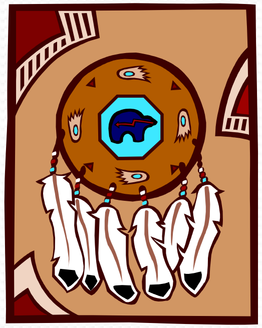
# Tribal Water Quality Monitoring and Assessment Workshop

## Ground Water Monitoring to Investigate Contamination and Protect Drinking Water Sources

*Well Siting, Installation, and Sampling*



# Importance of Ground Water?

- Presence almost everywhere
- Relatively better protected than surface water that exposes to atmosphere and surface activities
- Less treatment needed, in general, use extensively as drinking water supply sources because:
  - More protective in nature
  - Less treatment needed
  - More constant temperature and properties
  - Available across different landscapes

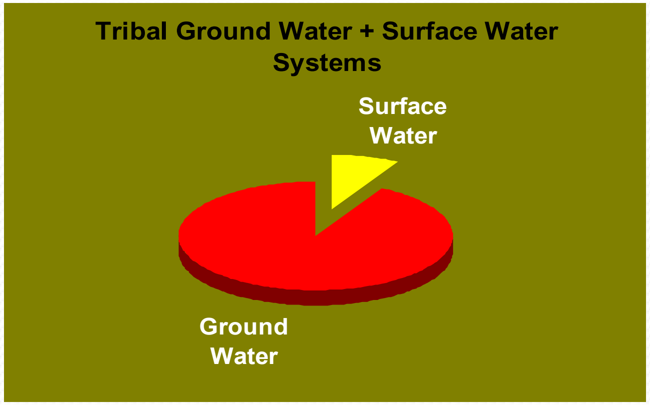
# Importance of Ground Water?

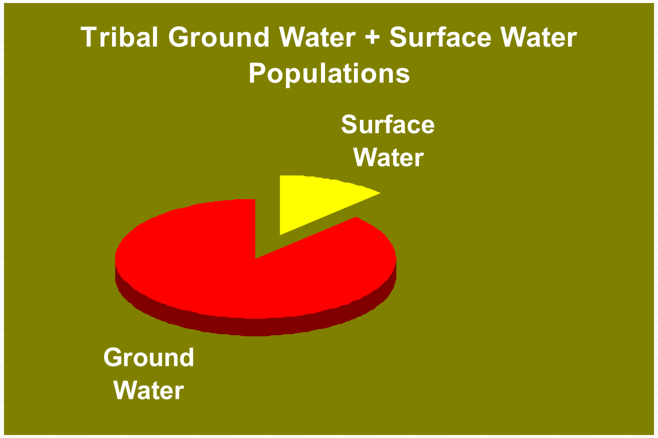
- Close linkage with surface water in many localities
  - Base flow in rivers during dry period
  - Receiving water from rivers via recharge
  - Ground water under the direct influence of surface water

# Tribal Surface Water vs. Ground Water System

- **Tribal Public Water Systems**
  - 92 % Ground Water
  - 8% Surface Water

- **Tribal Population**
  - 84 % Ground Water
  - 12 % Surface Water





# Why Monitor Ground Water?

- Track movement of known ground water contamination (the "contaminant plume")
- Identify potential threats to drinking water sources
- Monitor general ground water quality in and around drinking water source

- Allow for assessment of ground water quantity (i.e., availability, variability, and sustainability)

# Background/Preparation

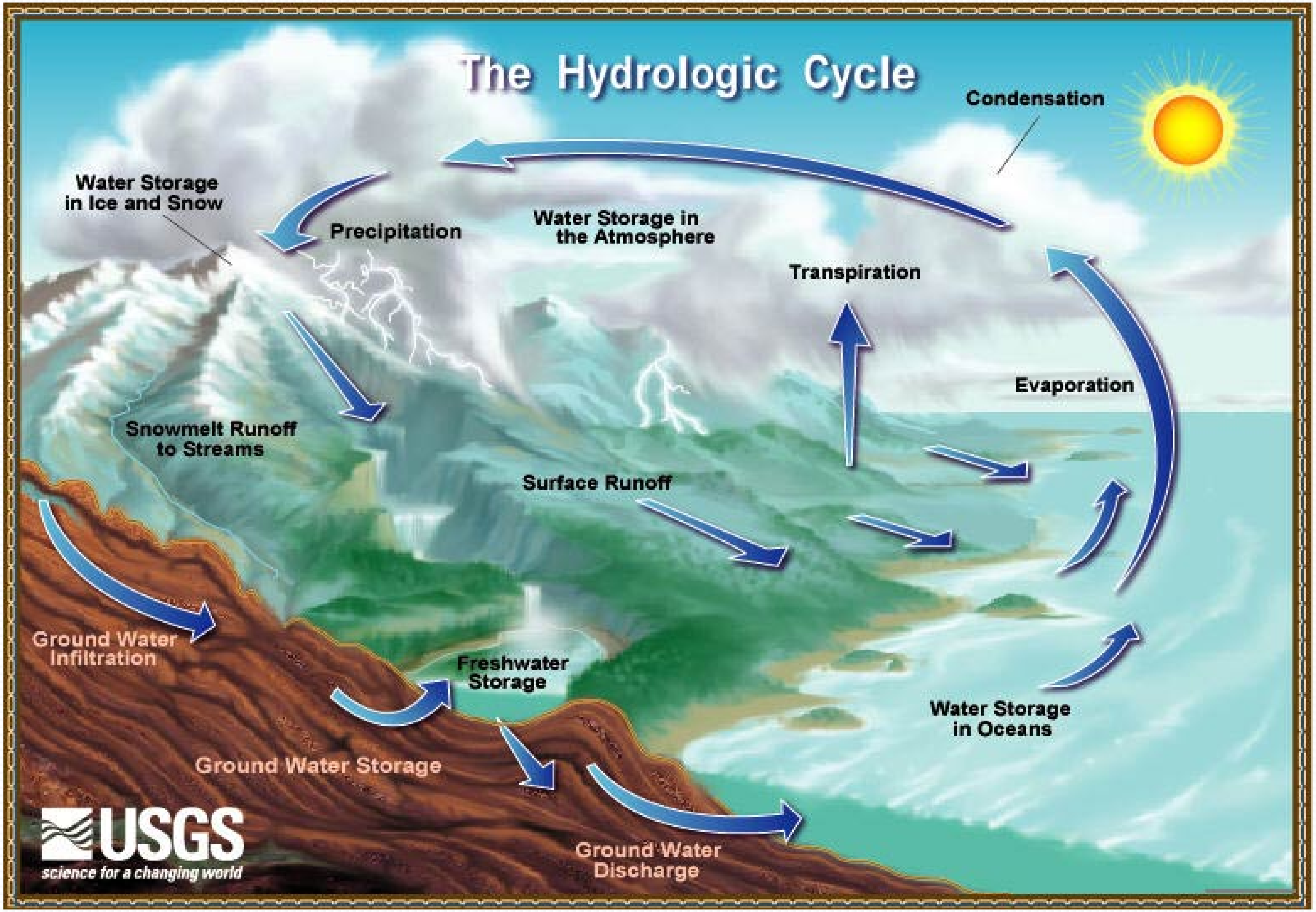
- First gather existing information on:
  - Regional geology
  - Regional hydrogeology (i.e., nature of aquifers – unconsolidated sediments, fractured bedrock, confined vs. unconfined)
  - Recharge areas

# Background/Preparation (cont.)

- Information on existing monitoring and drinking water wells (location, depths of wells, screened intervals, elevation of water table)
- Inventory of known sources of potential contamination
- Inventory of contamination events

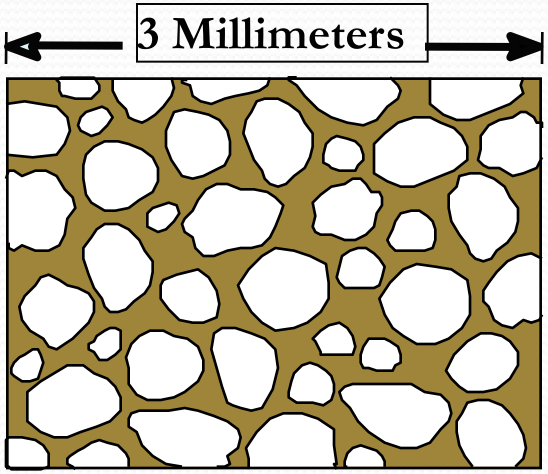
- Allow for susceptibility analysis of water supply sources

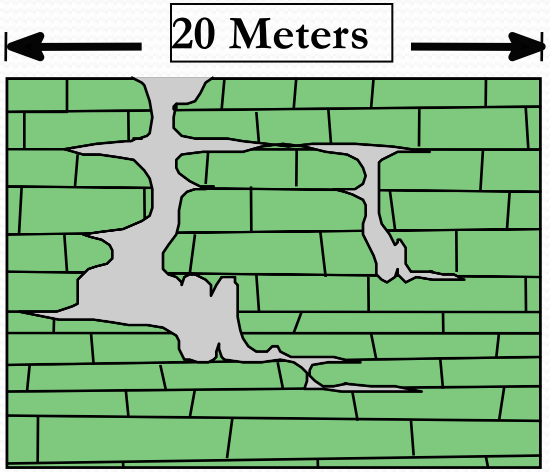
# Basic Hydrogeologic Concepts


The Hydrologic Cycle
Condensation
Water Storage in Ice and Snow
Precipitation
Water Storage in the Atmosphere
Transpiration
Evaporation
Snowmelt Runoff to Streams
Surface Runoff
Ground Water Infiltration
Freshwater Storage
Water Storage in Oceans
Ground Water Storage
Ground Water Discharge
USGS
science for a changing world

# Types of Openings In Selected Water-Bearing Rocks

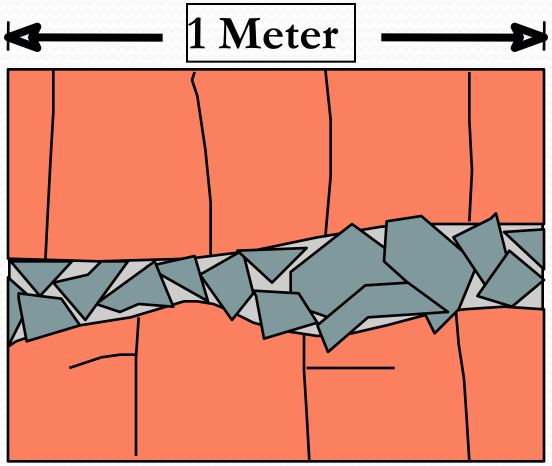
Pores in unconsolidated sedimentary deposits

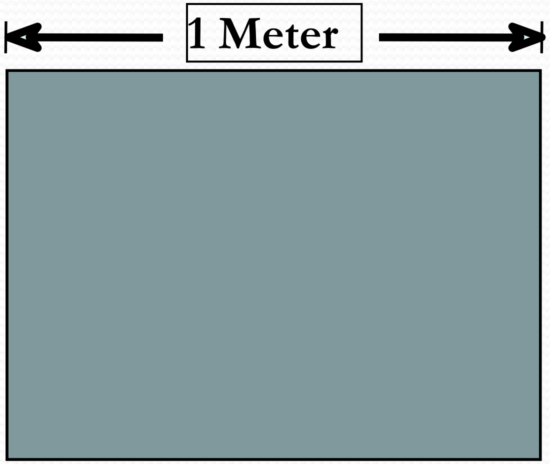




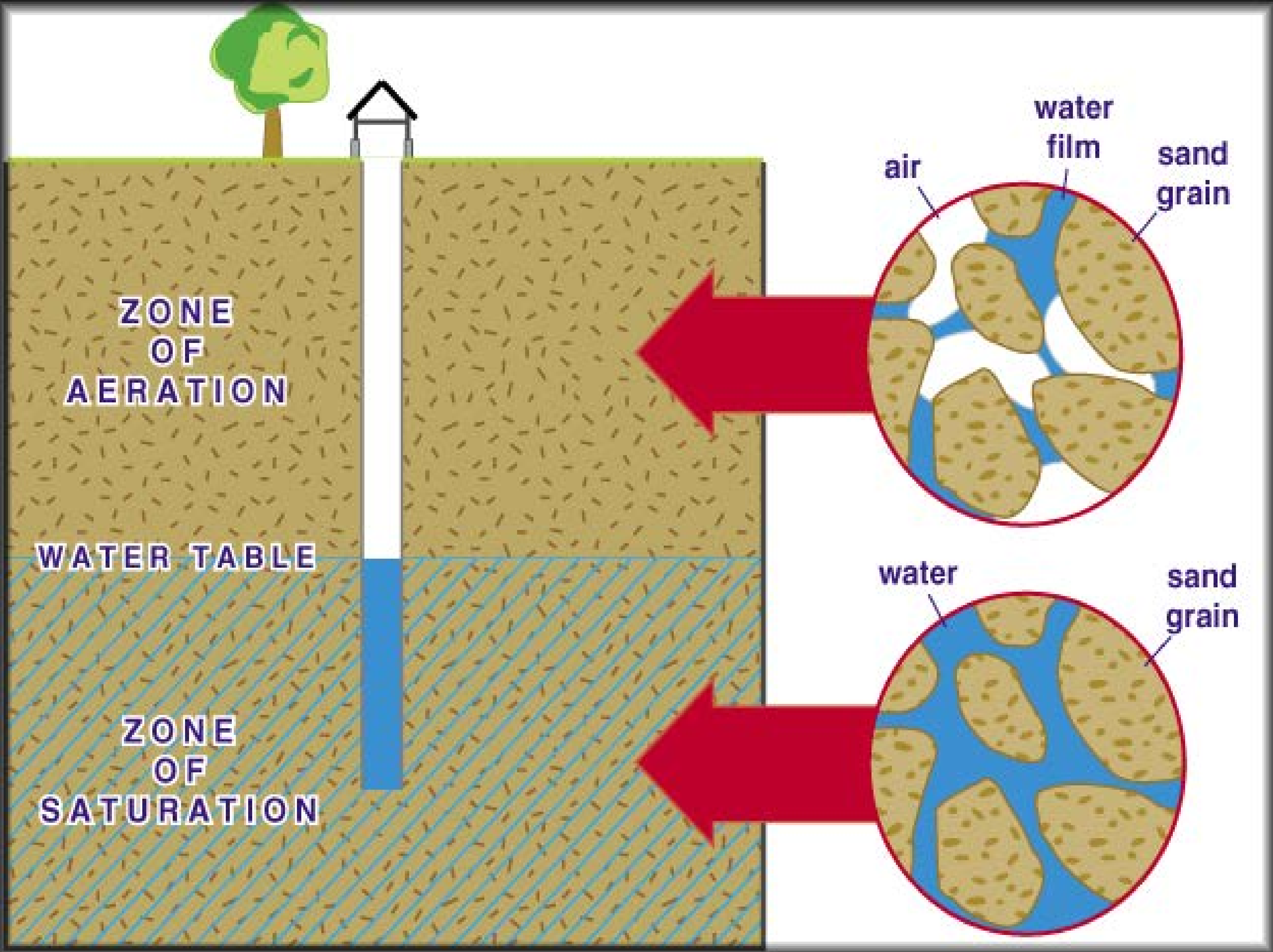
Caverns in limestone and dolomite

Rubble zone and cooling fractures in extrusive igneous rocks





Fractures in intrusive igneous rocks


ZONE OF AERATION
WATER TABLE
ZONE OF SATURATION
air
water film
sand grain
water
sand grain

# Pores and Saturation

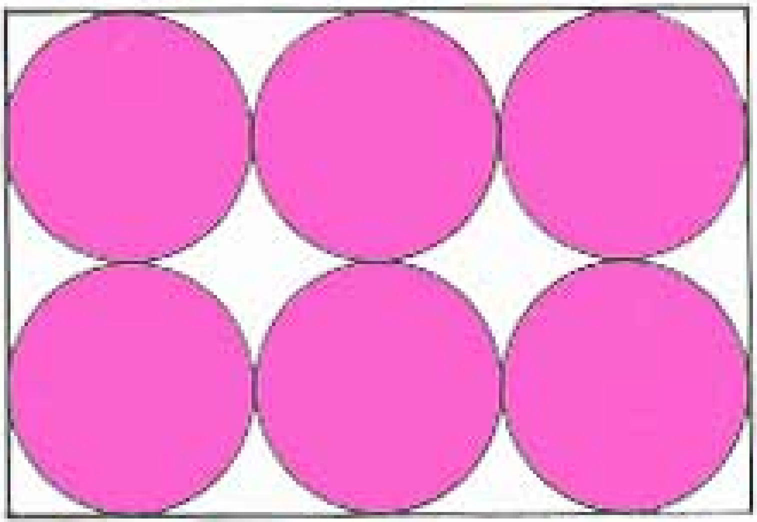
- Pores are the spaces between sediment grains
  - These spaces can be filled with air (e.g., when sand is dry). They can be filled with water (e.g., in an aquifer). Or they can be filled with some air and some water.
  - When the pores in a sample of sediment are filled with water, the sample is FULLY SATURATED.

# Pore Size

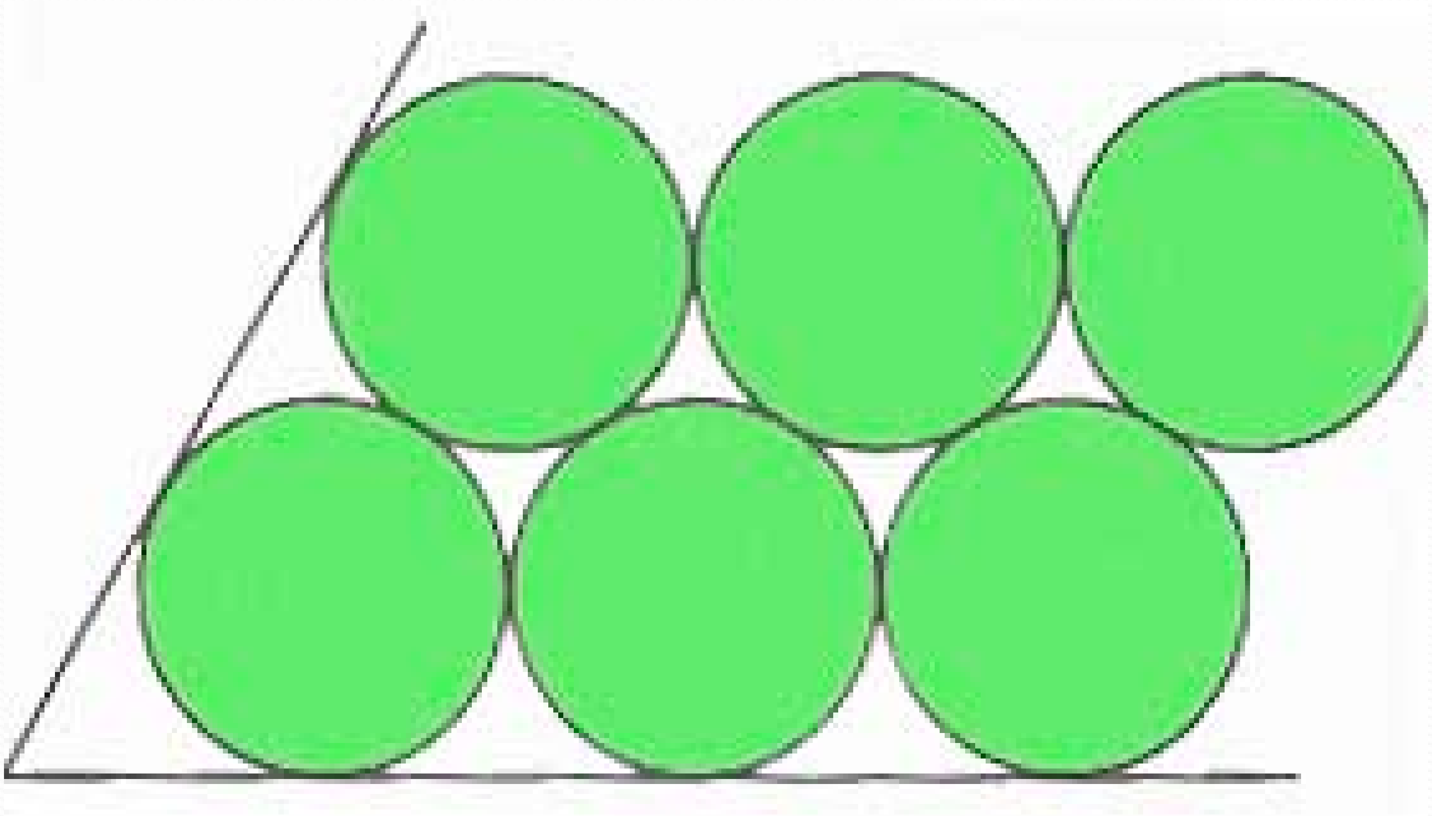
- Big grains tend to result in big pores
- Small grains tend to result in small pores
- Sorting: Are the grains all the same size?

  - **Poorly sorted (well-mixed) sediment has lots of different sizes of grains. The small grains fill in part of the spaces between the big grains.**

# One grain on top of another: “Cubic Packing”

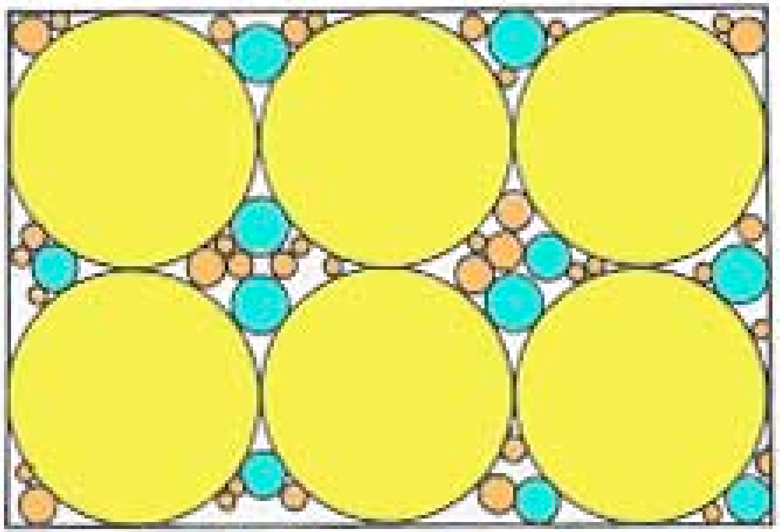


# More tightly packed grains (lower porosity)



# Small grains fill in the empty spaces between large grains.

(This sample is poorly sorted.)



# Grain Size

| Name | Size Range (mm) |
|---|---|
| gravel | > 2.0 |
| very coarse sand | 1.0-1.999 |
| coarse sand | 0.500-0.999 |
| medium sand | 0.250-0.499 |
| fine sand | 0.100-0.249 |
| very fine sand | 0.050-0.099 |
| silt | 0.002-0.049 |
| clay | < 0.002 |

(Loxnachar et al, 19)

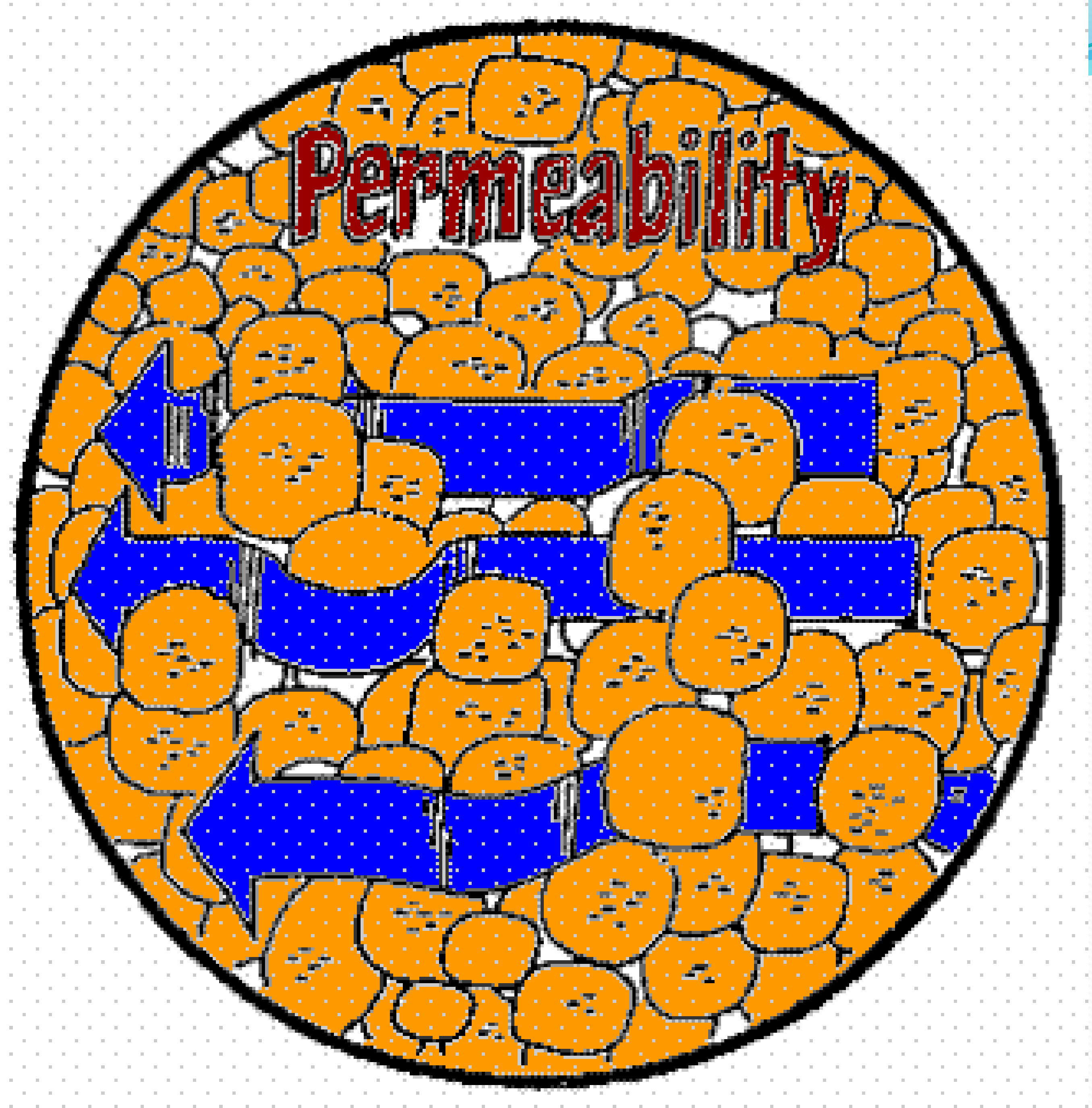
# Porosity

- The % of pores in a given volume of aquifer
  - Sometimes few of the pores are connected.
  - Sometimes there's a lot of FRICTION as the water tries to get out of the skinny part of the pore
  - So high porosity does NOT automatically mean high permeability.
- Definition of porosity: [volume of pores / volume of your sample] x 100
  - $([V_v/V_T] \times 100)$

# Porosity Ranges for Sediments

| Material | Porosity (%) |
|---|---|
| well-sorted sand or gravel | 25-50 |
| sand and gravel, mixed | 20-35 |
| glacial till | 10-20 |
| silt | 35-50 |
| clay | 33-60 |

(Based on Meinzer (1923a); Davis (1969); Cohen (1965); and MacCary and Lambert (1962) as quoted by C.W. Fetter [2])


Permeability

# Permeability depends on pore size

- Permeability - the ability to transmit water or other fluid
- Friction slows water down as it moves against the sides of the pore (e.g., as it moves past individual grains of sand)
- When pores are big, less water has to touch the sides of the pore
  - So water moves faster through big pores

# Hydraulic Conductivity

- The permeability of sand is the same whether water or oil or any other fluid flows through it.

- Hydraulic conductivity is a concept similar to permeability, but its value will vary depending on the fluid flowing through the aquifer.

- We are only concerned about water here.

# Hydraulic Conductivity (K) for Sediments

| Material | Hydraulic Conductivity (cm/s) | (ft/day) |
|---|---|---|
| **well-sorted gravel** | **$10^{-2}$ to 1** | **28.3 to 28300** |
| **well-sorted sands, glacial outwash** | **$10^{-3}$ to $10^{-1}$** | **2.83 to 283** |
| **silty sands, fine sands** | **$10^{-5}$ to $10^{-3}$** | **0.0283 to 2.83** |
| **silt, sandy silts, clayey sands, till** | **$10^{-6}$ to $10^{-4}$** | **0.00283 to 0.283** |
| **clay** | **$10^{-9}$ to $10^{-6}$** | **0.00000283 to 0.00283** |
| (C.W. Fetter [2]) | | |

# Expressing Small Numbers

$$0.001 = \frac{1}{1{,}000} = \frac{1}{1\text{x}10^{3}} = 1\text{x}10^{-3}$$

$$0.000001 = \frac{1}{1{,}000{,}000} = \frac{1}{1\text{x}10^{6}} = 1\text{x}10^{-6}$$

# What makes groundwater flow?

Answer:

Hydraulic head differences!

# Question: What is hydraulic head?

Answer: A measure of the energy water has at a particular point in the aquifer.

So…. what gives water that energy???

# Most of the energy of groundwater at a particular location in an aquifer is derived from…

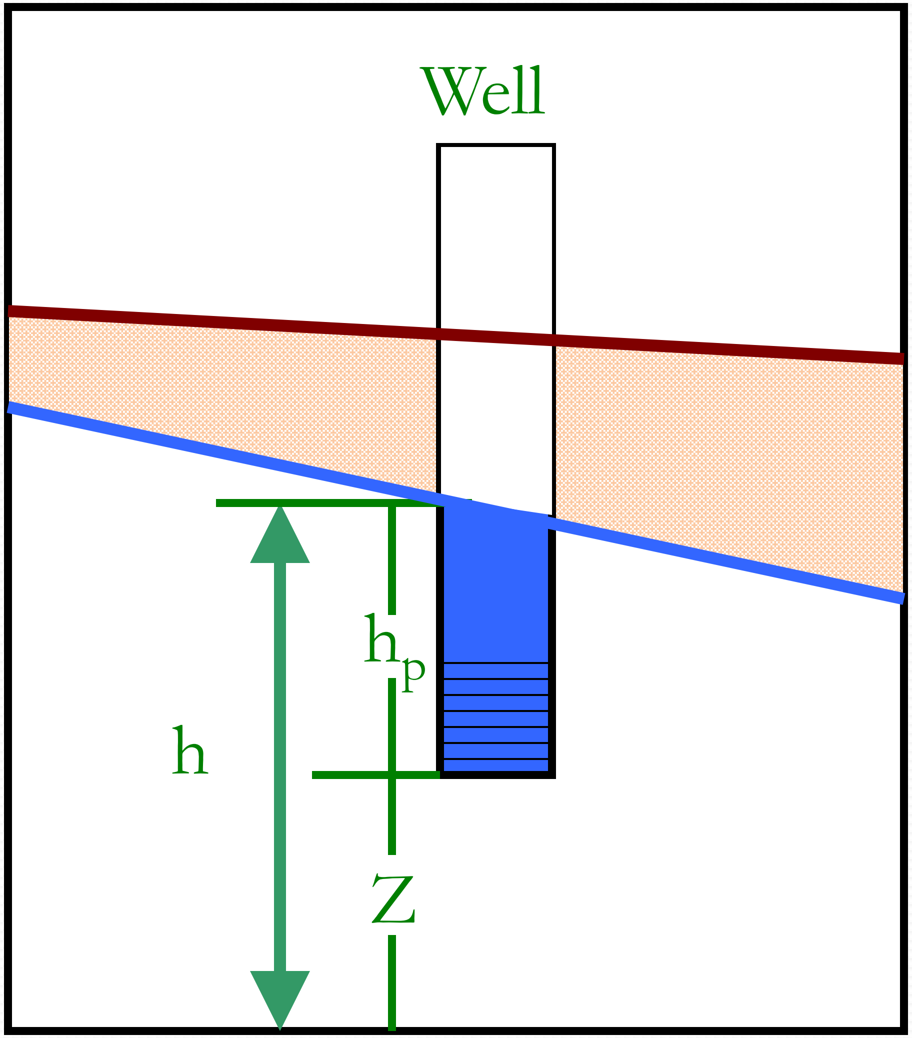
1. Its ELEVATION.

and…

2. How much PRESSURE it is under.

- Elevation and pressure head add up to total head.

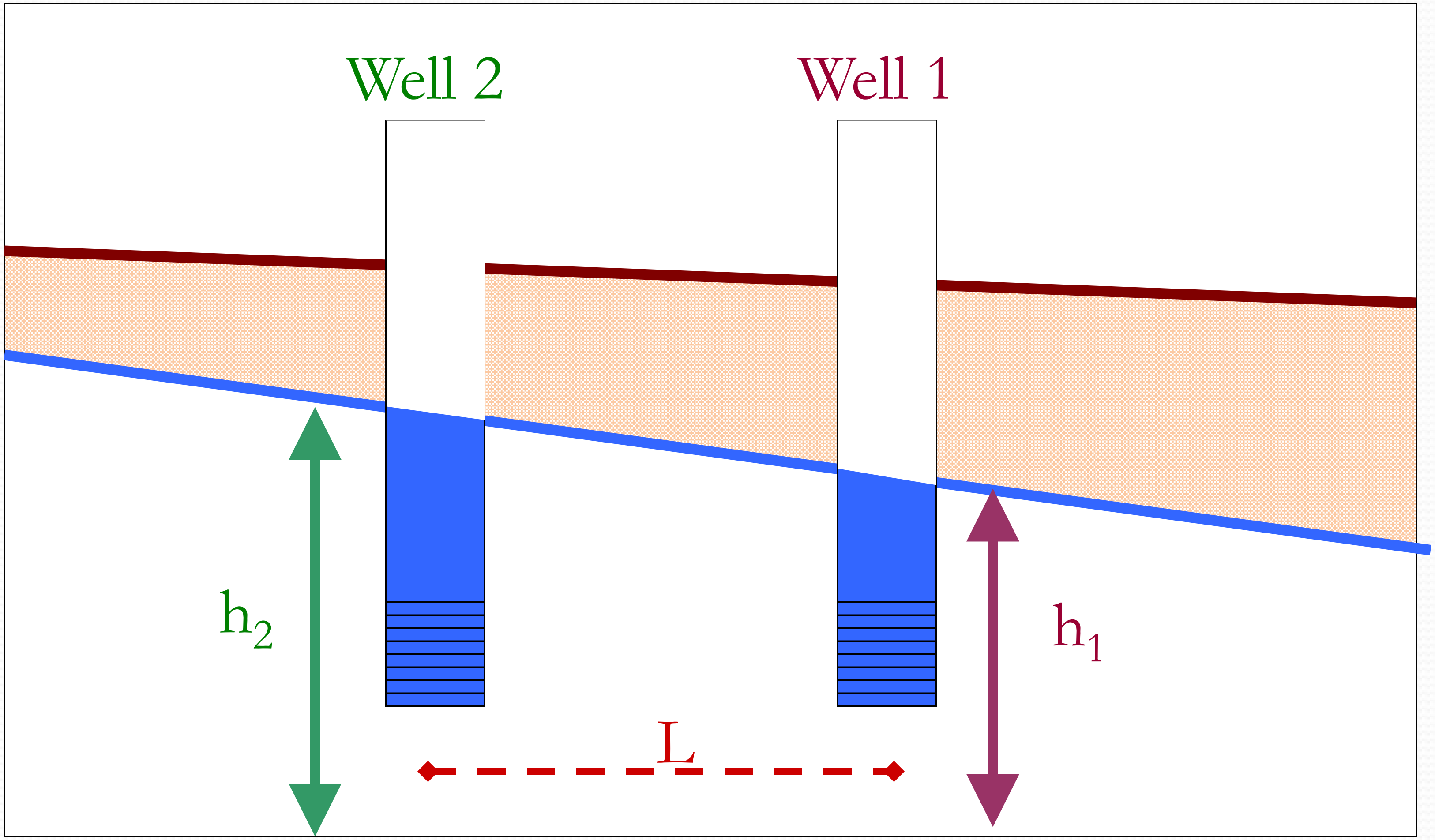
- **$h = z + h_p$**



# Surface water flows downhill

- Groundwater flows from areas of HIGH head to areas of LOW head.
- This is analogous to surface water (e.g., rivers), which flows from areas of HIGH elevation to areas of LOW elevation.

# Horizontal Hydraulic Gradient



# Hydraulic Gradient

$$= (h_2 - h_1) / L$$

# How much water?
# How fast does it flow?

## Darcy's Law

$$Q = -K A \Delta h / L$$

$Q$ = volumetric flux

$K$ = hydraulic conductivity

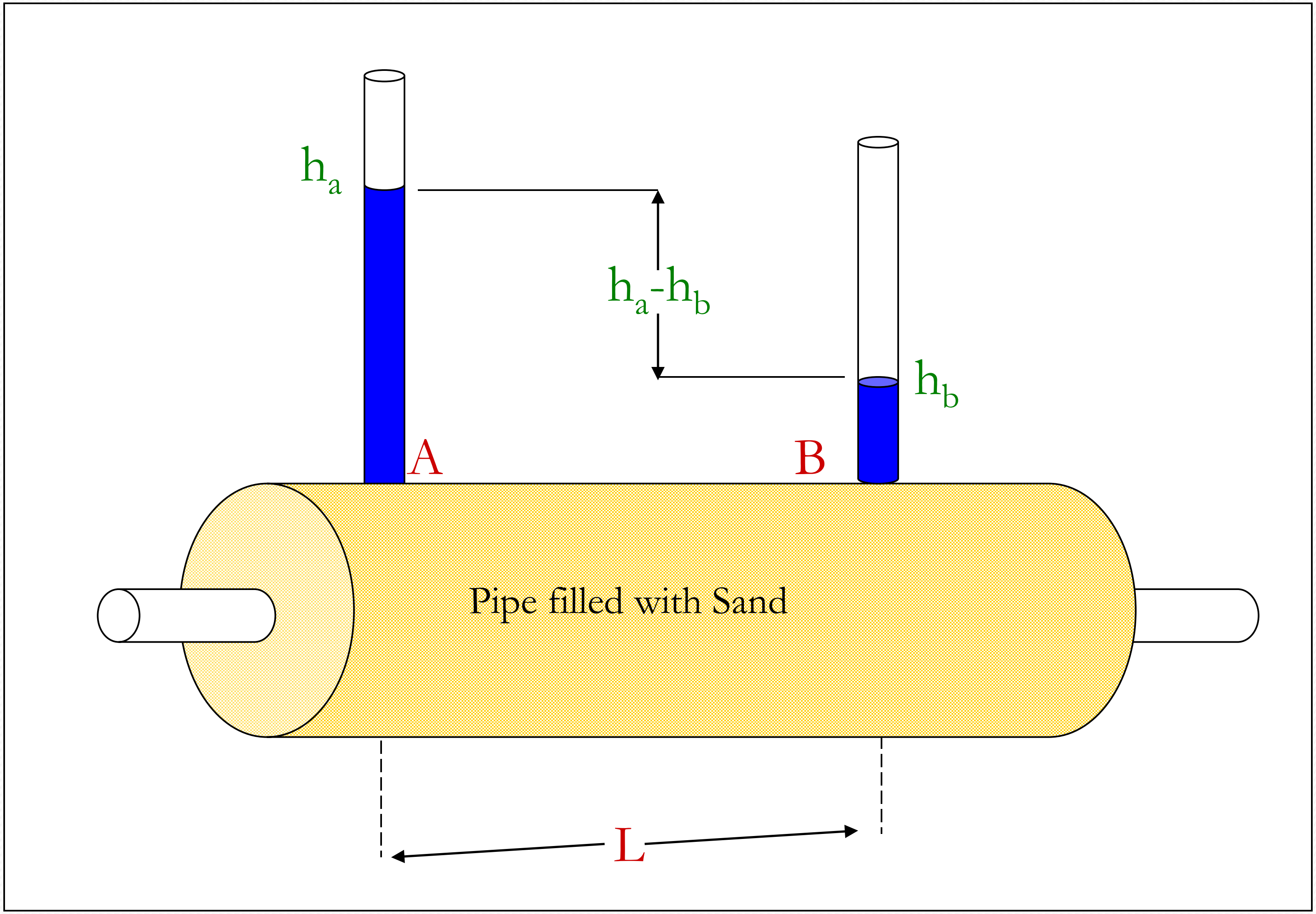
$A$ = cross-sectional area of flow

$\Delta h$ = head difference from one location to another ($h_2 - h_1$)

$L$ = distance from one location to another

$\Delta h/L$ = hydraulic gradient

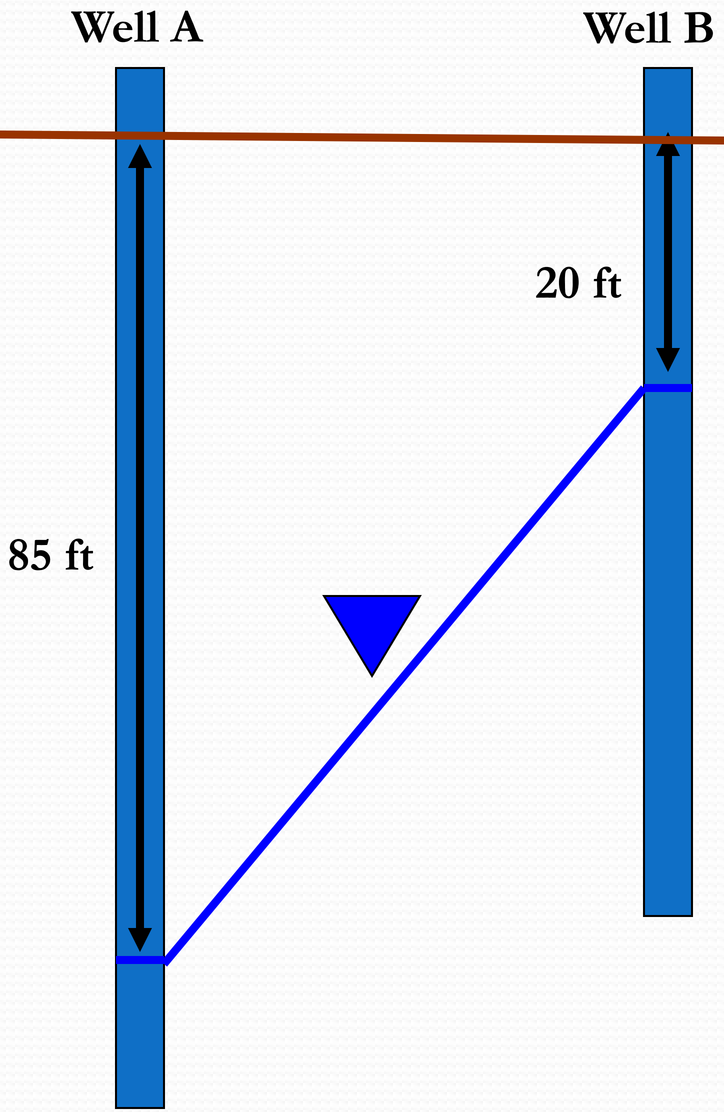
# Darcy’s Experiment



# The Difference Between Water Elevation in a Well and “Depth to Water”

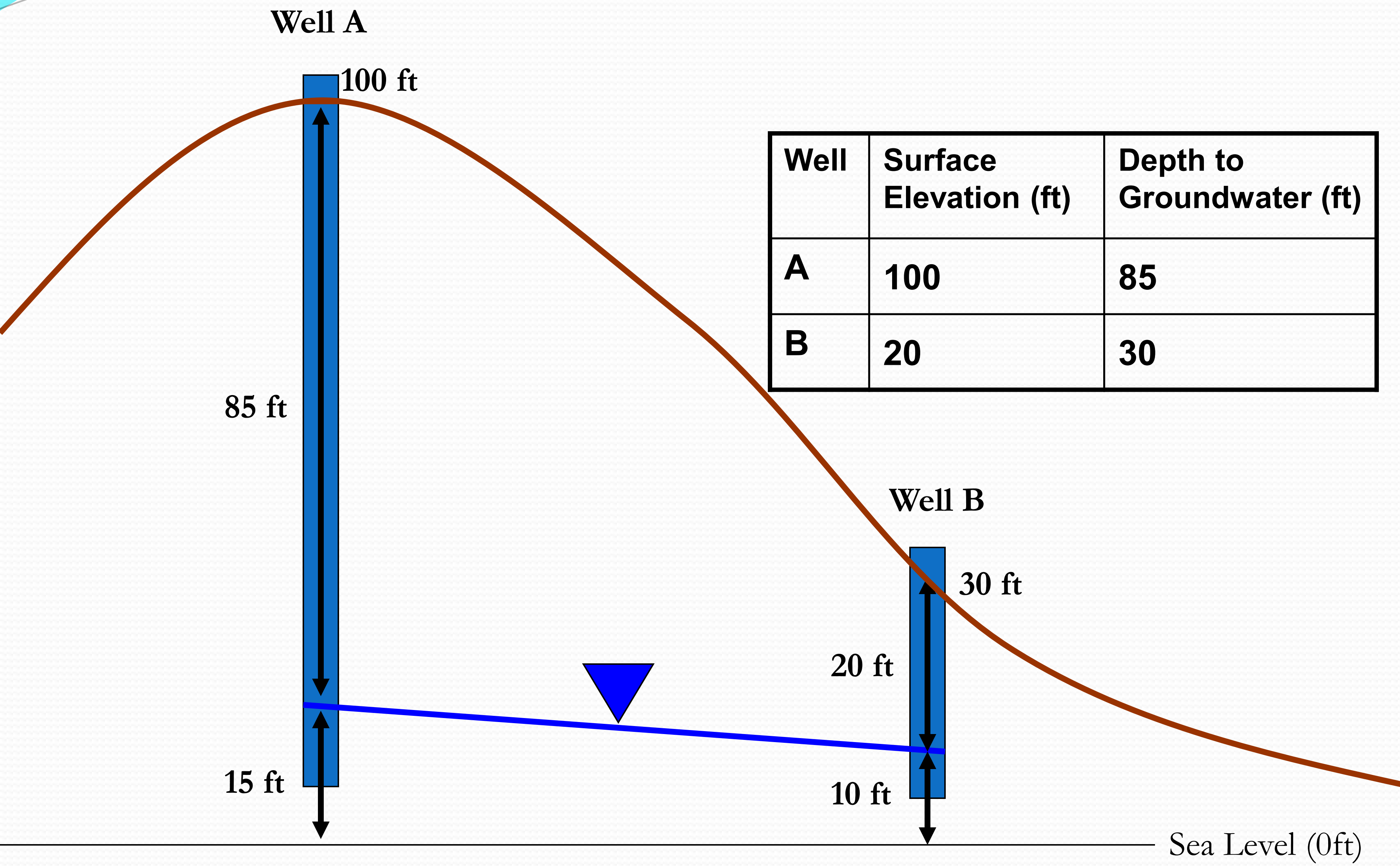
- If a site’s land surface is FLAT, it’s easy to interpret depth to water measurements and determine which well has the highest head.  (Then flow directions can be determined.)
- If wells are located in a hilly area, it’s important to know the land surface elevation at each well.

# When the land surface is flat…



| Well | Depth to Groundwater (ft) |
|---|---|
| A | 85 |
| B | 20 |

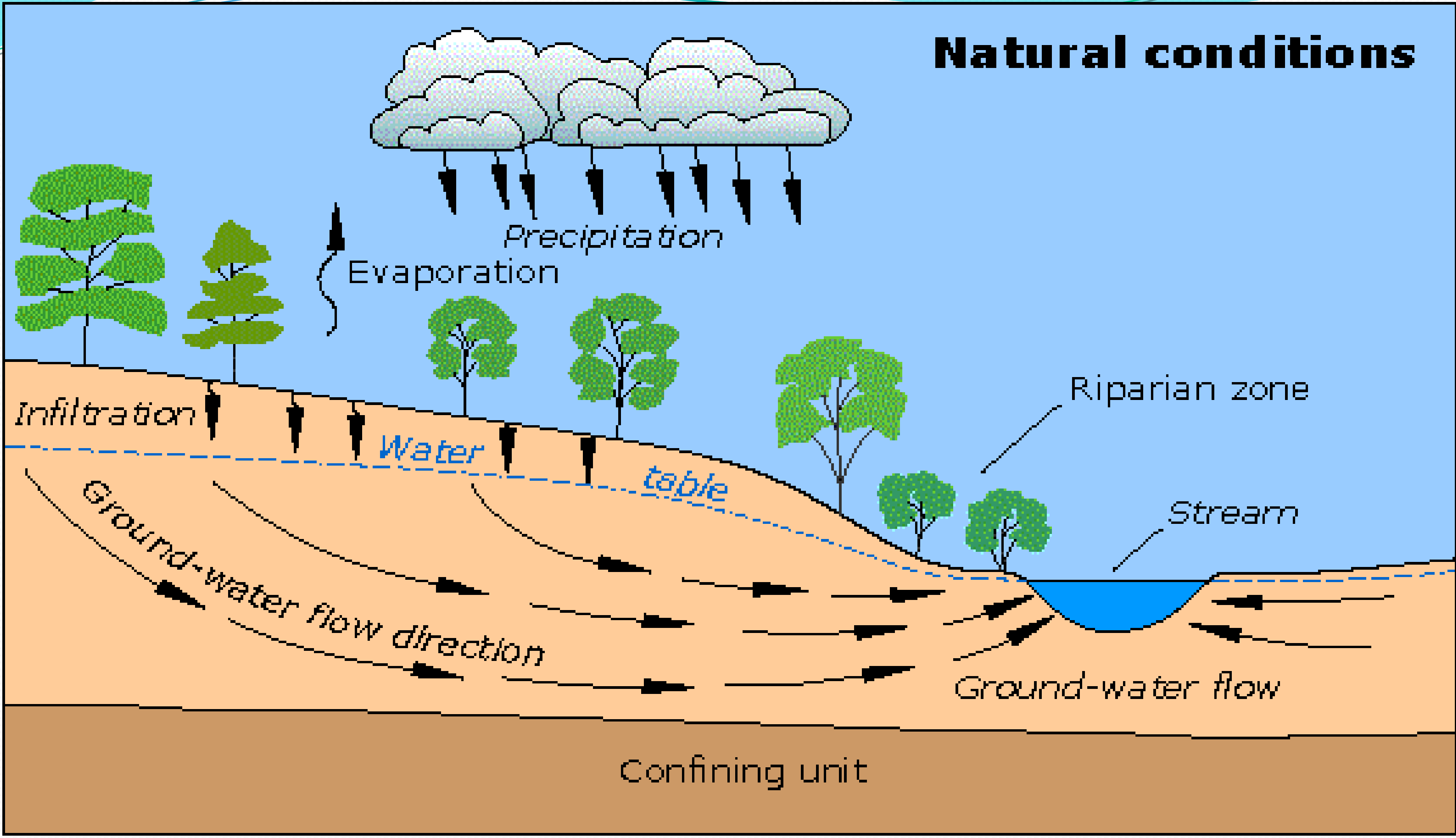
# When the land surface is not flat…



| Well | Surface Elevation (ft) | Depth to Groundwater (ft) |
|---|---|---|
| A | 100 | 85 |
| B | 20 | 30 |

# Unconfined Aquifers

- Also called Water Table Aquifers
- Unconfined aquifers have no confining layer (e.g., clay or silt) on top
- Water table (top of the saturated zone) rises and fall according to recharge and discharge
- Wells that are open or “screened” in unconfined aquifers will have water levels that site at the level of the water table

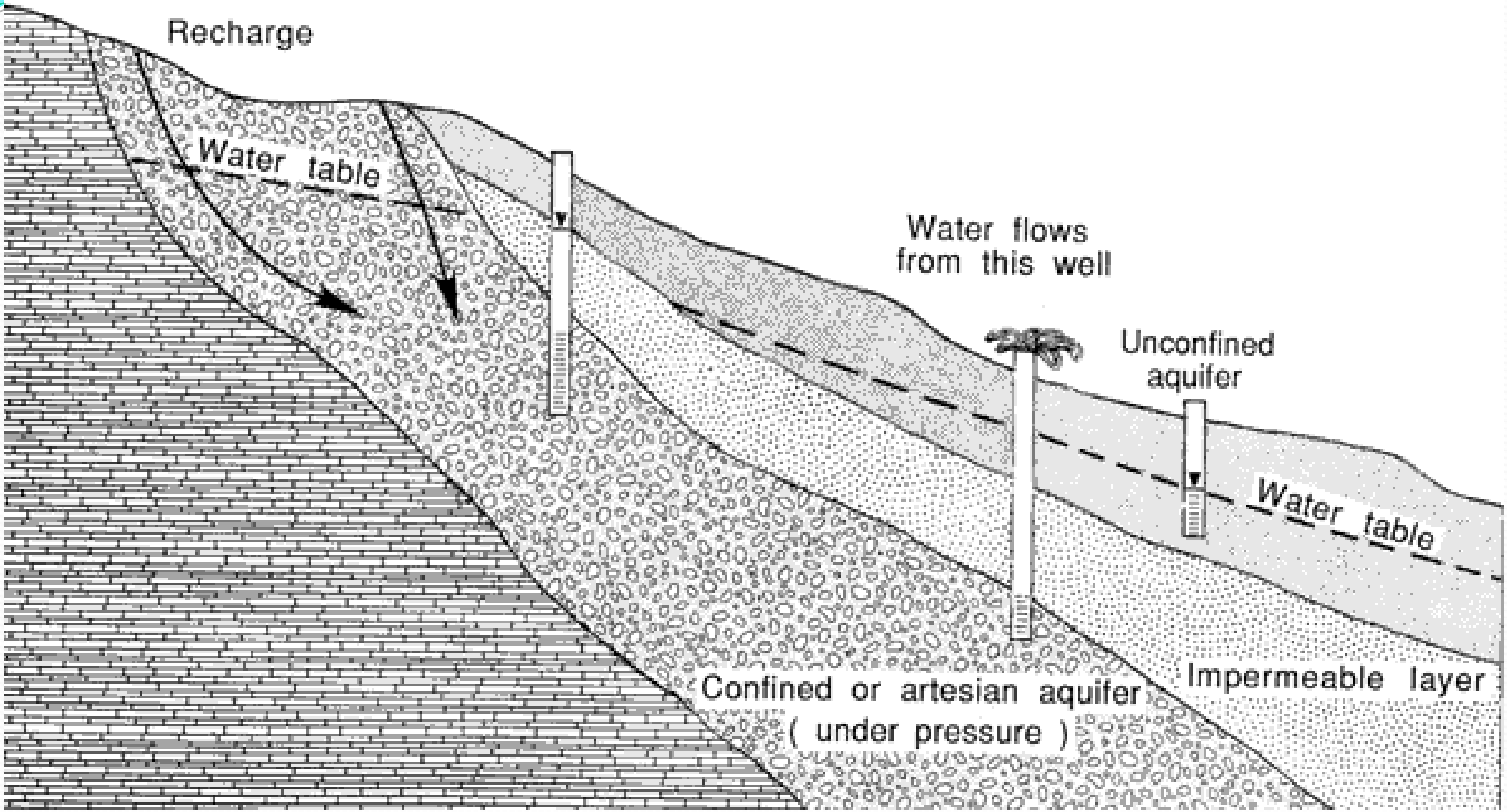


# Confining Layers

- Aquitard = confining layer; a geologic unit that does not transmit very much water
- Confining layers are part of what keeps water in certain aquifers under a lot of pressure
- Confining layers also protect some aquifers from being easily contaminated

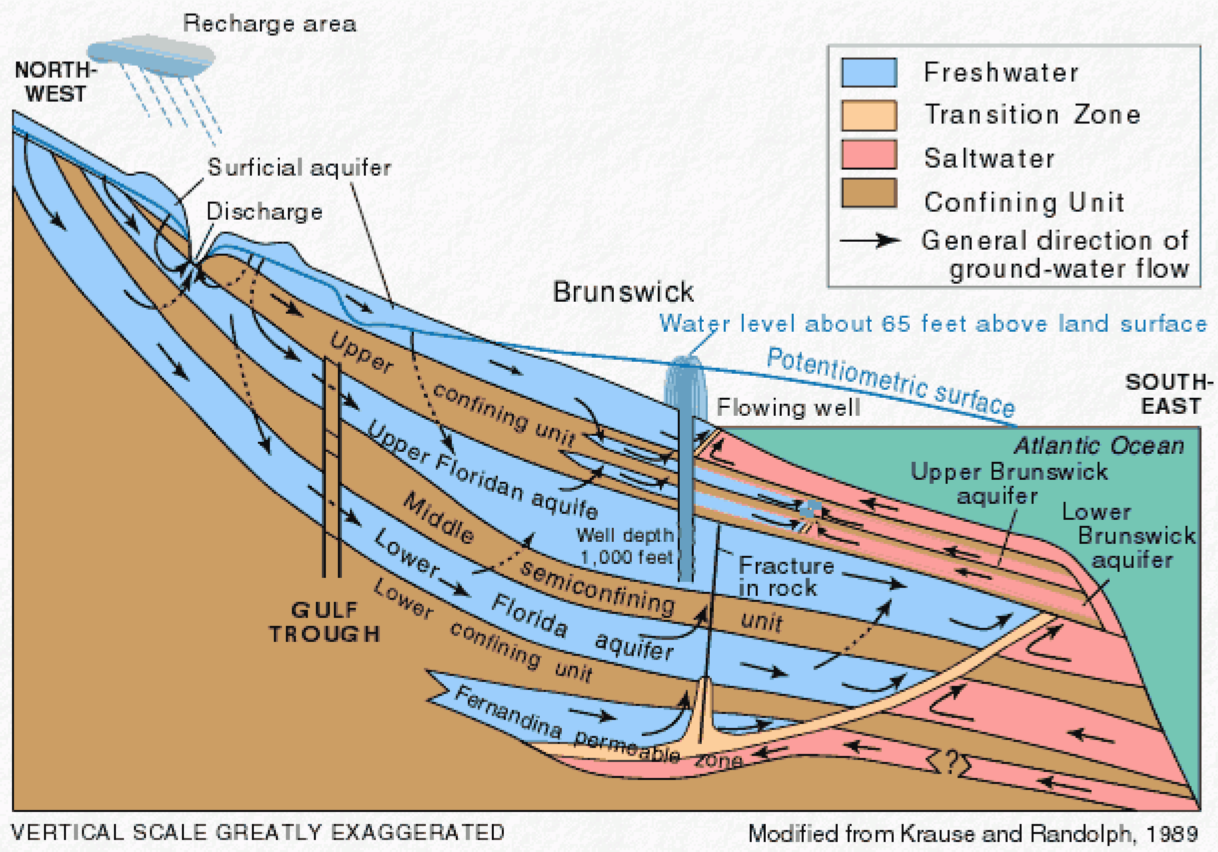
# Confined Aquifers

- Confined aquifers have a confining layer above them (i.e., there is no water table)
- The water in confined aquifers are under pressure (like the gases in a bottle of soda)
- When you “screen” a well in a confined aquifer (after drilling through the confining layer), water will rise ABOVE the top of the aquifer



http://www.ianr.unl.edu/pubs/Water/g1128.htm#OCCOGRNDW

# CONFINED & UNCONFINED



VERTICAL SCALE GREATLY EXAGGERATED

Modified from Krause and Randolph, 1989

# So which kind of aquifer is “better” – confined or unconfined?

Confined aquifers are more protected from contamination. Their water quality tends to be better.

# Vulnerable Aquifers

- Fractured Rock Aquifers
- Conduit Flow Aquifers
- High Energy Deposition Aquifers

# Fractured Rock Aquifers

- Most of the flow is through the fractures
  - Pores may be present
  - Pores may not be well-connected
- Very complex systems
  - More difficult to predict flow direction and velocities than for unconsolidated aquifers
- Very rapid flow is possible

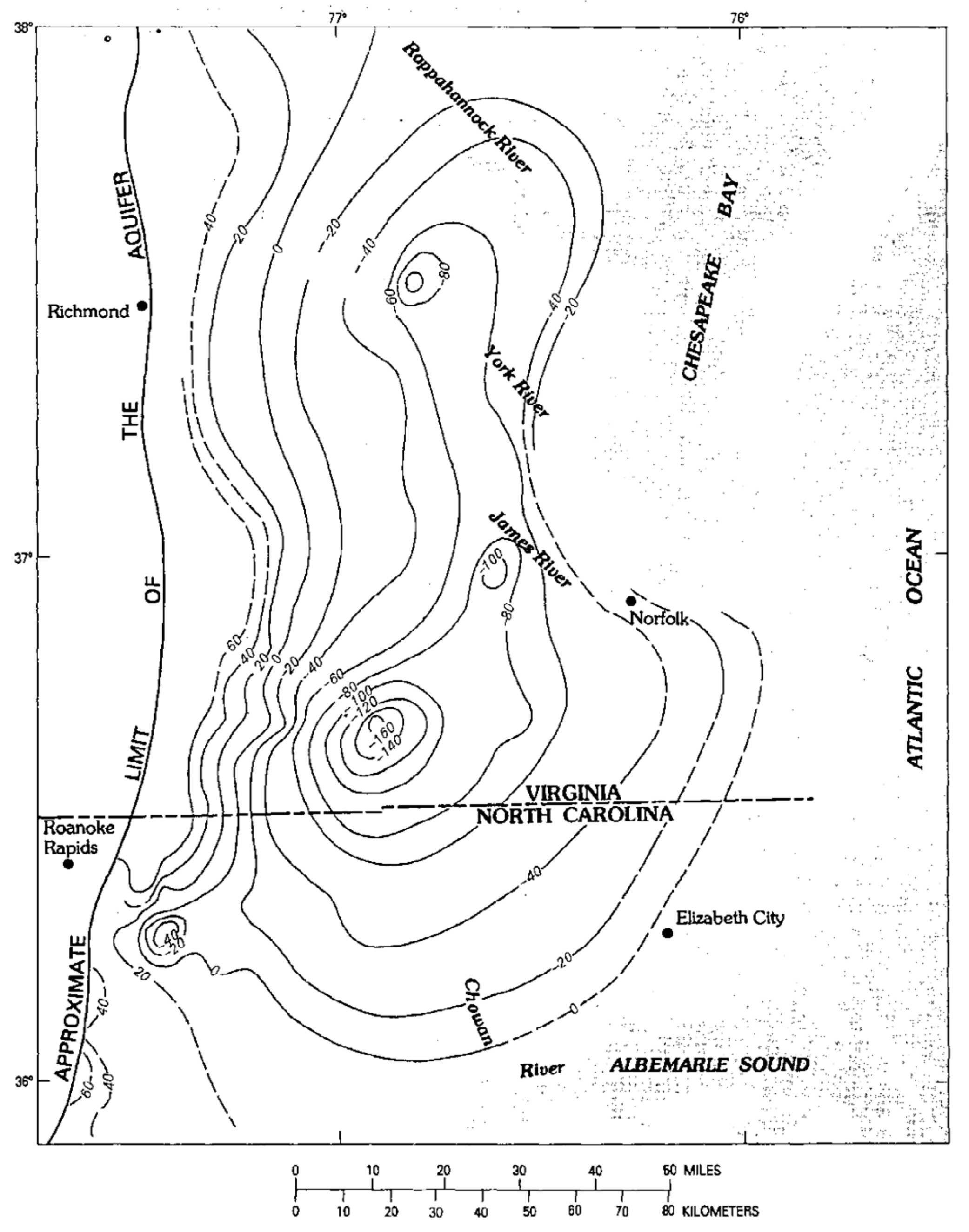
# Conduit Flow Aquifers

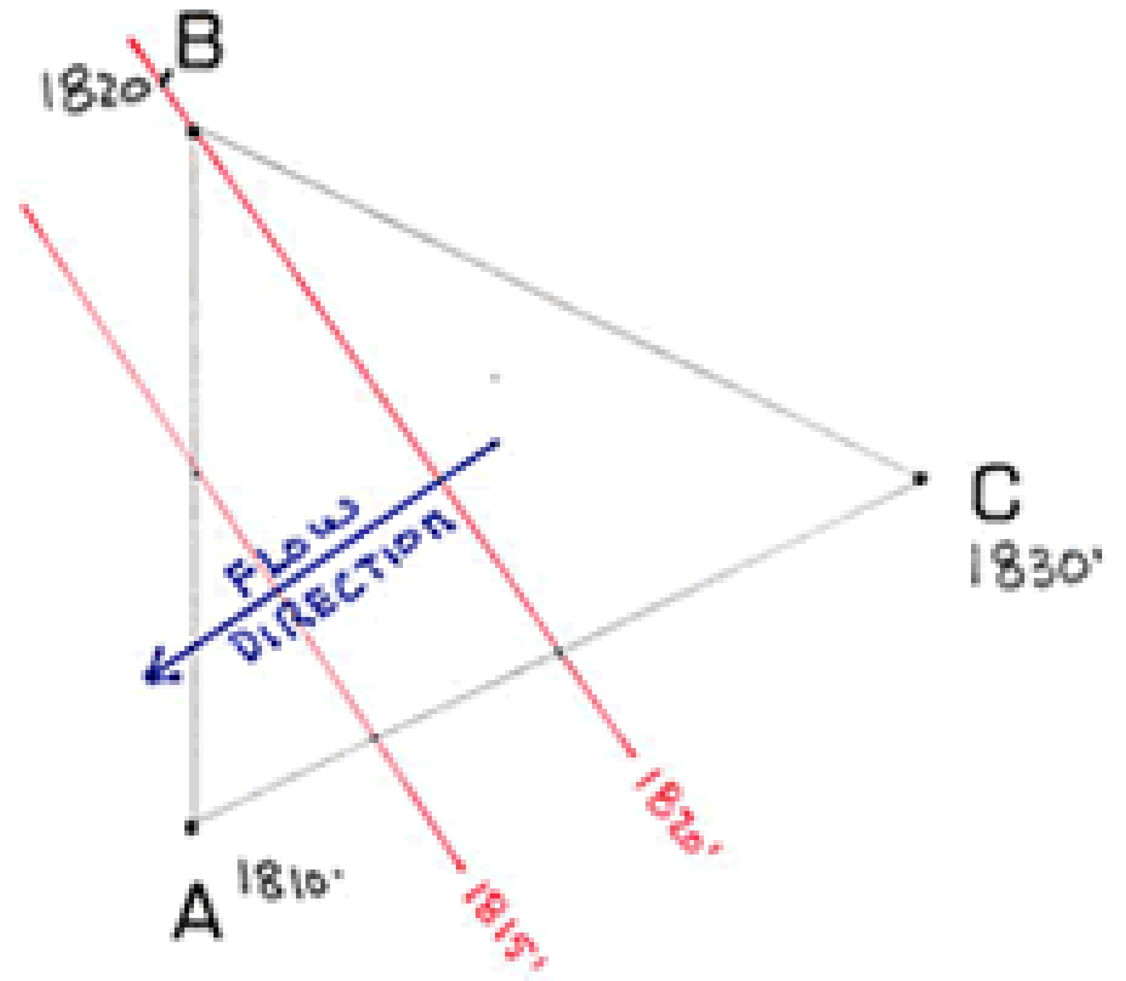
- Most of the flow is through tunnels resulting from dissolution of rock materials (e.g., limestone)
  - Pathways may not be well defined
  - Flow may be uncertain in directions
- Very complex systems
  - More difficult to predict flow direction and velocities than for unconsolidated aquifers
- Very rapid flow

# High Energy Deposition Aquifers

- Very large grain size
- Most of the flow is through inter-connected pores
- Very rapid flow

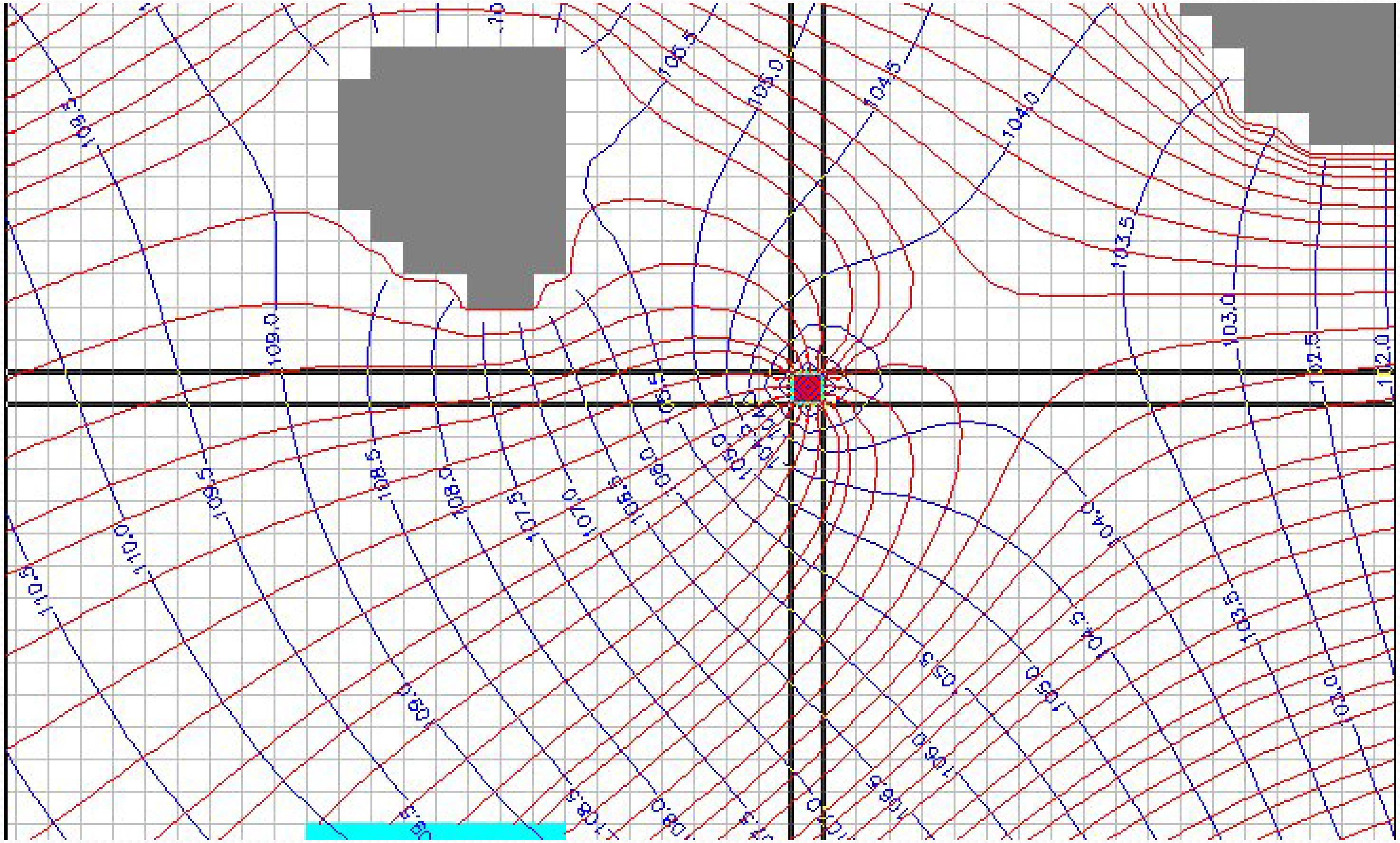
# Water Level Contours



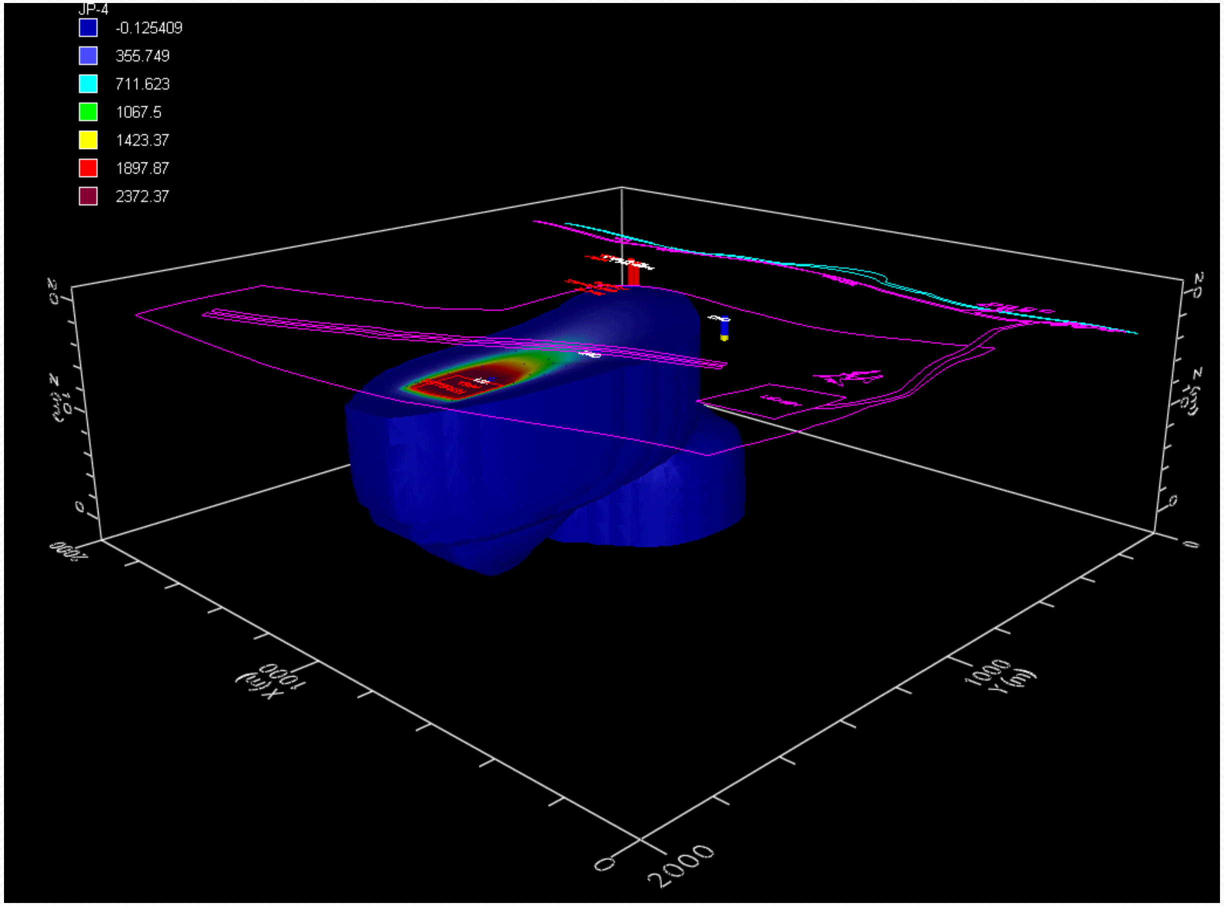


http://www.geologyeducation.com/hydrology/three-point.gif

# GRADIENT CONTOURS + FLOW PATHS = FLOWNET



# Aquifer Modeling
# Visual MODFLOW
# Three Dimensional Groundwater Flow Modeling



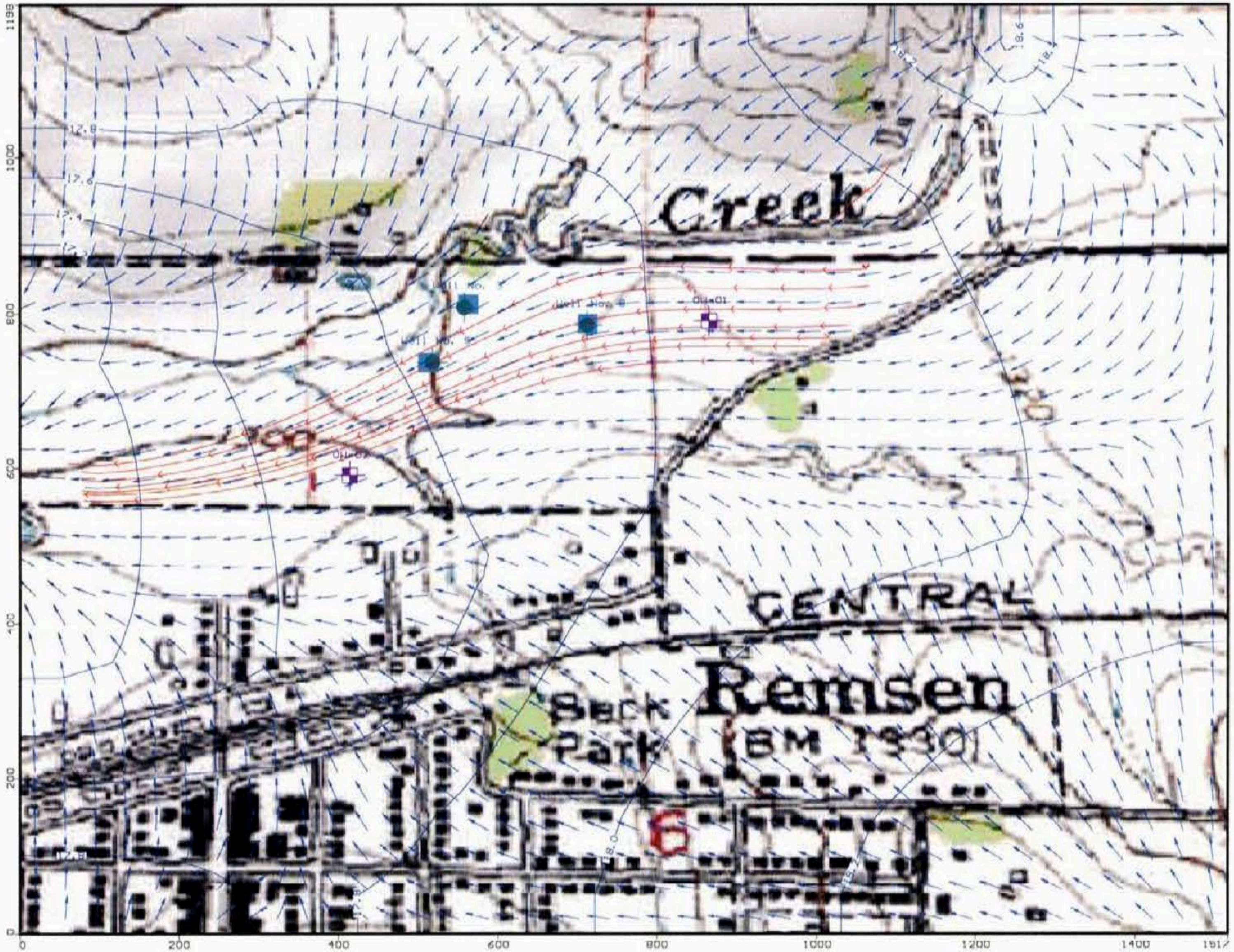


**Figure 4**

**All Wells Off (Steady State)**

← Modeled Groundwater Flow Direction

← Modeled Contaminant Flow Direction

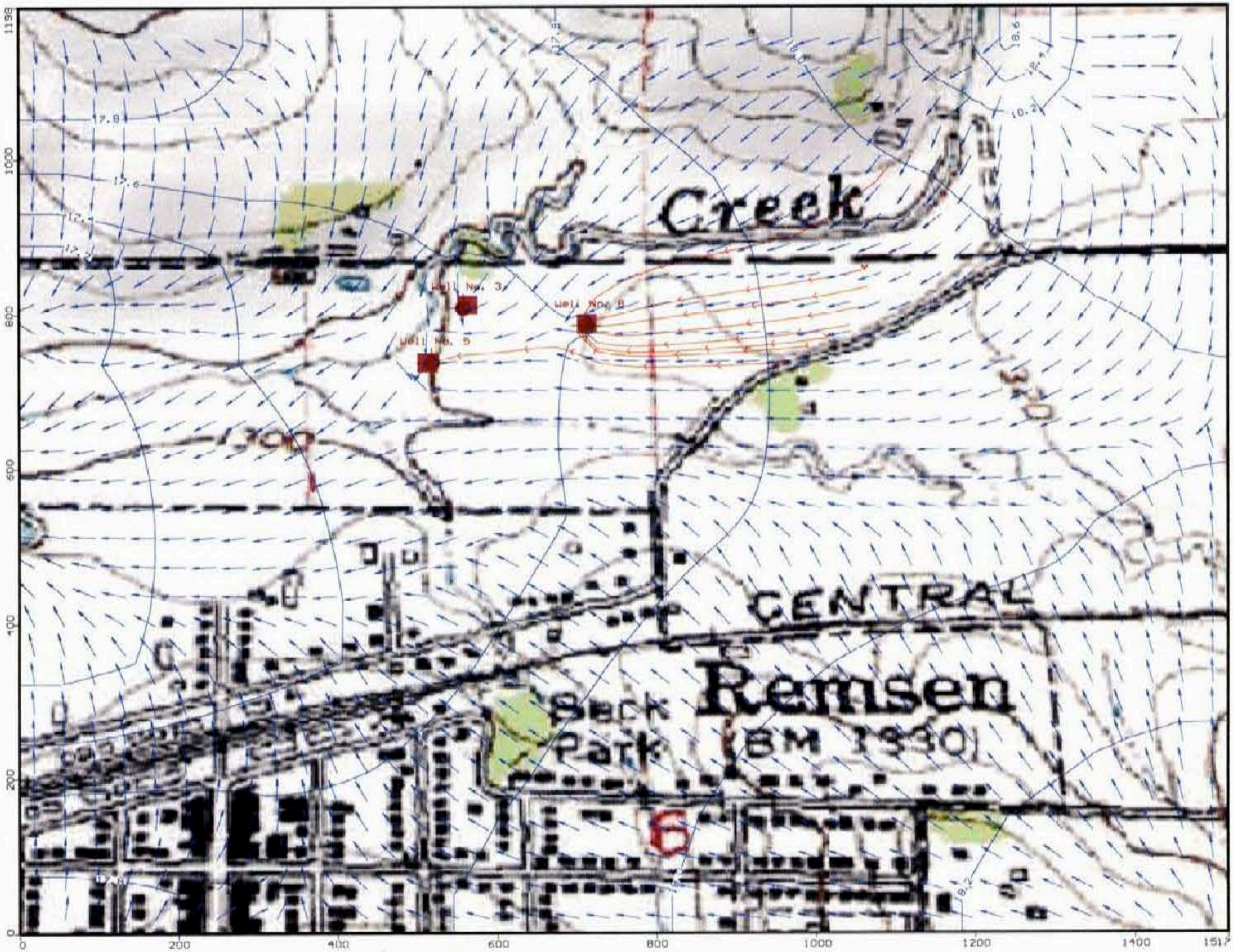


**Figure 5**
**All Wells On (Steady State)**

← Modeled Groundwater Flow Direction
← Modeled Contaminant Flow Direction

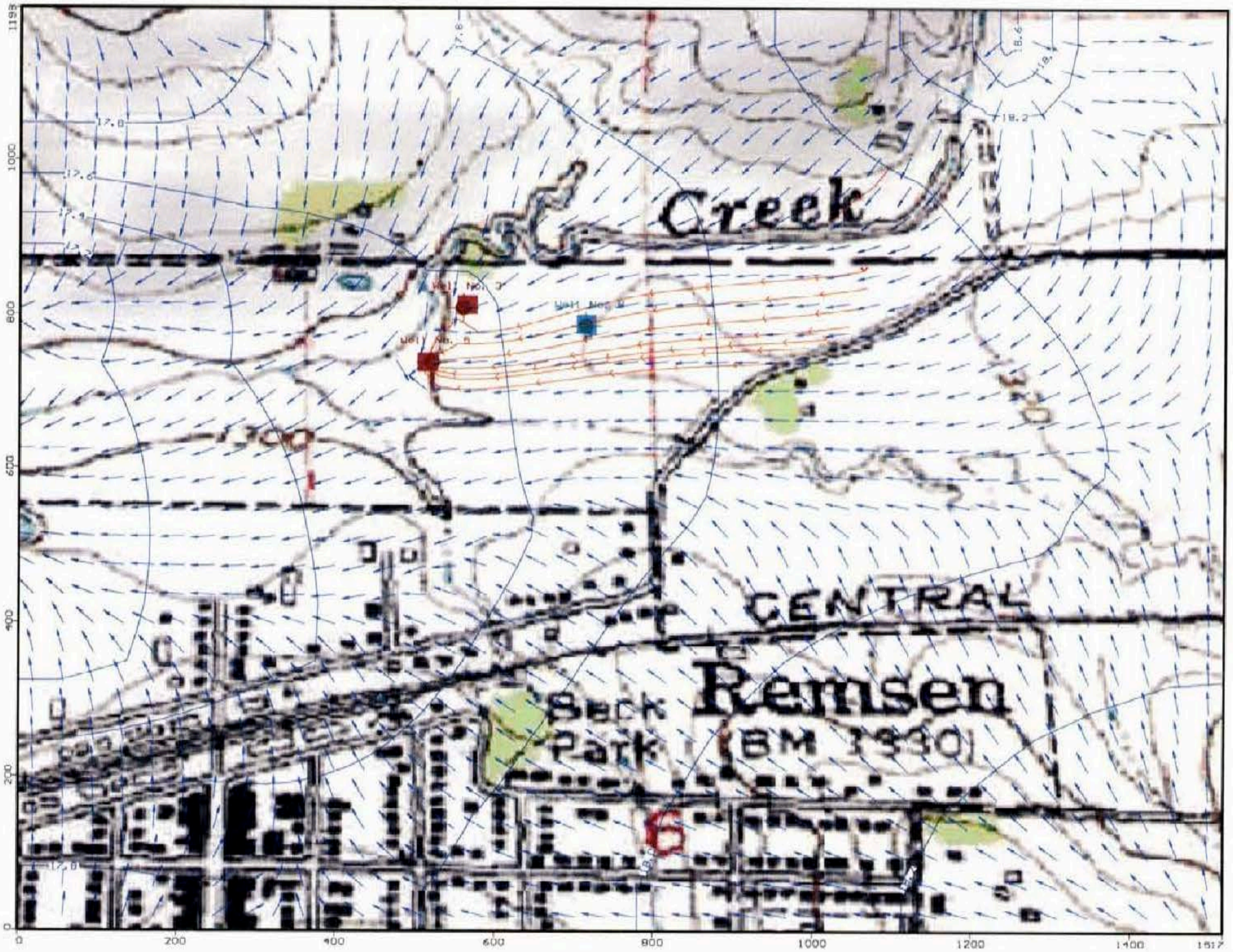


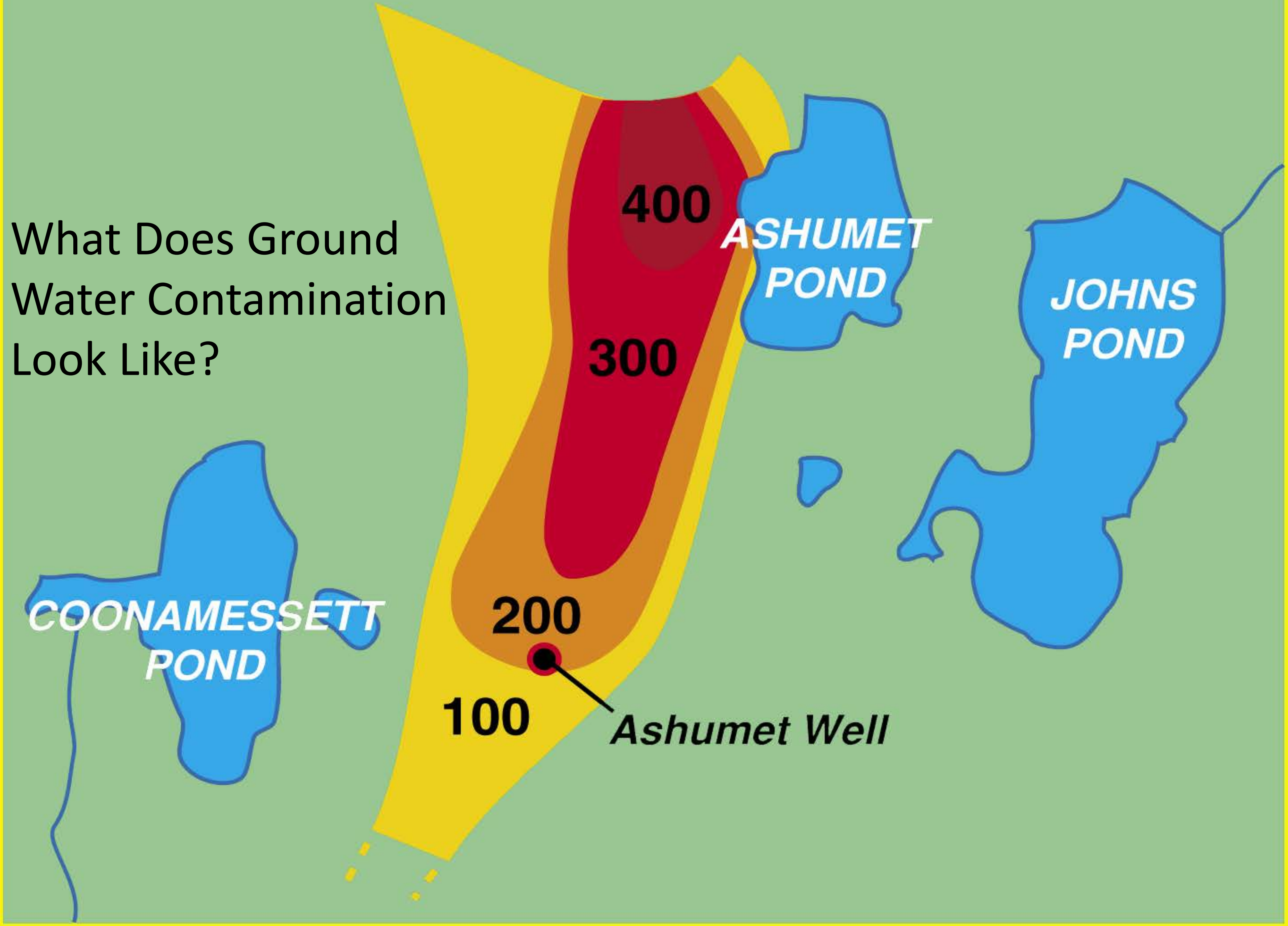
**Figure 9**

**Wells 3 And 5 On (Steady State)**

← Modeled Groundwater Flow Direction

← Modeled Contaminant Flow Direction

# What Does Ground Water Contamination Look Like?



# Threats to Underground Sources of Drinking Water

- Infiltration from the surface
- Injection of contaminants
- Naturally occurring substances

# What Health Effects Can Contaminated Source Water Cause?

- Acute health effects

- Chronic health effects

# What Contaminants Cause Acute Health Effects?

- Viruses (e.g., Norwalk virus)
- Bacteria (e.g., *Shigella, E.Coli*)
- Parasites, protozoa or cysts
- Nitrate

Parasite -
*Giardia Lamblia*

Parasite -
*Cryptosporidium*

Warning Sign About
Dangers of Nitrate

# What Are the Sources of Contaminants With Acute Health Effects?

- Industrial activities
- Animal feeding operations
- Agriculture
- Septic systems and cesspools

# What Contaminants Cause Chronic Health Effects?

- Volatile organic chemicals (VOCs)
- Inorganic chemicals (IOCs)
- Synthetic organic chemicals (SOCs)

# What are the Sources of Contaminants with Chronic Health Effects?

- Industrial and commercial activities
- Agriculture
- Landfills and surface impoundments
- Urban uses

# Sources of Contamination

# Examples of Contaminations Sources

- Pesticides and Fertilizer uses
- Stormwater
- Septic systems
- Sanitary sewers
- Industrial chemicals and storage tanks
- Animal waste
- Abandoned wells

# Siting Considerations for New Monitoring Wells

Issues to consider when siting new wells:

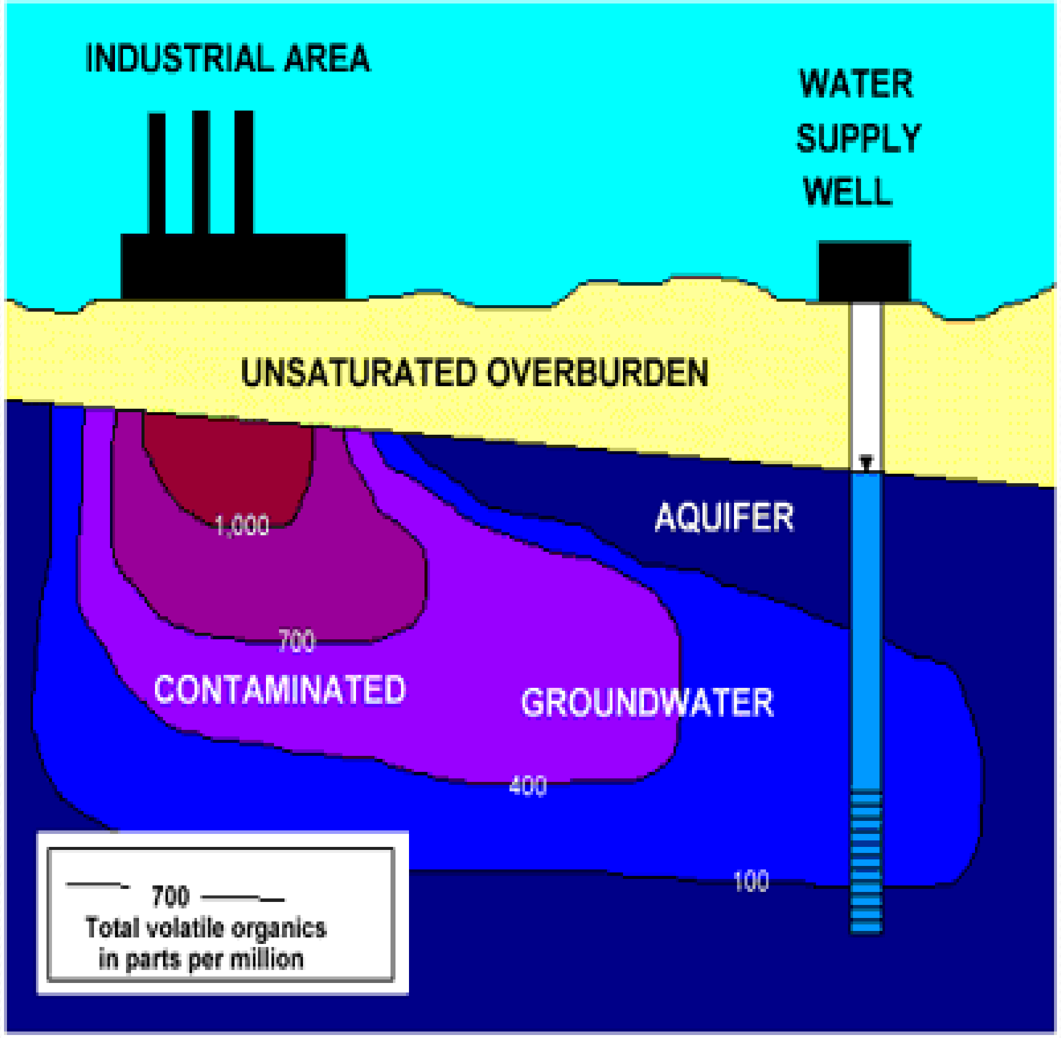
- Locations of contamination sources will help determine where to conduct
  - "Background" sampling
  - Contamination sampling
- Direction of water flow
  - Upgradient and downgradient
- To determine hydraulic gradient, a minimum of three ground water elevation measurements is needed

# Siting Considerations for New Monitoring Wells (cont.)

Possible well locations may include:

- Upgradient of contamination sources
- In contaminant plumes
- At source of contamination ("hot spot")
- Downgradient of contaminant plumes
- Between plume and drinking water well(s)

# Cross-Section of Contaminant Plume



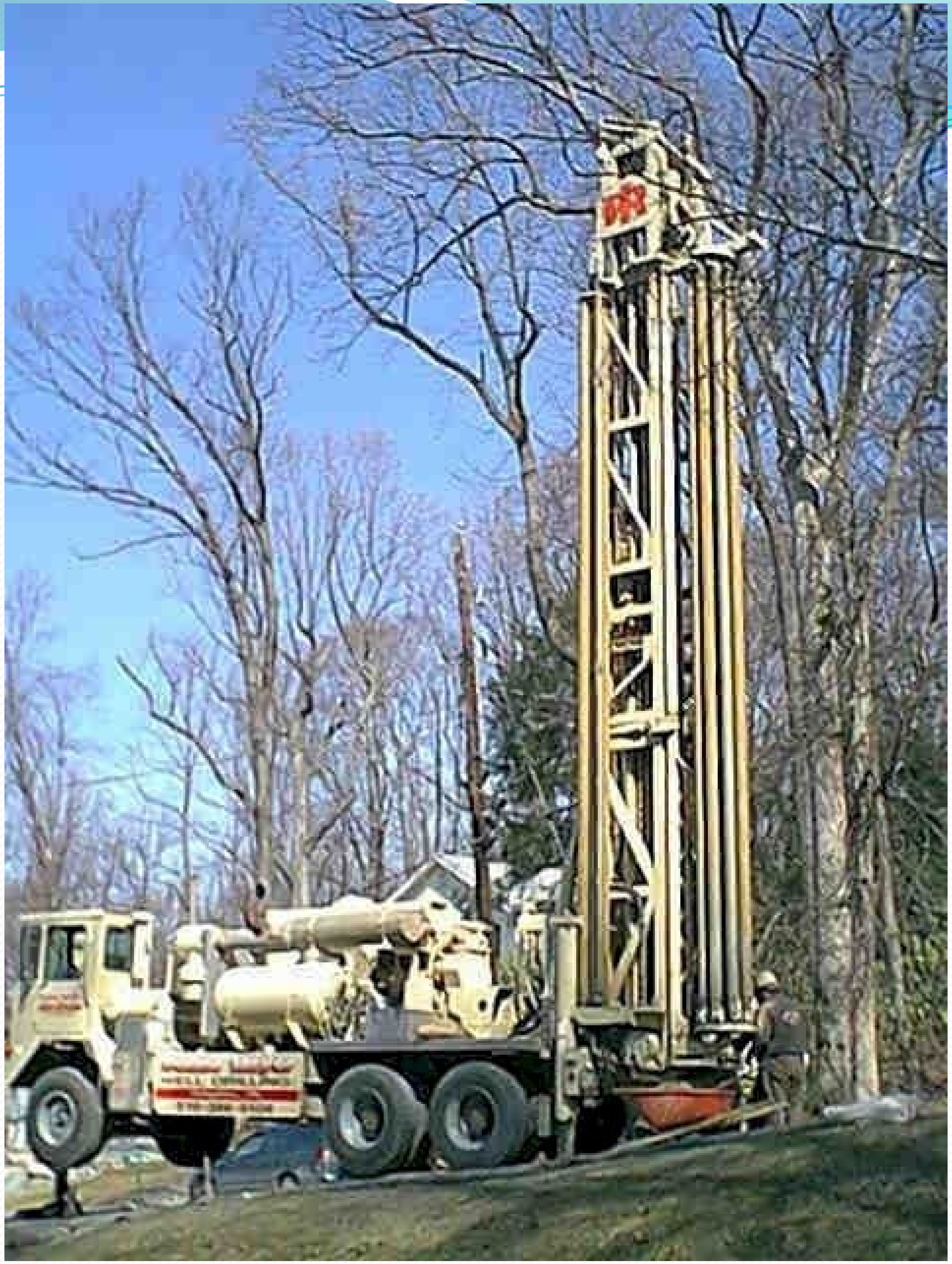
# Installing the Well

# Drilling Methods

- Drilling method depends upon subsurface materials
  - Different methods for unconsolidated sediments vs. bedrock
- Common methods
  - Hollow stem auger
  - Rotary drilling (air or mud)
  - See literature for more complete descriptions and additional drilling methods

Hollow Stem Auger Flight

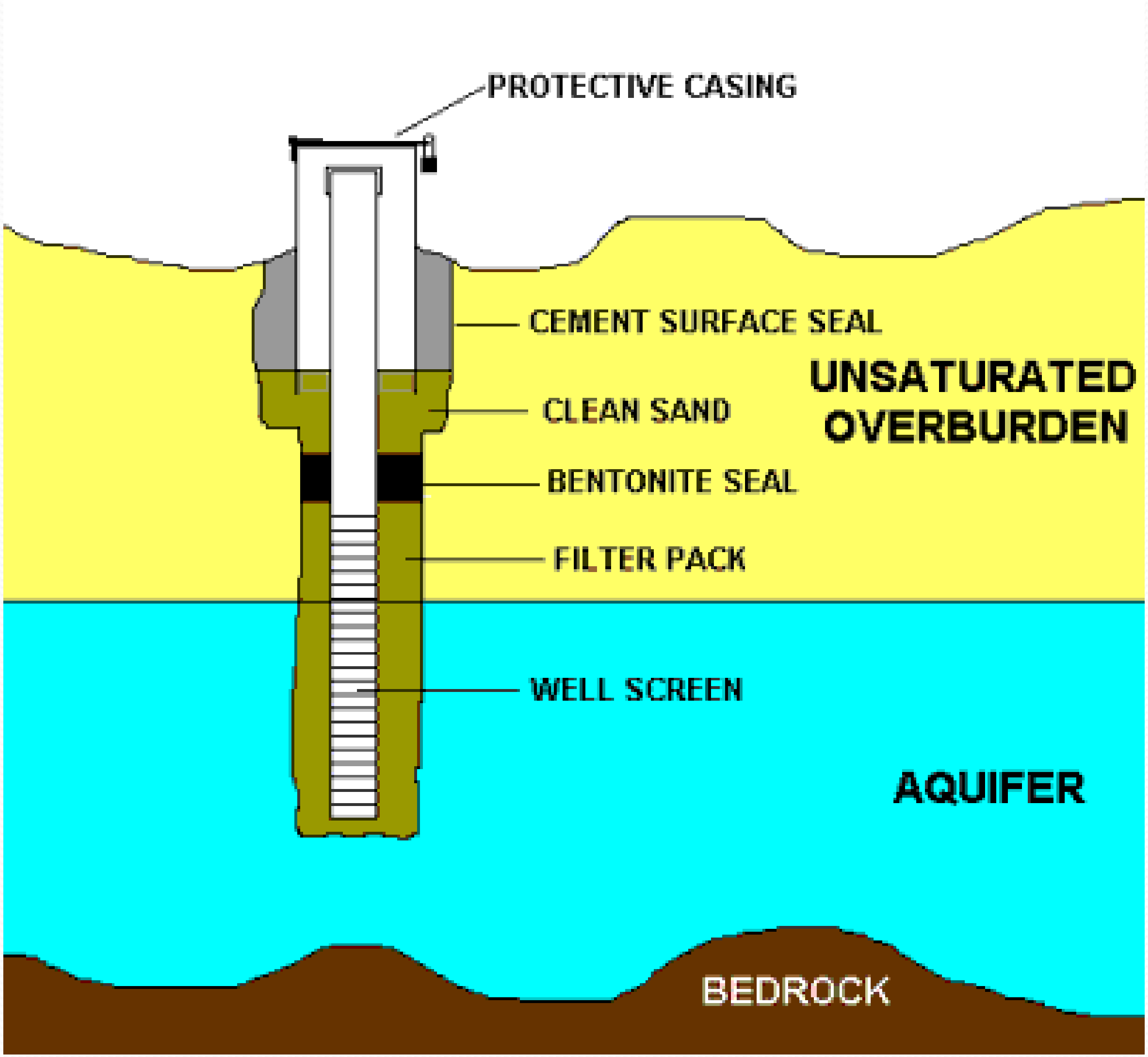
Rotary Drill Bit



http://www.water.ky.gov/NR/rdonlyres/3DEFD1FB-5F23-42DC-A726-17E790572923/0/GWBdrilling_rig.jpg

http://www.environmentalservices.com.au/images/services/4b.jpg

# MONITORING WELL



# Basic Information About Your Well

- Elevation of top of casing (surveyed after installation)
- Well location
- Total depth of well
- Well material (PVC, stainless steel, etc.)
- Length of screened interval
- Depth of screened interval

# Need to Monitor More than One Depth?

- Well nests
- Multi-level wells

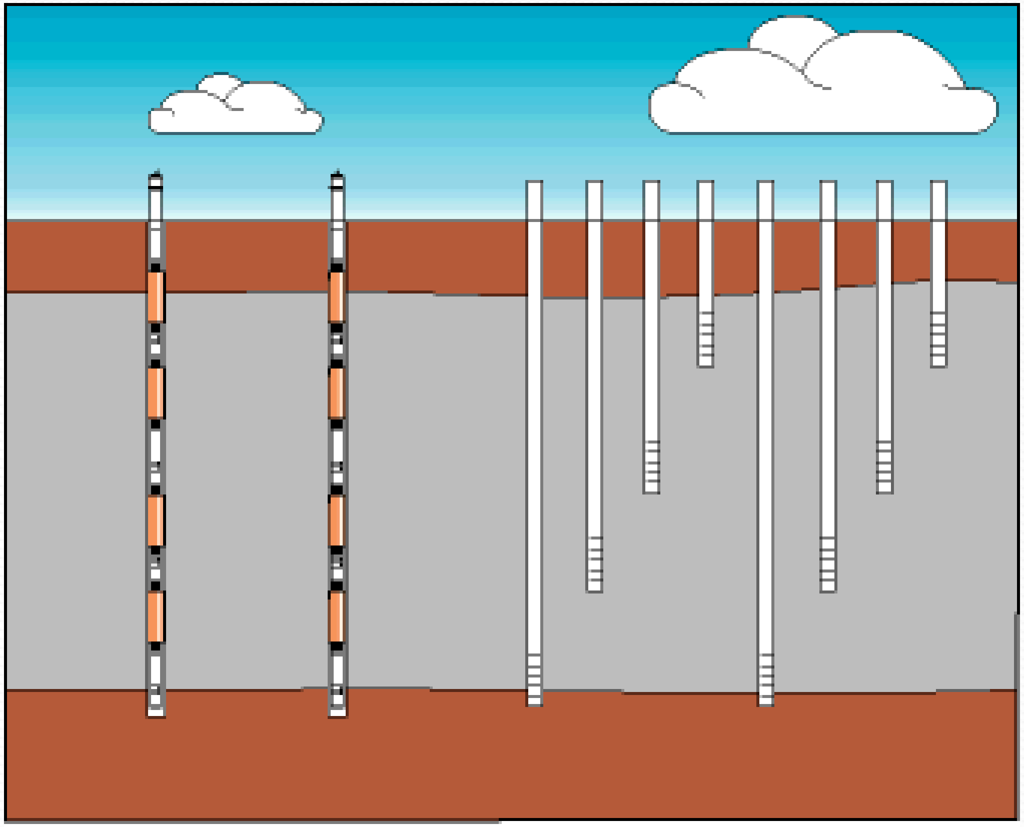


Figure 3. Comparison of single hole, nested type piezometer vs. multilevel system installation.

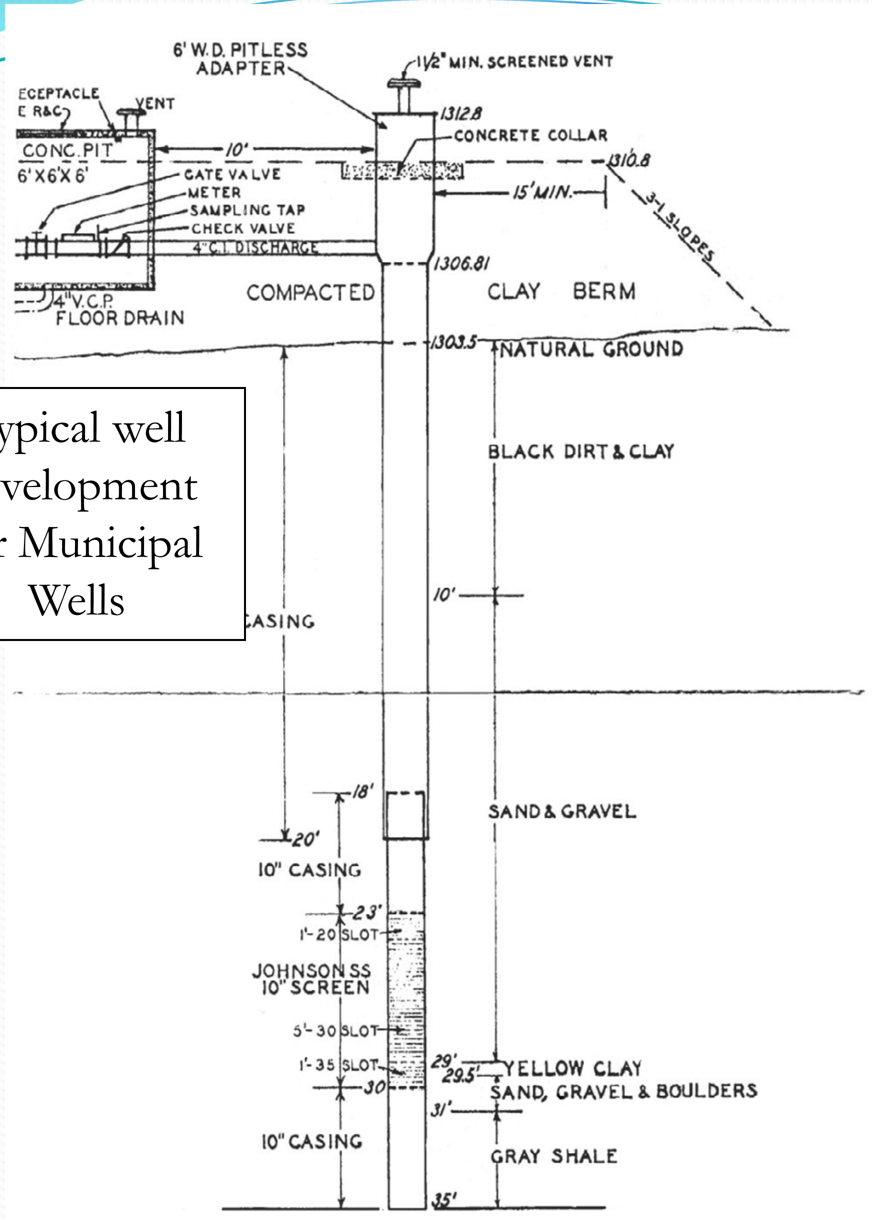
http://www.solinst.com/Images/401art/401F3.gif

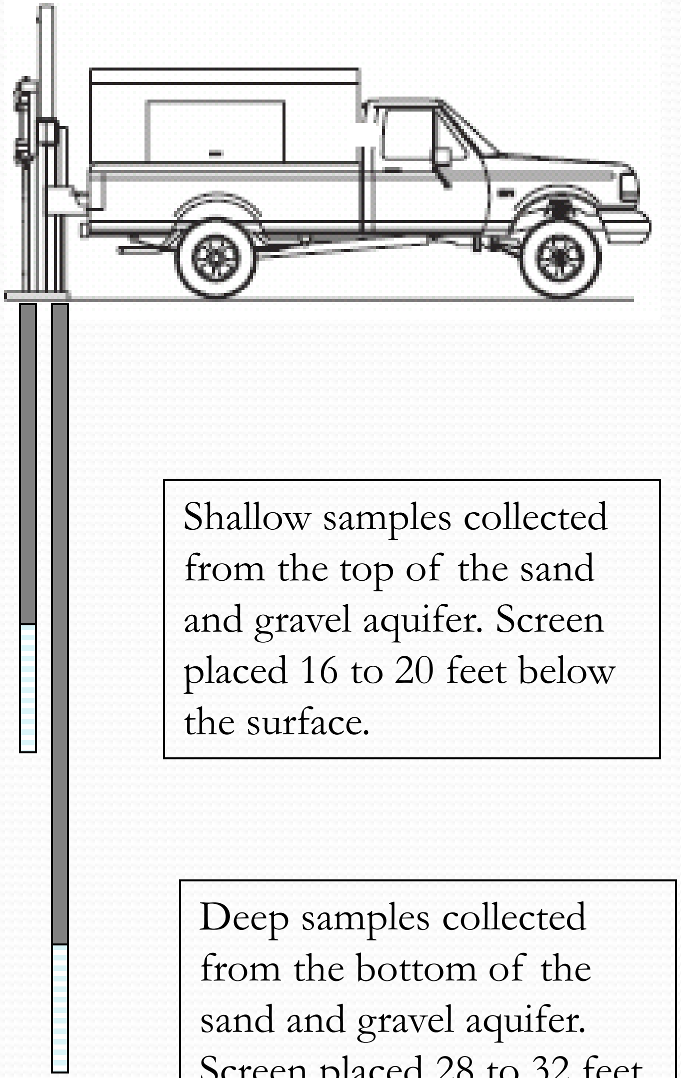
# Geoprobe

- Good for shallow, unconsolidated aquifers
- Limited to roughly 100 feet
- Inexpensive sampling of soil and ground water
- May be useful if contamination suspected or poorly characterized
- May help in siting more expensive, permanent wells

# Iowa DNR Groundwater Sampling

Typical well development for Municipal Wells

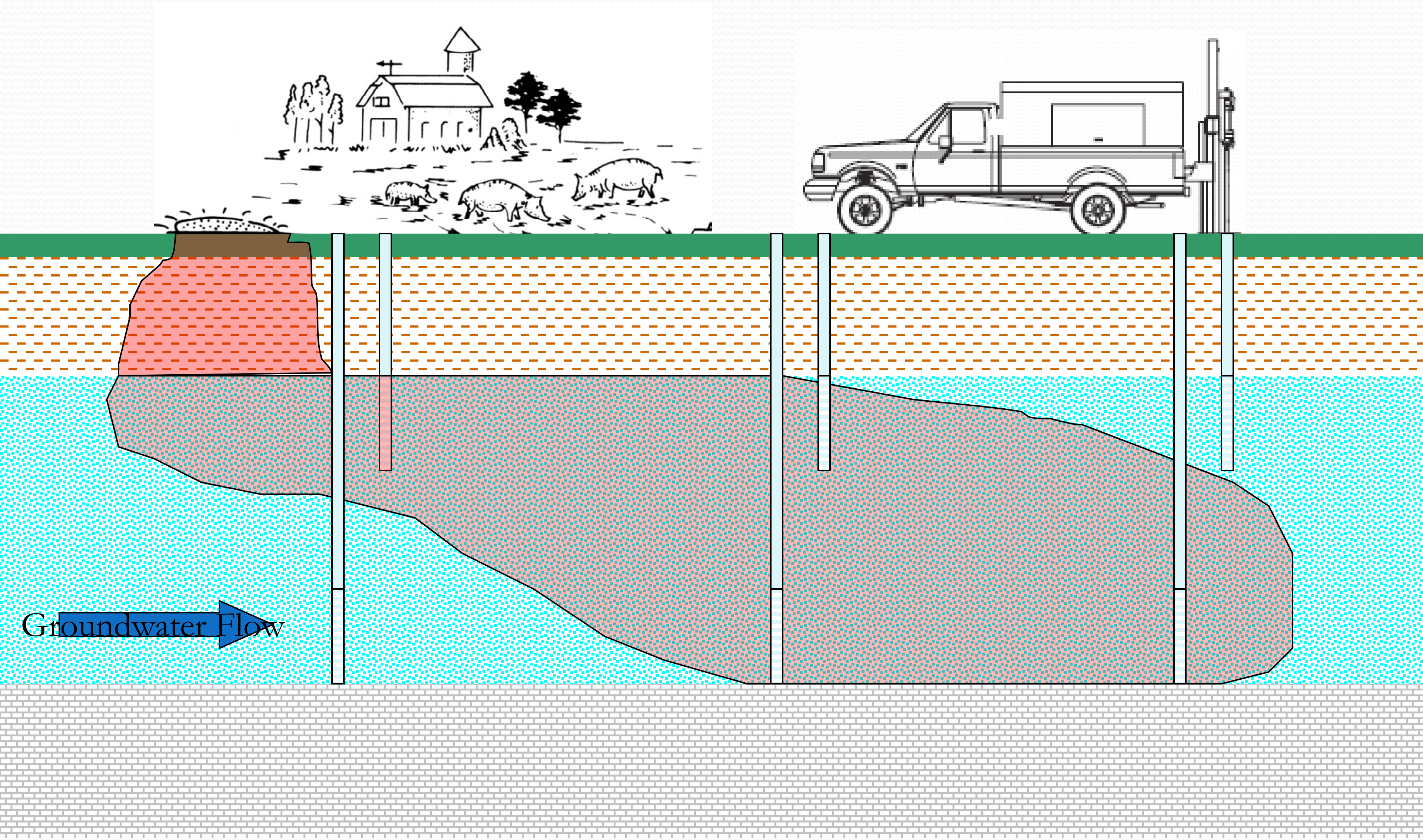




Shallow samples collected from the top of the sand and gravel aquifer. Screen placed 16 to 20 feet below the surface.

Deep samples collected from the bottom of the sand and gravel aquifer. Screen placed 28 to 32 feet below the surface.

# Why use split level sampling (nested wells).



# Ground Water Sampling

# General Considerations

- One sample for analysis is usually sufficient to describe the water quality of the aquifer at that sampling point at a given time
- Sampling should progress from the well that is expected to be least contaminated to the well that is expected to be most contaminated
- Physically or chemically unstable parameters should be measured in the field, rather than in the laboratory
  - Unstable parameters include: pH, redox potential, dissolved oxygen, and temperature

# Basic Field Procedures to Record

- Purge volume, pumping rate, and time
- Well sampling procedures
- Samples taken and preservation methods
- Chain of custody for samples
- See literature for more detail

# Basic Information to Record Prior to Taking Sample

- Condition of the monitoring well
- Depth to water
- Presence of floating immiscible layers
- Odors
- Temperature (once stabilized)
- pH and specific conductivity (once stabilized)
- Dissolved oxygen (once stabilized)
- Redox potential

# Depth to Water

- Take depth measurement prior to purging, bailing, pumping, or hydraulic testing
- Methods for measuring depth to water:
  - Depth to water meter (conductivity based)
  - Steel tape coated with carpenter's chalk
  - Other methods described in ground water literature
- Measure from surveyed datum on top of inner well casing
- Convert to ground water elevation, which can be used to calculate hydraulic gradient.
- Decontaminate equipment before use

# Well Purging

- Purge stagnant water from the well prior to sampling
  - Helps to ensure that samples collected from the well are representative of the ground water to be monitored
- Purging is accomplished by using a pump to remove ground water from a well at a low flow rate
- Detailed step-by-step procedures for purging should be included in your ground water monitoring quality assurance plan

# Ground Water Sampling Equipment

- Grab samplers
  - Bailers
  - Syringe devices
- Pumps

  Examples:
    - Submersible pumps
    - Peristaltic pumps

# Grab Samplers: Bailers

- Rigid tube that fills with water when lowered into the well (use restricted to shallower wells)
- Advantages
  - Inexpensive and easy to clean
  - Portable and simple to operate
  - Does not require external power source
- Disadvantages
  - Use can be time consuming
  - Transfer of water to sample container may alter the chemistry of the ground water sample

# Sampling Using a Pump

- Advantages:
  - Can be used with shallow or deep wells
  - Can control rate of withdrawal of water (with proper pump type)
  - Can be used when sampling for volatile compounds or anoxic waters
- Disadvantages:
  - Requires power
  - Long tubing to decontaminate between wells

# Collecting Samples and Conducting In-field Tests

- In-line flow cells or meters with probes that can be lowered into the well are the recommended methods for measuring unstable parameters
- Do not perform field analysis (e.g., pH, temperature, dissolved oxygen) on samples that will be sent to the lab (it may contaminate the sample)

# What Analyses to Have Done in the Laboratory

- Basic chemistry:
  - Major cations (Ca, Mg, Na, K)
  - Major anions (sulfate, nitrate, chloride)
  - Alkalinity
  - Other constituents: Fe, Mn, organic carbon, ammonia
  - Total Dissolved Solids (TDS)

# Types of Contaminants to Consider Analyzing

- Specific contaminants will depend on local knowledge of contamination sources
  - Volatile Organic Compounds (VOCs)
  - Heavy metals
  - Pesticides
  - Light non-aqueous phase liquids (LNAPLs)
  - Dense non-aqueous phase liquids (DNAPLs)
  - Microbial constituents

# Preparing Samples to Send to the Lab

- Preservation procedures are different for different constituents
- Anoxic (oxygen-free) samples require careful handling and preservation
- Samples should be kept chilled
- Sample collection (date, procedures, person) should be documented

# Post-Ground Water Monitoring

- Plot elevation data on map
  - Useful for confirming/determining flow direction
- Plot concentrations of contaminants/ lab sample results for each well
  - Helps to identify levels and locations of contamination in ground water
- Graph concentrations through time
  - Can provide insight on the emergence or progression of any contamination problems

# Ground Water Field Logbook

- Sample withdrawal procedure and equipment
- Date and time of collection
- Well sampling sequence
- Types of sample bottles used and sample identification numbers
- Preservatives used
- Parameters requested for analysis
- Field observations of sampling event
- Name of collector
- Weather conditions, including air temperature
- Internal temperature of field and shipping containers

# Case Study - Navajo Nation Source Water Assessments

US Environmental Protection Agency
Office of Ground Water and Drinking Water
Region 9 Ground Water Office
Navajo Nation Environmental Protection Agency
Navajo Tribal Utility Authority
The Cadmus Group, Inc.

# Navajo Nation Location Map

Four Corner Area
NM, AZ, CO, UT

# Water Use on the Reservation

- Navajo Tribal Utility Authority
- Private Systems
- Water Hauling

# Key Water Sources

## Ground Water Resources

- Confined Aquifers
- Unconfined Aquifers

## Surface Water Resources

- San Juan River

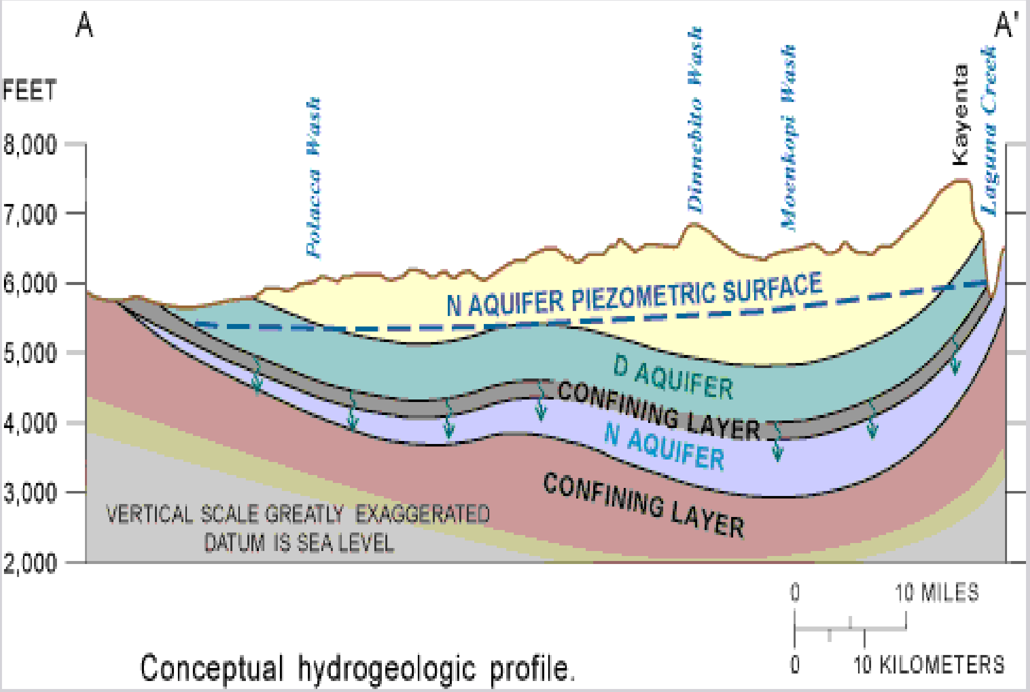
# Element 1 - Source Water Delineation

Used to Identify Zone of Contribution
Water System

- Fixed radius – Confined Aquifers
- 3-D Particle Track Modeling - Unconfined Aquifers
- Watershed Mapping - Surface Water Sources

# Confined Aquifer Delineations

## Fixed Radius

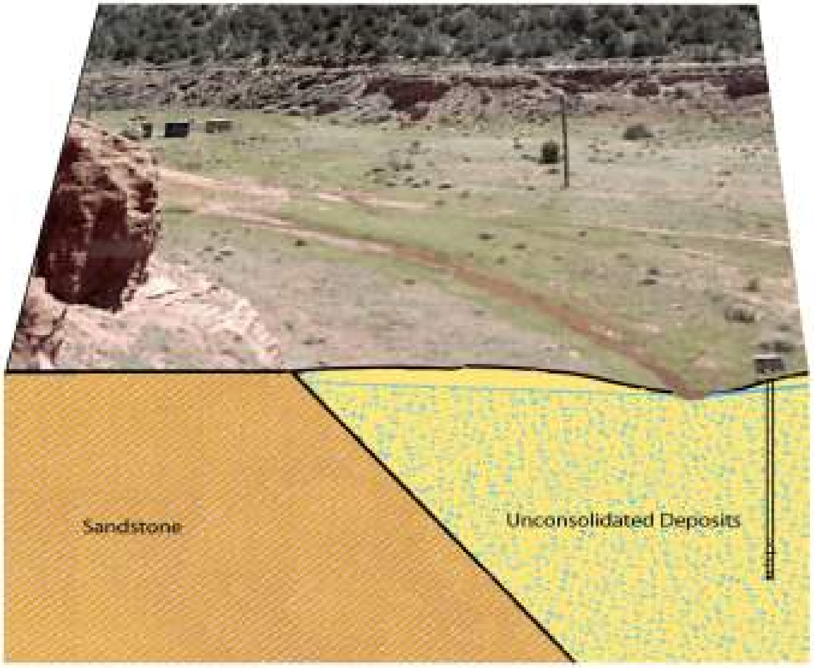


Conceptual hydrogeologic profile.

# Unconfined Aquifer Delineation

## 3D Particle Track Modeling

Idealized Cross-Section



# Unconfined Aquifer Delineations

## 3D Particle Track Modeling

Plan View

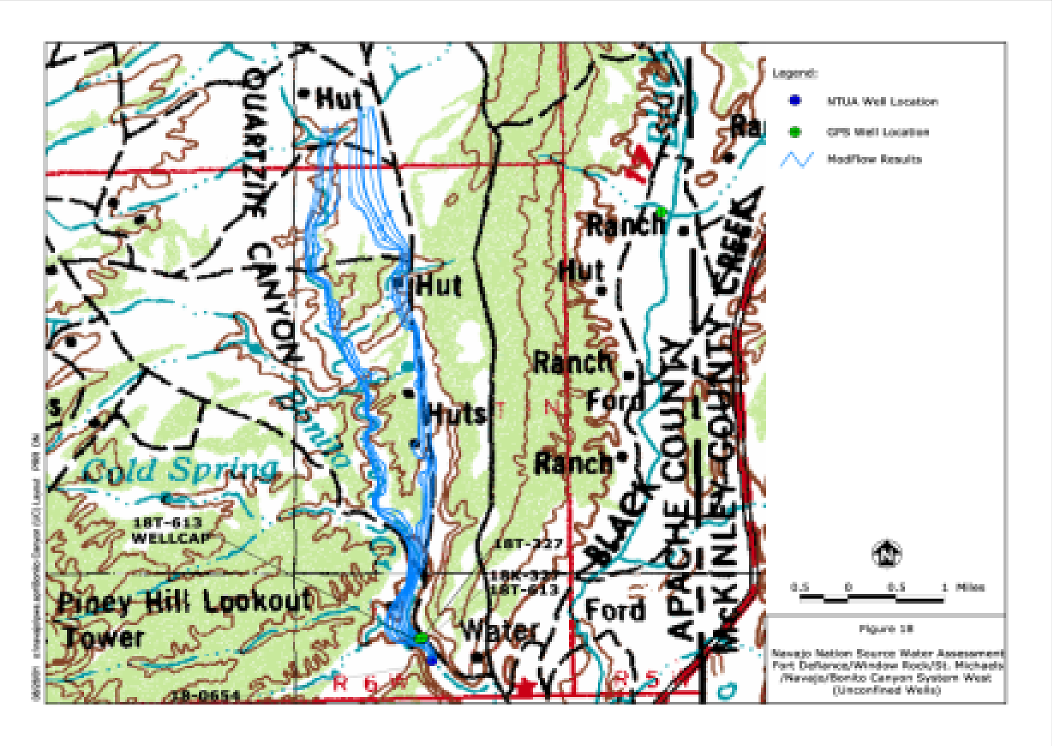


Figure 18

Navajo Nation Source Water Assessment
Fort Defiance/Window Rock/St. Michaels
/Navajo/Bonito Canyon System West
(Unconfined Wells)

# Element 2 - Contaminant Evaluation

Completed in two Phases

- Phase 1 – Evaluation of Existing Data
- Phase 2 – Field Investigations

# Phase 1 – Evaluation of Existing Data

- EPA – RCRA, CERCLA, NPDES
- NAVAJO NATION EPA
- AZ Department of Environmental Quality

# Phase 2 - Field Investigations

- Wellhead (intake) Assessment
- Capture Zone Assessment

# Phase 2 – Field Investigations

- Potential Contaminant Source Identification

- Global Positioning Survey (GPS)

# Contaminant Source Examples

Waste Storage &
Potential Discharge

Indiscriminate Dumping

# Contaminant Source Examples

Chemical Handling and Storage

# Element 3 - Susceptibility Assessment (Well 18t-06)

| Potential Contaminant Source | Contaminant | Location Within Delineation area? | Natural Barriers | Well Integrity | Historical MCL Exceedance | Total |
|---|---|---|---|---|---|---|
| Pressure Wash | 3 | 1 | 2 | 1 | 0 | 7 |
| Septic Systems | 2 | 1 | 2 | 0 | 0 | |
| Fuel Storage | 3 | 1 | 2 | 0 | 0 | 6 |
| Total | | | | | | 17 |

# Element 4 - Public Notification

- Navajo Nation EPA
- Consumer Confidence Report

# Questions?

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