

Well Flow Dynamics and the Application of Passive Sampling Techniques

Sanford (Sandy) Britt, PG, CHG
QED Environmental Systems, Inc.

SBritt@QEDenv.com

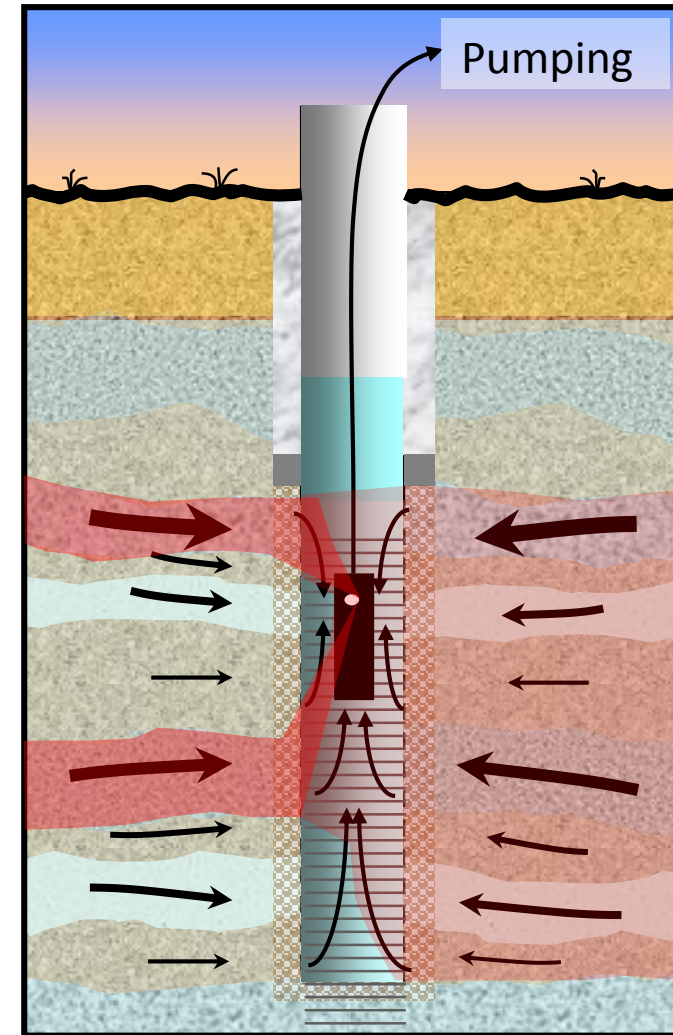
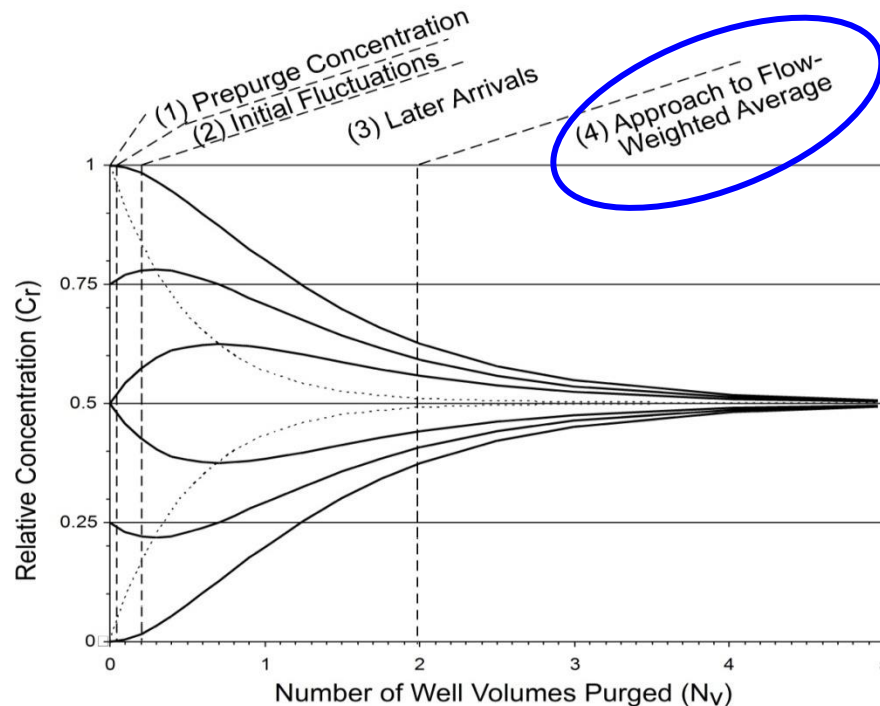
EnviroTech, Calgary, 25 April 2019



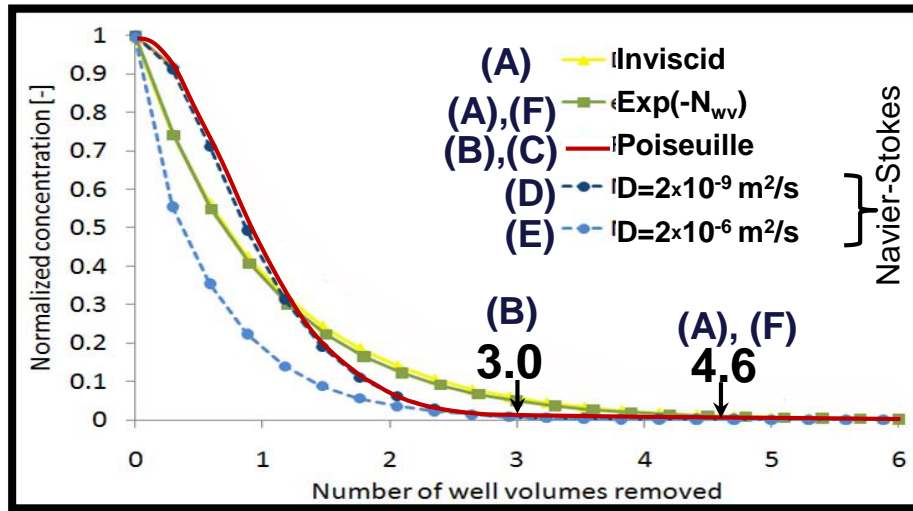
Purging a well...

What controls flow-weighting during pumping?

- Contaminant stratification
- Inflow distribution
- Pump position relative to stratification



How do we get to a Flow-Weighted Average?



Martin-Hayden, J., M. Plummer and S. Britt
 (2014) Controls of Wellbore Flow Regimes on
 Pump Effluent Composition, Ground water, v52,
 p. 96-104.

Arrival time and FWA depends on....

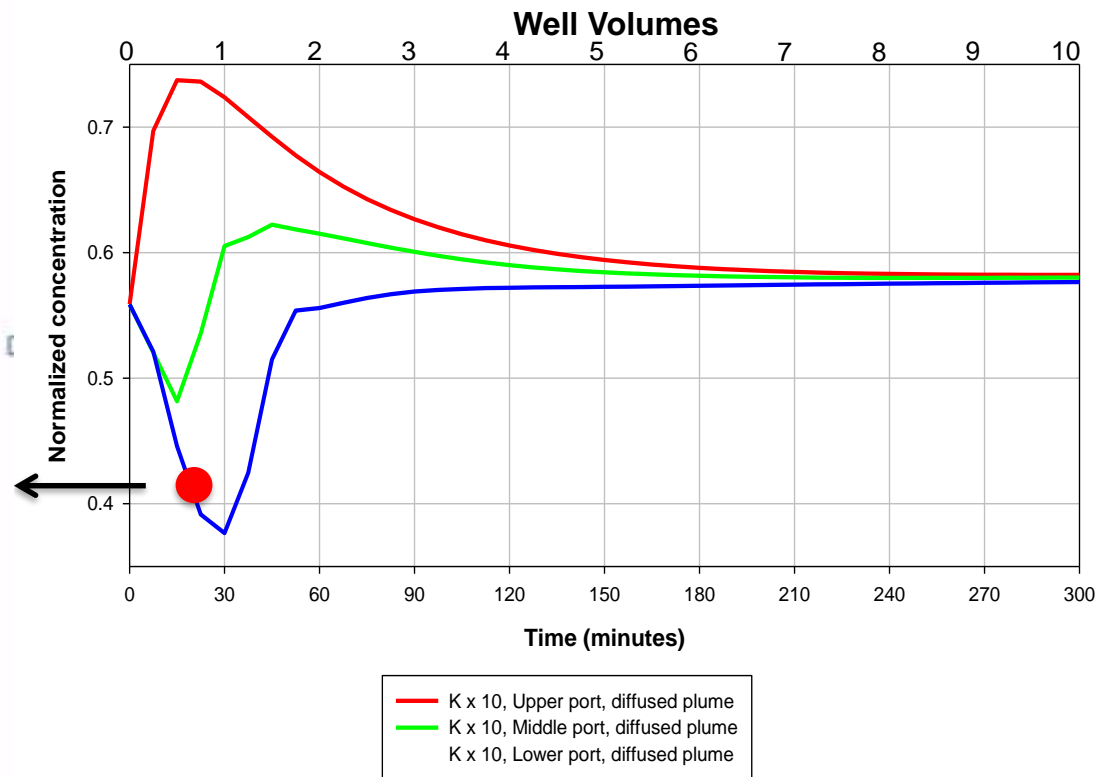
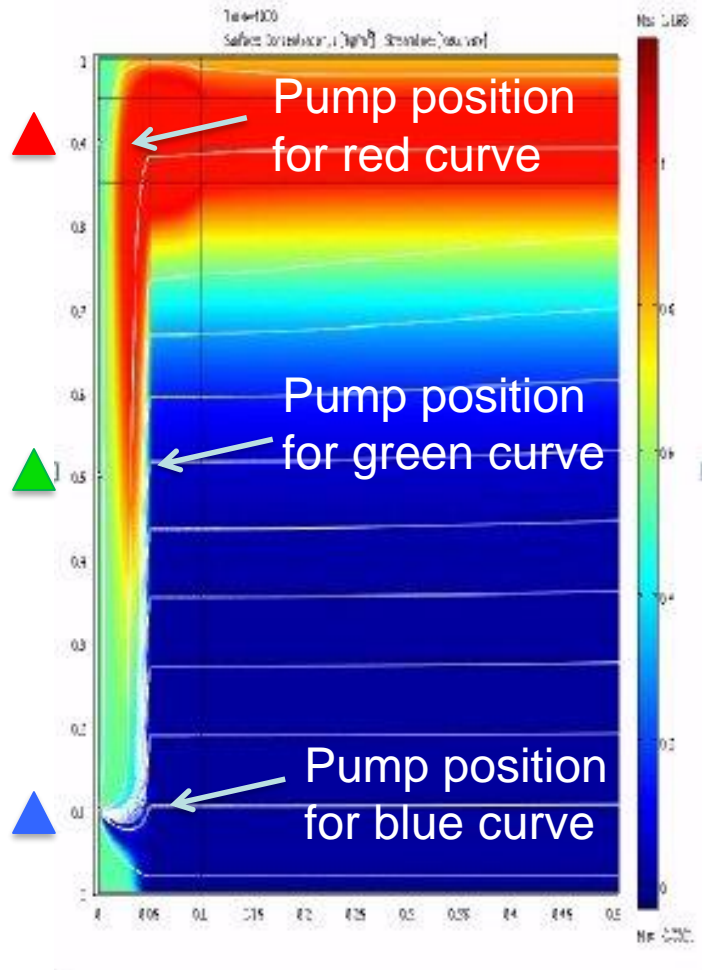
- Pumping rate
- Well diameter
- Well screen length
- @ 250ml/min in a 3m/10ft well....
 - 1WV in 50mm/2" takes ~23 minutes
 - 1WV in 100mm/4" well takes ~ 94 minutes

Pumping



Modelled well flow

Pump near/far from contaminant inflow?



1 meter long, 10cm screen

250ml/minute pump rate

K= 1×10^{-2} cm/sec in contaminated zone, 1×10^{-3} in remaining aquifer

Pump located 10cm from bottom position

Field Confirmation....

Stratification testing at existing wells

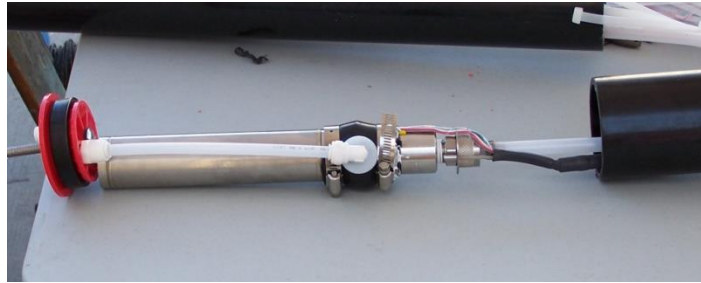
- 8 wells
- 2 to 4 depths
- prep for “purge curve” testing

Three new wells built to accommodate equipment

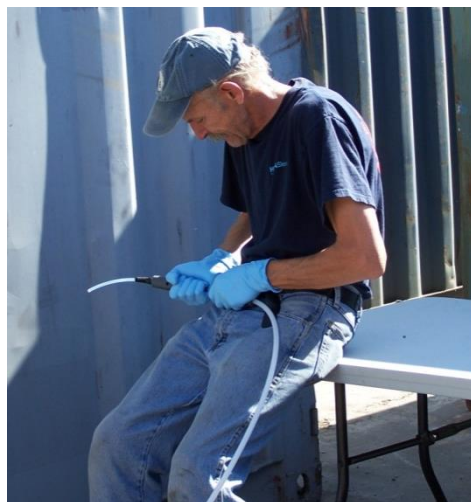


Purge Test Set-Up

- Pump
- Sensors-level, Conductivity, pH, ORP, Chloride
- Snap Samplers— over/under...before/after



Low Rate purge—multiple VOC samples collected along “purge curve”



Contaminant Chemistry

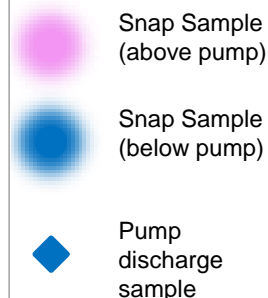
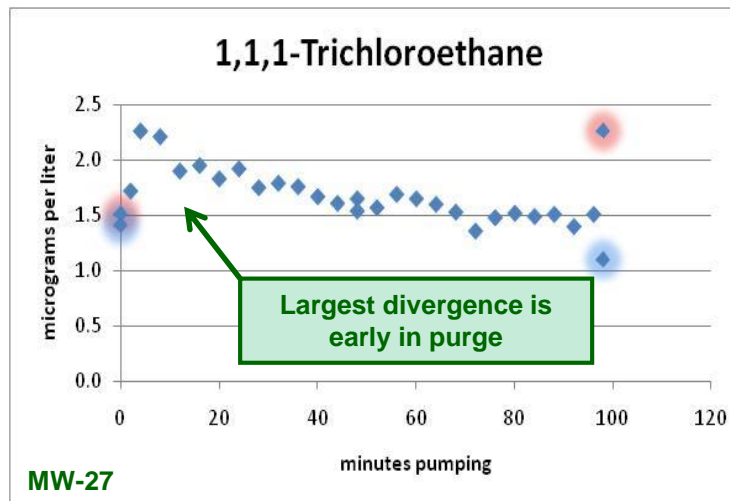
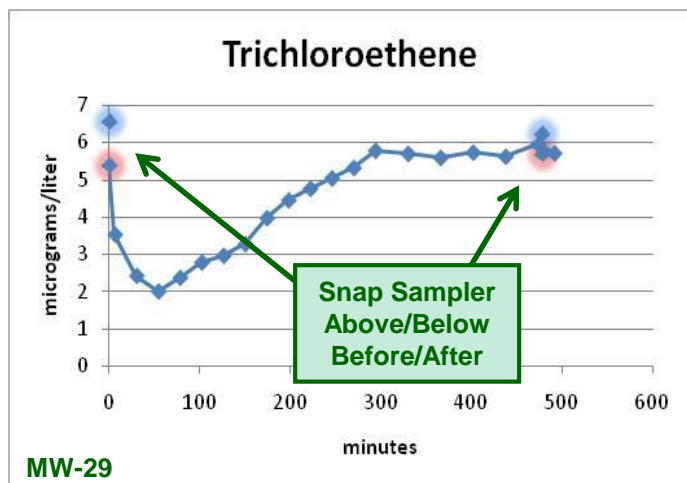
Sample ID	29-SS-L1	29-SS-U1	MW29-1	MW29-2	MW29-3	MW29-4
Sample Date			9/1/2009	9/1/2009	9/1/2009	9/1/2009
Laboratory Job Number			53966	53966	53966	53966
time			1112	1136	1200	1224
minutes elapsed	0	0	6	30	54	78
volume pumped	0	0	0.5	2.7	4.9	7.0
Acetone	18.4	19.3	10	10	10	10
Benzene	19.2	16.5	11.3	6.64	5.09	5.66
sec-Butylbenzene	1.18	0.78	0.5	0.5	0.5	0.5
Chlorobenzene	18.4	14.2	8.75	6.02	5.49	6.69
Chloroethane	39.2	32.8	24.1	14.2	11.9	10.3
1,2-Dichlorobenzene	0.5	1.38	0.5	0.5	0.5	0.5
1,1-Dichloroethane	6,000	4,000	3,920	2,710	2,490	2,590
1,2-Dichloroethane (EDC)	45	39.2	24.5	16.7	14.2	15.6
1,1-Dichloroethene	234	201	162	117	85.8	89.3
cis-1,2-Dichloroethene	111	98.5	85.3	58.5	44.8	45.9
trans-1,2-Dichloroethene	0.91	0.96	0.5	0.5	0.5	0.5
Ethylbenzene	5.98	4.8	1.63	1.02	0.68	0.75
Isopropylbenzene	0.84	0.6	0.5	0.5	0.5	0.5
p-Isopropyltoluene	0.5	0.5	0.5	0.5	0.5	0.5
4-Methyl-2-pentanone (MIBK)	63.4	31.5	12.8	3.12J	2.5	3.02
n-Propylbenzene	0.5	0.5	0.5	0.5	0.5	0.5
Tetrachloroethene	10.2	7.51	4.21	3.45	2.98	3.39
Toluene (Methyl benzene)	5.87	6.35	3.15	2.15	1.62	1.67
Trichloroethene	6.57	5.39	3.54	2.43	2.01	2.38
1,2,4-Trimethylbenzene	14.9	11.2	2.54	1.27	1.06	1.19
1,3,5-Trimethylbenzene	2.76	2.08	0.67	0.5	0.5	0.5
Vinyl chloride (Chloroethene)	332	297	228	170	118	117
o-Xylene	2.01	1.86	0.79	0.5	0.5	0.5
m,p-Xylenes	7.9	6.27	2.04	1.24	1	1
Diisopropyl ether (DIPE)	0.5	0.5	0.5	0.7	0.66	0.5
1,4-Dioxane	35,500	30,100	40,300	27,200	27,400	26,600

“Purge curve” samples collected from pump discharge

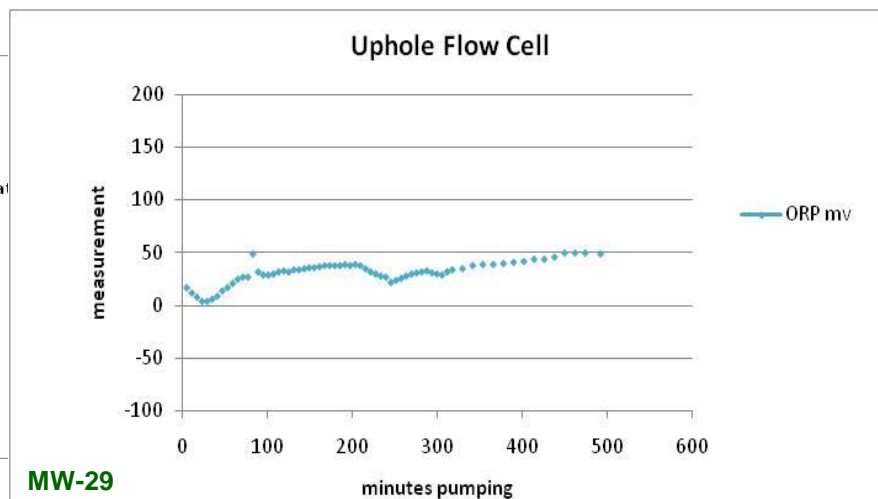
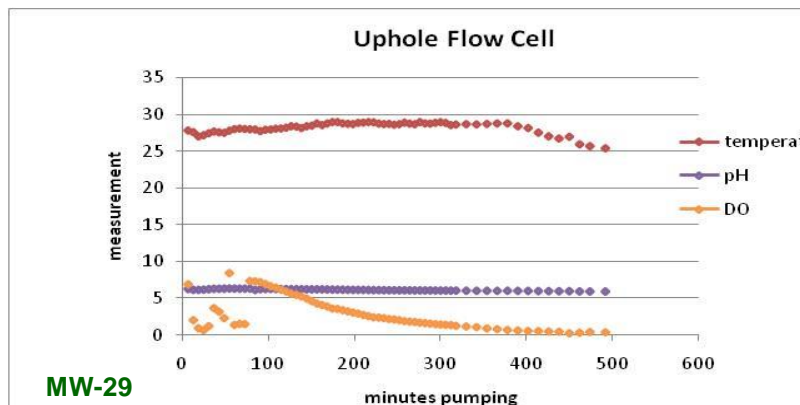
In situ Snap Samples collected
 Above/below pump
 Before/after pumping

Purge “curve” test results

Contaminant Chemistry Curves over Five Well Volumes

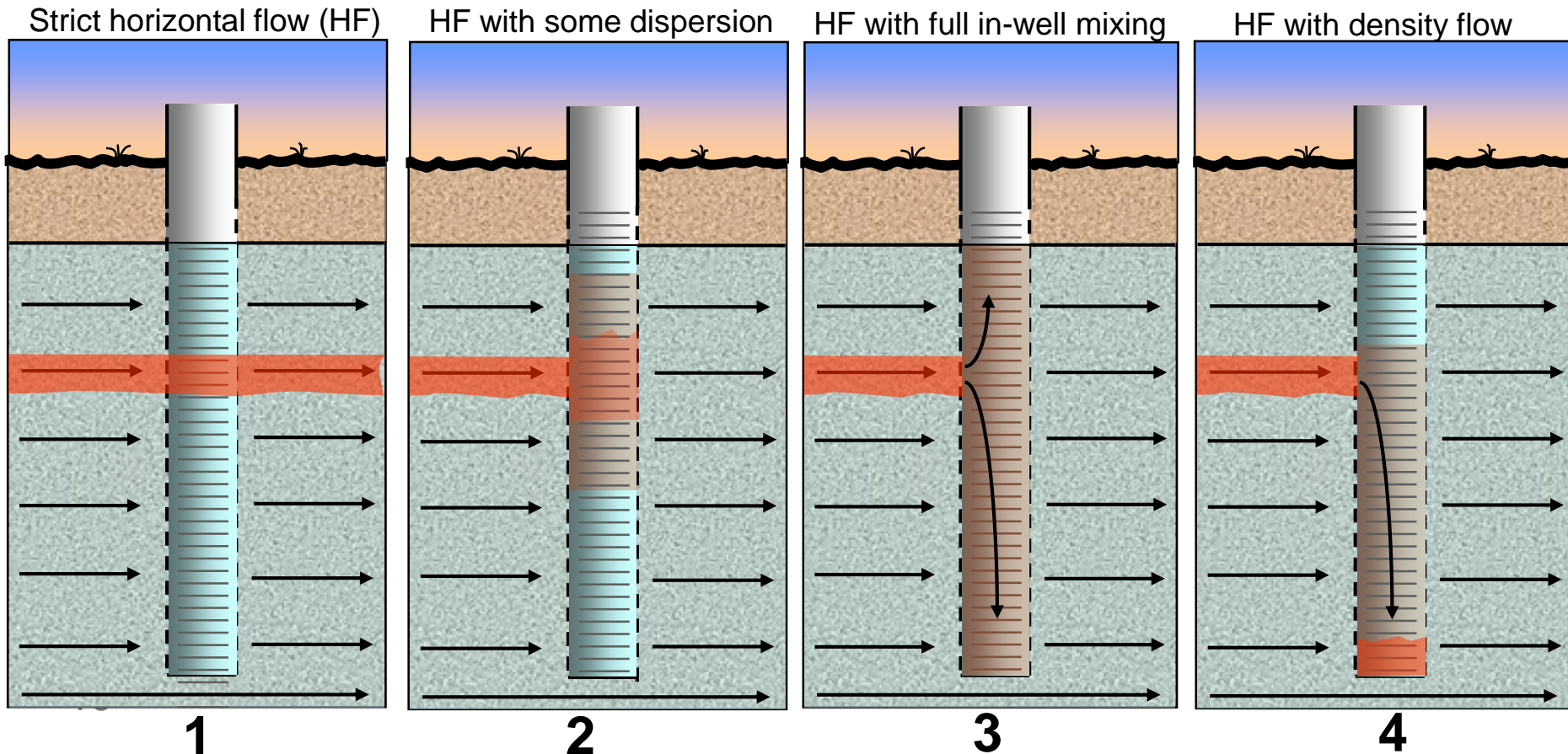


Indicator Parameters?



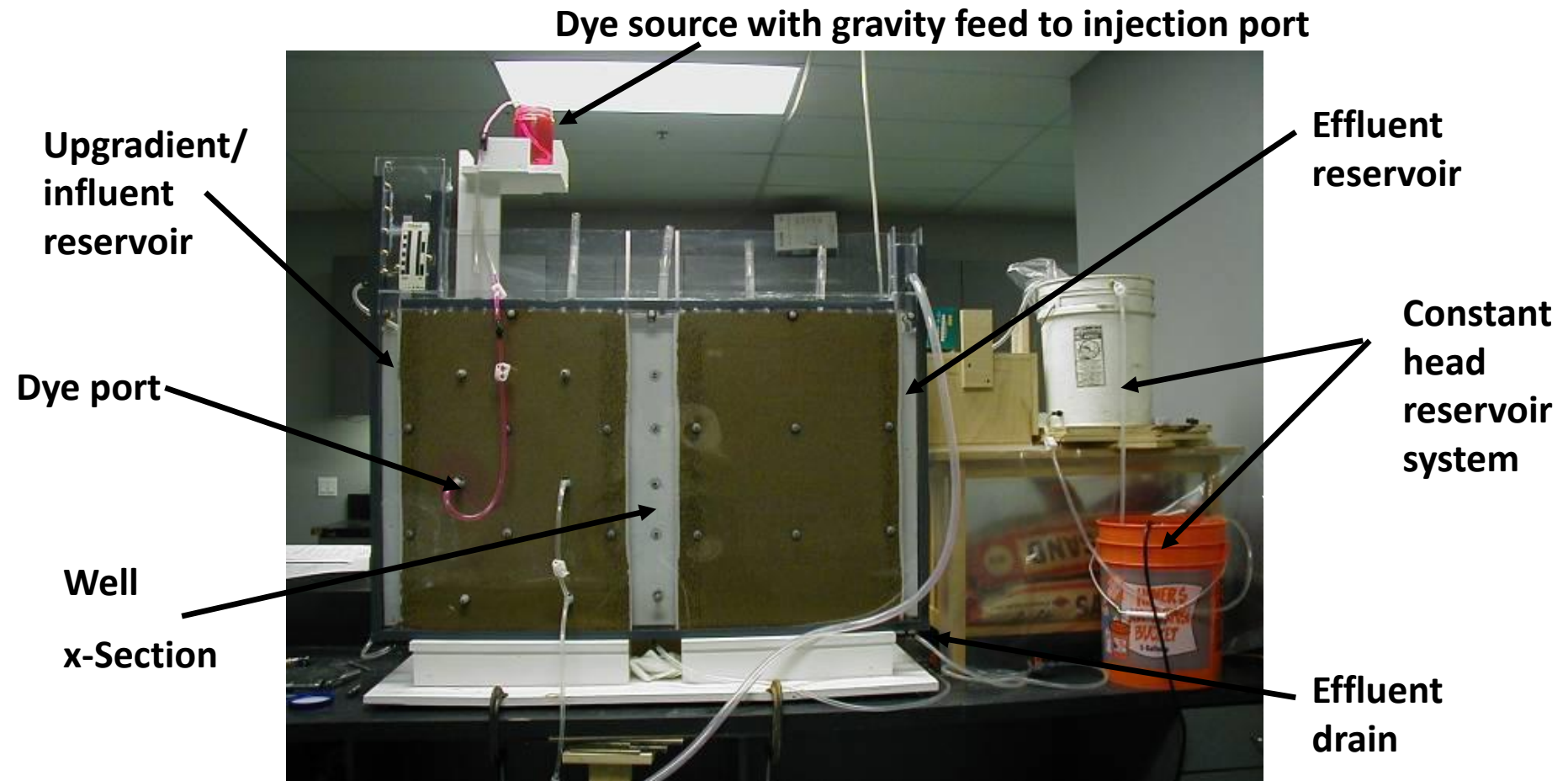
Passive flow-through concepts

Some conditions tested by Britt, 2005
density contrast, mild heterogeneity

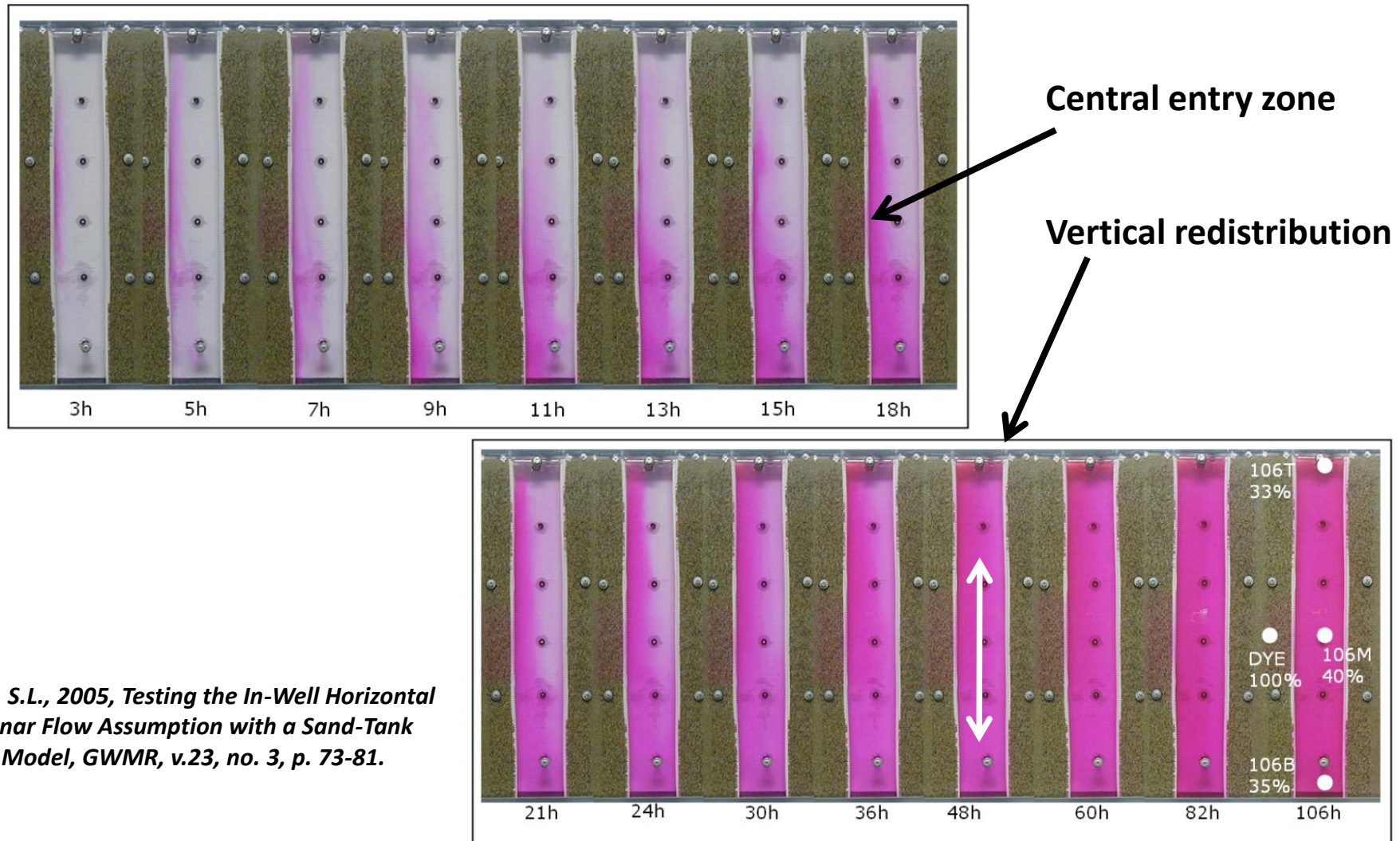


Modeled in-well behavior

What resides in the well between sampling events?



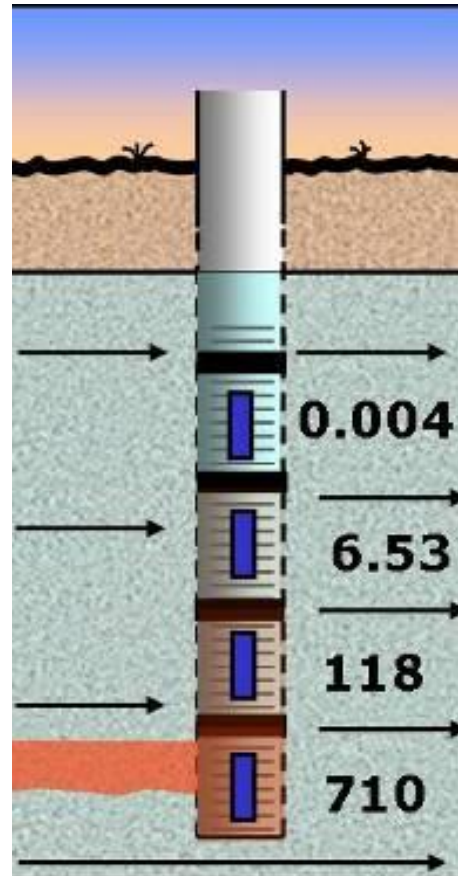
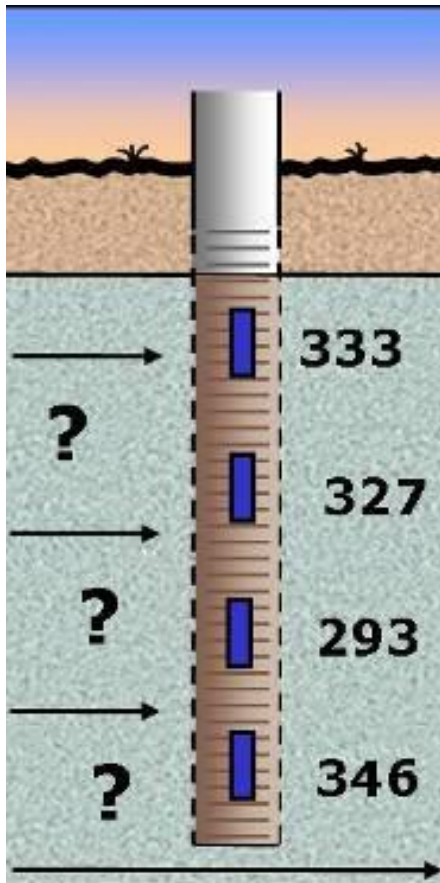
Inflow and residence time yields flow-weighted mixing—



Britt, S.L., 2005, Testing the In-Well Horizontal Laminar Flow Assumption with a Sand-Tank Well Model, GWMR, v.23, no. 3, p. 73-81.

Field verification of concepts

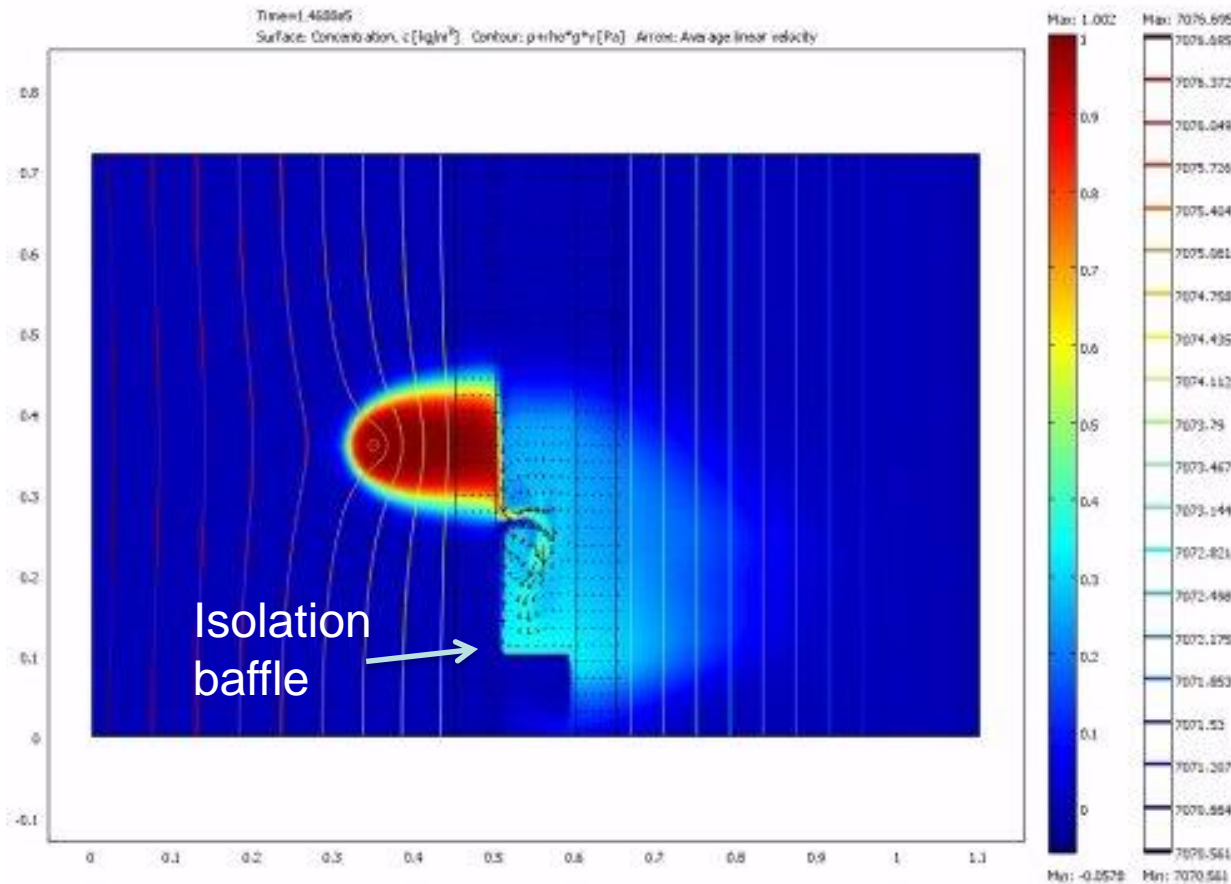
Field example illustrates the flow-weighted mixing concept



**In-well baffle device/
Mixing inhibitor**

Britt, SL and Calabria M, 2008, Baffles may allow effecting multilevel monitoring in traditional monitoring wells, Battelle Chlorcon Conference, Monterey California, May 2008

Physical and Numerical Model results

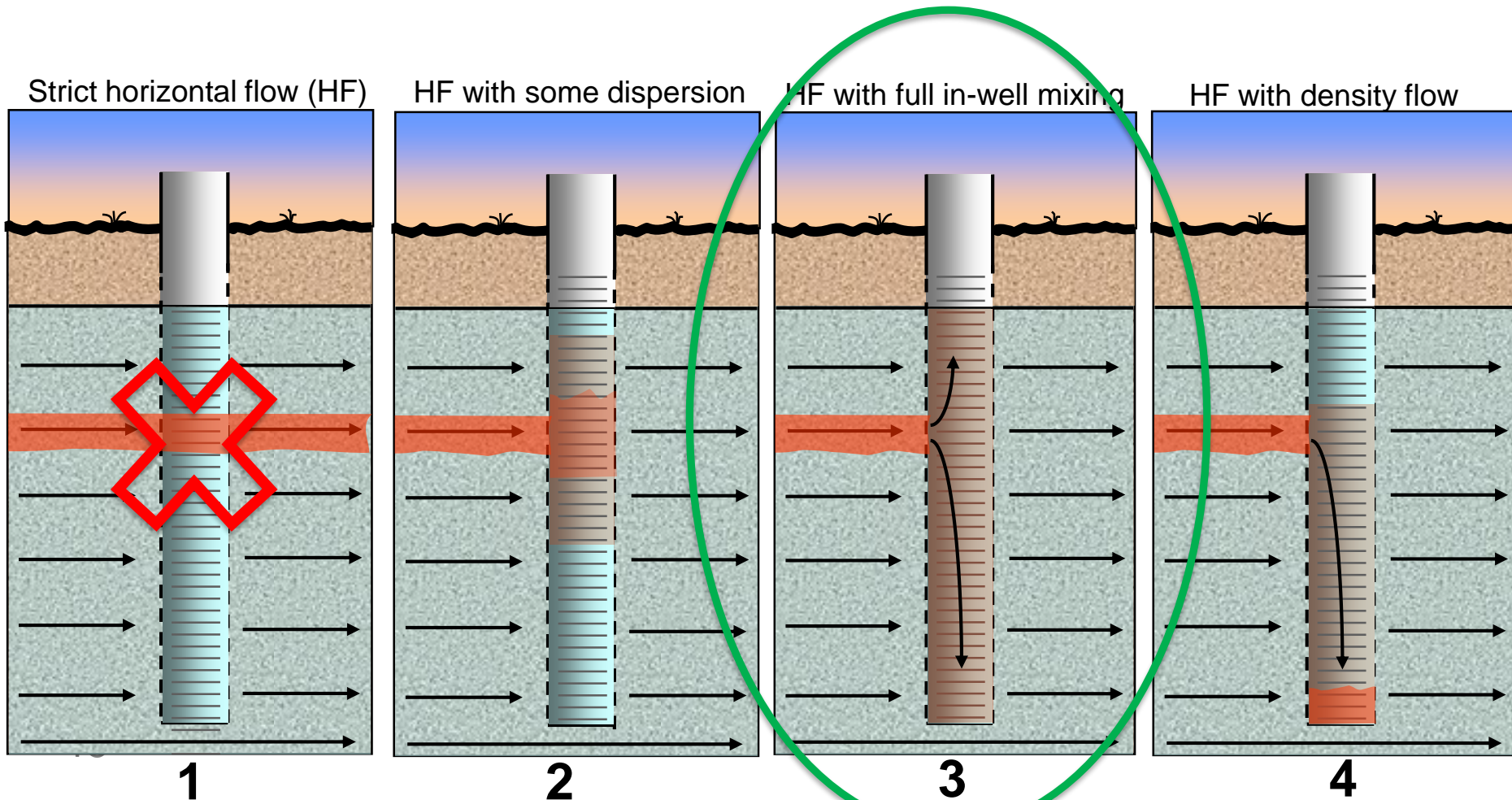


- Physical Model
- Density nearly neutral
- Numerical Model
- Match is pretty good
- Density $+3 \times 10^{-7}$ greater than neutral

Britt, S.L., 2005, Testing the In-Well Horizontal Laminar Flow Assumption with a Sand-Tank Well Model, GWMR, v.23, no. 3, p. 73-81.

Britt, Sanford L., James Martin-Hayden, Mitchell A. Plummer, 2015, SERDP Project ER-1704 Final Report, An Assessment of Aquifer/Well Flow Dynamics: Identification of Parameters Key to Passive Sampling and Application of Downhole Sensor Technologies, 76p.

Passive flow-through expectation...

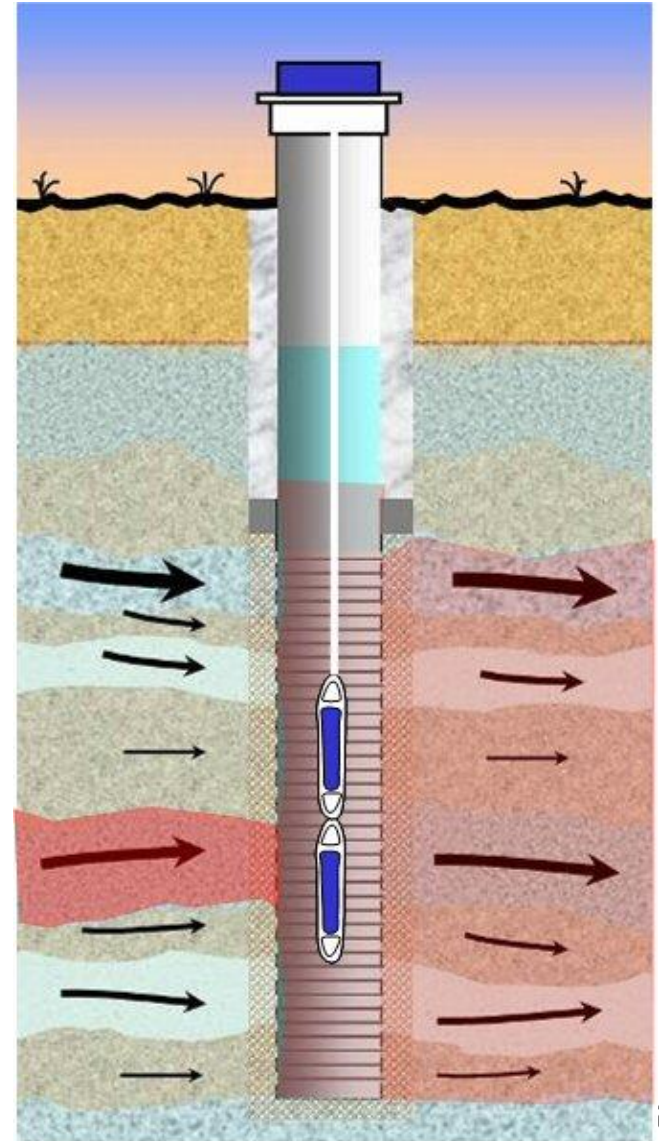


The Take Away?

Passive equilibration is often very similar to end-stage purge-to-stability sampling

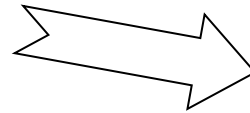
- Natural flow delivered to well
- Ambient / passive mixing according to native flow dynamics
- Flow-weighted averaging effect

***Passive Sampling
normally yields a Flow Weighted
Average too***



Less Work

...without this truck...



...and with almost none of this equipment



Safety and efficiency is improved

- No drums
- No generator
- No compressed gas
- No fuel
- Shorter time at the well

Lower Cost

Purging requires time in the field, equipment, and waste

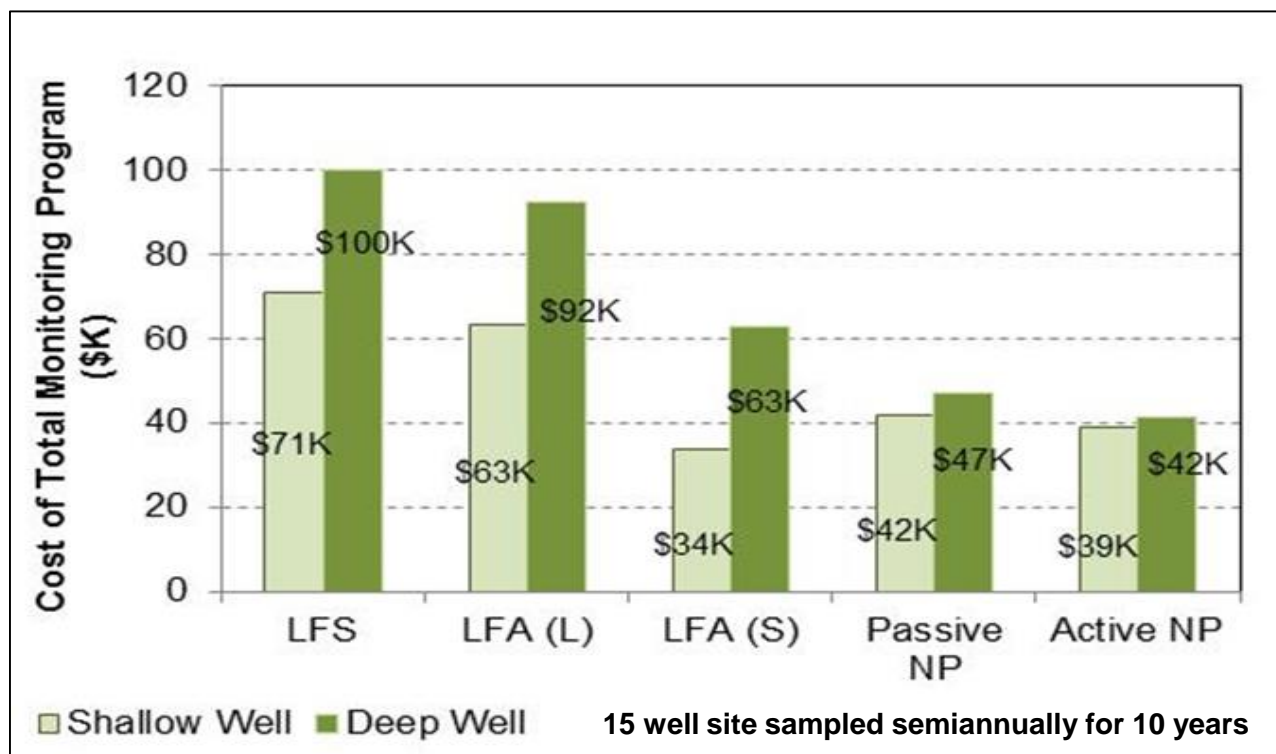
Passive sampling allows you to sample right away

NO More:

- Equipment rentals
- Pumping
- Troubleshooting meters
- Measuring parameters
- Waste handling

ALWAYS:

- Sample right away
- Sample faster
- Know your sample
- Improve Data Quality



Passive prove-out assessments

- Polyethylene Diffusion Sampler

USGS Reports
US Air Force Reports
Peer-reviewed lit.



- Regenerated Cellulose Diffusion Sampler

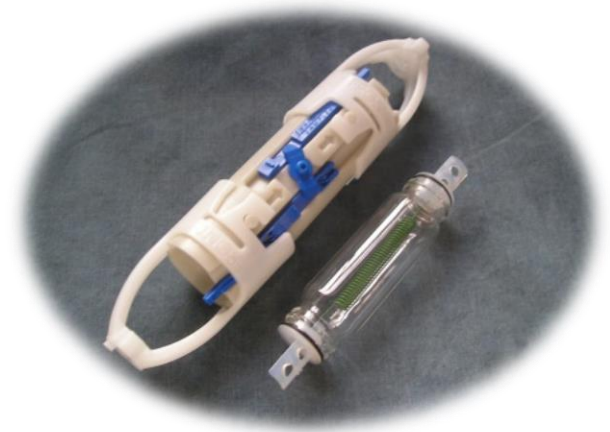
ER-200313
4 Reports by NAVFAC
Peer-reviewed lit.



- Snap Sampler



ER-200603
5 Reports by Army Corps ERDC/CRREL
Peer-reviewed lit.

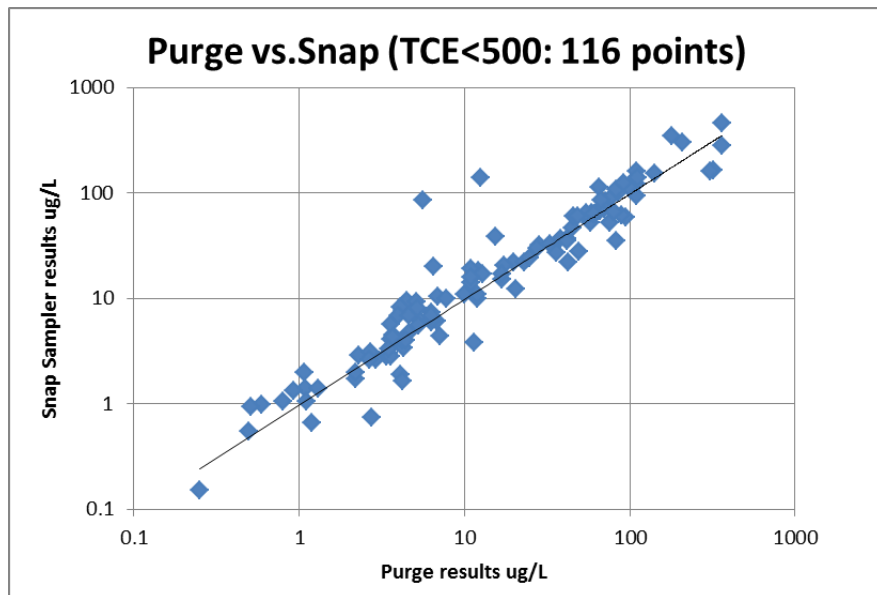


- Gore Module (AGI Sampler)

ER-200921
2010 ESTCP Start



Snap Sampler Data Comparison

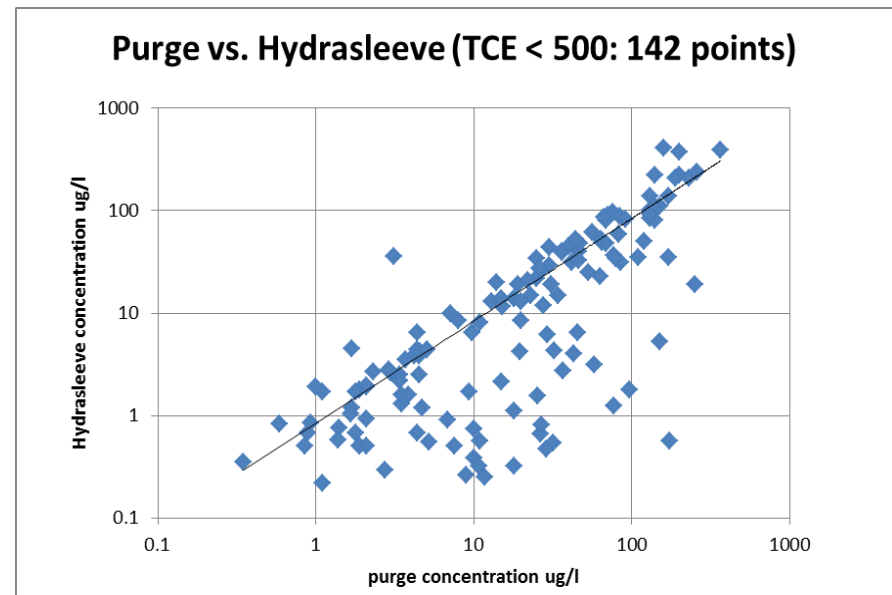


Snap Sampler 2x higher: 6 (5%)

Purge sample 2x higher: 5 (4%)

Snap Sampler 10x higher: 2 (2%)

Purge sample 10x higher: 0 (0%)



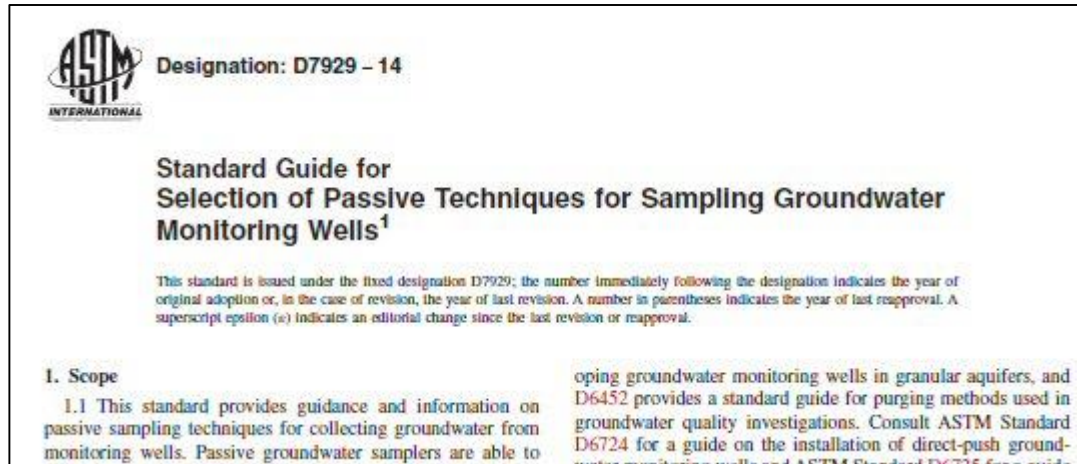
HydraSleeve 2x higher: 3 (2%)

Purge sample 2x higher: 53 (37%)

HS 10x higher: 1 (<1%)

Purge 10x higher: 22 (15%)

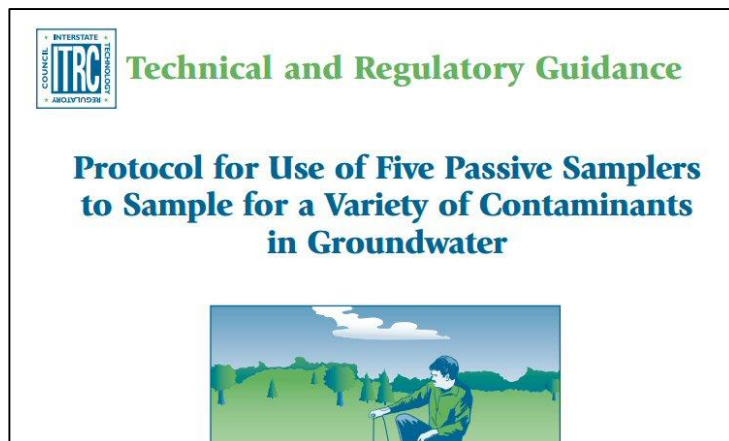
Regulatory guides



Recent guide, 2014, applies to “passive” methods only

Snap Sampler, Diffusion, Sorptive

<http://www.astm.org/Standards/D7929.htm>



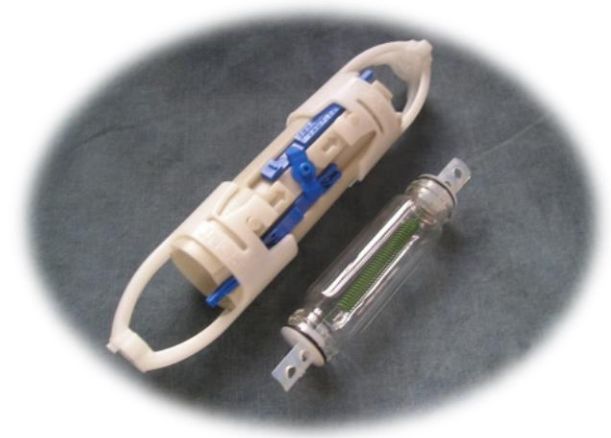
Early guide from 2007

Snap Sampler, Diffusion, Sorptive, Sleeve

<http://www.itrcweb.org/Guidance/Documents/DSP-5.pdf>

Wrap Up

- *Wells normally flow through*
- *Passive sampling takes advantage of well flow dynamics*
- *Results are normally very similar to low flow purging*
- *Several methods and approaches*
 - *diffusion, grab, sorption*
- *Cost savings is substantial, waste reduced, sustainability improved*
- *Regulatory understanding and acceptance is growing*



Reports and Papers are Available....

Cold Regions Research and Engineering Laboratory

ERDC/CREL TR-07-14

Evaluation of the Snap Sampler for Sampling Ground Water Monitoring Wells for VOCs and Explosives

Louise V. Parker and Nathan D. Mulhearn

Approved for public release, distribution is unlimited.

ERDC/CREL TR-09-12

Demonstration/Validation of the Snap Sampler Passive Ground Water Sampling Device for Sampling Inorganic Analytes at the Former Pease Air Force Base

Louise V. Parker, Nathan Mulhearn, Gordon Good, William Major, Richard Wiley, Thomas Ingrigg, Jacob Gibb, and Donald Groat

Approved for public release, distribution is unlimited.

ERDC/CREL TR-11-3

DEMONSTRATION/VALIDATION OF THE SNAP SAMPLER PASSIVE GROUNDWATER SAMPLING DEVICE AT THE FORMER MCLELLAN AIR FORCE BASE

Louise Parker, Nathan Mulhearn, Tommie Hall, Constance Scott, Kristy Dapkin, Jay Clavess, William Major, Richard Wiley, Jacob Gibb, Thomas Ingrigg, and Donald Groat

Approved for public release, distribution is unlimited.

FINAL

Results Report for the Demonstration of No-Purge Groundwater Sampling Devices at Former McClellan Air Force Base, California

Prepared For

U.S. Army Corps of Engineers

Air Force Center for Environmental Research

Contract F49620-01-2-0001

Deliver Oct

A Downhole Passive Sampling System to Avoid Bias and Error from Groundwater Sample Handling

SANFORD L. BRITT, BETH L. PARKER, AND JOHN A. CHERRY

ProfHydro Inc., 1017 Fairport Road, Fairport, New York 14450, and School of Engineering, University of Guelph, Guelph, Ontario, N1G 2W1 Canada

Received March 15, 2010. Revised manuscript received May 10, 2010. Accepted May 10, 2010.

A new downhole groundwater sampler using low flow or no-purge sampling techniques. A few studies have shown horizontal flow over short distances within the well for short periods of time. Others have demonstrated specific concentrations under which the assumption fails. But no principle, little focus has been given to confirming the underlying concept—that under “normal” conditions (i.e., no vertical hydraulic gradient) water moves over one side of a well and exits the other side of the well at the same elevation. To test the horizontal flow assumption, a physical sandpack model was constructed to observe flow through a constant monitoring well. The well filter pack, and aquifer largely minus red wood conditions of a subsaturated well in a moderately high permeability sand. To observe flow behavior in the simulated well, a dye “tracer” was introduced into an injection port adjacent to the simulated well. In all tests, regardless of flow rate or small density differences, the dye tracer eventually moved throughout the model monitoring well. Since the model approximates a section of an actual well subjected to real world well flow rates, mixing appears to be the rule rather than the exception for one-concentrate hydraulic conditions in homogeneous flow fields. Despite additional heterogeneities introduced by field conditions, there are several direct and important implications of this study: (1) some degree of well mixing and flow-weighted concentration averaging may occur in a well before any purge or sampling efforts are made; (2) low well mixing may lead to moderate contaminant modification in an aquifer; (3) contaminant modification, if present inside a well, implies strong contaminant modification outside the well; (4) contaminant modification inside a well may not correspond to modification at the same interval outside the well; and (5) vertical stratification within an aquifer may not be accurately measured by sampling multiple intervals within an open well.

Introduction

Although low flow and no-purge sampling techniques are developing currently, low-flow and passive sampling techniques are conventionally thought to represent constant concentrations at intervals of the aquifer near the pump intake or sampler deployment position. The conventional thought for the low flow and passive sampling largely assumes horizontal laminar flow within a monitoring well—due water from the aquifer enters the well, flows horizontally, and exits the well at roughly the same elevation (e.g., an introduction of Parker and Clark 2003, 2004).

The study presented here tests aspects of this critical assumption. How does a contaminant “tracer” behave when it enters a ground water monitoring well in natural background flow conditions? Does it flow straight across the well? Or does it mix and dilute with cleaner water from other intervals? In this study mixing and dilution were visually observed using time-lapse photography of a dye

escape of VOCs and dissolved gases (e.g., CH₄, CO₂). Gillham (1983) developed a technique for downhole sampling using modified low-cost polyethylene syringes. The syringe was lowered to sampling depth, and then the plunger (and sample) withdrawn by vacuum applied via a hand pump at the surface. The syringe was then raised to surface and immediately capped. A new syringe was used for every sample, thus avoiding the need for sampler decontamination. This device has been used for studies of redox parameters, metals, and radon (1983). Other downhole samplers included small cylindrical cartridges filled with sorbent material (1983). After lowering to sampling depth, water was drawn through the sorbent material for capture of the contaminant mass; the cartridges were then removed and transferred to the laboratory for analysis. Similar to the syringe sampler, this method avoided sample exposure between sampling and analysis but required a thermal desorption step in the analytical procedure that is not standard in commercial

Testing the In-Well Horizontal Laminar Flow Assumption with a Sand-Tank Well Model

by Sanford L. Britt

Abstract

The assumption of horizontal laminar flow within a monitoring well is a commonly cited basis for interval sampling using low flow or no-purge sampling techniques. A few studies have shown horizontal flow over short distances within the well for short periods of time. Others have demonstrated specific concentrations under which the assumption fails. But no principle, little focus has been given to confirming the underlying concept—that under “normal” conditions (i.e., no vertical hydraulic gradient) water moves over one side of a well and exits the other side of the well at the same elevation. To test the horizontal flow assumption, a physical sandpack model was constructed to observe flow through a constant monitoring well. The well filter pack, and aquifer largely minus red wood conditions of a subsaturated well in a moderately high permeability sand. To observe flow behavior in the simulated well, a dye “tracer” was introduced into an injection port adjacent to the simulated well. In all tests, regardless of flow rate or small density differences, the dye tracer eventually moved throughout the model monitoring well. Since the model approximates a section of an actual well subjected to real world well flow rates, mixing appears to be the rule rather than the exception for one-concentrate hydraulic conditions in homogeneous flow fields. Despite additional heterogeneities introduced by field conditions, there are several direct and important implications of this study: (1) some degree of well mixing and flow-weighted concentration averaging may occur in a well before any purge or sampling efforts are made; (2) low well mixing may lead to moderate contaminant modification in an aquifer; (3) contaminant modification, if present inside a well, implies strong contaminant modification outside the well; (4) contaminant modification inside a well may not correspond to modification at the same interval outside the well; and (5) vertical stratification within an aquifer may not be accurately measured by sampling multiple intervals within an open well.

Introduction

Although low flow and no-purge sampling techniques are developing currently, low-flow and passive sampling techniques are conventionally thought to represent constant concentrations at intervals of the aquifer near the pump intake or sampler deployment position. The conventional thought for the low flow and passive sampling largely assumes horizontal laminar flow within a monitoring well—due water from the aquifer enters the well, flows horizontally, and exits the well at roughly the same elevation (e.g., an introduction of Parker and Clark 2003, 2004).

The study presented here tests aspects of this critical assumption. How does a contaminant “tracer” behave when it enters a ground water monitoring well in natural background flow conditions? Does it flow straight across the well? Or does it mix and dilute with cleaner water from other intervals? In this study mixing and dilution were visually observed using time-lapse photography of a dye

* Corresponding author; e-mail: sandy@profhydro.com.
University of Guelph.

10/10/2010 10:21 AM American Chemical Society on Web 10/10/2010

[https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater-Monitoring/ER-200630/ER-200630/\(language\)/eng-US](https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater-Monitoring/ER-200630/ER-200630/(language)/eng-US)