GROUND WATER POLLUTION POTENTIAL OF OTTAWA COUNTY, OHIO

BY

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ABSTRACT

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

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

Ottawa County lies with in the Eastern Lake Plains Section of the Central Lowlands Physiographic Province (Fenneman, 1938). The county is covered by a variable thickness of glacial till, lacustrine deposits, and outwash. These unconsolidated glacial deposits are underlain by Devonian and Silurian age limestones and dolomites. Ground water yields are dependent upon the type of aquifer and vary throughout the county. Pollution potential indexes are relatively low to moderate in areas of glacial lake plain deposits, moderate to moderately high in areas of alluvium over sedimentary rock, buried valleys, glacial till over solution limestone, river alluvium over glacial till, and moderately high to high in areas of thin till over glacial till. Areas of beaches, beach ridges, and sand dunes along with marshes and swamps have high to very high vulnerabilities to contamination.

Ground water pollution potential analysis in Ottawa County resulted in a map with symbols and colors which illustrate areas of varying ground water contamination vulnerability. Eight hydrogeologic settings were identified in Ottawa County with computed ground water pollution potential indexes ranging from 88 to 220.

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 Ottawa County has been prepared to assist planners, managers, and local officials in evaluating the potential for contamination from various sources of pollution. This information can be used to help direct resources and land use activities to appropriate areas, or to assist in protection, monitoring, and clean-up efforts.

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INTRODUCTION

The need for protection and management of ground water resources in Ohio has been clearly recognized. About 42 per cent 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 700,000 rural households depend on private wells; approximately 4,500 of these wells exist in Ottawa County.

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

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

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

APPLICATIONS OF POLLUTION POTENTIAL MAPS

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

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

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

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

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

SUMMARY OF THE DRASTIC MAPPING PROCESS

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

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

The application of DRASTIC to an area requires the recognition of a set of assumptions made in the development of the system. DRASTIC evaluates the pollution potential of an area assuming a contaminant with the mobility of water, introduced at the surface, and flushed into the ground water by precipitation. Most important, DRASTIC cannot be applied to areas smaller than one-hundred 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 fifteen 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 Ottawa County. Inherent within each hydrogeologic setting are the physical characteristics which affect the ground water pollution potential. These characteristics or factors identified during the development of the DRASTIC system include:

D - Depth to Water

R - Net Recharge

A - Aquifer Media

S - Soil Media

T - Topography

I - Impact of the Vadose Zone Media

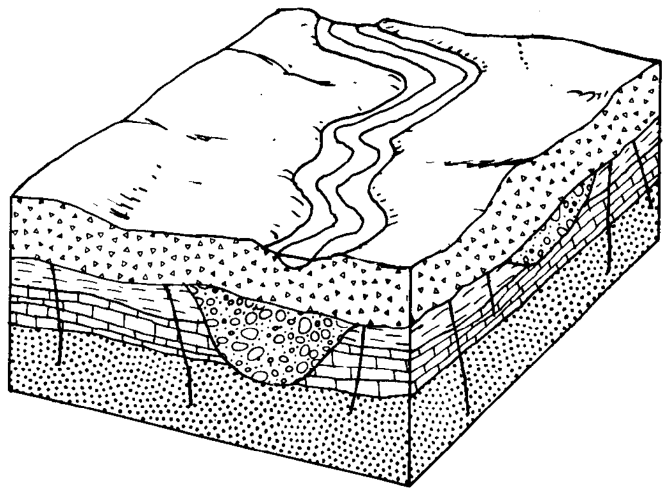
C - Conductivity (Hydraulic) of the Aquifer

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

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

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

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



7D Buried Valleys

This hydrogeologic setting is characterized by thick deposits of sand and gravel that have been deposited in a former topographic low (usually a pre-glacial river valley) by glacial meltwaters. These deposits are capable of yielding large quantities of ground water. The deposits may or may not underlie a present-day river and may or may not be in direct hydraulic connection with a stream. Glacial till or recent alluvium often overlies the buried valley. Usually the deposits are several times more permeable than the surrounding bedrock. Soils are typically a sandy loam. Recharge to the sand and gravel is moderate and water levels are commonly relatively shallow, although they may be quite variable.

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

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

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

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

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

Weighting and Rating System

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

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

Pesticide DRASTIC

A special version of DRASTIC was developed to be used where the application of pesticides is a concern. The weights assigned to the DRASTIC factors were changed to reflect the processes that affect pesticide movement into the subsurface with particular emphasis on soils. 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 significantly differs.

TABLE 1. ASSIGNED WEIGHTS FOR DRASTIC FEATURES

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

TABLE 2. RANGES AND RATINGS FOR DEPTH TO WATER

DEPTH TO WATER (FEET)	
Range	Rating
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
100+	1
Weight: 5	Pesticide Weight: 5

TABLE 3. RANGES AND RATINGS FOR NET RECHARGE

NET RECHARGE (INCHES)	
Range	Rating
0-2	1
2-4	3
4-7	6
7-10	8
10+	9
Weight: 4	Pesticide Weight: 4

TABLE 4. RANGES AND RATINGS FOR AQUIFER MEDIA

AQUIFER MEDIA		
Range	Rating	Typical Rating
Massive Shale	1-3	2
Metamorphic/Igneous	2-5	3
Weathered Metamorphic / Igneous	3-5	4
Glacial Till	4-6	5
Bedded Sandstone, Limestone and Shale Sequences	5-9	6
Massive Sandstone	4-9	6
Massive Limestone	4-9	6
Sand and Gravel	4-9	8
Basalt	2-10	9
Karst Limestone	9-10	10
Weight: 3	Pesticide Weight: 3	

TABLE 5. RANGES AND RATINGS FOR SOIL MEDIA

SOIL MEDIA	
Range	Rating
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and / or Aggregated Clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Nonshrinking and Nonaggregated Clay	1
Weight: 2	Pesticide Weight: 5

TABLE 6. RANGES AND RATINGS FOR TOPOGRAPHY

TOPOGRAPHY (PERCENT SLOPE)	
Range	Rating
0-2	10
2-6	9
6-12	5
12-18	3
18+	1
Weight: 1	Pesticide Weight: 3

TABLE 7. RANGES AND RATINGS FOR IMPACT OF THE VADOSE ZONE MEDIA

IMPACT OF THE VADOSE ZONE MEDIA		
Range	Rating	Typical Rating
Confining Layer	1	1
Silt/Clay	2-6	3
Shale	2-5	3
LImestone	2-7	6
Sandstone	4-8	6
Bedded Limestone, Sandstone, Shale	4-8	6
Sand and Gravel with significant Silt and Clay	4-8	6
Metamorphic/Igneous	2-8	4
Sand and Gravel	6-9	8
Basalt	2-10	9
Karst Limestone	8-10	10
Weight: 5	Pesticide Weight: 4	

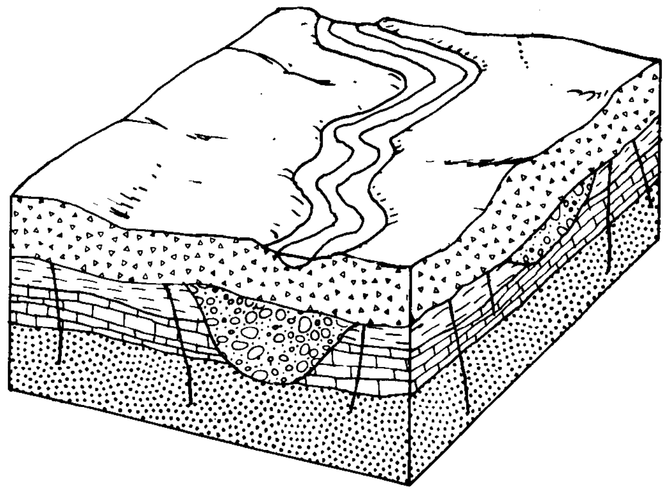
TABLE 8. RANGES AND RATINGS FOR HYDRAULIC CONDUCTIVITY

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

Integration of Hydrogeologic Settings and DRASTIC Factors

Figure 2 illustrates the hydrogeologic setting 7D1, identified in mapping Ottawa 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 147. 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 Ottawa County produces settings with a wide range of vulnerability to ground water contamination. Calculated pollution potential indexes for the eight settings identified in the county range from 88 to 220.

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 Ottawa 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 Ottawa County is included with this report.



SETTING 7D1		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5'-15'	5	9	45
Net Recharge	4"-7"	4	6	24
Aquifer Media	Sand & Gravel	3	7	21
Soil Media	Aggregated Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Glacial Till	5	3	15
Hydraulic Conductivity	700-1000	3	6	18
		DRASTIC	INDEX	147

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

INTERPRETATION AND USE OF A GROUND WATER POLLUTION POTENTIAL MAP

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

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

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

Here the first number (7) refers to the major hydrogeologic region and the upper case letter (D) refers to a specific hydrogeologic setting. The following number (1) references a certain set of DRASTIC parameters that are unique to this setting and are described in the corresponding setting chart. The second number (147) is the calculated pollution potential index for this unique setting. The charts for each setting provide a reference to show how the pollution potential index was derived in an area.

The maps are color-coded using ranges depicted on the map legend. The color codes used are part of a national color-coding scheme developed to assist the user in gaining a general insight into the vulnerability of the ground water in the area. The color codes were chosen to represent the colors of the spectrum, with warm colors (red, orange, and yellow), representing areas of higher vulnerability (higher pollution potential indexes), and cool colors (greens, blues, and violet), representing areas of lower vulnerability to contamination.

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

GENERAL INFORMATION ABOUT OTTAWA COUNTY

Ottawa County occupies an area of approximately 270 square miles in northwest Ohio (Figure 3). It is bounded on the north by Lucas County and Lake Erie, on the east by Lake Erie, on the south by Sandusky County, and on the west by Wood County. The county seat is the city of Port Clinton. The estimated population of the county for 1994, according to the Ohio Department of Development (1991), is approximately 40,029. Agriculture accounted for 57.7 percent of the land use in Ottawa County in 1992 (Ohio Department of Agriculture, 1992).

Physiography

The physiography of Ottawa County consists of a mantle of unconsolidated glacial deposits overlying a sequence of relatively flat-lying sedimentary rocks. The county is located in the generally flat-lying Eastern Lake Plains section of the Central Lowlands physiographic province (Fenneman, 1938), an area characterized by the presence of lake bed sediments deposited by a series of Pleistocene-aged lakes of glacial origin. Topographic relief in western Ottawa County is nearly level to gently sloping, barely elevated above Lake Erie; however, the relief of eastern Ottawa County is undulating or gently rolling where ridges of carbonate bedrock protrude above the surrounding lake plain topography.

Drainage and Climate

Surface drainage in Ottawa County consists of two major river basins, the Portage River basin and The Pickerel-Pipe Creek basin. The Portage River basin, which also includes three minor stream drainage basins directly tributary to Lake Erie, comprises 81.8% of the county. The Pickerel-Pipe Creek basin which consists only of minor creeks directly tributary to Lake Erie east of the Portage River, comprises 18.2% of the county (ODNR 1966).

The climate of Ottawa County is typical of the temperate mid-continent region, characterized by a wide range between summer and winter temperatures and moderate amounts of precipitation. The average monthly precipitation at the U.S. Weather Bureau Station at Put-In-Bay, South Bass Island for the thirty year period from 1961 to 1990 ranged between 1.50 inches for February and 3.52 inches for August (U.S. Department of Commerce, 1992). The average annual precipitation for the county was 31.68 inches (U.S. Department of Commerce, 1992). The average annual temperature range for the same thirty-year period was between 30.1^{o} F (January) and 81.5^{o} F (July) with an average annual temperature of 56.8^{o} F (U.S. Department of Commerce, 1992).

Figure 3. Location of Ottawa County

Glacial Geology

Approximately 2 million years ago, the Pleistocene Epoch commenced with a series of continental glaciers covering the northern half of North America. Four major glacial advances: the Nebraskan (oldest), Kansan, Illinoian, and Wisconsinan (youngest) are known to have occurred in North America during the Pleistocene Epoch. In Ohio, evidence exists for three glacial periods: the Pre-Illinoian, which includes Kansan and possibly Nebraskan-age deposits but is not reliably dated (Norton et al., 1983); the Illinoian, which occurred at least 120,000 years ago; and the Wisconsinan, which occurred between 70,000 and 10,000 years ago (Fullerton, 1986).

Continental glaciation greatly altered much of Ohio's preglacial landscape by burying its Tertiary topographic relief and drainage systems beneath a mantle of unconsolidated clastic deposits. This mantle consists of both sorted and unsorted deposits of clay, silt, sand, and gravel derived from a number of glacially-related processes.

Glacial sediments deposited in Ottawa County consist mainly of three material types: lacustrine (lake) deposits, glacial till, and outwash. The lacustrine deposits consist primarily of two landforms: hummocky beach ridges/sand dunes and flat, clay-rich lake bed deposits. As the Wisconsinan glacier retreated from northern Ohio, meltwater from the glacier could not drain south to the Ohio River because of the Great Lakes drainage divide. The meltwater became impounded by the retreating glacier, creating a lake much larger than Lake Erie. As the glacier retreated north, the lake levels declined leaving behind a series of abandoned beach ridges or strand lines marking the successive former lake elevations (Forsyth, 1959; Hosfeld, 1984).

Because of the low relief and close proximity to Lake Erie, abandoned beach ridges in Ottawa County are poorly developed and discontinuous. The best developed beach ridges in Ottawa County occur along the present Lake Erie shoreline. Lake bed deposits are the dominant lacustrine landform in Ottawa County with a typically flat, poorly-drained terrain underlain by sorted, clay-rich soils. Soils of the lake plains are either developed upon fine-grained silt and clay sediments deposited in the former lakes (i.e. Toledo soils) or upon glacial till that has been slightly modified by wave action (Hoytville and Nappanee soils) (Musgrave and Derringer, 1985).

Glacial till is an unsorted mixture of silt and clay with variable amounts of sand and gravel deposited directly from the glacier upon the ground surface over which the glacier advanced. Surface till in Ottawa County was deposited during the last Wisconsinan ice advance. The surficial soils of southwestern Ottawa County, Catawba Island, and the Bass Islands are developed on glacial till. As the Wisconsinan ice sheet receded, Ottawa County was inundated by meltwater which created the ancestral stages of Lake Erie. Lacustrine sediments are the primary surficial deposit over most of Ottawa County.

Outwash deposits consisting of sorted sand and gravel are also commonly found in Ottawa County, often as lenses of sand and gravel interbedded in the glacial till. In addition, a buried valley containing deposits of outwash trends northeast-southwest through Danbury Township (Larsen, 1984a, 1984b; Schmidt, 1986). Well logs on file with Ohio Department of Natural Resources (ODNR), Division of Water indicate that the buried valley ranges in depth up to 104 feet below ground surface and contains sand and gravel deposits up to 30 feet in thickness.

Bedrock Geology

Ottawa County is underlain by a relatively flat-lying sequence of Paleozoic sedimentary rocks consisting primarily of dolomite from the Silurian and Devonian Systems (Table 9). Silurian bedrock beneath Ottawa County consists of three formations: the Lockport Dolomite, the Salina Group Dolomite (undifferentiated), and the Bass Islands Dolomite (Janssens, 1977). The eastern half of Danbury Township is underlain by Devonian bedrock comprised of three formations: the Amhurstberg Dolomite, the Lucas Dolomite, and the Columbus Limestone (Sparling, 1965).

The Silurian bedrock beneath Ottawa County is generally comprised of a microcrystalline brown to gray argillaceous dolomite. Anhydrite and shale is often interbedded with the dolomite throughout the northwestern region of the state (Janssens, 1977). The Devonian carbonates consist of brown, sparsely fossiliferous, microcrystalline dolomite except for the upper portion of the Columbus Limestone which is typically brown, cherty, fossiliferous dolomitic limestone to calcitic limestone. Bedding thicknesses range from thin-bedded to massive (Sparling, 1965).

The bedrock structure of Ottawa County is influenced by a large regional structure referred to as the Findlay Arch. The arch, a geologic structure resulting from differential subsidence along two major basinal areas in the region (the Michigan Basin to the northwest and the Appalachian Basin to the southeast), influenced the present configuration of bedrock formations in Ohio. The Findlay Arch splits from the Cincinnati Arch in west-central Ohio and trends northeast through Allen and Clay Townships of western Ottawa County into Ontario, Canada. The bedrock beneath Ottawa County is generally flat-lying along the axis of the Findlay Arch and dips gently upon the flank of the arch at approximately 1^{o} to 2^{o} east toward the Appalachian Basin (Hosfeld, 1984).

Extensive large-scale jointing (fracture surfaces) in the bedrock of Ottawa County is believed to have resulted from extensional forces created by the differential subsidence of the Michigan and Appalachian Basins (Armstrong, 1976). The systematic jointing in the bedrock produced fracture traces or lineaments that are clearly evident on aerial photos despite the cover of glacial drift in the region (Snyder, 1989). The average trend of the fracture traces are 60 degrees NE and 65 degrees NW and have indirectly influenced the shapes of the Bass Islands. The significance of fracture traces and lineaments is that they are surficially detectable signs of fractured, porous bedrock that can potentially produce high-yielding water wells (Kessler, 1986) or provide potential escape routes for contaminants from waste management areas.

Karst Geology

A unique geologic setting referred to as karst terrain occurs in parts of northwestern Ohio. A karst terrain contains distinctive characteristics of relief and drainage resulting from the dissolution of limestone or dolomite by the action of surface and ground water (Bloom, 1978). Karst terrain typically has a strong underground drainage network ranging from fractures and minor solution channels to caverns with subterranean streams. Dolines (sinkholes), springs, sinking streams, ponors (swallow holes), and caves are surface expressions related to the underground drainage network.

Table 9 Generalized Stratigraphic Column of Ottawa County (Modified form Janssen, 1977 and Sparling, 1965).

SYSTEM	GROUP	FORMATION	DESCRIPTION
DEVONIAN		Columbus	Limestone, light gray-buff, thin to massive bedded, fossiliferous, highly solutioned, Karstic
	DETROIT RIVER	Lucas	Dolomite, massive bedded, highly solutioned, fractured, fossiliferous
		Amherstberg	Dolomite, massive bedded, solutioned
SILURIAN	SALINA	undifferentiated (Put-In-Bay*) (Bass Islands*) (Raisin River*)	Dolomite, thin to massive bedded, argillaceous to shaly layers, granular, vesicular ("vuggy") layers, contains zones of gypsum and anhydrite, minor solution zones, some fracturing
	LOCKPORT	undifferentiated (Guelph*)	Dolomite, massive, fossiliferous, some porous zones

*Denotes older terminolgy having historical significance. Current preference is to leave the Salina and Lockport undifferentiated.

In Ottawa County, karst terrain is found on the Bass Islands and on Catawba Island (Mohr, 1931; White, 1926; and Verber and Stansbery, 1953). Some of Ohio's most famous caves such as Perry's Cave and Crystal Cave are found on South Bass Island. Caves in the area are generally formed by a combination of carbonate/sulfate dissolution along joints, fractures and bedding planes, and by collapse of carbonate layers into the solution openings. Sinkholes and sinking streams are also found on both South Bass Island and Catawba Island.

Hydrogeology

In northwest Ohio, the thick sequence of carbonate bedrock from the Devonian and Silurian Periods comprises a vast regional aquifer that serves as a primary source of ground water for the counties in this region (ODNR, 1970). Ottawa County lies near the northeastern corner of this regional aquifer.

The hydrogeologic system of Ottawa County consists of the regional carbonate aquifer buried by unconsolidated glacial deposits. The regional carbonate aquifer underlies all of Ottawa County and serves as a primary source of ground water for much of the county's rural population. Ground water within the dolomite of the carbonate aquifer occurs in a network of interconnected fractures, bedding planes, and solution channels. Yields to individual wells drilled into the carbonate aquifer are highly variable, depending upon the number of fractures and solution channels intersected by the well bore.

Yields to wells in the Devonian carbonate bedrock of eastern Ottawa County are generally low with known ranges up to 25 gallons per minute. However, potential well yields for the Silurian carbonate bedrock are generally higher with known ranges of 500+ gallons per minute occurring. Well yields in western Ottawa County are generally lower with potential yields up to 100 gallons per minute. Well yields in the karst terrain of the Bass Islands and Catawba Island region can potentially range up to 500 gallons per minute (Schmidt, 1986; Kessler, 1986).

Potentiometric surface maps of the carbonate aquifer for the mainland of Ottawa County show a general northeastward trending slope, indicating regional ground water flow from sources of recharge in northern Ohio towards zones of discharge along Lake Erie (Hosfeld, 1984; Snyder, 1989). The potentiometric surface for Danbury Township, Catawba Island Township, and the Bass Islands is generally symmetrical with the respect to the shape of the various land masses, indicating the principal source of recharge to the aquifer is from infiltration of precipitation through the soil and bedrock of the land mass, creating a ground water mound. Ground water discharge for these areas is generally symmetrically outward from the land mass into adjacent Lake Erie or Sandusky Bay.

Overlying the bedrock aquifer of Ottawa County is a mantle of glacial till and lacustrine deposits. Glacial till and lake bed deposits are not considered an aquifer because of their high clay-silt content and low hydraulic conductivities making them a poor source of ground water. However, weathered glacial till commonly has an interconnected network of vertical fractures which can impart an enhanced capability for ground water flow and contaminant migration through the till (Ruland, et al., 1991; Hendry, 1982; Williams and Farvolden, 1967). In addition, glacial till often contains intermittent water-bearing pockets of sand and gravel which serve as a source of recharge to the carbonate aquifer and a source of ground water for some domestic wells. Other potential sources of ground water include the buried valley outwash deposits of Danbury Township.

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APPENDIX A

DESCRIPTION OF THE LOGIC IN FACTOR SELECTION

Depth to Water

Depth to water was evaluated using information obtained from well logs on file with ODNR, Division of Water. In areas where well log information was sparse, water levels were inferred based on surrounding water level patterns, topographic expression of the land, and elevations of nearby surface water bodies.

Because of its proximity to Lake Erie, depth to water in Ottawa County was generally shallow with depth ranges of 0 to 5 feet (DRASTIC rating: 10); 5 to 15 feet (9) and 15 to 30 feet (7) comprising the three most common ranges mapped in the county. However, some areas in the county had ranges of 30 to 50 feet (5), and 50 to 75 feet (3), such as a number of abrupt, steep bedrock hills in Catawba Township and South Bass Island. In addition, the northwest quarter of the county had a general increase in depth to water in a westward-trending fashion towards Wood and Lucas Counties where static water levels exceeded 50 feet below ground surface (ODNR, Well Logs).

Net Recharge

Net recharge rates were evaluated based upon a number of sources including soil types (Musgrave and Derringer, 1985), topography, proximity to lakes and rivers, and recharge results determined for area river basins in Pettyjohn and Henning (1979).

Recharge for much of the lake plains region in Ottawa County was evaluated as ranging from 2 to 4 inches (3) because of the inherently poor drainage characteristics the lake plain soils exhibit when saturated during the rainy season. Areas containing glacial till overlying shallow bedrock, such as in southwestern Ottawa County, some of the Bass Islands, and parts of Danbury Township, were evaluated as ranging from 4 to 7 inches (6) because of the presence of fractures in the glacial till (Snyder, 1989).

The recharge rate for the karstic areas of Catawba Island and South Bass Island was evaluated as being 10+ inches (9) because of the presence of sink holes and solution cavities. These karst features are very effective in capturing and funnelling precipitation into the subsurface, thus providing high recharge rates to the area. Areas with thin or absent soils overlying karstic limestone free of sinkholes or massive limestone were evaluated as having a recharge rate of 7 to 10 inches (8).

Areas with sandy soils such as the beaches, sand spits, and river alluvium were given a recharge rate of 7 to 10 inches (8). Wetland areas were also given a recharge rate of 7 to 10 inches in order to reflect the condition of continual saturation that is prevalent in these areas. Recharge in wetland areas is not only a function of the quantity of precipitation available to the area and the absorptive capacity of the soil, but also of the water level elevations in Lake Erie and Sandusky Bay and of the local water table elevations beneath the wetlands.

Aquifer Media

The majority of Ottawa County is underlain by an extensive carbonate aquifer consisting of dolomite and limestone (Hosfeld, 1984). This carbonate aquifer comprised the aquifer media for all of the county except for the buried valley in Danbury Township.

The majority of the carbonate aquifer in Ottawa County was evaluated as being a massive limestone with a DRASTIC rating of 8, because of its very extensive occurrence, its rather porous, brecciated dolomitic structure of the Salina Group (Sparling, 1965), and the potential for high-yielding wells (Schmidt, 1986). The carbonate aquifer of southwestern Ottawa County was evaluated as being a massive limestone with a rating of 7 because of the generally thick-bedded to massive nature of the Lockport Dolomite (Sparling, 1965) and the lower well yields in this region (Schmidt, 1986).

The Devonian carbonate aquifer of Danbury Township was evaluated as being a massive limestone with a rating of 6 because of its generally massive nature and its very low well yields (Schmidt, 1986).

The carbonate aquifer beneath Catawba Island and the Bass Islands was rated as being a karst limestone aquifer with a rating of 9 to 10 depending upon the magnitude of karstification present in the area. Areas containing caves and sinkholes evident at the surface were given a rating of 10. The carbonate aquifers of North and Middle Bass Islands are generally more massive in nature and were evaluated as being massive limestone with a rating of 8. The aquifer media for the Danbury Township buried valley was evaluated as being a sand and gravel aquifer with a rating of 7.

Soil Media

The classification of the soils is based upon the dominant soil properties as described in the soil survey for Ottawa County (Musgrave and Derringer, 1985). The majority of soils in Ottawa County have developed on the clay-rich lake plain deposits and consist primarily of the Hoytville-Nappanee-Toledo soil association. The Hoytville, Nappanee, and Toledo series were classified as being a "shrinking/aggregated clay" with a rating of 7 because of their high shrink-swell potential, their low sand and gravel composition, and their high plastic indexes (Musgrave and Derringer, 1985). Although these soils are typically characterized as being clay-rich, nearly level, and very poorly drained with a seasonally high water table, the soils are subject to extensive cracking and fracturing during the summer months (Keim, 1989) that permits easy access for surficially spilled contaminants to infiltrate into the subsurface.

Clay rich soils developed upon glacial till or lake bed deposits with lesser shrink-swell potentials were classified as being clay loam soils with a DRASTIC rating of 3. Soils comprised of silt loams (4), loams (5), sandy loams (6) and sands (9) are generally associated with deposits of beach ridges and river alluvium.

Two soil series, the Castalia and Milton series, were classified as "thin or absent" with a rating of 10 for areas with a soil cover less than 2 feet overlying bedrock. These soil series are commonly associated with bedrock knolls and rock outcrops of southwestern Ottawa County, Danbury Township, Catawba Island and the Bass Islands (Stith, 1973, Musgrave and Derringer, 1985; ODNR Well Logs).

Topography

The topography of Ottawa County was evaluated using a combination of U.S. Geological Survey topographic maps and the county soil survey manual (Musgrave and Derringer, 1985).

Generally the topography in Ottawa County is flat to gently-rolling with slopes ranging from 0% to 2% with a DRASTIC rating of 10 dominating the county. The low relief is due in part to the fact that Ottawa County is part of an extensive Pleistocene glacial lake complex that extends across much of northern Ohio. A combination of wave action and sediment deposition during various former water level stages of the lake successfully planed down and buried any previous topography that may have occurred in the region.

Some topographic relief does occur in areas where rivers and streams have cut down into the lake plain deposits, producing topographic slopes commonly ranging 2 to 6% (9). However, considerable relief does occur in Catawba, Danbury, and Put-in-Bay Townships where steep slopes with a range of 6% to 12% (5) are found because of the rise of the carbonate bedrock in the area. Steep cliffs are often encountered in these townships where wave activity along the lake shore is currently cutting into the bedrock.

Impact of the Vadose Zone Media

The vadose zone is defined as that zone between the ground surface and the water table which is unsaturated or discontinuously saturated. The impact of the vadose zone in retarding contaminant migration is generally determined by the type of material comprising the zone. Depending upon the depth to ground water in any particular hydrogeologic setting, the vadose media can be comprised of a single geologic media such as glacial till or a combination of media such as glacial till overlying karst limestone or shale. To reflect this variability in vadose media, the dominant vadose media of the area in question may be given a range of rating values in order to assess the ratio of lower permeability media to higher permeability media.

For instance, glacial till is a common material comprising the vadose media in many parts of Ottawa County. For those areas with shallow water levels where glacial till comprises most or all of the material between ground surface and the water table, a low rating of 4 was given to the media. However, for deeper water levels where glacial till comprises only a fraction of the vadose media, the remainder being comprised by a second media such as sand and gravel or the bedrock aquifer media of the area, a higher rating such as 5 or 6 was given to the vadose media.

For those areas where the vadose media contains clay-rich lake bed deposits, the media was evaluated as being "silt and clay" with ratings of either 2 or 3. The ratings varied with the proportion of silt and clay and depth of weathering. For marshes and swamps, the vadose media was evaluated as being silt and clay and given a rating of (6) in order to reflect the presence of porous peat material from partially decayed marsh vegetation in the silt and clay deposits comprising the vadose media. The marsh and swamp areas also contain a relatively higher proportion of silt and fine sand.

For areas where thin glacial drift deposits overlie a massive limestone aquifer, such as on North Bass Island, the vadose media was evaluated as being massive limestone and given a rating of 7.

The karstic terrains of Catawba Island and South Bass Island were evaluated as being karst limestone vadose media with ratings of either 8, 9, or 10, depending upon the thickness of the soil cover and the maturity of the karst development. Areas with a thin or absent soil cover and numerous sinkholes and caves were given a higher rating of 10. The high ratings were given because sinkholes in the area can capture and quickly channel surface pollutants into the subsurface without significant filtration and attenuation affecting the contaminants. The sensitivity of karstic vadose media is best exemplified by the Catawba Island aquifer which has incurred some bacterial contamination resulting from domestic waste disposal from septic tanks (Kessler, 1986). The numerous solution cavities prevalent to the karst aquifer have very little capacity for filtering and attenuating sewage effluent.

Vadose media for rivers and streams in Ottawa County was generally evaluated as being "silt and clay" and given ratings of 3, 4, or 5. For beaches and beach ridges, the vadose media was generally evaluated as being sand and gravel with a rating of 8. Ratings for both settings were established based upon the sand content of both the area well logs (ODNR, Div. of Water) and of the soil types occurring in each setting (Musgrave and Derringer, 1985).

Hydraulic Conductivity

The hydraulic conductivity of an aquifer is a measure of its ability to transmit ground water as a function of the media comprising the aquifer (i.e. sand and gravel, sandstone, limestone, etc...). Aquifers with significant silt and clay have low hydraulic conductivities, whereas aquifers that are porous and permeable (such as clean sands and gravels) or highly-fractured and solutioned (such as cavernous or karst limestone bedrock) have high hydraulic conductivities.

Available data characterizing the hydraulic conductivity of the various aquifer medias, such as pump test data are generally sparse for much of Ottawa County. Some information is available from a series of test wells installed as part of ODNR's 1970 carbonate aquifer study for northwestern Ohio. Where the data are sparse, the hydraulic conductivity was estimated from a combination of available data regarding the physical nature of the aquifer media and from published conductivity ranges presented in Table 2.2, of Freeze and Cheery (1979) entitled "Range of Values of Hydraulic Conductivity and Permeability."

The majority of the carbonate aquifer in Ottawa County was evaluated as having a hydraulic conductivity of 300-700 gpd/ft. sq. with a rating of 4 because of its very extensive occurrence, its rather porous, brecciated dolomitic structure of the Salina Group (Sparling, 1965), and the potential for high-yielding wells (Schmidt, 1986). The carbonate aquifer of southwestern Ottawa County was evaluated having a hydraulic conductivity range of 100-300 gpd/ft. sq. with a rating of 2 because of the generally thick-bedded to massive nature of the Lockport Dolomite (Sparling, 1965) and the lower well yields in this region (Schmidt, 1986).

The Devonian carbonate aquifer of Danbury Township was evaluated as having a hydraulic conductivity range of 100-300 gpd/ft. sq. and a rating of 2 because of its generally massive nature and its very low well yields.

The carbonate aquifer beneath Catawba Island and the Bass Islands was rated as having a hydraulic conductivity range of either 1000-2000 gpd/ft. sq. (8) or 2000+ gpd/ft. sq. (10), depending upon the magnitude of karstification present in the area. Areas containing caves and sinkholes evident at the surface were given the higher rating.

The hydraulic conductivity for the sand and gravel aquifer media of the buried valley beneath Danbury Township was estimated as having a hydraulic conductivity ranging from 700 to 1000 gpd/ft. sq. with a rating of 6. This rating range corresponds closely to typical values for silty sands to clean sands as presented in Table 2.2, entitled "Range of Values of Hydraulic Conductivity and Permeability" from Freeze and Cherry (1979).

APPENDIX B

DESCRIPTION OF HYDROGEOLOGIC SETTINGS AND CHARTS

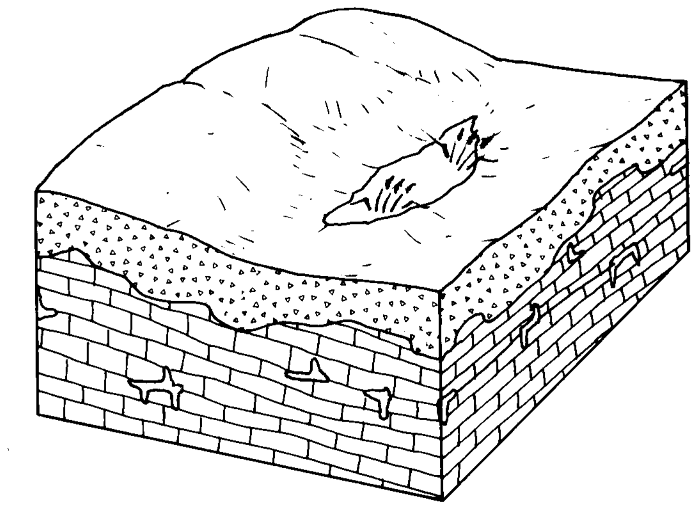
During the pollution potential mapping of Ottawa County, eight hydrogeologic settings with the Glaciated Central Region were identified. The list of these settings, the range of pollution potential index calculations, and the number of pollution potential index calculations for each setting are provided in Table 10. Computed pollution potential index values range from 88 to 220.

Table 10. Hydrogeologic Settings Mapped in Ottawa County, Ohio

Hydrogeologic Settings	Range of GWPP Indexes	Number of Index Calculations
7Ac-Glacial Till Over Solution Limestone	110 - 207	48
7D-Buried Valley	137 - 147	2
7Ec-Alluvium Over Sedimentary Rock	134 - 154	3
7Ed-River Alluvium Over Glacial Till	114 - 148	8
7F- Glacial Lake Plain Deposits	88 - 143	26
7Gb-Thin Till Over Glacial Till	145 - 220	25
7H-Beaches, Beach Ridges, and Sand Dunes	173 - 201	10
7I-Marshes and Swamps	172 - 193	2

DRASTIC HYDROGEOLOGIC SETTING CHARTS

The following setting charts are a schematic breakdown of each hydrogeologic setting mapped in Ottawa County. 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. The charts are grouped according to their respective hydrogeologic setting with an accompanying block diagram illustrating the characteristics of each setting. 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.



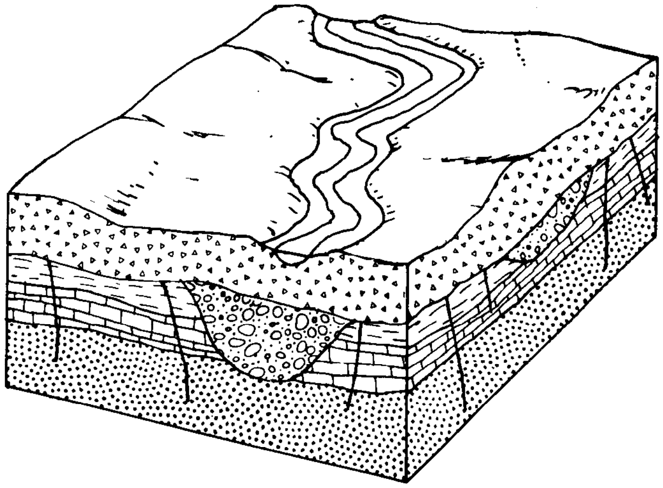
7Ac Glacial Till Over Solution Limestone

This hydrogeologic setting is characterized by low topography and solution limestone which is covered by varying thicknesses of glacial till. The till is principally unsorted deposits which may be interbedded with loess or localized deposits of sand and gravel. Surficial deposits have usually weathered to a clay loam. Although ground water occurs in both the glacial deposits and in the underlying limestone, the limestone, which typically contains solution cavities, generally serves as the principal aquifer. The limestone is in direct hydraulic connection with the glacial till and the glacial till serves as a source of recharge for the underlying limestone. Although precipitation is abundant in most of this region, recharge is moderate because of the relatively low permeability of the overlying glacial till. Depth to water is extremely variable depending in part on the thickness of the glacial till, but is typically moderately deep.

GWPP index values for the hydrogeologic setting of glacial till over solution limestone range from 110 to 207 with the total number of GWPP index calculations equaling 48.

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Ac1	5-15	4-7	Massive Limestone	Clay Loam	2-6	Glacial Till	1000-2000	162	175
7Ac10	5-15	4-7	Massive Limestone	Aggregated Clay	2-6	Glacial Till	100-300	141	173
7Ac11	5-15	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	100-300	142	176
7Ac12	15-30	4-7	Massive Limestone	Clay Loam	2-6	Glacial Till	100-300	123	143
7Ac13	5-15	7-10	Karst Limestone	Clay Loam	2-6	Glacial Till	2000+	182	193
7Ac14	30-50	10+	Karst Limestone	Aggregated Clay	2-6	Karst Limestone	2000+	194	213
7Ac15	15-30	10+	Karst Limestone	Clay Loam	2-6	Karst Limestone	2000+	186	195
7Ac16	15-30	10+	Karst Limestone	Aggregated Clay	2-6	Karst Limestone	2000+	204	223
7Ac17	15-30	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	100-300	132	166
7Ac18	15-30	4-7	Karst Limestone	Sandy Loam	2-6	Karst Limestone	2000+	190	206
7Ac19	5-15	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	100-300	140	175
7Ac2	15-30	4-7	Massive Limestone	Aggregated Clay	2-6	Massive Limestone	100-300	141	171
7Ac20	5-15	4-7	Massive Limestone	Clay Loam	0-2	Glacial Till	100-300	132	155
7Ac21	15-30	4-7	Karst Limestone	Clay Loam	2-6	Karst Limestone	1000-2000	168	179
7Ac22	5-15	4-7	Karst Limestone	Clay Loam	2-6	Karst Limestone	1000-2000	178	189
7Ac23	15-30	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	300-700	144	176

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Ac24	15-30	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	100-300	130	165
7Ac25	30-50	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	100-300	120	155
7Ac26	30-50	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	300-700	129	162
7Ac27	50-75	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	300-700	119	152
7Ac28	50-75	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	100-300	110	145
7Ac3	5-15	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	1000-2000	171	198
7Ac30	15-30	10+	Karst Limestone	Sandy Loam	2-6	Karst Limestone	2000+	194	211
7Ac31	5-15	10+	Karst Limestone	Sandy Loam	2-6	Karst Limestone	2000+	204	221
7Ac32	15-30	10+	Karst Limestone	Clay Loam	2-6	Karst Limestone	2000+	188	196
7Ac33	5-15	10+	Karst Limestone	Clay Loam	2-6	Karst Limestone	2000+	198	206
7Ac34	15-30	10+	Karst Limestone	Aggregated Clay	2-6	Karst Limestone	2000+	196	216
7Ac35	15-30	10+	Karst Limestone	Aggregated Clay	0-2	Karst Limestone	2000+	197	219
7Ac36	5-15	10+	Karst Limestone	Aggregated Clay	2-6	Karst Limestone	2000+	206	226
7Ac37	5-15	4-7	Karst Limestone	Aggregated Clay	0-2	Glacial Till	2000+	175	201
7Ac38	5-15	4-7	Karst Limestone	Clay Loam	6-12	Glacial Till	2000+	162	166
7Ac39	5-15	4-7	Karst Limestone	Clay Loam	2-6	Glacial Till	2000+	166	178
7Ac4	5-15	4-7	Massive Limestone	Aggregated Clay	2-6	Massive Limestone	1000-2000	175	199
7Ac40	15-30	4-7	Karst Limestone	Clay Loam	2-6	Glacial Till	2000+	156	168
7Ac41	15-30	4-7	Karst Limestone	Clay Loam	6-12	Karst Limestone	2000+	172	172
7Ac42	5-15	10+	Karst Limestone	Aggregated Clay	0-2	Karst Limestone	2000+	207	229
7Ac43	0-5	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	100-300	147	181
7Ac44	5-15	7-10	Massive Limestone	Aggregated Clay	0-2	Glacial Till	1000-2000	179	206
7Ac45	15-30	7-10	Karst Limestone	Aggregated Clay	0-2	Glacial Till	1000-2000	169	196
7Ac46	5-15	7-10	Karst Limestone	Aggregated Clay	2-6	Karst Limestone	2000+	197	218
7Ac47	5-15	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	1000-2000	166	194
7Ac48	15-30	4-7	Massive Limestone	Aggregated Clay	0-2	Glacial Till	1000-2000	156	184
7Ac5	5-15	4-7	Massive Limestone	Clay Loam	2-6	Massive Limestone	1000-2000	167	179
7Ac6	15-30	4-7	Massive Limestone	Clay Loam	2-6	Glacial Till	100-300	126	146
7Ac7	15-30	4-7	Massive Limestone	Clay Loam	6-12	Glacial Till	100-300	119	131
7Ac8	5-15	4-7	Massive Limestone	Clay Loam	0-2	Glacial Till	1000-2000	163	178
7Ac9	15-30	4-7	Massive Limestone	Aggregated Clay	2-6	Glacial Till	100-300	131	163

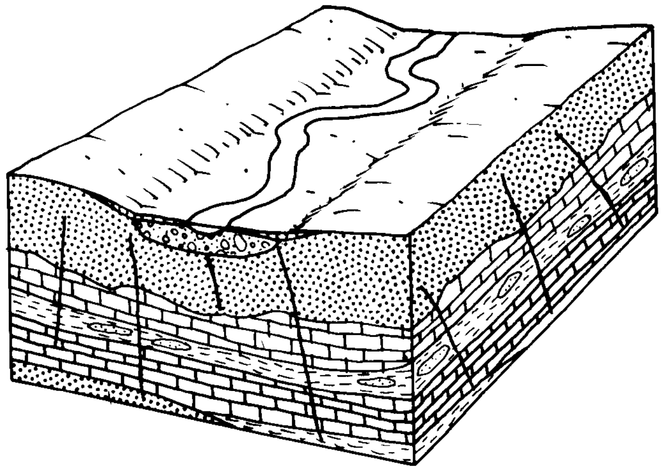


7D Buried Valleys

This hydrogeologic setting is characterized by thick deposits of sand and gravel that have been deposited in a former topographic low (usually a pre-glacial river valley) by glacial meltwaters. These deposits are capable of yielding large quantities of ground water. The deposits may or may not underlie a present-day river and may or may not be in direct hydraulic connection with a stream. Glacial till or recent alluvium often overlies the buried valley. Usually the deposits are several times more permeable than the surrounding bedrock. Soils are typically a sandy loam. Recharge to the sand and gravel is moderate and water levels are commonly relatively shallow, although they may be quite variable.

GWPP index values for the hydrogeologic setting of buried valley range from 137 to 147 with the total number of GWPP index calculations equaling 2.

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7D1	5-15	4-7	Sand & Gravel	Aggregated Clay	0-2	Glacial Till	700-1000	147	179
7D2	15-30	4-7	Sand & Gravel	Aggregated Clay	0-2	Glacial Till	700-1000	137	169

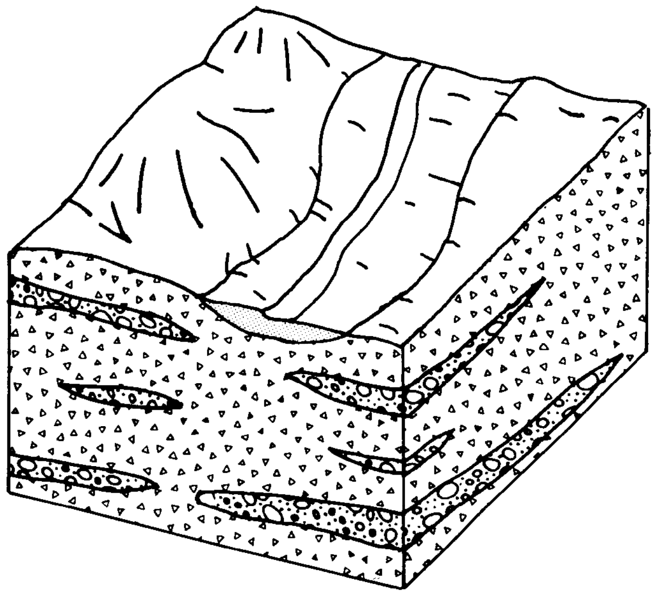


<u>7Ec Alluvium Over Sedimentary Rock</u>

This hydrogeologic setting is characterized by low relief with thin to moderate thicknesses of modern, stream-deposited alluvium. The alluvium is composed of silt, sand, gravel, and clay. Depth to water is shallow, and the stream is usually in hydraulic contact with the alluvial deposits. The alluvial deposits are underlain by fractured sandstone, limestone, shale, or bedded sedimentary sequences. It's usually the upper, weathered portion of the bedrock that serves as the principal aquifer with the alluvial deposits serving as a source of recharge to the bedrock in this setting. Soils are typically silty loams.

GWPP index values for the hydrogeologic setting of alluvium over sedimentary rock range from 134 to 154 with the total number of GWPP index calculations equaling 3.

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Ec1	0-5	7-10	Massive Limestone	Loam	0-2	Silt & Clay	100-300	154	182
7Ec2	5-15	4-7	Massive Limestone	Silt Loam	0-2	Silt & Clay	100-300	134	160
7Ec3	5-15	7-10	Massive Limestone	Silt Loam	0-2	Silt & Clay	100-300	150	175

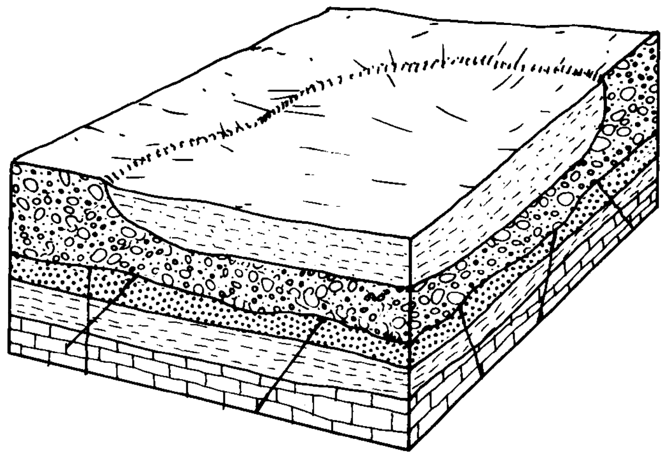


7Ed Alluvium Over Glacial Till

This hydrogeologic setting is characterized by low relief with thin to moderate thicknesses of modern, stream-deposited alluvium overlying glacial till. The alluvium is composed of silt, sand, gravel, and clay. The underlying sand and gravel lenses within the till serve as the aquifer. The depth to the water table is shallow, and the stream is usually in hydraulic connection with the alluvial deposits. Soils are typically classified as silty loams. The alluvial deposits serve as a source of recharge for the sand and gravel lenses within the till. Recharge is moderately high.

GWPP index values for the hydrogeologic setting of alluvium over glacial till range from 114 to 148 with the total number of GWPP index calculations equaling 8.

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Ed1	5-15	4-7	Massive Limestone	Silt Loam	0-2	Silt & Clay	300-700	138	163
7Ed2	5-15	4-7	Massive Limestone	Clay Loam	6-12	Silt & Clay	300-700	131	143
7Ed3	5-15	4-7	Massive Limestone	Silt Loam	0-2	Silt & Clay	100-300	129	156
7Ed4	0-5	4-7	Massive Limestone	Silt Loam	0-2	Silt & Clay	300-700	148	172
7Ed5	5-15	4-7	Massive Limestone	Silt Loam	0-2	Silt & Clay	300-700	143	167
7Ed6	15-30	4-7	Massive Limestone	Silt Loam	0-2	Silt & Clay	300-700	133	157
7Ed7	30-50	4-7	Massive Limestone	Silt Loam	0-2	Silt & Clay	300-700	123	147
7Ed8	30-50	4-7	Massive Limestone	Silt Loam	0-2	Silt & Clay	100-300	114	140



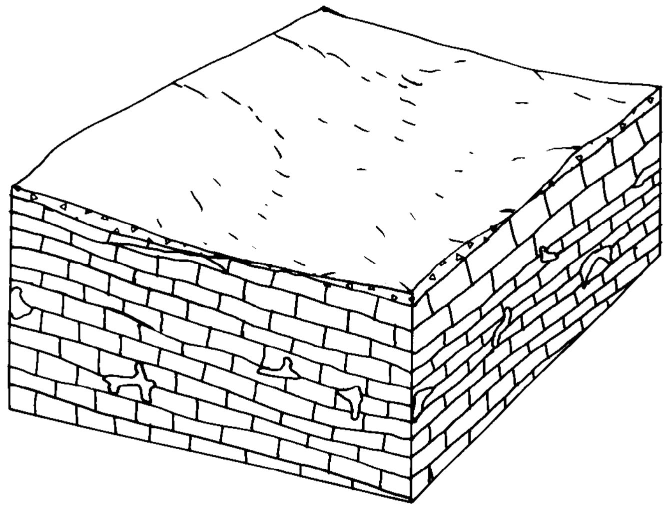
7F Glacial Lake Deposits

This hydrogeologic setting is characterized by flat topography and varying thicknesses of fine-grained sediments that overlie sequences of fractured sedimentary rocks. The deposits are composed of fine-grained silts and clays interlayered with fine sand that settled out in glacial lakes and exhibit alternating layers relating to seasonal fluctuations. As a consequence of the thin, alternating layers there is a substantial difference between the vertical and horizontal permeability with the horizontal commonly two or more orders of magnitude greater than the vertical. Due to their fine-grained nature, these deposits typically weather to organic-rich sandy loam with a range in permeabilities reflecting variations in sand content. Underlying glacial deposits or bedrock serve as the major source of ground water in the region. Although precipitation is abundant, recharge is controlled by the permeability of the surface clays; however, in all instances recharge is moderately high because of the impact of the low topography. Water levels are variable, depending on the thickness of the lake sediments and the underlying materials.

GWPP index values for the hydrogeologic setting of glacial lake deposits range from 88 to 143 with the total number of GWPP index calculations equaling 26.

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7F1	5-15	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	300-700	138	170
7F10	15-30	2-4	Massive Limestone	Clay Loam	0-2	Silt & Clay	100-300	100	125
7F11	5-15	2-4	Massive Limestone	Loam	0-2	Silt & Clay	300-700	123	152
7F12	15-30	2-4	Massive Limestone	Silt Loam	0-2	Silt & Clay	100-300	102	130
7F13	5-15	2-4	Massive Limestone	Clay Loam	6-12	Silt & Clay	100-300	105	120
7F14	5-15	2-4	Massive Limestone	Clay Loam	0-2	Silt & Clay	100-300	115	139
7F15	15-30	2-4	Massive Limestone	Loam	0-2	Silt & Clay	100-300	104	135
7F16	15-30	2-4	Massive Limestone	Silt Loam	0-2	Silt & Clay	100-300	107	134
7F17	15-30	2-4	Massive Limestone	Loam	0-2	Silt & Clay	100-300	109	139
7F18	15-30	2-4	Massive Limestone	Clay Loam	0-2	Silt & Clay	100-300	105	129
7F19	15-30	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	100-300	113	149
7F2	5-15	2-4	Massive Limestone	Clay Loam	0-2	Silt & Clay	300-700	130	150
7F20	5-15	2-4	Massive Limestone	Silt Loam	0-2	Silt & Clay	100-300	117	144

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7F21	5-15	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	100-300	123	159
7F22	30-50	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	100-300	103	139
7F23	30-50	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	300-700	112	146
7F24	30-50	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	300-700	107	142
7F25	50-75	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	300-700	97	132
7F26	50-75	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	100-300	88	125
7F3	5-15	2-4	Massive Limestone	Clay Loam	6-12	Silt & Clay	300-700	125	135
7F4	0-5	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	300-700	143	175
7F5	15-30	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	300-700	128	160
7F6	5-15	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	300-700	127	162
7F7	15-30	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	100-300	108	145
7F8	15-30	2-4	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	300-700	117	152
7F9	5-15	2-4	Massive Limestone	Clay Loam	0-2	Silt & Clay	300-700	119	142



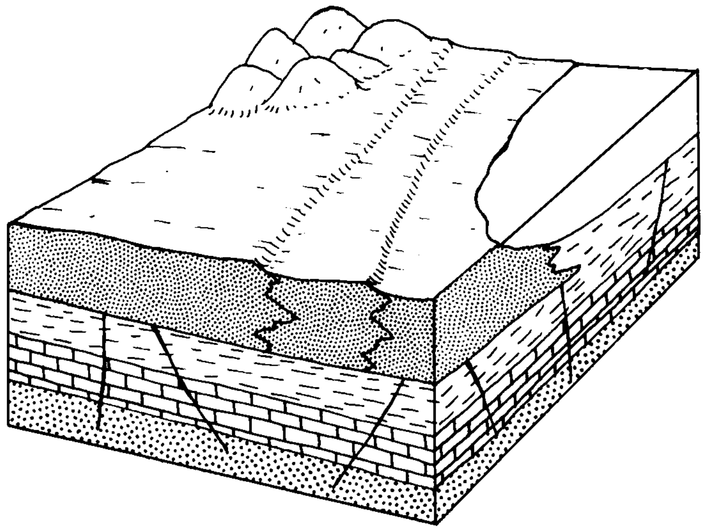
7Gb Thin Till Over Limestone

This hydrogeologic setting is characterized by thin deposits of glacial till overlying limestone bedrock. In some areas the limestone is directly overlain by shale. The till and soil are usually very thin or absent in areas of steep relief. Till consists primarily of clay with little, if any, sand and gravel and does not serve as a source of water. Ground water is obtained from the upper, weathered, and solutioned portion of the limestone. Recharge is generally low due to the steep relief and the presence of restrictive shale. Depth to water is fairly shallow where the shale is absent, but deepens with increased thickness of shale.

GWPP index values for the hydrogeologic setting of thin till over limestone range from 145 to 220 with the total number of GWPP index calculations equaling 25.

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Gb1	5-15	7-10	Massive Limestone	Thin or Absent	2-6	Massive Limestone	1000-2000	189	222
7Gb10	0-5	7-10	Massive Limestone	Thin or Absent	0-2	Karst Limestone	1000-2000	200	234
7Gb11	5-15	10+	Massive Limestone	Thin or Absent	6-12	Karst Limestone	2000+	205	226
7Gb12	15-30	10+	Karst Limestone	Thin or Absent	6-12	Karst Limestone	2000+	198	219
7Gb13	15-30	10+	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	202	231
7Gb14	30-50	10+	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	192	221
7Gb15	30-50	10+	Karst Limestone	Thin or Absent	6-12	Karst Limestone	2000+	188	209
7Gb16	5-15	10+	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	212	241
7Gb17	15-30	7-10	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	193	223
7Gb18	5-15	7-10	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	203	233
7Gb19	30-50	7-10	Massive Limestone	Thin or Absent	2-6	Massive Limestone	100-300	145	184
7Gb2	5-15	7-10	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	208	237
7Gb20	15-30	7-10	Massive Limestone	Thin or Absent	2-6	Massive Limestone	100-300	155	194
7Gb21	5-15	7-10	Massive Limestone	Thin or Absent	2-6	Massive Limestone	100-300	165	204
7Gb22	30-50	7-10	Massive Limestone	Thin or Absent	0-2	Massive Limestone	100-300	146	187
7Gb23	5-15	7-10	Massive Limestone	Thin or Absent	0-2	Massive Limestone	100-300	169	210

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7Gb24	5-15	7-10	Massive Limestone	Thin or Absent	0-2	Massive Limestone	300-700	178	217
7Gb25	15-30	7-10	Massive Limestone	Thin or Absent	0-2	Massive Limestone	300-700	168	207
7Gb3	5-15	4-7	Massive Limestone	Thin or Absent	2-6	Massive Limestone	1000-2000	181	214
7Gb4	15-30	4-7	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	198	226
7Gb5	15-30	10+	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	210	238
7Gb6	30-50	10+	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	200	228
7Gb7	5-15	10+	Karst Limestone	Thin or Absent	2-6	Karst Limestone	2000+	220	248
7Gb8	5-15	7-10	Karst Limestone	Thin or Absent	2-6	Karst Limestone	1000-2000	205	236
7Gb9	15-30	7-10	Karst Limestone	Thin or Absent	2-6	Karst Limestone	1000-2000	195	226

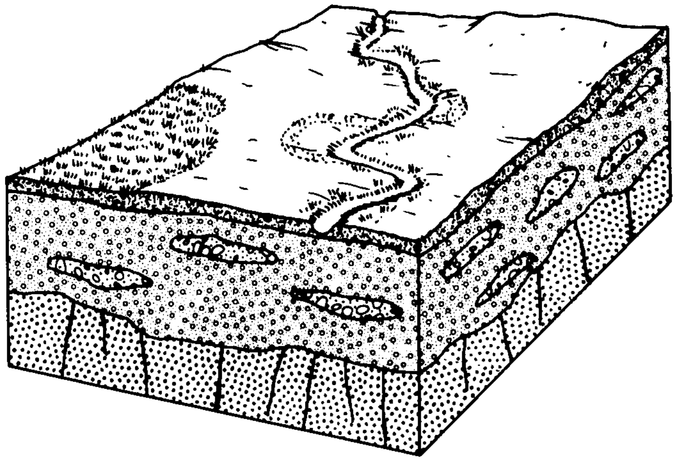


7H Beaches, Beach Ridges and Sand Dunes

This hydrogeologic setting is characterized by low relief, sandy surface soil that is predominantly silica sand, extremely high infiltration rates, and low sorptive capacity in the thin vadose zone. The water table is very shallow beneath the beaches bordering the Great Lakes. These beaches are commonly ground water discharge areas. The water table is slightly deeper beneath the rolling dune topography and the vestigial inland beach ridges. All of these areas serve as recharge sources for the underlying sedimentary bedrock aquifers, and they often serve as local sources of water supply.

GWPP index values for the hydrogeologic setting of beaches, beach ridges and sand dunes range from 173 to 201 with the total number of GWPP index calculations equaling 10.

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7H1	0-5	7-10	Karst Limestone	Sand	2-6	Sand & Gravel	1000-2000	200	229
7H10	5-15	7-10	Massive Limestone	Sand	0-2	Massive Limestone	1000-2000	188	220
7H2	0-5	7-10	Karst Limestone	Sand	0-2	Sand & Gravel	1000-2000	201	232
7H3	0-5	7-10	Sand & Gravel	Sand	0-2	Sand & Gravel	700-1000	189	222
7H4	0-5	7-10	Sand & Gravel	Sand	2-6	Sand & Gravel	700-1000	188	219
7H5	0-5	7-10	Massive Limestone	Sand	0-2	Sand & Gravel	100-300	174	211
7H6	0-5	7-10	Massive Limestone	Sand	2-6	Sand & Gravel	100-300	173	208
7H7	0-5	7-10	Massive Limestone	Sand	0-2	Sand & Gravel	300-700	192	225
7H8	0-5	7-10	Massive Limestone	Sandy Loam	0-2	Sand & Gravel	300-700	186	210
7H9	0-5	7-10	Massive Limestone	Sand	2-6	Sand & Gravel	300-700	191	222



7I Swamp / Marsh

This hydrogeologic setting is characterized by low topographic relief, high water levels, and high organic silt and clay deposits. These wetlands occur along the courses of floodplains and in upland areas as a result of vertically restricted drainage. Common features of upland wetlands include those characteristics attributable to glacial activity such as filled-in glacial lakes, potholes, and cranberry bogs. Recharge is moderate in most of the region due to restriction by clay-rich soils and limited by precipitation. The swamp deposits very rarely serve as significant aquifers but frequently recharge the underlying sand and gravel or bedrock aquifers.

GWPP index values for the hydrogeologic setting of swamp / marsh range from 172 to 193 with the total number of GWPP index calculations equaling 2.

Setting	Depth to Water (ft)	Recharge (In/Yr)	Aquifer Media	Soil Media	Topography	Vadose Zone Media	Hydraulic Conductivity	Rating	Pest Rating
7I1	0-5	7-10	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	300-700	172	203
7I2	0-5	7-10	Massive Limestone	Aggregated Clay	0-2	Silt & Clay	2000+	193	218

Ground Water Pollution Potential of OTTAWA COUNTY

by
Kelly C. Smith
ERM-Midwest, Inc.

Prepared in cooperation with
Ohio Department of Natural Resources, Division of Water

Description of Map Symbols

Hydrologic Region — 7Ad 6 — Hydrogeologic Setting
98 — Relative Pollution Potential

Observation Well Site*
Gravel Pit / Quarry

County Line
Township Line
Incorporated City Limit

CONTOUR INTERVAL 5 FEET

Pollution Potential Index Range

Higher	200+
	180 - 199
	160 - 179
to	140 - 159
	120 - 139
	100 - 119
Lower	80 - 99

Hydrogeologic Settings

- 7Ac - Glacial Till Over Limestone
- 7D - Buried Valley
- 7Ec - Alluvium Over Sedimentary Rock
- 7Ed - Alluvium Over Glacial Till
- 7F - Glacial Lake Deposits
- 7Gb - Thin Till Over Limestone
- 7H - Beaches, Beach Ridges and Sand Dunes
- 7I - Marshes and Swamps

A more detailed description of the hydrogeologic settings and the evaluation of the pollution potential may be found in the publication "Ground Water Pollution Potential of Ottawa County," GWPP Report No. 20, Ohio Department of Natural Resources, Division of Water.

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

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

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