


## **Groundwater Sampling with HydraSleeves™ – Standard Operating Procedure**

Rev. #: 2

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**Approval Signatures**

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## I. Scope and Application

This Standard Operating Procedure (SOP) establishes guidelines and procedures for use by field personnel in the deployment of HydraSleeves™ and subsequent collection and documentation of groundwater samples for chemical analysis. Proper collection procedures are necessary to assure the quality and integrity of all groundwater samples. The details within this SOP should be used in conjunction with site-specific work plans.

The HydraSleeve™ groundwater sampler can be used to collect a representative sample for most physical and chemical parameters without purging the well. It collects a groundwater sample from a user-defined interval (typically within the well screen), without mixing fluid from other intervals. The HydraSleeve™ is placed within the screened interval of the monitoring well, and a period of time is allocated for the well to re-equilibrate following HydraSleeve™ down-hole deployment. The sealed HydraSleeve™ can be activated and removed for sample collection within several hours to several months. When activated, the HydraSleeve™ collects a sample with no drawdown and minimal agitation or displacement of the water column. Once the sampler is full, the one-way reed valve collapses, preventing mixing of extraneous, non-representative fluid during HydraSleeve™ recovery from the well.

Use of this SOP will provide samples for Level III and Level IV analytical data for use in risk assessments, site characterizations, evaluation of remediation alternatives, engineering design of remediation activities, and in support during remediation activities.

## II. Personnel Qualifications

All personnel shall meet the requirements of the site-specific Health and Safety Plan (HASP).

The Project Manager is responsible for ensuring that all sample collection activities are conducted in accordance with this SOP and any other appropriate procedures. This will be accomplished through staff training and by maintaining quality assurance/quality control (QA/QC).

The Field Manager is responsible for periodic observation of field activities and review of field generated documentation associated with this SOP. The Field Manager is also responsible for implementation of corrective action (e.g., retraining personnel, additional review of work plans and SOPs, variances to QC sampling requirements, issuing non-conformances, etc.) if problems occur.

Field personnel assigned to collect groundwater samples are responsible for completing their tasks according to specifications outlined in this SOP and other appropriate procedures. Field staff shall have prior experience in groundwater sampling. The determination of placement of the HydraSleeve™ in the monitoring well shall be made by a qualified geoscientist. All staff are responsible for reporting deviations from procedures in the Field Activity Daily Log, and to the Field Manager or Project Manager.

### III. Equipment List

There are three main steps for collecting groundwater samples with HydraSleeves™: 1) assembly and deployment of the HydraSleeve™, 2) collecting the groundwater samples after the equilibration period, 3) and pouring the groundwater samples into containers. The equipment needed for each step is listed below.

Equipment needed for assembly and deployment of the HydraSleeves™:

- Appropriate personal protective equipment (PPE)
- Well location maps and table identifying HydraSleeve™ deployment locations/depths
- Well keys
- Flame ionization detector (FID) (as appropriate)
- Photoionization detector (PID) (as appropriate)
- Electronic water-level indicator, 0.01 ft accuracy
- Oil/water interface probe (as appropriate)
- Plastic sheeting to protect all down-hole sampling equipment from contact with potential sources of contamination.
- Decontamination equipment
- Appropriate size HydraSleeves™ for the wells being sampled. Some examples are provided below. Check the manufacturer's website for additional options:
  - 2-L 2" HydraSleeve™ SuperSleeve (SS) (1.9" OD, 60" long; volume of 2 liters; requires special 2-piece top weight) for 2" Schedule 40 wells

- 1-L 2" HydraSleeve™ (1.75" OD, 36" long; volume of 1 liter) for 2" wells
- 1.5" HydraSleeve™ (1.5" OD, 30" long; volume of 625 mL) for 1.5" wells
- 1" HydraSleeve™ (1" OD, 48" long; volume of 325 mL) for wells less than 1.5"
- 1/8-inch diameter braided polypropylene rope (for tethers)
- Weights (stainless steel or other inert material) to anchor HydraSleeves™ in wells (note special weights are required for SuperSleeve-style HydraSleeves™)
- Cable ties to anchor HydraSleeves™ to tether
- Measuring tape
- Cutting implement, such as scissor or knife
- Approved site-specific workplan, Field Sampling Plan (FSP), and HASP

Equipment needed for collection/dispensing of groundwater samples:

- Appropriate PPE
- Planned Sample Table (PST), sample labels, and Chain of Custody forms (COC)
- Sample bottles, coolers, ice
- Blank collection field forms
- Well keys, site maps, and sample list
- Electronic water-level indicator, 0.01 ft accuracy
- Oil/Water interface probe (as appropriate)
- Decontamination equipment

- Plastic sheeting to protect all down-hole sampling equipment from contact with potential sources of contamination.
- Bucket or other container to hold extra groundwater
- Additional HydraSleeves™ and zip ties to deploy for the next sampling event, as appropriate
- Approved site-specific workplan, FSP, and HASP

Unless otherwise specified in the site-specific workplan, it is advisable to establish a sampling order starting with the least contaminated well and progressing to the most contaminated last.

#### **IV. Cautions**

Selection of the appropriate size HydraSleeve™ depends on sample volume requirements, well diameter, and the length of the saturated screened interval (which dictates the maximum distance allowed over which to pull and fill the HydraSleeve™). The largest HydraSleeve™ (60-inch) holds 2 liters of sample; the smallest holds 325 mL of sample. The sample volume requirements must be verified with the laboratory before deploying the HydraSleeve™ samplers. The HydraSleeve™ sampler is designed for single use (deployment and sample collection) only; tethers and weights should be reused after proper decontamination.

According to the manufacturer, HydraSleeve™ has been used successfully with no equilibration period at some sites for some analytical parameters. HydraSleeve™ does not require dissolved compounds to diffuse across a membrane as in the case of polyethylene diffusion bag (PDB) samplers (ITRC, 2004). Because the HydraSleeve™ mechanically obtains a “core” of the water column, rather than relying on diffusion through a membrane, the HydraSleeve™ sampler can be retrieved shortly after deployment in many cases. One way to conservatively estimate the maximum required equilibration period is to estimate the flush-out period for the well based on the Darcy velocity within the formation (hydraulic conductivity times gradient) (Attachment B). It should be noted, however, that representative groundwater sampling may occur with a shorter flushing period, or no flushing period, if the well contains minimal accumulated silt and care is taken to minimize well disturbance during HydraSleeve™ deployment. Site-specific testing versus another accepted groundwater sampling method can be performed at a subset of wells – preferably spanning a range of hydraulic conductivity, geologic materials, and chemical concentrations – to verify that the HydraSleeve™ device produces samples similar to those obtained from the other accepted method.

## V. Health and Safety Considerations

The HASP will be followed at all times. Appropriate personal protective equipment (PPE) will be worn at all times. Other safety considerations include exposure to contaminated groundwater or non aqueous phase liquid (NAPL) and using sharp cutting tools (scissors, knife).

## VI. Procedure

Field personnel will perform deployment of the HydraSleeves™ in accordance with the following procedures.

### Preliminary Site Activities

1. Visually inspect the well to ensure that it is undamaged, properly labeled and secured. Damage or other conditions that may affect the integrity of the well will be recorded on the Field Activity Daily Log and brought to the attention of the Field Manager or Project Manager.
2. Equipment will either be new or decontaminated in accordance with SOPs prior to use.
3. Lay out plastic sheeting and set up monitoring and sampling equipment.
4. Don appropriate PPE.
5. If specified in the site-specific workplan, measure volatile organic compounds (VOCs) at the rim of the unopened well with a PID and FID and record the reading in the field logbook.
6. Observe if any air is flowing into or out of the casing (e.g., bubbles, hissing sounds). In the event such conditions are observed, they should be noted on the HydraSleeve™ Field Form (Attachment A).
7. Remove well cap.
8. If specified in the site-specific workplan, measure VOCs at the rim of the well with a PID and FID instrument record the reading in the field logbook.
9. If the well casing does not have a reference point (usually a V-cut or indelible mark in the well casing), make one. Record all measurements from this mark.

10. If specified in the site-specific workplan, determine if non-aqueous phase liquid (NAPL) is present in the well using an oil/water interface probe in accordance with SOPs. If NAPL is present, record the depth to NAPL and static water level on the HydraSleeve™ Field Form. A HydraSleeve™ will not be deployed nor will samples be collected from wells where NAPL is present. If NAPL is not present, measure the static water level followed by the total depth of the well with an electronic interface probe, and record the measurements on the HydraSleeve™ Field Form.
11. Measure and record the depth to water and the total depth of the groundwater monitoring well (to 0.01 ft) in all wells to be sampled. Care should be taken to minimize disturbance to the water column and to any particulates attached to the sides or at the bottom of the well.
12. Determine the total depth of the well. Compare the measurement of the total depth of the well with the previous measurement and check against the well construction logs to determine the percent of screen occluded by sediment (if any). If more than 20 percent of a well screen is occluded by sediment, the well will not be sampled until it is re-developed.

#### **Assembly and Deployment of Standard HydraSleeves™**

1. Begin assembling the HydraSleeve™ by removing the HydraSleeve™ from the package and grasp top to “pop” open (Figure 1). Squeeze side fins together at top to bend reinforcing strips outward (Figure 2). Attach rope to hole at top of HydraSleeve™ (using cable ties) (Figure 3). Fold the two holes at bottom of HydraSleeve™ together and attach weight (using zip tie) (Figure 4). Sampler is ready to insert into the well at the predetermined depth specified in the site-specific workplan (Figure 5).



Figure 1

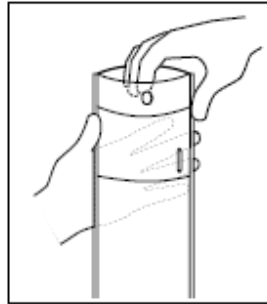


Figure 2

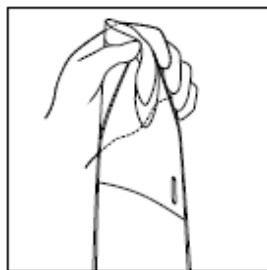


Figure 3

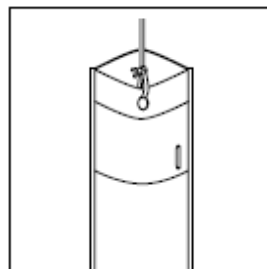


Figure 4

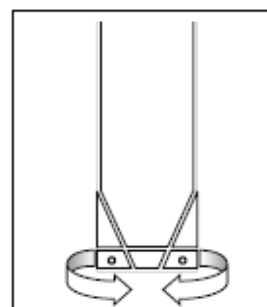
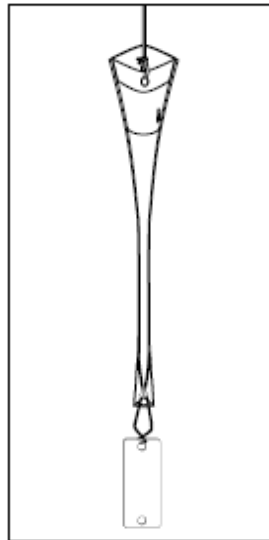


Figure 5



2. Two methods of deployment can be used. Either way, the top of the HydraSleeve™ will be positioned below the midpoint of the saturated screened interval by a distance approximately equal to 0.75 times the full length of the HydraSleeve™. For example, a 36" HydraSleeve™ will be lowered so that the top of the HydraSleeve™ is approximately 27" below the midpoint of the saturated screened interval. This position is appropriate to collect the groundwater sample from approximately the middle of the saturated screened interval when the HydraSleeve™ is pulled upward.
  - a. Bottom Anchor Deployment (preferred). Using the determined well depth, calculate the distance from the bottom of the well to the desired sampling depth (specified on the HydraSleeve™ Field Form). Attach an appropriate length anchor line between the weight and the bottom of the sampler and *slowly* lower the assembly until the weight rests on the bottom of the well, allowing the top of the sampler to float at the correct sampling depth. Attach the suspension line to the well cap to suspend the HydraSleeve™ at the correct depth until activated for sampling. Allow sufficient extra tether length such that if the tether becomes untied from the well cap and the sampler sinks to the bottom it may still be easily retrieved.
  - b. Top-Down Deployment. Measure the correct amount of suspension line needed to "hang" the top of the

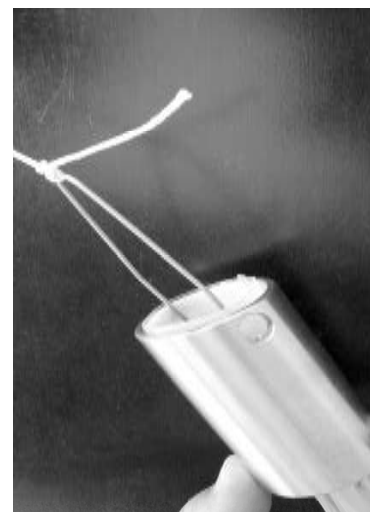
HydraSleeve™(s) at the desired sampling depth (specified on the HydraSleeve™ Field Form). Once constructed, slowly lower the assembly in the well and attach the suspension line to the well cap to suspend the HydraSleeve™ at the correct depth until activated for sampling. Allow sufficient extra tether length such that if the tether becomes untied from the well cap and the sampler sinks to the bottom it may still be easily retrieved.

3. For wells in which another passive sampling device (e.g., passive diffusion bag [PDB]) is to be used concurrently, the HydraSleeve™ should be suspended from the same line directly beneath the other passive sampler. If the top-down deployment method is used, care should be taken to ensure the weight is not resting on the bottom of the well. If necessary, the weight may be placed at the top of the HydraSleeve™, as described below.
4. For wells with screen lengths less than 10 feet (specified on the HydraSleeve™ Field Form) or where the saturated screen length is less than 10 feet (determined during water level gauging), top-down deployment will be used as described above with the exception of the placement of the weight. The weight for these wells will be placed on the top of the HydraSleeve™ as shown in the figure below (Photo 1). The hanging clip is inserted locking the top of the HydraSleeve™ and the weight together. The tether will be attached to the apex of the clip, as shown below (Photo 2).

Photo 1



Photo 2



5. At this point deployment is complete. The well must be allowed time for the stabilization of well water and formation water following any disturbance caused by the sampler deployment before groundwater samples can be collected. The manufacturer's recommended deployment time is hours to months. The time shall be specified in the site-specific workplan. The maximum deployment time at the site will be one year.
6. After the equilibration period is complete; the groundwater samples are ready to be collected for analysis.

#### **Assembly and Deployment of SuperSleeve-style HydraSleeve™ SS**

1. Begin assembling the HydraSleeve™ by removing the HydraSleeve™ SS from the package and attaching the bottom weight (Photos 3 and 4). Fold the two holes at bottom of HydraSleeve™ together. Open prongs of bottom weight clip by squeezing. Insert reusable weight clip through holes and attach the bottom weight.

Photo 3



Photo 4



2. Attach the top weight as follows: Insert the open (check valve) end of the HydraSleeve™ SS through the bottom of the stainless steel portion of top weight until about 1/2 inch of the open sleeve protrudes above the female threads. Thread stainless steel weight (female thread) onto PVC top piece (male thread) locking the top of the HydraSleeve SS between the threads (Photo 5).

Photo 5



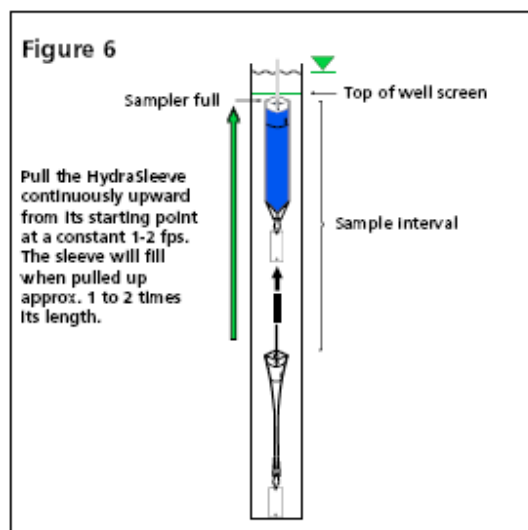
3. Attach rope to top weight (using cable ties).
4. Sampler is ready to insert into the well (Photo 6). Lower the HydraSleeve SS into the well until the bottom weight touches the bottom. Provide enough slack to allow the top weight to fully compress the sampler into the bottom of the well. For example, the 2-liter HydraSleeve™ SS (5-feet long) will compress to within 2 feet of bottom of a 2-inch well screen in about 4 hours. The 2-liter HydraSleeve™ SS requires about 5 feet of water over the top of the sampler to completely fill; thus it should not be used in wells with shorter than a 10-ft saturated screen length.

Photo 6

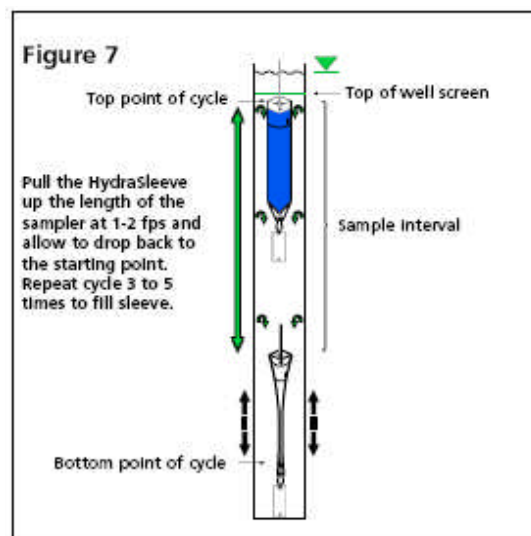


### Collecting Groundwater Samples from HydraSleeves™

1. Conduct the Preliminary Site Activities detailed above with the following exception: The depth to groundwater should be collected prior to retrieval of the HydraSleeve™, while the total well depth should be collected only after the HydraSleeve™ has been retrieved from the well.
2. The Continuous Pull method is preferred and will be used for the majority of the wells. If the well to be sampled has a saturated screen length less than 10 feet in length, the Short Strokes method may be used. However, to minimize disturbance of well sediments, a preferable alternative is to use a top-weighted HydraSleeve deployment method (standard style HydraSleeve™ or SuperSleeve). The HydraSleeve™ Field Form will state the screen length and sample collection method for each well.
  - a. Continuous Pull method – The HydraSleeve™ must move upward at an approximate rate of one foot per second or faster (about the speed a bailer is usually pulled upward) for water to pass through the check valve into the sample sleeve. The total upward distance the check valve must travel to fill the sample sleeve is about 1 to 2 times the length of the sampler. For example, a 36-inch HydraSleeve™ needs a total upward movement of 36 to no more than 72 inches to fill. Pull the HydraSleeve™ continuously upward from its starting point at a constant 1 to 2 feet per second until full. This method usually provides the least turbid samples and is analogous to coring the water column from the bottom up (Figure 6).



- b. Short Strokes method – Pull the sampler upward at about 1 to 2 feet per second for the length of the sampler (36 inches) and let it drop back to the starting point. Repeat the cycle 3 to 5 times (Figure 7).
3. If the HydraSleeve™ is retrieved from the well and is not completely full, the sample will not be collected and a new HydraSleeve™ will be deployed. The replacement HydraSleeve™ will be allowed to equilibrate, as appropriate, prior to retrieval. After the equilibration time, the HydraSleeve™ may be collected again.



4. Collect sample parameters in the following order: VOCs (care should be taken to avoid agitation and volatilization of sample during the decanting process), explosives, metals, and other parameters. Samples will be collected and labeled in accordance with SOPs. Types of sample bottles and volume requirements for each analysis are provided in the Quality Assurance Project Plan (QAPP) and site-specific workplan. Metals samples will not be field filtered unless otherwise specified. If field filtering is required for any analyte, sample groundwater to be filtered will be decanted into an unpreserved bottle and filtered using a small hand pump as shown below in Photo 7.

5. The 36-inch long HydraSleeve™ has a capacity of 1 liter, and the largest (60-inch long) HydraSleeve™ SS for a 2-inch diameter well has a capacity of 2 liters. All groundwater samples, including QA/QC samples for a given well will be collected with one HydraSleeve™. If the volume requirement for sample analysis exceeds the capacity of the HydraSleeve™, it is not acceptable to redeploy the same or a second HydraSleeve to fill additional bottles. Rather, sampling of the well must be completely repeated. A larger size HydraSleeve™ must be deployed for the appropriate duration of time, or another approved sampling method (e.g., low-flow) must be used. Complete sample documentation on the Groundwater Sample Log.
6. Inspect the sampling bottles (obtained from the analytical laboratory prior to the sampling event) to be used to ensure that they are appropriate for the samples being collected, are undamaged, and have had the appropriate types and volumes of preservatives added. The types of sample containers to be used and sample preservation requirements will be provided in the site-specific workplan.

Photo 7



7. To remove a sample from the HydraSleeve™ with the least amount of aeration and agitation use the short plastic discharge tube (included). First, squeeze the full sampler just below the top to expel water resting above the flexible check valve (Photo 8).



Photo 8



8. Then, push the pointed discharge tube through the outer polyethylene sleeve about 3-4 inches below the white reinforcing strips (Photo 9).

Photo 9



9. Discharge the sample into the desired container in the order described in step 4 (Photo 10). Raising and lowering the bottom of the sampler or pinching the sample sleeve just below the discharge tube will control the flow of the sample. The sample sleeve can also be squeezed, forcing fluid up through the discharge tube, similar to squeezing a tube of toothpaste.

Photo 10



10. To obtain a duplicate/blind duplicate sample, collect a duplicate from the same bag as an original sample and send for analysis with the appropriate labeling.
11. To obtain an equipment blank, pour deionized water into a HydraSleeve and collect the blank using the same method as the samples and send for analysis with the appropriate labeling.
12. Place collected samples immediately in a sample cooler that is already full of ice or ice packs such that the samples are immediately chilled and stored at a temperature of 4 degrees Celsius, in accordance with SOPs.
13. Record depth to groundwater and total well depth.
14. Field parameters will be collected mid-screen from wells specified in the site-specific workplan. Calibrate all field analytical test equipment (e.g., pH, temperature, conductivity, ORP, turbidity, and DO) according to the instrument manufacturer's specifications and SOPs. Daily calibration results will be recorded on the appropriate form(s) as specified by the FSP and site-specific workplans. Instruments that cannot be calibrated according to the manufacturer's specifications will be removed from service and tagged.
15. Field parameter measurements (temperature, specific conductance, pH, DO, and ORP) will be taken after the HydraSleeve™ is removed from the well and the groundwater samples collected. This would occur through the use of a down-hole multi-meter (e.g., a YSI 600XL). Gently lower the probe of the meter down the well until it reaches the middle of the screen (screen intervals are found on the HydraSleeve™ Field Form). Follow the manufacturer's guidelines on how to determine

stability of parameter readings. Once the meter readings have stabilized, record them on the HydraSleeve™ Field Form. Turbidity will be measured from groundwater taken directly from the HydraSleeve™, after analytical samples have been dispensed.

16. After the groundwater samples and field measurements have been collected, it may be necessary to deploy another HydraSleeve™ in the well for future sampling events (e.g., quarterly, semi-annually, etc.). The site-specific workplan will state if another HydraSleeve™ is to be deployed. The same suspension line will be reused for additional deployment to ensure consistency in the deployment depth. Follow the steps outlined previously in this SOP for deployment instructions.
17. Secure the well.
18. Properly dispose of PPE and disposable equipment.
19. Decontaminate any cutting devices, reusable weights, suspension lines, or sampler attachment mechanisms after each usage in accordance with SOPs.

## **VII. Waste Management**

Any unused water from the PDB sampler and water used to decontaminate cutting devices should be disposed following SOPs and in accordance with local, State, and Federal regulations.

## **VIII. Data Recording and Management**

All data will be recorded on HydraSleeve™ field forms and groundwater sampling field forms. Daily field logs will be maintained. Records generated as a result of this SOP will be controlled and maintained in the project record files in accordance with project requirements.

## **IX. Quality Assurance**

Quality assurance procedures shall be conducted in accordance with the site-specific QAPP.

## X. References

Cordry, K.E., 2006. HydraSleeve™ Field Manual. Las Cruces, N.M.: GeolInsight, Inc.  
[http://www.hydrasleeve.com/images/stories/support/HydraSleeve\\_No-Purge\\_manual\\_updated.pdf](http://www.hydrasleeve.com/images/stories/support/HydraSleeve_No-Purge_manual_updated.pdf)

GeolInsight, Inc. 2010a. Standard Operating Procedure: Sampling Groundwater With a HydraSleeve™. Las Cruces, N.M.: GeolInsight, Inc.  
[http://www.hydrasleeve.com/images/stories/support/HydraSleeve\\_SOP.pdf](http://www.hydrasleeve.com/images/stories/support/HydraSleeve_SOP.pdf)

GeolInsight, Inc. 2010b. SuperSleeve Assembly Instructions. Las Cruces, N.M.  
[http://www.hydrasleeve.com/images/stories/support/SSfield\\_manual.pdf](http://www.hydrasleeve.com/images/stories/support/SSfield_manual.pdf)

Interstate Technology and Regulatory Council. 2004. Technical and Regulatory Guidance for Using Polyethylene Diffusion Bag Samplers to Monitor Volatile Organic Compounds in Groundwater. February.

## XI. Attachments

- A. HydraSleeve™ Field Form
- B. Calculation Of Maximum Required Equilibration Period (Flush-Out Time) Based On Well Geometry And Darcy Velocity



### HydraSleeve™ Field Form

Site: \_\_\_\_\_

Location: \_\_\_\_\_

Well ID: \_\_\_\_\_

Well Type:  Monitoring  Other: \_\_\_\_\_

Well Finish:  Stick Up  Flush Mount

Measuring Pt:  Top of Casing  Other (specify): \_\_\_\_\_

Total Depth As Constructed (ft bgs): \_\_\_\_\_ Screened Interval (ft bgs): \_\_\_\_\_

Well Casing: Diameter: \_\_\_\_\_ Material: \_\_\_\_\_

Well Screen: Diameter: \_\_\_\_\_

#### Deployment

Date and Time of Deployment:	Date: _____	Time: _____
Weather Conditions: _____		
Depth to groundwater at time of deployment: _____		
Total well depth at time of deployment: _____		
Dimensions of HydraSleeve™:	Length (in.) _____	Diameter (in.) _____
Deployment Method/Position of Weight:	<input type="checkbox"/> Bottom Anchor: Weight attached to bottom of HydraSleeve™. Weight rests on well bottom. <input type="checkbox"/> Top-Down: Weight attached to bottom of HydraSleeve™. Weight suspended in well. <input type="checkbox"/> Top-Down: Weight attached to top of HydraSleeve™. Weight suspended in well.	
Deployment Depth (Top of HydraSleeve™) (ft bgs): _____		

#### Retrieval

Date and Time of Retrieval:	Date: _____	Time: _____
Total # of days deployed: _____		
Weather Conditions: _____		
Retrieval Method:	<input type="checkbox"/> Continuous Pull (preferred) <input type="checkbox"/> Short Strokes	
Depth to groundwater at time of retrieval (measured before retrieval): _____		
Total well depth at time of retrieval (measured after retrieval): _____		
Downhole Field Parameters Upon Retrieval:		
Temp: _____ (°C)	ORP: _____ (mV)	Water quality meter: _____
pH: _____	DO: _____ (mg/L)	Serial #: _____
Turbidity of Groundwater Sample (dispensed from HydraSleeve™):		
Turbidity: _____ (NTU)	Turbidity meter: _____	Serial #: _____

#### Notes/Observations:

#### Field Sampling Technician: Name(s) and Company

Name \_\_\_\_\_ Company \_\_\_\_\_

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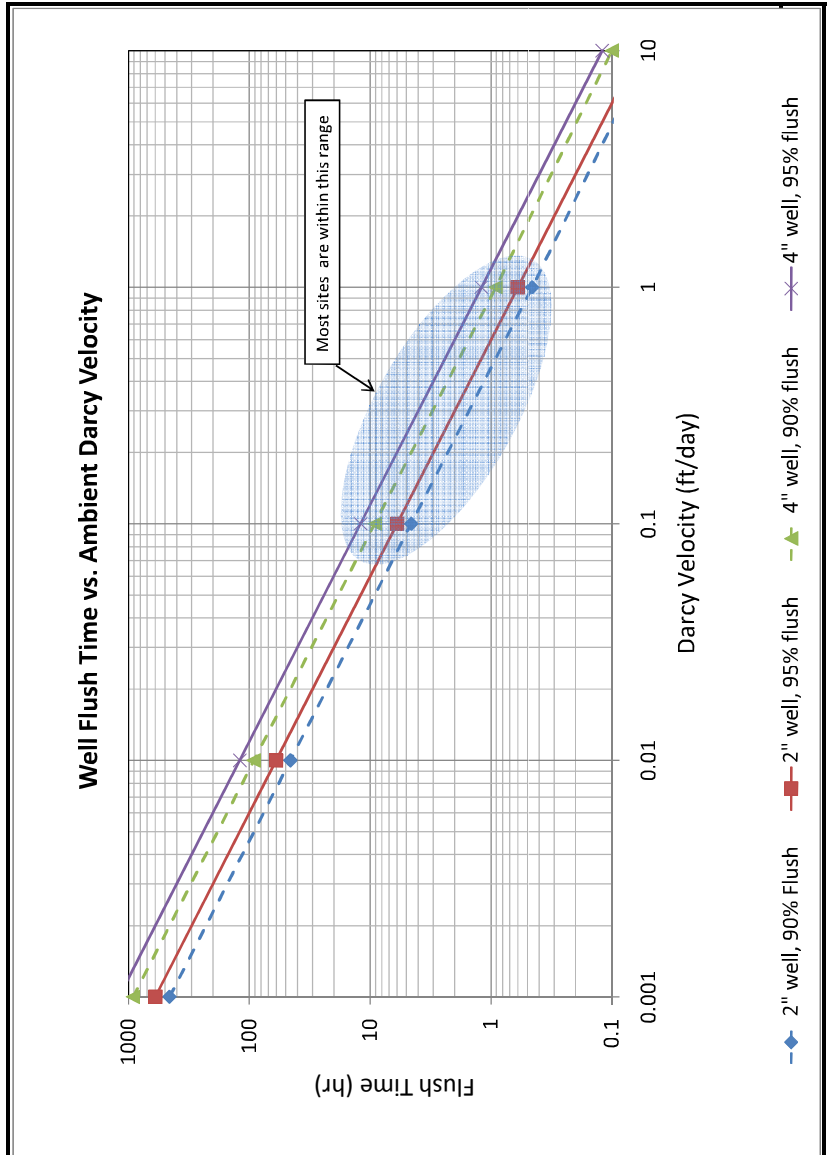
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**ATTACHMENT B**  
**CALCULATION OF MAXIMUM REQUIRED EQUILIBRATION PERIOD (FLUSH-OUT TIME) BASED ON WELL GEOMETRY AND DARCY VELOCITY**

Example Calculations			
Well Diam (inches)	Darcy v (ft/day)	Flush %	Flush Time (hours)
2	0.001	90	458
2	0.01	90	46
2	0.1	90	4.6
2	1	90	0.46
2	10	90	0.05
2	0.001	95	600
2	0.01	95	60
2	0.1	95	6.0
2	1	95	0.60
2	10	95	0.06
4	0.001	90	917
4	0.01	90	92
4	0.1	90	9.2
4	1	90	0.92
4	10	90	0.10
4	0.001	95	1200
4	0.01	95	120
4	0.1	95	12.0
4	1	95	1.20
4	10	95	0.12

**General Equation for Flushing Time**  
 $t = [0.25 \text{ wd} / (\text{vd cf})] [-\ln(1-f)]$

where:  
t = maximum required flushing time (hours)  
wd = well diameter (inches)  
vd = Darcy velocity, Ki (feet per day)  
K = hydraulic conductivity (feet per day)  
i = hydraulic gradient (dimensionless)  
cf = flow convergence factor (typically between 2 and 3)  
example calcs. assume cf = 2.5  
f = % flush expressed as fraction  
(e.g., 95% = 0.95, 90% = 0.90, etc.)



(Based on: Gaspar, E., and M. Onescu. 1972. Radioactive tracers in hydrology. Elsevier Publishing Co., Amsterdam)