GROUND WATER POLLUTION POTENTIAL
OF ALLEN COUNTY, OHIO

BY

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GROUND WATER POLLUTION POTENTIAL REPORT NO. 37

OHIO DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATER

WATER RESOURCES SECTION

2005

ABSTRACT

A ground water pollution potential map of Allen 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 Allen County resulted in a map with symbols and colors, which illustrate areas of varying ground water pollution potential indexes ranging from 100 to 175.

Allen 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 eastern 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 in the main trunk of the deep buried valley system found in central Allen County. These buried valleys are tributaries of the ancient Teays River valley system. Yields over 100 gpm are possible from properly designed large diameter wells completed in these deeper units. Wells yielding 5 to 100 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.

Outside of the buried valley system, sand and gravel lenses interbedded in the glacial till locally serve as aquifers in portions of southwestern and northeastern Allen 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 Allen County has been prepared to assist planners, managers, and local officials in evaluating the potential for contamination from various sources of pollution. This information can be used to help direct resources and land use activities to appropriate areas, or to assist in protection, monitoring, and clean-up efforts.

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ACKNOWLEDGEMENTS

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

Map preparation and review:	Michael P. Angle Kelly Barrett
GIS coverage production and review:	Ryan Baie David Pitzer Paul Spahr Michael P. Angle
Report production and review:	Michael P. Angle
Report editing:	Katherine Sprowls Jim Raab

Truman W. Bennett and Mark D. Bennett of Bennett & Williams, Inc. compiled preliminary work on the Ground Water Pollution Potential of Allen County during the early 1990's. Their work proved quite valuable in helping to establish the DRASTIC ratings and hydrogeologic settings utilized during the mapping of Allen County.

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; 8,400 of these wells exist in Allen 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 Allen 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 Allen County. Inherent within each hydrogeologic setting are the physical characteristics that affect the ground water pollution potential. These characteristics or factors identified during the development of the DRASTIC system include:

D – Depth to Water

R – Net Recharge

A – Aquifer Media

S – Soil Media

T – Topography

I – Impact of the Vadose Zone Media

C – Conductivity (Hydraulic) of the Aquifer

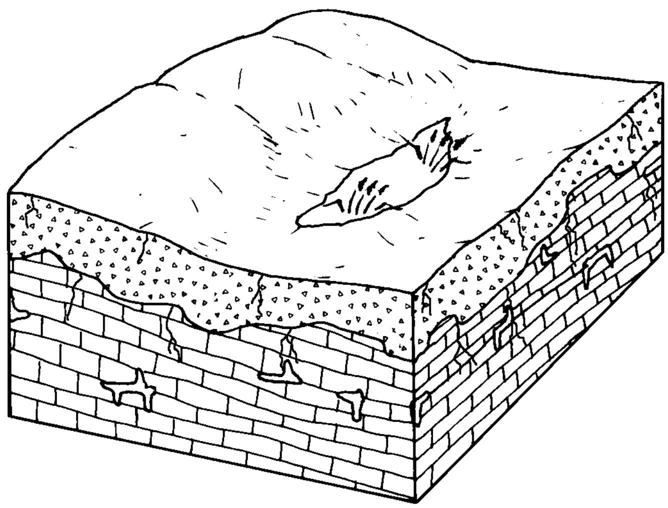
These factors incorporate concepts and mechanisms such as attenuation, retardation, and time or distance of travel of a contaminant with respect to the physical characteristics of the hydrogeologic setting. Broad consideration of these factors and mechanisms coupled with existing conditions in a setting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

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

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

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

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



7Ac-Glacial Till over Limestone

This hydrogeologic setting is widespread in Allen County. The area is characterized by flat-lying topography and low relief associated with ground moraine. The setting basically occupies three wide belts that lie between the end moraines and, on the northern edge, the lake plain. 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. Greater depths to water are found in the vicinity of Lima. Soils are 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. 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 102 to 175, with the total number of GWPP index calculations equaling 24.

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	

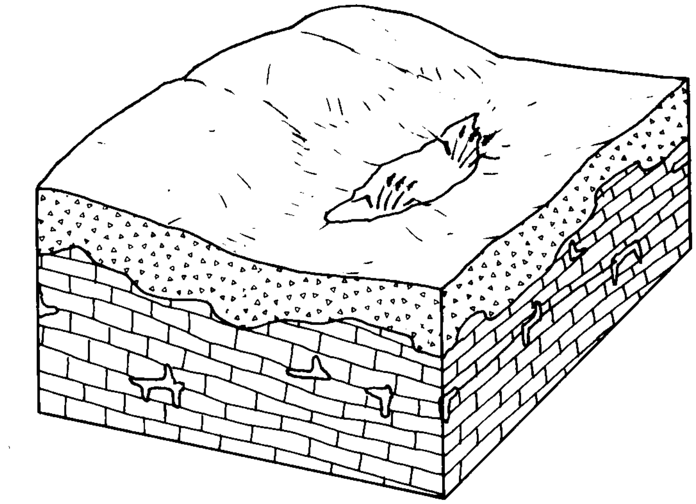
Table 8. Ranges and ratings for hydraulic conductivity

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 Allen 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 Allen County produces settings with a wide range of vulnerability to ground water contamination. Calculated pollution potential indexes for the nine settings identified in the county range from 100 to 175.

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 Allen 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 Allen 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 ALLEN COUNTY

Demographics

Allen County occupies approximately 410 square miles (Heffner et al., 1965) in north central Ohio (Figure 3). Allen County is bounded to the northeast by Hancock County, to the west by Van Wert County, to the north by Putnam County, to the southeast by Hardin County, and to the south by Auglaize County.

The approximate population of Allen County, based upon year 2000 census estimates, is 108,473 (Department of Development, Ohio County Profiles, 2005). Lima is the largest community and the county seat. Most of the growth in the county is in the suburban areas surrounding Lima. Agriculture accounts for roughly 84 percent of the land usage in Allen 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 (formerly OCAP).

Climate

The *Hydrologic Atlas for Ohio* (Harstine, 1991) reports an average annual temperature of approximately 51 degrees Fahrenheit for Allen County. Harstine (1991) shows that precipitation approximately averages 35 inches per year for the county. The mean annual precipitation for Lima is 37.2 inches per year based upon a thirty-year (1971-2000) period (National Oceanographic and Atmospheric Administration (NOAA), 2002). The mean annual temperature at Lima for the same thirty-year period is 50.9 degrees Fahrenheit (NOAA, 2002).

Physiography and Topography

The vast majority of Allen County lies within the Central Till Plains Lowland Province, while the northwestern corner 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 Allen County except the far northwestern corner as belonging in the Central Ohio Clayey Till Plain. The northwestern corner is part of the Maumee Lake Plains. Allen County is characterized by flat to gently rolling ground moraine separated by wide belts of hummocky end moraines. The lake plains area in northwestern Allen County is characterized by especially flat topography associated with ground moraine that was heavily wave eroded.

Figure 3. Location map of Allen County, Ohio.

Modern Drainage

Allen County lies north of the major drainage divide crossing north central Ohio; all of Allen County drains toward Lake Erie. The entire county ultimately drains into the Auglaize River, either directly or through tributaries. The Auglaize River directly drains the southeastern corner and western third of the county. The Ottawa River and Sugar Creek drain the majority of central and eastern Allen County. Cranberry Creek and Riley Creek drain the northeastern corner of the county near Bluffton. These tributaries flow northward to the Blanchard River eventually joining the Auglaize River in Putnam County.

Pre- and Inter-Glacial Drainage Changes

The drainage patterns of Allen 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 Allen 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. Drainage in Allen County was to the south, towards the Teays River. Stout et al. (1943) referred to a large, southwesterly-flowing tributary that drained Allen County as Wapakoneta Creek (Figure 4). Modern bedrock topography data (Kostelnick, 1981 and Open File Bedrock Topography Maps, ODNR, Division of Geological Survey) show a deep, north-south trending channel extending across the entire county and passing just west of Lima. A second, shorter channel lies to the east of the main channel, underlying most of Perry Township.

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 Allen County evolved and drainage shifted towards the north during ice-free intervals. The modern drainage reflects the nature of landforms deposited during the Wisconsinan advances, particularly end moraines and the southern extension of the Lake Maumee basin.

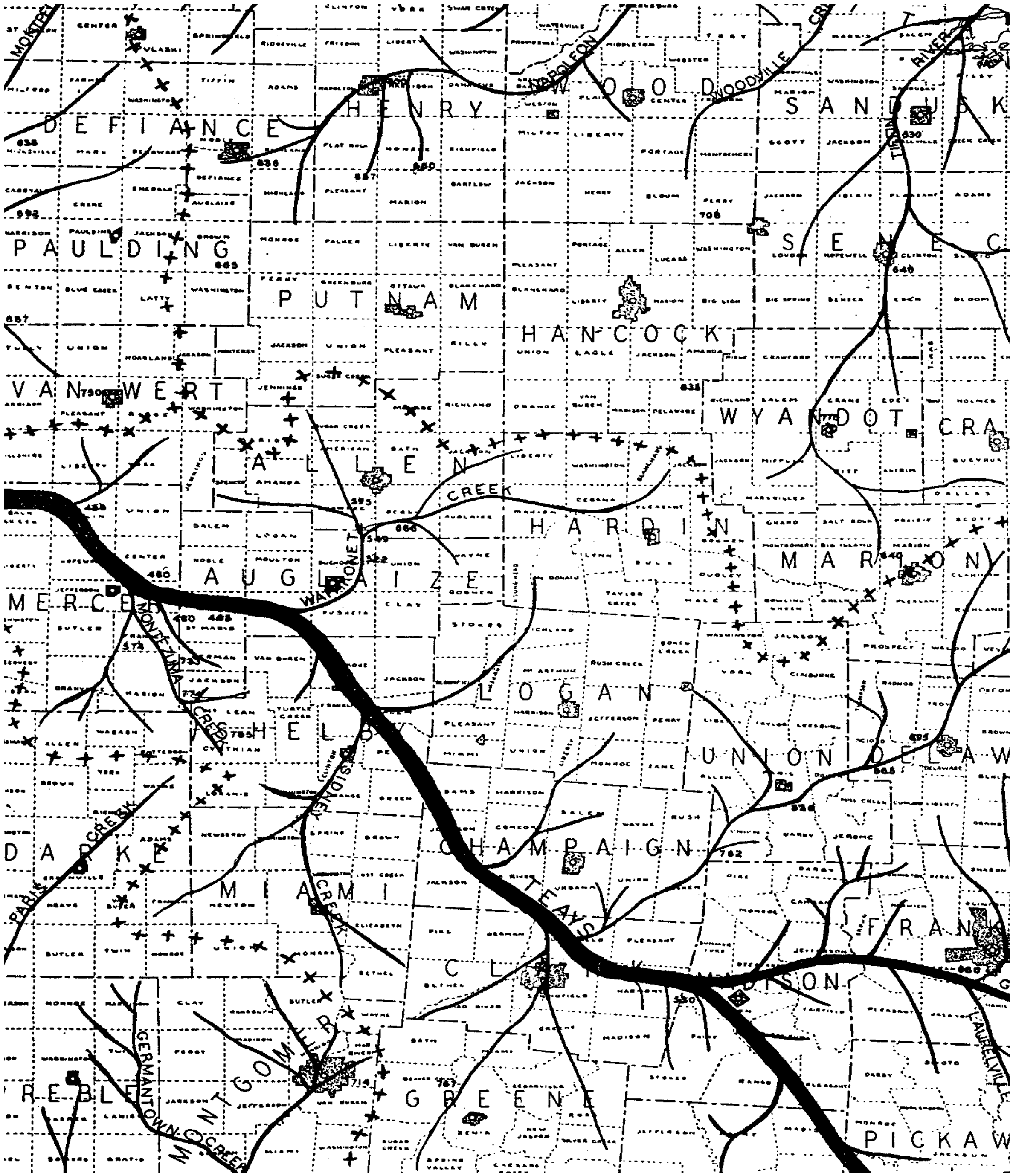


Figure 4. Teays Stage drainage in Allen County (after Stout et al., 1943).

Glacial Geology

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

The unconsolidated (glacial) deposits in Allen County fall into five main types: (glacial) till, lacustrine deposits, beach/deltaic/dune deposits, alluvial (river) deposits and ice-contact sand and gravel (kames, eskers) 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. Overall, drift is thinner in areas of ground moraine and thickens in end moraines. Drift is thickest in the buried valleys associated with the Teays River System in central Allen County. Along the northern edge of Allen 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 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 Allen County. These types of tills are associated with ancestral Lake Maumee in the northern fringe of the county. These types of tills would be deposited when a relatively thin ice sheet would alternately float and ground depending on the water level of the lake and thickness of the ice sheet. Such tills may more closely resemble lacustrine deposits (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 western Allen County, passing just south of Spencerville and then turns northeast extending from Lima to Beaverdam. The Wabash Moraine occupies a broad area in the southeast corner of Allen 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 Allen County tend to be relatively low elevation and are at elevations just above the current floodplain. Alluvium will vary in nature from fine sand to silty-sand to clayey silt.

Kames and eskers are ice contact features. They are composed of masses of generally poorly sorted sand and gravel with minor till, deposited in depressions, holes, tunnels, or other cavities in the ice. As the surrounding ice melts, a mound of sediment remains behind. Typically, these deposits may collapse or flow as the surrounding ice melts. These deposits may display high angle, distorted or tilted beds, faults, and folds. Kames are comprised of isolated or small groups of rounded mounds of dirty sand and gravel with minor till. Eskers are comprised of elongate, narrow, sinuous ridges of sand and gravel. The best examples of ice contact deposits are small, isolated kames found in Auglaize Township in the southeastern corner of the county (Goldthwait et al, 1961 and Pavey et al., 1999).

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 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 Allen County, the lacustrine deposits are typically very thin and may occur in isolated pockets. The surficial material is more typically either wave-planed till or fine sand associated with beaches, dunes, and deltas.

The beach levels in Allen County are all associated with ancestral Lake Maumee. Elevations for these features occur between 775 ft and 800 ft above mean seal level (msl). Forsyth (1959 and 1973) gives a detailed discussion of the beach levels and lake history in northwestern Ohio. The beaches form long, narrow low ridges of sand. Coarser sand and gravel form the core of the ridges. Thin sheets of fine sand may lie between the ridges. Wind activity has reworked the beach ridges creating dunes. Dunes cap many of the beach ridges, making it difficult to distinguish the features.

Bedrock Geology

Bedrock underlying the surface of Allen County belongs to the Silurian System. Carbonate (limestone and dolomite) bedrock underlies the entire county. Table 9 summarizes the bedrock stratigraphy found in Allen 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 Allen 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.

Underlying the Salina Undifferentiated Group are rocks of the Silurian Tymochtee and Greenfield Formations, which were also deposited in warm, shallow seas. These two formations tend to become thinner along the margins of the deep buried valley system in central Allen County. The units are also similar to the Salina Undifferentiated in that they thin appreciably in far western Allen County.

The oldest unit typically encountered by water wells is the Silurian Lockport Group. Rocks of the Lockport are commonly found in the subsurface across Allen County, and are the uppermost bedrock unit in the northwestern corner of Allen 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 Allen County is obtained from both unconsolidated (glacial-alluvial) and consolidated (bedrock) aquifers. Deep layers of sand and gravel are utilized as the aquifer in the main trunk of the deep buried valley system found in central Allen County. Yields over

Table 9. Bedrock stratigraphy of Allen County

System	Group/Formation (Symbol)	Lithologic Description
Silurian	Undifferentiated Salina Dolomite (Sus)	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.
	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. Thickness decreases to the west, south, and along margins of buried valleys. Yields can be >100 gpm, especially in the Tymochtee in the northeastern corner of the county.
	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.

100 gpm are possible from properly designed large diameter wells completed in these deeper units. Yields up to 400 gpm have been obtained from these deposits just south of the county line at Cridersville (Kostelnick, 1983). Wells yielding 5 to 100 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.

Thin lenses of sand and gravel interbedded with till comprise the glacial aquifers in many portions of western and southern Allen County. These thin sand and gravel aquifers are commonly associated with glacial complexes that flank the buried valley system in central Allen County. Glacial complexes are areas of thick glacial drift that is predominantly comprised of dense till (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.

Thin lenses of sand and gravel interbedded in glacial till also serve as the local aquifer for isolated areas of end moraine and ground moraine in both southwestern Allen County and also along the northeastern corner of the county, bordering Hancock County. The sand and gravel lenses may directly overlie the carbonate bedrock. These lenses may serve as an aquifer or, more commonly, serve as an extra source of recharge to the underlying fractured bedrock. Well drillers may penetrate the bedrock directly below the sand and gravel to complete the well. In such cases the bedrock acts as a “screen” to help filter fines out of the gravel.

The carbonate aquifer is an important regional aquifer for most of northwestern and north central Ohio and underlies all of Allen County (ODNR, Div. of Water, 1970 and Kostelnick, 1981). Completed water wells typically penetrate multiple bedrock units. Yields exceeding 100 gpm are available from deep, large diameter wells drilled into the Silurian Salina Undifferentiated Group and the Tymochtee and Greenfield Dolomites in eastern Allen 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 Kostelnick, 1981). In areas of western Allen County and along the margins of the buried valleys, the thicknesses of the Salina Undifferentiated Group and the Tymochtee and Greenfield Dolomites decrease appreciably, and their yields drop 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, where shallower wells had relatively poor yields (under 10gpm), 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. Deeper wells are more likely to contain highly mineralized water and have objectionable water quality.

REFERENCES

Aller, L., T. Bennett, J.H. Lehr, R.J. Petty, and G. Hackett, 1987. DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeological settings. U.S. Environmental Protection Agency EPA/600/2-87-035, 622 pp.

Anderhalt, R., C.F. Kahle, and D. Sturgis, 1984. The sedimentology of a Pleistocene glaciolacustrine delta near Toledo, Ohio. Society of Economic Paleontologists and Mineralogists, Great Lakes Section, Fourteenth Annual Field Conference, Field Guidebook, p. 59-90.

Bier, J.A., 1956. Landforms of Ohio. Ohio Department of Natural Resources, Division of Geological Survey, map.

Bowser-Morner (1987). Application for permit to install and supplemental report for Timberline Landfill, Allen County, Ohio. Unpublished consultants report, Bowser-Morner, Inc., Dayton, Ohio.

Brockman, C.S., 1998. Physiographic regions of Ohio. Ohio Department of Natural Resources, Div. of Geological Survey, map with text.

Brockman, C.S. and J.P. Szabo, 2000. Fractures and their distribution in the tills of Ohio. The Ohio Journal of Science, Vol. 100, No. ¾, p. 39-55.

Driscoll, F.G., 1986. Groundwater and wells. Johnson Filtration Systems , St. Paul, Mn, 1089 pp.

Dumouchelle, D.H. and M.C. Schiefer, 2002. Use of streamflow records and basin characteristics to estimate ground-water recharge rates in Ohio. Ohio Department of Natural Resources, Division of Water, Bulletin 46, 45 pp.

Eyles, N. and J.A. Westgate, 1987. Restricted regional extent of the Laurentide Ice Sheet in the Great Lakes Basin during early Wisconsinan Glaciation. Geology, v. 15, p. 537-540.

Fenneman, N.M., 1938. Physiography of the eastern United States. McGraw-Hill Book Co., New York, New York, 714 pp.

Fetter, C.W., 1980. Applied hydrogeology. Charles E. Merrill Publishing Co., Columbus, Ohio, 488 pp.

Floyd G. Browne and Associates, 1963. Report on North Well Field for the city of Delphos, Ohio. Unpublished Consultant's report, Marion, Ohio, 14 pp.

Forsyth, J.L., 1959. The beach ridges of northern Ohio. Ohio Department of Natural Resources, Division of Geological Survey, Information Circular, No. 25.

Forsyth, J. L., 1965. Water-modified till of the lake plain of northwestern Ohio. Ohio Journal of Science, v. 65, no. 2, p. 96

Forsyth, J.L., 1973. Late-glacial and postglacial history of western Lake Erie. Compass of Sigma Gamma Epsilon, v. 51, no. 1, p. 16-26.

Freeze, R.A. and J.A. Cherry, 1979. Ground water. Prentice-Hall, Englewood Cliffs, N.J., 604 pp.

Frost, R.B., 1931. Physiographic map of Ohio. Oberlin College, The Geographical Press, Columbia Univ., N.Y., N.Y., map with text.

Goldthwait, R.P., G.W. White, and J.L. Forsyth, 1961. Glacial map of Ohio. U. S. Department of Interior, Geological Survey, Miscellaneous Map, I-316, map with text.

Haefner, R.J., 2000. Characterization methods for fractured glacial tills. The Ohio Journal of Science, Vol. 100, No. ¾, p. 73-87.

Harstine, L.J., 1991. Hydrologic atlas for Ohio. Ohio Department of Natural Resources, Division of Water, Water Inventory Report, No. 28, 13 pp.

Heath, R.C., 1984. Ground-water regions of the United States. U. S. Geological Survey, Water Supply Paper 2242, 78 pp.

Heffner, R.L., A.R. Brock, R.L. Christman, and D.D. Waters, 1965. Soil Survey of Allen County Ohio. U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey, 99 pp.

Kaser, P., 1952. Ground-water levels in the vicinity of Spencerville, Ohio. Ohio Department of Natural Resources, Division of Water, report, 9 pp.

Kostelnick, R.J., 1981. Ground-water resources of Allen County. Ohio Department of Natural Resources, Division of Water, Ground Water Resources Map, map with text.

Kostelnick, R.J., 1983. Ground-water resources of Auglaize County. Ohio Department of Natural Resources, Division of Water, Ground Water Resources Map, map with text.

Leggette, Brashears & Graham. Unpublished pump test data for the Standard (Sohio) Oil (B.P.) Company wells in Lima , Ohio. Pump test data on limestone aquifer.

National Oceanographic and Atmospheric Administration, 2002. Monthly station normals of temperature, precipitation, and heating and cooling degree-days, 1971-2000. Climatography of the United States No. 81, OHIO. U.S. Department of the Interior, Project A-051-OHIO, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 30 pp.

Norris, S.E. and R.E. Fidler, 1973. Availability of water from limestone and dolomite aquifers in southwest Ohio and the relation of water quality to the regional flow system. U.S. Geological Survey, Water-Resources Investigations 17-73. 42 pp.

Ohio Department of Natural Resources, Division of Geological Survey, Open File, Reconnaissance Bedrock Geology Maps. Available on a U.S.G.S. 7-1/2 minute quadrangle basis.

Ohio Department of Natural Resources, Division of Geological Survey, Open File, Bedrock Topography Maps. Available on a U.S.G.S. 7-1/2 minute quadrangle basis.

Ohio Department of Natural Resources, Division of Water, 1970. Ground water for planning in northwest Ohio: A study of the carbonate rock aquifers. Ohio Water Plan Inventory Report no. 22, 63 pp.

Ohio Department of Natural Resources, Division of Water, 2000. In the vicinity of Delphos's Amanda Township Wellfield Allen County. Ohio Department of Natural Resources, Division of Water, Ground Water Conflict Investigation Report, 12 pp.

Ohio Department of Natural Resources, Division of Water, Open File Bedrock State Aquifer Maps, 2000. Available on a U.S.G.S. 7-1/2 minute quadrangle basis.

Ohio Department of Natural Resources, Division of Water, Open File Glacial State Aquifer Maps, 2000. Available on a U.S.G.S. 7-1/2 minute quadrangle basis.

Pavey, R.R., R.P. Goldthwait, C.S. Brockman, D.N. Hull, E.M. Swinford, and R.G. Van Horn, 1999. Quaternary geology of Ohio. Ohio Department of Natural Resources, Division of Geological Survey, Map No. 2, map with text.

Pettyjohn, W.A. and R. Henning, 1979. Preliminary estimate of ground water recharge rates, related streamflow and water quality in Ohio. U.S. Department of the Interior, Project A-051-OHIO, Project Completion Report No. 552, Water Resources Center, The Ohio State University, Columbus, Ohio, 323 pp.

Schiefer, M. C., 2002. Basin descriptions and flow characteristics of Ohio streams. Ohio Department of Natural Resources, Div. of Water, Bulletin 47, 161 pp.

Smith, K.C., 1994. Ground Water Pollution Potential of Hancock County, Ohio. Ohio Department of Natural Resources, Division of Water, GWPP Report No. 14, 78 pp.

Stith, D.A., 1977. Limestone in the Tymochtee Dolomite(?) (Upper Silurian), Shawnee Township, Allen County, Ohio. Ohio Department of Natural Resources, Division of Geological Survey, Geological Note No. 5, 4 pp.

Stout, W., K. Ver Steeg, and G.F. Lamb, 1943. Geology of water in Ohio. Ohio Department of Natural Resources, Division of Geological Survey, Bulletin 44, 694 pp.

UNPUBLISHED DATA

Ohio Department of Development. Ohio County Profiles, 2005.

Ohio Department of Natural Resources, Division of Water. Well log and drilling reports for Allen County.

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 8,400 water well log records are on file for Allen County. Data from roughly 2,500 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 Allen County* (Kostelnick, 1981) 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 Hancock County (Smith, 1994) were used as a guideline. Localized studies providing information on the depth to water included Kaser (1952), Bowser-Morner (1987), and ODNR, Division of Water (2000). 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 most of the alluvial settings and for almost all of the 7Fd-Wave-eroded Lake Plain hydrogeologic setting in Allen 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 the 7Af-Sand and Gravel interbedded in Glacial Till setting. Depths to water of 30 to 50 feet (5) were utilized for the majority of the 7C-Moraine settings for both the Fort Wayne Moraine and 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.

Depths to water of 75 to 100 feet (2) were selected for areas in the vicinity of Lima. Water well log data showed a number of very deep static water levels throughout this area. It is possible that the local water elevation has been depressed due to high pumping rates at nearby limestone quarries and a major oil refinery.

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 Hancock County (Smith, 1994) were used as a guideline.

Values of 7 to 10 inches per year (8) were used for areas of high recharge. These areas were limited to where limestone bedrock was within a few feet of the ground surface, soils were essentially thin or absent and these settings were adjacent to streams. 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 Allen County.

Aquifer Media

Information on evaluating aquifer media was obtained from the *Ground Water Resources of Allen County* (Kostelnick, 1981). 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 Hancock County (Smith, 1994) 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 Floyd Browne and Assoc. (1963), Leggette, Brashears & Graham (1970), Stith (1977), Bowser and Morner (1987), and ODNR, Div. of Water (2000), 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 Allen County. A rating of (7) was applied to all of the Silurian limestone aquifers in Allen County.

Sand and gravel was evaluated as the aquifer along 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 7C-End Moraine and 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 and the 7Ed-Alluvium over Glacial Till settings and given a rating of (6). Sand and gravel aquifers associated with 7C-End Moraine and 7J-Glacial Complex settings located further away from the 7D-Buried Valley settings were given a rating of (6), as the sand and gravel lenses tended to thin and become finer-grained further from the buried valleys. 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. To help make this delineation more consistent, a bedrock surface elevation of 700 feet msl was selected as the cut-off between these two settings. Valleys that were cut deeper than 700 feet msl based on bedrock topography data (Kostelnick, 1981, Open File Bedrock Topography Maps, ODNR, Division of Geological Survey, and ODNR, Division of Water, Glacial State Aquifer Map, 2000) were evaluated as buried valleys, adjoining areas were evaluated as glacial complexes.

Soils

Soils were mapped using the data obtained from the *Soil Survey of Allen County* (Heffner et al., 1965). Each soil type was evaluated and given a rating for soil media. Evaluations were based upon the texture, permeability, and shrink-swell potential for each soil material. Special emphasis is placed upon determining the most restrictive layer. The soils of Allen 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 Allen County.

Soils were considered to be thin or absent (10) for a very limited number of areas in northern Allen County where the limestone bedrock was within a few feet of the ground surface. Most of these areas were adjacent to streams and were on the fringes of the 7Fd-Wave-eroded Lake Plain setting. Shrink-swell (non-aggregated) clays (7) were selected for the highly clayey soils found at the surface of the 7Fd-Wave-eroded Lake Plain. These soils were formed on the water-eroded till and lacustrine sediments associated with ancestral Lake Maumee. 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 terraces 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.

Topography

Topography, or percent slope, was evaluated using U.S.G.S. 7-1/2 minute quadrangle maps and the *Soil Survey of Allen County* (Heffner et al., 1965). Slopes of 0 to 2 percent (10) 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) were widespread in Allen County and reflected most areas of both slightly rolling ground moraine and end moraines. Slopes of 6 to 12 percent (5) were selected for a limited number of areas along the margins of end moraines where down-cutting streams had more steeply-dissected the topography.

Table 10. Allen County soils

Soil Name	Parent Material/ Setting	DRASTIC Rating	Soil Media
Belmore	Beach ridges	6	Sandy loam
Blount	Clayey till	3	Clay loam
Casco	Outwash, kame	6	Sandy loam
Colwood	Fine beach, deltaic	5	Loam
Digby	Beach ridge	6	Sandy loam
Eel	Alluvium	4	Silt loam
Fox	Outwash, kames	6	Sandy loam
Genesee	Alluvium	4	Silt 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
Lenawee	Silty lacustrine	4	Silt loam
Linwood	Peat, muck	8	Peat
Milgrove	Thin outwash over till	5	Loam
Milsdale	Limestone near surface	10	Thin or absent
Montgomery	Clayey lacustrine or oxbow	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
Randolph	Limestone at surface	10	Thin or absent
Rawson	Thin beach sand over till	5	Loam
Rimer	Beach ridge, dune	6	Sandy Loam
St. Clair	Clayey lacustrine	7	Shrink-swell clay
Seward	Thin outwash over till	5	Loam
Shoals	Alluvium	4	Silt loam
Sloan	Alluvium	4	Silt loam
Spinks	Dune	9	Sand
Tedrow	Beach ridge, dune	6	Sandy loam
Toledo	Clayey lacustrine	7	Shrink-swell clay
Tuscola	Deltaic, fine beach ridge	5	Loam
Wabash	Fine-grained alluvium	4	Silty Loam

Impact of the Vadose Zone Media

Information on evaluating vadose zone media was obtained primarily from the *Ground Water Resources of Allen County* (Kostelnick, 1981) 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 Hancock County (Smith, 1994) 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 Allen County* (Heffner et al, 1965) 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 Floyd Browne and Assoc. (1963), Leggette, Brashears & Graham (1970), Bowser and Morner (1987), and ODNR, Div. of Water (2000) provided valuable information.

The vadose zone media is a critical component of the overall DRASTIC rating in Allen 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 was selected as the vadose zone media for a limited number of locations where limestone bedrock was within a few feet of the land surface and given a rating of (7) or (6). Limestone/fractured till with a vadose zone media rating of (6) was selected for parts of Allen 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 portions of northern Allen County and given a rating of (5) or (6). This vadose zone media was limited to the 7Ec-Alluvium over Sedimentary Rocks setting where the stream had eroded down close to the surface of the limestone, typically leaving less than fifteen feet of alluvium. Glacial till was given vadose zone media ratings of (6), (5), or (4). A rating of (6) was applied to a limited number of areas where the till was underlying thin, highly permeable beach ridge deposits and was thin and highly weathered and fractured. 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. 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 and 7J-Glacial Complex settings.

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 Allen County. A vadose zone rating of (6) for sand and gravel with significant silt and clay was also used for some areas featuring coarse alluvium or terraces. Sand and gravel with significant silt and clay was given a vadose zone rating of (5) for most alluvial areas and for most of the 7D-

Buried Valley setting. A vadose zone media rating of (4) was derived for sand and gravel with significant silt and clay for portions of the 7D-Buried Valley setting where the static water levels were very deep and the majority of the vadose zone could be considered to be unweathered. Silt and clay with a vadose zone media rating of (5) was selected for most alluvial settings in the county. Silt and clay with a rating of (5) was applied to fine-grained alluvium associated with some minor tributary streams. 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 (non-aggregated) clay soils developed from these clayey sediments.

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 Allen County* (Kostelnick, 1981). 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 Hancock County (Smith, 1994) 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 includes reports by Floyd Browne and Associates (1963), Leggette, Brashears & Graham (1970), and Bowser and Morner (1987). 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. Sand and gravel aquifers in the 7D-Buried Valley setting have been assigned a hydraulic conductivity range of 700-1,000 gallons per day per square foot (gpd/ft^2) (6). This rating reflects the higher yields of the deeper sand and gravel layers in the core of the ancestral tributary to the Teays River Valley. All remaining sand and gravel aquifers were assigned a hydraulic conductivity range of 300-700 (4). All limestone aquifers were assigned a hydraulic conductivity range of 300-700 gpd/ft^2 (4).

APPENDIX B

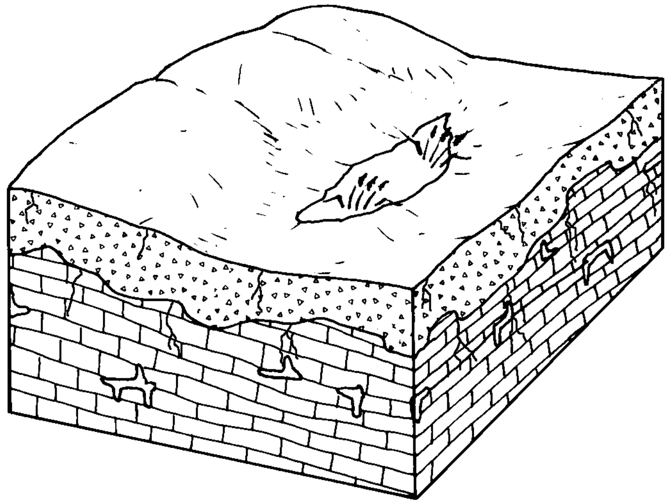
DESCRIPTION OF HYDROGEOLOGIC SETTINGS AND CHARTS

Ground water pollution potential mapping in Allen County resulted in the identification of nine 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 Allen County range from 100 to 175.

Table 11. Hydrogeologic settings mapped in Allen County, Ohio

Hydrogeologic Settings	Range of GWPP Indexes	Number of Index Calculations
7 Ac-Glacial till over limestone	102-175	24
7 Af-Sand and gravel interbedded in glacial till	104-144	12
7 C-Moraine	100-142	29
7 D-Buried valley	102-159	27
7 Ec-Alluvium over sedimentary rock	142-170	10
7 Ed-Alluvium over glacial till	142-153	6
7 Fd-Wave-eroded lake plain	135-146	4
7 H-Beaches, beach ridges, and sand dunes	148-154	5
7 J-Glacial complex	102-141	16

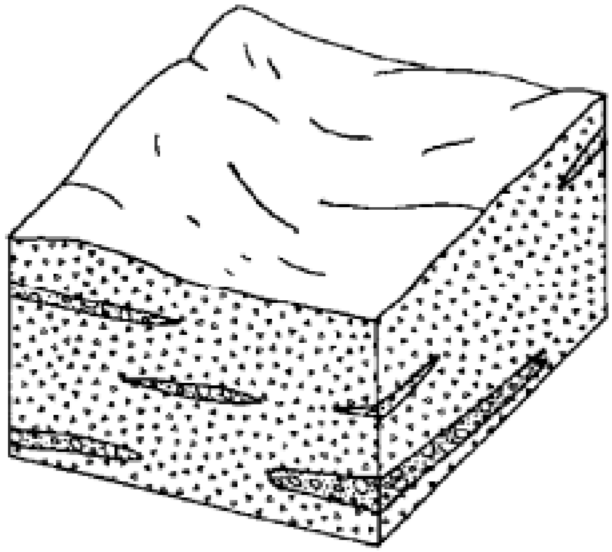
The following information provides a description of each hydrogeologic setting identified in the county, a block diagram illustrating the characteristics of the setting, and a listing of the charts for each unique combination of pollution potential indexes calculated for each setting. The charts provide 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 widespread in Allen County. The area is characterized by flat-lying topography and low relief associated with ground moraine. The setting basically occupies three wide belts that lie between the end moraines and, on the northern edge, the lake plain. 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. Greater depths to water are found in the vicinity of Lima. 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. 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.

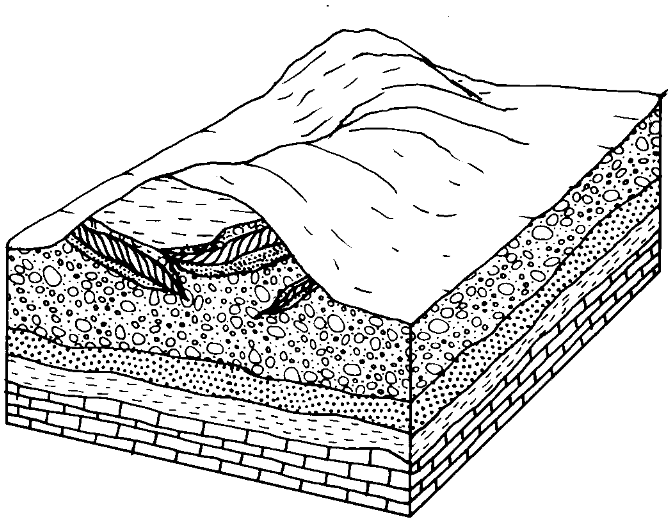
GWPP index values for the hydrogeologic setting of Glacial Till over Limestone range from 102 to 175, with the total number of GWPP index calculations equaling 24.



7Af-Sand and Gravel Interbedded in Glacial Till

This hydrogeologic setting is limited to the southwestern portion of Allen County and to the far northeastern corner adjacent to Hancock County. The area is characterized by flat lying topography and low relief. The setting is commonly associated with areas of ground moraine. The vadose zone is composed of silty to clayey glacial till. The till may be fractured or jointed, particularly in areas where it is predominantly thin and weathered. Depth to water is usually shallow to moderate averaging less than 50 feet. Soils are generally clay loams. 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.

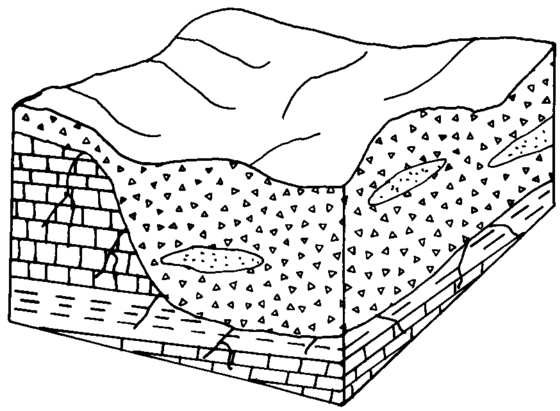
GWPP index values for the hydrogeologic setting of Sand and Gravel Interbedded in Glacial Till range from 104 to 144, with the total number of GWPP index calculations equaling 12.



7C-Moraine

This hydrogeologic setting consists of elongated, broad belts of end moraines that cross Allen County. This setting is characterized by hummocky to rolling topography. Relief tends to become steeper near the margins of the moraine, especially if enhanced by the downcutting of an adjacent stream. The aquifer consists of sand and gravel lenses interbedded with the fine-grained glacial till. In areas of the moraine where useable sand and gravel lenses are not encountered, the wells are completed in the underlying Silurian limestone and dolomite bedrock. Yields for the sand and gravel lenses average from 5 to 25 gpm. 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. In general, depths to water are deeper in the vicinity of Lima. 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.

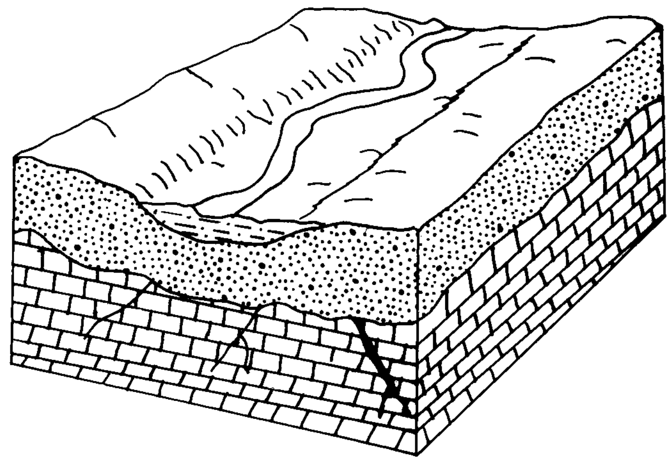
GWPP index values for the hydrogeologic setting of Moraine range from 100 to 142, with the total number of GWPP index calculations equaling 29.



7D-Buried Valley

This hydrogeologic setting consists of a narrow, north-south running band that extends across central Allen County and just to the east, a shorter buried valley in Perry Township. The axis of 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. At greater depths, the layers of sand and gravel become thicker, cleaner, and more productive. 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 usually clay loams derived from the overlying glacial till. Depths to water are highly variable. The depths tend to be greatest in the vicinity of Lima and are shallowest in the northern part of the county adjacent to the lake plain. 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.

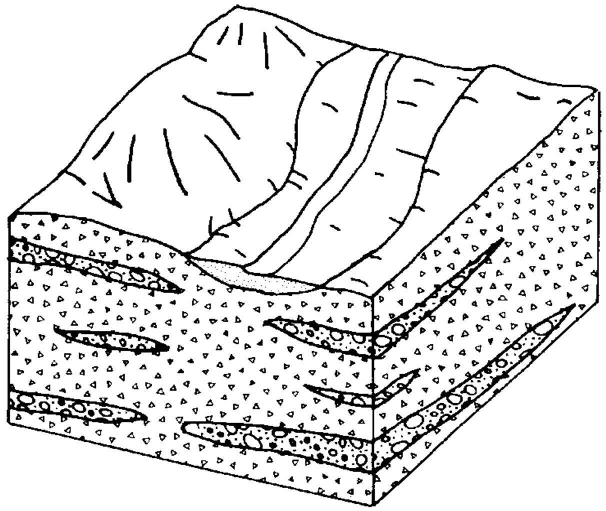
GWPP index values for the hydrogeologic setting of Buried Valley range from 102-159, with the total number of GWPP index calculations equaling 27.



7Ec-Alluvium over Sedimentary Rock

This hydrogeologic setting is common throughout Allen County. This hydrogeologic setting is comprised of flat-lying floodplains and stream terraces containing thin to moderate thicknesses of modern alluvium. This setting is similar to the 7Ed-Alluvium over Glacial Till except that the underlying aquifers consist of bedrock. The aquifers consist of Silurian limestones and dolomites. The vadose zone consists of the sandy to 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. 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.

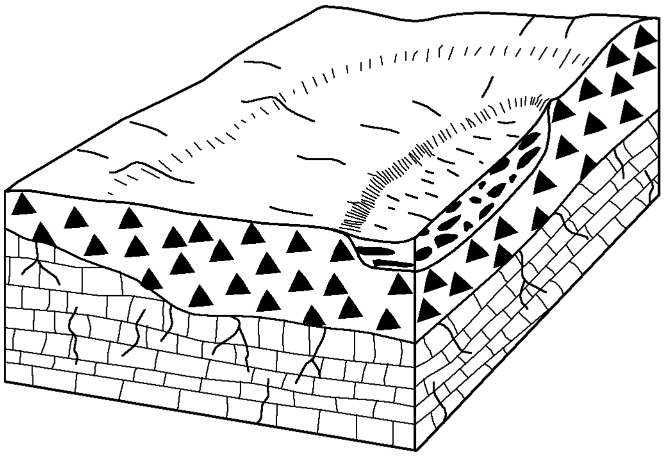
The GWPP index values for the hydrogeologic setting Alluvium over Sedimentary Rocks range from 142 to 170, with the total number of GWPP index calculations equaling 10.



7Ed-Alluvium over Glacial Till

This hydrogeologic setting is comprised of flat-lying floodplains and stream terraces containing thin to moderate thicknesses of modern alluvium. This setting is limited to south central Allen County. This setting is similar to the 7Af–Sand and Gravel interbedded in Glacial Till setting except for the presence of the modern stream and related deposits. The setting is also similar to the 7Ec-Alluvium over Sedimentary Rock except that the underlying aquifer consists of shallow sand and gravel lenses instead of bedrock. 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, loams, or sandy loams. Yields commonly range from 5 to 25 gpm from the sand and gravel lenses. Depth to water is typically shallow with depths averaging less than 20 feet. Recharge is moderately high due to the shallow depth to water, flat-lying topography, and the moderate permeability of the glacial till and alluvium.

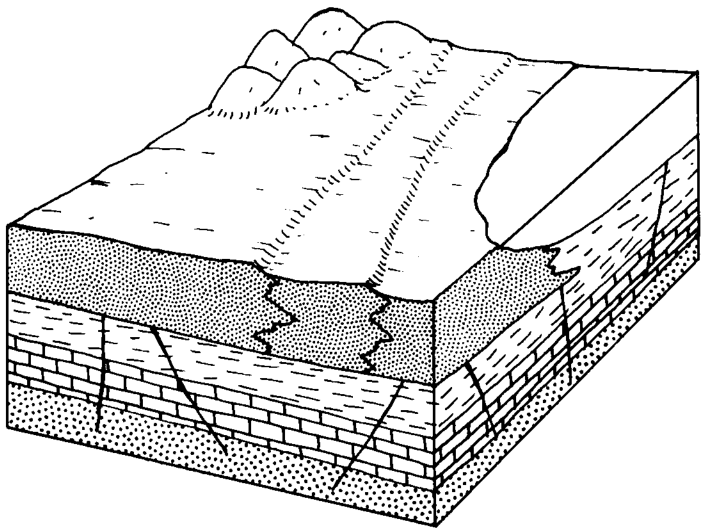
The GWPP index values for the hydrogeologic setting Alluvium Over Glacial Till range from 142 to 153, with the total number of GWPP index calculations equaling 6.



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

This hydrogeologic setting is characterized by very flat-lying topography caused by wave-erosion of glacial Lake Maumee. The setting 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. This setting occupies the northwestern corner of the county at elevations below 775 feet msl. The vadose zone media consists of thin silty to clayey lacustrine sediments that overlie clayey 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.

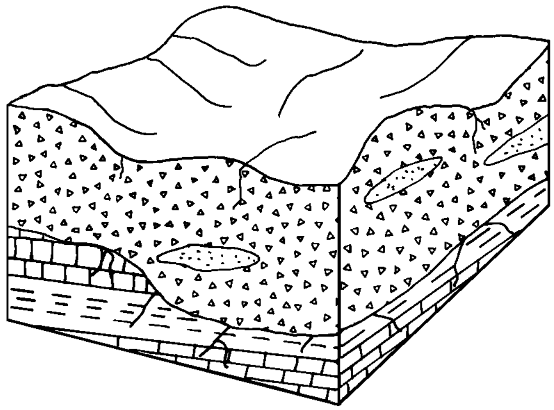
GWPP index values for the hydrogeologic setting of Intermorainal Lake Deposits range from 135 to 146, with the total number of GWPP index calculations equaling 4.



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 lies on the edge of the lake plain and roughly fringes the northern borders of Allen County. The vadose zone media is composed of thin, clean, fine-grained quartz sand that has moderately high permeability and low sorptive capability. These thin sands overlie clayey lacustrine deposits and water-modified till. Wells are completed in Silurian limestone and dolomite bedrock that underlies the till and lacustrine sediments. 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 148 to 154, with the total number of GWPP index calculations equaling 5.



7J-Glacial Complex

This setting is found in central Allen County. This setting is comprised of predominantly thick glacial till that lies adjacent to the 7D-Buried Valley setting and lacks the distinctive surficial topography of the 7C-Moraine 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 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 variable, they are typically shallow to moderate, but become deeper near Lima. 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 102 to 141, with the total number of GWPP index calculations equaling 16.

Table 12. Hydrogeologic Settings, DRASTIC Factors, and Ratings

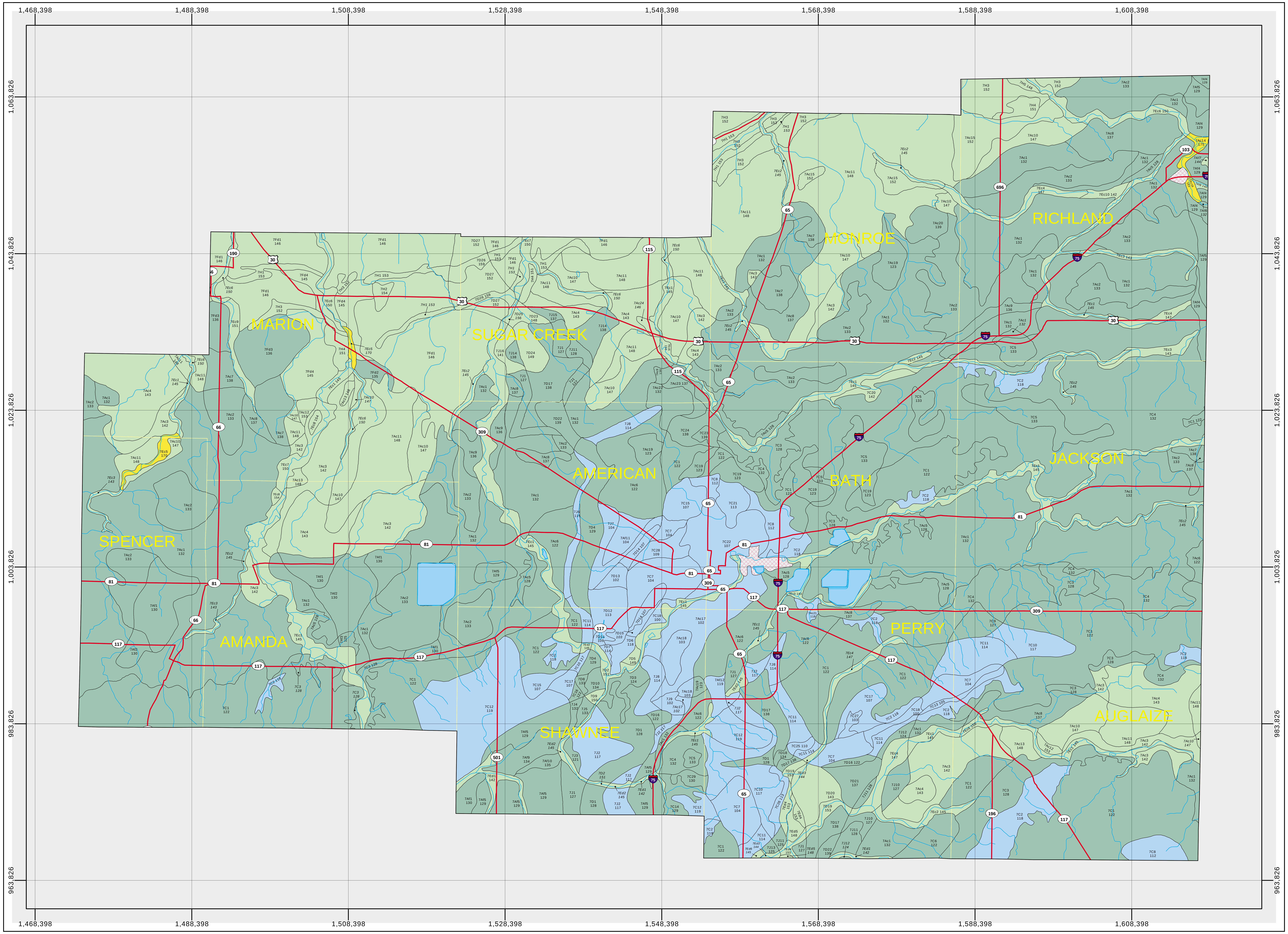
Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating_
7Ac1	15-30	4-7	limestone	Clay Loam	2-6	till	300-700	132	150
7Ac2	15-30	4-7	limestone	Clay Loam	0-2	till	300-700	133	153
7Ac3	5-15	4-7	limestone	Clay Loam	2-6	till	300-700	142	160
7Ac4	5-15	4-7	limestone	Clay Loam	0-2	till	300-700	143	163
7Ac5	15-30	4-7	limestone	Clay Loam	6-12	till	300-700	128	138
7Ac6	30-50	4-7	limestone	Clay Loam	2-6	till	300-700	122	140
7Ac7	15-30	4-7	limestone	Clay Loam	0-2	lst-frac till	300-700	138	157
7Ac8	15-30	4-7	limestone	Clay Loam	2-6	lst-frac till	300-700	137	154
7Ac9	15-30	4-7	limestone	Loam	2-6	till	300-700	136	160
7Ac10	5-15	4-7	limestone	Clay Loam	2-6	lst-frac till	300-700	147	164
7Ac11	5-15	4-7	limestone	Clay Loam	0-2	lst-frac till	300-700	148	167
7Ac12	5-15	4-7	limestone	Sandy Loam	2-6	lst-frac till	300-700	153	179
7Ac13	5-15	4-7	limestone	Sandy Loam	2-6	till	300-700	148	175
7Ac14	5-15	7-10	limestone	Thin or absent	0-2	limestone	300-700	175	214
7Ac15	5-15	4-7	limestone	Loam	0-2	lst-frac till	300-700	152	177
7Ac16	5-15	4-7	limestone	Thin or absent	0-2	limestone	300-700	162	202
7Ac17	75-100	4-7	limestone	Clay Loam	2-6	till	300-700	102	121
7Ac18	75-100	4-7	limestone	Clay Loam	0-2	till	300-700	103	124
7Ac19	30-50	4-7	limestone	Clay Loam	0-2	till	300-700	123	143
7Ac20	15-30	4-7	limestone	Sandy Loam	0-2	till	300-700	139	168
7Ac21	30-50	4-7	limestone	Clay Loam	6-12	till	300-700	118	128
7Ac22	15-30	4-7	limestone	Loam	0-2	till	300-700	132	159
7Ac23	15-30	4-7	limestone	Loam	0-2	till	300-700	137	163
7Ac24	5-15	4-7	limestone	Loam	2-6	till	300-700	146	170
7Af1	15-30	4-7	sand and gravel	Clay Loam	0-2	till	300-700	130	150
7Af2	15-30	4-7	sand and gravel	Clay Loam	0-2	sd +gvl w/sl + cl	300-700	130	150
7Af3	15-30	4-7	sand and gravel	Clay Loam	6-12	till	300-700	125	135
7Af4	15-30	4-7	sand and gravel	Clay Loam	2-6	sd +gvl w/sl + cl	300-700	129	147
7Af5	15-30	4-7	sand and gravel	Clay Loam	2-6	till	300-700	129	147
7Af6	15-30	4-7	sand and gravel	Silty Loam	0-2	sd +gvl w/sl + cl	300-700	132	155
7Af7	5-15	4-7	sand and gravel	Loam	0-2	sd +gvl w/sl + cl	300-700	144	170
7Af8	5-15	4-7	sand and gravel	Clay Loam	0-2	sd +gvl w/sl + cl	300-700	140	160
7Af9	15-30	4-7	sand and gravel	Loam	0-2	till	300-700	134	160

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating_
7Af10	15-30	4-7	sand and gravel	Sandy Loam	2-6	till	300-700	135	162
7Af11	50-75	4-7	sand and gravel	Clay Loam	2-6	till	300-700	104	123
7Af12	30-50	4-7	sand and gravel	Clay Loam	2-6	till	300-700	119	137
7C1	30-50	4-7	limestone	Clay Loam	2-6	till	300-700	122	140
7C2	30-50	4-7	limestone	Clay Loam	6-12	till	300-700	118	128
7C3	15-30	4-7	limestone	Clay Loam	6-12	till	300-700	128	138
7C4	15-30	4-7	limestone	Clay Loam	2-6	till	300-700	132	150
7C5	15-30	4-7	limestone	Clay Loam	0-2	till	300-700	133	153
7C6	30-50	4-7	sand and gravel	Clay Loam	2-6	till	300-700	122	140
7C7	50-75	4-7	sand and gravel	Clay Loam	2-6	till	300-700	104	123
7C8	50-75	4-7	limestone	Clay Loam	2-6	till	300-700	112	130
7C9	15-30	4-7	limestone	Clay Loam	2-6	till	300-700	127	146
7C10	30-50	4-7	limestone	Clay Loam	2-6	till	300-700	117	136
7C11	30-50	4-7	sand and gravel	Clay Loam	2-6	till	300-700	114	133
7C12	30-50	4-7	sand and gravel	Clay Loam	2-6	till	300-700	119	137
7C13	50-75	4-7	sand and gravel	Clay Loam	6-12	till	300-700	105	115
7C14	15-30	4-7	sand and gravel	Clay Loam	2-6	till	300-700	129	147
7C15	50-75	4-7	limestone	Clay Loam	2-6	till	300-700	107	126
7C16	30-50	4-7	sand and gravel	Loam	0-2	till	300-700	122	149
7C17	50-75	4-7	sand and gravel	Clay Loam	2-6	till	300-700	107	126
7C18	50-75	4-7	sand and gravel	Clay Loam	6-12	till	300-700	100	111
7C19	30-50	4-7	limestone	Clay Loam	0-2	till	300-700	123	143
7C20	5-15	4-7	limestone	Clay Loam	2-6	till	300-700	142	160
7C21	50-75	4-7	limestone	Clay Loam	0-2	till	300-700	113	133
7C22	75-100	4-7	limestone	Clay Loam	2-6	till	300-700	107	125
7C23	15-30	4-7	limestone	Sandy Loam	0-2	till	300-700	139	168
7C24	15-30	4-7	limestone	Sandy Loam	2-6	till	300-700	138	165
7C25	30-50	4-7	sand and gravel	Clay Loam	6-12	till	300-700	110	121
7C26	30-50	4-7	sand and gravel	Clay Loam	6-12	till	300-700	113	124
7C27	50-75	4-7	limestone	Clay Loam	6-12	till	300-700	103	114
7C28	50-75	4-7	sand and gravel	Clay Loam	2-6	till	300-700	109	127

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating_
7C29	15-30	4-7	sand and gravel	Clay Loam	0-2	till	300-700	130	150
7D1	30-50	4-7	sand and gravel	Clay Loam	2-6	sd +gvl w/sl + cl	700-1000	128	144
7D2	5-15	4-7	sand and gravel	Silty Loam	0-2	sd +gvl w/sl + cl	700-1000	151	172
7D3	30-50	4-7	sand and gravel	Clay Loam	6-12	sd +gvl w/sl + cl	700-1000	124	132
7D4	30-50	4-7	sand and gravel	Clay Loam	0-2	sd +gvl w/sl + cl	700-1000	129	147
7D5	15-30	4-7	sand and gravel	Sandy Loam	2-6	sd +gvl w/sl + cl	700-1000	149	173
7D6	50-75	4-7	sand and gravel	Clay Loam	2-6	sd +gvl w/sl + cl	700-1000	118	134
7D7	50-75	4-7	sand and gravel	Clay Loam	6-12	sd +gvl w/sl + cl	700-1000	114	122
7D8	30-50	4-7	sand and gravel	Loam	0-2	sd +gvl w/sl + cl	700-1000	133	157
7D9	15-30	4-7	sand and gravel	Sandy Loam	0-2	sd +gvl w/sl + cl	700-1000	150	176
7D10	30-50	4-7	sand and gravel	Sandy Loam	2-6	sd +gvl w/sl + cl	700-1000	134	159
7D11	75-100	4-7	sand and gravel	Clay Loam	6-12	sd +gvl w/sl + cl	700-1000	109	117
7D12	75-100	4-7	sand and gravel	Clay Loam	2-6	sd +gvl w/sl + cl	700-1000	113	129
7D13	75-100	4-7	sand and gravel	Clay Loam	2-6	sd +gvl w/sl + cl	300-700	102	121
7D14	50-75	4-7	sand and gravel	Clay Loam	2-6	sd +gvl w/sl + cl	300-700	107	126
7D15	50-75	4-7	sand and gravel	Clay Loam	6-12	sd +gvl w/sl + cl	300-700	103	114
7D16	30-50	4-7	sand and gravel	Clay Loam	2-6	sd +gvl w/sl + cl	300-700	122	140
7D17	15-30	4-7	sand and gravel	Clay Loam	2-6	sd +gvl w/sl + cl	700-1000	138	154
7D18	15-30	4-7	sand and gravel	Clay Loam	6-12	sd +gvl w/sl + cl	700-1000	134	142
7D19	5-15	4-7	sand and gravel	Loam	0-2	sd +gvl w/sl + cl	700-1000	153	177
7D20	15-30	4-7	sand and gravel	Loam	0-2	sd +gvl w/sl + cl	700-1000	143	167
7D21	15-30	4-7	sand and gravel	Loam	0-2	sd +gvl w/sl + cl	300-700	137	163
7D22	15-30	4-7	sand and gravel	Clay Loam	0-2	sd +gvl w/sl + cl	700-1000	139	157
7D23	5-15	4-7	sand and gravel	Clay Loam	2-6	sd +gvl w/sl + cl	700-1000	148	164
7D24	5-15	4-7	sand and gravel	Clay Loam	0-2	sd +gvl w/sl + cl	700-1000	149	167

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating_
7D25	5-15	4-7	sand and gravel	Silty Loam	0-2	sd +gvl w/sl + cl	700-1000	156	176
7D26	5-15	4-7	sand and gravel	Sandy Loam	2-6	sd +gvl w/sl + cl	700-1000	159	183
7D27	5-15	4-7	sand and gravel	Shrink/Swell Clay	0-2	sl + cl w/till	700-1000	152	183
7Ec1	5-15	4-7	limestone	Silty Loam	0-2	sd +gvl w/sl + cl	300-700	145	168
7Ec2	5-15	4-7	limestone	Silty Loam	0-2	silt and clay	300-700	145	168
7Ec3	5-15	4-7	limestone	Clay Loam	0-2	silt and clay	300-700	143	163
7Ec4	5-15	4-7	limestone	Loam	0-2	sd +gvl w/sl + cl	300-700	147	173
7Ec5	5-15	7-10	limestone	Thin or absent	0-2	limestone	300-700	170	210
7Ec6	5-15	4-7	limestone	Silty Loam	0-2	ls/sl-cl-sd	300-700	150	172
7Ec7	5-15	4-7	limestone	Silty Loam	0-2	sd +gvl w/sl + cl	300-700	150	172
7Ec8	5-15	4-7	limestone	Sandy Loam	0-2	sd +gvl w/sl + cl	300-700	154	182
7Ec9	5-15	4-7	limestone	Shrink/Swell Clay	0-2	ls/sl-cl-sd	300-700	151	183
7Ec10	5-15	4-7	limestone	Loam	0-2	sd +gvl w/sl + cl	300-700	142	169
7Ed1	5-15	4-7	sand and gravel	Silty Loam	0-2	sd +gvl w/sl + cl	300-700	142	165
7Ed2	5-15	4-7	sand and gravel	Silty Loam	0-2	sd +gvl w/sl + cl	300-700	145	168
7Ed3	5-15	4-7	sand and gravel	Loam	0-2	sd +gvl w/sl + cl	300-700	144	170
7Ed4	5-15	4-7	sand and gravel	Loam	0-2	sd +gvl w/sl + cl	700-1000	153	177
7Ed5	5-15	4-7	sand and gravel	Sandy Loam	2-6	sd +gvl w/sl + cl	300-700	148	175
7Ed6	5-15	4-7	sand and gravel	Sandy Loam	2-6	sd +gvl w/sl + cl	300-700	145	172
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	2-6	sl + cl w/till	300-700	135	166
7Fd3	15-30	4-7	limestone	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	136	169
7Fd3	15-30	4-7	limestone	Shrink/Swell Clay	0-2	sl + cl w/till	300-700	136	169
7Fd4	5-15	4-7	limestone	Shrink/Swell Clay	2-6	sl + cl w/till	300-700	145	176
7H1	5-15	4-7	limestone	Sandy Loam	2-6	sd +gvl w/sl + cl	300-700	153	179

Setting	Depth to Water (feet)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography (% Slope)	Vadose Zone Media	Hydraulic Conductivity	Rating	Pesticide Rating_
7H2	5-15	4-7	limestone	Sandy Loam	0-2	sd +gvl w/sl + cl	300-700	154	182
7H3	5-15	4-7	limestone	Loam	0-2	sd +gvl w/sl + cl	300-700	152	177
7H4	5-15	4-7	limestone	Loam	2-6	till	300-700	151	174
7H5	5-15	4-7	limestone	Clay Loam	0-2	sd +gvl w/sl + cl	300-700	148	167
7J1	15-30	4-7	sand and gravel	Clay Loam	2-6	till	300-700	127	146
7J2	30-50	4-7	sand and gravel	Clay Loam	2-6	till	300-700	117	136
7J3	30-50	4-7	sand and gravel	Loam	2-6	till	300-700	121	146
7J4	15-30	4-7	sand and gravel	Loam	0-2	till	300-700	132	159
7J5	15-30	4-7	sand and gravel	Sandy Loam	2-6	till	300-700	133	161
7J6	30-50	4-7	sand and gravel	Clay Loam	0-2	till	300-700	115	136
7J7	50-75	4-7	sand and gravel	Clay Loam	2-6	till	300-700	104	123
7J8	30-50	4-7	sand and gravel	Clay Loam	2-6	till	300-700	114	133
7J9	75-100	4-7	limestone	Clay Loam	2-6	till	300-700	102	121
7J10	15-30	4-7	limestone	Clay Loam	2-6	till	300-700	127	146
7J11	15-30	4-7	limestone	Clay Loam	0-2	till	300-700	128	149
7J12	15-30	4-7	sand and gravel	Clay Loam	2-6	till	300-700	124	143
7J13	15-30	4-7	sand and gravel	Clay Loam	0-2	till	300-700	125	146
7J14	5-15	4-7	limestone	Clay Loam	0-2	till	300-700	138	159
7J15	5-15	4-7	limestone	Clay Loam	2-6	till	300-700	137	156
7J16	5-15	4-7	limestone	Loam	2-6	till	300-700	141	166



Ground Water Pollution Potential of Allen County

by
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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

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March 2005