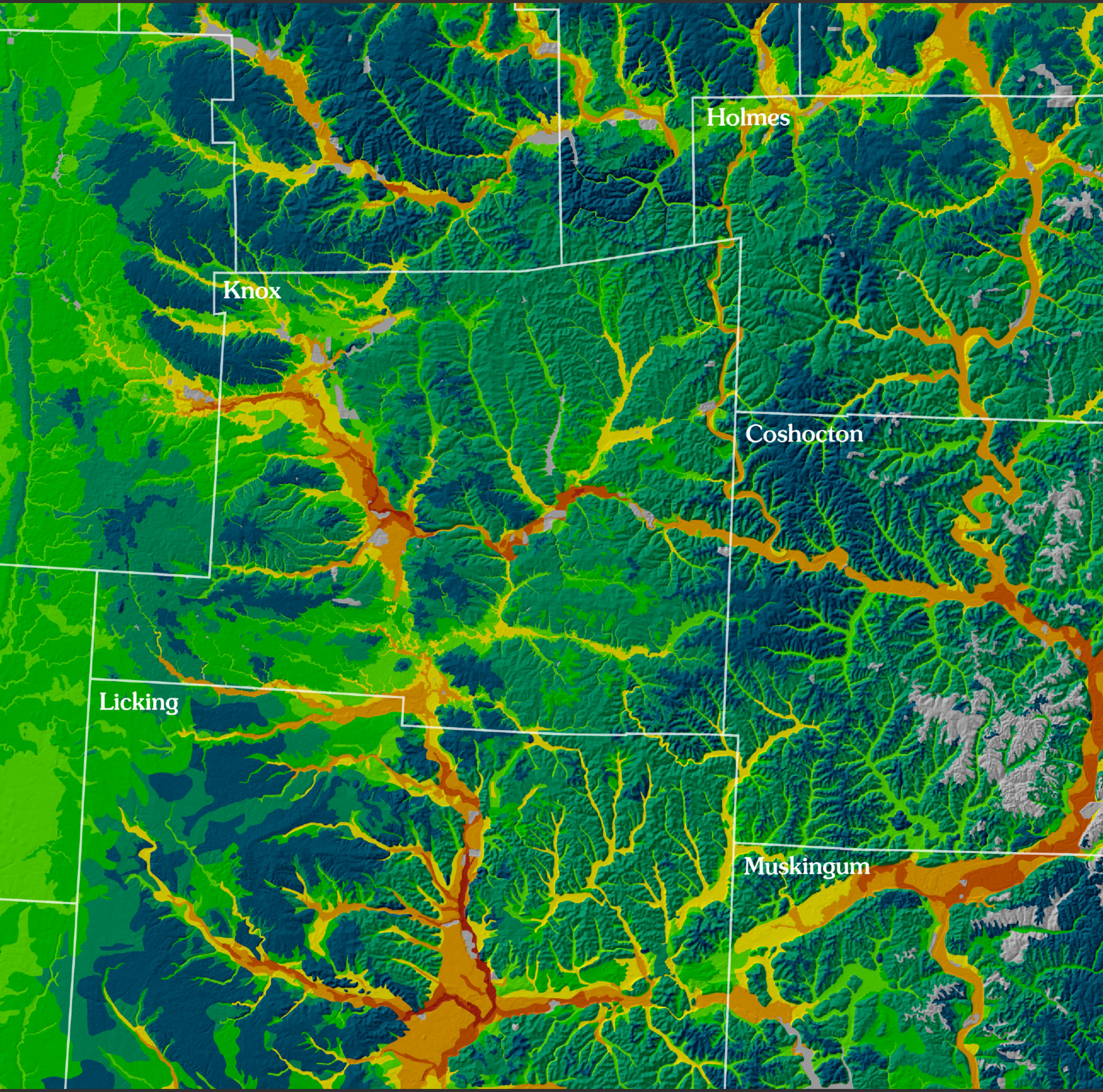
Guide to the

GROUNDWATER VULNERABILITY MAP OF OHIO

by Craig B. Nelson and Thomas R. Valachovics



OPEN-FILE REPORT
2022-1
Columbus 2022

OHIO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES

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EDITING: Anthony J. Bresnen and and Charles R. Salmons
FRONT COVER: Mapped Groundwater Vulnerability Indices in central Ohio.

RECOMMENDED CITATION: Nelson, C.B., and Valachovics, T.R., 2022, Guide to the groundwater vulnerability map of Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2022-1, 25 p.

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ABBREVIATIONS USED IN THIS REPORT

day . . . d
feet . . . ft
gallons per day . . . gpd
gallons per minute . . . gpm
inches . . . in
not rated . . . NR
year . . . yr

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Groundwater Vulnerability Mapping

Introduction

Groundwater Vulnerability (GV) maps depict an area's vulnerability to groundwater contamination based upon its hydrogeologic, topographic, and soil media characteristics. Conceptually, GV maps consider the case in which a generic contaminant is introduced at the land surface and allowed to percolate into the aquifer, be attenuated by natural processes, or be transported out of the area. As the hydrogeologic parameters controlling the fate of the contaminant change, the likelihood of the aquifer's contamination increases or decreases. This likelihood is reflected in the overall GV Index. Notably, GV maps do not consider the presence of contaminant sources, only the hydrogeology of the area in question. Therefore, a pristine, uninhabited plot of land with hydrogeologic characteristics conducive for water to flow into its aquifer would exhibit (despite having no known case or source of contamination) a GV Index higher than the location of a chemical storage facility, if hydrogeologic conditions at the facility limited the aquifer's potential pathways for contamination. In short, GV Index is a contaminant- and land use-indifferent measure of groundwater contamination potential.

Background Information

The Ohio Department of Natural Resources (ODNR) began county-based mapping of groundwater "Pollution Potential" (PP) using the DRASTIC system in the mid-1980s (Weatherington-Rice and others, 2006). Originally developed by the National Ground Water Association with funding from the U.S. Environmental Protection Agency, DRASTIC evaluations determine vulnerability using seven key parameters: Depth to Water, Net Recharge, Aquifer Media, Soil Media, Topography, Impact of Vadose Zone Media, and Hydraulic Conductivity (Aller and others, 1987). Under the ODNR Division of Water Resources Ground Water Pollution Potential Mapping Program, the State of Ohio published its first PP map, *Ground Water Pollution Potential of Madison County, Ohio*, in 1987 (Hallfrisch and Voytek, 1987). By 1995, ODNR had modified its DRASTIC methodology to account for fractured glacial deposits, till as a vadose zone media, the impact of till weathering, and double-block porosity. Earlier maps were not always reassessed to match the new methods. Geographic Information Systems (GIS) technology was first used for PP mapping at ODNR in 2000, replacing the use of Mylar and peel-coat separation techniques. Figure 1 shows the Ground Water Pollution Potential of Ross County, mapped prior to the use of GIS techniques.

GIS-based mapping continued for the next 15 years, with the most recent PP map, *Ground Water Pollution Potential of Monroe County, Ohio*, published in 2016 (Sprowls, 2016).

In 2019, with funding from the Ohio Water Development Authority (OWDA), the Division of Geological Survey began the process of editing, adapting, or completely remapping the existing PP maps into a new statewide, seamless coverage using a modified DRASTIC model. Survey geologists standardized mapping methodology; aquifer, vadose zone, and soil media classifications; ratings ranges; and hydrogeologic settings by removing, modifying, or adding values using new data and a more developed understanding of Ohio's diverse hydrogeology. Eleven previously unmapped counties were also mapped using the new system. The remapping process was completed in 2021, and its result is the new statewide, seamless GV map shown here.

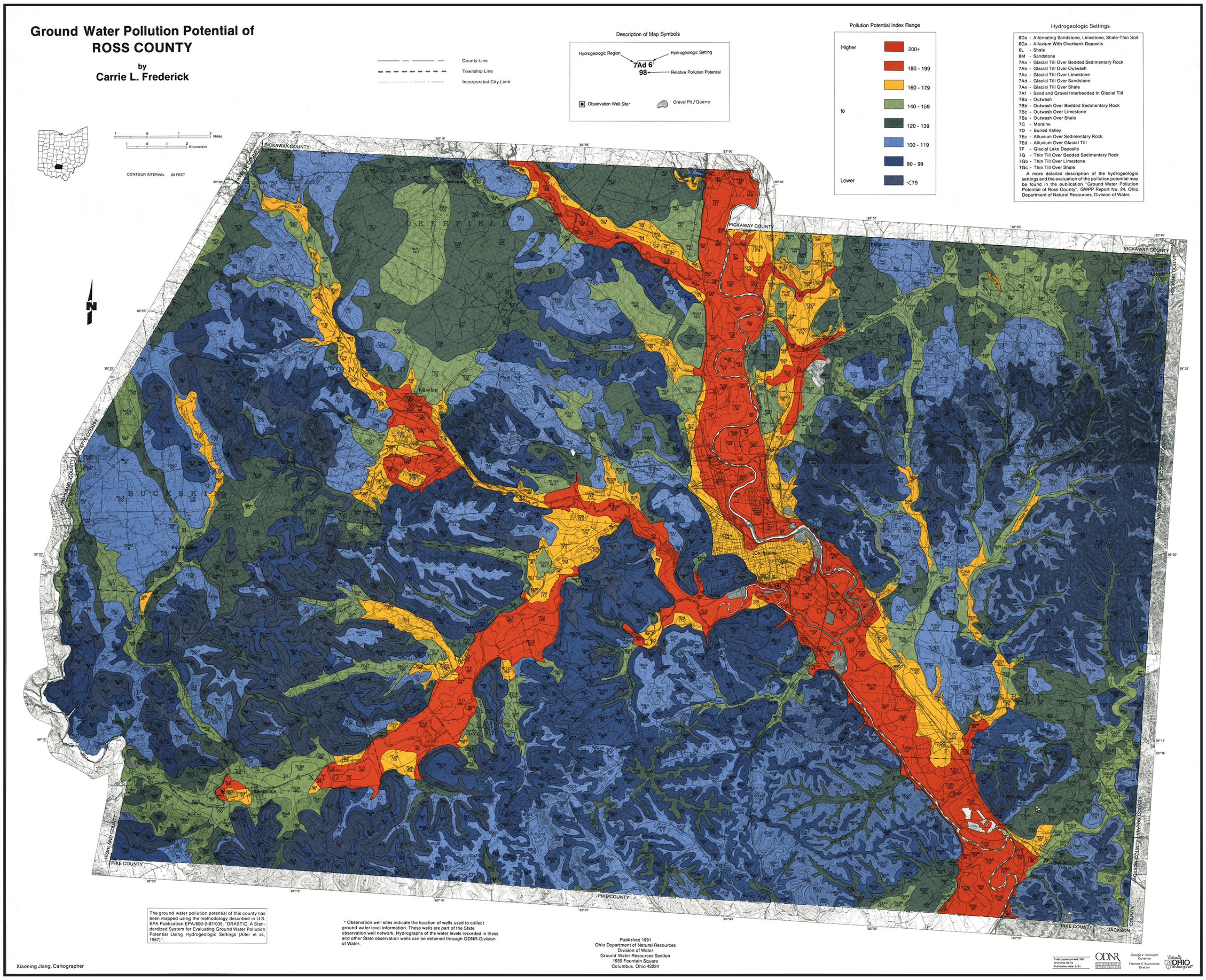


FIGURE 1. ***Ground Water Pollution Potential of Ross County*** **(Frederick, 1991).**

Mapping Methodology

The Index values depicted on GV maps describe each area aquifer's relative vulnerability to groundwater contamination, with lower values indicating less vulnerable conditions and higher values indicating higher vulnerability. They are calculated by weighting and summing the seven DRASTIC parameters (D – Depth to Water, R – Net Recharge, A – Aquifer Media, S – Soil Media, T – Topography, I – Impact of Vadose Zone Media, C – Hydraulic Conductivity) according to the following formula, where *W* is the parameter's weight and *R* is its rating:

$$\text{GV Index} = (W_D \cdot R_D) + (W_R \cdot R_R) + (W_A \cdot R_A) + (W_S \cdot R_S) + (W_T \cdot R_T) + (W_I \cdot R_I) + (W_C \cdot R_C)$$

For GV maps, parameter weights followed the original DRASTIC model described in Aller and others (1987) and are shown in figure 2. Pesticide-specific weighting of parameters is also included in the digital dataset.

The delineation of parameter values constituted the bulk of the work undertaken in this project. Each parameter had to be considered in isolation—a line on the map indicates at least one parameter value (or hydrogeologic setting) has changed—but parameters affect one another, so their interplay also had to be considered. Mapping was performed at a 1:10,000 scale.

Hydrogeologic Setting provides summary information designed to help users quickly and concisely conceptualize the hydrogeologic nature of a region of interest, including characteristics of its vadose zone, aquifer, and depositional environment. Settings are comprised of an alphanumeric code and a title description (e.g., **7D – Buried Valley**), the code classifying the area and the title description naming it in hydrogeologic terms. In some cases, such as with **7Ad – Till over Sandstone**, the title description explicitly names the expected vadose zone and/or aquifer. In others, such as with **7Fa – Ice-dammed Lakes and Slackwater Terraces**, the title describes not the aquifer or vadose zone media but the unique depositional environment distinguishing the area from its surroundings. Hydrogeologic Setting codes beginning with a *"6"* are used in the unglaciated portions of the state, while codes beginning with "7" represent glaciated regions or glacially impacted streams, valleys, and terraces extending into the unglaciated zone. Setting title descriptions often give clues as to the dominant aquifer's yields, its relative capacity for recharge, and/or the relative permeability of its vadose zone. For example, **7Bc – Outwash over Limestone** indicates a permeable, coarse vadose material over a typically higher-yielding bedrock aquifer, whereas a setting of **7Ae – Till over Shale** denotes a restrictive vadose zone and low-yielding bedrock. In a landscape context, several or more of these settings may be present (see fig. 3).

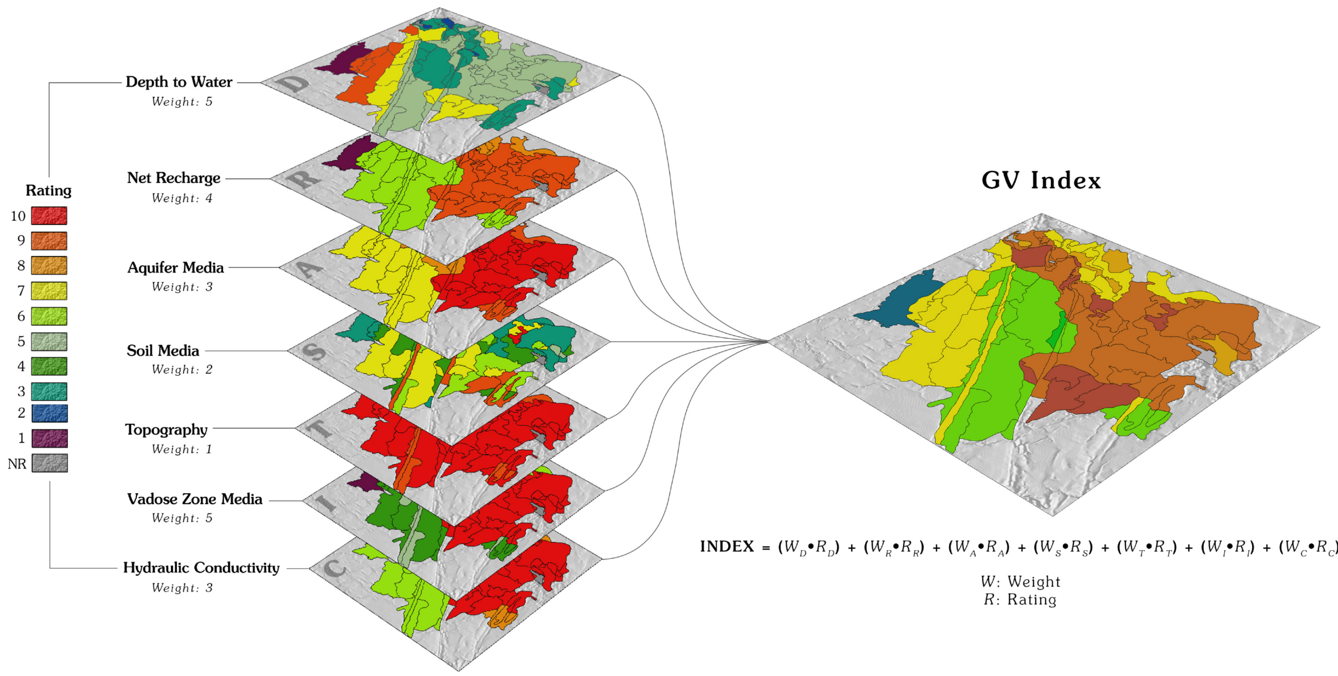


FIGURE 2. For each polygon, the seven DRASTIC parameter ratings are weighted and then summed to generate its GV Index value.

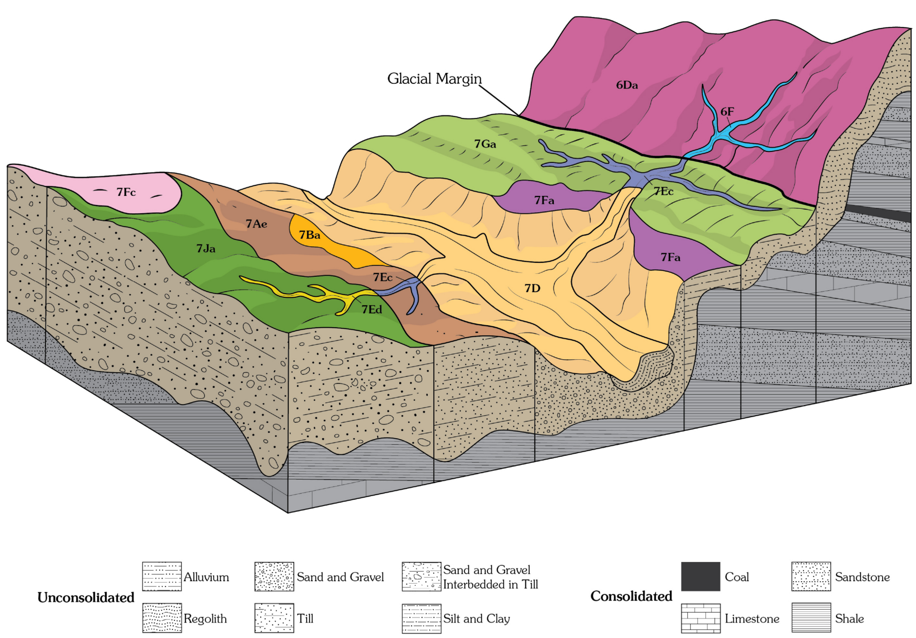


FIGURE 3. Conceptual landscape composite showing how hydrogeologic settings fit together and represent distinct vadose zone and aquifer medias. Note the transitions in alluvial settings, the gradient of the drift thickness, and the change in setting codes at the glacial margin.

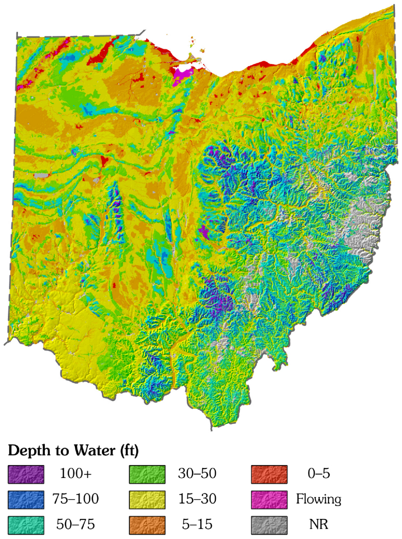


FIGURE 4. Depth to water map of Ohio.

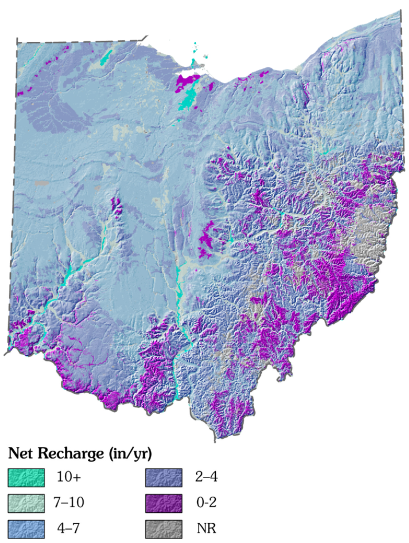


FIGURE 5. Recharge map of Ohio.

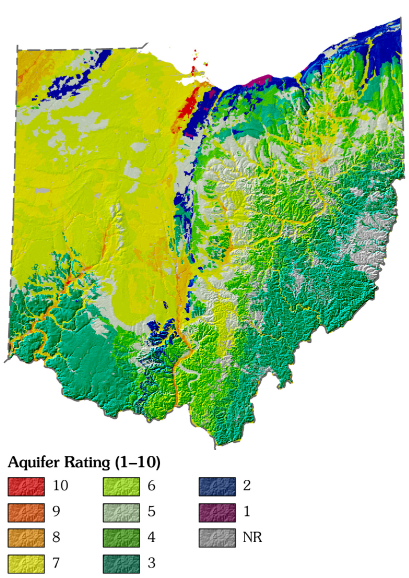


FIGURE 6. Aquifer rating map of Ohio.

Depth to Water was assessed under several conceptual models depending on the degree of aquifer confinement, the relative importance of local vs. regional water tables, and the existence of artesian or karst conditions (see fig. 4). In unconfined aquifers, depth to water was mapped with respect to the free surface hydraulic head as determined by well static water levels. In fully confined aquifers, depth to water was defined as the bottom of the confining zone. More commonly and in much of the glaciated portion of the state, semiconfined conditions prevailed. Here, depth to water was determined by means of averaging well static water levels, with the tendency to round down (shallower) in some cases, such as when perched zones were of high importance or degree of confinement was higher, or up (deeper) in other cases, such as when basal coarse units were more productive than overlying lenses or seams. Where karst or significant solution limestone features were present, depth to water was modified to represent the direct connection of the surface to the aquifer, even though reported static water levels often varied enormously. Where flowing wells were found, a special "Flowing" value was used to represent the upward hydraulic gradient that would serve to prevent the downward movement of contaminants, even though the static water level was at (or above) the land surface. In many unglaciated parts of the state, a regional model was used to represent the depth to regional-scale water tables instead of localized, perched zones.

Net Recharge represents the volume of water per unit area expected to replenish the aquifer each year. Direct measurement of recharge is difficult, so recharge values were estimated from the combination of other parameters, particularly topography, vadose zone rating, and soil media. Flatter topography, a more permeable vadose zone, sandier soil, shallower depth to water, and higher conductivity were all factors considered to increase aquifer recharge (see fig. 5). Stream or valley aquifers flanked by areas of lower recharge, such as steep uplands or impermeable zones, were expected to receive higher recharge rates. Because it is so dependent on the values of other parameters, recharge was the parameter typically mapped last.

Aquifer Media designates the material of the dominant, uppermost aquifer. While groundwater is often present in multiple formations, including combinations of unconsolidated and bedrock units, for the purposes of GV maps, only the dominant, uppermost unit or series of units was assessed for vulnerability. Some aquifer media classifications, such as "Interbedded Sedimentary Rocks," explicitly capture a sequence of different formations. Others, such as "Sandstone," express the dominance of one rock or media type. Aquifer ratings reflect a relative (1–10) evaluation of that aquifer's suitability for use, with more highly rated aquifers typically exhibiting higher hydraulic conductivity ratings and, as a result, being more vulnerable to contamination (see fig. 6). In some cases, areas with lower-medium conductivity ratings were given higher aquifer ratings to reflect large-scale formation interconnectivity, high storativity, or regional or subregional scale.

Soil Media specifies the permeability of the first six feet of the soil profile. Soils were classified into 12 distinct "GV soil types" based on loosely applied texture classifications. These types were assigned on a series-by-series basis using a U.S. Dept. of Agriculture Natural Resources Conservation Service Soil Survey Geographic Database (SSURGO) dataset for Ohio; county-by-county soil surveys; existing Pollution Potential map designations; and fieldwork (Soil Survey Staff, 2019).

Topography was mapped as the percent slope of the land surface, with steeper areas producing more overland runoff and flatter areas permitting more ponding and infiltration. Digital Elevation Model slope data and soil series slope ranges were used as its primary data sources. As a practice, streams and valleys were given topography values of “0–2” to reflect the longitudinal slope of the river system, despite in some cases having slopes greater than 2 percent.

Vadose Zone Media defines the unsaturated material below the soil horizon but above the aquifer itself. Its rating was dependent on both the media and its thickness relative to the aquifer (see fig. 7). For sand-and-gravel vadose zone classifications, vadose ratings were mapped to reflect the coarseness and/or sorting of the vadose material, with higher ratings indicating more gravel and/or sand and lower ratings indicating finer, “dirtier” material. In silt-and-clay vadose zones, ratings were adjusted to reflect the tightness of the deposits, the degree of lamination, and the relative amounts of silt to clay. Bedrock vadose zones were mapped to correspond to each unit’s rating as an aquifer, often lowered by 1 if overlain by thin till, when not well weathered, or to reflect the upward fining found in many Ohio rock sequences. Till exhibited the widest variability in vadose zone ratings, with till age, degree of fracturing, weathering, and the unique characteristics of individual till series being considered wherever possible. Till thickness was the most common source of rating distinctions, especially in the Glacial Complex and certain till-dominated Buried Valley settings, or where thick sequences of till were found to overlay bedrock aquifers.

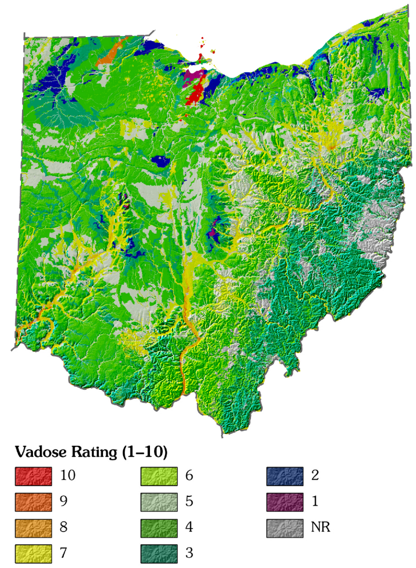


FIGURE 7. Vadose zone rating map of Ohio.

Hydraulic Conductivity is the measure by which a porous media permits the flow of water (see fig. 8). A measurable physical value, hydraulic conductivity was mapped using data available from pump tests, groundwater flow models, and conversions from the specific capacity of wells, where available. Commonly, reliable data were not available, so Hydraulic Conductivity was mapped using generalizations by bedrock unit or the sustainable yield or well test pumping rate data of local water wells. When paired with Aquifer Media and Aquifer Rating, Hydraulic Conductivity provides an indication of potential well yield.

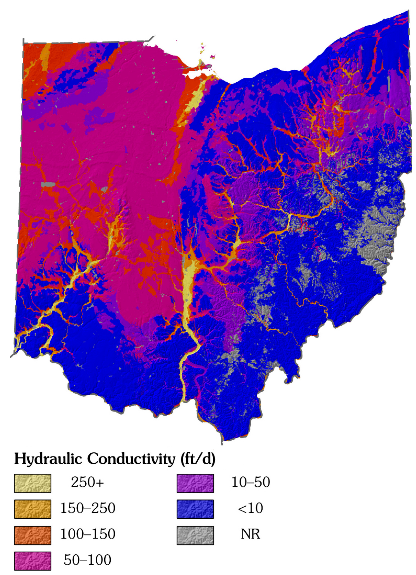


FIGURE 8. Hydraulic conductivity map of Ohio.

Discussion

The new statewide, seamless GV map both parallels and diverges from existing PP maps. In counties where methodology and data coverage changed little, ratings and parameter values remained comparable. In counties where methodology and/or data availability changed significantly, hydrogeologic settings and DRASTIC parameters were extensively edited or entirely remapped, and the overall GV Index may have changed dramatically.

This project established a new standard for statewide hydrogeologic assessment. Standardization resulted in a more equitable, systematic mapping process, especially with respect to more subjective parameter values such as Aquifer Media Rating and Vadose Zone Media Rating. Hydrogeologic Settings were combined, split, added, and removed. The thin-vs-thick regolith distinction was abandoned, as was the presence of overbank deposits for alluvium. The distinction between pits, quarries, mines, and water features from other nonrated areas was dropped, and the mapping of outwash under glacial lake deposits was made implicit via increased vadose zone ratings. The **“7C – Moraine”** setting was eliminated, with moraines remapped as either till over bedrock or a glacial complex setting, depending on the primary aquifer media. **A "6K – Karst Limestone"** setting was added to capture unglaciated karst areas in Adams, Brown, and Highland Counties. Till, outwash, and thin till settings over bedded limestone and shale were added to represent settings where water-poor Ordovician limestones and shales were the only available aquifer. **"7Db – Coarse-limited Buried Valley"** was added to represent buried valleys where coarse material was absent or so limited that the aquifer was the underlying bedrock, even when deep and/or unproductive. **"7Hb – Thick Beaches, Beach Ridges, Dunes, and Deltaic Deposits"** was added to distinguish areas such as the Oak Openings aquifer in Fulton and Lucas Counties, where sandy dune deposits were thick enough to be used as the primary aquifer. The roles and interplay of the **"7D – Buried Valley," "7Ja – Glacial Complex,"** and **"7Jb – Sand and Gravel Interbedded in Till"** settings were codified, with distinctions made for the thickness and texture of unconsolidated material, as well as the bedrock morphology. Finally, the names of many settings were altered to be more systematic and/or descriptive.

Aquifer Media was completely reclassified to simplify its naming convention and provide information on bedrock age: "Interbedded Sedimentary Rocks" now represent Pennsylvanian units; "Interbedded Sandstone and Shale" represents Mississippian and Upper Devonian sandstones and shales; and "Limestone and Shale" represents water-poor Ordovician rock. "Sandstone," "Shale," and "Limestone" were used when one rock type was dominant, such as in the cases of the Berea Sandstone, the Antrim Shale, and the many limestone and dolomite units found throughout the state. Each bedrock unit was restricted to a range of possible Aquifer Media Ratings, and a schema was developed to relate the Rating and Hydraulic Conductivity designations to expected well yields. For example, the Lockport Dolomite was mapped as either an 8/100–150, a 7/50–100, a 6/50–100, or a 6/10–50 (for Aquifer Rating/Hydraulic Conductivity in ft/d), corresponding to expected well yields of 100–500, 25–100, 10–25, and 3–10 gpm, respectively. Unconsolidated sand-and-gravel deposits were also grouped by Aquifer Rating, Conductivity, and expected well yield, with a stair-stepping scale of increasing Rating/Conductivity pairings from a low of 4/10–50 to a high of 10/250+ spanning the least- to most-productive unconsolidated aquifers in the state. See the appendix, which shows how Aquifer Media, Aquifer Rating, and Hydraulic Conductivity were related to expected well yield.

A similar system was developed for Vadose Zone Media and Vadose Zone Media Ratings, with a consolidation of media designations reducing the dozens of variants in the original PP maps to a standardized set of 12 types. The rating of Vadose Zone Media was also standardized, with ranges provided per media that mirrored the Aquifer Media Rating schema for bedrock but followed defined rules for unconsolidated media. These were rated according to thickness, coarseness, and age. An "Alluvium" media was added to distinguish modern alluvial deposits from lacustrine deposits still classified as "Silt and Clay." Where alluvium was found to overlay coarser sand-and-gravel deposits, the relative thicknesses of the deposits were weighed to determine the proper Vadose Zone Media designation. Particular attention was given to unifying the rating of till, with consideration made to its age, thickness, and degree of fracturing.

Soil Media was standardized using a statewide SSURGO dataset and county-based soil surveys. Soil series were classified into 12 distinct "GV Soil Media" distinctions based on texture, parent material, lithology, and thickness. Shrink-swell clay series were defined by percentage of fat clays known to crack as they dry, thereby increasing downward flow through the soil profile. "Peat" and "Muck" were combined to "Organic" to resolve the issue of their similar texture, permeability, and parent material but differing ratings in the original PP maps. "Thin or Absent" Soil Media designations were reserved for soil series described as channery, reported as thinner than 36 inches, or known to be thin or mostly absent in a given county. Distinctions were made for soil series variants and the accounting of conflicting soil survey assessments across series and/or counties.

Following standardization, the 11 previously unmapped counties were mapped according to the new system. Maps were reviewed by a team of hydrogeologists and changes to standard parameter ranges and hydrogeologic settings, and their uses, developed continuously throughout the project. Once the entire state had been mapped, the process of eliminating border conflicts began. In many cases, the effort to make the state "seamless" required extensive remapping. Because the system and interpretation of hydrologic data had evolved so dramatically since the publication of the original PP maps, complete reassessments were often required to make adjacent counties agree at their borders. Seamless editing constituted the bulk of this project, taking more than two years to complete. All counties were reviewed prior to publication.

The GV map and its underlying data are version 1.0 of what will be a continuous effort to better map Ohio's hydrogeology. As new data sources become available and subsequent projects more accurately model hydrogeologic parameters, the digital GV dataset will be updated to reflect further developments.

DRASTIC Parameters

Depth to Water

See table 1. Depth from the land surface to the top of the water table in unconfined conditions or to the top of the aquifer in confined conditions. In “leaky” and semiconfined conditions, depth to water approximates the depth from the land surface to the area’s average piezometric head. In high-relief areas dominated by multiple perched aquifers, depth to water represents the depth from the ground surface to the regional water table, which may not correlate to reported water well static water levels.

TABLE 1. Depth to Water

Depth to Water (ft)	Rating
0–5	10
5–15	9
15–30	7
30–50	5
50–75	3
75–100	2
100+	1
Flowing	1
NR	0
Weight: 5	

Net Recharge

See table 2. Total volume of water per unit area that effectively infiltrates the aquifer from the land surface. Infiltration includes contributions from precipitation, rivers, lakes, irrigation, and artificial recharge sources. Recharge ranges are a function of an area’s topography, soil media, vadose zone media, vadose rating, and the infiltration capacity of the aquifer itself.

TABLE 2. Net Recharge

Net Recharge (in/yr)	Rating
10+	9
7–10	8
4–7	6
2–4	3
0–2	1
NR	0
Weight: 4	

Aquifer Media

See table 3. Consolidated or unconsolidated material comprising the media of the aquifer itself. Aquifer media represents the area’s dominant, uppermost aquifer capable of yielding sufficient water for use.

TABLE 3. Aquifer Media

Aquifer Media	Ratings
Interbedded Sandstone and Shale	3–6
Interbedded Sedimentary Rocks	3–6
Limestone	4–10
Limestone and Shale	2–4
Sand and Gravel	4–10
Sandstone	4–6
Shale	1–3
NR	0
Weight: 3	

Soil Media

See table 4. Upper six feet of the unsaturated zone, characterized by significant biological activity and soil development processes. Based on textural classifications and in consideration of the relative thicknesses and attenuation characteristics of each element of the soil profile. In areas of complex soil profiles, typically mapped as the most restrictive texture layer. Where soil is highly channery, eroded, or thinner than approximately 1–2 feet, mapped as "Thin or Absent," regardless of texture. "Shrink-swell" clays refer to the percentage of "fat" clays that shrink and crack when dried, thereby increasing flow through the soil profile.

TABLE 4. Soil Media

Soil Media	Rating
Thin or Absent	10
Gravel	10
Marl	9
Sand	9
Organic	8
Clay Shrink-swell	7
Sandy Loam	6
Loam	5
Silt Loam	4
Clay Loam	3
Clay	1
NR	0
Weight: 2	

Topography

See table 5. Slope of the land surface expressed as a percent. Topography affects soil development and net recharge potential, and often determines the direction and gradient of groundwater flow (especially in unconfined conditions). At lowest values, ponding and pooling will promote infiltration. At higher values, overland flow will dominate, with precipitation exiting the area as surface water. In karst areas, topography is artificially lowered to simulate karst features acting as negative slope zones that will receive overland flow.

TABLE 5. Topography

Topography (% slope)	Rating
0–2	10
2–6	9
6–12	5
12–18	3
18+	1
NR	0
Weight: 1	

Impact of Vadose Zone Media

See table 6. Consolidated or unconsolidated material comprising the media of the unsaturated zone below the soil horizon but above the aquifer itself. In confined and semiconfined conditions, vadose zone media represents the primary confining layer. In areas where multiple media are encountered above the water table, vadose zone media is typically mapped as the most restrictive and/or thickest material. Weathering and fracturing may increase the rating.

TABLE 6. Vadose Zone Media

Vadose Zone Media	Ratings
Alluvium	4–6
Interbedded Sandstone and Shale	3–6
Interbedded Sedimentary Rocks	3–6
Limestone	4–10
Limestone and Shale	3–4
Sand and Gravel	7–9
Sand and Gravel w/sig Silt and Clay	4–8
Sandstone	4–7
Shale	2–4
Silt and Clay	2–6
Till	1–6
NR	0
Weight: 5	

Hydraulic Conductivity

See table 7. The ease with which groundwater flows through the pore spaces of the aquifer media, defined formally (in an isotropic porous medium) as the specific discharge per unit hydraulic gradient. Mapped ranges correlate to relative aquifer ratings and take into consideration available water well logs, pumping tests, and other data sources.

TABLE 7. Hydraulic Conductivity

Hydraulic Conductivity (gpd/ft^2)	Hydraulic Conductivity (ft/d)	Rating
2,000+	250+	10
1,000–2,000	150–250	8
700–1000	100–150	6
300–700	50–100	4
100–300	10–50	2
1–100	<10	1
NR	NR	0
Weight: 3		

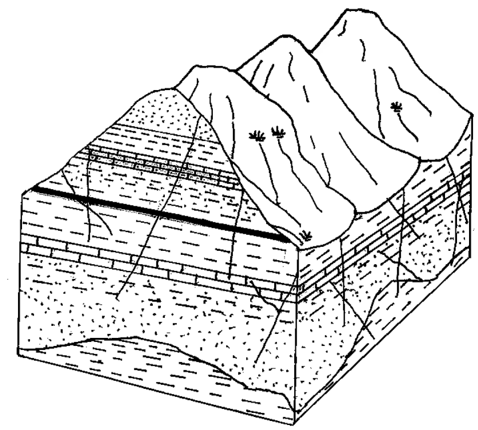
Hydrogeologic Settings of Ohio

Block diagram illustrations modified from Aller and others (1987).

Table 8. Unglaciated Hydrogeologic Settings

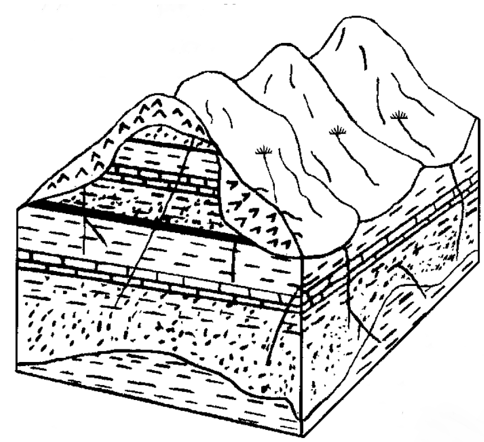
6Da – Regolith over Bedded Sedimentary Rock (Unglaciated)

Areas of high-relief, broad, steeply dipping slopes and narrow, somewhat flatter ridgetops. Soils are derived from residuum and colluvium and generally thin or absent, especially on steeper slopes. Vadose zone and aquifer consist of dipping, alternating, fractured beds of sandstone, shale, clay, coal, and limestone. Multiple aquifers may be present. Depth to regional groundwater table is typically deep, with perched aquifers overlying low-permeability shales and limestones. Recharge is low in areas with high relief and where the aquifer is separated from the surface by confining beds. In low-topography areas, recharge to shallow aquifers can be higher. Yields are dependent on the rock formation and extent of local fracturing.



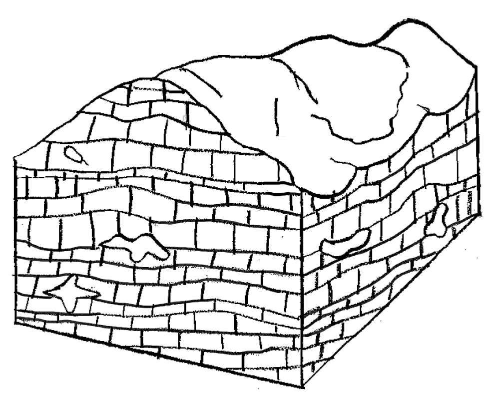
6Dc – Thick Loess over Bedded Sedimentary Rock (Unglaciated)

Areas where thick accumulations of loess have deposited downwind from major stream valleys and blanketed slopes and ridgetops. Loess may be adjacent to lacustrine deposits. Soils are predominantly silt loams and vadose zone silt (with some clay). Aquifers consist of dipping, fractured, alternating sequences of sandstone, shale, clay, coal, and limestone. Multiple stepped or perched aquifers may be present. Depth to water is typically deep. Recharge is low because of slope, low-permeability vadose zone, and soil media. Yields are dependent on the rock formation and local fracturing.



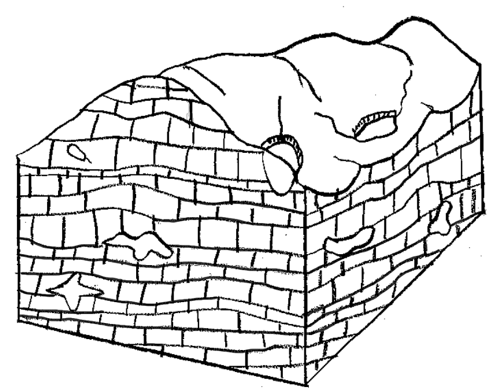
6E – Limestone (Unglaciated)

Relatively dense, low-po rosity limestones and dolomites underlying thin or absent soils. Vadose zone is the fractured, weathered limestone. Aquifer is limestone. Slopes are generally steep and depth to water is deep. Recharge is moderate, with yields dependent on the bedrock unit and presence of local solution features.



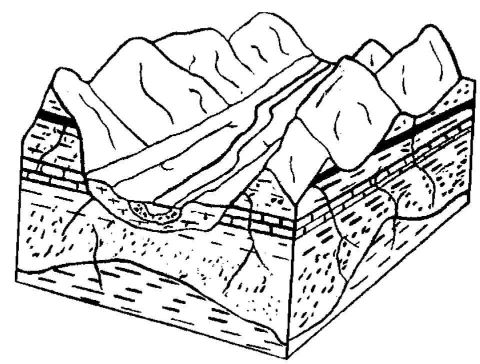
6K – Karst Limestone (Unglaciated)

Limestone in unglaciated southern areas of the state characterized by well-developed networks of solution features. Sinkholes are readily observable at the surface. Soils are thin and variable or absent. Vadose zone is limestone. Recharge is very high because of connectivity between the surface karst features and the aquifer. Depth to water is highly variable and can be flashy because of high recharge rate. Aquifer is limestone with relatively high yields because of well-developed networks of solution features. Topography is represented as lower than that of neighboring settings because of surface flow being directed into sinkholes.



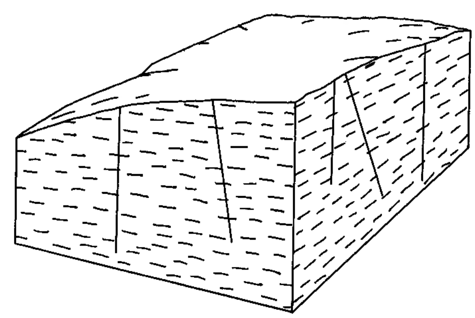
6F – Alluvium over Bedded Sedimentary Rock (Unglaciated)

Low-topography stream valleys flanked by bedrock uplands. Depth to water is typically shallow and soils are predominantly silt loams, sandy loams, or loams. Vadose zone is alluvium, or the underlying bedrock when alluvium is particularly thin. Alluvium is composed of primarily fine-grained floodplain sediments with minor lenses of sand and gravel. These deposits are commonly saturated but are too thin to be utilized as an aquifer. Instead, the underlying interbedded sandstones, limestones, and shales are typically the aquifer. Alluvium is commonly in direct hydrologic connection to the aquifer. Recharge is generally moderate, and yields are dependent on the bedrock unit and local fracturing.



6L – Shale (Unglaciated)

Aquifer and vadose zone of relatively dense, low-permeability shale. Uppermost several feet of weathered and/or broken shale supplies most of the well production. Yields are typically very poor, averaging less than 5 gpm. Soils are typically silt loams, shrink-swell clay, or thin or absent. Slopes are commonly steep but can be gentle depending on the weathering of the shale. Recharge is low, and depths to water moderately shallow.



6M – Sandstone (Unglaciated)

Areas dominated by conglomerates and highly productive sandstone members of Pennsylvanian and Mississippian bedrock and characterized by high relief and broad ridge tops. Aquifer and vadose zone consist of relatively dense, coarse-grained sandstone (with limited porosity when highly cemented). May contain conglomeratic zones that do not necessarily influence yields. Factures, joints, and bedding planes may increase permeability. Recharge is low to moderate, slopes steep, and depth to water high. Well yields typically average less than 10 gpm but can reach as high as 100 gpm in thick, coarse, fractured zones. Soils are variable or absent, with silty and sandy loams common.

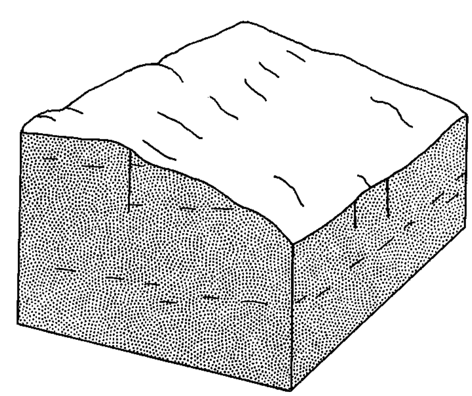
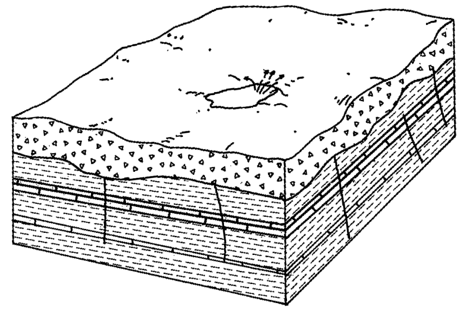


Table 9. Glaciated and Glacially Impacted Hydrogeologic Settings

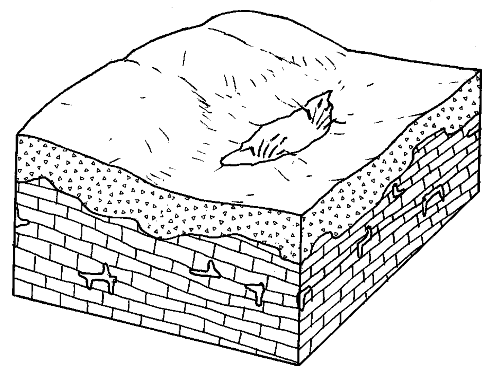
7Aa – Till over Bedded Sedimentary Rock

Highly variable throughout the glaciated portions of the state, these areas consist of till overlying interbedded sandstones, siltstones, and shales in flat-to-rolling relief areas in the eastern half of the state and steeper areas nearer to the glacial margin. Overlying glacial till thickness varies, and the aquifer is the underlying interbedded sedimentary rock. Soils are variable and vadose zone is till. Depth to water is extremely variable, and recharge depends on the slope and thickness of till cover. Yields depend on the bedrock unit and local fracturing of the aquifer. Where till is thin (less than 15–20 ft), substituted by the **7Ga** setting.



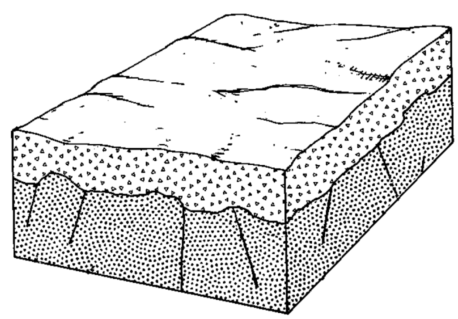
7Ac – Till over Limestone

Low-relief limestone or dolomite bedrock covered by varying thicknesses of glacial till. Till thickness may represent ground versus end moraines. Till may be locally interbedded with sand, gravel, or silt. Soils are typically shrink-swell clay or clay loam, and the vadose zone is usually till. The aquifer is underlying limestone bedrock, which may contain significant solution features. Recharge is moderate but can vary with the thickness of the till. Depth to water is extremely variable. Yields are dependent on the bedrock unit and local solution features but are typically moderate or moderately high. Where till is thin (less than 15–20 ft), substituted by the **7Gb** setting.



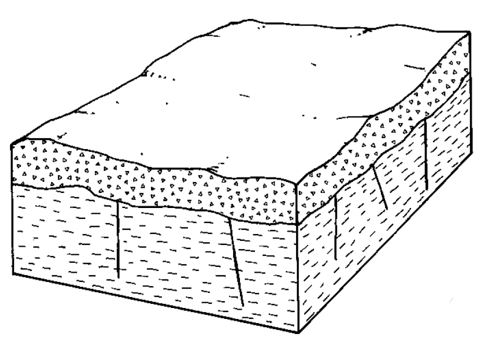
7Ad – Till over Sandstone

Till of varying thickness overlying sandstone with generally low to moderate topography and a vadose zone of till. Soils are variable but typically loams or clay loams. Recharge is moderate because of compactness and thickness of overlying till, and depths to water are highly variable as a function of specific sandstone formation, topographic location, and till thickness. Yields are dependent on the bedrock unit. Where till is thin (less than 15–20 ft), substituted by the **7Gd** setting.



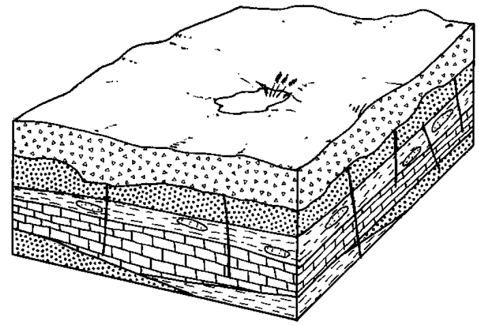
7Ae – Till over Shale

Shale bedrock covered by variable thicknesses of glacial till. Relief is low-to-moderate with topography ranging from gently rolling ground moraines to hummocky end moraines or steeper bedrock uplands. Aquifer consists of interbedded shales and siltstones buried under till of varying thicknesses. The vadose zone of till may be fractured or jointed, especially in areas where it is thin and/or weathered. Soils are generally clay loams. Depth to water is variable and yields rarely exceed 10 gpm. Recharge is dependent on the thickness and fracturing of the till. Where till is thin (less than 15–20 ft), substituted by the **7Gc** setting.



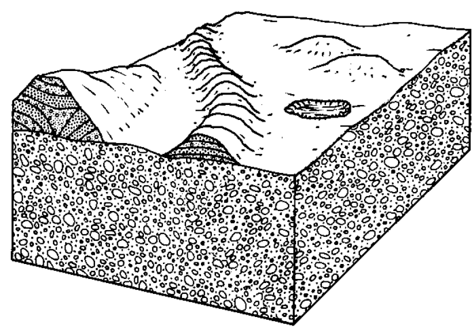
7Ah – Till over Bedded Limestone and Shale

Till overlying bedded Ordovician limestones and shales in flat-to-rolling relief areas in the southwestern corner of the state. Overlying glacial till thickness varies, and the aquifer is the underlying interbedded limestones and shales. Soils are variable but frequently clay loam or shrink-swell clay, and the vadose zone is till. Depth to water is extremely variable, with generally low recharge depending on the slope and thickness of till cover. Yields are very low. Where till is thin (less than 15–20 ft), substituted by the **7Gh** setting.



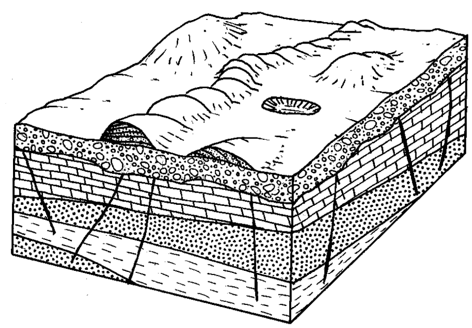
7Ba – Outwash

Outwash plains, outwash terraces, and ice-contact features such as kames and eskers consisting of water-washed deposits of sand and gravel that serve as the principal aquifer. Characterized by low-to-moderate topography and varying thicknesses of outwash materials. Vadose zone contains outwash interbedded with finer alluvial and lacustrine deposits. Depth to water is typically shallow, and soils are mostly sandy loams. Recharge is moderately high but may be impeded by silty deposits. Yields can be moderate to high depending on silt content. May resemble adjacent **7D** settings, but drift is thinner and not constrained by pre-existing, bedrock-incised valleys.



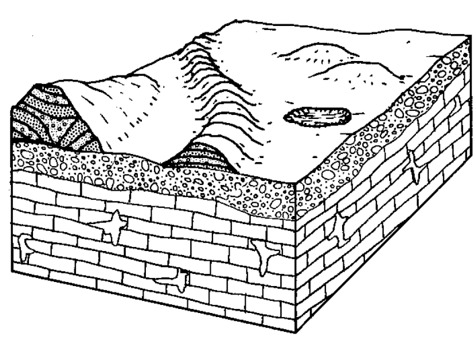
7Bb – Outwash over Bedded Sedimentary Rock

Sand-and-gravel outwash and outwash terraces where the vadose zone is sand and gravel, but the aquifer is the underlying bedrock. The sand-and-gravel terraces are low relief and not thick enough to be considered aquifers. Typically present along or outside the glacial boundary and representing meltwater from the receding ice. Depth to water is shallow to moderate, soils vary from sandy loam to gravel. Recharge is moderately high. Aquifer type and yields vary by bedrock unit.



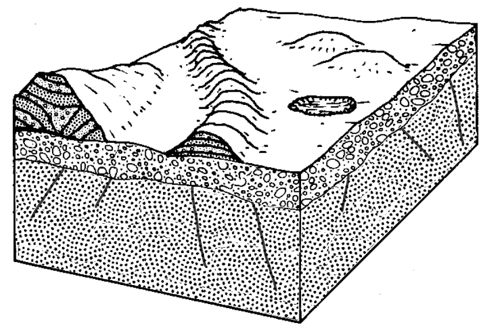
7Bc – Outwash over Limestone

Outwash, outwash terraces, and glacial drainage channels overlying limestone bedrock. Soils are typically sandy loam, sand, gravel, and other loams. Topography is relatively flat. Either sand-and-gravel deposits are too thin to be an aquifer, or the underlying limestone is a better source of groundwater. Vadose zone is sand and gravel or sand and gravel with significant silt and clay. Limestone can be the vadose zone if vertical groundwater flow through the limestone is more restrictive than outwash or if outwash deposits are very thin. Degree of fracturing and solution features will determine the yields of the limestone. Recharge is moderately high, and depth to water is shallow.



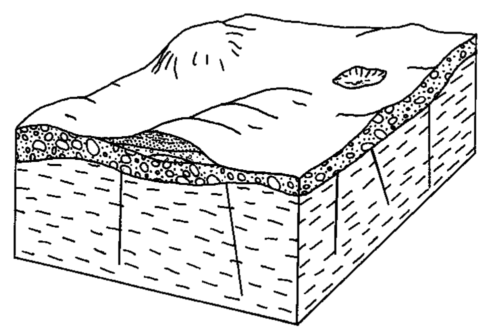
7Bd – Outwash over Sandstone

Sand-and-gravel outwash deposits overlying sandstone bedrock. Soils are sandy loam, sand, gravel, and other loams. Topography typically relatively flat. Sand-and-gravel deposits are too thin to comprise the aquifer; groundwater is obtained instead from the underlying sandstone. Vadose zone may be sand and gravel or sand and gravel with significant silt and clay. Degree of fracturing and cementation in sandstone will determine well yields. Recharge is moderately high, and the depth to water is shallow.



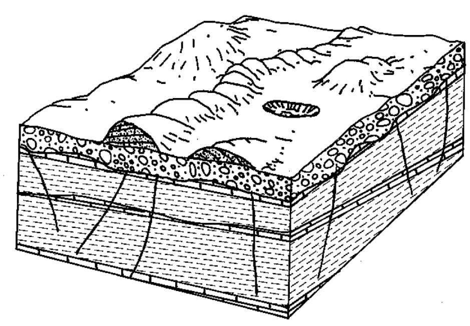
7Be – Outwash over Shale

Shale bedrock covered with glacial outwash of varying thicknesses. Soil can be sandy loam, sand, gravel, or other loams. Outwash is too thin or contains too much silt to be considered an aquifer; groundwater is obtained from the upper, weathered portions of the underlying shale. Vadose zone is sand and gravel or sand and gravel with significant silt and clay. Recharge is moderate to poor, depending on the percentage of fine-grained sediments within the outwash and the bedding and fracturing of the shale. Depth to water is shallow, and relief is low. Yields are poor and depend on fracturing within the shale formation.



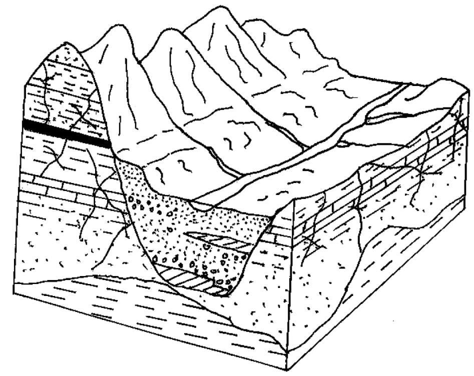
7Bh – Outwash over Bedded Limestone and Shale

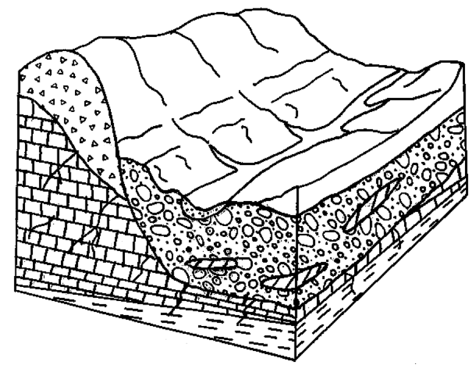
Sand-and-gravel outwash and outwash terraces where the vadose zone is sand and gravel, but the aquifer is the underlying bedded Ordovician limestone-and-shale bedrock. Sand-and-gravel terraces are low relief and not thick enough to be considered aquifers and are typically present along or outside the glacial boundary, representing meltwater from the receding ice. Depth to water is shallow to moderate, soils vary from sandy loam to gravel. Recharge is moderate. Aquifer yields are very low.



7D – Buried Valley

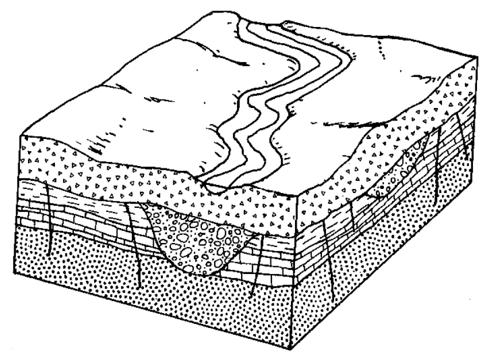
Pre- or interglacial bedrock valleys filled with interbedded sands, gravels, tills, and/or alluvial deposits that may be overlain by more recent till or lacustrine sediments. Two distinct models are found in Ohio: the pre- and interglacial bedrock river valley and the large glacial drainageway.





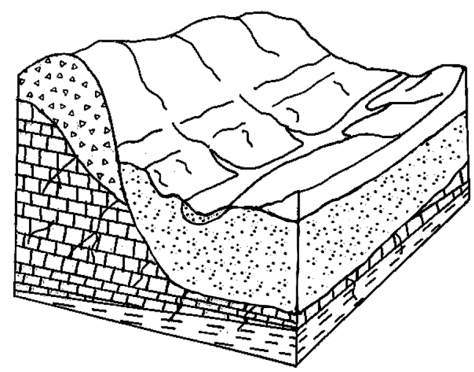
Pre- and interglacial buried valleys are bedrock valleys filled with alluvium but covered in younger tills and other glacial deposits and showing little to no surficial expression. Soils are variable but are commonly clay loams. Vadose zone is typically till but can be lacustrine silts and clays in former glacial lake basins. Aquifers are sand-and-gravel seams and/or lenses in the till or basal sand-and-gravel deposits. Topography and recharge both depend upon the glacial deposits covering the aquifer. Yields vary with the amount of silt and clay and the extents and interconnectedness of the sand-and-gravel deposits. Depth to water is typically deep but is dependent on thickness of overlying glacial deposits

Large glacial drainageways are the result of meltwater exiting glaciers and eroding into the bedrock. These valleys are then filled by thick glacial outwash deposits and may or may not contain modern stream systems that can add to recharge. Soils can be sandy loam, sand, gravel, or occasionally other loams. Vadose zone is sand and gravel or sand and gravel with significant silt and clay. Aquifers are sand and gravel. Yields and recharge are generally high where sediments are coarse but can be lower in areas with significant finer material. Depth to water is shallow and recharge is high. This model includes the modern Ohio River.



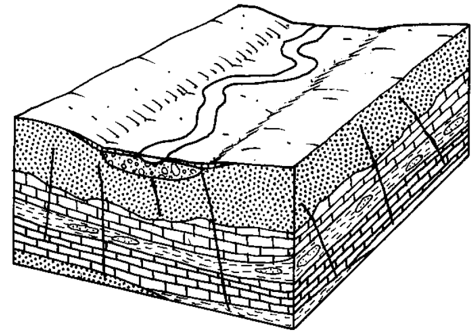
7Db – Coarse-limited Buried Valley

Pre- or interglacial bedrock valleys infilled with thick glacial deposits in areas where coarse-grained sand-and-gravel materials are limited, lacking, or a lower-yielding aquifer relative to the underlying bedrock. These areas may resemble **7D** settings in all parameters but aquifer media, which for **7Db** will be bedrock. In areas where underlying bedrock is particularly productive, sand-and-gravel deposits may be present but unutilized. Where coarse deposits are extremely limited, wells may be forced to be developed in underlying shales or other unproductive bedrock units.



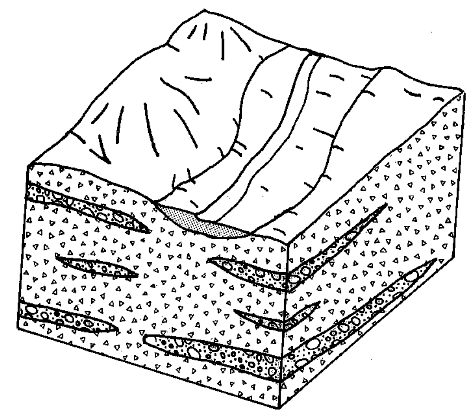
7Ec – Alluvium over Sedimentary Rock

Areas characterized by modern alluvial streams located directly over bedrock or thin glacial deposits over bedrock. Soils are mostly silt loam or loam, but sandy loam is also common. Vadose zone is alluvium, sand and gravel with significant silts and clays, or occasionally bedrock. The aquifer is the bedrock beneath the alluvium and glacial deposits. Sand-and-gravel lenses are typically minor or absent. Depth to water is shallow but can be deeper where glacial deposits are thick. Recharge is moderate to high, depending on the vadose zone and aquifer itself. Relief is very low. Yields are dependent upon the bedrock formation.



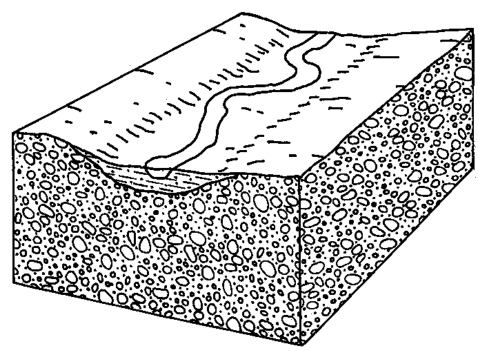
7Ed – Alluvium over Glacial Complex

Modern alluvial areas located inside **7Ja**, **7Jb**, and some lake plain settings. Contain significant overlying streams with alluvial fill. Alluvium is typically saturated but is not sufficiently thick enough for well development. Aquifer consists of thin, discontinuous seams and/or lenses of sand and gravel interbedded in the underlying glacial till. Vadose zone is alluvium or till (depending on their relative thicknesses), with moderate recharge and relatively shallow depth to water. Relief is very low. Yields are dependent on the amount of silt and clay in the sand-and-gravel deposits and their interconnectivity.



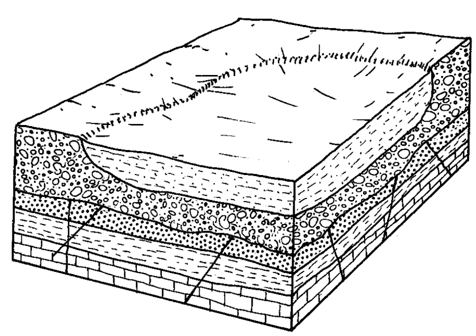
7Ee – Alluvium over Sand and Gravel

Low-relief areas of modern, stream-deposited, thin to moderately thick alluvium overlying coarser, glacial sand-and-gravel deposits. Alluvium consists of silt, sand, gravel, and clay, with the underlying sand and gravel serving as the aquifer. Depth to water is usually shallow, with the stream in direct hydraulic connection with the aquifer. Soils are typically silt or sandy loams and vadose zone is alluvium, sand and gravel, or sand and gravel with significant silt and clay. Recharge is high. Yields depend on the amount of silt and clay in underlying sand-and-gravel deposits.



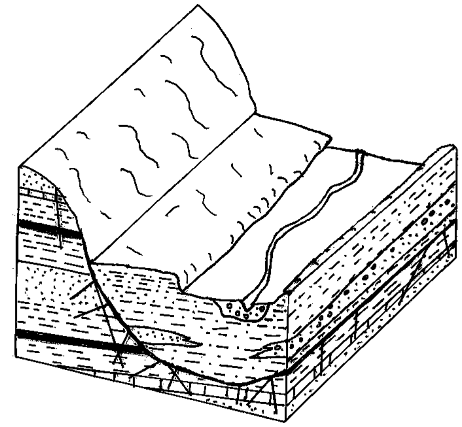
7F – Glacial Lake Deposits

Very low-relief, poorly drained topography with variable thicknesses of fine-grained deposits overlying till sequences. The lakebed and fine-grained deltaic deposits consist of sequences of fine clays and silts alternating with fine sand. These sediments may be laminated or varved. Laminated and varved sediments have a preferential horizontal component that moves water towards streams and tile drainage instead of vertically downward to the aquifer. Secondary fractures may help increase vertical permeability. Soils are clay, shrink-swell clay, clay loam, silt loam, or loam. May include local areas of peat and/or muck. Vadose zones are silt and clay or till (where it is thick). Underlying regional bedrock or local sand-and-gravel beds in glacial till form the primary aquifer. Recharge is moderately low, and depth to water is shallow. Yields will depend upon the aquifer.



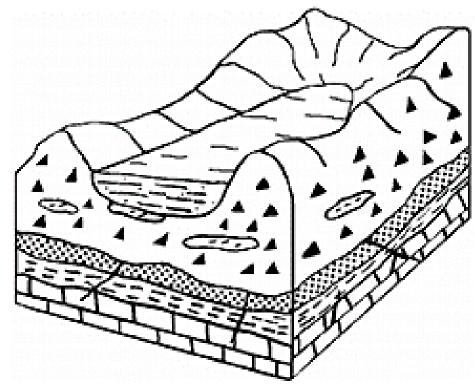
7Fa – Ice-dammed Lakes and Slackwater Terraces

Flat-lying or gently sloped areas formed from the low-velocity water of glacial and slack-water lakes that once filled pre-existing drainage systems. Typically dissected by modern streams and containing remnant low-lying terraces. Soils are clay, clay loam, silt loam, and loams. Aquifer consists of the sedimentary rock underlying the silt-and-clay deposits or, occasionally and when present, thin lenses of sand and gravel. Depth to water is commonly shallow. Vadose zone consists of silty and clayey lacustrine and alluvial deposits. Recharge is moderate to low. Yields depend upon the type and characteristics of the aquifer. Typically flanked by steeper, bedrock-controlled topography.



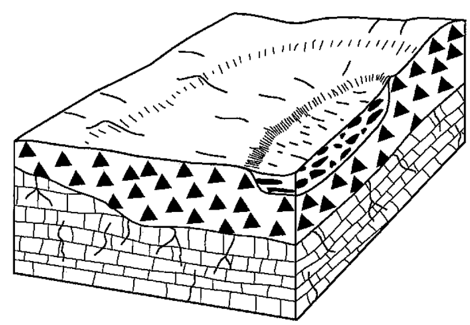
7Fc – Morainal Lake Deposits

Sediments deposited in shallow lakes formed between end moraines, containing varying thicknesses of fine-grained lacustrine deposits. Surficial drainage poor with ponding common after precipitation. Aquifer is the underlying bedrock or sand-and-gravel lenses within the till when present. Depth to water is variable, and relief is low. Soils are silt or clay loams derived from lacustrine deposits. Recharge is low, and the vadose zone consists of silty to clayey lacustrine material overlying the glacial till. Yields are dependent on the aquifer type and unit.



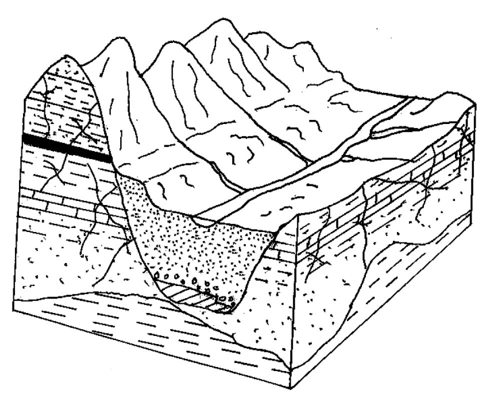
7Fd – Wave-modified Till

Topographically flat, wave-eroded till formed by the erosion of glacial lakes. Surficial drainage typically poor, with ponding common after precipitation. Soils are shrink-swell clays derived from till. Vadose zone consists of till or, when thin, bedrock. Aquifer is bedrock or sand-and-gravel lenses within the till. Depth to water is dependent on the thickness of till. Recharge is low to moderate, depending on thickness and denseness of vadose zone. Yields are dependent upon the aquifer type and unit.



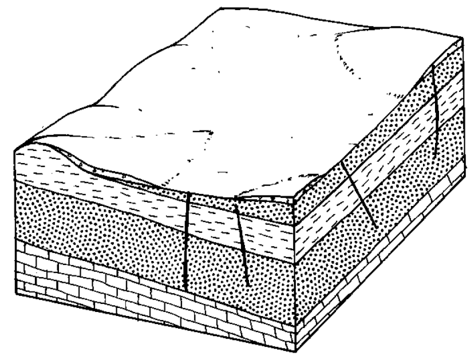
7Fe – Pre-glacial Valley

Abandoned main-trunk channels of the former Teays drainage system characterized by deep, preglacial valleys filled with alluvial and/or lacustrine clays. Modern surficial drainage may be limited or absent. Soils are typically silt or sandy loams, with the vadose zone consisting of silt and clay or sand and gravel with significant silt and clay where fine particles have been eroded away by modern drainage. Depth to water varies with valley thickness. Aquifer consists of minor sand-and-gravel lenses; basal, alluvial sand-and-gravel deposits; or underlying zones of fractured bedrock. Recharge is low, and yields dependent on the thickness of sand and gravel and fracturing of the bedrock.



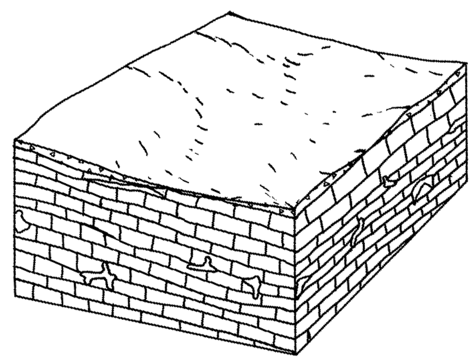
7Ga – Thin Till over Bedded Sedimentary Rock

Patchy, thin (less than 15 ft), or totally absent deposits of glacial till overlying bedded sedimentary rocks. May be either flat or characterized by rugged topography and high relief consisting of steep, bedrock-controlled ridges with fractured, absent, or thin overlying till. Soils are variable but commonly thin or absent. Vadose zone is the aquifer itself or overlying bedrock units. Aquifer is interbedded Pennsylvanian sandstones, shales, or limestones or interbedded Mississippian shales, siltstones, and fine-grained sandstones. Depth to water and recharge is moderate. Well yields will depend upon the aquifer unit and the degree of local fracturing.



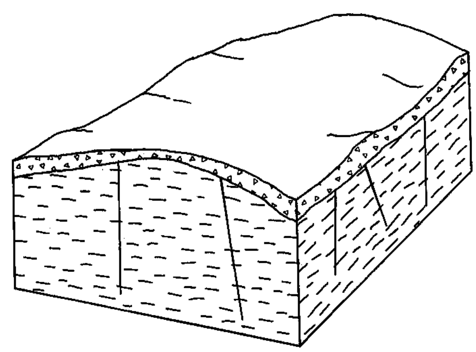
7Gb – Thin Till over Limestone

Patchy, thin (less than 15 ft), or nearly absent deposits of glacial till overlying an aquifer of limestone bedrock. Soils are thin to absent or shrink-swell clays. Vadose zone is the limestone aquifer itself or another bedrock unit, most commonly another thinner or less-productive limestone. Recharge is rapid, and bedrock may be fully or partially exposed at the surface. Depth to water is variable but commonly shallow and topography is generally flat. Yields are dependent upon the limestone formation and existence of local solution features.



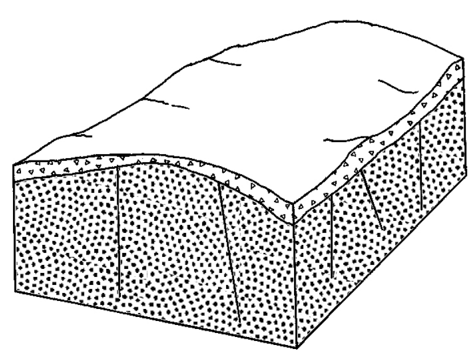
7Gc – Thin Till over Shale

Patchy, thin (less than 15 ft), or nearly absent deposits of glacial till overlying shale bedrock. Till is thin or absent, especially on steep slopes, and soil is thin or absent, occasionally clay loam. Vadose zone consists of the upper shale layers or rarely an overlying bedrock unit. Groundwater is obtained from the uppermost, weathered and/or fractured portion of the shale. Recharge is low, and depth to water ranges widely, though it is often shallow. Topography is variable, and aquifer yields are very low.



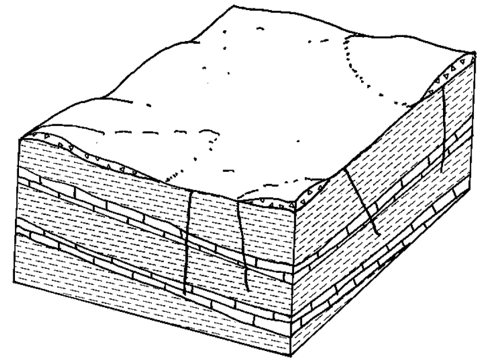
7Gd – Thin Till over Sandstone

Patchy, thin (less than 15 ft), or nearly absent deposits of glacial till overlying sandstone bedrock. Soils are sand, sandy loam, silt loam, or thin to absent. Vadose zone is the sandstone itself or an overlying bedrock unit. Recharge may be rapid, but its amount will depend on the existence and permeability of overlying units. Depth to water is variable but commonly shallow. Topography is highly variable. Aquifer yields are dependent upon the sandstone unit and the existence of local fractures and cementation.



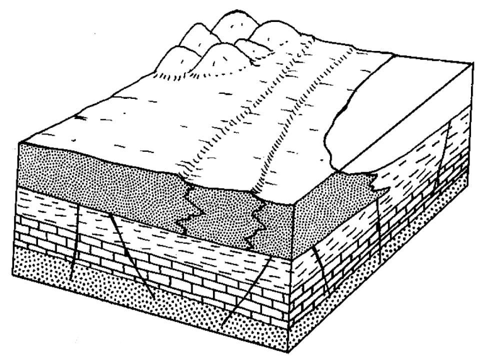
7Gh – Thin Till over Bedded Limestone and Shale

Patchy, thin (less than 15 ft), or nearly absent deposits of glacial till overlying bedded Ordovician limestones and shales. Till and soil is thin or absent. Vadose zone consists of bedded limestone and shale or overlying limestone units. Recharge is low, and depth to water ranges widely, though it is often shallow. Topography is variable, and aquifer yields are very low.



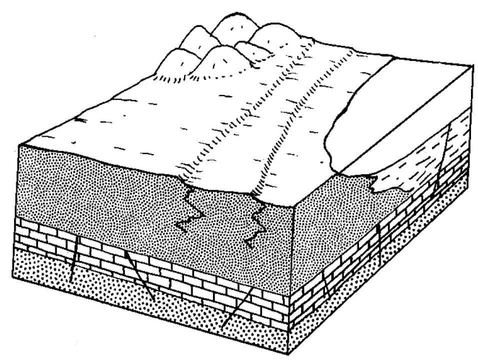
7Ha – Beaches, Beach Ridges, Dunes, and Deltaic Deposits

Beach, delta, and dune features characterized by moderate to low relief, sandy soils, and high infiltration rates. Sandy deposits are typically underlain by fine till or lacustrine deposits over bedrock. Sandy surficial deposits are thin or unproductive enough not to constitute the aquifer; instead, groundwater sources are the underlying bedrock or thin gravel deposits bedded between the till. Vadose zone is sand and gravel or till. Depth to water varies with thickness of the till and sand deposits. Recharge depends on the characteristics of the vadose zone, and yields depend on the aquifer type and formation.



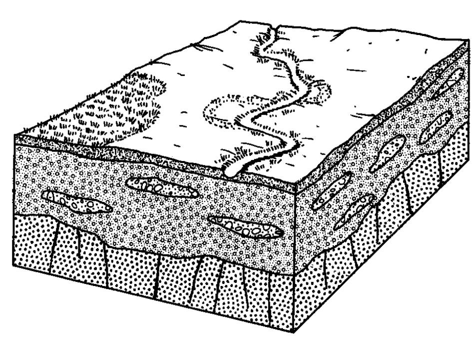
7Hb – Thick Beaches, Beach Ridges, Dunes, and Deltaic Deposits

Surficial beach, delta, and dune features where sandy deposits are thick enough to be used as the aquifer. Sandy deposits are typically underlain by fine till or lacustrine deposits over water-poor and/or deep bedrock. Depth to water is shallow. Vadose zone is sand and gravel, and recharge is very high. Topography is moderate to low. Yields are moderate and may be limited by the capacity and extent of the aquifer. Historically, dug wells and well points were commonly used in shallower aquifers.



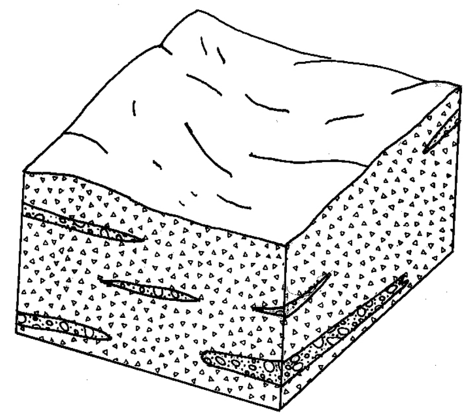
7I – Marshes and Swamps

Sensitive wetland and peat areas characterized by extremely low topographic relief and poor drainage, including marshy or estuarine areas adjacent to **7F** settings and kettles within **7B** settings. Soils are mixtures of silts and clays and contain appreciable organic detritus and peat materials. Vadose zone is typically silt and clay or till. Aquifer is either the underlying bedrock or sand-and-gravel lenses within the till. The water table is generally at or very near the surface, and recharge is relatively high. Yields range widely, depending upon the aquifer type and underlying geologic formations.



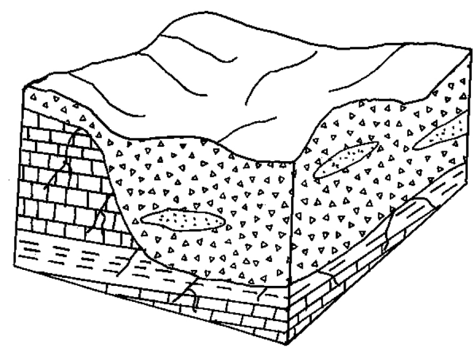
7Ja – Glacial Complex

Thick sequences of glacial till containing sand-and-gravel seams and/or lenses, distinguished from **7D** settings by not containing a traditional "valley train" or incised-bedrock channel morphology. In some areas, a bedrock valley or low is present, but till is thick enough to mitigate the utility of buried outwash (if present). Includes many areas formerly mapped as end moraines. Aquifer consists of seams and/or lenses of sand and gravel at various depths and varying degrees of interconnectivity interbedded in the till. Soils are typically clay loams, and the vadose zone is till or till overlain by outwash deposits. Depth to water is moderate to deep. Recharge is moderate to low, and topography is hummocky to flat. Most of the till sequence is not weathered or fractured, but lower till units may be very compacted. Yields are moderate but may vary with the amount of silt and clay present in the sand-and-gravel deposits.



7Jb – Sand and Gravel Interbedded in Thin Till

Glacial complex-adjacent (or isolated) areas where drift is not thick enough for it to be considered a **7Ja** (less than approximately 50 ft). Typically found on ground moraines and common in areas with low-yielding bedrock aquifers. Aquifer consists of seams and lenses of sand and gravel interbedded in the glacial till. Yields are low to moderate but will vary with the amount of silt and clay in the aquifer. Relief is low to moderate, and soils are typically clay loams. Sand-and-gravel lenses are generally discontinuous and isolated from one another. Depth to water is typically shallow, recharge is moderate, and till comprises the vadose zone. Much of the till sequence may be weathered and/or fractured.



7K – Karst Limestone

Low-relief limestone bedrock areas covered by till thin enough to reveal karst features. Typically found near the glacial margin or near streams where downcutting has exposed sinkholes. Soils are typically shrink-swell clays, clay loams, or thin to absent. Aquifer is the underlying limestone, which contains significant, well-developed networks of solution features. Recharge is high to very high because of the connectivity between the surface and aquifer, reflecting drainage into the karst features instead of runoff into streams. Recharge rate is controlled by the thickness of the till and soil. Depth to water is extremely variable, especially seasonably. Topography is rated higher than neighboring settings to reflect surface flow being directed into sinkholes. Aquifer yields tend to be higher than nearby, nonkarst limestone units.

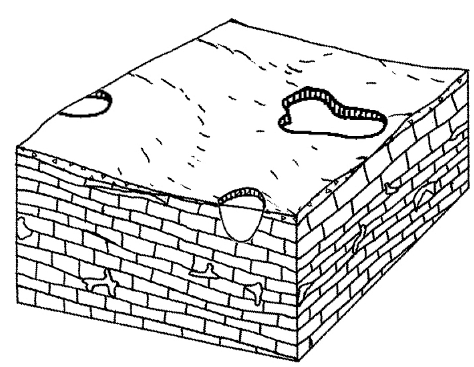


Table 10. Other Hydrogeologic Settings

NR – Not Rated

Not rated areas, including bodies of water, mines, pits, quarries, landfills, areas of significant land disturbance, reclaimed land where determination of parameter ratings is difficult or impossible, and any other area where one or more DRASTIC parameter is indeterminable.

Acknowledgements

GV maps are the product of over 30 years of groundwater contamination and hydrogeologic research at ODNR and with its collaborators. For the full list of publications released under the Groundwater Pollution Potential Mapping program, please see the ODNR Division of Geological Survey Publications Catalog at **geology.ohiodnr.gov**.

This project was made possible with funding from the OWDA Research and Development Grant Program. OWDA provides financial assistance for water-related research, remediation, education, and infrastructure projects throughout Ohio.

Ohio Water
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Appendix

Table 11 can be used to estimate aquifer suitability and potential well yield based on the Aquifer Media, Aquifer Rating, and Hydraulic Conductivity values of a GV polygon. For unconsolidated aquifers, Aquifer Rating and Hydraulic Conductivity values were designed to increase in a stairstep pattern paralleling higher well yields. For consolidated aquifers, ratings and well yields depended on the bedrock unit or group of interest. Please refer to a bedrock geology map and/or water wells to determine the uppermost, dominant bedrock unit or group in an area. All expected well yields are approximate.

TABLE 11. Aquifer Media Worksheet

Age	Unit or Group	Aquifer Media	Aquifer Rating	Hydraulic Conductivity (ft/d)	Well Yield (gpm)
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	10	250+	500+
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	9	250+	500+
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	9	150–250	100–500
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	8	250+	100–500
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	8	150–250	100–500
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	8	100–150	25–100
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	7	150–250	25–100
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	7	100–150	25–100
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	6	100–150	25–100
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	6	50–100	10–25
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	5	10–50	10–25
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	5	10–50	3–10
Quaternary	Glacial sand-and-gravel deposits	Sand and Gravel	4	10–50	3–10
Permian	Dunkard	Interbedded Sedimentary Rocks	3	<10	0–3
Pennsylvanian	Monongahela Group	Interbedded Sedimentary Rocks	3	<10	0–3
Pennsylvanian	Conemaugh Group	Interbedded Sedimentary Rocks	3	<10	0–3
Pennsylvanian	Alleghany and Pottsville, undifferentiated	Interbedded Sedimentary Rocks	5	10–50	10–25
Pennsylvanian	Alleghany and Pottsville, undifferentiated	Interbedded Sedimentary Rocks	4	10–50	3–10
Pennsylvanian	Alleghany and Pottsville, undifferentiated	Interbedded Sedimentary Rocks	4	<10	3–10
Pennsylvanian	Sharon and Massillon	Sandstone	6	50–100	25–100
Pennsylvanian	Sharon and Massillon	Sandstone	6	10–50	10–25
Pennsylvanian	Sharon and Massillon	Sandstone	5	10–50	10–25
Mississippian	Maxville Limestone	Limestone	4	<10	3–10
Mississippian	Logan and Cuyahoga	Interbedded Sandstone and Shale	5	10–50	10–25

TABLE 11. Aquifer Media Worksheet (continued)

Age	Unit or Group	Aquifer Media	Aquifer Rating	Hydraulic Conductivity (ft/d)	Well Yield (gpm)
Mississippian	Logan and Cuyahoga	Interbedded Sandstone and Shale	5	<10	3–10
Mississippian	Logan and Cuyahoga	Interbedded Sandstone and Shale	4	10–50	3–10
Mississippian	Logan and Cuyahoga	Interbedded Sandstone and Shale	4	<10	3–10
Mississippian	Logan and Cuyahoga	Interbedded Sandstone and Shale	3	<10	3–10
Mississippian	Black Hand Member (Cuyahoga)	Sandstone	6	10–50	25–100
Mississippian	Black Hand Member (Cuyahoga)	Sandstone	5	10–50	10–25
Mississippian	Coldwater Shale	Shale	3	<10	3–10
Mississippian	Sunbury Shale	Shale	3	<10	3–10
Devonian	Bedford Shale, Berea Sandstone, Sunbury Shale, undivided	Interbedded Sandstone and Shale	4	<10	3–10
Devonian	Bedford Shale, Berea Sandstone, Sunbury Shale, undivided	Interbedded Sandstone and Shale	3	<10	3–10
Devonian	Bedford Shale, Berea Sandstone, Sunbury Shale, undivided	Interbedded Sandstone and Shale	2	<10	0–3
Devonian	Berea Sandstone	Sandstone	5	10–50	10–25
Devonian	Berea Sandstone	Sandstone	4	10–50	3–10
Devonian	Bedford Shale	Shale	2	<10	0–3
Devonian	Antrim Shale	Shale	2	<10	0–3
Devonian	Ohio Shale	Shale	3	<10	3–10
Devonian	Ohio Shale	Shale	2	<10	0–3
Devonian	Ohio Shale	Shale	1	<10	0–3
Devonian	Ten Mile Creek Dolomite and Silica Formation (Traverse Group)	Limestone	5	10–50	3–10
Devonian	Ten Mile Creek Dolomite and Silica Formation (Traverse Group)	Limestone	4	<10	0–3
Devonian	Delaware Limestone	Limestone	7	50–100	25–100
Devonian	Delaware Limestone	Limestone	6	50–100	10–25
Devonian	Delaware Limestone	Limestone	6	10–50	10–25
Devonian	Dundee Limestone	Limestone	7	50–100	25–100
Devonian	Dundee Limestone	Limestone	6	10–50	3-25
Devonian	Columbus Limestone	Limestone	10	250+	500+
Devonian	Columbus Limestone	Limestone	9	150-250	100–500

TABLE 11. Aquifer Media Worksheet (continued)

Age	Unit or Group	Aquifer Media	Aquifer Rating	Hydraulic Conductivity (ft/d)	Well Yield (gpm)
Devonian	Columbus Limestone	Limestone	8	100–150	100–500
Devonian	Columbus Limestone	Limestone	7	100–150	25–100
Devonian	Columbus Limestone	Limestone	7	50–100	25–100
Devonian	Columbus Limestone	Limestone	6	50–100	10–25
Devonian	Detroit River Group	Limestone	7	50–100	25–100
Devonian	Detroit River Group	Limestone	6	50–100	10–25
Silurian	Bass Islands Dolomite	Limestone	8	100–150	100–500
Silurian	Bass Islands Dolomite	Limestone	7	50–100	25–100
Silurian	Bass Islands Dolomite	Limestone	6	50–100	10–25
Silurian	Salina Group	Limestone	8	100–150	100–500
Silurian	Salina Group	Limestone	7	100–150	25–100
Silurian	Salina Group	Limestone	7	50–100	25–100
Silurian	Salina Group	Limestone	6	50–100	10–25
Silurian	Salina Group	Limestone	5	50–100	10–25
Silurian	Salina Group	Limestone	5	10–50	3–10
Silurian	Tymochtee and Greenfield Dolomites	Limestone	7	50–100	25–100
Silurian	Tymochtee and Greenfield Dolomites	Limestone	6	50–100	10–25
Silurian	Tymochtee and Greenfield Dolomites	Limestone	5	50–100	5–15
Silurian	Tymochtee and Greenfield Dolomites	Limestone	5	10–50	5–15
Silurian	Lockport Dolomite	Limestone	8	100–150	100–500
Silurian	Lockport Dolomite	Limestone	7	50–100	25–100
Silurian	Lockport Dolomite	Limestone	6	50–100	10–25
Silurian	Lockport Dolomite	Limestone	6	10–50	3–10
Silurian	Peebles Dolomite, Lilley, and Bisher Formations	Limestone	6	10–50	10–25
Silurian	Peebles Dolomite, Lilley, and Bisher Formations	Limestone	5	10–50	3–10
Silurian	Peebles Dolomite, Lilley, and Bisher Formations	Limestone	4	10–50	3–10
Silurian	Peebles Dolomite, Lilley, and Bisher Formations	Limestone	4	<10	3–10
Silurian	Estill Shale	Shale	4	<10	3–10
Silurian	Estill Shale	Shale	3	<10	0–3
Silurian	Cedarville, Springfield, and Euphemia Dolomites	Limestone	7	50–100	25–100

TABLE 11. Aquifer Media Worksheet (continued)

Age	Unit or Group	Aquifer Media	Aquifer Rating	Hydraulic Conductivity (ft/d)	Well Yield (gpm)
Silurian	Cedarville, Springfield, and Euphemia Dolomites	Limestone	6	50–100	10–25
Silurian	Cedarville, Springfield, and Euphemia Dolomites	Limestone	5	10–50	10–25
Silurian	Clinton and Cataract Group	Limestone	5	10–50	10–25
Silurian	Clinton and Cataract Group	Limestone	4	<10	3–10
Silurian	Massie Shale, Laurel Dolomite, Osgood Shale, Dayton Limestone, and Brassfield Formation	Limestone and Shale	4	<10	3–10
Ordovician	Cincinnati Group	Limestone and Shale	3	<10	0–3
Ordovician	Cincinnati Group	Limestone and Shale	2	<10	0–3
Ordovician	Drakes, Whitewater, Saluda, and Liberty Formations	Limestone and Shale	3	<10	0–3
Ordovician	Drakes, Whitewater, Saluda, and Liberty Formations	Limestone and Shale	2	<10	0–3
Ordovician	Waynesville and Arnheim Formations	Limestone and Shale	3	<10	0–3
Ordovician	Waynesville and Arnheim Formations	Limestone and Shale	2	<10	0–3
Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation	Limestone and Shale	3	<10	0–3
Ordovician	Grant Lake Formation, Miamitown Shale, and Fairview Formation	Limestone and Shale	2	<10	0–3
Ordovician	Kope Formation	Limestone and Shale	2	<10	0–3

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