

U.S. Department of the Interior  
U.S. Geological Survey

# Ground-Water Quality Atlas of Oakland County, Michigan

Water-Resources Investigation Report 00-4120

Prepared in cooperation with the  
Oakland County Health Division



# Ground-Water Quality Atlas of Oakland County, Michigan

*By Stephen Scranton Aichele*

U.S. Geological Survey  
Water-Resources Investigation Report 00-4120

Lansing, Michigan  
August, 2000



U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY

Charles G. Groat, *Director*

Any use of firm, brand, or trade names in this publication is  
for descriptive purposes only and does not constitute  
endorsement by the U.S. Government.

---

For additional information write:

District Chief  
U.S. Geological Survey  
6520 Mercantile Way, Ste. 5  
Lansing, MI 48911-5991

Copies of this report can purchased from:

U.S. Geological Survey  
Branch of Information Services  
Box 25286  
Denver, CO 80225-0286

<b>CONTENTS</b>	<b>Page</b>
Abstract . . . . .	1
Introduction . . . . .	1
Purpose and scope . . . . .	2
Acknowledgments . . . . .	2
Study-area description – Oakland County, Michigan . . . . .	3
Population growth and land-use change . . . . .	4
Water supply . . . . .	6
Surface-water resources . . . . .	8
Surficial geology . . . . .	10
Soils . . . . .	12
Ground-water resources . . . . .	14
Sites of USGS ground-water-quality sampling . . . . .	16
Ground-water quality . . . . .	18
Sample collection and analysis . . . . .	18
Field-measured characteristics . . . . .	18
Inorganic chemical constituents . . . . .	20
Nutrients . . . . .	22
Sources . . . . .	22
Occurrence . . . . .	22
Potential health effects . . . . .	24
Major ions and trace metals . . . . .	24
Chloride . . . . .	26
Occurrence . . . . .	26
Potential health effects . . . . .	26
Arsenic . . . . .	28
Occurrence . . . . .	28
Potential health effects . . . . .	30
Results of time-series analyses . . . . .	31
Results of replicate sample analysis . . . . .	31
Summary . . . . .	31
References cited . . . . .	32
Appendix 1 . . . . .	35
Appendix 2 . . . . .	49

**CONTENTS--Continued**

Page

**Figures**

Figure 1 - 10 Maps showing:

1. Rate of population growth in Oakland County, Michigan, from 1990 through 1998 . . . . .	5
2. Principal sources of drinking water, by municipality, in Oakland County, Michigan in 1999 . . . . .	7
3. Surface-water drainage basins of Oakland County, Michigan . . . . .	9
4. Surficial geology of Oakland County, Michigan. . . . .	11
5. Minimum soil permeability in Oakland County, Michigan. . . . .	13
6. Elevation of the water-table surface in Oakland County, Michigan . . . . .	15
7. Sites of U.S. Geological Survey ground-water-quality sampling in Oakland County, Michigan. . . . .	17
8. Nitrate distribution in Oakland County, Michigan . . . . .	23
9. Chloride distribution in Oakland County, Michigan . . . . .	27
10. Arsenic distribution in Oakland County, Michigan. . . . .	29

**Tables**

1. Land use in Oakland County as a percentage of total county area, 1978 and 1995 . . . . .	4
2. Water-quality characteristics analyzed by the USGS National Water Quality Laboratory . . . . .	19
3. Inorganic constituents analyzed in this study with USEPA drinking water standards . . . . .	20
4. Summary statistics for selected inorganic constituents detected in water samples from selected wells in Oakland County. . . . .	21

**Appendix 1: Water-quality data collected by the U.S. Geological Survey in Oakland**

County, Michigan, 1998 . . . . .	35
----------------------------------	----

**Tables**

1A. Index of station names with U.S. Geological Survey station identification numbers . . . . .	36
1B. Field measurements of water-quality characteristics for ground-water samples from selected wells in Oakland County, Michigan . . . . .	37
1C. Results of analyses for selected inorganic chemical constituents in ground-water samples from selected wells in Oakland County, Michigan . . . . .	39
1D. Seasonal comparison of selected water-quality parameters for samples from selected wells in Oakland County, Michigan . . . . .	44
1E. Total arsenic concentrations in drinking water at selected ground-water sampling sites in Oakland County, Michigan . . . . .	46
1F. Total manganese concentrations in drinking water at selected ground-water sampling sites in Oakland County, Michigan . . . . .	47
1G. Total iron concentrations in drinking water at selected ground-water sampling sites in Oakland County, Michigan . . . . .	48

**CONTENTS--Continued**

Page

**Appendix 2:** Results of replicate sample analyses by U.S. Geological Survey National Water Quality Laboratory and the Michigan Department of Environmental Quality Drinking Water

Laboratory. . . . . 49

**Figures**

2A. Graph showing nitrate concentrations . . . . . 50

2B. Graph showing chloride concentrations. . . . . 50

2C. Graph showing arsenic concentrations . . . . . 50

**Tables**

2A. Analytical results of nitrate and nitrite analyses . . . . . 51

2B. Analytical results of chloride analyses. . . . . 52

2C. Analytical results of arsenic analyses . . . . . 53

---

## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

---

MULTIPLY	BY	TO OBTAIN
inches (in)	25.4	millimeters (mm)
foot (ft)	0.3048	meters (m)
mile (mi)	1.609	kilometer (km)
cubic foot (ft <sup>3</sup> )	0.02832	cubic meter (m <sup>3</sup> )
gallon	3.785	liter (L)

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$^{\circ}\text{F} = 32 + (^{\circ}\text{C} * 1.8)$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

milligrams per liter (mg/L) or micrograms per liter (µg/L): Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

ABBREVIATIONS (in addition to those above)

DO, concentration of dissolved oxygen

SC, specific conductance

DS, dissolved solids

MRL, minimum reporting level

MCL, maximum contaminant level

SMCL, secondary maximum contaminant level

µS, microsiemens

cm, centimeter

µg, microgram

mm, millimeter

mg, milligram

L, liter

mV, millivolts

eH, oxidation-reduction potential in mV

pH, negative logarithm of the concentrations of hydrogen ions

# Ground-Water Quality Atlas of Oakland County, Michigan

By Stephen Scranton Aichele

## ABSTRACT

The U.S. Geological Survey (USGS), in cooperation with Oakland County Health Division (OCHD), collected 140 water samples from 38 wells in Oakland County during 1998 to better understand ground-water quality. OCHD had observed temporal variations in concentrations of various constituents, so two additional sets of samples were collected to evaluate potential short-term variability related to sample collection procedures and long-term seasonal variability. Replicate samples from 28 wells were analyzed in the Michigan Department of Environmental Quality (MDEQ) Drinking Water Laboratory to compare MDEQ's analytical results to those obtained from the USGS National Water Quality Laboratory. Several additional databases describing population, land use, water supply, soils, geology, and flows of ground water and surface water are presented in the first part of the report to assist in interpreting the water-quality data. Maps created from these databases are provided in the first portion of the report as an extension of the study-area description.

The U.S. Environmental Protection Agency (USEPA) has established Maximum Contaminant Levels (MCL) and Secondary Maximum Contaminant Levels (SMCL) for which samples were analyzed in this study. Water from the 38 wells sampled by the USGS did not exceed the SMCL or MCL for sulfate, fluoride, or nitrite. However, water from 26 wells exceeded the SMCL for iron, water from 12 wells exceeded the SMCL for manganese, and water from 12 wells exceeded the SMCL

for dissolved solids. Water from two wells exceeded the MCL for nitrate, although nitrate concentrations in water from most wells was below the detection limit. Water from seven wells exceeded the SMCL for chloride, and water from all wells contained detectable concentrations of chloride. Water from five wells exceeded the MCL for arsenic, and most of the wells sampled contained detectable concentrations of arsenic. These five wells were identified from previous MDEQ analyses to have elevated arsenic concentrations, and were sampled to obtain additional chemistry information. Replicate samples were collected from 26 of the 38 wells for analysis at the MDEQ Drinking-Water Laboratory to compare the results with the USGS National Water Quality Laboratory. The results of the replicate analyses indicate close agreement between the laboratories, with mean differences for nitrate, chloride, and arsenic of 0.10 milligrams per liter (mg/L) as nitrogen, 6.8 mg/L, and 0.0008 mg/L, respectively between the USGS and MDEQ analyses. Potential health effects associated with ingesting nitrate, chloride, and arsenic are provided with the water-quality data, along with references for further information.

## INTRODUCTION

In 1996, the U.S. Geological Survey (USGS), in cooperation with the Michigan Department of Environmental Quality (MDEQ), the University of Michigan, and nine counties in southeastern Michigan, began a

study of the occurrence and distribution of arsenic in ground water in southeastern Michigan. The early results of this study raised broader concerns in Oakland County about the quality of ground water used for drinking water. In response to these concerns, the USGS, in cooperation with the Oakland County Health Division (OCHD) initiated a study of distributions of arsenic, nitrate, and chloride in ground water in Oakland County. A series of USGS Fact Sheets were produced in December 1998 to present maps and information to residents of Oakland County about the distribution and potential health effects of these chemicals in ground water.

Understanding the distribution of these chemicals required the compilation of several supporting data sets describing the geologic and hydrologic setting of Oakland County. These data sets are presented in the first part of this report. Water samples from 38 wells across Oakland County were analyzed for arsenic, nitrate, chloride, and more than 20 additional physical and chemical characteristics. Complete analytical results are provided in Appendix 1. A comparison of analytical results from the USGS National Water-Quality Laboratory (NWQL) and the MDEQ Drinking Water Laboratory is presented in Appendix 2.

### **Purpose and Scope**

This report provides information on the distribution of arsenic, nitrate and chloride in ground water in Oakland County and the potential health effects of each chemical. Analytical results are presented for water samples collected by the USGS in Oakland County in 1998, as well as several supporting spatial databases describing the demographic, geologic, and hydrologic context of Oakland County. This report also provides several maps, generated by the Center for Applied Environmental Research at the University of

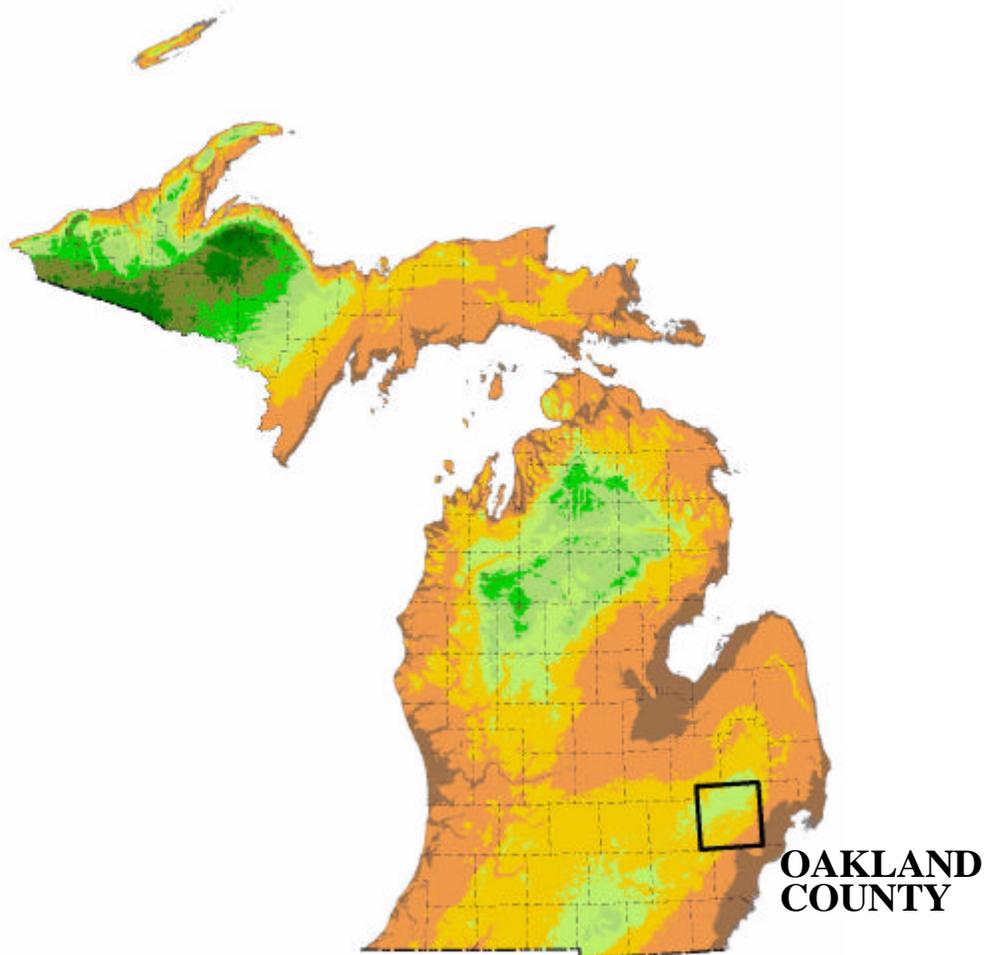
Michigan-Flint (CAER) from information in MDEQ databases, to describe the occurrence of arsenic, nitrate, and chloride in ground water.

### **Acknowledgments**

The author gratefully acknowledges the assistance of Dr. Thomas Gordon, Robert Long, and Karen Kubik of Oakland County Health and Human Services in obtaining historical data, coordinating access to sample sites, and providing background information for interpreting the water-quality data. Scott Oppmann and Brian Ely of the Oakland County GIS Utility provided digital base map data with municipal boundaries. Dr. Richard Hill-Rowley and Matt Malone of CAER provided assistance with validating and geocoding the MDEQ database, as well as with strategies for mapping the data at the county scale. Thomas McClain of the CAER mapped the elevation of the water-table surface.

## **STUDY-AREA DESCRIPTION – OAKLAND COUNTY, MICHIGAN**

A variety of spatial databases were generated or modified for use in this study, and are presented in the next several pages to provide a context for the study. Included are descriptions of the glacial geology, soils, surface- and ground-water resources, as well as summary information about water-use, population growth, and land-use change in Oakland County. Oakland County, with a land area of 900 square miles, contains 25 survey townships and is the largest county in the Lower Peninsula of Michigan. With more than 1.2 million residents, Oakland County is the second most populous county in Michigan.



## Population Growth and Land-Use Change

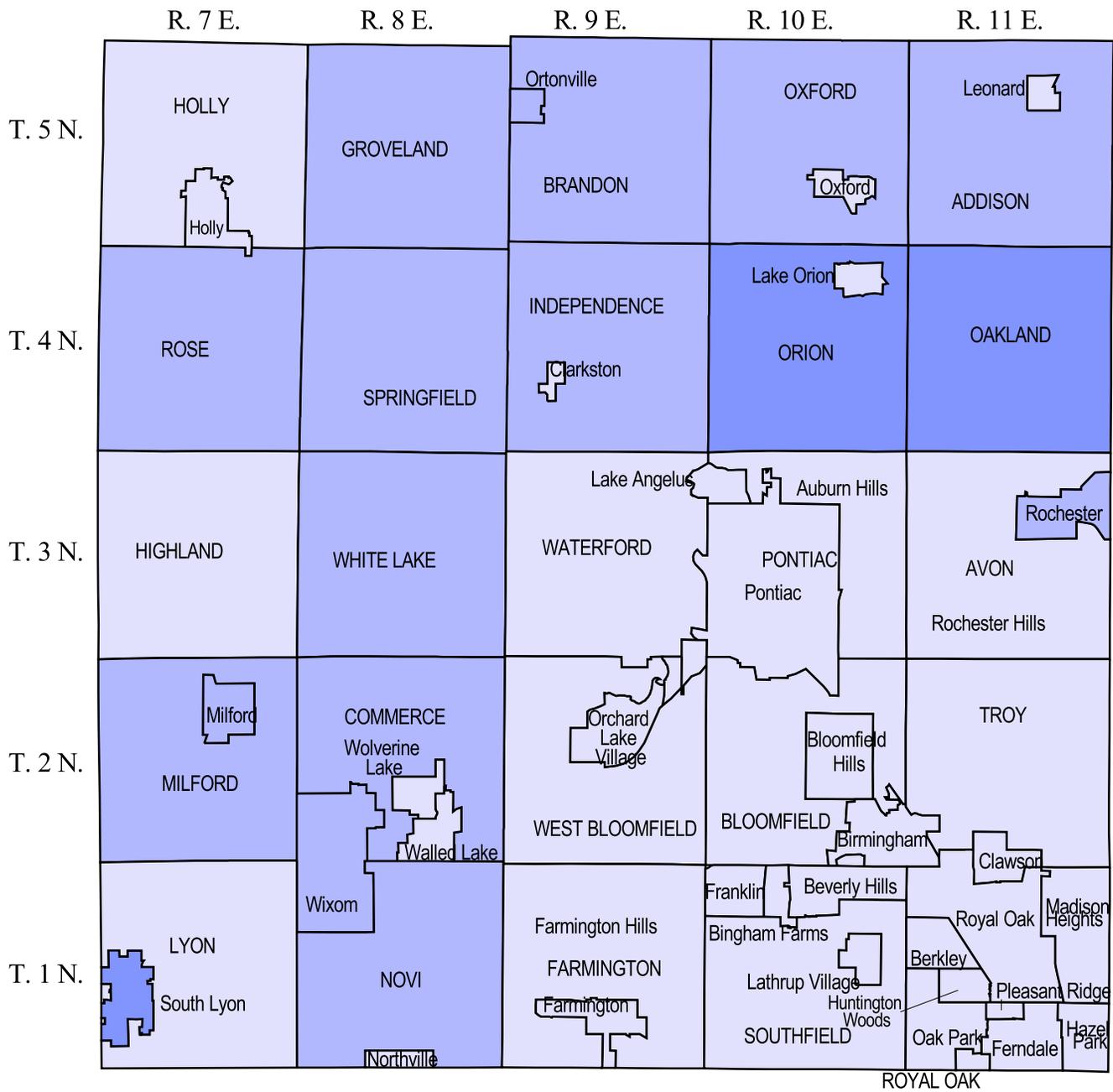
Oakland County has grown dramatically in the last several decades. The Southeast Michigan Council of Governments (SEMCOG) provides estimates of actual population based on information from county and local governments to supplement Census data. The population has increased from about 700,000 in 1960 to nearly 1.2 million in 1998. The rate of population growth has been relatively consistent, with the population increasing by more than 100,000 people per decade. Population growth has not been spatially uniform (fig. 1). Population growth between 1990 and 1998 has exceeded 60 percent in some municipalities, and has exceeded 20 percent in 18 of 58 minor civil divisions (Southeast Michigan Council of Governments, 1999).

The expansion of residential areas resulting from the increase in population has resulted in marked changes in land use. A comparison of land-use data compiled by the Michigan Department of Natural Resources (1978) and SEMCOG data compiled in 1995 indicates an increase in urban land use, primarily residential, accompanied by decreases in agricultural land, pasture land, and forest land (table 1). While some of these differences may be because of differences in the methods of compilation between agencies (specifically identification of wetlands in the 'Other' category), the trend is toward increasing allocation of land for urban use, with decreasing allocation for agriculture, forest, and pasture.

**Table 1.** Land use in Oakland County as a percentage of total county area, 1978 and 1995

Land use	1995 (percent)	1978 (percent)
Urban	48.7	39.3
Agriculture	11.7	15.0
Pasture	16.2	21.3
Forest	8.4	13.7
Other	15.0	10.7

The effects of human activities on water resources, whether ground water or surface water, are complex (Winter and others, 1998). The increased proportion of the county devoted to urban and residential land uses is accompanied by more wells that extract water, more impervious surfaces that block or redirect recharge, and more storm drains that divert precipitation into streams instead of aquifers. Over time, this can alter the availability and quality of hydrologic resources, both ground water and surface water, in Oakland County. Modifications in land use may also affect the proportions of ground water and surface runoff in rivers and streams, which can affect the chemistry, temperature, and general quality of the water for wildlife and for recreation. The need to better understand how the increased use of water for agriculture, recreation, and residential household uses affects ground-water and surface-water resources will surely increase as development intensifies (Winter and others, 1998).



Source:  
Population data provided by Southeast Michigan Council of Governments (1999).

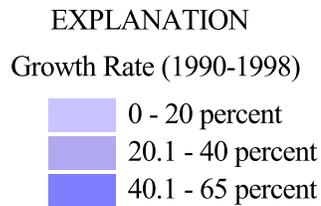
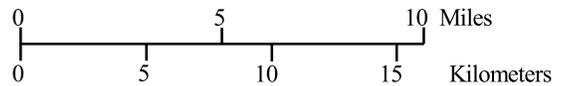


Figure 1. Rate of population growth in Oakland County, Michigan, from 1990 through 1998.

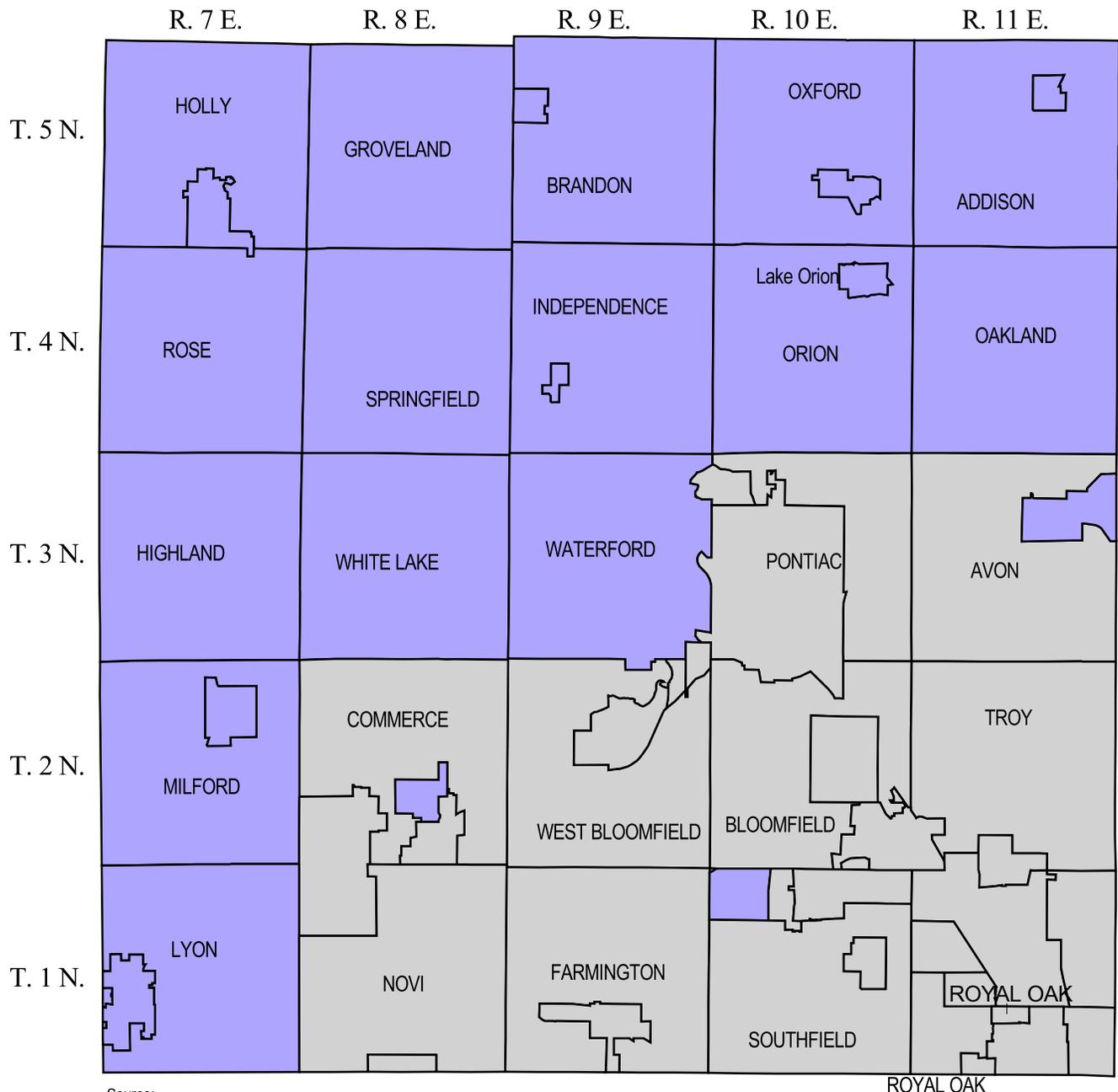
## Water Supply

Most of Oakland County is served by public water supplies. These supplies are subject to regulation by Federal, State, and other authorities to ensure the water produced meets public health standards. The Detroit Water and Sewerage Department (DWSD) provides 137 million gallons per day (MGD) of water to the southeastern townships of Avon (Rochester Hills), Pontiac, Troy, Bloomfield, West Bloomfield, Royal Oak, Southfield, Farmington, Novi and Commerce (fig. 2). Several additional mains have been constructed to provide water to adjoining areas. Water provided by DWSD is drawn from Lake Huron and Lake St. Clair, as well as the St. Clair River and Detroit River.

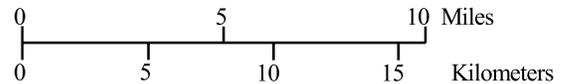
More than 140 smaller community supplies use ground-water resources to provide 21.4 MGD to more than 160,000 residents (C. Luukkonen, USGS, written commun., 1999). The communities served by these supplies range in size from Waterford Township, with a population of more than 70,000 (Southeast Michigan Council of Governments, 1999), to individual subdivisions, with only a few homes. More than 233,000 Oakland County residents are not connected to public water supplies, but obtain water from domestic wells. These withdrawals amount to approximately 16.7 MGD (C. Luukkonen, USGS, written commun., 1999). Domestic wells are not currently monitored by any governmental agency, and are the responsibility of the owner.



*Interior of a community water supply pump house in Oakland County, Michigan. Community water supplies like this one provide water to over 160,000 residents.*



Source:  
Water supply information obtained in consultation with Oakland  
County Health Division and local suppliers.



EXPLANATION

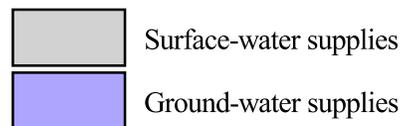


Figure 2. Principal sources of drinking water, by municipality, in Oakland County, Michigan in 1999. Sources of drinking water for individual structures or uses may vary.

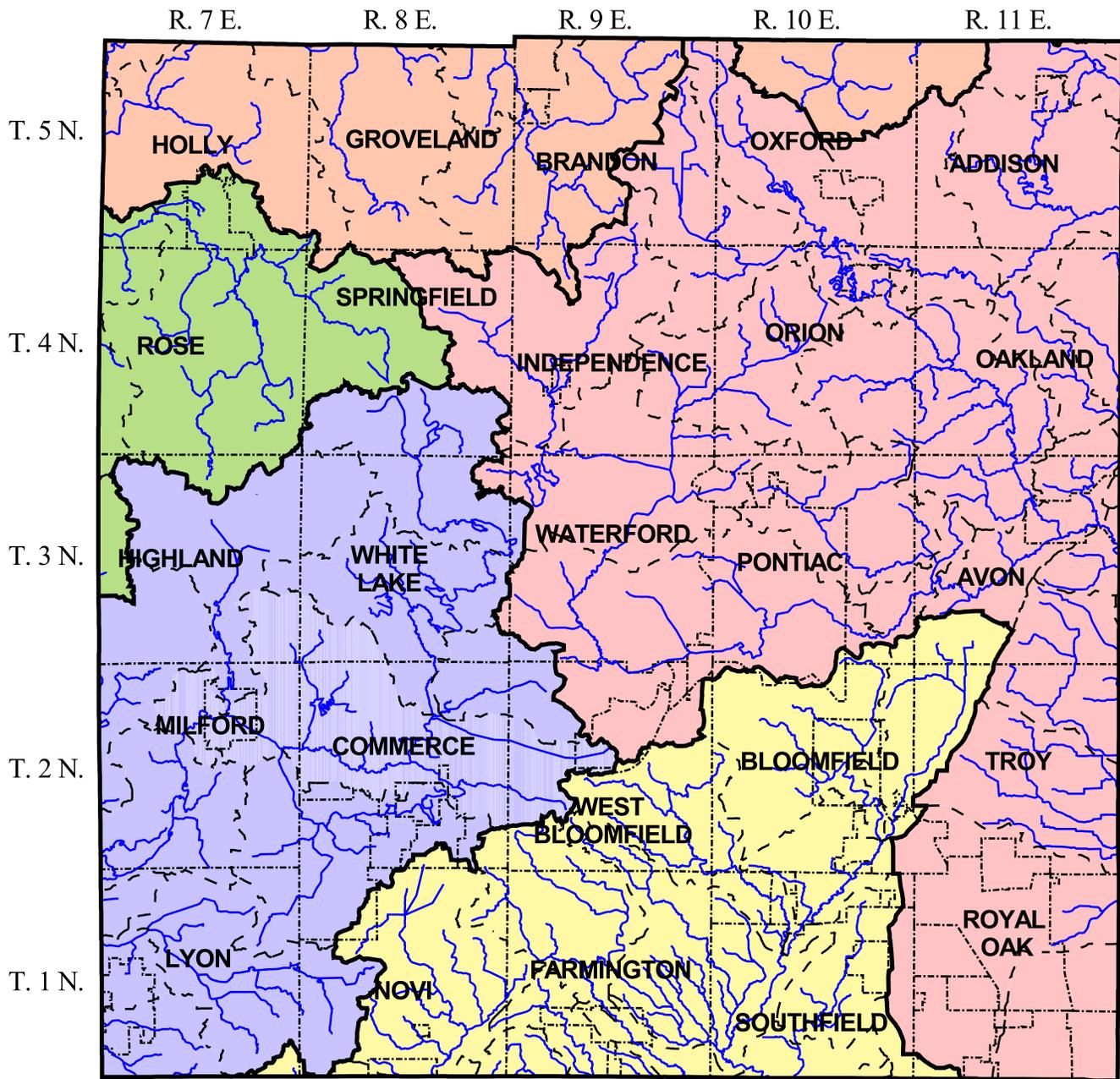
## Surface-Water Resources

Surface-water resources abound in Oakland County. More than 1,600 lakes of varying sizes were recorded in a 1958 inventory (Humphrys, 1962). A substantial number of these lakes are large enough for recreational use, such as boating, swimming, and fishing. Most of these lakes receive water from ground water most of the year (Mozola, 1954).

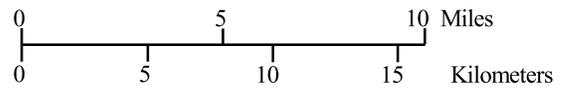
Oakland County spans the headwaters of six major rivers (fig. 3). The Shiawassee and Flint Rivers drain the northwestern part of the County, eventually joining the Saginaw River to flow into Lake Huron. The Huron River drains the southwestern part of the county, delivering the water to Lake Erie. The Clinton River in the north and the River Rouge in the south drain the central and southeastern parts of the county into Lake St. Clair and the Detroit River. The Belle River drains a very small area (less than 1 sq. mi.) of Addison Township. More than half of the water flowing in these rivers over the course of a year is groundwater discharge to the river through the streambed (Holtschlag and Nicholas, 1998).



*The 1,600 lakes in Oakland County are important hydrologic and recreational resources.*



Source:  
 Municipal boundaries provided by Oakland County GIS Utility.  
 Hydrologic divides from MDEQ Land and Water Management.  
 Hydrologic features from MiRIS.



**EXPLANATION**

Drainage basins

- Drainage to Clinton River
- Drainage to Huron River
- Drainage to River Rouge
- Drainage to Flint River
- Drainage to Shiawassee River
- Rivers and streams
- Municipal boundaries
- Sub-watershed divides



Figure 3. Surface-water drainage basins of Oakland County, Michigan. Drainage to Belle River not shown due to scale constraints.

## **Surficial Geology**

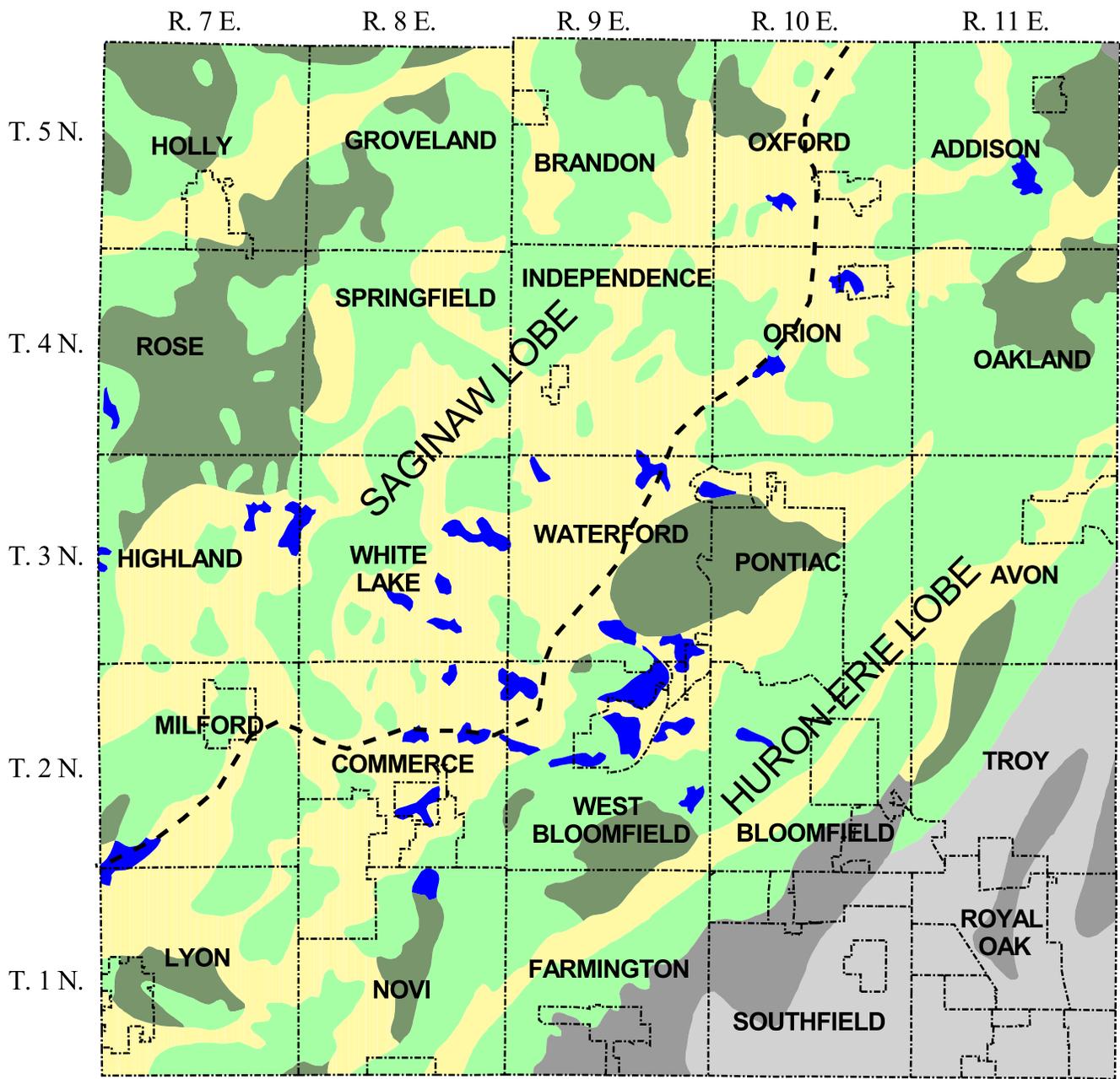
Nearly all of the hills and lakes in Oakland County were formed during the retreat of the last continental glacier, approximately 14,000 years ago (Winters and others, 1985). For the preceding 60,000 years, the area that is now Oakland County was intermittently covered by as much as a mile of ice. During the retreat of the ice, an ice-free area formed between the Saginaw Lobe in the northern part of the county and the Huron-Erie Lobe to the south (fig. 4), the axis of which tracks through Commerce, Waterford, and Oxford (Leverett and Taylor, 1915; Winters and others, 1985). This area formed a conduit for large quantities of water and sediment flowing off the melting glacier, known as outwash. Outwash environments deposit sorted sediments, so that materials of a certain size and composition are layered vertically and are exposed together on the landscape. A broad outwash plain (shown in yellow in figure 4) stretches across central Oakland County from northeast to southwest.

On either edge of the outwash plain region are areas of moraine and other types of till (shown in green hues in figure 4), deposited directly by the ice at the margins of the glacial lobes. The materials in these features are unsorted, and include clays, sands, pebbles, and boulders. These areas usually have much higher clay fractions than the outwash plain region, which results in lower permeability.

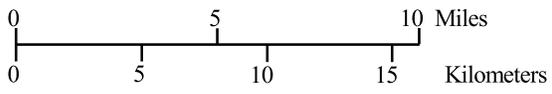
Following the retreat of the ice back to the Great Lakes basins, large lakes formed from meltwater occurred at much higher elevations than the current elevations of the Great Lakes (Eschman and Karrow, 1985). The beds of these lakes collected clays and other sediments in broad blankets. The highest of these lakes in the Huron-Erie basin was Lake Maumee, which maintained an elevation between 775 and 810 ft above sea level (covering much of southeastern Oakland County) for a period of approximately 300 years starting 14,000 years ago (Eschman and Karrow, 1985). The beds of these proglacial lakes are evident in the flat-lying, clay-rich sediments of southeastern Oakland County (shown in gray tones in figure 4). These clay-rich sediments have dramatically lower permeability than the outwash sediments.

The thickness of these glacial materials vary greatly across the county. The thickness of the surficial sediments exceeds 400 feet across the central part of the county, but can be less than 100 feet in the southeast and northwest corners (Twenter and Knutilla, 1972). Throughout most of the county, the surficial deposits are the primary aquifer. Fewer than 3 percent of the wells in the county's WELLKEY database are completed in bedrock.

The underlying bedrock units throughout most of the county are not considered good sources of potable water, and water drawn from these units is frequently high in sulfate, iron, chloride, and dissolved solids. The Marshall Sandstone is a productive bedrock aquifer for the northwestern townships of Holly, Groveland, Brandon, and Rose. Even in this area, the vast majority of wells are completed in the glacial sediments.



Source:  
 Geologic information modified from Ferrand and Bell(1982).  
 Interlobate divide modified from Winters and others (1985).



EXPLANATION

- Glacial till
- End moraines of glacial till
- Glacial outwash sand and gravel
- Lacustrine clay and silt
- Lacustrine sand and gravel
- Lakes
- Municipal boundaries
- Interlobate divide



Figure 4: Surficial geology of Oakland County, Michigan.

## Soils

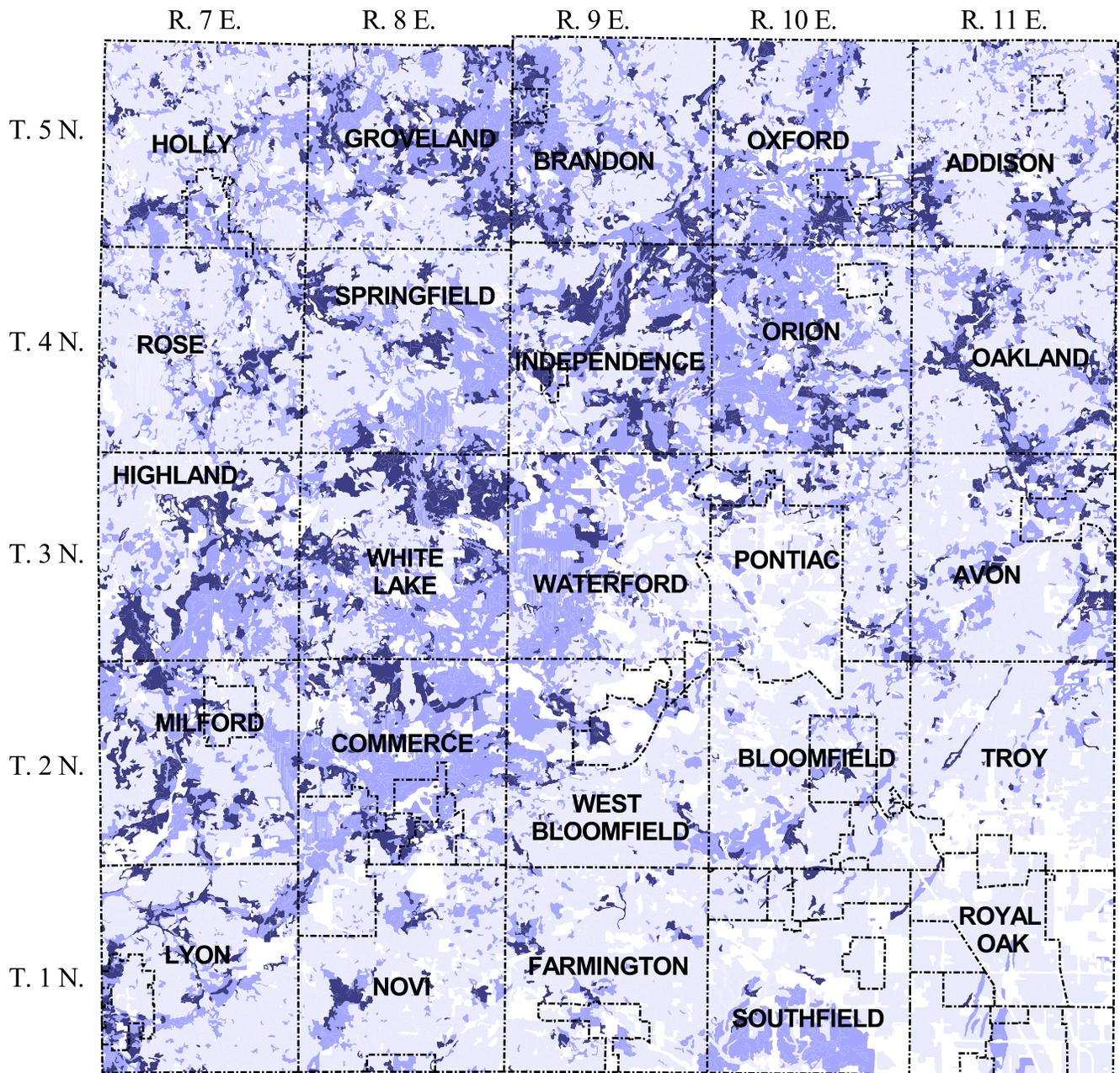
The soils of Oakland County are the direct result of the surficial geologic processes previously described. Physical and chemical characteristics reported by the Soil Conservation Service (1982) show patterns similar to the surficial geology map shown previously.

Minimum soil permeability, for example, ranges over two orders of magnitude, from 0.06 inches/hour (in/hr) to 20 in/hr. The region with minimum infiltration rates of 6 in/hr or greater closely resembles the region mapped as outwash (fig. 5). Infiltration rates directly affect the amount of recharge, and thus the potential for transport of contaminants into an aquifer. The lowest permeability soils correspond spatially to till and lake-bed sediments. High permeability, sandy soils have been widely identified as being susceptible to contamination by anthropogenic pollutants, such as nitrate (Kittleson, 1987; Fetter, 1994).

The chemical properties of the soils also reflect the surficial geologic processes. The highest concentrations of calcium carbonate in the soil are generally clustered in regions formed of till. Calcium carbonate concentrations are generally lower in the outwash plain region located in the central part of the county. Bicarbonate ( $\text{HCO}_3^-$ ), an ion formed when calcium carbonate is dissolved by infiltrating water, has been shown to encourage the dissolution of arsenic (Kim, 1999).



*The top several feet of soil contain different layers called horizons. The permeability of these horizons controls how quickly water and potential contaminants are transported into aquifers. (Photo courtesy of R.J. Schaetzl.)*



Sources:  
Soils information provided by Soil Conservation Service (1982).

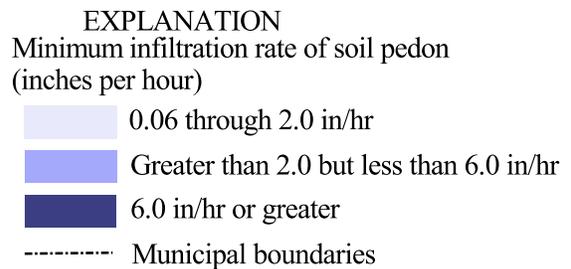
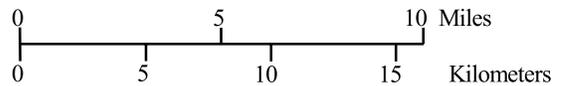


Figure 5. Minimum soil permeability rates in Oakland County, Michigan.

## Ground-Water Resources

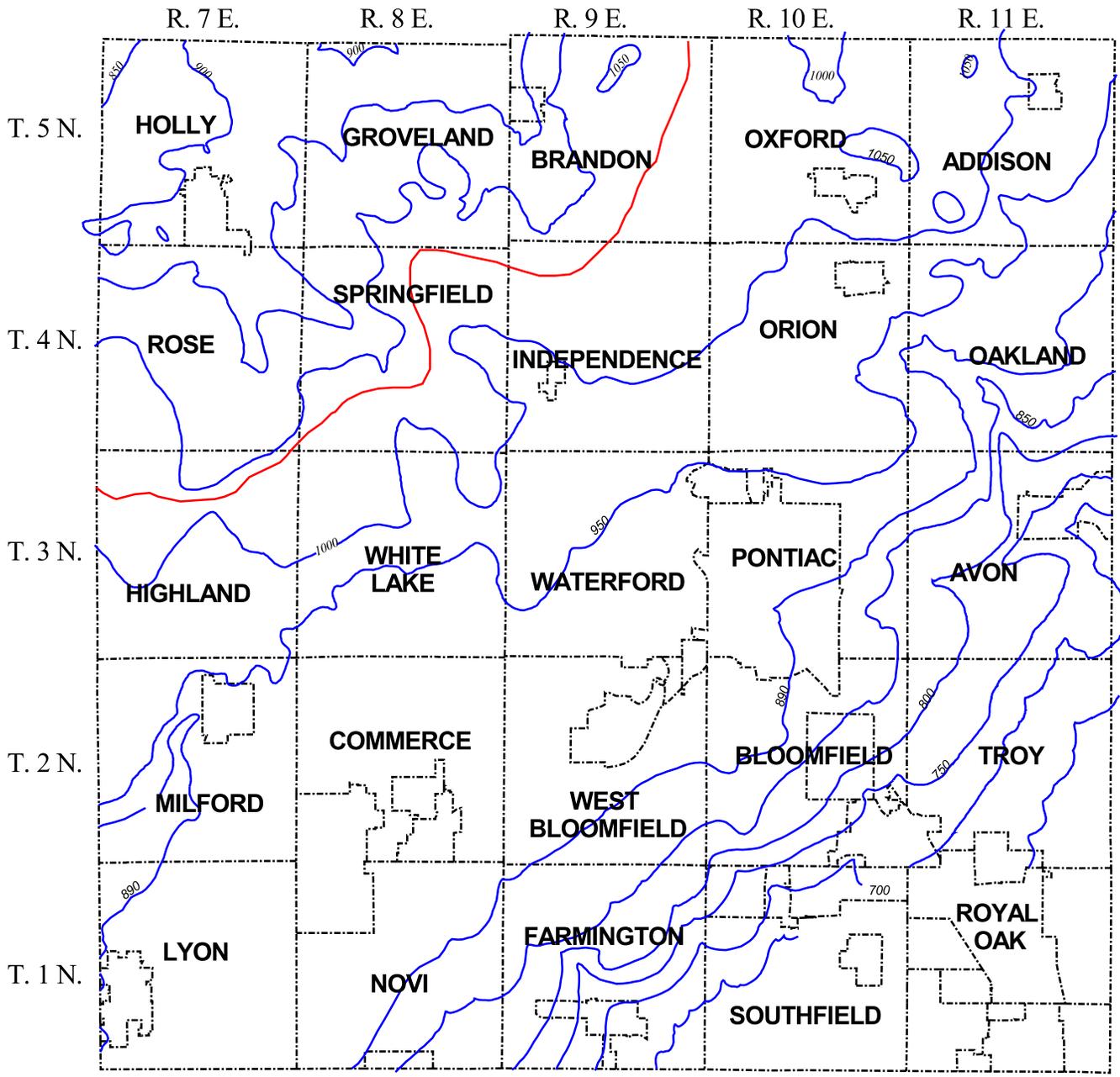
The CAER developed a map of ground-water levels in Oakland County (fig. 6), derived from the elevations of rivers and lakes and the elevations of ground water in the glacial aquifer. Ground-water elevations were obtained from drillers' logs and Oakland County's WELLKEY database. Because the drillers' logs were collected over a period of several decades, the derived surface represents an approximation over time, rather than a specific time.

In general, the configuration of the water table is a subdued version of the landscape topography. Accordingly, the water-level map developed by the CAER shows a region of higher water levels along the northern edge of the outwash plain region, corresponding to the part of Oakland County where the land surface is highest. The high region in the water table surface forms a ground-water-flow divide. Northwest of this divide, ground water generally flows towards Saginaw Bay. Southeast of this divide, ground water generally flows toward Lake Erie and Lake St. Clair.

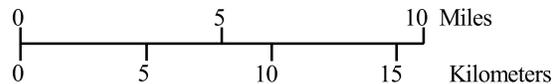
This map represents the water levels in the glacial aquifer only. Evaluation of Oakland County's WELLKEY database indicates more than 97 percent (8,458 of 8,654) of the wells in the database are completed in the glacial aquifer. Several examples of confined aquifers and artesian wells have been noted by authors in the past (Mozola, 1954; Leverett and others, 1906). In these regions, water within these confined systems may be under pressure, and would rise to a different level than the level portrayed in figure 6.



*Domestic wells like this one provide drinking water to more than 233,000 Oakland County residents.*



Source:  
Elevation contours and flow divide produced  
by the Center for Applied Environmental  
Research at the University of Michigan - Flint.



EXPLANATION

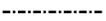
-  Water-table contour. Elevation in feet above sea level. Contour interval 50 feet.
-  Municipal boundary
-  Ground-water flow divide

Figure 6. Elevation of the water-table surface in Oakland County, Michigan.

## Sites of USGS Ground-Water-Quality Sampling

The USGS collected water samples from 68 wells in Oakland County in 1997 and 1998 (fig 7). Thirty of these wells were sampled as part of ongoing USGS activities. The results of these analyses are presented in Blumer and others (1998).

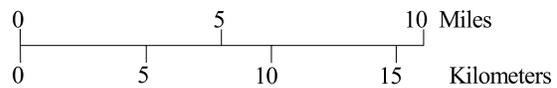
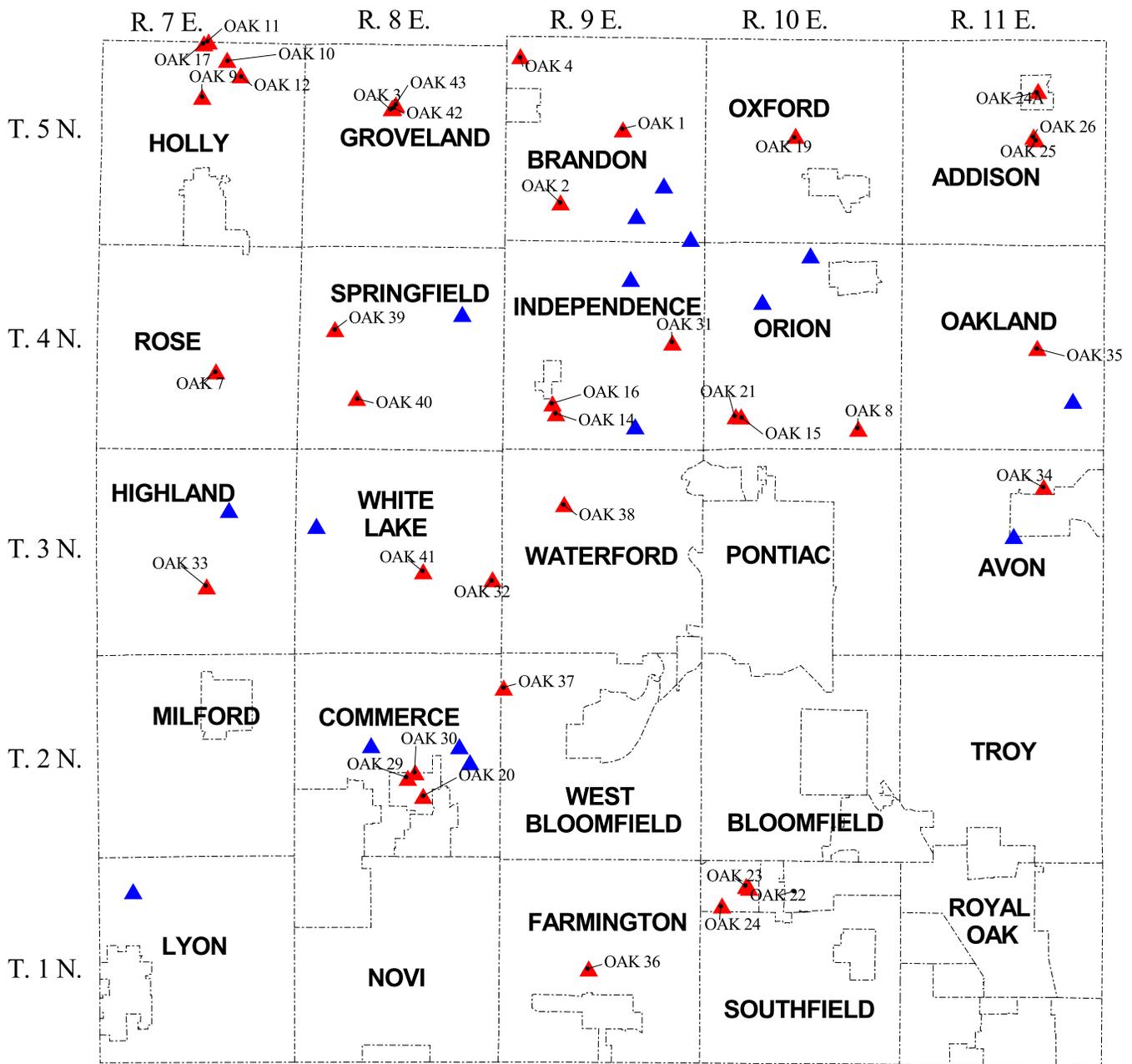
Thirty-eight wells were sampled specifically for this project between June and December 1998. These wells were selected for several reasons. All selected wells had a previous water quality analysis in the Michigan Department of Environmental Quality (MDEQ) database. The water from approximately half of these wells had exceeded at least one U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) or Secondary MCL (SMCL) on at least one occasion. Additional wells with previous water chemistry information and lower concentrations of the chemical constituents of concern were selected in the vicinity of the wells with exceedances of the regulatory contaminant levels.

All but six of the wells selected for sampling were privately owned domestic water wells supplying a single-family dwelling. Two of the selected wells supplied water to institutions, one to a restaurant, one to a car wash, one to a community water supply, and one to a government building. Well depths, obtained from well construction logs when available, are included in appendix table 1C.

Two additional sets of samples were collected in December 1998. Each set included samples from five wells, which were selected on the basis of results of previous USGS and MDEQ water-quality analyses. These samples were collected to evaluate possible short- and long-term variation in water quality.



*Sampling equipment in use outside a community water supply well in Oakland County, Michigan.*



**EXPLANATION**

- ▲ USGS ground-water sampling sites used for this study
- ▲ Ongoing USGS ground-water sampling sites
- Municipal boundaries

Figure 7. Sites of U.S. Geological Survey ground-water-quality sampling in Oakland County, Michigan.

## GROUND-WATER QUALITY

The ground-water quality investigation in Oakland County included field analysis of physical characteristics, as well as laboratory analysis for nutrients, major inorganic ions, and selected trace metals. A brief discussion of the methods and results of each type of analysis will be presented, along with a table of summary statistics. The complete results are provided in table 1C of Appendix 1. More detailed discussions of the geochemistry and the potential health effects of nitrate and arsenic are included to assist Oakland County and local governments in water-resource management issues specific to these chemicals.

### Sample collection and analysis

All samples were collected using the clean sampling procedures specified by the USGS National Water-Quality Assessment (NAWQA) program (Shelton, 1994). Unsoftened water samples were collected from domestic wells by connecting to external, garden hose taps. All tubing used in sample collection was Teflon-lined, with high-density poly-ethylene (HDPE) or Teflon fittings and connectors. Physical characteristics (temperature, specific conductance, dissolved oxygen, pH, eH) were measured at the well-site with a Hydrolab H20 connected in-line through a flow-through cell. Before a ground-water sample was collected for laboratory analysis, wells were purged for a period of at least 20 minutes until the above field characteristics had stabilized. Stability was determined on the basis of the following criteria; specific conductance variation less than 2  $\mu\text{S}/\text{cm}$ , pH variation less than 0.05 pH units, dissolved oxygen variation less than 0.05 mg/L, and a temperature variation of less than 1°C. Alkalinity titrations were performed on filtered samples in the field.

All wells were sampled for analysis of major cations, major anions, nutrients, and arsenic. A complete list of laboratory analyses is included in table 2. The USGS National Water Quality Laboratory (NWQL) in Arvada, Colorado performed all analyses listed in table 2.

At 26 sites, replicate samples were collected for analysis by the MDEQ. These samples were collected to examine the comparability of MDEQ analytical results for arsenic, nitrate, and chloride

to results from the USGS NWQL. The MDEQ laboratory uses an inductively coupled plasma mass spectrometry (ICPMS) method for arsenic analyses (MRL = 0.0001 mg/L), and colorimetric methods for nitrate (MRL = 0.4 mg/L) and chloride (MRL = 4 mg/L) analyses.

Five wells were selected to provide information on long-term seasonal variations in ground-water quality. These wells were sampled using methods identical to those described previously for the collection of ground-water-quality samples.

Five wells were sampled to evaluate short-term (0 - 25 minutes) variations in chemical composition of drinking water. Operationally, drinking water is distinguished from ground water by the fact that the well and plumbing system are not purged before sample collection. The sample is thus reflective of what a resident might consume if simply getting a glass of water. Sampling procedures were designed to evaluate potential changes in concentrations of arsenic, manganese, and iron within a domestic plumbing system. Four wells were selected on the basis of detection of arsenic, manganese, and iron in samples analyzed at the NWQL. One well, OAK 41, was added to this sample group because of extensive prior data on record at MDEQ. At wells selected for the short-interval, time-series sample collection, unfiltered samples were collected at intervals ranging from 30 seconds to 2 minutes for the first 20 to 25 minutes of well pumping. Wells were not purged prior to collecting the first sample. These samples were analyzed for total arsenic using a flame atomic absorption method (Brown, 1998). Manganese and iron were analyzed using an ICPMS method (Garbarino and Struzeski, 1998).

### Field-Measured Characteristics

Temperature, specific conductance, oxidation-reduction potential (eH), dissolved oxygen (DO), pH, and alkalinity were measured in the field. Results of these analyses are shown in appendix table 1B. No health standards exist for any of these constituents, but the USEPA has issued a Secondary Maximum Contaminant Level for pH based on aesthetic considerations.

**Table 2:** Water quality characteristics analyzed by the USGS National Water Quality Laboratory [µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter]

Parameter name	Units	MRL	Parameter code	Method	Reference
Specific Conductance	µS/cm	1	90095	I278185	Fishman and Friedman, 1989
pH, Laboratory	Standard Units	0.1	403	I258785	Fishman and Friedman, 1989
Total Residue @ 180 °C	mg/L	1	530	I376585	Fishman and Friedman, 1989
Calcium, dissolved	mg/L as Ca	0.02	915	I147287	Fishman and Friedman, 1989
Magnesium, dissolved	mg/L as Mg	0.004	925	I147287	Fishman, 1993
Sodium, dissolved	mg/L as Na	0.06	930	I147287	Fishman, 1993
Potassium, dissolved	mg/L as K	0.1	935	I163085	Fishman and Friedman, 1989
Acid Neutralizing Capacity	mg/L as CaCO <sub>3</sub>	1.0	90410	I203085	Fishman and Friedman, 1989
Sulfate, dissolved	mg/L as SO <sub>4</sub>	0.1	945	I205785	Fishman and Friedman, 1989
Chloride, dissolved	mg/L as Cl	0.1	940	I205785	Fishman and Friedman, 1989
Flouride , dissolved	mg/L as F	0.1	950	I232785	Fishman and Friedman, 1989
Bromide, dissolved	mg/L as Br	0.01	71870	I212985	Fishman and Friedman, 1989
Silica , dissolved	mg/L as SiO <sub>2</sub>	0.1	955	I270085	Fishman and Friedman, 1989
Residue, dissolved 180°C	mg/L	10	70300	I175085	Fishman and Friedman, 1989
Nitrogen, Ammonia, dissolved	mg/L as N	0.02	608	I252290	Fishman, 1993
Nitrogen, Nitrite, dissolved	mg/L as N	0.01	613	I254090	Fishman, 1993
Nitrogen, Ammonia + Organic	mg/L as N	0.1	623	I261091	Patton and Truitt, 1992
Nitrogen, Nitrite + Nitrate, dissolved	mg/L as N	0.05	631	I254590	Fishman, 1993
Phosphorus, total	mg/L as P	0.05	665	I461091	Patton and Truitt, 1992
Phosphorus, dissolved	mg/L as P	0.004	666	EPA 365.1	U.S.EPA, 1993
Phosphorus, Orthophosphate	mg/L as P	0.01	671	I260190	Fishman, 1993
Arsenic, total*	mg/L as As	.001	1002	I406398	Brown, 1998
Arsenic, total, EPA	mg/L as As	.001	1002D	EPA 200.9	U.S.EPA, 1993
Iron, total*	mg/L as Fe	.014	1045	I447197	Garberino and Struzeski, 1998
Iron, dissolved	mg/L as Fe	.01	1046	I147287	Fishman, 1993
Manganese, total*	mg/L as Mn	.003	1055	I447197	Garberino and Struzeski, 1998
Manganese, dissolved	mg/L as Mn	.003	1056	I147287	Fishman, 1993

\* denotes method used for short-interval, time-series sample analysis.

The temperature of water pumped from wells during sampling ranged from 10.4°C to 15.5°C, with a mean of 12°C (approximately 54°F). The annual average daily air temperature for the Pontiac area is between 9 and 10°C (Soil Conservation Service, 1982). Ground-water temperatures are usually 1 to 2°C higher than the mean annual air temperature (Todd, 1980).

The concentration of dissolved solids in water can be approximated in the field by measuring the specific conductance of a sample (Hem, 1985). Fresh water is usually considered to be water containing less than 1,000 mg/L total dissolved solids (Drever, 1988). The USEPA SMCL for dissolved solids is 500 mg/L. On the basis of data collected in this study, the total dissolved solids concentration in ground water in Oakland County [in milligrams per liter (mg/L)] is typically about 58 percent of the specific conductance [measured in microsiemens/centimeter ( $\mu\text{S}/\text{cm}$ )]. Thus, the threshold between fresh and brackish water in Oakland County would be represented by a specific conductance of approximately 1,800  $\mu\text{S}/\text{cm}$ , and the USEPA's SMCL would be represented by a specific conductance of approximately 900  $\mu\text{S}/\text{cm}$ . The specific conductance of ground water used for drinking in Oakland County ranged from 395 to 2,950  $\mu\text{S}/\text{cm}$ , with a mean value of 925  $\mu\text{S}/\text{cm}$ .

Dissolved oxygen concentrations ranged between <0.1 and 7.8 mg/L, with a mean of 0.8 mg/L. In Michigan, the presence of DO in concentrations higher than 1.0 mg/L is typically associated with recently recharged, and usually shallow, ground water. The concentration of dissolved oxygen in the water, along with the oxidation-reduction potential (redox), controls the chemical and microbial reactions that can occur in ground water.

The pH of ground water in Oakland County varies between 6.5 and 7.6, with a mean of 7.1. Most ground water in the United States falls in the range of 6.0 to 8.5 (Hem, 1985). The USEPA SMCL for pH specifies pH should fall between 6.5 and 8.0.

The redox potential of Oakland County ground water ranged from -25mV to 876mV. The redox potential is not directly related to any health effects; rather, it is monitored as an indication of whether the subsurface environment is conducive to removing electrons from materials (high eH) or adding electrons to material (low eH). Higher eH values are often found in recently recharged waters, while lower eH values are found in older waters that have been

exposed to more organic matter, carbonates, or bacteria (Drever, 1988). The redox potential of water is an important control on geochemical processes, and the determination of eH can indicate which ions are likely to be mobile in the system. The measurements included in appendix table 1B and elsewhere are approximate, based on results from an electrode measurement, rather than direct measurement of different species of the same ion.

The alkalinity of ground water in Oakland County ranged from 214 to 462 mg/L as  $\text{CaCO}_3^-$ . Alkalinity is a measure of the acid neutralizing ability of a sample, which can be the result of several ions in solution. In the pH ranges described above, the principal ion responsible for alkalinity is bicarbonate,  $\text{HCO}_3^-$  (Hem, 1985). Like the redox potential, alkalinity is an indicator of the state of the geochemical system, and aids in the interpretation of other chemical constituents.

### Inorganic Chemical Constituents

The USEPA has set drinking-water MCLs and SMCLs for several inorganic constituents analyzed in this study. These constituents, the USEPA threshold, and the type of threshold are shown in table 3 (U.S. Environmental Protection Agency, 1996). A complete list of inorganic chemistry analyses can be found in appendix table 1C. A summary of results for each inorganic constituent are shown in table 4.

**Table 3.** Inorganic constituents analyzed in this study with USEPA Drinking Water Standards [mg/L, milligrams per liter; MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level]

Constituent	Limit	Units	Standard type
Nitrite	1	mg/L as N	MCL
Nitrate	10	mg/L as N	MCL
Chloride	250	mg/L as Cl	SMCL
Sulfate	250	mg/L as $\text{SO}_4^-$	SMCL
Flouride	4	mg/L as F	SMCL
Arsenic	.05	mg/L as As	MCL
Iron	.3	mg/L as Fe	SMCL
Manganese	.05	mg/L as Mn	SMCL
Total Dissolved Solids	500	mg/L	SMCL

**Table 4:** Summary statistics for selected inorganic constituents detected in water samples from selected wells in Oakland County, Michigan  
[mg/L, milligrams per liter;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius;  $^{\circ}\text{C}$ , degree Celsius]

Constituent	Maximum	Minimum	Mean	Median
Laboratory pH (Standard Units)	7.9	7.1	7.42	7.43
Nitrogen, Ammonia (mg/L as N)	1.4	<.02	.19	.14
Nitrogen, Nitrite (mg/L as N)	.1	<.01	.01	<.01
Nitrogen, Ammonia + Organic (mg/L as N)	1.52	<.01	.22	.15
Nitrogen, Nitrate + Nitrite, dissolved (mg/L as N)	23.9	<.05	.90	<.05
Phosphorus, dissolved (mg/L as P)	.5	<.004	.02	<.004
Phosphorus, ortho (mg/L as P)	.5	<.01	.02	<.01
Calcium, dissolved (mg/L as Ca)	175	0.15	79.3	76.2
Magnesium, dissolved (mg/L as Mg)	57.7	0.02	29.0	27.5
Sodium, dissolved (mg/L as Na)	431	3.73	66.0	22.8
Potassium, dissolved (mg/L as K)	13	0.1	2.1	1.7
Chloride, dissolved (mg/L as Cl)	661	0.48	103.	23.3
Sulfate, dissolved (mg/L as $\text{SO}_4^-$ )	80.7	1.26	29.8	18.5
Fluoride, dissolved (mg/L as F)	1.1	<.1	0.4	0.2
Silica, dissolved (mg/L as $\text{SiO}_2$ )	23.0	9.25	14.7	14.3
Arsenic, total (mg/L as As)	.176	<.001	.021	.003
Iron, dissolved (mg/L as Fe)	3.58	<.014	1.09	.927
Manganese, dissolved (mg/L as Mn)	.330	<.003	.055	.032
Dissolved Residue of Evaporation, 180 $^{\circ}\text{C}$ (mg/L)	1620	228	529	387
Bromide, dissolved (mg/L as Br)	5.5	.01	.24	.06
Specific Conductance, ( $\mu\text{S}/\text{cm}$ at 25 $^{\circ}\text{C}$ )	2950	408	913	640

None of the samples contained concentrations of sulfate or fluoride in excess of the SMCL. Samples from two wells exceeded the MCL for nitrate. Samples from more than half of the wells contained concentrations of iron in excess of the SMCL, and samples from nearly half of the wells contained concentrations of manganese in excess of the SMCL. Concentrations of arsenic in samples from five wells exceeded the MCL; although all of those wells were previously identified by MDEQ as having concentrations above the MCL. Samples from seven wells exceeded the SMCL for chloride. Samples from twelve wells exceeded the SMCL for total dissolved solids.

Elevated concentrations of iron, manganese, and arsenic are associated with ground water with lower redox potential at near-neutral pH (Hem, 1985; Kim, 1999; Korte and Fernando, 1991). This association can be observed in wells in Oakland County. However, nitrate and nitrite are readily reduced to nitrogen in low-redox environments. Appropriately, nitrate and nitrite were not present in any well with a concentration of arsenic, manganese, or iron in excess of the USEPA standard. Consumption of water with iron or manganese concentrations above the SMCL is not considered dangerous from a health perspective; however, both materials leave deposits in pipes and on fixtures, impart taste to beverages, and can discolor laundry (Shelton, 1997).

Sulfur is a common element in the Earth's crust, and occurs as sulfate ( $\text{SO}_4^{2-}$ ) in waters with near-neutral pH and redox potential above  $-100$  mV (Hem, 1985). Sulfate can be reduced under certain conditions to hydrogen sulfide, a compound with the smell of rotten eggs. In addition to leaving greenish deposits on plumbing fixtures, sulfate in concentrations above the SMCL can result in diarrhea (Shelton, 1997).

Fluoride is present in many natural waters in concentrations less than 1.0 mg/L. The MCL of 4.0 mg/L has been set to protect public health. Fluoride in excess of 4.0 mg/L can cause skeletal fluorosis, a serious bone disorder (Shelton, 1997). Concentrations in excess of 2.0 mg/L can cause dental fluorosis, a staining and pitting of the teeth (Shelton, 1997).

The SMCL for dissolved solids is based on aesthetic concerns, and is primarily related to the life expectancy of domestic plumbing and appliances. The service life for a hot water heater is reduced by one year for every 200 mg/L of dissolved solids in water above the average 220 mg/L (Shelton, 1997).

## Nutrients

Species of nitrogen and phosphorus are frequently referred to as nutrients, because they are essential to plant life and are common in fertilizers, including manure, and in human waste. There are no health restrictions on consumption of phosphorus in drinking water, but the USEPA has set restrictions on nitrate ( $\text{NO}_3^-$ ) and nitrite ( $\text{NO}_2^-$ ).

## Sources

Nitrogen and phosphorus are essential to all known forms of life. Consequently, they can be found throughout the environment in varying concentrations, even in rainwater. Typical nitrate concentrations in the precipitation of southwestern Michigan are approximately 0.6 mg/L as N, and typical phosphorus concentrations are 0.05 mg/L (Cummings, 1978)

Human activities have done much to alter the distribution of nutrients in the environment. Application of manure and chemical fertilizers to crops and lawns results in local abundance of nutrients, which is the desired outcome. But over-application can result in local excesses of nutrients, which can reach ground water. Septic tanks are designed to provide a means of containing and treating sewage, which typically contains elevated concentrations of nitrogen and phosphorus. But when environmental conditions, such as a high water table, alter the operation of a septic tank, nitrogen and phosphorus can be released into the ground water. The USEPA considers nitrate concentrations of 3 mg/L as N or higher to be the result of anthropogenic contamination (U.S. Environmental Protection Agency, 1996b).

## Occurrence

Concentrations of nitrate and nitrite in Oakland County drinking water ranged from below the reporting limit (0.1 mg/L) to 23.9 mg/L as N, more than twice the MCL. Samples collected from two wells exceeded the MCL, although samples from three more wells contained concentrations greater than 2 mg/L as N. While not above the USEPA threshold for anthropogenic contamination, these concentrations are more than twice the median, and more than three times the atmospheric loading. Nitrite concentrations were consistently less than the MCL of 1.0 mg/L as N, ranging from 0.08 to less than the reporting limit of 0.01 mg/L as N.

The CAER used 6,198 of the 12,942 nitrate analyses performed by MDEQ to generate the map of nitrate occurrence in Oakland County (fig. 8). The majority of the discarded records were removed because of obvious errors in recording the address in the database. In the case of duplicate entries for a well, the highest concentration was retained. Each of the 900 survey sections in Oakland County was then assigned to one of four groups; nitrate present above the MCL, nitrate present below the MCL, nitrate present below 3 mg/L-N, or no observations. Approximately one percent (96) of the 7,814 unique wells identified by the CAER contained concentrations of nitrate greater than the MCL. A more detailed discussion of the mapping methods employed and the comparison between USGS analytical results and MDEQ analytical results is included in Appendix 2.

The map provides a summary of the nitrate data in the MDEQ database. Nitrate concentrations above 3 mg/L-N generally occur along a northeast-southwest axis, coincident with the region previously identified as both the interlobate outwash plains and the region of with the most permeable soils (see figure 5). This pattern of nitrate contamination of ground water through high permeability surface sediments has been widely documented in Michigan (Kittleson, 1987) and elsewhere (Madison and Brunett, 1985).

Nitrate concentrations in ground water change at spatial scales smaller than the square-mile mapping unit used in these maps. The classification applied to any square-mile mapping unit does not necessarily reflect the current status of all wells in that mapping unit. The data archived in the MDEQ database reflect analyses of samples collected between 1983 and 1997, with varying sample collection, handling, and analysis techniques. For example, replicate samples collected in this study, and some samples collected by state and county personnel, employed clean sampling techniques to minimize contamination. Samples in this study (excluding the short-interval samples, discussed later), as well as samples collected by state and county workers, were collected only after the well and plumbing system had been purged. Samples were returned to the state laboratory the same day for analysis within the next two days. The majority of the samples in the MDEQ database, however, were collected by homeowners and shipped by mail to the State laboratory for analysis. Thus there is no standard control on sampling procedures, handling techniques, or the time elapsed between sample collection and analysis.

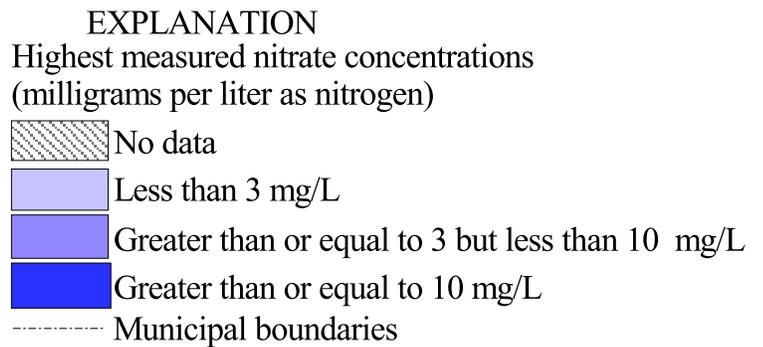
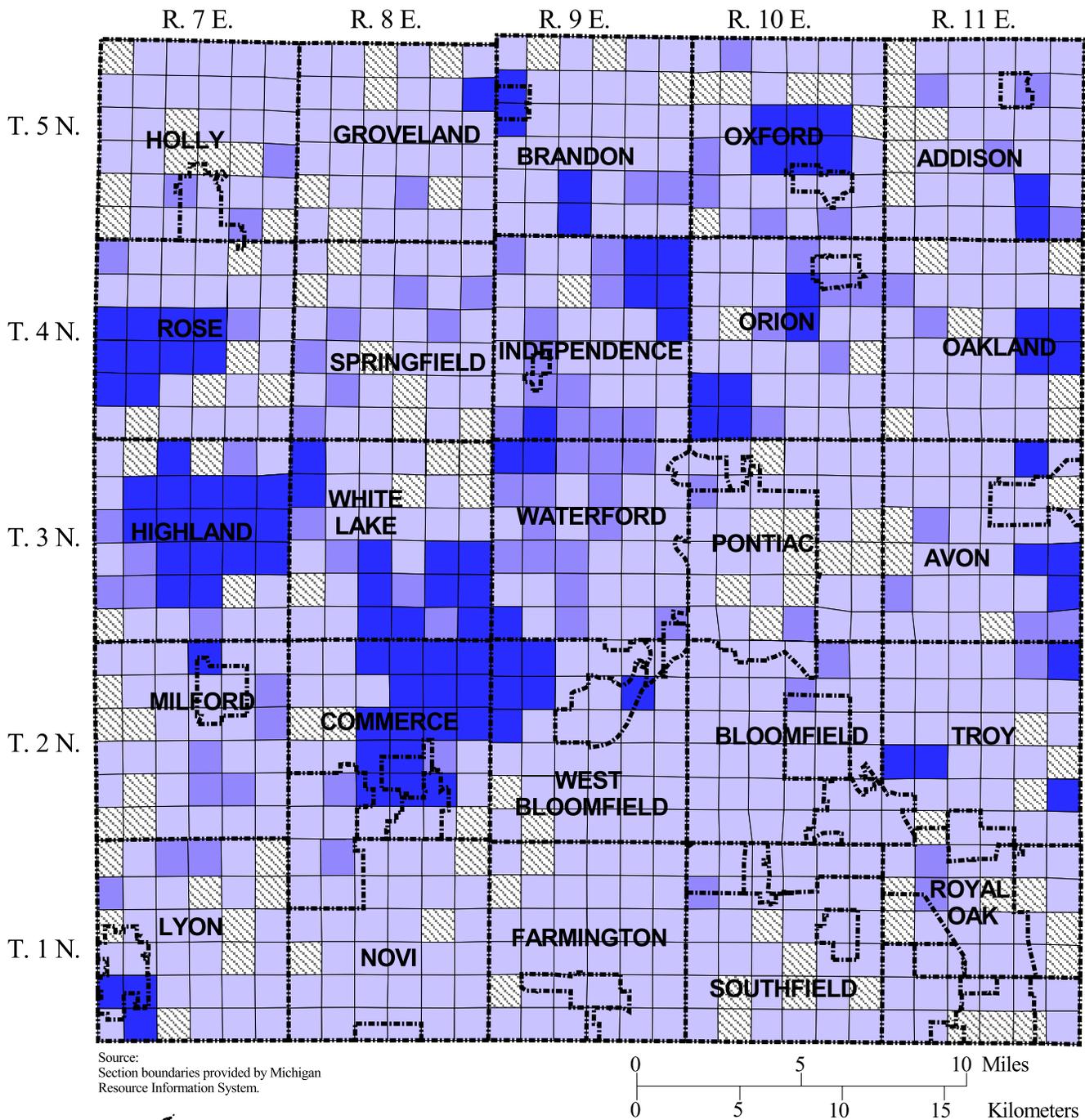


Figure 8. Nitrate distribution in Oakland County, Michigan. Map based on analyses performed at Michigan Department of Environmental Quality Drinking Water Laboratory.

### Potential Health Effects

Nitrate has long been linked to methemoglobinemia in infants (Comly, 1945), commonly known as “blue baby syndrome.” Methemoglobinemia occurs when nitrite ( $\text{NO}_2^-$ ), a reduced form of nitrate, interacts with red blood cells and impairs their ability to carry oxygen (Mirvish, 1991). This impairment results in anoxia (deficiency of oxygen in the blood) and cyanosis (blue blood). In severe cases, blue-baby syndrome can be fatal (U.S. Environmental Protection Agency, 1996b). Susceptibility varies depending on age, body mass, and diet, but fetuses and infants under 6 months are most at risk. This is because 1) infantile hemoglobin is more susceptible to oxidation by nitrite than adult hemoglobin, 2) infants consume more water

per unit body weight than do adults, and 3) the activity of the enzyme system that removes methemoglobin in infants is lower in infants than in adults (Keeney and Follett, 1991). For this reason, the USEPA has set restrictions on nitrate ( $\text{NO}_3^-$ ) and nitrite ( $\text{NO}_2^-$ ) concentrations of 10.0 and 1.0 mg/L as nitrogen, respectively (U.S. Environmental Protection Agency, 1996a). Most laboratories report nitrate and nitrite concentrations in terms of the weight of nitrogen (as above). In terms of the mass of the whole molecule, the MCLs are approximately 45 mg/L as  $\text{NO}_3^-$  and 3.3 mg/L as  $\text{NO}_2^-$ .



*USGS scientists use clean sampling techniques to collect water for analysis from a residential well, Oakland County, Michigan.*

Several authors (Keeney, 1986; Keeney and Follett, 1991; Moller and Forman, 1991; Crespi and Ramazotti, 1991) have accepted the correlation between nitrate consumption and various forms of cancer. Nitrosamines, formed from ingested nitrite and amines, which occur naturally in the digestive tract, also have been identified as carcinogens in laboratory experiments (Crespi and Ramazotti, 1991). Because nitrate and nitrite can be ingested from other sources, such as food and wine, no evidence currently exists for evaluating potential carcinogenic effects of nitrate on human populations (Crespi and Ramazotti, 1991).

### Major Ions and Trace Metals

In addition to nutrients, water samples from the wells in Oakland County were analyzed for more than a dozen other characteristics. Summary statistics are provided in table 4. The complete listing of these results is included in appendix tables 1A to 1G. A more detailed description of the sources, occurrence, and health effects of chloride and arsenic has been developed to assist county employees and citizens in making decisions about drinking-water resources.



*Collection of water samples for analysis, Oakland County, Michigan.*

## **Chloride**

Chloride is found in virtually all ground water. Chloride can occur in ground water naturally, but is also found throughout southeastern Michigan as the result of human activities (Thomas, in press). The principal natural source of chloride in ground water is seawater trapped within the rock matrix (Long and others, 1986). Several anthropogenic sources exist as well, including the salts used on roads for deicing and dust control, and water softeners. Chloride is a conservative ion in solution, and seldom interacts in organic or inorganic reactions in the subsurface (Hem, 1985). As a result, the evidence of anthropogenic additions of chloride may be present for many years.

## **Occurrence**

Samples collected from 7 of the 37 wells exceeded the SMCL for chloride. Samples from every well contained a detectable concentration of chloride, ranging from 0.48 mg/L to 661 mg/L. The mean concentration was 104 mg/L and the median concentration was 23 mg/L.

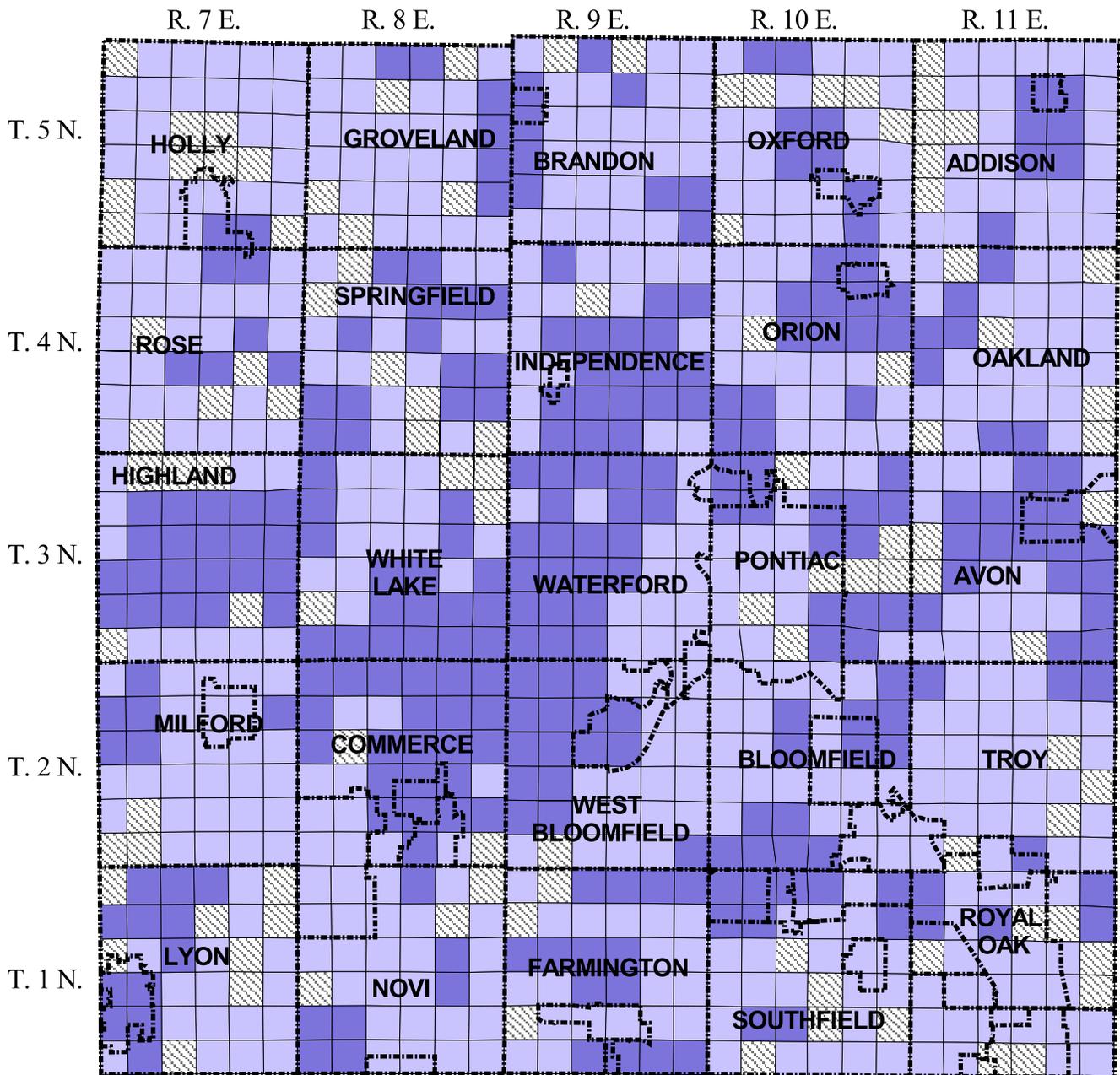
The CAER used 6,228 of the 12,960 chloride analyses performed by MDEQ to generate the map of chloride occurrence in Oakland County (fig. 9). The majority of the discarded records were removed because of obvious errors in the database. In the case of duplicate entries for a well, the highest concentration was retained. Each of the 900 survey sections in Oakland County was then assigned to one of four groups; chloride present above the SMCL, chloride present below the SMCL, chloride present below the MRL, or no observations. Approximately 5 percent (383) of the 7,809 unique wells identified by the CAER contained chloride in concentrations greater than the SMCL of 250 mg/L. Of the unique wells identified from the database, 1,581 did not have sufficient address location data to place them accurately on the map. A more detailed discussion of the mapping methods employed and the comparison between USGS analytical results and MDEQ analytical results is included in Appendix 2.

This map provides a summary of the chloride data in the MDEQ database. Because elevated chloride concentrations in ground water can come from both anthropogenic and natural sources, elevated chloride concentrations can be found throughout the county. Chloride concentrations in ground water can change at spatial scales smaller than the square-mile mapping unit used in these maps. The classification applied to any square-mile mapping unit does not necessarily reflect the current status of all wells in that mapping unit.

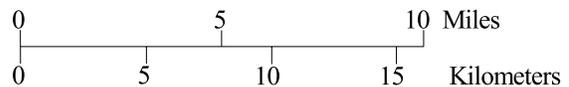
The data archived in the MDEQ database reflect analyses on samples collected between 1983 and 1997, with varying sample collection, handling, and analysis techniques. For example, replicate samples collected in this study, and some samples collected by state and county personnel, employed clean sampling techniques to minimize contamination. Samples in this study (excluding the short-interval samples, discussed later), as well as samples collected by state and county workers, were collected only after the well and plumbing system had been purged. The majority of the samples in the MDEQ database, however, were collected by homeowners and shipped by mail to the State laboratory for analysis. Thus there is no standard control on sampling procedures, handling techniques, or the time elapsed between sample collection and analysis.

## **Potential Health Effects**

Hutchinson (1970) suggested that elevated chloride concentrations could have an effect on persons with pre-existing cardiac (heart) or renal (kidney) problems. The chloride SMCL of 250 mg/L is based on the aesthetic consideration of taste; water with higher concentrations of chloride tastes 'salty' to most people. A greater concern might be the presence of cations with chloride, such as sodium and potassium. Sodium in drinking water can be a concern for those on low sodium diets because of cardiac, circulatory, renal or other problems (Shelton, 1997).



Source:  
Section boundaries provided by Michigan  
Resource Information System.



- EXPLANATION**
- Highest measured chloride concentrations  
(milligrams per liter)
- No data
  - Less than 250 mg/L
  - Greater than or equal to 250 mg/L
  - Municipal boundary

Figure 9. Chloride distribution in Oakland County, Michigan. Map based on analyses performed by the Michigan Department of Environmental Quality Drinking Water Laboratory.

## **Arsenic**

Arsenic is a common element in the Earth's crust, and occurs naturally throughout southeastern Michigan in several forms. In ground water, arsenic has been observed to occur in two forms; the oxidized form, arsenate ( $\text{As}^{+5}$ ), or the reduced form, arsenite ( $\text{As}^{+3}$ ). Kim (1999), working with the USGS Drinking Water Initiative (DWI) project, has shown that most (65-94 percent) of the arsenic in ground water in Oakland County is arsenite. Kim (1999) has also observed that the presence of the bicarbonate ion ( $\text{HCO}_3^-$ ) in solution can enhance the rate of arsenic dissolution into ground water, although the species of arsenic released by this process is arsenate. Arsenate is readily sorbed to metal oxides, such as iron oxide, and rendered immobile (Korte and Fernando, 1996). For arsenic to be released into solution from the mineral form, arsenian pyrite (Kolker and others, 1998), aquifer sediments must first be oxidized, then reduced. The hydrologic mechanism facilitating this process has not yet been determined.

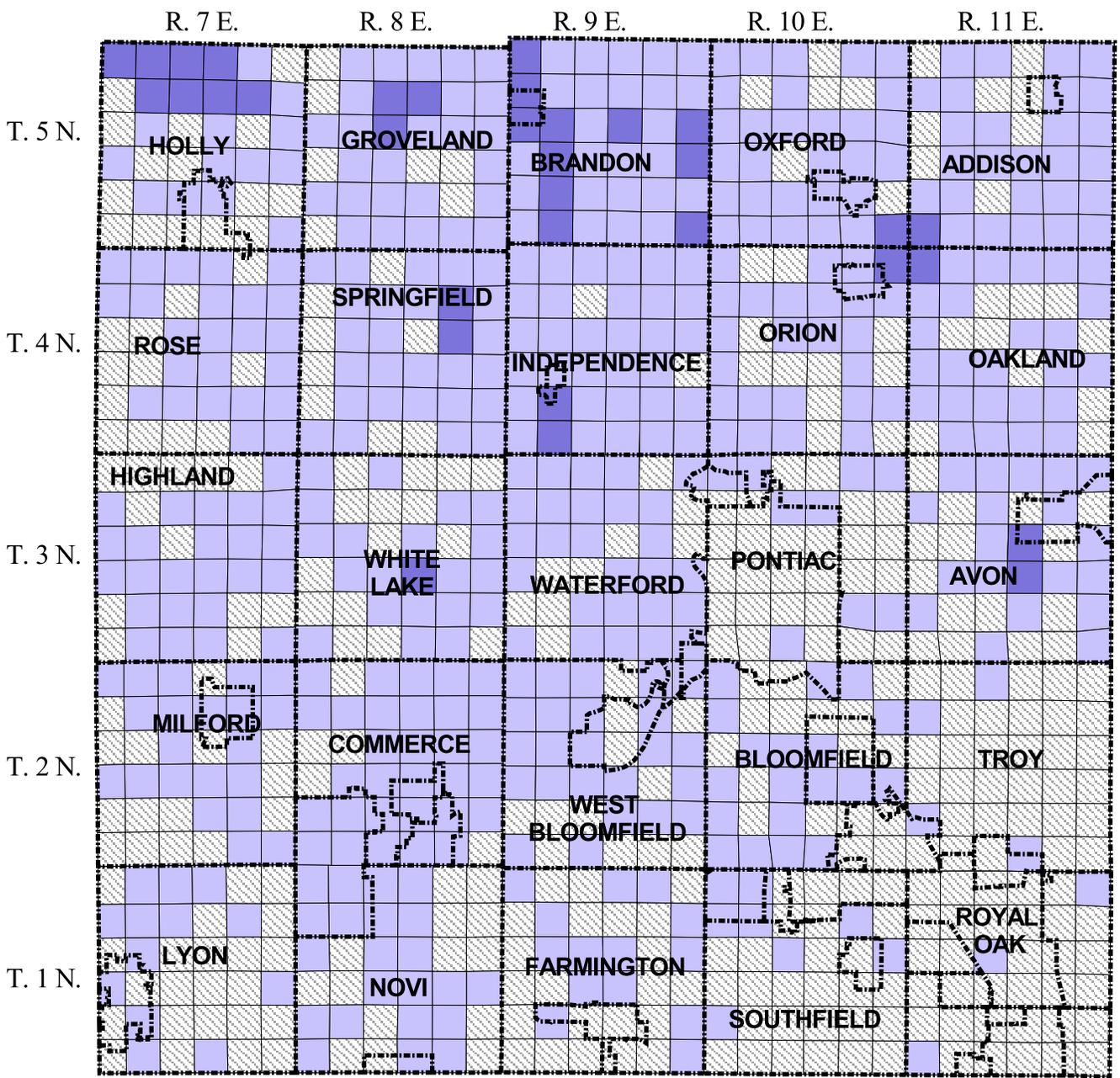
## **Occurrence**

Low concentrations of arsenic are found throughout southeastern Michigan. The largest concentration detected in Oakland County by this study was 0.175 mg/L. Samples from five of the 38 wells exceeded the MCL, 0.05 mg/L, although all had previously been noted to exceed the MCL based on results from the MDEQ laboratory and were sampled to obtain additional supporting chemistry. Of the other wells sampled, 9 contained arsenic in concentrations below the minimum reporting level of 0.001 mg/L. The remaining 24 wells all contained some detectable concentration between 0.001 and 0.050 mg/L.

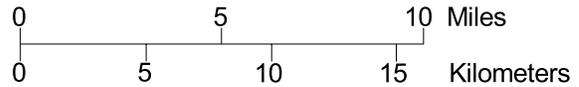
The CAER used 1,988 of the 3,509 arsenic analyses performed by MDEQ to generate the map of arsenic occurrence (fig. 10) using procedures similar to those described for nitrate and chloride. These maps are similar to those released previously in USGS Fact Sheet 135-98 (Aichele and others, 1998). Approximately one percent (24) of the 2,373 unique wells identified by the CAER contained arsenic at concentrations greater than the MCL of 0.05 mg/L. Of the unique wells identified from the database, 385 did not have sufficient address location data to place them accurately on the map. A more detailed discussion of the mapping methods employed and the comparison between USGS analytical results and MDEQ analytical results is included in Appendix 2.

The map provides a summary of the arsenic data in the MDEQ database. Arsenic concentrations in ground water can change at spatial scales smaller than the square-mile mapping unit used in these maps. The classification applied to any square-mile mapping unit does not necessarily reflect the current status of all wells in that mapping unit.

The data archived in the MDEQ database reflect analyses on samples collected between 1983 and 1997, with varying sample collection, handling, and analysis techniques. For example, replicate samples collected in this study, and some samples collected by state and county personnel, employed clean sampling techniques to minimize contamination. Samples in this study (excluding the short-interval samples, discussed later), as well as samples collected by state and county workers, were collected only after the well and plumbing system had been purged. The majority of the samples in the MDEQ database, however, were collected by homeowners and shipped by mail to the State laboratory for analysis. Thus there is no standard control on sampling procedures, handling techniques, or the time elapsed between sample collection and analysis.



Source:  
Section boundaries provided by Michigan  
Resource Information System.



### EXPLANATION

Highest measured arsenic concentrations  
(milligrams per liter)

-  No data
-  Less than 0.05 mg/L
-  Greater than or equal to 0.05 mg/L
-  Municipal boundaries

Figure 10. Arsenic distribution in Oakland County, Michigan. Map based on analyses performed by the Michigan Department of Environmental Quality Drinking Water Laboratory. The Maximum Contaminant Level (MCL) for arsenic, currently 0.05 mg/L, is being reviewed by the U.S. Environmental Protection Agency.

### Potential health effects

The USEPA has set an MCL of 0.05 mg/L for arsenic in drinking water, although no distinction is made between the two arsenic species. In May, 2000 the USEPA proposed revising the MCL to 0.005 mg/L, and is accepting public comment on MCLs of 0.003 mg/L, 0.005 mg/L, 0.010 mg/L, and 0.020 mg/L. A final decision is expected early in 2001.

Several authors have suggested that arsenite may be a more serious health concern than arsenate (Pontius and others, 1994; Kosnett, 1997). The effects of chronic arsenic ingestion are based on the total daily dose and length of exposure, not the concentration specifically. The daily dosage from drinking water can be estimated based on the concentration in the water and the quantity of water consumed. For example:

[As concentration]	* Quantity of	= Dose
	of water	
0.050 mg/L	* 2 L	= 0.100 mg
0.025 mg/L	* 2 L	= 0.050 mg

This calculation is only an estimate of total daily arsenic ingestion, because there are other environmental sources of arsenic. Some of these sources include shellfish, meats, dust, soil, and some pigments. The U.S. Food and Drug Administration has estimated that US adults ingest about 0.053 mg As/day from the diet, not including drinking water (Guo and others, 1998). Nearly half of this amount comes from fish and shellfish. Marine shellfish and cod typically contain arsenic concentrations between 10 and 40 mg/kg based on fresh weight (National Academy of Science, 1977). Freshwater fish, other marine fish, pork and beef typically contain less than 1 mg As/kg (National Academy of Science, 1977).

Kosnett (1997) defines three classes of arsenic exposure, and outlines the symptoms and risks associated with each class. For an average adult, low exposure includes inorganic arsenic doses up to 0.5 mg/day. Moderate exposure includes dose of 0.5 to 1.5 mg/day, and high exposures are doses in excess of 1.5 mg/day. These exposure classes are based on the total mass of arsenic ingested from water (described above) and from food. Low doses seldom result in any noticeable symptoms of illness. Moderate exposures for prolonged periods (5 to 15

years) may result in skin discoloration and lesions, anemia, peripheral neuropathy and peripheral vascular disease. In addition to the symptoms of moderate exposure, high doses may result in edema, more pronounced peripheral neuropathy including motor weakness, diminished reflexes, and muscle atrophy. High doses also may result in gastrointestinal disturbances such as nausea and diarrhea, as well as general fatigue and weight loss.

Arsenic has been listed as a Group A human carcinogen by the USEPA on the basis of inhalation and ingestion exposure. The carcinogenic effects of low-level arsenic ingestion in drinking water are widely disputed in the medical literature and are currently under review by the USEPA. Several case studies of groups exposed to arsenic occupationally or medicinally, such as Moselle wine growers (Luchtrath, 1983) and users of the Victorian health tonic 'Fowler's solution,' an alkaline solution of potassium arsenate marketed in the US until 1980, have indicated increased risks of bladder cancers (Cuzick and others, 1992). Several studies in Taiwan (Tsuda and others, 1995; Pontius and others, 1994) have observed increased risk of urinary tract cancers as a result of consuming water containing arsenic. No statistically significant relation was observed between arsenic concentration in drinking water and the occurrence of liver, kidney, bladder, or urinary tract cancer for persons consuming water containing less than 0.33 mg/L in Taiwan (Guo and others, 1998).

Different populations may also have different processes to remove arsenic from the body. Most mammals remove arsenic from their bodies by incorporating the arsenic into organic compounds, a process known as methylation. These organic compounds are easier for the body to remove. Dr. Vasken Aposhian of the University of Arizona has determined that several South American mammals have developed a means of removing arsenic from the body other than methylation (Kaiser, 1998). Several native human populations in the Andes Mountains exhibit a similar trait (Kaiser, 1998). Despite drinking water with levels of arsenic more than twice the USEPA MCL, these populations do not exhibit any increased occurrence of cancer (Kaiser, 1998).

At this point, no comprehensive epidemiological study has been performed on a US population consuming arsenic in drinking water over an

extended period of time. The best information available comes from studies in Taiwan and Bangladesh, whose populations differ sharply from United States populations in lifestyle, diet, and genetic inheritance.

### **Results of Time-Series Analyses**

Analyses of well water samples collected by the Oakland County Health Division and homeowners as part of routine sampling have indicated changes in arsenic concentration of as much as 0.05 mg/L or more over periods of time ranging from days to years. This variation has raised concerns that 1) concentrations of arsenic and other dissolved constituents may be changing in the aquifer, or that 2) some samples may have been collected without an adequate well purge. An inadequate well purge would mean that drinking water (water drawn from a tap immediately) was being compared to ground water (water drawn after the plumbing system and well bore have been purged). As part of this study, ground-water samples were collected from selected wells to attempt to observe long-term variability in the aquifer, while drinking-water samples were collected to evaluate the potential to obtain varying results based on an inadequate purging of the well.

Very little change was observed in any characteristic between ground-water samples collected in June/July 1998 and those collected in December 1998.

All sites exhibited some chemical changes in the short-term drinking-water sampling (Appendix table 1E-1G). Total iron concentrations fluctuated with time in all wells, although the magnitude of the fluctuation was usually less than 10 percent of the concentration. OAK 35 exhibited a marked increase in iron and arsenic concentration over time. Iron concentrations increased from 216 to 1500 µg/L over a span of 10 minutes. Arsenic concentrations increased from 0.001 mg/L to 0.01 mg/L over a time span of four minutes. This sample was collected from a tap at an outbuilding that had not been used for more than two days. This point was sampled because, based on the chemistry data collected earlier, this well was expected to exhibit a short-term change. Improper purging of a well prior to sampling may result in lower concentrations of both arsenic and iron, particularly when the water has been standing in the pipes for a prolonged period.

### **Results of Replicate Sample Analysis**

The analytical results from the USGS NWQL and the MDEQ Drinking Water Laboratory for nitrate, chloride, and arsenic agree closely. Mean differences in concentration measurements for nitrate, chloride, and arsenic were 0.1, 6.8, and 0.0008 mg/L, respectively. The standard deviation of the differences was 0.3, 9.6, and 0.003 mg/L for nitrate, chloride, and arsenic, respectively. Graphs showing the comparative analytical results over a range of concentrations are provided in Appendix 2.

### **SUMMARY**

The quality of ground water in Oakland County is the result of a combination of natural and anthropogenic processes. Many wells produce highly reduced water with high concentrations of iron and manganese. All of the wells sampled during 1998 contained chloride, although most contained concentrations below the U.S. Environmental Protection Agency (USEPA) Secondary Maximum Contaminant Level (SMCL). Twenty-nine of thirty-eight wells contained detectable concentrations of arsenic, although only five contained arsenic concentrations above the USEPA Maximum Contaminant Level (MCL). These five wells are best considered separately, because they were known from previous samplings to contain arsenic, and were sampled to provide additional chemical information. Only two wells contained nitrate in concentrations above the MCL, although three additional wells contained concentrations several times higher than would be expected to be found in precipitation.

Seasonal variations in water-quality were not observed in any of the five wells resampled in December 1998. Some short-term variations during the purging of the wells were observed in all wells. All wells exhibited variation in iron concentration; three of five exhibited fluctuations of approximately 10 percent, while 2 of the five exhibited increasing trends. One well exhibited an increasing trend in arsenic concentration, coincident with an increasing trend in iron concentration. Thus, while in many cases analytical results may not be affected by the length of time a well is purged, in at least one of the five subject wells purge time would have influenced the resulting arsenic concentration.

## REFERENCES CITED

- Aichele, Steve, Hill-Rowley, Richard, and Malone, Matt, 1998, Arsenic, Nitrate, and Chloride in Groundwater, Oakland County, Michigan: U.S. Geological Survey Fact Sheet 135-98, 6 p.
- Blumer, S.P., Behrendt, T.E., Ellis, J.M., Minnerick, R.J., LeuVoy, R.L., and Whited, C.R., 1998, Water Resources Data for Michigan, Water Year 1998: U.S. Geological Survey Water-Data Report MI-98-1, 477 p.
- Britton, L.J., and Greeson, P.E., 1988, Methods for collection and Analysis of Aquatic Biological and Microbiological Samples: U.S. Geological Survey Techniques of Water Resources Investigations, Book 5, Chapter A4, 363 p.
- Brown, G.E., 1998, Graphite Furnace Atomic Adsorption Spectrophotometry (GFAAS) to replace Hydride Generation Atomic Adsorption Spectrophotometry (HGAAS) for the determination of Arsenic and Selenium in Filtered and Whole Water Recoverable Water, and Recoverable Bottom Material Sediment: U.S. Geological Survey Technical Memorandum 98.11, 2 p.
- Comly, H.H., 1945, Cyanosis in infants caused by nitrates in well-water: *Journal of the American Medical Association*, vol. 129, p.112-116.
- Crespi, M. and Ramazotti, V., 1991, Evidence that N-nitroso compounds contribute to the causation of certain human cancers, *in* Bogardi, I. and Kuzelka, R. (eds.) Nitrate Contamination: Exposure, Consequence and Control: Springer-Verlag, New York, p. 233-253.
- Cummings, T.R., 1978, Agricultural Land Use and Water Quality in the Upper St. Joseph River Basin, Michigan: U.S. Geological Survey Open-File Report 78-950, 106 p.
- Cuzick, J., Saaieni, P., and Evans, S., 1992: Ingested Arsenic, Keratosis, and Bladder Cancer: *American Journal of Epidemiology*, vol. 136, p. 417-412.
- Drever, J.I., 1988. *The Geochemistry of Natural Waters*, 2<sup>nd</sup> Edition: Prentice Hall, Inc., Englewood Cliffs, New Jersey, 402 p.
- Environmental Systems Research Institute, 1998, *Introduction to ArcView GIS*: Environmental Systems Research Institute, Inc., Redlands, California.
- Eschman, D.F., and Karrow, P.F., 1985, Huron Basin Glacial Lakes: A Review, *in* Karrow, P.F., and Calkin, P.E., *Quaternary Evolution of the Great Lakes*: Geological Association of Canada, Special Paper 30, p. 79-94.
- Ferrand, W.R., and Bell, D.L., 1982, *Quaternary Geology of Southern Michigan*: Michigan Geological Survey, 1:500,000 scale, 2 sheets.
- Fetter, C.W., 1994, *Applied Hydrogeology*, 3<sup>rd</sup> ed.: Macmillan College Publishing, Inc., New York, 616 p.
- Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water Resources Investigations, Book 5, Chapter A1, 454 p.
- Fishman, M.J., 1993, Methods of Analysis of the U.S. Geological Survey National Water Quality Laboratory – Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 273 p.
- Garbarino, J.R., and Struzeski, T.M., 1998, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory -- Determination of elements in whole-water digests using inductively coupled plasma-optical emission spectrometry and inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 98-165, 101 p.
- Guo, H.R., Chiang, H.S., Hu, H., Lipsitz, S.R., and Monson, R.R., 1998, Arsenic in Drinking Water and incidence of Urinary Tract Cancers: *Epidemiology*, vol. 8, no. 5, p. 545-550.

- Hem, J.D., 1985, Study and Interpretation of the Chemical Characteristics of Natural Water, 3<sup>rd</sup> Edition: U.S. Geological Survey Water-Supply Paper 2254, 249 p.
- Holtschlag, D.J., and Nicholas, J.R., 1998, Indirect Ground-water discharge to the Great Lakes: U.S. Geological Survey Open-File Report 98-579, 25 p.
- Humphrys, C.R., and Green, R.F., 1962, Michigan Lake Inventory: Michigan State University Department of Resource Development, Bulletin 63, p. 63A-63H.
- Hutchinson, F.E., 1970, Environmental pollution from highway deicing compounds: Journal of Soil and Water Conservation, vol. 25, p. 144-146.
- Kaiser, J., 1998, Toxicologists shed new light on old poisons: Science, vol. 279, p. 1850.
- Keeney, D., 1986, Sources of nitrate to ground water: CRC Critical Reviews in Environmental Control, vol. 16, no. 3, p. 257-304.
- Keeney, D. and Follett, R., 1991, Managing nitrogen for ground-water quality and farm profitability: Soil Science Society of America, Madison, Wisconsin. 357 p.
- Kim, M.J., 1999, Arsenic Dissolution and Speciation in Ground water in Southeast Michigan: Ann Arbor, University of Michigan, Doctoral Dissertaion, 202 p.
- Kittleson, K., 1987, The groundwater problem in Michigan: an overview in D'Itri, F., and Wolfson, L. (eds.), Rural groundwater contamination: Lewis Publishers, Chelsea, Michigan, p. 69-84.
- Kolker, A., Cannon, W.P., Westjohn, D.B., and Woodruff, L., Arsenic-rich Pyrite in the Mississippian Marshall Sandstone: Source of Anomalous Arsenic in Southeastern Michigan Drinking Water [abs.]: Geologic Society of America Abstracts with Programs, vol. 30, no. 7, p. A-59.
- Korte, N.E., and Fernando, Q., 1991, A review of arsenic (III) in ground water: Critical Reviews in Environmental Control, vol. 21, no. 1, p. 1-39.
- Kosnett, M., 1997, Clinical Guidance in the evaluation of patients with potential exposure to arsenic in drinking water: Michigan Department of Community Health, Lansing, Michigan, 10 p.
- Leverett, F., and others, 1906, Flowing Wells and Municipal Water Supplies in the Southern Portion of the Southern Peninsula of Michigan: U.S. Geological Survey Water-Supply Paper 182, 292 p.
- Leverett, F., and Taylor, F.B., 1915, The Pleistocene of Indiana and Michigan and the History of the Great Lakes: U.S. Geological Survey Monograph 53, 529 p.
- Long, D.T., Rezabek, T.P., Takacs, M.J., and D.H., Wilson, 1986, Geochemistry of ground waters, Bay County, Michigan: Report to Michigan Department of Public Health and Michigan Department of Natural Resources (MDPH: ORD 385553), 265 p.
- Luchtrath, H., 1983, The consequences of chronic arsenic poisoning among Moselle wine growers: Journal of Cancer Research and Clinical Oncology, vol. 105, p. 173-182.
- Madison, R.J., and Brunett, J.O., 1985, Overview of the occurrence of nitrate in ground water of the United States: U.S. Geological Survey Water-Supply Paper 2275, 105 p.
- Mirvish, S.S., 1991, The significance for human health of nitrate, nitrite, and N-nitroso compounds, in Bogardi, I. and Kuzelka, R. (eds.), Nitrate Contamination: Exposure, Consequence and Control: Springer-Verlag, New York, p. 253-266.
- Moller and Forman, 1991, Epidemiological Studies of the endogenous formation of N-nitroso compounds, in Bogardi, I. and Kuzelka, R. (eds.), Nitrate Contamination: Exposure, Consequence and Control: Springer-Verlag, New York, p. 276-280.

- Mozola, A.J., 1954, A Survey of the Ground-water Resources in Oakland County, Michigan: Michigan Department of Conservation, Publication 48, Part II, 348 p.
- National Academy of Science, 1977, Drinking Water and Health: National Academy Press, Washington D.C.
- Patton, C.J., and Truitt, E.P., 1992, Methods of Analysis of the U.S. Geological Survey National Water Quality Laboratory – Determination of total phosphorus by a Kjeldahl digestion method and an automated colorimetric finish that includes dialysis: U.S. Geological Survey Open-File Report 92-146, 39 p.
- Pontius, F. Brown, K, and Chen, C., 1994, Of arsenic in drinking water: Journal of the American Water Works Association, vol. 86, no. 10, p. 52-63.
- Southeast Michigan Council of Governments, 1995, Land Use/Land Cover, Southeast Michigan, 1995 - Geographic Information Systems Data Set, Nominal Scale 1:175,000: Southeast Michigan Council of Governments, Detroit, Michigan.
- Southeast Michigan Council of Governments, 1999, 1999 Southeast Michigan Population and Household Estimates: Southeast Michigan Council of Governments, Detroit, Michigan, 1 sheet.
- Shelton, L.R., 1994, Field guide for collecting and processing stream water samples for the National Water Quality Assessment Program: U.S. Geological Survey Open-File Report 94-455, 42 p.
- Shelton, T.B., 1997, Interpreting Drinking Water Quality Analysis: What do the numbers mean? 5<sup>th</sup> ed.: Rutgers Cooperative Extension Publication E214, New Brunswick, New Jersey, 67 p.
- Soil Conservation Service, 1982, Soil Survey of Oakland County, Michigan: U.S. Department of Agriculture, Soil Conservation Service, Washington D.C., 162 p.
- Thomas, M.A., The Effect of Recent Residential Development on the Quality of Ground Water near Detroit, Michigan. Accepted for publication in Ground Water [in press].
- Todd, D.K., 1980, Groundwater Hydrology, 2<sup>nd</sup> ed.: John Wiley and Sons, New York, 516 p.
- Tsuda, T., Babazono, A., Yamamoto, E., Kurumatsani, N., Mino, Y., Ogawa, T., Kishi, Y., Aoyama, H., 1995, Ingested arsenic and internal cancer, a historical cohort study followed for 33 years: American Journal of Epidemiology, vol. 141, p. 198-209.
- U.S. Environmental Protection Agency, 1994, Methods for the Determination of Inorganic Substances in Environmental Samples: National Technical Information Service PB94-120821, 169 p.
- \_\_\_\_\_, 1996a, Drinking Water Regulation and Health Advisories, U.S. Environmental Protection Agency, Office of Water, EPA 822-B-96-002.
- \_\_\_\_\_, 1996b, Environmental Indicators of Water Quality in the United States: U.S. Environmental Protection Agency, Office of Water, EPA 841-R-96-002.
- Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground water and surface water - a single resource: U.S. Geological Survey Circular 1139, 78p.
- Winters, H.A., Rieck, R.L., and Lusch, D.P., 1985, Quaternary Geomorphology of Southeastern Michigan, Field Trip Guide for 1985 Annual Meeting of the American Association of Geographers: Department of Geography, Michigan State University, East Lansing, Michigan, 98 p.

**APPENDIX 1: Water-quality data collected by the USGS in Oakland County, Michigan**

The following several pages contain the results of water-quality sample collection activities conducted by the USGS in cooperation with the Oakland County Health Division. Included is a key for cross-referencing station names (e.g. OAK 1) to USGS site identification numbers, a table of field-analyzed characteristics for each sample site, a table with the results of analyses for selected inorganic constituents, a table containing the results of seasonal analyses for selected inorganic constituents, and a series of tables containing the results of short-interval time-series sampling for arsenic, manganese and iron.

**Table 1A.** Index of station names with U.S. Geological Survey (USGS) station identification numbers

Station name	USGS Station ID
OAK 1	425032083230101
OAK 2	424835083250601
OAK 3	425050083310901
OAK 4	425219083264301
OAK 7	424351083365501
OAK 8	424303083142101
OAK 9	425055083374901
OAK 10	425154083370001
OAK 11	425221083374101
OAK 12	425131083363001
OAK 14	424308083245701
OAK 15	424315083182801
OAK 16	424323083250501
OAK 17	425218083375001
OAK 19	425033083165701
OAK 20	423307083290201
OAK 21	424315083183901
OAK 22	423105083173201
OAK 23	423108083173801
OAK 24	423036083182701
OAK 24A	425157083083001
OAK 25	425042083083101
OAK 26	425046083083601
OAK 29	423334083293601
OAK 30	423343083292101
OAK 31	424505083205901
OAK 32	423847083265601
OAK 33	423817083365501
OAK 34	424144083074701
OAK 35	424519083081101
OAK 36	422850083230101
OAK 37	423600083262301
OAK 38	424048083243201
OAK 39	424504083324901
OAK 40	424319083315701
OAK 41	423855083292201
OAK 42	425051083310701
OAK 43	425056083310101

**Table 1B.** Field measurements of water-quality characteristics for ground water samples from selected wells in Oakland County, Michigan

[ $\mu\text{S/cm}$ , microsiemens per centimeter at 25 degrees Celsius; mV, millivolts; mg/L, milligrams per liter;  $^{\circ}\text{C}$ , degrees Celsius]

Station name	Sample date	Sample time	Depth, (feet)	Field Specific Conductance ( $\mu\text{S/cm}$ )	Oxidation-reduction Potential (mV)	Oxygen, Dissolved (mg/L)	pH, Field (Standard Units)	Temperature ( $^{\circ}\text{C}$ )	Bicarbonate, Dissolved, (mg/L as $\text{HCO}_3$ )
OAK 1	6/3/98	930		474	35	0.1	7.3	11.3	240
OAK 2	6/3/98	1225		711	35	<.1	7.2	11.5	270
OAK 4	6/4/98	905		482	40	<.1	7.4	11.5	376
OAK 3	6/4/98	1225	86	503	81	.1	7.4	12.3	236
OAK 7	6/4/98	1430		695	180	<.1	7.1	11.4	344
OAK 8	6/9/98	930		1560	65	.1	6.9	11.1	368
OAK 9	6/9/98	1130		520	55	.1	7.3	11.6	462
OAK 10	6/9/98	1300	300	581	88	.1	7.2	13.1	420
OAK 11	6/25/98	1630		--	--	--	--	--	--
OAK 12	6/26/98	1146	300	600	100	.1	7.0	11.4	376
OAK 14	6/25/98	1350	142	570	40	<.1	7.1	12.2	264
OAK 15	6/25/98	1000		753	26	<.1	7.0	13.5	244
OAK 16	6/25/98	1220	161	556	175	<.1	7.3	13.5	276
OAK 17	6/25/98	1520		634	44	<.1	7.0	12.7	322
OAK 19	6/26/98	920		2950	288	7.8	6.5	12.3	320
OAK 21	6/25/98	915		1344	244	3.1	6.6	12.1	422
OAK 22	6/30/98	900	60	1910	66	.1	6.6	13.0	354
OAK 23	6/30/98	1000		1325	92	.1	6.7	12.0	319
OAK 24	6/30/98	1100	75	1439	51	<.1	--	11.8	270
OAK 24A	7/1/98	900		2420	94	.1	7.0	11.4	450
OAK 25	7/1/98	1030		681	70	.1	7.4	12.2	299
OAK 26	7/1/98	1130	54	680	321	4.9	7.2	11.3	318
OAK 29	7/7/98	900		1540	65	1.5	7.1	12.0	330
OAK 30	7/7/98	1010		1209	43	<.1	7.3	13.0	354
OAK 31	7/7/98	1215	73	1174	233	5.4	6.9	10.4	440
OAK 32	7/7/98	1400		1307	46	.1	7.3	12.1	214
OAK 33	7/7/98	1530		1155	169	.1	7.1	12.2	306
OAK 34	7/8/98	930		395	-25	.1	7.6	11.6	334

**Table 1B.** Field measurements of water-quality characteristics for ground water samples from selected wells in Oakland County, Michigan – Continued

[ $\mu$ S/cm, microsiemens per centimeter at 25 degrees Celsius; mV, millivolts; mg/L, milligrams per liter; °C, degrees Celsius]

Station name	Sample date	Sample time	Depth	Field Specific Conductance ( $\mu$ S/cm)	Oxidation – Reduction Potential (mV)	Oxygen, Dissolved (mg/L)	pH, Field (Standard Units)	Temperature (°C)	Bicarbonate, Dissolved, (mg/L as HCO <sub>3</sub> )
OAK 35	7/8/98	1055		601	19	<0.1	7.2	10.9	324
OAK 36	7/8/98	1310		605	33	.1	7.1	11.3	350
OAK 20	7/8/98	1430		491	35	.1	7.0	12.3	246
OAK 37	7/20/98	930		967	208	<.1	6.9	11.7	376
OAK 38	7/20/98	1120		795	876	7.0	7.2	15.5	278
OAK 39	7/20/98	1330		636	61	<.1	7.0	11.5	290
OAK 40	7/20/98	1445		519	64	.1	7.0	11.1	230
OAK 41	11/23/98	2000		577	33	.1	7.5	11.3	--
OAK 42	12/16/98	1115		492	195	.2	7.2	10.8	244
OAK 43	12/16/98	1230		462	230	.1	7.4	11.1	316

**Table 1C.** Results of analyses for selected inorganic chemical constituents in ground-water samples from selected wells in Oakland County, Michigan  
[mg/L, milligrams per liter; µg/L, micrograms per liter; E, estimate; --, No data]

Station name	Station ID	Sample date	Sample time	Depth, feet	Nitrogen, Ammonia mg/L as N	Nitrogen, Nitrite mg/L as N
OAK 1	425032083230101	06/03/98	930		0.25	<0.01
OAK 2	424835083250601	06/03/98	1225		.34	.02
OAK 4	425219083264301	06/04/98	905		.30	.02
OAK 3	425050083310901	06/04/98	1225	86	.11	.02
OAK 7	424351083365501	06/04/98	1430		.02	.08
OAK 8	424303083142101	06/09/98	930		.11	.01
OAK 9	425055083374901	06/09/98	1130		.20	.01
OAK 10	425154083370001	06/09/98	1300	300	.21	.01
OAK 11	425221083374101	06/25/98	1630		--	--
OAK 12	425131083363001	06/26/98	1146	300	.16	<.01
OAK 14	424308083245701	06/25/98	1350	142	.12	<.01
OAK 15	424315083182801	06/25/98	1000		.20	<.01
OAK 16	424323083250501	06/25/98	1220	161	<.02	<.01
OAK 17	425218083375001	06/25/98	1520		.21	<.01
OAK 19	425033083165701	06/26/98	920		.02	.01
OAK 21	424315083183901	06/25/98	900		.02	.01
OAK 22	423105083173201	06/30/98	900	60	.16	<.01
OAK 23	423108083173801	06/30/98	1000		.07	<.01
OAK 24	423036083182701	06/30/98	1100	75	.07	<.01
OAK 24A	425157083083001	07/01/98	900		.05	<.01
OAK 25	425042083083101	07/01/98	1030		.11	<.01
OAK 26	425046083083601	07/01/98	1130	54	.04	<.01
OAK 29	423334083293601	07/07/98	900		.24	<.01
OAK 30	423343083292101	07/07/98	1010		.24	<.01
OAK 31	424505083205901	07/07/98	1215	73	.04	<.01
OAK 32	423847083265601	07/07/98	1400		.04	<.01
OAK 33	423817083365501	07/07/98	1530		.05	.03
OAK 34	424144083074701	07/08/98	930		.31	<.01
OAK 35	424519083081101	07/08/98	1055		.29	<.01
OAK 36	422850083230101	07/08/98	1310		.32	<.01
OAK 20	423307083290201	07/08/98	1430		.56	<.01
OAK 37	423600083262301	07/20/98	930		.40	<.01
OAK 38	424048083243201	07/20/98	1120		<.02	<.01
OAK 39	424504083324901	07/20/98	1330		.05	<.01
OAK 40	424319083315701	07/20/98	1445		.02	<.01
OAK 41	423855083292201	11/23/98	2000		1.40	<.01
OAK 42	425051083310701	12/16/98	1115		.26	.03
OAK 43	425056083310101	12/16/98	1230		.05	.02

**Table 1C.** Results of analyses for selected inorganic chemical constituents in ground-water samples from selected wells in Oakland County, Michigan – Continued  
[mg/L, milligrams per liter; µg/L, micrograms per liter; E, estimate; --, No data]

Station name	Nitrogen, Ammonia + Organic mg/L as N	Nitrite + Nitrate, Dissolved mg/L as N	Phosphorus, Dissolved mg/L as P	Phosphorus, Ortho mg/L as P	Calcium, Dissolved mg/L as Ca
OAK 1	.24	<.05	<.01	<.01	49.1
OAK 2	.27	.06	<.01	.02	67.7
OAK 4	.27	.06	<.01	.01	48.5
OAK 3	.12	.05	<.01	.01	63.9
OAK 7	<.1	.92	<.01	.02	81.7
OAK 8	<.1	<.05	<.01	<.01	149.
OAK 9	.16	<.05	<.01	.01	57.0
OAK 10	.15	<.05	<.01	<.01	63.4
OAK 11	--	--	--	--	--
OAK 12	.18	<.05	<.01	<.01	66.1
OAK 14	<.1	<.05	<.01	<.01	69.3
OAK 15	.33	<.05	<.01	<.01	93.5
OAK 16	<.1	<.05	.03	.05	0.2
OAK 17	.31	<.05	<.01	<.01	79.1
OAK 19	.15	23.86	<.01	<.01	84.0
OAK 21	.11	13.97	<.01	<.01	145.
OAK 22	.23	<.05	<.01	<.01	131.
OAK 23	<.1	<.05	<.01	<.01	115.
OAK 24	.13	<.05	<.01	<.01	65.2
OAK 24A	<.1	<.05	<.01	<.01	175.
OAK 25	.14	<.05	<.01	<.01	79.8
OAK 26	<.1	2.34	<.01	<.01	89.4
OAK 29	.31	<.05	<.01	<.01	114.
OAK 30	.40	<.05	<.01	<.01	87.2
OAK 31	.12	2.56	<.01	<.01	130.
OAK 32	.11	<.05	.01	<.01	101.
OAK 33	<.10	2.12	<.01	<.01	100.
OAK 34	.36	<.05	.03	.04	30.8
OAK 35	.31	<.05	<.01	.02	59.9
OAK 36	.37	<.05	<.01	<.01	69.7
OAK 20	.68	<.05	<.01	<.01	69.8
OAK 37	.49	.20	<.01	.02	88.5
OAK 38	<.10	.16	.54	.52	83.6
OAK 39	<.10	<.05	<.01	.01	86.7
OAK 40	<.10	<.05	<.01	.01	73.3
OAK 41	1.52	.05	.02	.10	67.3
OAK 42	.41	<.05	<.01	.01	65.0
OAK 43	<.10	<.05	.02	.04	0.1

**Table 1C.** Results of analyses for selected inorganic chemical constituents in ground-water samples from selected wells in Oakland County, Michigan – Continued  
 [mg/L, milligrams per liter; µg/L, micrograms per liter; E, estimate; --, No data]

Station name	Magnesium, Dissolved mg/L as Mg	Sodium, Dissolved mg/L as Na	Potassium, Dissolved mg/L as K	Chloride, Dissolved mg/L as Cl	Sulfate, Dissolved mg/L as SO <sub>4</sub>
OAK 1	24.9	14.8	1.3	3.6	12.0
OAK 2	32.8	26.6	1.6	53.5	18.9
OAK 4	24.2	17.7	1.8	6.8	2.0
OAK 3	23.7	6.2	1.1	1.2	14.1
OAK 7	27.9	19.1	1.5	26.2	42.0
OAK 8	48.1	85.2	3.9	253.	80.7
OAK 9	26.7	16.5	1.4	0.5	11.3
OAK 10	32.6	14.0	1.9	0.5	9.8
OAK 11	--	--	--	--	--
OAK 12	36.6	13.0	1.6	.58	11.3
OAK 14	26.8	14.4	1.0	13.0	15.2
OAK 15	27.5	18.7	1.8	68.2	48.1
OAK 16	.02	139.	.1	6.1	13.7
OAK 17	33.1	7.2	1.8	6.9	10.4
OAK 19	57.7	431.	13.0	661.	58.8
OAK 21	51.8	64.5	1.9	110.	68.7
OAK 22	37.6	198.	2.5	367.	60.2
OAK 23	37.8	90.8	2.7	194.	65.2
OAK 24	45.8	145.	4.2	249.	68.6
OAK 24A	51.5	204.	1.9	444.	57.7
OAK 25	30.7	9.2	1.3	10.4	34.4
OAK 26	28.5	3.7	.8	4.1	31.0
OAK 29	29.3	156.	2.9	289.	62.5
OAK 30	22.6	124.	4.1	226.	14.9
OAK 31	40.2	54.2	1.9	140.	17.3
OAK 32	26.9	116.	2.4	253	53.3
OAK 33	27.4	101.	2.4	156.	51.9
OAK 34	18.6	26.8	1.3	3.5	1.3
OAK 35	25.6	26.6	1.3	30.5	10.7
OAK 36	26.1	18.2	1.5	29.2	1.7
OAK 20	18.3	3.8	.8	.9	6.4
OAK 37	20.1	86.7	1.9	132.	33.6
OAK 38	30.0	37.3	1.8	66.0	34.3
OAK 39	29.8	6.8	1.0	3.5	46.2
OAK 40	22.9	4.0	1.1	7.7	30.7
OAK 41	--	11.4	1.4	20.3	18.2
OAK 42	23.1	10.0	1.8	2.6	8.2
OAK 43	0.1	120.	.4	1.2	15.2

**Table 1C.** Results of analyses for selected inorganic chemical constituents in ground-water samples from selected wells in Oakland County, Michigan – Continued  
[mg/L, milligrams per liter; µg/L, micrograms per liter; E, estimate; --, No data]

Station name	Silica, Dissolved mg/L as SiO <sub>2</sub>	Arsenic, Total µg/L as As	Iron, Dissolved µg/L as Fe	Manganese, Dissolved µg/L as Mn	Residue, Dissolved, 180°C mg/L
OAK 1	16.1	40	742	9	278
OAK 2	14.5	26	2116	38	411
OAK 4	13.5	46	581	38	278
OAK 3	16.7	27	459	23	294
OAK 7	9.25	<1	89	330	410
OAK 8	14.6	8	2815	65	862
OAK 9	17.6	39	746	17	307
OAK 10	19.3	53	577	13	343
OAK 11	--	68	--	--	--
OAK 12	19.4	56	499	18	350
OAK 14	18.3	24	1100	26	330
OAK 15	14.5	2	2299	51	428
OAK 16	17.8	11	<10	<4	350
OAK 17	19.6	39	1853	15	367
OAK 19	13.8	<1	<30	<12	1620
OAK 21	15.0	<1	13	<4	794
OAK 22	13.1	--	2123	93	1050
OAK 23	11.5	1	1206	37	752
OAK 24	11.7	2	2228	76	794
OAK 24A	12.9	2	1506	158	1282
OAK 25	17.2	19	1152	31	375
OAK 26	14.6	<1	<10	<4	387
OAK 29	13.1	<1	1978	49	894
OAK 30	12.2	<1	1317	95	688
OAK 31	11.5	<1	27	<4	686
OAK 32	11.0	1	2028	94	750
OAK 33	9.85	<1	24	77	684
OAK 34	14.2	<1	549	9	228
OAK 35	16.7	12	1246	21	331
OAK 36	17.2	4	1329	14	348
OAK 20	16.9	3	2361	51	301
OAK 37	10.3	<1	68	285	561
OAK 38	16.6	3	<10	<4	482
OAK 39	14.0	3	1534	32	388
OAK 40	11.0	<1	755	36	316
OAK 41	23.0	176	3575	--	--
OAK 42	10.4	34	206	114	299
OAK 43	13.9	57	E 6	<3	304

**Table 1C.** Results of analyses for selected inorganic chemical constituents in ground-water samples from selected wells in Oakland County, Michigan – Continued  
 [mg/L, milligrams per liter; µg/L, micrograms per liter; E, estimate; --, No data]

Station name	Bromide, Dissolved mg/L as Br	Acid Neutralizing Capacity, pH 4.5 mg/L as CaCO <sub>3</sub>
OAK 1	0.07	252
OAK 2	.08	286
OAK 4	.03	263
OAK 3	.03	268
OAK 7	.05	296
OAK 8	.09	344
OAK 9	.03	280
OAK 10	.02	319
OAK 11	--	--
OAK 12	.05	332
OAK 14	.06	281
OAK 15	.17	247
OAK 16	.04	284
OAK 17	.05	336
OAK 19	5.51	325
OAK 21	.19	445
OAK 22	.24	353
OAK 23	.28	308
OAK 24	.24	275
OAK 24A	.64	367
OAK 25	.03	295
OAK 26	.03	290
OAK 29	.12	294
OAK 30	.07	263
OAK 31	.06	413
OAK 32	.06	226
OAK 33	.13	325
OAK 34	.03	215
OAK 35	.07	276
OAK 36	.09	287
OAK 20	.03	267
OAK 37	.09	279
OAK 38	.04	288
OAK 39	.06	308
OAK 40	.05	246
OAK 41	.08	--
OAK 42	.04	272
OAK 43	.01	247

**Table 1D.** Seasonal comparison of selected water-quality parameters for samples from selected wells in Oakland County, Michigan  
 [mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius]

Station name	OAK 3		OAK 4		OAK 9		OAK 12		OAK 35	
Station number	425050083310901		425219083264301		425055083374901		425131083363001		424519083081101	
Sample date	6/4/98	12/16/98	6/4/98	12/15/98	6/9/98	12/3/98	6/26/98	12/3/98	7/8/98	12/15/98
Sample time	1225	950	905	1545	1130	1500	1146	1700	1055	1300
pH, Laboratory (Standard Units)	7.3	7.6	7.5	7.7	7.6	7.6	7.4	7.4	7.6	7.6
Nitrogen, Ammonia (mg/L as N)	.11	.11	.30	.25	.20	.18	.16	.18	.29	.26
Nitrogen, Nitrite (mg/L as N)	.02	.02	.02	.02	.01	<.01	<.01	<.01	<.01	.02
Nitrogen, Ammonia + Organic (mg/L as N)	.12	<.1	.27	.31	.16	.28	.18	.24	.31	.34
Nitrite + Nitrate, Dissolved (mg/L as N)	.05	<.05	.06	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Phosphorus, Dissolved (mg/L as P)	<.01	<.05	<.01	<.05	<.01	<.05	<.01	<.05	<.01	<.05
Phosphorus, Ortho (mg/L as P)	.01	.01	.01	.01	.01	.01	<.01	<.01	.02	.02
Calcium, Dissolved (mg/L as Ca)	63.9	63.1	48.5	50.5	57.0	57.4	66.1	66.4	59.9	62.0
Magnesium, Dissolved (mg/L as Mg)	23.7	22.6	24.2	24.3	26.7	24.6	36.6	33.6	25.6	25.1
Sodium, Dissolved (mg/L as Na)	6.2	5.9	17.7	15.9	16.5	15.0	13.0	12.0	26.6	23.8

4

**Table 1D.** Seasonal comparison of selected water-quality parameters for samples from selected well in Oakland County, Michigan--Continued  
 [mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius]

Station name	OAK 3		OAK 4		OAK 9		OAK 12		OAK 35	
Station number	425050083310901		425219083264301		425055083374901		425131083363001		424519083081101	
Sample date	6/4/98	12/16/98	6/4/98	12/15/98	6/9/98	12/3/98	6/26/98	12/3/98	7/8/98	12/15/98
Sample time	1225	950	905	1545	1130	1500	1146	1700	1055	1300
Flouride, Dissolved (mg/L as F)	.3	.3	.8	.8	.7	.6	.9	.9	.8	.8
Silica, Dissolved (mg/L as SiO <sub>2</sub> )	16.7	16.2	13.5	14.0	17.6	17.7	19.4	20.1	16.7	16.9
Arsenic, Total (µg/L as As)	27	27	46	48	39	38	56	58	12	13
Iron, Dissolved (µg/L as Fe)	459	577	581	974	746	745	499	504	1245	1201
Manganese Dissolved (µg/L as Fe)	23	20	38	42	17	17	18	15	21	20
Residue, Dissolved, 180°C (mg/L)	294	294	278	270	307	305	350	290	331	343
Bromide, Dissolved (mg/L as Br)	.03	.12	.03	.15	.03	.05	.05	.04	.07	.21
Specific Conductance (µS/cm)	497	509	493	484	513	525	611	609	610	604
Acid Neutralizing Capacity, pH 4.5 (mg/L as CaCO <sub>3</sub> )	268	234	263	255	280	278	332	330	276	276

**Table 1E.** Total arsenic concentrations in drinking water at selected ground-water sampling sites in Oakland County, Michigan  
 [All concentrations are in micrograms per liter; --, No data. Time is measured in seconds from the time water began to flow]

Station name	Oak 41	Oak 9	Oak 12	Oak 35	Oak 4	
Sample date	11/23/98	12/3/98	12/3/98	12/15/98	12/15/98	
Seconds	0	177	17	50	1	47
	30	--	40	--	--	--
	60	180	38	52	2	47
	90	180	--	--	--	--
	120	177	36	50	3	48
	150	181	36	--	--	--
	180	173	37	51	2	47
	210	--	37	--	--	--
	240	194	37	48	10	49
	270	188	--	--	--	--
	300	180	36	58	10	51
	360	172	37	56	11	51
	420	177	37	55	11	53
	480	174	39	53	12	50
	540	--	38	52	11	50
	600	173	38	63	11	49
	660	--	--	--	12	49
	720	179	41	59	11	48
	780	--	--	--	11	51
	840	171	39	56	11	48
	900	--	38	--	12	48
	960	181	40	60	12	49
	1020	--	--	58	12	50
	1080	176	40	58	12	51
	1140	--	--	--	12	50
	1200	176	--	58	11	--
	1260	--	--	--	--	--
	1320	--	--	--	12	--
	1380	--	--	--	12	--
	1440	--	--	--	12	--

**Table 1F.** Total manganese concentrations in drinking water at selected ground water sampling sites in Oakland County, Michigan  
 [All concentrations are in micrograms per liter; -- No data. Time is measured in seconds from the time water began to flow]

Station name	Oak 41	Oak 9	Oak 12	Oak 35	Oak 4	
Sample date	11/23/98	12/3/98	12/3/98	12/15/98	12/15/98	
Seconds	0	59	<10.	15	22	42
	30	--	15	--	--	--
	60	56	17	15	23	45
	90	56	--	--	--	--
	120	57	17	15	23	44
	150	56	16	--	--	--
	180	60	16	14	23	44
	210	--	17	--	--	--
	240	58	16	14	23	44
	270	59	--	--	--	--
	300	59	17	14	24	42
	360	60	16	14	23	43
	420	60	17	14	24	43
	480	61	16	14	24	44
	540	--	16	14	24	43
	600	62	16	13	24	44
	660	--	--	--	24	43
	720	65	16	13	25	44
	780	--	--	--	25	44
	840	62	16	14	23	44
	900	--	--	--	23	44
	960	62	16	12	23	44
	1020	--	--	--	24	44
	1080	63	16	13	24	45
	1140	--	--	--	25	44
	1200	65	--	13	24	--
	1260	--	--	--	--	--
	1320	--	--	--	24	--
	1380	--	--	--	24	--
	1440	--	--	--	23	--

**Table 1G.** Total iron concentrations in drinking water at selected ground water sampling sites in Oakland County, Michigan  
 [All concentrations are in micrograms per liter; -- No data. Time is measured in seconds from the time water began to flow]

Station name	Oak 41	Oak 9	Oak 12	Oak 35	Oak 4	
Sample date	11/23/98	12/3/98	12/3/98	12/15/98	12/15/98	
Seconds	0	4040	38	398	216	1013
	30	--	854	--	--	--
	60	3790	685	413	171	1280
	90	3710	--	--	--	--
	120	3740	668	388	374	1191
	150	3880	676	--	--	--
	180	4095	674	392	432	1260
	210	--	668	--	--	--
	240	4050	674	416	1345	1193
	270	4130	--	--	--	--
	300	4190	671	525	1325	906
	360	4090	670	501	1525	930
	420	4110	676	465	1455	949
	480	3995	696	432	1455	1083
	540	--	687	440	1415	1097
	600	4155	686	553	1500	1114
	660	--	--	--	1440	973
	720	4290	758	491	1370	1005
	780	--	--	--	1390	985
	840	4350	698	462	1365	1001
	900	--	--	--	1325	1138
	960	4235	692	507	1355	1122
	1020	--	--	--	1520	1116
	1080	4115	724	502	1550	1137
	1140	--	--	--	1500	1132
	1200	4265	--	489	1480	--
	1260	--	--	--	--	--
	1320	--	--	--	1570	--
	1380	--	--	--	1470	--
	1440	--	--	--	1480	--

## **APPENDIX 2 – Results of replicate sample analyses by U.S. Geological Survey National Water Quality Laboratory and the Michigan Department of Environmental Quality Drinking Water Laboratory**

### **Mapping Methods**

The maps showing the distribution of nitrate, chloride, and arsenic in Oakland County (figs. 8, 9, and 10, this report) were produced in collaboration with the Center for Applied Environmental Research at the University of Michigan – Flint (CAER). Results of water-quality analyses by the MDEQ Drinking Water Laboratory were checked by manual and automated methods for accuracy and completeness by CAER. Results were then sorted to identify unique wells. If two or more samples were analyzed from any one well, the highest value was retained. These unique wells were then assigned a geographic coordinate location using the Geocoding process in ArcView 3.1 (Environmental Systems Research Institute, 1998). In each case, some fraction of the unique wells identified did not contain sufficient address information to obtain a unique position.

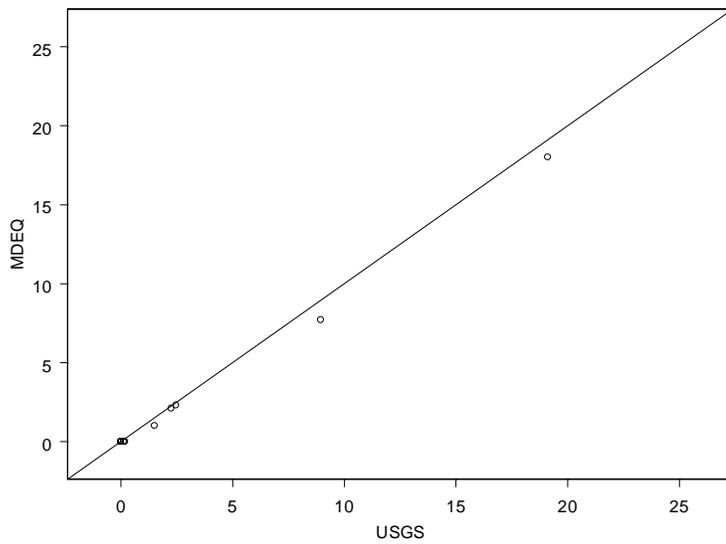
These point files were then spatially joined to an Oakland County section map provided by Michigan Department of Natural Resources. Once each point had been assigned to a section, the highest concentration value for the section was determined from the database, and the section classified. For points exceeding the Maximum Contaminant Level (MCL) or the Secondary Maximum Contaminant Level (SMCL), a buffer of one-quarter mile was placed around the well head. Any section that entered the buffer was reclassified into the MCL or SMCL exceedance class. This classification superceded any previous classification.

Geocoding, development of mapping methods, and production of maps for USGS Fact Sheet 135-98 (Aichele and others, 1998) was performed by the CAER. Production of the maps seen in this report used the same data bases and methods, but maps were modified to meet USGS publication guidelines.

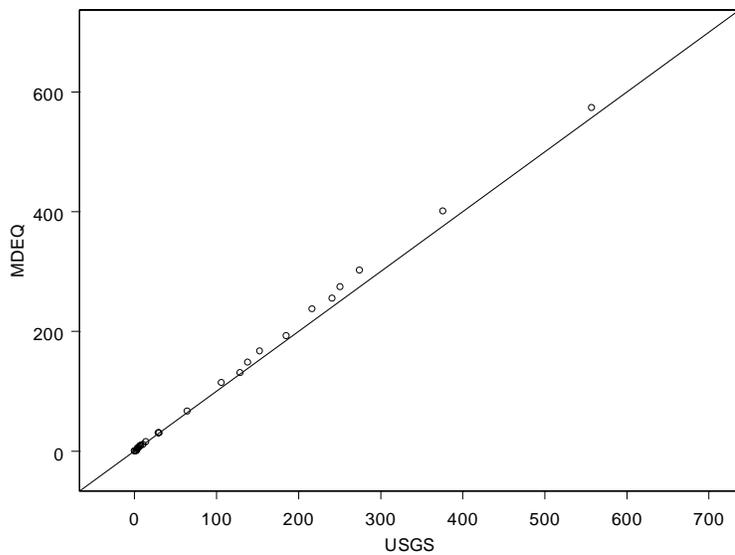
### **Replicate Sample Analysis**

Twenty-six replicate samples were collected for analysis by the MDEQ Drinking Water Laboratory. Samples were collected from sites with a wide variety of concentration levels for each constituent, based on the results of previous water-quality analyses. The purpose of this activity was to provide a basis for comparison between USGS analytical results for arsenic, nitrate and chloride and the results obtained by the MDEQ. Neither laboratory was informed that a replicate sample was being analyzed elsewhere. Collection procedures were identical, and samples were handled in accordance with each laboratory's specified procedures, including limitations on holding times in the case arsenic and nitrate. Graphs of the results of these analyses are presented in the figures A2.1, A2.2, and A2.3.

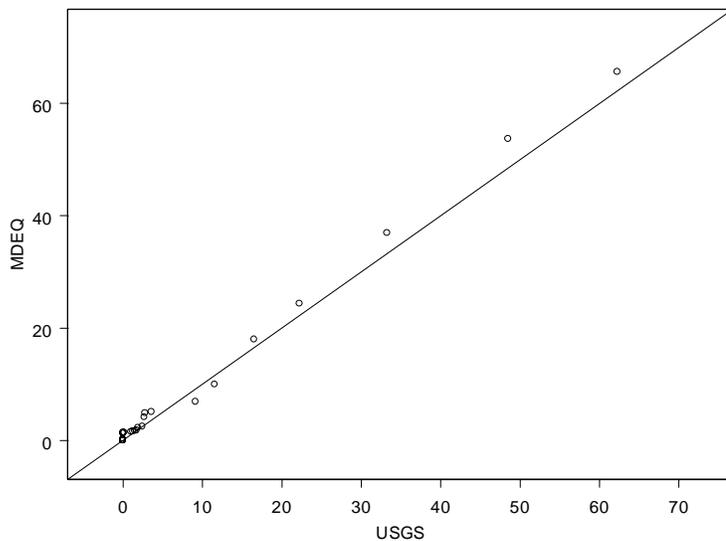
The mean difference between the USGS results and the MDEQ results was 0.1, 6.8 and 0.0008 mg/ L for nitrate, chloride, and arsenic, respectively. The standard deviation of the differences was 0.3, 9.6, and 0.003 for nitrate, chloride, and arsenic, respectively.



**Figure 2A.** Nitrate concentrations as determined by the Michigan Department of Environmental Quality Drinking Water Laboratory (MDEQ) and the U.S. Geological Survey National Water Quality Laboratory (USGS). Concentrations in milligrams per liter as nitrogen.



**Figure 2B.** Chloride concentrations as determined by the Michigan Department of Environmental Quality Drinking Water Laboratory (MDEQ) and the U.S. Geological Survey National Water Quality Laboratory (USGS). Concentrations in milligrams per liter.



**Figure 2C.** Arsenic concentrations as determined by the Michigan Department of Environmental Quality Drinking Water Laboratory (MDEQ) and the U.S. Geological Survey National Water Quality Laboratory (USGS). Concentrations in micrograms per liter.

**Table 2A.** Analytical results of nitrate and nitrite analyses from the U.S. Geological Survey National Water Quality Laboratory and the Michigan Department of Environmental Quality Drinking Water Laboratory  
 [USGS, U.S. Geological Survey National Water Quality Laboratory; MDEQ, Michigan Department of Environmental Quality Drinking Water Laboratory; mg/L, milligrams per liter; --, no data]

Station ID	USGS Nitrite (mg/L as N)	USGS Nitrite + Nitrate (mg/L as N)	MDEQ Nitrite (mg/L as N)	MDEQ Nitrate (mg/L as N)
423307083290201	<0.01	0.0	<0.05	<0.4
424144083074701	<.01	.0	<.05	<.4
425221083374101	--	--	<.05	<.4
425131083363001	<.01	.0	<.05	<.4
425033083165701	.01	23.9	<.05	23
425157083083001	<.01	.0	<.05	<.4
423105083173201	<.01	.0	<.05	<.4
423334083293601	<.01	.0	<.05	<.4
423847083265601	<.01	.0	<.05	<.4
423036083182701	<.01	.0	<.05	<.4
423343083292101	<.01	.0	<.05	<.4
423108083173801	<.01	.0	<.05	<.4
423817083365501	.03	2.12	<.05	2
424505083205901	<.01	2.56	<.05	2.4
423600083262301	<.01	.20	<.05	<.4
424315083183901	.01	14.00	<.05	13
424048083243201	<.01	.16	<.05	<.4
424519083081101	<.01	.0	<.05	<.4
422850083230101	<.01	.0	<.05	<.4
424308083245701	<.01	.0	<.05	<.4
425042083083101	<.01	.0	<.05	<.4
424319083315701	<.01	.0	<.05	<.4
425218083375001	<.01	.0	<.05	<.4
424323083250501	<.01	.0	<.05	<.4
424504083324901	<.01	.0	<.05	<.4
425046083083601	<.01	2.34	<.05	2.2

**Table 2B.** Analytical results of chloride analyses from the U.S. Geological Survey National Water Quality Laboratory and the Michigan Department of Environmental Quality Drinking Water Laboratory  
 [USGS, U.S. Geological Survey National Water Quality Laboratory; MDEQ, Michigan Department of Environmental Quality Drinking Water Laboratory; mg/L, milligrams per liter; --, no data]

Station ID	MDEQ Chloride (mg/L)	USGS Chloride (mg/L)
422850083230101	30	29.2
423036083182701	256	248.5
423108083173801	199	194.4
423307083290201	<4	0.9
423334083293601	314	289.2
423343083292101	252	225.6
423600083262301	132	131.6
423817083365501	171	156.2
423847083265601	284	252.5
424048083243201	68	66.0
424144083074701	0	3.5
424308083245701	14	13.0
424315083182801	--	68.2
424315083183901	118	109.8
424319083315701	9	7.7
424323083250501	7	6.1
424504083324901	4	3.5
424505083205901	151	139.5
424519083081101	30	30.5
425033083165701	670	661.4
425042083083101	10	10.4
425046083083601	4	4.1
425131083363001	<4	0.6
425157083083001	469	444.2
425218083375001	8	6.9
425221083374101	<4	--

**Table 2C.** Analytical results of arsenic analyses from the U.S. Geological Survey National Water Quality Laboratory and the Michigan Department of Environmental Quality Drinking Water Laboratory  
 [USGS, U.S. Geological Survey National Water Quality Laboratory; MDEQ, Michigan Department of Environmental Quality Drinking Water Laboratory; mg/L, milligrams per liter]

Station ID	USGS Total Arsenic (mg/L as As)	MDEQ Total Arsenic (mg/L as As)
423307083290201	0.003	0.0014
424144083074701	<.001	<.0001
425221083374101	.068	.0698
425131083363001	.056	.0612
425033083165701	<.001	.0075
425157083083001	.002	.0025
423334083293601	<.001	<.0001
423847083265601	.001	.0016
423036083182701	.002	.0023
423343083292101	<.001	.0012
423108083173801	.001	.0014
423817083365501	<.001	<.0001
424505083205901	<.001	<.0001
423600083262301	<.001	<.0001
424315083183901	<.001	<.0001
424048083243201	.003	.0051
424519083081101	.012	.0018
422850083230101	.004	.0050
424308083245701	.024	.0261
425042083083101	.019	.0214
424319083315701	.000	.0015
425218083375001	.039	.0443
424323083250501	.011	.0110
424504083324901	.003	.0044
425046083083601	<.001	<.0001
424315083182801	.002	.0017