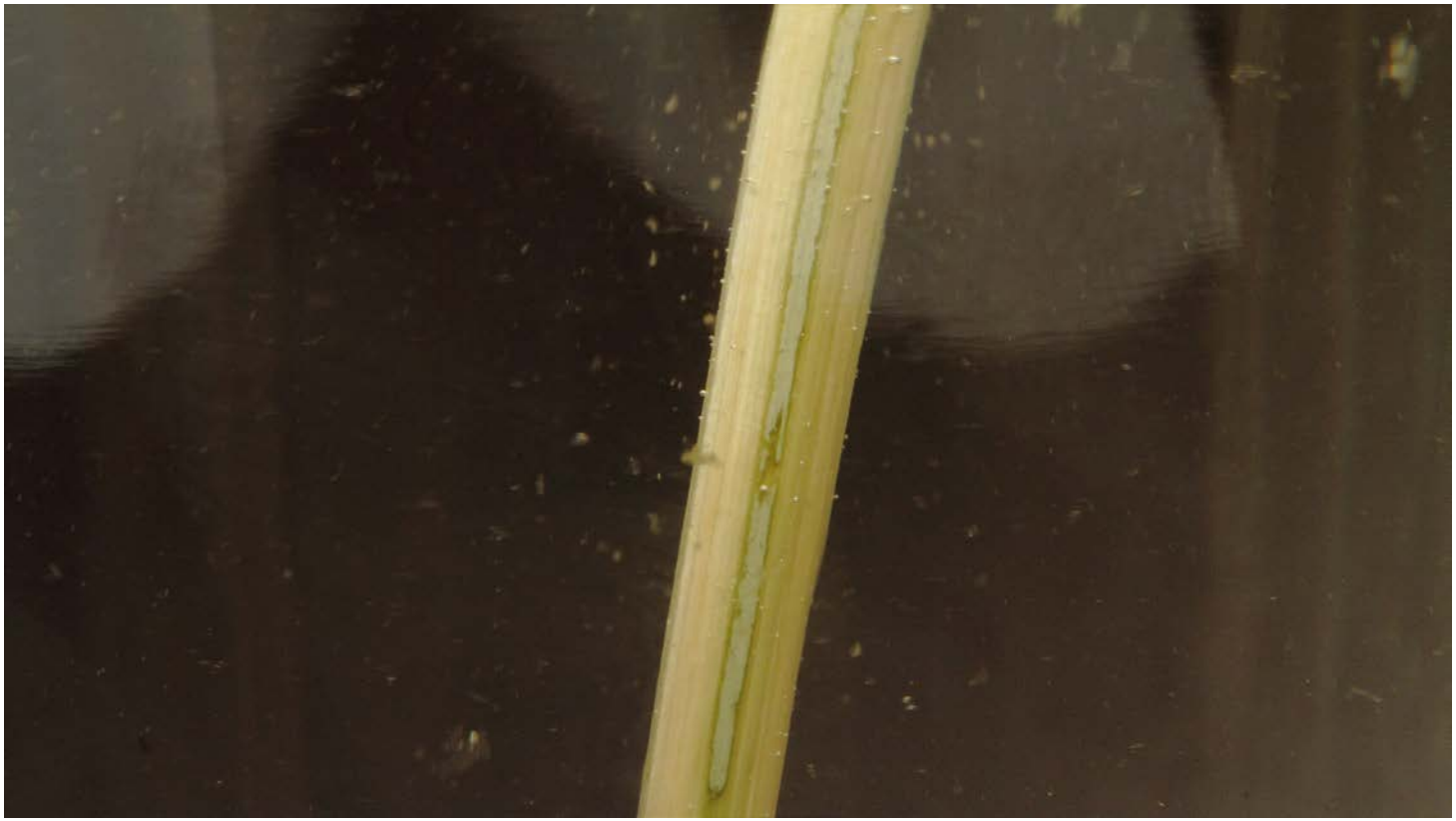


Adapted from: Francisco Esquembre, Fu-Kwun and Lookang

Matrix diffusion is really important for limiting contaminant transport

Chemical Processes that Affect Contaminant Transport

Precipitation

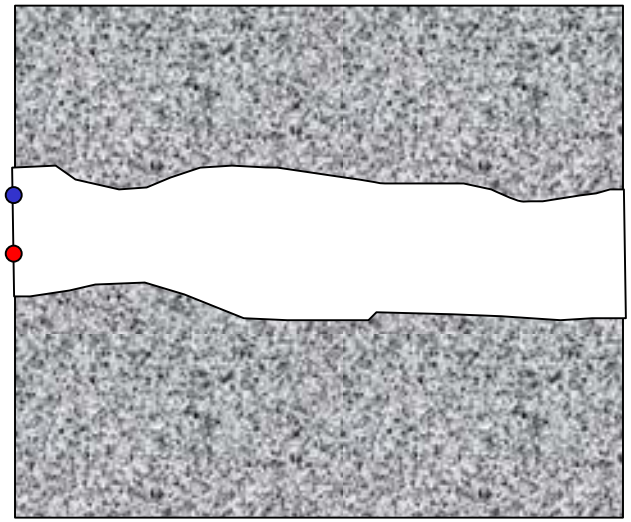


Chemical Processes that Affect Contaminant Transport (continued)

Dissolution

Chemical Processes that Affect Contaminant Transport

Sorption/Desorption*



Radioactive Decay

Radioisotope	Half-Life	Finnegan Inventory (Ci)	Activity after 1,000 years (Ci)
^{3}H	12.32	40,700,000	1.5E-17
^{14}C	5,730	2,830	2,508
^{36}Cl	301,000	616	615

Finnegan et al., (2016) – Inventory for all Corrective Action Units Decay Corrected to September 30, 2012

^{3}H equals tritium

^{14}C equals carbon-14

^{36}Cl equals chlorine-36

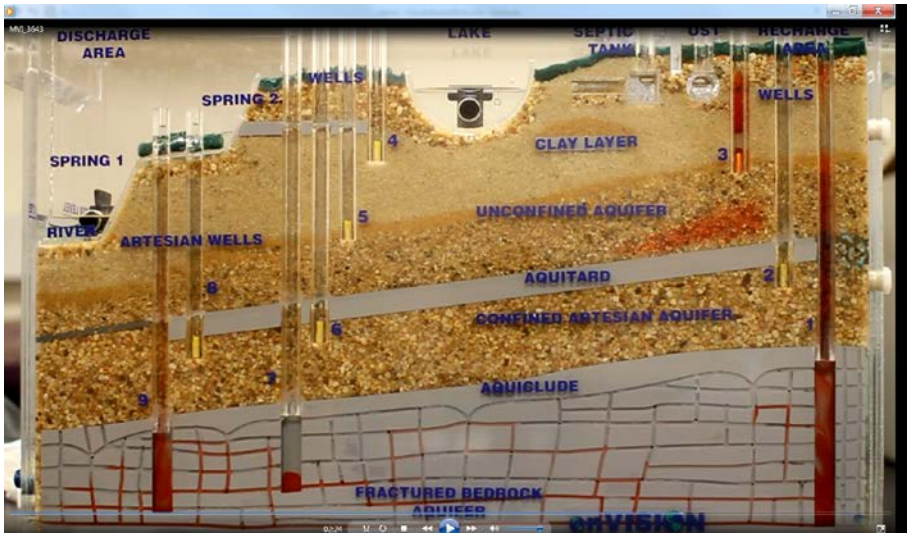
Ci equals curie

1.5E-17 equals 0.000000000000000015

***Spreads, dilutes, and slows down contaminant movement**

Conceptual Model

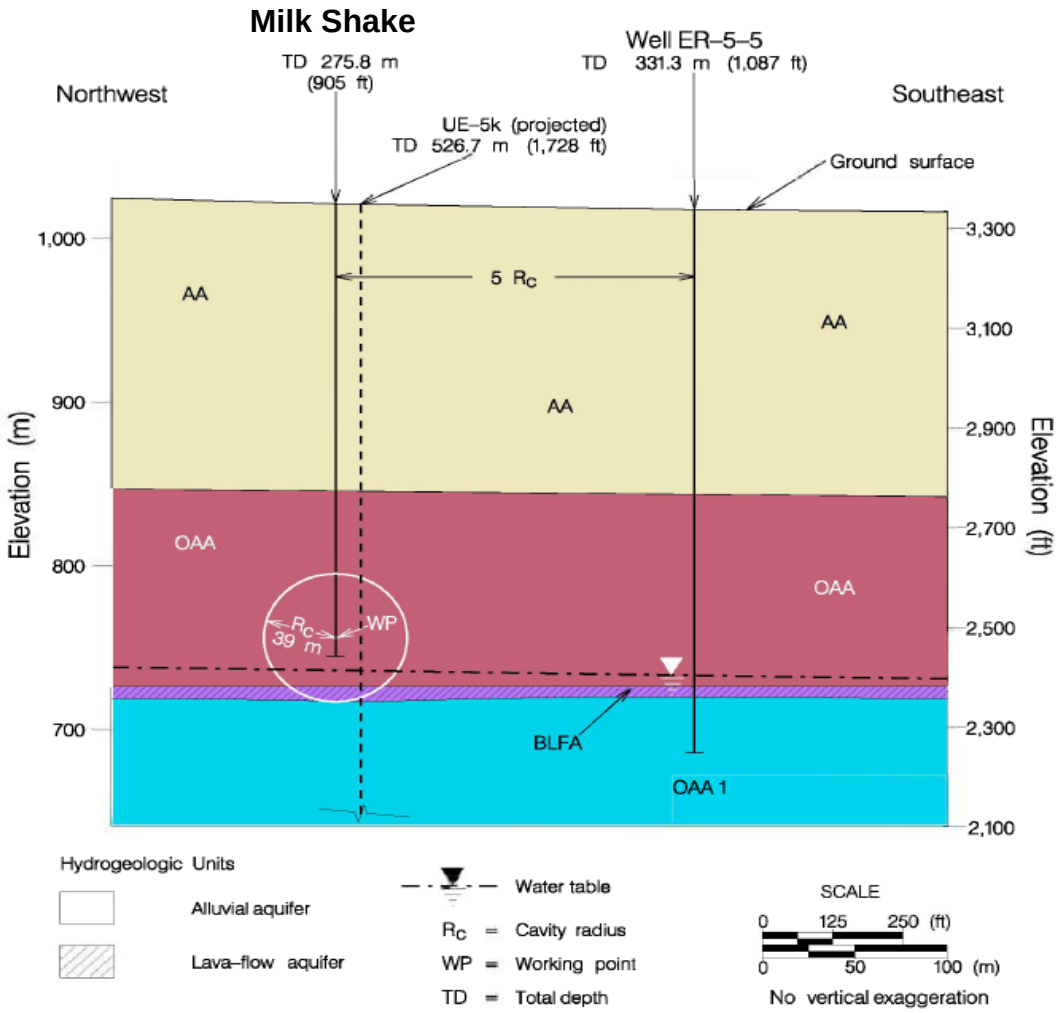
- A collection of concepts that explains observations
- Can use new observations to test conceptual model for internal consistency
- Can be used to guide the development of a numerical model



Milk Shake Test Initial Conceptual Model

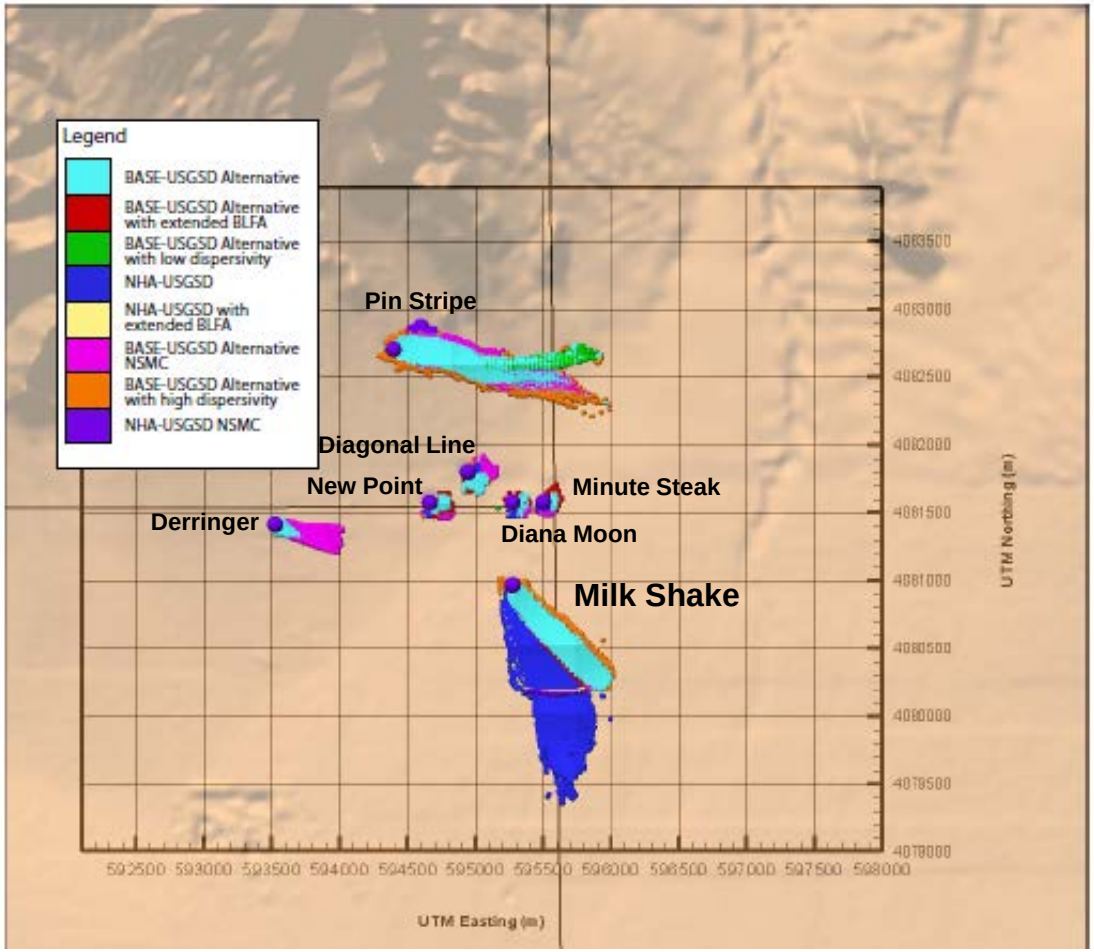
- Milk Shake detonated in Frenchman Flat at a depth of 868 feet in March 1968
- Announced yield less than 20 kilotons

Source: Navarro-Intera (2014)



Cavity radius is calculated using the maximum of the announced yield range in DOE/NV-209 (2015) and the equation in Pawloski (1999)

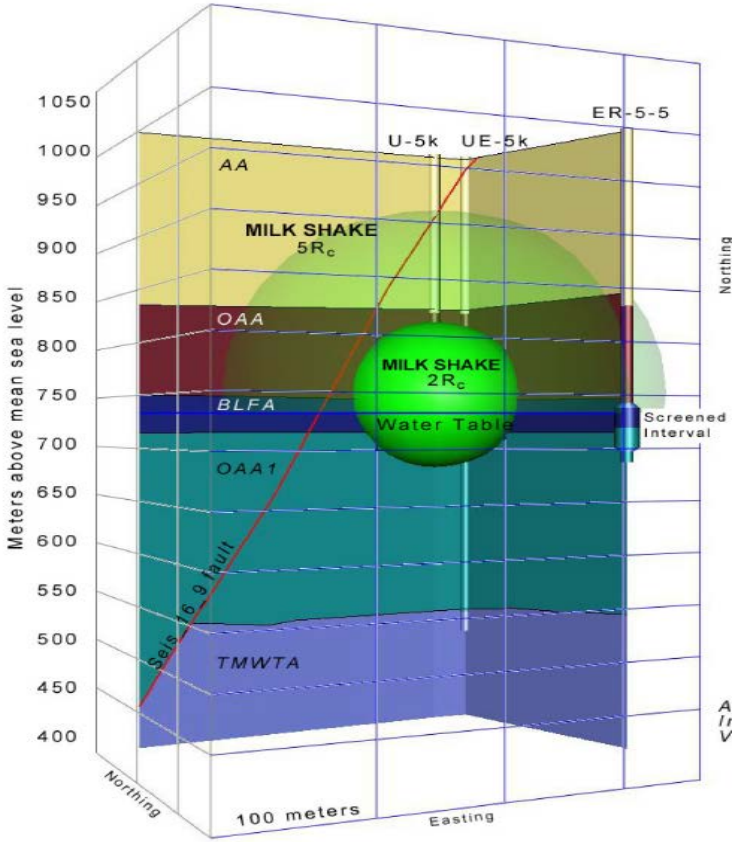
Milk Shake Test Initial Contaminant Boundary



Source: Navarro-Intera (2010)

Milk Shake Test Model Evaluation

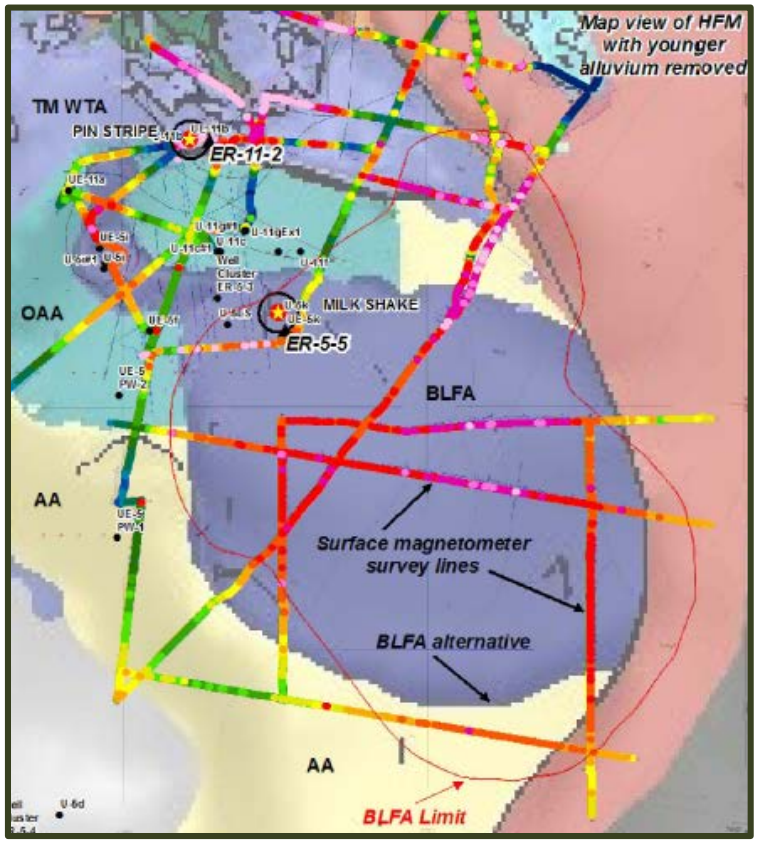
- Hydraulic Gradient – reanalyzed water level data
- Continuity of Lava Flow Aquifer – drilled and conducted surface magnetic geophysical surveys
- Nature of Lava Flow Aquifer – drilled and conducted aquifer testing
- Permeability of Lava Flow Aquifer – conducted aquifer testing



Cavity radius is calculated using the maximum of the announced yield range in DOE/NV-209 (2015) and the equation in Pawloski (1999)

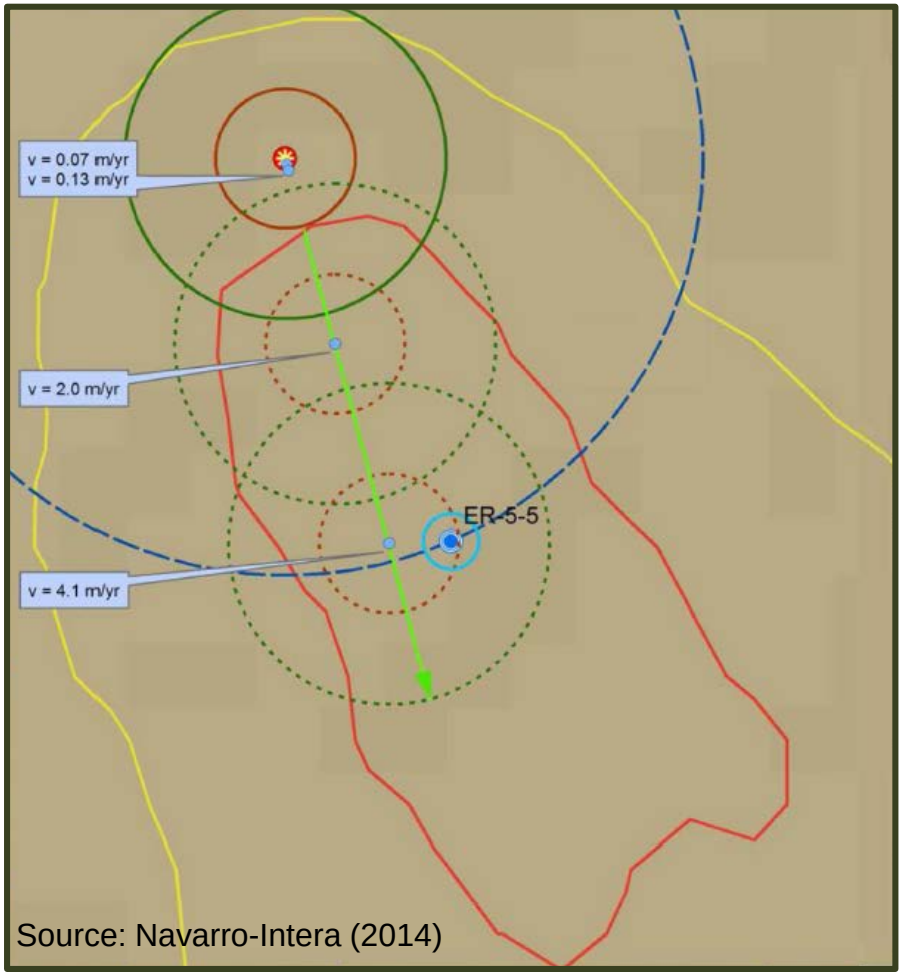
Milk Shake Test
Model Evaluation Results

- Hydraulic Gradient – refined hydraulic gradient by a few degrees
- Lava Flow Aquifer more spatially extensive than modeled
- Lava Flow Aquifer is actually rubbleized and not a dense fractured unit; acts more like a porous media rather than a fractured media
- Hydraulic conductivity similar to what was modeled



Surface Magnetic Geophysical Surveys

Milk Shake Test Forecasted Versus Actual Results



Probability of Exceeding SDWA at 50 Years
(Red line = 95% and Yellow line = 5%)

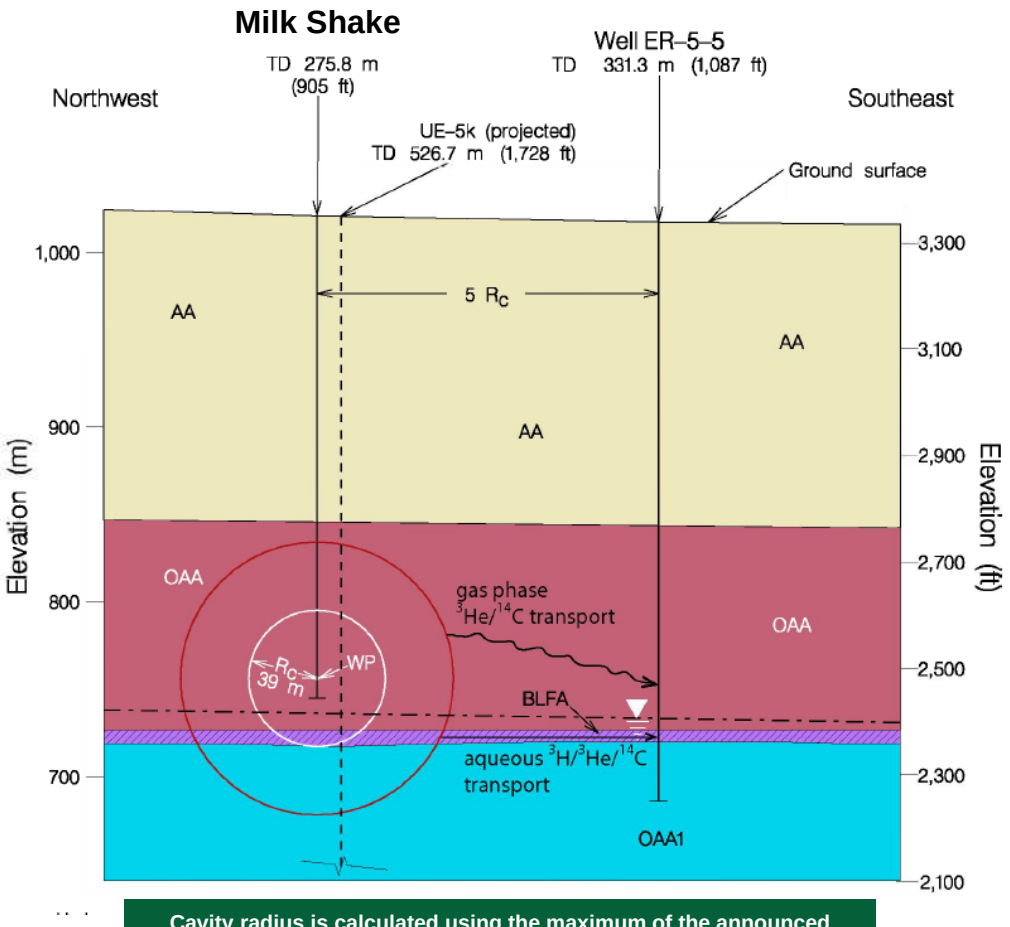
Radionuclide	Value	Error	MCL
	(pCi/L)		
^{3}H	1.1 [a]	0.4	20,000
^{14}C	0.1413	0.0005	2,000
^{36}Cl	3.37E-04	4.9E-06	700
^{99}Tc	<0.00086	N/A	900
^{129}I	2.5E-06	2.0E-07	1

[a] 2 sigma detection limit is 0.8 pCi/L.

Cl = Chlorine
I = Iodine
N/A = Not applicable
Tc = Technetium

Safe Drinking Water Act (SDWA) maximum contaminant level (MCL) for tritium is 20,000 picocuries per liter (pCi/L)

Source: Navarro-Intera (2014)



Cavity radius is calculated using the maximum of the announced yield range in DOE/NV-209 (2015) and the equation in Pawloski (1999)

Milk Shake Test Refined Conceptual Model

- Lava Flow Aquifer not acting like a fractured rock aquifer as contaminant transport significantly less
- Gaseous phase transport important in the near field

Takeaway Messages

- Scientific understanding of nature is constantly evolving
- Groundwater characterization strategy addresses this through the periodic evaluation of monitoring data against models
- Long-term monitoring is the foundation of closure, not the end point