GROUND WATER POLLUTION POTENTIAL OF VAN WERT COUNTY, OHIO

BY

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ABSTRACT

A ground water pollution potential map of Van Wert 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 Van Wert County resulted in a map with symbols and colors, which illustrate areas of varying ground water pollution potential indexes ranging from 107 to 165.

Van Wert County lies entirely within the Glaciated Central hydrogeologic setting. Limestones and dolomites of the Silurian System compose the aquifer for most of the county. Yields in the uppermost carbonate aquifers range from 5 to 100 gallons per minute (gpm) for most of the county, to over 100 gpm in the northern part of the county. Yields over 100 gpm are possible from larger diameter wells drilled deeper into the limestone for almost the entire county.

Deep layers of sand and gravel are utilized as the aquifer for limited areas of a deep buried valley system that extends into south central Van Wert County. These buried valleys represent northern tributaries of the ancient Teays River valley system. Yields ranging from 5 to 25 gpm are obtained from wells completed in the deeper areas of these valleys. These wells obtain water from thin sand and gravel lenses interbedded with fine-grained glacial till or lacustrine (lake) deposits. These wells are suitable for domestic and farm purposes.

Outside of the buried valley system, wells producing water from sand and gravel are very uncommon in the remainder of Van Wert County. Yields for these sand and gravel lenses range from 5 to 25 gpm. The sand and gravel lenses may lie directly on top of the limestone bedrock and serve as the aquifer, or provide additional recharge to the underlying bedrock.

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 Van Wert 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

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Map preparation and review:	Michael P. Angle
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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; 3,200 of these wells exist in Van Wert 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 Van Wert 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 Van Wert 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

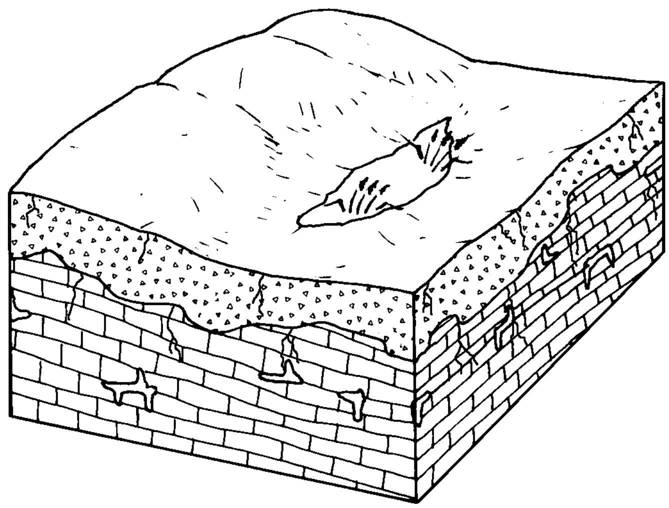
These factors incorporate concepts and mechanisms such as attenuation, retardation, and time or distance of travel of a contaminant with respect to the physical characteristics of the hydrogeologic setting. Broad consideration of these factors and mechanisms coupled with existing conditions in a setting 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 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>7Ac-Glacial Till over Limestone</u>

This hydrogeologic setting is common in western, southern, and central Van Wert County. The area is characterized by flat-lying topography and low relief associated with ground moraine. The setting basically occupies a broad area between the Lake Plain and the Fort Wayne Moraine. A smaller area of ground moraine is found south of the Fort Wayne Moraine in the southwestern corner of the county. The vadose zone consists primarily of silty to clayey glacial till. The till may be fractured or jointed, particularly in areas where it is predominantly thin and weathered. Where the till is very thin, fractured limestone is considered to be the vadose zone media, either partially or entirely. The aquifer is composed of fractured Silurian limestones and dolomites. These carbonate rocks may contain significant solution features. Depth to water is typically shallow to moderate, ranging from 15 to 50 feet. Soils typically are clay loams derived from till. Maximum ground water yields greater than 100 gpm are possible from the Silurian Tymochtee, Greenfield and Salina Groups in northern Van Wert County and the Lockport Group throughout Van Wert County. Recharge is moderate due to the clayey nature of the soils and vadose zone and the relatively shallow depth to water and permeable nature of the bedrock aquifer. Recharge rates increase somewhat where the limestone bedrock is closer to the ground surface.

GWPP index values for the hydrogeologic setting of Glacial Till over Limestone range from 115 to 148, with the total number of GWPP index calculations equaling 19.

Figure 1. Format and description of the hydrogeologic setting – 7Ac Glacial Till over Limestone.

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	

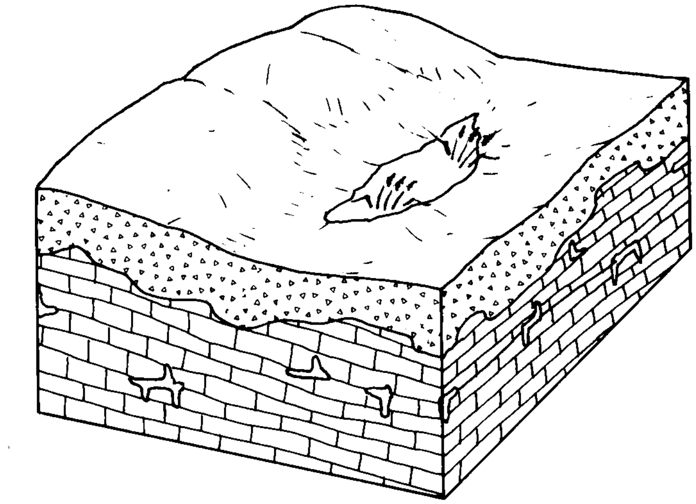
Table 8. Ranges and ratings for hydraulic conductivity

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 7Ac1, Glacial Till over Limestone, identified in mapping Van Wert 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 132. 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 Van Wert County produces settings with a wide range of vulnerability to ground water contamination. Calculated pollution potential indexes for the ten settings identified in the county range from 107 to 165.

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 Van Wert 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 Van Wert County is included with this report.



SETTING 7Ac1		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Limestone	3	7	21
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact of Vadose Zone	Till	5	5	25
Hydraulic Conductivity	300-700	3	4	12
		DRASTIC	INDEX	132

Figure 2. Description of the hydrogeologic setting – 7Ac1 Glacial Till over Limestone.

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:

7Ac1 - defines the hydrogeologic region and setting
132 - defines the relative pollution potential

The first number (**7**) refers to the major hydrogeologic region and the upper case letter and lower case letter (**Ac**) 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 (**132**) 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 VAN WERT COUNTY

Demographics

Van Wert County occupies approximately 409 square miles (Brock and Tornes., 1972) in northwestern Ohio (Figure 3). Van Wert County is bounded to the north by Paulding County, to the northeast by Putnam County, to the east by Allen County, to the southeast by Auglaize County, to the south by Mercer County and to the west by Allen County and Adams County, Indiana.

The approximate population of Van Wert County, based upon year 2004 estimates, is 29,276 (Department of Development, Ohio County Profiles, 2005). Van Wert is the largest community and the county seat. Agriculture accounts for roughly 95 percent of the land usage in Van Wert 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 51 degrees Fahrenheit for Van Wert County. Harstine (1991) shows that precipitation approximately averages 36 inches per year for the county, with precipitation declining slightly to the north and east. The mean annual precipitation for the city of Van Wert is 36.862 inches per year based upon a thirty-year (1971-2000) period (National Oceanographic and Atmospheric Administration (NOAA), 2002). The mean annual temperature at the city of Van Wert for the same thirty-year period is 50.1 degrees Fahrenheit (NOAA, 2002).

Physiography and Topography

The majority of Van Wert County lies within the Central Till Plains Lowland Province, while the northern portion of the county lies within the Lake Plains Province (Frost, 1931; Fenneman, 1938, and Bier, 1956). Brockman (1998) and Schiefer (2002) depict the majority of Van Wert County as belonging in the Central Ohio Clayey Till Plain. The northern portion is part of the Maumee Lake Plains. The majority of Van Wert County is characterized by flat to gently rolling ground moraine. The southwestern and southeastern corners of the county contain more steeply rolling, hummocky end moraine. The lake plains area in northern Van Wert County is characterized by especially flat topography associated with ground moraine that was heavily wave eroded.

Figure 3. Location map of Van Wert County, Ohio.

Modern Drainage

Van Wert County lies north of the major drainage divide crossing north central Ohio; all of Van Wert County drains toward Lake Erie. The entire county except for the southwestern corner drains into tributaries of the Auglaize River. Major tributaries from east to west include the Little Auglaize River, Dog Creek, Town Creek, Maddox Creek, Hoaglin Creek, Hagerman Creek, and Blues Creek. The southwestern corner of the county, in the vicinity of Wilshire, drains into the St. Mary's River. The St. Mary's River flows westward to Fort Wayne, Indiana where it merges to form the Maumee River.

Pre- and Inter-Glacial Drainage Changes

The drainage patterns of Van Wert 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 Van Wert 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. Stout et al. (1943) show rough divides running through Van Wert County (see Figure 4). Drainage in southern Van Wert County was to the south, towards the Teays River (Stout et al., 1943). Drainage for the northwestern corner was to the northwest and eventually joined more northerly flowing tributaries to the Teays River. Drainage in the northeastern corner was to the northeast, perhaps towards an ancestor of the Maumee River referred to as the Napoleon River. Modern bedrock topography data (Open File Bedrock Topography Maps, ODNR, Division of Geological Survey) show two deep valleys extending into south central Van Wert County, one to the east and one to the west of Ohio City. These valleys were tributaries to the Teays 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. Slowly the drainage patterns of Van Wert County evolved and drainage shifted towards the north during ice-free intervals.

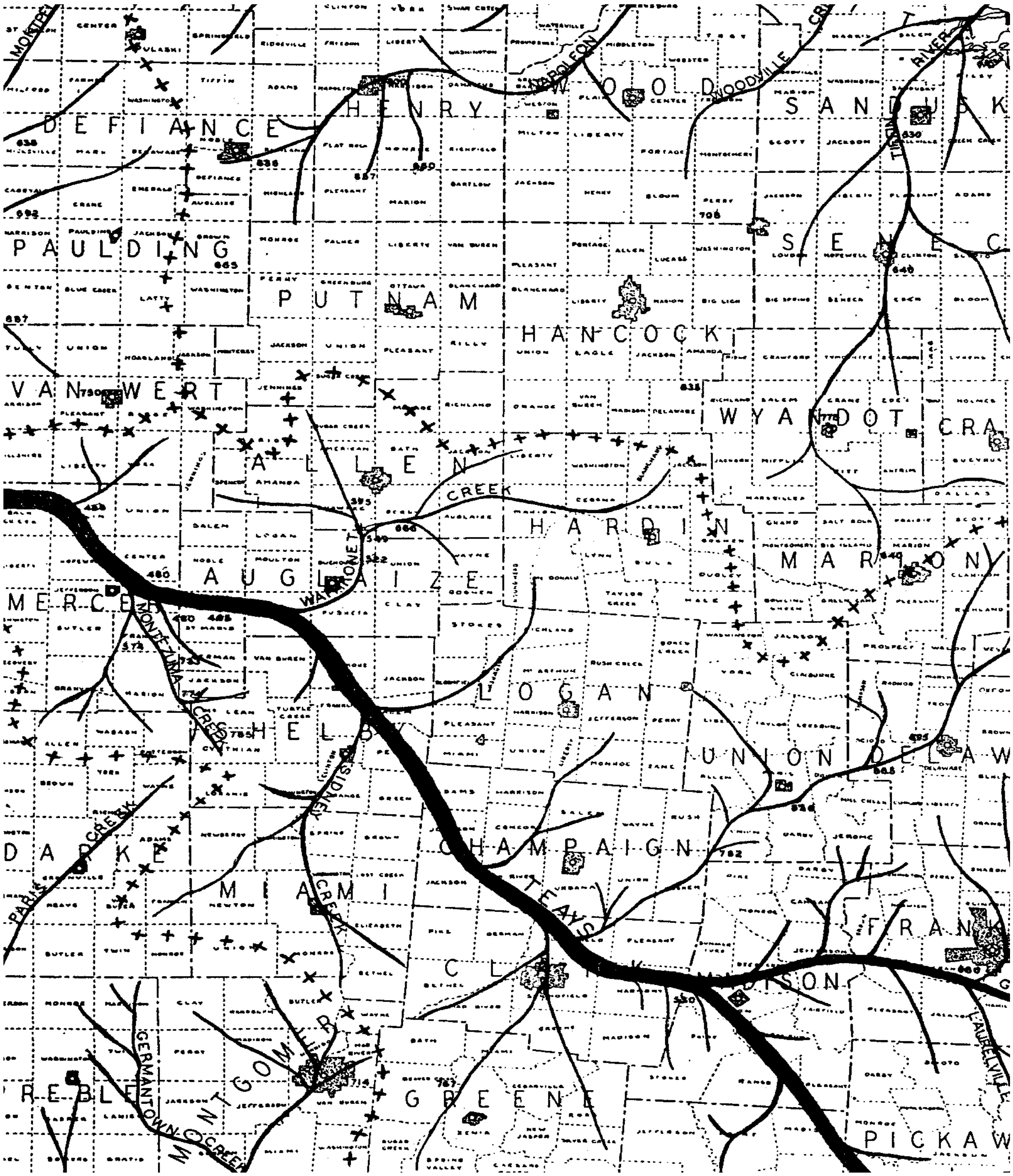


Figure 4. Teays Stage drainage in Van Wert County (after Stout et al., 1943).

The modern drainage reflects the nature of landforms deposited during the Wisconsinan advances, particularly the end moraine in the southern part of the county and the southern extension of the Lake Maumee basin into northern Van Wert County.

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 Van Wert County. Evidence for the earlier glaciations is lacking or obscured.

The unconsolidated (glacial) deposits in Van Wert 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 Van Wert County, drift is thinner in areas of the lake plain in the northern part of the county, and thickens to the south and west. Drift is thickest in the buried valleys associated with the Teays River System in south central Van Wert County. Along the northern edge of Van Wert County there are areas where the drift is very thin and the bedrock is very 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 much of the pre-existing ground moraine away.

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 some of the tills were deposited in a water-rich environment in Van Wert County. These types of tills are associated with ancestral Lake Maumee in the northern fringe of the county. These types of tills are deposited when a relatively thin ice sheet alternately floats and grounds. The floating and grounding actions depend on the water level of the lake and thickness of the ice sheet. Such tills may more closely resemble lacustrine deposits (Forsyth, 1965).

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.

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 roughly extends along a west to east line in southern Van Wert County

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 Van Wert County tend to be relatively low elevation and are at elevations just above the current floodplain. The majority of the alluvium in Van Wert 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, the northerly flowing streams have a very low gradient and cannot carry coarse sediments well except following major storm or flood events. The alluvial deposits associated with the St. Mary's River tend to be much more silty and contain some fine sand.

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.

In the lake plain area of Van Wert County, lacustrine deposits are limited to the northern fringe of the county. These deposits tend to be very clayey and are typically thin. The surficial material is more typically wave-planed till or fine sand associated with beaches, dunes, and deltas. South of the boundary of the lake plain, isolated pockets of thin lacustrine clay or areas of wave-planed till exist at the surface. These pockets may indicate some areas of greater erosion. Conversely, they may reflect areas of shallow ponding that allowed thin lacustrine deposits to accumulate in low-lying areas.

The beach levels in Van Wert County are all associated with ancestral Lake Maumee. Elevations for these features occur between 755 ft and 800 ft above mean seal level (msl). A distinct band of beach ridges lies along the outer edge of the lake plain of ancestral Lake Maumee. This line of ridges extends from the northwest to the southeast, roughly following a line from Dixon, to Convoy, to Van Wert city, to Middlepoint. 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 forms 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 Van Wert County belongs to the Silurian System. Carbonate (limestone and dolomite) bedrock underlies the entire county. Table 9 summarizes the bedrock stratigraphy found in Van Wert 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 in eastern Van Wert 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 western Van Wert County, the uppermost formation is the Salina Group. The difference is that in eastern Van Wert 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 Van Wert 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 Van Wert County. These rocks become progressively deeper to the east. The Lockport Group rocks were associated with tidal reefs deposited in warm, high-energy shallow seas.

Ground Water Resources

Ground water in Van Wert County is obtained primarily from consolidated (bedrock) aquifers. Sand and gravel (unconsolidated) aquifers are typically limited to deep layers of sand and gravel occurring in the main trunk of the deep buried valley system found in south

Table 9. Bedrock Stratigraphy of Van Wert County.

System	Group/Formation (Symbol)	Lithologic Description
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 western 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.
	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. Present in the subsurface across the county.

central Van Wert County. These deeper sand and gravel units are associated with glacial complexes that overlie the former channels belonging to the Teays River System. Glacial complexes are areas of thick glacial drift that are predominantly comprised of dense till or lacustrine deposits (ODNR, Division of Water, Glacial State Aquifer Map, 2000). Complexes typically lack surface expression, unlike end moraines and some buried valleys. Modern perennial streams usually do not overlie complexes. Wells yielding 5 to 25 gpm can be obtained from sand and gravel lenses interbedded with fine-grained glacial till or lacustrine (lake) deposits. These wells are suitable for domestic and farm purposes.

The carbonate bedrock aquifer is an important regional aquifer for most of northwestern and north central Ohio and underlies all of Van Wert County (ODNR, Div. of Water, 1970 and Schmidt, 1982). Completed water wells typically penetrate multiple bedrock units. Yields exceeding 100 gpm are available from deep, large diameter wells drilled into the Silurian Salina Group in northwestern Van Wert County, the Tymochtee and Greenfield Dolomites in northeastern Van Wert County, and from the Lockport Dolomite throughout the county (ODNR, Div. of Water, Open File, Bedrock State Aquifer Map, 2000, ODNR, Div. of Water, 1970, and Schmidt, 1982). Farther south in Van Wert County, the thickness of the Salina Group and the Tymochtee and Greenfield Dolomites decrease appreciably, and the yields decrease correspondingly. However, higher yields may still be obtained by completing the wells deeper into the Lockport Dolomite. This was noticed specifically in the vicinity of Delphos and the city of Van Wert, where shallower wells had relatively poor yields (less than 10 gpm), while deeper wells were better producers. 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 (Eagon, 1983). Deeper wells are more likely to contain highly mineralized water and have objectionable water quality. Eagon (1973) and Schmidt (1982) cautioned that high pumping rates might reduce the yields of new wells in the vicinity of the city of Van Wert.

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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 3,200 water well log records are on file for Van Wert County. Data from roughly 1,600 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 Van Wert County* (Schmidt, 1982) 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 Mercer County (Sugar, 1989), Allen County (Angle and Barrett, 2005a), Auglaize County (Angle and Barrett, 2005b), and Putnam County (Angle, 2006) were used as a guideline. Localized studies providing information on the depth to water included Eagon (1973) and Petty et al. (1989). Trends noted in these areas could be extrapolated to surrounding areas. 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 parts of the 7F-Glacial Lake Plain Deposits and 7Fd-Wave-eroded Lake Plain hydrogeologic settings in northeastern Van Wert County. In these settings, the limestone aquifer is covered with thin drift and is close to the ground surface. Depths to water of 5 to 15 feet (9) were also utilized for the alluvial settings in Van Wert County. Depths to water of 15 to 30 feet (7) were used for most areas of ground moraine associated with the 7Ac-Glacial Till over Limestone setting and are common in eastern and northern Van Wert County. Depth to water of 15 to 30 feet (7) was also used for portions of the 7Fd-Wave-eroded Lake Plain and the 7H-Beaches, Beach Ridges, and Sand Dunes setting. Depths to water of 30 to 50 feet (5) were utilized for the majority of the 7C-Moraine settings for the Wabash Moraine. The cover of glacial till overlying the aquifer was thicker in most of these areas. Depths to water of 50 to 75 feet (3) were utilized for some higher elevation crests of the end moraines.

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 Mercer County (Sugar, 1989), Allen County (Angle and Barrett, 2005a), Auglaize County (Angle and Barrett, 2005b), and Putnam County (Angle, 2006) were used as a guideline.

Values of 7 to 10 inches per year (8) were limited to the 7Ed-Alluvium over Glacial Till setting that locally contains highly permeable layers of sand and gravel. Values of 4 to 7 inches per year (6) were used for areas with moderate recharge. This range of recharge values was selected for all remaining settings in Van Wert County.

Aquifer Media

Information on evaluating aquifer media was obtained from the *Ground-Water Resources of Van Wert County* (Schmidt, 1982). 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 Mercer County (Sugar, 1989), Allen County (Angle and Barrett, 2005a), Auglaize County (Angle and Barrett, 2005b), and Putnam County (Angle, 2006) were used as a guideline. 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 Eagon (1973 and 1983) and Petty et al. (1989), 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 Van Wert County. A rating of (8) was selected for limited areas of the Silurian Limestone bordering Mercer County along the southern edge of Van Wert County. Limestone in Mercer County was evaluated as being more highly fractured. A rating of (7) was applied to all of the remaining Silurian limestone aquifers in Van Wert County.

Sand and gravel was evaluated as the aquifer for limited areas of southern Van Wert County. Most of the sand and gravel aquifers are associated with the buried valleys that reflect the tributaries of the ancestral Teays River System. Sand and gravel in these 7D-Buried Valley settings and in immediately adjacent 7J-Glacial Complex settings were assigned an aquifer rating of (7). Sand and gravel was selected as the aquifer for the 7Af-Sand and Gravel Interbedded in Glacial Till setting and was given a rating of (6). Yields and drawdown data reported on water well log records were also used to help evaluate the sand and gravel deposits.

An arbitrary decision was made to evaluate the trunk or axis of the Teays River Valley as being in the 7D-Buried Valley hydrogeologic setting and adjacent areas with thick drift were evaluated as 7J-Glacial Complex or 7C-End Moraine settings depending upon their surficial geomorphology.

Soils

Soils were mapped using the data obtained from the *Soil Survey of Van Wert County* (Brock and Tornes, 1972). 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 was placed upon determining the most restrictive layer. The soils of Van Wert County showed a high degree of variability. This is a reflection of the parent material. Table 10 is a list of the soils, parent materials, setting, and corresponding DRASTIC values for Van Wert County.

Shrink-swell (non-aggregated) clays (7) were selected for the 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. Sandy loam (6) soils were also found on a few high terraces north of the St. Mary's River and along a limited number of areas adjacent to end moraines. 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. Clay loam (3) soils were evaluated for the majority of the county including till overlying ground moraine and end moraine areas. This includes the 7Ac-Till over Limestone and the 7C-Moraine settings.

Topography

Topography, or percent slope, was evaluated using U.S.G.S. 7-1/2 minute quadrangle maps and the *Soil Survey of Van Wert County* (Brock and Tornes, 1972). Slopes of 0 to 2 percent (10) are widespread in Van Wert County and were selected for the 7Fd-Wave-eroded Lake Plain setting, alluvial and floodplain deposits, and flatter-lying portions of ground moraine. Slopes of 2 to 6 percent (9) are mostly found in southwestern Van Wert County and reflect areas of both slightly rolling ground moraine and end moraines. The slopes of 2 to 6 percent (9) typically occur with the Wabash Moraine or flank the St. Mary's River. Slopes of 2 to 6 percent (9) are also associated with some beach ridges capped by dunes.

Table 10. Van Wert County soils

Soil Name	Parent Material/ Setting	DRASTIC Rating	Soil Media
Belmore	Beach ridges	6	Sandy loam
Blount	Clayey till	3	Clay loam
Colwood	Fine beach, deltaic	5	Loam
Defiance	Clayey alluvium	7	Shrink-swell clay
Digby	Beach ridge	6	Sandy loam
Eel	Alluvium	4	Silt loam
Elliot	Clayey till	3	Clay loam
Haney	Beach ridge	6	Sandy loam
Haskins	Beach sand over till	5	Loam
Hoytville	Wave-planed till	7	Shrink-swell clay
Kibbie	Fine deltaic sand	5	Loam
Latty	Clayey lacustrine	7	Shrink-swell clay
McGary	Clayey lacustrine	7	Shrink-swell clay
Mermill	Sandy beach over lacustrine	5	Loam
Milgrove	Thin outwash over till	5	Loam
Montgomery	Clayey lacustrine	7	Shrink-swell clay
Morley	Clayey till	3	Clay loam
Nappanee	Water-modified till	7	Shrink-swell clay
Pewamo	Clayey till, drainage ways	3	Clay loam
Rawson	Thin beach sand over till	5	Loam
St. Clair	Clayey lacustrine	7	Shrink-swell clay
Shoals	Alluvium	4	Silt loam
Sloan	Alluvium	4	Silt loam
Toledo	Clayey lacustrine	7	Shrink-swell clay
Wabasha	Clayey alluvium	7	Shrink-swell clay

Impact of the Vadose Zone Media

Information on evaluating vadose zone media was obtained primarily from the *Ground-Water Resources of Van Wert County* (Schmidt, 1982) 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 Mercer County (Sugar, 1989), Allen County (Angle and Barrett, 2005a), Auglaize County (Angle and Barrett, 2005b), and Putnam County (Angle, 2006) were used as a guideline. The ODNR, Division of Water, Glacial State Aquifer Map (2000) and Bedrock State Aquifer Map (2000) were important sources of vadose zone media data. The *Soil Survey of Van Wert County* (Brock and Tornes, 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.

Additional site-specific information on vadose zone media including reports by Eagon (1973 and 1983) and Petty et al. (1989) provided valuable information.

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

Limestone/fractured till with a vadose zone media rating of (6) was selected for parts of Van Wert County where the till covering the underlying limestone was thin, averaging from roughly 8 to 24 ft. Vadose zone media of limestone with silt, clay, and fine sand was selected for a stream in eastern Van Wert County and given a rating of (6). This vadose zone media was limited to a 7Ec-Alluvium over Sedimentary Rocks setting where the stream had eroded down close to the surface of the limestone, leaving less than fifteen feet of alluvium. Glacial till was given vadose zone media ratings of (5), (4), or (3). A vadose zone media rating of (5) was used for most areas where the thickness of till was thin to moderate and the depth to water was shallow. In these areas, it was assumed that the majority of the till was weathered and fractured. The till has a moderately fine-grained texture that weathered into clay loam soils. A vadose zone media rating of (4) was assigned to areas with a greater thickness of till and with moderate depths to water. Ratings of (4) were most common in the 7C-End Moraine setting. A vadose zone media rating of (3) was selected for areas with till over 100 feet in thickness. Ratings of (3) were limited to the 7J-Glacial Complex setting.

A vadose zone media rating of (6) was chosen for sand and gravel with significant silt and clay for the majority of the areas with beach ridges and dunes in northern Van Wert County. Vadose zone ratings of (7) or (6) for sand and gravel with significant silt and clay were used for some areas featuring coarse alluvium or terraces along the St. Mary’s River. 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 Van Wert County. Silt and clay with a rating of (4) was chosen for clayey lacustrine sediments that had weathered into shrink-swell clay soils in northeastern Van Wert County. Silt and clay with a vadose zone rating of (3) or (4) was used along the border of Mercer County. Silt and clay was utilized to represent glacial till as till was not recognized as a separate vadose zone media in Mercer County at the time it was mapped (Sugar, 1989).

The *Soil Survey of Van Wert County* (Brock and Tornes, 1972) 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 northern and eastern Van Wert County that serves as a transition between ground moraine (the 7Ac-Glacial Till over Limestone setting) and the 7F-Glacial Lake Plain Deposits.

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 Van Wert County* (Schmidt, 1982). 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 Mercer County (Sugar, 1989), Allen County (Angle and Barrett, 2005a), Auglaize County (Angle and Barrett, 2005b), and Putnam County (Angle, 2006) were used as a 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 report by Petty et al. (1989). 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. All sand and gravel aquifers were assigned a hydraulic conductivity range of 300-700 gpd/ft^2 (4). All limestone aquifers were assigned a hydraulic conductivity range of 300-700 gpd/ft^2 (4).

APPENDIX B

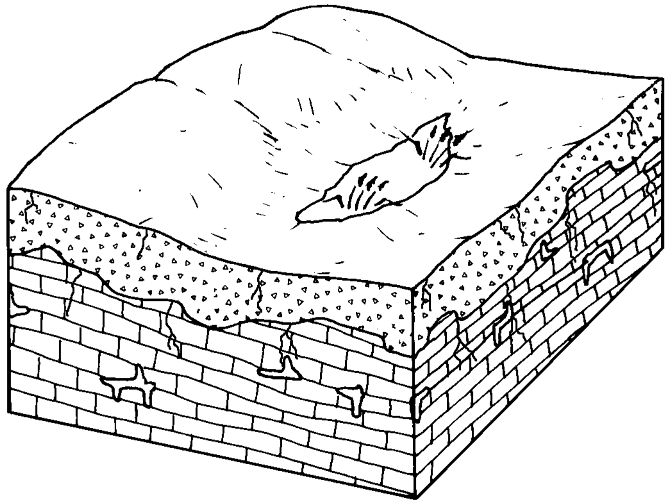
DESCRIPTION OF HYDROGEOLOGIC SETTINGS AND CHARTS

Ground water pollution potential mapping in Van Wert County resulted in the identification of ten 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 11. Computed pollution potential indexes for Van Wert County range from 107 to 165.

Table 11. Hydrogeologic settings mapped in Van Wert County, Ohio

Hydrogeologic Settings	Range of GWPP Indexes	Number of Index Calculations
7 Ac-Glacial till over limestone	115-148	19
7 Af-Sand and gravel interbedded in glacial till	130	1
7 C-Moraine	107-138	8
7 D-Buried valley	112-135	4
7 Ec-Alluvium over sedimentary rock	143-152	6
7 Ed-Alluvium over glacial till	165	1
7 F-Glacial lake plain deposits	146	1
7 Fd-Wave-eroded lake plain	126-146	3
7 H-Beaches, beach ridges, and sand dunes	141-153	5
7 J-Glacial complex	112-123	5

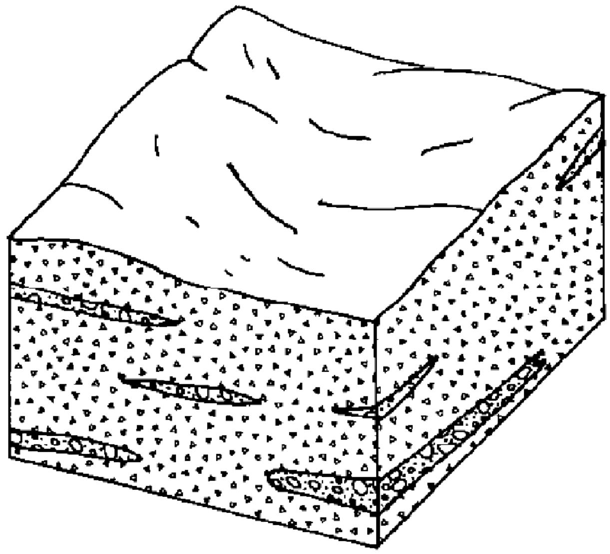
The following information provides a description of each hydrogeologic setting identified in the county, a block diagram illustrating the characteristics of the setting, and a listing of the charts for each unique combination of pollution potential indexes calculated for each setting. The charts provide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



7Ac-Glacial Till over Limestone

This hydrogeologic setting is common in western, southern, and central Van Wert County. The area is characterized by flat-lying topography and low relief associated with ground moraine. The setting basically occupies a broad area between the Lake Plain and the Fort Wayne Moraine. A smaller area of ground moraine is found south of the Fort Wayne Moraine in the southwestern corner of the county. The vadose zone consists primarily of silty to clayey glacial till. The till may be fractured or jointed, particularly in areas where it is predominantly thin and weathered. Where the till is very thin, fractured limestone is considered to be the vadose zone media, either partially or entirely. The aquifer is composed of fractured Silurian limestones and dolomites. These carbonate rocks may contain significant solution features. Depth to water is typically shallow to moderate, ranging from 15 to 50 feet. Soils typically are clay loams derived from till. Maximum ground water yields greater than 100 gpm are possible from the Silurian Lockport, Tymochtee, Greenfield and Salina Groups in Van Wert County. Recharge is moderate due to the clayey nature of the soils and vadose zone and the relatively shallow depth to water and permeable nature of the bedrock aquifer. Recharge rates increase somewhat where the limestone bedrock is closer to the ground surface.

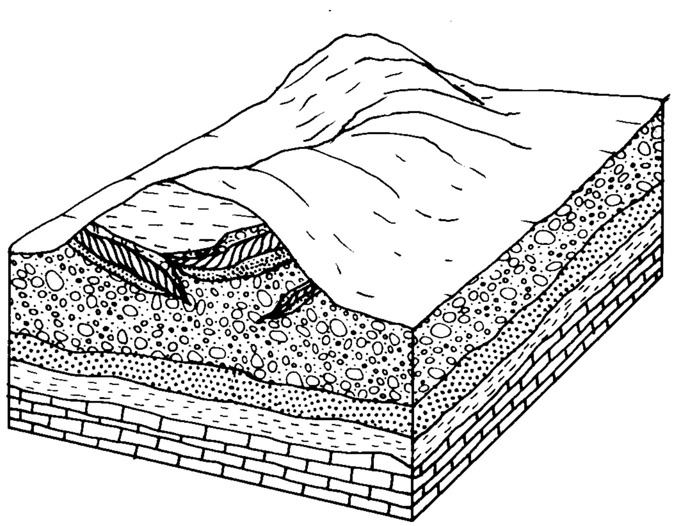
GWPP index values for the hydrogeologic setting of Glacial Till over Limestone range from 115 to 148, with the total number of GWPP index calculations equaling 19.



7Af-Sand and Gravel Interbedded in Glacial Till

This hydrogeologic setting is limited to a small pocket in the southeastern corner of Van Wert County. This area is comprised of a cluster of water wells that had been completed in relatively shallow lenses of sand and gravel. The area is characterized by flat lying topography and low relief. The setting is commonly associated with areas of ground moraine. The area is surrounded by the 7Ac-Till over Limestone setting that lacks the sand and gravel lenses and relies upon the underlying limestone aquifer. 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 shallow, averaging less than 30 feet. Soil is a clay loam. The aquifer consists of thin lenses of sand and gravel interbedded in the glacial till. Ground water yields range from 5 to 25 gpm. Recharge is moderate due to the relatively low permeability of the clayey soils and vadose zone material and the relative shallow depth to the sand and gravel aquifers.

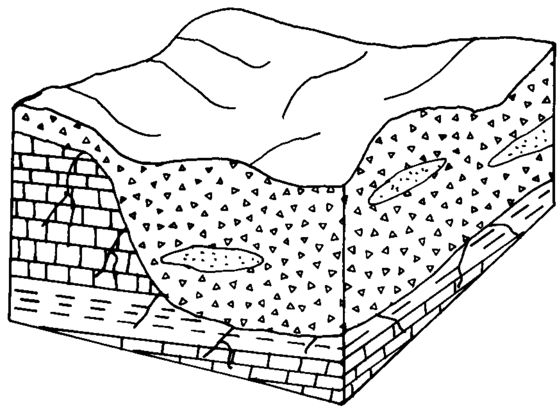
The GWPP index value for the hydrogeologic setting of Sand and Gravel Interbedded in Glacial Till is 130, with the total number of GWPP index calculations equaling 1.



<u>7C-Moraine</u>

This hydrogeologic setting consists of portions of the Fort Wayne End Moraine that overlie the southwestern and southeastern corners of Van Wert County. This setting is characterized by hummocky to rolling topography. Relief tends to become steeper near the margins of the moraine, especially to the south, bordering the St. Mary's River. The aquifer consists of Silurian limestone and dolomite bedrock. Maximum ground water yields greater than 100 gpm are possible from the Silurian Lockport, Tymochtee, Greenfield, and Salina Groups. 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 variable and depends primarily upon how deep the underlying aquifer is. Depths to water increase along the central axis or ridge of the end moraines. Soils are commonly clay loams. Recharge is moderate to low depending upon how thick the till is and how deep the underlying limestone is. The end moraines are the primary local sources of recharge.

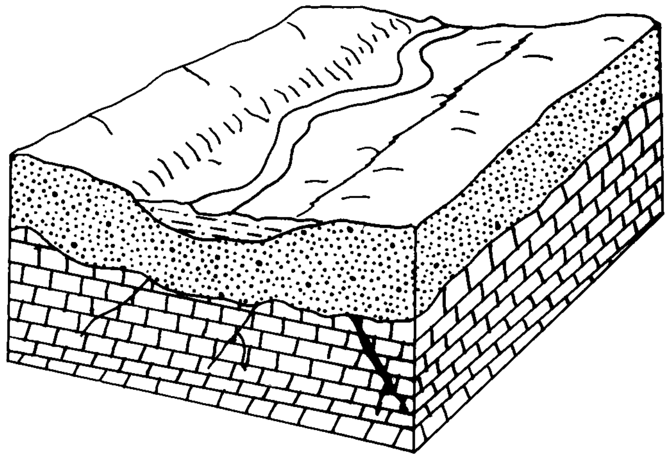
GWPP index values for the hydrogeologic setting of Moraine range from 107 to 138, with the total number of GWPP index calculations equaling 8.



<u>7D-Buried Valley</u>

This hydrogeologic setting consists of a narrow, north-south running band that extends into southern Van Wert County form Mercer County. These buried valleys mark the ancestral channel of a major tributary of the Teays River System. The surface topography is flat and has low relief. Modern streams typically do not overly these deposits. The setting is characterized by a thick sequence of glacial till. The aquifer consists of thinner, less continuous lenses of sand and gravel interbedded with thicker sequences of fine-grained glacial till. Thin layers of alluvial or lacustrine silt, clay, or fine sand may also be present at greater depths. The setting is similar to the 7J-Glacial Complex except that the sand and gravel lenses are more numerous, more continuous in lateral extent, and constitute the aquifer. The total drift thickness also tends to be greater than in the 7J-Glacial Complex setting. In the 7J setting, the underlying limestone is more commonly the aquifer. Yields from the sand and gravel lenses are commonly less than 25 gpm. Soils are variable. Depths to water are shallow to moderate averaging less than 50 feet. Recharge is typically moderate due to the fine-grained nature of the soils and vadose zone media and the relatively shallow depth to the sand and gravel aquifers.

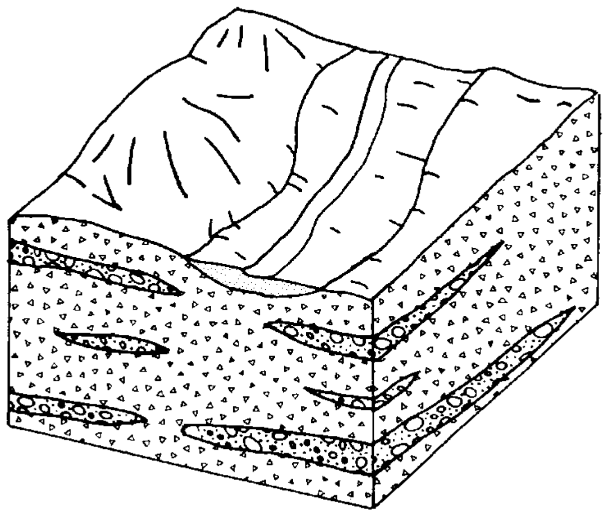
GWPP index values for the hydrogeologic setting of Buried Valley range from 112-135, with the total number of GWPP index calculations equaling 4.



7Ec-Alluvium over Sedimentary Rock

This hydrogeologic setting is common throughout Van Wert County. This hydrogeologic setting is comprised of flat-lying floodplains and stream terraces containing thin to moderate thicknesses of modern alluvium. The aquifers consist of Silurian limestones and dolomites. The vadose zone consists of silty to clayey alluvial deposits overlying thin glacial till. In some places, the limestone bedrock is close enough to the surface to comprise the vadose zone media. 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 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 Van Wert County. Recharge is typically moderately high 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.

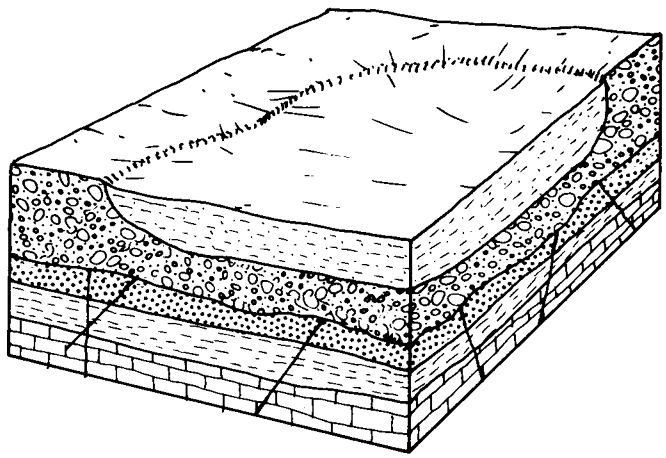
The GWPP index values for the hydrogeologic setting Alluvium over Sedimentary Rocks range from 143 to 152, with the total number of GWPP index calculations equaling 6.



7Ed-Alluvium over Glacial Till

This hydrogeologic setting is limited to a small area adjacent to the St. Mary's River extending northward from Mercer 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 alluvial deposits are coarser in nature and the underlying till is thicker. 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 silt loams. The aquifer consists of Silurian limestone and dolomite bedrock. Maximum ground water yields greater than 100 gpm are possible from the Silurian Lockport Group. 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.

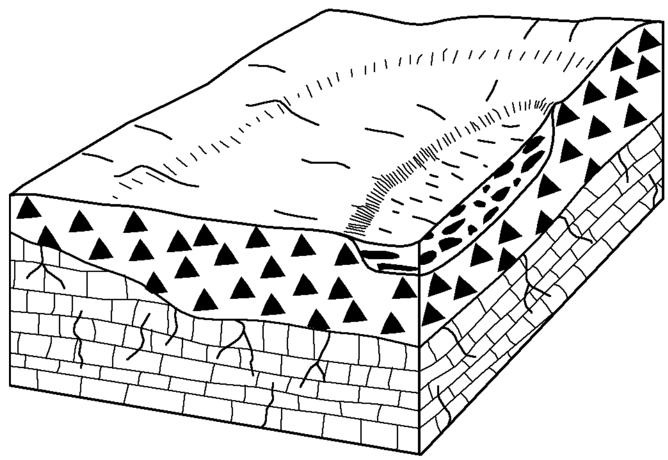
The GWPP index value for the hydrogeologic setting Alluvium Over Glacial Till is 165, with the total number of GWPP index calculations equaling 1.



7F Glacial Lake Plain Deposits

This hydrogeologic setting occupies a small area in northeastern Van Wert County, and 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 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. Depth to water is shallow, averaging less than 20 feet. Soils are shrink-swell (aggregated) clays. 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. 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.

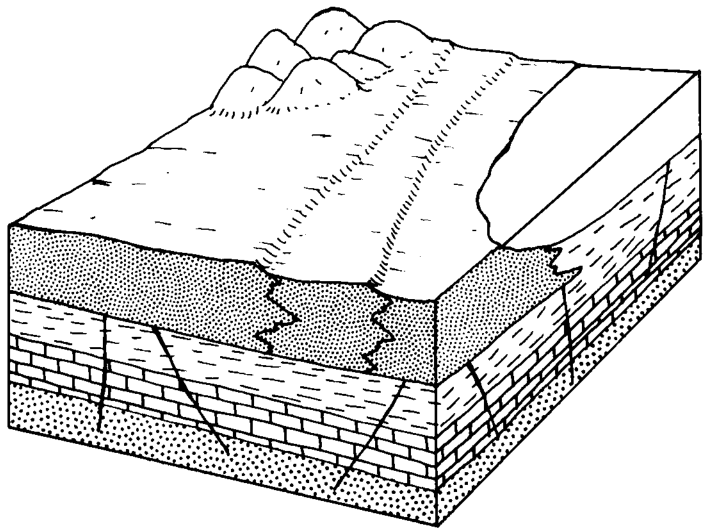
The GWPP index value for the hydrogeologic setting of Glacial Lake Plains Deposits is 146, with the total number of GWPP index calculations equaling 1.



7Fd-Wave-eroded Lake Plain

This hydrogeologic setting is characterized by very flat-lying topography caused by wave-erosion of glacial Lake Maumee. The setting forms a broad band extending across northern Van Wert County, and consists of thin, patchy silty to clayey lacustrine deposits and wave-eroded, "water-modified" 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. Depth to water is commonly very shallow. 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.

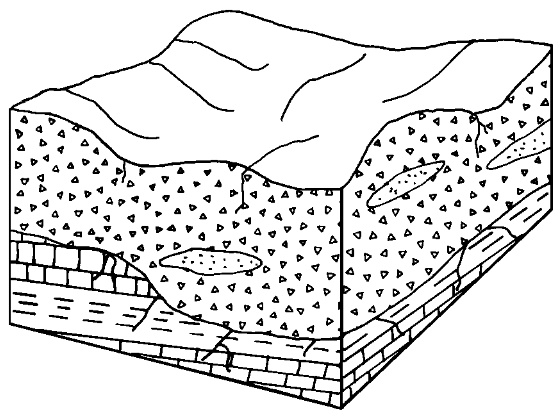
GWPP index values for the hydrogeologic setting of Wave-eroded Lake Plain range from 126 to 146, with the total number of GWPP index calculations equaling 3.



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 commonly lies on the southern edge of the lake plain and roughly fringes the northern border of the ground moraine. 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. Depth to water is typically fairly shallow. Soils are loams or sandy loams 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 141 to 153, with the total number of GWPP index calculations equaling 5.



7J-Glacial Complex

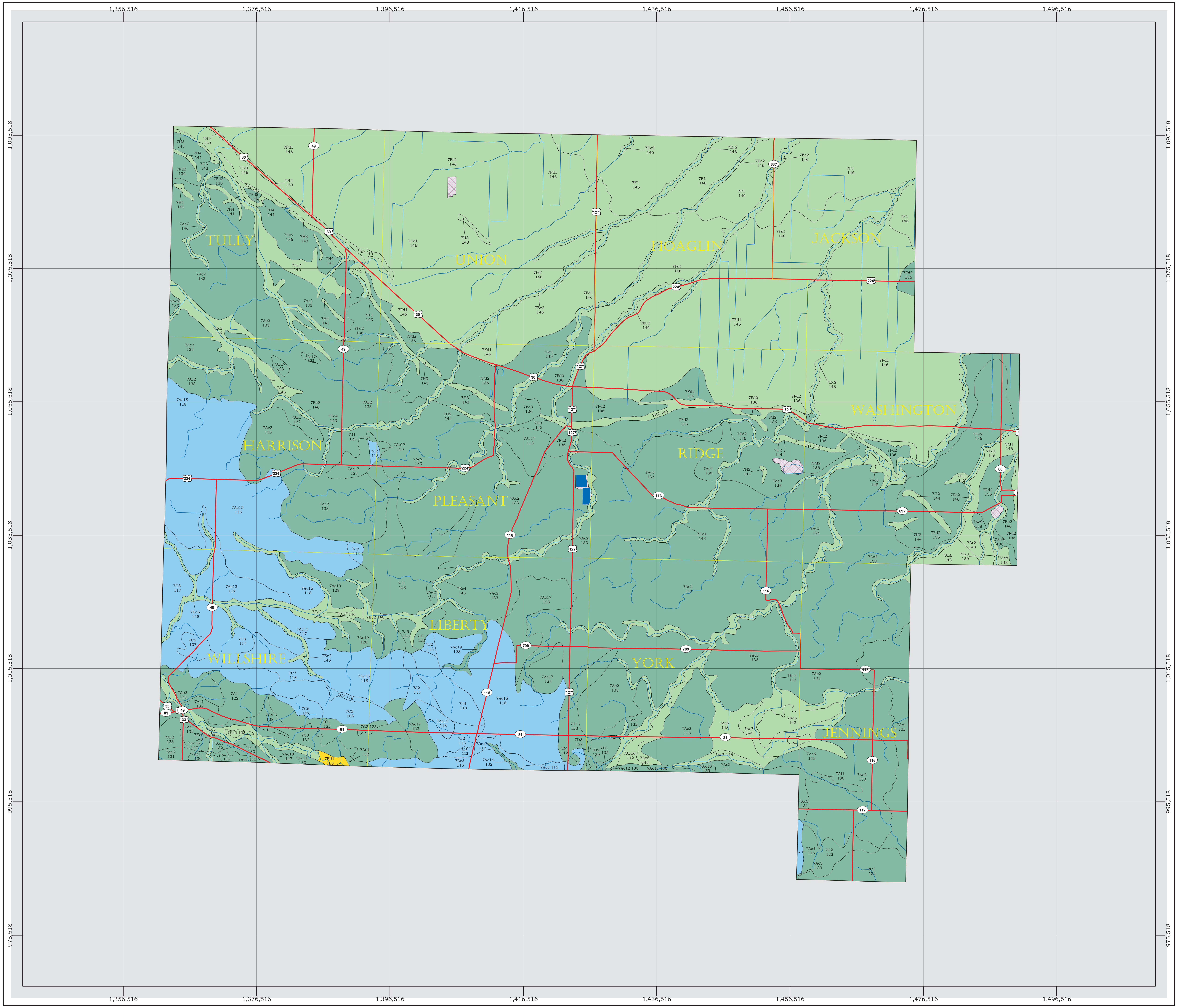
This setting is found in central Van Wert County. It is comprised predominantly of thick glacial till that lies just north of the 7D-Buried Valley setting. The surface topography is flat and has low relief. Modern streams typically do not overly these deposits. The aquifer consists of thinner, less continuous lenses of sand and gravel interbedded with thicker sequences of fine-grained glacial till. Wells completed in the sand and gravel commonly yield less than 25 gpm. Wells that do not encounter adequate-yielding sand and gravel deposits are completed in the limestone bedrock. Maximum ground water yields greater than 100 gpm are possible from the Silurian Lockport, Tymochtee, Greenfield and Salina Groups. The setting is similar to the 7D-Buried Valley except that the sand and gravel lenses are less common, less continuous in lateral extent, and the overall thickness of drift is somewhat less. Soils are usually clay loams derived from the overlying glacial till. Depths to water are shallow to moderate, averaging less than 50 feet. Recharge is typically moderate to low due to the fine-grained nature of the soils and vadose zone media, and the moderate depth to the limestone aquifers.

GWPP index values for the hydrogeologic setting of Glacial Complex range from 112 to 123, with the total number of GWPP index calculations equaling 5.

Table 12. 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_
7Ac1	15-30	4-7	limestone	Clay Loam	2-6	till	300-700	132	150
7Ac2	15-30	4-7	limestone	Clay Loam	0-2	till	300-700	133	153
7Ac3	30-50	4-7	limestone	Clay Loam	2-6	silt and clay	300-700	115	135
7Ac4	30-50	4-7	limestone	Clay Loam	0-2	silt and clay	300-700	116	138
7Ac5	15-30	4-7	limestone	Clay Loam	0-2	silt and clay	300-700	131	152
7Ac6	5-15	4-7	limestone	Clay Loam	0-2	till	300-700	143	163
7Ac7	5-15	4-7	limestone	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	146	179
7Ac8	5-15	4-7	limestone	Clay Loam	0-2	lst-frac till	300-700	148	167
7Ac9	15-30	4-7	limestone	Clay Loam	0-2	lst-frac till	300-700	138	157
7Ac10	15-30	4-7	limestone	Shrink/Swell Clay	0-2	silt and clay	300-700	139	172
7Ac11	15-30	4-7	limestone	Clay Loam	2-6	silt and clay	300-700	130	149
7Ac12	15-30	4-7	limestone	Shrink/Swell Clay	2-6	silt and clay	300-700	138	169
7Ac13	30-50	4-7	limestone	Clay Loam	2-6	till	300-700	117	136
7Ac14	15-30	4-7	limestone	Silty Loam	2-6	silt and clay	300-700	132	154
7Ac15	30-50	4-7	limestone	Clay Loam	0-2	till	300-700	118	139
7Ac16	5-15	4-7	limestone	Clay Loam	2-6	till	300-700	142	160
7Ac17	30-50	4-7	limestone	Clay Loam	0-2	till	300-700	123	143
7Ac18	5-15	4-7	limestone	Silty Loam	2-6	silt and clay	300-700	147	168
7Ac19	15-30	4-7	limestone	Clay Loam	0-2	till	300-700	128	149
7Af1	15-30	4-7	sand and gravel	Clay Loam	0-2	till	300-700	130	150
7C1	30-50	4-7	limestone	Clay Loam	2-6	till	300-700	122	140
7C2	30-50	4-7	limestone	Clay Loam	0-2	till	300-700	123	143
7C3	15-30	4-7	limestone	Clay Loam	2-6	till	300-700	132	150
7C4	15-30	4-7	limestone	Sandy Loam	2-6	till	300-700	138	165
7C5	50-75	4-7	limestone	Clay Loam	0-2	till	300-700	108	129
7C6	50-75	4-7	limestone	Clay Loam	2-6	till	300-700	107	126
7C7	30-50	4-7	limestone	Clay Loam	0-2	till	300-700	118	139
7C8	30-50	4-7	limestone	Clay Loam	2-6	till	300-700	117	136
7D1	15-30	4-7	sand and gravel	Shrink/Swell Clay	2-6	silt and clay	300-700	135	166
7D2	15-30	4-7	sand and gravel	Silty Loam	0-2	silt and clay	300-700	130	154
7D3	15-30	4-7	sand and gravel	Clay Loam	2-6	silt and clay	300-700	127	146
7D4	30-50	4-7	sand and gravel	Clay Loam	2-6	silt and clay	300-700	112	132

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	Silty Loam	0-2	ls/sl-cl-sd	300-700	150	172
7Ec2	5-15	4-7	limestone	Shrink/Swell Clay	0-2	silt and clay	300-700	146	179
7Ec3	5-15	4-7	limestone	Silty Loam	0-2	sd + gvl w/sl + cl	300-700	150	172
7Ec4	5-15	4-7	limestone	Clay Loam	0-2	silt and clay	300-700	143	163
7Ec5	5-15	4-7	limestone	Loam	0-2	sd + gvl w/sl + cl	300-700	152	177
7Ec6	5-15	4-7	limestone	Silty Loam	0-2	silt and clay	300-700	145	168
7Ed1	5-15	7-10	limestone	Silty Loam	2-6	sd + gvl w/sl + cl	300-700	165	184
7F1	5-15	4-7	limestone	Shrink/Swell Clay	0-2	silt and clay	300-700	146	179
7Fd1	5-15	4-7	limestone	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	146	179
7Fd2	15-30	4-7	limestone	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	136	169
7Fd3	30-50	4-7	limestone	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	126	159
7H1	15-30	4-7	limestone	Loam	0-2	sd + gvl w/sl + cl	300-700	142	167
7H2	15-30	4-7	limestone	Sandy Loam	0-2	sd + gvl w/sl + cl	300-700	144	172
7H3	15-30	4-7	limestone	Sandy Loam	2-6	sd + gvl w/sl + cl	300-700	143	169
7H4	15-30	4-7	limestone	Loam	2-6	sd + gvl w/sl + cl	300-700	141	164
7H5	5-15	4-7	limestone	Sandy Loam	2-6	sd + gvl w/sl + cl	300-700	153	179
7J1	15-30	4-7	limestone	Clay Loam	0-2	till	300-700	123	145
7J2	30-50	4-7	limestone	Clay Loam	0-2	till	300-700	113	135
7J3	30-50	4-7	limestone	Clay Loam	2-6	till	300-700	112	132
7J4	30-50	4-7	sand and gravel	Clay Loam	0-2	till	300-700	113	135
7J5	15-30	4-7	sand and gravel	Clay Loam	0-2	till	300-700	123	145



Ground Water Pollution Potential of Van Wert County

by

Michael P. Angle
Ohio Department of Natural Resources
Division 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

Ohio Department of Natural Resources
Division of Water
Ground Water Resources Section
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May 2007
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