# Low Flow Sampling and Hydraulic Conductivity Analysis

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Course Outline

- 12:30pm   Registration
- 1:00 -1:10   Introduction
- 1:10-2:10   Why low flow sampling
- 2:10-2:25   Break
- 2:25-3:25   Low flow sampling procedures, K determination and Analyses
- 3:25-3:30   Transition to field site
- 3:30-4:30   Field test
- 4:30-5:20   Data analysis
- 5:20   End of Seminar

Why Low Flow Sampling
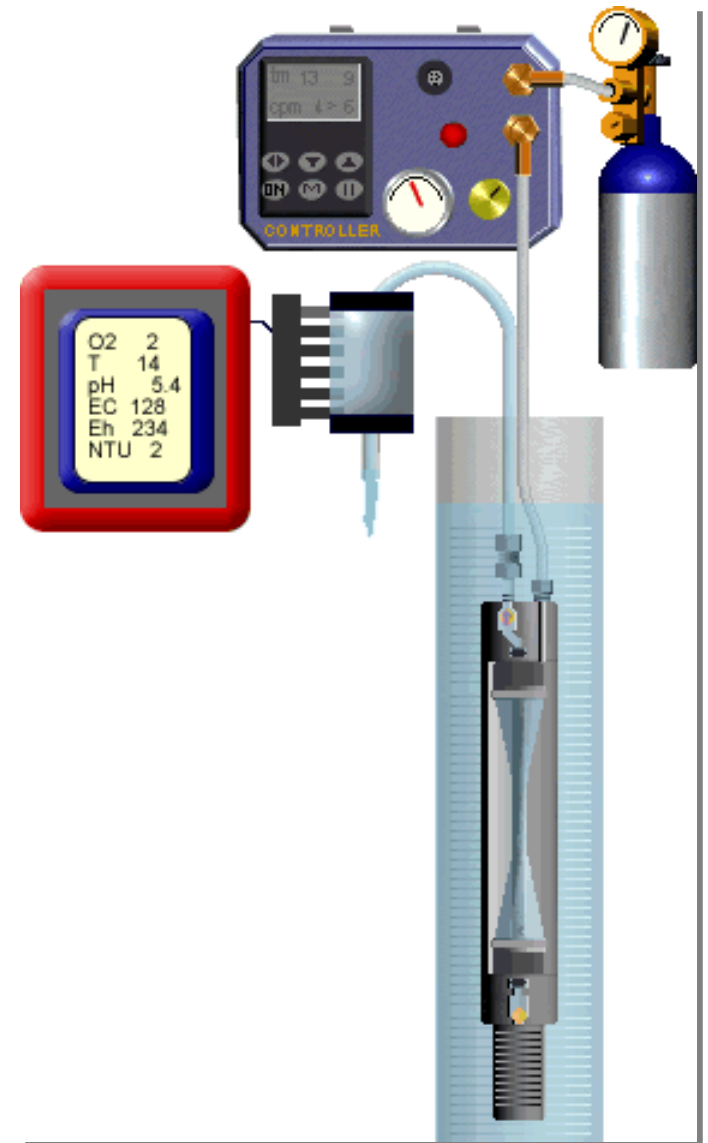
Sampling Objective

- Collect a "representative sample"
- What is a representative sample?
  - Sample of formation water representative of conditions in space and time.
  - What factors could influence sample representativeness?
    - In-well related processes and conditions;
    - Sampling bias (concentration averaging, purging completeness);
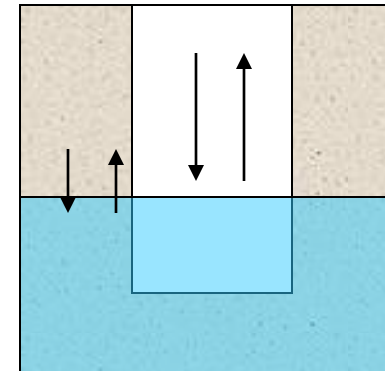   - Analytical error.

In-Well Related Processes and Conditions

- Why might the water quality in a non-purged well differ from that of the formation?
  - Stagnant water above screen;
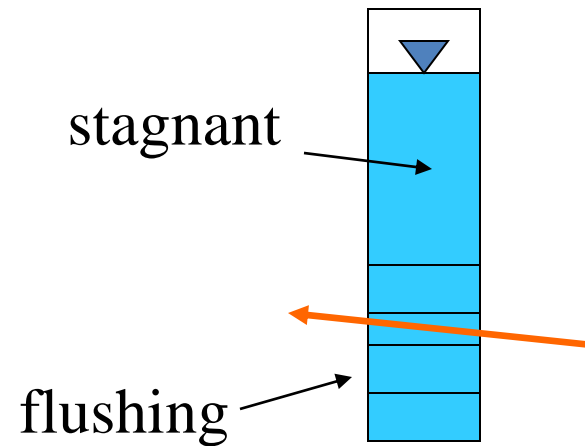
stagnant

flushing

In-Well Related Processes and Conditions

- Why might the water quality in a non-purged well differ from that of the formation?

  – Well head-atmosphere gas exchange >>water table-vadose gas exchange:

    • Promotes differences in rates of:

      o Biodegradation;

      o Volatile loss;

   o Precipitation of metal oxides.

In-Well Related Processes and Conditions

- Why might the water quality in a non-purged well differ from that of the formation?

    – Surface water and material leakage in casing;

        • Accumulation of rotting organic debris;

        • Accumulation of fines with high CEC.

In-Well Related Processes and Conditions

- Why might the water quality in a non-purged well differ from that of the formation?

  – Well (casing and sand pack) can act as flow short circuit if vertical gradient is present.

C1

C1

C2
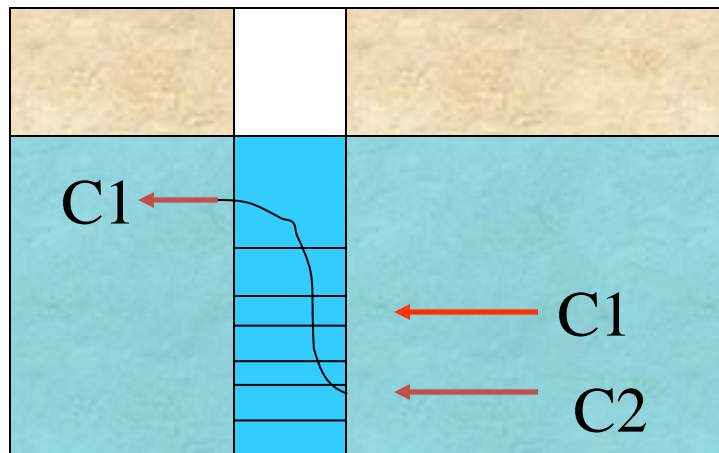
upward gradient
Kh >> Kv

Sampling Bias

- Includes losses or gains in constituents related to:
    - Reactions with sampling system components;
    - Gas losses from pressure drop or air exposure;
- Concentration averaging over the screened interval;
- Purging completeness (mixing).

Concentration Averaging

- Concentration in well (assuming purging completeness) represents an average of the vertical concentration gradient outside the well.
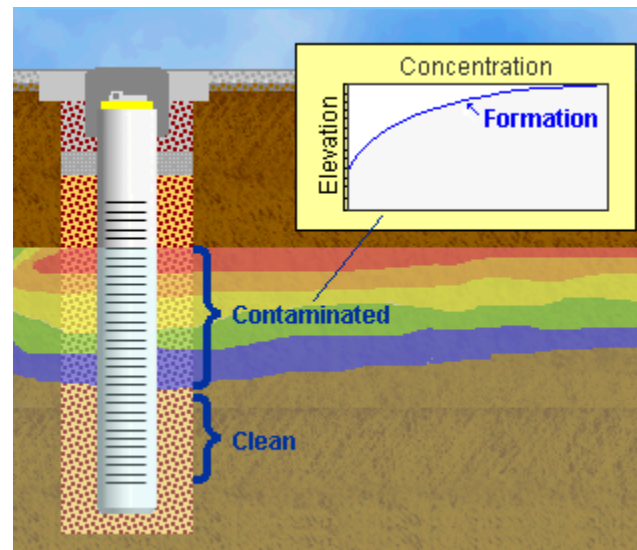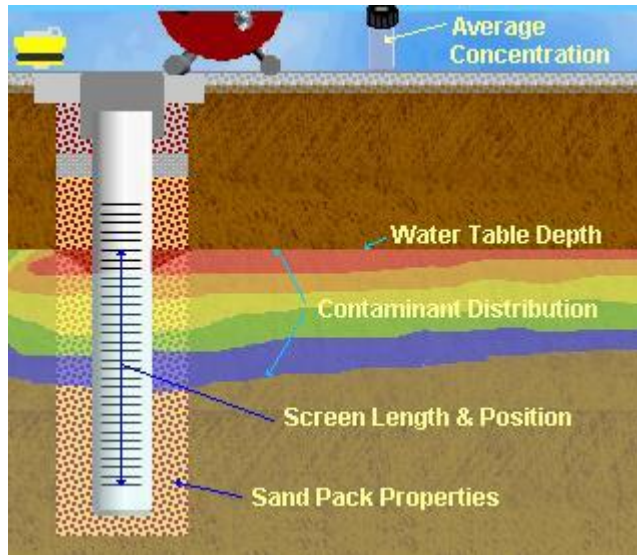
Case I: High K, Uniform material
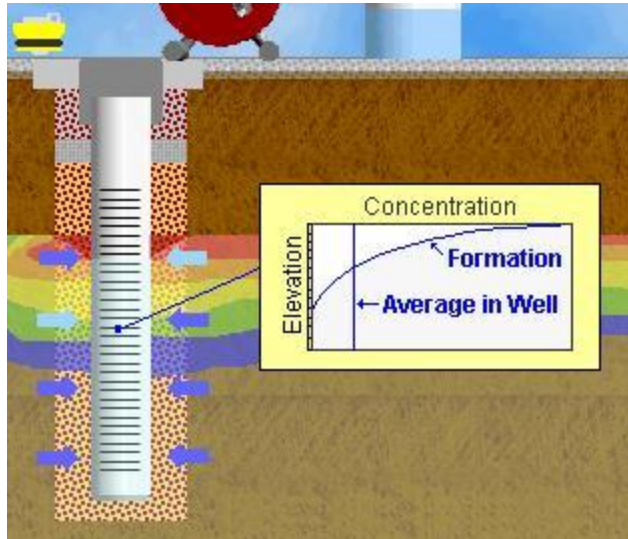
•Notes:

•During purging and sampling

  ▪ Little drawdown

  ▪ Radial flow

Case I: High K, Uniform material

- Notes:
- Ave C depends on:
  - vertical concentration gradient
  - location of water table
  - saturated screen length
  - sand pack uniformity

Case II: Low K, Uniform material
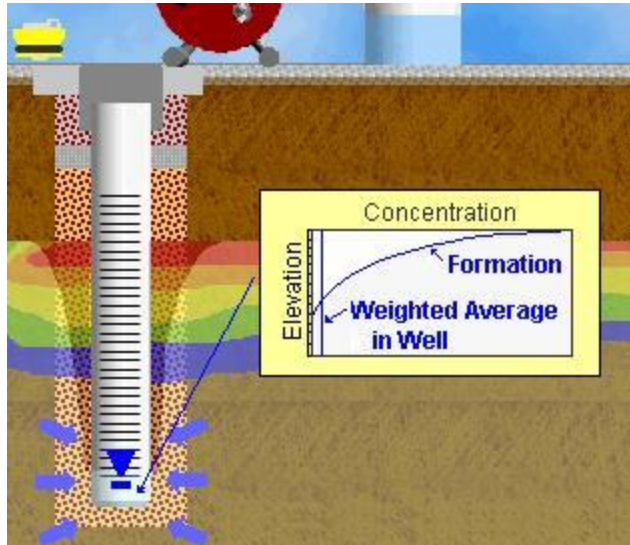
•Ave C also depends on:

▪ degree of drawdown

▪ weighted toward formation concentrations where screen remains saturated during purging and sampling

Source: Expedited Site Assessment: The CD (http://www.esacd.uconn.edu)

Case III: Stratified Material
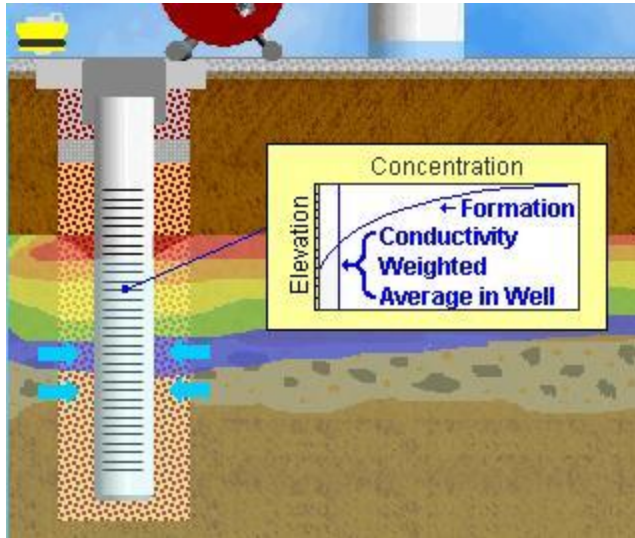
•Notes:

•Ave C weighted toward concentration in highest K and thickest formation (that remains saturated)

IV: Vertical Flow Influenced Average
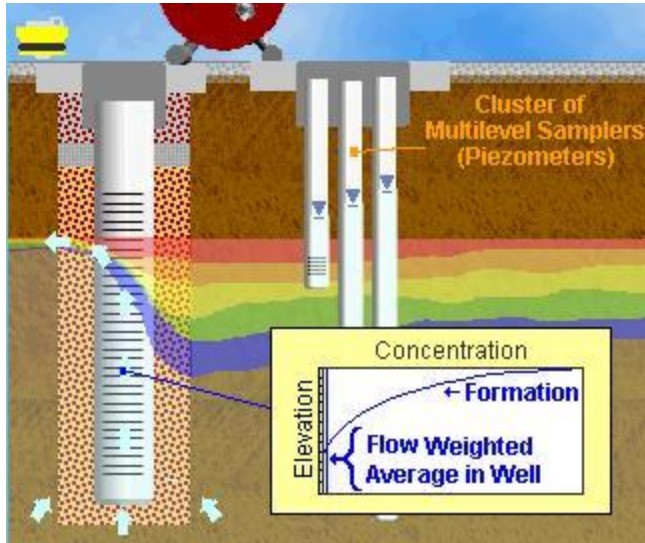
• Vertical gradient present

• Under static conditions well is short circuit results in disturbance of concentration conditions in well and in formation near well

Source: Expedited Site Assessment: The CD (http://www.esacd.uconn.edu)

representative sample = accurate sample ??

- 3D (multilevel sampling required)

• Screen lengths and vertical intervals between samplers are short relative to vertical concentration distribution
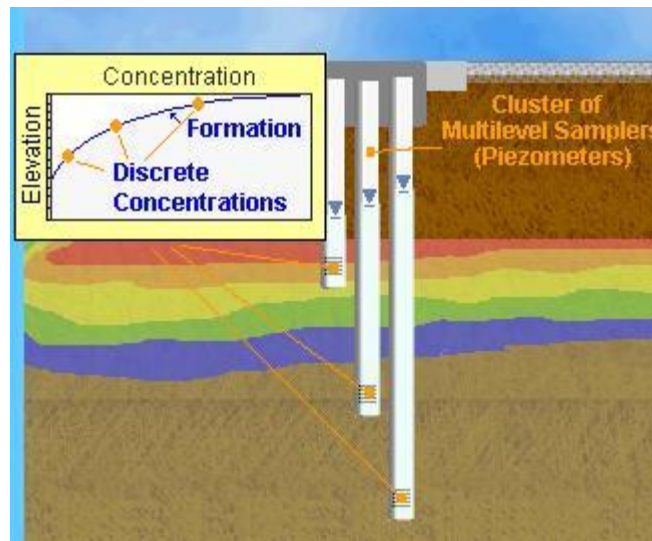
Purging Completeness

- Purging completeness = replaced well bore water with formation water in your sample pump (or bailer).

- Degree of purging depends on:

  – Not just the amount of water you remove but how you remove it!!!!

  – Differences in concentration between well and formation;

  – Volume of well (sand pack + casing volume);

  – Pumping rate (bailer volume).

PURGING PHYSICS
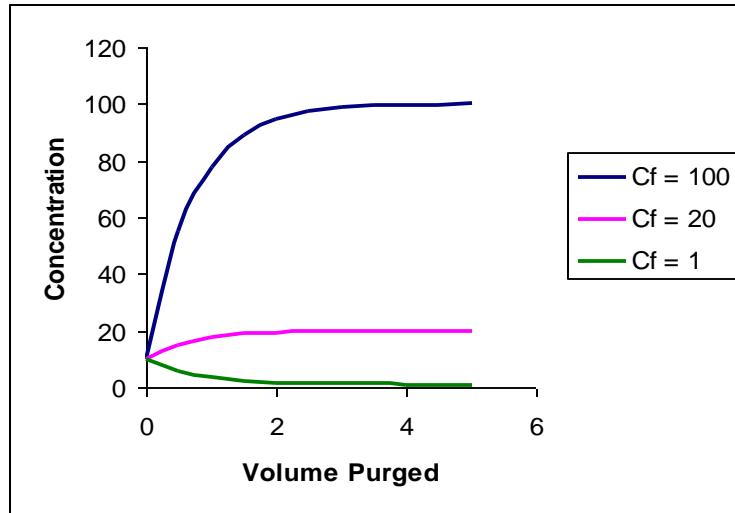
Notes:

• Purging patterns differ for different constituents depending on Co/Cf ratio

• Unstable drawdown during purging Cf (= Cave) can vary

What does it all imply with respect to representative sampling

- Use short screens and conduct multilevel sampling;

- Minimize drawdown during purging (low flow)

- To monitor purging completeness:

  - ideally want to monitor constituent of interest but not practical;

  - monitor surrogate parameters that are sensitive to water quality differences

But what if the formation K is so low that low flow sampling is impractical?

- Follow regulatory guidelines (increase drawdown)
- Purge well (to above top of screen) several times
  - Keep screen saturated if you can
  - Put tubing inlet in screen section or section that recharges the screen
- Construct sampler using large diameter screen

Use of the DOAM to Assess Recharge Section of Screen
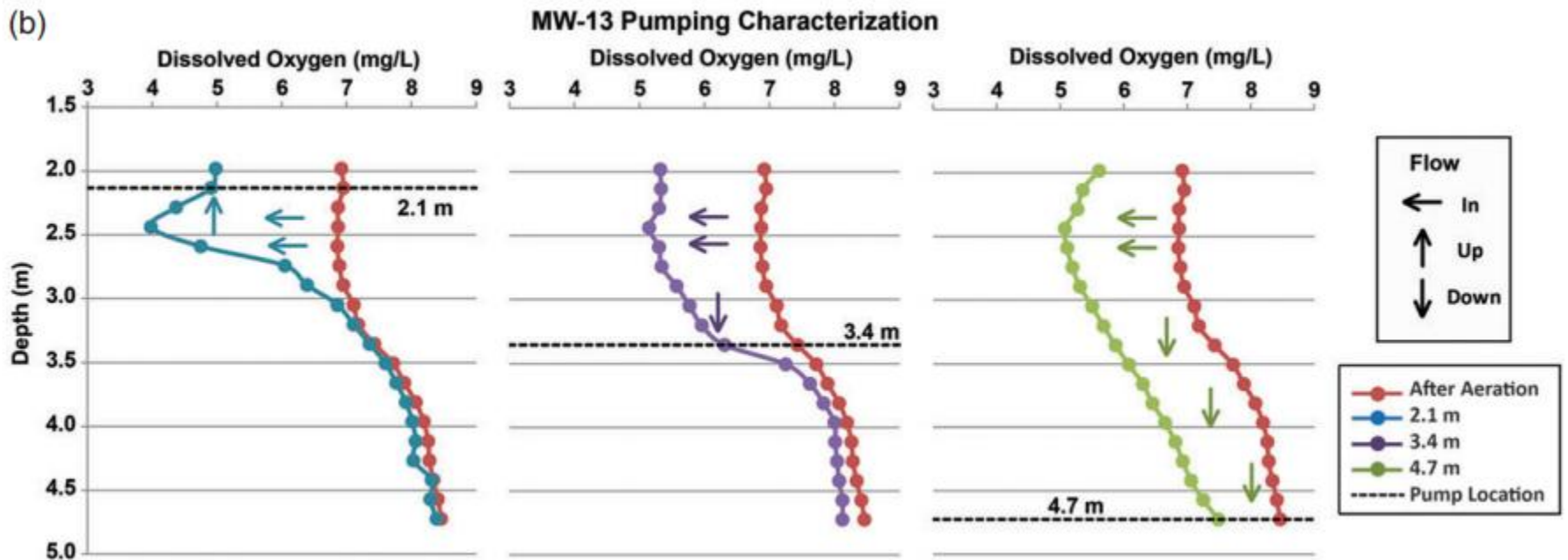
From S.A. Vitale and G.A. Robbins/ Groundwater Monitoring & Remediation, 2017, 36, no. 2: 59–67

Low Flow Sampling Procedures

Key Principles

- Representative sample
- No losses in collections and transfers
  - VOCs no air exposure
  - Metals no precipitation
- No cross contamination in transit or storage

Passive (Grab) Samplers
(when low flow cannot be achieved)

- Bailer
- Diffusion Bag
- Hydrasleeve
- Snap Sampler
- Pump line to specific depth

Bailer

animation

Issues:
- Disturbing material on bottom of well (turbidity)
- Exposing sample to air when you transfer to bottle

Diffusion Bag

- Original concept:
  - Bag = semipermeable membrane filled with deionized water
  - Bury bag in stream sediment to determine where contaminants discharge to stream
- Well concept:
  - Leave bag in well to get well sample, no purging, equilibrate for several weeks
  - Research shows bag does equilibrate/different materials for different things
  - Assumes well is well mixed or hang several at different depths

Hydrasleeve

Geoinsight product

Lower in well, when you pull up bag fills, valve closes
Push sampler into bag to fill bottle, minimize air exposure

Snap Sampler

Lower spring loaded sampler to desired depth, then send messenger down well, closes sampler, get discrete sample

Pump Line
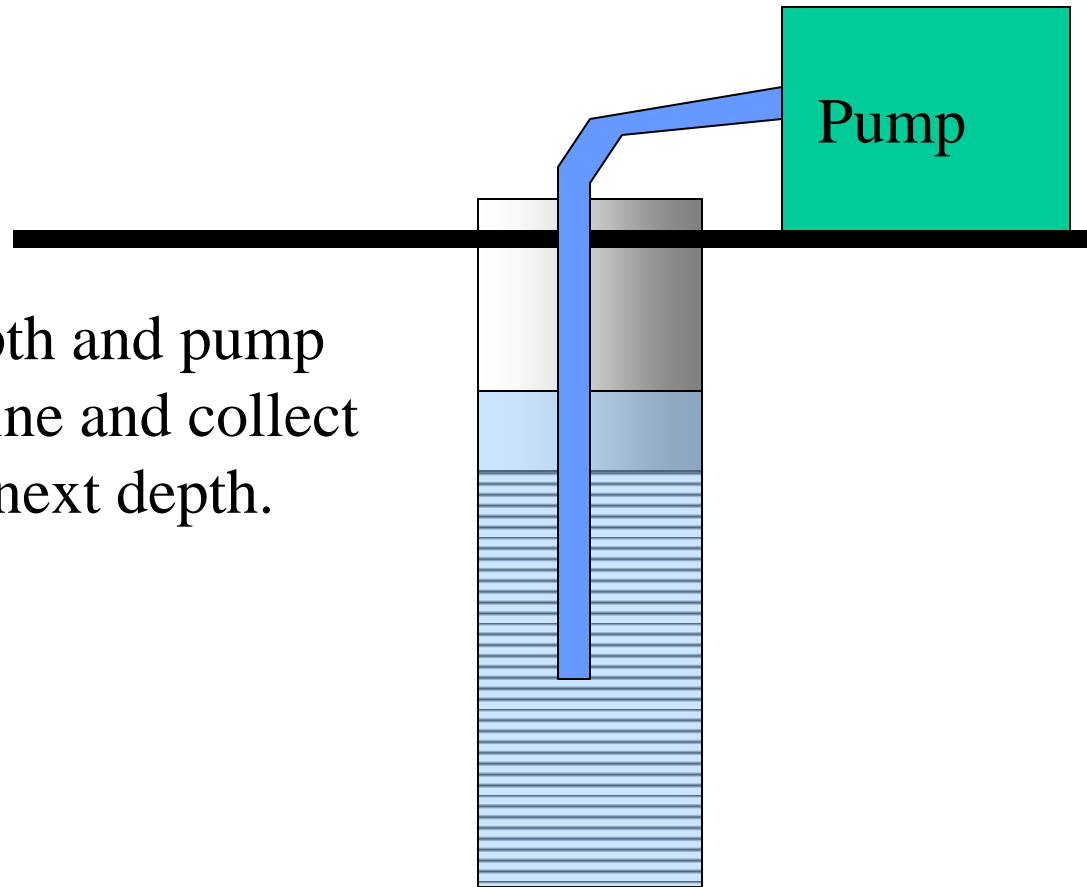
Lower tubing to depth and pump sufficient to purge line and collect sample. Then go to next depth.

Pump

Pumps

- [Peristaltic](#)- shallow, VOC loses?
- [Inertial](#) – disturbing material on bottom of well
- [Bladder](#) – need compressed gas
- [Mechanical bladder](#) – alot of cranking
- [Submersible](#) – contamination of parts (metals)

Sampling System

Flow Cells
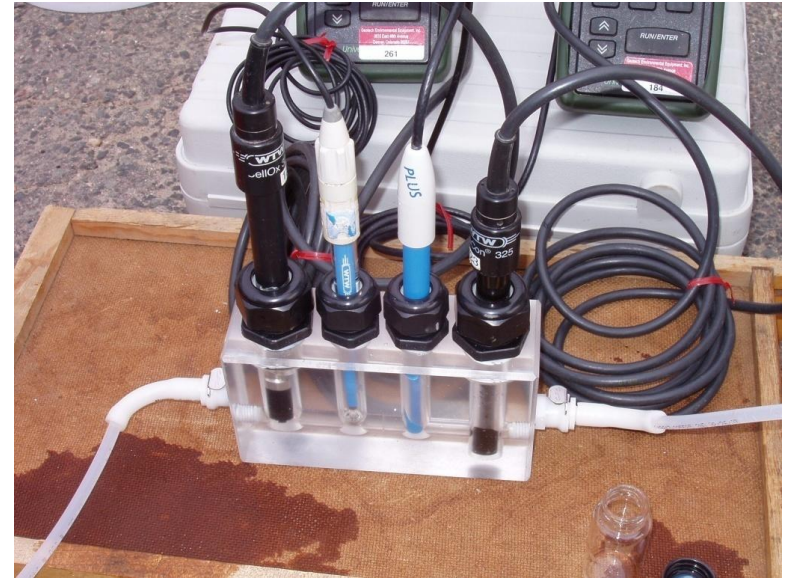
Low-flowProcedures

1. Adjust the pumping rate to match the formation K

2. Control the drawdown in the well to prevent dewatering of the screen

   - Only when you have achieved steady state drawdown are you pumping formation water (prior you are mixing wellbore water and formation water).

3. Monitor indicator parameters to determine when purging is completed.

Adopted from Kaminsky

Pumping and Sampling

- Purging rate < 1 L/min
- < 100 mL/min for till
- Sampling rate = or < purging rate
- Indicator parameters are only important after drawdown is stable.

APPENDIX C
EXAMPLE (Minimum Requirements)
WELL PURGING-FIELD WATER QUALITY MEASUREMENTS FORM

Location (Site/Facility Name)_____   Depth to _____/_____ of screen
Well Number_____ Date_____   (below MP)   top   bottom
Field Personnel_____   Pump Intake at (ft. below MP)_____
Sampling Organization_____   Purging Device; (pump type)_____
Identify MP _____   Total Volume Purged _____

Clock Time 24 HR	Water Depth below MP ft	Pump Dial[1]	Purge Rate ml/min	Cum. Volume Purged liters	Temp. °C	Spec. Cond.[2] µS/cm	pH	ORP[3] mv	DO mg/L	Turb-idity NTU	Comments
Stabilization Criteria					3%	3%	±0.1	± 10 mv	10%	10%	

1. Pump dial setting (for example: hertz, cycles/min, etc).
2. µSiemens per cm(same as µmhos/cm)at 25°C.
3. Oxidation reduction potential (ORP)

EPA 2010, region 1 SOP

EPA Low Flow Guidelines

- The mid-point of the saturated screen length is used by convention as the location of the pump intake.

- Stabilization of indicator field parameters is used to indicate that conditions are suitable to begin sampling. Achievement of turbidity levels of less than 5 NTU and stable drawdowns of less than 0.3 feet, while desirable, are not mandatory. (minimize drawdown) Pump < 1L

- Stabilization is considered to be achieved when three consecutive readings, taken at three (3) to five (5) minute intervals, are within the following limits:

- turbidity (10% for values greater than 1 NTU),

- DO (10%),

- specific conductance (3%),

- temperature (3%),

- pH (± 0.1 unit),

- ORP/Eh (± 10 millivolts).

Temperature

- Why measure?
  - Any thermodynamic calcs require T
  - $K = f(T)$
  - Calibrations require T
  - Depth of sample (leaks in MLS clusters)
  - Recharge to rivers from thermal gradients
- How
  - In well or immediately after collection (collect a lot of water)
  - Thermometer
  - Thermister
- Issues
 - Must be measured quickly if sample collected

Electrical Conductivity

- Why Measure?
  - Gross measure of total dissolved solids
  - Ability of a solution to conduct electrical current
    - TDS (mg/l) ~ .5 * EC (microsiemens/cm or microohms/cm)
  - Salt pollution, biodegradation, salt water intrusion, potability, landfills
- How
  - Electrical Conductivity Meter
    - One point Calibration against standard solution of known EC, near sample EC
- Issues
  - Non-linear at very high (thousands of mg/l) concentrations
  - Water T or standard T (EC rises 2% for every degree C increase

EC   (graph: EC vs T, linear increasing)   T

EC   (graph: EC vs C, curved increasing)   C
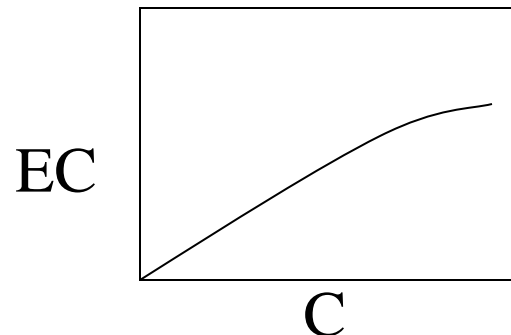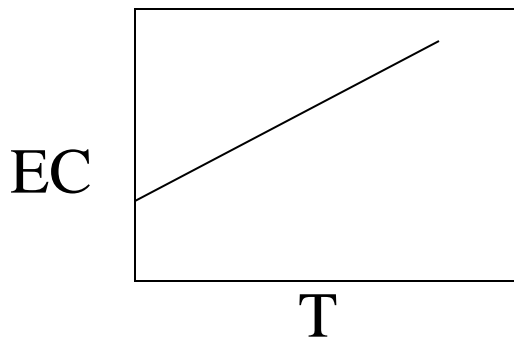
Turbidity

- Why?
  - Turbidity = the amount of solid particles suspended in water
  - Most states limit drinking water to a maximum of .5 NTUs, however usually drinking water is .1 NTUs or less.
  - Issues with metals
- How?
  - Nephelometer (turbidimeter) used to measure turbidity
  - Measures in nephelometric turbidity units, or NTUs.
  - Employs a light beam and a detector set to 90°of the source;
  - Amount of light reaching the detector is a function of particle density and properties of the particles, such as their shape, color, and reflectivity.
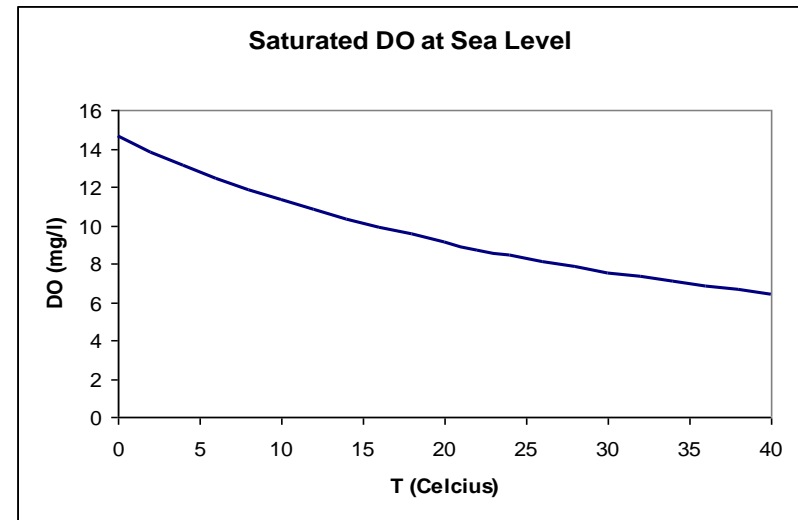
detector
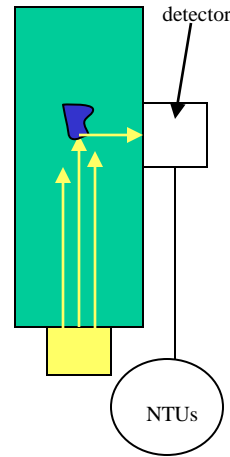
NTUs

< 10 NTUs

>1000 NTUs

Dissolved Oxygen

- Why?
  - Purging, redox conditions, biodegradation, organic pollution, metal speciation
- How?
  - Meter (if C> 1-2 mg/l)
  - Colorimetric (if clear)
- Issues?
  - Sensitive to sample exposure to air
  - Colorimetric hard to use if cloudy

Saturated DO at Sea Level

ORP

- ORP stands for *oxidation-reduction potential, which is* a measure, in millivolts, of the tendency of a chemical substance to oxidize or reduce (controls valence state and solubility).
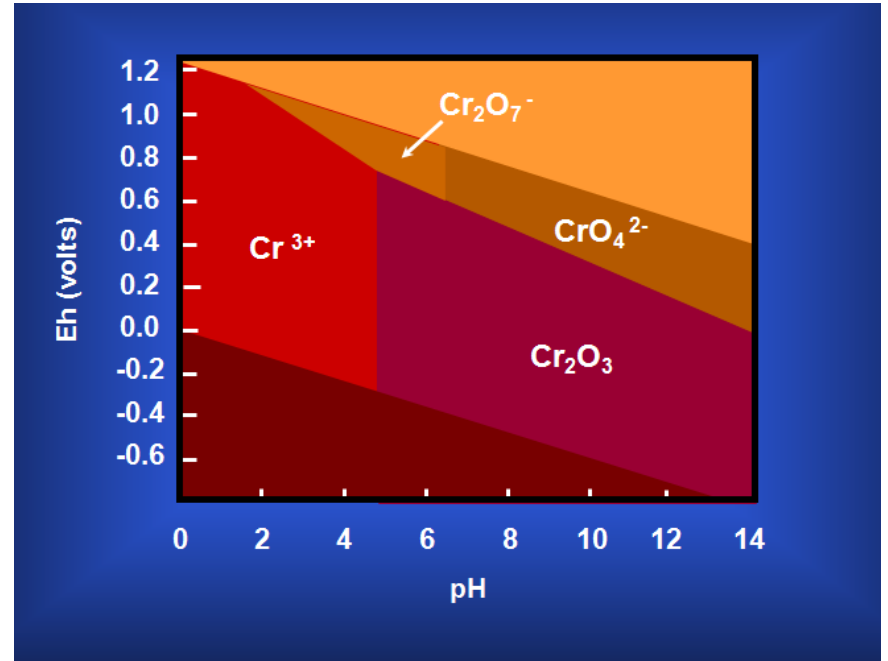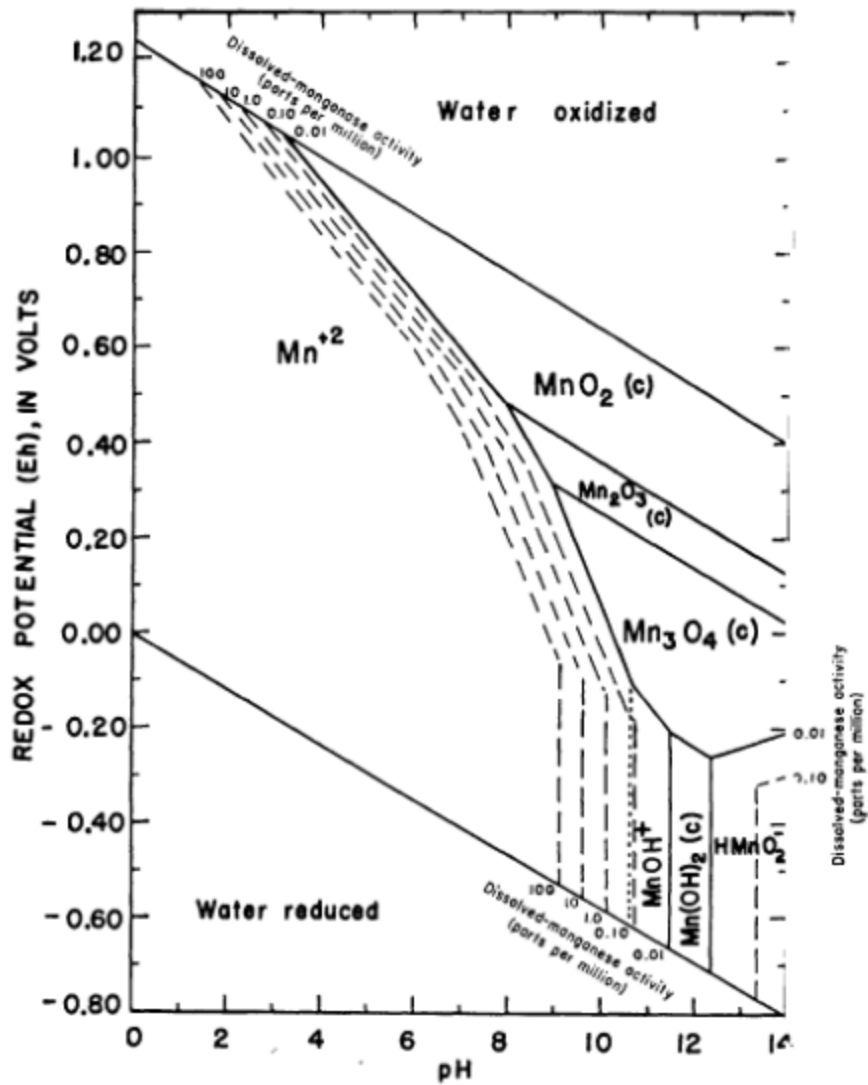
www.**ccaresearch.org**/tag14/Cr_Spec.ppt

INFLUENCES ON WATER QUALITY SAMPLES OBTAINED FROM OPEN BOREHOLE WELLS IN FRACTURED CRYSTALLINE BEDROCK

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Meredith J. Metcalf
Environmental Earth Science Department
Eastern Connecticut State University,
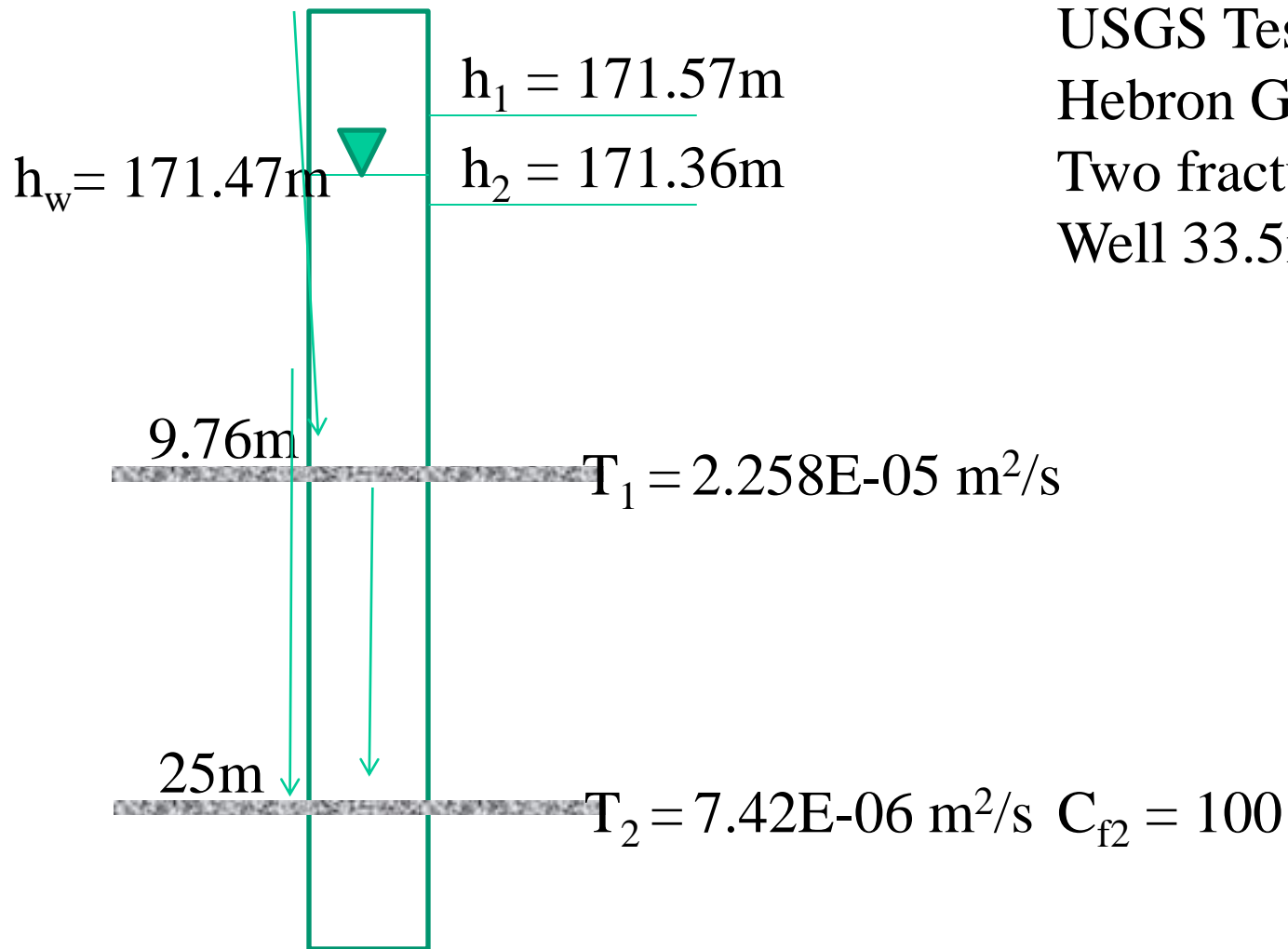Willimantic, CT

Well water quality = Flow Weighted Average

$$C_w = \frac{Q_1 C_1 + Q_1 C_1 \dots}{Q_1 + Q_1 \dots}$$

C_w is a function of
- number of contributing fractures
- transmissivity of fractures
- fracture heads
- water levels achieved in the well during sampling
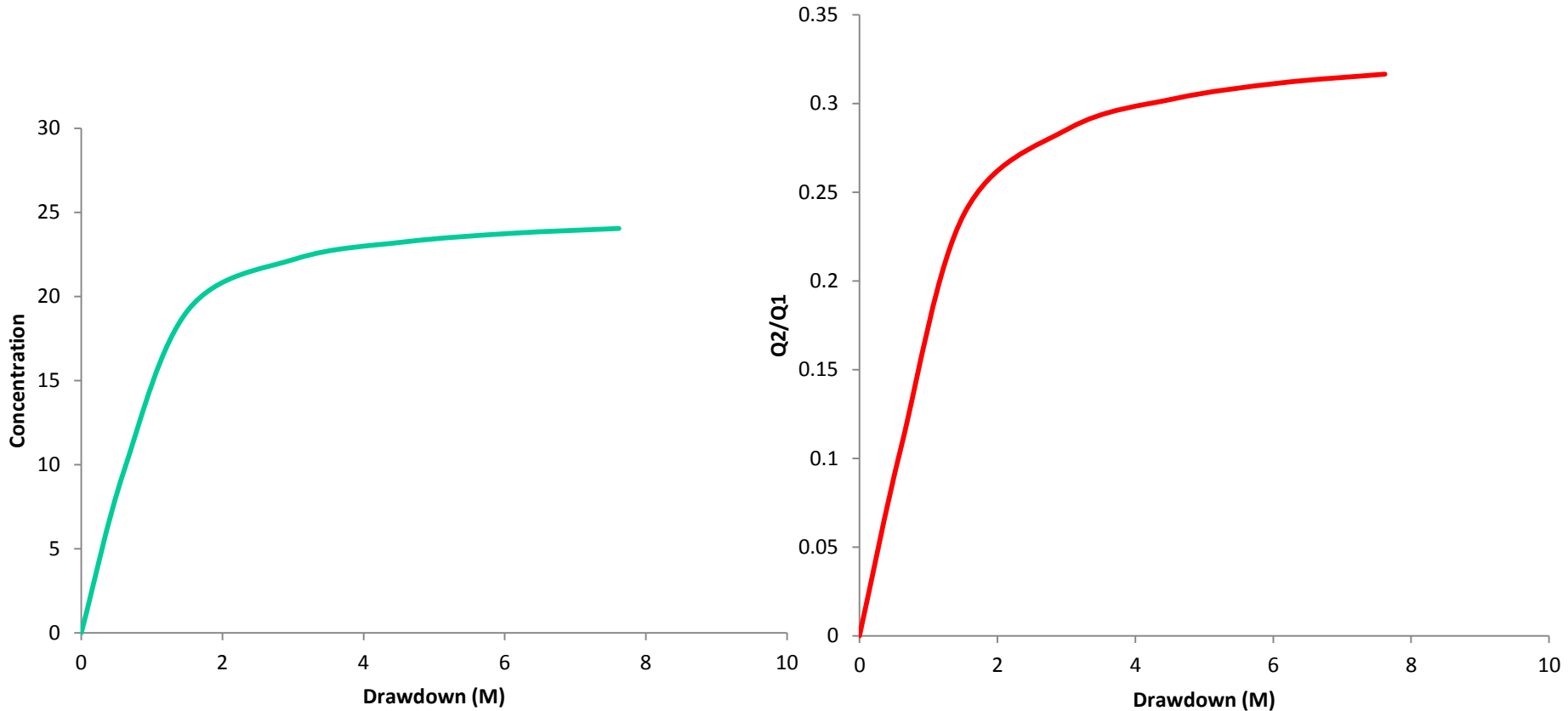- sample timing
- pump placement

Example Base Case Model

$h_1 = 171.57$ m

$h_w = 171.47$ m

$h_2 = 171.36$ m
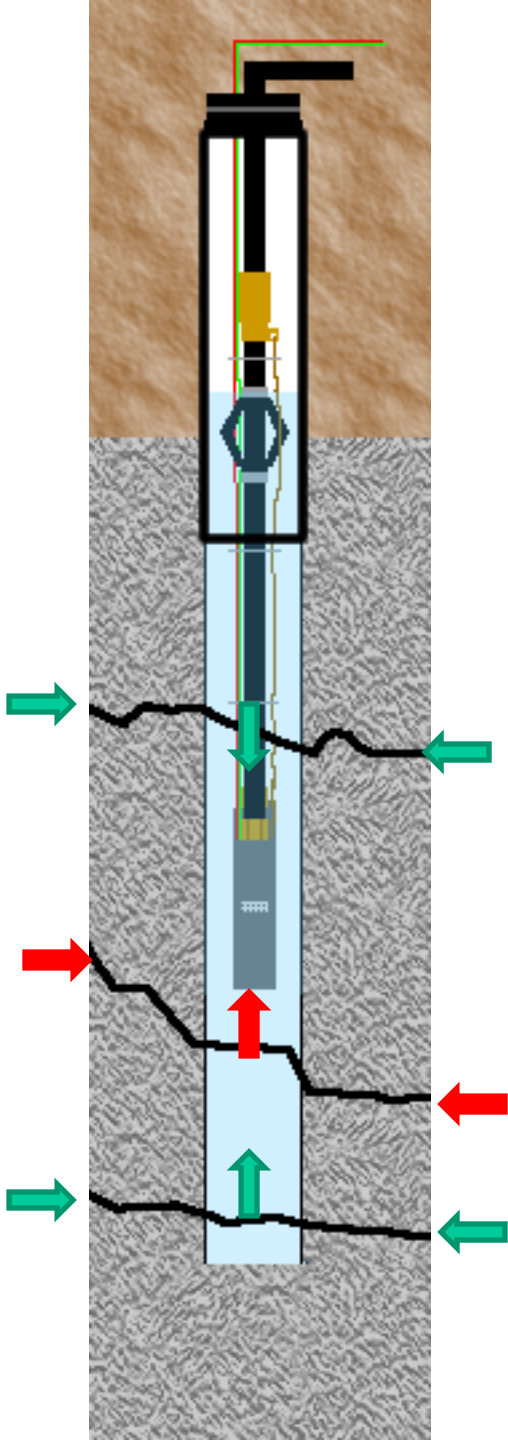
USGS Test Well 103R
Hebron Gneiss
Two fractures
Well 33.5m deep

9.76m

$T_1 = 2.258\text{E-}05 \text{ m}^2/\text{s}$

25m

$T_2 = 7.42\text{E-}06 \text{ m}^2/\text{s} \quad C_{f2} = 100$

Base Case Concentration and Discharge Variation with Drawdown

2. One Well Constant Head Test

Utility

- Miniature pump test to determine K in high K formations in small diameter wells

- Avoid oscillatory response in high K wells

- Avoid problems with sand pack drainage

- Can be conducted in conjunction with low flow sampling

Method

- Pump well at three or more flow rates and determine steady state drawdowns at each flow rate

Need to handle contaminated water

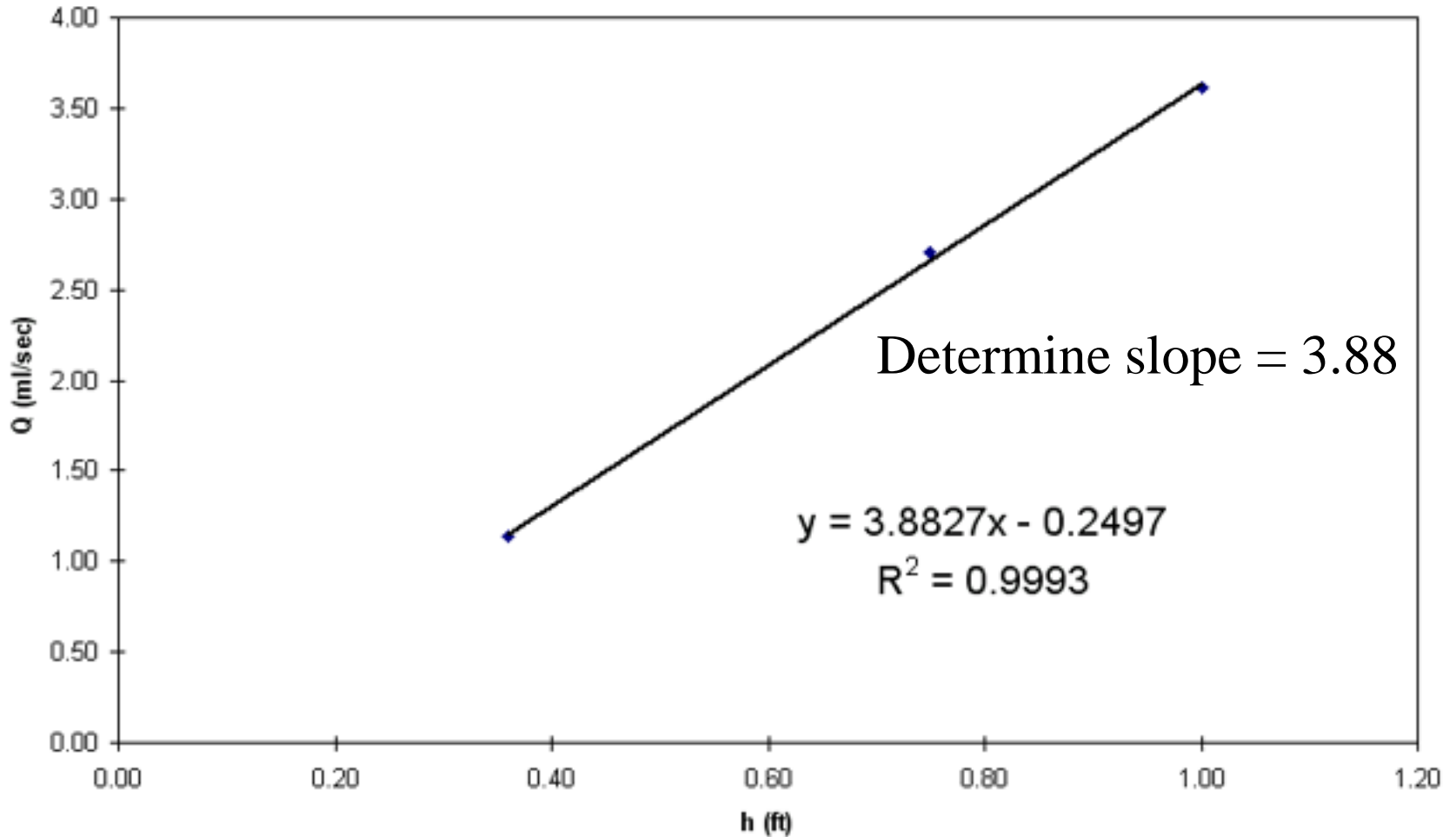Measure flow rate with graduated cylinders and stop watch

Measure drawdown with P-transducer
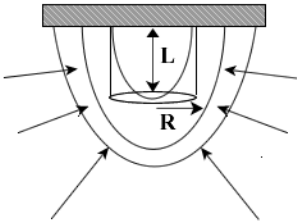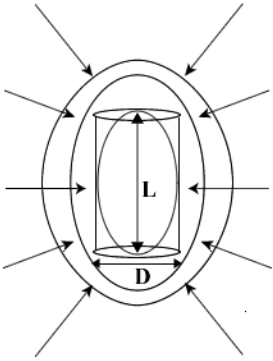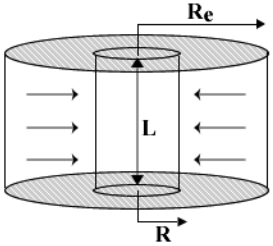
Plot Q vs. H Data

Constant Head test

Determine slope = 3.88

$y = 3.8827x - 0.2497$

$R^2 = 0.9993$

Find K

- Substitute slope, L (screen length) and intake diameter (D) into steady state flow equations (Q = slope*H)

K= slope $\dfrac{2.303 \log [L/D + (1+(L/D)^2)^{1/2}]}{2\pi L}$

Example spreadsheet

HALF ELLIPSOID
Dachler (1936)

FULL ELLIPSOID
Hvorslev (1951)

RADIAL FLOW
Muskat (1937)

$$Q = \frac{2\pi LKH}{2.303 \log \left[\frac{L}{R} + \sqrt{1 + \left(\frac{L}{R}\right)^2} \right]}$$

$$Q = \frac{2\pi LKH}{2.303 \log \left[\frac{L}{D} + \sqrt{1 + \left(\frac{L}{D}\right)^2} \right]}$$

$$Q = \frac{2\pi LKH}{2.303 \log [R_e / R]}$$

Where:
Q = steady state flow rate
L = intake length
K = hydraulic Conductivity
H = steady state drawdown
R = intake radius
D = intake diameter
R_e = radius of influence

Determining K from Low Flow Data

- Must accurately determine Q and drawdown
- Substitute values directly into steady state equations.

K Reproducibility From Low Flow Data

Central Connecticut Monitoring Well Low Flow Hydraulic Conductivity Determinations

Well	Date	Q (ml/min)	SDTW (m)	SSDTW (m)	H (m)	SSL (m)	Tech.	Model	K (cm/s)	Mean K (cm/s)	Std. Dev. (cm/s)	%RSD
W 3-5	Dec-06	130	3.48	4.45	0.97	3.05	A	Half Ellipsoid	4.64E-05			
	Mar-07	150	3.36	4.67	1.30	3.05	A	Half Ellipsoid	3.98E-05	3.96E-05	6.87E-06	17
	Jun-07	135	3.44	4.86	1.43	3.05	A	Half Ellipsoid	3.27E-05			
W 6-1	Dec-06	380	14.48	14.61	0.13	6.10	B	Half Ellipsoid	5.89E-04			
	Mar-07	380	14.40	14.55	0.16	6.10	A	Half Ellipsoid	4.97E-04	5.57E-04	5.18E-05	9
	Jun-07	140	14.70	14.75	0.05	6.10	D	Half Ellipsoid	5.83E-04			
W 6-3	Dec-06	500	16.86	17.91	1.05	4.95	B	Radial Flow	7.34E-05			
	Mar-07	200	16.75	17.30	0.55	5.56	C	Radial Flow	5.14E-05	8.29E-05	3.72E-05	45
	Jun-07	120	17.16	17.30	0.14	5.56	D	Radial Flow	1.24E-04			