Guidance for Hydrogeologic Sensitivity Assessment

Division: DDAGW
Number: WQ-21-001
Category: Water Quality – Guidance
Status: Final
Issued: 01-14-2014

I. Purpose

To provide guidance on hydrogeologic sensitivity assessments (HSA) which are identified as a potential requirement in rule 3745-81-42 of the Ohio Administrative Code (OAC).

II. Background

Pursuant to 40 CFR 141.402 and rule 3745-81-42 of the OAC, a system with a ground water source may be subject to a hydrogeologic sensitivity assessment. The HSA, a major tool to assess source water, is used to determine the pathogen sensitivity of a well or wellfield. The HSA uses all available data to assess the presence of hydrogeologic barriers at public water system well(s) with detected *E. coli*. The conditions under which this assessment is required and techniques used will be determined by Ohio EPA.

III. Guidance

The attached guidance is intended to be used by Ohio EPA staff and/or a person(s) appointed by a public water system to assist in the evaluation of pathogen sensitivity and pathways for contamination of a ground water source.

IV. Attachments

Attached is the guidance document as developed by the Ground Water Rule Workgroup.

V. History

The Division of Drinking and Ground Waters first issued this guidance on January 14, 2014.

Table of Contents

Table of Contents
(continued)

Figures

Guidance for Hydrogeologic Sensitivity Assessment
September 17, 2013

Introduction

The Ground Water (GW) Rule Workgroup discussed approaches to evaluate pathogen sensitivity at length and concluded the best solution is a standard, but flexible approach for evaluating the probability that a local aquifer will be contaminated by pathogens. The approach developed includes two components:

1. Hydrogeologic Sensitivity Assessment (HSA); and
2. Assessment Source Water Monitoring (ASWM).

The HSA report is produced in a short time frame for a specific public water system (PWS) and uses available data to complete a risk assessment of the pathogen sensitivity of the local hydrogeologic setting. If water quality data is inconclusive and the HSA identifies possible pathogen sensitivity, ASWM may be utilized to collect additional water quality data to determine the concentrations of *E. coli*, other microbial indicators, and/or select inorganic parameters. Recommendations in the HSA report will address the need for ASWM.

A request for an HSA may result from a review of sampling results associated with multiple procedures, including:

- *E. coli*-positive results from GW Rule triggered source water samples;
- Total coliform or *E. coli* detections in new well approval samples;
- Evaluation of source water designation issues; and
- Questions concerning wells with persistent total coliform detections.

The reader is referred to procedures for requesting HSAs (WQ-19-001) and program standard operating procedures for determining when to consider using the HSA and ASWM tools. Section 4.5 of the GW Rule SOP includes a table that provides a framework for when to require HSAs.

This guidance describes the rationale and step-by-step procedures for completing an HSA. Risk assessments are required in the HSA process to produce a relative ranking of source water sensitivity to pathogen contamination. The prescriptive nature of the process promotes uniform application at PWS wells. The geology of Ohio, with horizontal stratigraphy, major bedrock aquifers covered with glacial drift or colluvium, and widespread buried valley aquifers, is relatively uniform, which allows the application of a standard approach for evaluating pathogen sensitivity. A separate guidance is available for completing ASWM (Guidance for Assessment Source Water monitoring – WQ-22-001).

The HSA is requested by drinking water (DW) staff and is completed by ground water (GW) staff as part of the investigation into the causes of confirmed pathogen contamination at a PWS. Information acquired by the DW inspectors during their interaction with the PWS is useful, thus, active communication between GW and DW staff is encouraged. The HSA is part of an evaluation process with the goal of identifying appropriate corrective actions to address the detection of pathogens in drinking water. Clearly, the steps to bring a PWS with *E. coli* detections in its source water into compliance will vary from system to system. The HSA provides an overall picture of the geologic setting and hydrogeologic barriers present, to generate a relative ranking of pathogen sensitivity, to summarize the water quality data and local pathogen sources, and to recommend corrective actions for DW staff consideration.

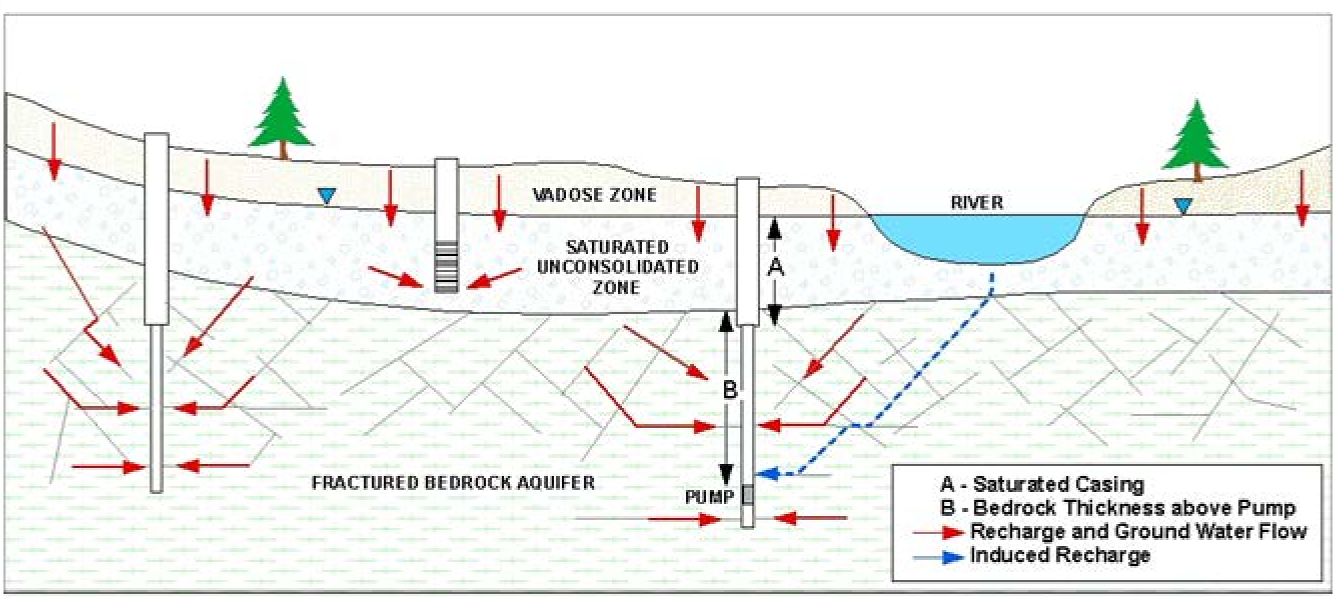
Rationale of the HSA Approach

The HSA utilizes the concept of multiple barriers as an essential element for protecting human health at ground water-based PWSs. The definition of hydrogeologic barrier used is broad and includes any “physical, biologic, or chemical factors, singularly or in combination, that prevent the movement of viable pathogens from a contamination source to a water supply well” (US EPA Ground Water Rule Source Assessment Guidance Manual, July 2008, pg. 2-8).

The HSA approach focuses on identifying recharge pathways and the hydrogeologic barriers that provide natural filtration at specific sites. Then, relative barrier values are selected to represent natural filtration effectiveness for eliminating pathogens for each hydrogeologic barrier. Finally, the barrier values are summed to generate a Barrier Index, which provides a relative measure of the risks of pathogen migration at a specific site. The continuum of pathogen sensitivity is divided into pathogen-sensitive, intermediate pathogen-sensitive and pathogen non-sensitive categories.

Figure 1 is a schematic diagram that illustrates the recharge water flow paths through the vadose zone, the saturated unconsolidated zone and into the aquifer, for several well configurations. A flow path for induced recharge is also indicated. As recharge passes through these zones in route to the aquifer, the hydrogeologic barriers in each zone have specific concerns for pathogen migration that need to be considered in the HSA.

Schematic Diagram Illustrating
Recharge Pathways



Not drawn to scale.

Figure 1. Schematic diagram illustrating recharge and ground water flow to aquifers and wells.

Steps for Completing an HSA

When DW Managers request an HSA to be completed, a well log or ODNR well log number, a short summary of the recent pathogen indicator detections and PWS responses, and other information that the DW inspector considers important for evaluating the pathogen sensitivity of the PWS needs to be provided to the GW staff. Site visits coordinated with DW staff and the PWS are encouraged to improve communication and knowledge of the local conditions. The steps for completing an HSA include:

1. Determine the regional pathogen sensitivity;
2. Initiate the local HSA;
    - Collect and review available data;
    - Draft schematic diagram of well and hydrogeologic setting;
    - Rate hydrogeologic barriers (Tables 1 & 2); and
    - Sum for Barrier Index.
3. Review water quality data;
4. Evaluate the location of pathogen sources; and
5. Draft summary report with recommendations.

Each of these steps is discussed in separate sections below.

Regional HSA

The regional HSA identifies areas of regional aquifers that are likely to be pathogen-sensitive utilizing statewide GIS coverages (ODNR State Aquifer Maps, 1997-2000) and desktop analysis. Figure 2 illustrates the distribution of regional scale hydrologic conditions that may be associated with pathogen-sensitive aquifers. These include:

- Fractured bedrock aquifers below areas of thin drift (till and lacustrine deposits) may be sensitive to pathogen contamination. The rationale applied is that thin glacial overburden (<25 feet) allows recharge to pass rapidly through macropores and fractures into fractured bedrock aquifers. These pathways in glacial drift and bedrock allow rapid flow and provide limited filtration, and thus, may not remove pathogens.

- Beach ridges or other well sorted sands, do not exhibit significant natural filtration and these aquifer may be considered pathogen-sensitive.

Glacial sand and gravel aquifers in Ohio are dominantly outwash deposits and are poorly sorted. Special studies (Ohio EPA, 2007) have documented that the poorly sorted nature of these sands provides significant natural filtration. Consequently, most sand and gravel aquifers in Ohio are not considered pathogen-sensitive and are not included in Figure 2.

An HSA starts with determining if the PWS to be evaluated is located in a regional area where wells are likely to be sensitive to pathogen contamination. If a PWS well is located in a regional pathogen-sensitive area, it does not automatically mean that the production aquifer utilized is pathogen sensitive. Pathogen sensitivity requires a site-specific analysis.

Local HSA

The goal of the local HSA is to identify the sensitivity of a PWS well or wellfield to pathogen contamination using site-specific information. This is not a trivial process due to the complex geometry of the surface water-ground water boundary, the variability of local hydrogeologic settings, the presence of multiple aquifers, and the existence of numerous recharge pathways. The pathogen sensitivity of wells within a wellfield varies according to multiple factors and thus, it is anticipated that each well will have its pathogen sensitivity determined. The HSA assumes that wells are properly constructed and that well integrity is good.

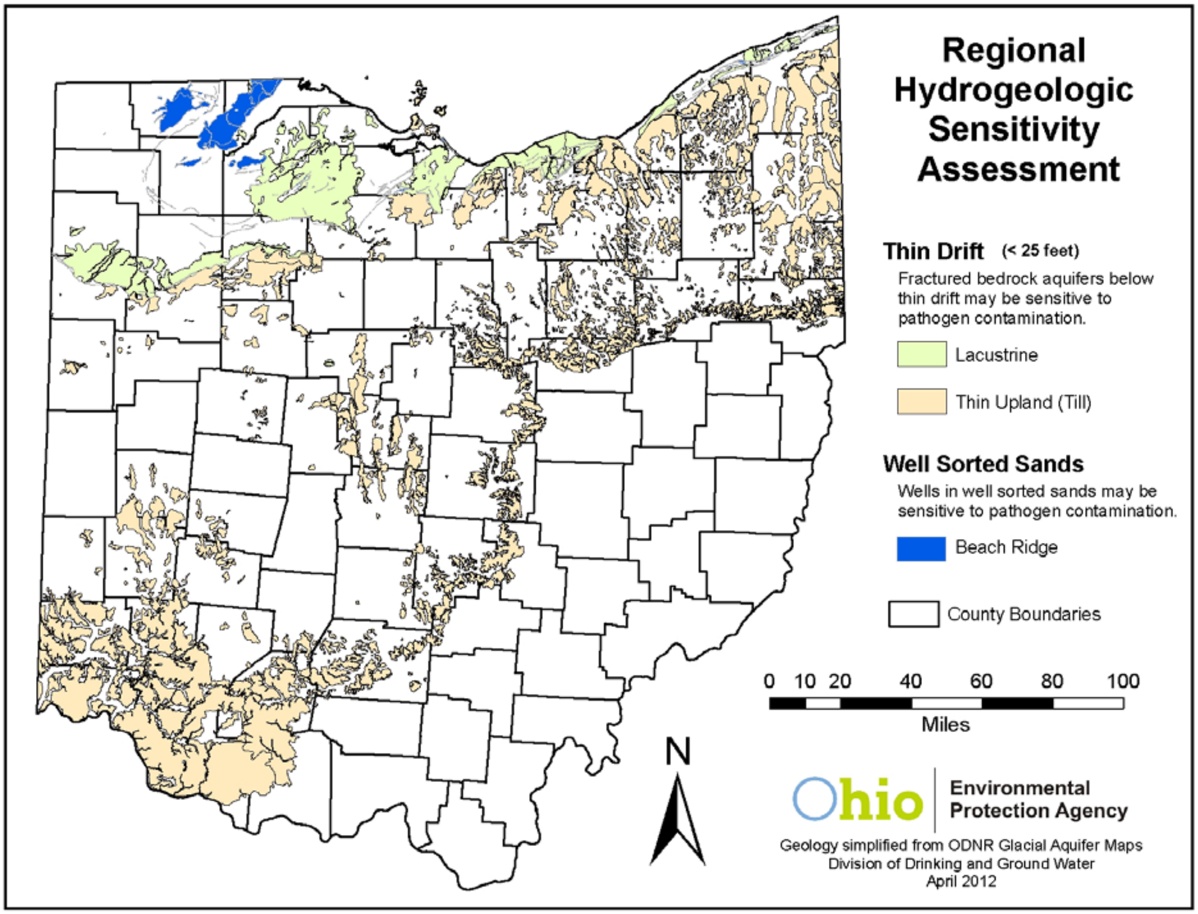


Figure 2. Regional Hydrogeologic Sensitivity Assessment for Ohio.

One of the results of the local HSA is the Barrier Index, a relative number representative of the sensitivity of the PWS. The HSA identifies three categories along the continuum of pathogen sensitivity with the following characteristics:

- Pathogen-Sensitive – hydrogeologic barriers are absent or compromised, allowing rapid recharge and pathogen migration to impact the aquifer;
- Intermediate Pathogen Sensitivity – insufficient information is available to identify pathogen sensitivity or the sensitivity cannot be confidently included in pathogen-sensitive or pathogen non-sensitive groups; or
- Pathogen Non-sensitive – multiple barriers are present and provide sufficient filtration/ retardation so that pathogen migration to the aquifer is considered unlikely.

This guidance focuses on completing the local HSA. The sub-steps of the local HSA are discussed in order of completion and significant detail is provided to promote generation of uniform ratings.

Collect and Review Available Data - All available data needs to be reviewed to understand the local hydrogeologic setting and the construction of the wells being evaluated. Local well logs are critical. If logs for a specific site are not available, use adjacent logs and local geologic maps to identify the likely aquifer and typical well construction in the area. Other data and GIS layers that can be utilized include, but are not limited to:

- Source water protection susceptibility assessment;
- ODNR potentiometric surface maps;
- ODNR Aquifer Maps;
- ODNR Ground Water Resource Maps;
- ODNR Ground Water Pollution Potential Maps (DRASTIC methodology);
- Well construction details; and
- Special reports; etc.

The distillation of this information allows the identification of the local production aquifer, the hydrogeologic barriers present, and the probable recharge flow paths from the vadose zone to the production aquifer. Identifying these elements correctly is critical to an accurate HSA.

Draft Schematic Diagram - Drafting a local schematic diagram summarizes and documents the hydrogeologic setting, the local hydrogeologic barriers and well construction details in relation to the production aquifer. Figure 3 provides an example, which includes the following information:

- lithology is listed on the right side;
- well construction is provided in the center;
- the primary aquifer and water levels are provided on the left side; and
- pump test and drawdown data is summarized at the bottom.

Rate Hydrogeologic Barriers - A system with equivalent points for equivalent pathogen barriers and a consistent approach for identifying the hydrogeologic barriers at a PWS promotes uniform HSAs across the state.

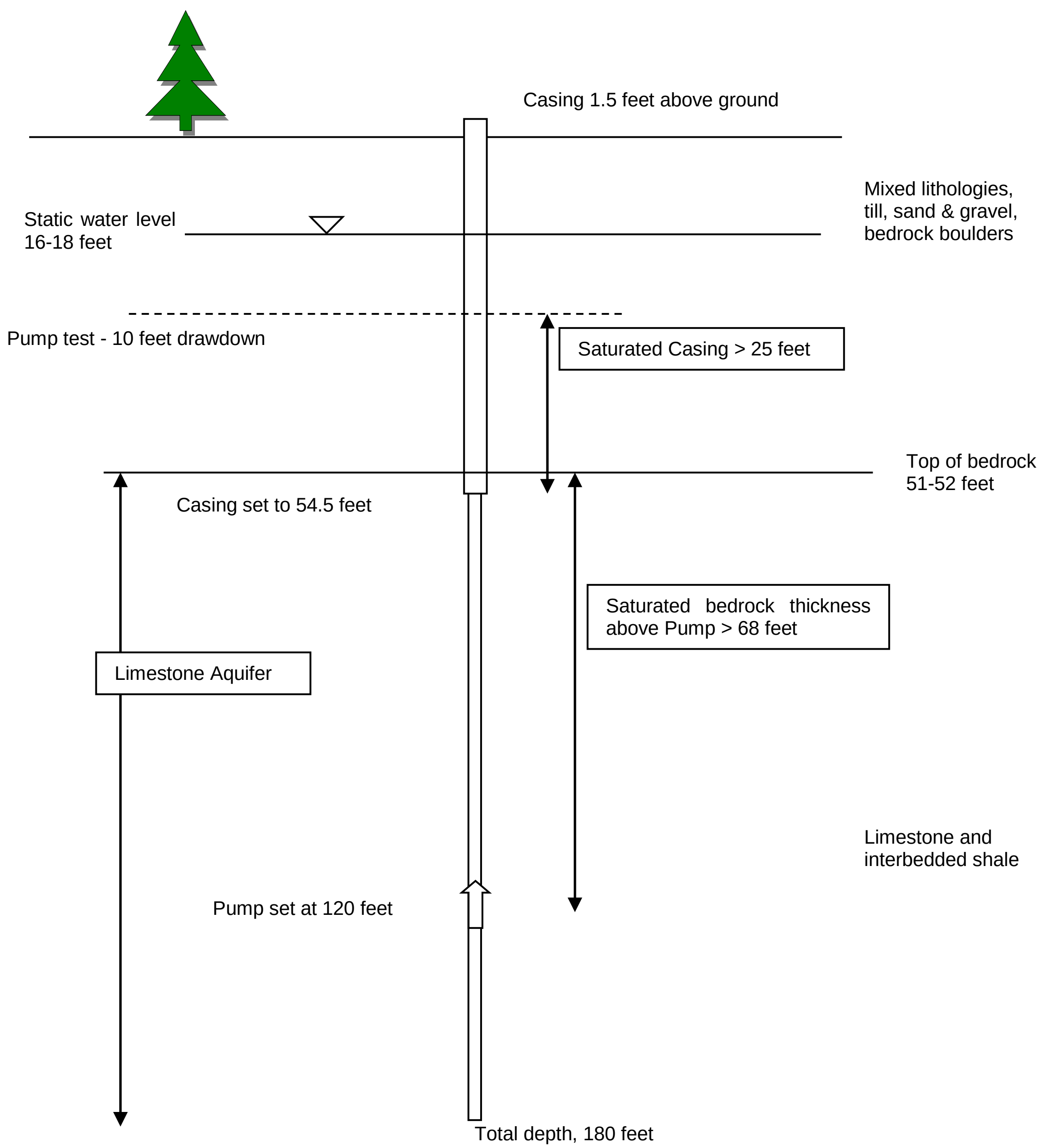
Point values of the hydrogeologic barriers present along recharge and ground water flow paths to a well are summed to provide the site Barrier Index. Based on the schematic diagram, barrier values for hydrogeologic barriers are recorded in Table 1. The relative barrier values are selected from Table 2 (2A- 2F). The barriers identified need to be associated with the shortest flow path (time or distance) to wells in order to be protective of human health. Effective barriers are given positive values and compromised barriers receive negative values. Higher barrier values provide greater pathogen removal and inactivation.

The GW Rule Pilot Project collected data at sites considered to be pathogen-sensitive. The final analysis and summary of the GW Rule Pilot Project evaluated the HSA approach and confirmed correlations between the microbiologic and inorganic results and the calculated Barrier Index which documents the HSA procedures provide a reasonable, relative measure of the sensitivity of pathogen migration in a range of hydrogeologic settings (GW Rule Pilot Summary, Ohio EPA 2012).

Figure 3. Schematic Well Log Example

Site: Ohio PWS Name, OHXXXXXXX
Darke County
Aquifer – Limestone; 52-180 feet
Saturated casing > 25 feet
Bedrock thickness above pump > 68 feet
Not drawn to scale

Well Number:XX
Well Log: XXXXXXX
Drilled: mm/dd/yyy



Pump Test at 100 gpm for 8 hours produced 10 feet of drawdown

Table 1 provides a template for combining the barrier values for the hydrogeologic barriers present at a specific site/well. These barriers are arranged to follow recharge pathways, starting with vadose zone, where recharge is primarily vertical flow. In the saturated zone, ground water recharge and flow may exhibit vertical and horizontal components. In a pumped aquifer, horizontal flow paths dominate. Table 1 also includes special circumstances and horizontal flow threat categories that need to be considered when they provide potential short or rapid recharge pathways. The comments column provides space for important qualifiers about specific barriers. Although the local HSA derives much of the information from the well log, the area of concern includes the area around the well or wellfield. At a minimum, the hydrogeologic setting of the DW source assessment inner management zone needs to be evaluated.

Tables 2A to 2F are used to determine values for various hydrogeologic barriers and compromised barriers. These tables are presented in the order of the zones listed in Table 1. Several special categories are also included that represent identified threats, such as cascading wells and induced surface recharge that may provide rapid recharge flow paths. The geologist needs to correlate the local setting and lithologies identified in the local well logs and summarized in the schematic diagram with equivalent hydrogeologic barriers listed in Tables 2A to 2F and enter appropriate barrier values into Table 1.

Brief comments are provided after each section of Table 2 on critical factors to be considered. In Appendix A, the logic applied to determine the relative barrier values is discussed in greater detail. These longer explanations provide additional information to help select appropriate barrier values and to improve consistency in applying barrier values across Ohio. The order of items in Appendix A follows the order of recharge flow paths and the Appendix A table of contents lists each topic for quick access to the topic of concern.

As a general rule, if the thickness of a hydrogeologic barrier sits at a thickness boundary in Table 2, use the average of the two barrier values for the site-specific barrier value. For example, if the sand and gravel (S&G) in the vadose zone is 25 feet thick, the barrier value will be 0.75, determined by averaging the S&G 10-25 feet barrier value of 0.5 with the S&G 25 -50 feet barrier value of 1 ((0.5 +1.0)/2 = 0.75).

Table 1
Local HSA – Site Specific Barrier Index

Site and Well:
County:
PWSID:

Date:

Completed By:

Hydrogeologic Barrier Along Recharge Flow Path	Barrier Value*	Comment
SWAP Susceptibility		
Vadose Zone (vertical flow dominates)		
Unsaturated Unconsolidated		
Unsaturated Consolidated		
Saturated Zone (vertical and horizontal components)		
Saturated Unconsolidated		
Saturated Consolidated		
Aquifer (horizontal flow dominates)		
Aquifer		
Thick aquifer adjustment		
Confined/Semi-confined		
Induced Recharge /Horizontal Flow		
Induced recharge		
Flood Plain Location		
Bedrock Horizontal Flow		
Well Construction Concerns		
Turbid Production Water		
Cascading well		
Saturated Casing		
Other		
Barrier Index - Total		

* Select barrier value from Table 2 – HSA Scoring Sheet

Aquifer =

Static water =

Static water + drawdown =

Barrier Index Boundaries
Pathogen Sensitive
- 0.5
Intermediate
- 3.5
Pathogen Non-Sensitive

Table 2A
HSA Scoring Sheet for SWAP Susceptibility

Hydrogeologic Barrier	Barrier Value	Comments
SWAP Susceptibility	High=0 Medium=1 Low = 2	The SWAP susceptibility analysis evaluated barriers to migration of dissolved contaminants, so it is an appropriate starting point.

SWAP Susceptibility - The SWAP susceptibility analysis effort focused on many of the same questions considered for the HSA, except for dissolved components instead of pathogens. This approach for incorporating SWAP susceptibility, generally works with the exception of buried valley aquifers, which are sensitive to dissolved components, however, the poorly sorted nature of the buried valley sand and gravels provides reasonable natural filtration to remove pathogens. Consequently, for a buried valley aquifer that has a SWAP susceptibility of high, the barrier value can be listed as 1 rather than 0 if the sand and gravel thickness overlying the production aquifer is greater than 25 feet. DW Source Assessment Reports are available on the DDAGW intranet page at; http://epaintra.epa.ohio.gov/ddagw/Programs/GroundWaterPrograms.aspx#3167444-swap

Table 2B
HSA Scoring Sheet for the Vadose Zone

Hydrogeologic Barrier	Barrier Value	Comments
Vadose Zone		**If multiple units occur in the vadose zone rate the unit that is the best hydrogeologic barrier.**
Vadose Zone (unsaturated) Unconsolidated		Unsaturated nature allows piping and macro-pore/fracture flow, producing an ineffective hydrogeologic barrier.
Less than 10' of unconsolidated material over bedrock or to the water table	-1	
Sand & Gravel 10-25 feet	0.5	
Sand & Gravel 25-50 feet	1.0	
Sand & Gravel >50 feet	1.5	
Gravel/Boulders/Cobbles	-1	(noted in well log - with void space)
Colluvium 10-25 feet	0.5	
Colluvium 25-50 feet	1	
Till - 10-25feet	0	Macropores and fractures more likely in till than in sand & gravel or colluvium
Till - 25-50 feet	2	
Till - 50-75 feet	2.5	
Till - 75-100 feet	3.0	

Hydrogeologic Barrier	Barrier Value	Comments
Vadose Zone (unsaturated) Consolidated		Fractures allow rapid flow - Fracture density likely to be highest at upper surface of bedrock
Fractured rock - shale	-0.5	Fractures tend to have short vertical extent
Fractured mixed lithologies	-0.75	
Fractured rock - sandstone	-1	
Fractured rock - dolomite	-1.25	
Fractured rock - limestone	-1.5	Fractures likely enlarged by dissolution

Vadose Zone - The thickness of the vadose is the depth to the water table with no drawdown. In the vadose zone, flow is generally vertical and the rate of flow depends on material properties and distribution of fractures and macropores. The unsaturated nature of the vadose zone generally provides limited protection from pathogen migration due to the presence of rapid flow along fractures and macropores, or piping along areas of coarser material. **If multiple units occur in the vadose zone, rate the unit that is the best hydrogeologic barrier.** Since vertical flow is dominant in the vadose zone, in areas with multiple horizontal layers, the most protective layer can be used since it is the rate limiting layer.

Vadose Zone – Unconsolidated - The barrier values for unconsolidated material in the vadose zone are based on the probability of the presence of fractures and macropores, or other pathways that would allow rapid flow. Any material that is unsaturated and less than 10 feet thick is not considered a hydrogeologic barrier (-1 barrier value).

Vadose Zone – Consolidated - For unsaturated bedrock material, the barrier value is related to the probability of the presence and vertical extent of fractures. Generally, the vertical extent of joints in sedimentary rocks depends on the lithology and the bedding thickness. Thicker and more tightly cemented units exhibit longer vertical joints.

Table 2C
HSA Scoring Sheet for the Saturated Zone Above the Aquifer

Hydrogeologic Barrier	Barrier Value	Comments
Saturated Zone - Unconsolidated (saturated material above well screen)		Water level considered needs to be deepest water level (static water + drawdown) to assure long-term protection
0-10 feet of saturated material	0	
Sand & Gravel 10-25 feet	1	
Sand & Gravel 25-50 feet	2	
Sand & Gravel >50 feet	3	
Gravel/Boulders/Cobbles	-1	(noted in well log - with void space)
Colluvium 10-25 feet	1	
Colluvium 25-50 feet	2	
Till - 10-25feet	2	
Till - 25-50 feet	4	
Till > 50 feet	6	

Hydrogeologic Barrier	Barrier Value	Comments
Saturated Zone – Consolidated (saturated and above pump, but not part of aquifer)		Non-aquifer bedrock thickness above pump; barrier values controlled by potential fracture path-ways; some isolation can be achieved when vertical connectivity or intersection of fractures are limited.
Fractured Carbonate – 0-25 feet	-1.5	
Fractured Carbonate – 25-50 feet	-1.0	
Fractured Carbonate > 50 feet	-0.5	
Fractured SS – 0-25 feet	-1.0	
Fractured SS – 25-50 feet	-0.5	
Fractured SS > 50 feet	0	
Mixed Lith. Thick beds– 0-25 feet	- 0.5	
Mixed Lith. Thick beds– 25-50 feet	0	
Mixed Lith. Thick beds > 50 feet	+0.5	
Mixed Lith. Thin beds– 0-25 feet	0	
Mixed Lith. Thin beds– 25-50 feet	+ 0.5	
Mixed Lith. Thin beds > 50 feet	1.0	
Fractured Shale – 0-25 feet	+ 0.5	
Fractured Shale – 25-50 feet	+ 1.0	
Fractured Shale > 50 feet	+ 1.5	

Saturated Zone - The saturated zone above the aquifer is more protective than the vadose zone because the forces driving surface contaminants downward are reduced. To determine barrier values, the aquifer needs to be identified and the pumping water level needs to be established before the thickness of the saturated material lying above the aquifer can be determined.

Identify the Aquifer - In unconsolidated material, the aquifer will be the screened interval and the saturated material overlying the screened interval will be rated using the saturated zone – unconsolidated options in Table 2C. Filtration in unconsolidated material is controlled by grain size and sorting.

Determining the vertical extent of the aquifer in bedrock units is more difficult. For massive lithologies like the Silurian limestones, the aquifer is likely to extend from the top of the bedrock to the bottom of the well with rapid flow through vertical fractures to bedding plane production zones penetrated by the well. In this case, the Saturated Zone – Consolidated section of Table 2C would not be used and the entire limestone section would be considered the aquifer (as illustrated in Figure 3). In contrast, the Mississippian Logan Formation is a sandstone aquifer that can be identified within interbedded sandstones, siltstones and shales. In this case, the sandstone aquifer can be identified and the overlying interbedded siltstones and shales would be identified as saturated bedrock above the aquifer. For sections where multiple layers are present (for example - a detailed well log), professional judgments need to be made to distill the section into saturated bedrock above the aquifer and the aquifer zone and then select appropriate barrier values from Table 2C and 2D.

Thickness of Saturated Zone - The thickness of the saturated bedrock used for completing the Local HSA – Site Specific Barrier Index (Table 1) depends on the amount of drawdown during pumping. To assure long-term protection, the water level used to measure the thickness of the saturated bedrock above the aquifer is the distance between the top of the aquifer and the maximum level of drawdown during pumping. Drawdown during pumping introduces vertical gradients in the upper portion of the saturated zone, which may increase the vertical migration of pathogens. The vertical gradients are significantly reduced in the bedrock below the level of maximum drawdown.

Table 2D
HSA Scoring Sheet for Aquifers

Hydrogeologic Barrier	Barrier Value	Comments
Aquifer		Consider horizontal flow. The values for fractured aquifers can be reduced with documentation of extensive and protective overburden upgradient
Sand & gravel	1	
Fine sand – poor sorting	2	
Gravel/Boulders/Cobbles	-2	(noted in well log - with void space)
Fractured rock - shale	-1	
Fractured rock - sandstone	-2	
Fractured rock – dolomite	-2.5	
Fractured rock – limestone	-3	
Thick Aquifer Adjustment (for fractured bedrock only)		Adjustment is based on vertical distance between level of drawdown during pumping and pump location (saturated well above pump indicates saturated bedrock)
Saturated well above pump > 50’	0.5	
Saturated well above pump > 100’	1.0	
Saturated well above pump > 150’	1.5	
Confined Aquifer		Over pressured zone
Confined	4	Documented with artesian pressure in confined aquifer and confirmation that recharge zone is beyond the 1 year TOT delineation.
Semi-confined	2	

Aquifer - Flow paths in the aquifer itself are dominated by horizontal flow during pumping. The Federal GW Rule identifies gravels, fractured bedrock and karst as sensitive aquifers due to rapid ground water flow with little pathogen attenuation. Barrier values increase with reduced flow rates because longer travel times of horizontal flow within the aquifer will result in greater pathogen predation and die off.

Thick Aquifer Adjustment - Deeper production zones provide longer fractured flow pathways to the production well, resulting in increased travel time to the well, which provides more time for bacteria inactivation. Thus, a thick saturated aquifer can get some credit as a barrier. The thickness of the aquifer is considered the distance between the pump and maximum drawdown during pumping (saturated well above pump). Sites with longer saturated well length above the pump are assigned larger thick aquifer adjustments. The adjustment will generally be applied to the massive carbonate aquifers in western Ohio. In no case should the thick aquifer adjustment shift a carbonate aquifer from a negative barrier value to a positive barrier value.

> Note: The thick aquifer adjustment is difficult to evaluate and apply. If there is reason to believe that water is cascading into the open hole from shallow sections of the well during pumping, do not apply the adjustment.

Confined Aquifers - A confined aquifer should be considered isolated and resistant to flow into the aquifer. This significantly restricts pathogen migration into the aquifer from local sources. It is important to assure that the recharge area for the confined aquifer is not in a location close enough to a production well to allow lateral migration of viable pathogens to the well. To identify aquifer as confined or semi-confined, significant impermeable units must be present above the aquifer.

If an aquifer appears confined based on the static water level, but pumping pulls the potentiometric surface level into the production aquifer, this aquifer should not be considered confined. It may be considered semi-confined if the casing is set in the confining layer.

An aquifer with a confining layer above it, but in which the potentiometric pressure does not rise into or above the confining layer, will not be considered confined. In an under-pressured aquifer, the pressure gradient drives surface contaminants to the deeper aquifer. If abandoned wells or other breaches of the confining layer are present, these pathways may allow rapid recharge to the deep aquifer. Even if this aquifer is not over-pressured, the presence of impermeable units above the aquifer should provide some protection from migrating pathogens, as any saturated unit above the aquifer will (Table 2C).

Table 2E
HSA Scoring Sheet for Induced Recharge

Hydrogeologic Barrier	Barrier Value	Comments
Induced Recharge/Horizontal Flow		
Well in floodplain	-1	
Well < 50 feet from surface water	-2	
Well < 100 feet from surface water	-1	
Bedrock Horizontal Flow	-2	Special case, e.g. SW recharge flowing down dip to recharge aquifer, etc.

Induced Recharge – A well sited to induce surface water recharge for increased production needs to be evaluated carefully because the siting has been selected to purposely shorten recharge flow paths. Generally, riverbank filtration appears to provide significant natural filtration, but flow paths to many wells are designed to be short. The evaluation of induced recharge considers the shortest flow paths between the surface water body and the production well. As a general rule, all Ranney wells should be considered vulnerable/ sensitive to pathogens if they have laterals under a river, until demonstrated otherwise. Since most wells sited to induce recharge are located in flood plains, the correlation between pathogen detections and flooding events need to be evaluated.

Table 2F
HSA Scoring Sheet for Well Construction Concerns

Hydrogeologic Barrier	Barrier Value	Comments
Well Construction Concerns		
Turbid Production Water	-2	Difficult to document but local knowledge or anecdotal evidence is useful
Cascading well	-2	If drillers log indicates water at xx' that is above static water level, and section of well is not cased, consider as a cascading well.
Saturated Casing		Use water level during pumping conditions (maximum drawdown) to determine length of saturated casing.
Saturated casing < 10' Fine grained material	-1	
Saturated casing < 10' S&G	-2	
Saturated casing < 10' bedrock	-2	
Saturated casing 10 - 25 feet	0	
Saturated casing 25 - 50 feet	1	
Saturated casing > 50 feet	2	

<u>Well Construction Concerns</u> - The HSA assumes proper well construction. The HSA may help to identify well construction issues by identifying wells in pathogen non-sensitive hydrogeologic settings that record *E. coli* detections in raw water samples. In these cases, the most obvious explanation is improper well construction or deteriorated well casing. The HSA report includes a section on well construction to highlight potential deficiencies. A distinction needs to be made between well construction and the deterioration of what was once proper well construction, but both need to be considered.

<u>Turbid Water</u> - A well that produces turbid water at irregular intervals is likely to be a well in which effective hydrogeologic barriers are not present or are bypassed and thus, is subject to pulses of rapid recharge that may transport pathogens. The intermittent nature of turbid water in sensitive wells makes it difficult to document, but local observations or anecdotal evidence provided by the well users are valid for identifying the problem. Turbid water produced from a well, even if infrequent, is cause for concern; however, if the turbidity is associated with precipitation of iron, it should not be considered turbidity associated with rapid recharge.

<u>Cascading Water</u> - If you hear water draining or cascading into the well through casing or from fracture flow in bedrock below the casing, it is likely the hydrogeologic barriers present are being short-circuited or bypassed. If possible, the source of the cascading water should be determined. Cascading water due to a hole or holes in the well casing or from the

bottom of the casing are clear indicators of a well integrity problem that needs to be addressed.

Cascading water is caused by water moving horizontally along fractures, bedding planes or other permeable zones to the open borehole due to limited vertical permeability within the pumping zone of influence. This zone of limited vertical permeability acts as a hydrogeologic barrier at some level to water below the zone. The shallowest level of water cascading into the well above a low permeability zone, however, is likely to be associated with more rapid surface water recharge and may transport pathogens. If the driller's log indicates water in an uncased portion of a well that is above the static water plus drawdown level, the well is considered a cascading well.

<u>Saturated Casing</u> - Saturated casing is the length of casing that extends below the water level during active pumping. From the well log, the length of saturated casing can be determined by subtracting the static water level (depth below ground surface) plus the drawdown during the pump test from the length of casing below the ground surface. Negative values for saturated casing indicate that the bottom of the casing is located above the depth of static water plus drawdown during pumping. Negative saturated casing should not occur in unconsolidated materials because the casing is necessary to keep the well open. Negative values for saturated casing in bedrock wells, however, are common. This situation increases the likelihood of cascading water into open boreholes. Saturated casing is an effective hydrogeologic barrier if the saturated length is long enough to restrict the ground water near the surface of the water table from flowing rapidly into the well.

To avoid penalizing a well twice for the same compromised barrier, if a well is given a -2 for cascading water, it is clear that the saturated casing is negative and the well should not be given a barrier value for saturated casing.

Perched water tables may provide saturated casing through the perched aquifer. The saturated casing associated with a perched water table can be credited as saturated casing if the impermeable material that is causing the perched condition is extensive laterally. At a minimum, the impermeable zone should extend beyond the drinking water source protection inner management zone and remain saturated through the year.

Sum for Barrier Index – Summing the barrier values listed in Table 1 produces the Barrier Index, which provides a relative number for the pathogen sensitivity of the PWS wells or wellfield. The Barrier Index continuum is divided into three groups: pathogen-sensitive; intermediate sensitivity; and pathogen non-sensitive as illustrated in Figure 4 with boundaries at -0.5 and 3.5.

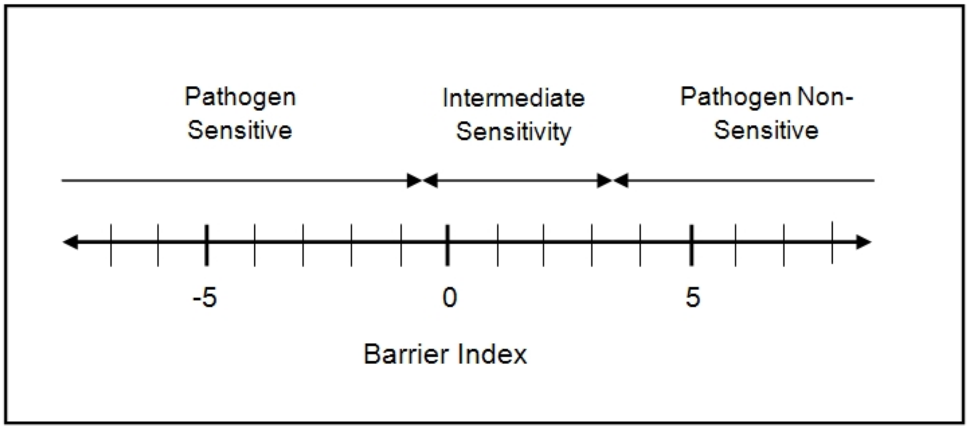


Figure 4. Categories of pathogen sensitivity based on Barrier Index values.

Review Water Quality Data
Any water quality data that is available should be evaluated. The compliance data that are most informative will be the microbial, nitrate, and arsenic results. These data are stored in SDWIS and can be reviewed using standard reports:

- Report 145 - Chemical Sample Results; and
- Report 166 - TCR Individual Results.

Other reports may be useful; talk to the DW or IMS staff to identify them.

Ohio uses *E. coli* as the fecal indicator for the GW Rule. It is expected that most compliance data for microbiological parameters are MMO-MUG tests, which indicate the presence or absence of *E. coli* but do not provide *E. coli* counts or concentrations. In most cases, if an HSA is being completed, the presence of *E. coli* has been confirmed. Compliance decisions will be based on data from the last year, but a review of the Total Coliform Rule (TCR) sampling history provides valuable insight into the frequency of *E. coli* and total coliform detections. Bacteria in water are suspended particles, and as a result, *E. coli* are not easy to sample accurately in small volume samples (100 mL sample volume for bacteria). The concentration of bacteria in water may vary at individual sampling sites due to normal biofilm processes and pulses of recharge. Consequently, in some cases it is important to determine or confirm the concentration of bacteria in a PWS's source water prior to requiring corrective actions.

The inorganic data are used as oxidation-reduction proxies to assess the isolation of the local aquifer from the atmosphere. Water at the surface of the water table is exchanging oxygen with the atmosphere. At depths below the water table, dissolved oxygen concentrations are lower because the dissolved oxygen is consumed by microbes or interactions with surrounding earth materials. These reactions are systematically controlled by microbes (Terminal Electron Accepting Processes or TEAPS; McMahon and Chapelle, 2008), resulting in an orderly set of reaction products producing more reduced conditions with greater depth below the water table. Thus, redox conditions can be identified by the presence and absence of the reactants and products. For example, if nitrate is present, it indicates interaction with the atmosphere, which may suggest the presence of rapid recharge of surface water elevated in nitrate. In contrast, if arsenic is present (or dissolved iron), it indicates that the aquifer is reduced and suggests the aquifer is isolated from the atmosphere, which reduces the likelihood for rapid recharge of oxygenated surface water.

The reader is referred to the Assessment Source Water Monitoring Guidance (Ohio EPA, 2013), where the TEAPS relationships are discussed in more detail. They are mentioned here as a way to help confirm the pathogen sensitivity that the HSA Barrier Index indicates for the local site. If a site was determined to be pathogen non-sensitive it suggests the production aquifer is reduced and that nitrate will not be present in the production water.

Evaluate the Location of Pathogen Sources

Information on the distribution and concentration of pathogen sources in the vicinity of the well or wellfield is critical to evaluating the potential for pathogen contamination. The focus should be the drinking water source water protection inner-management zone (1 year TOT) because a year is a conservative estimate for enteric pathogen viability (at least for bacteria) in surface environments. A pathogen-sensitive setting with no pathogen sources is less likely to result in pathogen contamination than a pathogen-sensitive setting with numerous pathogen sources. The Drinking Water Source Assessment Report for the PWS being evaluated, communications with the PWS operators, and site visits all provide information on the distribution of pathogen sources around the wellfield. Although the SWAP sensitivity analysis focused on dissolved components, the potential contaminant source inventory identified pathogen sources.

The DDAGW Source Water Assessment and Protection Program's Potential Contaminant Source Inventory Process Manual (Ohio EPA, Revised September 2009) is recommended for providing information for conducting a contaminant source inventory. The integration of the pathogen distribution data with the pathogen sensitivity determined by the HSA is important to help identify appropriate corrective actions. Examples of ways pathogen source data influence the assessment process and source management in each category of pathogen sensitivity are provided below.

In **pathogen-sensitive** settings, any pathogen sources have potential to impact the ground water. Consequently, reducing the pathogen concentrations around PWS wells helps to reduce the potential for ground water quality impacts. If a site is pathogen-sensitive, management of pathogen sources within the inner management zone (1 year TOT) should be a high priority.

In **pathogen non-sensitive** settings, the natural hydrogeologic barriers should protect the ground water unless they are breeched. As a result, PWS operators in pathogen non-sensitive settings are generally not required to complete ASWM sampling. In cases with pathogen sources in the isolation radius, ASWM using MMO-MUG samples may be required. If no *E. coli* is detected and/or inorganic parameters support isolation from the atmosphere, no corrective actions will be required. Source water protection activities in pathogen non–sensitive areas will focus on repairing breeches in hydrogeologic barriers, such as properly abandoning unused wells.

Decisions on how to manage PWS wells in areas of **pathogen intermediate sensitivity** are more difficult. The general approach is to require ASWM to confirm or refine the pathogen sensitivity determination. MMO-MUG samples are acceptable, but as Quantitray becomes available, it is recommended because numeric information is more useful than simple presence-absence data. Detections of *E. coli* necessitates ASWM sampling with Quantitray methods. ASWM may include inorganic parameters, like nitrate and iron, to determine the redox conditions of the aquifer to help confirm the degree of isolation of the production aquifer. Inorganic parameters are particularly useful in helping evaluate intermediate pathogen-sensitive and pathogen non-sensitive settings, but any corrective actions required for the GW Rule will be based on detections of *E. coli*. Source water protection activities in areas of pathogen intermediate sensitivity should focus on reducing the concentration of pathogens within the inner management zone and on reducing breeches in hydrogeologic barriers.

Draft Summary Report with Recommendations
The HSA Report summarizes the hydrogeologic setting and describes the pathogen sensitivity of the local PWS. The report also integrates analysis of the water quality data and the distribution of pathogen sources around the well or wellfield. The purpose is to summarize these data and to provide recommendations for collecting additional data or for appropriate corrective actions for the DW inspectors to consider. Recommendations need to include a statement on the need for ASWM. The HSA Summary Report includes the following sections:

- Summary
- Introduction
- Regional HSA
- Hydrogeologic Setting
- Well Construction Information
- Site Specific HSA
- Water Quality Data
- Pathogen Sources
- Conclusions and Recommendations

Example reports are included in Appendix B. The examples include a site that is pathogen-sensitive and one that is pathogen non-sensitive and were generated to evaluate the PWSs for GW Rule compliance issues. It is hoped that the uniform structure of these reports promotes the consistent application of the HSA. However, if the HSA is completed for issues related to source water designation, new well approval, or chronic presence of TC in wells, the report may change to accommodate the purpose of the investigation.

Additional Analysis - Additional tools may be utilized at selected PWSs, to refine pathogen sensitivity. If the HSA determines intermediate pathogen sensitivity, ASWM will probably be recommended to collect additional water quality data. If the HSA is determined to be intermediate and ASWM evaluation is inconclusive, the following may be considered:

- Particulate analysis – for example, if micro-particulate analysis (MPA) documents no surface water particulates, it suggests that filtration is sufficient to exclude crypto oocysts or other surface water pathogens.

- Secure local rainfall data or local stream gauge data to identify recharge events. If geochemical variation or MPA results correlate with rainfall events, it suggests the setting is pathogen-sensitive.

- Time -of-Travel – modeling of flow paths can be used to support aquifer isolation if the time for recharge to reach the aquifer is greater than one year. The SWAP assessment delineations provide an initial time-of-travel model for evaluation, but more detailed models could be applied, but the analysis needs to focus on the shortest flow paths.

- Age of water – tritium measurement or other methods of determining water age (time since interaction with atmosphere) to identify water with resident times longer than pathogen viability.

These types of tools will be used infrequently. DDAGW's knowledge and experience with some of these tools is limited, but in special cases, they may provide hard data at specific sites. At some sites, it may be necessary to initiate a special study to collect data and gain experience with some of these tools to address specific questions about pathogen contamination.

References Cited

ARGOSS 2001; Guidelines for Assessing the Risk to Ground Water from On-site Sanitation; British Geological Survey, Commissioned Report, CR/01/142, 97 pages.
http://www.bgs.ac.uk/downloads/browse.cfm?sec=9&cat=37

Federal Register, 2006; Environmental Protection Agency, 40 CFR Parts 9,141 and 142; National Primary Drinking Water Regulations: Ground Water Rule; Federal Register vol. 71, no. 216, November 8, 2006

McMahon, P.B. and F.H. Chapelle 2008; Redox Processes and Water Quality of Selected Principal Aquifer Systems; GROUND WATER, Vol. 46, No. 2 -March–April 2008, pages 259–271.
http://oh.water.usgs.gov/tanc/NAWQATANCRedox.htm

Ohio Department of Natural Resources, 2000; Statewide Aquifer Mapping Project, 1997-2000; Unconsolidated Aquifer Mapping Component (digital formats).
http://www.dnr.state.oh.us/water/samp/sampinfo/tabid/4226/Default.aspx

Ohio EPA, 2013; Guidance for Assessment Source Water Monitoring; Ohio EPA (WQ-22-001) 11 pages.

Ohio EPA, 2012; Ground Water Rule Pilot Report: Ground Truth for Hydrogeologic Sensitivity Assessment and Assessment Source Water Monitoring Procedures; Ohio EPA, DDAGW Report, May 2012, 27 pages plus Appendices.

Ohio EPA, 2009; Ground Water Susceptibility Analysis Process Manual, DDAGW, April 2009
http://www.epa.state.oh.us/portals/28/documents/swap/swap_susceptibility_guidance.pdf

Ohio EPA, 2009; Potential Contaminant Source Inventory Process Manual, September 2009
http://epa.ohio.gov/portals/28/documents/swap/swap_psci_guidance.pdf

Ohio EPA, 2007; Ground Water Quality Impacts of Infiltration of Partially Treated Wastewater at Catalina MHP, Butler Co. Ohio; Ohio EPA DDAGW Report, October 2007, 45 pages plus Appendices.

U.S. EPA, 2008; Ground Water Rule - Source Assessment Guidance Manual, EPA815-R-07-023, July 2008;
http://www.epa.gov/safewater/disinfection/gwr/pdfs/guide_gwr_sourcewaterassessments_draft09192007.pdf

Appendix A

Hydrogeologic Barriers and Logic for Determining Barrier Values

Appendix A

Hydrogeologic Barriers and Logic for Determining Barrier Values

Appendix A provides insights on what constitutes a hydrogeologic barrier and then summarizes the logic applied to determine the relative barrier values listed in Table 2. These longer explanations provide additional information to the user to help select appropriate barrier values and to improve consistency across Ohio. After the section providing examples of hydrogeologic barriers, the order of items in Appendix A follows the order of recharge flow paths. The Appendix A table of contents lists each topic so the user can find additional information quickly to help determine an appropriate barrier value.

Basis for Hydrogeologic Barriers

The GW Rule Preface (Federal Register, 12-8-2006) identifies the following risk factors as useful for identifying PWSs that are susceptible to pathogen contamination:

- High population density with on lot septic systems;
- Well sorted aquifers in which viruses will travel faster than bacteria;
- Shallow unconfined aquifers;
- Aquifers with thin or absent soil and/or thin colluvium cover;
- Wells previously identified as having fecal contamination;
- Sensitive aquifers (karst, fractured bedrock, gravel).

Several of these risk factors are source based and others relate to the hydrogeologic setting of the production aquifer. Generally, we see positive correlations between PWSs with a history of *E. coli* detections and these risk factors. We expect that data collection for PWSs with *E. coli* detections associated with GW Rule source water evaluation will further illuminate these risk factors. Recognizing the geologic settings sensitive to pathogen migration and the processes that short-circuit or compromise hydrogeologic barriers is critical to completing accurate evaluations. For discussion purposes, we are using a broad definition of hydrogeologic barrier, defined as "the physical, biologic, or chemical factors, singularly or in combination, that prevent the movement of viable pathogens from a contamination source to a water supply well" (US EPA Ground Water Rule Source Assessment Guidance Manual, July 2008, Pg. 2-8).

The local HSA utilizes the concept of multiple barriers, as an essential element for protecting human health at ground water-based PWSs. The HSA focuses on identifying all hydrogeologic barriers present at a specific site along recharge pathways and then determining which of the barriers along the flow path provide natural filtration to remove pathogens.

Examples of Hydrogeologic Barriers

Examples of effective and ineffective hydrogeologic barriers provide a better understanding of what constitutes a hydrogeologic barrier. The following descriptions of geologic materials or hydrogeologic elements that provide natural filtration or flow restrictions that lead to inactivation or removal of pathogens. Well construction characteristics that restrict ground water flow and lengthen flow paths and/or time of travel of surface recharge to production aquifers also increase the opportunity for pathogen inactivation or removal. Where these hydrogeologic barriers are compromised or do not exist, ground water resources are more likely to be contaminated with pathogens if sources are present in the vicinity of the wellfield.

Confined Aquifer – A confined aquifer has a layer of till or shale, or other low permeability material, above the aquifer that restricts flow to the aquifer. In addition, confined aquifers are over pressured so the flow direction is from the confined aquifer upward, which restricts the flow of pathogen-contaminated recharge or ground water into the confined aquifer. Significant head above the confining layer indicates recharge above the top of the aquifer. If the recharge area is outside the one year time-of-travel, pathogens should die off prior to reaching the production well. This illustrates the importance of knowing the recharge area.

Low Yield Wells - In areas of low yield aquifers, the tendency is to construct wells in ways to maximize yields. For example, the minimum amount of casing may be installed to capture shallow flow paths. The purpose is to maximize the flow to the well, and frequently this increased flow is tied closely to capturing surface recharge, which may transport pathogens. Well construction issues that favor short flow paths of surface water to the well need to be carefully evaluated because they compromise the integrity of hydrogeologic barriers. The rating system discussed below does not provide a barrier value for low yield wells because the geologic setting and elements of the well construction, for example, thin vadose zones, limited saturated casing, and well drawdown, should identify the lack of barriers. The issue is included here to alert evaluators to look carefully for compromised barriers associated with low yield wells.

Saturated Bedrock - Ground water flow in fractured bedrock can be rapid, and flow paths can be difficult to identify. If the vertical gradients in fractured bedrock are limited by low drawdown during pumping, then the forces driving surface contaminants (concentrated at the water table surface) to depth are reduced as compared to bedrock wells with large pump drawdown producing strong vertical gradients. Thus, relative barrier values are provided for the thicknesses of saturated fractured bedrock above the pump. In general fractured bedrock is not considered protective, but shales are considered more protective than sandstones which are more protective than limestones based on vertical fracture extent and enlargement due to dissolution. Greater thicknesses of fractured bedrock do lengthen the travel path to the deep aquifers. For the HSA, the thickness of the saturated bedrock is the distance between the top of bedrock or the water level during pumping (whichever is lower) and the pump.

Well Drawdown - Significant drawdown introduces stronger vertical gradients in the material above the production aquifer within the cone of influence, which increase the potential for pulling surface contaminants, including pathogens, to depth. This is not easy to account for, but as a conservative approach, we will use the pumped drawdown level as the water level for determining saturated thickness of units. This reduces the saturated thickness of the overburden, and provides lower barrier values than if the area was saturated to help account for the vertical gradients in the cone of influence.

Basis for Barrier Values

The discussion of the rationale for determining barrier values is provided to help the user select appropriate barrier values when completing HSAs. The barrier values listed in Table 2 were generated by Ohio EPA based on concepts of recharge and ground water flow, and associated pathogen migration. The recharge and ground water flow pathways are significantly different in unsaturated and saturated conditions, and the HSA Scoring Sheet for Local Hydrogeologic Barriers accounts for these differences. The order of items in Appendix A follows the order of recharge flow paths and the order of the zones presented in Tables 1 and 2.

Discussion of Zones and Special Situations

Table 2A

SWAP Susceptibility - The SWAP susceptibility analysis evaluated barriers to migration of dissolved contaminants and ranked the susceptibility as high, medium or low. To benefit from this effort, which focused on many of the same questions considered for the HSA (except for dissolved components, not pathogens), the SWAP susceptibility classes were given barrier values: high = 0; medium = 1; and low = 2. This approach generally works, except for buried valley aquifers, which are sensitive to dissolved components but the poorly sorted nature of the sand and gravels provide reasonable natural filtration to remove pathogens. Consequently, for a buried valley aquifer that has a SWAP susceptibility of high, the barrier value can be listed as 1 rather than 0 if the sand and gravel thickness overlying the production aquifer is greater than 25 feet.

Table 2B

Vadose Zone - The unsaturated material above the water table is the vadose zone and the thickness is the depth to the water table with no drawdown. In the unsaturated vadose zone, flow pathways are difficult to predict, but tend to be vertical. Piping or rapid flow through fractures or other macropores is likely to provide rapid flow through the soil and vadose zone to the ground water table. Although the vadose zone material may provide good adsorption capacity leading to pathogen attenuation and predation, the potential for rapid vertical flow suggests that thin vadose zones may be traversed rapidly and consequently are not effective pathogen barriers. This is demonstrated by the general sensitivity of shallow aquifers. As the vadose zone thickness increases, the filtration characteristics improve, but the potential for piping flow or fracture flow still exists, so the barrier values are low to moderate as listed in Table 2B.

If multiple units occur in the vadose zone, rate the zone that is the best hydrogeologic barrier. Since vertical flow is dominant in the vadose zone, in areas with multiple horizontal layers the most protective layer can be used since it is the rate-limiting layer.

Vadose Zone – Unconsolidated - The barrier values for unconsolidated material in the vadose zone are based on the probability of the presence of fractures and macropores, or other pathways that would allow rapid flow. Any material that is unsaturated and less than 10 feet thick is not considered a hydrogeologic barrier (-1 barrier value). Sand and gravel deposits are not likely to be fractured and generally provide natural filtration; consequently, unsaturated sand and gravel deposits are given positive barrier values that increase with increased thickness. Colluvium in the unglaciated portions of Ohio is considered to be similar to sand and gravel deposits, although its weathered nature should result in inclusion of more clay and thus, provide more adsorption sites than sand and gravel. Increased clay content also increases the possibility of fractures developing. Boulders, cobbles or gravel without significant finer grained material filling the voids, can provide large pore space and, consequently, are associated with rapid flow rates. The result is a negative barrier value for these materials. Tills are generally tight and exhibit low permeability, but in the vadose zone tills may be fractured. Most fracturing in tills is restricted to the upper 25 feet so tills thicker than 25 feet are given positive barrier values. Soil is part of the vadose zone but is not considered separately due to its high permeability and the fact that several common pathogen sources, septic discharges for example, discharge below the soil zone.

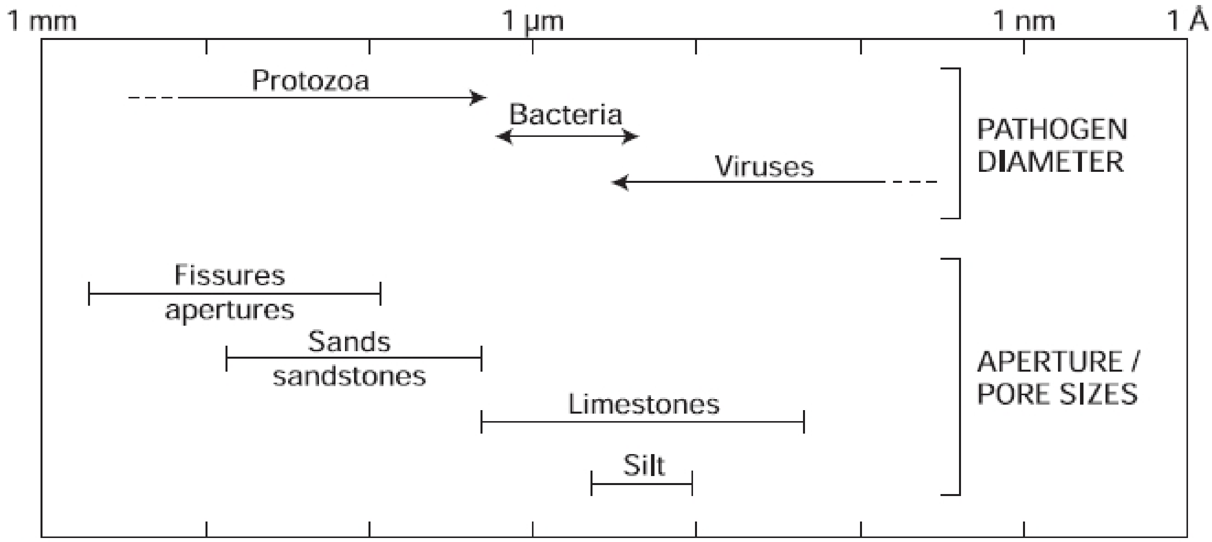
Vadose Zone – Consolidated - For unsaturated bedrock material, the barrier value is related to the probability of the presence and vertical extent of fractures. Generally, the vertical extent of joints in sedimentary rocks depends on the lithology and the bedding thickness. Bedding thickness and unit strength control fracture density and joint/fracture spacing. Sediments with thick beds and tightly cemented or lithified units exhibit greater vertical extent of joints, but wider spaced joints. Thus, well-cemented sandstones and limestones have joints with longer vertical extent and poorly lithified shales exhibit numerous bedding plane fractures and joints with limited vertical extent. Longer vertical joints or fractures promote rapid vertical flow paths, and this logic is applied to bedrock lithologies in the vadose zone with barrier indexes of + 1.5 for thick shale to -1.5 for limestone (Table 2B).

Table 2C
Saturated Zone - Flow in saturated material is easier to predict than in unsaturated material. Once recharge reaches the water table, the driving forces for vertical flow are reduced and the rate of vertical migration of recharge and associated contamination is reduced. Consequently, saturated material is more protective than unsaturated material and this fact is reflected in greater barrier values for saturated material in Table 2C. An additional complication in the saturated zone is that horizontal flow components are common.

To evaluate the saturated zone for the Local HSA, the **PWS aquifer has to be identified first**. The importance of identifying the aquifer is related to deciding what saturated units occur above the aquifer and, consequently, have potential to inactivate or remove pathogens during migration of recharge and ground water through the saturated zone to the identified aquifer. Determining the aquifer thickness is discussed in the aquifer section.

Saturated Zone – Unconsolidated - Filtration in unconsolidated material is controlled by grain size. Smaller grain size increases the time of travel and interaction of suspended particles with grains and, thus, the opportunities for, entrapment, adsorption and predation of pathogens increase accordingly. Figure A illustrates the size relationships between pathogen diameters and pore sizes of some geologic materials as reported in ARGOSS (2001). Crypto cysts (3,000-7,000 nm) are medium to small protozoa, but are significantly larger than bacteria and can be removed by natural filtration in sands. Small fecal bacteria (2500-300 nm) are more difficult to remove than crypto cysts, and the smaller viruses (300-20 nm) are very difficult to remove in unconsolidated aquifers. The small size of viruses (300 -20 nm) allows them to migrate farther in unconsolidated aquifers than bacteria (2,500-300 nm). Very fine silt and coarse clay (silt size diameter range 50,000- 2,000 nm, clay-sized material < 2,000 nm) may provide reasonably good filtration of viruses, but productive aquifers are composed of coarser-grained material and, consequently, viruses may not be effectively filtered. The barrier index values focus on the removal of bacteria, since *E. coli* is Ohio's indicator for the GW Rule. Progressively thicker sections of unconsolidated material with filtration capacity get higher barrier index values as listed in Table 2C.

In unconsolidated material, sorting influences filtration effectiveness. Poorly sorted material, typical of glacial outwash, improves the effectiveness of natural filtration. The bulk of Ohio's buried valleys are glacial outwash deposits, which provide effective natural filtration (Ohio EPA, 2007). In saturated unconsolidated material, barrier values increase as the thickness of the units increase as a result of longer flow paths to the aquifer. Ten feet or less of saturated unconsolidated material is given a barrier value of 0. Sand and gravel, colluvium, or finer-grained, non-cohesive material of 10-25 feet is given a barrier value of 1, thicker sections of these materials are given higher barrier values as listed in Table 2C. Saturated till is not likely to be fractured, and its fine-grained nature and low permeability make it an excellent hydrogeologic barrier. Saturated till units greater than 10 feet thick are given significant barrier values which increase with increased thickness.



Units: 0.001 mm = 1 µm = 1,000 nm; millimeter, micrometer, nanometer

Figure A. Pathogen diameters compared to aquifer matrix apertures (From ARGOSS 2001)

Saturated Zone - Consolidated - Bedrock units that lie above the aquifer but are not considered part of the aquifer may provide barriers to the migration of pathogens. The removal or inactivation of bacteria in saturated bedrock is inversely related to the vertical length of the fractures or joints. Longer vertical joints promote more rapid vertical transport. The vertical extent of joints depends on the lithology and the bedding thickness, with thicker beds exhibiting greater vertical extent of joints or fractures. Bedrock composed of interbedded, mixed lithologies generate different joint spacing in different lithologies, which limits the vertical extent of joints and requires more contorted and longer flow paths to reach the aquifer. Shale is thinly bedded and friable, which reduces the development of long vertical joints. This logic is applied to bedrock lithologies in the vadose zone with lower barrier values for more massive bedrock types like limestone and higher barrier values for interbedded sandstone and shale. Increasing the thickness of the bedrock package increases the flow path length resulting in larger barrier values for thicker sedimentary bedrock units as listed in Table 2C.

Thickness of Saturated Zone - The thickness of the saturated bedrock used for completing the Local HSA in Table 1 depends on the amount of drawdown during pumping. To assure long-term protection, the distance between the top of the aquifer and the maximum level of drawdown during pumping is used as the thickness of the saturated bedrock above the aquifer. Drawdown during pumping introduces vertical gradients in surrounding rock units within the cone of depression, which may increase the vertical migration of pathogens. The vertical gradients are significantly reduced in the bedrock below the level of maximum drawdown.

Table 2D

Aquifer - Flow in the aquifer is predominantly horizontal during pumping. Bedrock aquifers are considered to be fractured and that some portion of the production water comes from fracture flow. Barrier values need to account for rapid flow rates that can occur in aquifers. Fractured bedrock aquifers receive significantly lower barrier values than unconsolidated aquifers with porous media flow in Table 2D. The logic is that longer travel times of horizontal flow within porous media aquifers will result in greater pathogen predation and die off. This cannot be said for dissolved contaminants and illustrates a significant difference in evaluating the sensitivity for pathogens and chemical contaminants. The Federal GW Rule specifically identifies gravels, fractured bedrock and karst as sensitive aquifers due to rapid ground water flow with little pathogen attenuation.

A comment on the carbonate bedrock is appropriate. Limestone is more soluble than dolomite, and in northern Ohio, karst features are more common in the Devonian limestones than the Silurian dolomites. This solubility difference is the main reason for the higher barrier value for dolomite than limestone (- 2.5 versus - 3.0) provided in Table 2D. This is a slight difference and rapid flow rates are common in dolomite and have been documented in the Silurian dolomites around Gibsonburg in Sandusky County (Gibsonburg Karst Investigation, Ohio EPA, 2010). Karst formation is a complicated process dependent on many factors. The main point is that karst features do not need to be present for fracture flow to be significant.

Aquifer Thickness - In unconsolidated material, the aquifer will be the screened interval and the saturated material overlying the screened interval will be rated using the saturated zone – unconsolidated options in Table 2C. Determining the vertical extent of the aquifer in bedrock units is not always easy. For massive lithologies like the Silurian limestones, the aquifer is likely to extend from the top of the bedrock to the bottom of the well, with flow through vertical fractures to bedding plane production zones penetrated by the well. In this case, the Saturated Zone – Consolidated section of Table 2C would not be used and the entire limestone section would be considered the aquifer (as illustrated in Figure 3). In contrast, the Mississippian Logan Formation is a sandstone aquifer that can be identified within interbedded sandstones, siltstones and shales. In this case, the sandstone aquifer can be identified and the overlying interbedded siltstones and shales would be identified as saturated bedrock above the aquifer. For sections where multiple layers are present (for example - a well log with lots of detail), professional judgment needs to be used to distill the section into saturated bedrock above the aquifer and the aquifer zone and then select appropriate barrier values from Tables 2C and 2D.

Thick Aquifer Adjustment - In thick fractured bedrock aquifers, the open hole may receive water throughout the length of the open borehole, but it is likely that there may be several zones in a well that provide most of the water production. The major production zones are probably areas where the well intersects vertical fractures or where the well intersects bedding planes with significant porosity that allows higher flow rates. In carbonates, the fractures and bedding planes may be enlarged by dissolution, promoting even greater flow rates. During drilling, these high production zones may be identified. The point is, deeper production zones require longer fractured flow pathways to the production well resulting in increased travel time to the well, which provides more time for bacteria inactivation.

In massive aquifers, if the pump is located below these high production zones and these deep zones provide the bulk of the production water, the longer travel times to the deeper production zones provide more time for pathogen inactivation. The potential for rapid flow rates, however, may compromise this protection. The amount of drawdown during pumping is also critical, as larger drawdown pulls surface contaminants delivered to the water table to depth. The larger the drawdown the less likely the deeper fractures zones are providing all the production water and the larger the vertical gradients are to transport pathogens at the water table to depth. Consequently, the aquifer thickness is considered the distance between the pump and maximum drawdown (saturated well above pump). Sites with longer saturated well length above the pump are assigned larger thick aquifer adjustments. The thick aquifer adjustment will generally be applied to the massive carbonate aquifers in western Ohio. In no case should the thick aquifer adjustment shift a carbonate aquifer from a negative barrier value to a positive barrier value.

> Note: The thick aquifer adjustment is a difficult barrier to evaluate and apply. If there is cascading of shallow ground water into the open hole during pumping do not apply this adjustment.

Confined Aquifers - If an aquifer is confined and documented as over-pressured compared to the surface/shallower aquifers, it will be considered isolated. Aquifers with potentiometric pressure that rises above the aquifer or above the static water level of the shallow aquifers are isolated and resistant to flow into the confined aquifer. This significantly restricts pathogen migration into the aquifer from local sources. For confined aquifers, knowledge of the recharge area is important to assure that the recharge to the confined wells is not in a location close enough to the production wells to allow lateral migration of viable pathogens to the aquifer. For confined aquifers to be protected from pathogen contamination, the transport time of recharge to the aquifer or producing well has to be greater than pathogen viability, considered as the 1 year TOT for bacteria but possibly longer for viruses. Confined aquifers have a high barrier value (4) and semi-confined aquifers have a barrier value of 2.

If an aquifer appears confined based on the static water level, but pumping pulls the potentiometric surface level into the production aquifer, this aquifer should not be considered confined. This aquifer may be considered semi-confined if the casing is set in a confining layer. If pumping pulls the potentiometric surface into the aquifer, the open hole allows cascading of shallow water into the open hole and provides a possible rapid pathway to the aquifer. If the casing is set into a confining layer, any water cascading into the well bore due to the lowered potentiometric surface is sourced from below the confining layer, the aquifer can be considered semi-confined.

An aquifer with a confining layer above it, but in which the potentiometric pressure does not rise into or above the confining layer, will not be considered confined. In an under-pressured aquifer the pressure gradient drives surface contaminants to the deeper aquifer. If abandoned wells or other breaches of the confining layers are present, numerous pathways may allow rapid recharge to flow to the deep aquifer. To identify an aquifer area as confined or semi-confined significant impermeable units must be present above the aquifer. Even if this aquifer is not over-pressured, the presence of impermeable units above the aquifer should provide some protection, and are included in the Local HSA by using the saturated zone – consolidated options in Table 2C (saturated bedrock above the aquifer).

Table 2E

Induced Recharge - Wells sited to induce surface water recharge for increased production need to be evaluated carefully because the siting has been selected to purposely shorten recharge flow paths. Generally, riverbank filtration appears to provide significant natural filtration, but flow paths to many wells are designed to be short. The evaluation of induced recharge should consider the shortest flow paths between the surface water body and the production well. As a general rule, all Ranney wells should be considered vulnerable/sensitive to pathogens if they have laterals under a river, until demonstrated otherwise. Since most wells sited to induce recharge are located in floodplains the correlation of pathogen detections with flooding events needs to be evaluated as well.

If a well does not exhibit the potential for these short flow paths (<100 feet from river) then the horizontal flow path is not considered a risk, and thus, not considered further in the HSA to determine pathogen sensitivity. In wells that do not have the risk of rapid induced recharge, the HSA focuses on the potential for other pathways that may provide rapid flow to a pumping well. We do not want to mask pathogen sensitivity by overweighting flow paths with good natural filtration. Pathogen sensitivity is controlled/defined by the shortest flow paths with poor natural filtration not the longer flow paths with good filtration.

Table 2F

Well Construction Concerns - The HSA assumes proper well construction. It is difficult to evaluate well construction because the well is out of sight except for a short section of surface casing. The HSA may help to identify well construction issues by identifying wells in pathogen non-sensitive hydrogeologic settings that record *E. coli* detections in raw water samples. The most obvious explanation in these cases is improper well construction or deteriorated well casing. The HSA report includes a section on well construction in order to highlight potential deficiencies. A distinction needs to be made between well construction and the deterioration of what was once proper well construction, but both need to be evaluated.

Turbid Water - A well that produces turbid water at irregular intervals likely lacks effective natural barriers and is subject to pulses of rapid recharge that may transport pathogens. The intermittent nature of turbid water in sensitive wells makes it hard to document, but local observations or anecdotal evidence provided by the well users provides useful observations. Turbid water produced from a well, even if infrequent, is given a barrier value of -2. If the turbidity is associated with precipitation of iron oxides due to dissolved iron or iron bacteria, it should not be considered turbidity associate with rapid recharge.

Cascading Water - If you hear water draining or cascading into the well through casing or from fracture flow in bedrock below the casing, it is likely the hydrogeologic barriers present are being short circuited or bypassed. If possible, the source of the cascading water should be determined. Cascading water due to a hole or holes in the well casing or from the bottom of the casing are clear indicators of a well integrity problem that needs to be addressed.

Cascading water that is not associated with well integrity issues is usually due to greater horizontal than vertical hydraulic conductivity. This results in water moving horizontally along fractures or bedding planes to the open borehole above the pumping level of water in the well because the limited vertical permeability restricts the vertical flow in the zone of influence. This zone of limited vertical permeability acts as a hydrogeologic barrier at some level to water below the zone. The shallowest water cascading into the well above a low permeability zone is more likely to be associated with surface water recharge and may transport pathogens. Consequently, a cascading well is given a barrier value of -2. If the drillers log indicates the presence of water at a depth in an uncased portion of a well that is above the static water level or above the depth of static water plus drawdown, the well is considered a cascading well.

Saturated Casing - Saturated casing is the length of casing that is consistently below the water table or always saturated – that is the length of casing that extends below the water level when the pump is pumping. From the well log, the length of saturated casing can be determined by subtracting the static water level (depth below ground surface) plus the length of drawdown during the pump test from the length of casing below the ground surface. Negative values for saturated casing indicate that the casing does not reach the water table or the bottom of the casing is located above the depth of drawdown during pumping. Negative saturated casing should not occur in unconsolidated materials because the casing is necessary to keep the well open. However, negative values for saturated casing are common in bedrock wells, a situation that increases the likelihood of cascading water into open boreholes. It appears that saturated casing is an effective hydrogeologic barrier if the length is sufficiently long to restrict the ground water near the surface of the water table from flowing rapidly into production wells.

Perched water tables may provide saturated casing through the perched aquifer. The casing associated with a perched water table can be credited as saturated if the impermeable material that is causing the perched condition is extensive laterally. At a minimum, the impermeable zone should extend beyond the drinking water source protection inner management zone and is expected to remain saturated through the year.

Table 2F lists various barrier values for the length of saturated casing. Saturated casing of less than 10 feet does not provide much of a hydrogeologic barrier because surface pathogens delivered to the water table can migrate rapidly to depth by cascading into the open well bore. If the saturated material in the area of the saturated casing is fine-grained, then the transient drop of the static water level during pumping will not cause significant change in the saturated conditions of the material around the casing due to slow ground water flow. In coarse material, desaturation of the area in the cone of depression is more likely and, consequently, coarse material is given a lower barrier value. For saturated casing of less than 10 feet, the barrier value for fine-grained material (till and fine silt) is -1, and for coarser material or bedrock the barrier value is -2. It is assumed that the static water level returns to the original static water level during times of limited pumping to resaturate the material around the casing. As the length of the saturated casing increases, the barrier value of saturated casing increases as listed in Table 2F.

To avoid penalizing a well twice for the same compromised barrier, if a well is given a -2 for cascading water it is clear that the saturated casing is negative and the well should not be given a barrier value for saturated casing.

Appendix B

Hydrogeologic Sensitivity Assessment Examples

Interoffice Memo

To: XXXXXXXX

From: Chris Kenah, Geologist, CO

Date: XXXXXXXXX

Property: Pathogen Sensitive Example

Subject: Hydrogeologic Sensitivity Assessment (HSA)

Summary

The site specific evaluation of the Pathogen Sensitive Example well, produced a Barrier Index of -2.5 to -1.0, which suggest the site is pathogen sensitive. The lack of a well log for the Pathogen Sensitive Example well makes this relative determination a bit more uncertain than usual, but in general terms, the pathogen sensitive determination is consistent with the hydrogeologic setting. This determination is strengthened by the addition of 60 feet of liner to the well in 1997 to "isolate surface contamination" from the well. Recommendations are provided at the end of this report with the conclusions.

Introduction

The Division of Drinking and Ground Waters – Drinking Water (DDAGW-DW) requested that DDAGW – Ground Water (DDAGW-GW) complete a Hydrogeological Sensitivity Assessment (HSA) for the Pathogen Sensitive Example in Portage County (PWS ID# OHXXXXXXX). CO was requested to help with this HSA on November 7. The Draft HSA Guidance procedures (dated July 6, 2012) were used to complete this HSA.

Regional HSA

From a regional view point the Pathogen Sensitive Example well occurs in a hydrogeologic setting of thin upland with a thickness of 25-100 feet which is not considered pathogen sensitive on a regional basis.

Hydrogeologic Setting

The hydrogeologic setting is characterized by the presence of glacial till overlying bedded sedimentary rocks. The till thickness in the surrounding wells ranges from 14- 41 feet which suggest the till thickness is frequently below the 25 foot thickness used as the boundary for determination of the regional pathogen non-sensitive. The sedimentary rock units include the Alleghany and Upper Pottsville undivided which includes black shales, siltstones and sandstones with minor clay, and coal. The sandstones and siltstones are the primary aquifers but fracture flow can contribute water to wells in any of the interbedded units. The Ground-Water Resource Map for Portage County indicates that the maximum yield from the Pottsville group interbedded sediments is unlikely to exceed 25 gallons per minute. Other information that helps to characterize the local hydrogeologic setting includes:

- SWAP susceptibility is listed as moderate due to the presence of a moderately thick till layer, no evidence of impacts to ground water quality, but the presence of contamination sources in the area.

- The DRASTIC index for the area of the Pathogen Sensitive Example is 109-119, in the range of lower pollution potential ranges, most likely associated with the presence of till overlying the bedrock.

- Soils – the local soils are Mahoning silt loam and Ellsworth Silt loam. The Mahoning-Ellsworth Association includes areas that are nearly level to sloping, somewhat poorly drained and moderately well drained soils that formed mostly in moderately fine textured glacial till. In level areas the Mahoning soils are saturated in winter to spring unless drained. On slopes the Ellsworth soils are seasonally wet. These characteristics provide some protection to ground water through restricting recharge of surface water.

Well Construction Information
There is no well log for this site which makes it difficult to evaluate the well integrity. The well does have 60 feet of 4 inch liner installed within 5 inch casing. We do not know when the original casing was installed, so it is difficult to predict the casing integrity. The liner was installed in May 1997 to isolate the well from surface water. There may be some interesting microbiologic sample data associated with sampling used to determine the vulnerability of the well in 1996 -1997, which would be useful to review.

Site Specific HSA
There is no well log for the Pathogen Sensitive Example which makes the site specific HSA more difficult. The well information available is that the well is 89 feet depth and a 4 inch liner was run to a depth of 60 feet. We do not know the depth of the casing, how the casing was grouted, or how the liner was grouted.

Surrounding wells (well logs: 279066 – 280 feet to the north; 254402 – 380 feet to the north; 177983 – 680 feet to the west; 58854 – 520 feet to the south; 630944 – 690 feet to the southeast; and 178428 – 740 feet to the southeast) are all bedrock wells using the sandstones as the local aquifer. Depth to bedrock ranges from 14-41 feet in these wells. The static water level ranges from 20 to 30 feet and the drawdown in wells with recorded pump test data ranged from 22 to 55 feet. There is little evidence for artesian pressure and pumping pulls the water level into the area of the bedrock. Where pump test data is available in these wells, saturated casing is not present during significant pumping.

The unconsolidated material is till and the interbedded shale, siltstone and sandstones provide sufficient yield for small wells through fracture flow and permeable siltstones and sandstones. To provide a reasonable barrier index for the Pathogen Sensitive Example without a well log, two schematic diagrams and associated tables were generated. The first, Figure 1A and Table 1A, uses mid-range values on the depth to bedrock and drawdown determined from the surrounding wells. This should give a sense for an average Barrier Index to establish the local pathogen sensitivity. The second, Figure 1B and Table 1B uses the well log with the thinnest section of till (well log 279066) and the well construction parameters for the Pathogen Sensitive Example well where possible, to provide a sense for the possible variability of the Barrier Index.

Figure 1 provides a schematic diagram of the Pathogen Sensitive Example based on six surrounding well logs. The depth to bedrock and the water table used are mid-range values from the available well logs. The well construction details of the Pathogen Sensitive Example well were used with a total depth of 89 feet and a liner installed to 60 feet. The casing depth is unknown, so it is assumed that the casing is set in the bedrock, at around 27-28 feet. The drawdown is not known but the mid-range of drawdown is around 30 feet, pulling the water level well into the bedrock during pumping.

Table 1A lists the relative values of these features in determining the Barrier Index for this site:

- The moderate SWAP susceptibility gets a value of 1.
- The 25 feet of unsaturated till in the vadose zone gets a 1.0 credit as a pathogen barrier (25 feet is on the boundary so average the 0-25 feet till and 25-50 feet till values; (0+2)/2 = 1.0).
- The interbedded section of mixed lithology of bedrock to the bottom of the liner is considered equivalent to 0-25 feet of thin beds gets a barrier value of 0.
- The Pennsylvanian sandstone aquifer is given a barrier value of -2.0.
- There is no saturated casing, but the casing is set in till so < 10 feet of saturated casing gets a barrier value of -1.0.

The sum of these barrier values is -1.0 indicating a pathogen sensitive setting, but close to the index values of intermediate pathogen sensitivity.

Figure 1B used the well log with the thinnest till (279066) to define the parameters for the depth to bedrock and static water level combined with the well construction of the Pathogen Sensitive Example well, in order to consider a worst case scenario. The bedrock is located at 14 feet with the static water level at 20 feet with a drawdown to the bottom of the well. The same well construction parameters are used as in figure 1A. This composite requires making several judgment calls. The first concerns the liner and whether it is properly grouted. The production from the Pathogen Sensitive Example well suggests the well is not being dewatered, unlike well 279066, which is another variable that is difficult to evaluate without the well log

Table 1B lists the relative values of these features in determining the Barrier Index for this site:

- The moderate SWAP susceptibility gets a value of 1.
- The 14 feet of unsaturated till in the vadose zone gets a 0 credit as a pathogen barrier.
- The interbedded section of mixed lithology of bedrock to the bottom of the liner is considered equivalent to 0-25 feet of thin beds and gets a barrier value of 0.
- The Pennsylvanian sandstone aquifer is given a barrier value of -2.0.
- There is less than 10 feet of saturated casing (assuming 30+ feet of drawdown). The casing/liner is set in bedrock and so < 10 feet of saturated casing gets a barrier value of -2.0.

The sum of these barrier values is -2.5 indicating a pathogen sensitive setting. This number may be too low if the drawdown is limited (say less than 15 feet) and too high if the liner is not properly grouted.

Water Quality Data

Although this facility has been a PWS before, only limited data is included in SDWIS. The earliest TCR sample is dated 3/1/11 and most of the chemical data were collected after 3/1/11. One sample is dated 3/28/01 for nitrate with a result of 2.66 mg/L.

The TCR results were negative from 3/1/11 to 10/24/12 when a routine sample was TC+. The repeat samples were all TC+ and FC+ (membrane filtration was used for repeats, so the growth may not be *E. coli* but are considered positive fecal indicators in the TCR). Recent nitrate samples have been less than 0.054 to non-detect (3/1/11 = 0.54 mg/L; 9/28/11 = non-detect; 7/10/12 = non-detect). However, the 3/28/01 result was significantly higher at 2.66 mg/L. The fact that nitrate is detected indicates that the aquifer is not strongly reduced, which suggests it is not totally isolated from the atmosphere. If there is more historical data it would be nice to review it, particularly in light of the decision to install the liner to isolate the well from surface contamination in 1997, but the data is not in SDWIS.

The sample results for the Pathogen Sensitive Example collected on 11/7/12 are available. The bar sink sample was total coliform positive and *E. coli* negative, but the three raw water and pressure tank samples came back with TC+ and *E. coli* presence. The one Quantitray sample recorded a most probable number of 3. The recent data documents and confirms the presence of *E. coli*. The source or sources of the *E. coli* is **not** certain. The 11/7/12 sample for nitrate was non-detect.

Pathogen Sources

Based on the SWAP Report there are several septic systems in the area. The Pathogen Sensitive Example has a discharging wastewater treatment system, and apparently a couple of summer cottages have been turned into permanent residences and they share a septic system that may be undersized.

Just to the north, about 150 feet, from the Pathogen sensitive well a small gully is present. The contours indicate 10 feet of relief in this gully with a 20-30 foot drop from the road to Berlin Lake. The closest well (279066) indicates 14 feet of till. This suggests that bedrock may be exposed or not far below the gully floor. If surface water periodically flowing in this gully infiltrates into the bedrock, this may provide rapid fracture flow pathways for pathogen migration to the Pathogen Sensitive Example well. I would suggest that the gully be walked to look for bedrock exposure. The thin till in the well north of the gully with only 14 feet of till makes this pathway a potential concern, even if the bedrock is not exposed.

Conclusions

The site specific evaluation of the Pathogen Sensitive Example well, produced a Barrier Index of -2.5 to -1.0, which suggest the site is pathogen sensitive. The lack of a well log for the Pathogen Sensitive Example well makes this relative determination a bit more uncertain than usual, but in general terms the pathogen sensitive determination is consistent with the hydrogeologic setting. This determination is strengthened by the addition of 60 feet of liner to the well in 1997 to “isolate surface contamination” from the well. With the well under the west portion of the building in a pit that is maintained dry, it is hard to see how surface water could be flowing to the well and down the casing, if drainage around the building is graded properly.

The confirmation of *E. coli* in the 11/7/12 samples also supports the pathogen sensitive hydrogeologic setting. The most likely pathogen migration pathways are down the annular space of the casing/liner or infiltration through fractures in thin till and then migration along fracture permeability to the well.

Recommendations

It is clear that the area appears to be pathogen sensitive, but the solutions are not obvious. The following recommendations are provided for consideration by Drinking Water staff:

- The gully north of the Pathogen Sensitive Example should be walked to determine if bedrock is exposed in the gully.

- Assessment Source Water Monitoring could be initiated, but it seems that the presence of *E. coli* has been determined and some sort of corrective action is required. Knowing more about the pathogen concentrations present will provide additional information, but it may not be necessary. Nitrate is detected sometimes so the aquifer is not strongly reduced.

- A down-hole camera may be useful to evaluate the integrity of the liner, but the original casing and the grouting associated with the installation of the liner are going to be hard to evaluate if the liner does not have obvious breeches.

- Someone familiar with the options available for evaluating wells with liners needs to evaluate this well. The historical data (possibly in DRINK and/or NEDO files) may help explain why the liner was installed in 1997. Proper reinstallation of a liner that is effectively grouted may solve the issue, particularly if the pathogens are migrating down the annular space.

- Determining the drawdown during pumping may help to define the depth to which casing/liner should be installed, with the idea that the presence of significant saturated casing during pumping helps reduce migration of pathogens to the production zone.

- Considering the well has been modified in the past with a liner, it may be reasonable to drill a new well and abandon the older/modified well.

- Request the local health department determine whether area septic systems are functioning as designed.   It would be nice to determine if the septic system use is significantly higher during the summer indicating seasonal use patterns.

Figure 1A – Schematic Well Log

Site: Pathogen Sensitive Example, PWS # OHXXXXXXX Portage County
Drilled: unknown; liner installed 1997
Well logs: none found for the Pathogen Sensitive Example
Surrounding Logs: 279066; 254402; 177983; 58854; 630944; and 178428

Aquifer – Sandstone
Casing length = unknown

Not drawn to scale
Using Mid-Range values

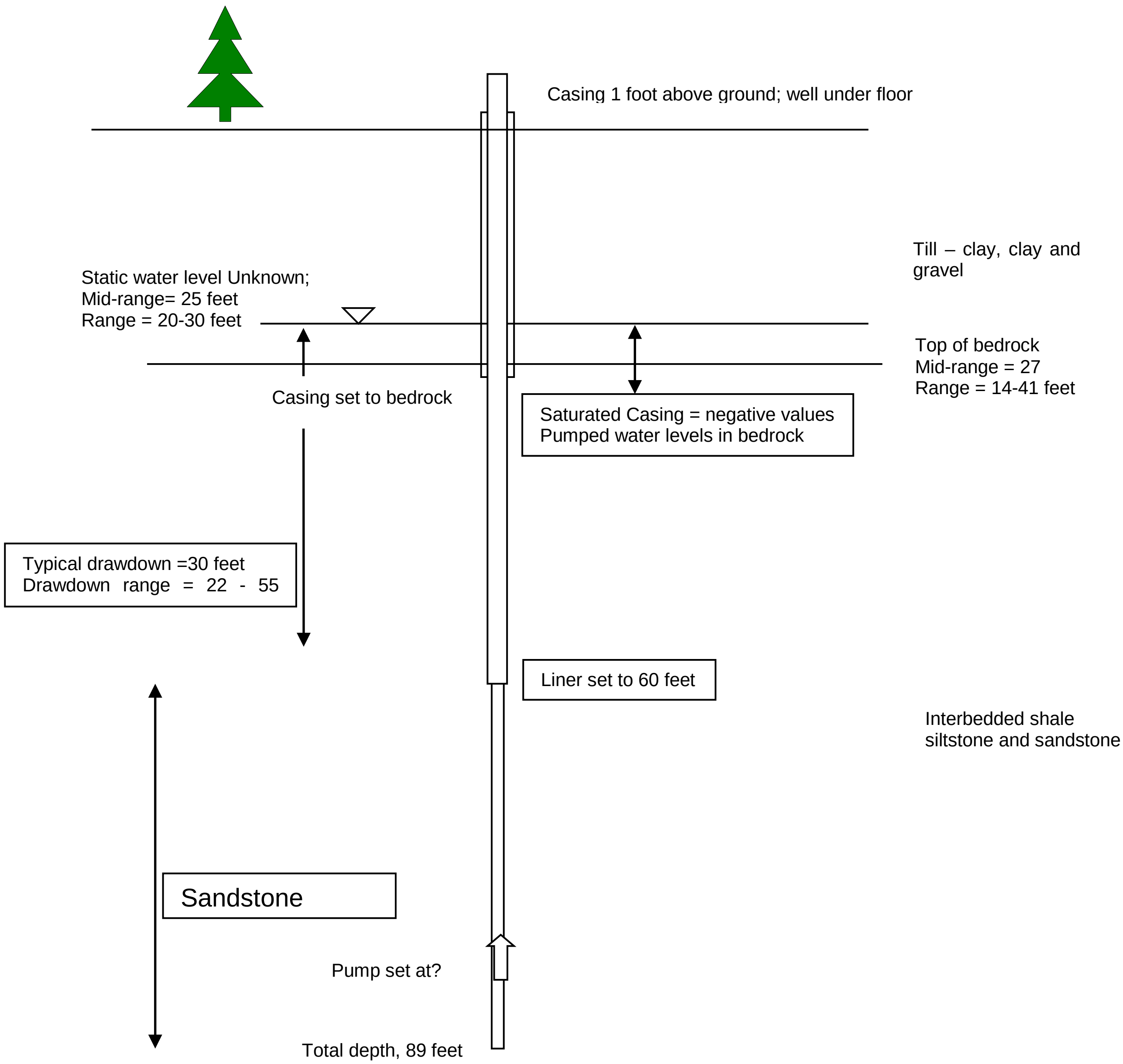


Table 1A
Local HSA – Site Specific Barrier Index

Site: Pathogen Sensitive Example
County: Portage County
PWSID: OHXXXXXXX
Mid-Range values

Date: 11/9/2012

Completed By: Chris Kenah

Flow Path Zone Recharge and Horizontal Flow	Barrier Value*	Comment
SWAP Susceptibility	+1	Moderate SWAP Susceptibility
Vadose Zone (vertical flow dominates)		
Unsaturated material	+1	25’ till on boundary ((0+2)/2 =1)
Saturated Zone (vertical and horizontal components)		
Saturated Unconsolidated		
Saturated Consolidated	0	0-25’ thin beds mixed lithology
Gravel/Cobbles/Boulders		
Aquifer (horizontal flow dominates)		
Aquifer	-2.0	Sandstone
Thick aquifer adjustment		
Confined/Semi-confined		
Horizontal Flow Threats		
Induced recharge		
Flood Plain Location		
Other		
Special Circumstances		
Turbid Production Water		
Cascading well		
Saturated Casing	-1	< 10 feet of fine grained material
Other		
Barrier Index - Total	-1.0	Pathogen Sensitive

* Select barrier value from Table 2 – HSA Scoring Sheet

Aquifer = Sandstone, 60- 89 feet

Static water = 25 feet (20-30’ range)

Barrier Index Boundaries
Pathogen Sensitive
-0.5
Intermediate
3.5
Pathogen Non-sensitive

Figure 1B – Schematic Well Log

Site: Pathogen Sensitive Example, PWS # OHXXXXXXX Portage County

Well logs: none found for the Pathogen Sensitive Example - used 279066
Surrounding Logs: 254402; 177983; 58854; 630944; and 178428
(280 feet NNW of Pathogen Sensitive Example well)
Aquifer – Sandstone Drilled: mm/dd/yyyy
Casing length = 20 feet Not drawn to scale
Worst case – Well Log 279066

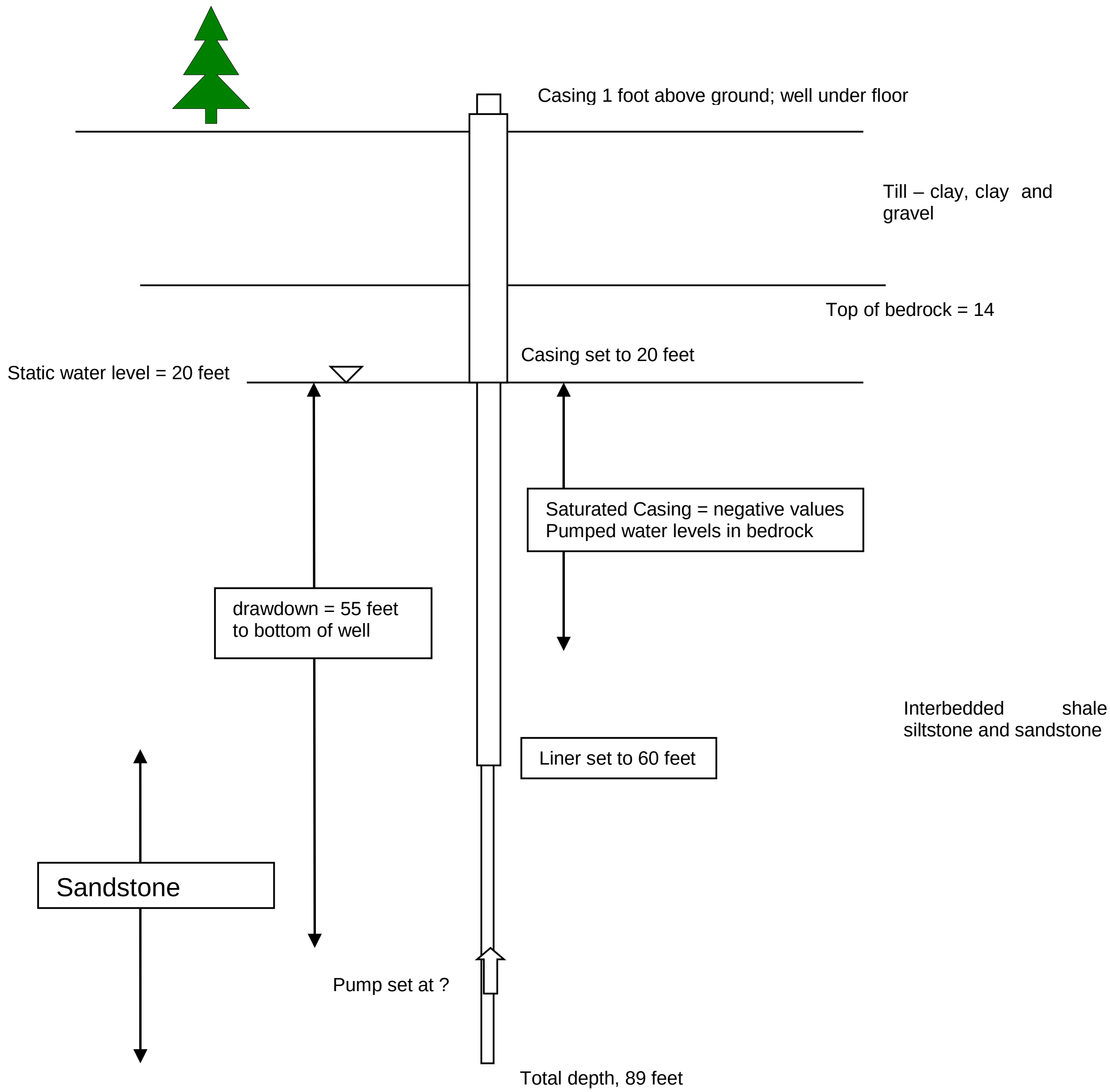


Table 1B
Local HSA – Site Specific Barrier Index

Site: Pathogen Sensitive Example - Mid-Range Values
County: Portage County
PWSID: OHXXXXXXX

Date: 11/9/2012

Completed By: Chris Kenah

Flow Path Zone Recharge and Horizontal Flow	Barrier Value*	Comment
SWAP Susceptibility	+1	Moderate SWAP Susceptibility
Vadose Zone (vertical flow dominates)		
Unsaturated material	0	14 feet of till is more protective than unsaturated bedrock
Saturated Zone (vertical and horizontal components)		
Saturated Unconsolidated		
Saturated Consolidated	+0.5	25-50' Thin Beds - mixed lithology (if liner is in place and grouted)
Gravel/Cobbles/Boulders		
Aquifer (horizontal flow dominates)		
Aquifer	-2.0	Sandstone
Thick aquifer adjustment		
Confined/Semi-confined		
Horizontal Flow Threats		
Induced recharge		
Flood Plain Location		
Other		
Special Circumstances		
Turbid Production Water		
Cascading well		
Saturated Casing	-2	< 10 feet of bedrock
Other		
Barrier Index - Total	-2.5	Pathogen Sensitive

* Select barrier value from Table 2 – HSA Scoring Sheet

Aquifer = Sandstone, 60- 89 feet

Static water = 20 feet + drawdown

Barrier Index Boundaries
Pathogen Sensitive
-0.5
Intermediate
3.5
Pathogen Non-sensitive

Interoffice Memo

To: XXXXXXXXXX

From: Chris Kenah, DDAGW, CO

Date: XXXXXXX

Subject: Pathogen Non-sensitive Example

Summary

The site specific evaluation of the Pathogen Non-sensitive Example wells produces a Barrier Index between +12 to +10 placing the setting as clearly pathogen non-sensitive. The range results from differences in the thickness of the till in the vadose and saturated zones and the resulting thickness in saturated casing. Water quality data with consistent non-detects for nitrate documents the isolation of the limestone aquifer from the atmosphere, supporting the pathogen non–sensitive rating.

Introduction

The Pathogen Non-sensitive Example in Franklin County pulled a routine total coliform sample on October 20, 2012 that was positive for total & fecal coliforms. Five follow up samples taken on 10/25 confirmed the fecal hit-two of those five samples were positive for both total and fecal coliforms, causing a violation of the TCR (Total Coliform Rule) and GWR (Ground Water Rule). After further discussion at CDO, a follow up LSSV was conducted on 10/31 and the facility was instructed to move all sampling taps out of the mop closet and into a cleaner area. The district requested as part of the GWR process that central office conduct an HSA.

Regional HSA

The northwest corner of Franklin County is glaciated and the glacial drift in the area is mapped as various units of till, including ground moraine (25-100 feet), complex (>100 feet), and end moraine (25-100 feet). Consequently, the wells at Pathogen Non-sensitive Example are not considered pathogen sensitive on a regional basis.

Hydrogeologic Setting

The Pathogen Non-sensitive Example and surrounding well logs indicate that bedrock is typically 73 to 105 feet below the surface, consistent with the Glacial Aquifer Map with tills mapped as 25-100 feet thick. Well logs are plentiful to the north and south of the park and most well logs document that the production aquifer is the limestone bedrock (194884, 251835, 4842864,502776, 950781 for example). Some wells do use sand and gravel units in the till as local aquifers (478208, 982433), but from a quick check of local well logs, wells producing from the glacial sand and gravels are not as common as bedrock wells. The glacial drift overlying the limestone bedrock aquifers in the area should supply significant natural filtration. All well logs reviewed indicated over pressured aquifers with the static water rising above the glacial and bedrock aquifers and in all cases pump test drawdown did not pull the static water level data into the aquifer. Other information that helps to characterize the hydrogeologic setting includes:

- *The Ground Water Pollution Potential of Franklin County, Ohio* (Michael Angle, 1995) indicates that the pollution potential is given a value of 121 in the area of the Pathogen Non-sensitive Example wells, which is not considered a sensitive geologic setting.

- The Drinking Water Source Protection Assessment Report lists the susceptibility to contamination as low. This determination is based on the presence of a thick till layer and the lack of water quality impacts.

Well Construction Information

The Pathogen Non-sensitive Example wells were drilled in 1992 and 1996 respectively and casing was set through the till at 101 and 95 feet using the dry driven method. Steel casing with threaded joints was used and considering the date of installation, it should be in good shape. The Pathogen Non-sensitive Example well log notes that the well was drilled to 120 feet with 101-120 feet in weathered limestone and that the well collapsed/caved in so the total depth is 105 feet.

Site Specific HSA

The Pathogen Non-sensitive Example well logs (743039 and 832786 respectively) document the general hydrogeologic setting in the area. At Pathogen Non-sensitive Example the till is 94 - 101 feet thick and consists of clay and sandy clay till. Both wells use the limestone bedrock as the production zone, although the wells do not penetrate far into the limestone bedrock. The bedrock in the area is Devonian Columbus and Delaware Limestone with the Silurian Salina Formation underlying the Devonian limestones.

Figure 1A and 1B provide schematic diagrams of the Pathogen Non-sensitive Example wells using well logs 743039 and 832786 respectively. Well construction details that may provide barriers to pathogen migration include significant lengths of casing set through the till. The static water level was recorded at 26 feet and 46 feet, but the static water plus drawdown is similar for both wells (about 42-48 feet). Significant lengths of saturated casing are present during pumping (59 feet and 46 feet respectfully), based on information available in the well logs.

Tables 1A and 1B list the relative values of these features in determining the Barrier Index for this site. Table 1A lists the barrier values as presented in Figure 1A for the Pathogen Non-sensitive Example well and include:

- The Low SWAP susceptibility gets a value of +2.0;
- The 26 feet of unsaturated till in the vadose zone is given a barrier value of +1.0;
- The 59-79 feet of saturated till is given a barrier value of 6.0 (> 50 feet of saturated till);
- The limestone aquifer is given a barrier value of -3.0;
- The 59 feet of saturated casing is given a barrier value of 2.0;
- The well exhibits artesian pressure indicating a confined aquifer – gets barrier value of 4.0.

The sum of the barrier values is 12.0 indicating a pathogen non-sensitive setting

Table 1B lists the barrier values for the Pathogen Non-sensitive Example well as presented in Figure 1B, including:

- The Low SWAP susceptibility gets a value of +2.0;
- The 46-48 feet of unsaturated till in the vadose zone is given a barrier value of +2.0;
- The 46 feet of saturated till is given a barrier value of 4.0 (> 25 feet of saturated till);
- The limestone aquifer is given a barrier value of -3.0;
- The 46 feet of saturated casing is given a barrier value of 1.0;
- The well exhibits artesian pressure indicating a confined aquifer – gets barrier value of 4.0.

The sum of the barrier values is 10.0 indicating a pathogen non-sensitive setting

The sum of these values produces a barrier index of +12.0 for the Pathogen Non-sensitive Example well and +10.0 for the Pathogen Non-sensitive Example other well. Both are clearly pathogen non-sensitive due to the thick till and the confined nature of the aquifer, providing natural hydrogeologic barriers. The differences are not great but result from the difference in the unsaturated and saturated till thickness, with the Pathogen Non-sensitive Example well getting a bit more natural filtration due to thicker saturated till and longer saturated casing due to a shallower water table.

Water Quality Data

Water quality results indicate the presence of nitrate consistently at non-detect values (< 0.1 mg/L) from 2000-2011 for both wells. These nitrate concentrations suggest the aquifer is isolated from the atmosphere, consistent with the confined nature of the aquifer. In the Pathogen Non-sensitive Example other well, since November 2006 total coliform was detected twice in TCR samples (7/30/09 and 8/30/10) and *E. coli* was detected once on 7/30/09. The repeat samples were clean. For the Pathogen Non-sensitive Example well, since August 2006 total coliform and fecal coliform were detected on 8/30/10 and 10/20/11. The repeat samples for the 8/30/10 routine samples were clean but two repeat samples (10/25/11) for the 10/20/11 routine sample detected total coliform and fecal coliform. These repeats confirm the presence of fecal coliform (for TCR and GWR considered equivalent to *E. coli*) and move the PWS into consideration of GW Rule corrective actions.

Pathogen Sources

The SWAP report documents the presence of a septic system as the primary potential pathogen source in the drinking water protection area as well as natural pathogen sources on the surface.

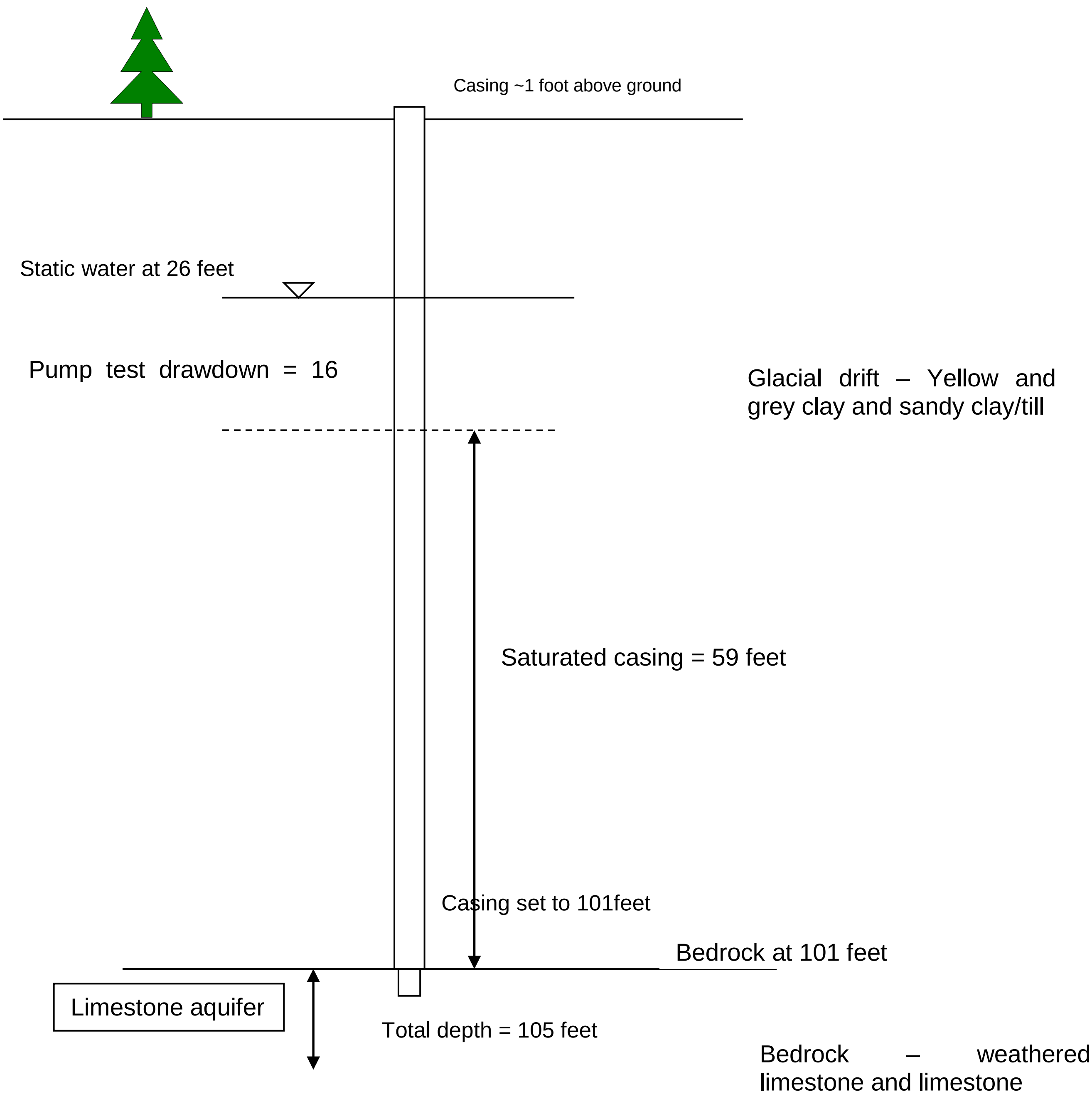
Conclusion

The site specific evaluation of the Pathogen Non-sensitive Example and Pathogen Non-sensitive Example Park wells produces a Barrier Index between +12 to +10 clearly identifying the setting as pathogen non-sensitive. The range results from variable thickness of unsaturated and saturated till and saturated casing. The lack of nitrate detections confirms the isolated nature of the limestone aquifers. This geologic setting does not appear to be sensitive to pathogen migration and with the confined nature of the aquifer, migration down the annular space of the well should not allow pathogen to reach the production aquifer. If *E. coli* is really present in the source water, the well construction/breeches in the casing appear to be the most obvious explanation. The other consideration is that the fecal coliform detected is not equivalent to *E. coli* (fecal coliform is a larger subset than *E. coli*). It may be TCR detections were the result of the poor sampling tap locations and that moving the sampling tap locations to better, cleaner locations has reduced the possibility of getting false positive results.

Figure 1A – Schematic Well Log

Site: Pathogen Non-sensitive Example, PWS ID # OHXXXXXX
Franklin County
Aquifer – limestone: 101-105+ feet

ODNR Well Log: 743039;
Drilled: mm/dd/1992
Saturated casing = 59 feet
Not to scale



Pump test – 34 gpm for 4 hours produced 16 feet of drawdown.

Well drilled to 120, but "after pumping well caved to 105 total depth".

Table 1A
Local HSA – Site Specific Barrier Index

Site: Pathogen Non-sensitive Example, well log 743039 — Date: 11/7/2011
County: Franklin County
PWS ID # OHXXXXXXX — Completed By: C. Kenah

Flow Path Zone Recharge and Horizontal Flow	Barrier Value*	Comment
SWAP Susceptibility	+2.0	Low SWAP Susceptibility
Vadose Zone (vertical flow dominates)		
Unsaturated material	+1.0	26 feet of glacial till – close to boundary ((0+2)/2 =1)
Saturated Zone (vertical and horizontal components)		
Saturated Unconsolidated	+6.0	59 -75 feet of till/sandy till
Saturated Consolidated		
Boulders		
Aquifer (horizontal flow dominates)		
Aquifer	-3.0	Limestone
Thick aquifer adjustment		
Confined/Semi-confined		
Horizontal Flow Threats		
Induced recharge		
Flood Plain Location		
Other		
Special Circumstances		
Turbid Production Water		
Cascading well		
Saturated Casing	+2.0	59 feet of saturated casing
Confined aquifer	+4.0	Over pressured when pumping
Semi-confined aquifer		
Other		
Barrier Index - Total	+12.0	Pathogen Non-Sensitivity

* Select barrier value from Table 2 – HSA Scoring Sheet

Aquifer = Limestone (94-95 + feet)

Static water = 26 feet

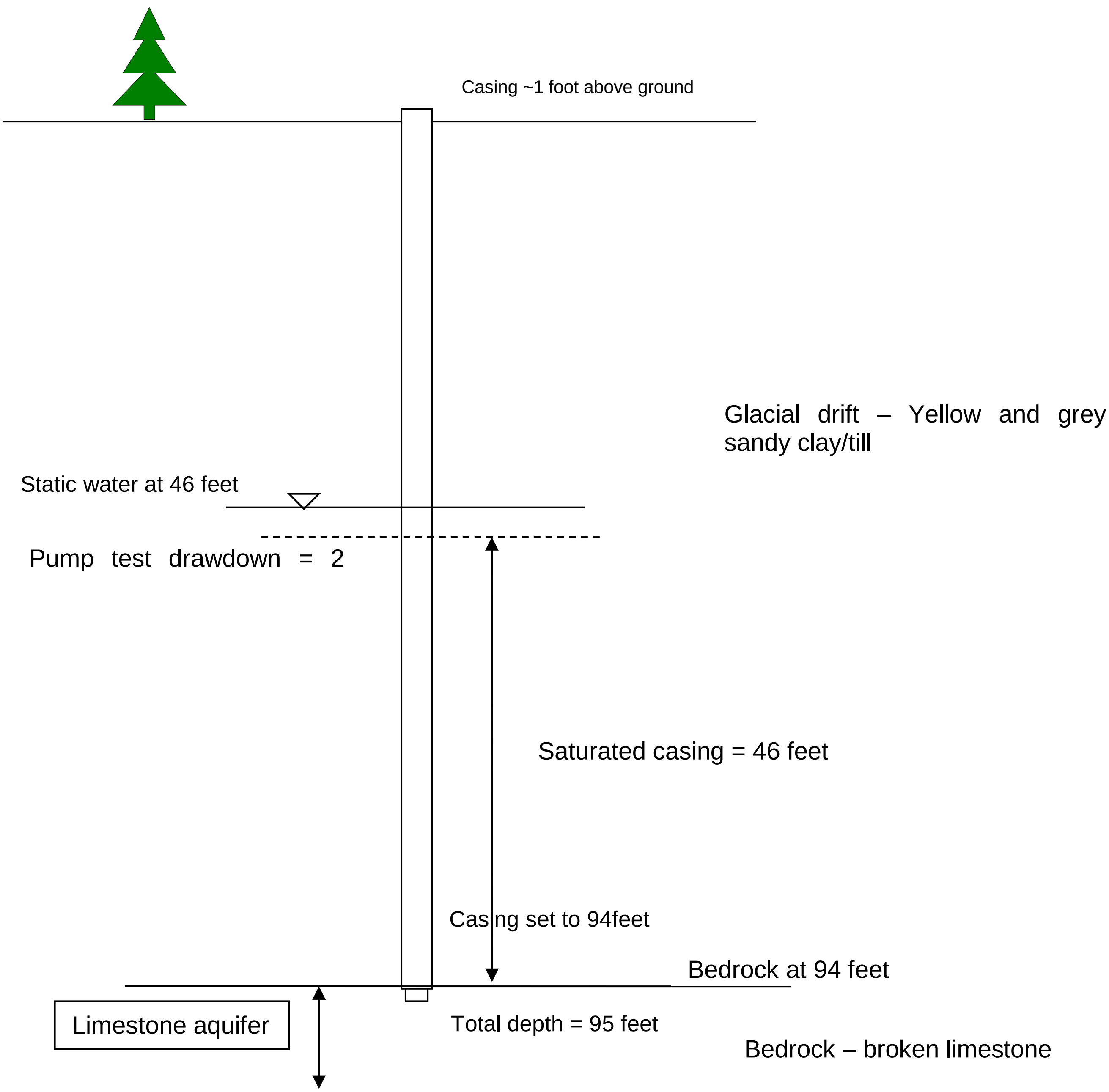
Static + drawdown = 42 feet

Barrier Index Boundaries
Pathogen Sensitive
- 0.5
Intermediate
3.5
Pathogen Non-Sensitive

Figure 1B – Schematic Well Log

Site: Pathogen Non-sensitive Example, Other, Franklin County
Aquifer – limestone: 95- 95+ feet

PWS ID#OHXXXXXX
ODNR Well Log: 832786
Drilled mm/dd/1996
Saturated casing = 46 feet
Not to scale



Pump test – 16 gpm for 24 hours produced 2 feet of drawdown.

Table 1B
Local HSA – Site Specific Barrier Index

Site: Pathogen Non-sensitive Example Park, Other, well log 832786

Date: 10/27/2011

County: Franklin County
PWS ID#OHXXXXXX

Completed By: C. Kenah

Flow Path Zone Recharge and Horizontal Flow	Barrier Value*	Comment
SWAP Susceptibility	+2.0	Low SWAP Susceptibility
Vadose Zone (vertical flow dominates)		
Unsaturated material	+2.0	46-48 feet of glacial till
Saturated Zone (vertical and horizontal components)		
Saturated Unconsolidated	+4.0	46 feet of saturated till
Saturated Consolidated		
Boulders		
Aquifer (horizontal flow dominates)		
Aquifer	-3.0	Limestone
Thick aquifer adjustment		
Confined/Semi-confined		
Horizontal Flow Threats		
Induced recharge		
Flood Plain Location		
Other		
Special Circumstances		
Turbid Production Water		
Cascading well		
Saturated Casing	+1.0	46 feet saturated casing
Confined aquifer	+4.0	Over pressured when pumping
Semi-confined aquifer		
Other		
Barrier Index - Total	+ 10.0	Pathogen Non-Sensitive

* Select barrier value from Table 2 – HSA Scoring Sheet

Aquifer = Sandstone (40-172 feet)

Static water = 46 feet

Static + Drawdown = 48 feet

Barrier Index Boundaries
Pathogen Sensitive
- 0.5
Intermediate
3.5
Pathogen Non-Sensitive