GROUND WATER POLLUTION POTENTIAL OF PAULDING COUNTY, OHIO

BY

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ABSTRACT

A ground water pollution potential map of Paulding 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 incorporate hydrogeologic factors that 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 Paulding County resulted in a map with symbols and colors, which illustrate areas of varying ground water pollution potential indexes ranging from 105 to 158.

Paulding County lies entirely within the Glaciated Central hydrogeologic setting. Limestones and dolomites of the Devonian System and Silurian System compose the aquifer for all but the northern fringe of the county. Yields in the uppermost carbonate aquifers range from 5 to 100 gallons per minute (gpm) for most of the county. Yields over 100 gpm are possible from large diameter wells drilled deep into the limestone for almost the entire county. Shale of the Devonian System composes the aquifer in limited areas of the northern fringe of the county. Yields from the shale are poor, typically yielding less than 5 gpm.

Sand and gravel lenses interbedded in the glacial till locally serve as aquifers throughout the northern edge of the county. The sand and gravel lenses may lie directly on top of the shale or limestone bedrock and serve as the aquifer or provide additional recharge to the underlying bedrock. The sand and gravel lenses are utilized more frequently by wells in areas where the underlying bedrock is low-yielding shale instead of the higher-yielding limestones and dolomite. The sand and gravel lenses become relatively thick and more laterally extensive in the northwestern corner of the county.

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 Paulding 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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INTRODUCTION

The need for protection and management of ground water resources in Ohio has been clearly recognized. Approximately 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; 3,900 of these wells exist in Paulding 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 remediation 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 Paulding 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 Paulding 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

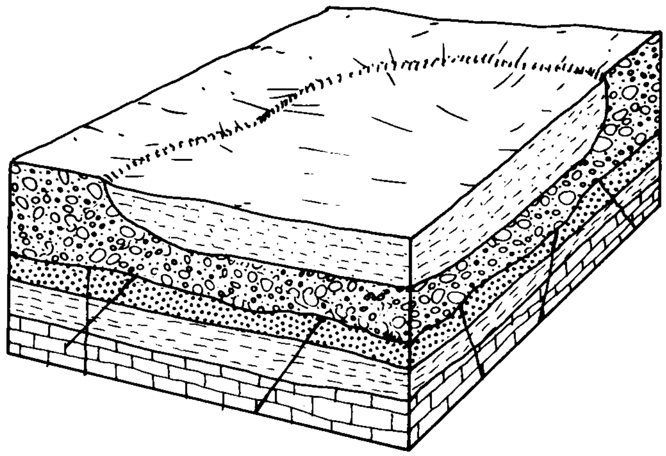
These factors incorporate concepts and mechanisms such as attenuation, retardation, and time or distance of travel of a contaminant with respect to the physical characteristics of the hydrogeologic setting. Broad consideration of these factors and mechanisms coupled with existing conditions in a setting 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 reaching the land surface 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.

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.



<u>7F Glacial Lake Plain Deposits</u>

This hydrogeologic setting occupies most of eastern, central, and northern Paulding County and is characterized by flat-lying topography and varying thickness of fine-grained lacustrine sediments. These sediments were deposited by a sequence of ancestral lakes. The vadose zone media consists of clayey lacustrine sediments that overlie glacial till. Wells in most of the county are completed in the underlying Silurian and Devonian limestone and dolomite. Maximum ground water yields greater than 100 gpm are possible from the Silurian Lockport, Tymochtee, Greenfield and Salina Groups. Along the northern edge of the county, wells may be completed in sand and gravel lenses or in shale bedrock. Yields from the sand and gravel lenses range from 5 to 25 gpm for the eastern part of this zone to 25 to 50 gpm for the extreme northwestern corner of the county. Yields from the Devonian Antrim Shale are poor, averaging less than 5 gpm. Depth to water is variable and seems to be dependent upon the overall thickness of the glacial drift and the depth to the aquifer in which the wells are completed. Soils are shrink-swell (aggregated) clays. The presence of shrink-swell clay soils is important; 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. The vadose zone is comprised of fine-grained lacustrine sediments overlying till in some areas. Recharge in this setting is moderate to low depending upon the depth to water and the thickness of the fine-grained lacustrine sediments and till.

The GWPP index values for the hydrogeologic setting of Glacial Lake Plains Deposits range from 105 to 152, with the total number of GWPP index calculations equaling 14.

Figure 1. Format and description of the hydrogeologic setting – 7F Glacial Lake Plain Deposits.

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/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	

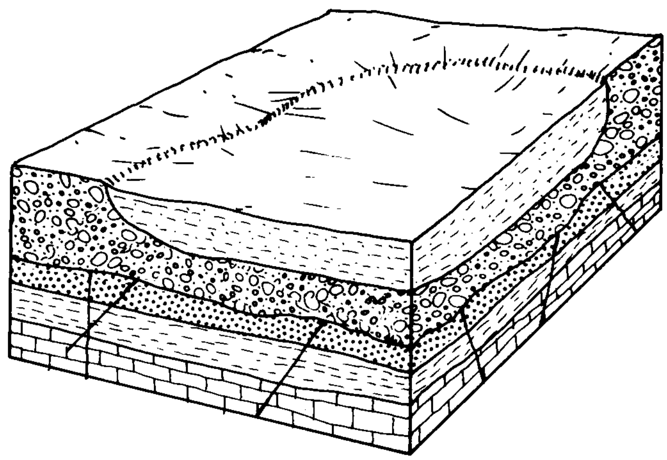
Table 8. Ranges and ratings for hydraulic conductivity

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 7F1, Glacial Lake Plain Deposits, identified in mapping Paulding 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 146. 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 Paulding County produces settings with a wide range of vulnerability to ground water contamination. Calculated pollution potential indexes for the five settings identified in the county range from 105 to 158.

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 Paulding 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 Paulding County is included with this report.



SETTING 7F1		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Limestone	3	7	21
Soil Media	Shrink-swell Clay	2	7	14
Topography	0-2%	1	10	10
Impact of Vadose Zone	Silt and Clay	5	4	20
Hydraulic Conductivity	300-700	3	4	12
		DRASTIC	INDEX	146

Figure 2. Description of the hydrogeologic setting – 7F1 Glacial Lake Plain Deposits.

INTERPRETATION AND USE OF GROUND WATER POLLUTION POTENTIAL MAPS

The application of the DRASTIC system to evaluate an aquifer's vulnerability to contamination produces hydrogeologic settings with corresponding pollution potential indexes. The susceptibility to contamination is greater as the pollution potential index increases. 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:

7F1 - defines the hydrogeologic region and setting
146 - defines the relative pollution potential

The first number (**7**) refers to the major hydrogeologic region and the upper case letter (**F**) 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 (**146**) 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. The maps also delineate large man-made and natural features such as lakes, landfills, quarries, and strip mines, but these areas are not rated and therefore are not color-coded.

GENERAL INFORMATION ABOUT PAULDING COUNTY

Demographics

Paulding County occupies approximately 419 square miles (Feusner et al., 2005) in northwestern Ohio (Figure 3). Paulding County is bounded to the north by Defiance County, to the east by Putnam County, to the south by Van Wert County and to the west by Allen County, Indiana.

The approximate population of Paulding County, based upon year 2004 estimates, is 19,486 (Department of Development, Ohio County Profiles, 2005). Paulding Village is the largest community and the county seat. Agriculture accounts for roughly 93 percent of the land usage in Paulding County. Row crops are the primary agricultural land usage. Woodlands, 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.

Climate

The *Hydrologic Atlas for Ohio* (Harstine, 1991) reports an average annual temperature of approximately 50 degrees Fahrenheit for Paulding County. Harstine (1991) shows that precipitation approximately ranges from an average of 35 inches per year for the southern part of the county to an average of 34 inches per year for the northern part of the county. The mean annual precipitation for Paulding Village is 34.44 inches per year based upon a thirty-year (1971-2000) period (National Oceanographic and Atmospheric Administration (NOAA), 2002). The mean annual temperature at Paulding Village for the same thirty-year period is 48.1 degrees Fahrenheit (NOAA, 2002).

Physiography and Topography

All of Paulding County lies within the Lake Plains Province (Frost, 1931; Fenneman, 1938, and Bier, 1956). Brockman (1998) and Schiefer (2002) depict the western half of Paulding County as belonging to the Maumee Lake Plains, and the eastern half of the county as being in the Paulding Clay Bottom section of the Maumee Lake Plains. The Paulding Clay Bottom was believed to be the deepest portion of the ancestral Lake Maumee basin and is characterized by exceptionally clayey, flat-lying sediments. All of Paulding County is characterized by very flat, lake plain topography. Portions of the flat-lying lake plain are comprised of ground moraine that was heavily wave-eroded.

Figure 3. Location map of Paulding County, Ohio.

Modern Drainage

Paulding County lies north of the major drainage divide crossing north central Ohio; all of Paulding County drains toward Lake Erie. The entire county except for the northwestern corner drains into either tributaries of the Auglaize River or the Auglaize River itself. Major tributaries from east to west include the Little Auglaize River, Dog Creek, Town Creek, Maddox Creek, Hoaglin Creek, Hagerman Creek, Prairie Creek, Blues Creek, and Flatrock Creek. The northwestern corner of the county, in the vicinity of Antwerp, drains into either the Maumee River or its tributaries.

Pre- and Inter-Glacial Drainage Changes

The drainage patterns of Paulding County have changed significantly as a result of the multiple glaciations. The drainage changes are complex and not yet fully understood. More research and data are necessary in both Paulding County and adjacent counties. Particularly, well log data for deeper wells that penetrate the entire drift thickness would be helpful in making interpretations. This would allow a more accurate reconstruction of the system of buried valleys and former drainage channels for the county.

Prior to glaciation, the drainage in Ohio is referred to as the Teays Stage. The Teays River drained the southern and western two thirds of the state and was the master stream for what is now the upper Ohio River Valley. The Teays River ran to the south of Paulding County, extending across northern Mercer County. Stout et al. (1943) shows a rough divide running through eastern Paulding County (see Figure 4). Drainage in western Paulding County was to the west, towards westerly-flowing tributaries of the Teays River in Indiana (Stout et al., 1943). Drainage in the eastern part of Paulding County was to the northeast, perhaps towards an ancestor of the Maumee River referred to as the Napoleon River.

As ice advanced through Ohio during the pre-Illinoian (Kansan) glaciations, drainage ways to the north and west were blocked. The pre-existing channels and valleys created by the Teays River drainage system were overrun by the advancing glaciers and filled with glacial till from the advancing ice sheets. Subsequent ice advances during the Illinoian and Wisconsinan ice advances further filled these former channels. These sediment-filled ancestral valleys are referred to as buried valleys. Modern bedrock topography data (Open File Bedrock Topography Maps, ODNR, Division of Geological Survey) does not show any major buried valley systems underlying Paulding County. Buried valleys representing major tributaries of the Teays River lie to the south in Van Wert County and Allen County.

Slowly the drainage patterns of Paulding County evolved and drainage shifted towards the north and east during ice-free intervals. The modern drainage reflects the nature of landforms deposited during, and immediately following, the Wisconsinan advances, particularly the lake plain associated with Lake Maumee.

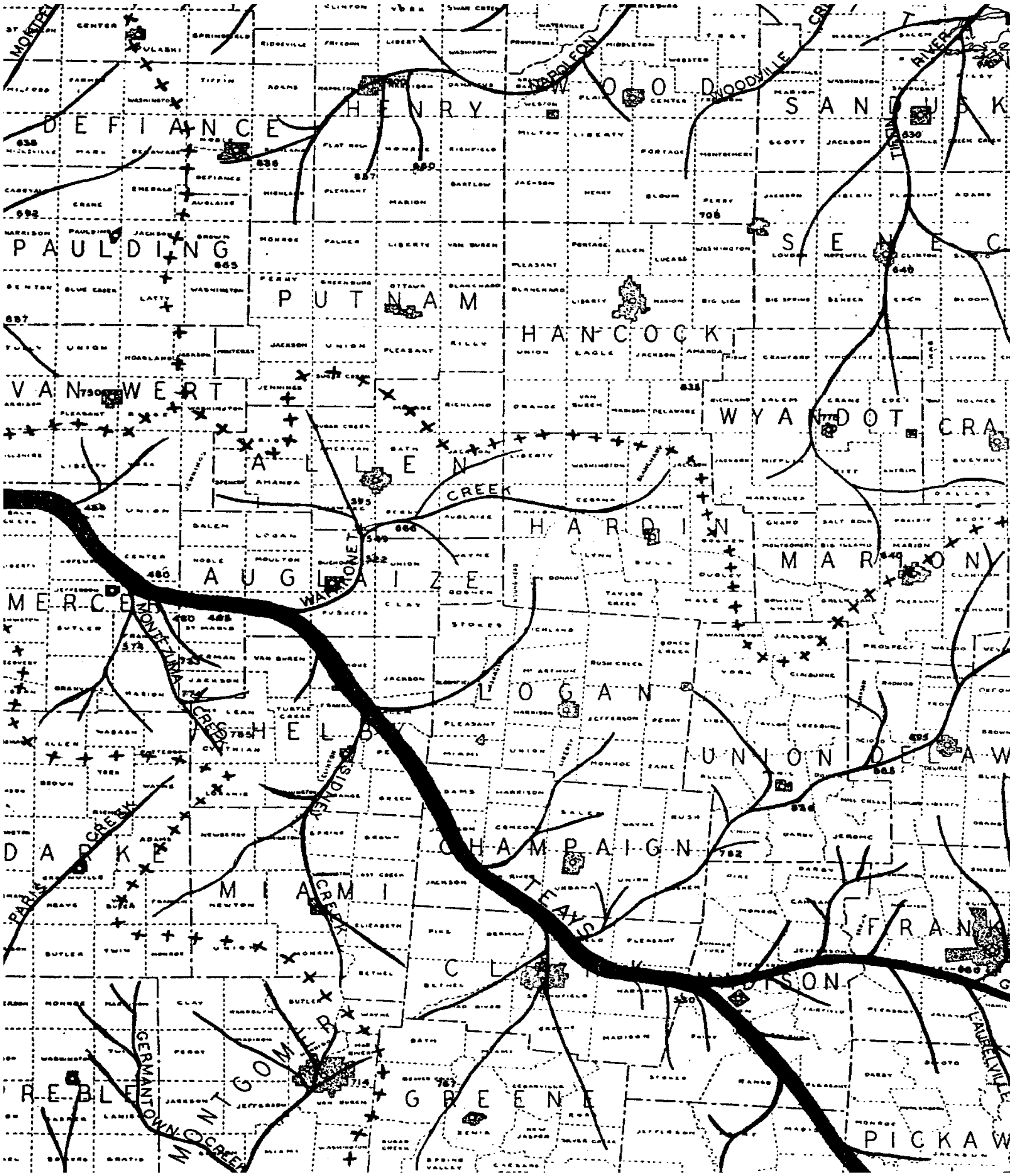


Figure 4. Teays Stage drainage in western Ohio (after Stout et al., 1943).

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 last advance, the Late Wisconsinan Ice Sheet, deposited the surficial till in Paulding County. Evidence for the earlier glaciations is lacking or obscured.

The unconsolidated (glacial) deposits in Paulding County fall into four main types: (glacial) till, lacustrine deposits, beach/deltaic/dune deposits, and alluvial (river) deposits. Alluvium consists of both ancestral and relatively modern sediments deposited by rivers. Drift is an older term that collectively refers to the entire sequence of glacial deposits. In Paulding County, drift is thinner in the south central part of the county, and thickens to the north and west. Drift is thickest in the northwest corner of the county bordering Defiance County. Along the southern edge of Paulding County there are areas where the drift is thin and the bedrock is close to the ground surface (ODNR, Division of Geological Survey, Open File Bedrock Topography and ODNR, Division of Water, Glacial State Aquifer Map, 2000). These areas typically correspond to areas where wave activity associated with ancestral Lake Maumee eroded away much of the pre-existing ground moraine.

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 and ablation tills. 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 or broken and have a preferred direction or orientation. "Hardpan" and "boulder-clay" are two common terms used for lodgement till. Ablation or "melt-out" till 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 most of the till was deposited in a water-rich environment in Paulding County. These types of tills are associated with ancestral Lake Maumee and are more common at the surface in western Paulding County. Further east in Paulding County, the till is covered by a layer of lacustrine sediment. 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 (Forsyth, 1965). Wave activity in the shallow areas from these ancestral lakes had the effect of eroding or “planing” existing till or lacustrine deposits. The net effect of the planning is typically an enhanced flattening in areas of low relief such as Paulding County. The 7Fd-Wave-eroded Lake Plain setting includes these areas where wave action has eroded pre-existing till or 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). Fractures may also interconnect sand and gravel lenses.

The number of sand and gravel lenses interbedded within the glacial till tends to increase along the northern edge of the county, particularly in the northwestern corner. In some areas, there are multiple zones of sand and gravel lenses in the vertical sequence. The sand and gravel lenses may "stack" in places, creating another possible window for contaminant migration. The thickness and lateral extent of these lenses also increases along the northern edge of the county. The sand and gravel lenses become coarser-grained and better sorted, making the lenses better local aquifers in northernmost Paulding County. The sand and gravel lenses may directly overlie the bedrock and provide additional recharge.

Alluvial deposits are sediments deposited by either the floodplain or channel of rivers and streams. As modern streams downcut, the older, now higher elevation remnants of the original valley floor are called terraces. Terraces in Paulding County tend to be relatively low elevation and are at elevations just above the current floodplain. The majority of the alluvium in Paulding County is very fine-grained and is more clayey than silty. This reflects the very clayey nature of the till and lacustrine sediments in this area. Also, many of these streams have a very low gradient and cannot carry coarse sediments except following major storm or flood events.

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. The resulting land surface is flat, gently sloping towards the Maumee River and Lake Erie. 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 of the sediment 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.

All elevations in Paulding County lie below an elevation of 785 feet above mean sea level (msl). This elevation corresponds to the highest level of ancestral Lake Maumee. This indicates that all of Paulding County lies within the Lake Plain region of Ohio (Pavey et al., 1999). Lacustrine deposits that comprise the 7F-Glacial Lake Plain Deposits hydrogeologic setting are found at the surface through most of eastern and central Paulding County. Wave-planed till that comprises the 7Fd-Wave-eroded Lake Plain hydrogeologic setting is commonly found at the surface in western Paulding County. The *Soil Survey of Paulding County* (Feusner et al., 2005) and the *Quaternary Geology of Ohio* (Pavey et al., 1999) were the primary sources used to differentiate between these two settings. All of these deposits tend to be very clayey, are poorly drained, and pond water after precipitation events. Small pockets of wave-planed till extend along the banks of tributaries into areas where lacustrine sediments otherwise are the surficial material. It is assumed that erosion by the streams eroded the thin lacustrine sediments away, exposing the underlying till. Portions of eastern Paulding County contain thicker than typical sequences of very clayey lacustrine sediments. It is believed that this area was part of a deeper central basin of Lake Maumee, in which fine-grained sediments accumulated in this relatively low-energy environment.

Beach ridge and related deposits primarily are found in northeastern Paulding County, and occur as minor, isolated features elsewhere in the county. The sequence of ancestral lake levels and elevations of beaches in Paulding County are listed in Table 9.

Table 9. Sequence of ancestral lake levels and beaches in Paulding County (after Forsyth, 1959 and 1973)

Lake Stage	Age (Years B.P)	Elevation (ft.)	Outlet	Found in Paulding County
Erie (modern)	4,000	573	Niagara	No
Algonquin	> 12,000	605	Grand River, Mi or Mohawk River, N.Y.	No
Lundy	>12,200	?	Grand River, Mi or Mohawk River, N.Y.	No
(Elkton)		615	Grand River, Mi or Mohawk River, N.Y.	No
(Dana)		620	Grand River, Mi or Mohawk River, N.Y.	No
(Grassmere)		640	Grand River, Mi	No
Lower Warren		675	Grand River, Mi or Mohawk River, N.Y.	No
Wayne		655-660	Grand River, Mi or Mohawk River, N.Y.	No
Upper Warren	<13,000	685-690	Grand River, Mi.	No
Whittlesey	>13,000	735	Grand River, Mi	No?
Lower Arkona		700-705	Grand River, Mi	No
Upper Arkona		715-720	Grand River, Mi	Yes
Middle Maumee	14,000	775-780	Wabash River, In	No
Lower Maumee		755	Grand River, Mi	No
Upper Maumee		800	Wabash River, In	No

Forsyth (1959 and 1973) gives a detailed discussion of the beach levels and lake history in northwestern Ohio. The better-developed beach features in Paulding County occur at elevations of 720 to 725 feet msl. These features are assumed to correspond to the Upper Arkona lake level. It is interesting to note that beach ridge features are absent at 735 feet msl, which corresponds with Lake Whittlesey. Lake Whittlesey commonly has relatively strong beach development; however that is not the case in Paulding County. 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.

Historically, this area was very poorly drained due to the clayey soils and flat topography. During the time of early settlement, most of Paulding County was within the Great Black Swamp (Kaatz, 1955). Settlement and transportation were limited to the well-drained beaches and dunes. The remaining areas were not inhabited until the swamp was drained artificially in the 1870's.

Bedrock Geology

Bedrock underlying the surface of Paulding County is limestones and dolomites (carbonates) of the Silurian and Devonian System. Along the northernmost edge of the county, Devonian shale is the uppermost bedrock unit, overlying the limestone. Table 10 summarizes the bedrock stratigraphy found in Paulding County. The ODNR, Division of Geological Survey has Open-File Reconnaissance Bedrock Geological Maps completed at a 1:24,000 scale on USGS topographic map bases available for the entire county. The ODNR, Division of Water has Open File Bedrock State Aquifer maps available for the county also.

The youngest unit encountered is the Devonian Antrim shale that is limited to the northernmost edge of Paulding County. The Antrim Shale is dark brown to black, marine, fissile to platy shale. The Antrim shale may contain abundant pyrite, organic matter, and locally, natural gas pockets. These fine sediments were deposited in a deep, quiet environment, under reducing conditions with little circulation of waters.

The next youngest unit is the Devonian Traverse Group, Dundee Limestone, and Detroit River Group that are mapped together as a single unit. These rocks are brown limestones and dolomites and are somewhat variable. They contain units with sandy pockets, shale-rich zones, and sections with chert, evaporates, and fossiliferous zones. These units underlie all of Paulding County except for the southern edge and southeastern corner.

The uppermost Silurian units are the Salina Group and the Salina Undifferentiated Group. In eastern Paulding County is the Salina Undifferentiated Group, which consists of dolomites, fine-grained limestones, and some minor evaporite deposits such as gypsum. These rocks were deposited in warm, shallow tidal areas. Units of the Salina Undifferentiated Group tend to thin to the west and south. In southwestern Paulding County, the uppermost formation is

Table 10. Bedrock stratigraphy of Paulding County.

System	Group/Formation (Symbol)	Lithologic Description
Devonian	Antrim Shale (Da)	Thick, brown to black, fissile to platy shale. Carbonaceous, contains pyrite, hydrogen sulfide, and pockets of methane gas. Poor aquifer with meager yields and poor water quality.
Devonian	Traverse Group Dundee Limestone Detroit River Group (Dtddr)	Interbedded brown limestones and dolomites. Contains sandy, shale-rich, cherty, evaporate, and fossiliferous zones. Unit underlies entire county except foe southern edge and southeastern corner. Moderate aquifer, yields average 5 to 25 gpm. Water quality may be poor where overlain by the Antrim Shale.
Silurian	Undifferentiated Salina Dolomite (Sus) and Salina Group (Ssg)	Gray to brown, thin-bedded, argillaceous dolomite. Thin evaporite zones common. This unit thins to the west. Yields and thickness increase to the east. Yields may exceed 100 gpm when fractures or solution features are encountered and this unit is sufficiently thick. Sus found in the eastern portion of the county; Ssg found in southwestern part of the county.
	Tymochtee and Greenfield Dolomites (Stg)	Thin- to massive-bedded, olive-gray to yellowish-brown. The Tymochtee contains shale partings. The Greenfield has a laminated dolomite lithology. Found in eastern part of county, underlies the Sus. Thickness decreases to the west and south. Yields are usually less than100 gpm.
Silurian	Lockport Dolomite (Sl)	White to medium gray, medium- to massive-bedded dolomite. Commonly contains cavernous solution zones. Thickness >100 feet. Yields can exceed 100 gpm, especially in cavernous or solution zones. Is in the subsurface across the county.

the Salina Group. The difference is that in eastern Paulding County, the units of the Salina Undifferentiated Group can be separated from the underlying units of the Tymochtee and Greenfield Dolomites.

Underlying the Salina Undifferentiated Group in eastern Paulding County are rocks of the Silurian Tymochtee and Greenfield Formations, which were also deposited in warm, shallow seas. These two formations tend to become thinner toward the west and south.

The oldest unit typically encountered by water wells is the Silurian Lockport Group. Rocks of the Lockport are commonly found in the subsurface across Paulding County except for the extreme northeast and northwest corners. The Lockport Group rocks were associated with tidal reefs deposited in warm, high-energy shallow seas.

Ground Water Resources

Ground water in Paulding County is obtained from both consolidated (bedrock) and unconsolidated (sand and gravel) aquifers. Bedrock aquifers are primarily carbonate (limestones and dolomites) throughout the county except for the northern edge. Shale is utilized as an aquifer for limited areas in northernmost Paulding County. Sand and gravel wells are common along the northern edge of the county.

Yields of 5 to 10 gpm are possible from wells completed in sand and gravel lenses interbedded within the glacial till or lacustrine units in the northern edge of Paulding County (Raab, 1986). These wells are suitable for domestic and farm purposes. In some areas, there may be multiple layers of sand and gravel lenses in the vertical sequence. The sand and gravel lenses may directly overlie the shale or limestone bedrock, providing additional recharge to these units. It is common in many older wells for the well driller to drill only a few feet into the bedrock and use it as a "screen" for immediately overlying sand and gravel deposits. Sand and gravel wells are much more common in areas where the underlying bedrock is low-yielding shale instead of the better-yielding limestones and dolomites.

In the northwestern corner of the county, the sand and gravel lenses become thicker and more numerous. Also, the sand and gravel within the lenses tends to become coarser-grained, cleaner, and better sorted. Properly designed and constructed large diameter wells completed in these intervals may be capable of yielding up to 100 gpm (Raab, 1986, ODNR, Division of Water, Glacial State Aquifer Map, 2000). This area of higher-yielding sand and gravel deposits forms the leading edge of a thick wedge of interbedded, sand-and-gravel-rich till that extends across much of Defiance County (Schmidt, 1982) and Williams County (Haiker, 1996, Angle et al., 1993).

The Devonian Antrim Shale is a very poor aquifer, typically yielding less than 5 gpm. It provides a meager supply of water, suitable for limited domestic use. Also, the water quality is typically objectionable due to hydrogen sulfide, high iron, and natural gas.

The carbonate bedrock aquifer is an important regional aquifer for most of northwestern and north central Ohio and underlies all of Paulding County (ODNR, Div. of Water, 1970 and Schmidt, 1982). Completed water wells typically penetrate multiple bedrock units. Along the northern edge of Paulding County, the wells may have to be drilled much deeper to penetrate the overlying thicker drift and Antrim Shale, where present. The Devonian Traverse Group, Dundee Limestone, and Detroit River Group cover all but the southern edge and southeastern corner of Paulding County. Yields in these units are commonly lower than in the underlying Silurian rocks and average 5 to 25 gpm. Water quality in the Devonian carbonates may be poor where they directly underlie or are adjacent to the Antrim Shale. Yields exceeding 100 gpm are available from deep, large diameter wells drilled into the Silurian Salina Group in southwestern Paulding County, the Tymochtee and Greenfield Dolomites in southeastern Paulding County, and from the Lockport Dolomite throughout the county except for the far northeast and northwest corners (ODNR, Div. of Water, Open File, Bedrock State Aquifer Map, 2000, ODNR, Div. of Water, 1970, and Schmidt, 1982). Farther north in Paulding County the thickness of the Salina Group and the Tymochtee and Greenfield Dolomites decrease appreciably, and the yields drop correspondingly. However, higher yields may still be obtained by completing the wells deeper into the Lockport Dolomite. The assumption that a deeper well will always produce higher yields is a generalization. The amount of fracturing, solution, and vuggy (porous) zones has great local importance. Deeper wells are more likely to contain highly mineralized water and have objectionable water quality.

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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 3,900 water well log records are on file for Paulding County. Data from roughly 2,600 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 at which water was encountered were taken from these records. The *Ground-Water Resources of Paulding County* (Raab, 1986) provided generalized depth to water information throughout the county. Generalized regional depth to water information was obtained from the ODNR, Division of Water (1970) report. Depth to water trends mapped in adjoining Putnam County (Angle, 2006) and Van Wert County (Angle, 2007) were used as a guideline. The thesis of He (1992) was helpful in estimating the depths of water across the county. Topographic and geomorphic trends were utilized in areas where other sources of data were lacking.

Depths of 5 to 15 feet (9) were selected for the southern portion and the extreme northwestern corner of Paulding County. This included large areas mapped as the 7F-Glacial Lake Plain Deposits and 7Fd-Wave-eroded Lake Plain, and hydrogeologic settings. Depths to water of 5 to 15 feet (9) were also utilized for the alluvial settings in Paulding County. Depths to water of 15 to 30 feet (7) were used for much of northern Paulding County including areas of the 7F-Glacial Lake Plain Deposits, 7Fd-Wave-eroded Lake Plain, and the 7H-Beaches, Beach Ridges, and Sand Dunes hydrogeologic setting. Depths to water of 30 to 50 feet (5) were utilized for small areas containing deeper static water levels to wells in northern Paulding County. The wells in these areas tended to be somewhat deeper in these areas than average.

Net Recharge

Recharge is the precipitation that reaches the aquifer. This factor was evaluated using many criteria, including depth to water, topography, soil type, surface drainage, vadose zone material, aquifer type, and annual precipitation. General estimates of recharge provided by Pettyjohn and Henning (1979) and Dumouchelle and Schiefer (2002) proved to be helpful. Recharge ratings from neighboring Putnam County (Angle, 2006) and Van Wert County (Angle, 2007) were used as a guideline. The thesis of He (1992) was used to help determine recharge rates for Paulding County.

Values of 4 to 7 inches per year (6) were used for all of Paulding County. It was determined that the entire county was in an area of moderate recharge. The relative shallow depth to water, flat topography, and permeable aquifers was counterbalanced by the clayey, lower permeability nature of the soils and vadose zone media.

Aquifer Media

Information on evaluating aquifer media was obtained from the *Ground-Water Resources of Paulding County* (Raab, 1986). 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 Putnam County (Angle, 2006) and Van Wert County (Angle, 2007) were used as a guideline. The thesis of He (1992) was useful in determining the distribution of aquifers in Paulding County. The ODNR, Division of Water, Glacial State Aquifer Map (2000) and Bedrock State Aquifer Map (2000) were an important source of aquifer data. The *Glacial Map of Ohio* (Goldthwait et al., 1961), and the *Quaternary Geology of Ohio* (Pavey et al., 1999) provided useful information on the nature of the glacial aquifers and the delineation of the hydrogeologic settings. Additional information on limestone aquifers was obtained from a report (Division of Water, 1970) on carbonate rocks in northwestern Ohio. Additional site-specific aquifer data, including reports by Ortman Drilling Inc. (1994) and Stremmel & Hill Inc. (1986), provided valuable information. 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). Limestone was evaluated as the aquifer for the majority of Paulding County. A rating of (7) was applied to all of the Silurian and Devonian limestone aquifers in Paulding County.

Sand and gravel was evaluated as the aquifer for a narrow area extending across the northern edge of Paulding County. In these areas, sand and gravel lenses interbedded in the underlying till or lacustrine deposits were used as the aquifer. These sand and gravel lenses tended to become thicker, more numerous, and coarser-grained in the northwestern corner of the county. An aquifer rating of (7) was applied to all of the sand and gravel aquifers.

Shale was evaluated as the aquifer for very limited areas in northern Paulding County. Shale was randomly encountered in well logs throughout this area. In some instances, sand and gravel deposits directly overlie the shale and the wells were completed 1 or 2 feet into the shale, essentially using the shale as a “well screen”. In these cases, yields were good and sand and gravel was evaluated as the aquifer. In a limited number of wells, the well was drilled through thin shale and into the underlying limestone. In these cases, limestone was evaluated as the aquifer. Shale was only evaluated as an aquifer where the well penetrated a reasonable thickness of the shale and there was no directly overlying sand and gravel or underlying limestone present in the well log record. An aquifer rating of (3) was applied to the shale aquifers due to their poor aquifer characteristics.

Soils

Soils were mapped using the data obtained from the *Soil Survey of Paulding County* (Feusner et al., 2005). 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 Paulding 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 Paulding County.

Sand (9) was utilized for one setting that probably consisted of fine-grained dune sand overlying a low beach ridge feature. Shrink-swell (non-aggregated) clays (7) were selected for the highly clayey soils found at the surface of the 7Fd-Wave-eroded Lake Plain and the 7F-Glacial lake Plain Deposits settings. These soils were formed on the water-eroded till and lacustrine sediments associated with ancestral Lake Maumee. Shrink-swell clay (7) was also selected for some fine-grained alluvial deposits. Sandy loam (6) soils were associated with sandy sediments found in the 7H-Beaches, Beach Ridges, and Sand Dunes setting. Loam (5) soils were selected for a number of areas where the surficial deposits had an intermediate texture soil. These areas included thin layers of fine sand that had been eroded off beach ridges and in areas with coarser alluvial deposits. Silt loam (4) was designated for silty, finer-grained alluvial and floodplain deposits. The loam (5) and silt loam (4) alluvial deposits were usually associated with the main trunk of the Maumee River and Auglaize River, whereas the tributary streams more likely contained the shrink-swell clay (7) soils.

Topography

Topography, or percent slope, was evaluated using U.S.G.S. 7-1/2 minute quadrangle maps and the *Soil Survey of Paulding County* (Feusner et al., 2005). Paulding County has exceptionally flat-lying terrain and low relief. Slopes of 0 to 2 percent (10) are common across the entire county and were selected for almost all hydrogeologic settings mapped in the county. Slopes of 2 to 6 percent (9) were limited to areas where there was some moderately steep stream dissection along the banks of rivers. Slopes of 2 to 6 percent (9) are also associated with some beach ridges capped by dunes.

Impact of the Vadose Zone Media

Information on evaluating vadose zone media was obtained primarily from the *Ground Water Resources of Paulding County* (Raab, 1986) and water well log records on file at the ODNR, Division of Water. 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 media ratings from neighboring Putnam County (Angle, 2006) and Van Wert County (Angle, 2007) were used as a guideline. Vadose zone media ratings provided by the thesis of He (1992) were helpful. The ODNR, Division of Water, Glacial State Aquifer Map (2000) and Bedrock State Aquifer Map (2000)

Table 11. Paulding County soils

Soil Symbol	Soil Name	Parent Material/ Setting	DRASTIC Rating	Soil Media
BeB	Belmore	Beach-dune	6	Sandy loam
BkA	Bixler	Thin beach over lacustrine	6	Sandy Loam
BrB2,BrC2,BrD2,BrE2 BsC3,BsD3	Broughton	Lacustrine along stream banks	7L	Shrink-swell Clay
Db, Dc	Defiance	Clayey alluvium	7Al	Shrink-swell Clay
Fb, Fc	Flatrock	Alluvium	4	Silt Loam
FtA,FuA,FuB2,FxA,FxB	Fulton	Clayey lacustrine	7L	Shrink-swell Clay
Gr	Granby	Beaches, dunes, deltas	6	Sandy Loam
HaA,HkA,HkB	Haskins	Beach over lacustrine or till	5	Loam
Hs,Ht	Hoytville	Water-modified, wave-planed till	7T	Shrink-swell Clay
Kn	Knoxdale	Coarse alluvium	5Al	Loam
La	Landes	Coarse alluvium	5Al	Loam
Lb.Lc	Latty	Clayey lacustrine	7L	Shrink-swell Clay
LtA,LuB2,LuC2	Lucas	Clayey lacustrine	7L	Shrink-swell clay
Md	Medway	Coarse alluvium	5Al	Loam
Me	Mermill	Thin loam over lacustrine	5	Loam
Mg	Milgrove	Thin beach over till	5	Loam
NnA,NpA,NpB,NpB2	Nappanee	Water-modified, wave-planed till	7T	Shrink-swell Clay
OsB	Oshtemo	Beach ridge, over till	6	Sandy Loam
OtB	Ottokee	Dune, beach ridge	9	Sand
Pc	Paulding	Clayey lacustrine	7L	Shrink-swell Clay
Pt	Pits, quarries	Not rated	NR	NR
RkA,RkB,RmA	Rimer	Beach ridge, dune over lacustrine	6	Sandy Loam
RnA,RoA,RoB,RpA,RpB2	Roselms	Clayey lacustrine	7L	Shrink-swell Clay
Rt	Rossburg	Alluvium, floodplains	4	Silt Loam
Sb	Saranac	Clayey alluvium	7Al	Shrink-swell Clay
Sh,Sk	Shoals	Alluvium	4	Silt Loam
StB2,StC2,StD2,StE2, SuC3,SuE3	St. Clair	Clayey till along stream banks	7T	Shrink-swell Clay
TeA	Tedrow	Beach ridge, dune	6	Sandy Loam
Tn, To	Toledo	Clayey lacustrine	7L	Shrink-swell clay
Uc	Udorthent	Man-made, cut-fill	NR	NR
W	Water	Pond, lake, reservoir	NR	NR
Wb	Wabasha	Clayey alluvium over lacustrine	7Al	Shrink-swell Clay
WhA	Whitaker	Silty to sandy lacustrine, deltaic	5	Loam

were important sources of vadose zone media data. The *Soil Survey of Paulding County* (Feusner et al., 1972) provided valuable information on parent materials. The *Glacial Map of Ohio* (Goldthwait et al., 1961), and the *Quaternary Geology of Ohio* (Pavey et al., 1999) were useful in delineating vadose zone media.

The vadose zone media is a critical component of the overall DRASTIC rating in Paulding 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.

A vadose zone media rating of (6) was chosen for sand and gravel with significant silt and clay for the 7H-Beaches, Beach Ridges, and Sand Dunes hydrogeologic settings across Paulding County. Silt and clay with a vadose zone media rating of (5) was selected for alluvial settings in the county containing moderately fine-grained alluvium that weathers into silt loam or clay loam soils. Silt and clay with a rating of (4) was applied to fine-grained alluvium that weathers into shrink-swell clay associated with the majority of streams in Paulding County. Silt and clay with a rating of (4) was chosen for clayey lacustrine sediments that had weathered into shrink-swell clay soils in eastern and northern Paulding County.

The *Soil Survey of Paulding County* (Feusner et al., 2005) was used to help separate areas with silt and clay vadose zone media from areas of silt and clay with till vadose zone media, depending upon whether lacustrine sediments or water-modified (wave-planed) till were the parent material for the soil. This distinction also was the primary criteria for separating the 7Fd-Wave-eroded Lake Plain from the 7F-Glacial Lake Deposits settings.

Silt and clay with till (4) was selected for areas in the 7Fd-Wave-eroded Lake Plain for areas of exceptionally fine-grained till containing pockets of lacustrine silt and clay. Shrink-swell clay soils developed from these clayey sediments. The 7Fd-Wave-eroded Lake Plain forms a broad belt across the southwestern and western portion of Paulding County. The 7Fd-Wave-eroded Lake Plain setting featuring a vadose zone media of silt and clay with till (4) was also selected for areas where there was some moderately steep stream dissection along the banks of rivers. In these areas, stream bank erosion had removed the overlying lacustrine sediments and exposed the underlying wave-cut till units.

Hydraulic Conductivity

Information on evaluating the hydraulic conductivity was obtained from the maps and report of the ODNR, Div. of Water, (1970), Norris and Fidler (1973), and the *Ground-Water Resources of Paulding County* (Raab, 1986). 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. Hydraulic conductivity ratings from neighboring Putnam County (Angle, 2006) and Van Wert County (Angle, 2007) were used as a guideline. The range of hydraulic conductivity values found in He (1992) was a useful guideline. The ODNR, Division of Water, Glacial State Aquifer Map (2000) and

Bedrock State Aquifer Map (2000) were important sources of hydraulic conductivity data. Additional site-specific hydraulic conductivity data included the reports by Ortman Drilling Inc. (1994) and Stremmel & Hill Inc. (1986). Water well log records on file at the ODNR, Division of Water, were also used to help determine hydraulic conductivity. Textbook tables (Freeze and Cherry, 1979, Fetter, 1980, and Driscoll, 1986) were useful in obtaining estimated values for hydraulic conductivity in a variety of aquifers.

Values for hydraulic conductivity correspond to aquifer ratings; i.e., the more highly rated aquifers have higher values for hydraulic conductivity. The limited shale aquifers were assigned a hydraulic conductivity range of 1-300 gallons per day per foot squared (gpd/ft^2) (1). All limestone aquifers were assigned a hydraulic conductivity range of 300-700 gpd/ft^2 (4). The majority of the sand and gravel aquifers were given a hydraulic conductivity range of 300-700 gpd/ft^2 (4). A limited number of higher-yielding sand and gravel aquifers in the extreme northwestern corner of the county were given a hydraulic conductivity range of 700-1000 gpd/ft^2 (6).

APPENDIX B

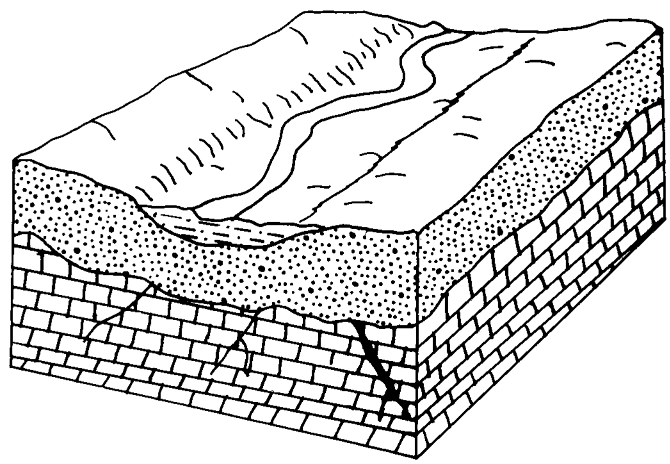
DESCRIPTION OF HYDROGEOLOGIC SETTINGS AND CHARTS

Ground water pollution potential mapping in Paulding County resulted in the identification of five 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 Paulding County range from 105 to 158.

Table 12. Hydrogeologic settings mapped in Paulding County, Ohio

Hydrogeologic Settings	Range of GWPP Indexes	Number of Index Calculations
7 Ec-Alluvium over sedimentary rock	124-147	5
7 Ed-Alluvium over glacial till	145-152	4
7 F-Glacial lake plain deposits	105-152	15
7 Fd-Wave-eroded lake plain	126-152	11
7 H-Beaches, beach ridges, and sand dunes	132-158	11

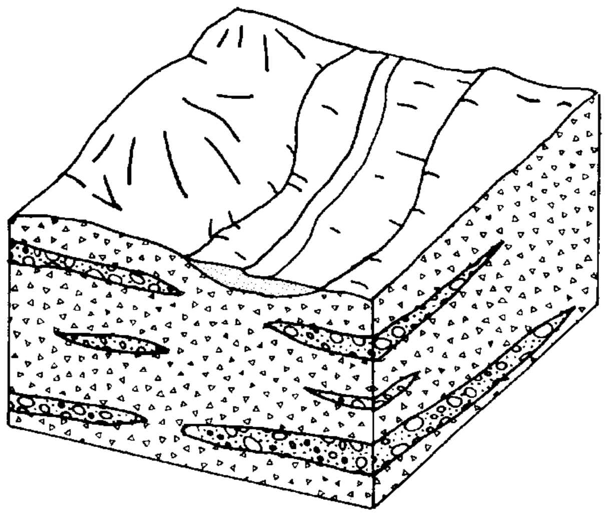
The following information provides a description of each hydrogeologic setting identified in the county, a block diagram illustrating the characteristics of the setting, and a listing of the charts for each unique combination of pollution potential indexes calculated for each setting. The charts provide 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.



7Ec-Alluvium over Sedimentary Rock

This hydrogeologic setting is common throughout Paulding County, and is comprised of flat-lying floodplains and stream terraces containing thin to moderate thicknesses of modern alluvium. The aquifers consist of Silurian and Devonian limestones and dolomites. There are some limited areas where the aquifer consists of Devonian Antrim Shale. The vadose zone consists of silty to clayey alluvial deposits overlying thin glacial till. Soils are variable due to the varying texture of the alluvial materials and are usually silt loams. Depth to water is commonly very shallow, averaging less than 20 feet. The alluvium may be in direct hydraulic connection with the underlying bedrock or there may be a varying thickness of thin till or lacustrine deposits in between. Maximum ground water yields greater than 100 gpm are possible from the Silurian Lockport, Tymochtee, Greenfield and Salina Groups in Paulding County. Wells developed in the Devonian Antrim Shale typically yield less than 5 gpm unless they are obtaining additional recharge from overlying sand and gravel deposits. Recharge is typically moderate due to the flat-lying topography, shallow depth to water, the moderate permeability of the soils and vadose zone media, and the relatively high permeability of the underlying bedrock.

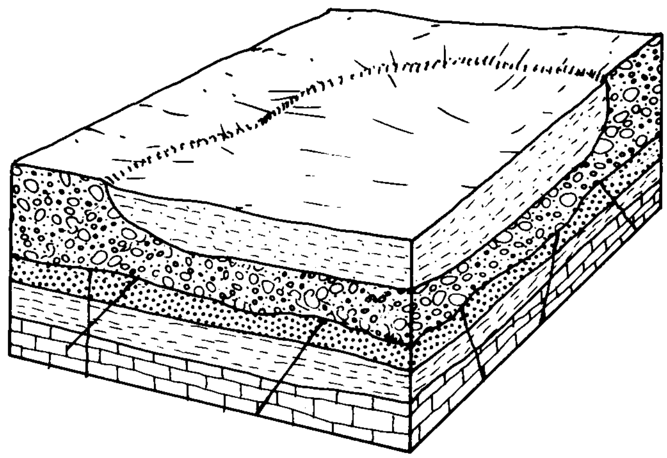
The GWPP index values for the hydrogeologic setting Alluvium over Sedimentary Rocks range from 124 to 147, with the total number of GWPP index calculations equaling 5.



<u>7Ed-Alluvium over Glacial Till</u>

This hydrogeologic setting is limited to streams occupying the northern edge of Paulding County. The setting is comprised of flat-lying floodplains and stream terraces containing thin to moderate thicknesses of modern alluvium. The setting is similar to the 7Ec-Alluvium over Sedimentary Rock except that the underlying till is thicker and contains sand and gravel lenses. The stream may or may not be in direct hydraulic connection with the underlying sand and gravel lenses that constitute the aquifer. The surficial, silty to sandy alluvium is typically more permeable than the underlying till. The alluvium is too thin to be considered the aquifer. The vadose zone consists of the sandy to silty to clayey alluvial deposits. Soils are variable and depend upon the texture of the alluvium. Ground water yields average 5 to 25 gpm for the wells completed in the underlying sand and gravel lenses. Depth to water is typically shallow with depths averaging less than 20 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.

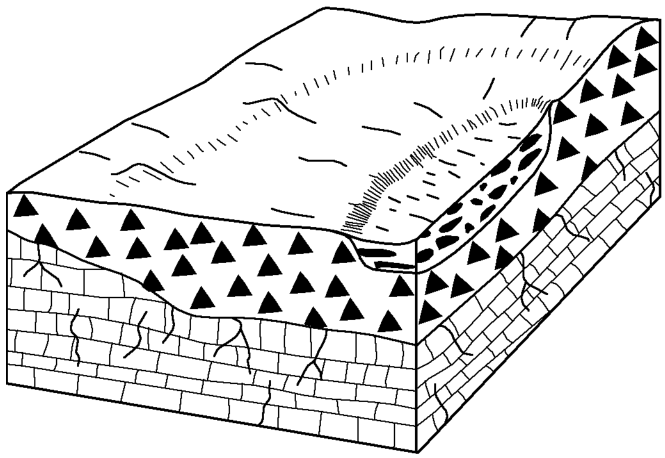
The GWPP index values for the hydrogeologic setting Alluvium Over Glacial Till range from 145-152, with the total number of GWPP index calculations equaling 4.



7F Glacial Lake Plain Deposits

This hydrogeologic setting occupies most of eastern, central, and northern Paulding County. It is characterized by flat-lying topography and varying thickness of fine-grained lacustrine sediments. These sediments were deposited in lakes by a sequence of ancestral lakes. The vadose zone media consists of clayey lacustrine sediments that overlie glacial till. Wells in most of the county are completed in the underlying Silurian and Devonian limestone and dolomite. Maximum ground water yields greater than 100 gpm are possible from the Silurian Lockport, Tymochtee, Greenfield and Salina Groups. Along the northern edge of the county, wells may be completed in sand and gravel lenses or in shale bedrock. Yields from the sand and gravel lenses range from 5 to 25 gpm for the eastern part of this zone to 25 to 50 gpm for the extreme northwestern corner of the county. Yields from the Devonian Antrim Shale are poor, averaging less than 5 gpm. Depth to water is variable and seems to be dependent upon the overall thickness of the glacial drift and the depth to the aquifer in which the wells are completed. Soils are shrink-swell (aggregated) clays. The presence of shrink-swell clay soils is important; 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. The vadose zone is comprised of fine-grained lacustrine sediments overlying till in some areas. Recharge in this setting is moderate to low depending upon the depth to water and the thickness of the fine-grained lacustrine sediments and till.

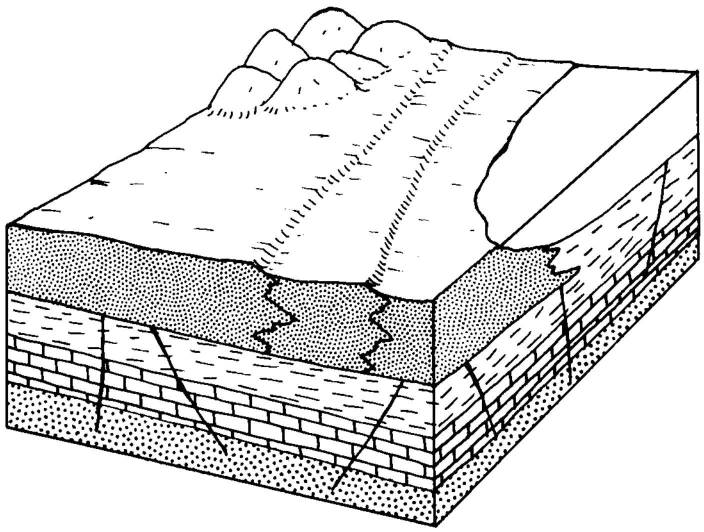
The GWPP index values for the hydrogeologic setting of Glacial Lake Plains Deposits range from 105 to 152, with the total number of GWPP index calculations equaling 15.



<u>7Fd-Wave-eroded Lake Plain</u>

This hydrogeologic setting is characterized by very flat-lying topography caused by wave-erosion of glacial Lake Maumee. The setting forms a band extending across western and southwestern Paulding County. The setting consists of thin, patchy silty to clayey lacustrine deposits and wave-eroded, "water-modified" till. The setting also can be found along the banks of major streams where erosion has removed the overlying lacustrine sediments, exposing the till. Surficial drainage is typically very poor; ponding is very common after rains. The vadose zone media consists of very thin silty to clayey lacustrine sediments that overlie clayey glacial till. This setting is similar to the 7F-Glacial Lake Plain Deposits setting except that waves have eroded away all or most of the fine-grained lacustrine sediments overlying the glacial till. The aquifer consists of the underlying limestone bedrock. Maximum ground water yields greater than 100 gpm are possible from the Silurian Lockport, Tymochtee, Greenfield and Salina Groups. In some portions along the northern edge of the county, the aquifer consists of sand and gravel lenses interbedded in the glacial till. Yields from the sand and gravel lenses range from 5 to 25 gpm for the eastern part of this setting to 25 to 50 gpm for the extreme northwestern corner of the county. Depth to water is variable and seems to be dependent upon the overall thickness of the glacial drift and the depth to the aquifer in which the wells are completed. Soils are shrink-swell (non-aggregated) clay derived from clayey lacustrine sediments and clayey till. Recharge in this setting is moderately low due to the relatively low permeability soils and vadose zone material and the relatively shallow depth to the water table and bedrock aquifer.

GWPP index values for the hydrogeologic setting of Wave-eroded Lake Plain range from 126 to 152, with the total number of GWPP index calculations equaling 11.



7H-Beaches,Beach Ridges, and Sand Dunes

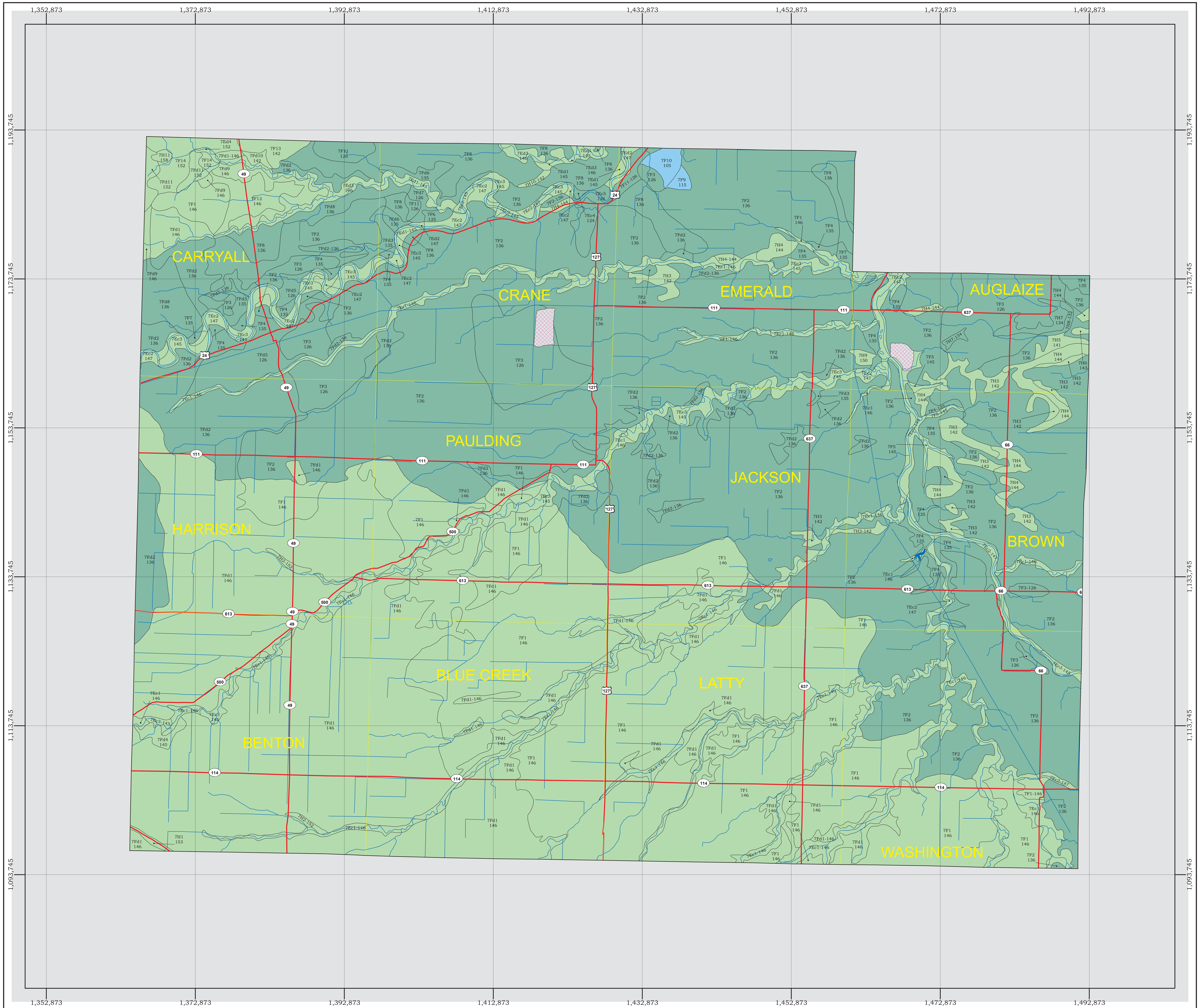
This hydrogeologic setting is characterized by narrow, elongate, low-lying ridges of sand overlying the lacustrine plain or wave-planed till uplands. This setting is scattered throughout the county, but is most commonly found in the northeastern part of Paulding County. The vadose zone media is composed of thin, clean, fine-grained quartz sand that has moderately high permeability and low sorptive capability. These thin sands overlie clayey lacustrine deposits and water-modified till. Wells are completed in Silurian limestone and dolomite bedrock that underlies the till and lacustrine sediments. Maximum ground water yields greater than 100 gpm are possible from the Silurian Lockport, Tymochtee, Greenfield and Salina Groups. In a small area in northwestern Paulding County, the beach ridges overlie sand and gravel lenses interbedded in the glacial till that comprise the aquifer. Depth to water is variable and seems to be dependent upon the overall thickness of the glacial drift and the depth to the aquifer that the wells are completed in. Soils are loams, sandy loams, or sand depending upon how fine-grained the beach deposits are. 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 158, with the total number of GWPP index calculations equaling 11.

Table 13. Hydrogeologic Settings, DRASTIC Factors, and Ratings

Setting	Depth to Water (Feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating
7Ec1	5-15	4-7	limestone	Shrink/Swell Clay	0-2	silt and clay	300-700	146	179
7Ec2	5-15	4-7	limestone	Loam	0-2	silt and clay	300-700	147	173
7Ec3	5-15	4-7	limestone	Silty Loam	0-2	silt and clay	300-700	145	168
7Ec4	5-15	4-7	shale	Silty Loam	0-2	silt and clay	1-100	124	150
7Ec5	5-15	4-7	shale	Loam	0-2	silt and clay	1-100	126	155
7Ed1	5-15	4-7	sand and gravel	Silty Loam	0-2	silt and clay	300-700	145	168
7Ed2	5-15	4-7	sand and gravel	Loam	0-2	silt and clay	300-700	147	173
7Ed3	5-15	4-7	sand and gravel	Shrink/Swell Clay	0-2	silt and clay	300-700	146	179
7Ed4	5-15	4-7	sand and gravel	Shrink/Swell Clay	0-2	silt and clay	700-1000	152	183
7F1	5-15	4-7	limestone	Shrink/Swell Clay	0-2	silt and clay	300-700	146	179
7F2	15-30	4-7	limestone	Shrink/Swell Clay	0-2	silt and clay	300-700	136	169
7F3	30-50	4-7	limestone	Shrink/Swell Clay	0-2	silt and clay	300-700	126	159
7F4	15-30	4-7	limestone	Shrink/Swell Clay	2-6	silt and clay	300-700	135	166
7F5	5-15	4-7	limestone	Shrink/Swell Clay	2-6	silt and clay	300-700	145	176
7F6	30-50	4-7	limestone	Shrink/Swell Clay	2-6	silt and clay	300-700	125	156
7F7	15-30	4-7	sand and gravel	Shrink/Swell Clay	2-6	silt and clay	300-700	135	166
7F8	15-30	4-7	sand and gravel	Shrink/Swell Clay	0-2	silt and clay	300-700	136	169
7F9	15-30	4-7	shale	Shrink/Swell Clay	0-2	silt and clay	1-100	115	151
7F10	30-50	4-7	shale	Shrink/Swell Clay	0-2	silt and clay	1-100	105	141
7F11	30-50	4-7	sand and gravel	Shrink/Swell Clay	0-2	silt and clay	300-700	126	159
7F12	5-15	4-7	sand and gravel	Shrink/Swell Clay	0-2	silt and clay	300-700	146	179
7F13	15-30	4-7	sand and gravel	Shrink/Swell Clay	0-2	sl + cl w/till	700-1000	142	173
7F14	5-15	4-7	sand and gravel	Shrink/Swell Clay	0-2	silt and clay	700-1000	152	183
7F15	15-30	2-4	limestone	Shrink/Swell Clay	0-2	silt and clay	300-700	124	157
7Fd1	5-15	4-7	limestone	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	146	179

Setting	Depth to Water (Feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating
7Fd2	15-30	4-7	limestone	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	136	169
7Fd3	15-30	4-7	limestone	Shrink/Swell Clay	2-6	sl + cl w/till	300-700	135	166
7Fd4	5-15	4-7	limestone	Shrink/Swell Clay	2-6	sl + cl w/till	300-700	145	176
7Fd5	30-50	4-7	limestone	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	126	159
7Fd6	15-30	4-7	sand and gravel	Shrink/Swell Clay	2-6	sl + cl w/till	300-700	135	166
7Fd7	30-50	4-7	sand and gravel	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	126	159
7Fd8	15-30	4-7	sand and gravel	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	136	169
7Fd9	5-15	4-7	sand and gravel	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	146	179
7Fd10	15-30	4-7	sand and gravel	Shrink/Swell Clay	0-2	sl + cl w/till	700-1000	142	173
7Fd11	5-15	4-7	sand and gravel	Shrink/Swell Clay	0-2	sl + cl w/till	700-1000	152	183
7H1	5-15	4-7	limestone	Sandy Loam	2-6	sd + gvl w/sl + cl	300-700	153	179
7H2	5-15	4-7	limestone	Loam	0-2	sd + gvl w/sl + cl	300-700	152	177
7H3	15-30	4-7	limestone	Loam	0-2	sd + gvl w/sl + cl	300-700	142	167
7H4	15-30	4-7	limestone	Sandy Loam	0-2	sd + gvl w/sl + cl	300-700	144	172
7H5	15-30	4-7	limestone	Loam	2-6	sd + gvl w/sl + cl	300-700	141	164
7H6	15-30	4-7	limestone	Sandy Loam	2-6	sd + gvl w/sl + cl	300-700	143	169
7H7	30-50	4-7	limestone	Sandy Loam	0-2	sd + gvl w/sl + cl	300-700	134	162
7H8	30-50	4-7	limestone	Loam	0-2	sd + gvl w/sl + cl	300-700	132	157
7H9	15-30	4-7	limestone	Sand	0-2	sd + gvl w/sl + cl	300-700	150	187
7H10	15-30	4-7	sand and gravel	Loam	0-2	sd + gvl w/sl + cl	300-700	142	167
7H11	5-15	4-7	sand and gravel	Loam	0-2	sd + gvl w/sl + cl	700-1000	158	181



Ground Water Pollution Potential of Paulding County

by

Michael P. Angle

Ohio Department of Natural Resources

Divison of Water

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 with 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

Hydrogeologic Region → 7D24 ← Hydrogeologic Setting

170 ← Relative Pollution Potential

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

Index Ranges

- Not Rated
- Less Than 79
- 80 - 99
- 100 - 119
- 120 - 139
- 140 - 159
- 160 - 179
- 180 - 199
- Greater Than 200

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

0 1 2 3 4 5 Miles

0 1 2 4 6 8 Kilometers

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Cartography by Carolyn Rund