GROUND WATER POLLUTION POTENTIAL
OF WARREN COUNTY, OHIO

BY

THE CENTER FOR GROUND WATER MANAGEMENT

WRIGHT STATE UNIVERSITY

AND

THE OHIO DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATER

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ABSTRACT

A ground water pollution potential mapping program for Ohio has been developed under the direction of the Division of Water, Ohio Department of Natural Resources, using the DRASTIC mapping process. The DRASTIC system consists of two major elements: the designation of mappable units, termed hydrogeologic settings, and the superposition of a relative rating system for pollution potential.

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

Ground water pollution potential mapping in Warren County resulted in a map with symbols and colors which illustrate areas of varying ground water contamination vulnerability. Four hydrogeologic settings were identified in Warren County with computed ground water pollution potential indexes ranging from 61 to 202.

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 Warren 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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Map preparation and review:	Ronald G. Schmidt Lori L. Wenz James A. Wasserbauer
Map print production and review:	David Orr Michael Hallfrisch
Report production and review:	Michael Angle Lori L. Wenz Michael Hallfrisch
Report editing:	Rebecca J. Petty William Mattox
Desktop publishing and report design:	David Orr

INTRODUCTION

The need for protection and management of ground water resources in Ohio has been clearly recognized. About 42 per cent of Ohio citizens rely on ground water for their drinking and household uses from both municipal and private wells. Industry and agriculture also utilize significant quantities of ground water for processing and irrigation. In Ohio, over 700,000 rural households depend on private wells; approximately 5,000 of these wells exist in Warren County.

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

Considerable interest in the mapping program followed successful production of a demonstration county map and led to the inclusion of the program as a recommended initiative in the Ohio Ground Water Protection and Management Strategy (Ohio EPA, 1986). Based on this recommendation, the Ohio General Assembly funded the mapping program. A dedicated mapping unit has been established in the Division of Water, Ground Water Resources Section to implement the ground water pollution potential mapping program on a county-wide 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 partly 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 more or less 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 results of 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 Warren 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 to assist 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 more or less suitable for land 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 also 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 also 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 also 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.

Other beneficial uses of the pollution potential maps will be recognized by individuals in the county who are familiar with specific land use and management problems. Planning commissions and zoning boards can use these maps to help make informed decisions about the development of areas within their jurisdiction. Developments proposed to occur 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

The system chosen for implementation of a ground water pollution potential mapping program in Ohio, DRASTIC, was developed by the National Water Well Association for the United States Environmental Protection Agency. 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. The vulnerability of an area 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 which 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 assuming a contaminant with the mobility of water, 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 Warren County. Inherent within each hydrogeologic setting are the physical characteristics which 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

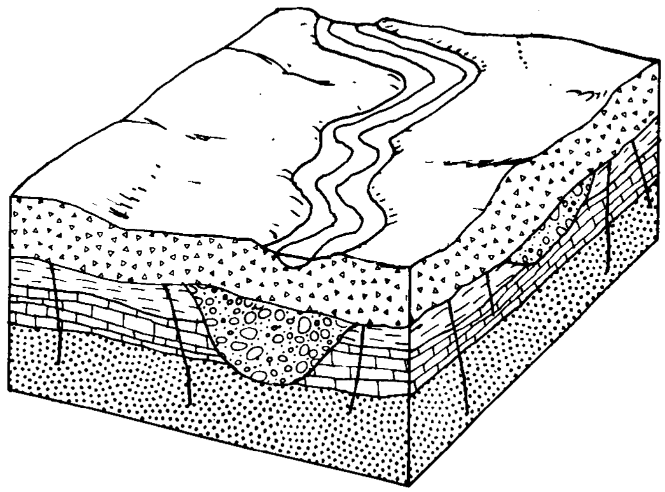
C - Conductivity (Hydraulic) of the Aquifer

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

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



7D Buried Valley

This hydrogeologic setting is characterized by thick deposits of sand, gravel, and sorted till which have been deposited in an incised pre-glacial river valley by glacial meltwaters. These units are thick and permeable, yielding large quantities of ground water. Large rivers or creeks (e.g., Great Miami, and Todd Fork) overlie the buried valleys and thus are in hydraulic connection with the subsurface. Soils of loam and sand trail the buried valleys. Recharge to the valley fill material is high to moderate. Depth to water in this setting is quite shallow, approximately 5-15 feet. Depth to water may also be high in areas of small creeks where a majority of the till has not been eroded.

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

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

Topography refers to the slope of the land expressed as percent slope. The amount of slope in an area affects the likelihood that a contaminant will run off from an area 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 significantly impacts 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 judgement. 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 to be used 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
Massive Shale	1-3	2
Metamorphic / Igneous	2-5	3
Weathered Metamorphic / Igneous	3-5	4
Glacial Till	4-6	5
Bedded Sandstone, Limestone and Shale Sequences	5-9	6
Massive Sandstone	4-9	6
Massive Limestone	4-9	6
Sand and Gravel	4-9	8
Basalt	2-10	9
Karst Limestone	9-10	10
Weight: 3	Pesticide Weight: 3	

TABLE 5. RANGES AND RATINGS FOR SOIL MEDIA

SOIL MEDIA	
Range	Rating
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and / or Aggregated Clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Nonshrinking and Nonaggregated 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
Bedded Limestone, Sandstone, Shale	4-8	6
Sand and Gravel with significant Silt and Clay	4-8	6
Metamorphic/Igneous	2-8	4
Sand and Gravel	6-9	8
Basalt	2-10	9
Karst Limestone	8-10	10
Weight: 5	Pesticide Weight: 4	

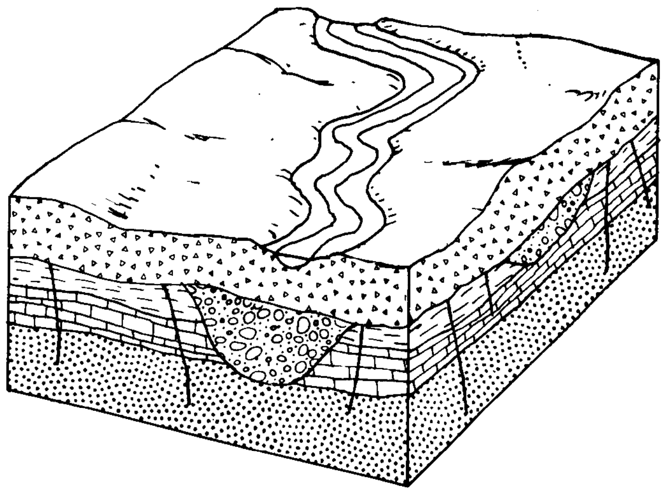
TABLE 8. RANGES AND RATINGS FOR HYDRAULIC CONDUCTIVITY

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

Integration of Hydrogeologic Settings and DRASTIC Factors

Figure 2 illustrates the hydrogeologic setting 7D1 Buried Valley, identified in mapping Warren 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 189. 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 65 to 223. The diversity of hydrogeologic conditions in Warren County produces settings with a wide range of vulnerability to ground water contamination. Calculated pollution potential indexes for the four settings identified in the county range from 61 to 202.

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 mapping in Warren 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 Warren County is included with this report.



SETTING 7D1		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand & Gravel	3	9	27
Soil Media	Loam	2	5	10
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand & Gravelw/sig Silt and Clay	5	7	35
Hydraulic Conductivity	2000+	3	10	30
		DRASTIC	INDEX	189

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

INTERPRETATION AND USE OF A GROUND WATER POLLUTION POTENTIAL MAP

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

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

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

Here the first number (7) refers to the major hydrogeologic region and the upper case letter (D) refers to a specific hydrogeologic setting. The following number (1) references a certain set of DRASTIC parameters that are unique to this setting and are described in the corresponding setting chart. The second number (189) 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 in an area.

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 map also includes information on the locations of selected observation wells. Available information on these observation wells is referenced in Appendix A, Description of the Logic in Factor Selection. Large man-made features such as landfills, quarries or strip mines have also been marked on the map for reference.

GENERAL INFORMATION ABOUT WARREN COUNTY

Warren County occupies an area of approximately 403 square miles in southwestern Ohio. It is bounded on the north by parts of Montgomery and Greene Counties, to the west by Butler and Hamilton Counties, on the east by Clinton County, and on the south by Clermont County. The county seat is Lebanon. The population of Warren County is approximately 114,000 (U.S. Dept. of Commerce, 1991).

Physiography

Warren County lies in the Till Plains section of the Central Lowlands physiographic province (Fenneman, 1938). The county is characterized by relatively flat-lying upland areas which have been dissected by streams. Valley sides are generally steep, particularly where bedrock is near the surface. The major rivers have broad, flat-bottomed valleys. The uplands are composed primarily of Ordovician shale and limestone bedrock covered by varying thicknesses of glacial till deposits.

Prior to glaciation the region was a gently rolling bedrock surface known as the Lexington Peneplain. This relatively even surface was interrupted by tributary stream valleys of the Teays drainage system.

The modern land surface is a result of glacial and post-glacial processes. Valleys reflect complex drainage changes spanning the Pleistocene Epoch. Till covering the flat-lying uplands of southeastern Warren County reflects the older Illinoian glaciation; whereas, the gently rolling uplands in northwestern Warren County reflect the most recent Wisconsinan glaciation.

End moraines in Warren County are not particularly prominent. End moraines are linear ridges which reflect a thickening of glacial deposits. Figure 4 depicts the distribution of end moraines within the county.

Moraine development is most noticeable in the Caeser Creek area of extreme northeastern Warren County. Elements of the Vandervort Moraine (Teller, 1967; Rosengreen, 1970; 1974) and Cuba Moraine (Goldthwait et al., 1961) are found south of Caesar Creek and an extension of the Hartwell Moraine exists north of Caesar Creek. Minor elements of the Hartwell Moraine also exist in central Warren County (Goldthwait et al., 1961). A minor element of the Camden Moraine is located in far northwestern Warren County (Goldthwait et al., 1961). With the exception of the Caesar Creek region, end moraines in Warren County are weakly developed and are obscured by the highly stream-dissected nature of the area and the presence of shallow bedrock uplands.

Figure 3. Location of Warren County, Ohio

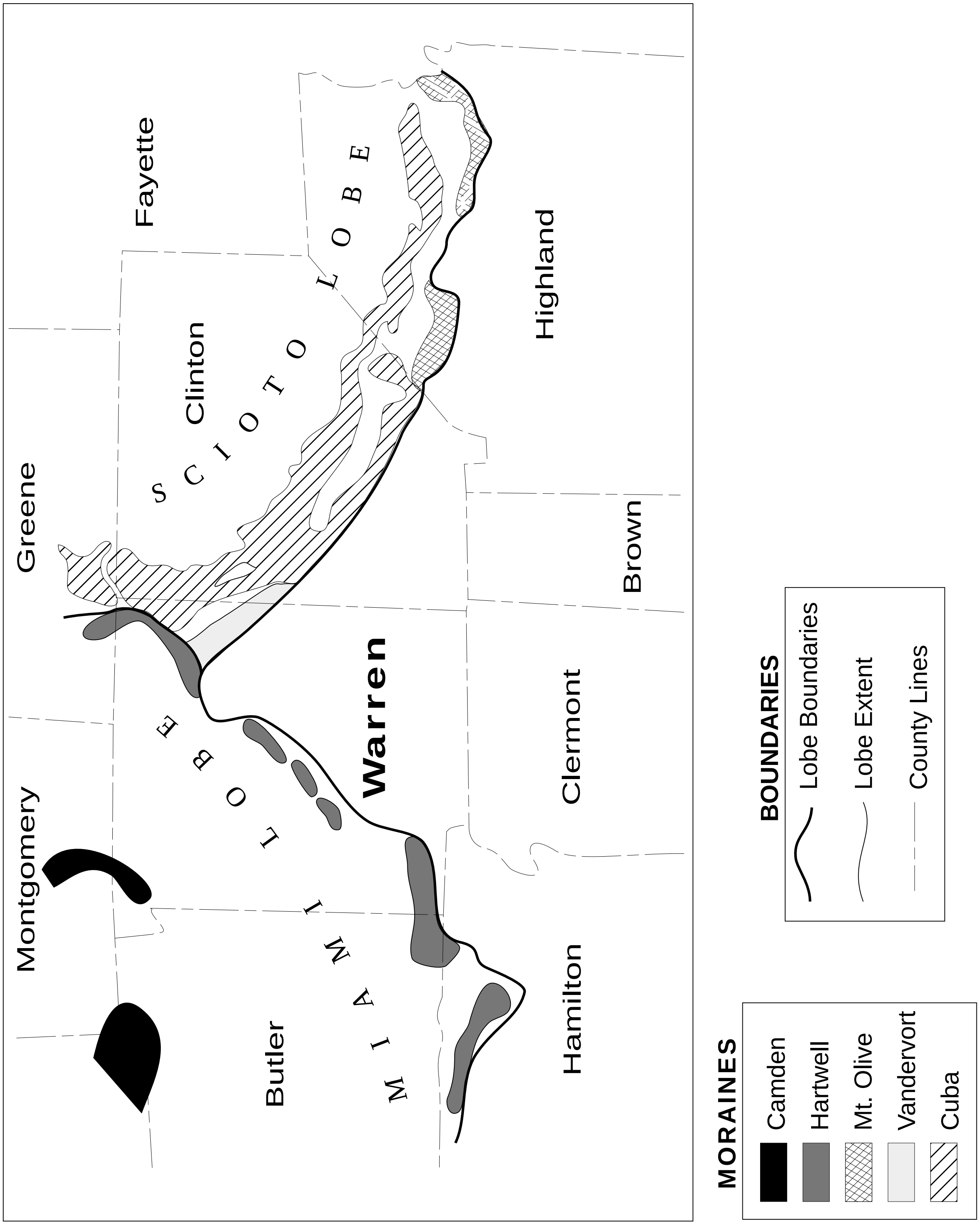


Figure 4. Glacial end moraines in southwest Ohio
(After Goldthwait et al., 1961 and Rosengreen, 1970; 1974)

Climate

Average annual precipitation recorded at the NOAA weather station in Franklin for the period from 1951 to 1980 was 38.10 inches (U.S. Dept. of Commerce, 1982). Average temperature at Franklin for the period from 1953 to 1980 was 51.58 degrees Fahrenheit (U. S. Dept. of Commerce, 1954 - 1981).

Modern Drainage

Warren County lies entirely within the Ohio River drainage system. The Little Miami River and its tributaries drain the majority of the county. Major tributaries of the Little Miami River include Todd Fork and Caesar Creek in eastern Warren County, and Mud Creek and Turtle Creek which drain west-central Warren County. The Great Miami River drains approximately 15% of the northwestern portion of the county.

Pre-glacial and Pleistocene Drainage

The pre-glacial drainage of Warren County is relatively complex and still poorly understood in many areas. The major drainage pathway is represented by the large, westward-trending buried valley occupying central Warren County. Buried valleys are trough-like features eroded into the bedrock and later filled with glacially-derived sediments. These sediments may subsequently be cut by younger channels which, in turn, may also be filled. Modern streams and valleys may coincidentally overlie buried valleys, or evidence for the ancestral valleys may be entirely lacking at the surface.

The ancestral stream which cut the large buried valley through central Warren County is referred to as Monroe Creek (Stout et al., 1943). Monroe Creek flowed westward into Butler County where it merged with the ancestral Great Miami River system. Ultimately, the ancestral Great Miami system drained into the Teays River system. The Teays flowed northwards from Portsmouth to Chillicothe before veering northwestwards and eventually entering Indiana west of Grand Lake St. Mary's in Mercer County. Once in Indiana, the Teays followed a course similar to that of the modern Wabash River.

Glaciation early in the Pleistocene blocked the northerly-flowing Teays system. As the streams backed up, large lakes were created in southeastern Ohio. Eventually, the merging lakes overflowed their divide and cut a new channel, initiating a new drainage system. This system is referred to as the Deep Stage because it cut very wide, deep channels into the bedrock (Smallwood, 1958). A major segment of the Deep Stage channel looped north of Cincinnati, nearly encircling the city with a prominent valley. During this interval, downcutting in Monroe Creek increased and the deeper channel was named South Lebanon Creek (Stout et al., 1943). This deeper channel followed the already established westwards course through central Warren County and merged with the ancestral Great Miami River System in Butler County.

The ancestral drainage systems in western, central, and northern Warren County underwent several episodes of cutting (erosion) and filling (deposition) throughout the Illinoian and Wisconsinan glaciations (Goldthwait et al., 1981). Lacustrine (lake bottom) clays and silts were deposited as streams were blocked and lakes formed. Till was deposited in the valleys by advancing ice sheets. Till is typically a dense, unsorted deposit comprised of clay, silt, sand, and gravel. Meltwater from the ice sheets both eroded valleys and deposited sandy to gravelly outwash.

The modern Great Miami River hugs the eastern margin of a 2.75-mile-wide buried valley in northern Franklin Township. A tributary buried valley roughly underlies Clear Creek and joins this larger valley near Franklin. An important buried valley underlies the present Little Miami River from Morrow to South Lebanon and then follows the course of present Mud Creek towards Monroe. The channel associated with this valley served as an important drainage-way during the Teays and Deep Stage, and presumably through the Illinoian. A tributary buried valley underlies Turtle Creek and extends approximately from Lebanon to South Lebanon. A narrow, northerly-trending buried valley underlying the Little Miami River runs from Clermont County to South Lebanon.

A buried valley system also underlies the Little Miami River from Morrow northwards toward Greene County. This valley broadens considerably in Wayne Township. The origin of this valley and its drainage characteristics are poorly understood. The theses of Henry (1973) and Jehn (1973) indicate the presence of northerly-trending buried valleys underlying Caesar Creek. Maxis (1983) also indicates the presence of a buried valley to the south of Caesar Creek. These valleys were roughly delineated using geophysical methods. Deep well log data in this area is lacking; therefore, determining the extent of these valleys and the nature of the sediments within them is difficult. The presence of moraines overlying these proposed valleys further complicates the situation.

The Little Miami River itself is believed to have formed during the Late Wisconsinan. Evidence for this is based primarily upon the fact that the Little Miami's valley is narrow and lacks significant outwash deposits and terraces in areas where the river does not coincidentally overlie previously deposited coarse buried valley sediments.

Glacial Geology

During the Pleistocene Epoch (two million to 10,000 years ago) at least four major episodes of glaciation, referred to as stages, occurred in north-central North America. Each stage experienced numerous periods of advance and retreat referred to as sub-stages. Each of these sub-stages brought complex changes to portions of Warren County. Bedrock and previous glacial deposits were eroded, drainage was altered, and new layers of glacial till were deposited.

Evidence for the two earliest major glacial stages, the Nebraskan and the Kansan (collectively referred to as the pre-Illinoian) is lacking or obscured in Warren County. Table 9 lists the generalized Pleistocene stratigraphy for Warren County. Evidence for pre-Illinoian (formerly identifyed as Kansan) glaciation in Cincinnati has been inferred from ancient, buried soil profiles (Norton et al., 1983). These are the oldest known glacial sediments in Ohio.

Illinoian age (at least 120,000 years ago) till is found at or near the surface in much of southeastern Warren County. As mentioned in the previous section, till is an unsorted mixture of clay, silt, sand, and gravel. Till deposited at the base of an actively moving ice sheet is commonly referred to as lodgement till and is relatively dense and well-compacted. Lodgement tills characteristically have low permeability; water movement typically follows vertical fractures. Till deposited at the base of a melting (stagnating) ice sheet is referred to as ablation or melt-out till and tends to be less well compacted. Ablation till generally is more permeable than lodgement till. Small lenses of sorted sand, gravel, or silt are commonly found in till deposits. Ice-contact deposits such as kames and eskers, as well as outwash deposits, are commonly associated with melt-out till.

The Illinoian till deposits are relatively flat-lying in upland areas which have not yet undergone stream dissection. Illinoian till differs from the Wisconsinan till in that the upper portion is much more extensively weathered. Thickness of the Illinoian till plain varies but is generally less than 40 feet. No end moraines or kames are associated with the Illinoian till in Warren County. The majority of the Illinoian till plain is covered by a mantle of windblown silt (loess). Loess is derived from the wind reworking dried silty deposits along major outwash valleys. Thickness of the loess varies; thicker accumulations are generally found on uplands. The loess is typically highly weathered, and may be of both Illinoian and Wisconsinan origin (Teller, 1967; Goldthwait and Rosengreen, 1969).

The surficial tills in western and northern Warren County are believed to be late Wisconsinan (Woodfordian) in age (Teller, 1967; Rosengreen 1970, 1974; Goldthwait et al., 1981). The presence of early Wisconsinan (Altonian) tills in the region is currently considered to be doubtful (Miller et al., in preparation).

TABLE 9. GENERALIZED PLEISTOCENE (GLACIAL) STRATIGRAPHY OF WARREN COUNTY (modified from Goldthwait et al., 1981; Rosengreen 1974)

EPOCH	STAGE		SUBSTAGE	UNIT or INTERVAL	
PLEISTOCENE	WISCONSINAN	late	Woodfordian	Miami Lobe Crawfordsville Till (1) Shelbyville Till (2) Fayette Till	Scioto Lobe Caesar Till (3) Boston Till (4)
		middle	Farmdalian	Paleosol ?	
		early	Altonian	Whitewater Till (5)	
	Sangamonian			Paleosol	
	Illinoian			Whitewater Till (5) Richmond Till Centerville Till Rainsboro (Danville) Till	
	Pre–Illinoian			Not Exposed	

(1) Crawfordsville Till is associated with the Camden Moraine.
(2) Shelbyville Till is associated with the Hartwell Moraine.
(3) Caesar Till is associated with the Cuba Moraine.
(4) Boston Till is associated with the Vandervort Moraine.
(5) Age of the Whitewater Till is in dispute.

The Woodfordian-age tills mark the limit of ice advance during the Wisconsinan (Goldthwait and Rosengreen, 1969). A complicating factor to interpreting these tills is that Warren County has been influenced by deposition from two major glacial lobes during the Woodfordian (Table 9). The eastern margin of the Miami Lobe covered western Warren County, whereas the northeastern corner of Warren County marks the far southwestern edge of the Scioto Lobe (Norris et al., 1950; Goldthwait et al., 1961). End moraines roughly mark both the limit of the ice margin and the lobe boundaries. Figure 4 delineates end moraines and approximate lobe boundaries in Warren County. As with the Illinoian till, a thin mantle of loess covers the Wisconsinan-age till in most of Warren County.

Meltwater derived from the ablating ice sheets tended to be funnelled into major stream valleys. This meltwater deposited highly variable sand and gravel outwash referred to as valley trains. The relative degree of sorting (the "cleanness" of a deposit) and the coarseness depended upon the amount and nature of the sediment and the amount and velocity of the meltwater. Proximity to the ice sheet and the relative temperature at any given time were crucial factors in determining the composition of the outwash. During times of particularly sluggish drainage, the outwash could become quite silty in nature, resembling lacustrine sediments.

Changes in environment could be gradational or extremely rapid; these changes commonly appear in the sediment record. Major outwash deposits are associated with the Great Miami River and Clear Creek in northwestern Warren County. Extensive outwash deposits are associated with the Little Miami River in Wayne Township. It is possible that this area initially drained northward into Greene County before subsequent ice-blockage diverted drainage to the present direction. Somewhat less extensive deposits are found in the Little Miami River Valley near South Lebanon and along Muddy Creek. These outwash deposits are all presumed to be Late Wisconsinan in age; however, it is important to remember that underlying deposits within the buried valleys are probably pre-Wisconsinan.

Evidence for two, large, presumably Wisconsinan-aged lakes exists in Warren County. The larger occupies the Muddy Creek basin southeast of Monroe; it was probably created by stagnating ice which blocked drainage to the south. This same stagnating ice was also responsible for depositing a small kame-field in Muddy Creek Valley in northwestern Union Township. The smaller lake is located in a low basin ringed by bedrock highs in southern Massie Township. This lake was probably created by blockage of drainage in Todd Fork in Clinton County (Teller, 1967).

For a more detailed discussion of the Pleistocene geology of Warren County, the reader may wish to review the references mentioned in this section and: Gooding (1975), Schumacher et al. (1987), and Lowell et al. (1990).

Bedrock Geology

The bedrock geology of Warren County primarily consists of Late Ordovician shales and limestones of the Edenian, Maysvillian, and Richmondian Stage of the Cincinnatian Series (Table 10). A limited number of Silurian shales and limestones crop-out in northern and eastern Warren County (see Figure 5). Excellent descriptions of the Ordovician System rocks appear in Tobin (1986), and Schumacher et al. (1987; 1991). Descriptions of the Silurian rocks can be obtained from Norris et al. (1950), Horvath and Sparling (1967), and Kleffner and Ausich (1988).

The Ordovician System is characterized by soft, calcareous shales, interbedded with thin, hard limestone layers. Tobin (1986) and Schumacher et al. (1991) provide summaries of the various bedrock schemes for the Ordovician. Horvath and Sparling (1967) and Kleffner and Ausich (1988) summarize both the lithologic nature and common fossil assemblages of the Silurian rocks. The stratigraphic relationship of the rock units encountered in Warren County and their characteristics are detailed in Table 10.

Sedimentation was influenced during the Late Ordovician by the presence of the Cincinnati Arch, a broad, gently sloping structural ridge. Deposition occurred in a shallow marine shelf (ramp) environment along the rise associated with the Cincinnati Arch. Limestones were deposited in these areas of clear water containing abundant marine life. The water deepened somewhat to the east where a relatively shallow sea existed between the Arch and the uplifting ancestral Appalachian Mountain chain. This uplift provided a source for abundant fine sediments from erosion of the mountains. These sediments were washed into the shallow sea where storm events suspended them and redeposited them along the shelf. Shaley units reflect these terrigenous clastic (i.e. "land-derived") deposits.

Typically, within each unit there were numerous fluctuations or cycles between the two modes of sedimentation. Over time, more generalized long-term cycles occurred which affected multiple units. Tobin (1986) and Schumacher et al. (1987) have referred to these as shoaling (shallowing) upwards cycles. The depositional environment tends to shift from a lower energy, somewhat deeper water setting where shale deposition is predominant, to a shallower, higher energy setting where limestone deposition occurs. Such cycles tend to repeat over time and reflect periods of transgression (a relative rise in sea level) or regression (a relative decline in sea level). These cycles are ultimately controlled by the overall (eustatic) sea level, occurrence of tectonic subsidence or uplift, and sedimentation rates among other factors.

TABLE 10 GENERALIZED BEDROCK STRATIGRAPHY OF WARREN COUNTY (modified from Kleffner and Ausich, 1988; Horvath and Sparling, 1967)

<table>
<tr><th>SYSTEM</th><th>SERIES</th><th>STAGE</th><th colspan="2">FORMATION AND MEMBER</th><th>ROCK TYPE</th></tr>
<tr><td rowspan="4">SILURIAN</td><td rowspan="4"></td><td rowspan="4"></td><td colspan="2">Laurel Dolomite</td><td>Dark gray, dense, even–bedded, impure, fossiliferous limestone to dolomite, contains recrystalized zones</td></tr>
<tr><td colspan="2">Osgood Shale</td><td>Blue–gray, silty, calcarous shale, fossiliferous, contains thin limestone to dolomite</td></tr>
<tr><td colspan="2">Dayton Limestone</td><td>Gray, dense, even–bedded, fossiliferous limestone to dolomite</td></tr>
<tr><td colspan="2">Brassfield Limestone</td><td>White to pink, coarse hard, massively–bedded fossiliferous limestone, contains shale partings</td></tr>
<tr><td rowspan="11">ORDOVICIAN</td><td rowspan="11">CINCINNATIAN</td><td rowspan="5">RICHMONDIAN</td><td colspan="2">Drakes Formation</td><td>Limestone containing minor shale (shale averages 13%)</td></tr>
<tr><td colspan="2">Whitewater Formation</td><td>Limestone containing minor shale (shale averages 14%)</td></tr>
<tr><td colspan="2">Liberty Formation</td><td>Interbedded shale and limestone (shale averages 45% of unit)</td></tr>
<tr><td colspan="2">Waynesville Formation</td><td>Interbedded shale and limestone (shale 65% or more of unit)</td></tr>
<tr><td colspan="2">Arnheim Formation</td><td>Interbedded limestone and shale</td></tr>
<tr><td rowspan="5">MAYSVILLIAN</td><td rowspan="3">Grant Lake Formation</td><td>Mt. Auburn Member</td><td>Limestone and shale (shale 60% or more of unit)</td></tr>
<tr><td>Corryville Member</td><td>Interbedded limestone and shale (shale 60% or more of unit)</td></tr>
<tr><td>Bellevue Member</td><td>Limestone</td></tr>
<tr><td colspan="2">Miamitown Formation</td><td>Interbedded shale and limestone (shale averages 60% of unit)</td></tr>
<tr><td colspan="2">Fairview Formation</td><td>Inerbedded shale and limestone (shale averages 60% of unit)</td></tr>
<tr><td>EDENIAN</td><td colspan="2">Kope Formation</td><td>Interbedded shale and limestone (shale 75% or more of unit)</td></tr>
</table>

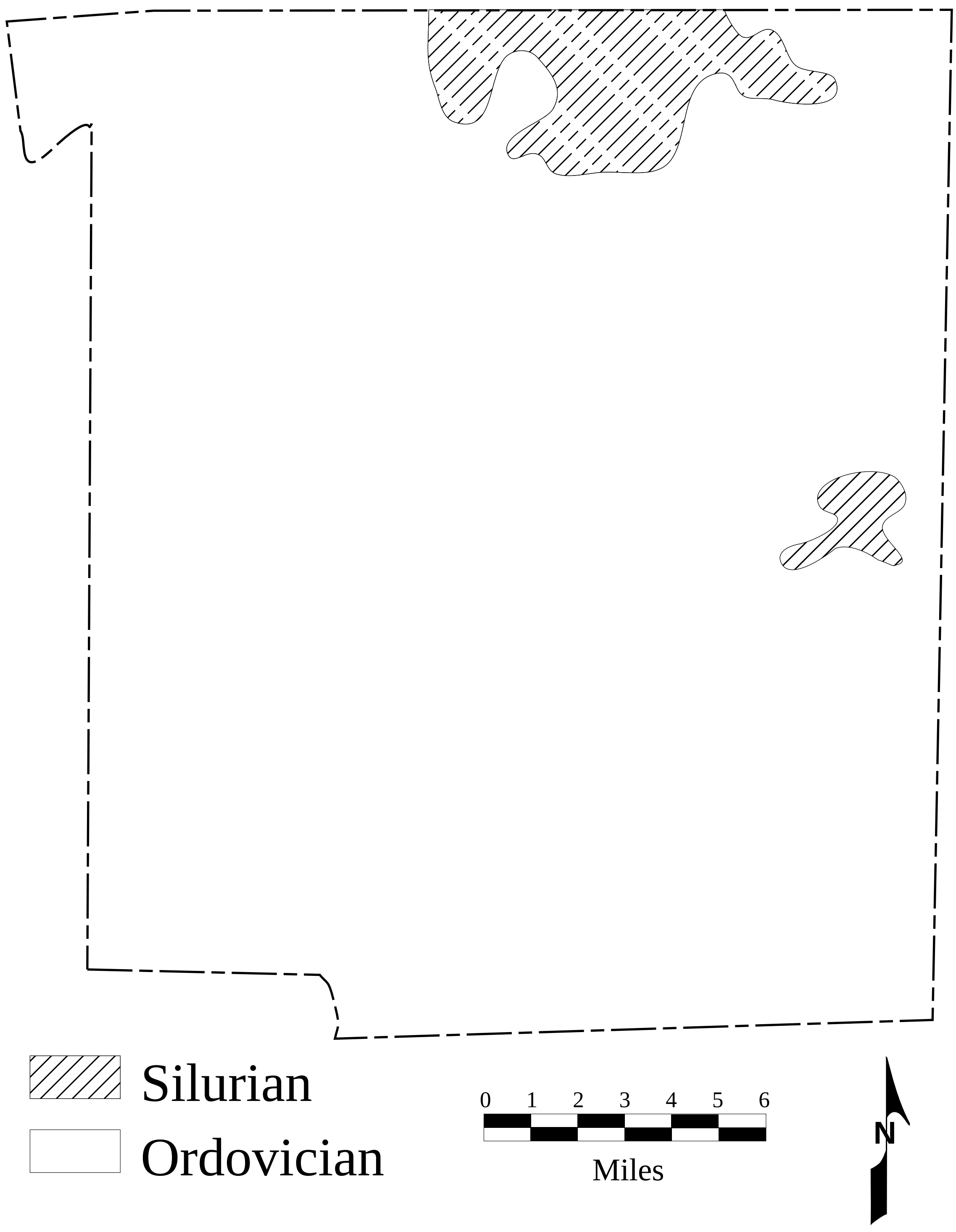


Figure 5 Bedrock map of Warren County
(modified from Maxis, 1983)

Tobin (1986) and Schumacher et al. (1987) provide a detailed discussion of the depositional environments during the Late Ordovician. Deposition in shallow marine environments experiencing various degrees of clastic debris input continued into the Silurian. Horvath and Sparling (1967) and Kleffner and Ausich (1988) give a thorough description of deposition during the Silurian.

Bedrock underlying the Edenian Stage does not crop-out in Warren County and does not constitute an aquifer due to the great depth of these units and poor water quality. A complete description of these rocks is available in Shrake et al. (1990; 1991), and Shrake (1991).

Hydrogeology

There are two main types of aquifers in Warren County: sand and gravel, and bedrock. Higher yielding aquifers in Warren County are restricted to the buried valley networks and are developed in extensive sand and gravel outwash deposits. The highest yielding zones reported by Walker (1986) are found in the Great Miami River Valley, the Muddy Creek Valley, and the Little Miami River south of South Lebanon. These areas are able to sustain yields in excess of 500 gallons per minute (Walker, 1986). Outwash deposits in these area are relatively coarse, well-sorted (clean), and are fairly extensive. Areas capable of sustaining high yields typically have permeable soils and overlying streams which contribute to the recharge.

Surface-derived recharge is crucial in Warren County as the impermeable nature of the surrounding bedrock discounts any appreciable amounts of ground water entering the valley systems at depth. Buried valleys which contain outwash deposits capable of sustaining yields in the 100 gallon per minute range include the Little Miami River Valley near Waynesville and South Lebanon. Tributary buried valleys such as those underlying Clear Fork and Turtle Creek near Lebanon have deposits capable of sustaining yields over 50 gallons per minute (Walker, 1986). Other segments of the buried valley underlying the Little Miami River do not appear to have extensive outwash deposits. These portions of the valley were probably cut during the Late Wisconsinan.

In the upland areas, sand and gravel aquifers are generally poor sources of water (Walker, 1986). Wells developed in these areas are typically limited to small, discontinuous lenses of sand and gravel interbedded within the glacial till. Yields from these areas are generally under ten gallons per minute and are suitable only for domestic purposes. Morainic areas adjacent to Caesar Creek are somewhat of an exception, because yields from sand and gravel lenses in this region average between 10 and 25 gallons per minute (Walker, 1986). Moraines located elsewhere in Warren County lack appreciable sand and gravel lenses and also proved difficult to delineate. The majority of upland areas in Warren County are covered by varying thicknesses of predominantly silt and clay-rich till. The till may show varying degrees of saturation, but is generally incapable of sustaining yields adequate for domestic purposes.

In the majority of upland areas, the till lacks interbedded sand and gravel lenses capable of supplying domestic needs; therefore, wells must be developed in the underlying bedrock. The thinly-bedded shale and limestone units are, in general, relatively impermeable and constitute very poor aquifers. Yields are typically less then three gallons per minute and the water quality is usually poor as well. Yields are generally derived from bedding planes and minor fracture zones. The contact between the overlying drift and the upper, most-weathered, portion (usually five to ten feet) of the rock is typically the primary source of water. Drilling to a greater depth is generally done to acquire extra borehole water storage. The Silurian bedrock units may be lithologically somewhat superior to the Late Ordovician rocks; however, the thin nature and limited extent of these units precludes the possibility of higher yielding wells. In upland areas where neither the till or bedrock is productive, cisterns or municipal water systems become a necessity.

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APPENDIX A

DESCRIPTION OF THE LOGIC IN FACTOR SELECTION

Depth to Water

In Warren County, aquifer characteristics range from unconfined to semi-confined. The DRASTIC system recognizes only confined and unconfined aquifers (Aller et al., 1987). Because the semi-confined aquifers in Warren County closely resemble unconfined conditions rather than confined conditions, all aquifers in the county were rated as unconfined. Depth to water in an unconfined aquifer is defined as the static water level (potentiometric surface).

Depth to water was primarily evaluated using information obtained from water well logs on file at Ohio Department of Natural Resources, Division of Water. In areas with little or no depth to water data, interpretation of topography and elevation were used to estimate the ratings. Water levels in the upland Glacial Till Over Sedimentary Rock (7A) hydrogeologic setting average between 15-30 feet (7) below the surface, but localized areas with depths of 5-15 feet (9), 30-50 feet (5), and 50-75 feet (3) were also encountered. A depth to water of 0-5 ft. (10) was given to a localized area of artesian conditions. Ratings in the Buried Valley (7D) hydrogeologic setting were 30-50 feet (5), 15-30 feet (7), 5-15 feet (9), and 0-5 feet (10). The Moraine (7C) hydrogeologic setting in northeast Warren County has depths to water of 15-30 feet (7) and 50-75 feet (3). The Sand and Gravel Interbedded in Glacial Till (7Af) hydrogeologic setting included depths of 5-15 feet (9), 15-30 feet (7), 30-50 feet (5), and 50-75 feet (3).

Net Recharge

Net Recharge is the amount of water that actually reaches the water table. Net Recharge = Precipitation - Evapotransporation and Runoff. Pettyjohn and Henning (1979) determined the state-wide average for recharge is 6 inches. In Warren County, however, the average net recharge is lower because of the prevalence of impermeable clay/silt soils and vadose material. Steep slopes also influence net recharge. A steep slope increases the amount of runoff, leaving less water to infiltrate into the subsurface.

The net recharge rating is 2-4 inches (3) in the Glacial Till Over Bedded Sedimentary Rock (7Aa) hydrogeologic setting throughout Warren County. Net recharge in the Sand and Gravel Interbedded in Glacial Till (7Af) hydrogeologic setting varies from 2-4 inches (3) to 4-7 inches (6) per year. The Moraine (7C) hydrogeologic setting also has ratings of 2-4 inches (3) and 4-7 inches (6) per year. Portions of the Buried Valley (7D) hydrogeologic setting containing highly permeable soils and vadose materials and sand and gravel aquifers with high hydraulic conductivities allow water to infiltrate readily; therefore, recharge is estimated at 10+ inches (9) per year. Net recharge in less permeable sections of the Buried Valley (7D) hydrogeologic setting ranges from 2-4 inches (3), 4-7 inches (6), and 7-10 inches (8) per year.

Aquifer Media

Aquifer characteristics were determined by using information obtained from water well log records on file at the Ohio Department of Natural Resources, Division of Water, Ground Water Resources Section and in unpublished reports from Nielson-Watson & Associates (1969) and Dames & Moore (1972). The bedrock topography maps of Cummins (1959) and Lopez (in progress) were useful in evaluating the buried valley system within Warren County.

Aquifer ratings for outwash sand and gravel deposits in the Buried Valley (7D) setting ranged from (9) to (4). Variations in the ratings were obtained from the Ground-Water Resources Map of Warren County (Walker, 1986). These variations in part reflect the degree of coarseness, uniformity and sorting within these deposits. Glacial till (5) was rated as the aquifer in the Moraine (7C) hydrogeologic setting adjacent to Caesar Creek. Aquifer media in the upland areas associated with the Glacial Till Over Bedded Sedimentary Rock (7Aa) hydrogeologic setting is considered to be interbedded limestone/shale with a typical rating of (3). A rating of (4) was utilized for an area of somewhat higher-yielding interbedded limestone/shale. The increased yield is possibly due to increased fracturing locally. Sand and gravel lenses were given aquifer ratings of (4) and (5) within the Sand and Gravel Interbedded in Glacial Till (7Af) setting. The relatively low ratings reflect the typically poorly-sorted nature of these deposits.

Soil Media

Data for the soils were evaluated from the Soil Survey for Warren County (Garner et al., 1973). Soils were classified according to U.S.D.A. texture, permeability, and shrink-swell potential. These characteristics were then used to obtain a pollution potential rating.

Soils in the Glacial Till Over Bedded Sedimentary Rock (7Aa) hydrogeologic setting were rated as clay loam (3), silty loam (4), loam (5), sandy loam (6), shrink/swell (aggregated) clay (7), and sand (9). Soils in the Sand and Gravel Interbedded in Glacial Till (7Aa) setting were rated clay loam (3), loam (5), sandy loam (6), and sand (9). Soils in the Buried Valley (7D) hydrogeologic setting were evaluated as muck (2), clay loam (3), silty loam (4), loam (5), sandy loam (6), shrink/swell (aggregated) clay (7), and sand (9). Soils in the Moraine (7C) hydrogeologic setting are rated as clay loam (3), shrink/swell (aggregated) clay (7), and sand (9).

Topography

Percent slope was determined using 7-1/2 minute USGS topographic quadrangle maps. Modern floodplains within the Buried Valley (7D) hydrogeologic setting have slopes of 0-2% (10) and 2-6% (9). Steeply dissected areas along the margins of the buried valleys have slopes of 18+% (1), 12-18% (3), and 6-12% (5). Upland areas of Warren County typically have slopes of 2-6% (9) and 0-2% (10).

Impact of the Vadose Zone Media

For this factor, determinations were made using information obtained from water well logs on file at the Ohio Department of Natural Resources, Division of Water. The vadose zone media for the majority of Warren County is glacial till of varying thickness. The till is primarily composed of silt and clay, therefore silt/clay was rated as the vadose zone media. The vadose zone material was assumed to be homogeneous throughout the county with respect to its hydrogeologic setting. Vadose zone material for the Glacial Till Over Bedded Sedimentary Rock (7Aa) hydrogeologic setting was rated as sand and gravel with significant silt and clay (6) or silt/clay (4). The Moraine hydrogeologic setting (7C) has the vadose zone media rated as sand and gravel with significant silt and clay (6). Vadose zone media for the Sand and Gravel Interbedded in Glacial Till (7Af) hydrogeologic setting was typically evaluated as sand and gravel with significant silt and clay and given ratings of (6) and (7). Vadose zone media for portions of the Sand and Gravel Interbedded in Glacial Till (7Af) hydrogeologic setting containing fewer sand and gravel lenses was considered to be silt/clay and given ratings of (4) and (5). In the Buried Valley (7D) setting areas, vadose zone material is sand and gravel with significant silt and clay with ratings of (6), (7), and (8) and silt/clay with a rating of (5).

Hydraulic Conductivity

Hydraulic conductivity values were based on the Ground Water Resources of Warren County, Ohio (Walker, 1986) and from unpublished boring logs from Dames & Moore (1972). Tables from Freeze and Cherry (1979) were useful for estimating hydraulic conductivity ratings. Hydraulic conductivity values range in increments of gallons per day per square foot (gpd/ft^2). Hydraulic conductivity values in the limestone/shale aquifer in the Glacial Till Over Bedded Sedimentary Rock (7Aa) setting range from 1-100 gpd/ft^2 (1) to 100-300 gpd/ft^2 (2). Sand and gravel lenses in the Sand and Gravel Interbedded in Glacial Till setting have hydraulic conductivities of 100-300 gpd/ft^2 (2) and 300-700 gpd/ft^2 (4). Sand and gravel lenses within the Moraine (7C) hydrogeologic setting in northeast Warren County are relatively productive and were given a hydraulic conductivity rating of 300-700 gpd/ft^2 (4). The Buried Valley (7D) hydrogeologic setting contains a wide range of hydraulic conductivities because of the differing sand and gravel aquifers. The estimates for hydraulic conductivity range from 100-300 gpd/ft^2 (2), 300-700 gpd/ft^2 (4), 700-1000 gpd/ft^2 (6), 1000-2000 gpd/ft^2 (8) and 2000+ gpd/ft^2 (10).

APPENDIX B

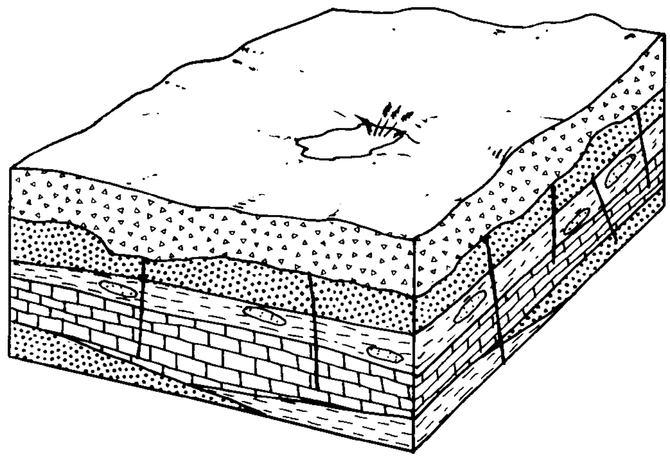
DESCRIPTION OF HYDROGEOLOGIC SETTINGS AND CHARTS

In the pollution potential mapping of Warren County, four hydrogeologic settings within the Glaciated Central Region were identified. The list of these settings, the range of ground water pollution potential index (GWPP) calculations and the number of pollution potential index calculations for each setting are provided in Table 11. Computed pollution potential index values range from 61 to 202.

Table 11. Hydrogeologic Settings Mapped in Warren County, Ohio.

Hydrogeologic Setting	Range of GWPP Indexes	Number of Index Calculations
7Aa - Glacial Till Over Bedded Sedimentary Rock	61-122	46
7Af - Sand and Gravel Interbedded in Glacial Till	92-148	26
7C - Moraine	99-143	8
7D - Buried Valley	113-202	71

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.



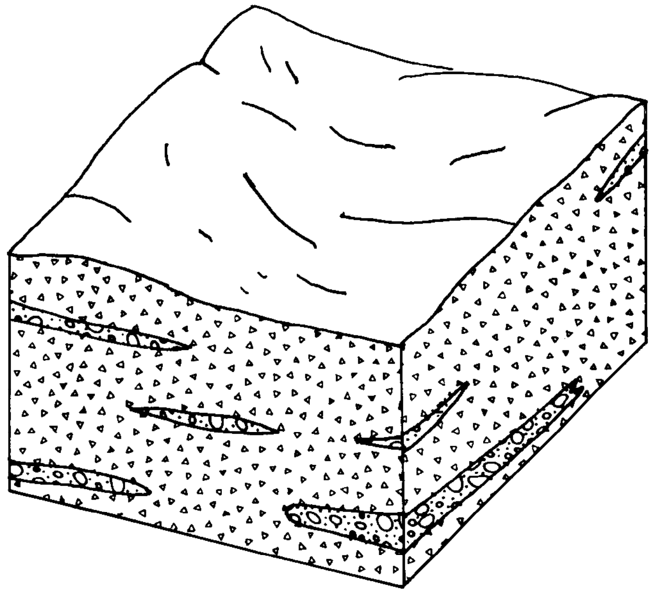
7Aa Glacial Till Over Bedded Sedimentary Rock

This hydrogeologic setting is characterized by low topography and flat-lying, fractured sedimentary rock. The underlying bedrock consists of thick sequences of Ordovician shale interbedded with thin layers of limestone. These sedimentary rock units are covered by varying thicknesses of glacial till. The till layer consists of unsorted deposits of interbedded clay, silt, and sand. Although ground water occurs in both the glacial deposits and the fractured bedrock, bedrock is usually the principal aquifer. The main source of recharge to the bedrock aquifer is from the overlying glacial till. This recharge is low to moderate due to the impermeable nature of the till and soils. Depth to water varies depending on glacial till thickness, but is usually between 15-30 feet.

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Aa1	15-30	2-4	Interbedded Limestone, Shale	Clay Loam	2-6	Silt/Clay	1-100	94	116
7Aa2	5-15	2-4	Interbedded Limestone, Shale	Clay Loam	6-12	Silt/Clay	1-100	100	114
7Aa3	15-30	2-4	Interbedded Limestone, Shale	Clay Loam	0-2	Silt/Clay	1-100	95	119
7Aa4	15-30	2-4	Interbedded Limestone, Shale	Clay Loam	6-12	Silt/Clay	1-100	90	104
7Aa5	15-30	2-4	Interbedded Limestone, Shale	Clay Loam	18+	Silt/Clay	1-100	86	92
7Aa6	15-30	2-4	Interbedded Limestone, Shale	Silty Loam	18+	Silt/Clay	1-100	88	97
7Aa7	5-15	2-4	Interbedded Limestone, Shale	Clay Loam	2-6	Silt/Clay	1-100	104	126
7Aa8	15-30	2-4	Interbedded Limestone, Shale	Silty Loam	2-6	Silt/Clay	1-100	96	121
7Aa9	15-30	2-4	Interbedded Limestone, Shale	Silty Loam	6-12	Silt/Clay	1-100	92	109
7Aa10	5-15	2-4	Interbedded Limestone, Shale	Loam	0-2	Silt/Clay	1-100	109	139
7Aa11	15-30	2-4	Interbedded Limestone, Shale	Clay Loam	12-18	Silt/Clay	1-100	88	98
7Aa12	15-30	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	0-2	Silt/Clay	1-100	103	139

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Aa13	5-15	2-4	Interbedded Limestone, Shale	Clay Loam	12-18	Silt/Clay	1-100	98	108
7Aa14	15-30	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	12-18	Silt/Clay	1-100	96	118
7Aa15	15-30	2-4	Interbedded Limestone, Shale	Sandy Loam	0-2	Silt/Clay	1-100	101	134
7Aa16	15-30	2-4	Interbedded Limestone, Shale	Sand	18+	Silt/Clay	1-100	98	122
7Aa17	15-30	2-4	Interbedded Limestone, Shale	Sand	2-6	Silt/Clay	1-100	106	146
7Aa18	30-50	2-4	Interbedded Limestone, Shale	Silty Loam	12-18	Silt/Clay	1-100	80	93
7Aa19	15-30	2-4	Interbedded Limestone, Shale	Silty Loam	12-18	Silt/Clay	1-100	90	103
7Aa20	30-50	2-4	Interbedded Limestone, Shale	Clay Loam	18+	Silt/Clay	1-100	76	82
7Aa21	5-15	2-4	Interbedded Limestone, Shale	Loam	0-2	Silt/Clay	100-300	115	144
7Aa22	15-30	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	2-6	Silt/Clay	1-100	102	136
7Aa23	5-15	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	2-6	Silt/Clay	1-100	112	146
7Aa24	5-15	2-4	Interbedded Limestone, Shale	Sand	2-6	Silt/Clay	1-100	116	156
7Aa25	30-50	2-4	Interbedded Limestone, Shale	Sand	2-6	Silt/Clay	1-100	96	136
7Aa26	15-30	2-4	Interbedded Limestone, Shale	Sand	6-12	Silt/Clay	1-100	102	134
7Aa27	50-75	2-4	Interbedded Limestone, Shale	Clay Loam	2-6	Silt/Clay	1-100	74	96
7Aa28	15-30	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	6-12	Silt/Clay	1-100	98	124
7Aa29	30-50	2-4	Interbedded Limestone, Shale	Clay Loam	2-6	Silt/Clay	1-100	84	106
7Aa30	30-50	2-4	Interbedded Limestone, Shale	Clay Loam	6-12	Silt/Clay	1-100	80	94
7Aa31	15-30	2-4	Interbedded Limestone, Shale	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	1-100	104	124
7Aa32	5-15	2-4	Interbedded Limestone, Shale	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	1-100	115	137
7Aa33	5-15	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	2-6	Sand and Gravel w/sig Silt and Clay	1-100	122	154
7Aa34	5-15	2-4	Interbedded Limestone, Shale	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	1-100	114	134
7Aa35	15-30	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	2-6	Sand and Gravel w/sig Silt and Clay	1-100	112	144
7Aa36	15-30	2-4	Interbedded Limestone, Shale	Clay Loam	6-12	Sand and Gravel w/sig Silt and Clay	1-100	100	112
7Aa37	15-30	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	6-12	Sand and Gravel w/sig Silt and Clay	1-100	108	132
7Aa38	15-30	2-4	Interbedded Limestone, Shale	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	1-100	105	127
7Aa39	15-30	2-4	Interbedded Limestone, Shale	Sandy Loam	2-6	Silt/Clay	1-100	100	131
7Aa40	5-15	2-4	Interbedded Limestone, Shale	Loam	2-6	Silt/Clay	1-100	108	136
7Aa41	15-30	2-4	Interbedded Limestone, Shale	Loam	6-12	Silt/Clay	1-100	94	114
7Aa42	15-30	2-4	Interbedded Limestone, Shale	Sandy Loam	12-18	Silt/Clay	1-100	94	113

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Aa43	15-30	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	18+	Silt/Clay	1-100	94	112
7Aa44	75-100	2-4	Interbedded Limestone, Shale	Clay Loam	18+	Silt/Clay	1-100	61	67
7Aa45	75-100	2-4	Interbedded Limestone, Shale	Clay Loam	2-6	Silt/Clay	1-100	69	91
7Aa46	5-15	2-4	Interbedded Limestone, Shale	Shrinking and/or Aggregated C	0-2	Silt/Clay	1-100	113	149

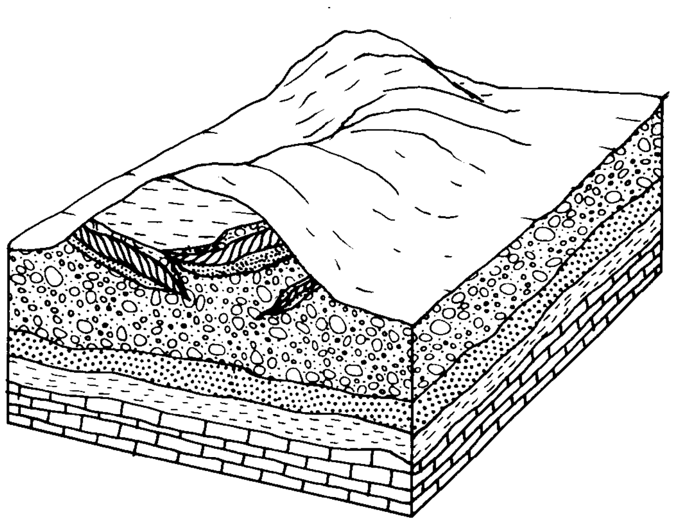


7Af Sand and Gravel Interbedded in Glacial Till

This hydrogeologic setting is characterized by low topography and flat-lying, fractured sedimentary rock. The underlying bedrock consists of thick sequences of Ordovician shale interbedded with thin layers of limestone. These sedimentary rock units are covered by varying thicknesses of glacial till. The till layer consists of unsorted deposits of interbedded clay, silt, and sand and gravel lenses. These lenses are partially associated with pre-glacial buried valleys. They are located adjacent to, or are nearby Buried Valley (7D) hydrogeologic settings. Recharge to these lenses is mainly through the overlying till. Therefore, recharge is moderate. Depth to water is variable, but on an average is 15-30 feet.

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Af1	15-30	2-4	Sand and Gravel	Clay Loam	6-12	Silt/Clay	100-300	96	109
7Af2	15-30	2-4	Sand and Gravel	Clay Loam	2-6	Silt/Clay	100-300	100	121
7Af3	15-30	4-7	Sand and Gravel	Sand	2-6	Sand and Gravel w/sig Shale and Clay	100-300	134	171
7Af4	15-30	4-7	Sand and Gravel	Sand	6-12	Silt/Clay	100-300	125	155
7Af5	15-30	4-7	Sand and Gravel	Sand	2-6	Sand and Gravel w/sig Silt and Clay	300-700	148	182
7Af6	15-30	2-4	Sand and Gravel	Clay Loam	6-12	Sand and Gravel w/sig Silt and Clay	100-300	109	120
7Af8	5-15	4-7	Sand and Gravel	Loam	2-6	Sand and Gravel w/sig Silt and Clay	100-300	139	164
7Af9	15-30	4-7	Sand and Gravel	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	100-300	125	144
7Af10	5-15	4-7	Sand and Gravel	Sand	2-6	Sand and Gravel w/sig Silt and Clay	100-300	147	184
7Af11	30-50	4-7	Sand and Gravel	Clay Loam	12-18	Sand and Gravel w/sig Silt and Clay	100-300	109	116
7Af12	30-50	4-7	Sand and Gravel	Sand	6-12	Silt/Clay	100-300	115	145
7Af13	15-30	2-4	Sand and Gravel	Loam	6-12	Sand and Gravel w/sig Silt and Clay	100-300	113	130

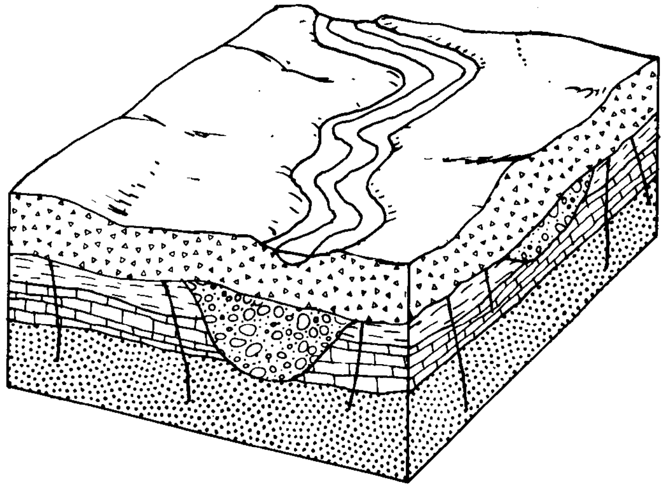
Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Af14	15-30	2-4	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	100-300	111	132
7Af16	15-30	2-4	Sand and Gravel	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	100-300	110	129
7Af18	30-50	2-4	Sand and Gravel	Clay Loam	2-6	Silt/Clay	300-700	104	122
7Af19	15-30	4-7	Sand and Gravel	Clay Loam	2-6	Silt/Clay	300-700	126	144
7Af20	15-30	4-7	Sand and Gravel	Sandy Loam	2-6	Silt/Clay	300-700	132	159
7Af21	15-30	4-7	Sand and Gravel	Clay Loam	12-18	Silt/Clay	300-700	120	126
7Af22	15-30	4-7	Sand and Gravel	Sand	0-2	Silt/Clay	300-700	139	177
7Af23	75-100	4-7	Sand and Gravel	Clay Loam	2-6	Silt/Clay	100-300	92	112
7Af24	15-30	4-7	Sand and Gravel	Clay Loam	6-12	Silt/Clay	100-300	113	125
7Af25	15-30	4-7	Sand and Gravel	Sand	2-6	Silt/Clay	100-300	129	167
7Af26	15-30	4-7	Sand and Gravel	Clay Loam	2-6	Silt/Clay	100-300	117	137



7C Moraine

This hydrogeologic setting is characterized by hilly to moderately steep topography with varying thicknesses of glacial deposits overlying flat-lying sedimentary rocks. Moraines are typically mounds or ridges of glacial till which were deposited along the margin of a stagnant or retreating glacier. Depth to water varies, ranging from 15 to 75 feet; this is due to varying till thickness. Ground water recharge is moderate to poor because of impermeable fines. Soils are clay loam, sand, or shrinking and / or aggregated clay.

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7C1	15-30	2-4	Glacial Till	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	300-700	119	136
7C2	50-75	2-4	Glacial Till	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	300-700	99	116
7C3	15-30	4-7	Glacial Till	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	300-700	131	148
7C4	50-75	4-7	Glacial Till	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	300-700	111	128
7C5	15-30	4-7	Glacial Till	Sand	12-18	Sand and Gravel w/sig Silt and Clay	300-700	137	160
7C6	15-30	4-7	Glacial Till	Sand	2-6	Sand and Gravel w/sig Silt and Clay	300-700	143	178
7C7	15-30	4-7	Glacial Till	Shrinking and/or Aggregated C	6-12	Sand and Gravel w/sig Silt and Clay	300-700	135	156
7C8	15-30	4-7	Glacial Till	Clay Loam	6-12	Sand and Gravel w/sig Silt and Clay	300-700	127	136
7C9	15-30	2-4	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	300-700	120	139



7D Buried Valley

This hydrogeologic setting is characterized by thick deposits of sand, gravel, and sorted till which have been deposited in an incised pre-glacial river valley by glacial meltwaters. These units are thick and permeable, yielding large quantities of ground water. Large rivers or creeks (e.g., Great Miami, and Todd Fork) overlie the buried valleys and thus are in hydraulic connection with the subsurface. Soils of loam and sand trail the buried valleys. Recharge to the valley fill material is high to moderate. Depth to water in this setting is quite shallow, approximately 5-15 feet. Depth to water may also be high in areas of small creeks where a majority of the till has not been eroded.

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7D2	5-15	4-7	Sand and Gravel	Loam	0-2	Silt/Clay	300-700	144	170
7D3	5-15	7-10	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	171	193
7D4	5-15	7-10	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	179	213
7D5	5-15	7-10	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	180	200
7D6	5-15	4-7	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	163	198
7D7	15-30	4-7	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	300-700	147	184
7D8	15-30	7-10	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	170	190
7D9	15-30	4-7	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	156	191
7D10	15-30	4-7	Sand and Gravel	Sand	2-6	Sand and Gravel w/sig Silt and Clay	700-1000	155	188
7D11	15-30	7-10	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	164	199
7D12	15-30	10+	Sand and Gravel	Sand	0-2	Sand and Gravel	700-1000	178	211

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7D13	5-15	10+	Sand and Gravel	Sand	0-2	Sand and Gravel	1000-2000	202	232
7D15	15-30	4-7	Sand and Gravel	Clay Loam	0-2	Silt/Clay	1000-2000	148	164
7D16	15-30	4-7	Sand and Gravel	Shrinking and/or Aggregated C	0-2	Silt/Clay	1000-2000	156	184
7D17	15-30	7-10	Sand and Gravel	Shrinking and/or Aggregated C	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	169	196
7D18	5-15	10+	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	192	224
7D19	5-15	7-10	Sand and Gravel	Sandy Loam	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	182	205
7D20	5-15	7-10	Sand and Gravel	Shrinking and/or Aggregated C	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	179	206
7D21	5-15	4-7	Sand and Gravel	Clay Loam	2-6	Silt/Clay	300-700	139	157
7D22	15-30	4-7	Sand and Gravel	Shrinking and/or Aggregated C	0-2	Silt/Clay	300-700	138	170
7D23	5-15	4-7	Sand and Gravel	Shrinking and/or Aggregated C	0-2	Silt/Clay	300-700	148	180
7D24	15-30	7-10	Sand and Gravel	Shrinking and/or Aggregated C	0-2	Sand and Gravel w/sig Silt and Clay	2000+	178	203
7D25	5-15	7-10	Sand and Gravel	Shrinking and/or Aggregated C	0-2	Sand and Gravel w/sig Silt and Clay	2000+	188	213
7D26	15-30	4-7	Sand and Gravel	Shrinking and/or Aggregated C	0-2	Sand and Gravel w/sig Silt and Clay	300-700	143	174
7D27	5-15	4-7	Sand and Gravel	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	300-700	144	161
7D28	5-15	4-7	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	300-700	157	194
7D29	15-30	4-7	Sand and Gravel	Clay Loam	2-6	Silt/Clay	300-700	129	147
7D30	15-30	4-7	Sand and Gravel	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	300-700	134	151
7D31	30-50	4-7	Sand and Gravel	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	300-700	124	141
7D32	15-30	7-10	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	152	169
7D33	5-15	7-10	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	166	189
7D34	5-15	7-10	Sand and Gravel	Loam	6-12	Sand and Gravel w/sig Silt and Clay	700-1000	161	174
7D35	5-15	10+	Sand and Gravel	Loam	0-2	Sand and Gravel	1000-2000	189	208
7D36	0-5	10+	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	189	209
7D37	0-5	10+	Sand and Gravel	Loam	0-2	Sand and Gravel	1000-2000	194	213
7D38	0-5	10+	Sand and Gravel	Sand	0-2	Sand and Gravel	1000-2000	202	233
7D39	15-30	10+	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	182	214
7D40	5-15	10+	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	184	204
7D41	15-30	7-10	Sand and Gravel	Muck	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	164	175
7D42	15-30	10+	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	170	184
7D43	5-15	4-7	Sand and Gravel	Clay Loam	6-12	Silt/Clay	300-700	135	145

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7D44	5-15	7-10	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	188	220
7D45	15-30	7-10	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	178	210
7D46	15-30	7-10	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Gr	700-1000	169	203
7D47	15-30	4-7	Sand and Gravel	Sand	2-6	Sand and Gravel w/sig Silt and Clay	300-700	146	181
7D48	5-15	4-7	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	300-700	149	174
7D49	15-30	4-7	Sand and Gravel	Loam	2-6	Sand and Gravel w/sig Silt and Clay	300-700	138	161
7D50	5-15	4-7	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	167	188
7D51	15-30	4-7	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	153	168
7D52	15-30	4-7	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	1000-2000	165	198
7D53	5-15	4-7	Sand and Gravel	Sand	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	166	201
7D54	15-30	4-7	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	144	161
7D55	5-15	4-7	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	154	171
7D56	30-50	4-7	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	134	151
7D57	5-15	7-10	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	300-700	150	169
7D58	5-15	10+	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	171	187
7D59	0-5	10+	Sand and Gravel	Clay Loam	0-2	Sand and Gravel	700-1000	181	196
7D60	15-30	7-10	Sand and Gravel	Clay Loam	2-6	Sand and Gravel w/sig Silt and Clay	700-1000	151	166
7D61	5-15	4-7	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	300-700	149	174
7D62	15-30	2-4	Sand and Gravel	Clay Loam	0-2	Sand and Gravel w/sig Silt and Clay	300-700	120	139
7D63	5-15	4-7	Sand and Gravel	Loam	0-2	Silt/Clay	100-300	132	160
7D64	15-30	4-7	Sand and Gravel	Loam	18+	Silt/Clay	100-300	113	123
7D65	15-30	4-7	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	300-700	139	164
7D66	5-15	7-10	Sand and Gravel	Shrinking and/or Aggregated C	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	170	199
7D67	15-30	4-7	Sand and Gravel	Loam	0-2	Sand and Gravel w/sig Silt and Clay	700-1000	148	171
7D68	15-30	4-7	Sand and Gravel	Shrinking and/or Aggregated C	18+	Silt/Clay	300-700	129	143
7D69	15-30	4-7	Sand and Gravel	Sand	0-2	Silt/Clay	100-300	130	170

ERRATUM
WARREN COUNTY
GROUND WATER POLLUTION POTENTIAL NO. 17

Errors on Map: (Note: values in report setting tables are correct.)

Hydrogeologic Setting (As Shown On Map)	**Hydrogeologic Setting (Corrected)**
7Aaf5 120	7Aaf5 **148**
7Af2 93	7Af2 **100**
7Aa17 108	7Aa17 **106**
7D6 136	7D6 **163**
7D13 197	7D13 **202**
7D28 147	7D28 **157**
7D49 139	7D49 **138**
7D62 158	7D62 **120**

Changes to Map and Report:

The following settings have been omited from both the map and report setting tables:

7Af7; 7Af15; 7Af17; 7D 1; 7D14.

Ground-Water Pollution Potential of WARREN COUNTY

by

The Center for Ground Water Management, Wright State University

Ronald G. Schmidt, Director, Project Manager

Lori L. Wenz, Project Assistant

James A. Wasserbauer, Project Assistant

Prepared in Cooperation With

Ohio Department of Natural Resources, Division of Water

Scale bars: 1 0 1 2 Miles; 1 0 1 2 Kilometers

CONTOUR INTERVAL 10 FEET

County Line

Township Line

Incorporated City Limit

Pollution Potential Index Range

Higher

- 200+
- 180 - 199
- 160 - 179
- 140 - 159
- 120 - 139
- 100 - 119
- 80 - 99
- <79

to

Lower

Description of Map Symbols

Hydrogeologic Region → 7Ad 6 ← Hydrogeologic Setting

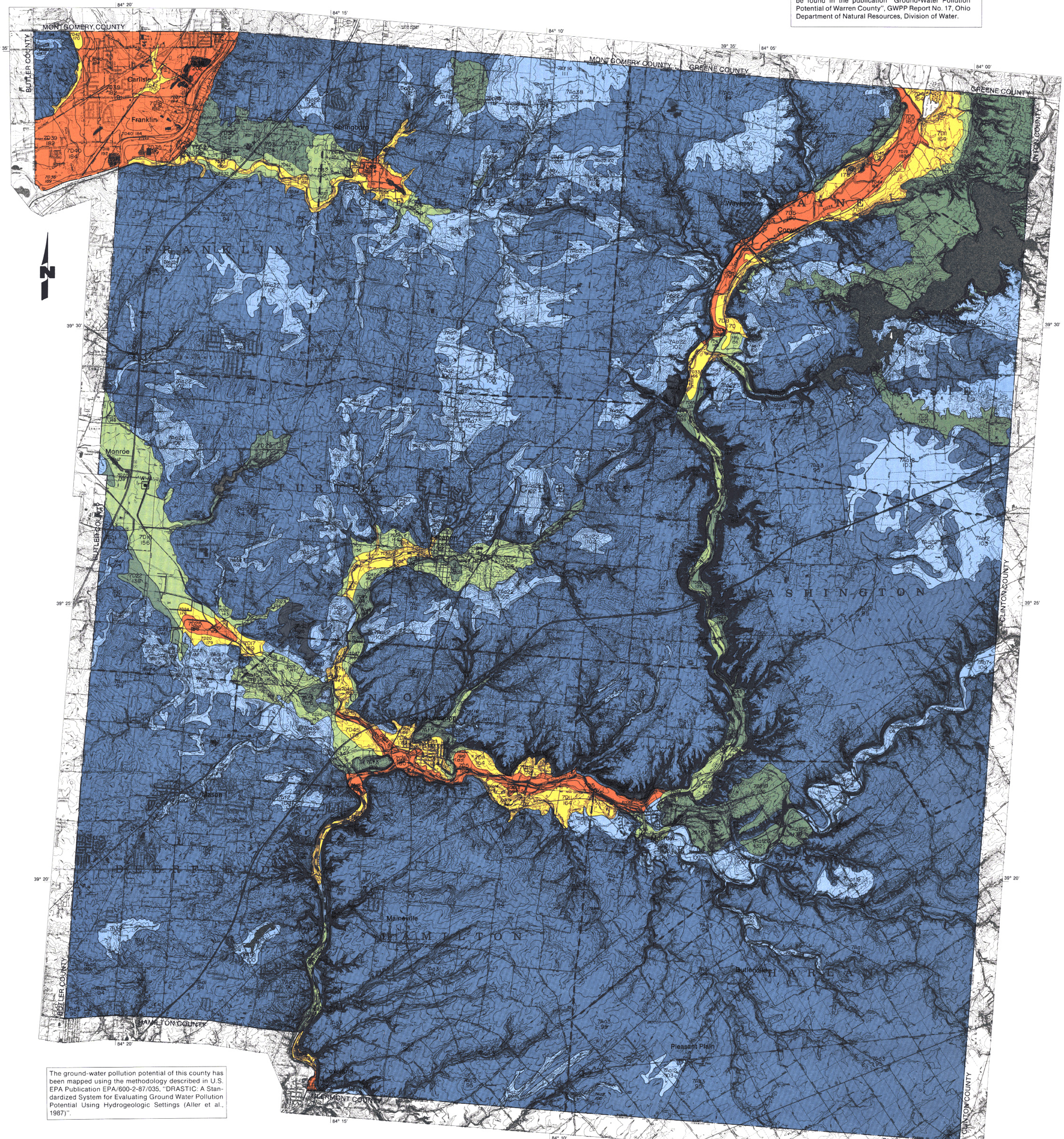
98 ← Relative Pollution Potential

Observation Well Site**

Hydrogeologic Settings

- 7Aa Glacial Till Over Sedimentary Rock
- 7Af Sand and Gravel In Glacial Till
- 7C End Moraine
- 7D Buried Valley

A more detailed description of the hydrogeologic settings and the evaluation of the pollution potential may be found in the publication "Ground-Water Pollution Potential of Warren County", GWPP Report No. 17, Ohio Department of Natural Resources, Division of Water.



The ground-water pollution potential of this county has been mapped using the methodology described in U.S. EPA Publication EPA/600-2-87/035, "DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings (Aller et al., 1987)".

** Observation well sites indicate the location of wells used to collect ground-water level information. These wells are part of the State observation well network. Hydrographs of the water levels recorded in these and other State observation wells can be obtained through ODNR-Division of Water.

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David S. Orr, Cartographer

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Richard F. Celeste
Governor

Joseph J. Sommer
Director