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Forest Lake – Lake Board Water Quality Assessment

Prepared By: Hubbell, Roth, & Clark
555 Hulet Dr.
Bloomfield Hills, MI 48302

October 18, 2014



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October 18, 2014

Forest Lake – Lake Board
c/o: Bloomfield Township
4200 Telegraph Road
Bloomfield Township, Michigan 48303-0489

Attn: Mr. Leo Savoie, Chairperson for the Forest Lake – Lake Board

Re: Forest Lake Water Quality Assessment

HRC Job No. 20140142.02

Dear Mr. Savoie,

Hubbell, Roth and Clark, Inc. (HRC) is pleased to provide this report summarizing our findings concerning the assessment on the quality of the water in Forest Lake. HRC has prepared this report with technical assistance from the Michigan Department of Environmental Quality (MDEQ), Water Resources Division, several contractors who have conducted water quality testing on similar lakes in southeast Michigan, including Forest Lake, and published internet resources.

Project Understanding

Riparian property owners around Forest Lake are concerned about the condition of the lake, more specifically towards its water quality. For several years the residents have retained LakePro Inc., an aquatic services company, to sample the water and provide a report on the Lake's overall water quality. HRC has reviewed the LakePro reports and attempted to discuss the findings with the author on several occasions, without success. While the report documents the current (2013) status of the lake's water quality, the residents petitioned the established Lake Board to review the matter with the intent of potentially taking corrective actions, if necessary.

Background Research

The oversight of the surface water quality in the State of Michigan lies with the Michigan Department of Environmental Quality (MDEQ), Water Resources Division. The protocol used by the MDEQ to assess water quality was developed by the US EPA and is referred to as the Carlson Trophic State Index (TSI). The Carlson's TSI is used to classify Michigan's 730 public access lakes, but is also used on other lakes as needed. This classification system is based on an index derived from a combination of four field measurements:

- (1) summer Secchi depth (transparency);
- (2) total phosphorus concentration (epilimnetic);
- (3) chlorophyll-a concentration (photic zone), and
- (4) macrophyte abundance.

The numerical value of the index increases as the degree of eutrophication (productive and fertile with low clarity and high chlorophyll-a, and phosphorus concentration) increases. When compared to the TSI index, Forest Lake appears to fall into the mesotrophic classification or very productive and fertile with low clarity and high chlorophyll-a and phosphorus concentrations. Forest Lake reflects quantitative data for 2013 as retaining mostly moderate levels of all listed water quality parameters.

Data Collected

Historically, inland lake monitoring efforts have been directed toward obtaining baseline data for all 730 public access lakes. During 2011 and 2012, over 200 lakes were sampled each year as part of the Cooperative Lakes Monitoring Program, under the Michigan Clean Water Corps. Forest Lake, having no public access was not sampled under this program. However, a review of the Forest Lake water quality data was compared to nearby lakes that were sampled. Salinity levels are of primary concern for residents. HRC has taken the initiative to analyze water quality parameters such as chloride content, total phosphorus, and nitrates that have potential in impacting Forest Lake's overall water quality. We aim to define the lake classification for Forest Lake and identify trends in water quality data over a three year time period in addition to performing data comparisons among other Oakland County inland lakes.

Data on salinity, chloride, total phosphorus and nitrates was documented for the 2013 sampling year. With the exception of chloride and transparency lake measures, it should be noted that the Lake's nutrient levels, as stated in the LakePro Inc. report are trending downward. The chart also indicated that the downward trend is also occurring in other nearby lakes (both Upper and Lower Long Lakes). Attached to this letter is a spreadsheet which provides water quality data for several nearby Oakland County lakes for comparison to Forest Lake (See Attachment A).

In order to verify that Forest Lake's water quality parameters were in fact on the decline, data from three consecutive years (2011-2013) were compared. Samples from five different locations throughout the lake were taken and recorded. In a graphical representation, the overall trend of chlorides and other nutrients is decreasing (See Attachment B).

Water Quality Impacts

Forest Lake is a 50 acre lake with a several square mile surface drainage area. Stormwater runoff and groundwater recharge flow into Forest Lake and contribute to impacts on water quality. The constituents of the geological materials for the bedrock in the Forest Lake region are likely high in sulfate, iron, chloride, and other dissolved solids that contribute to higher calcium chloride content in the water which directly affects the salinity of Forest Lake (See Attachment C).

Habits of residents and communities have a significant impact on water quality of nearby lakes. Utilizing excessive salt on the roads throughout the winter season increases chloride levels, while over-fertilizing vegetation during the summer months increases unwanted algae growth (See Attachment D).

Recommendations

Due to the relatively good quality of the water in Forest Lake and evidence that the levels of nitrates, total phosphorus, and chloride are in fact improving (levels are trending downward), we recommend that at this time no further actions are necessary except to continue monitoring the water quality. With no additional projects being proposed for changing Forest Lake water quality conditions, a cost estimate is not

Mr. Leo Savoie
October 18, 2014
HRC Job Number 20140142.86
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practical at this time. To alleviate the concerns of Forest Lake property owners and other residents in the Forest Lake District, we also recommend the implementation or continuation of a public education program. The Lake Board may elect to partner with the Township, the Oakland County Water Resources Commissioner (OCWRC), or other communities that have a lake focused public education plan already implemented or create their own by allowing expert professionals to conduct workshops and training sessions specifically for resident attendance.

HRC sincerely appreciates the opportunity to submit this report for the Lake Board for Forest Lake, Bloomfield Township, and the residents within the Forest Lake District. If you have any questions or require any additional information, please contact the undersigned at (248) 454-6370.

Very truly yours,

HUBBELL, ROTH & CLARK, INC.



For/ Derek J. Stratelak
Senior Project Manager

DJS/ds

pc: Bloomfield Township; W. Domine
HRC; T.Biehl, R. Ford, J. Burton

Attachments

Attachment A - Oakland County Lake Data

Forest Lake (50 acres)				
Year	Water Quality Component	Value	Unit	Trend
2013	Salinity		ppm	
2013	Chloride	298	ppm	Decline
2013	Total Phosphorus	76	ppb	Decline
2013	Nitrate	299	ppb	Decline
2013	Temperature	71.3	°F	Decline
2013	Dissolved Oxygen	7.7	mg/L	Decline
2013	Phosphate	47	ppb	Decline
2013	Chlorophyll-a	2.1	ppb	Decline
2013	Transparenc	9.8	feet	Decline
2013	pH	8.1	SU	Decline
2013	Total Dissolved Solids	479	ppm	Decline
2013	Conductivity	959	ppm	Decline
2013	Alkalinity	122	ppm	Decline
2013	Sulfate	16.6	ppm	Decline
2013	Fluoride	0.1	ppm	Decline

Pine Lake (30 acres) - data analyzed from STA 10 only				
Year	Water Quality Component	Value	Unit	Trend
Aug-11	Salinity		ppm	
Aug-11	Chloride	108	ppm	
Aug-11	Total Phosphorus	46.6	ppb	
Aug-11	Nitrate	360	ppb	
Aug-11	Temperature @ depth 16.4 ft	77	°F	
Aug-11	Dissolved Oxygen @ depth 16.4 ft	9.2	mg/L	
Aug-11	Phosphate		ppb	
Aug-11	Chlorophyll-a		ppb	
Aug-11	Transparenc		feet	
Aug-11	pH		SU	
Aug-11	Total Dissolved Solids		ppm	
Aug-11	Conductivity		ppm	
Aug-11	Alkalinity		ppm	
Aug-11	Sulfate		ppm	
Aug-11	Fluoride		ppm	

Upper Long Lake (131 acres)				
Year	Water Quality Component	Value	Unit	Trend
Oct-13	Salinity		ppm	
Oct-13	Chloride	81	ppm	
Oct-13	Total Phosphorus		ppb	
Oct-13	Nitrate	0	ppb	
Oct-13	Temperature		°F	
Oct-13	Dissolved Oxygen		mg/L	
Oct-13	Phosphate		ppb	
Oct-13	Chlorophyll-a		ppb	
Oct-13	Transparenc		feet	
Oct-13	pH	8.05	SU	
Oct-13	Total Dissolved Solids	423	ppm	
Oct-13	Conductivity		ppm	
Oct-13	Alkalinity	130	ppm	
Oct-13	Sulfate	14	ppm	
Oct-13	Fluoride	0.29	ppm	

Lower Long Lake (191 acres)				
Year	Water Quality Component	Value	Unit	Trend
2013	Salinity		ppm	
2013	Chloride	192	ppm	Decline
2013	Total Phosphorus	70	ppb	Decline
2013	Nitrate	211	ppb	Decline
2013	Temperature	70.7	°F	Decline
2013	Dissolved Oxygen	7.6	mg/L	Decline
2013	Phosphate	23	ppb	Decline
2013	Chlorophyll-a	2.3	ppb	Decline
2013	Transparenc	18.3	feet	Decline
2013	pH	8.17	SU	Decline
2013	Total Dissolved Solids	375	ppm	Decline
2013	Conductivity	750	ppm	Decline
2013	Alkalinity	115	ppm	Decline
2013	Sulfate	16	ppm	Decline
2013	Fluoride	0.06	ppm	Decline

Island Lake (111 acres)				
Year	Water Quality Component	Value	Unit	Trend
2013	Salinity		ppm	
2013	Chloride	144	ppm	Decline
2013	Total Phosphorus	38	ppb	Decline
2013	Nitrate	211	ppb	Decline
2013	Temperature	71.8	°F	Decline
2013	Dissolved Oxygen	7.5	mg/L	Decline
2013	Phosphate	19	ppb	Decline
2013	Chlorophyll-a	3.1	ppb	Decline
2013	Transparenc	8.9	feet	Incline
2013	pH	8.6	SU	Decline
2013	Total Dissolved Solids	359	ppm	Decline
2013	Conductivity	717	ppm	Decline
2013	Alkalinity	120	ppm	No Change
2013	Sulfate	15.2	ppm	No Change
2013	Fluoride	0.1	ppm	Decline

Salinity (ppm)		
	Min	Max
Lake Pro	0	500
WQTS - Highly Saline	10,000	35,000
WQTS - Moderately Saline	3,000	10,000
WQTS - Slightly Saline	1,000	3,000
WQTS - Freshwater	0	1,000

Dissolved Oxygen (mg/L)		
	Min	Max
Lake Pro	4	12
Intro to Enviro Eng.	4	9

Total Dissolved Solids (ppm)		
	Min	Max
Lake Pro	0	1,000
Iowa DNR	0	1,000
WQTS	25	500

Sources	
Lake Pro - Data Ranges from Oakland County Lake Reports	
EPA - Standards on the EPA website	
Wyoming DEQ - Water Quality Rules and Regulations Chapter 1	
Intro to Enviro Eng Textbook - 2006 4th Edition	
Iowa DNR - 2009 Water Quality Standards Review	
USGS - Sulfate Presentation	
WQTS - "Water Quality Tests Summary" (link below)	
http://www.sasta.asn.au/v2/adc/datalogging/DataSinglePagePDFs/ADCBookDatalog13-23.pdf	
Indiana.edu - "Water Chemistry Field Measurements" (link below)	
http://www.indian.edu/~ereg444/Field%20Water%20Chemistry.pdf	
Missouri DNR - 2014 Regulations	

Chloride (ppm)		
	Min	Max
Lake Pro	0	230
WQTS	0	250
EPA	0	230

Phosphate (ppb)		
	Min	Max
Lake Pro	0	100
WQTS	0	100

Conductivity (ppm)		
	Min	Max
Lake Pro	0	1500
Indiana.edu	1	66
EPA	100	330

Total Phosphorus (ppb)		
	Min	Max
Lake Pro	0	100
Intro to Enviro Eng.	10.9	95.6

Chlorophyll-a (ppb)		
	Min	Max
Lake Pro	0	7
Intro to Enviro Eng.	3	11

Alkalinity (ppm)		
	Min	Max
Lake Pro	100	250

Nitrate (ppb)		
	Min	Max
Lake Pro	0	1,000
WQTS	0	1,000
Wyoming DEQ	0	1,000

Transparency (feet)		
	Min	Max
Lake Pro		> 6.5
Intro to Enviro Eng.	1.5	8.1

Sulfate (ppm)		
	Min	Max
Lake Pro	3	30
USGS	0	50

Temperature (°F)		
	Min	Max
Lake Pro		< 75
Missouri DNR		68

pH (SU)		
	Min	Max
Lake Pro	7	9
EPA	6.5	9
WQTS	6.5	8.2

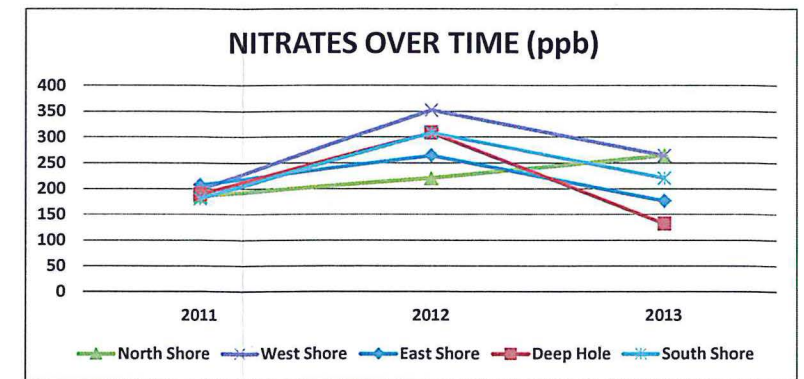
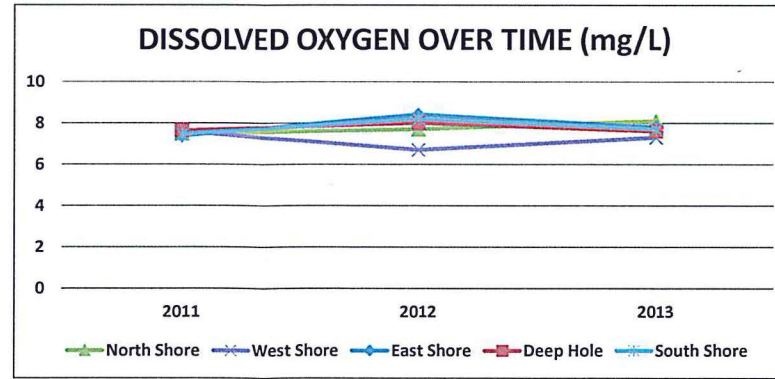
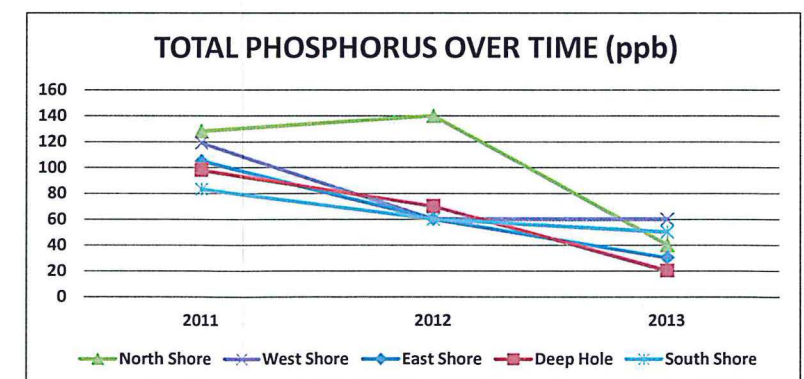
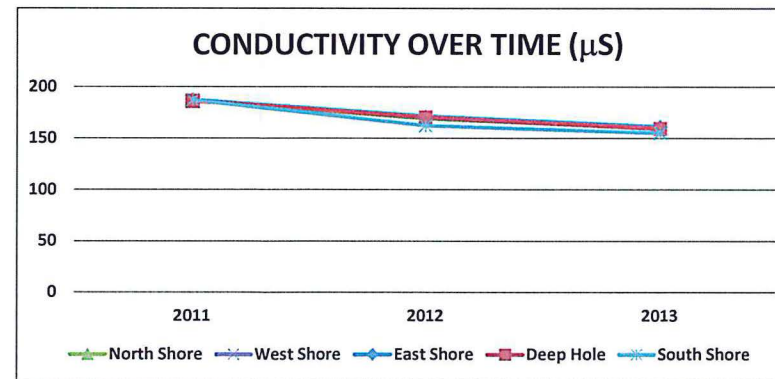
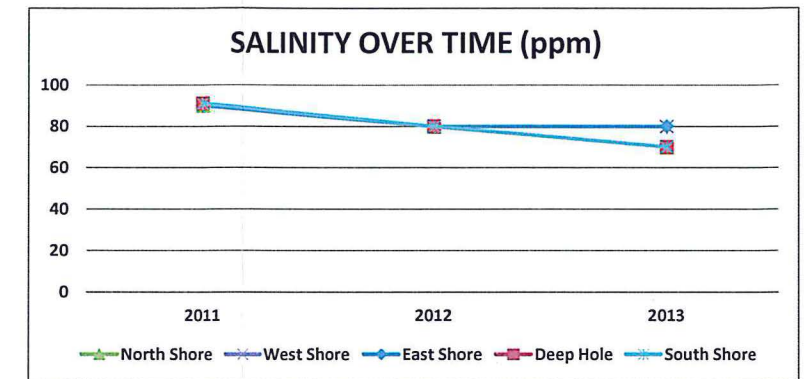
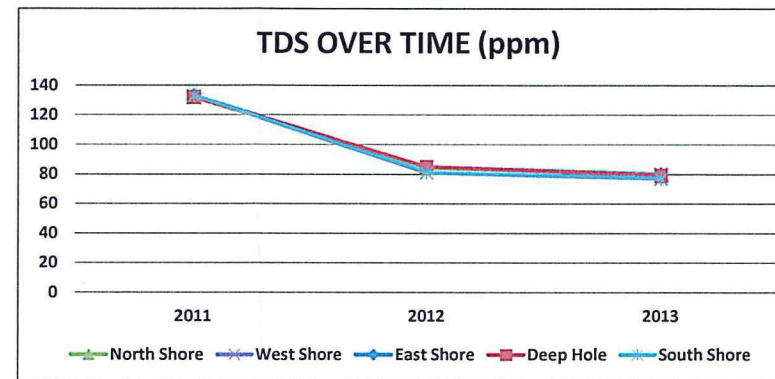
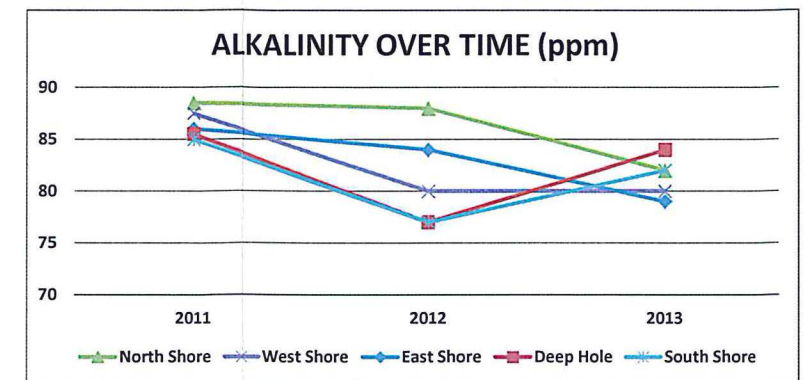
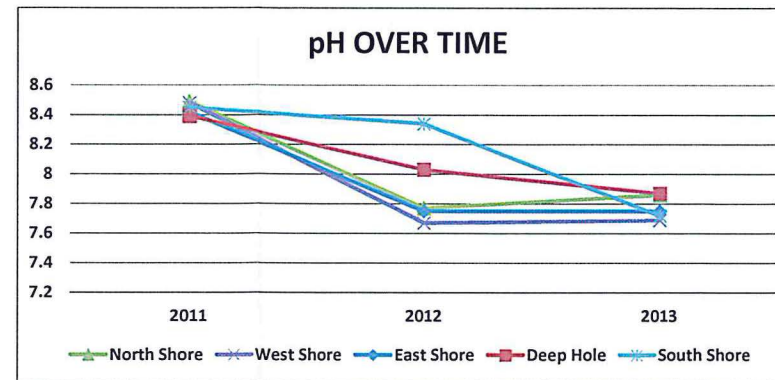
Fluoride (ppm)		
	Min	Max
Lake Pro	0.01	0.30
Wyoming DEQ	0	2

Attachment B - Forest Lake Data 2011-2013

2011	
East Shore	
Temperature	21.9 °C
Transparency	8.35 Feet
pH	8.42
TDS	133 ppm
Conductivity	187 µS
Dissolved Oxygen	7.38 mg/L
Alkalinity	86 ppm
Hardness	98.5 ppm
Salinity	90 ppm
Total Phosphorus	105 ppb
Nitrates	207 ppb
Deep Hole	
Temperature	22.1 °C
Transparency	9.1 Feet
pH	8.39
TDS	132 ppm
Conductivity	186 µS
Dissolved Oxygen	7.63 mg/L
Alkalinity	85.5 ppm
Hardness	103 ppm
Salinity	91 ppm
Total Phosphorus	98 ppb
Nitrates	189 ppb
North Shore	
Temperature	22 °C
Transparency	9.45 Feet
pH	8.49
TDS	132 ppm
Conductivity	186 µS
Dissolved Oxygen	7.48 mg/L
Alkalinity	88.5 ppm
Hardness	97.5 ppm
Salinity	90 ppm
Total Phosphorus	128 ppb
Nitrates	185 ppb
West Shore	
Temperature	22.2 °C
Transparency	9.05 Feet
pH	8.48
TDS	133 ppm
Conductivity	187 µS
Dissolved Oxygen	7.59 mg/L
Alkalinity	87.5 ppm
Hardness	101.5 ppm
Salinity	91 ppm
Total Phosphorus	119 ppb
Nitrates	198 ppb
South Shore	
Temperature	22 °C
Transparency	8.3 Feet
pH	8.45
TDS	133 ppm
Conductivity	187 µS
Dissolved Oxygen	7.45 mg/L
Alkalinity	85 ppm
Hardness	101 ppm
Salinity	91 ppm
Total Phosphorus	83 ppb
Nitrates	180 ppb

2012	
East Shore	
Temperature	19.1 °C
Transparency	11.1 Feet
pH	7.75
TDS	85 ppm
Conductivity	171 µS
Dissolved Oxygen	8.4 mg/L
Alkalinity	84 ppm
Hardness	112 ppm
Salinity	80 ppm
Total Phosphorus	60 ppb
Nitrates	264 ppb
Deep Hole	
Temperature	18.9 °C
Transparency	10.8 Feet
pH	8.03
TDS	85 ppm
Conductivity	170 µS
Dissolved Oxygen	8 mg/L
Alkalinity	77 ppm
Hardness	106 ppm
Salinity	80 ppm
Total Phosphorus	70 ppb
Nitrates	308 ppb
North Shore	
Temperature	19.3 °C
Transparency	9.75 Feet
pH	7.77
TDS	84 ppm
Conductivity	169 µS
Dissolved Oxygen	7.7 mg/L
Alkalinity	88 ppm
Hardness	118 ppm
Salinity	80 ppm
Total Phosphorus	140 ppb
Nitrates	220 ppb
West Shore	
Temperature	19.1 °C
Transparency	8 Feet
pH	7.67
TDS	85 ppm
Conductivity	171 µS
Dissolved Oxygen	6.7 mg/L
Alkalinity	80 ppm
Hardness	111 ppm
Salinity	80 ppm
Total Phosphorus	60 ppb
Nitrates	352 ppb
South Shore	
Temperature	18.9 °C
Transparency	8.8 Feet
pH	8.34
TDS	81 ppm
Conductivity	162 µS
Dissolved Oxygen	8.2 mg/L
Alkalinity	77 ppm
Hardness	104 ppm
Salinity	80 ppm
Total Phosphorus	60 ppb
Nitrates	308 ppb

2013	
East Shore	
Temperature	20.8 °C
Transparency	11.6 Feet
pH	7.75
TDS	80 ppm
Conductivity	161 µS
Dissolved Oxygen	7.8 mg/L
Alkalinity	79 ppm
Hardness	94 ppm
Salinity	80 ppm
Total Phosphorus	30 ppb
Nitrates	176 ppb
Deep Hole	
Temperature	20.8 °C
Transparency	12.6 Feet
pH	7.87
TDS	79 ppm
Conductivity	159 µS
Dissolved Oxygen	7.6 mg/L
Alkalinity	84 ppm
Hardness	103 ppm
Salinity	70 ppm
Total Phosphorus	20 ppb
Nitrates	132 ppb
North Shore	
Temperature	21 °C
Transparency	12.1 Feet
pH	7.86
TDS	80 ppm
Conductivity	160 µS
Dissolved Oxygen	8.1 mg/L
Alkalinity	82 ppm
Hardness	99 ppm
Salinity	70 ppm
Total Phosphorus	40 ppb
Nitrates	264 ppb
West Shore	
Temperature	20.7 °C
Transparency	10.4 Feet
pH	7.69
TDS	80 ppm
Conductivity	160 µS
Dissolved Oxygen	7.3 mg/L
Alkalinity	80 ppm
Hardness	98 ppm
Salinity	80 ppm
Total Phosphorus	60 ppb
Nitrates	264 ppb
South Shore	
Temperature	20.8 °C
Transparency	10.6 Feet
pH	7.72
TDS	77 ppm
Conductivity	155 µS
Dissolved Oxygen	7.7 mg/L
Alkalinity	82 ppm
Hardness	97 ppm
Salinity	70 ppm
Total Phosphorus	50 ppb
Nitrates	220 ppb





Water Resources of Michigan

Ground-Water Quality Atlas of Oakland County, Michigan

US Geological Survey Water-Resources Investigation 00-4120
Lansing, Michigan August 2000

By: *Stephen Scranton Aichele*

Table of Contents including Figures, Maps, Graphs, Tables, Appendix, Conversion Factors and Vertical Datum, and Additional Information.

<http://mi.water.usgs.gov/pubs/WRIR/WRIR01-4120/WRIR00-4120TOC.php>

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

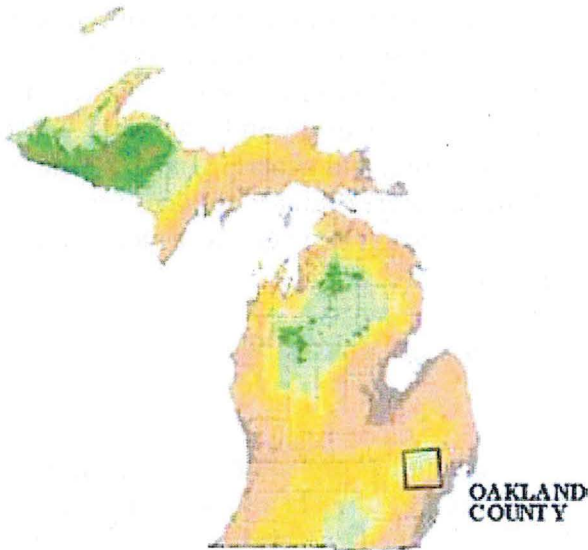
The author gratefully acknowledges the assistance of Dr. Thomas Gordon, Robert Long, and Karen Kubik of Oakland County Health and Human Services in obtaining historical data, coordinating access to sample sites, and providing background information for interpreting the water-quality data. Scott Oppmann 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	1978
	(percent)	(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
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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).

[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.

[Image of: 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. \(68 KB\)](#)

[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 ground-water discharge to the river through the streambed (Holtschlag and Nicholas, 1998).

[Image of: The 1,600 lakes in Oakland County are important hydrologic and recreational resources. \(87 KB\)](#)

[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.

[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 (HCO_3^-), an ion formed when calcium carbonate is dissolved by infiltrating water, has been shown to encourage the dissolution of arsenic (Kim, 1999).

[Image of: 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. \(89 KB\) \(Photo courtesy of R.J. Schaetzl.\)](#)

[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.

[Image of: Domestic wells like this one provide drinking water to more than 233,000 Oakland County residents. \(73 KB\)](#)

[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.

[Image of: Sampling equipment in use outside a community water supply well in Oakland county, Michigan. \(60 KB\)](#)

[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 polyethylene (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

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

Parameter Name	Units	MRL	Parameter Code	Method	Reference
Specific Conductance	$\mu\text{S}/\text{cm}$	1	90095	I278185	Fishman and Friedman, 1989
pH, Laboratory	Standard Units	0.1	403	I258785	Fishman and Friedman, 1989
					Fishman

Total Residue @ 180 oC	mg/L	1	530	I376585	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 ₃	1	90410	I203085	Fishman and Friedman, 1989
Sulfate, dissolved	mg/L as SO ₄	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 ₂	0.1	955	I270085	Fishman and Friedman, 1989
Residue, dissolved 180oC	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	0.001	1002	I406398	Brown, 1998
Arsenic, total, EPA	mg/L as As	0.001	1002D	EPA 200.9	U.S.EPA, 1993
Iron, total*	mg/L as Fe	0.014	1045	I447197	Garberino and Struzeski, 1998
Iron, dissolved	mg/L as Fe	0.01	1046	I147287	Fishman, 1993
Manganese, total*	mg/L as Mn	0.003	1055	I447197	Garberino and Struzeski, 1998
Manganese, dissolved	mg/L as Mn	0.003	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 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, 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 SO ₄ ⁻	SMCL
Flouride	4	mg/L as F	SMCL
Arsenic	0.05	mg/L as As	MCL
Iron	0.3	mg/L as Fe	SMCL
Manganese	0.05	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; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25°C]

	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	0.19	0.14
Nitrogen, Nitrite (mg/L as N)	0.1	<.01	0.01	<.01
Nitrogen, Ammonia + Organic (mg/L as N)	1.52	<.01	0.22	0.15
Nitrogen, Nitrate + Nitrite, dissolved (mg/L as N)	23.9	<.05	0.9	<.05
Phosphorus, dissolved (mg/L as P)	0.5	<.004	0.02	<.004
Phosphorus, ortho (mg/L as P)	0.5	<.01	0.02	<.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	27.5
Sodium, dissolved (mg/L as Na)	431	3.73	66	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 SO ₄ ⁻)	80.7	1.26	29.8	18.5
Flouride, dissolved (mg/L as F)	1.1	<.1	0.4	0.2
Silica, dissolved (mg/L as SiO ₂)	23	9.25	14.7	14.3
Arsenic, total (mg/L as As)	0.176	<.001	0.021	0.003
Iron, dissolved (mg/L as Fe)	3.58	<.014	1.09	0.927
Manganese, dissolved (mg/L as Mn)	0.33	<.003	0.055	0.032
Dissolved Residue of Evaporation, 180°C (mg/L)	1620	228	529	387
Bromide, dissolved (mg/L as Br)	5.5	0.01	0.24	0.06
Specific Conductance, (µs/cm)	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 (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 (NO_3^-) and nitrite (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 (Kittleston, 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 (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 (NO_3^-) and nitrite (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 NO_3^- and 3.3 mg/L as NO_2^- .

[Image of: USGS scientists use clean sampling techniques to collect water for analysis from a residential well, Oakland County, Michigan. \(80 KB\)](#)

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.

[Image of: Collection of water samples for analysis, Oakland county, Michigan. \(122 KB\)](#)

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).

[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 (As^{5+}), or the reduced form, arsenite (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 (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.

[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 $\mu\text{g/L}$ 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.

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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](#)

[Table 1B](#)

[Table 1C](#)

[Table 1D](#)

[Table 1E](#)

[Table 1F](#)

[Table 1G](#)

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 superseded 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.

[Table 2A](#)

[Table 2B](#)

[Table 2C](#)

[Figure 2A](#)

[Figure 2B](#)

[Figure 2C](#)

Citation:

[Aichele, S.S., 2000, Ground-Water Quality Atlas of Oakland County, Michigan US Geological Survey Water-Resources Investigation Report 00-4120](#)

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3

EFFECTS OF DEICING MATERIALS ON NATURAL RESOURCES, VEHICLES, AND HIGHWAY INFRASTRUCTURE

This chapter evaluates the effects of deicing materials on the natural resources and on structures with which the deicers come into contact. For each of the 11 components present in one or more of the evaluated materials, the available geochemical and toxicological information are summarized, and the corrosive effects on vehicles and the highway infrastructure and corrosivity rates of each deicing material also are discussed.

GEOCHEMICAL CHARACTERISTICS AND POTENTIAL TOXICOLOGICAL EFFECTS

A basic understanding of the characteristics, transport, fate, and ecological impacts of each deicing material is necessary to make an informed decision on whether to adopt deicing alternatives. Each deicing material evaluated in this report contains one or more of the following components: chloride (Cl), sodium (Na), acetate ($C_2H_3O_2$), calcium (Ca), magnesium (Mg), nitrogen (N), potassium (K), phosphorous (P), silicon (Si), sulfur (S), and zinc (Zn). For each, a geochemical and toxicological evaluation is made. (The deicing materials and their primary components are listed in Exhibit 3.1.) Information on the six primary components (chloride, sodium, acetate, calcium, magnesium, and potassium) as well as sand is presented in considerable detail. Information on the four secondary components (phosphorous, nitrogen, sulfate, and zinc), which may be present in deicer in very small amounts, is presented in less detail. Heavy metals-sometimes present in very small amounts on road

Exhibit 3.1: Primary Components of Selected Deicing Materials

Deicing Material	Component ²	Component Concentration
Calcium magnesium acetate (CMA)	Ca, Mg, $C_2H_3O_2$	91%
Calcium chloride	Ca, Cl	>90
Calcium chloride (Verglimit)	Ca, Cl	3.5 to 1.5
Sodium chloride (road salt)	Na, Cl	= 95
Corrosion inhibitor (CC-90 Surface Saver)	Na, Cl and Mg, Cl	75 23
Potassium chloride (CMS-B/Motech)	K, Cl	Unknown
Sand	Si, 0	= 95

SOURCE: Public Sector Consultants.
² Ca = calcium; Mg = magnesium; $C_2H_3O_2$ = acetate; Cl = chloride; Na = sodium; K = potassium; Si = silicon.

surfaces and in roadside soils-also are discussed. Exhibit 3.2 presents a summary of the effects of each deicer on the environment.

General Processes

This section provides an overview of the terms, processes, and impacts referred to in the evaluations of the specific components.

Characterization/Transport/Fate

The *characterization* of each deicing component includes a description of its composition, sources, and natural abundance in the environment. *Transport* refers to the manner by which a deicing material and its components travel from the road surface to the environment; also described are factors that influence the mode of transport. Exhibit 3.3 illustrates the transport of the deicers to the environment. *Fate* explains how a component is reconfigured and incorporated into the environment.

Transport from Road Surface to Roadside

As indicated in Exhibit 3.3, there are several pathways by which the deicers may be transported; all are transported off the roadway by one or more of these means. Following application, the deicer may remain on the road and eventually dry. Once dried, the material can be suspended by the movement of vehicles and blown off the road. The airborne material then falls onto roadside foliage, the ground, and adjacent water bodies.

Some deicing material stays on the road surface (this is referred to as *residual material*) until rainfall mixes with it and a solution is formed. The solution either flows off the road or remains and is sprayed and splashed off the road by vehicles.¹ Generally, the spray/splash either is blown downwind to vegetation within 15 meters of the road or back onto the road or roadside soil.² The amount of deicer transported by splash/spray often depends on the volume and speed of traffic.³

The largest volume of deicer is transported to the roadside in solution running off the highway and by snowplowing. The runoff immediately following the first rainfall after application is highest in deicer concentration; as time passes and more rain falls, the concentration rapidly decreases.⁴ Plowing often moves deicing materials held in snow and ice from the road surface to the roadside, where frequently they combine with water and dissolve.

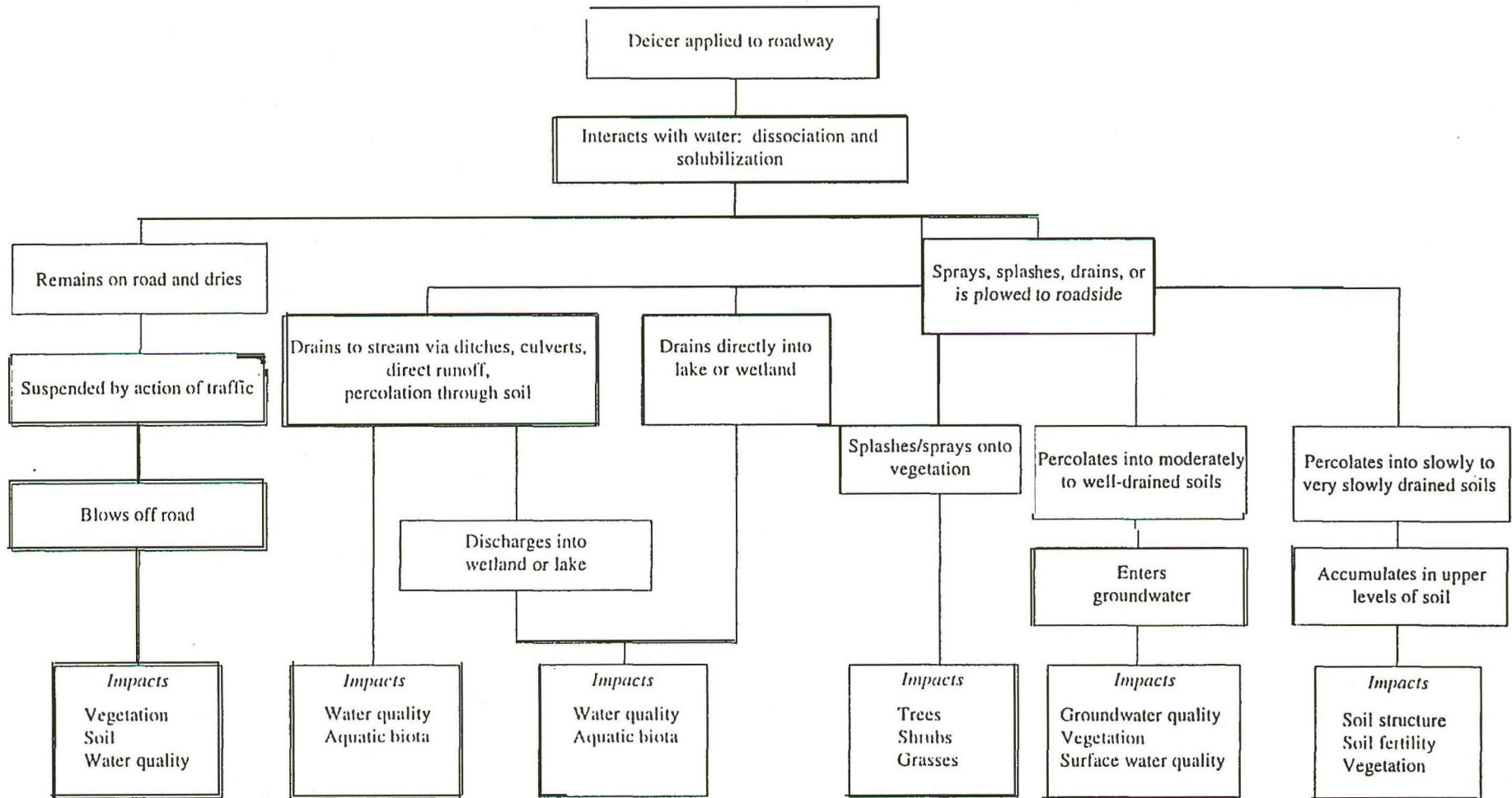
Where roadway runoff can accumulate, such as in unlined ditches, it can infiltrate the soil, and high concentrations of deicer can drain directly into adjacent soil and surface water. In developed areas where there is impermeable roadside, runoff may be uncontrolled; that is, it simply flows until it reaches an area into which it can infiltrate. When the runoff is channeled into controlled, man-made drainage, e.g., storm sewers or drainage ditches, it usually is carried directly to a lake, river, or stream, although in metropolitan areas it may be combined with domestic sewage and passed through a waste treatment process.

Exhibit 3.2: Impacts of Selected Deicer Components and Products on the Environment and Human Use

	Sodium Chloride (NaCl)	CMA (CaMgC₂H₃O₂)	CC-90 Surface Saver	Potassium Chloride (KCl)	Sand (SiO₂)	Calcium Chloride (CaCl)
Soils	Cl is not adsorbed on soils. Na can bind to soil particles, break down soil structure, and decrease permeability. Cl can form complexes with heavy metals in the soil, releasing them into the environment	Ca and Mg can exchange with heavy metals in soil, potentially releasing them into the environment	Same as NaCl. Also, Mg can exchange with heavy metals in soil, potentially releasing them into the environment	Cl is not adsorbed on soils. K can exchange with heavy metals in soil, potentially releasing them into the environment.	Gradually will accumulate on soil.	Cl is not adsorbed on soils. Ca can exchange with heavy metals in soil, potentially releasing them into the environment. Ca can increase soil aeration and permeability.
Vegetation	Salt spray/splash can cause leaf scorch and browning or dieback of new plant growth up to 50' from road. Osmotic stress can be caused by uptake of NaCl. Grass is more tolerant than trees and woody plants. Red and white pine, balsam fir, red and sugar maple, and pin and red oak are salt sensitive.	Little effect	Same as NaCl.	Similar to NaCl.	Can accumulate on and around low vegetation and cause stress.	Similar to NaCl.
Groundwater	Mobile Na and Cl ions readily reach groundwater, and concentration levels can increase in areas of low flow temporarily during spring thaws. Shallow wells near roadways are most vulnerable.	Can release heavy metals from soil into groundwater.	Same as NaCl. Also, Mg can release heavy metals from soil into groundwater.	Similar to NaCl. Also, K can release heavy metals from soil into groundwater.	No known effect.	Similar to NaCl. Also, Ca can release heavy metals from soil into groundwater.
Surface Water	Can cause density stratification in small lakes having closed basins, potentially leading to anoxia in lake bottoms.	Can deplete dissolved oxygen in small lakes and streams when degrading.	Same as NaCl. Also, phosphorous, a nutrient, can accelerate eutrophication.	In high concentration can cause density stratification in closed-basin water bodies. K, a nutrient, can accelerate eutrophication.	No known effect.	In high concentration can cause density stratification in closed-basin water bodies.
Aquatic Biota	No effect in large or flowing bodies at amounts expected from current road salting. Small streams that are end points for runoff can receive harmful concentration of Cl. Cl from NaCl generally not toxic until it reaches levels of 1,000-36,000 ppm.	Can cause oxygen depletion, leading to anoxic conditions.	Same as NaCl. Also, eutrophication from phosphorous can cause species shifts.	Similar to NaCl. Cl from KCl is reported to be more toxic than Cl from NaCl.	Particles settling to stream bottoms degrade habitat for aquatic organisms.	Similar to NaCl. Cl from CaCl is reported to be more toxic than Cl from NaCl.
Human Use	Mild irritant to skin and eyes. Potential negative effects if drinking water concentrations of Na and Cl exceed recommendations.	Mild irritant to skin and eyes. Ca and Mg can cause water hardness.	Same as NaCl. Also, potential negative effect if drinking water recommendations for Cl and Na are exceeded. hlg can cause water hardness.	Potential negative effects if drinking water standard for Cl is exceeded.	Particles in air can contribute to respiratory problems.	Potential negative effects if drinking water standard for Cl is exceeded. Ca can cause water hardness.

SOURCE: Public Sector Consultants, Inc.

Exhibit 3.3: Deicer Transport Pathways and Impacts on the Environment



SOURCE: Public Sector Consultants, using information from Transportation Research Board, 1991.

Transport through Soil

Generally, deicer concentrations decrease as solutions move laterally and vertically through the soil.⁵ Factors affecting the amount of deicer that enters the soil and the rate of transport are soil type, cation exchange capacity (CEC), permeability, and infiltration capacity.⁶

SOIL TYPE AND TEXTURE The size of the particles in the soil and the soil texture together determine soil *type*. Although soils typically consist of particles of several sizes, a “well-sorted” sediment contains grains of approximately equal size. A soil’s *texture* refers to its relative proportion of sand, silt, and clay. For example, a fine-textured soil consists mostly of small particles such as silt. These variables affect such other soil characteristics as cation exchange capacity, permeability, and infiltration capacity.

CATION EXCHANGE CAPACITY Cations (positive ions) are attracted to negatively charged soil particles. *Cation exchange* occurs when one cation on a soil particle switches with another of a weaker charge. This ability of soil to replace ions is the *cation exchange capacity* (CEC) and is particularly important since sodium, calcium, magnesium, and potassium in deicing materials can exchange with heavy metals in the soil and *mobilize* them, that is, release them into the environment.

PERMEABILITY A soil’s *permeability* is its capacity to transport water, and it depends largely on the size of the soil’s pores. Pore size is related to the soil grain size—the smaller the particles, the smaller the pores. Smaller grains increase frictional resistance to water flow and lower permeability.⁷

INFILTRATION CAPACITY The measure of the quantity of water that a soil can absorb is defined as its *infiltration capacity*, and it is affected by soil permeability and moisture. Heavily packed soils with low permeability have low infiltration rates. For example, soils used for pasture or meadow generally have greater infiltration rates than soils used for crops, because the latter are packed down by repeated use of heavy machinery.⁸ When a soil is saturated, there is no infiltration capacity, and any additional water runs off the surface.

Frozen ground or frost can impede but not necessarily stop the infiltration of deicing solutions. One study indicates that *percolation* (permeation) occurs in light-textured soils even when frozen.”

Distribution in Groundwater and Surface Water

Deicing materials can enter groundwater and surface water by moving laterally or vertically through soil or by running off the roadway directly into adjacent water bodies.

GROUNDWATER Water containing deicing materials can percolate through the soil and enter an *aquifer* (a rock or sediment unit from which water can be extracted) through its *recharge* (input) area, or source. The amount of road salt reaching groundwater depends on the frequency of precipitation, the texture and drainage characteristics of roadside soil, how near the groundwater is to the surface, how far it is from the highway, the permeability of the aquifer material, the direction and rate of groundwater flow, and the application rate of the deicing material.¹⁰

The groundwater system is classified into two categories: shallow/local and deep/regional systems. Of the two types, shallow aquifers close to roadways are more susceptible to contamination. Contaminants in shallow/local systems move in the direction of groundwater flow to outlets such as springs, rivers, lakes, and wetlands. Water containing deicing components may penetrate to the deep/regional parts of the aquifer through infiltration; this may be aided by the pumping action of deep wells, which can draw contaminated water from the shallow/local aquifer down into the regional groundwater flow system.¹¹ The time required for an aquifer to return to normal once contaminated may vary from a few days to years.¹²

SURFACE WATER Rivers and streams may receive water containing deicing compounds directly from the highway or through ditches, culverts, and storm sewers.¹³ Deicers also enter surface water during periods when water flow is low and groundwater becomes the major contributor to its base flow. The time it takes for the deicer solution to reach a water body is a function of the distance it has to travel from the road.¹⁴ The concentration of deicer reaching a surface water body can range from one to thousands ppm, depending on the amount of deicer applied and the volume of water available to dilute it. Streams and rivers generally maintain a flow sufficient to dilute deicing chemicals entering the water bodies at current and anticipated levels of use to concentrations weaker than those directly harmful to aquatic life. Small streams that receive channeled runoff are particularly likely to reach high concentrations of deicing components.

Lakes and wetlands can receive water containing deicing elements and compounds as direct runoff from drainage channels or from rivers and streams. The concentration of deicing components in lakes and wetlands is affected in the same way it is in rivers and streams: by the amount of deicer applied and the volume of water available to dilute it. An additional factor in lakes is *turnover* time, which is the period required for a lake to reach a uniform concentration of a chemical input; variables affecting turnover time include such factors as water body volume and shape, discharge of the watershed (the region or area draining into the water body), annual snow and rain, evaporation, flow rates, and man-made influences.¹⁵ One study finds that the method of deicer component input is important in determining its impact.¹⁶ If the inflow is diffuse (spread out) rather than from a point (specific) source, complete mixing will take place, and contaminants entering at currently anticipated levels will be diluted.¹⁷ Most studies indicate that dissolved substances in larger streams and rivers are diluted almost immediately, reducing the likelihood that they or downstream lakes or wetlands will suffer adverse impacts from deicing materials.¹⁸ The lakes and wetlands most vulnerable to high concentrations of deicing components are those with only seasonal outflow and/or partially or completely closed basins; these factors increase water turnover time and allow deicing materials to accumulate.¹⁹

Impacts

The discussion of impacts presents the general ecological effects of deicing material components on the terrestrial and aquatic environments.

Soils

The concentration of deicing compounds in soils decreases with distance from the roadways and the depth of the soil. The impact of deicers on soils is complex and is affected by the soil's permeability and type and the chemical components of the deicer. As explained above, when cations (positive ions) are introduced into a soil, an exchange with other cations on soil particles can occur. Adsorption abilities for selected cations are illustrated by the following spectrum: $H^+ > Ca^{++} > Mg^{++} > K^+ > Na^+$.²⁰ As the spectrum indicates, of the selected ions, hydrogen binds most strongly, and sodium is the weakest. Therefore, calcium, magnesium, and potassium introduced to a soil will be adsorbed more readily than sodium if all concentrations of the components are equal.

Terrestrial Vegetation

The following factors affect the impact of deicers on vegetation: the amount of a plant's exposure to deicer; the proximity of a plant to the area of deicer application; topography and drainage; soil type and texture; plant age; and plant species.*'

Plants can be affected by spray/splash and by uptake of deicing components through their roots. Symptoms of spray/splash and by uptake damage include leaf scorch, twig and branch browning, and, in extreme cases, dieback. It is difficult to differentiate clearly between the effects of spray/splash and root uptake because spray/splash can accumulate on plants and drip to the soil surrounding the plant and affect the plant secondarily through root uptake.**

Plant species vary in their ability to absorb high concentrations of particular ions and in their adaptability to changes in salinity levels. Increased ion concentrations in soils may create osmotic stress on certain plants. Through osmosis every cell in an organism maintains a balance of dissolved solids and water. As dissolved solids outside the cell walls increase, salinity increases, and water passes through the cell membrane to compensate; this creates stress sufficient to retard growth and, in extreme cases, leads to cell destruction and plant death.²³ Younger trees tend to absorb larger amounts of deicing components than do older trees; however, over time the ions accumulated by older, established trees potentially can reach toxic levels.

The distance within which vegetation is susceptible to damage varies depending on soil drainage, topography, and species type. Generally, studies indicate that damage occurs within 50 feet of the roadside, although a few studies show effects as far as 92, 98, and 328 feet.²⁴

Damage to vegetation due to deicers generally occurs only where sensitive species are located adjacent to a heavily used roadway. Under drought conditions the damage to sensitive species can be exacerbated, and even nonsensitive species may suffer some harm.

Bacteria in soils cause organic materials to decompose in forms that can be utilized by plants. Very few studies have evaluated the effect of deicer components on how soil bacteria and fungi contribute to nutrient cycling and transfer. Deicer components also may affect soil pH (hydrogen ion concentration) and metabolic rates of soil bacteria, both of which are crucial in making nutrients available to vegetation.

Terrestrial Animals

Animals may be drawn to roadways to consume the deicing residuals that accumulate on roadsides. Generally speaking, however, animals are in less danger from consuming deicing residuals than from being hit by vehicles.

Water and Aquatic Biota

Calcium, magnesium, sodium, potassium, chloride, and sulfates comprise 80-90 percent of dissolved solids in natural water bodies; therefore, the introduction of these components do not pose a threat unless the concentration of any one component entering a water body is very high.

Water bodies susceptible to contamination are (1) wetlands that have long turnover time, low flow, and/or salt accumulation in their soils; (2) rivers and streams that have low flow, are fed by deicer-contaminated groundwater, and/or have deicing components stored in soil along their banks; and (3) lakes and ponds that have long turnover time, closed or partially closed basins, and/or deicing components in their bottom sediment.

The effects of contamination are of particular concern when high concentrations of components (1) accumulate in localized areas (such as end points of runoff drainage channels) and groundwater supplies; (2) increase biochemical oxygen demand; (3) accelerate eutrophication; (4) alter pH level; and (5) stratify water bodies. These conditions can have a variety of effects on aquatic biota, ranging from reducing their growth and reproduction to causing mortality.

CONCENTRATION Water bodies vulnerable to high concentrations of deicing materials include shallow groundwater drinking supplies adjacent to roadways, small rivers and streams adjacent to roadways, and small lakes and wetlands that have only seasonal outflow and/or partially closed or closed basins.²⁵ (Chloride concentrations in the Great Lakes are discussed in chapter 4.)

BIOCHEMICAL OXYGEN DEMAND The BOD (the amount of dissolved oxygen required for a substance to biologically degrade in an aquatic system) of deicing materials can reduce dissolved oxygen in aquatic systems and adversely affect organisms dependent on it.²⁶

EUTROPHICATION The introduction of nutrients from deicers can accelerate the aging process (eutrophication) of lakes. Eutrophication is characterized by the depletion of oxygen in lower depths, the excessive growth of rooted plants and algae, a shift to species tolerant of low levels of dissolved oxygen, and, in the extreme, the impairment of swimming, boating, and fishing.*⁷

pH LEVEL pH is a measure of the concentration of hydrogen ions in water and is an important factor in the maintenance of aquatic ecosystems. As pH changes there is a simultaneous change in the solubility of potentially toxic compounds. The European Inland Fisheries Advisory Commission's review of pH effects on freshwater fish concludes that

there is no definite pH range within which a fishery is unharmed and outside which it is damaged, but rather there is a gradual deterioration as the pH values are further removed from the normal range.

The pH range . . . not directly lethal to fish is from 5.0 to 9.0. However, the toxicity of certain common pollutants is markedly affected by pH changes within this range, and increasing acidity and alkalinity may make these pollutants more toxic. . . .²⁸

DENSITY STRATIFICATION Water containing dissolved contaminants is more dense than normal lake water. If the density difference is great, the contaminated water will settle to the bottom when it enters a lake. This density stratification may interfere with the lake's spring and fall overturn, causing oxygen depletion (*anoxia*) at the lake bottom and interfering with nutrient cycles.²⁹ If mixing does not occur, anoxic conditions will lead to the death of oxygen-dependent bottom-dwelling organisms.³⁰ Density stratification is most likely to occur in small lakes with little water *exchange* (input and output).

Human Health/Use

Generally, public health is not threatened by the use of any of the selected deicing materials. Precautions that people who handle and apply the materials must take include wearing gloves, long-sleeved shirts, and long pants for most materials, and respiratory devices for calcium chloride and sometimes calcium magnesium acetate. Individuals with hypertension may be affected if the sodium concentration in groundwater used for public water supplies exceeds certain levels. Michigan water quality standards specify that dissolved solids—which can include chlorides, sodium, calcium, magnesium, and potassium—in water bodies not used for public water supplies may not exceed a monthly average of 500 ppm or a maximum of 750 ppm at any time.³¹

Primary Components in Deicing Materials

The characterization, transport, fate, and impacts specific to each primary component in the selected deicers are discussed below.

Chloride

The symbol commonly used for chloride is Cl, although Cl⁻ is the correct reference to the chloride ion; Cl is the symbol for chlorine, an element. Throughout this report, chloride will be referred to as Cl, the more common but scientifically incorrect nomenclature.

The predominant chloride salts used as deicers are sodium chloride, calcium chloride, magnesium chloride, and potassium chloride. Most studies focus on the effects of sodium chloride since it is the most commonly used deicing salt. Studies analyzing the effects of sodium chloride on terrestrial and aquatic environments usually do not differentiate between the effects of its two components. Although chloride is easier to trace than sodium, studies frequently involve the presence of both ions. This section references studies that evaluate the effects of sodium chloride in general and effects attributed specifically to chloride. Studies that evaluate other chloride salts are presented under the discussions of calcium, potassium, and magnesium.

Sodium chloride is 40 percent sodium and 60 percent chloride by weight. Trace elements, including trace metals, may comprise up to 5 percent, however.” Substances potentially present include

phosphorous (14-26 ppm), sulphur (6.78–4,200 ppm), nitrogen (6.78–4,200 ppm), copper (0.14 ppm on average), and zinc (0.02-0.68 ppm).³³

Characterization/Transport/Fate

Chloride is an ion formed from chlorine (an element) and is considered to be *conservative*, meaning that it is extremely mobile: It does not biodegrade, does not easily precipitate (react with other ions to form a solid), does not volatilize (turn into a gas), is not involved in biological processes, and does not adsorb (adhere) significantly on mineral surfaces.³⁴ Chloride is used as a tracer in water because compared to other elements it is not significantly slowed in its passage through soils. Its concentration in surface waters is low, in part because rainfall— a major contributor to surface waters—contains only 0.2-0.4 ppm (this is the average for continental rainfall, as contrasted with coastal rainfall, which has higher levels); North American rivers average 7 ppm except where they come into contact with (1) sea water, (2) deposits left after evaporation occurs, or (3) brines. Sources of chloride are sea salt, the release of sodium chloride from the weathering of bedded evaporites and shales, and discharges from human use.³⁵ Its presence in water can be detected by a salty taste, sometimes at concentrations as low as 200 ppm.³⁶

The circulation of chloride through the hydrologic cycle is due mostly to physical rather than chemical processes.³⁷ The chloride ion (formed when a chloride salt dissociates-separates-in water) passes readily through soil, enters groundwater, and eventually drains into surface waters, although the passage through the groundwater may take many years. When chloride ions reach a body of water, their removal from water occurs only by seeping through bottom sediments; precipitating as a solid, and/or flushing out of the system.

Impacts of Chloride

SOIL The chloride ion is negatively charged and typically is not involved in adsorption on soils. As a result, it is transported along water pathways. As soil depth increases, the chloride in soil water disperses and dilutes.³⁸ Chloride does not seem to have any direct impact on soils, although studies find evidence in laboratory tests suggesting that it can contribute to the release of heavy metals in soils.³⁹ Little field data to support this laboratory evidence have been found, however.

Guntner and Wilke evaluated the effect of chloride on soil microbial activity. They detected a general decrease in microbial activity, but the effects were temporary, and the microbial activity returned to previous levels after the road salt leached from the soil.⁴⁰

TERRESTRIAL VEGETATION Most research has focused on the effects of road salt on trees, but studies examining the effects of salt from roadways on adjacent vegetation generally find that damage is limited to areas both (1) exposed to high levels of road salt spray/splash or runoff and (2) containing salt-sensitive plant species. Exhibit 3.4 lists the general tolerance of several common plants. Appendix B is a more comprehensive list. In general, grassy vegetation is more salt tolerant than are trees and woody plants.⁴¹

Exhibit 3.4: General Salt Tolerance Levels of Selected Plants and Grasses

Deciduous Trees		Deciduous Shrubs		Evergreen Trees and Shrubs		Grasses	
Common Name of Plant	Tolerance Level and Reference To Source	Common Name of Plant	Tolerance Level and Reference To Source	Common Name of Plant	Tolerance Level and Reference To Source	Common Name of Plant	Tolerance Level and Reference To Source
Thomless Honey Locust	High (H)	Privet	High (H)	Pfitzer Juniper	High (H)	Kentucky 3 Fescue	High (H)
Yellow Birch	Moderate (K)	Honeysuckle	tigh (H)	Creeping Juniper	High (H)	Red Fescue	Moderate (H)
Paper Birch	High (K)	Forsythia	Moderate (H)	Adam's Needle	tigh (H)	Bromegrass	Moderate (H)
White Birch	Moderate (H)	Weigela	Moderate (H)	White Pine	Low(K)	Kentucky Blue Grass	Low(H)
Red Maple	Low(K)	Spirea	Low (H)	Red Pine	Low(K)		
Sugar Maple	Moderate (H); Low (K)	Rose	Low (H)	Jack Pine	High (K)		
Redbud	Moderate (H)			White Spruce	Moderate (K)		
Green Ash	Low (H)			Canadian Hemlock	Low(H)		
White Ash	High (K)			White Fir	Moderate (K)		
Tulip Poplar	Low (H)			Douglas Fir	Moderate (K)		
White Oak	High (K)						
Red Oak	Low (K)						
Pin Oak	Low (K)						
Bitternut Hickory	Moderate (K)						
Shagbark Hickory	Moderate (K)						
Quaking Aspen	tigh (K)						
Red Elm	Low (K)						
American Elm	Low (K)						
Cottonwood	tigh (K)						

SOURCES: P.D. Kelsey and R.G. Hootman, "Deicing Salt Dispersion and Effects on Vegetation Along Highways," in *Deicing Chemicals and the Environment*, ed., P.M. D'Itri (Chelsea, Mich.: Lewis Press, 1992); R.E. Hanes, *Effects of De-icing Salts on Water Quality and Biota* (Washington, D.C.: Transportation Research Board, National Research Council, 1976).

(H) = Hanes.

(K) = Kelsey and Hootman

Road salt does not threaten whole forests of salt-sensitive species, but it can damage individual trees close to roadways. Road salt enters plants by spray/splash being deposited on their surfaces and through root uptake.

A 1976 study by the TRB indicates that it is difficult to identify concentrations of ions toxic to vegetation because ion amounts vary with the vegetation's age, species type, tissue type, nutrient balance, the season in which the sample is taken, and other factors.⁴² Because there is variance, a species' road salt tolerance level should be considered when areas adjacent to roadways are planted. Red and white pine, balsam fir, sugar and red maple, pin and red oak, and cedar are found to be susceptible to browning and possible dieback due to road salt. Younger trees absorb chloride in larger quantities than do older, established trees and can suffer osmotic stress.⁴³

Salt Spray/Splash Damage to roadside vegetation caused by road salt spray/splash include leaf scorch, twig and branch browning, and possibly dieback. A study conducted by the University of Minnesota College of Forestry finds that spray/splash damage diminishes rapidly the farther back from the road a tree stands. Beyond 50 feet only the most sensitive species are affected and then only at moderate levels. More plants along higher-speed roads with heavy truck use may suffer damage because spray/splash distances from such roadways are greater. The effects of salt splash/spray are exacerbated during drought.&

The 1976 TRB study finds that road salt spray/splash damage to dormant deciduous trees and grasses is unlikely because new growth is most susceptible to damage, although salt ions can continue to be taken up through their roots during the winter because temperatures are higher below than above ground.⁴⁵

Urban locales present particular problems for vegetation. Larger amounts of deicers tend to be used on urban roadways. Furthermore, trees lining urban streets and highways frequently are within 30 feet of the roadway, exposing them to high amounts of deicing components from runoff and spray/splash. Attempts to correctly attribute vegetation damage along urban streets and roads are complicated by impacts other than exposure to road salt, such as root damage caused by paving over root zones, compacted soil surfaces, root rot, drought, and high ozone levels.⁴⁶

Root Uptake The high solubility of chloride makes it possible for plants to absorb chloride through their roots. Evidence indicates that most injury to trees and shrubs from road salt is caused by chloride ions. However, sodium may augment injury and inhibit plant growth by increasing salinity levels, which leads to osmotic stress.

Vegetation also can be affected by road salt where water tables are high and groundwater becomes saline." Levels of chloride toxic to plants in this situation depend on species' tolerance and environmental conditions.

TERRESTRIAL ANIMALS Studies find that levels at which road salt is toxic to animals are exceptionally high (6,000 ppm is the lowest level found for domestic animals).⁴⁸ Generally, salt tolerance is proportional to animal size. Jones et al. attribute the deaths of ring-necked pheasants and

cottontail rabbits from toxic encephalitis to very high road salt concentrations caused by high snowfall, which resulted both in more salt being used to deice roads and in the animals' water supplies being limited.⁴⁹ No other evidence has been found indicating that road salt application results in toxicity to larger animals.

The predominant hazard that road salt poses to animals is vehicle injury to deer: they apparently are attracted to salt residuals on roadsides, which exposes them to danger from vehicles moving at high speed. In 1989, 46,784 accidents involving deer occurred in Michigan, but the correlation between road salting and vehicle-deer collisions in Michigan has not been studied.⁵⁰ In 1987 recommendations made by the MDNR to reduce the number of vehicle-deer accidents in Michigan included eliminating the use of road salt at two "hot spots" in the Upper Peninsula. Other recommendations to decrease the number of deer/vehicle collisions in that area included providing "lure crops" to keep deer from grazing near roads, providing more information to drivers about deer hazards, and erecting deer crossing signs. According to the MDNR's wildlife biologist in the region, these recommendations have not been adopted.⁵¹

WATER Concern about chloride in water centers on the percolation of high concentrations into shallow aquifers used as drinking water by salt-sensitive populations and on the consequences of channeling high deicing concentrations into small streams, ponds, lakes, and wetlands. Generally, because of dilution, road salt contamination is not a problem in flowing bodies of water, and insofar as small water bodies are concerned, a literature search and inquiries to the MDNR find very few anecdotal cases that document significant damage to aquatic systems due to the application of road salt.

Groundwater Concern about road salt concentration levels in groundwater relate to the end point of the water. If the groundwater discharges into a flowing river or large lake, road salt is diluted, and its presence is not a problem. If the groundwater reaches public water supplies, road salt levels can be a problem; standards and findings regarding human consumption of salt in drinking water are discussed below.

Salt in Michigan groundwater comes from various sources, both natural and anthropogenic. Natural salt comes from precipitation and from the upward movement of brines from rocks; human activities that contribute to salt in groundwater are mining, application of fertilizers, use of pesticides, oil and gas drilling, discharge of industrial wastes, road deicing, and use of home water softeners.⁵²

There is little information about road salt contamination of groundwater in Michigan. Results from monitoring 29 wells along highways in Michigan indicate that roadside groundwater chloride levels increase for a few years immediately after deicing practices are initiated but eventually stabilize.⁵³ From 1971 to 1984 the MDOT monitored 47 roadside locations, 4 streams, and 30 wells (at 4 locations), sampling soil and water as appropriate. Roadside soils and surface waters had greatly fluctuating chloride levels, but with few exceptions all were within published limits of tolerance for plants and animals. Chloride in groundwater was found to dissipate by water flow, and levels were below established drinking water standards.⁵⁴

One case of groundwater contamination was found in 1988; the MDOT determined that approximately three residential wells had been contaminated by the application of road salt on a nearby road. The wells were under 40 feet of sand, with a cap of clay. The MDOT remediated the contamination by extending the wells to approximately 150 feet and reducing salting on the nearby roadway, relying predominantly on sand for winter road maintenance.⁵⁵

In the past the major source of chloride contamination of groundwater from road salt in Michigan has been from spillage and uncontrolled runoff at storage and handling facilities.⁵⁶ In Michigan at least 88 such sites are suspected to be contaminated. The MDOT states that most salt used on roads under its jurisdiction is stored in covered storage sheds, and the material is loaded and unloaded in contained facilities.

Some states have documented contamination of water supplies due to the use or storage of road salt. By the mid-1960s, 200 wells in New Hampshire had to be closed or replaced due to road salt contamination, but it is not known how many were affected by road salt use or storage.⁵⁷ Massachusetts has had significant problems with road salt infiltrating into public and private drinking water wells adjacent to roadways. From 1983 through 1990 the Massachusetts Public Works Department received complaints of salt contamination and replaced or remediated contaminated wells.⁵⁸ Although very old, the only comparative data available indicate that the MDOT uses about one-third less road salt than does Massachusetts. In the winter of 1981-82 Massachusetts used 21.8 tons per mile, and Michigan used 14.5 tons per mile; in 1982-83 the figures were 14.8 tons and 8.4 tons, respectively.

Surface Water Studies indicate that most surface waters are not impacted by road salt.⁵⁹ Some studies show significant temporary increases in salt, especially during the spring thaw, but dilution appears to limit most problems.⁶⁰ One case of toxicity due to runoff surges is documented in Michigan: In 1989 the Surface Water Quality Division of the MDNR conducted tests to examine the effects on aquatic biota of water from various tributaries and segments of the Rouge River. In water samples from 2 of 20 sites the reproductive capacities of *ceriodaphnia dubia*, one of the tested aquatic biota, were significantly reduced, although the effect was temporary; the toxicity was attributed to road salt runoff following a snowstorm.⁶¹

Lakes and wetlands with long turnover times, little water exchange, and significant salt accumulation in their sediments and banks are most vulnerable to the impacts of road salt. Small, relatively deep lakes may be density stratified by incoming contaminated water and fail to mix. This phenomenon is discussed further in the following section describing effects on aquatic biota. There is little documentation of the effects of road salt on wetlands. One study indicates that the plant type predominant in wetlands is not affected by salt, but if concentrations reach very high levels, some species within the plant community may shift, that is, disappear and be replaced by others.⁶² Fen wetlands are characterized by their alkalinity. If soil and water pH levels were to decrease, species characteristic of fens could be replaced by species more tolerant of the lower pH levels; the risk to endangered or threatened species associated with fens would increase.

Another reported effect of chloride on surface waters is that chloride ions may form strong complexes with heavy metals, such as mercury, in bottom sediments and release the metals to the surface water.⁶³

Few field studies could be found that identify effects from metal mobilization characteristics of chloride in sediments.

AQUATIC BIOTA Although one case of temporary toxicity has been documented in Michigan (discussed above), studies find that sodium chloride is quickly diluted and does not have a significant impact on aquatic biota in large or flowing water bodies.⁶⁴ As a result, aquatic biota are threatened only in specific situations, i.e., when water bodies become density stratified, or when sodium chloride reaches a very high concentration.

Small lakes with closed basins adjacent to roadways are vulnerable to salt density stratification and interference with natural lake overturn. This effect has been observed in lakes in Wisconsin, Michigan, and New York and attributed to deicing runoff from nearby roadways.⁶⁵ The only such case documented in Michigan is a small urban lake near Ann Arbor that was the subject of a study in the mid-1960s. First Sister Lake, located in a residential subdivision, is four acres in size and has a maximum depth of 23 feet. Two- and four-lane highways run adjacent to the lake, and drainage from the highways and the entire subdivision ran into First Sister Lake. The lake became salt density stratified and did not overturn one spring, leading to anoxia of the lake bottom and the eventual death of most of its oxygen-dependent organisms. The following year, however, saline water leached through the lake bottom, and the density stratification was eliminated; natural overturn occurred and has continued in subsequent years.⁶⁶

Small streams or lakes receiving large quantities of roadway deicer runoff may reach levels of sodium chloride toxic to aquatic biota, although Wetzel finds that most aquatic flora and fauna are adaptable to a wide range of salinity.⁶⁷ When chloride concentrations are held constant, laboratory studies show that sodium chloride is less toxic to aquatic biota than are potassium, calcium, and magnesium chlorides.⁶⁸ According to the MDNR, fish and other aquatic organisms generally are not affected by road salt until levels higher than 1,000 ppm sodium chloride are reached.⁶⁹

Because chloride is a conservative ion, more chloride than sodium will reach surface water from road salt, and chloride will reach levels of toxicity faster. In 1988 the U.S. Environmental Protection Agency (EPA) published ambient water quality criteria that establish levels at which chloride becomes toxic to aquatic plants and animals. The concentrations resulting from the normal use of road salt generally are well below these levels. Most of the aquatic biota listed do not suffer acute toxicity until sodium chloride levels reach 1,000 ppm. Sodium chloride levels toxic to freshwater plants found in Michigan range from 220 ppm for desmid, *Metrium digitus* to 23,400 ppm for alga, *Anacystis nidulans*. Acute (one-time exposure) levels of sodium chloride toxic to freshwater animals found in Michigan range from 1,470 ppm for cladoceran, *Daphnia pulex* to 11,940 ppm for the American Eel, *Anguilla rostrata*.⁷⁰

Other studies find that levels of chloride toxic to various fish range from 8,100–12,000 ppm; for lower organisms the toxicity levels range from 600–14,564 ppm.⁷¹

HUMAN HEALTH/USE No federal *primary* (enforceable) drinking water standard has been established for chloride; the *secondary* (nonenforceable) standard is 250 ppm.⁷² According to monitoring results, this standard has not been exceeded consistently in drinking water supplies in

Michigan.⁷³ Michigan water quality standards for dissolved chloride solids are 125 ppm (monthly average) in public water supplies and 50 ppm (monthly average) in the Great Lakes and connecting waters.⁷⁴

Sodium

Sodium is a component (40 percent by weight) of the most widely used deicer, sodium chloride (road salt). In water, sodium dissociates from chloride, the other component in road salt.

Characterization/Transport/Fate

Elemental sodium is an alkali metal that oxidizes rapidly in moist air; therefore, sodium occurs in nature only in a combined state. Sources of sodium are the weathering of igneous and sedimentary rock.⁷⁵ Once in a water solution, sodium can remain in this state because of its high solubility.

Although sodium is highly soluble, it is readily adsorbed on soil particles and therefore is less apt than chloride to reach groundwater and surface water. However, if adsorption does not take place, or the sodium is leached from the soil, it will follow water pathways and eventually find its way to groundwater and surface water. Typical concentrations of sodium in continental rainfall are 0.2-1 ppm, and average concentrations in North American rivers are 6.5 ppm.⁷⁶

Impacts of Sodium

SOIL The amount of sodium accumulated in soils increases as the period and intensity of road salt application increases. In general, the concentration of sodium in soil decreases with distance from the highway. The highest concentrations occur within 30 feet of the roadway, but in exceptional cases elevated values have been recorded up to 200 feet from roadways." Vertically, sodium concentrations decrease with depth, with the largest percentage remaining in the top 20 centimeters of soil because of adsorption.*

The adsorption of sodium depends on the composition of the soil: Coarse granitic soils adsorb little sodium and chloride, and finer soils with increased clay content retain higher amounts.⁷⁹ Generally, road salt adsorbed on soil particles is leached by spring rains before the growing season, although some soils retain salt through the summer and fall, and it will accumulate in dry conditions.⁸⁰

The amount of cation exchange capacity taken up by sodium is its exchangeable *sodium percentage*. In extreme cases, when the exchange exceeds 15 percent, damage to soil structure may occur.⁸¹ The structure of the soil is destroyed when excessive amounts of sodium exchange with calcium and magnesium. Calcium and magnesium ions tend to *aggregate* (bind) organic and inorganic particles, whereas sodium causes them to break apart. When the soil is broken up, the particles wash down through the soil, which results in pores becoming sealed and permeability reduced. Clay soil structure also is affected because sodium adsorption causes clay particles to swell and reduces soil permeability. Soil impermeability means more water can flow overland and cause erosion.⁸²

TERRESTRIAL VEGETATION Studies do not attribute specific damage to vegetation from excessive sodium levels. Following the application of salt on roads, more chloride than sodium is

absorbed by plants because sodium is more readily adsorbed onto soil particles. Sodium may contribute to plant injury by increasing osmotic stress.

WATER If sodium ions are not adsorbed on soil particles, they will follow the path of the soil water and eventually may be discharged to surface water or enter groundwater.⁸³

Groundwater Site-specific features that affect the amount of runoff that reaches groundwater include permeability, vegetation cover, gradient, and roadside drainage design.⁸⁴ There is little information on road salt's direct impact on Michigan groundwater sodium levels. For a discussion of road salt in groundwater, see this chapter's chloride section (above).

A study conducted in 1986 for the Michigan Department of Public Health tested 373 water wells in central Michigan and found that sodium content in groundwater varied throughout the region.⁸⁵ Sodium levels in the Lansing area ranged from nondetectable to 20 ppm. In Roscommon and Gaylord sodium was not detected. The Saginaw Bay area and western Tuscola County had sodium levels reaching 1,000–10,000 ppm. As mentioned in the groundwater discussion of chloride, salt (and sodium) levels in groundwater are affected by both natural and anthropogenic factors.

In the past the greatest danger from contamination by road salt arose from the way in which it was stored and handled; it was not sheltered and could infiltrate adjacent soils and run into water bodies. To reduce the risk of contamination, the MDOT currently stores almost all road salt in covered facilities.

Surface Water Studies regarding the effects of road salt on surface water focus predominantly on chloride, the more easily traced ion. The literature does not have information describing the specific effects of sodium on surface water.

AQUATIC BIOTA As mentioned, chloride is toxic to aquatic biota at lower levels than is sodium; as a result, chloride toxicity levels have been extensively studied, but sodium levels have not.

HUMAN HEALTH/USE Sodium in groundwater is the only ion that may directly affect human health at the levels generated by road deicers. If water wells are vulnerable, shallow, and adjacent to roadways, road salt can cause sodium levels in water supplies to increase. As described above, sodium in groundwater is attributed to natural and anthropogenic factors, and levels can vary significantly across the state. See the discussion under groundwater in the chloride section for a report of two other states' experiences with sodium chloride in groundwater.

Health studies demonstrate that if hypertensive people lower their salt intake, their blood pressure will be reduced. There is no distinct correlation, however, between consumption of high sodium concentrations with the onset of human hypertension, although research with rodents shows that excessive salt intake does cause hypertension.⁸⁶ To put into perspective the risk to human health posed by sodium in drinking water, the TRB recently noted that "drinking water and all other beverages combined account for less than 5 percent of daily sodium intake."⁸⁷

There are no federally, enforced drinking water standards for sodium, but the American Heart Association recommends levels no higher than 20 ppm for persons on a restricted sodium diet and 100 ppm for the general population.

Acetate

Acetate is a component of CMA, a commercial product containing calcium, magnesium, and acetate. Studies describing the effects of CMA are discussed in this section as well as effects of acetate itself.

Laboratory studies indicate that the maximum concentration of acetate expected in runoff is 1,000 ppm; the worst case expected is 5,000 ppm, which could occur during a small, intense storm following application.⁸⁸

Characterization/Transport/Fate

Acetate is an organic compound composed of $C_2H_3O_2$ and is formed through the reaction of acetic acid with dolomite. Generally, all acetate degrades by microbiotic action to carbon dioxide and water in both soil and aquatic systems.⁸⁹ Work with models indicates that at air temperatures above 51°F/10°C, degradation can be complete within two weeks. At 34°F/2°C, degradation takes two to four weeks because of reduced microbial activity at lower temperatures.⁹⁰ In water, acetate degrades within 100 days.⁹¹

Impacts of Acetate

SOIL Although further research is needed, models indicate that 10 percent of CMA can remain in soil at distances up to 30 feet from a highway.⁹² The remaining acetate percolates to groundwater and surface water, where it eventually degrades.

Acetate is used as a *reagent* (a substance that because of the reactions it causes is used in analysis and synthesis) for extracting metals from soils.⁹³ Because of this characteristic, there is concern that metals in roadside soils could be released after CMA application to roads. Soil types from several regions in the United States that use deicing materials were studied in the laboratory, and results indicate that mobilization is unlikely to occur because of the chemical processes involved with CMA degradation.⁹⁴ Calcium and magnesium ions in solution may exchange in soil for the hydrogen ion, the release of which decreases soil pH, which in turn may release metals that are mobilized at a lower pH level. However, an important effect of acetate degradation is that it also creates neutralizing conditions through the production of bicarbonate, which increases the pH of soils, thus immobilizing solubilized metals.⁹⁵

Amrhein and Strong indicate in their study of CMA application on several soils that metals are not mobilized at CMA concentrations of 10 millimoles per liter (mmol/L). However, at concentrations of 100 mmol/L, metals are released and the drinking water standard for cadmium is exceeded. The study concludes that at concentrations of less than 100 mmol/L, CMA is likely to have no more effect on metal mobility than an equal concentration of road salt.⁹⁶ Another laboratory study indicates that CMA could cause mobilization of iron, aluminum, sodium, and potassium.⁹⁷ A study by Homer examined the impact of CMA on metal mobility in soil and reports some trace metal mobilization.⁹⁸

These researchers all recommend further field study over an extended period of time to verify the effects of CMA on metal mobilization.

Elliott and Linn identify strongly acid (low pH) roadside soils as areas sensitive to the addition of acetate.⁹⁹ This is because the bicarbonate released during acetate decomposition may be unable to raise the pH sufficiently to immobilize metals released from soils.

TERRESTRIAL VEGETATION A study by Homer finds that various herbaceous and woody plant species tolerate CMA concentrations up to 2,500 ppm in the root zone. Plants sprayed and flooded with 3,000 ppm CMA show no external symptoms of damage.¹⁰⁰ There are no anticipated adverse effects of CMA on vegetation at levels generated by deicing activities.

WATER AND AQUATIC BIOTA Laboratory experiments, limited field experiments, and work with models indicate that when acetate degrades it creates an increased biochemical oxygen demand and can deplete dissolved oxygen in water. The factors influencing the extent of the effect are the deicer application rate, how much degradation occurs enroute to the water body, how diluted the acetate is when it reaches the water body, the presence in the water body of other mechanisms for degradation that do not utilize oxygen, water temperature, and how much new oxygen is entering the water body.

Potentially sensitive areas are shallow, biologically productive lakes as well as poorly flushed small lakes, ponds, and wetlands that are adjacent to the highway and directly receive runoff.¹⁰¹ To avoid problems, water bodies should have the capacity to dilute incoming CMA runoff to at least 100:1.¹⁰²

Laboratory studies conducted in California identify 50 ppm as the highest concentration of CMA that will not cause harm to aquatic life; subsequent field trials in three ponds appear to confirm that severe oxygen depletion occurs where concentration levels are higher than this. In a study by the TRB, application of approximately 10 ppm CMA temporarily reduced dissolved oxygen levels in field ponds by about half, and in laboratory and field tests 100 ppm or more of CMA fully depleted the dissolved oxygen in water bodies within two days.¹⁰³

Studies identifying toxicity levels of CMA on aquatic biota find CMA to be less toxic than sodium chloride to rainbow trout and fathead minnows. Aquatic invertebrates survive and reproduce when exposed to levels up to 500 ppm. Levels above 500 ppm could cause osmotic stress and low oxygen levels. Laboratory experiments show algae to be more sensitive to CMA than to sodium chloride, and concentrations less than 50 ppm have been identified as necessary to avoid damaging effects to algae.¹⁰⁴

HUMAN HEALTH/USE There are no established drinking water standards for acetate.

Calcium

Calcium is a component of calcium chloride, a salt compound, and CMA. (Studies evaluating CMA are discussed above under acetate.)

Characterization/Transport/Fate

Calcium, an alkaline earth metal, does not exist as a pure substance but in an ionic form in a variety of compounds.¹⁰⁵ Calcium is a major constituent of many common rock minerals—such as calcite, dolomite, and gypsum—and is an essential element for plants and animals. It is soluble in water and can travel along water pathways. It also may adsorb on soil particles or be transformed to limestone or dolomite in mineral-forming reactions in soil.¹⁰⁶ Calcium may be absorbed by a plant and is released only during decomposition, when it reenters the soil. In surface water, calcium may be utilized directly by organisms, may precipitate, or may be adsorbed onto sediments. Calcium is present in continental rain at 0.24 ppm and averages 20 ppm in North American rivers.¹⁰⁷

Impacts of Calcium

SOIL The effects of calcium in the soil are mixed. Like magnesium and potassium (discussed below), Michigan soils are deficient in calcium, and calcium released into the soil by deicing materials may displace sodium and heavy metals (such as lead, cadmium, and zinc) in soils at cation exchange sites.¹⁰⁸ (Studies describing results of similar tests on CMA are reported above under acetate.) A positive effect is that soil permeability and aeration can increase when calcium exchanges with cations on the surface of soil particles.¹⁰⁹

TERRESTRIAL VEGETATION Calcium is a plant nutrient, and although it is necessary in maintaining the structure of plants, extremely high concentrations can lead to excessive salinity and toxicity caused by osmotic stress.¹¹⁰

No studies on the direct effects of calcium chloride were found. The chloride section of this report details the effects on vegetation of sodium chloride; the effects of calcium chloride are similar.

WATER As mentioned, calcium may have the ability to exchange with and release heavy metals in roadside soil, which ultimately may increase metals reaching surface water or groundwater; little documentation of this phenomenon in the field was found, however.

No studies were found that focus specifically on the effect of calcium chloride on water bodies, although potential effects can be identified. Like sodium chloride, calcium chloride is a salt compound, and if small streams, lakes, and wetlands with little water exchange receive significant amounts of it, they can be adversely affected by high concentrations and density stratification. For more detailed descriptions of such effects, see the chloride section of this report.

AQUATIC BIOTA At high concentrations calcium can increase water salinity levels, which will contribute to osmotic stress on aquatic biota.

HUMAN HEALTH/USE No drinking water standards have been set for calcium, although the World Health Organization recommends a limit of 30-75 ppm.

Elevated levels of calcium increase water hardness, defined as a level of ions in water that react with sodium soap to precipitate an insoluble residue. A high level of hardness affects domestic water use: soap does not suds satisfactorily, and calcium deposits appear in plumbing.”

Magnesium

The magnesium-based deicers are CMA and magnesium chloride, which is used in CG-90 Surface Saver. General information and studies about CMA are reported above under acetate. CG-90 Surface Saver is predominantly sodium chloride and magnesium chloride. Therefore, its potential effects are those caused by sodium chloride (discussed under chloride) and magnesium chloride (presented below).

Characterization/Transport/Fate

Magnesium, an alkaline earth metal, is a common element essential to plant and animal nutrition.” It is released to the environment by rock weathering, predominantly from dolomite. It is freely soluble in water and transports along water pathways. In soil and surface water, magnesium ions are adsorbed on soil particles and may precipitate in mineral-forming reactions to produce dolomite.

Impacts of Magnesium

SOIL Michigan soils are deficient in calcium, magnesium, and potassium, which creates a high demand for these ions on exchange sites of soil particles.¹¹³ Magnesium is adsorbed on cation exchange sites and has the potential-like calcium-to mobilize roadside heavy metals, e.g., cadmium, lead, and zinc, particularly when the substance first reaches the soil. A study by Homer examines metal mobility in soil, and the results indicate that there are no significant environmental problems with magnesium; however, because the effects on highly contaminated roadside soils were not examined, a recommendation is made for further field study over an extended period of time.¹¹⁴

TERRESTRIAL VEGETATION Magnesium is a plant nutrient and does not have significant adverse impacts on vegetation unless toxic concentrations are reached.¹¹⁵ Studies examining the effects of magnesium chloride on vegetation were not found. See the chloride section above in this report for a detailed explanation of sodium chloride effects, which are similar to the effects expected of magnesium chloride.

WATER Magnesium may have the ability to exchange with and release heavy metals in roadside soil, and this ultimately can increase metals reaching surface or groundwater; however, little field documentation of this phenomenon was found.¹¹⁶

Studies that focus specifically on the effect of magnesium chloride on water bodies were not found, although potential effects can be identified. Like sodium chloride, magnesium chloride is a salt compound, and if small streams, lakes, and wetlands with little water exchange receive significant amounts of it, they can suffer damage from high concentrations and density stratification.. For more detail on such effects, see the chloride section in this chapter (above).

AQUATIC BIOTA At high concentrations magnesium can increase water salinity levels, which will contribute to osmotic stress on aquatic biota.

HUMAN HEALTH/USE No drinking water standards have been established for magnesium. Like calcium, elevated levels of magnesium increase water hardness and affect domestic uses of water.

Sand

Silica sand is the most common sand and is used by the MDOT on roadways as an abrasive to provide wheel traction. Sand is generally mixed with salt or calcium chloride to prevent freezing and facilitate spreading.

Characterization/Transport/Fate

Silica sand is a natural material in the environment. It is composed mainly of quartz (SiO_2), with minor amounts of feldspar and mica. These components are relatively insoluble, particularly the quartz. Sand does not react or combine with other elements.“

Sand accumulates on roadsides and is transported by physical processes such as wind, water pathways, and soil erosion. If sand reaches surface waters, the lighter particles may remain in suspension, while the heavier particles settle to the bottom. Typically, streams in the United States have fewer than 10 ppm of silica.¹¹⁸

Impacts of Sand

Sand has few impacts because it does not chemically react.

SOIL Sand remains on the surface of the soil.

TERRESTRIAL VEGETATION Due to its gradual accumulation, sand can cause stress to low roadside vegetation.

WATER AND AQUATIC BIOTA Sand particles settling to the bottom of streams can destroy the rock and cobble habitat of some aquatic organisms; when this occurs other, often less-desirable, bottom-dwelling organisms take over.

HUMAN HEALTH/USE When finely ground sand becomes airborne, it can contribute to human respiratory problems.¹¹⁹

Potassium

Potassium is a component of potassium chloride, a deicing material. CMS-B (Motech) is the product name of a potassium chloride material that is a by-product of sugar beet processing.

Characterization/Transport/Fate

Potassium is a rock-forming element and is essential for plants and animals. It is released to the environment by rock and soil erosion. Potassium is water soluble and remains ionized until such removal processes as adsorption onto soil particles take place.¹²⁰ Because potassium is readily soluble, it is easily leached from light or sandy soil particles into adjacent waters. Potassium concentrations in continental rain range from 0.1–0.5 ppm, and the average concentration in North American rivers is 1.5 ppm.¹²¹ Potassium levels are much higher in hot springs or natural brines.

Impacts of Potassium

SOIL Potassium can exchange on soil particles with such essential soil nutrients as calcium and magnesium and with heavy metals. This exchange, like that of calcium, magnesium, and sodium, can release heavy metals. Little field data were found documenting this release, however.

TERRESTRIAL VEGETATION Increasing the availability of potassium to plants encourages their synthesis of carbohydrates, which results in increased cell wall thickness and stalk strength. No adverse effects of potassium on vegetation are documented. Potassium chloride is a salt compound; the chloride section above contains a detailed explanation of sodium chloride effects, which may be similar to those expected of potassium chloride.

WATER AND AQUATIC BIOTA If potassium ions are not adsorbed on soil particles, they will follow the path of the soil water and eventually may be discharged to surface waters or enter groundwater. Because potassium is a nutrient, in limited situations it may induce eutrophication.*?

Like sodium chloride, potassium chloride is a salt compound, and if small streams, lakes, and wetlands with little water exchange receive significant amounts of it, they can be negatively impacted by high concentrations and density stratification.

HUMAN HEALTH/USE No drinking water standards have been set for potassium.

SECONDARY COMPONENTS IN DEICING MATERIALS

The secondary components in the deicing materials under consideration are (1) substances present in sodium, calcium, and magnesium chlorides in small amounts (3-5 percent), such as phosphorous, nitrogen, sulfate, and zinc; and (2) the corrosion inhibitors used in corrosion-inhibiting salts in very small amounts (0.5–4.5 percent), such as sodium phosphate.¹²³

Phosphorous

Phosphorous can be introduced into the environment in road salt (usually in concentrations of 14-26 ppm) or as the inhibitor in corrosive-inhibiting salt.¹²⁴ The Michigan water quality criterion for phosphorous is 1 ppm (monthly average) at point discharges.¹²⁵

Phosphorous can be adsorbed on clay minerals in soil and strongly stimulates terrestrial plant growth. When in solution, phosphorous is transported by water flow. Phosphorous concentrations in natural

waters usually are low, not greater than a few hundredths of a milligram per liter, because as an essential nutrient it is utilized quickly by aquatic plants. Increases in phosphorous concentration stimulate plant growth and can accelerate eutrophication.

Nitrogen

Nitrogen sometimes is present in road salt in amounts ranging from 64,200 ppm.¹²⁶ Nitrogen can be found in four recognized spheres of Earth: lithosphere (rock material), atmosphere, hydrosphere (ocean), and biosphere (living matter). Although nitrogen is an essential nutrient for plants and animals, when it combines with hydrogen it forms ammonia, which is toxic to freshwater organisms in concentrations of 0.53-22.8 ppm for 19 invertebrates and 0.0834.6 ppm for 29 fish species.¹²⁷ In addition, in the presence of oxygen, ammonia can convert to the nitrate form of nitrogen. Nitrate is negatively charged and able to move readily through soil; a federal primary drinking water standard of 10 ppm has been established for nitrate.

Sulfate

Sulfate often is a secondary constituent of sodium chloride in amounts of 6.78-4,200 ppm.¹²⁸ It is formed when sulfur-an essential nutrient for plants that is released to the environment when igneous and sedimentary rocks erode--combines with water. A secondary federal drinking water standard for sulfate has been established at 250 ppm. Concentrations of sulfate in continental rain range from 1-3 ppm, and most natural waters contain approximately 200 ppm. No negative effects are expected from exposure to low quantities of sulfate.

Zinc

Zinc often is a secondary constituent of road salt in amounts of 0.02-0.68 ppm.¹²⁹ It is a fairly commonly found metal that is soluble in water and is essential to plant and animal metabolism. There are an estimated 10 ppb (parts per billion) zinc in all surface water.¹³⁰ The federal secondary drinking water limit for zinc is 5 ppm. The Michigan water quality criteria specify a maximum of 81 ppb zinc in water with a hardness level of 178 ppm (the hardness level typical in Michigan) for surface areas outside of a mixing *zone* (area where contaminants enter a water body).

Heavy Metals

Vehicle traffic can release heavy metals into the environment; examples are lead from gasoline and chromium from metal plating. The metals are transported from the roadway via runoff and can contribute to the contamination of roadside soil. Heavy metals can reach groundwater and surface water if released from the soil by ionic exchange with calcium, magnesium, potassium, and sodium in deicing materials.¹³¹ Exhibit 3.5 shows the primary sources of the heavy metals released by vehicles, with standards for their presence in drinking water.

Laboratory tests indicate that in aquatic organisms high concentrations of heavy metals can delay embryonic development, suppress reproduction, inhibit growth rates, and cause mortality.¹³² How-

Exhibit 3.5: Heavy Metals Released by Vehicles, with Sources and Drinking Water Standards

Heavy Metal	Traffic Sources	Drinking Water Standard
Lead	Tetra ethyl lead gasoline, tire wear, lubricating oil and grease, bearing wear	15 ppb (enforcement action level)
Zinc	Tire wear, motor oil, grease	5,000 ppb (nonenforced SMCL)
Iron	Vehicle rust, highway structures, moving engine parts	300 ppb (nonenforced SMCL)
Copper	Metal plating, bearing and bushing wear, brake lining wear	1,300 ppb (enforcement action level)
Cadmium	Diesel oil, tire wear	5 ppb (MCL)
Chromium	Metal plating, brake lining wear	100 ppb (MCL)

SOURCE: Public Sector Consultants, Inc., from information in "Alternative Road Deicers," Resource Concepts, 1992, and memo, James Sygo to Robert Sills, MDNR, May 1993.

SMCL = Secondary maximum contaminant level.
MCL = Maximum contaminant level.

ever, the conditions experienced in the lab may be extreme; further field study is needed to determine if heavy metals in roadside soil are indirectly released by deicers.

CORROSIVE EFFECTS OF DEICING MATERIALS ON VEHICLES AND HIGHWAY INFRASTRUCTURE

This section reports on basic corrosion processes, the effects on automobiles and the highway infrastructure, and the corrosive properties of the deicing materials evaluated in this study. Estimates of the costs of vehicle and highway infrastructure corrosion in Michigan are included in the economic analysis in chapter 4.

In 1991 the TRB published *Highway Deicing: Comparing Salt and CMA*. The report provides an exhaustive description of corrosion processes affecting motor vehicles, bridge decks, bridge structural components, pavement, highway drainage systems, highway fixtures, sidewalks and driveways, snow- and ice-control equipment, parking garages, and materials underground. Corrosion prevention measures used by the automobile industry and bridge and roadway engineers are described and their costs provided. Additionally, costs to repair and maintain the transportation infrastructure already affected by salt are quantified in the report.¹³³

Corrosion occurs when metal is oxidized in the presence of oxygen and moisture. It is accelerated when chloride from salt is in the moisture solution, because the conductivity of the moisture is increased. Therefore, corrosion of automobiles, bridges, road surfaces, road signs, parking garages, and underground objects is partially attributed to road salting. The rate of corrosion is affected by

moisture, temperature, and other corrosives present, as well as the use of corrosion-resistant materials.¹³⁴ Michigan's humid climate provides a naturally moist and corrosive environment, which is exacerbated by the corrosive effects of acid rain in the northern United States. As the temperature increases, so does the amount of corrosion. Because chloride lowers the freezing point of solution, it enables corrosion to occur at lower temperatures. Beginning in the 1960s the use of corrosion-resistant materials, such as plastics and galvanized steel, as well as changes in frame design have reduced the extent of corrosion affecting vehicles and the highway infrastructure.

Motor Vehicles

Some studies attribute approximately 50 percent of automobile corrosion to road salt.¹³⁵ The effects of corrosion on automobiles range from metal thinning, ultimately leading to perforation, to aesthetic damage such as paint blistering and bubbling of the metal surface. Common corrosion impacts on automobiles are crevice corroding and pitting. *Crevice* corroding involves areas about 0.1 millimeter or smaller in diameter that are adjacent to fasteners, under bolts, or in places in the frame that can harbor corroding contaminants contained in dirt or debris. *Pitting* occurs where paint has been chipped and the metal exposed to oxidation. In the 1960s automobile manufacturers began using corrosion-resistant materials in areas particularly susceptible to corrosion, and they redesigned bodies to reduce exposure to corrosion. An industry goal is to eliminate exterior surface rust on new vehicles for at least five years and perforations for at least ten.¹³⁶ As a result, corrosion damage to today's automobiles has been significantly reduced; the corrosion that occurs on new cars is largely cosmetic. Corrosion persists, however, on vehicles manufactured before the early to mid-1980s.

Bridge Decks and Structural Components

Bridges built before the 1970s are suffering corrosive damage to their reinforcing steel, structural steel, and concrete components. This damage has been attributed largely to road salt. The predominant adverse effect of road salting has been to bridge decks. When road salt mixes with water, the salt solution penetrates the concrete deck through cracks in the bridge deck and corrodes reinforcing steel bars, welds, and joints. As the steel rusts, it expands and puts pressure on the concrete, causing cracks and potholes in the concrete surface. Scaling, which also can occur on bridge decks, is described below in the discussion of road surfaces. Other bridge deck components vulnerable to corrosion are grid decks, joint devices, and drainage systems.

Structural components vulnerable to corrosion are bearings (used to allow the bridge structure to expand or contract without damage), steel framing and supports, concrete supports, prestressed concrete supports, and joint devices. Road salt reaches these components through deck cracks, poor drainage, and splash/spray from traffic. Damage frequently can be slowed by good maintenance, such as cleaning and painting.

Preventive measures that have been instituted to reduce corrosion to new bridges include the use of thicker and denser concrete decks, more covering on reinforcing steel, waterproof membranes, epoxy coating of rebar, and cathodic protection. Other changes include structural modifications to better accommodate or remove the necessity for bridge expansion and contraction. Newer bridges are being

built to resist the expansion and contraction caused by temperature change, making the need for expansion joints obsolete, and bearings now can be produced from rubber or teflon, which do not corrode.¹³⁷ Bridges built before 1985 and those built with no corrosion prevention or receiving low maintenance continue to degrade.

Road Surfaces

Reinforcing steel used in road surfaces degrades in the same way it does in bridge decks. As the steel rusts, the expansion puts pressure on the concrete overlay, causing cracks and potholes in the surface. *Scaling* also can occur, which involves degradation of the top layer of the road surface and exposure of the underlying aggregate. This degradation can be caused by several factors. Salt on the road lowers the freezing temperature of the top layer of the surface, but bottom layers may freeze; the temperature differential creates stress. One study finds that if material to be laid is presoaked in deicing fluid, the stress caused by differences in deicing concentrations is reduced. Differential freezing also can occur on the surface of the road due to pockets of varying concentrations of salt. Another cause of scaling could be that crystals grow in road surface cracks, causing the top layer to chip. Scaling and rusting of reinforced steel bars both can be reduced by using coated reinforced steel and thicker concrete overlays to discourage chloride infiltration. In general, older roads are more susceptible to damage, and roads built without these corrosion prevention measures will age faster than those that are protected.

Parking Garages

Like bridges, parking garages built before the 1970s have little corrosion protection, and they suffer similarly from road salt. Chloride from the salt drips off vehicles and penetrates the overlays, corroding embedded steel reinforcements. As the corroded steel rusts and expands, pressure builds on the concrete, causing cracks and potholes. In recently built parking structures, the use of epoxy coated rebars and thicker concrete overlays is reducing corrosion.

Materials Underground

Underground utility pipes and cables suffer corrosion damage, although this has not been attributed directly to road salt. The extent of corrosion depends on the soil type, permeability, and moisture content. As the amount of moisture increases, so too does the probability of corrosion. The presence of chloride increases the conductivity of the electric circuit from the soil to the metal. Poorly drained pipe and cable ditches can capture salt and create a corrosive environment.

CORROSIVITY OF SELECTED DEICERS

Calcium Magnesium Acetate

As mentioned, in 1988 the TRB compared the corrosive effects of salt and CMA. The research shows that asphalts, plastics, elastomers, ceramics, wood, sign sheetings and paints, rubber compounds, sealers, and adhesives appear to be similarly affected or unaffected by solutions of road salt or CMA. The corrosive effects of salt are greater than those of CMA on Portland Cement concrete, vehicle paint

and coatings, automobile hydraulic brake-line tubing, automobile steel, aluminum alloys, stainless steel, and combined metals. Generally, road salt causes more localized pitting and crevice corrosion than CMA on all materials tested except aluminum. CMA is less corrosive than road salt on exposed steel and on the metal components of bridges used for joints, gutters, railings, and beams. CMA is much less damaging to new reinforced concrete than is road salt, and where reinforced concrete already has been contaminated by road salt, corrosion is not accelerated by CMA. It is not known whether CMA can reduce the rate of corrosion of bridges already damaged by road salt.¹³⁸

Studies conducted by the MDOT Materials and Technology Division indicate that sheltered exposure metals (those most susceptible to dampness and corrosion) exposed to CMA experience roughly 6-10 percent the corrosion of the same metals exposed to road salt. An additional MDOT study of a mixture of 6.125 percent CMA and 3.5 percent road salt finds that this mixture performs as well as does pure CMA in such experiments. Currently, CMA is used by the MDOT on the Zilwaukee Bridge because it inhibits corrosion.¹³⁹

Corrosion Inhibitors

Research indicates that CMA is significantly less corrosive than road salt, but its cost is significantly higher. Corrosion-inhibiting salts, which create a film around metal surfaces to act as a barrier to chloride, are a less expensive means of decreasing corrosion.

Cargill, the manufacturer of the CG-90 corrosion-inhibitor products, reports that in laboratory tests its products are better corrosion inhibitors than water, calcium chloride, and road salt-in that order. More specifically, CG-90 Surface Saver is reported to be 46 percent as corrosive as road salt. Scaling resistance laboratory test results find CG-90 Surface Saver to be the top performer, followed by water, CG-90 Surface Saver Liquid, calcium chloride, road salt, and CG-90.¹⁴⁰ CMA was not tested against the corrosion inhibitors.

Calcium Chloride

Calcium chloride is a salt compound that is used with sand or road salt to enhance performance. Tests conducted by Cargill, the manufacturer of CG-90 Surface Saver, indicate that calcium chloride is more corrosive than water and is 36 percent less corrosive than road salt.

Sand

Sand itself is not corrosive, although moisture in it can be.

Others

Specific corrosion information for Verglimit and CMS-B was not found. In theory, Verglimit should have a lower corrosion rate than road salt, because the calcium chloride pellets are embedded in pockets that are below the road surface and therefore not in direct contact with vehicles. In addition, less road salt has to be applied on Verglimit surfaces as a supplemental deicer. The effect of chloride infiltrating the Verglimit overlay and rusting reinforcing bars is not known.

CMS-B is a potassium chloride-based material and, not considering the rate of usage, it may have corrosion effects similar to salt, due to the chloride ion.

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