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Low-Flow Ground Water Sampling: An Update on Proper Application and Use

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GW Sampling Program Objectives

- Collect a representative sample of the current ground water conditions in the proximity of the well screen zone.
- Reproduce the “same sample” at each subsequent sampling to identify real trends in data, rather than “noise”.
- Ideally, the sampling equipment, methodology and sample handling procedures should not measurably alter the chemistry of the sample.

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Early research into purging resulted in guidelines to purge wells to remove “stagnant” water

- Where wells would produce sufficient water, the “rule of thumb became 3 to 5 well volumes prior to sampling.
- Where wells would not yield sufficient water, they were evacuated and sampled upon recovery, typically within 24 hours.
- In practice, little concern was given to how purging methods and devices (e.g., bailers) affected the chemistry of subsequent ground water samples.

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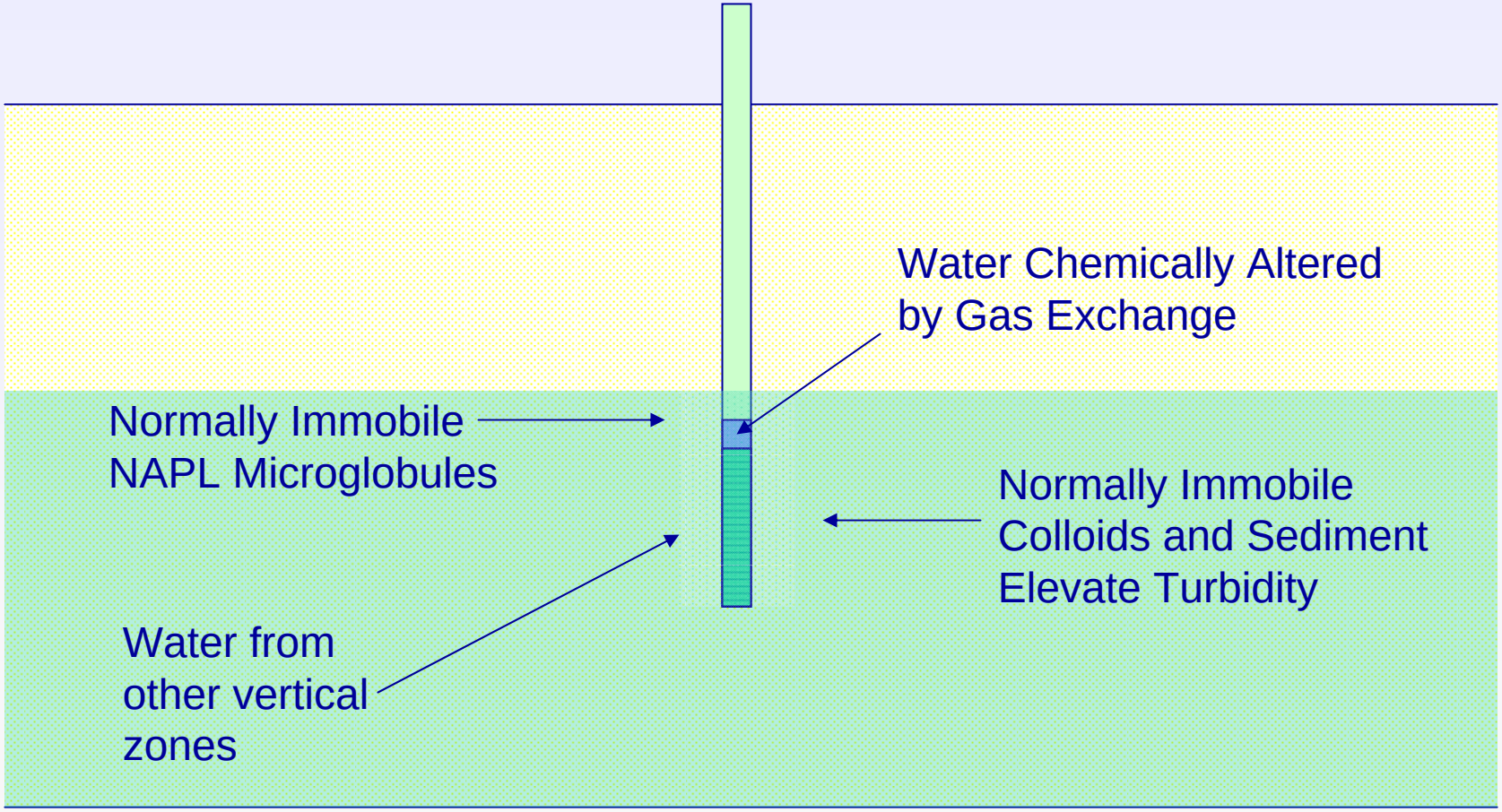
What does the sample represent with traditional purging methods?



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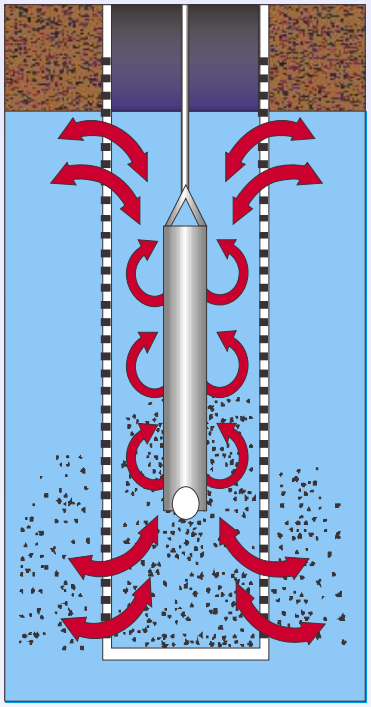
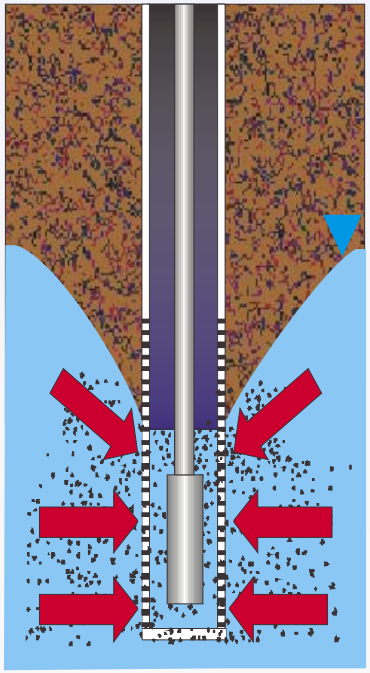
Bias and Error from Improper Well Purging Practices

- Incomplete purging can bias results due to sorptive losses onto casing, volatilization and biological degradation, or gases within the well.
- Over-purging can cause underestimation due to dilution or overestimation due to induced plume migration, contaminant mobilization and turbidity.
- Evacuation of low-yield wells causes losses of VOCs and metals, affects DO and CO_2 levels, and can increase sample turbidity.
- Excessive drawdown can cause overestimation (“false positives”) from landfill gas within the well or in the surrounding formation.





Hand Bailing and High-Rate Pumping Elevate Turbidity

- Turbidity can elevate metals and some organics (e.g., PAHs) bound to soils (e.g. “false positive” results)
- Sample filtration adds cost and time in the field (don’t filter in the laboratory!)
- Filtration affects sample chemistry
  - Turbid samples that are filtered are not the same as low turbidity samples
- Gibbons & Sara,1993: no statistical difference between total and filtered samples when turbidity <10 NTU.
  - Naturally-occurring groundwater turbidity can exceed 10 NTU (USEPA, 1996)
  - Some guidance suggests <20 NTU is sufficient for sampling (Florida Guidance)

Filtering samples to remove turbidity can bias results through sorption, leaching, oxidation and pass-through

Effects of Sample Filtration

- Failure to properly pre-condition filters can affect metals concentrations through sorption and leaching, causing biased results or false-positive artifacts.
- Handling during filtration of grab samples can cause bias and artifacts due to loss of CO_2 and gain of O_2.
- Small colloidal solids mobilized by bailing or excessive pumping may pass through filters, resulting in high metals values and overestimation of mobile contaminants.
- Not all filters are created equal! Membrane filters have a sharp pore-size cutoff, while depth filters will average this size, passing larger and more particles. Different filter designs and materials can yield different results.

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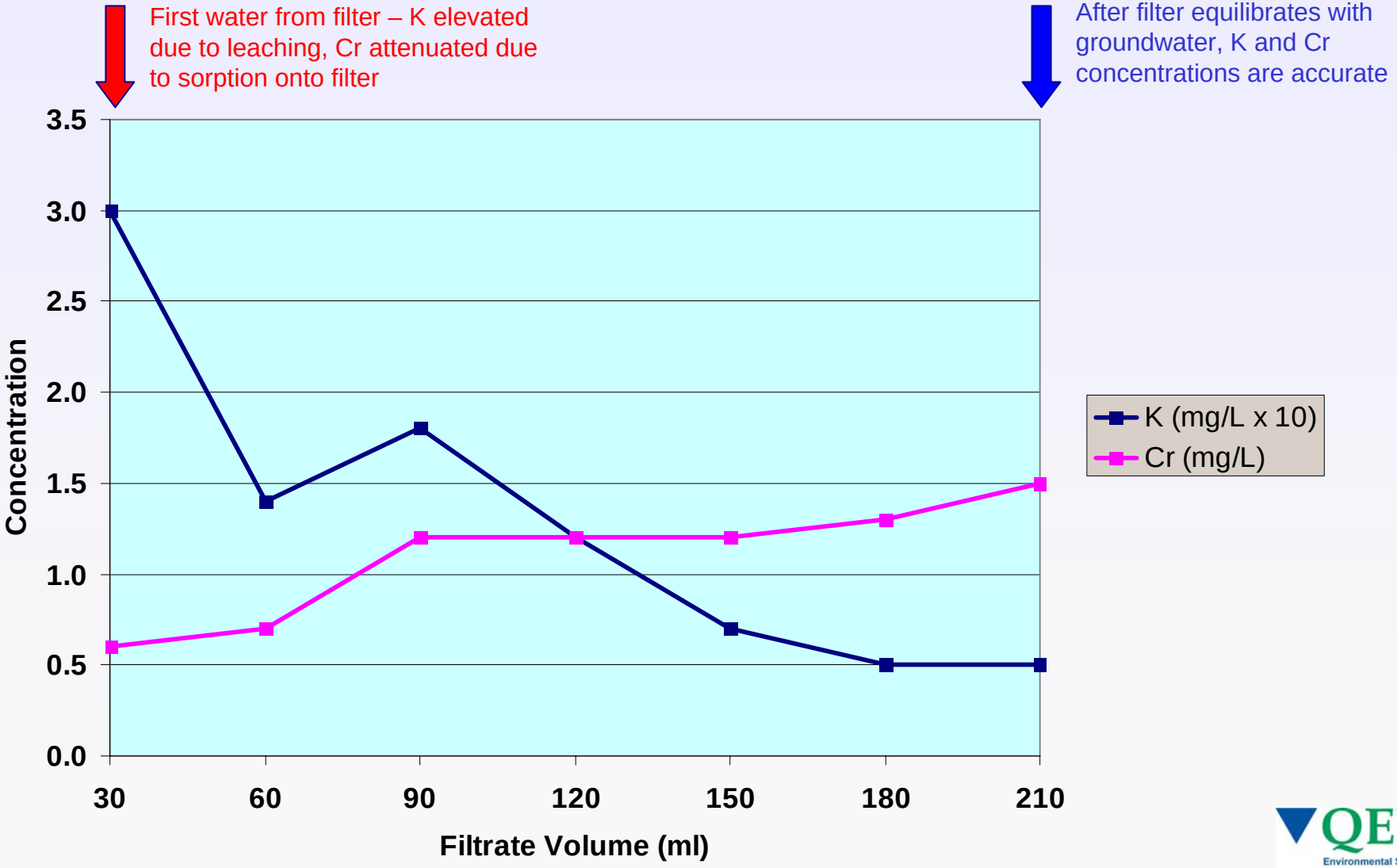
Bias from Improper Filter Use

(from Puls and Powell, 1992)



Limitations in traditional purging methods led to the evolution of low-flow purging

- Low-flow purging and sampling is a methodology that reduces disturbance to the well and aquifer typically caused by bailing or over-pumping.
- Low-flow pumping from the well screen controls turbidity that could affect analytical results.
- Because turbidity is low, unfiltered samples provide a better estimation of the true mobile contaminant load.
- Samples represent a flow-weighted average of the well screen zone.
- Sampling accuracy and precision are greatly improved.

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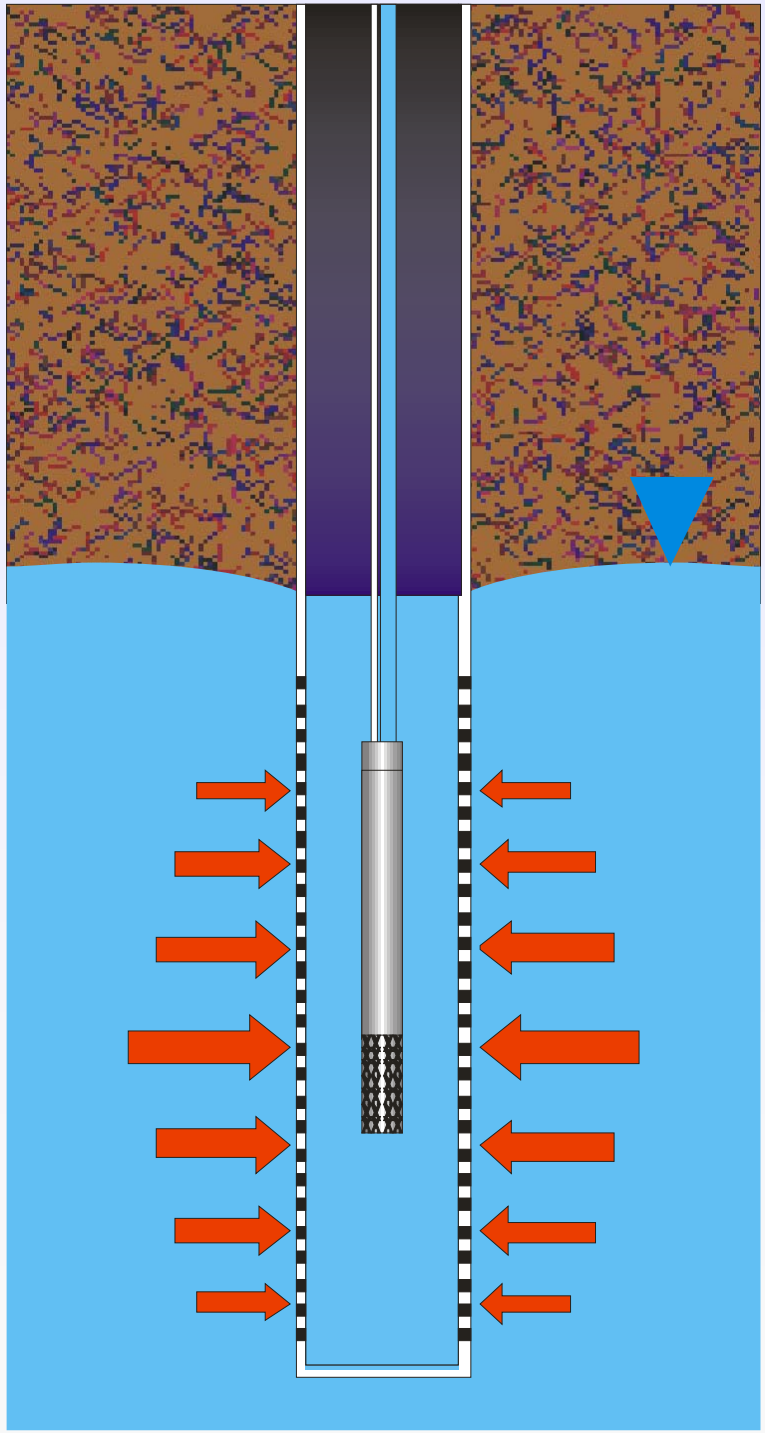
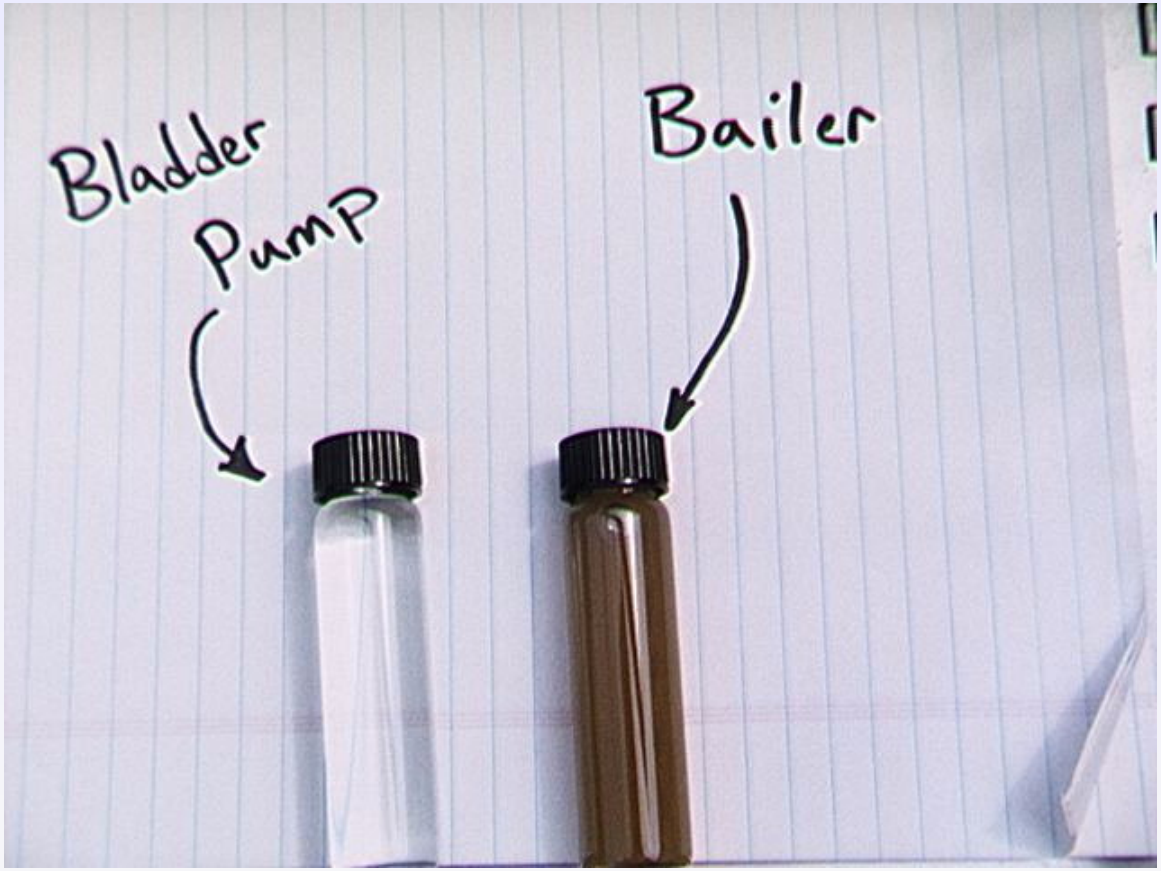
Low-Flow Purging

- Low pumping rate minimizes drawdown, mixing and formation stress, isolates stagnant water.
- Low stress = low turbidity, improved sample accuracy, reduced purge volumes.
- Samples represent formation water and naturally mobile contaminants, not stagnant water in the well or mobilized contaminants.



Lower flow = better samples



Low-flow purging and sampling controls turbidity and delivers higher quality samples - *a clear advantage*.

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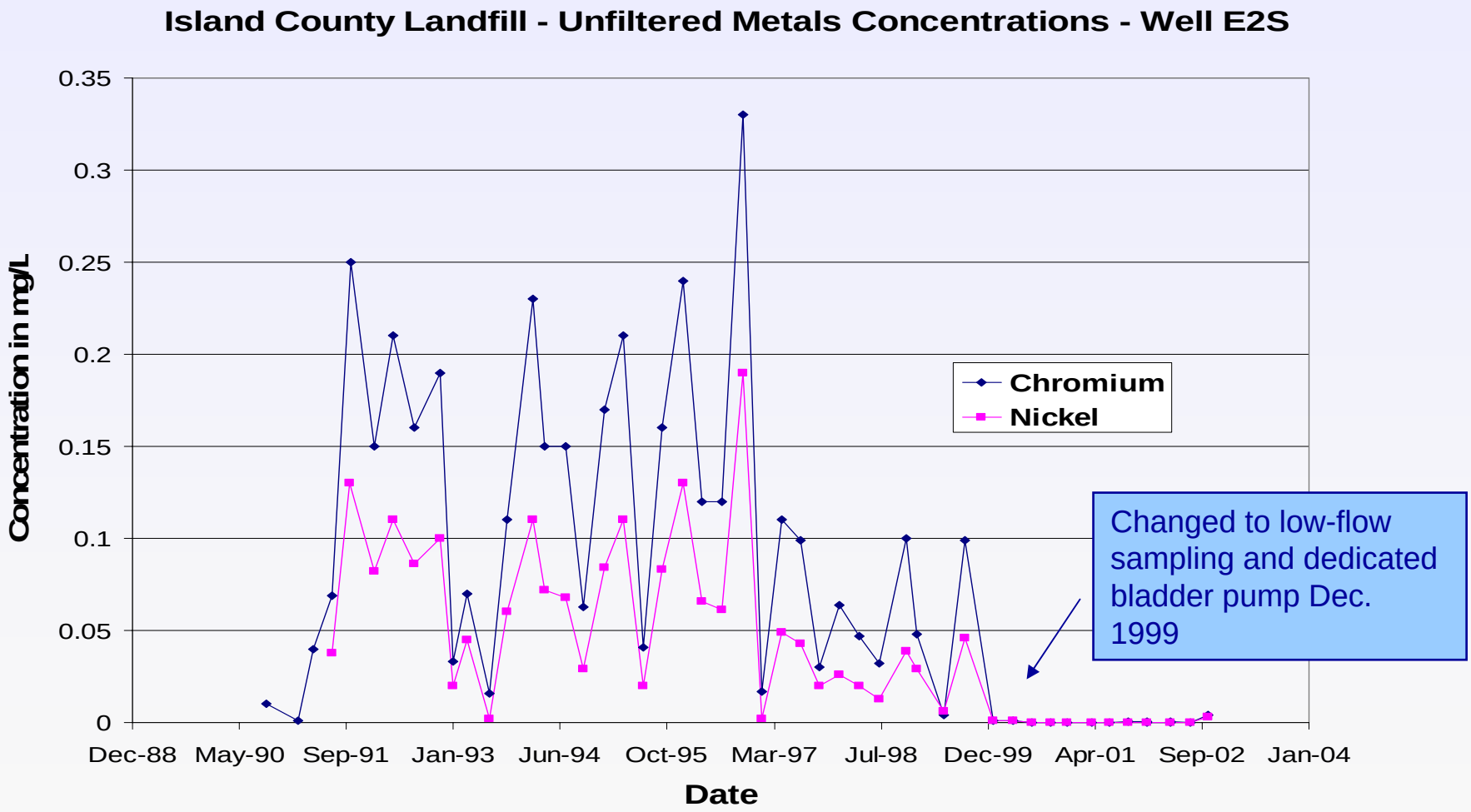
Effect of low-flow sampling data accuracy and precision



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Reduced Purge Water Handling/Disposal

Traditional Purge System

Low-Flow System

Cost Savings with Low-Flow Sampling

(From Schilling, 1995)

	Low-flow Purging	Three Well Volumes
Purging Analysis:		
Total Purge Volume (15 wells)	61 gallons	743 gallons
Average Volume Purged	3.3 gallons	50 gallons
Average Pumping Rate	0.3 GPM	2-5 GPM
Average Purging Time per Well	13 minutes	50 minutes
Total Purging Time (15 wells)	3.25 hours	12.5 hours
Economic Analysis (in US Dollars):		
Time for Purging Wells (a)	$500	$1,875
Disposal costs (b)	$1,300	$3,750
Cost per Sampling Event	$1,800	$5,625
Annual Sampling Costs (quarterly sampling)	$7,200	$22,500
Sampling costs for 30 years	$216,000	$675,000

(a) Two-person crew at $150/hr.USD

(b) First drum = $1,000; additional drums = $300 (drum = 55 US gallons/208 liters).

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Advantages of Low-Flow Sampling

- Low-flow is a consistent, performance based standard for purging, rather than an arbitrary rule of thumb.
- It documents completeness of purging for every sample, overcoming potential temporal variability in factors that can affect required purge volume.
- Low-flow sampling can reduce sampling costs:
  - Sample Quality - reduced turbidity, more accurate dissolved concentrations, and a better estimate of the true mobile contaminant load
  - Direct cost savings - reduced purge water handling & disposal, reduced purging time (in some wells).
  - Indirect cost savings - improved data accuracy and precision (no false statistical “hits”), and better data = better decisions.

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What Does a Low-Flow Sample Represent?

- While low-flow sampling is recognized as a solution for improving sample quality and reducing purge water volume, defining what the sample represents, in terms of the zone within the well screen that is sampled, is still often questioned.
- Pump placement can be an issue when changing to LFS from traditional purging; the concern is that samples will come from a narrow zone within the well screen, possibly “missing” contamination above or below the pump intake.
- Field experiments, laboratory simulations and numerical modeling support the position that samples are derived from the entire screen zone under low-flow pumping conditions.

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Vertical Concentration Profiles (Puls and Paul, 1998)

- Chromium concentrations were averaged throughout the well screen zone under very low flow pumping conditions (0.25 lpm), whereas concentrations were known to be measurably stratified within the surrounding formation based on direct-push samples taken next to the screen.
- The concentrations from low-flow samples were virtually identical to the mean concentration of the multi-level and direct-push samples taken.
- Bailed sample concentrations were biased lower than the low-flow pumped sample results.

Device	DMLS	Geoprobe	Low-Flow	Bailer
Cr (mg/l)	1.69	1.86	1.76	1.05

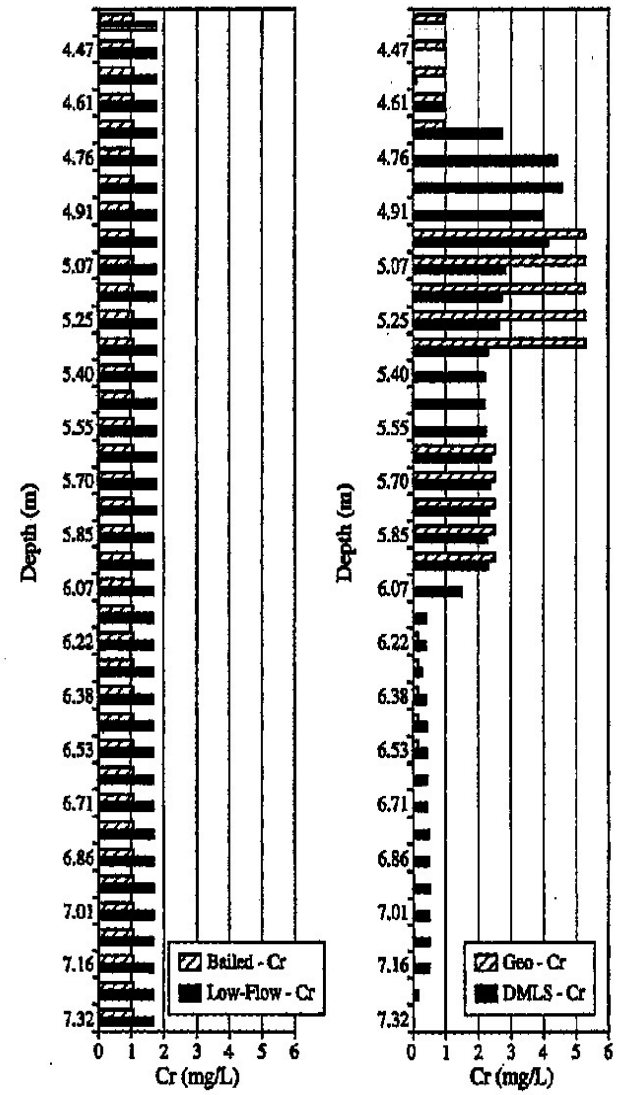
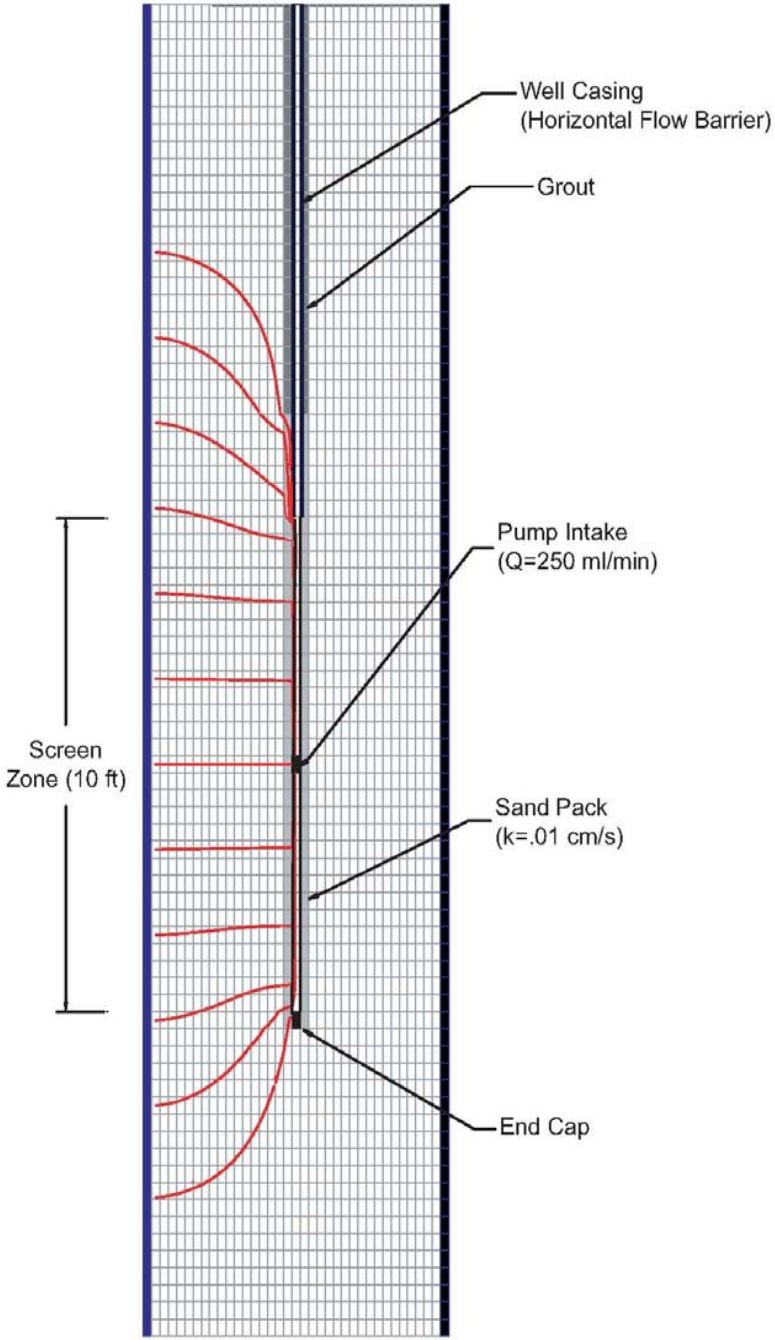


FIG. 6. Chromium Data for Samples Collected Using DMLS, Low-Flo, and Bailed Sampling Approaches for Well 45 in September 1995

Numerical Simulations of Low-Flow Purging (Varljen, et. al., 2006)

High vertical resolution MODFLOW study shows that when purging at low flow rates:

- The entire well screen is sampled
  - Flow pattern into the screen remains the same, regardless of pump position – controlled by geology
  - Same for 5, 10, and 20 foot screens
- Applies to wells with fully submerged screens and screens intersecting the water table
  - some flow paths originate from above and below the screen
  - actual zone monitored is longer than the length of the screen
  - heterogeneities in permeability will control contribution to the screen (higher K zones produce more water)



Model Output at 0.25 L/min Steady State Flow

Low-Flow Sampling Application Guidelines – The Basics

- Flow rates must be controlled to pump without continuous drawdown (water level must stabilize) and not increase turbidity. Rates of 200 to 1,000 mL/minute are typical.
- Drawdown is based on well performance, not arbitrary guidance.
- Indicator parameters are monitored for stabilization to indicate formation water and purging completeness.
- Dedicated sampling equipment is preferred. Portable pumps require larger purge volumes, can increase turbidity and require decontamination between wells, but are still better than bailing or high-rate pumping.

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Purging Flow Rates and Drawdown

- From US EPA, 1996: “Typically, flow rates on the order of 0.1 - 0.5 L/min are used, however this is dependent on site-specific hydrogeology. Some extremely coarse-textured formations have been successfully sampled in this manner at flow rates to 1 L/min.”
- The goal is to achieve a stabilized pumping water level in the well as quickly as possible. This reduces mixing within the borehole, and draws water only from the sampling zone.
- Flow rates are established for each well based on drawdown and turbidity values measured during purging.

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Drawdown

- From USEPA 1996: "*The goal is minimal drawdown (0.1m) during purging. This goal may be difficult to achieve under some circumstances… and may require adjustment based on site-specific conditions and personal experience*."
- This drawdown example has been interpreted as a maximum drawdown limit by some agencies without any consideration for site-specific conditions. There is no data to support this, or any other drawdown limit.
- A study by Vandenberg and Varljen shows that the true goal is to establish a stable pumping water level during purging, with indicator parameter stabilization following this.

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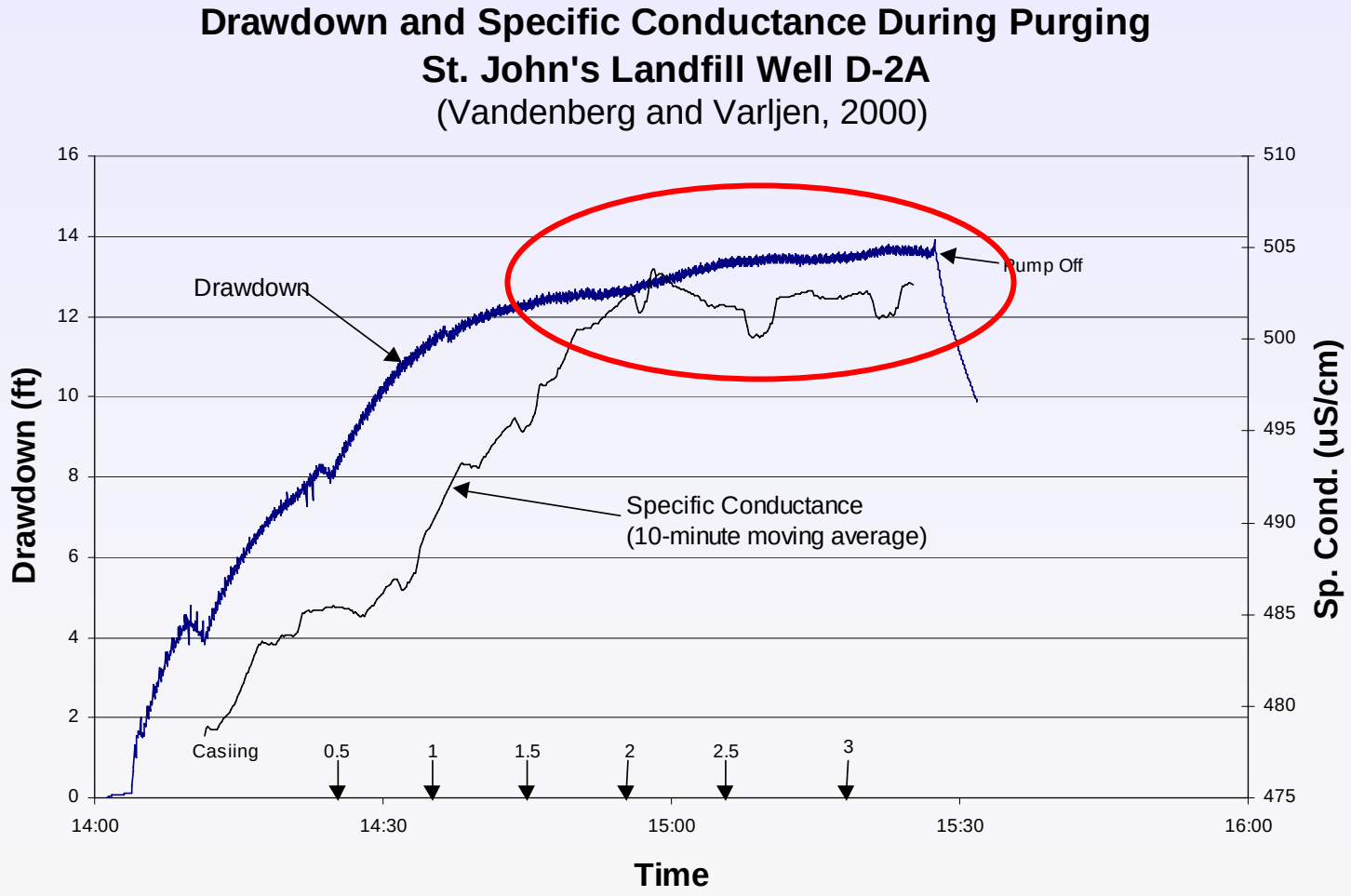
Correlation of Drawdown and Indicator Parameter Stabilization



At the point where the water level stabilized, the indicator parameters measured (conductivity shown above) also stabilized.

Drawdown Recommendations

- Drawdown should be observed and recorded for each well based on a stabilized pumping water level
- Extended purging at low flow rates, even where drawdown exceeds several feet, is preferable to high-rate well volume pumping, bailing or well evacuation.
- Drawdown within the screen should be avoided, but is still preferable to evacuation and recovery, and may be unavoidable in water table wells and low yield wells.
- Very-low-yield wells that will not stabilize at flow rates of 0.1 - 1.0 L/min should be candidates alternative sampling methods (such as “passive” or minimal purge sampling) in lieu of well evacuation.

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Sampling Flow Rates

- Sampling flow rates “less than 0.5 L/min are appropriate.” (US EPA 1996).
- Use rates at or below the purging flow rate for metals and other inorganic parameters, lower rates (100 ml/min.) for VOCs and filtered samples.
- Fill larger sample bottles first, then reduce the flow rate (if needed) for VOCs and any filtered parameters.
- Sampling at 100 ml/minute for all parameters can extend sampling times unnecessarily.

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Indicator Parameters for Purging

- Indicator parameters often include pH, temperature, conductivity, DO, ORP (redox) and turbidity.
- DO and C are the most reliable indicators, based on published research and field experience.
  - pH stabilizes readily, often shows little change.
  - Temperature measured at the well head is affected by sunlight, ambient temperature, and some electric pumps
  - Turbidity cannot indicate when purging is completed. It should be measured primarily to support sample data and prevent excessive pumping/formation stress.
- Stabilization criteria are typically ± 5-10% of readings, or a range of units (e.g., ± 0.2 mg/L DO) where percentages are not appropriate. Stabilization occurs when three consecutive readings fall within the criteria.

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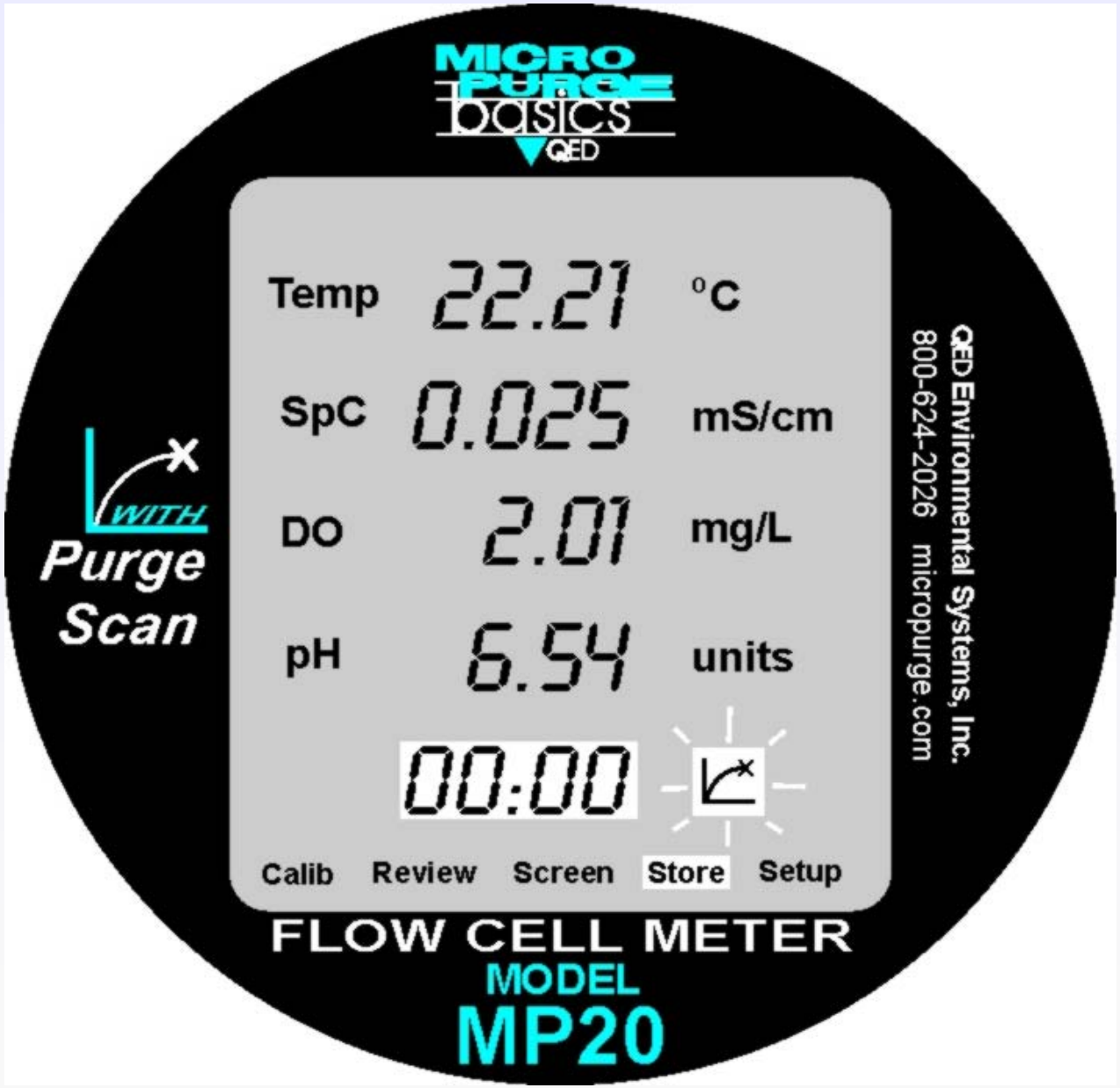
Measuring indicator parameters

- Traditional approaches use hand-held or bench-top instruments that expose samples to air and make precise measurement intervals difficult.
- Readings may not appear stable even though water chemistry has stabilized.

An in-line flow cell isolates water from air, maintaining water chemistry and allowing automated measurement. Open-top “flow containers” can’t achieve accurate values for dissolved oxygen or redox due to rapid gas exchange.

Typical flow-cell output provides simultaneous display of parameters while storing readings for future recall



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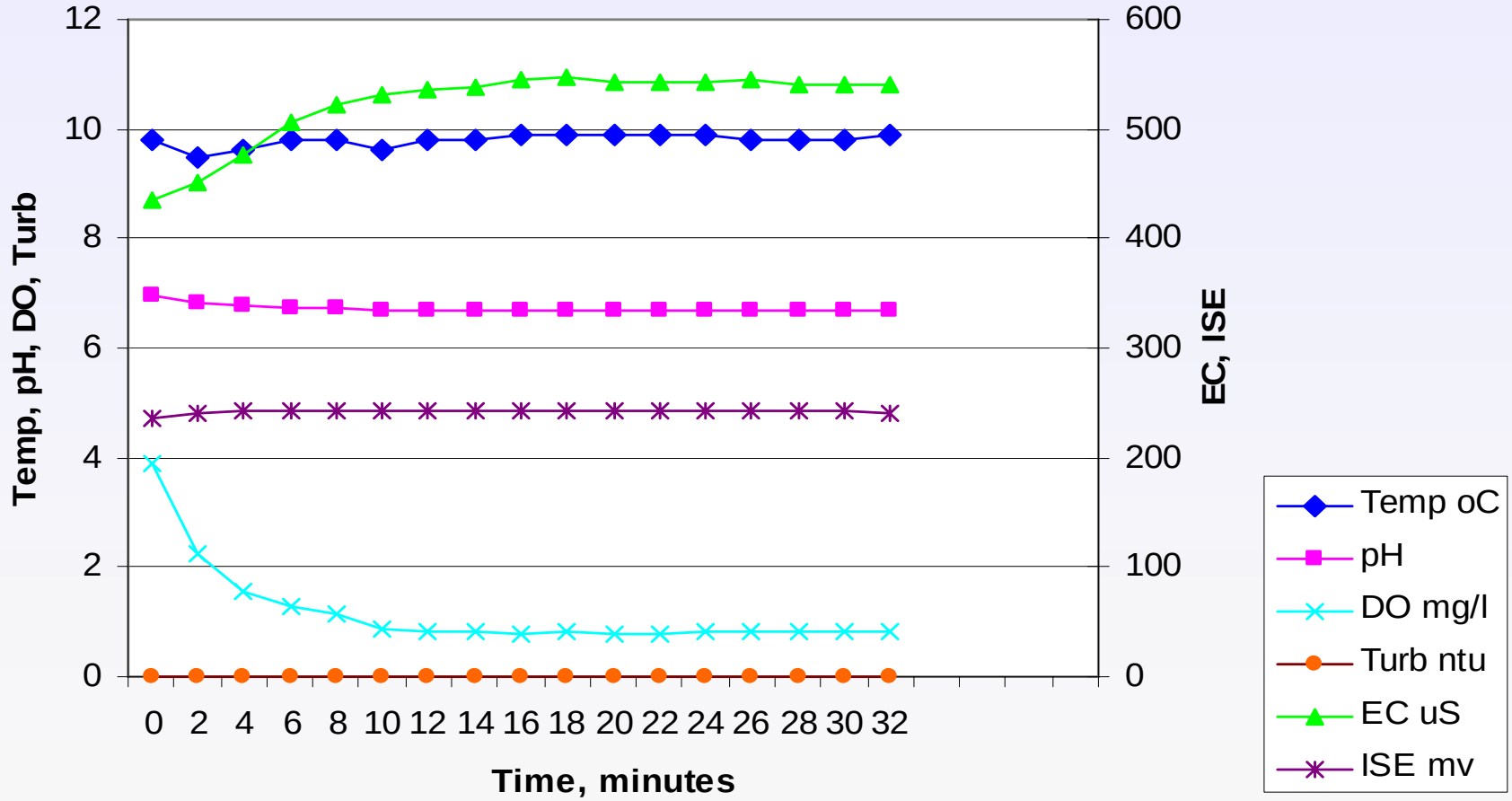
Typical Indicator Parameter Stabilization Curves



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Passive and No-Purge Sampling: The next evolutionary step?

- Over the past decade, researchers and manufacturers have studied sampling wells without purging.
- The methodology is based on the concept that ambient groundwater flow through the well screen would maintain an approximation of the groundwater chemistry within the screen zone of the well.
- Samples taken represent the discrete interval within the screen where the samplers are placed or activated, rather than a flow-weighted average of the screen zone.
- Several passive or no-purge samplers can be deployed at various depths in the well screen in order to identify any contaminant stratification within the water column.

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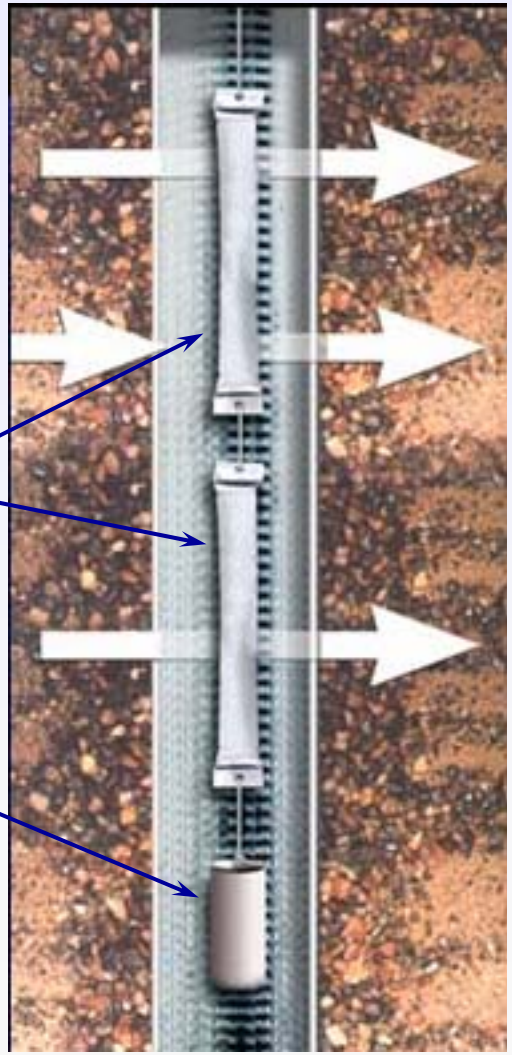
Polyethylene Diffusion Samplers



Cross Sectional View

Typical sampler is 1-2 feet in length

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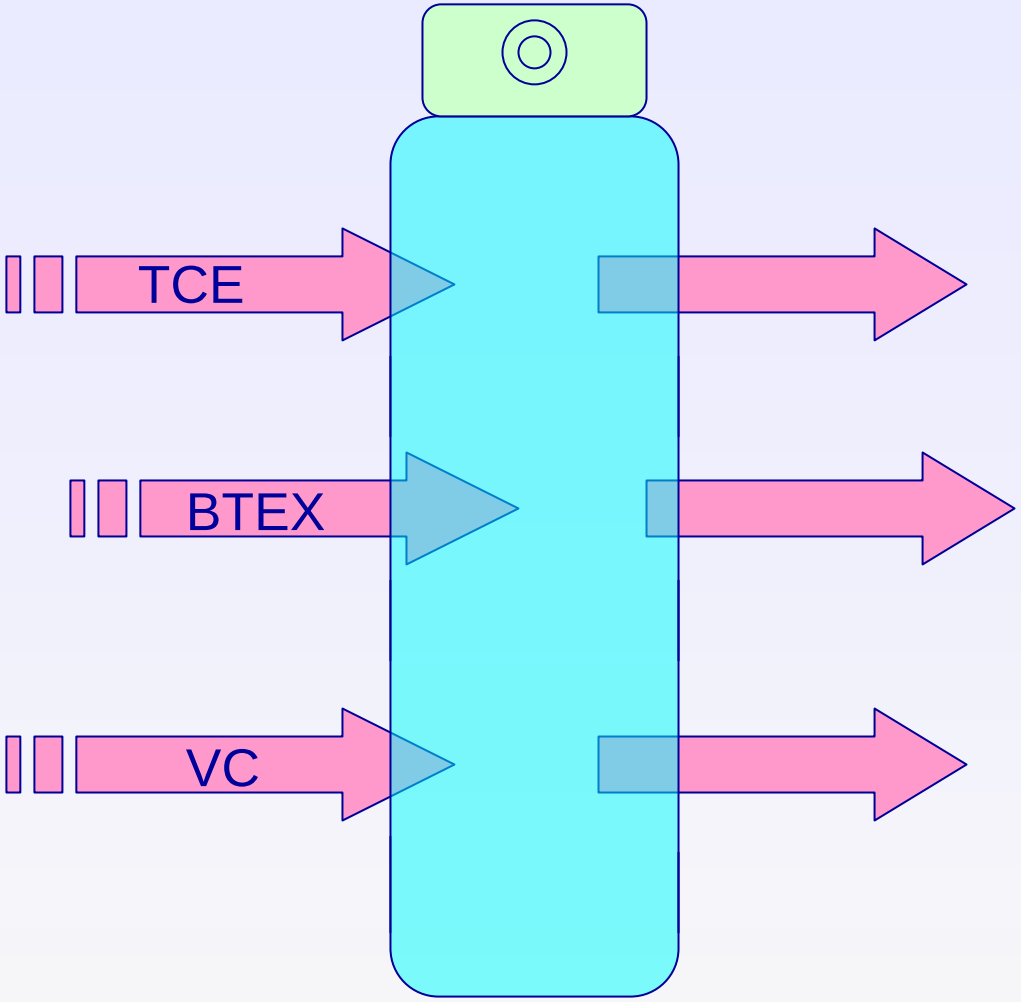

Certain VOCs, primarily chlorinated and aromatic hydrocarbons, will diffuse through the polyethylene bag

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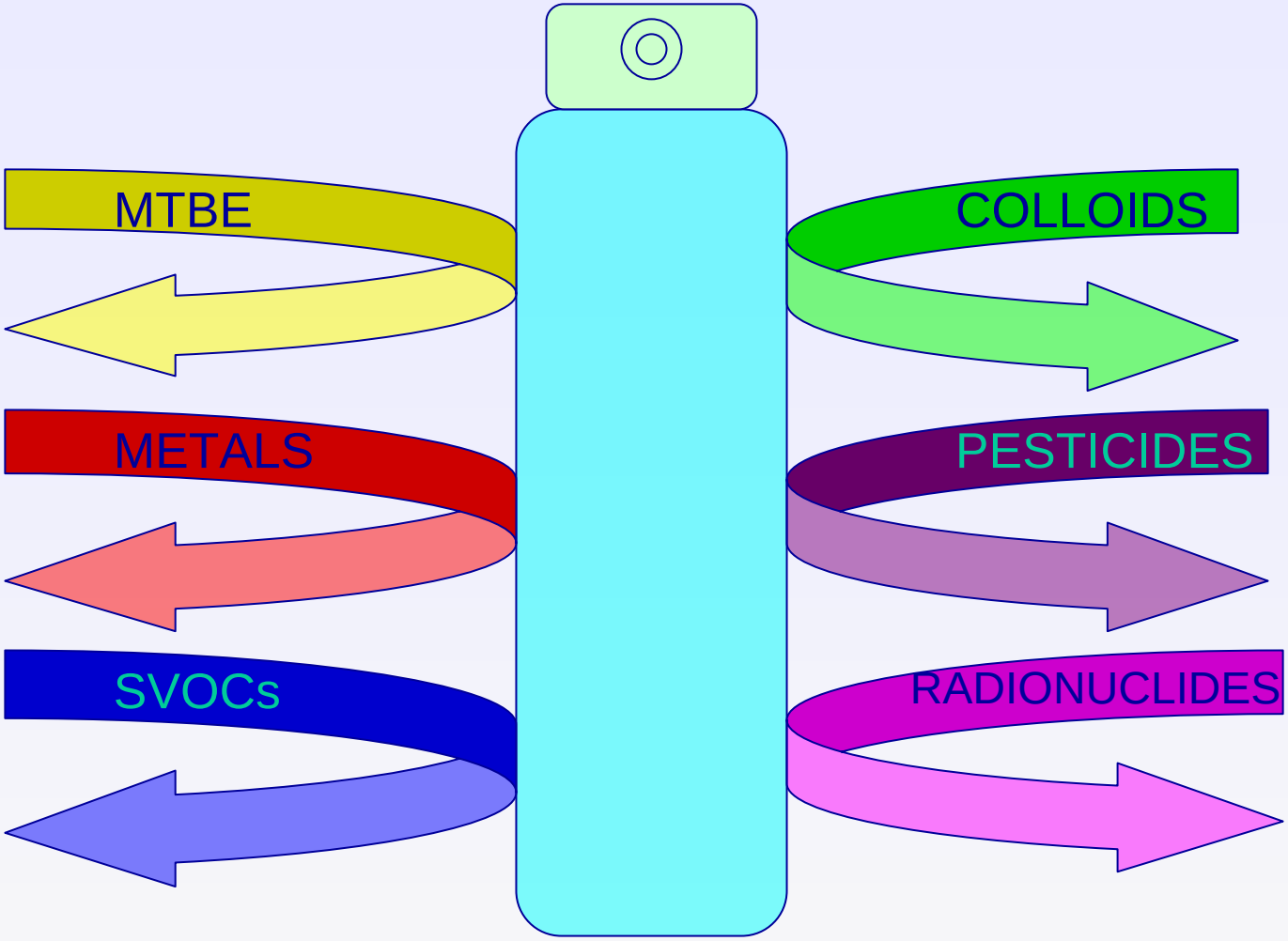

Most other common analytes, such as metals, pesticides, semi-volatiles and some volatiles can’t diffuse into the bag

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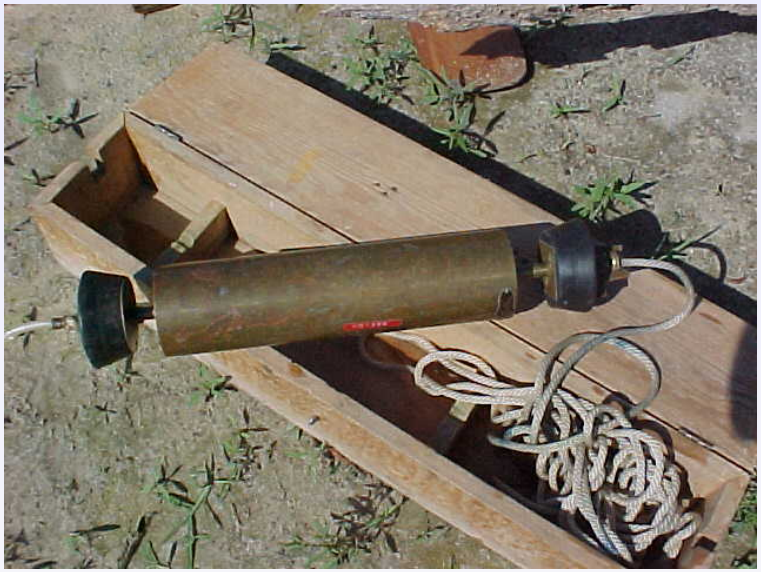
No-Purge Sampling can be performed with various grab samplers

HydraSleeve ™

Snap Sampler™



Kemmerer Sampler

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How do low-flow sampling and no-purge/passive sampling compare?

- Studies comparing LFS and no-purge/passive sampling show good correlation in some wells but significant differences in others. This may be the effects of contaminant stratification in the well, ambient vertical flow and mixing and the operational limitations of some passive sampling devices.
- Cost comparisons are typically based on a single sampling point. If multiple passive/no-purge samplers are used, sampling cost savings are quickly offset by increased analytical costs of multiple samples.
- The biggest difference is in what the sample represents. LFS represents a flow-weighted average of the well screen, while a no-purge/passive sample may represent either a depth-discrete sample of the well screen (but not necessarily the surrounding formation), or may represent some undefined average value of the screen zone due to ambient vertical flow and mixing within the well.

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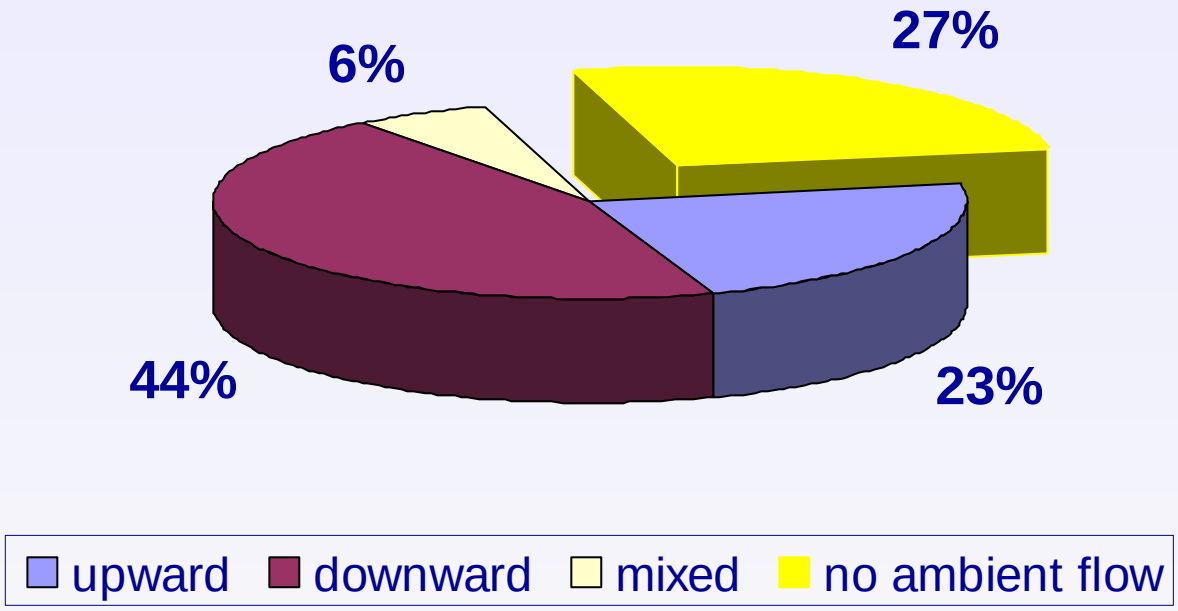
How Common Is Measurable Ambient Flow?

(from Elci, et al., 2001)



- 142 wells at 16 sites in 12 states
- 73% of the cases had measurable amounts of ambient flow
- Range of measured ambient flow at all sites: 0.01 L/min - 6.2 L/min

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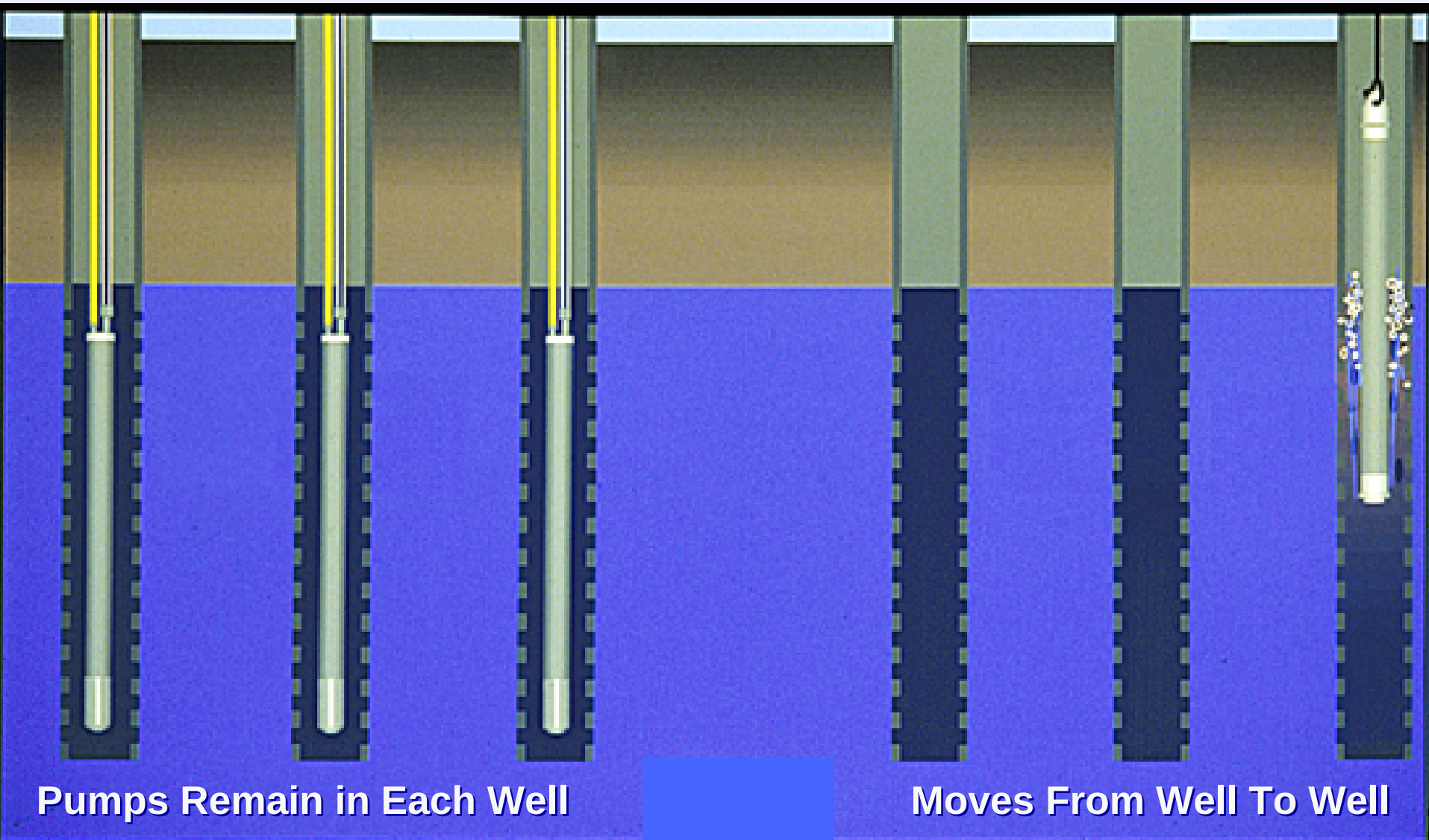
Should your sampling system be dedicated or portable?

Dedicated System

Portable System



Portable Sampling Systems

- Lower equipment cost (purchase/rent/lease)
- Higher operating costs (operation/maintenance)
  - assembly/disassembly at each well
  - cleaning labor (average 1 labor-hour/well)
  - cleaning supplies (buckets, brushes, detergent & water)
  - reagents (isopropanol, methanol, hexane, acid wash)
  - cleaning blank sample analysis
  - re-sampling & added analysis if any “suspect” samples
- Potential for cross-contamination of samples & wells
- Greater exposure to contaminants & cleaning agents

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Dedicated Sampling Systems

- Higher initial equipment cost (purchase/lease)
- Lower operating costs (operation/maintenance)
  - no assembly/disassembly at each well
  - no cleaning labor
  - no cleaning supplies or reagents
  - no cleaning blank samples
  - labor typically 30% - 50% lower overall
- Eliminates cross-contamination from sampling equipment
- Reduces potential for operator exposure to contaminants

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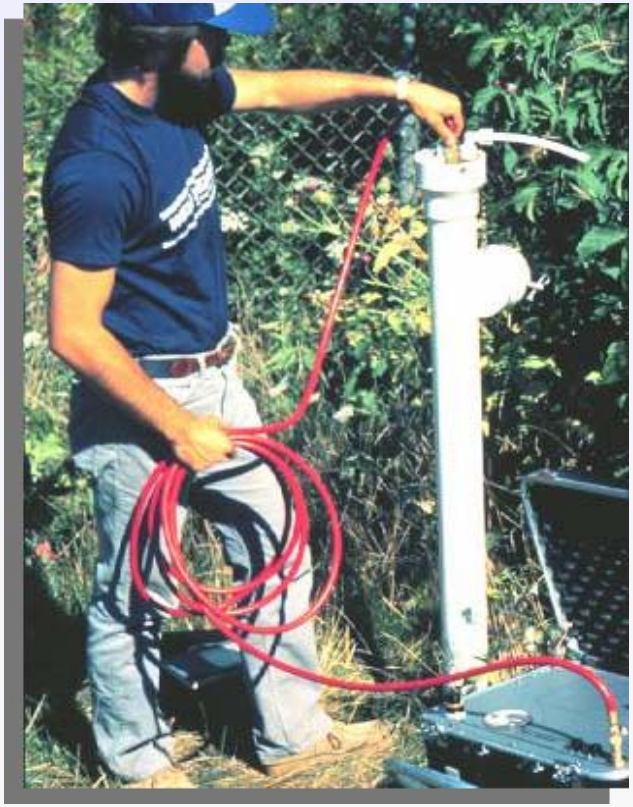
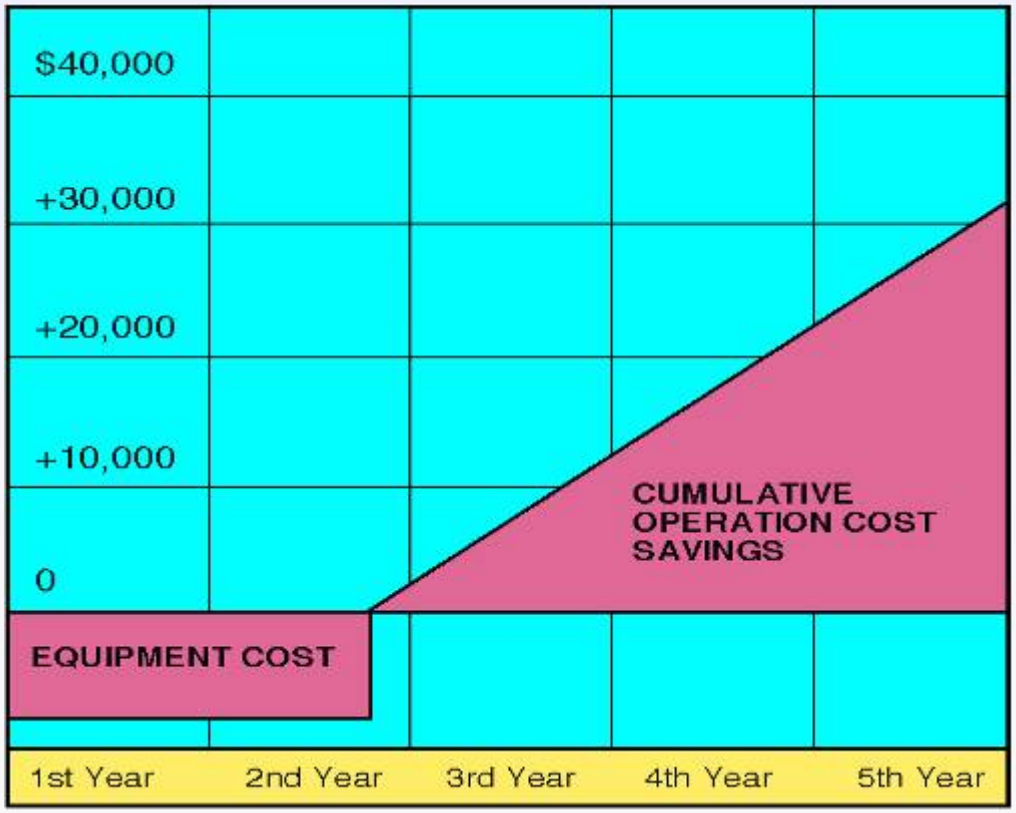
Cost Savings / Ease of Use

- End-user design is simpler than bailers or portable pumps
- Dedicated systems reduce sampling labor and expenses, resulting in a break-even in two years or less for most sites doing quarterly sampling





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Summary

- Sampling methods are like tools in a toolbox – each has an appropriate use based on the task at hand.
- Traditional purging and sampling methods often bias sample results and can generate significant waste.
- Passive and no-purge sampling methods can identify contaminant stratification within a well screen, but this information may not reflect the actual concentration in the formation due to ambient vertical flow and redistribution of contaminants within the borehole.
- Low-flow sampling can improve sample accuracy and precision and avoid biases associated with turbid samples. It provides flow-weighted average concentrations from typical monitoring wells, and is the best approach for determining the true mobile contaminant load in most routine compliance monitoring scenarios.
- Dedicated sampling systems can reduce sampling costs by eliminating decontamination between wells and reducing field labor.

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Thank you!

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