Baseline Water Quality of Minnesota’s Principal Aquifers

TWIN CITIES METROPOLITAN REGION

Minnesota Pollution Control Agency
Baseline Water Quality of Minnesota’s Principal Aquifers - Region 6, Twin Cities Metropolitan Area

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Foreword

Ground Water Monitoring and Assessment Program (GWMAP) staff believe the enclosed report represents a comprehensive study of water quality in the principal aquifers of the seven-county Twin Cities Metropolitan Area, which corresponds with Minnesota Pollution Control Agency (MPCA), Region 6. Information in this report, when used in conjunction with Baseline Water Quality of Minnesota’s Principal Aquifers (MPCA, 1998a), can be used by water resource managers to identify baseline or background water quality conditions in areas or aquifers of concern, prioritize ground water problems, and assist in site decision-making, provided the limitations and assumptions outlined in the document are understood. Although data have been carefully analyzed, compiled, and reviewed independently, mistakes are inevitable with a data set this large. If mistakes are found in this report, please forward them to GWMAP staff. Errata sheets will be prepared as needed.

The report is divided into four parts. Part I briefly summarizes sample design and collection. Part II briefly describes analysis methods. Results and discussion are provided in Part III. Part IV includes a summary of results and recommendations.
List of Abbreviations

CWI - County Well Index
GWMAP - Ground Water Monitoring and Assessment Program
HBV - Health Based Value
HI - Hazard Index
HRL - Health Risk Limit
MCL - Maximum Contaminant Level
MPCA - Minnesota Pollution Control Agency
QA/QC - Quality Assurance/Quality Control
RLs - Reporting Limits
SMCL - Secondary Maximum Contaminant Level
USGS - United States Geological Survey
UTM - Universal Trans Mercator
VOC - Volatile Organic Compound
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Executive Summary

In 1993, 1994, and 1996 the Minnesota Pollution Control Agency’s (MPCA) Ground Water Monitoring and Assessment Program (GWMAP) sampled 93 primarily domestic wells in MPCA Region 6, which encompasses the seven-county Twin Cities Metropolitan Area in eastern Minnesota. This sampling effort was part of the statewide baseline assessment (baseline study). The objectives of the baseline study were to determine water quality in Minnesota’s principal aquifers, identify chemicals of potential concern to humans, and identify factors affecting the distribution of chemicals. An important benefit of this study was establishment of contacts with state and local ground water groups. GWMAP efforts in 1998 and 1999 are focused on providing information from the baseline study, helping ground water groups prioritize monitoring efforts, and assisting with sampling and analysis of ground water monitoring data at the state and local levels.

Samples were collected statewide from a grid at eleven-mile grid node spacing. One well was sampled from each aquifer located within a nine-square mile target area centered on each grid node. Sampling parameters included major cations and anions, trace inorganics, total organic carbon, volatile organic compounds, and field measurement of dissolved oxygen, oxidation-reduction potential, temperature, pH, alkalinity, and specific conductance. Statewide, 954 wells were sampled from thirty different aquifers.

Water quality varied between the major aquifers of Region 6. The Franconia aquifer had high concentrations of many chemicals, particularly the major ions. Ground water in this aquifer appears to be old and highly evolved geochemically. This contrasts with the Prairie du Chien aquifer, which is well oxygenated and susceptible to human activity, as evidence by elevated nitrate and chloride concentrations. The Jordan aquifer has good quality water, with low concentrations of dissolved solids compared to other aquifers. Water quality in the St. Peter aquifer varied widely, with half the samples showing oxygenated conditions and half showing strongly reducing conditions. The surficial drift aquifers showed impacts from humans, with concentrations of chloride, sodium, and some trace metals being high compared to other aquifers. There were few
exceedances of drinking criteria, but this may be partly related to sampling bias, since few samples were collected from sensitive aquifers in the older, more industrialized portions of the Twin Cities.

There were two exceedances each of drinking water criteria for nitrate, selenium, and manganese. Water quality in the major aquifers was similar to water quality found in the same aquifers statewide. Volatile Organic Compounds (VOCs) were detected in only four wells, but there was more than one VOC in each of these wells. Chlorinated solvents and VOCs typically associated with fuel oils and gasoline accounted for nearly all the VOC detections. The results suggest there are local human impacts to some aquifers due to industrial activity, use of automobiles, leaking tanks, and other commercial uses of organic chemicals.

Research needs for Region 6 include:
1. Determining the overall distribution of VOCs in the major aquifers of the Twin Cities Metropolitan Area;

2. Identifying major plumes containing chlorinated solvents;

3. Determining relationships between land use and ground water quality, including evaluation of long-term changes in ground water quality, in the major aquifers of the Twin Cities; and

4. Determining the relationship between geology, particularly mineralogy, and water quality.

Monitoring needs for Region 6 include:
1. Expanding data bases for the Paleozoic and water table aquifers by approximately 10 wells each;

2. Incorporating data from regulated sites into the regional baseline data;

3. Employing models to assist in tracking plumes, particularly for chlorinated solvents;
4. Conducting ambient monitoring in aquifers impacted by humans, particularly for VOCs;

5. Establishing agency-wide sampling, data management, and data analysis protocol by an intra-agency group consisting of staff from all programs dealing with ground water cleanup and monitoring; and

6. Collect monitoring information on the distribution of pesticides and metabolites

The discussion of baseline water quality and chemistry presented in Ground Water Quality of Minnesota’s Principal Aquifers (MPCA, 1998a) focused on statewide results. There was no attempt to explain differences in water quality between regions. Since ground water is largely managed on a regional basis, it is important to identify water quality issues at the regional level.

This report focuses on MPCA Region 6. Region 6 is located in eastern Minnesota and includes the Twin Cities Metropolitan Area counties of Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington (Figure B.1). The MPCA regional office is located in St. Paul.

The following needs for Region 6 were identified in The Redesign of the Ambient Ground Water Monitoring Program (Myers et al., 1992) as meeting local government needs for groundwater information:

• water quality trends, especially organics;
• regional water quality assessment;
• water quantity assessments;
• statewide baseline data;
• ground water and surface water interactions; and
• impacts from gravel mining.

Assistance needs were identified in the following areas:
• data interpretation;
• program design for local aquifers (state should be responsible for major
  aquifers); and
• coordination of existing efforts.

The baseline study conducted by GWMAP may be used to fulfill the informational
needs of regional water quality assessment and statewide baseline data. The baseline study
can assist with data interpretation through analysis of the data for the region, and by
describing analysis methods useful in local interpretation.

This report provides baseline water quality information for Region 6. Comparisons are made between water quality in the principal aquifers of Region 6 to that
in the remainder of the state. Significant differences in ground water quality between
Region 6 and the statewide data were determined, factors contributing to these differences
were identified, and potential health implications were investigated. **NOTE: Water
quality is a relative term which may have multiple meanings. In this report, water
quality typically refers to the chemical nature of ground water, although the term is
occasionally used in risk evaluations to describe potential effects on humans
consuming ground water. The reader should be aware of these different
applications of water quality.**
1. **Baseline Design and Implementation**

Design and implementation of the baseline study are described in Myers et al. (1992) and MPCA (1994, 1995, and 1998a). A systematic grid design was implemented, with sampling nodes spaced at eleven mile intervals. Samples were collected from all major aquifers where a suitable domestic well was located within a nine square mile area centered on each grid node. The County Well Index (CWI) (Wahl and Tipping, 1991) was used to determine suitability of wells within the sampling area. CWI aquifer codes are summarized in Table A.1. Wells were purged until field measurement of pH, temperature, and specific conductance stabilized to 0.1 pH unit, 0.1°C, and 10% for three consecutive readings, with each reading being taken after approximately one well volume had been purged. Sampling parameters included field parameters (dissolved oxygen, oxidation-reduction potential, pH, temperature, specific conductance, and alkalinity) major cations and anions, volatile organic compounds (VOCs), total organic carbon, and 34 trace inorganic chemicals. Tritium and pesticides were sampled in select wells. Samples were not filtered. Rigorous analysis of the data was conducted. Sampling and analysis methods are described in MPCA 1996 and 1998b, respectively. Sample locations, by aquifer, are illustrated in Figure B.2 for the Franconia, Ironton, and Galesville aquifers; in Figure B.3 for the St. Peter, Jordan, and Prairie du Chien aquifers; in Figure B.4 for buried drift aquifers; and in Figure B.5 for water table drift aquifers. Sampling is summarized by aquifer in Table A.1 and for all data in Table A.2. Detailed aquifer descriptions are provided in Section 3.5.

2. **Analysis Methods**

Quality assurance/quality control analysis of the data are reported in MPCA (1998a). Data analysis consisted of

- establishing descriptive statistics (mean, median, minimum, etc.) for each chemical and each aquifer;

- conducting hypothesis tests between aquifers and different well diameter classes;
• conducting factor analysis related to the distribution of chemicals in the principal aquifers;

• conducting an analysis of health and risk.

Methods used in conducting these analyses are described in MPCA (1998b).

3. Results and Discussion

Results are separated into:

• descriptive statistics;
• group (hypothesis) tests;
• health and risk;
• discussions for individual aquifers;
• discussions for individual chemicals and chemical parameters.

3.1. Descriptive Summaries

Descriptive statistics include the number of samples, number of censored samples (samples below the maximum reporting limit), the type of distribution for the data, and the mean, upper 95th percent confidence limit of the mean, median, 90th or 95th percentile, minimum, and maximum concentrations. Results are summarized in Tables A.3 through A.17 for the fifteen aquifers sampled in Region 6. All concentrations are in ug/L (ppb) except for Eh (mV), temperature (°C), pH (negative log of the hydrogen ion concentration), and specific conductance (umhos/cm). Sample sizes for the Franconia-Ironton-Galesville (CFIG), Ironton-Galesville (CIGL), Mt. Simon (CMTS), St. Lawrence-Franconia (CSLF), St. Lawrence (CSTL), Platteville (OPVL), St. Peter-Prairie du Chien (OSPC), and Precambrian (PCUU) aquifers were small and no further discussion of these aquifers is presented in this report.

Examples of how to use information from Tables A.3 through A.17 in site applications are provided in MPCA, 1998a. To use these data in site applications, the coefficients presented in Tables A.18 and A.19 will be needed. Mean and median concentrations are considered to represent background concentrations with which
site or other local water quality information can be compared. Upper 95th percent confidence limits and 90th or 95th percentiles represent extremes in the distribution for a chemical. The distribution of a chemical indicates whether concentrations need to be log-transformed and whether concentrations below the detection limit will be encountered during subsequent sampling.

3.2. Group Tests

Group tests are statistical tests which compare concentrations of a chemical or parameter in one group with concentrations in another group or groups. A group might be month of sampling, for example, and a group test might explore potential differences in concentrations of a chemical between two or more months. Concentrations of sampled chemicals and chemical parameters were compared between different aquifers.

Concentrations of many chemicals differed between different aquifers. Median chemical concentrations were compared between the Franconia (CFRN), Jordan (CJDN), Prairie du Chien (OPDC), St. Peter (OSTP), buried confined drift (QBAA), buried unconfined drift (QBUA), and surficial drift (QWTA) aquifers. Results are summarized in Table A.20. P-values are included for each chemical. The p-value indicates the probability that median concentrations between aquifers are equal. Median concentrations are given in ug/L (except for Eh, pH, temperature, and specific conductance).

Different median concentrations were observed for many chemicals. Some of these differences will be discussed in greater detail in the section for individual aquifers, but the primary conclusions are summarized below.

1. Concentrations of calcium, magnesium, sodium, sulfate, and bicarbonate were highest in the Franconia and buried drift aquifers. These aquifers are covered by glacial or Paleozoic deposits and are therefore well protected. Ground water residence times are likely to be long compared to other aquifers. The higher concentrations of these major ions may reflect increased dissolution of parent material.

2. Boron, iron, and arsenic concentrations were higher in the Franconia aquifer compared to other aquifers.
3. Concentrations of chloride and sodium were highest in the water table aquifer, possibly due to anthropogenic sources such as leaching of road salts, fertilizers, and animal wastes.

4. Eh was low in the Jordan and St. Peter aquifers. This contrasts with the Prairie du Chien aquifer, which had high Eh and low concentrations of iron and manganese, as would be expected in an oxidizing environment. It is unclear why the Prairie du Chien, which is positioned between the St. Peter and Jordan aquifers, would have such an oxidizing environment compared to these two aquifers. Degradation of organic compounds present in the aquifer as a result of human activity may impact oxidation-reduction conditions locally. These results may have implications for cleanup programs, since some chemicals such as vinyl chloride are persistent in reducing environments, while others such as trichloroethylene are persistent in oxidizing environments.

### 3.3. Health and Risk

Drinking water criteria for individual chemicals are summarized in Table A.21. The Health Risk Limit (HRL) and Health-Based Value (HBV) are health-based criteria. HRLs are defined in the following manner: *HRLs are promulgated concentrations of a ground water contaminant, in ug/L, which estimates the long-term exposure level which is unlikely to result in deleterious effects to humans. HRLs strictly incorporate factors related to human health* (Minn. R., Pts. 4717.7100 to 4717.7800). HBVs have a similar definition, with the exception that they are not promulgated and have not undergone rigorous external peer review. Drinking water criteria are calculated based on a standard adult (70 kg) ingestion rate of two liters of water per day. Uncertainty and other exposure pathways, such as showering, cooking, and inhalation of water vapor, are addressed through the use of safety factors. Lifetime exposure is assumed to apply to baseline data, since the sampled wells are used for domestic supply. Maximum Contaminant Levels
(MCLs) and Secondary Maximum Contaminant Levels (SMCLs) are not strictly health-based and may include factors such as treatability.

The number and percent of samples exceeding health-based ground water drinking criteria are summarized in Tables A.22 and A.23, respectively. **In anticipation of a change in the HRL for manganese from 100 ug/L to a value of 1000 ug/L or greater, the drinking criteria for manganese used in this report is modified from the HRL (MDH, 1997).** Sample size was not sufficient for the Ironton-Galesville, Precambrian, and buried unconfined (QBUA) aquifers to provide meaningful results. No chemical appeared to represent a significant potential risk in any aquifer. The HRL of 10000 ug/L for nitrate was exceeded once each in the Prairie du Chien and buried drift aquifers. The drinking criteria of 1000 ug/L for manganese was exceeded once each in the St. Peter, buried drift, and water table aquifers. The HRL of 30 ug/L for selenium was exceeded twice in the water table aquifer.

The number and percent of samples exceeding non-health-based ground water drinking criteria are summarized in Tables A.24 and A.25, respectively. Non-health-based drinking criteria include chemicals with a Maximum Contaminant Level (MCL) or Secondary Maximum Contaminant Level (SMCL). Iron exceeded its SMCL in 67, 64, 40, 67, 65, and 50 percent of the sampled wells in the CFRN, CJDN, OPDC, OSTP, QBAA, and QWTA aquifers, respectively. Criteria were not exceeded for any other chemical.

Some chemicals have the same toxic endpoint. For example, Table A.18 indicates that barium and nitrate both affect the cardiovascular/blood system. A useful calculation is to estimate the probability that chemicals with the same endpoint will exceed drinking water criteria when assessed in a cumulative fashion. To make this calculation, a hazard index (HI) is used to add the contribution of each chemical with similar endpoints

\[
[\text{HI}_{\text{endpoint}} = \frac{C_{\text{chemical 1}}}{\text{HRL}_{\text{chemical 1}}} + \frac{C_{\text{chemical 2}}}{\text{HRL}_{\text{chemical 2}}} + \ldots + \frac{C_{\text{chemical n}}}{\text{HRL}_{\text{chemical n}}}]
\]

where C represents the concentration (ug/L) of a chemical. If the HI exceeds 1.0 in an individual sample, further investigation is recommended to evaluate the potential factors controlling chemical concentrations and the validity of the exposure assumptions. These calculations were not made for this report, primarily because there are a limited number of
samples for all aquifers except the buried drift. These calculations were made for statewide data and are reported in MPCA, 1998a.

3.4. Discussion of Individual Chemicals and Chemical Parameters

Concentrations of nitrate, chloride, volatile organic compounds (VOCs) and arsenic were sufficient to warrant additional discussion.

3.4.1. Nitrate

Median nitrate concentrations were below the reporting limit of 500 ug/L in all aquifers except the Prairie du Chien, which had a median concentration of 1650 ug/L. The Health Risk Limit of 10000 ug/L was exceeded in only two wells. Despite these results, there was a very strong spatial pattern to nitrate distribution, with most of the detections occurring in the eastern third of the study area (Figure B.6). Detections of nitrate were distributed among each of the major aquifers. There were 20 detections of nitrate and the median oxidation-reduction potential (Eh), dissolved oxygen, and chloride concentrations in these wells was 276 mV, 3330 ug/L, and 21560 ug/L, respectively. Tritium samples collected in 13 of the wells with detectable nitrate had concentrations exceeding 10 TU, reflecting recent water. Conversely, wells with no detectable nitrate had a median Eh of 115 mV and median dissolved oxygen and chloride concentrations of < 300 and 2250 ug/L, respectively. Only five of the 23 wells sampled for tritium and containing no detectable nitrate had tritium concentrations exceeding 10 TU. The results suggest that nitrogen inputs into aquifers of Region 6 are considerable. Under reducing conditions within these aquifers (low Eh, low dissolved oxygen concentration), nitrate will undergo denitrification and concentrations will be less than the reporting limit of 500 ug/L. These results are supported by the correlation with chloride. Elevated chloride concentrations are probably related to anthropogenic sources.

The spatial distribution of nitrate in Paleozoic bedrock aquifers is related to the proximity of these aquifers to the land surface. In the eastern third of Region 6, unconsolidated deposits overlying the bedrock aquifers are thin or absent. In these areas, the uppermost bedrock aquifer appears to be sensitive to pollution. Walsh (1992) and
MPCA (1998c) found strong correlations between nitrate concentration and thickness of deposits overlying the uppermost aquifer, with little nitrate found in aquifers overlain by more than 70 feet of unsaturated surficial material.

Even within surficial drift aquifers, nitrate concentrations were greatest in the eastern part of Region 6. There are large areas of shallow sand aquifers in Washington County, and nitrate may associated with agriculture and unsewered developments. The lack of high nitrate concentrations in the Anoka Sand Plain Aquifer (Hennepin and Anoka Counties) is surprising, since this area is often intensively farmed and irrigated. Well depths, static water elevations, and screened interval were not different in wells containing detectable nitrate and those with no detectable nitrate.

3.4.2. Chloride

Chloride does not represent a health concern in ground water. It is, however, a chemical tracer because it is not attenuated and moves freely with water. Chloride is also an indicator of human impacts, since it is found in road salt, fertilizer, human waste, and animal waste.

Median concentrations of chloride within the surficial drift aquifer were 24980 ug/L, which is significantly greater than the statewide concentration of 5810 ug/L. Chloride was most strongly correlated with other major cations and anions, such as sodium, calcium, and magnesium. The greatest chloride concentrations were found in the central part of Region 6, which is the oldest and most industrialized part of the Twin Cities Metropolitan area (Figure B.7). The density of roads is also greater in this area compared to other areas of Region 6. Road salts and decreased recharge in these areas may account for the elevated chloride concentrations. Chloride was not well correlated with Eh, nitrate concentration, or dissolved oxygen concentration. The distribution of chloride appears to primarily be related to road salt, since fertilizer and human wastes would also contribute nitrate to ground water. Chloride is therefore a good indicator of young water but not necessarily of contamination, especially if multiple contaminant sources exist.

3.4.3. Volatile Organic Compounds (VOCs)
VOC results are summarized in Table A.26. There were only four wells in which a VOC was detected (Figure B.8). This represents 4.3 percent of the sampled wells, which is less than the overall statewide rate of 11 percent. All four wells had more than one VOC detected. Statewide, only 2.6 percent of sampled wells had more than one VOC detected. All the detected VOCs were either halogenated aliphatic compounds or chemicals commonly associated with fuels oils and gasoline.

There was one VOC detection each in the Franconia, Prairie du Chien, St. Peter, and buried drift aquifers. The occurrence of VOCs was correlated with geochemical conditions in an aquifer. Each of the four wells with a detectable VOC had a tritium concentration of 19.3 TU or greater. There was detectable nitrate in each of these wells and Eh exceeded 250 mV in all four wells.

The VOC results for Region 6 differ from those for other regions. While the incidence of VOC detections was low, affected wells are more contaminated than wells from other parts of the state. Since most of the samples collected for Region 6 were outside sewered areas of the Twin Cities Metropolitan area, these results do not reflect water quality under much of the Twin Cities, including heavily industrialized areas. These data suggest more information is needed to determine the distribution and associated risk from VOCs in Region 6.

3.4.4. Arsenic

The Maximum Contaminant Level (MCL) of 50 ug/L was not exceeded in any well sampled in Region 6. The MCL is not strictly health-based, but considers factors such as treatability. A strictly health-based value for arsenic is likely to be less than 10 ug/L, perhaps as low as 2 or 3 ug/L. An arsenic concentration of 3.0 ug/L was exceeded in 22
percent of the sampled wells. Higher concentrations of arsenic occur almost exclusively in the St. Lawrence (median = 3.9 ug/L), Franconia (median = 2.3 ug/L), and buried drift (median = 2.1 ug/L) aquifers. The greatest concentrations also occur near the western edge of the study area (Figure B.9). Arsenic is more soluble under reducing conditions, but conditions within the Franconia and buried drift aquifers are not particularly reducing (Eh = 206 and 195 mV, respectively), suggesting some of the aquifer materials are enriched in arsenic. Correlations between arsenic and most other chemical parameters were weak, but significant correlations were observed with iron and suspended solids. Since the samples were not filtered, arsenic may be associated with suspended matter or metal oxides.

3.5. Aquifers

The hydrology and geology of Region 6 is described in numerous reports, although there is no specific report which encompasses the entire area. The Hydrologic Investigations Reports for the Lower St. Croix River (Lindholm et al., 1974), Crow River (Lindholm et al., 1974), Rum River (Ericson et al., 1974), and Lower Minnesota River (Anderson et al., 1974) watersheds provide information about climate, the water budget, surface water, and ground water. Annual precipitation is about 28.5 inches and is relatively uniform across the study area. Annual surface water runoff varies from about 3 inches in the west to more than 9 inches in the east. Annual recharge to surficial aquifers may be greater than these amounts and will vary widely with annual precipitation and local geology. The major rivers in the region are gaining streams in that they have a baseflow component (ground water discharges to them). County hydrologic atlases have been completed for Ramsey (Minnesota Geological Survey, 1992), Scott (Minnesota Geological Survey, 1982), Washington (1986), and Hennepin (Minnesota Geological Survey, 1989) counties, and a regional assessment of the Anoka Sand Plain (Minnesota Department of Natural Resources, 1993) has been completed.

The hydrogeology of the southern and eastern portions of Region 6 is dominated by Paleozoic bedrock geology consisting primarily of limestone, dolomite, and sandstone. In the northern part of the study area, surficial and buried drift aquifers are important
sources of drinking water. The primary bedrock aquifers in Region 6 include the St. Peter sandstone, the Prairie du Chien Group (carbonate aquifers), the Jordan sandstone, and the Franconia sandstone. The bedrock aquifers more or less act as continuous units, with regional flow being to the major rivers in the area. Travel times within these aquifers range from a few years to several thousand years. Surficial and buried sand and gravel aquifers may behave as a regional flow system in which ground water flow is toward the major rivers in the area. Individual buried aquifers are poorly connected hydrologically with each other. The Mt. Simon and Ironton-Galesville aquifers are important sources of drinking water toward the northern and western portion of Region 6, where the Jordan aquifer is absent.

Ground water originates as precipitation which percolates through the soil and vadose zone and into the saturated zone (ground water). Most recharge originates in spring following snowmelt and prior to plant growth. Recharge to the different bedrock aquifers in the study area will vary widely with their vertical position relative to other bedrock units. In areas with sufficient thickness of overlying glacial deposits, the water table reflects, in a subdued way, surface topography. Ground-water flow is controlled by local factors such as topography, extent of fracturing and dissolution, permeability of glacial deposits, and local stresses such as pumping.

A limited amount of background water quality information exists for Region 6. This is partly due to the lack of wells for sampling in the older, residential and commercial areas of the region. Regional hydrologic studies in Region 6 were often conducted with limited budgets for water quality analysis. For these reasons, water quality information from other studies was not incorporated into this report. The aquifers considered in this report include surficial and buried sand and gravel, St. Peter, Prairie du Chien, Jordan, and Franconia. Locations of sampling points from these aquifers are summarized in Figures B.2 through B.5.

3.5.1. Surfacial Drift Aquifers

The glacial geology of Region 6 is complex because most of the area was covered by ice from both the Superior and Des Moines lobes. The materials deposited by these ice
sheets differ significantly. In addition, the Des Moines lobe overrode areas previously covered with material deposited by the Superior lobe, thus mixing materials deposited by the different ice sheets.

There are few surficial drift (QWTA) aquifers in the southern and western portions of Region 6. Surficial drift aquifers primarily occur in alluvium deposited along the major drainageways, such as the Mississippi, Minnesota, Crow, and St. Croix rivers (Minnesota Geological Survey, 1982). Surficial outwash deposits increase in frequency toward the northern part of the study area. Significant areas of surficial outwash occur in Hennepin, Anoka, and the western portion of Washington counties (Minnesota Geological Survey, 1989; Minnesota Department of Natural Resources, 1993).

Surficial drift aquifers appear to reflect impacts from humans, although data analysis is hampered by small sample size. This is partly due to a lack of wells drilled in sewered areas, which would be areas likely to show the greatest impacts from human activity. Concentrations of most chemicals are low compared to other aquifers in Region 6. Concentrations of chloride, sodium, zinc, copper, lead, and sulfate are higher in water table aquifers from Region 6 than in water table aquifers statewide. These may reflect inputs from human activity, including road salts (chloride and sodium), deposition of automotive emissions (lead), and industrial processes (copper and zinc).

Drinking water criteria were exceeded for manganese, iron, and selenium. These chemicals are discussed below.

**Manganese**

The drinking water criteria of 1000 ug/L for manganese was exceeded in one sample. The current HRL for manganese (100 ug/L) was exceeded in five samples. The overall median concentration for the aquifer was 111 ug/L. Manganese was correlated with copper ($R^2 = 0.83$), chloride ($R^2 = 0.83$), tritium ($R^2 = 0.83$), and static water elevation ($R^2 = -0.50$). These are not typical correlations for manganese, which generally increases with depth and as residence time increases.

**Iron**
The Secondary Maximum Contaminant Level (SMCL) for iron (300 ug/L) was exceeded in 50 percent (5 wells) of the samples. The median concentration of 225 ug/L is below the SMCL. There were significant correlations with many other chemicals. In general these indicated increasing iron concentrations in older, more reducing ground water and in water having high concentrations of organic carbon ($R^2 = 0.97$) and suspended solids ($R^2 = 0.99$). Samples were not filtered and dissolved concentrations of iron would be lower than the observed values. Iron concentrations in the surficial drift aquifer are low with respect to similar drift aquifers statewide and compared to different aquifers in Region 6.

Selenium

The HRL for selenium (30 ug/L) was exceeded in two samples. Selenium was not detected at a reporting limit of 1.0 ug/L in five of the nine samples and two of the samples had selenium concentrations at the reporting limit. There were no strong correlations between selenium and other chemicals. Water quality in the two wells with high concentrations did not differ from the remaining wells. The two wells were not geographically isolated from the remaining water table wells. There is no information in the database useful for identifying reasons for the elevated selenium concentrations in these two wells. It is possible the two higher occurrences of selenium are associated with particular geologic deposits, such as Des Moines Lobe till. Statewide, elevated concentrations of selenium were observed in Precambrian and Quaternary aquifers.

3.5.2. Buried Drift Aquifers

Well-sorted sand and gravel were deposited in bedrock valleys and as outwash plains by advancing and retreating glaciers. These deposits, which are typically less than 30 feet thick, were subsequently buried by fine textured material. Buried sand and gravel deposits comprise aquifers with limited potential supply for high capacity uses, but they yield sufficient quantities for domestic use. Buried aquifers occur throughout Region 6.
except in the southeast portion of the region, where bedrock occurs close to the land surface. These aquifers are in general, protected from contamination resulting from human activity at the land surface.

Using the County Well Index (CWI) nomenclature, the buried drift group is comprised of artesian (QBAA) and unconfined (QBUA) aquifers. The unconfined aquifers are classified differently than water-table aquifers (QWTA) because more than 10 feet of confining material (e.g. clay) was encountered during drilling. The statewide baseline report (MPCA, 1998b) indicates that the QBUA group has water quality which is more similar to the surficial drift aquifers than to the buried artesian aquifers. Physically, this makes sense since the difference in thickness of confining material between QWTA and QBUA aquifers is arbitrary. Consequently, only the QBAA group is discussed in this section. Water quality information for the QBAA and QBUA groups is illustrated in Tables A.15 and A.16, respectively.

Water quality of the QBAA aquifers appears to be more similar to water quality of the overlying surficial drift aquifers than the underlying bedrock aquifers. Concentrations of zinc, manganese, and sulfate were higher in QBAA aquifers from Region 6 than in similar aquifers statewide. Concentrations of these chemicals were also elevated in the surficial drift aquifers. Overall, concentrations of most major cations and anions were higher in the buried drift aquifers than in other aquifers of Region 6. This may reflect older, more highly evolved ground water.

Water quality of buried drift aquifers in Region 6 is very good. There was one exceedance of the drinking criteria for nitrate and manganese and 13 exceedances of the SMCL for iron. These chemicals are discussed below.

*Manganese*

The HRL for manganese (100 ug/L) was exceeded in 13 of the 20 sampled wells, but the drinking criteria used in this report (1000 ug/L) was exceeded in only one well. There were no strong correlations of manganese with other chemicals. Most of the higher concentrations of manganese were clustered in the western portion of the study area, in Hennepin and Carver counties. The overall median concentration was 259 ug/L, which is
much higher than the median concentration of 131 ug/L in similar aquifers statewide. If the drinking water criteria is raised to 1000 ug/L or more, manganese will not represent a health concern in Region 6.

Nitrate

The drinking water criteria of 10000 ug/L for nitrate was exceeded in one well. Nitrate was not detected in 15 of the 19 sampled wells. Three of the four wells with detectable nitrate had dissolved oxygen concentrations exceeding 1000 ug/L, while only two other wells in the study area had detectable dissolved oxygen. Samples with detectable nitrate were located in the eastern portion of the study area. This area is covered primarily by Superior lobe deposits, which may be more “permeable” than deposits of the Des Moines lobe (MPCA, 1998c). The strongest correlations of nitrate were with dissolved oxygen, tritium, and some of the more mobile elements such as antimony, chloride, and vanadium.

The areas in which nitrate was detected are a mix of residential development, unsewered developments and agricultural land. There are therefore sources of nitrogen in these areas. Nitrate is a potential health concern in these areas.

Iron

Iron exceeded its SMCL of 300 ug/L in 65 percent (13 wells) of the samples from the buried drift aquifer. The median concentration was 481 ug/L. This is well below the statewide median concentration of 1170 ug/L for similar aquifers. Iron was not well correlated with other chemicals except for total suspended solids ($R^2 = 0.94$). The samples collected for this study were not filtered and dissolved iron concentrations will be much lower, probably below the SMCL of 300 ug/L.

Iron, which stains plumbing fixtures, does not appear to represent a significant concern in ground water from buried drift aquifers in Region 6.

3.5.3. St. Peter, Prairie du Chien, and Jordan Aquifers
The St. Peter Sandstone, Prairie du Chien Formation (a carbonate formation), and Jordan Sandstone aquifers are often treated as a single aquifer. This grouping of aquifers is generally based on measured heads within the aquifers, which often suggest there is no effective confining unit between the aquifers. Recent studies, however, indicate when one aquifer is stressed there is often little hydraulic response in the adjacent aquifer. In addition, definitions based solely on hydraulics ignore the actual movement of chemicals within the aquifers since residence time and geochemistry change with depth. Comparisons of water quality in the three aquifers indicates significant differences in water quality between the three aquifers (MPCA, 1998b). In particular, specific conductance and concentrations of calcium, magnesium, potassium, sodium, chloride, nitrate, sulfate, total dissolved solids, and total suspended solids differ between the aquifers. These three aquifers are therefore treated individually in the discussion below.

3.5.3.1. St. Peter Aquifer

The St. Peter formation, which consists of fine- to medium-grained, well sorted quartzose sand, is separated from the Upper Carbonate formations by the Decorah Shale and the Platteville and Glenwood formations, which act as confining units. The St. Peter formation is easily eroded and therefore is only rarely found at the land surface. More often, the formation is covered by glacial deposits. The St. Peter formation is an important aquifer in the central portion of Region 6. The basal layer of the St. Peter formation can act as a confining unit when present, but the effectiveness of this layer varies considerably across the region (Ruhl and Wolf, 1983).

The water quality of the St. Peter aquifer is highly variable in Region 6. Concentrations of chloride are higher in Region 6 than the statewide median concentration for the St. Peter aquifer. This suggests some effect of human activity. However, Eh is lower and manganese concentrations higher compared to the statewide median for the St. Peter aquifer. These suggest older, more highly evolved water which should not reflect human effects. The data break into two distinct groups. One group of four wells had Eh values greater than 250 mV. Three of these wells had dissolved oxygen concentrations greater than 1000 ug/L, detectable nitrate, and tritium concentrations greater than 10 TU.
Chloride concentrations were also high in these wells. The other 5 wells had Eh values less than 50 mV and no detectable nitrate or dissolved oxygen. Concentrations of iron and manganese were very high in these five wells. All four samples with the high Eh values were located along the eastern or western margin of the study area, presumably in locations where the St. Peter is close to the land surface.

Drinking water criteria were exceeded for manganese and iron. These chemicals are discussed below.

Manganese

The drinking water criteria of 1000 ug/L was exceeded in one well (1019 ug/L). The distribution of manganese was very uneven in the study area. All five wells with the Eh values less than 50 mV had manganese concentrations which exceeded the current HRL of 100 ug/L. Concentrations in three of the four wells with Eh values greater than 250 mV had manganese concentrations less than 5 ug/L. Manganese concentrations were not well correlated with the other oxidation-reduction parameters (dissolved oxygen, nitrate, and iron), but were correlated with boron ($R^2 = 0.94$), dissolved solids ($R^2 = 0.93$), and suspended solids ($R^2 = 0.84$). These results suggest a relationship between increasing ground water residence time and manganese concentrations.

The source of the manganese is unclear. If the drinking criteria is raised to 1000 ug/L or more, manganese will not represent a drinking water concern in Region 6.

Iron

Iron exceeded its SMCL (300 ug/L) in 67 percent (6) of the sampled wells. The median concentration of 443 ug/L is slightly higher than the statewide rate of 384 ug/L for the St. Peter aquifer. All six exceedances of the criteria occurred in the western portion of the study area. The results are similar to those for manganese, with the aquifer being more susceptible to elevated iron concentrations in areas where the aquifer is well protected by confining layers. There were a number of significant correlations with other chemicals,
but no apparent pattern to these correlations. For example, iron was positively correlated with zinc and negatively correlated with copper. As with other aquifers, iron was significantly correlated with suspended solids, indicating water filtration is a good mechanism for reducing iron concentrations.

3.5.3.2. Prairie du Chien Aquifer

The Prairie du Chien group comprises two principal formations, the Oneota dolomite and the overlying Shakopee formation. These consist of thin- to thick-bedded dolomite separated by the New Richmond sandstone. The Prairie du Chien formation was deposited when the interior of the Hollandale embayment was subsiding more rapidly than the margins. The formation may be as thick as 400 feet. The Prairie du Chien formation is vuggy and fractured, with interbedded thin layer of shale.

Ground water flow is predominantly toward the major rivers in the area, including the Mississippi, St. Croix, and Minnesota rivers. Recharge to the aquifer is greatest in the eastern part of Region 6, where the aquifer is close to or crops out at the land surface. The Prairie du Chien is an extremely important aquifer in Region 6, but is vulnerable to contamination when overlying deposits of glacial till or the St. Peter sandstone are thin or absent.

There was exceedance of drinking water criteria for nitrate and four exceedances for iron. These chemicals are discussed below.

*Nitrate*

The HRL of 10000 ug/L for nitrate was exceeded in one well. Nitrate was detected at concentrations greater than 1000 ug/L in six of the ten sampled wells. The overall median nitrate concentration for the Prairie du Chien aquifer was 1650 ug/L. This is well above the statewide median concentration, which was less than the reporting limit of 500 ug/L. Water from the Prairie du Chien aquifer is oxidized, with a median Eh of
263 mV and a median concentration of 1820 ug/L for oxygen. Nitrate is therefore stable in the aquifer.

Nitrate was most strongly correlated with dissolved oxygen ($R^2 = 0.813$), iron ($R^2 = -0.417$), manganese ($R^2 = -0.452$), Eh ($R^2 = 0.547$), tritium ($R^2 = 0.491$), total organic carbon ($R^2 = -0.701$), alkalinity ($R^2 = -0.633$), and potassium ($R^2 = 0.780$). These correlations indicate nitrate will be found in well oxygenated ground water, which is typically impacted by recharge. Nitrate inputs in Region 6 appear to be substantial, probably from a combination of rural and urban fertilizers, animal and human waste, industrial processes, and possibly atmospheric fallout. Nitrate concentrations increased from north to south. The correlation with potassium is interesting, since nitrate was either not correlated or negatively correlated with other major cations and anions. The nitrate correlation with potassium may be related to use of potassium in fertilizers.

Nitrate concentrations in areas of the Prairie du Chien aquifer impacted by recharge represent a potential drinking water concern. Because of the large number of different nitrate sources, additional information is needed to assess nitrate risk under different land use settings.

Iron

The SMCL of 300 ug/L for iron was exceeded in four wells. The overall median concentration of iron was 35 ug/L, which is well below the statewide median of 487 ug/L for the aquifer. In each of the four wells in which iron exceeded the drinking criteria, dissolved oxygen was below the reporting limit. In the remaining six wells, dissolved oxygen concentrations were greater than 1300 ug/L. Iron was correlated with dissolved oxygen ($R^2 = -0.581$), Eh ($R^2 = -0.651$), total suspended solids ($R^2 = 0.757$), and tritium ($R^2 = -0.728$). Iron, which stains plumbing fixtures, does not represent a concern in shallow, oxygenated portions of the Prairie du Chien aquifer.

3.5.3.3. Jordan Aquifer

The Jordan sandstone consists of a quartzose, fine- to medium-grained sandstone, ranging from massive or thick-bedded to thin-bedded. Like the Prairie du Chien aquifer,
ground water flow is toward the Mississippi River. Concentrations of several chemicals, including bicarbonate, calcium, potassium, sodium, sulfate, and total dissolved solids, are significantly lower in the Jordan aquifer than in the Prairie du Chien aquifer, however.

The SMCL of 300 ug/L for iron was exceeded in seven samples. The median concentration was 345 ug/L. Iron was correlated with alkalinity ($R^2 = 0.903$), calcium ($R^2 = 0.864$), magnesium ($R^2 = 0.821$), total dissolved solids ($R^2 = 0.836$), and total suspended solids ($R^2 = 0.889$). These results reflect increasing concentrations of iron as ground water residence time increases, since concentrations of dissolved solids increase and ground water becomes more reducing with increasing residence time.

### 3.5.4. Franconia-Ironton-Galesville Aquifer

The Franconia Formation, Ironton Sandstone, and Galesville Sandstone are separated from the Jordan aquifer by the St. Lawrence Formation, which acts as a confining layer. As with other aquifers of Paleozoic age, these aquifers are often treated as a single hydrologic unit. Each aquifer consists of sandstone, although there are scattered layers of shale and dolomite within the Ironton and Galesville sandstones. Data from the statewide baseline study indicates the chemistry of these aquifers is very similar. There were no sampled chemicals which differed in concentration between the three formations, suggesting they may act as a single hydrologic unit. The discussion below treats them as a single unit. Consequently, the CFIG, CFRN, and CIGL aquifers are grouped together for this analysis.

The aquifer covers most of the study area except along the major rivers, where the formation was eroded and filled with glacial material. Ground water flow is similar to the overlying aquifers, with discharge to the major rivers in the area. The aquifer is separated from overlying aquifers by the St. Lawrence confining layer.

In general, the aquifer is covered by overlying glacial or Paleozoic deposits and is therefore well protected from direct leaching through the unsaturated zone. Ground water is typically reducing, with a median Eh of 198 mV and detectable concentrations of dissolved oxygen and nitrate in only two wells. Tritium was sampled in one of the two wells with detectable nitrate and the concentration exceeded 10 TU, reflecting recent
water. Tritium concentrations were less than 10 TU in the remaining wells for the Franconia-Ironton-Galesville aquifer.

Concentrations of most major cations and anions are higher in the Franconia-Ironton-Galesville aquifer compared to other aquifers in Region 6. Despite this, ground water quality is generally good within the aquifer. The only chemical which exceeded a drinking criteria was iron.

Iron

Iron exceeded its SMCL of 300 ug/L in 87 percent (13 wells) of the sampled wells. The median concentration was 856 ug/L. The strongest correlation was with total suspended solids ($R^2 = 0.94$). Other correlations of iron were weak. The greatest concentrations of iron occurred north of the Minnesota River. There is insufficient geologic information for this area to evaluate the reasons for the observed distribution of iron.

The primary effects of iron are on plumbing fixtures, taste, and development of iron bacteria. Iron does appear to represent a potential concern in Region 6.

4. Summary and Recommendations

This chapter is divided into a section providing a summary of the results, a section providing recommendations for additional research, and a section providing monitoring recommendations.

4.1. Summary

1. Summary statistics (median, minimum, maximum, mean, 95th confidence limit, and 90th or 95th percentile concentrations) for a wide range of chemical parameters have been calculated for 15 aquifers sampled in MPCA Region 6 in the Twin Cities Metropolitan Area located in east-central Minnesota. Sample size was sufficient for the Franconia (CFRN), Jordan (CJDN), St. Peter (OSTP), Prairie du Chien (OPDC), buried artesian drift (QBAA), and surficial drift (QWTA) aquifers so that these values
may serve as initial estimates of background concentrations, although additional data should be collected for some of these aquifers due to small sample size. A high density grid supplemented the baseline study in Region 6, but additional sampling from over 100 wells indicated no change in descriptive statistics for the major aquifers.

2. There were differences in concentrations of many chemicals between different aquifers. The Franconia aquifer had high concentrations of many chemicals compared to other aquifers, including bicarbonate, calcium, magnesium, potassium, sodium, sulfate, iron, boron, and organic carbon. The buried drift aquifer also had high concentrations of many chemicals. Residence time and parent material appear to be the primary factors controlling water quality in these two aquifers. The Jordan aquifer had low concentrations of most chemicals compared to other aquifers. Only cadmium, silver, and zinc were elevated in this aquifer. Water quality in the Jordan is generally very good. The Prairie du Chien aquifer appears to be highly impacted by recent water (recharge). Eh and concentrations of dissolved oxygen, nitrate, and chloride were higher in the Prairie du Chien aquifer compared to other aquifers. The surficial drift aquifer showed some effects of human activity, with concentrations of sodium, chloride, and some trace metals such as copper being higher than concentrations in other aquifers. Water quality in the St. Peter aquifer was highly variable. This was best demonstrated by Eh, which was less than 40 mV in five wells and greater than 250 mV in four wells.

3. Health-based drinking water standards (HRL or HBV) were exceeded for the following compounds:

- manganese - 2 exceedances, one each in the buried drift and St. Peter aquifers;
- nitrate - 2 exceedances, one each in the buried drift and Prairie du Chien aquifers;
- selenium - 2 exceedances in the surficial drift aquifer.

1. Non-health based standards (MCL or SMCL) were exceeded for the following compounds:
• iron - 41 exceedances, scattered among all aquifers.

2. Median concentrations of most chemicals in all aquifers of Region 6 were similar to statewide median concentrations for similar aquifers, but there were some aquifer-specific differences. Concentrations of most chemicals were higher in the Franconia aquifer in Region 6 compared to the Franconia aquifer statewide. Sodium and chloride were higher in the water table aquifers and sulfate was higher in all aquifers compared to statewide concentrations. The Prairie du Chien aquifer had higher concentrations of nitrate and dissolved oxygen compared to statewide values, while iron and manganese were lower. The Prairie du Chien aquifer in the Twin Cities Metropolitan Area appears to be readily recharged and is therefore sensitive to human activity at the land surface.

3. Volatile organic compounds were detected in 4 wells or 4.3 percent of the samples. Each well with a detectable VOC had more than one VOC detected. Chlorinated aliphatic compounds and substituted benzenes accounted for all of the VOC detections. No drinking water criteria for VOCs was exceeded. Despite the low frequency of detection compared to other regions of the state, individual wells which are vulnerable to contamination appear to be at greater risk from industrial sources compared to other regions in the state. An additional factor in this study was that very few samples were collected in the older, more heavily industrialized portions of the region because these areas are serviced with municipal water.

4.2. Research Recommendations

The Paleozoic aquifers of the Twin Cities Area have been extensively studied and modeled, and there is considerable information on the chemistry of these aquifers compared to other aquifers in Minnesota. However, this information is poorly organized. There are few studies discussing the attenuation properties of these aquifers with respect to contaminants. Surficial aquifers, although not as widely studied, suffer from the same information gaps with respect to water quality. The data set discussed in this report is biased toward not finding contamination, since the more industrialized portions of the region were sparsely sampled. Andrews et al. (1998) observed a high detection rate for VOCs and some trace metals under an older, more intensely developed
residential/commercial portion of the Twin Cities. The fact that each of the four wells containing a detectable VOC contained more than one VOC, and that all detected VOCs are related to industrial processes, indicates a need for much more information on the distribution of VOCs in Twin Cities aquifers. Research recommendations for Region 6 are discussed below.

1. Determine the overall distribution of VOCs in the major aquifers of the Twin Cities Metropolitan Area and identify the locations of major plumes containing chlorinated solvents. Information from regulated sites should be compiled and used to complete this objective. This information must include upgradient wells which provide information on background concentrations of VOCs originating from nonpoint sources.

2. Determine relationships between land use and water quality in the major aquifers of the Twin Cities and evaluate changes in water quality under new or changing land uses. The primary chemicals of concern are VOCs. Chloride serves as an excellent indicator of human impacts.

3. Determine the relationship between water quality and geology. This primarily applies to trace elements which are occasionally found at higher concentrations in an aquifer, such as selenium in Quaternary aquifers.

**4.3. Monitoring Needs**

The objective of ground water monitoring is to provide information which can serve as a point of reference for ground water quality. Baseline monitoring is used to provide data which can be compared with site-specific or regional data. Ambient monitoring includes a time component and is intended to provide information regarding long-term trends in water quality of an aquifer. Monitoring needs for Region 6 are discussed below.

1. Baseline data: the baseline data for the buried confined drift (QBAA) aquifer is sufficient to be considered representative of background. These data can simply be updated over time. Data bases for the Paleozoic and water table aquifers should be
expanded by approximately 10 wells each and the data analyzed to establish baseline conditions. Information in this report provides an initial estimate of background water quality in these aquifers, but the values may change as additional data is incorporated. A proportionate amount of this data should be collected from older, more heavily industrialized areas of Region 6. A logical way of bridging the data gap would be to incorporate data from regulated sites. Because of the large number of sites associated with Superfund, the Voluntary Investigation and Cleanup Program, Resource Conservation and Recovery Act (RCRA), the closed Landfill Program, and the Tanks and Spills programs, there is potentially sufficient information to describe general water quality in the major aquifers of the Twin Cities. Coupled with models which have been developed for these aquifers, there is potential for tracking plumes with high concentrations of VOCs, particularly the more persistent and toxic chlorinated solvents.

2. Ambient monitoring: ambient monitoring is needed in aquifers impacted by humans. At this time, VOCs are the primary chemical of concern related to human activity in Region 6.

The GWMAP baseline data provides very little insight into the occurrence and distribution of VOCs in ground water of Region 6 and is not useful for identifying the major plumes containing chlorinated solvents.

1. Pesticide sampling for the baseline study was inadequate to evaluate their distribution in the major aquifers. Reporting limits were high and analyte lists were limited to a few parent compounds. Pesticide sampling should include a variety of pesticides and metabolites, since a wide variety of chemicals may be used in a variable land use setting such as the Twin Cities. Andrews et al. (1997), for example, found detection rates of greater than 10 percent for prometon and tebuthiuron, which are commonly used for weed control in right-of-ways.

2. Agency-wide sampling, data management, and data analysis protocol should be established by an intra-Agency group consisting of staff from all programs dealing with ground water cleanup and monitoring.
References


Appendix A - Tables

1. Distribution of samples, by aquifer.
2. Summary information for all chemical parameters. Censoring values were established just below the maximum reporting limit.
5. Descriptive statistics for Ironton-Galesville aquifer (CIGL).
6. Descriptive statistics for the Jordan aquifer (CJDN).
8. Descriptive statistics for the St. Lawrence-Franconia aquifer (CSLF).
9. Descriptive statistics for the St. Lawrence aquifer (CSTL).
11. Descriptive statistics for the Platteville aquifer (OPVL).
15. Descriptive statistics for the Quaternary buried artesian aquifer (QBA).
16. Descriptive statistics for the Quaternary buried unconfined aquifer (QBUA).
17. Descriptive statistics for Quaternary water table aquifers (QWTA).
18. Coefficients for log-censored data from analysis of descriptive statistics, for each aquifer and chemical. See MPCA, 1998a, for application of these coefficients.
19. Coefficients for log-normal data from analysis of descriptive statistics, for each aquifer and chemical. See MPCA, 1998a, for application of these coefficients.
20. Median concentrations, in ug/L, of sampled chemicals for each of the major aquifers. The p-value indicates the probability that aquifers have equal concentrations. Different letters within a row indicate different median concentrations between aquifers.
21. Summary of water quality criteria, basis of criteria, and endpoints, by chemical parameter.
22. Number of samples exceeding health-based water quality criteria, by aquifer.
23. Percentage of samples exceeding health-based water quality criteria, by aquifer.
24. Number of samples exceeding non-health-based water quality criteria, by aquifer.
25. Percentage of samples exceeding non-health-based water quality criteria, by aquifer.
Table A.1 : Distribution of samples, by aquifer.

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<td>Quaternary buried undifferentiated aquifer (QBUU)</td>
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**Table A.2 : Summary information for all chemical parameters. Censoring values were established just below the maximum reporting limit.**

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### Table A.2 continued.

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1 Fluoride was censored at several detection limits. Censoring at the highest detection limit would result in only a few values above the censoring limit. Consequently, all non-detections were treated as missing data and removed from the data set.
### Table A.3 : Descriptive statistics for the Franconia-Ironton-Galesville aquifer (CFIG).

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<th>Median</th>
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Ground Water Monitoring and Assessment Program

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Table A.4 continued.

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<th>90 or 95th percentile</th>
<th>Min</th>
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<th>State Median</th>
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1 = insufficient sample size for analysis
Temperature | 9 | 0 | normal | 10.3 | 10.9 | 10.3 | ins | 9.1 | 11.5 | 9.8
---|---|---|---|---|---|---|---|---|---|---
Thallium | 9 | 0 | log-censored | 0.0078 | 0.11 | 0.010 | ins | < 0.0050 | 0.060 | < 0.0050
---|---|---|---|---|---|---|---|---|---|---
Tin | 7 | 3 | log-censored | 1.6 | 27 | < 0.040 | ins | < 0.040 | 0.18 | 0.20
---|---|---|---|---|---|---|---|---|---|---
Titanium | 9 | 5 | log-censored | 0.011 | 8.1 | < 0.0035 | ins | < 0.0035 | 0.0058 | < 0.0035
---|---|---|---|---|---|---|---|---|---|---
Total dissolved solids | 9 | 0 | normal | 1 4 5911 | 1 5 689 | 18 | 4 2 800 | 1 1 2 4 2 000 | 1 0 7 00 00 | 1 3 3 9 00 00
---|---|---|---|---|---|---|---|---|---|---
Total organic carbon | 9 | 0 | normal | 2 2 89 | 1 3 28 | 2 0 00 | ins | 9 0 0 | 4 5 00 | 2 9 00
---|---|---|---|---|---|---|---|---|---|---
Total phosphate-P | 9 | 2 | log-censored | 25 | 502 | 2 0 | ins | < 2 0 | 6 3 0 | 2 0
---|---|---|---|---|---|---|---|---|---|---
Total suspended solids | 9 | 0 | normal | 3 7 78 | 1 6 9 88 | 2 0 00 | ins | 1 0 00 | 1 4 0 0 0 | 3 5 0 0
---|---|---|---|---|---|---|---|---|---|---
Vanadium | 9 | 4 | log-censored | 6.7 | 1 5 | 6.5 | ins | < 4.7 | 1 2 | < 4.7
---|---|---|---|---|---|---|---|---|---|---
Zinc | 9 | 0 | log-normal | 7.0 | 9 7 | 2 2 | ins | 5.3 | 4 1 2 | 8 8
---|---|---|---|---|---|---|---|---|---|---
Zirconium | 7 | 5 | ins | ins | ins | ins | < 0.030 | ins | < 0.030 | 0.030 | 0.040
---|---|---|---|---|---|---|---|---|---|---

Table A.5 : Descriptive statistics for the Ironton-Galesville aquifer (CIGL).

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<th>No. values censored</th>
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<th>UCL mean</th>
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<th>90 or 95th percentile</th>
<th>Min</th>
<th>Max</th>
<th>State Median</th>
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Table A.5 continued.

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Table A.6 continued.

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Ground Water Monitoring and Assessment Program
Table A.7: Descriptive statistics for the Mt. Simon aquifer (CMTS).

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### Table A.7 continued.

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<th>Mean</th>
<th>UCL</th>
<th>Median</th>
<th>90 or 95th percentile</th>
<th>Min</th>
<th>Max</th>
<th>State Median</th>
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### Table A.8: Descriptive statistics for the St. Lawrence-Franconia aquifer (CSLF).

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<th>Mean</th>
<th>UCL</th>
<th>Median</th>
<th>90 or 95th percentile</th>
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<th>Max</th>
<th>State median</th>
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Table A.9 : Descriptive statistics for the St. Lawrence aquifer (CSTL).

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### Table A.10: Descriptive statistics for the Prairie du Chien (OPDC).

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<th>90 or 95th percentile</th>
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<th>Max</th>
<th>State Median</th>
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Ground Water Monitoring and Assessment Program
Table A.10 continued.

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Table A.11 : Descriptive statistics for the Platteville aquifer (OPVL).

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<th>90 or 95th percentile</th>
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<th>Max</th>
<th>State Median</th>
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Ground Water Monitoring and Assessment Program
### Table A.13 continued.

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<th>State Median</th>
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### Table A.14 : Descriptive statistics for the Precambrian aquifer (PCUU).

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Table A.15 : Descriptive statistics for the Quaternary buried artesian aquifer (QBAA).

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<th>Max</th>
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Table A.16 : Descriptive statistics for the Quaternary buried unconfined aquifer (QBUA).

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Table A.17: Descriptive statistics for the Quaternary water table aquifer (QWTA).
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Table A.17 continued.
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**Table A.18: Coefficients for log-censored data from analysis of descriptive statistics, foreach aquifer and chemical. See MPCA, 1998a, for application of these coefficients.**

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Table A.19: Coefficients for log-normal data from analysis of descriptive statistics, for each aquifer and chemical. See MPCA, 1998a, for application of these coefficients.

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<th>OSTP std. dev.</th>
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Table A.20: Median concentrations, in ug/L, of sampled chemicals for each of the major aquifers. The p-value indicates the probability that aquifers have equal concentrations. Different letters within a row indicate different median concentrations between aquifers.

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<td>0.007</td>
<td>10818 a</td>
<td>7964 b</td>
<td>10321 a</td>
<td>12145 a</td>
<td>11986 a</td>
<td>11308 a</td>
</tr>
<tr>
<td>Silver</td>
<td>0.261</td>
<td>&lt; 0.0090</td>
<td>0.036</td>
<td>0.049</td>
<td>0.017</td>
<td>0.040</td>
<td>&lt; 0.0090</td>
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<tr>
<td>Sodium</td>
<td>0.133</td>
<td>18663</td>
<td>3476</td>
<td>4929</td>
<td>4207</td>
<td>5764</td>
<td>7718</td>
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<tr>
<td>Specific Conductance</td>
<td>0.238</td>
<td>703</td>
<td>492</td>
<td>590</td>
<td>569</td>
<td>664</td>
<td>553</td>
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<tr>
<td>Strontium</td>
<td>0.048</td>
<td>231 a</td>
<td>95 b</td>
<td>103 b</td>
<td>116 b</td>
<td>202 a</td>
<td>84 b</td>
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<tr>
<td>Sulfate</td>
<td>0.150</td>
<td>28170</td>
<td>18570</td>
<td>22425</td>
<td>15000</td>
<td>24375</td>
<td>31905</td>
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<tr>
<td>Sulfur</td>
<td>0.510</td>
<td>9891</td>
<td>6580</td>
<td>7777</td>
<td>5492</td>
<td>9478</td>
<td>10826</td>
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<td>Temperature</td>
<td>0.432</td>
<td>10.3</td>
<td>10.1</td>
<td>10.0</td>
<td>10.1</td>
<td>10.0</td>
<td>10.4</td>
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<tr>
<td>Thallium</td>
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<td>0.010</td>
<td>0.017</td>
<td>0.017</td>
<td>0.014</td>
<td>&lt; 0.0050</td>
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</tr>
<tr>
<td>Tin</td>
<td>0.506</td>
<td>&lt; 0.040</td>
<td>0.045</td>
<td>0.05</td>
<td>&lt; 0.040</td>
<td>&lt; 0.040</td>
<td>&lt; 0.040</td>
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<tr>
<td>Titanium</td>
<td>0.310</td>
<td>&lt; 0.0035</td>
<td>&lt; 0.0035</td>
<td>&lt; 0.0035</td>
<td>&lt; 0.0035</td>
<td>&lt; 0.0035</td>
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<tr>
<td>Total dissolved solids</td>
<td>0.131</td>
<td>428000</td>
<td>284000</td>
<td>395000</td>
<td>332000</td>
<td>443000</td>
<td>355000</td>
</tr>
<tr>
<td>Total organic carbon</td>
<td>0.143</td>
<td>2000</td>
<td>900</td>
<td>1500</td>
<td>1000</td>
<td>1900</td>
<td>1450</td>
</tr>
<tr>
<td>Total phosphate-P</td>
<td>0.050</td>
<td>20</td>
<td>&lt; 20</td>
<td>20</td>
<td>60</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td>0.797</td>
<td>2000</td>
<td>1000</td>
<td>1500</td>
<td>3000</td>
<td>2500</td>
<td>3000</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.925</td>
<td>6.5</td>
<td>5.0</td>
<td>5.6</td>
<td>5.2</td>
<td>6.6</td>
<td>6.6</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.609</td>
<td>22</td>
<td>38</td>
<td>34</td>
<td>15</td>
<td>30</td>
<td>32</td>
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<tr>
<td>Zirconium</td>
<td>0.978</td>
<td>&lt; 0.030</td>
<td>&lt; 0.030</td>
<td>&lt; 0.030</td>
<td>&lt; 0.030</td>
<td>&lt; 0.030</td>
<td>&lt; 0.030</td>
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</tbody>
</table>
### Table A.21: Summary of water quality criteria, basis of criteria, and endpoints, by chemical parameter.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Criteria (ug/L)</th>
<th>Basis of criteria</th>
<th>Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>50</td>
<td>MCL</td>
<td>-</td>
</tr>
<tr>
<td>Antimony (Sb)</td>
<td>6</td>
<td>HRL</td>
<td>-</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>50</td>
<td>MCL</td>
<td>Cancer</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>2000</td>
<td>HRL</td>
<td>Cardiovascular/blood</td>
</tr>
<tr>
<td>Beryllium (Be)</td>
<td>0.08</td>
<td>HRL</td>
<td>Cancer</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>600</td>
<td>HRL</td>
<td>Reproductive</td>
</tr>
<tr>
<td>Bromide (Br)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>4</td>
<td>HRL</td>
<td>Kidney</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>250000</td>
<td>SMCL</td>
<td>-</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>20000(^1)</td>
<td>HRL</td>
<td>-</td>
</tr>
<tr>
<td>Cobalt (Co)</td>
<td>30</td>
<td>HBV</td>
<td>-</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>1000</td>
<td>HBV</td>
<td>-</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fluoride (F)</td>
<td>4000</td>
<td>MCL</td>
<td>-</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>300</td>
<td>SMCL</td>
<td>-</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>15</td>
<td>Action level at tap</td>
<td>-</td>
</tr>
<tr>
<td>Lithium (Li)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>100 (1000)(^2)</td>
<td>HRL</td>
<td>Central nervous system</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>2</td>
<td>MCL</td>
<td>-</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>30</td>
<td>HBV</td>
<td>Kidney</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>100</td>
<td>HRL</td>
<td>-</td>
</tr>
<tr>
<td>Nitrate-N (NO(_3)-N)</td>
<td>10000</td>
<td>HRL</td>
<td>Cardiovascular/blood</td>
</tr>
<tr>
<td>Ortho-phosphate</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phosphorus(_{total})</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Redox/Eh</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rubidium (Rb)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>30</td>
<td>HRL</td>
<td>-</td>
</tr>
<tr>
<td>Silicate (Si)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Silver (Ag)</td>
<td>30</td>
<td>HRL</td>
<td>-</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>250000</td>
<td>SMCL</td>
<td>-</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Strontium (Sr)</td>
<td>4000</td>
<td>HRL</td>
<td>Bone</td>
</tr>
<tr>
<td>Sulfate (SO(_4))</td>
<td>500000</td>
<td>MCL</td>
<td>-</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Temperature</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Thallium (Tl)</td>
<td>0.6</td>
<td>HRL</td>
<td>Gastrointestinal/liver</td>
</tr>
<tr>
<td>Titanium (Ti)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total organic carbon</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total phosphate</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Vanadium (V)</td>
<td>50</td>
<td>HRL</td>
<td>-</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>2000</td>
<td>HRL</td>
<td>-</td>
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Table A.21 continued

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Criteria (ug/L)</th>
<th>Basis of criteria</th>
<th>Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,1,1-trichloroethane</td>
<td>600</td>
<td>HRL</td>
<td>gi/liv</td>
</tr>
<tr>
<td>1,1-dichloroethane</td>
<td>70</td>
<td>HRL</td>
<td>kid</td>
</tr>
<tr>
<td>1,1-dichloroethene</td>
<td>6</td>
<td>HRL</td>
<td>gi/liv</td>
</tr>
<tr>
<td>1,2-dichloroethane</td>
<td>4</td>
<td>HRL</td>
<td>cancer</td>
</tr>
<tr>
<td>1,2-dichloroethene</td>
<td>5</td>
<td>HRL</td>
<td>cancer</td>
</tr>
<tr>
<td>acetone</td>
<td>700</td>
<td>HRL</td>
<td>cv/bld; liv</td>
</tr>
<tr>
<td>benzene</td>
<td>10</td>
<td>HRL</td>
<td>cancer</td>
</tr>
<tr>
<td>bromodichloromethane</td>
<td>6</td>
<td>HRL</td>
<td>cancer</td>
</tr>
<tr>
<td>chlorodibromomethane</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>chloroform</td>
<td>60</td>
<td>HRL</td>
<td>cancer</td>
</tr>
<tr>
<td>dichlorodifluoromethane</td>
<td>1000</td>
<td>HRL</td>
<td>body weight</td>
</tr>
<tr>
<td>dichlorofluoromethane</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ethyl ether</td>
<td>1000</td>
<td>HRL</td>
<td>body weight</td>
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<tr>
<td>isopropylbenzene</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>xylene</td>
<td>10000</td>
<td>HRL</td>
<td>cns/pns</td>
</tr>
<tr>
<td>methyl ethyl ketone</td>
<td>4000</td>
<td>HRL</td>
<td>repro</td>
</tr>
<tr>
<td>methylene chloride</td>
<td>50</td>
<td>HRL</td>
<td>cancer</td>
</tr>
<tr>
<td>naphthalene</td>
<td>300</td>
<td>HRL</td>
<td>cv/bld</td>
</tr>
<tr>
<td>tetrachloroethene</td>
<td>7</td>
<td>HRL</td>
<td>cancer</td>
</tr>
<tr>
<td>tetrahydrofuran</td>
<td>100</td>
<td>HRL</td>
<td>gi/liv</td>
</tr>
<tr>
<td>toluene</td>
<td>1000</td>
<td>HRL</td>
<td>kid; gi/liv</td>
</tr>
<tr>
<td>trichloroethene</td>
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<td>HRL</td>
<td>cancer</td>
</tr>
<tr>
<td>1,2,4-trimethylbenzene</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1,3,5-trimethylbenzene</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>cis-1,2 dichloroethene</td>
<td>70</td>
<td>HRL</td>
<td>cv/bld</td>
</tr>
<tr>
<td>ethyl benzene</td>
<td>700</td>
<td>HRL</td>
<td>kid; gi/liv</td>
</tr>
<tr>
<td>n-butylbenzene</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>n-propyl benzene</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>p-isopropyltoluene</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>styrene</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>trichlorofluoromethane</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1 Trivalent chromium
2 The current HRL for manganese is 100, but calculations were made using a value of 1000 ug/L (MDH, 1997)

Table A.22 : Number of samples exceeding health-based water quality criteria, by aquifer.

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<tr>
<th>Chemical</th>
<th>OPDC</th>
<th>Number of Exceedances</th>
</tr>
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<tr>
<td></td>
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<td>OSTP</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Nitrate (NO₃⁻)</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table A.23 : Percentage of samples exceeding health-based water quality criteria, by aquifer.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>OPDC</th>
<th>OSTP</th>
<th>QBAA</th>
<th>QWTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manganese (Mn)</td>
<td>-</td>
<td>11</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Nitrate (NO₃⁻)</td>
<td>10</td>
<td>-</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20</td>
</tr>
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</table>

Table A.24 : Number of samples exceeding non-health-based water quality criteria, by aquifer.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>CFRN</th>
<th>CJDN</th>
<th>OPDC</th>
<th>OSTP</th>
<th>QBAA</th>
<th>QWTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron(Fe)</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>13</td>
<td>5</td>
</tr>
</tbody>
</table>

Table A.25 : Percentage of samples exceeding non-health-based water quality criteria, by aquifer.

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<tr>
<th>Chemical</th>
<th>CFRN</th>
<th>CJDN</th>
<th>OPDC</th>
<th>OSTP</th>
<th>QBAA</th>
<th>QWTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron(Fe)</td>
<td>67</td>
<td>64</td>
<td>40</td>
<td>67</td>
<td>65</td>
<td>50</td>
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</table>

Table A.26 : Summary of VOC detections for Region 6.

<table>
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<th>Unique No.</th>
<th>Chemical</th>
<th>Concentration</th>
<th>Chem_class</th>
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<tr>
<td>1</td>
<td>1,1-dichloroethene</td>
<td>0.5</td>
<td>Halogenated aliphatic</td>
</tr>
<tr>
<td>1</td>
<td>1,1,1-trichloroethane</td>
<td>10</td>
<td>Halogenated aliphatic</td>
</tr>
<tr>
<td>2</td>
<td>1,2-dichloroethane</td>
<td>0.2</td>
<td>Halogenated aliphatic</td>
</tr>
<tr>
<td>2</td>
<td>trichloroethene</td>
<td>0.2</td>
<td>Halogenated aliphatic</td>
</tr>
<tr>
<td>3</td>
<td>1,1-dichloroethene</td>
<td>0.6</td>
<td>Halogenated aliphatic</td>
</tr>
<tr>
<td>3</td>
<td>1,1,1-trichloroethane</td>
<td>10</td>
<td>Halogenated aliphatic</td>
</tr>
<tr>
<td>4</td>
<td>xylene</td>
<td>0.4</td>
<td>BTEX</td>
</tr>
<tr>
<td>4</td>
<td>ethylbenzene</td>
<td>0.2</td>
<td>BTEX</td>
</tr>
<tr>
<td>4</td>
<td>toluene</td>
<td>0.9</td>
<td>BTEX</td>
</tr>
<tr>
<td>4</td>
<td>tetrachloroethene</td>
<td>0.4</td>
<td>Halogenated aliphatic</td>
</tr>
<tr>
<td>4</td>
<td>1,1,1-trichloroethane</td>
<td>0.6</td>
<td>Halogenated aliphatic</td>
</tr>
<tr>
<td>4</td>
<td>1,1-dichloroethane</td>
<td>0.3</td>
<td>Halogenated aliphatic</td>
</tr>
</tbody>
</table>
Appendix B - Figures

1. Location of Region 6.
2. Locations of wells sampled from the Franconia (CFRN) and Ironton-Galesville (CIGL) aquifers.
3. Location of wells sampled from the St. Peter (OSTP), Prairie du Chien (OPDC), and Jordan (CJDN) aquifers.
4. Location of wells sampled from Quaternary, buried (QBAA) aquifers.
5. Location of wells sampled from Quaternary, water-table aquifers (QWTA).
6. Distribution of nitrate in Region 6.
7. Distribution of chloride in Region 6.
Figure B.1: Location of Region 6
Figure B.2: Location of wells sampled from the Franconia (CFRN) and Ironton-Galesville (CIGL) aquifers.
Figure B.3: Location of wells sampled from the St. Peter (OSTP), Prairie du Chien (OPDC), and Jordan (CJDN) aquifers.

- **St. Peter**
- **Prairie du Chien**
- **Jordan**
Figure B.4: Location of wells sampled from Quaternary, buried (QBAA) aquifers.
Figure B.5: Location of wells sampled from Quaternary, water-table aquifers (QWTA).
Figure B.6: Distribution of nitrate in Region 6.
Figure B.7: Distribution of chloride in Region 6.
Figure B.8: Distribution of Volatile Organic Compound detections in Region 6.
Figure B.9: Distribution of arsenic in Region 6.