A Primer on Well-Scale Processes

Ambient Flow-Through
Flow-Weighted Averaging vs. Stratification
Pump-Induced Flow Dynamics

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Subsurface Contaminant Transport and Monitoring

Site-Scale Process

NAPL (Free Product) Flow In the Unsaturated zone

Impact of NAPL at the water table

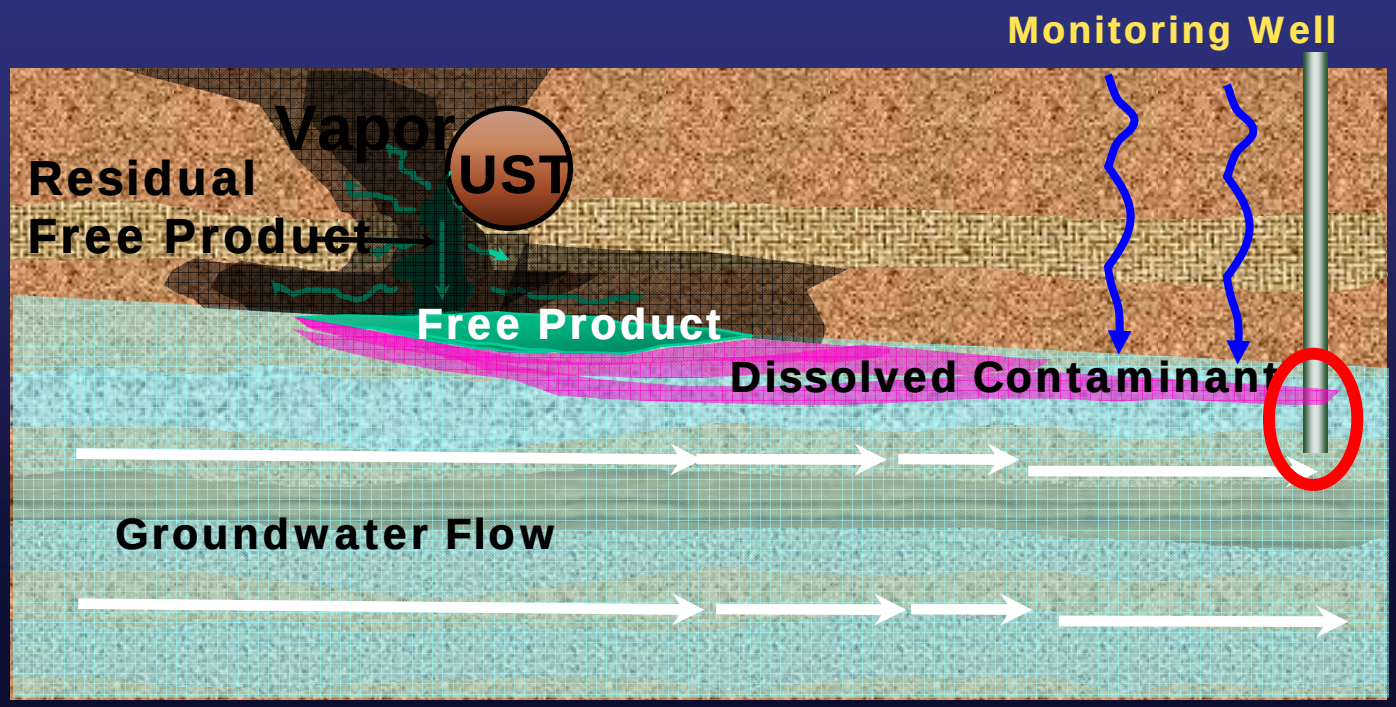
Volatilization of NAPL into soil gas

Dissolution into groundwater

Dissolved phase transport in ground water

Density important in NAPL phase

Density less important in dissolved phase (at least in the aquifer)



WHAT ABOUT THIS SCALE?

Well-Scale Processes-Ambient

Part 1

Ambient Flow-Through in Monitoring Wells:

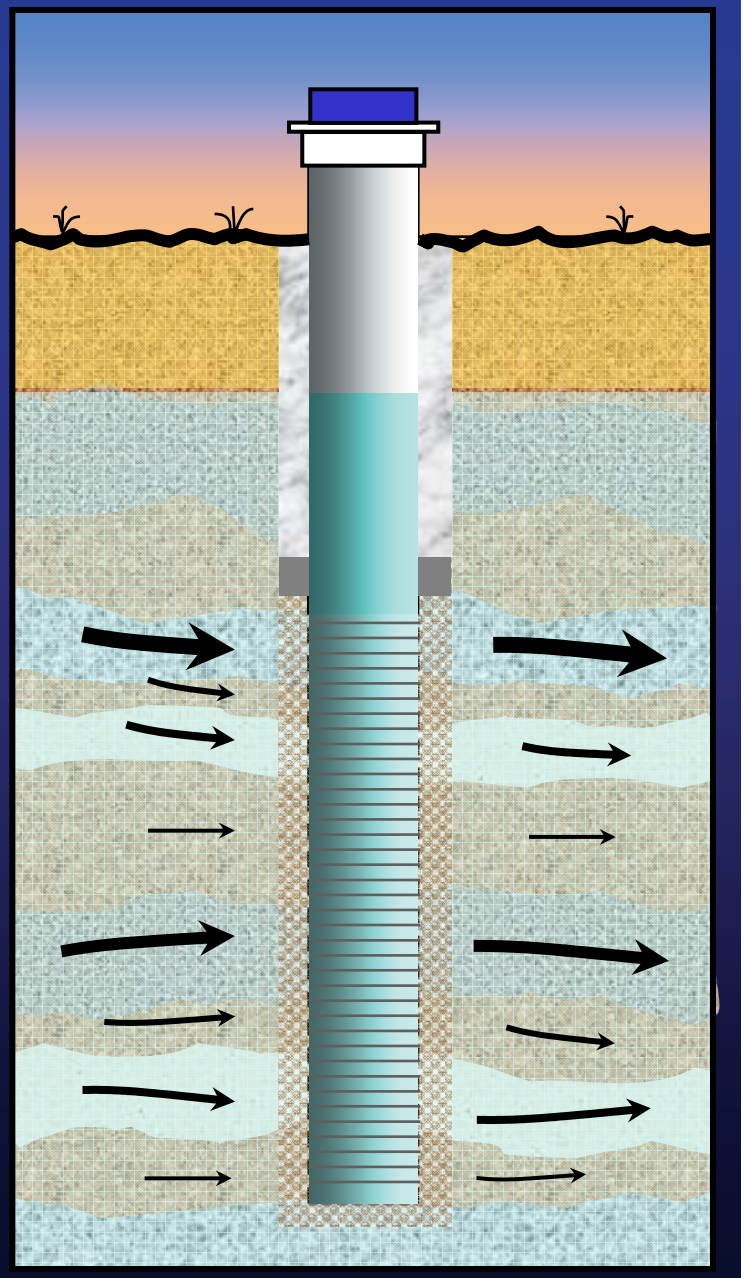
- "Stagnant" wells?
- Is there really "Horizontal Laminar Flow?"
- Flow-weighted averaging?

Homogeneous vs. Stratified:

- Contaminant inflow position
- Density effects
- Flow-weighted averaging

Vertical Gradient Flow:

- When does it occur?
- How does it affect sampling?



Well-Scale Processes-Pumped

Part 2

Flow to the well/within the well

- Hydraulically controlled
- Infinite permeability inside the well

Purging

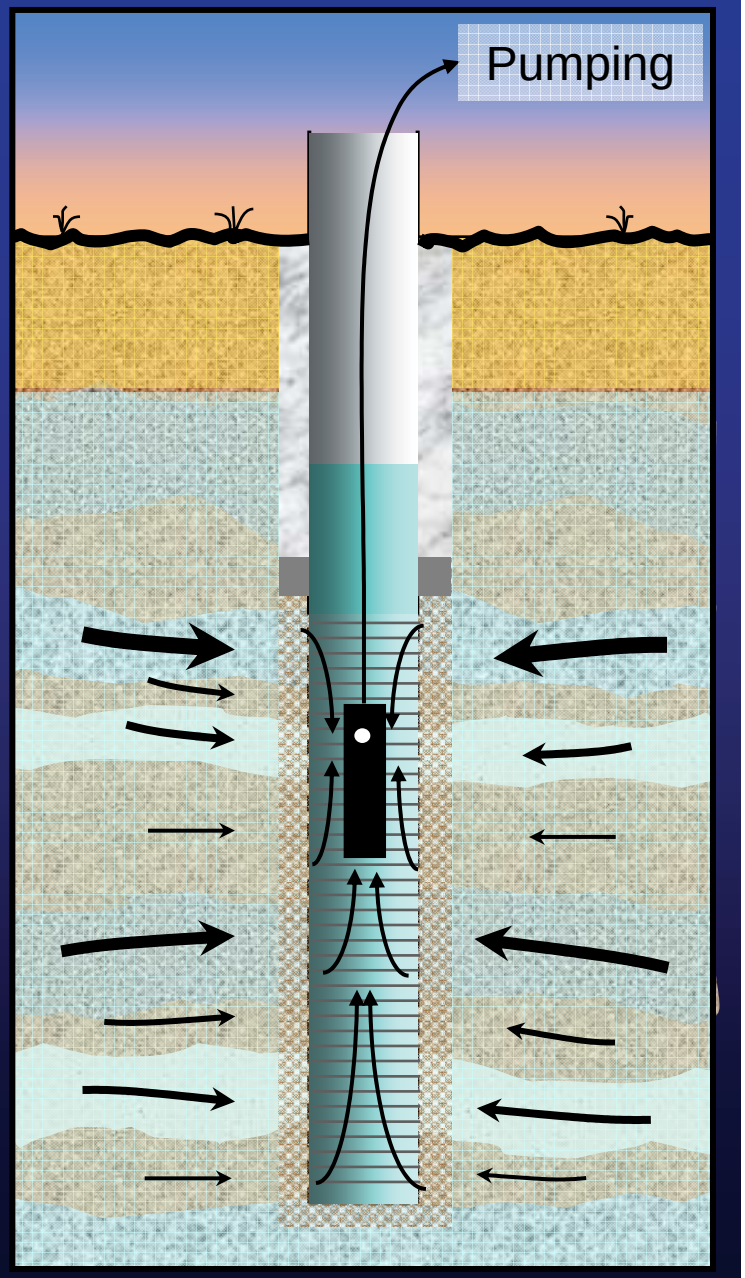
- Well Volume
- Low Flow

Parameter Stabilization

- Proxy for contaminant
- 1:1 match?
- Flow-weighted averaging?

Anecdotes

- Changing purge rate
- Density effects



Part 1

Horizontal Flow Through?

"**Horizontal Laminar Flow**"

A conventional assumption—but does it occur in wells?

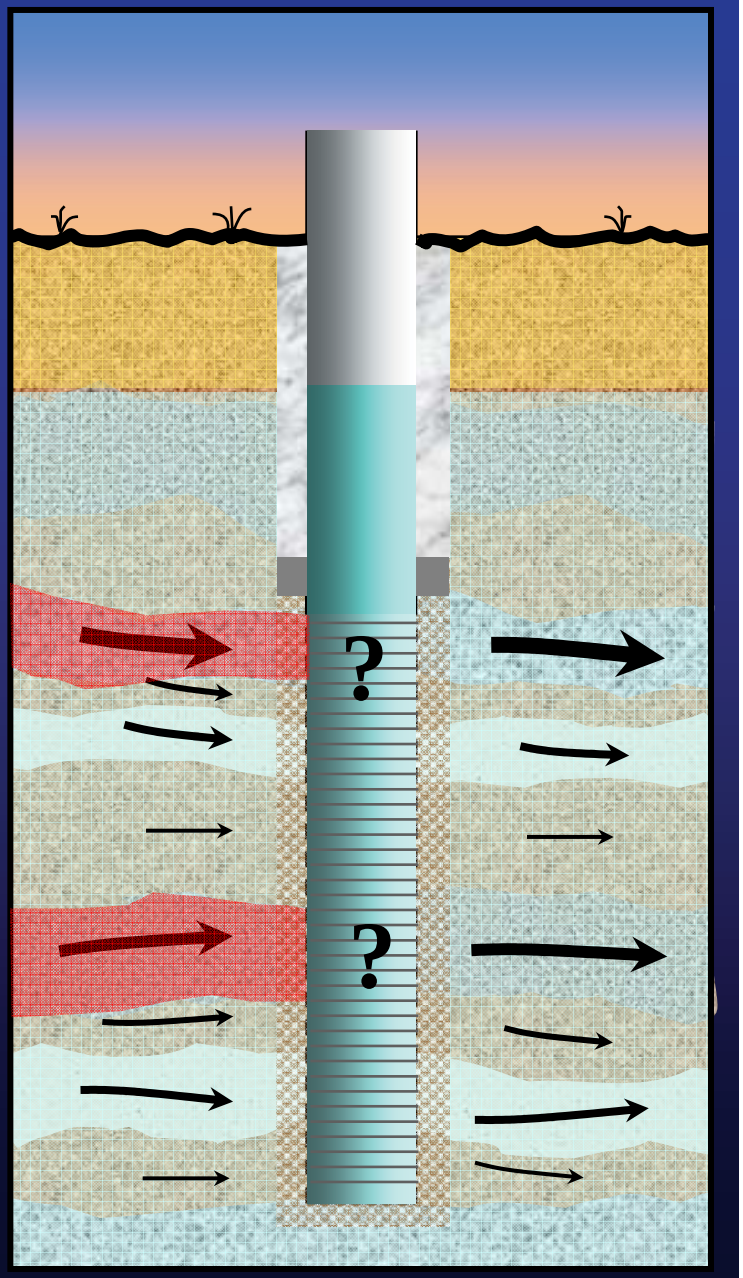
How does that assumption affect decision making?

What does happen to stratified contaminants between sampling events?

Maintain vertical position?

Reposition?

Mix and Average?



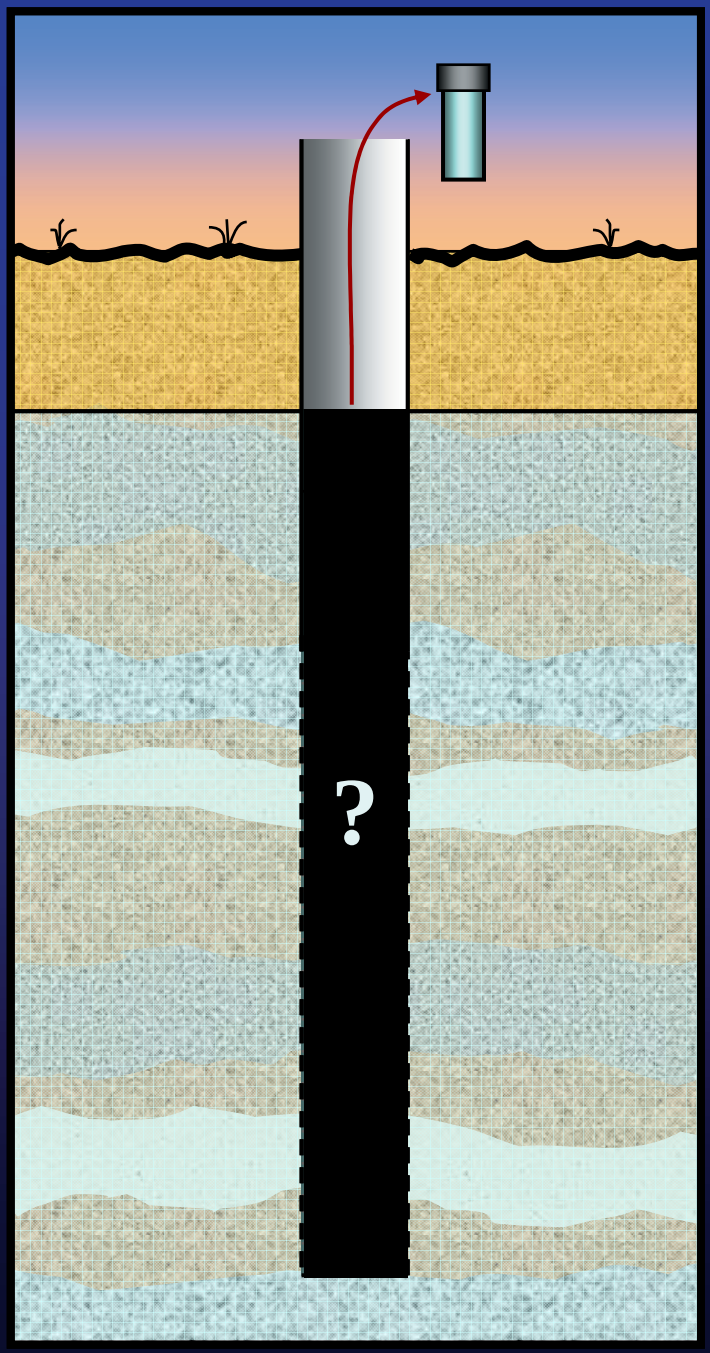
The Black Box

In many cases, all we get is one sample result

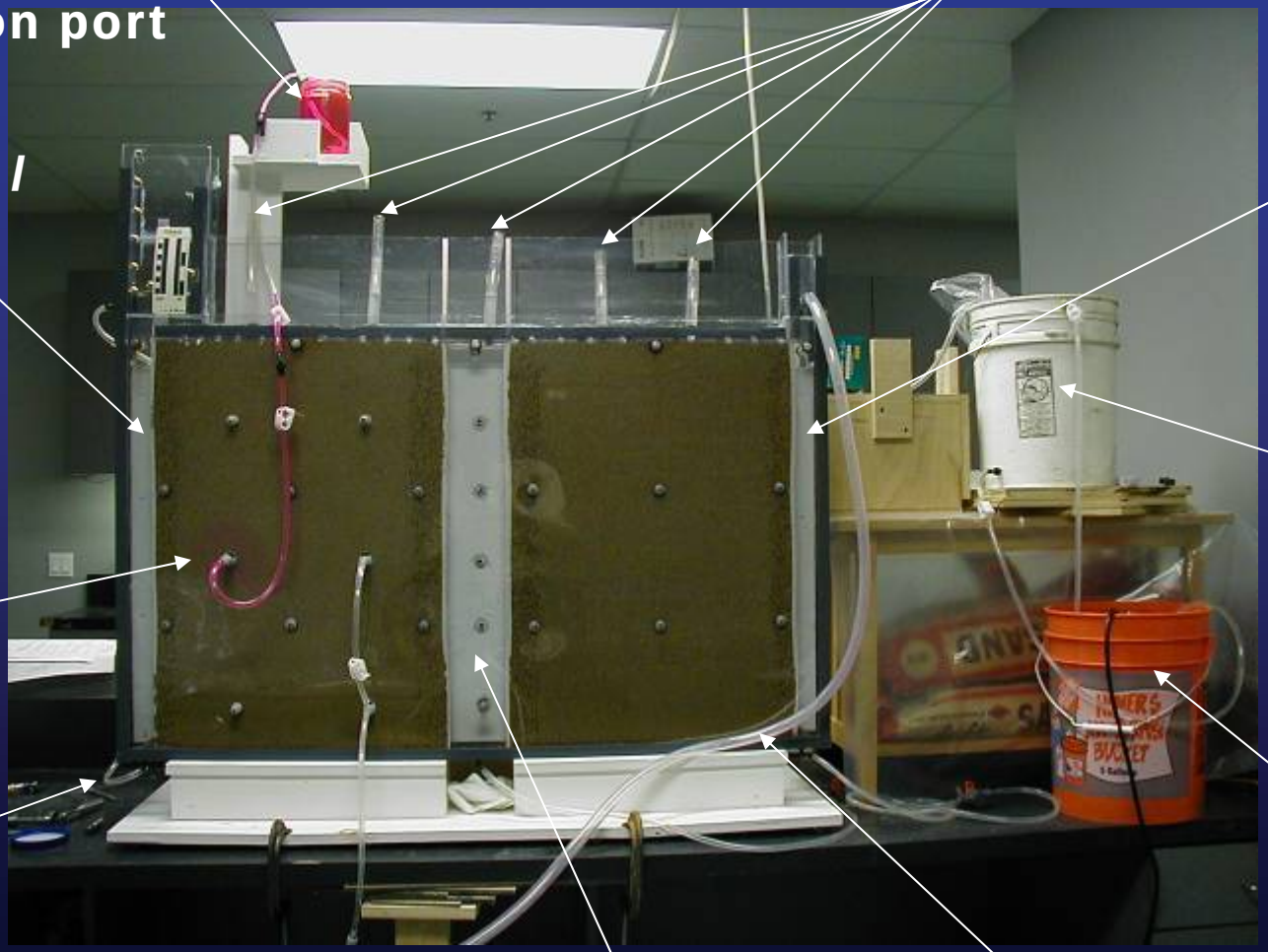
Internal monitoring well processes largely remain a black box.

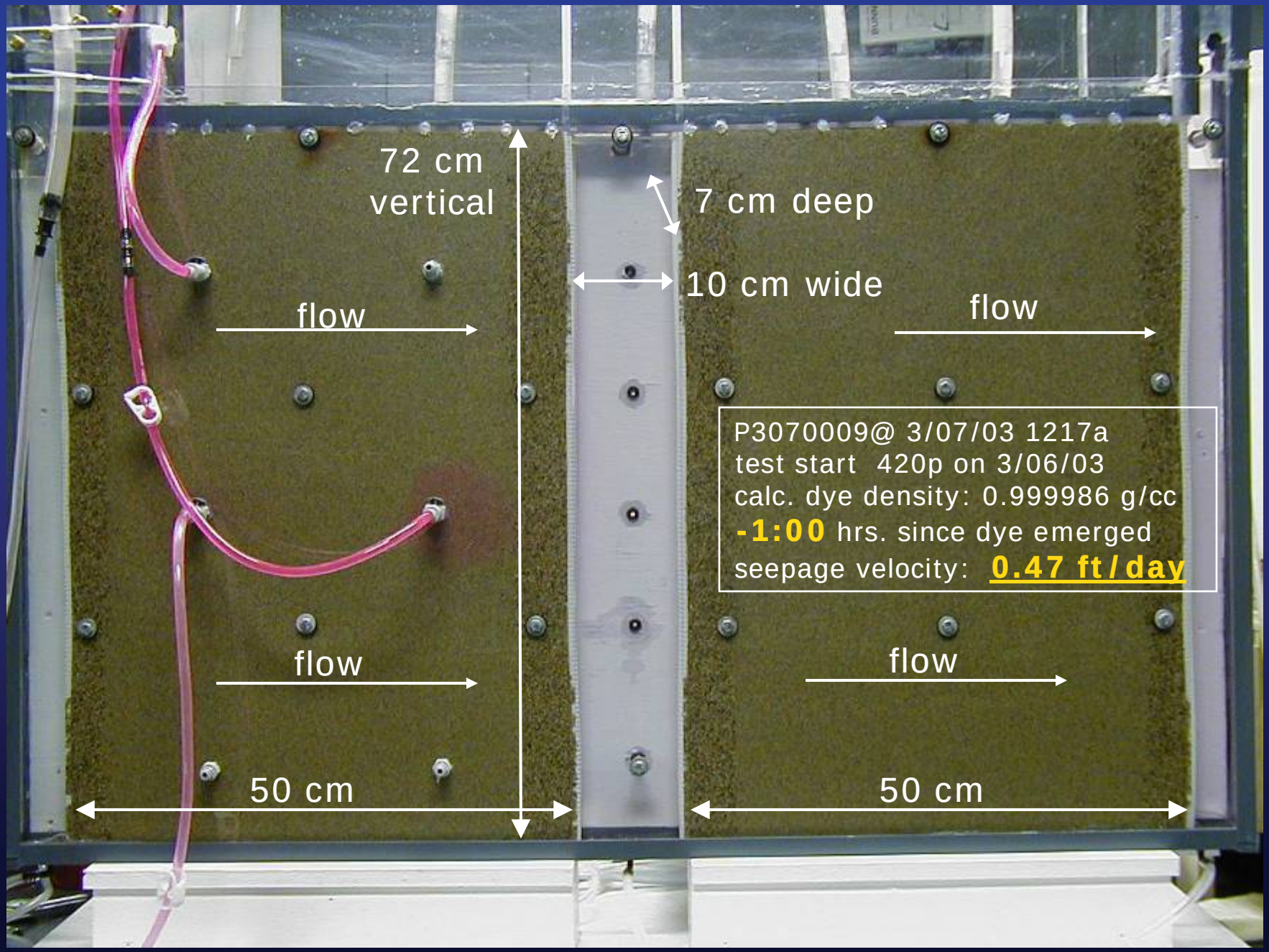
How do you test internal monitoring well dynamics?

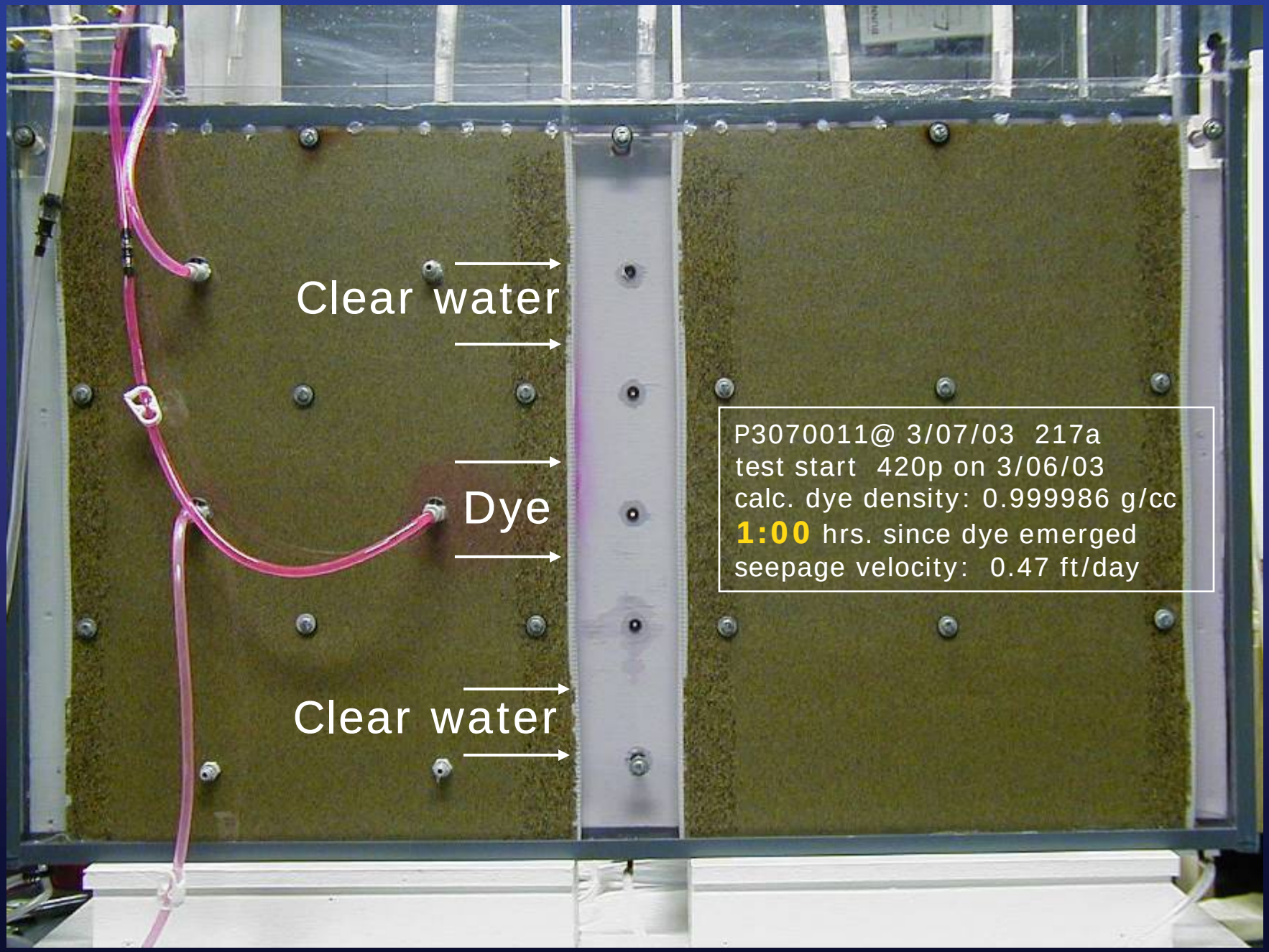
Build a physical model

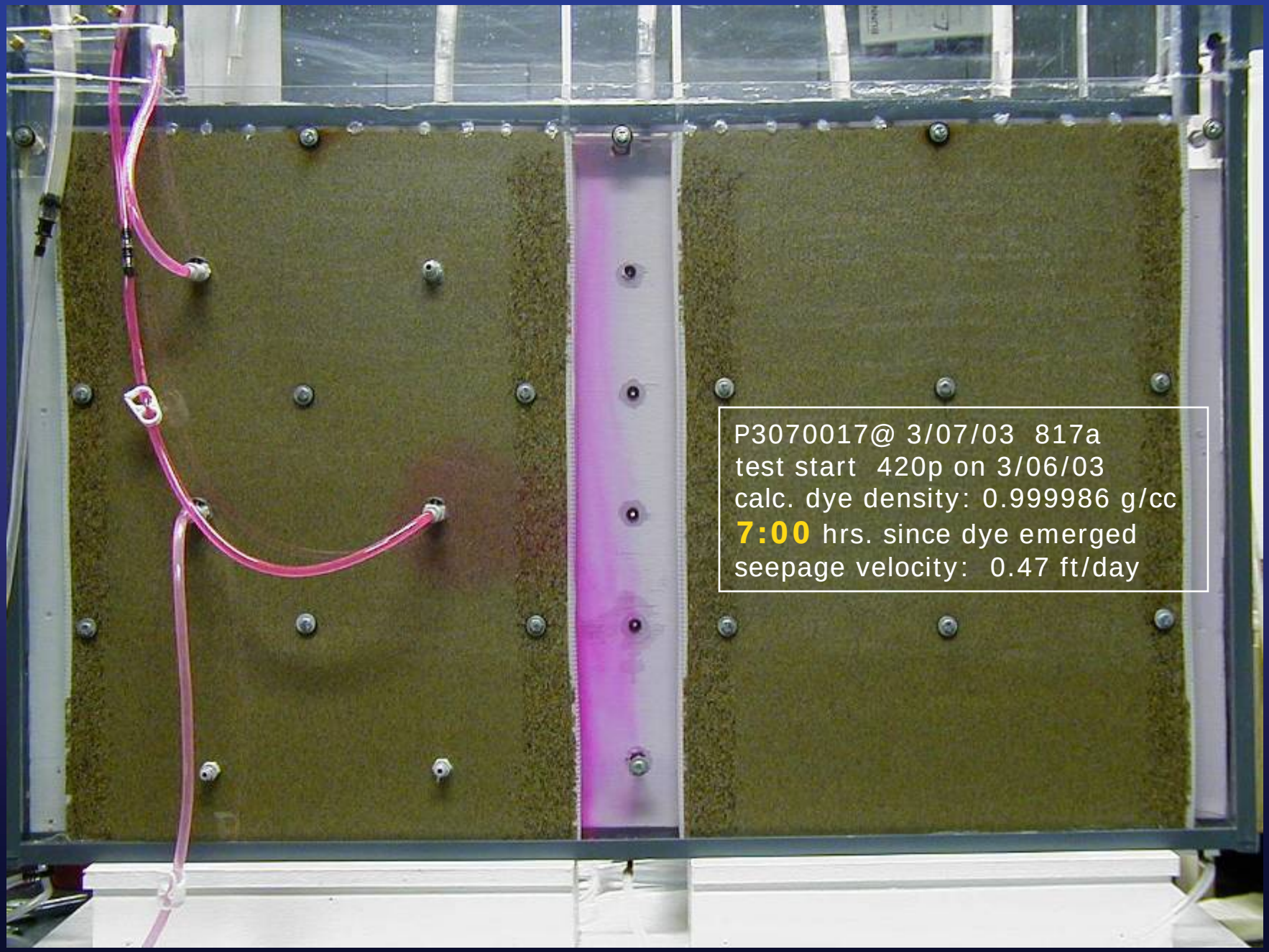


Sand Tank Well Model




72 cm
vertical
7 cm deep
10 cm wide
flow
flow
P3070009@ 3/07/03 1217a
test start 420p on 3/06/03
calc. dye density: 0.999986 g/cc
-1:00 hrs. since dye emerged
seepage velocity: 0.47 ft/day
flow
flow
50 cm
50 cm


Clear water
Dye
Clear water
P3070011@ 3/07/03 217a
test start 420p on 3/06/03
calc. dye density: 0.999986 g/cc
1:00 hrs. since dye emerged
seepage velocity: 0.47 ft/day


P3070017@ 3/07/03 817a
test start 420p on 3/06/03
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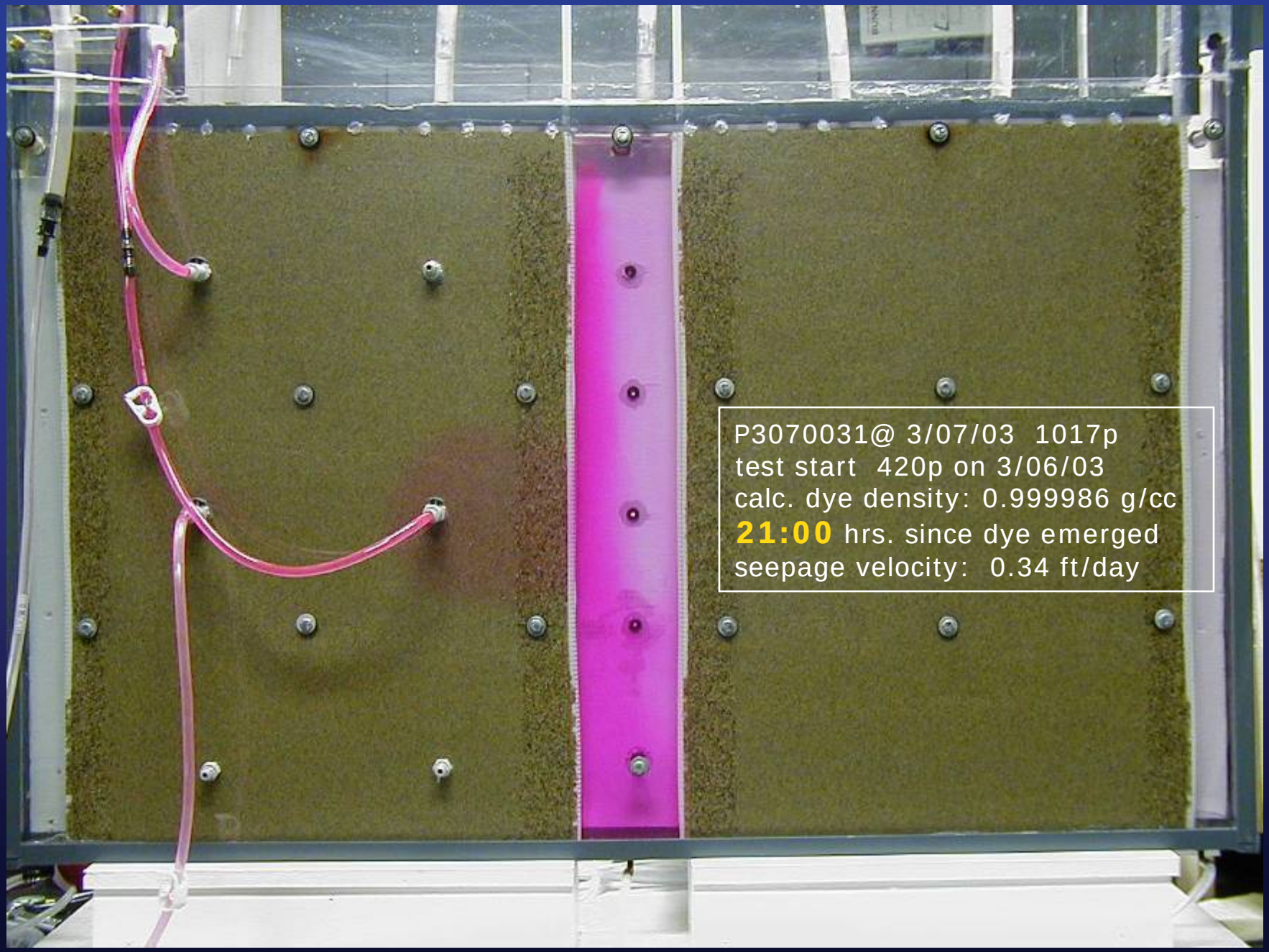
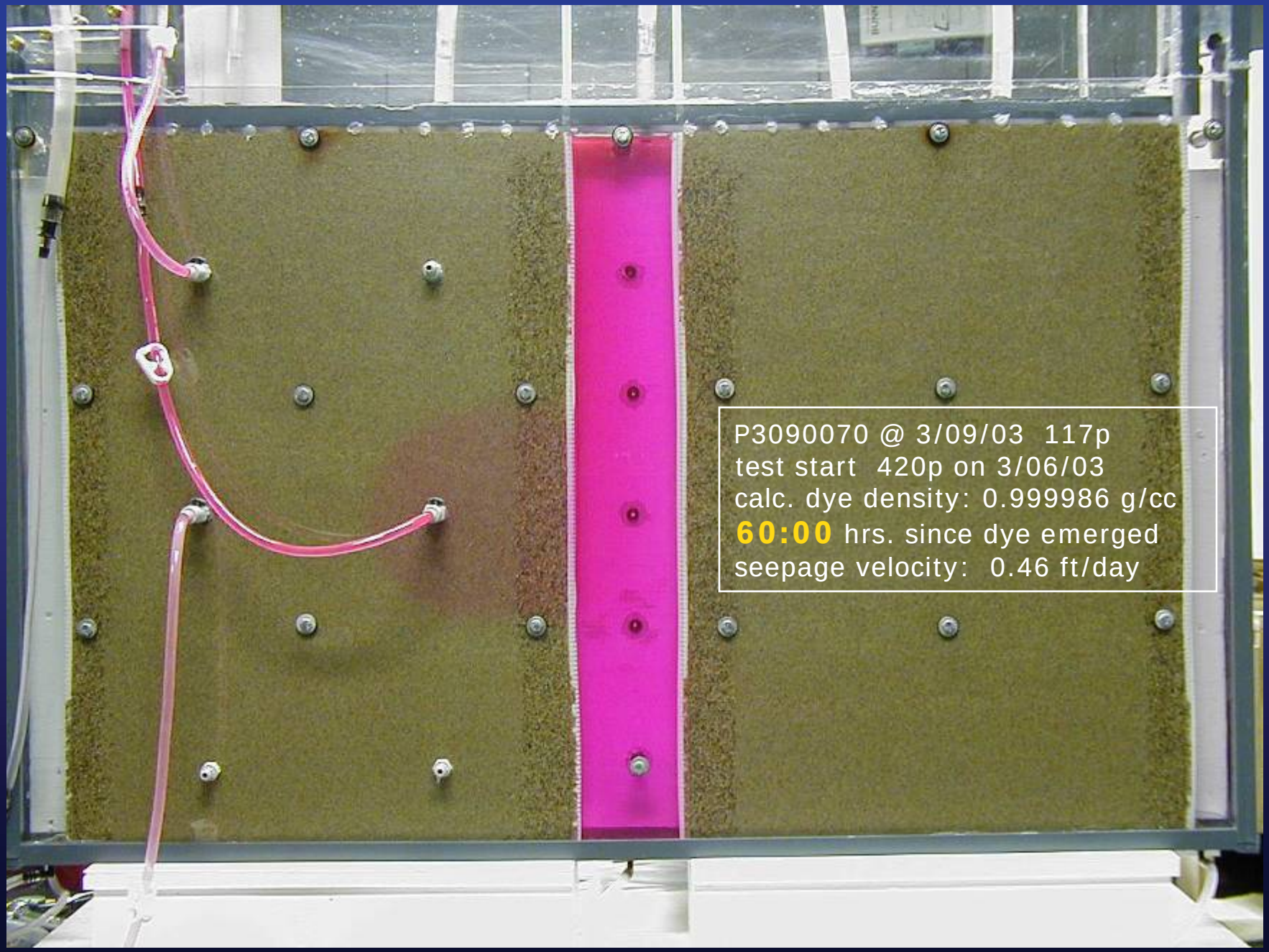
7:00 hrs. since dye emerged
seepage velocity: 0.47 ft/day


P3070031@ 3/07/03 1017p
test start 420p on 3/06/03
calc. dye density: 0.999986 g/cc
21:00 hrs. since dye emerged
seepage velocity: 0.34 ft/day

P3080046 @ 3/08/03 117p
test start 420p on 3/06/03
calc. dye density: 0.999986 g/cc
36:00 hrs. since dye emerged
seepage velocity: 0.55 ft/day


P3090070 @ 3/09/03 117p
test start 420p on 3/06/03
calc. dye density: 0.999986 g/cc
60:00 hrs. since dye emerged
seepage velocity: 0.46 ft/day

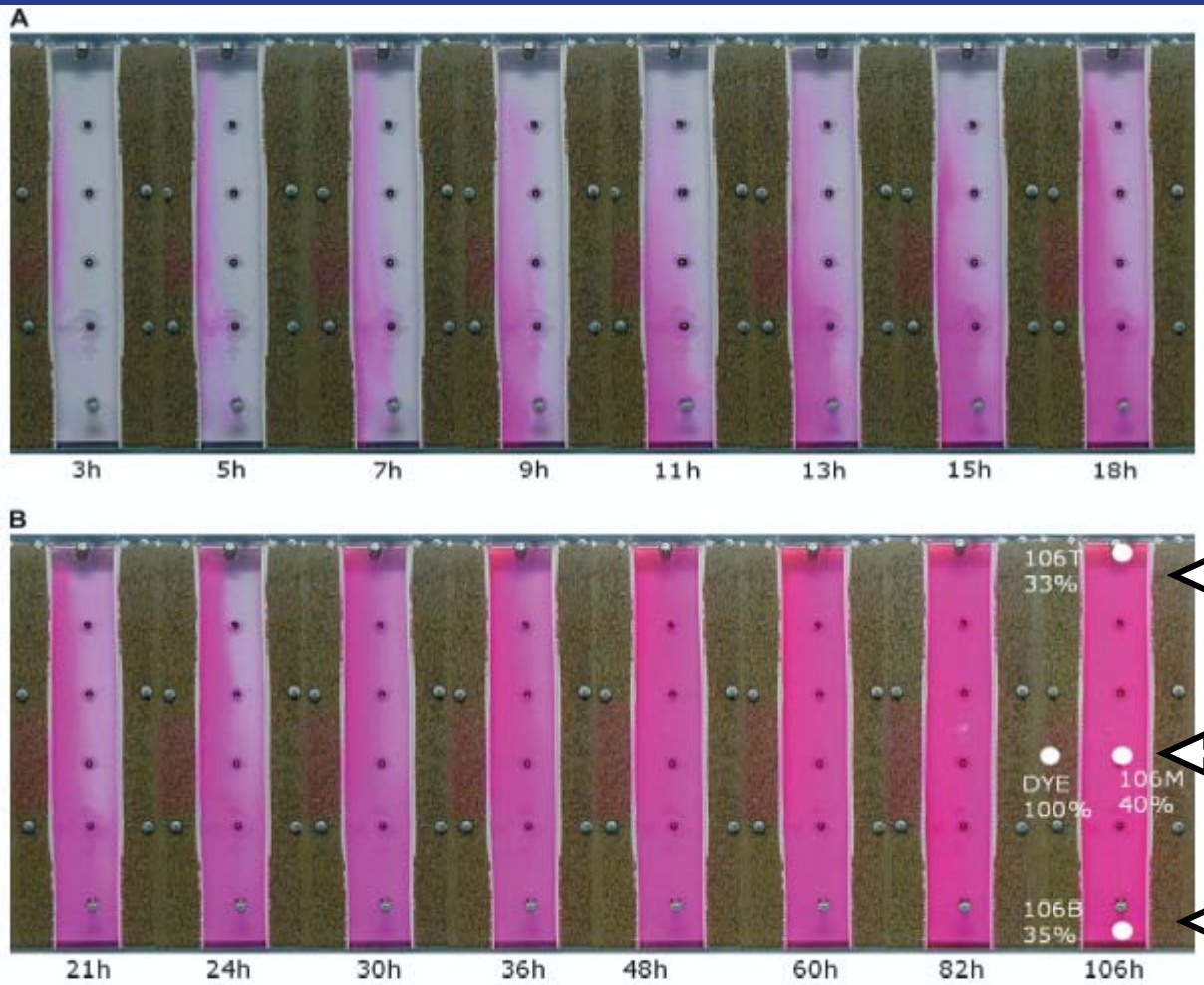


Figure 2. (A) Neutral buoyancy test run, first 18 hours. (B) Neutral buoyancy test run, continued (21 to 106 hours). Photograph captions indicate the number of hours since dye emerged in the model well. The data points identified as DYE, 106T, 106M, and 106B are locations where fluorescence samples were collected at the end of this test run. Percentages indicate dye saturation relative to the injected dye concentration.

percent of initial dye concentration

33 %

40 %

35 %

Flow weighted averaging

Britt, SL, 2005, Testing the In-Well Horizontal Laminar Flow Assumption with a Sand Tank Well Model. *Ground Water Monitoring and Remediation 25,* no. 3 p.73-81

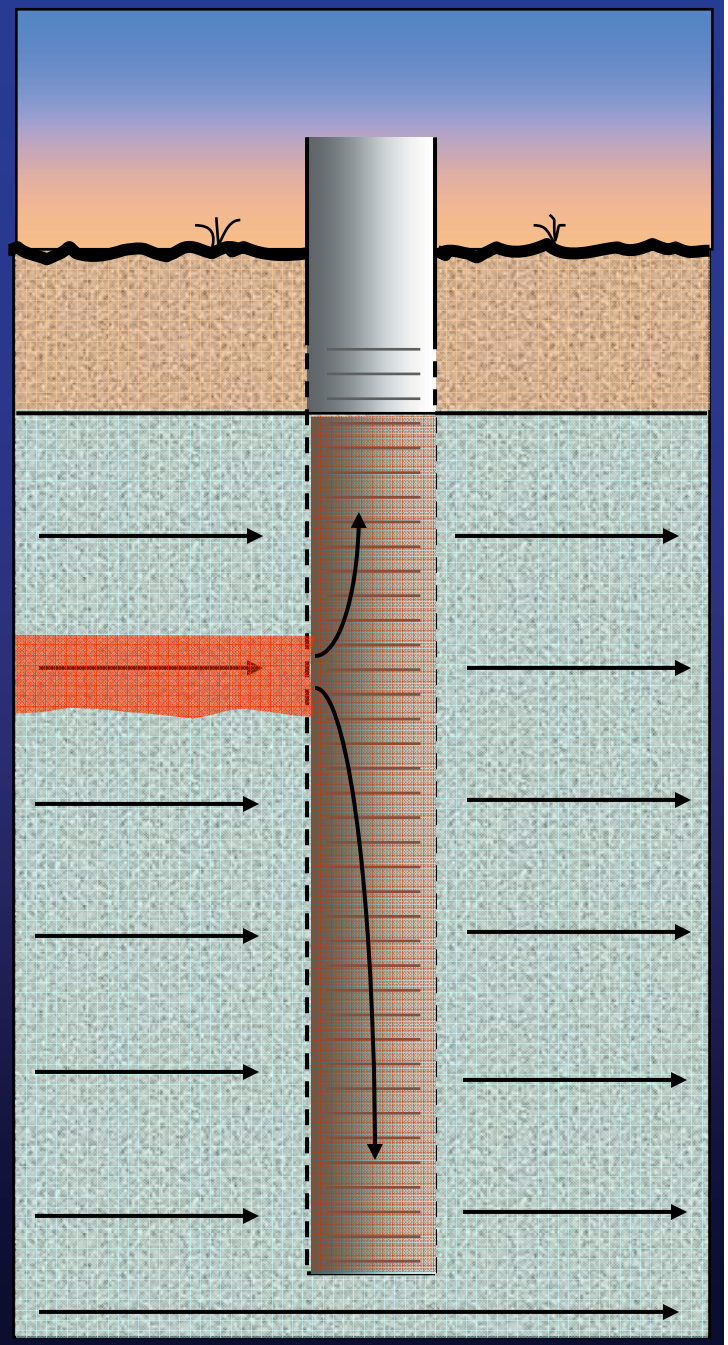
Flow-Weighting

Studies with the Polyethylene Diffusion Bag (PDB) Sampler:

~80% of wells show little or no stratification

Causes:

1. **Contaminants not stratified in the aquifer**
2. **Flow Weighted Averaging in the well**
3. **Vertical Flow**



Stratification

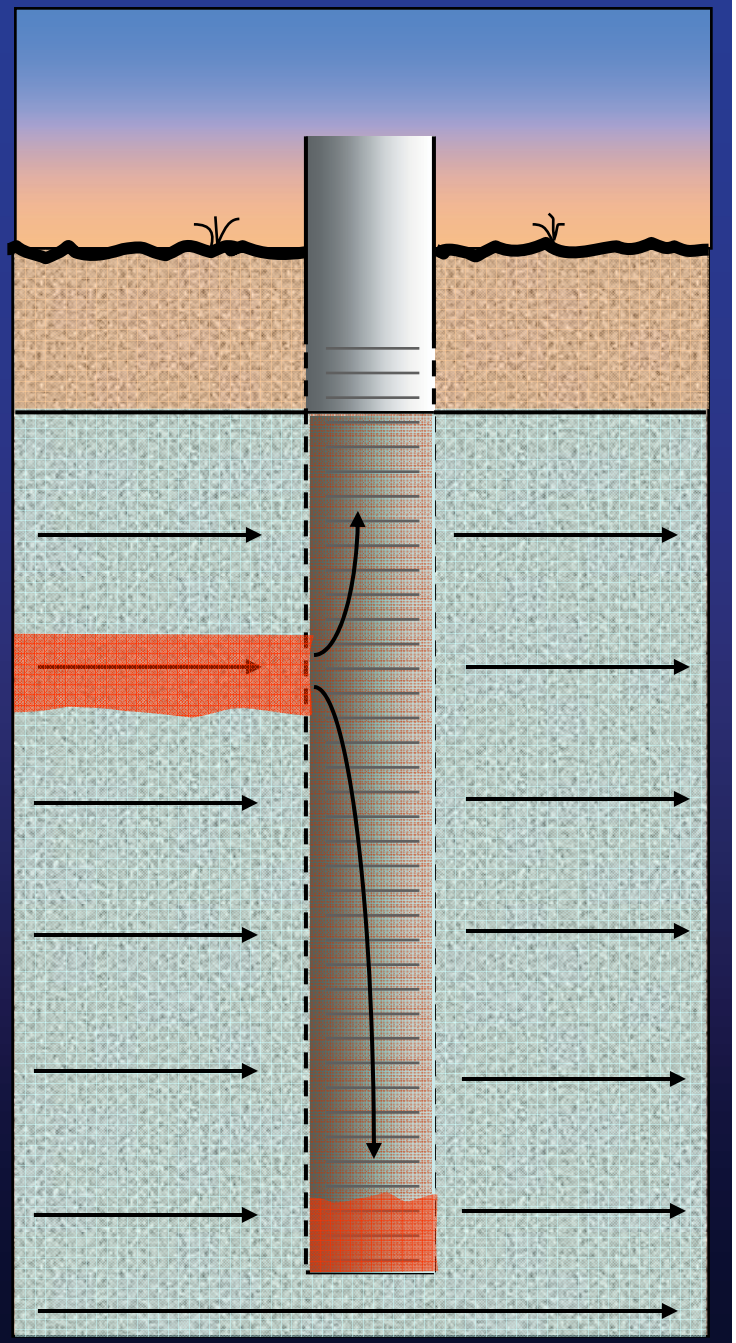
For those wells that *do* show ambient stratification:

Aquifer must be stratified

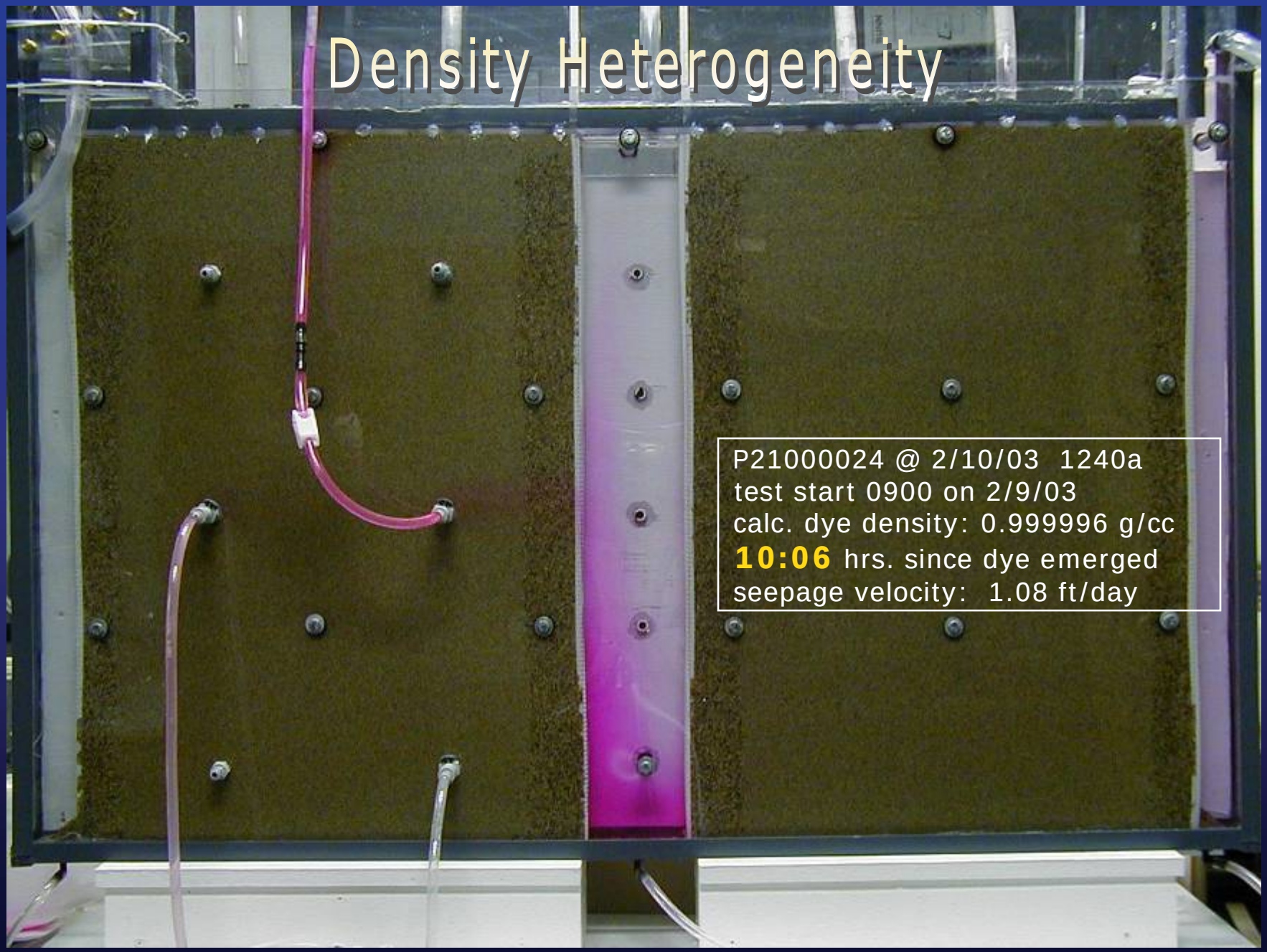
But what causes contaminants to maintain stratification?

- ∇ **Entry point**
- ∇ **Density differential**
- ∇ **Pressure gradient**

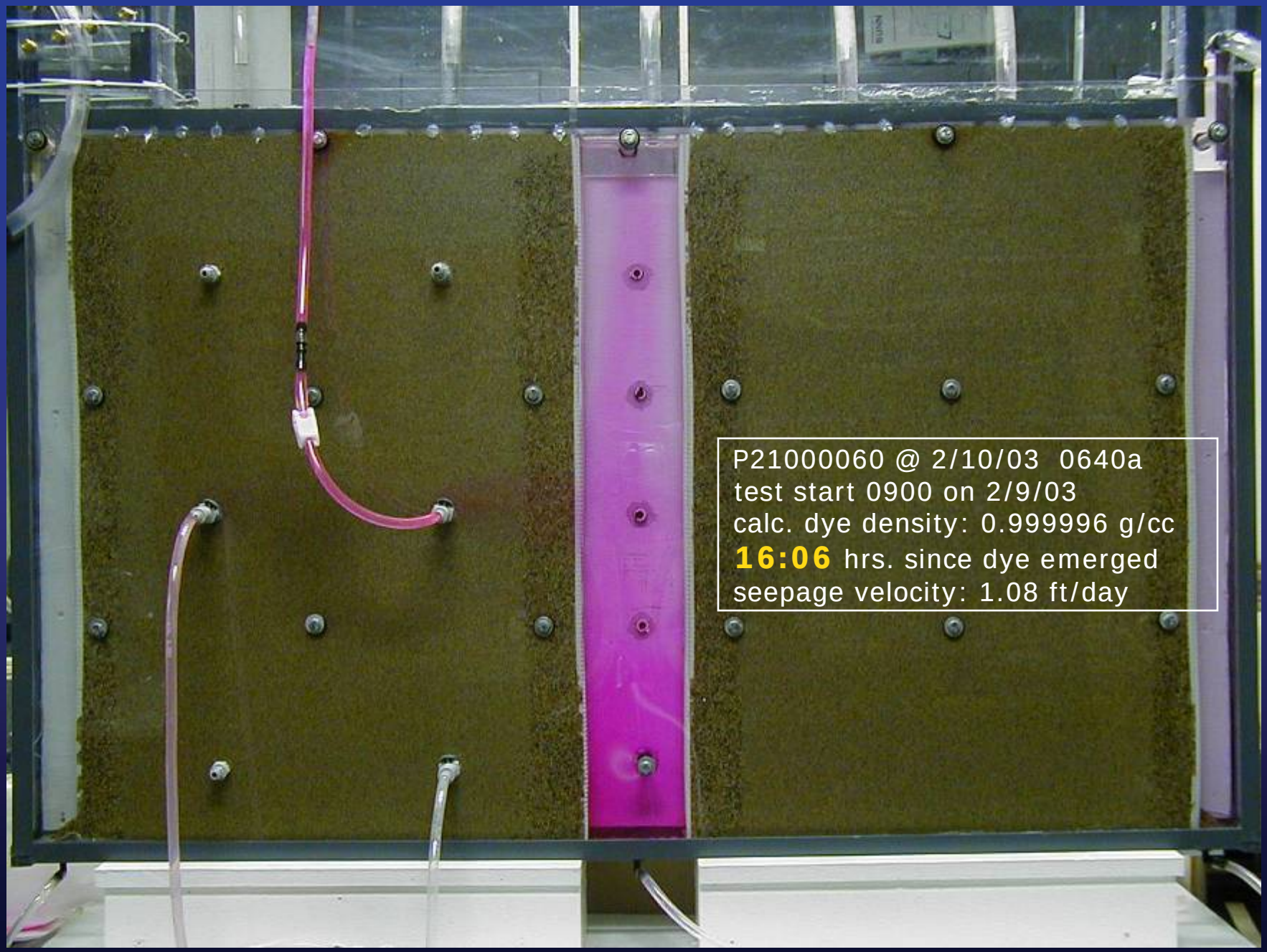
!! Contaminants may stratify at different intervals than they enter !!



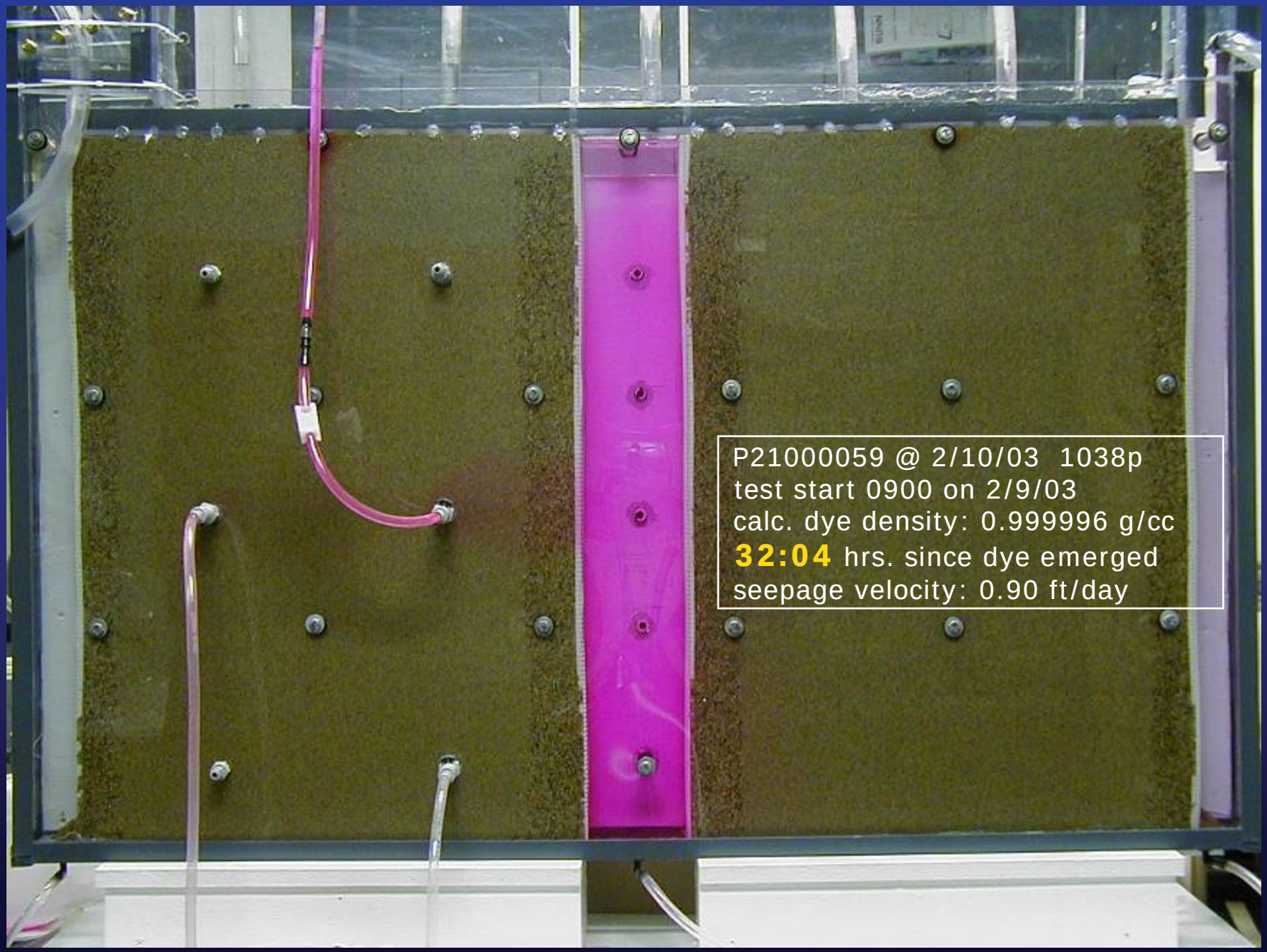
Density Heterogeneity



~1-4 x 10^{-5} higher density

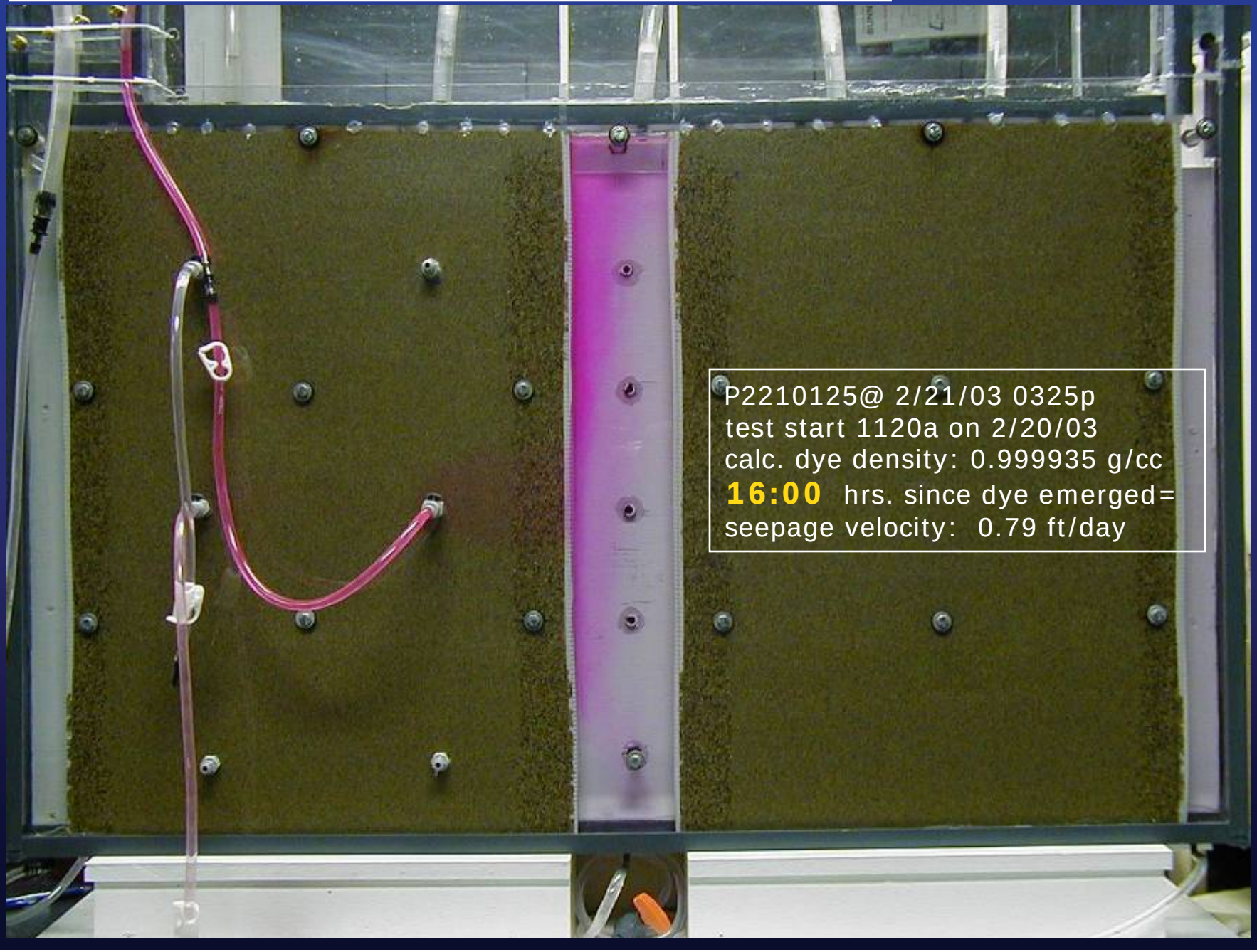


~1-4 x 10^{-5} higher density

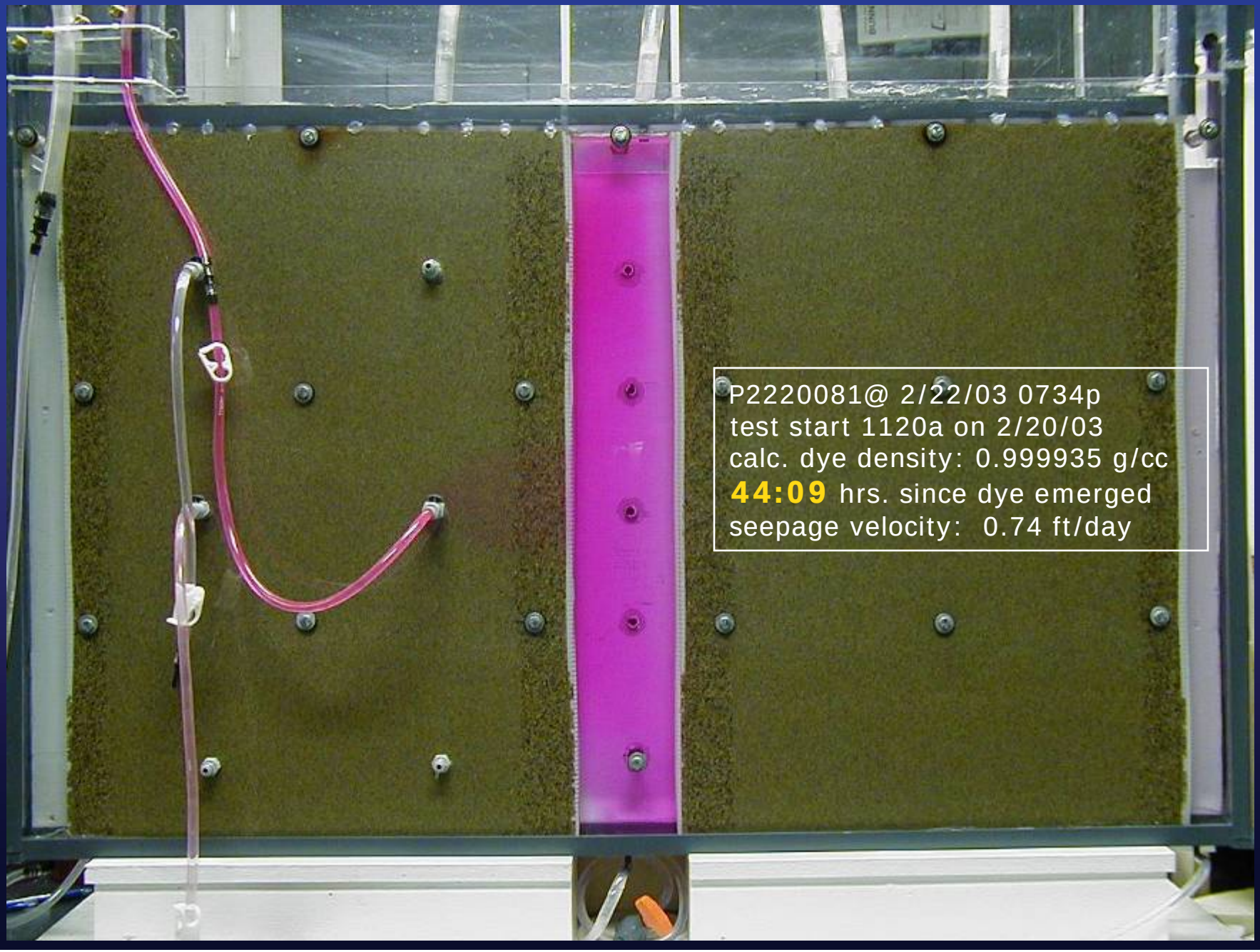


~1-4 x 10^{-5} higher density

~1-4 x 10^{-5} lower density



~1-4 x 10^{-5} lower density



~1-4 x 10^{-5} lower density

Got Heterogeneity?

Heterogeneous Sand Tank Well Model at NFESC

Inflow Heterogeneity

Dye introduced in high K zone

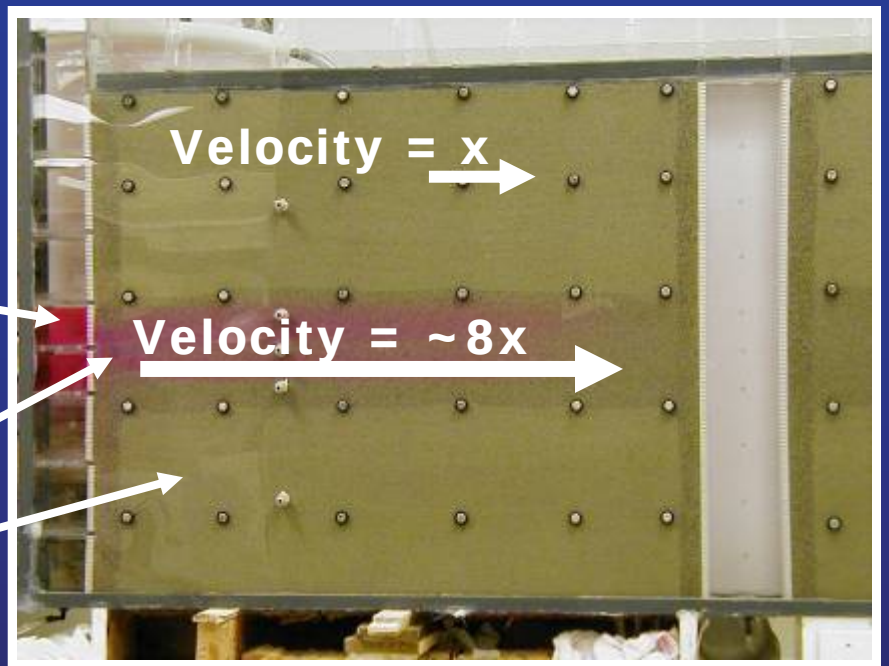
Bulk velocity is 0.5 ft/day

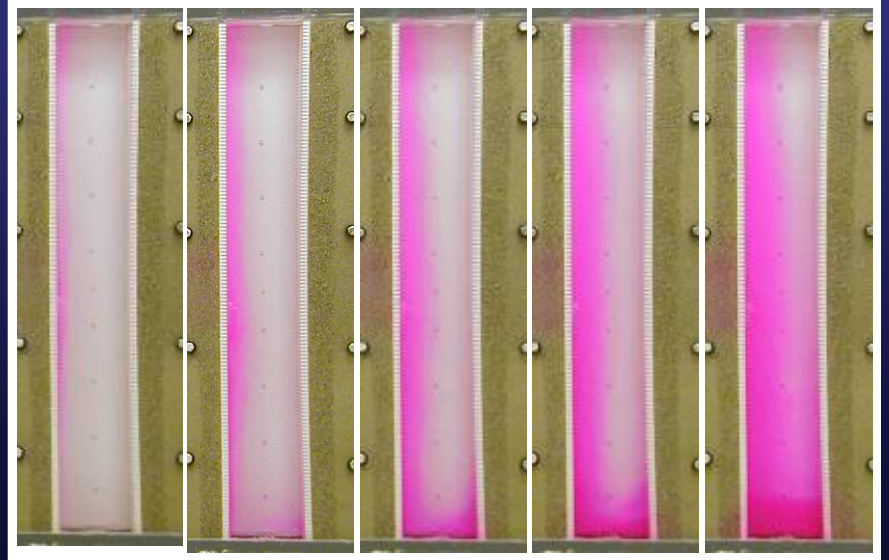
- High K unit ~1.6 ft/day
- Low K unit ~0.2 ft/day

➢ High K unit contributes ~2/3 of the well's inflow volume

Dye enters well only here {

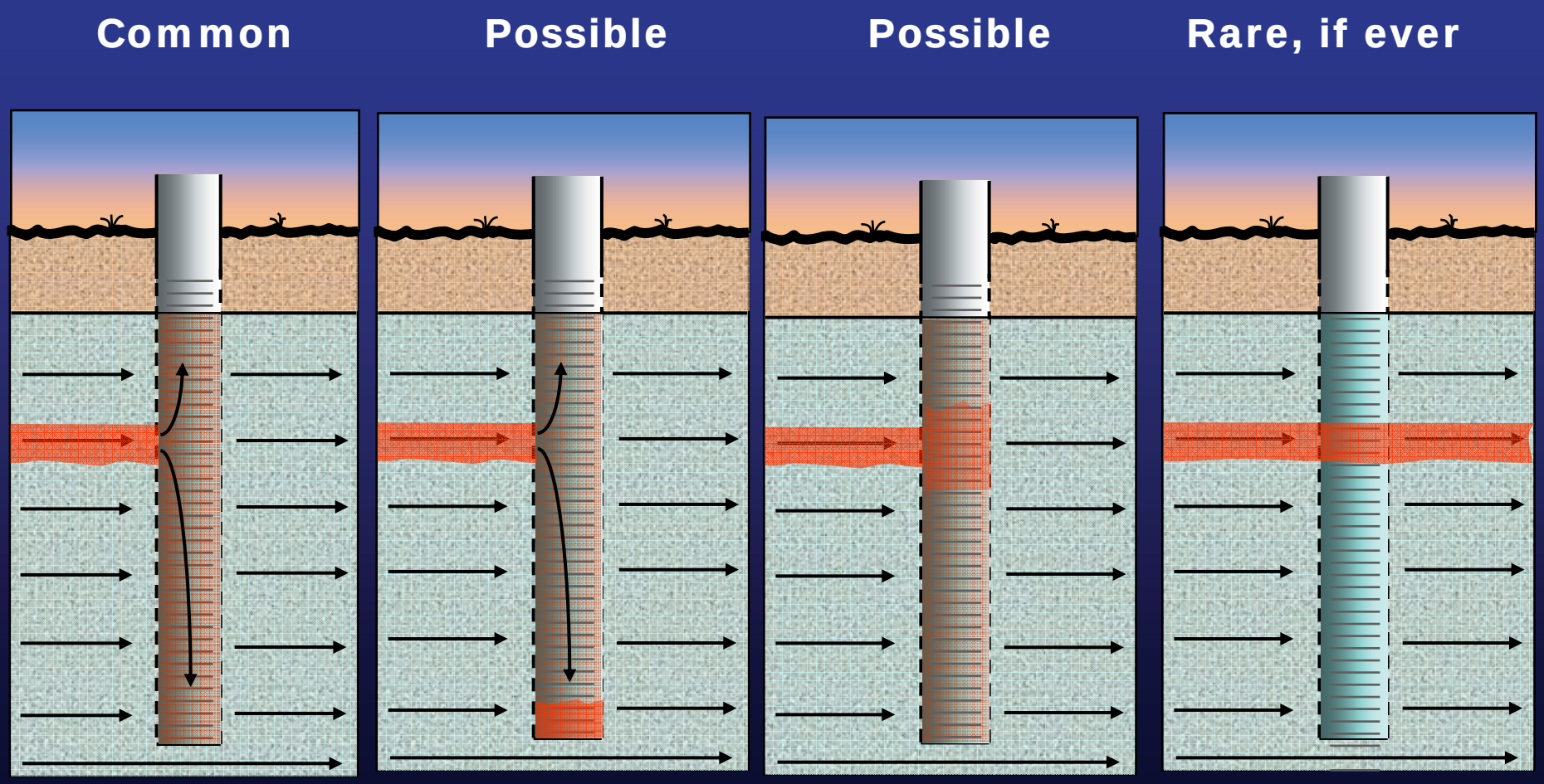
Dye migrates vertically in both directions





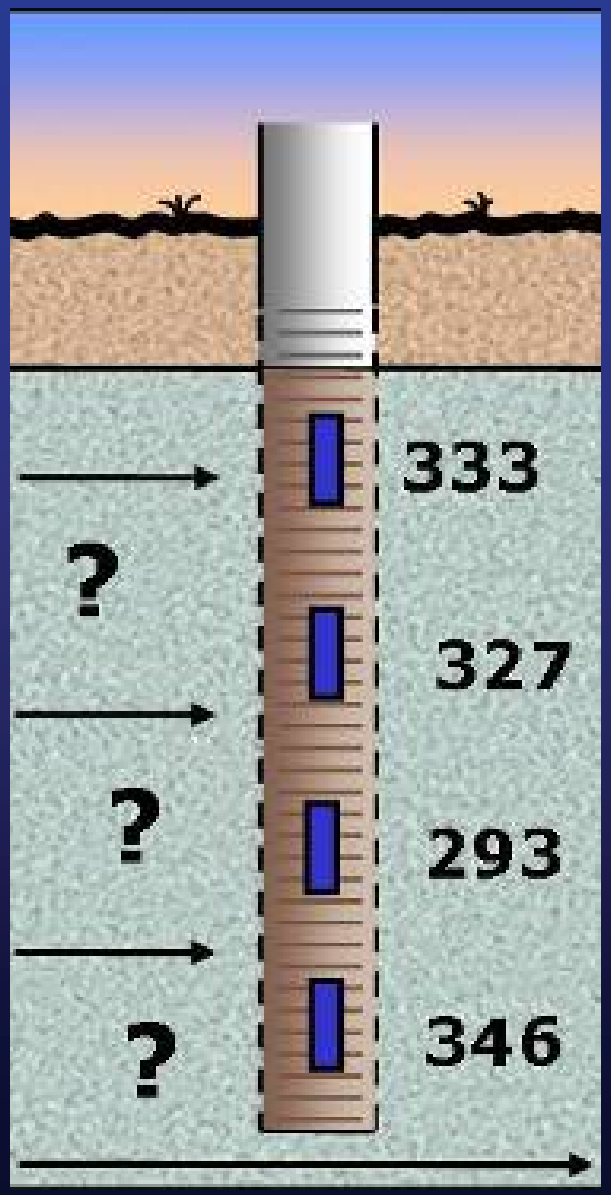
6h 9h 12h 15h 18h

Stratification



What about the real world???

- Stratification testing in an *open well*



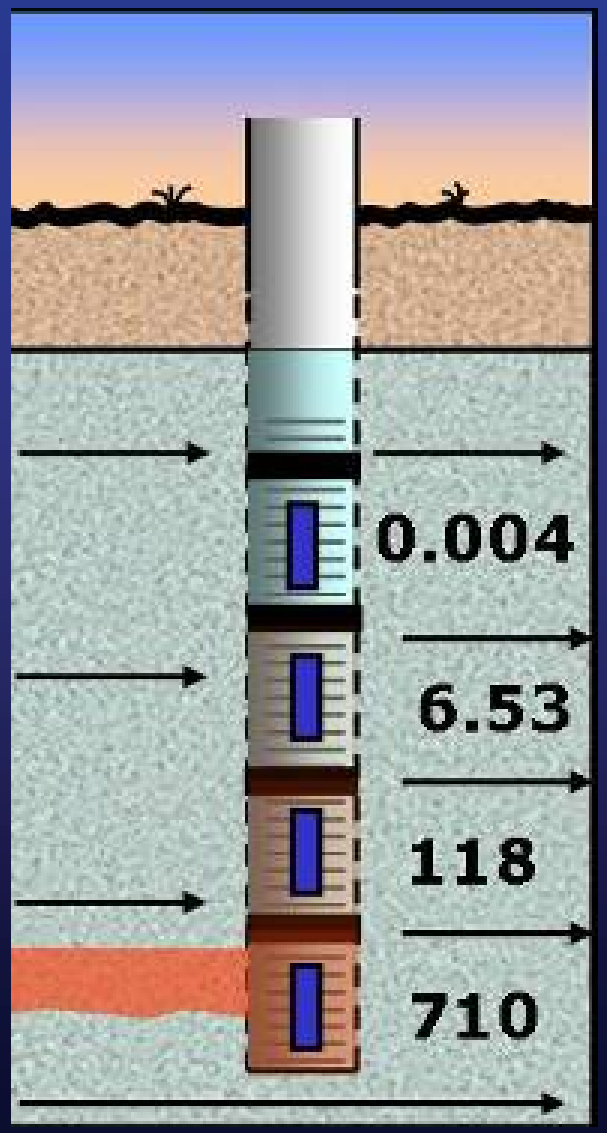
- 4” PVC well
- Overburden silty sand
- Submerged 10 foot screen
- 4 Snap Samplers at 2.5 ft intervals
- Phenol results in ppm

Results relatively close—

not stratified

Site in northern New Jersey
Data Courtesy CH2M Hill

Stratification testing in a *well with baffles*



- 4 Snap Samplers at 2.5 ft intervals
- ***Mixing inhibitor devices***
- Phenol results in ppm

Results range over 5 orders of magnitude

very stratified

Site in northern New Jersey
Data Courtesy CH2M Hill

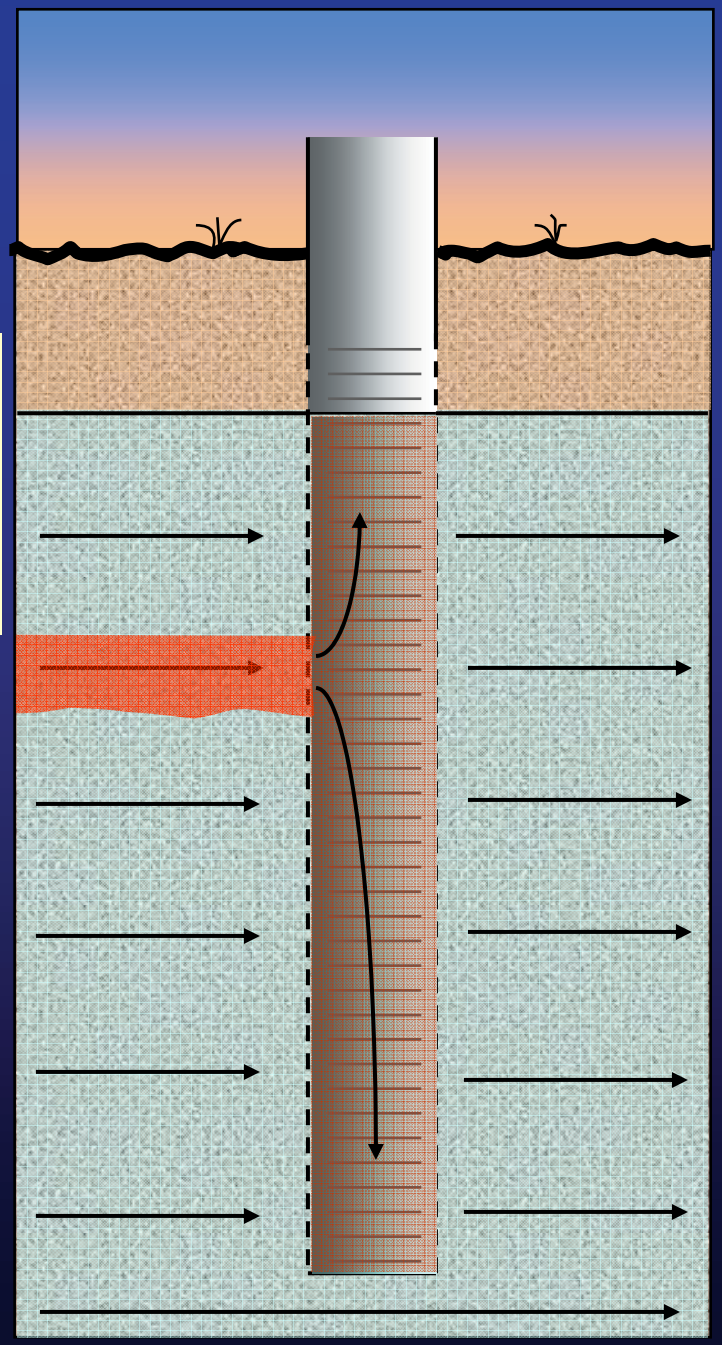
Part 1 Conclusions
Ambient Flow

No "Horizontal Laminar Flow"

Concept not replicated in the physical model study

<u>Flow-weighted averaging</u>

effect may be prevalent under ambient conditions



Part 1 Conclusions
Ambient Flow

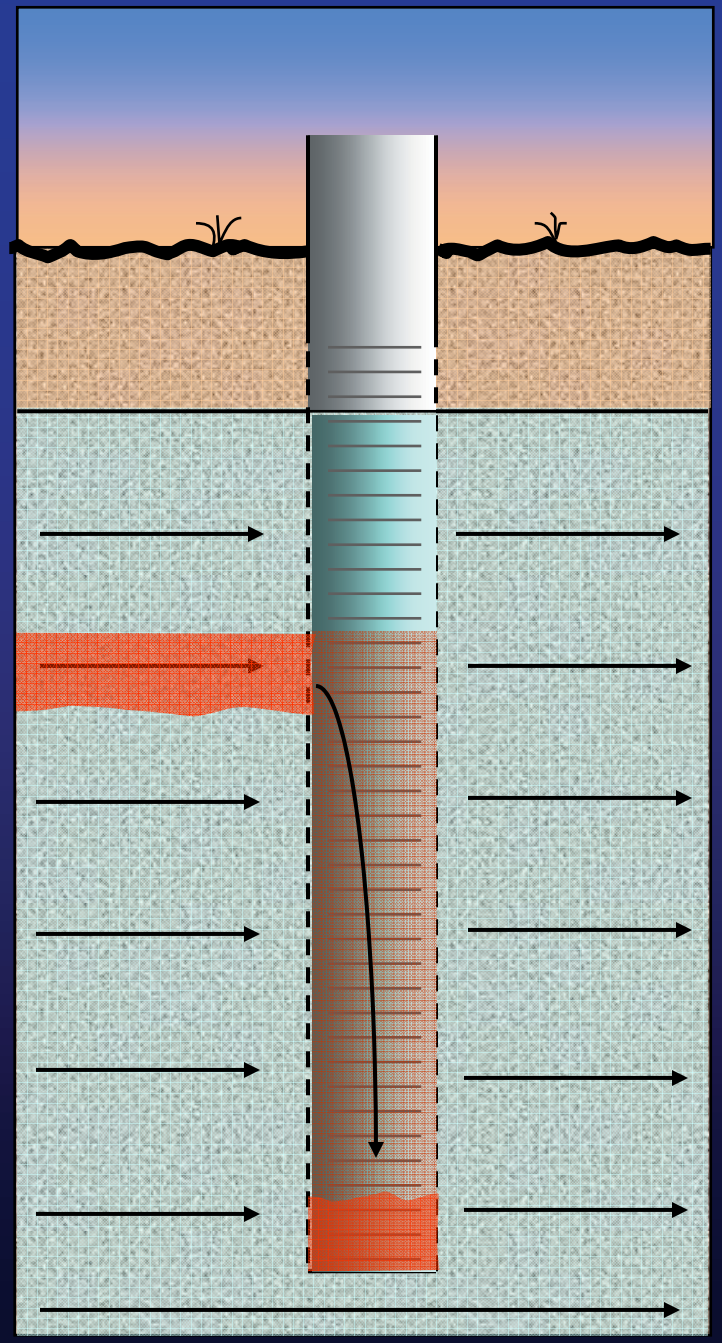
Contaminant Stratification

Reflects aquifer stratification

May not show direct 1:1 correspondence

Multilevel data useful for interpretation

Useful for selection of single sampling interval



Changing Gears....
...Purging

Part 2

Active Sampling Methods

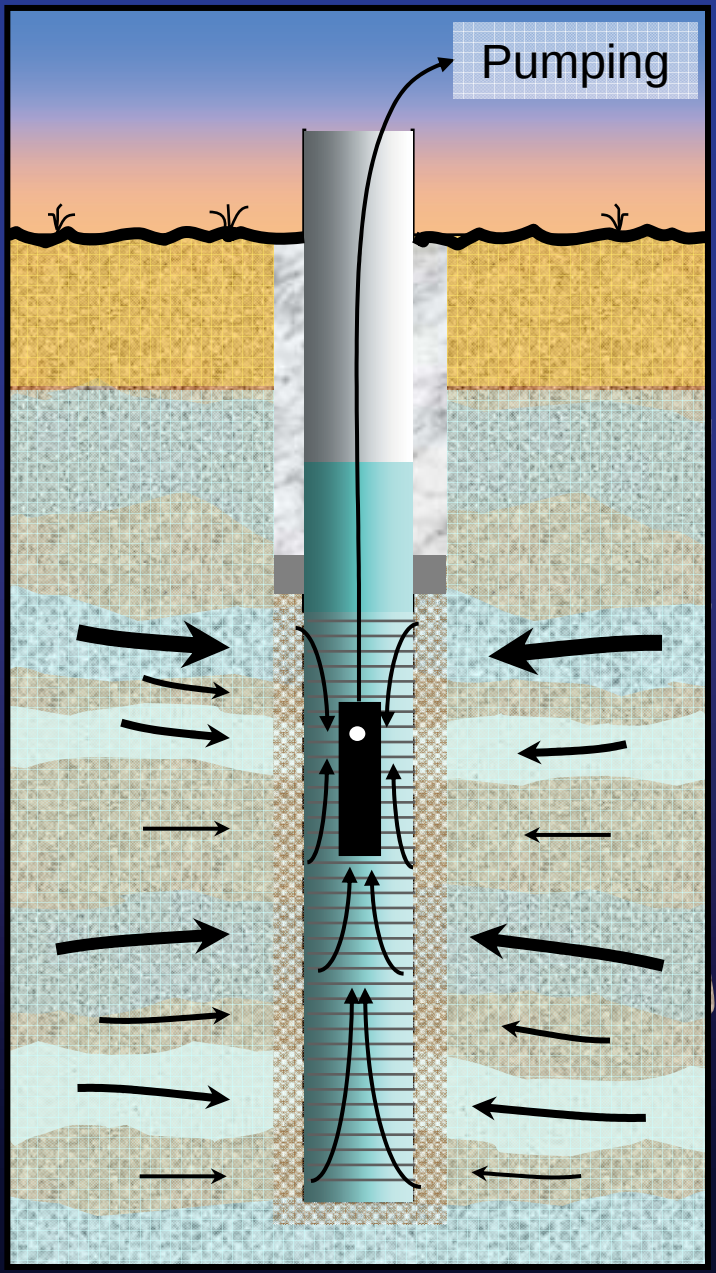
Water chemistry changes as a well is pumped

Why does chemistry change?

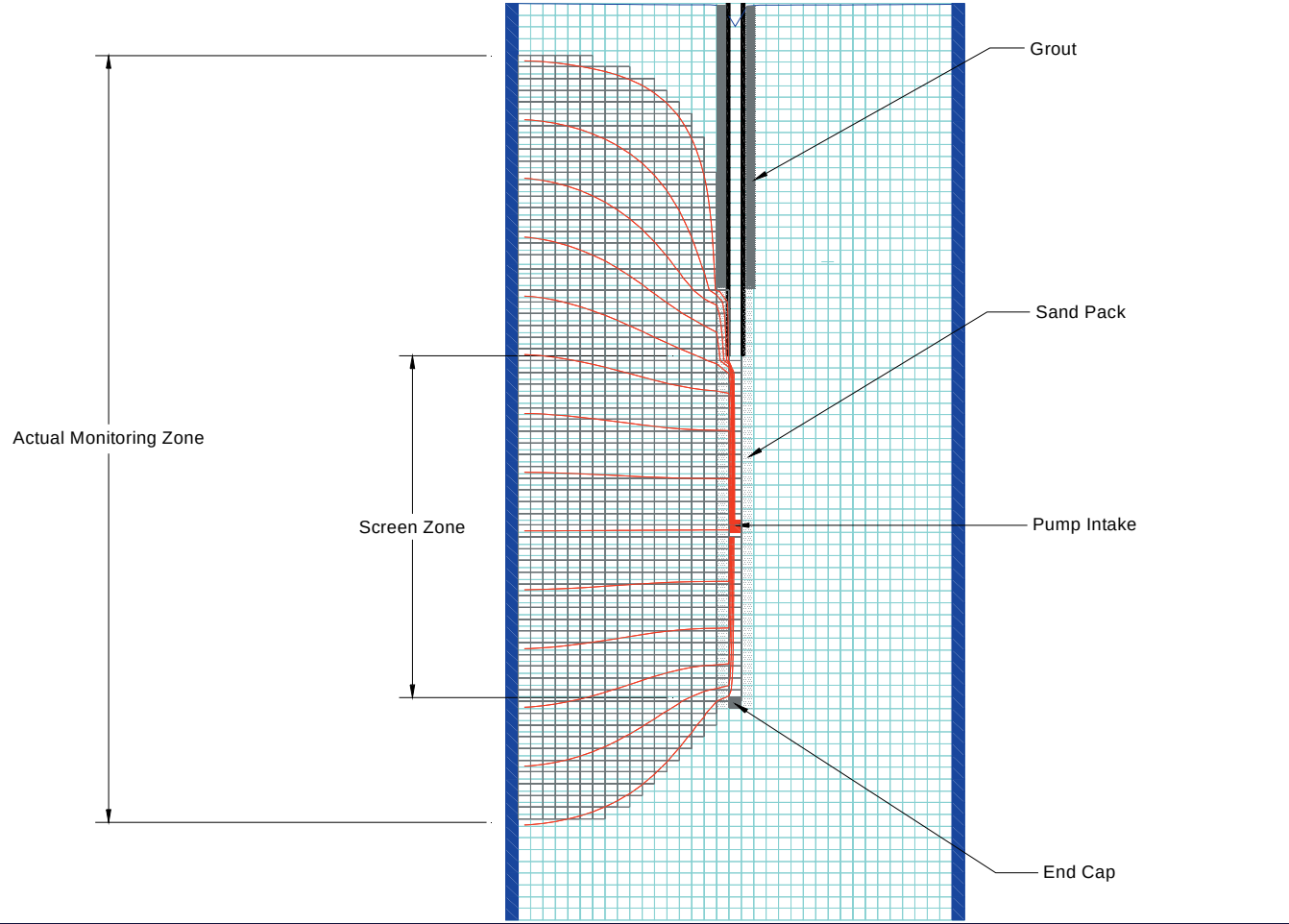
- **"Stagnant" water?**

  Or

- **A varying mix of water entering the pump?**



Traditional or Low Flow Well Purging



Varljen, *et al.*, 2006, Numerical Simulations to Assess the Monitoring Zone Achieved during Low-Flow Purging and Sampling, GWMR, 26: p. 44-52

<u>Hydraulics</u> controls flow

But <u>purge time</u> controls what water comes from the pump

Purge Equilibration

Stability parameters monitored

<u>Proxy</u> for contaminant

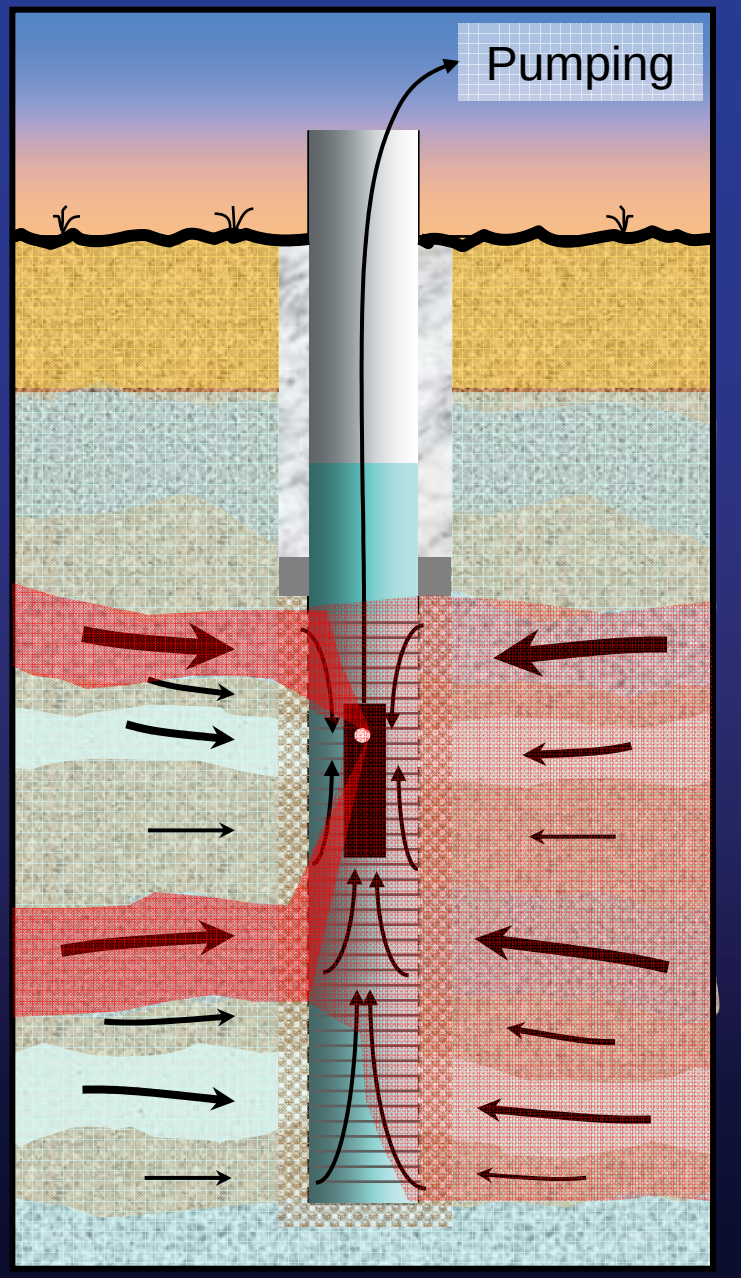
Stability could occur…

- ∇ early in pumping
- ∇ or late

Depends on:

- ∇ Pre-purge well stratification
- ∇ Stratification in the aquifer
- ∇ Inflow characteristics
- ∇ Shadow effects in the aquifer
- ∇ Density effects

- ∇ <u>How you measure</u>



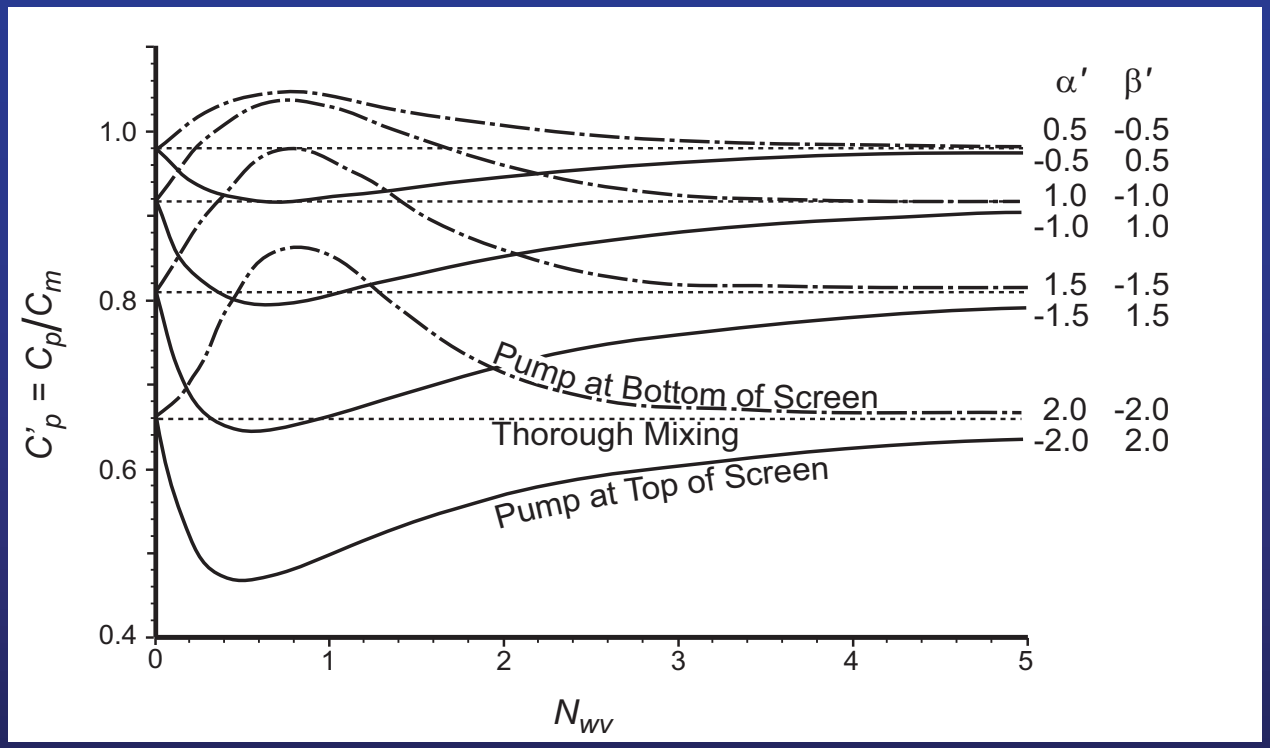
Well Purging is Designed to Collect Representative Samples

But how effective is it?

Gibs and Imbrigiotta (1990) showed **3 well volume purging** resulted in purge stability parameter stabilization 84% of the time, and ***VOC contaminant stabilization only 55% of the time.*** ***Groundwater, v. 28, p. 68-78***

Martin-Hayden (2000) indicated contaminant stratification in the aquifer outside the well may result in relatively large purge volumes to achieve a flow-weighted average—***5 well volumes may be needed to achieve 95% of the flow-weighed average.*** Groundwater, v.38, p. 12-19

Purge Curves



Martin-Hayden, 2000, Sample Concentration Response to Laminar Wellbore Flow: Implications to Ground Water Data Variability, Ground Water 38: p. 12-19.

<u>What controls when a FWA is achieved?</u>

- **Stratified or Unstratified Contaminant**
- **Inflow Location**
- **Pump position relative to stratification**

<u>Zero volume purge and late-time purge often closest to FWA</u>

Questions to Answer

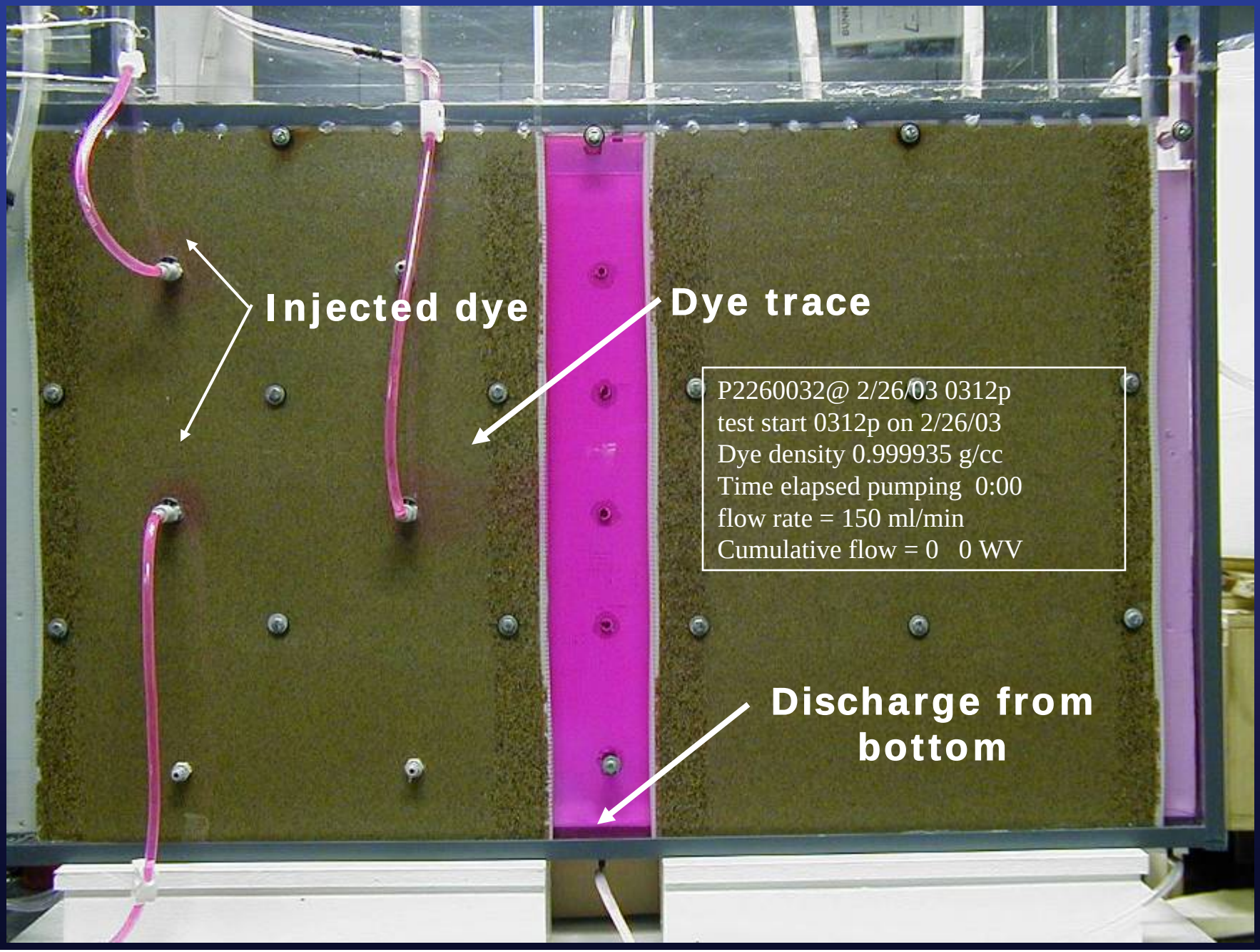
What other factors impact purge stability?

and how do you *KNOW* that reflects a "representative" sample?

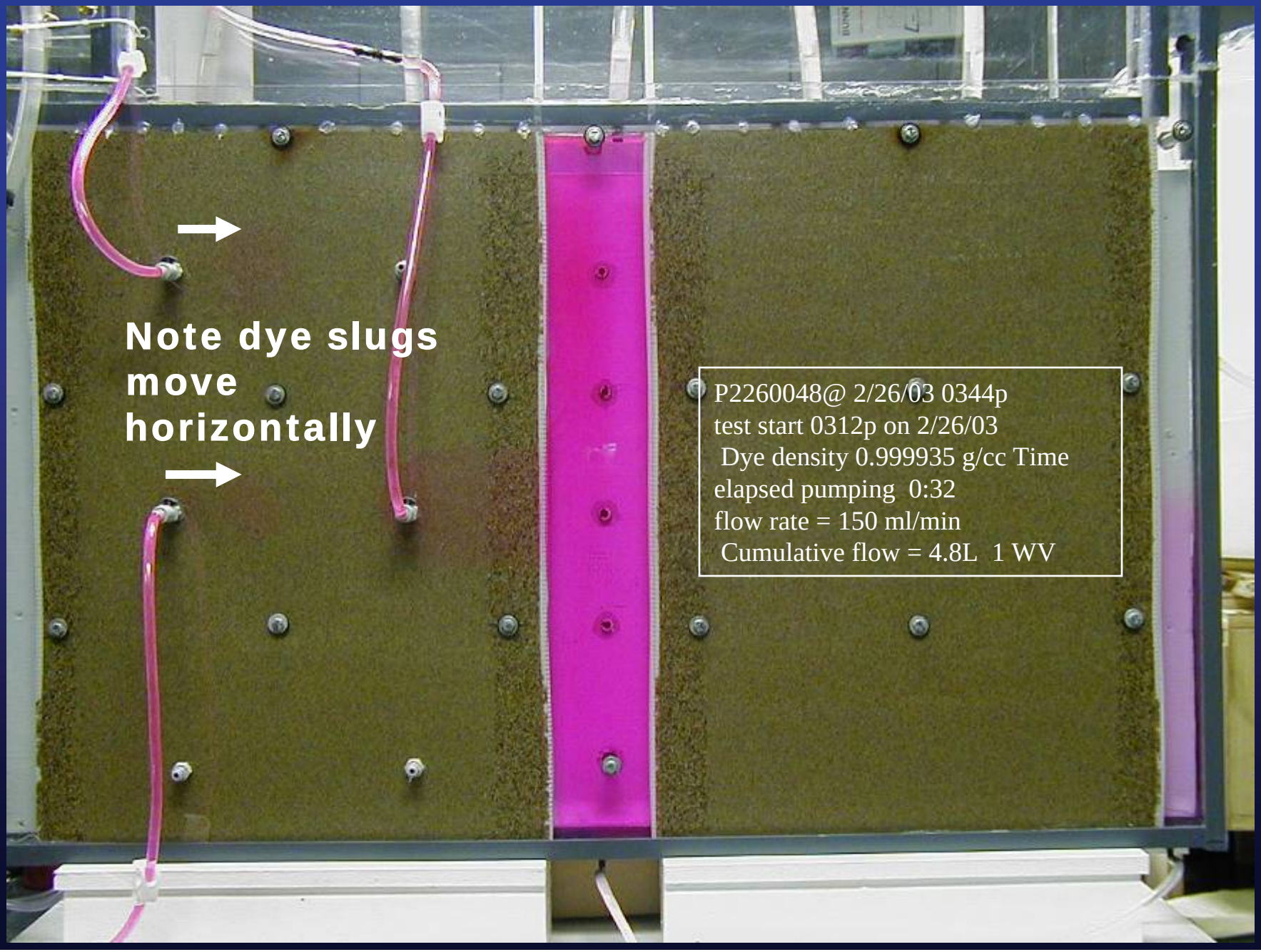
More Experiments…

- ***Density effects on purge capture***
- ***Flow rate changes***

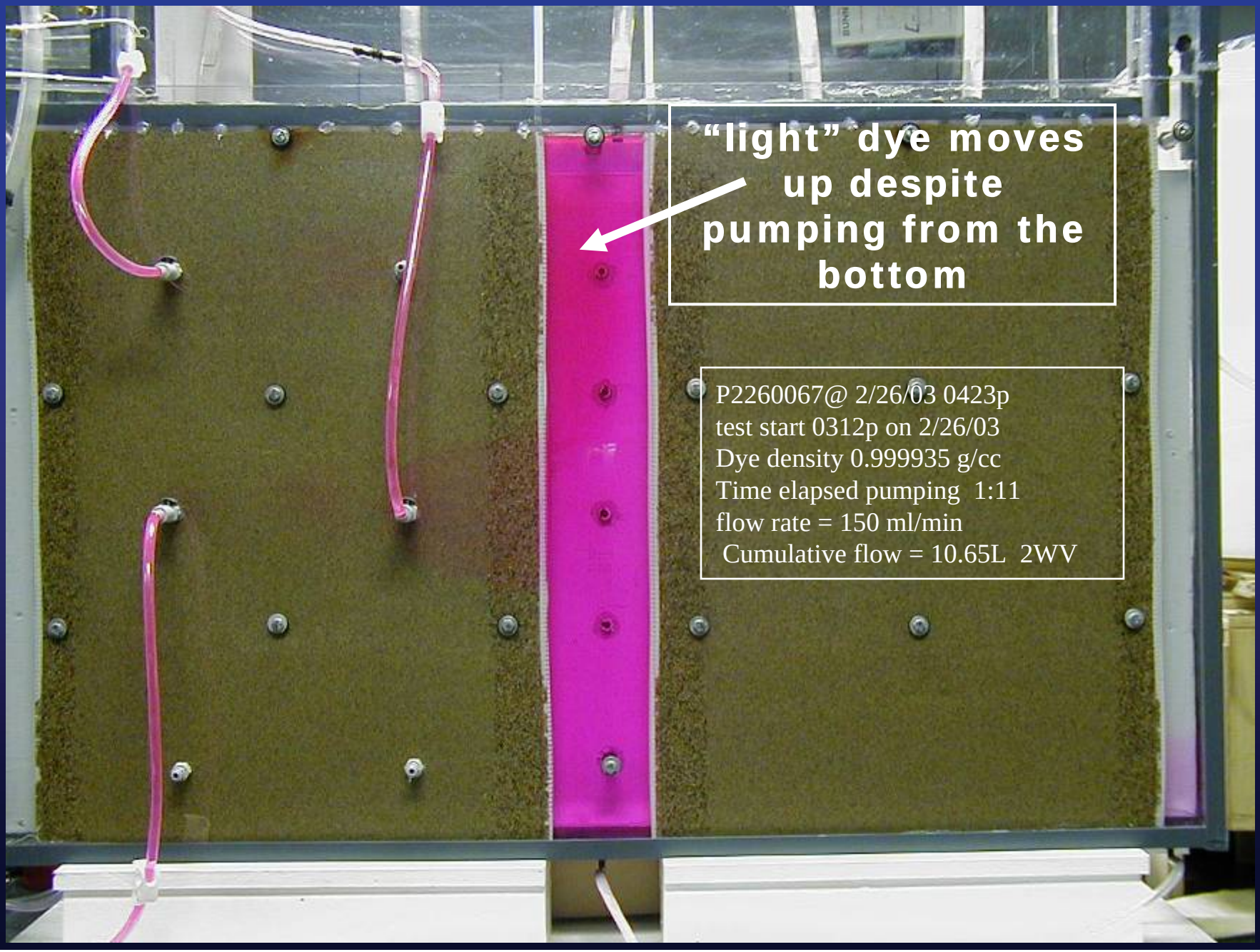
Density Effects During Purging



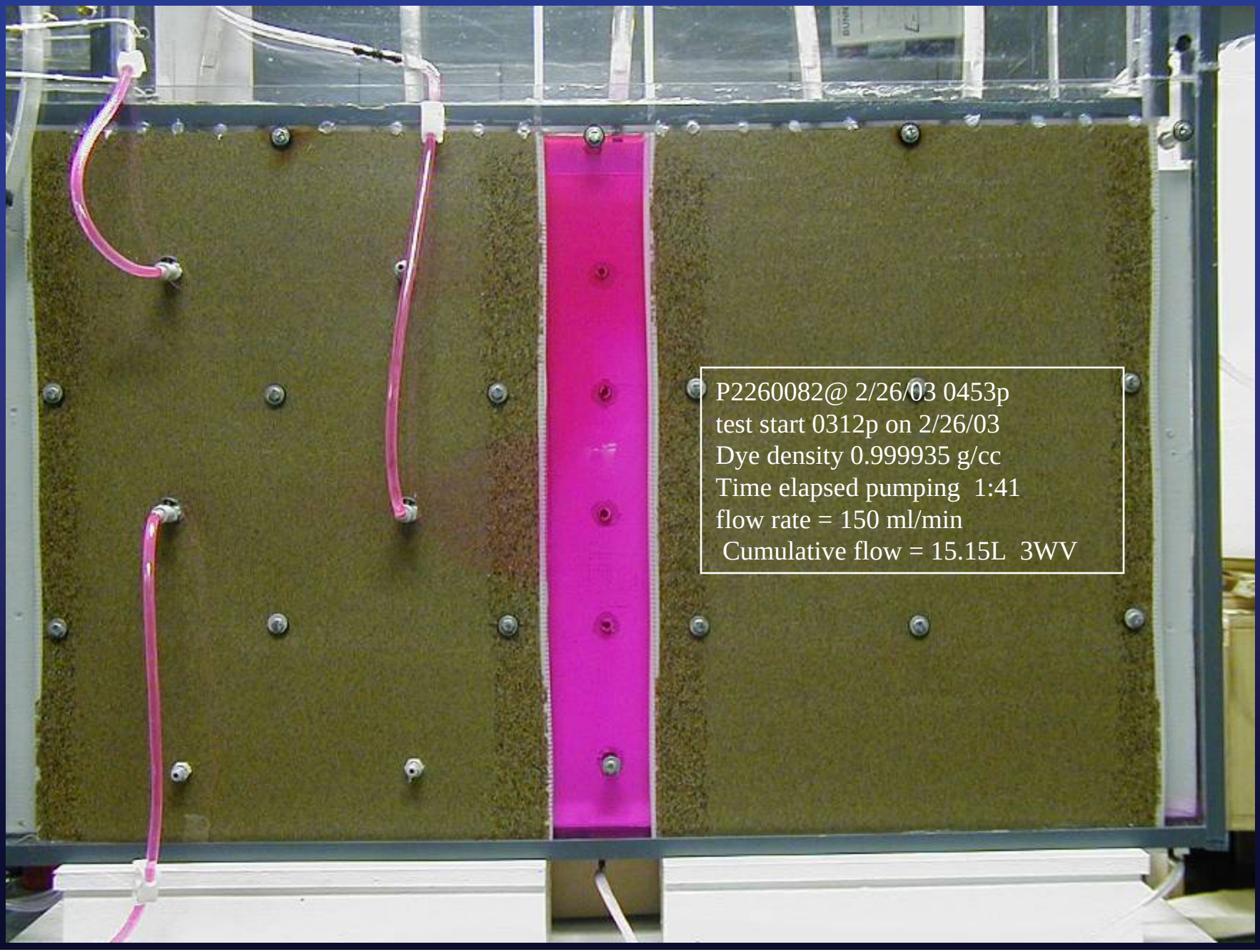
Density Effects During Purging



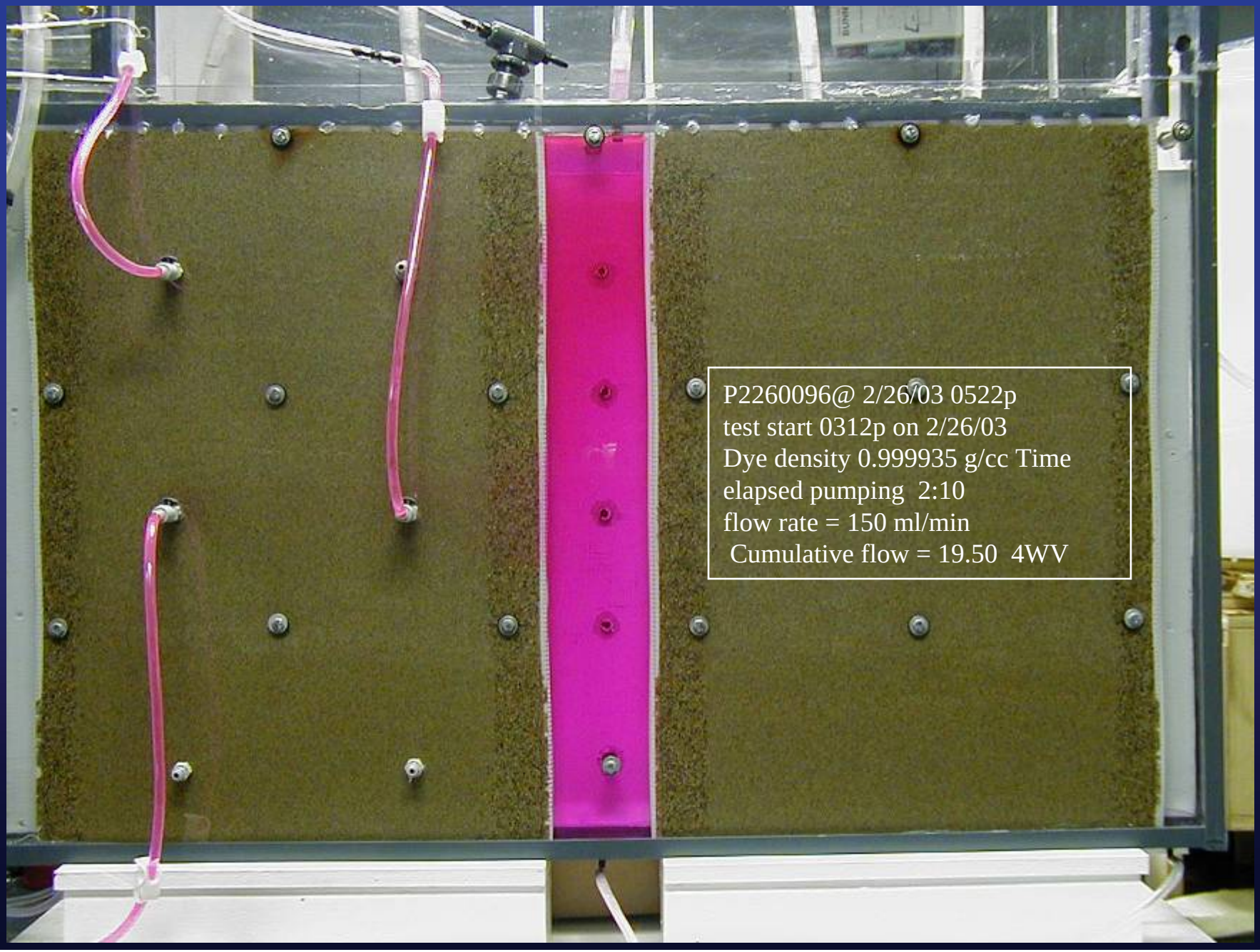
Density Effects During Purging



Density Effects During Purging



Density Effects During Purging



Reducing Purge Rate Prior to Sampling:

Good practice to limit VOC losses?

...or trading one problem for another?

- Historic understanding that filling bottles at a high rate may cause VOC loss during sampling
- Recognition of the advantages of low-flow purging
- In-well flow dynamics during purging and sampling hard to examine

Reducing flow rate as acceptable practice.

Historically….USEPA, September 1985, Practical Guide for Ground-Water Sampling, EPA 600/2-85/104

→Rate should be kept to a minimum. Reduce sampler purge rate to desired 100 ml/minute during sampling

Recently… USEPA, May 2002, Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers, EPA 542-S-02-001

→"…samples will be collected by lowering the flow rate to a rate that minimizes aeration of the sample while filling the bottles (approximately 300 ml/min)."

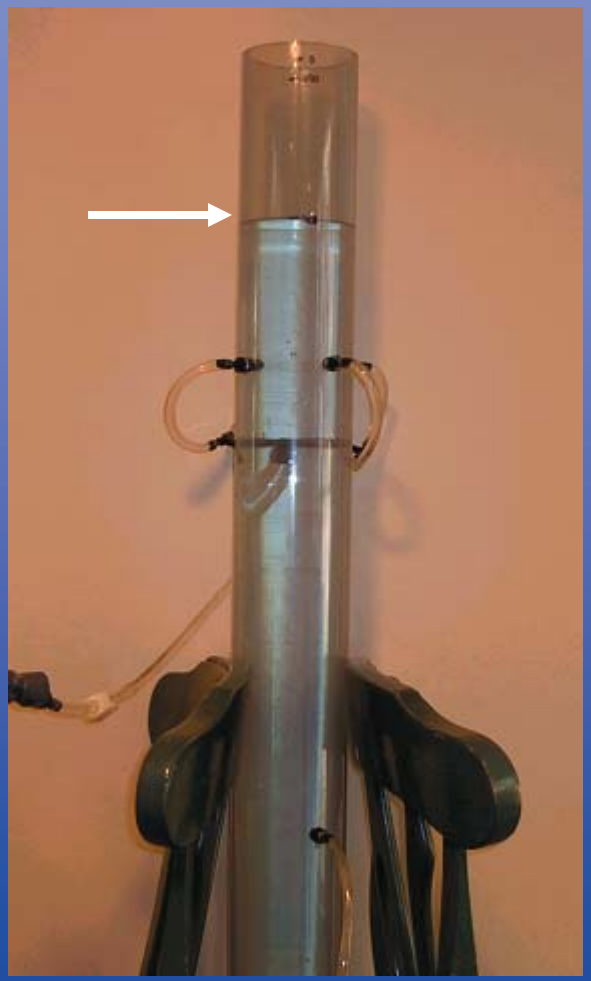
ASTM, March 2002, Standard Practice for Low Flow Purging and Sampling For wells and devices used for ground-water quality investigations, D 6771-02

→ "…pumping rate may remain at the established purging rate or it may be adjusted downward…"

Changing Flow Rate

No flow
No drawdown

250 ml/min
0.10 ft drawdown

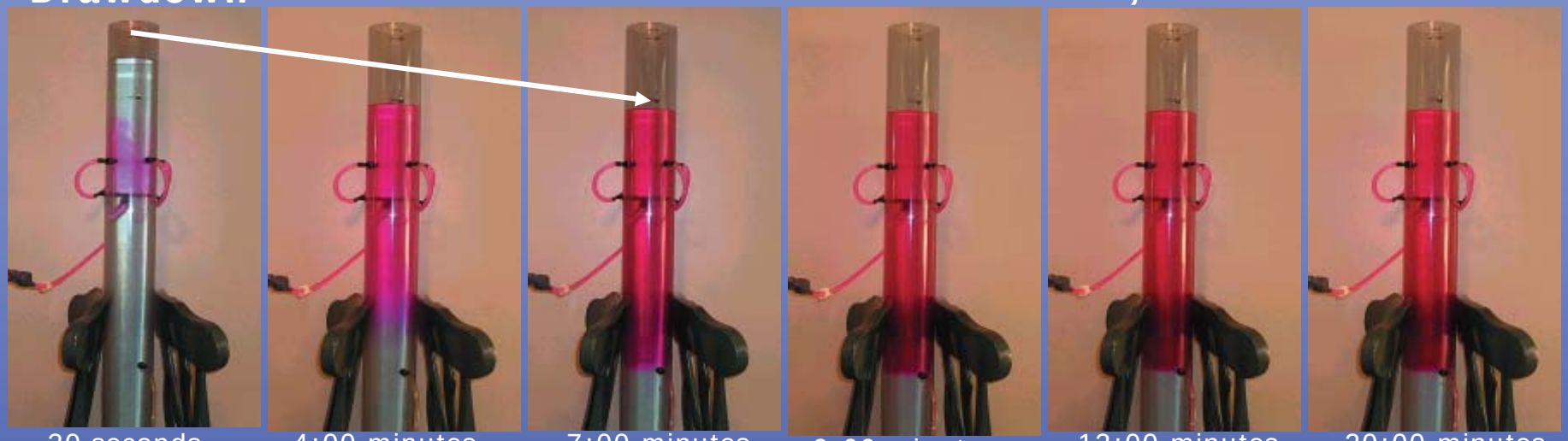


1000 ml/min
0.50 ft drawdown

Changing Flow Rate

Drawdown

Start Pumping with Tracer
Stable water level, stable concentration

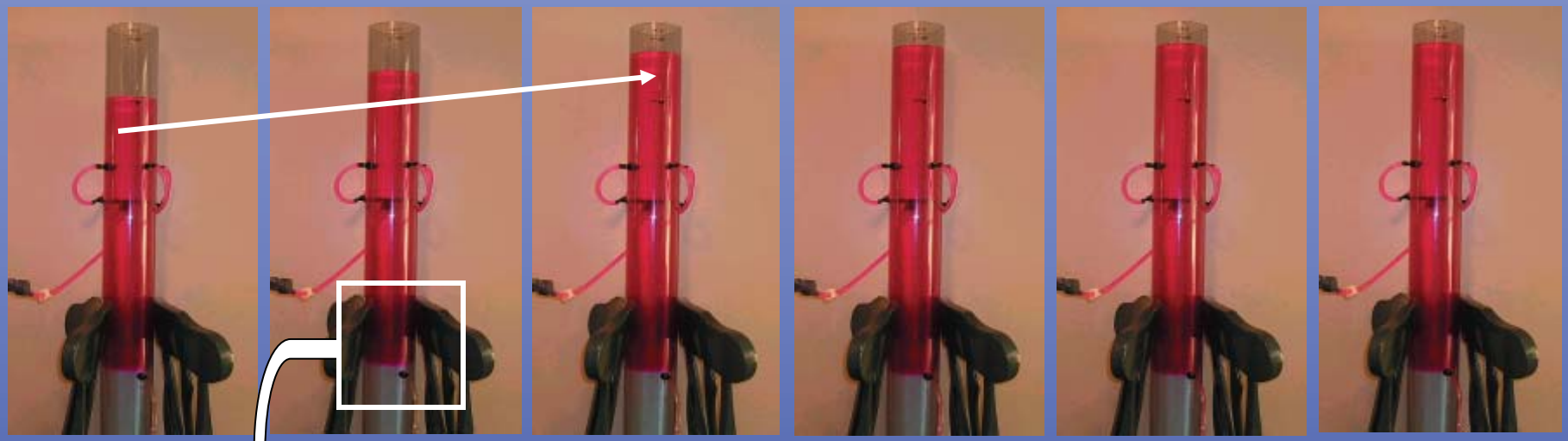


30 seconds | 4:00 minutes | 7:00 minutes | 9:00 minutes | 13:00 minutes stable | 20:00 minutes pump rate down

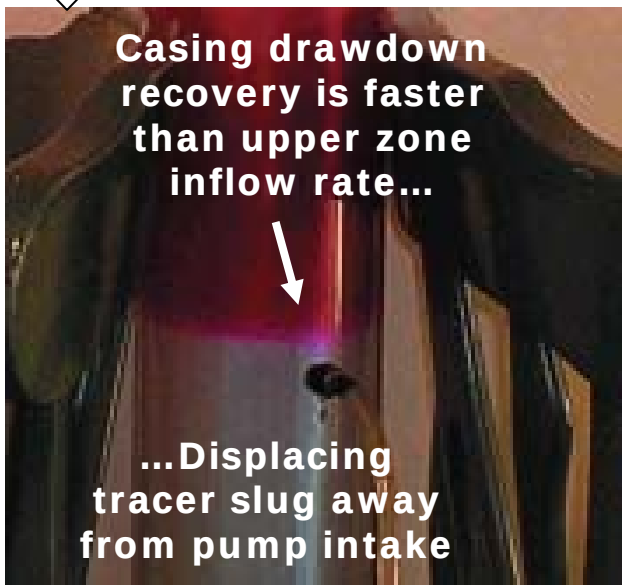
For suspense….

Changing Flow Rate

Reduce flow rate, reduce drawdown



30 seconds pump rate down | 2:00 minutes pump rate down | 3:00 minutes pump rate down | 5:00 minutes pump rate down | 7:00 minutes pump rate down | 9:00 minutes pump rate down



Resulting in….

Changing Flow Rate

Large tracer concentration drop

Reduce pump rate

Concentration stable in 9-13 minutes

concentration re-equilibrates in 5-7 minutes

(after you're done sampling)

Temporarily overweight water entering below the pump intake

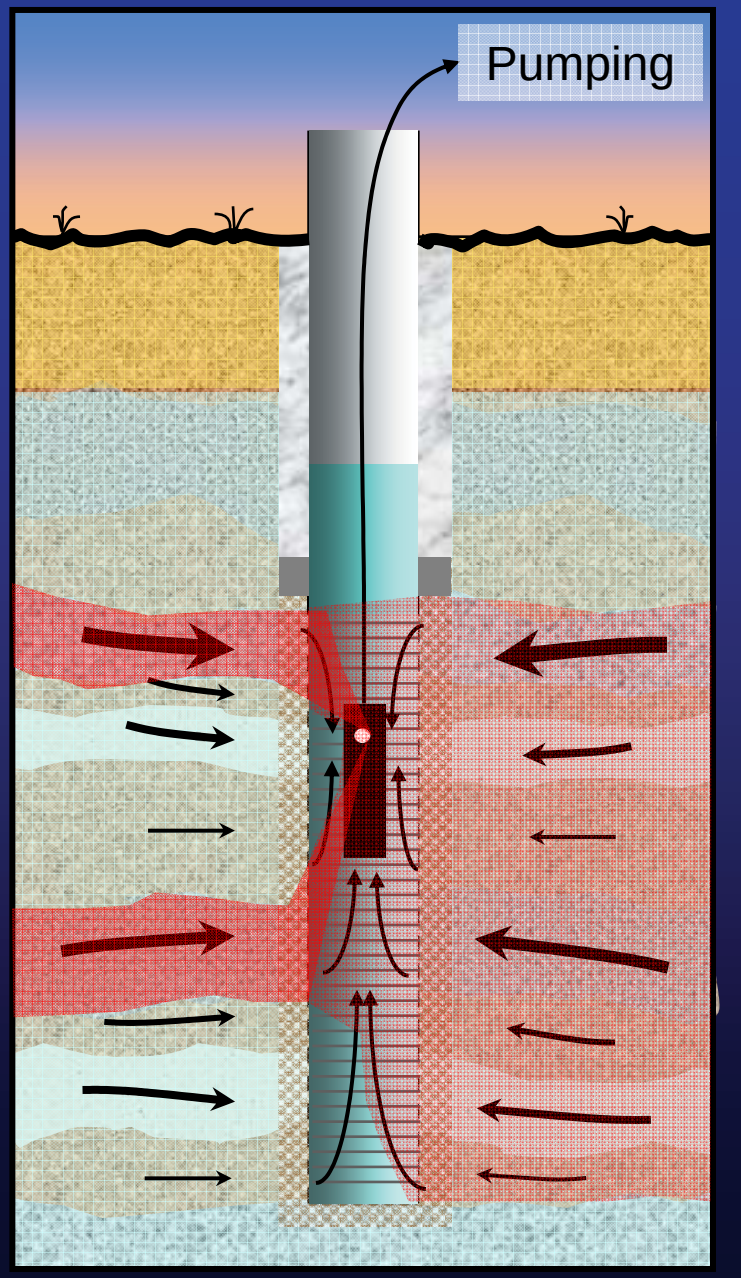
Part 2 Conclusions Purging

Lots of action occurs in the "Black Box"

Averaging of inflow occurs in the pump tubing, not in the well

Purge parameters need close watch

Utmost care is required to maintain consistency- disruption is easy



Acknowlegements

- Cal/EPA Department of Toxic Substances Control
- U.S. Air Force; U.S. Navy
- Dr. James Martin-Hayden, University of Toledo
- Interstate Technology and Regulatory Council (ITRC) Diffusion Sampler Workgroup

CAL/EPA

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