GROUND WATER POLLUTION POTENTIAL
OF WILLIAMS COUNTY, OHIO

BY

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GROUND WATER POLLUTION POTENTIAL REPORT NO. 60

OHIO DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATER

WATER RESOURCES SECTION

2003

ABSTRACT

A ground water pollution potential map of Williams County has been prepared using the DRASTIC mapping process. The DRASTIC system consists of two major elements: the designation of mappable units, termed hydrogeologic settings, and the superposition of a relative rating system for pollution potential.

Hydrogeologic settings form the basis of the system and incorporate the major hydrogeologic factors that affect and control ground water movement and occurrence including depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone media, and hydraulic conductivity of the aquifer. These factors, which form the acronym DRASTIC, are incorporated into a relative ranking scheme that uses a combination of weights and ratings to produce a numerical value called the ground water pollution potential index. Hydrogeologic settings are combined with the pollution potential indexes to create units that can be graphically displayed on a map.

Ground water pollution potential analysis in Williams County resulted in a map with symbols and colors that illustrate areas of varying ground water contamination vulnerability. Eleven hydrogeologic settings were identified in Williams County with computed ground water pollution potential indexes ranging from 66 to 183.

Williams County lies entirely within the Glaciated Central hydrogeologic setting. Shale of the Devonian System composes the aquifer in the southeastern corner of the county. Yields from the shale are poor, typically yielding less than 5 gallons per minute (gpm).

Sand and gravel lenses interbedded in the glacial till locally serve as aquifers throughout the remainder of the county. In the eastern part of the county, the sand and gravel lenses may lie directly on top of the shale bedrock and serve as the aquifer or provide additional recharge to the underlying bedrock. The sand and gravel lenses locally may be relatively thick and laterally extensive. In many areas, there are multiple sand and gravel-bearing lenses or zones. Yields for these sand and gravel lenses typically range from 5 to 25 gpm but can be as high as 500 gpm. The highest-yielding deposits are found within the end moraines and adjacent to the St. Joseph River.

The ground water pollution potential mapping program optimizes the use of existing data to rank areas with respect to relative vulnerability to contamination. The ground water pollution potential map of Williams County has been prepared to assist planners, managers, and local officials in evaluating the potential for contamination from various sources of pollution. This information can be used to help direct resources and land use activities to appropriate areas, or to assist in protection, monitoring, and clean-up efforts.

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ACKNOWLEDGEMENTS

The preparation of the Williams County Ground Water Pollution Potential report and map involved the contribution and work of a number of individuals in the Division of Water. Grateful acknowledgement is given to the following individuals for their technical review and map production, text authorship, report editing, and preparation:

Map preparation and review:	Michael Angle Brad Ziss Cory Bonifas
GIS coverage production and review:	Paul Spahr
Report production and review:	Michael P. Angle
Report editing:	Jim Raab Michael Hallfrisch

INTRODUCTION

The need for protection and management of the ground water resources in Ohio has been clearly recognized. About 42 percent of Ohio citizens rely on ground water for drinking and household use from both municipal and private wells. Industry and agriculture also utilize significant quantities of ground water for processing and irrigation. In Ohio, approximately 750,000 rural households depend on private wells; 6150 of these wells exist in Williams County.

The characteristics of the many aquifer systems in the state make ground water highly vulnerable to contamination. Measures to protect ground water from contamination usually cost less and create less impact on ground water users than clean up of a polluted aquifer. Based on these concerns for protection of the resource, staff of the Division of Water conducted a review of various mapping strategies useful for identifying vulnerable aquifer areas. They placed particular emphasis on reviewing mapping systems that would assist in state and local protection and management programs. Based on these factors and the quantity and quality of available data on ground water resources, the DRASTIC mapping process (Aller et al., 1987) was selected for application in the program.

Considerable interest in the mapping program followed successful production of a demonstration county map and led to the inclusion of the program as a recommended initiative in the Ohio Ground Water Protection and Management Strategy (Ohio EPA, 1986). Based on this recommendation, the Ohio General Assembly funded the mapping program. A dedicated mapping unit has been established in the Division of Water, Water Resources Section to implement the ground water pollution potential mapping program on a countywide basis in Ohio.

The purpose of this report and map is to aid in the protection of our ground water resources. This protection can be enhanced by understanding and implementing the results of this study, which utilizes the DRASTIC system of evaluating an area’s potential for ground water pollution. The mapping program identifies areas that are vulnerable to contamination and displays this information graphically on maps. The system was not designed or intended to replace site-specific investigations, but rather to be used as a planning and management tool. The map and report can be combined with other information to assist in prioritizing local resources and in making land use decisions.

APPLICATIONS OF POLLUTION POTENTIAL MAPS

The pollution potential mapping program offers a wide variety of applications in many counties. The ground water pollution potential map of Williams County has been prepared to assist planners, managers, and state and local officials in evaluating the relative vulnerability of areas to ground water contamination from various sources of pollution. This information can be used to help direct resources and land use activities to appropriate areas, or to assist in protection, monitoring, and clean-up efforts.

An important application of the pollution potential maps for many areas will be assisting in county land use planning and resource expenditures related to solid waste disposal. A county may use the map to help identify areas that are suitable for disposal activities. Once these areas have been identified, a county can collect more site-specific information and combine this with other local factors to determine site suitability.

Pollution potential maps may be applied successfully where non-point source contamination is a concern. Non-point source contamination occurs where land use activities over large areas impact water quality. Maps providing information on relative vulnerability can be used to guide the selection and implementation of appropriate best management practices in different areas. Best management practices should be chosen based upon consideration of the chemical and physical processes that occur from the practice, and the effect these processes may have in areas of moderate to high vulnerability to contamination. For example, the use of agricultural best management practices that limit the infiltration of nitrates, or promote denitrification above the water table, would be beneficial to implement in areas of relatively high vulnerability to contamination.

A pollution potential map can assist in developing ground water protection strategies. By identifying areas more vulnerable to contamination, officials can direct resources to areas where special attention or protection efforts might be warranted. This information can be utilized effectively at the local level for integration into land use decisions and as an educational tool to promote public awareness of ground water resources. Pollution potential maps may be used to prioritize ground water monitoring and/or contamination clean-up efforts. Areas that are identified as being vulnerable to contamination may benefit from increased ground water monitoring for pollutants or from additional efforts to clean up an aquifer.

Individuals in the county who are familiar with specific land use and management problems will recognize other beneficial uses of the pollution potential maps. Planning commissions and zoning boards can use these maps to help make informed decisions about the development of areas within their jurisdiction. Developers proposing projects within ground water sensitive areas may be required to show how ground water will be protected.

Regardless of the application, emphasis must be placed on the fact that the system is not designed to replace a site-specific investigation. The strength of the system lies in its ability to make a "first-cut approximation" by identifying areas that are vulnerable to contamination. Any potential applications of the system should also recognize the assumptions inherent in the system.

SUMMARY OF THE DRASTIC MAPPING PROCESS

DRASTIC was developed by the National Ground Water Association for the United States Environmental Protection Agency. This system was chosen for implementation of a ground water pollution potential mapping program in Ohio. A detailed discussion of this system can be found in Aller et al. (1987).

The DRASTIC mapping system allows the pollution potential of any area to be evaluated systematically using existing information. Vulnerability to contamination is a combination of hydrogeologic factors, anthropogenic influences, and sources of contamination in any given area. The DRASTIC system focuses only on those hydrogeologic factors that influence ground water pollution potential. The system consists of two major elements: the designation of mappable units, termed hydrogeologic settings, and the superposition of a relative rating system to determine pollution potential.

The application of DRASTIC to an area requires the recognition of a set of assumptions made in the development of the system. DRASTIC evaluates the pollution potential of an area under the assumption that a contaminant with the mobility of water is introduced at the surface and flushed into the ground water by precipitation. Most important, DRASTIC cannot be applied to areas smaller than 100 acres in size and is not intended or designed to replace site-specific investigations.

Hydrogeologic Settings and Factors

To facilitate the designation of mappable units, the DRASTIC system used the framework of an existing classification system developed by Heath (1984), which divides the United States into 15 ground water regions based on the factors in a ground water system that affect occurrence and availability.

Within each major hydrogeologic region, smaller units representing specific hydrogeologic settings are identified. Hydrogeologic settings form the basis of the system and represent a composite description of the major geologic and hydrogeologic factors that control ground water movement into, through, and out of an area. A hydrogeologic setting represents a mappable unit with common hydrogeologic characteristics and, as a consequence, common vulnerability to contamination (Aller et al., 1987).

Figure 1 illustrates the format and description of a typical hydrogeologic setting found within Williams County. Inherent within each hydrogeologic setting are the physical characteristics that affect the ground water pollution potential. These characteristics or factors identified during the development of the DRASTIC system include:

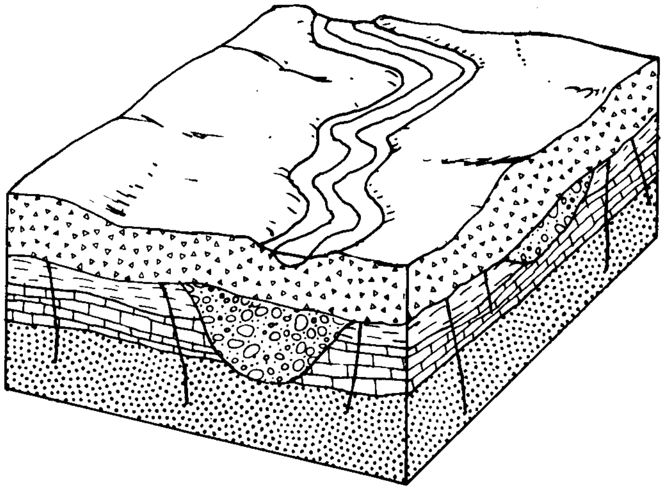
D – Depth to Water
R – Net Recharge
A – Aquifer Media
S – Soil Media
T – Topography
I – Impact of the Vadose Zone Media
C – Conductivity (Hydraulic) of the Aquifer

These factors incorporate concepts and mechanisms such as attenuation, retardation, and time or distance of travel of a contaminant with respect to the physical characteristics of the hydrogeologic setting. Broad consideration of these factors and mechanisms coupled with existing conditions in a setting provide a basis for determination of the area's relative vulnerability to contamination.

Depth to water is considered to be the depth from the ground surface to the water table in unconfined aquifer conditions or the depth to the top of the aquifer under confined aquifer conditions. The depth to water determines the distance a contaminant would have to travel before reaching the aquifer. The greater the distance the contaminant has to travel, the greater the opportunity for attenuation to occur or restriction of movement by relatively impermeable layers.

Net recharge is the total amount of water that infiltrates the aquifer measured in inches per year. Recharge water is available to transport a contaminant from the surface into the aquifer and affects the quantity of water available for dilution and dispersion of a contaminant. Factors to be included in the determination of net recharge include contributions due to infiltration of precipitation, in addition to infiltration from rivers, streams and lakes, irrigation, and artificial recharge.

Aquifer media represents consolidated or unconsolidated rock material capable of yielding sufficient quantities of water for use. Aquifer media accounts for the various physical characteristics of the rock that provide mechanisms of attenuation, retardation, and flow pathways that affect a contaminant reaching and moving through an aquifer.



7D Buried Valley

This setting is characterized by thick deposits of sand and gravel that have been deposited in a former topographic low (usually a pre-glacial river valley) by glacial meltwater. Many of the buried valleys in Williams County underlie the broad, flat lying floodplains of modern rivers. The boundary between the buried valley and the adjacent bedrock upland is usually prominent. The buried valleys contain substantial thicknesses of permeable sand and gravel that serve as the aquifer. The aquifer is typically in hydraulic connection with the modern rivers. The vadose zone is typically composed of sand and gravel but significant amounts of silt and clay can be found in discrete areas. Silt loams, loams, and sandy loams are the typical soil types for this setting. Depth to water is typically less than 30 feet for areas adjacent to modern rivers, and between 30 to 50 feet for terraces that border the bedrock uplands. Recharge is generally high due to permeable soils and vadose zones, shallow depth to water, and the presence of surface streams.

Figure 1. Format and description of the hydrogeologic setting - 7D Buried Valley.

Soil media refers to the upper six feet of the unsaturated zone that is characterized by significant biological activity. The type of soil media influences the amount of recharge that can move through the soil column due to variations in soil permeability. Various soil types also have the ability to attenuate or retard a contaminant as it moves throughout the soil profile. Soil media is based on textural classifications of soils and considers relative thicknesses and attenuation characteristics of each profile within the soil.

Topography refers to the slope of the land expressed as percent slope. The slope of an area affects the likelihood that a contaminant will run off or be ponded and ultimately infiltrate into the subsurface. Topography also affects soil development and often can be used to help determine the direction and gradient of ground water flow under water table conditions.

The impact of the vadose zone media refers to the attenuation and retardation processes that can occur as a contaminant moves through the unsaturated zone above the aquifer. The vadose zone represents that area below the soil horizon and above the aquifer that is unsaturated or discontinuously saturated. Various attenuation, travel time, and distance mechanisms related to the types of geologic materials present can affect the movement of contaminants in the vadose zone. Where an aquifer is unconfined, the vadose zone media represents the materials below the soil horizon and above the water table. Under confined aquifer conditions, the vadose zone is simply referred to as a confining layer. The presence of the confining layer in the unsaturated zone has a significant impact on the pollution potential of the ground water in an area.

Hydraulic conductivity of an aquifer is a measure of the ability of the aquifer to transmit water, and is also related to ground water velocity and gradient. Hydraulic conductivity is dependent upon the amount and interconnectivity of void spaces and fractures within a consolidated or unconsolidated rock unit. Higher hydraulic conductivity typically corresponds to higher vulnerability to contamination. Hydraulic conductivity considers the capability for a contaminant that reaches an aquifer to be transported throughout that aquifer over time.

Weighting and Rating System

DRASTIC uses a numerical weighting and rating system that is combined with the DRASTIC factors to calculate a ground water pollution potential index or relative measure of vulnerability to contamination. The DRASTIC factors are weighted from 1 to 5 according to their relative importance to each other with regard to contamination potential (Table 1). Each factor is then divided into ranges or media types and assigned a rating from 1 to 10 based on their significance to pollution potential (Tables 2-8). The rating for each factor is selected based on available information and professional judgment. The selected rating for each factor is multiplied by the assigned weight for each factor. These numbers are summed to calculate the DRASTIC or pollution potential index.

Once a DRASTIC index has been calculated, it is possible to identify areas that are more likely to be susceptible to ground water contamination relative to other areas. The higher the DRASTIC index, the greater the vulnerability to contamination. The index generated provides only a relative evaluation tool and is not designed to produce absolute answers or to represent units of vulnerability. Pollution potential indexes of various settings should be compared to each other only with consideration of the factors that were evaluated in determining the vulnerability of the area.

Pesticide DRASTIC

A special version of DRASTIC was developed for use where the application of pesticides is a concern. The weights assigned to the DRASTIC factors were changed to reflect the processes that affect pesticide movement into the subsurface with particular emphasis on soils. Where other agricultural practices, such as the application of fertilizers, are a concern, general DRASTIC should be used to evaluate relative vulnerability to contamination. The process for calculating the Pesticide DRASTIC index is identical to the process used for calculating the general DRASTIC index. However, general DRASTIC and Pesticide DRASTIC numbers should not be compared because the conceptual basis in factor weighting and evaluation differs significantly. Table 1 lists the weights used for general and pesticide DRASTIC.

Table 1. Assigned weights for DRASTIC features

Feature	General DRASTIC Weight	Pesticide DRASTIC Weight
Depth to Water	5	5
Net Recharge	4	4
Aquifer Media	3	3
Soil Media	2	5
Topography	1	3
Impact of the Vadose Zone Media	5	4
Hydraulic Conductivity of the Aquifer	3	2

Table 2. Ranges and ratings for depth to water

Depth to Water (feet)	
Range	**Rating**
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
100+	1
Weight: 5	Pesticide Weight: 5

Table 3. Ranges and ratings for net recharge

Net Recharge (inches)	
Range	**Rating**
0-2	1
2-4	3
4-7	6
7-10	8
10+	9
Weight: 4	Pesticide Weight: 4

Table 4. Ranges and ratings for aquifer media

Aquifer Media		
Range	**Rating**	**Typical Rating**
Shale	1-3	2
Glacial Till	4-6	5
Sandstone	4-9	6
Limestone	4-9	6
Sand and gravel	4-9	8
Interbedded Ss/Sh/Ls/Coal	2-10	9
Karst Limestone	9-10	10
Weight: 3	Pesticide Weight: 3	

Table 5. Ranges and ratings for soil media

Soil Media	
Range	**Rating**
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrink/Swell Clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Clay	1
Weight: 2	Pesticide Weight: 5

Table 6. Ranges and ratings for topography

Topography (percent slope)	
Range	**Rating**
0-2	10
2-6	9
6-12	5
12-18	3
18+	1
Weight: 1	Pesticide Weight: 3

Table 7. Ranges and ratings for impact of the vadose zone media

Impact of the Vadose Zone Media		
Range	**Rating**	**Typical Rating**
Confining Layer	1	1
Silt/Clay	2-6	3
Shale	2-5	3
Limestone	2-7	6
Sandstone	4-8	6
Interbedded Ss/Sh/Ls/Coal	4-8	6
Sand and gravel with Silt and Clay	4-8	6
Glacial Till	2-6	4
Sand and gravel	6-9	8
Karst Limestone	8-10	10
Weight: 5	Pesticide Weight: 4	

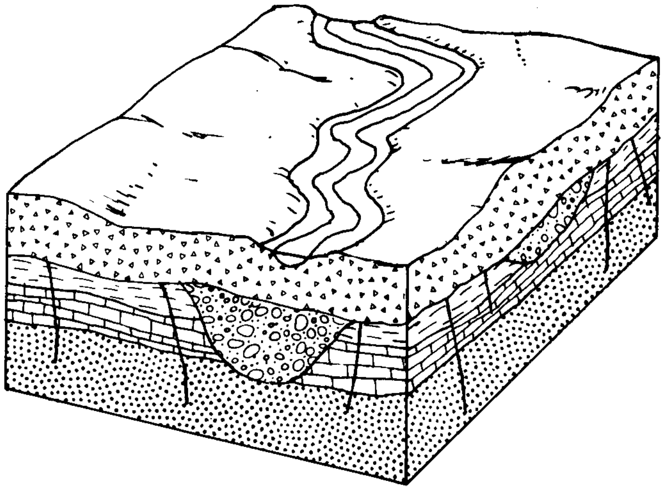
Table 8. Ranges and ratings for hydraulic conductivity

Hydraulic Conductivity (GPD/FT^2)	
Range	**Rating**
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8
2000+	10
Weight: 3	Pesticide Weight: 2

Integration of Hydrogeologic Settings and DRASTIC Factors

Figure 2 illustrates the hydrogeologic setting 7D1, Buried Valley, identified in mapping Williams County, and the pollution potential index calculated for the setting. Based on selected ratings for this setting, the pollution potential index is calculated to be 148. This numerical value has no intrinsic meaning, but can be readily compared to a value obtained for other settings in the county. DRASTIC indexes for typical hydrogeologic settings and values across the United States range from 45 to 223. The diversity of hydrogeologic conditions in Williams County produces settings with a wide range of vulnerability to ground water contamination. Calculated pollution potential indexes for the 11 settings identified in the county range from 66 to 183.

Hydrogeologic settings identified in an area are combined with the pollution potential indexes to create units that can be graphically displayed on maps. Pollution potential analysis in Williams County resulted in a map with symbols and colors that illustrate areas of ground water vulnerability. The map describing the ground water pollution potential of Williams County is included with this report.



SETTING 7D1		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand & Gravel	3	8	24
Soil Media	Shrink-swell clay	2	7	14
Topography	2-6%	1	9	9
Impact of Vadose Zone	Sand&gravel w/silt&clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
		DRASTIC	INDEX	148

Figure 2. Description of the hydrogeologic setting - 7D1 Buried Valley.

INTERPRETATION AND USE OF GROUND WATER POLLUTION POTENTIAL MAPS

The application of the DRASTIC system to evaluate an area's vulnerability to contamination produces hydrogeologic settings with corresponding pollution potential indexes. The higher the pollution potential index, the greater the susceptibility to contamination. This numeric value determined for one area can be compared to the pollution potential index calculated for another area.

The map accompanying this report displays both the hydrogeologic settings identified in the county and the associated pollution potential indexes calculated in those hydrogeologic settings. The symbols on the map represent the following information:

7D1 - defines the hydrogeologic region and setting
148 - defines the relative pollution potential

The first number (**7**) refers to the major hydrogeologic region and the upper case letter (**D**) refers to a specific hydrogeologic setting. The following number (**1**) references a certain set of DRASTIC parameters that are unique to this setting and are described in the corresponding setting chart. The second number (**148**) is the calculated pollution potential index for this unique setting. The charts for each setting provide a reference to show how the pollution potential index was derived.

The maps are color-coded using ranges depicted on the map legend. The color codes used are part of a national color-coding scheme developed to assist the user in gaining a general insight into the vulnerability of the ground water in the area. The color codes were chosen to represent the colors of the spectrum, with warm colors (red, orange, and yellow) representing areas of higher vulnerability (higher pollution potential indexes), and cool colors (greens, blues, and violet) representing areas of lower vulnerability to contamination. Large man-made features such as landfills, quarries, or strip mines have also been marked on the map for reference.

GENERAL INFORMATION ABOUT WILLIAMS COUNTY

Demographics

Williams County occupies approximately 421 square miles in the northwestern corner of Ohio (Figure 3). Williams County is bounded to the north by Hillsdale County, Michigan, to the east by Fulton County, to the southeast by Henry County, to the south by Defiance County, and to the west by Steuben and Dekalb Counties, Indiana.

The approximate population of Williams County, based upon year 2000 estimates, is 39,188 (Department of Development, Ohio County Profiles, 2002). Bryan is the largest community and the county seat. Agriculture accounts for roughly 85 percent of the land usage in Williams County. Row crops are the primary agricultural land usage. Woodlands account for approximately 10% of the land usage; many of the woodlands include or are adjacent to wetlands. Municipal, industry, and residential are the other major land uses in the county. More specific information on land usage can be obtained from the Ohio Department of Natural Resources, Division of Real Estate and Land Management (REALM), Resource Analysis Program (formerly OCAP).

Physiography and Climate

The *Hydrologic Atlas for Ohio* (Harstine, 1991) reports an average annual temperature of approximately 50 degrees Fahrenheit for Williams County. The average temperatures increase slightly towards the southeast. Harstine (1991) shows that precipitation approximately averages 34 to 35 inches per year for the county, with precipitation increasing towards the northwest. The mean annual precipitation for Montpelier is 34.5 inches per year based upon a twenty-year (1961-1980) period (Owenby and Ezell, 1992). The mean annual temperature for Montpelier for the same twenty-year period is 47.6 degrees Fahrenheit (Owenby and Ezell, 1992).

Williams County lies within the Lake Plains section of the Central Till Plains Lowland Province (Frost, 1931; Fenneman, 1938, and Bier, 1956). A flat lacustrine plain along with some subdued beach ridges and dunes characterizes southeastern Williams County. Gently rolling to hummocky topography characterizes the Wabash and Fort Wayne End Moraines. Areas between the end moraines feature flat-lying ground moraine.

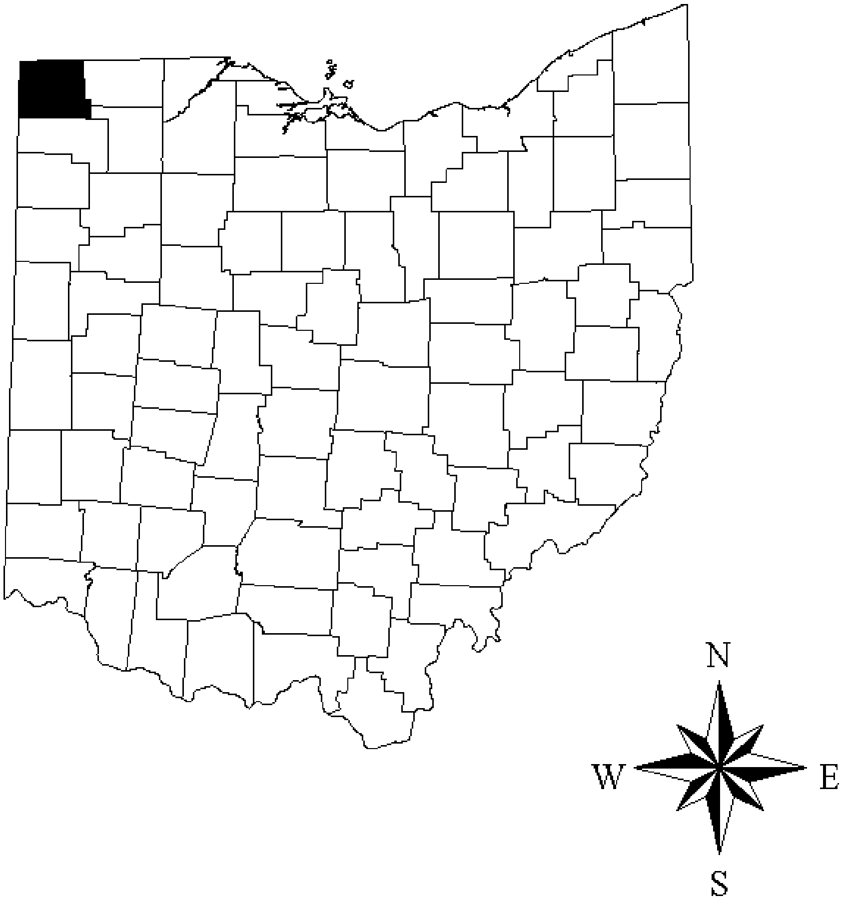


Figure 3. Location of Williams County, Ohio.

Modern Drainage

The St. Joseph River and its tributaries drain western and northern Williams County. The St. Joseph River empties into the Maumee River in Fort Wayne, Indiana. The Tiffin River and its tributaries drain southern and eastern Williams County. The Tiffin River empties into the Maumee River in the city of Defiance. Beaver Creek is an important tributary of the Tiffin River that drains south central Williams County. The Fort Wayne Moraine roughly serves as the drainage divide between the two drainage systems.

Pre- and Inter-Glacial Drainage Changes

The thick cover of glacial drift and the lack of water well log records encountering bedrock make it difficult to determine the bedrock topography underlying Williams County (King, 1977). Stout et al. (1943) speculated that Montpelier Creek drained the majority of Williams County. The course of Montpelier Creek is very similar to that of the modern St. Joseph River. The eastern margin of Williams County drained to the east into the Napoleon River. The course of the modern Maumee River is similar to that of the Napoleon River. King (1977), Baggett (1987), and Coen (1989) determined that there was lack of evidence for Montpelier Creek. They inferred that the bedrock topography data showed the possibility that the east central portion of the county served as the headwaters for two buried valley systems.

Glacial Geology

During the Pleistocene Epoch (2 million to 10,000 years before present (Y.B.P.)) several episodes of ice advance occurred in northwestern Ohio. Older ice advances that predate the most recent (Brunhes) magnetic reversal (about 730,000 Y.B.P.) are now commonly referred to as pre-Illinoian (formerly Kansan). Goldthwait et al., (1961) and Pavey et al., (1999) report that the late Wisconsinan Ice Sheet deposited the surficial till in Williams County. Evidence for the earlier glaciations is lacking or obscured.

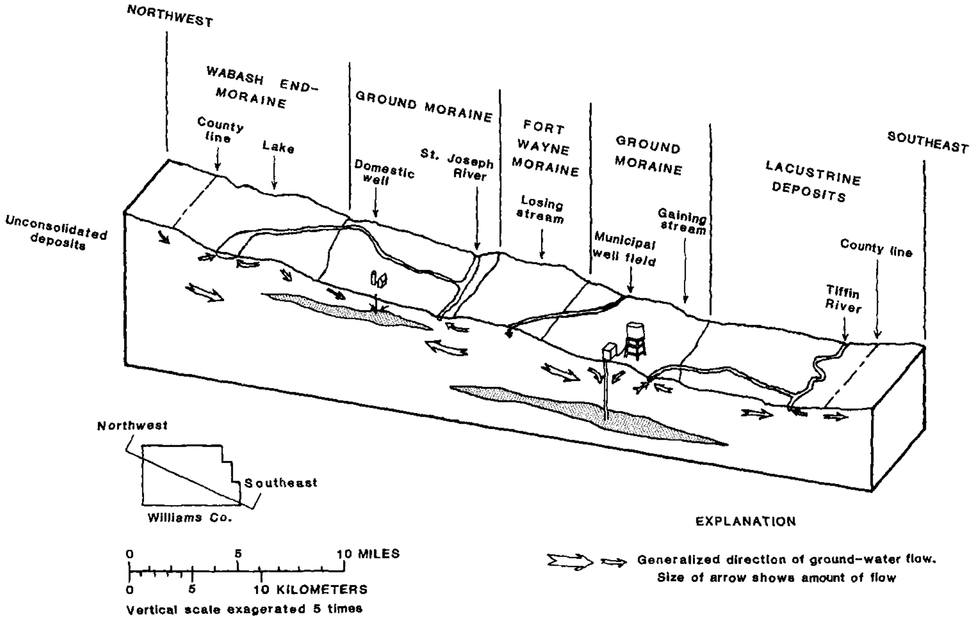
Till is an unsorted, non-stratified (non-bedded), mixture of sand, gravel, silt, and clay deposited directly by the ice sheet. There are two main types or facies of glacial till. Lodgement till is "plastered-down" or "bulldozed" at the base of an actively moving ice sheet. Lodgement till tends to be relatively dense and compacted and pebbles typically are angular, broken, and have a preferred direction or orientation. "Hardpan" and "boulder-clay" are two common terms used for lodgement till. The second main type of till is ablation or "melt-out" till which occurs as the ice sheet melts or stagnates away. Debris bands are laid down or stacked as the ice between the bands melts. Ablation till tends to be less dense, less compacted, and slightly coarser as meltwater commonly washes away some of the fine silt and clay. There is evidence that some of the tills were deposited in a water environment in southeastern Williams County. These types of tills would be deposited when a relatively thin ice sheet would alternately float and ground depending on the water level of the lake and thickness of the ice sheet. Such tills may more closely resemble lacustrine deposits.

Till has relatively low inherent permeability. Permeability in till is in part dependent upon the primary porosity of the till which reflects how fine-textured the particular till is. Vertical permeability in till is controlled largely by factors influencing the secondary porosity such as fractures (joints), worm burrows, root channels, sand seams, etc. (Brockman and Szabo, 2000 and Haefner, 2000). Of importance in Williams County is the high proportion of sand and gravel units interbedded in the till. These units may overlap enough ("stack") to help aid in permeability. Fractures may also interconnect the sand and gravel lenses.

At the land surface, till accounts for two primary landforms: ground moraine and end moraine. Ground moraine (till plain) is relatively flat to gently rolling. End moraines are ridge-like, with terrain that is steeper and more rolling or hummocky. End moraines commonly serve as a local drainage divide due to their ridge-like nature. The Fort Wayne Moraine is a relatively broad, low, lying ridge. It extends from northeast to southwest, roughly paralleling and lying just east of the St. Joseph River. The Wabash End Moraine occupies the northwest corner of the county. Water well log records, soils maps (Stone et al., 1978), and the reports of King (1977), Baggett (1987), Coen (1989), and Bennett and Williams (2002) all indicate that the end moraine areas contain more sand and gravel deposits at the surface and at depth than the areas of ground moraine. The Wabash Moraine in particular contains more sand and gravel and has more kettles and other features that may imply an origin reflecting the melting or ablation of an ice sheet. Figure 4 shows a cross-section of Williams County depicting the position of the end moraines and their relation to other settings, groundwater recharge, and the underlying bedrock (Coen, 1989).

Outwash deposits are created by active deposition of sediments by meltwater streams. These deposits are generally bedded or stratified and are sorted. Outwash deposits in Williams County are mostly associated with the St. Joseph River and with portions of the Wabash Moraine. Outwash deposits associated with stream valleys were referred to in earlier literature as valley trains. Sorting and degree of coarseness depend upon the nature and proximity of the melting ice sheet. Braided streams usually deposited the outwash. Such streams have multiple channels, which migrate across the width of the valley floor, leaving behind a complex record of deposition and erosion. Deposition of outwash may precede an advancing ice sheet or be associated with a melting ice sheet. As modern streams downcut, the older, now higher elevation, remnants of the original valley floor are called terraces.

Kames and eskers are ice contact features. They are composed of masses of generally poorly sorted sand and gravel with minor till, deposited in depressions, holes, tunnels, or other cavities in the ice. As the surrounding ice melts, a mound of sediment remains behind. Typically, these deposits may collapse or flow as the surrounding ice melts. These deposits may display high angle, distorted or tilted beds, faults, and folds. The best example of outwash deposits is the terraces immediately flanking the St. Joseph River. The ODNR, Div. of Water, Glacial State Aquifer Map (2000) delineates this area as a buried valley due to its strong resemblance of many of the “classic” buried valley settings found elsewhere throughout Ohio.



Regional Recharge Model
Modified from Coen, 1989

Figure 4. Cross-section of Williams County depicting the position of the end moraines and their relation to other features.

Sand and gravel deposits are also associated with the channels and terraces adjacent to the Tiffin River. These sand and gravel lenses are interbedded with finer-grained alluvial (floodplain) deposits. Some of these deposits receive recharge directly from the Tiffin River.

Although Williams County contains abundant sand and gravel deposits, the features are typically subdued and may not fit the classical description of outwash plains and terraces or kames and eskers. These features may in part be covered by till or altered by the advancing ice sheets which deposited the till. King (1977), Baggett (1987), Coen (1989), and Bennett and Williams (2002) all suggest that the sand and gravel is more abundant in specific “zones” within the till as opposed to distinct outwash features or kames.

Williams County contains abundant kettles. Melting blocks of ice formed these small, circular depressional features. As the ice block melted, it left behind a hole or low area surrounded by either till or outwash. Kettles may also reflect lows or “swales” in an end moraine which are flanked by highs or “swells”. Kettles commonly contain standing water. The water may reflect the local water table conditions or may collect and perch local runoff. Kettles also contain peat and muck. Peat and muck are organic-rich deposits associated with low-lying depression areas, bogs, kettles, and swamps. Muck is dense, fine silt with a high content of organics and a dark black color. Peat is typically brownish and contains pieces of plant fibers, decaying wood, and mosses. The two deposits commonly occur together, Pavey et al. (1999) and the Soil Survey of Williams County (Stone et al., 1978) show numerous organic deposits that have filled kettles. The kettles are typically underlain by either highly permeable sand and gravel outwash or by low permeability lacustrine silt and clay or till.

To the south and east of the Fort Wayne Moraine, the ground moraine has been modified by wave activity. This roughly corresponds to elevations below 800 feet above mean sea level (msl). The till has been “wave-planed” or “water-modified” (Forsyth, 1965) at the land surface. Wave activity has eroded away previously existing topographic features. The resulting land surface is flat, gently sloping towards the Maumee River and Lake Erie.

The Lake Plains region of Ohio was flooded immediately upon the melting of glacial ice due to its basin-like topography. River flow into the basin also contributed to the formation of these lakes. Various drainage outlets in Indiana, Michigan, and New York controlled lake levels over time.

This series of lakes, from ancestral Lake Maumee to modern Lake Erie, had a profound influence on the surficial deposits and geomorphology of the area. Shallow wave activity had a beveling affect on the topography. Clayey to silty lacustrine sediments were deposited into deeper, quieter waters. In shallower areas, beaches and bars were deposited. Some of the beach ridge sand and gravel was deposited by insitu erosion (Anderhalt et al., 1984); the remainder was transported in by local rivers and then re-deposited by wave activity. Coarser sand and gravel was deposited at the shoreline (strandline). Progressively offshore, finer sands, then silts, and then clay were deposited. This accounts for the variable soil types which progress from sands, to sandy loams, to silty loams, to either clays or shrink-swell clays. Lacustrine deposits tend to be laminated or "varved" and contain various proportions of silts and clays. Thin layers of fine sand may reflect storm or flood events. Permeability is preferentially horizontal due to the laminations and water-laid nature of these sediments. The inherent vertical permeability is slow, however, secondary porosity features such as fractures, joints, root channels, etc. help increase the vertical permeability.

The major beach levels in Williams County are listed in Table 9. Forsyth (1959 and 1973) gives a detailed discussion of the beach levels and lake history in northwestern Ohio. The beaches form long, narrow low ridges of sand. Coarser sand and gravel form the core of the ridges. Thin sheets of fine sand may lie between the ridges. Wind activity has reworked the beach ridges creating dunes. Dunes cap many of the beach ridges, making it difficult to distinguish the features.

Bedrock Geology

Bedrock underlying the surface of Williams County belongs to the Mississippian and Devonian Systems. The underlying bedrock is primarily shale. Due to the thick cover of glacial drift, no bedrock outcrops in Williams County. Table 10 summarizes the bedrock stratigraphy found in Williams County. The ODNR, Division of Geological Survey, has Open-File Reconnaissance Bedrock Geological Maps done on a 1:24,000 USGS Topographic map base available for the entire county. The ODNR, Division of Water, has Open File Bedrock State Aquifer mapping available for the county also.

Table 9. Lake level Sequence (after Hough, 1958 and Forsyth, 1973)

Lake Stage	Age (years B.P.)	Elevation (ft)	Outlet	Found in Williams County?
Erie (modern)	4,000	573	Niagara	no
Algonquin	>12,000	605	Grand River, Mich. Or Mohawk River, N.Y.	No
Lundy	>12,200	?	Grand River, Mich. Or Mohawk River, N.Y.	No
(Elkton)		615	Grand River, Mich. Or Mohawk River, N.Y.	No
(Dana)		620	Grand River, Mich. Or Mohawk River, N.Y.	No
(Grassmere)		640	Grand River, Mich.	no
Lower Warren		675	Grand River, Mich. Or Mohawk River, N.Y.	No
Wayne		655-660	Grand River, Mich. Or Mohawk River, N.Y.	No
Upper Warren	<13,000	685-690	Grand River, Mich.	No
Whittlesey	>13,000	735	Grand River, Mich.	Yes
Lower Arkona		700	Grand River, Mich.	No
Upper Arkona		710-715	Grand River, Mich.	No
Middle Maumee	14,000	775-780	Wabash River, Ind.	Yes
Lower Maumee		760	Grand River, Mich.	Yes
Upper Maumee		800	Wabash River, Ind.	yes

The rock units throughout Williams County are relatively flat lying, dipping to the northwest roughly 20 feet per mile (King, 1977, Baggett, 1987, and Coen, 1989). The northwest dip is attributed to Williams County lying on the western flank of the northeast trending Findlay Arch. The Findlay Arch is the northeastern extension of the Cincinnati Arch. The Findlay Arch is a deep, subsurface structural feature that has affected the deposition, solution, and hydrogeology of the rock units in the region. The overall bedrock surface tends to be highest toward the southwest and decrease gradually toward Lake Erie.

Table 10. Bedrock Stratigraphy of Williams County

System	Group/Formation (Symbol)	Lithologic Description
Mississippian	Coldwater Shale, Sunbury-Berea-Bedford undivided (Mcs-b)	This aquifer consists of gray to black carbonaceous and silty shales that are thinly laminated to thin-bedded. Thickness is less than 100 feet throughout Williams County, and yield is less than 5 gallons per minute.
Devonian	Antrim Shale (Da)	Dark brown to black, thinly laminated, carbonaceous shale. Meager yields are generally obtained from the upper fractured portion of the aquifer. Hydrogen sulfide is often present. This aquifer is utilized in the southeast corner of the county. Thickness exceeds 200 feet.

Devonian age Antrim Shale is encountered by water wells in the southeastern corner of Williams County (King, 1977, Baggett, 1987, and Coen, 1989 and ODNR, Division of Water, Bedrock State Aquifer Map, 2000). These thick, dark brown to black fissile shales were deposited in deep oceans that had limited circulation of fresher waters and sediments. These shales are rich in organic matter, pyrite, and locally, natural gas. Shales and siltstones of the Mississippian Coldwater Shale and Sunbury-Berea-Bedford undivided Formation underlies the northern half of Williams County. These units are primarily massive shale with minor siltstones and fine-grained sandstones.

Ground Water Resources

Ground water in Williams County is obtained primarily from unconsolidated (glacial-alluvial) aquifers. Consolidated (bedrock) aquifers are limited to the southeastern corner of the county. Glacial aquifers are found throughout the county except for the very southeast corner.

The Antrim Shale (or Ohio Shale) in southeastern Williams County is a poor source of ground water. Yields are typically less than 5 gpm (King, 1977, Coen, 1989, and Haiker, 1996). Typically, the uppermost 10 to 15 feet of the shale is weathered and broken and provides the most water. Wells drilled deeper into the shale provide increased well storage, but typically little additional water. Higher yields may be obtained from deep underlying limestones; however, the water quality in these units is quite objectionable. Water underlying the shale tends to be very high in sulfur, hydrogen sulfide, and iron. The shale underlying the remainder of the county is very deep and water is readily obtained from the overlying glacial sediments.

Yields over 500 gpm are obtained from relatively thick, continuous sequences of coarse sand and gravel. The higher-yielding sand and gravel units are commonly adjacent to the St. Joseph River. Yields also tend to be higher in areas of end moraines, especially the Wabash Moraine. There is also a zone of thicker, coarser sand and gravel lenses that extends from Bryan northward to Montpelier (King, 1977 and Baggett, 1987), the Ohio Turnpike Interchange No. 15 (Schmidt and Walker, 1954), and the village of Pioneer (Haiker, 1996). King (1977), Coen (1989), and Baggett (1987) suggested that this higher-yielding zone might reflect coarser materials that formed in front of and may be related to the deposition of the Fort Wayne Moraine. Perhaps this zone reflects a wedge of proglacial outwash extending ahead of the ice sheet that deposited the Fort Wayne Moraine or perhaps a precursor of this moraine. Maximum sustainable yields in the 100 to 500-gpm range are widespread through most of the remainder of Williams County. Yields from sand and gravel lenses interbedded with the fine-grained till and lacustrine deposits average 5 to 25 gpm (ODNR, Div. of Water, Glacial State Aquifer Map, 2000, King, 1977, Coen, 1989, and Haiker, 1996) in the southeastern corner of the county. The sand and gravel may also directly overlie the bedrock in this portion of the county (King, 1977, and Coen, 1989) and yield 5 to 25 gpm. These sand and gravel lenses tend to be thin and less continuous. Also, the gravel tends to consist of ground-up shale instead of the cleaner quartz-grained sand common throughout the rest of the county. The sand and gravel directly underlying the till boundary may undergo cementation due to the chemical precipitation of iron and calcite. Such localized zones are very hard and are referred to by well drillers as hardpan. (Note- Hardpan may also refer to dense till in some logs).

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APPENDIX A

DESCRIPTION OF THE LOGIC IN FACTOR SELECTION

Depth to Water

This factor was primarily evaluated using information from water well log records on file at the Ohio Department of Natural Resources (ODNR), Division of Water, Water Resources Section (WRS). Approximately 6,150 water well log records are on file for Williams County. Data from roughly 2,260 located water well log records were analyzed and plotted on U.S.G.S. 7-1/2 minute topographic maps during the course of the project. Static water levels and information as to the depths water was encountered were taken from these records. The *Ground Water Resources of Williams County* (Haiker, 1996), the study of Coen (1989), and the theses of King (1977) and Baggett (1987) provided generalized depth to water information throughout the county. Depth to water trends mapped in adjoining Fulton County (Plymale, 1999 and Plymale et al., 2002), and Henry County (Miller, 1997 and Miller and Angle, 2002) were used as a guideline. Topographic and geomorphic trends were utilized in areas where other sources of data were lacking.

DRASTIC evaluates aquifers as being either confined or unconfined. For unconfined aquifers, the depth to water is considered to be the level of the potentiometric surface (i.e. – the static water level in the well), and is not necessarily the depth at which water was first encountered during drilling. For shallow outwash and alluvial aquifers the potentiometric surface is analogous to the water table. For confined aquifers, the depth to water is considered to be from the ground surface to the top of the aquifer (or base of the confining layer).

DRASTIC doesn’t specifically address semi-confined or “leaky” aquifer conditions. King (1977), Baggett (1987), Coen (1989), Kleinheider (1998), and Bennett and Williams (2002) all discuss the likelihood that most of the aquifers in Williams County are under semi-confined as opposed to truly confined conditions. In southeastern Williams County where aquifer conditions were believed to be close to representing confining conditions, depth to water was evaluated as being the top of the aquifer. Where multiple sand and gravel lenses were encountered, depths to shallower, common water-producing zones were selected.

Depths to water of 0 to 5 (10) were used for some limited low-lying areas adjacent to Henry County and Fulton County. Depths to water of 5 to 15 feet (9) were selected for floodplains and low terraces adjacent to the St. Joseph River and the Tiffin River and their tributaries. Depths to water of 5 to 15 feet (9) were also common on the lake plain (7F-Glacial Lake Deposits) setting. Depths of 15 to 30 feet (7) were widespread across Williams County. Depths of 15 to 30 feet (7) were used for higher elevation floodplains and terraces and for tributaries of both the St. Joseph River and the Tiffin River. Depths to water of 15 to 30 feet (7) are also common for much of the lake plain (7F-Glacial Lake Deposits), ground moraine (7Af-Sand and gravel Interbedded in Glacial Till), beaches (7H-Beaches, Beach Ridges and Sand Dunes) and outwash settings (7Ba-Outwash). Depths of 30 to 50 feet (5) were utilized for end moraines (7C-Moraines), ground moraine west of the St. Joseph River, and portions of the lake plain in eastern Springfield Township. Depths to water of 50 to 75 feet (3) and 75 to 100 feet (2) were utilized for higher elevation crests of the Fort Wayne Moraine. Depths to water of 50 to 75 feet (3) and greater than 100 feet (1) were utilized for portions of the lake plain south of West Unity exhibiting confining conditions. Confining conditions with a depth to water greater than 100 feet were selected for the 7Fb-Glacial Lake Deposits over Outwash setting.

Net Recharge

This factor was evaluated using many criteria, including depth to water, topography, soil type, surface drainage, vadose zone material, aquifer type, and annual precipitation. Recharge is the precipitation that reaches the aquifer after evapotranspiration and run-off. General estimates of recharge provided by Pettyjohn and Henning (1979) and Dumouchelle and Schiefer (2002) proved to be helpful. Recharge ratings mapped in adjoining Fulton County (Plymale, 1999 and Plymale et al., 2002), and Henry County (Miller, 1997, and Miller and Angle, 2002) were used as a guideline. Figure 4 provides a generalized cross section showing how recharge varies across Williams County. The studies of King (1977), Baggett (1987), Coen (1989), Kleinheider (1998), and Bennett and Williams (2002) provided detailed analysis of recharge conditions within the county. Based upon the information obtained from these reports, it was decided that the aquifers should be evaluated as being semi-confined or leaky as opposed to being truly confined. As per DRASTIC (Aller et al., 1987), confined aquifers require that the recharge be in the 0-2 inches per year range (1). Recharge values of 2 to 4 inches per year (3) were assigned to areas containing the semi-confined aquifers.

Recharge values of 7 to 10 inches per year (8) were assigned to coarser-grained deposits in floodplains and terraces adjacent to the St. Joseph River and some of its tributaries. These high recharge rates are mostly limited to the 7D-Buried Valley setting. Values of 4 to 7 inches per year (6) were used for areas with moderate recharge. These areas include most of the streams in the county and areas of end moraines (7C- Moraines), outwash (7Ba-Outwash), and beach ridges (7H-Beaches, Beach Ridges, and Sand Dunes) as well as areas with moderate depths to water and moderately permeable soils. Values of 2 to 4 inches per year (3) were utilized for most areas of ground moraine and lake plain. These areas have clayey, low permeability soils and vadose zone materials and represent semi-confining conditions. Recharge values of 0 to 2 inches per year (1) were selected for the areas with confining aquifer conditions. These areas were limited to the 7Fb-Glacial Lake Deposits over Outwash setting bordering Fulton County.

Aquifer Media

Information on evaluating aquifer media was obtained from the maps and reports of Schmidt and Walker (1954), King (1977), Baggett (1987), Coen (1989), Haiker (1996), Kleinheider (1998), and Bennett and Williams (2002). Open File Bedrock Reconnaissance Maps and Open File Bedrock Topography Maps, based upon U.S.G.S. 7-1/2 minute topographic maps from the ODNR, Division of Geological Survey proved helpful. Aquifer ratings from neighboring Fulton County (Plymale, 1999 and Plymale et al., 2002) and Henry County (Miller, 1997 and Miller and Angle, 2002) were used as a guideline. The ODNR, Division of Water, Glacial State Aquifer Map and Bedrock State Aquifer Map were an important source of aquifer data. Water well log records on file at the ODNR, Division of Water, were the primary source of aquifer information.

All of the bedrock and most of the interbedded lenses of sand and gravel are semi-confined or leaky; however for the purposes of DRASTIC, they have been evaluated as being unconfined (Aller et al., 1987). Shale was evaluated as the aquifer in the 7Ae-Glacial Till over Shale and in the adjacent 7F-Glacial Lake Deposits settings with shale aquifers. A rating of (2) was applied to all of the shale aquifers.

Sand and gravel with aquifer ratings of (6) and (7) were selected for some of the aquifers in eastern Williams County. These sand and gravel lenses tend to be thin and directly overlie the shale bedrock. The sand and gravel is typically relatively dirty and is mostly comprised of ground-up shale fragments. All of the remaining sand and gravel aquifers in the county were given an aquifer rating of (8). These units tend to be thicker and are relatively coarse, clean, and well sorted.

Soils

Soils were mapped using the data obtained from the *Soil Survey of Williams County* (Stone et al., 1978). Each soil type was evaluated and given a rating for soil media. Evaluations were based upon the texture, permeability, and shrink-swell potential for each soil material. Special emphasis is placed upon determining the most restrictive layer. The soils of Williams County showed a high degree of variability. This is a reflection of the parent material. Table 11 is a list of the soils, parent materials, setting, and corresponding DRASTIC values for Williams County.

Soils were considered to be gravel (10) for a limited number of outwash terraces along the St. Joseph River, minor outwash deposits associated with the Wabash Moraine, and some coarse-grained beach ridges associated with the Lake Maumee. Sand (9) was selected for some isolated outwash deposits associated with the Wabash Moraine. Peat (8) was selected as the soil type for a number of isolated kettles and depressions. Most of these areas are associated with the 7I- Swamps and Marshes setting. Shrink-swell (aggregated) clay (7) was selected for most of the high-clay lacustrine soils and the high clay wave-planed glacial till in the 7F-Glacial Lake Deposits setting. These soils expand upon wetting and are relatively impermeable during normal to wet conditions. They behave similar to clay loams at these times. During dry summer months, these soils desiccate and shrink, creating large cracks or fractures that serve as effective avenues for contaminants to migrate downward into the water table. Shrink-swell clays (7) were also selected for minor depressional areas elsewhere in the county. Water ponded in these depressions and highly clayey material was deposited into them. Sandy loams (6) were selected for soils overlying beach ridges and some stream terraces and headwaters of tributary streams. Sandy loams (6) were also found capping some crests of the Wabash Moraine. Loam soils (5) were designated for medium-textured soils overlying on floodplain terraces. Loam soils (5) were also used for medium-textured, thin silty deltaic deposits. Silt loam (4) soils were evaluated for silty alluvial deposits particularly in the headwaters of tributaries. Silt loam (4) soils were also selected for thin, silty deltaic deposits. Clay loam (3) soils were widespread in Williams County and were used for most areas with ground moraine and end moraines.

Table 11. Williams County Soils

Soil Name	**Parent Material or Setting**	**DRASTIC Rating**	**Soil Media**
Arkport	Beach, outwash	6	Sandy loam
Belmore	Maumee beach ridge	6	Sandy loam
Blount	Loamy till	3	Clay loam
Bono	Clayey lacustrine	7	Shrink-swell clay
Boyer	Outwash, beach	10	Gravel
Carlisle	Peat, depressions	8	Peat
Ceresco	Coarse alluvium, outwash	6	Sandy loam
Cohoctah	Alluvium	6	Sandy loam
Colwood	Deltaic	5	Loam
DelRey	Silty lacustrine, deltaic	4	Silt loam
Digby	Outwash, beach	6	Sandy loam
Edwards	Peat, depressions	8	Peat
Eel	Alluvium	4	Silt loam
Fulton	Clayey lacustrine	7	Shrink-swell clay
Genesee	Alluvium	4	Silt loam
Gilford	Low lying beach areas	6	Sandy loam
Glynwood	Loamy till	3	Clay loam
Haney	Beach, outwash	6	Sandy loam
Haney-Rawson	Outwash, Wabash Moraine	6	Sandy loam
Haskins	Thin sand over clayey till or lacustrine	7	Shrink-swell clay
Hoytville	Water-modified till	7	Shrink-swell clay
Kibbie	Silty lacustrine, deltaic	4	Silt loam
Lamson	Sandy deltaic	5	Loam
Landes	Alluvial terraces, St. Joseph River	6	Sandy loam
Latty	Clayey lacustrine	7	Shrink-swell clay
Lenawee	Silty lacustrine, deltaic	4	Silt loam
Lucas	Clayey lacustrine	7	Shrink-swell clay
Martisco	Peat, kettles	8	Peat
Mermill	Sand over clayey till	3	Clay loam
Milgrove	Beach, outwash over till	6	Sandy loam
Nappanee	Water-modified till	7	Shrink-swell clay
Oshtemo	Outwash-beach	10	Gravel
Ottokee	Beach	9	Sand
Paulding	Clayey lacustrine	7	Shrink-swell clay
Pewamo	Clayey till, low areas	3	Clay loam
Rawson	Sandy deltaic over clayey lacustrine	7	Shrink-swell clay
Rimer	Beach over clayey lacustrine	7	Shrink-swell clay
Roselms	Clayey lacustrine	7	Shrink-swell clay
St. Clair	Clayey lacustrine	7	Shrink-swell clay
Seward	Sandy deltaic over clayey lacustrine	7	Shrink-swell clay
Shinrock	Silty deltaic, lacustrine	4	Silt loam
Shoals	Alluvium	4	Silt loam
Sloan	Alluvium	4	Silt loam
Spinks	Beach, dune sand	9	Sand
Toledo	Clayey lacustrine	7	Shrink-swell clay
Tuscola	Silty deltaic, lacustrine	4	Silt loam
Wallkill	Peat, kettles	8	Peat

Topography

Topography, or percent slope, was evaluated using U.S.G.S. 7-1/2 minute quadrangle maps and the *Soil Survey of Williams County* (Stone et al., 1978). Slopes of 0 to 2 percent (10) and 2 to 6 percent (9) were selected for almost all of the settings for Williams County due to the overall flat lying to gently rolling topography and low relief. Slopes of 6 to 12 percent (5) were used for steeper crests along the Wabash Moraine.

Impact of the Vadose Zone Media

Information on evaluating vadose zone media was obtained from the maps and reports of Schmidt and Walker (1954), King (1977), Baggett (1987), Coen (1989), Haiker (1996), Kleinheider (1998), and Bennett and Williams (2002). The Open File Bedrock Reconnaissance Maps and Open File Bedrock Topography Maps, based upon U.S.G.S. 7-1/2 minute topographic maps from the ODNR, Division of Geological Survey proved helpful. Vadose zone ratings for Fulton County (Plymale, 1999 and Plymale et al., 2002) and Henry County (Miller, 1997 and Miller and Angle, 2002) were used as a guideline. The ODNR, Division of Water, Glacial State Aquifer Map and Bedrock State Aquifer Map were an important source of aquifer data. The *Soil Survey of Williams County* (Stone et al., 1978) provided valuable information on parent materials. The State Glacial Map (Goldthwait et al., 1961 and Pavey et al., 1999) was useful in delineating vadose zone media. Water well log records on file at the ODNR, Division of Water, were the primary source of aquifer information.

The vadose zone media is a critical component of the overall DRASTIC rating in Williams County. The rating varies with the restrictive properties of the various glacial materials. The higher the proportion of silt and clay and the greater the compaction (density) of the sediments, the lower the permeability and the lower the vadose zone media are rated.

Sand and gravel with Silt and Clay with ratings of (7) and (8) were selected as the vadose zone material for the coarser outwash deposits associated with the St. Joseph River. Sand and gravel with Silt and Clay with ratings of (6), (5), and (4) were used for somewhat finer-grained beach ridges and sand dunes, silty deltaic and lacustrine sediments, most floodplains and terraces, and some of the surficial outwash deposits associated with the Wabash Moraine.

Silt and Clay with a rating of (4) was used for the vadose zone media for most areas with clayey lacustrine sediments. Silt and Clay with a rating of (3) was used for areas with thicker sequences of clayey lacustrine sediments. Typically in

Williams County, sand and gravel lenses are encountered at greater depths in the lake plains area than in other portions of the county.

Glacial till with a rating of (6) is associated with areas of central Williams County containing higher-yielding wells. This zone roughly extends north from Bryan to Montpelier and to Pioneer. Tills in this area contain relatively numerous lenses and sheets of sand and gravel (King, 1977, Haiker, 1996, Bennett and Williams, 2002). These sand and gravel units, in conjunction with fractures, could prove to be an effective means for the migration of contaminants, at least into the shallower lenses. Till elsewhere in the county typically have ratings of (4) or (5). Miller (1997), in neighboring Henry County, suggested that the till, in thicker accumulations, is less likely to be weathered and fractured and tends to be more compacted (dense). Sand and gravel lenses are commonly encountered at greater depths and therefore the overlying till is thicker, in the eastern part of the county.

Water-modified till was chosen as the vadose zone material for areas within the lake plain where water modified till was the surficial material. These areas commonly have soils belonging to the Holtville-Nappanee Association (Stone et al., 1978). These areas are limited to the southeastern corner of the county and lie at elevations below 800 feet msl. Vadose zone ratings of (5), (4), and (3) were selected depending upon how thick the sequences of material were overlying sand and gravel lenses. Thinner water-modified till sequences are commonly more highly weathered and fractured.

Till was evaluated as a confining layer and given a rating of (1) for the 7Fb-Glacial Lake Deposits over Outwash setting which is limited to the boundary with Fulton County. The remainder of the county was evaluated as being under semi-confining or “leaky” aquifer conditions.

Hydraulic Conductivity

Information on evaluating the hydraulic conductivity was obtained from the maps and reports of King (1977), Baggett (1987), Coen (1989), Haiker (1996), Kleinheider (1998), and Bennett and Williams (2002). Values of hydraulic conductivity from neighboring Fulton County (Plymale, 1999 and Plymale et al., 2002) and Henry County (Miller, 1997 and Miller and Angle, 2002) were evaluated. Water well log records on file at the ODNR, Division of Water, were the primary source of aquifer information. Textbook tables (Freeze and Cherry, 1979, Fetter, 1980, and Driscoll, 1986) were useful in obtaining estimated values for hydraulic conductivity in a variety of sediments.

Values for hydraulic conductivity correspond to aquifer ratings; i.e., the more highly rated aquifers have higher values for hydraulic conductivity. The highest-yielding zone of glacial aquifers, which extends from Bryan to Pioneer in north central Williams County, was assigned a hydraulic conductivity of 1,000-2,000 gallons per day per foot squared (gpd/ft^2). Parts of the St. Joseph River Valley southwest of Montpelier were also given this rating of 1,000-2,000 gpd/ft^2 (8). These areas tended to contain the thickest, cleanest, coarsest, best-sorted sand and gravel deposits in the county. A hydraulic conductivity of 700-1,000 gpd/ft^2 (6) was assigned to aquifers associated with the Fort Wayne and Wabash End Moraines and portions of the St. Joseph River Valley. Hydraulic conductivity values of 300-700 gpd/ft^2 were selected for all of the remaining glacial aquifers that underlie ground moraine and lake plain areas.

All of the shale aquifers in southeastern Williams County were assigned a hydraulic conductivity rating of 1-100 gpd/ft^2 (1).

APPENDIX B

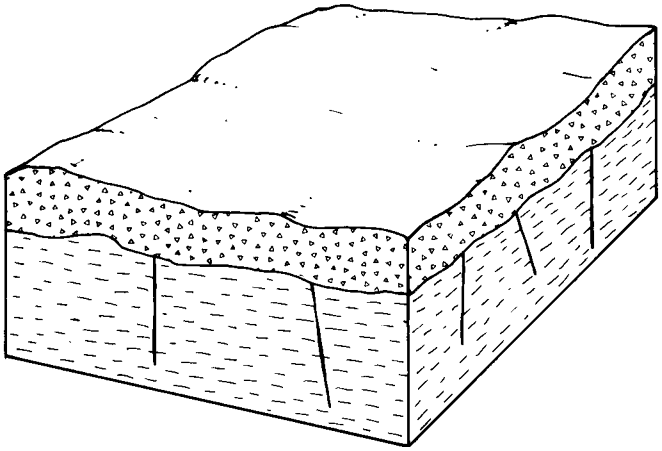
DESCRIPTION OF HYDROGEOLOGIC SETTINGS AND CHARTS

Ground water pollution potential mapping in Williams County resulted in the identification of 11 hydrogeologic settings within the Glaciated Central Region. The list of these settings, the range of pollution potential index calculations, and the number of index calculations for each setting are provided in Table 12. Computed pollution potential indexes for Williams County range from 66 to 183.

Table 12. Hydrogeologic settings mapped in Williams County, Ohio

Hydrogeologic Settings	Range of GWPP Indexes	Number of Index Calculations
7Ae - Glacial Till Over Shale	75-107	7
7Af – Sand+gravel Interbedded in Glacial Till	104-147	31
7Ba – Outwash	141-169	13
7C – Moraine	117-153	25
7D - Buried Valley	139-183	16
7Ea – River Alluvium with Overbank Deposits	102-121	4
7Ed - Alluvium Over Glacial Till	68-169	26
7F - Glacial Lake Plain Deposits	84-158	58
7Fb - Glacial Lake Deposits over Outwash	66-68	2
7H – Beaches, Beach Ridges and Sand Dunes	132-156	7
7I – Marches and Swamps	141-152	4

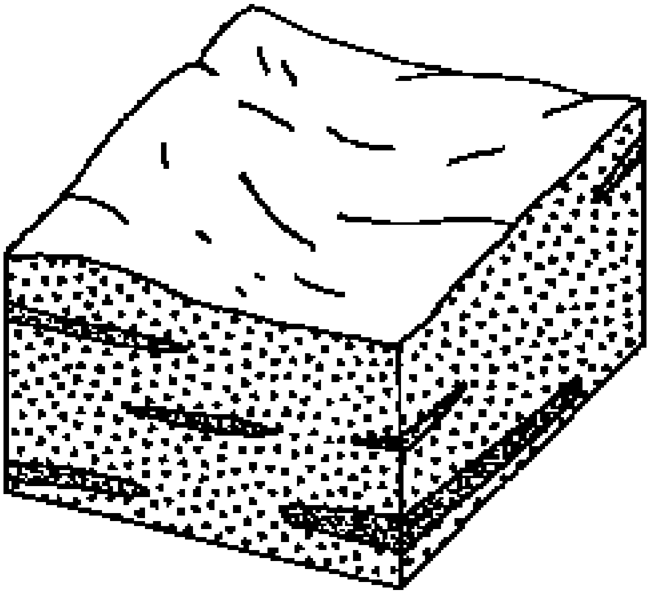
The following information provides a description of each hydrogeologic setting identified in the county, a block diagram illustrating the characteristics of the setting, and a listing of the charts for each unique combination of pollution potential indexes calculated for each setting. The charts provide information on how the ground water pollution potential index was derived and are a quick and easy reference for the accompanying ground water pollution potential map. A complete discussion of the rating and evaluation of each factor in the hydrogeologic settings is provided in Appendix A, Description of the Logic in Factor Selection.



7Ae-Glacial Till over Shale

This hydrogeologic setting is common in the southeastern corner of Williams County. The area is characterized by flat-lying topography and very low relief. The vadose zone is composed of loamy to clayey glacial till and clayey to silty lacustrine deposits. The till and clayey lacustrine sediments may be fractured or jointed, particularly in areas where it is predominantly thin and weathered. Depth to water is typically moderate to deep. Soils are generally shrink-swell (aggregated) clays. The aquifer is fractured, massive black Devonian-age shale. In some areas, wells are completed in thin lenses of dirty, shale–rich gravel that directly overly the shale. Yields from the shale are typically less than 5 gpm and range from 5 to 25 gpm for the shaley gravel lenses. Recharge is generally low due to the thick and clayey vadose zone and soils and the depth to water.

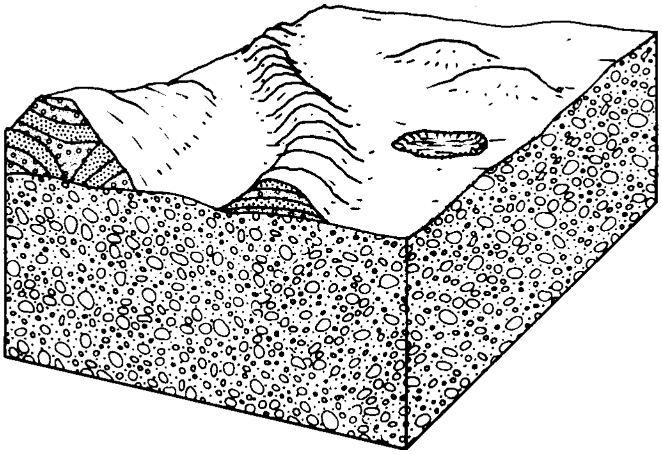
GWPP index values for the hydrogeologic setting of Glacial Till over Shale range from 75 to 107 with the total number of GWPP index calculations equaling 7.



7Af-Sand and gravel Interbedded in Glacial Till

This hydrogeologic setting is common and is associated with areas of ground moraine throughout Williams County. The area is characterized by flat-lying topography and very low relief. The vadose zone is composed of silty to clayey glacial till. The till may be fractured or jointed, particularly in areas where it is predominantly thin and weathered. Depth to water is usually shallow to moderate, averaging less than 60 feet. Soils are commonly clay loams. The aquifer consists of zones of lenses of sand and gravel interbedded in the glacial till. Ground water yields range up to 500 gpm for properly constructed, large diameter wells. Recharge is moderate to low due to the relatively shallow to moderate depth to water, flatter topography, and the relatively low permeability of the clayey soils and vadose materials.

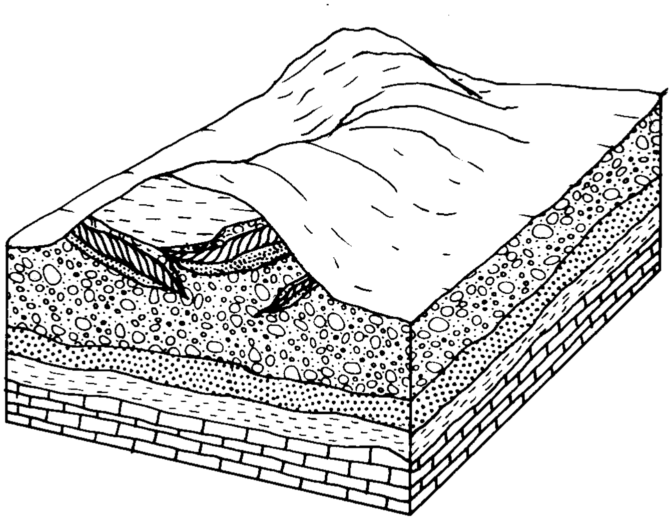
GWPP index values for the hydrogeologic setting of Sand and gravel Interbedded in Glacial Till range from 104 to 147 with the total number of GWPP index calculations equaling 31.



7Ba Outwash

This hydrogeologic setting consists of areas of outwash terraces flanking the St. Joseph River and kames and outwash deposits associated with the Wabash Moraine. This setting is characterized by flat-lying topography and low relief. The aquifer consists of relatively thick and continuous sand and gravel outwash deposits. These sand and gravel deposits tend to be shallower than in the neighboring 7D-Buried Valley and 7C-Moraine settings. Maximum yields range up to 500 gpm for properly constructed, large diameter wells. Test drilling may be necessary to locate higher-yielding areas. Vadose zone media consists of bedded sandy to gravelly outwash interbedded with varying thicknesses of glacial till. Depth to water is commonly shallow to moderate. Soils are usually sandy loams, gravel, or sand. Recharge is moderately high due to the relatively flat topography, relatively permeable soils and vadose media, and the shallow depth to water.

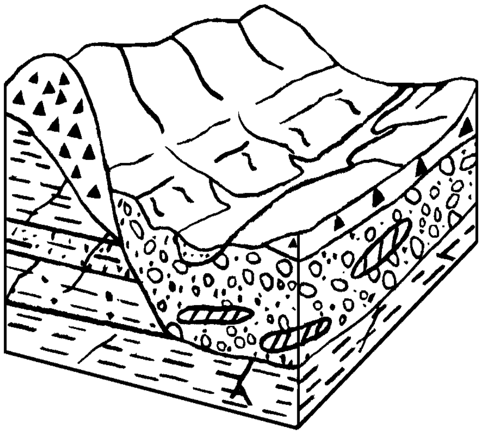
GWPP index values for the hydrogeologic setting of Outwash range from 141 to 169 with the total number of GWPP index calculations equaling 13.



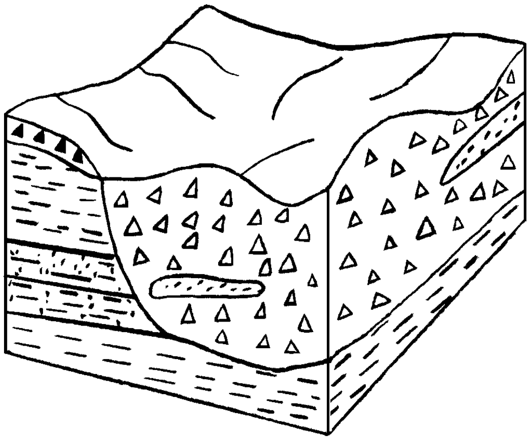
7C Moraine

This hydrogeologic setting consists of segments of the Wabash Moraine and Fort Wayne Moraine in central and northwestern Williams County. This setting is characterized by hummocky to rolling topography and low relief. The aquifer consists of relatively thick and continuous sand and gravel outwash deposits interbedded with glacial till underlying or within the moraine. These sand and gravel deposits are variable as to lateral extent and thickness and are found at variable depths. Maximum yields range up to 500 gpm. Test drilling may be necessary to locate higher-yielding areas. Vadose zone media consists of bedded sandy to gravelly outwash interbedded with varying thicknesses of glacial till. Depth to water is moderate and is a function of the thickness of the till overlying the sand and gravel lenses. Soils are commonly clay loams. Recharge is moderately high due to the proximity of sand and gravel lenses to the surface and the amount of weathering and fracturing in the till.

GWPP index values for the hydrogeologic setting of Moraine range from 117 to 153 with the total number of GWPP index calculations equaling 25.



a)



b)

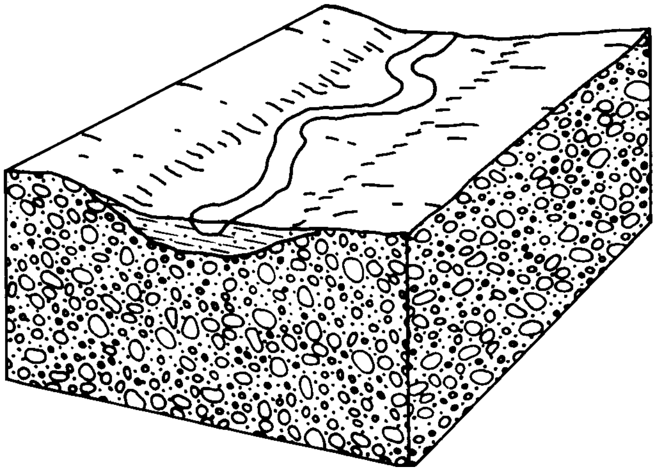
7D Buried Valleys

This hydrogeologic setting follows the St. Joseph River and some of its major tributaries through central and western Williams County. The low-lying terraces and floodplains adjacent to the river characterize the setting. There is also a small segment of a buried valley in the eastern margin of the county extending from Fulton County. This buried valley lacks surficial expression and is characterized by the overlying flat ground moraine. This eastern buried valley is not associated with a modern, overlying stream. Block diagram (a) characterizes the western, St. Joseph River buried valley and block diagram (b) represents the eastern, Fulton County buried valley.

In the buried valley underlying the St. Joseph River, depths to water are commonly shallow. Yields over 500 gpm are possible from properly developed, large diameter wells. Soils are variable depending upon whether the parent material is outwash terrace or finer-grained floodplain deposits. Vadose zone media consists of zones of clean sand and gravel lenses interbedded with finer-grained alluvial deposits and thin till. The overlying streams may be in direct hydraulic connection with the sand and gravel outwash in some areas. Recharge is typically high due to the shallow depth to water, flat topography, presence of nearby modern streams and the highly permeable soils, vadose, and aquifer materials.

In the eastern buried valley, depths to water are variable; they tend to be shallower to the west and deeper to the east. The aquifers are commonly deep and are composed of sand and gravel outwash that vary in thickness. Yields average 5 to 25 gpm with larger diameter wells yielding over 100 gpm from higher-producing zones. Vadose zone media consists of bedded sandy to gravelly outwash interbedded with glacial till with varying thickness. Soils are primarily shrink-swell clays and clay loams. Recharge is typically moderate to low due to the low permeability of the soils and vadose and the variable depth to water.

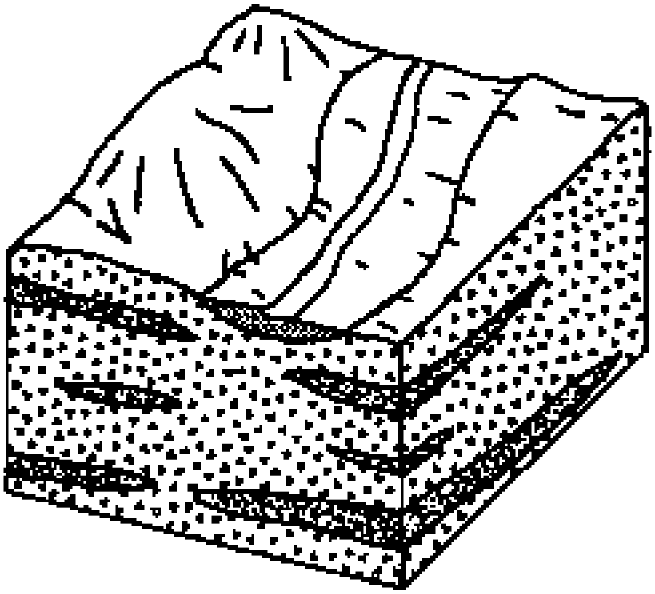
GWPP index values for the hydrogeologic setting of Buried Valley range from 139 to 183 with the total number of GWPP index calculations equaling 16.



7Ea-River Alluvium with Overbank Deposits

This hydrogeologic setting is associated with floodplains and terraces flanking the Tiffin River and its tributaries in the southeastern corner of the county. Relatively broad, flat-lying floodplains and low terraces characterize this setting. Vadose zone materials vary from clayey to silty floodplain deposits to sandy and loamy materials in the terraces. The setting is similar to the 7Ed Alluvium over Glacial Till except that wells are completed in shale bedrock instead of sand and gravel lenses interbedded in the glacial till. Yields vary from less than 5 gpm to 25 gpm. Soils are generally silt loams. The depth to water is typically shallow, averaging less than 30 feet. Depth to water typically increases in the headwaters of tributaries. Recharge is typically moderate due to shallow depth to water, flat topography, presence of nearby streams and low to moderate permeability soils and vadose zone materials.

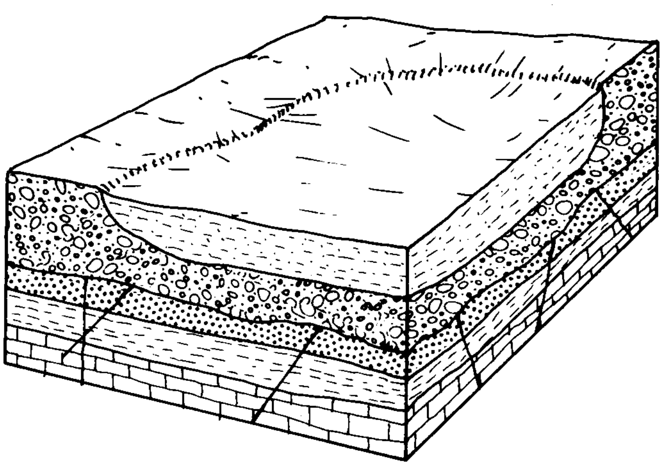
GWPP index values for the hydrogeologic setting of River Alluvium with Overbank Deposits range from 102 to 121 with the total number of GWPP index calculations equaling 4.



7Ed Alluvium Over Glacial Till

This hydrogeologic setting is comprised of flat-lying floodplains and stream terraces containing thin to moderate thicknesses of modern alluvium. This setting is similar to the 7Af–Sand and gravel interbedded in Glacial Till setting except for the presence of the modern stream and related deposits. The setting is similar to the 7Ea- River Alluvium with Overbank Deposits except that underlying sand and gravel is the aquifer as opposed to shale bedrock. This setting is relatively widespread through the county. The stream may or may not be in direct hydraulic connection with the underlying sand and gravel lenses, which constitute the aquifer. The surficial, silty alluvium is typically more permeable than the underlying till. The alluvium is too thin to be considered the aquifer. Soils are silt loams or sandy loams. Yields commonly range from 10 to 25 gpm from shallow sand and gravel lenses to greater than 100 gpm for properly constructed, large diameter wells. Depth to water is typically shallow with depths averaging less than 30 feet. Recharge is moderately high due to the shallow depth to water, flat-lying topography, and the moderate permeability of the glacial till and alluvium.

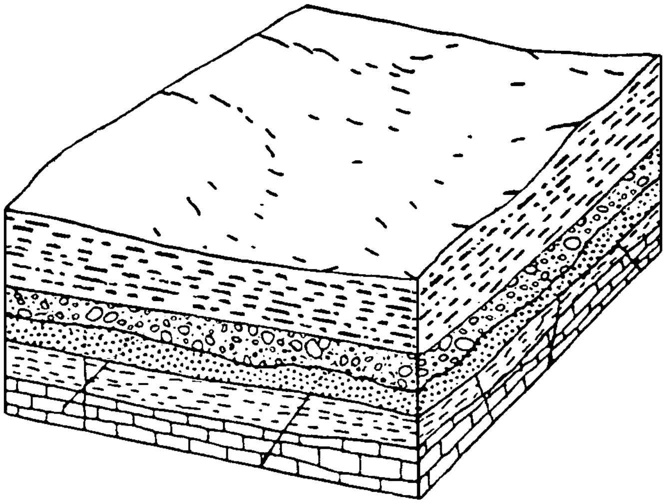
The GWPP index values for the hydrogeologic setting Alluvium Over Glacial Till range from 68 to 169 with the total number of GWPP index calculations equaling 26.



7F Glacial Lake Plain Deposits

This hydrogeologic setting is characterized by flat-lying topography and varying thicknesses of fine-grained lacustrine sediments. These sediments were deposited in lakes and deltas by a sequence of ancestral lakes. This setting is limited to the southeastern corner of Williams County. The vadose zone media consists of silty to clayey lacustrine sediments, silty deltaic sediments, or water-modified till that overlie glacial till. The aquifer consists of thin sand and gravel lenses interbedded in the underlying till and lacustrine sediments. If there is insufficient sand and gravel, wells are completed in the underlying shale. Yields are usually less than 5 gpm for the shale, 5 to 25 gpm for dirty, shale fragment-rich sand and gravel lenses and greater than 100 gpm for large diameter wells in cleaner, coarser sand and gravel. Depth to water is extremely variable depending upon the depth of the sand and gravel lenses. Depths are commonly shallow to moderate in the vicinity of the Tiffin River. Soils are shrink-swell (aggregated) clays or clay loams derived from clayey lacustrine sediments and water-modified till and silt loams and sandy loams derived from deltaic sediments. The presence of shrink-swell clay soils is important due to the fact that desiccation cracks in these soils form during prolonged dry spells. These cracks serve as conduits for contaminants to move through these normally low permeability soils. Recharge in this setting is low due to the relatively deep depth to water, flat-lying topography, and the low permeability soils and vadose.

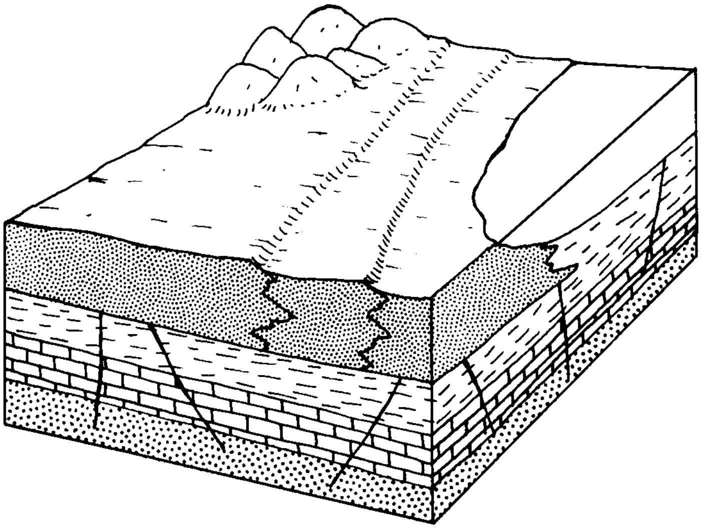
GWPP index values for the hydrogeologic setting of Glacial Lake Plains Deposits range from 84 to 158 with the total number of GWPP index calculations equaling 58.



7Fb Glacial Lake Deposits over Outwash

This hydrogeologic setting consists of a small area bordering Fulton County in which fine-grained lacustrine deposits overlie sand and gravel outwash. This setting is characterized by flat-lying topography and low relief and lies at elevations below the Fort Wayne Moraine. The aquifer consists of relatively thick and continuous sand and gravel outwash deposits. Yields average 10 to 25 gpm with maximum local yields over 100 gpm. Test drilling may be necessary to locate higher-yielding areas. Vadose zone media consists of thick clayey lacustrine sediments and underlying till. These materials are sufficiently thick to be considered a confining layer. This area historically has been known for flowing wells due to these confining conditions. Depth to water is considered to be the top of the aquifer due to the confining conditions. Soils are clay loams or silt loams. Recharge is very low due to the confining conditions.

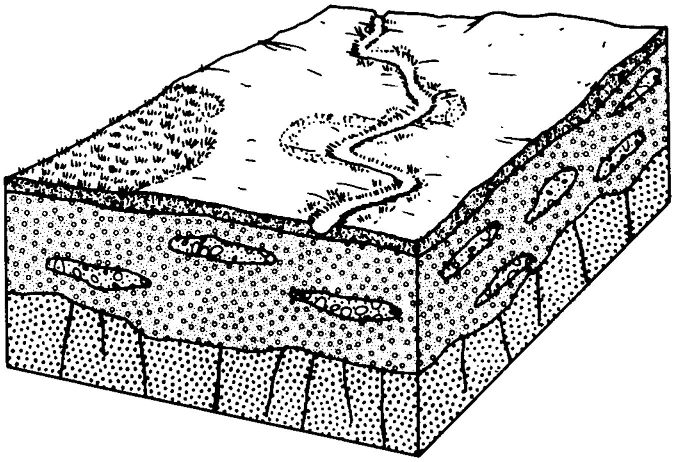
GWPP index values for the hydrogeologic setting of Glacial Lake Deposits over Outwash range from 66 to 68 with the total number of GWPP index calculations equaling 2.



7H-Beaches,Beach Ridge, and Sand Dunes

This hydrogeologic setting is characterized by narrow, elongate, low-lying ridges of sand overlying the lacustrine plain or wave-planed till uplands. This setting lies on the edge of the lake plain and roughly follows a line from Bryan to West Unity. The vadose zone media is composed of thin, clean, fine-grained quartz sand that has high permeability and low sorptive capability. These thin sands overlie clayey lacustrine deposits and water-modified till. Wells are completed in sand and gravel lenses interbedded with the underlying till. Depth to water is typically fairly shallow. Soils are gravel or sandy loams. Recharge is moderately high due to shallow depth to water and highly permeable soils and vadose material.

GWPP index values for the hydrogeologic setting of Beaches, Beach Ridges, and Sand Dunes range from 132 to 156 with the total number of GWPP index calculations equaling 7.



7I-Marshes and Swamps

This hydrogeologic setting is characterized by extremely low topographic relief, high water table, poor drainage, and thin, organic-rich silt and clay deposits. This setting is commonly associated with low depressional areas. These areas are commonly adjacent to areas of thin outwash found at the surface of the Wabash Moraine. In this setting, thin peat and organic-rich silt and clay deposits overlie gravel soils and vadose zone media. The aquifer is sand and gravel lenses that underlie the surface. Depth to water is very shallow due to the high water table. Recharge is high due to the shallow depth to water and relatively permeable vadose and aquifer.

The GWPP index values for the hydrogeologic setting of Swamps/Marshes range from 141 to 152 with the total number of GWPP index calculations equaling 4.

Table 13. Hydrogeologic Settings, DRASTIC Factors, and Ratings

Setting	Depth to Water	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating
7Ae1	30-50	2-4	shale	Shrink/Swell Clay	0-2	silt/clay	1-100	85	122
7Ae2	30-50	4-7	shale	Shrink/Swell Clay	0-2	till	1-100	107	142
7Ae3	50-75	4-7	shale	Shrink/Swell Clay	0-2	till	1-100	97	132
7Ae4	30-50	2-4	shale	Shrink/Swell Clay	0-2	till	1-100	95	130
7Ae5	50-75	2-4	shale	Shrink/Swell Clay	0-2	silt/clay	1-100	75	112
7Ae6	30-50	2-4	shale	Shrink/Swell Clay	2-6	silt/clay	1-100	84	119
7Ae7	15-30	2-4	shale	Shrink/Swell Clay	0-2	silt/clay	1-100	95	132
7Af01	15-30	4-7	sand+gravel	Shrink/Swell Clay	2-6	sand + gvl w/silt + clay	100-300	136	167
7Af02	30-50	4-7	sand+gravel	Shrink/Swell Clay	2-6	sand + gvl w/silt + clay	100-300	126	157
7Af03	15-30	4-7	sand+gravel	Clay Loam	0-2	till	100-300	129	150
7Af04	15-30	2-4	sand+gravel	Clay Loam	0-2	till	300-700	124	144
7Af05	30-50	2-4	sand+gravel	Clay Loam	0-2	till	300-700	114	134
7Af06	50-75	2-4	sand+gravel	Clay Loam	0-2	till	300-700	104	124
7Af07	15-30	4-7	sand+gravel	Shrink/Swell Clay	0-2	sand + gvl w/silt + clay	100-300	132	166
7Af08	15-30	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	300-700	138	161
7Af09	0-5	2-4	sand+gravel	Silty Loam	0-2	silt/clay	300-700	131	156
7Af10	0-5	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	300-700	137	171
7Af11	15-30	2-4	sand+gravel	Clay Loam	0-2	till	1000-2000	136	152
7Af12	30-50	2-4	sand+gravel	Clay Loam	0-2	till	1000-2000	126	142
7Af13	30-50	2-4	sand+gravel	Clay Loam	0-2	till	700-1000	120	138
7Af14	15-30	2-4	sand+gravel	Clay Loam	0-2	till	700-1000	130	148
7Af15	15-30	2-4	sand+gravel	Clay Loam	2-6	till	700-1000	129	145
7Af16	15-30	2-4	sand+gravel	Clay Loam	0-2	till	1000-2000	141	156
7Af17	30-50	2-4	sand+gravel	Clay Loam	0-2	till	1000-2000	131	146
7Af18	15-30	2-4	sand+gravel	Sandy Loam	0-2	till	1000-2000	147	171
7Af19	30-50	2-4	sand+gravel	Shrink/Swell Clay	0-2	sand + gvl w/silt + clay	700-1000	128	158
7Af20	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	sand + gvl w/silt + clay	1000-2000	144	172
7Af21	15-30	2-4	sand+gravel	Clay Loam	2-6	sand + gvl w/silt + clay	300-700	123	141
7Af22	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	till	300-700	127	160
7Af23	5-15	2-4	sand+gravel	Clay Loam	0-2	till	300-700	134	154

Setting	Depth to Water	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating
7Af24	30-50	2-4	sand+gravel	Shrink/Swell Clay	0-2	till	300-700	117	150
7Af25	30-50	2-4	sand+gravel	Peat	0-2	till	300-700	119	155
7Af26	30-50	2-4	sand+gravel	Sandy Loam	0-2	till	300-700	120	149
7Af27	15-30	2-4	sand+gravel	Sandy Loam	0-2	till	300-700	130	159
7Af28	15-30	2-4	sand+gravel	Clay Loam	2-6	sand + gvl w/silt + clay	700-1000	134	149
7Af29	15-30	4-7	sand+gravel	Clay Loam	0-2	sand + gvl w/silt + clay	700-1000	147	164
7Af30	15-30	2-4	sand+gravel	Silty Loam	0-2	till	300-700	126	149
7Af31	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	sand + gvl w/silt + clay	700-1000	133	164
7Ba01	15-30	4-7	sand+gravel	Shrink/Swell Clay	0-2	sand + gvl w/silt + clay	300-700	149	180
7Ba02	15-30	4-7	sand+gravel	Clay Loam	0-2	sand + gvl w/silt + clay	300-700	141	160
7Ba03	15-30	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	1000-2000	159	183
7Ba04	15-30	4-7	sand+gravel	Gravel	0-2	sand + gvl w/silt + clay	1000-2000	167	203
7Ba05	5-15	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	1000-2000	165	183
7Ba06	15-30	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	700-1000	153	179
7Ba07	30-50	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	700-1000	143	169
7Ba08	15-30	4-7	sand+gravel	Sandy Loam	2-6	sand + gvl w/silt + clay	1000-2000	158	180
7Ba09	5-15	4-7	sand+gravel	Sandy Loam	2-6	sand + gvl w/silt + clay	700-1000	162	186
7Ba10	5-15	4-7	sand+gravel	Peat	0-2	sand + gvl w/silt + clay	700-1000	157	191
7Ba11	30-50	4-7	sand+gravel	Sand	2-6	sand + gvl w/silt + clay	700-1000	148	181
7Ba12	15-30	7-10	sand+gravel	Gravel	0-2	sand + gvl w/silt + clay	700-1000	169	207
7Ba13	15-30	4-7	sand+gravel	Gravel	0-2	sand + gvl w/silt + clay	700-1000	161	199
7C01	50-75	4-7	sand+gravel	Shrink/Swell Clay	0-2	till	300-700	124	156
7C02	30-50	4-7	sand+gravel	Clay Loam	2-6	till	700-1000	131	147
7C03	15-30	4-7	sand+gravel	Clay Loam	2-6	till	700-1000	141	157
7C04	15-30	4-7	sand+gravel	Clay Loam	0-2	till	700-1000	142	160
7C05	30-50	4-7	sand+gravel	Clay Loam	0-2	till	700-1000	132	150
7C06	30-50	4-7	sand+gravel	Loam	0-2	till	700-1000	136	160
7C07	30-50	4-7	sand+gravel	Shrink/Swell Clay	0-2	till	700-1000	135	166
7C08	15-30	4-7	sand+gravel	Clay Loam	0-2	till	1000-2000	153	168
7C09	30-50	4-7	sand+gravel	Clay Loam	0-2	till	1000-2000	143	158

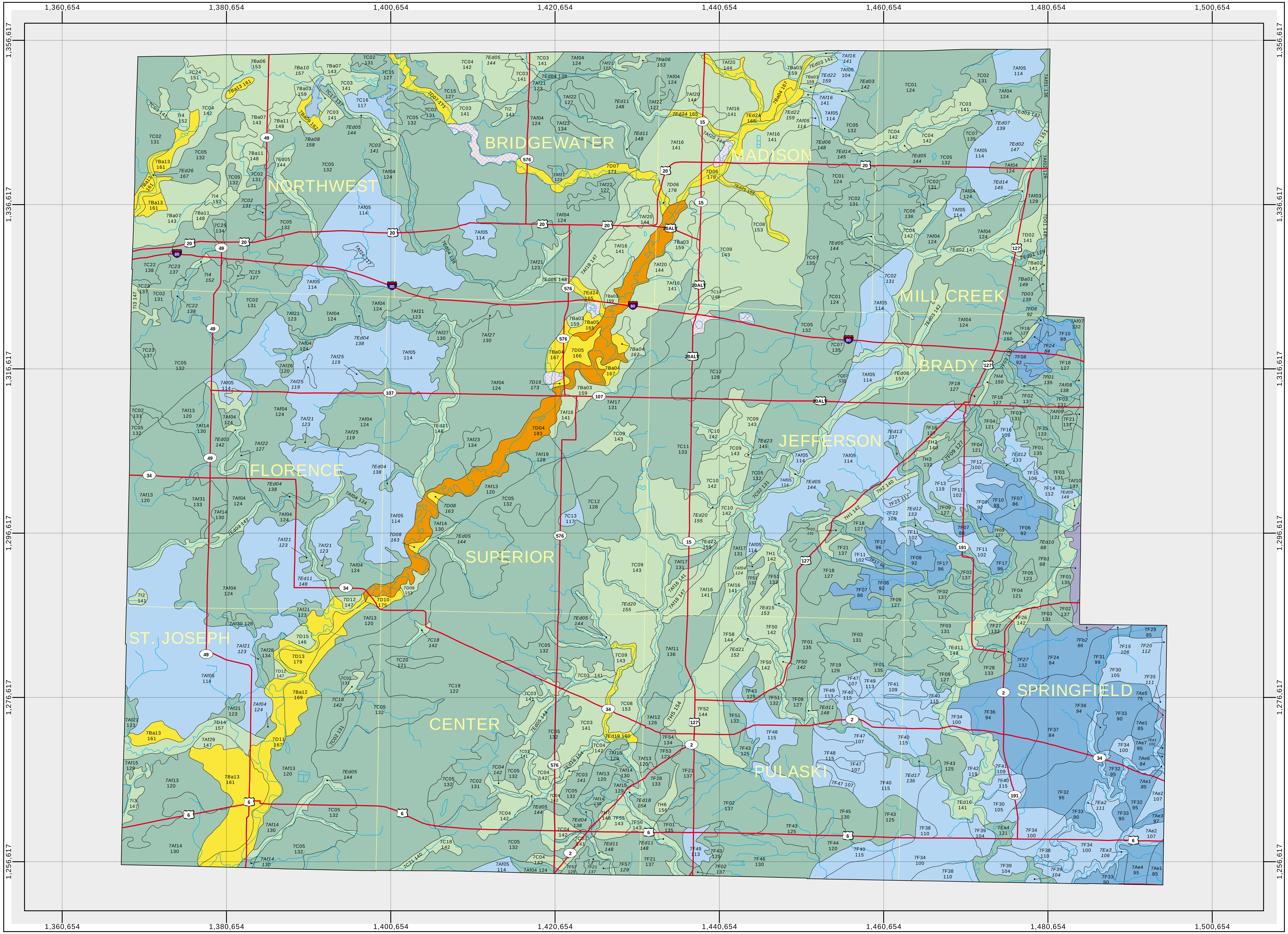
Setting	Depth to Water	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating
7C10	30-50	4-7	sand+gravel	Clay Loam	2-6	till	1000-2000	142	155
7C11	50-75	4-7	sand+gravel	Clay Loam	0-2	till	1000-2000	133	148
7C12	75-100	4-7	sand+gravel	Clay Loam	0-2	till	1000-2000	128	143
7C13	75-100	4-7	sand+gravel	Clay Loam	0-2	till	700-1000	117	135
7C14	30-50	4-7	sand+gravel	Peat	0-2	till	1000-2000	148	179
7C15	30-50	4-7	sand+gravel	Clay Loam	6-12	till	700-1000	127	135
7C16	50-75	4-7	sand+gravel	Clay Loam	6-12	till	700-1000	117	125
7C17	15-30	4-7	sand+gravel	Clay Loam	6-12	till	700-1000	137	145
7C18	30-50	4-7	sand+gravel	Peat	0-2	till	700-1000	142	175
7C19	50-75	4-7	sand+gravel	Clay Loam	0-2	till	700-1000	122	140
7C20	50-75	4-7	sand+gravel	Clay Loam	2-6	till	700-1000	121	137
7C21	30-50	4-7	sand+gravel	Shrink/Swell Clay	0-2	till	700-1000	140	170
7C22	30-50	4-7	sand+gravel	Sandy Loam	0-2	till	700-1000	138	165
7C23	30-50	4-7	sand+gravel	Sandy Loam	2-6	till	700-1000	137	162
7C24	5-15	4-7	sand+gravel	Clay Loam	2-6	till	700-1000	151	167
7C25	30-50	4-7	sand+gravel	Silty Loam	0-2	till	700-1000	134	155
7D01	15-30	4-7	sand+gravel	Shrink/Swell Clay	2-6	sand + gvl w/silt + clay	300-700	148	177
7D02	15-30	4-7	sand+gravel	Clay Loam	0-2	sand + gvl w/silt + clay	300-700	141	160
7D03	15-30	4-7	sand+gravel	Shrink/Swell Clay	2-6	sand + gvl w/silt + clay	100-300	139	170
7D04	5-15	7-10	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	1000-2000	183	199
7D05	15-30	7-10	sand+gravel	Clay Loam	0-2	sand + gvl w/silt + clay	1000-2000	166	180
7D06	5-15	7-10	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	1000-2000	178	195
7D07	5-15	7-10	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	700-1000	171	197
7D08	5-15	4-7	sand+gravel	Clay Loam	0-2	sand + gvl w/silt + clay	1000-2000	163	178
7D09	15-30	4-7	sand+gravel	Clay Loam	0-2	sand + gvl w/silt + clay	1000-2000	153	168
7D10	15-30	7-10	sand+gravel	Gravel	0-2	sand + gvl w/silt + clay	1000-2000	175	211
7D11	5-15	7-10	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	700-1000	167	187
7D12	15-30	4-7	sand+gravel	Clay Loam	0-2	sand + gvl w/silt + clay	700-1000	147	164
7D13	5-15	7-10	sand+gravel	Gravel	0-2	sand + gvl w/silt + clay	700-1000	179	217
7D14	15-30	7-10	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	700-1000	157	177
7D15	15-30	4-7	sand+gravel	Clay Loam	2-6	sand + gvl w/silt + clay	700-1000	146	161
7D16	15-30	7-10	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	1000-2000	173	189

Setting	Depth to Water	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating
7Ea1	30-50	4-7	shale	Loam	2-6	sand + gvl w/silt + clay	1-100	102	129
7Ea2	15-30	4-7	shale	Silty Loam	0-2	sand + gvl w/silt + clay	1-100	111	137
7Ea3	15-30	4-7	shale	Silty Loam	0-2	silt/clay	1-100	106	133
7Ea4	5-15	4-7	shale	Silty Loam	0-2	silt/clay	1-100	121	147
7Ed01	15-30	4-7	sand+gravel	Silty Loam	2-6	sand + gvl w/silt + clay	300-700	129	151
7Ed02	15-30	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	300-700	147	175
7Ed03	15-30	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	300-700	142	171
7Ed04	15-30	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	300-700	138	161
7Ed05	15-30	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	700-1000	144	165
7Ed06	15-30	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	700-1000	148	175
7Ed07	15-30	4-7	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	300-700	139	172
7Ed08	5-15	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	300-700	157	185
7Ed09	0-5	4-7	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	300-700	149	183
7Ed10	100+	0-2	sand+gravel	Silty Loam	0-2	confining	300-700	68	95
7Ed11	5-15	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	300-700	148	171
7Ed12	15-30	4-7	sand+gravel	Silty Loam	0-2	silt/clay	300-700	133	157
7Ed13	15-30	4-7	sand+gravel	Sandy Loam	0-2	silt/clay	300-700	137	167
7Ed14	15-30	4-7	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	700-1000	145	176
7Ed15	5-15	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	300-700	153	175
7Ed16	5-15	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	100-300	141	165
7Ed17	5-15	4-7	sand+gravel	Silty Loam	0-2	silt/clay	100-300	136	161
7Ed18	5-15	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	700-1000	154	175
7Ed19	5-15	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	1000-2000	160	179
7Ed20	15-30	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	1000-2000	155	173
7Ed21	5-15	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	300-700	152	181
7Ed22	15-30	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	1000-2000	159	183
7Ed23	30-50	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	1000-2000	145	163
7Ed24	5-15	4-7	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	1000-2000	165	183

Setting	Depth to Water	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating
7Ed25	5-15	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	1000-2000	169	193
7Ed26	5-15	7-10	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	700-1000	167	187
7F01	5-15	2-4	sand+gravel	Sandy Loam	0-2	silt/clay	300-700	135	165
7F02	5-15	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	300-700	137	170
7F03	5-15	2-4	sand+gravel	Silty Loam	0-2	silt/clay	300-700	131	155
7F04	15-30	2-4	sand+gravel	Silty Loam	0-2	silt/clay	300-700	121	145
7F05	15-30	2-4	sand+gravel	Loam	0-2	silt/clay	300-700	123	150
7F06	100+	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	300-700	92	126
7F07	100+	2-4	sand+gravel	Silty Loam	0-2	silt/clay	300-700	86	111
7F08	100+	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	300-700	92	126
7F09	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	300-700	127	160
7F10	100+	2-4	sand+gravel	Loam	0-2	silt/clay	300-700	88	116
7F11	50-75	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	300-700	102	136
7F12	50-75	2-4	sand+gravel	Sandy Loam	0-2	silt/clay	300-700	100	131
7F13	15-30	2-4	sand+gravel	Clay Loam	0-2	water-modified till	300-700	119	140
7F14	30-50	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	300-700	112	146
7F15	30-50	2-4	sand+gravel	Silty Loam	0-2	silt/clay	300-700	106	131
7F16	30-50	2-4	sand+gravel	Loam	0-2	silt/clay	300-700	108	136
7F17	50-75	2-4	sand+gravel	Silty Loam	0-2	silt/clay	300-700	96	121
7F18	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	300-700	127	160
7F19	5-15	2-4	sand+gravel	Clay Loam	0-2	silt/clay	300-700	129	150
7F20	30-50	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	300-700	112	146
7F21	5-15	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	300-700	137	170
7F22	30-50	2-4	sand+gravel	Clay Loam	0-2	water-modified till	300-700	109	130
7F23	30-50	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	300-700	117	150
7F24	100+	2-4	sand+gravel	Clay Loam	0-2	silt/clay	300-700	84	106
7F25	5-15	2-4	sand+gravel	Loam	0-2	silt/clay	300-700	133	160
7F26	5-15	2-4	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	700-1000	142	163
7F27	15-30	2-4	sand+gravel	Silty Loam	0-2	sand + gvl w/silt + clay	700-1000	132	153
7F28	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	700-1000	133	164
7F29	30-50	2-4	shale	Shrink/Swell Clay	0-2	silt/clay	1-100	85	122

Setting	Depth to Water	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating
7F30	30-50	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	100-300	105	140
7F31	30-50	2-4	sand+gravel	Silty Loam	0-2	silt/clay	100-300	99	125
7F32	30-50	2-4	shale	Shrink/Swell Clay	0-2	water-modified till	1-100	95	130
7F33	30-50	2-4	shale	Shrink/Swell Clay	0-2	silt/clay	1-100	90	126
7F34	15-30	2-4	shale	Shrink/Swell Clay	0-2	silt/clay	1-100	100	136
7F35	30-50	2-4	sand+gravel	Shrink/Swell Clay	2-6	silt/clay	300-700	111	143
7F36	15-30	2-4	shale	Silty Loam	0-2	silt/clay	1-100	94	121
7F37	30-50	2-4	shale	Silty Loam	0-2	silt/clay	1-100	84	111
7F38	5-15	2-4	shale	Shrink/Swell Clay	0-2	silt/clay	1-100	110	146
7F39	5-15	2-4	shale	Silty Loam	0-2	silt/clay	1-100	104	131
7F40	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	100-300	115	150
7F41	15-30	2-4	sand+gravel	Silty Loam	0-2	silt/clay	100-300	109	135
7F42	5-15	2-4	sand+gravel	Silty Loam	0-2	silt/clay	100-300	119	145
7F43	5-15	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	100-300	125	160
7F44	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	100-300	120	154
7F45	5-15	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	100-300	130	164
7F46	0-5	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	100-300	130	165
7F47	15-30	2-4	sand+gravel	Clay Loam	0-2	water-modified till	100-300	107	130
7F48	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	100-300	115	150
7F49	15-30	2-4	sand+gravel	Sandy Loam	0-2	silt/clay	100-300	113	145
7F50	5-15	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	300-700	142	174
7F51	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	300-700	132	164
7F52	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	1000-2000	144	172
7F53	30-50	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	700-1000	123	154
7F54	30-50	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	1000-2000	134	162
7F55	5-15	2-4	sand+gravel	Shrink/Swell Clay	0-2	water-modified till	700-1000	143	174
7F56	5-15	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	700-1000	143	174
7F57	5-15	2-4	sand+gravel	Clay Loam	0-2	water-modified till	300-700	129	150
7F58	15-30	2-4	sand+gravel	Shrink/Swell Clay	0-2	silt/clay	1000-2000	144	172
7Fb1	100+	0-2	sand+gravel	Silty Loam	0-2	confining	300-700	68	95

Setting	Depth to Water	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating
7Fb2	100+	0-2	sand+gravel	Clay Loam	0-2	confining	300-700	66	90
7H1	15-30	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	300-700	142	171
7H2	30-50	4-7	sand+gravel	Gravel	0-2	sand + gvl w/silt + clay	300-700	140	181
7H3	30-50	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	300-700	132	161
7H4	15-30	4-7	sand+gravel	Gravel	0-2	sand + gvl w/silt + clay	300-700	150	191
7H5	15-30	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	1000-2000	154	179
7H6	15-30	4-7	sand+gravel	Gravel	0-2	sand + gvl w/silt + clay	700-1000	156	195
7H7	15-30	4-7	sand+gravel	Sandy Loam	0-2	sand + gvl w/silt + clay	700-1000	148	175
7I1	15-30	4-7	sand+gravel	Peat	0-2	sand + gvl w/silt + clay	300-700	151	185
7I2	15-30	4-7	sand+gravel	Peat	0-2	sand + gvl w/silt + clay	300-700	141	177
7I3	15-30	4-7	sand+gravel	Peat	0-2	sand + gvl w/silt + clay	700-1000	147	181
7I4	15-30	4-7	sand+gravel	Peat	0-2	sand + gvl w/silt + clay	700-1000	152	185



Ground Water Pollution Potential of Williams County

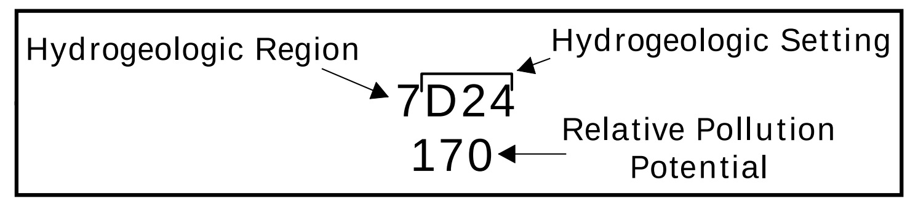
by

Mike Angle, Brad Ziss, and Cory Bonifas

Ground Water Pollution Potential maps are designed to evaluate the susceptibility of ground water to contamination from surface sources. These maps are based on the DRASTIC system developed for the USEPA (Aller et al., 1987). The DRASTIC system consists of two major elements: the designation of mappable units, termed hydrogeologic settings, and a relative rating system for determining the ground water pollution potential within a hydrogeologic setting. The application of DRASTIC to an area requires the recognition of a set of assumptions made in the development of the system. The evaluation of pollution potential of an area assumes that a contaminant with the mobility of water is introduced at the surface and is flushed into the ground water by precipitation. DRASTIC is not designed to replace specific on-site investigations.

In DRASTIC mapping, hydrogeologic settings form the basis of the system and incorporate the major hydrogeologic factors that affect and control ground water movement and occurrence. The relative rating system is based on seven hydrogeologic factors: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone media, and hydraulic Conductivity. These factors form the acronym DRASTIC. The relative rating system uses a combination of weights and ratings to produce a numerical value called the ground water pollution potential index. Higher index values indicate higher susceptibility to ground water contamination. Polygons (outlined in black on the map at left) are regions where the hydrogeologic setting and the pollution potential index are combined to create a mappable unit wtih specific hydrogeologic characteristics, which determine the region's relative vulnerability to contamination. Additional information on the DRASTIC system, hydrogeologic settings, ratings, and weighting factors is included in the report.

Description of Map Symbols



Legend

Colors are used to depict the ranges in the pollution potential indexes shown below. Warm colors (red, orange, yellow) represent areas of higher vulnerability (higher pollution potential indexes), while cool colors (green, blue, violet) represent areas of lower vulnerability to contamination (lower pollution potential indexes).

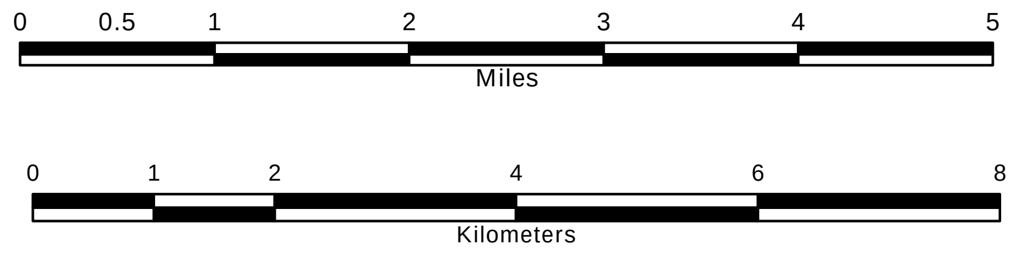
- Roads
- Streams
- Lakes
- Townships

<u>Index Ranges</u>

- ▨ Not Rated
- 🟪 Less Than 79
- 🟦 80 - 99
- 🟦 100 - 119
- 🟩 120 - 139
- 🟩 140 - 159
- 🟨 160 - 179
- 🟧 180 - 199
- 🟥 Greater Than 200

N

Black grid represents the State Plane South Coordinate System (NAD27, feet).



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