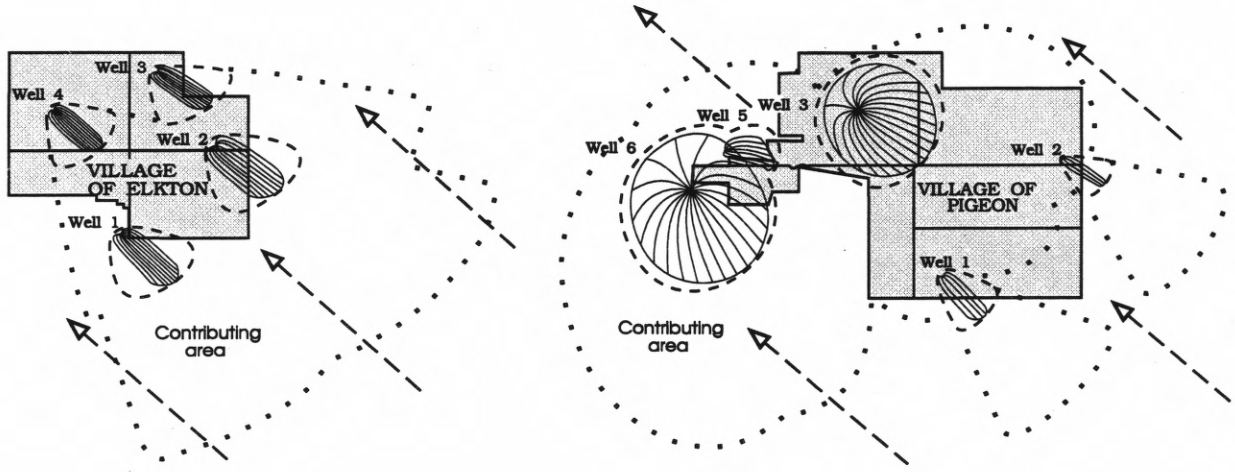
Contributing Areas Of Water-Supply Wells in Elkton and Pigeon, Huron County, Michigan

U.S. Geological Survey
Water-Resources Investigations Report 94-4089



Prepared in cooperation with the
MICHIGAN DEPARTMENT OF NATURAL RESOURCES, and
MICHIGAN DEPARTMENT OF PUBLIC HEALTH

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By GARY BARTON

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CONVERSION FACTORS AND ABBREVIATIONS

CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot squared per day (ft^2/d)	0.09290	meter squared per day
gallon per day (gal/d)	3.785	liter per day

OTHER ABBREVIATIONS

MDNR	Michigan Department of Natural Resources
MDPH	Michigan Department of Public Health
TOT	Time-of-travel
WHPA	Wellhead-protection area
WHPP	Wellhead Protection Program

Contributing Areas of Water-Supply Wells in Elkton and Pigeon, Huron County, Michigan

By Gary Barton

Abstract

The villages of Elkton and Pigeon in Huron County, Michigan, depend on wells completed in the Marshall aquifer to provide a reliable source of potable water. In order to protect the quality of water pumped from these wells, these municipalities need to ensure that potentially harmful contaminants do not enter the Marshall aquifer within the contributing areas of these wells. The Well Head Protection Plan for the State of Michigan requires the delineation of a contributing area based on a 10-year time-of-travel for public-supply wells. The U.S. Environmental Protection Agency recommends a 40-year time-of-travel as the basis for contributing areas of wells in confined aquifers.

The Marshall aquifer, composed of permeable sandstone, is the principal bedrock aquifer in the Elkton-Pigeon area and in the Michigan Basin. In the Elkton-Pigeon area, the top of the Marshall aquifer is roughly 90 to 150 feet below land surface and the aquifer is about 80 feet thick. Transmissivity ranges from 40 to 1,300 feet squared per day, effective porosity is estimated to be about 10 percent, and the hydraulic gradient ranges from 0.0013 to 0.0025. The recharge area of the aquifer is several miles southeast of Elkton and Pigeon, where the aquifer is a subcrop beneath the permeable unconsolidated sediments of the Port Huron End Moraine.

Water from wells at Elkton and Pigeon has tritium concentrations of less than 0.8 tritium unit, a concentration indicating that (1) the water in the Marshall aquifer at Elkton and Pigeon is more than 40 years old and (2) the aquifer is highly confined. On the basis of a semianalytical model, contributing areas for a the 10-year time-of-travel for water-supply wells in Elkton and Pigeon are almost entirely within village boundaries. The contributing areas for a 40-year time-of-travel encompass areas within approximately 1 mile of each village and are several miles from the recharge area of the aquifer.

Control of land-use activities within the contributing areas at Elkton and Pigeon will not ensure that water pumped from these supply wells will remain potable. The Marshall aquifer overlies the Coldwater Shale, which contains brine and brackish water that could migrate toward the pumped wells.

INTRODUCTION

The 1986 Amendments to the Safe Drinking Water Act established the Wellhead Protection Program (WHPP) to protect ground water used for public water supplies from possible contamination. Each State is required by the Amendments to develop a WHPP, which includes the delineation of Wellhead-Protection Area (WHPA). A WHPA is defined in the Safe Water Drinking Act as "the surface and subsurface area surrounding a water well or well field, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such a water well or well field" (U.S. Environmental Protection Agency, 1987, p. 1-2). The Michigan Department of Natural Resources (MDNR) and the Michigan Department of Public Health (MDPH), as co-lead agencies, have been developing guidelines for a comprehensive WHPP for the State of Michigan. The goal of this WHPP is to have all public water-supply systems involved in wellhead protection (Michigan Department of Natural Resources, 1992, p. i-iv). The U.S. Geological Survey, in cooperation with MDNR and MDPH began a demonstration project in 1993 to delineate the contributing areas of water-supply wells in a confined bedrock aquifer. These wells are located in the villages of Pigeon and Elkton, Huron County, Michigan (fig. 1). The contributing areas described in this report are

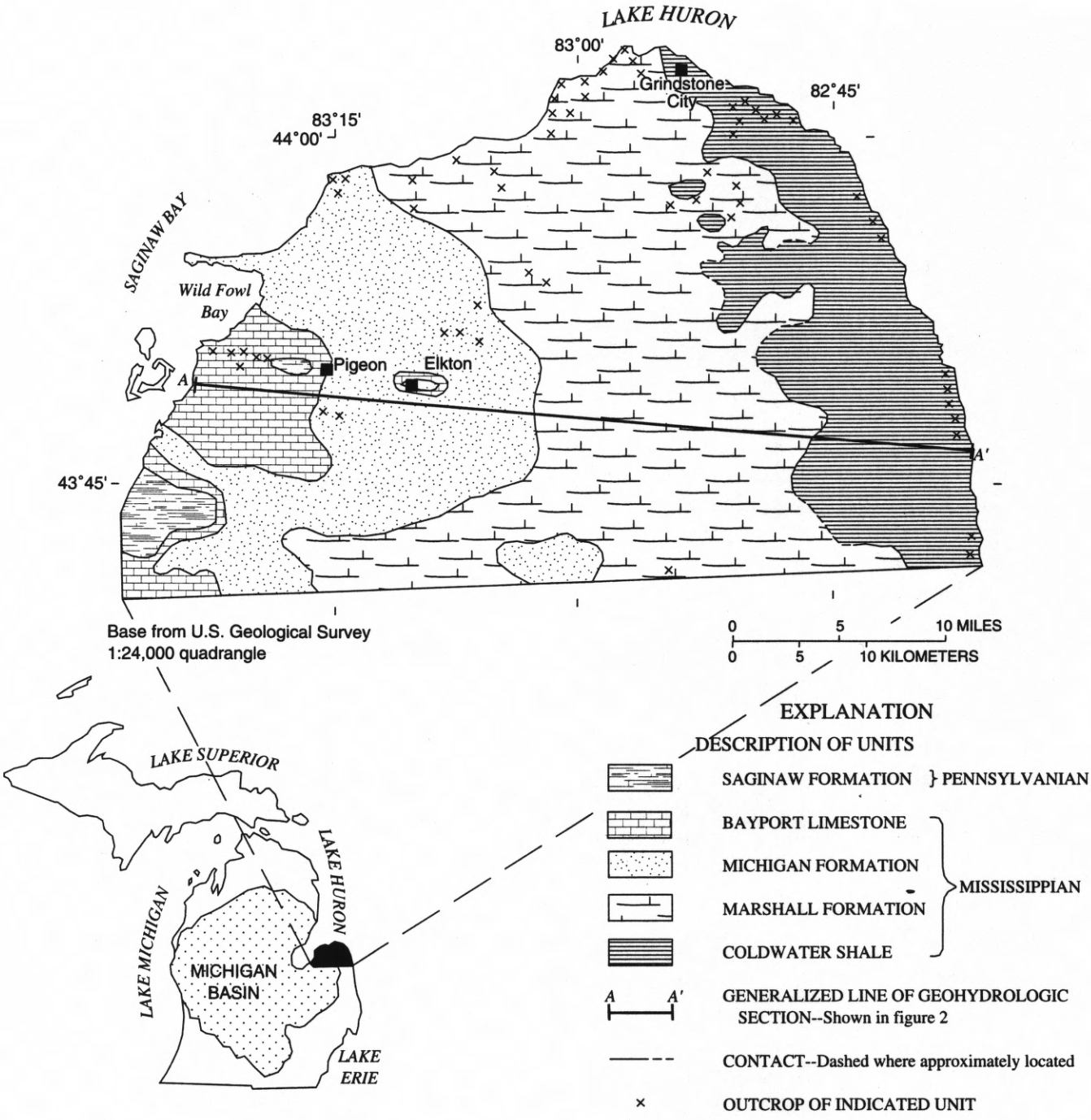


Figure 1. Bedrock geology of Huron County, Michigan.

referred to as WHPA's and are hydrologic in nature. Use of the term 'wellhead protection area' in this report does not have a regulatory or administrative connotation. A zone of contribution is the aquifer volume through which water is diverted to a well. The projection of this aquifer volume to land surface and adjacent surface areas that provide recharge to the aquifer defines the contributing area.

The villages of Elkton and Pigeon depend on wells for a reliable source of potable water. Four water-supply wells are in Elkton, and six wells are in Pigeon. In 1992, the average cumulative withdrawal rate from wells in Elkton was about 76,000 gal/d and from wells in Pigeon, about 166,000 gal/d (Lisa Harrington, Michigan Department of Public Health, written commun., 1993). Surface water from nearby streams is not a reliable source of water supply because the streams may not have sustained flows during summer months (Sweat, 1991, p. 19).

Purpose and Scope

This report describes the contributing areas of water-supply wells at Pigeon and Elkton and the degree of confinement of ground water. Because the wells are completed exclusively in the Marshall aquifer, this report describes the geohydrologic setting of the Marshall aquifer. Except for analyses of ground water for tritium, all other data in the report are from previous studies such as Sweat (1991) and the Michigan Basin Regional Aquifer System Analysis (Mandle, 1986). Contributing areas were determined by use of analytical equations and a semianalytical model.

Geohydrologic Setting

Water-supply wells at Elkton and Pigeon are completed in the Marshall Formation, the principal bedrock aquifer in Huron County and in the Michigan Basin (fig. 1). The Marshall Formation consists of a fine- to coarse-grained sandstone, the lower part containing siltstone. Beds within the formations dip gently toward the northwestern part of Huron County (fig. 2). The Marshall aquifer consists of permeable sandstone in the Marshall Formation, and in the Elkton-Pigeon area the top of the Marshall aquifer is approximately 90 to 150 ft below land surface and about 80 ft thick. Recharge area of the Marshall aquifer is located several miles southeast of Elkton and Pigeon, where the aquifer is a subcrop beneath the permeable unconsolidated sediments of the Port Huron End Moraine (fig. 3). The aquifer is confined except where it subcrops beneath the permeable unconsolidated sediment. Flowing wells that tap bedrock a few miles south of Elkton are evidence that the aquifer is confined. Regional groundwater flow is toward the northwestern part of the County (Sweat, 1991, p. 49; fig. 3).

Total porosity of the Marshall aquifer was measured in two rock specimens taken from quarries near Grindstone City, Huron County, and in rock cores collected from 13 wells and exploratory boreholes in Calhoun, Missaukee, and Osceola Counties (Westjohn and others, 1990, table 3). Rock specimens in Huron County had a total porosity of 19 percent. Rock cores were collected from confined aquifer settings, and the sandstone ranged from poorly to well cemented and appeared to be unfractured. Total porosity of the rock cores ranged from 16.4 to 22.8 percent. For this study, the effective porosity—pore space where fluid is mobile—of the Marshall aquifer is estimated to be about 10 percent. This estimate is less than total porosity, partly because some of the water is retained as a film on rock surfaces and partly because the porous matrix includes dead-end pores (Bear, 1979, p. 63).

Analyses of 12 single-well constant-discharge aquifer tests in Huron County (Michael Sweat, U.S. Geological Survey, written commun., 1993) indicate that transmissivity of the Marshall aquifer ranges from 40 to 1,300 ft^2/d. The test results were corrected for partial penetration. A Theis-curve analysis of a multiwell, constant-discharge aquifer test in the Marshall aquifer at Ubly, Huron County (Layne-Northern, Inc.[1], written commun., 1993) indicated in a transmissivity of about 1,000 ft^2/d and a storativity of 0.0004. The storativity is indicative of a confined aquifer (Heath, 1983, p. 28).

[1]Use of company names in this report is for identification only and does not constitute endorsement by the U.S. Geological Survey

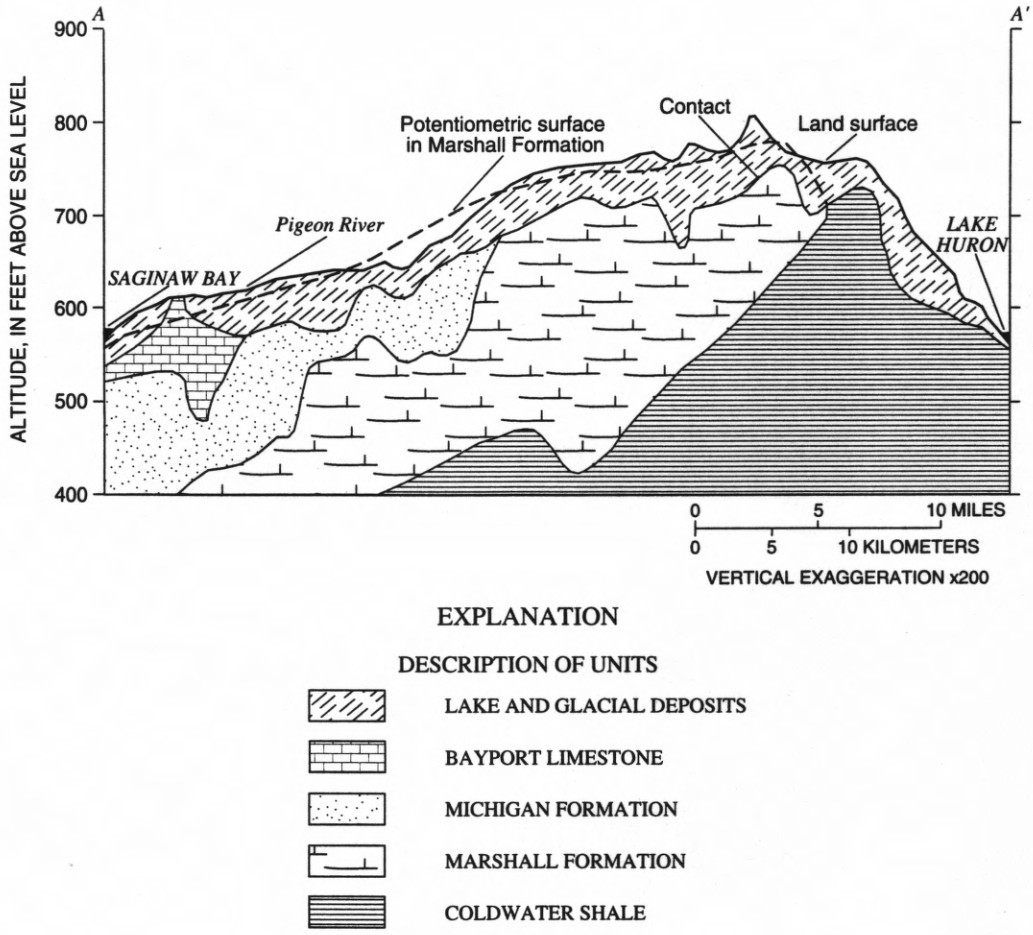


Figure 2. Stratigraphic relations of surficial deposits and bedrock units, Huron County, Michigan.

The Marshall Formation is underlain by the Coldwater Shale. The Coldwater Shale is more than 1,000 ft in thickness; the upper part is silty and sandy and contains brackish to saline water. At Elkton and Pigeon, the Marshall Formation is overlain by the Michigan Formation, which consists of sandstone, shales, limestones, and some anhydrite. In parts of Elkton and Pigeon, the Michigan Formation is overlain by the Bayport Limestone (fig. 1). Bedrock in the vicinity of Elkton and Pigeon is mantled by poorly permeable clay-rich unconsolidated sediments with a thickness generally less than 40 ft (Sweat, 1991, figs. 4 and 8).

Relation of Contributing Areas to Aquifer Confinement

In this study, contributing areas were defined in relation to time-of-travel (TOT); the time required for a conservative contaminant to travel from a point of entry in the ground-water system to a pumped well or well field. Two TOT's, 10 years and 40 years, were selected as the basis for contributing areas.

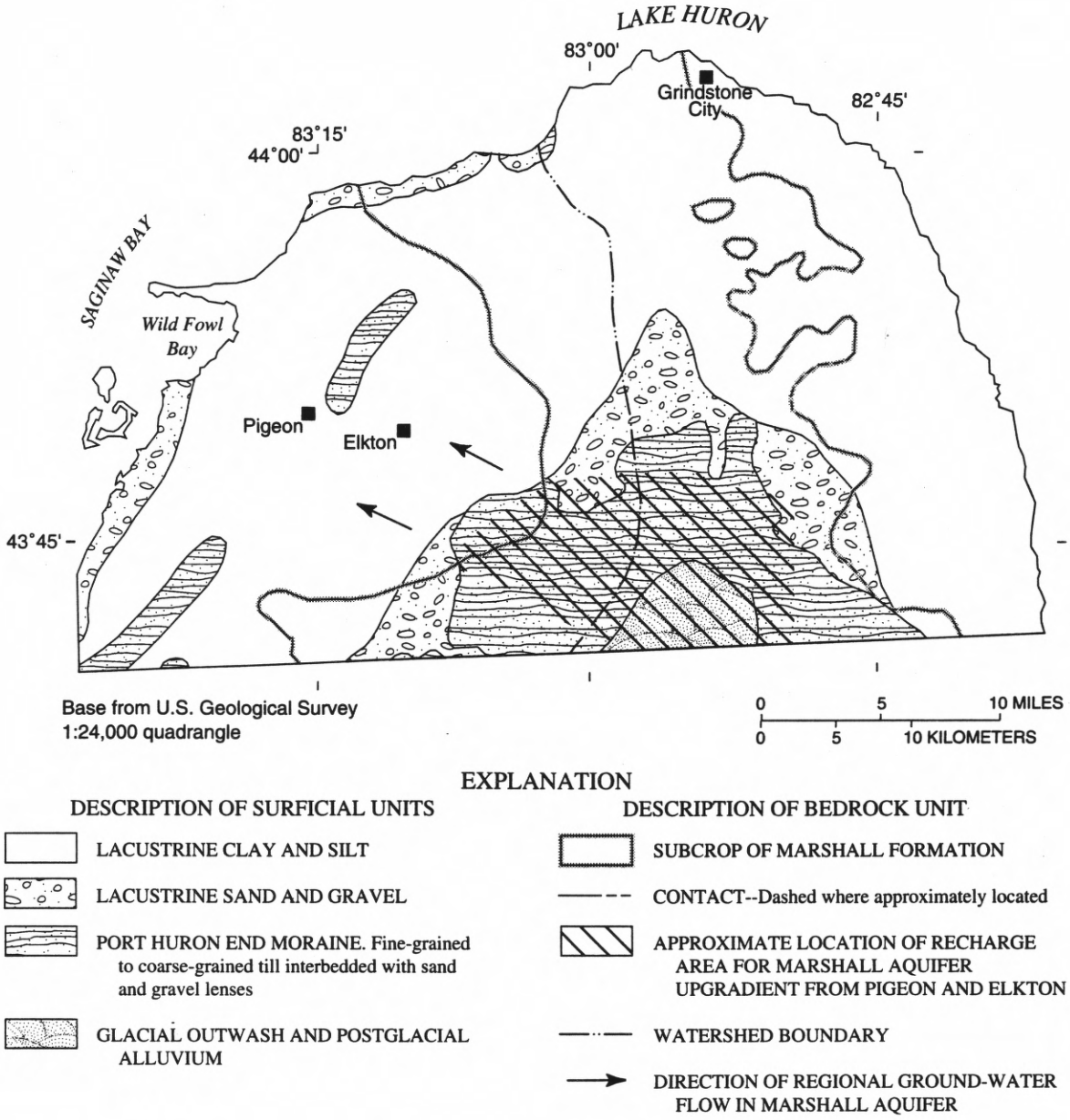


Figure 3. Approximate location of recharge area for the Marshall aquifer upgradient from Elkton and Pigeon, Huron County, Michigan.

The 10-year TOT has been established by the State of Michigan as the minimum for WHPP delineation (Michigan Department of Natural Resources, 1992, p. 32). This minimum applies to all geohydrologic settings.

A 40-year TOT is recommended by the U.S. Environmental Protection Agency for delineation of contributing areas in confined aquifers. A confined aquifer is overlain by layers of low permeability that retard vertical flow to the aquifer. The recharge area for a well completed in a confined aquifer is typically farther from the well than if the aquifer were semiconfined or unconfined.

METHODS OF INVESTIGATION

Measurement of tritium concentrations was used to determine age of the ground water and thereby determine the degree of aquifer confinement at Elkton and Pigeon. The contributing areas for water-supply wells were estimated by use of methods in which flow through a granular porous media is assumed.

Tritium Analyses for Determination of Aquifer Confinement

Tritium is a natural radioactive isotope of hydrogen that has a half-life of 12.3 years. The concentration of tritium in ground-water samples can be used to determine whether the ground water is younger or older than 40 years (U.S. Environmental Protection Agency, 1991). The natural concentration of tritium in precipitation is about 5 tritium units; however, atmospheric detonation of nuclear weapons added large quantities of tritium to precipitation during the 1950's and 1960's (Dumouchelle and others, 1993). Tritium concentrations in ground water recharged during and after the 1950's are greater than those in ground water recharged earlier. Ground water that recharged the aquifer before the 1950's generally contains less that 2 tritium units (Fritz and Fontes, 1980; U.S. Environmental Protection Agency, 1991, p. 45). Ground-water ages of more than 40 years indicate that the recharge area is at a considerable distance and, hence, that the aquifer is locally confined. In cases where an aquifer test indicates leakage, but the tritium concentration shows the water is older than 40 years, the U.S. Environmental Protection Agency states that the tritium results should be given priority and the aquifer should be considered confined (U.S. Environmental Protection Agency, 1991, p. xiv, 44, and 52).

Water samples for tritium analysis were collected from three water-supply wells in Elkton and from three water-supply wells in Pigeon. Analysis on these samples were performed by the Environmental Isotope Laboratory at the University of Waterloo, Waterloo, Ontario, Canada. The analytical detection limit is 0.8 tritium unit.

Delineation of Contributing Areas

The contributing area for a 10-year TOT was estimated for each supply well by use of the following methods: (1) average Darcian flow rate (Bear, 1979, p. 61), (2) uniform-flow equation (Bear, 1979, p. 282), (3) areal water balance, and (4) the semianalytical WHPA model (Blanford and Huyakorn, 1989). The WHPA model was used to refine the delineation of contributing areas from methods 1, 2, and 3. Delineation of the contributing areas for a 40-year TOT was done by a similar procedure as for the 10-year TOT using the WHPA model. In all of these methods it is assumed that ground-water flow can be conceptualized as being typical of flow in a granular porous media and that the aquifer is confined, nearly constant in thickness, and has a uniform horizontal hydraulic conductivity and prepumping hydraulic gradient. Numerical values of hydrologic parameters used as input for all methods are listed in table 1.

The Darcian flow equation is used to calculate the horizontal distance traveled by water moving along the regional ground-water-flow path toward water-supply wells. In the uniform-flow equation, steady flow to a pumping well is assumed. This equation is used to

Table 1. Selected hydrologic data for delineation of contributing areas at Elkton and Pigeon, Huron County, Michigan

[--, not applicable]

Village	Pumping rate, in cubic feet per day	Hydraulic gradient	Aquifer characteristics		
			Thickness, in feet	Porosity	Transmissivity, in feet squared per day
Elkton:	--	0.0025	80	0.1	1,000
Well 1	2,770	--	--	--	--
2	3,920	--	--	--	--
3	1,380	--	--	--	--
4	1,660	--	--	--	--
Pigeon:	--	0.0013	80	0.1	1,000
Well 1	946	--	--	--	--
2	350	--	--	--	--
3	7,627	--	--	--	--
5	1,008	--	--	--	--
6	12,273	--	--	--	--

calculate the maximum distance from a pumped well to the downgradient flow stagnation point—the downgradient extent of the contributing area of a well. The areal water balance is used to calculate the size of the contributing area: cumulative well discharge divided by the aquifer porosity multiplied by aquifer thickness.

The generalized particle-tracking module of the WHPA model delineates contributing areas for single and multiple wells and accounts for well interference caused by wells being pumped simultaneously. Several model simulations were constructed for Elkton and Pigeon to account for the effects of uncertainty in regional ground-water-flow direction on contributing areas of wells (the direction of regional ground-water flow is varied from N. 15° W. to N. 75° W).

CONTRIBUTING AREAS FOR WATER-SUPPLY WELLS

Contributing Areas for 10-Year Time-of-Travel

Contributing areas for water-supply wells at Elkton and Pigeon are shown in figures 4 and 5. Control of land-use activities within the contributing areas will not ensure that water pumped from these wells will remain potable. The Marshall aquifer overlies the Coldwater Shale, which contains brine and brackish water that may migrate toward the pumping supply wells.

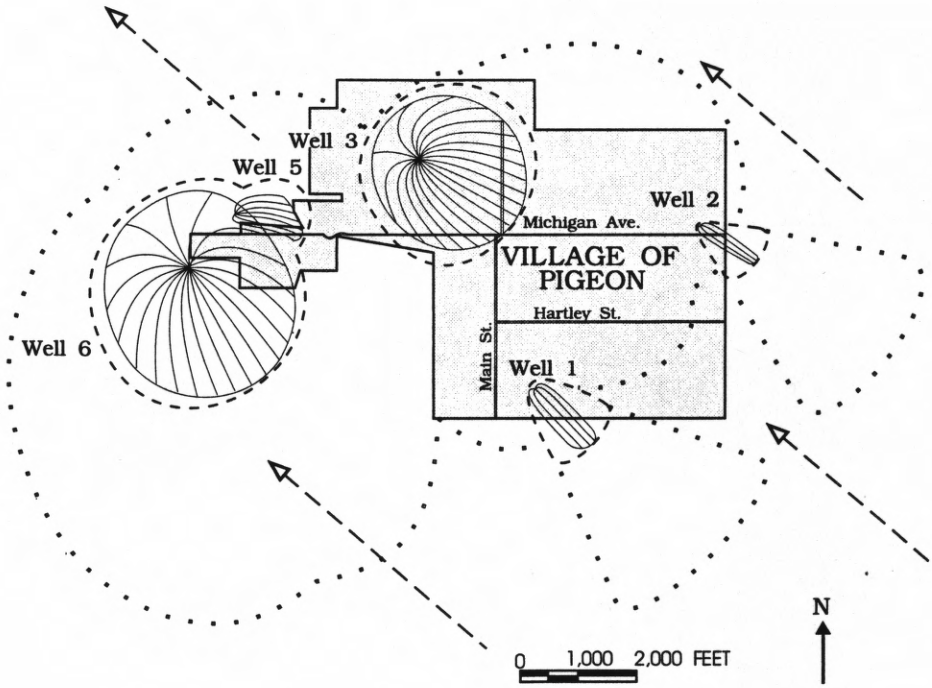
On the basis of average Darcian flow rates, the horizontal distance traveled by water moving along the regional ground-water-flow path toward wells in Elkton and Pigeon during a 10-year TOT is about 0.2 mi. According to calculations from the uniform-flow equation, the steady-state contributing area extends downgradient, northwest of water-supply wells in Elkton and Pigeon by about 0.03 and 0.1 mi, respectively. Areal calculations indicates that the contributing area for a 10-year TOT that encompasses wells in Elkton ranges from 0.03 mi^2 at well 4 to 0.06 mi^2 at well 1; in Pigeon, the contributing area ranges from 0.01 mi^2 at well 4 to 0.3 mi^2 at well 6.

The contributing areas for a 10-year TOT that were delineated by use of the WHPA model (figs. 4 and 5) are similar to the contributing areas calculated by use of average Darcian flow rates, uniform flow, and areal water-balance methods. WHPA delineations account for variability of flow direction, and allow for a greater margin of error, than does use of Darcian flow rates, thus, a more realistic contributing area results. The variability of flow direction has a greater effect on the location of contributing areas in Pigeon than in Elkton because of a larger hydraulic gradient. In Elkton, the contributing area for wells 3 and 4 is almost entirely within the village; for wells 1 and 2, it extends about 0.2 mi southeastward of the wells and thus beyond the village. In Pigeon, the contributing area for wells 3 and 5 is almost entirely within the village; for wells 1, 2 and 6, it extends less than 0.2 mi southeast of the wells and thus beyond the village.

Contributing Areas for 40-Year Time-of-Travel

The concentration of tritium in water from Elkton supply wells 1, 2, and 3 and from Pigeon supply wells 1, 3, and 6 (figs. 4 and 5) was less than 0.8 tritium unit on March 8, 1993. The results indicate that the water in the Marshall aquifer at Elkton and Pigeon was more than 40 years old. These chemical data support the geohydrologic data which indicate that the Marshall aquifer is highly confined. Therefore, contributing areas for a 40-year TOT were calculated in addition to those for the 10-year TOT.

The contributing areas for a 40-year TOT for wells in Elkton and Pigeon (figs. 4 and 5) encompass areas within about 1 mi of each village boundary. The contributing areas for the 40-year TOT are several miles from the recharge area in the southeastern part of Huron County.



Pigeon

Well discharge rates in cubic feet per day:
Well 1 = 946; Well 2 = 350; Well 3 = 7,627; Well 5 = 1,008; Well 6 = 12,273

EXPLANATION

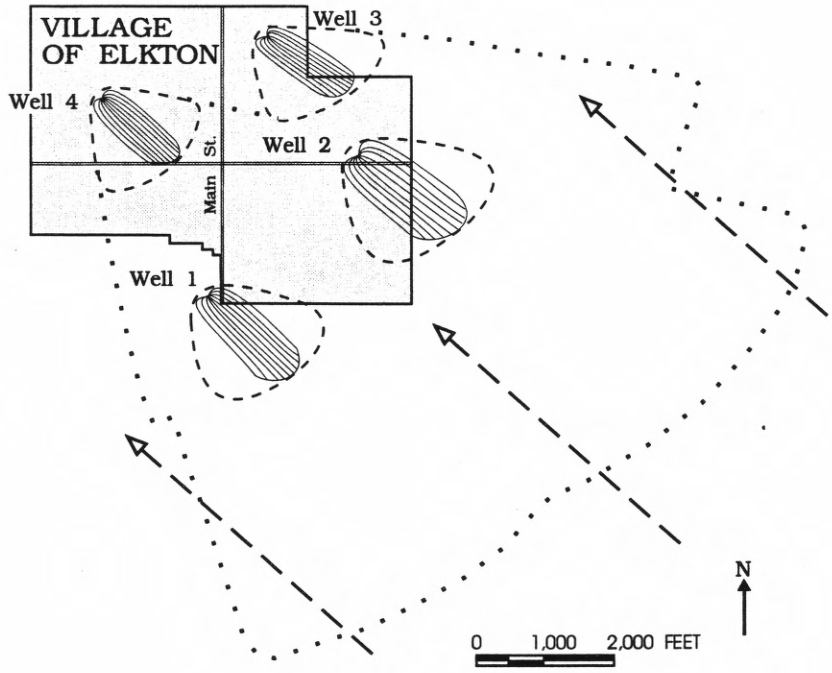
REGIONAL GROUND-WATER FLOW IN THE MARSHALL AQUIFER

CONTRIBUTING AREA FOR A 10-YEAR TIME-OF-TRAVEL AND FLOW LINES--Dashed line is contributing area assuming uncertainty of ground-water-flow direction is 60 degrees

CONTRIBUTING AREA FOR A 40-YEAR TIME-OF-TRAVEL--Assuming uncertainty of ground-water-flow direction is 60 degrees

Aquifer thickness: 80 feet
Aquifer porosity: 0.1
Hydraulic gradient: Pigeon = 0.0013
Transmissivity: 1,000 feet-squared per day

Figure 4. Contributing areas delineated by use of the Wellhead Protection Area model for water-supply wells in Elkton, Michigan.



Elkton
Well discharge rates in cubic feet per day:
Well 1 =2,770; Well 2 = 3,920; Well 3 = 1,380; Well 4 = 1,660

EXPLANATION

REGIONAL GROUND-WATER FLOW IN THE MARSHALL AQUIFER

CONTRIBUTING AREA FOR A 10-YEAR TIME-OF-TRAVEL AND FLOW LINES--Dashed line is contributing area assuming uncertainty of ground-water-flow direction is 60 degrees

CONTRIBUTING AREA FOR A 40-YEAR TIME-OF-TRAVEL--Assuming uncertainty of ground-water-flow direction is 60 degrees

Aquifer thickness: 80 feet
Aquifer porosity: 0.1
Hydraulic gradient: Elkton = 0.0025
Transmissivity: 1,000 feet-squared per day

Figure 5. Contributing areas delineated by use of the Wellhead Protection Area model for water-supply wells in Pigeon, Michigan.

SUMMARY AND CONCLUSIONS

Contributing areas of water-supply wells completed in the Marshall aquifer in Elkton and Pigeon, Huron County, Michigan were estimated by use of (1) average Darcian flow rates, (2) uniform-flow equation, (3) areal water balance, and (4) a semianalytical model that accounts for well interference caused by simultaneously pumping wells. Concentrations of tritium were used to determine the age of the ground water and the degree of aquifer confinement.

In the Elkton-Pigeon area, the top of the Marshall aquifer is roughly 90 to 150 ft below land surface and about 80 ft thick. Transmissivity ranges from 40 to 1,300 ft^2/d, effective porosity is estimated to be about 10 percent, and the hydraulic gradient ranges from 0.0013 to 0.0025. Flowing wells completed in bedrock a few miles south of Elkton are evidence that the aquifer is confined. The recharge area of the aquifer is several miles southeast of Elkton and Pigeon, where the aquifer is a subcrop beneath the permeable unconsolidated sediments of the Port Huron End Moraine.

Water from wells in Elkton and Pigeon has tritium concentrations of less than 0.8 tritium unit indicating that (1) the water in the Marshall aquifer at Elkton and Pigeon is more than 40 years old, and (2) the aquifer is highly confined. On the basis of a semianalytical model, the contributing areas for a 10-year TOT for supply wells in Elkton and Pigeon are almost entirely located within the village boundaries. The contributing areas for a 40-year TOT encompass areas within approximately 1 mi of each village and are several miles from the recharge area of the aquifer.

Control of land-use activities within the contributing areas for water-supply wells at Elkton and Pigeon will not ensure that water pumped from these supply wells will remain potable. The Marshall aquifer overlies the Coldwater Shale, which contains brine and brackish water that could migrate toward the pumped wells.

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