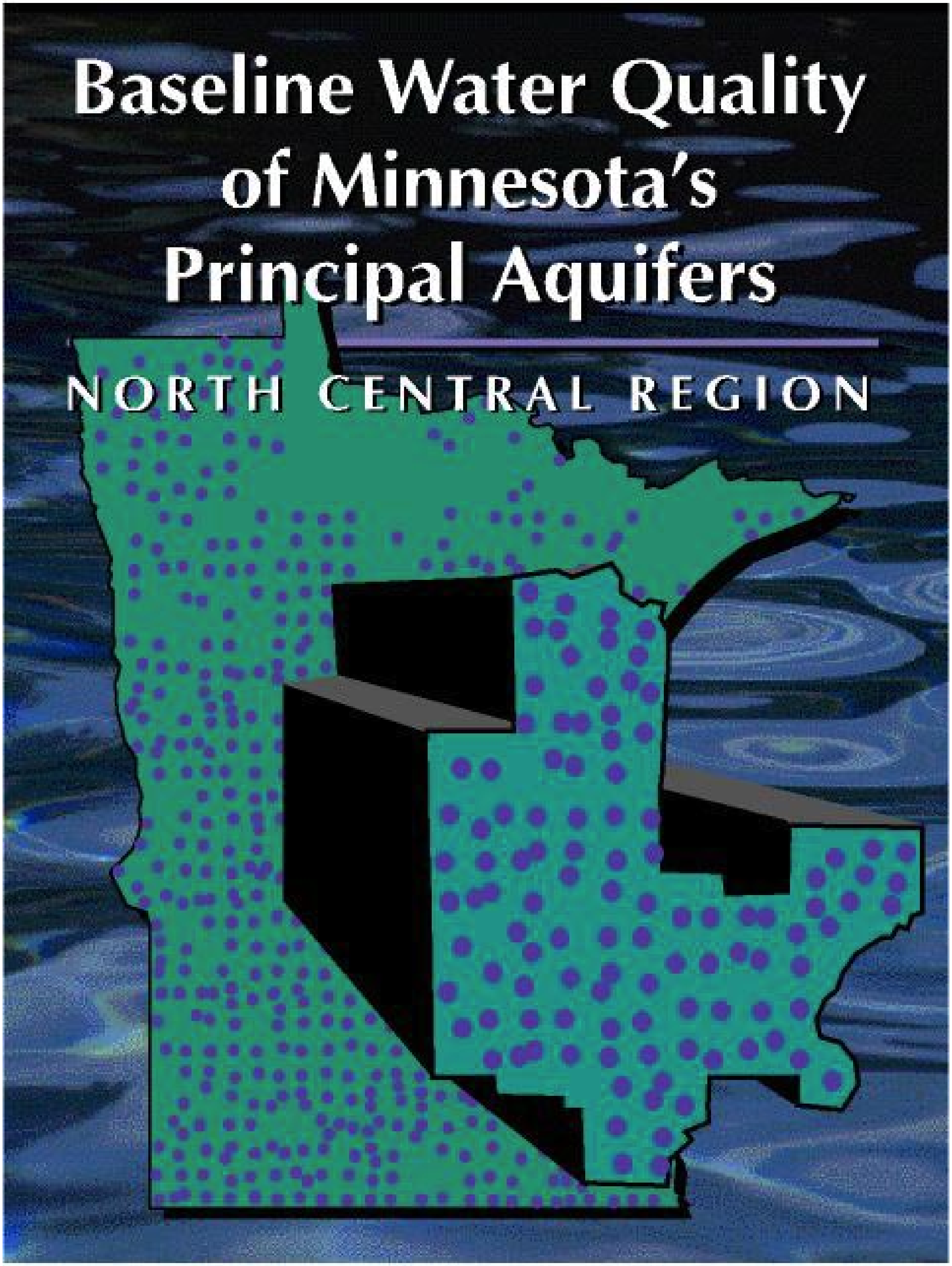
Baseline Water Quality of Minnesota's Principal Aquifers

NORTH CENTRAL REGION



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Baseline Water Quality of Minnesota's Principal Aquifers - Region 2, North Central Minnesota

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Foreword and Acknowledgements

Ground Water Monitoring and Assessment Program (GWMAP) staff believe the enclosed report represents a comprehensive study of water quality in the principal aquifers of MPCA Region 2 in north central Minnesota. 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.

Thanks to Joe Magner, Roman Kanivetsky, and Geoff Delin for their careful review of this document. Thanks to Chad Macheel for helping with data analysis.

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.

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

Between 1994 and 1996, the Minnesota Pollution Control Agency's (MPCA) Ground Water Monitoring and Assessment Program (GWMAP) sampled 238 primarily domestic wells in MPCA Region 2, which encompasses north central 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 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 locations were selected using a systematic grid. Grid node spacings were 11 miles. 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, 34 trace inorganics, total organic carbon, volatile organic compounds (VOCs), and field measurement of dissolved oxygen (DO), oxidation-reduction potential, temperature, pH, alkalinity, and specific conductance. Statewide, 954 wells were sampled from thirty different aquifers.

Ground water quality in most aquifers of Region 2 is very good. Concentrations of most chemicals were similar to or lower than concentrations in similar aquifers statewide. Water quality in surficial drift and buried unconfined aquifers is controlled by processes occurring in the unsaturated zone and in the upper portions of these aquifers. Some of these aquifers are likely to receive direct recharge from precipitation. The upper portions of these aquifers therefore show higher concentrations of chemicals which are mobile in soil, such as nitrate, selenium, and chloride. Concentrations of these chemicals were generally well below drinking water criteria. As depth below the water table increases, ground water becomes more reducing and concentrations of these chemicals decrease. Water quality of buried, confined drift aquifers and bedrock aquifers is

controlled by parent material and, to a lesser degree, residence time in ground water. Consequently, concentrations of many trace inorganics, such as boron and beryllium, are higher in Precambrian aquifers compared to other aquifers, while concentrations of sodium, potassium, and chloride are higher in Cretaceous aquifers. Despite these aquifer-specific effects, concentrations of most parameters were well below drinking water criteria.

The primary research needs for Region 2 include:

- Correlating water quality of surficial aquifers with land use, particularly for nitrate;
- determining geochemical conditions of shallow ground water, particularly redox status as it relates to nitrate;
- developing computer models to allow resource managers to predict impacts from changing or differing land uses; and
- collecting additional information on distribution of VOCs and pesticides in surficial aquifers.

Monitoring needs for Region 2 include:

- Collecting additional samples from Precambrian and Cretaceous aquifers;
- establishing a central database for water quality from surficial aquifers; and
- establish an ambient monitoring network of 100 to 200 wells for nitrate and possibly VOCs and pesticides in surficial aquifers for purposes of identifying spatial and temporal patterns to distribution and for identifying long-term trends in water quality.

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 2. Region 2 is located in north central Minnesota and includes the counties of Benton, Cass, Chisago, Crow Wing, Hubbard, Isanti, Kanabec, Mille Lacs, Morrison, Pine, Sherburne, Stearns, Todd, Wadena, and Wright (Figure B.1). The regional office is located in Brainerd.

The following information needs for Region 2 were identified in Myers et al., 1992:

- Determine agricultural land use impacts in different settings; and
- expand baseline water quality monitoring, especially for pesticides and VOCs;

Assistance needs were identified in the following areas:

- Data collection and proper sampling procedures; and
- access to state data.

The baseline study conducted by GWMAP may be used to partly fulfill the informational need of baseline water quality monitoring and can be used in conjunction with information from other studies to identify agricultural impacts. GWMAP protocol has been established for sample collection and this may be useful to local water planners and managers.

The purpose of this report is to provide baseline water quality information for Region 2. Comparisons are made between water quality in the principal aquifers of Region 2 to that in the remainder of the state. Significant differences in ground water quality between Region 2 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 water chemistry. Specific instances occur where water quality relates to potential effects on human consumption of ground

water or general quality of water. The reader should be aware of these different applications of the term water quality.

1. Baseline Design and Implementation

Design and implementation of the baseline study are described in Myers et al. (1991) and MPCA (1994, 1995, and 1998a). A systematic grid design was implemented, with sampling nodes spaced at eleven mile intervals. All major aquifers with a suitable domestic well located within a nine-square mile area centered on each grid node were sampled. The County Well Index (CWI) (Wahl and Tipping, 1991) was used to provide information on wells within the sampling area. CWI aquifer codes are summarized in Table A.1. Wells were purged until stabilization criteria were met. Sampling parameters included field parameters (DO, oxidation-reduction potential, pH, temperature, specific conductance, and alkalinity) major cations and anions, 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 Figures B.2 through B.6 for surficial drift, buried drift, Cretaceous, Precambrian bedrock, and Cambrian bedrock aquifers, respectively. The distribution of samples is summarized by aquifer in Table A.1 and a summary of all chemical parameters is included in Table A.2.

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 parameter 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; and

- 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; and
- 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 15 aquifers sampled in Region 2. All concentrations are in mircograms per liter (ug/L) parts per billion (ppb) except for Eh and redox potential (mV), temperature (^{o}C), pH (negative log of the hydrogen ion concentration), and specific conductance (umhos/cm). Sample sizes for the Franconia-Ironton-Galesville (CFIG), Franconia (CFRN), Ironton-Galesville (CIGL), Fond du Lac (PMFL), Hinckley (PMHN), North Shore Volcanics (PMNS), Precambrian undifferentiated (PMUD), and Quaternary buried undifferentiated (QBUU) aquifers were small and no further discussion of these aquifers is presented in this section.

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 are likely to 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 the month of sampling, for example, a group test might explore potential differences in concentrations of a chemical such as nitrate between two or more months. Concentrations of sampled chemicals and chemical parameters were compared between different aquifers, different well diameter classes, and different year of sampling. Concentrations of many chemicals differed between different aquifers and these results are discussed below. Concentrations did not differ between well diameter classes and year of sampling.

Median chemical concentrations were compared between the Mt. Simon-Hinckley (CMSH), Mt. Simon (CMTS), Cretaceous (KRET), crystalline Precambrian (PCCR), buried confined drift (QBAA), buried unconfined drift (QBUA), and surficial drift (QWTA) aquifers in Region 2. Results are summarized in Table A.20. P-values are included for each parameter. The p-value indicates the probability that median concentrations between aquifers are equal. Median concentrations are given in ug/L (except for Eh, redox, pH, temperature, and specific conductance). Specific aquifers which differed in concentration are not indicated in Table A.20.

In reviewing results for aquifers, caution must be exercised. Aquifer designations are assigned by the Minnesota Geological Survey based on information from driller’s logs. The designation is not based on hydrologic information. In particular, the difference between Quaternary aquifers classified as water table and unconfined buried is arbitrarily based on presence of confining materials which are ten feet thick. This is a thickness often used to evaluate hydrologic sensitivity of Quaternary aquifers and is not related to the actual permeability of the confining materials.

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

1. Concentrations of most chemicals were lower in the Mt. Simon and Hinckley aquifers compared to other aquifers. In particular, concentrations of bicarbonate, calcium, chloride, fluoride, magnesium, phosphorus, potassium, selenium, sodium, and sulfate were low in these aquifers.
2. Concentrations of bicarbonate (alkalinity), boron, chloride, copper, magnesium, phosphorus, potassium, selenium, sodium, and strontium were higher in Cretaceous (KRET) aquifers compared to most other aquifers. Eh was lower compared to most aquifers. The results reflect the importance of parent material and dissolution time on water quality in the KRET aquifer compared to other aquifers, although concentrations of most parameters were low in Cretaceous aquifers from Region 2 compared to statewide concentrations in Cretaceous aquifers (Table A.8).
3. pH and concentrations of aluminum, beryllium, boron, fluoride, molybdenum, nickel, and zinc were higher in Precambrian aquifers compared to other aquifers. Water quality in Precambrian aquifers appears to show a strong influence of parent material, although specific chemical analysis of water quality and geologic materials would be required because of the wide variety of Precambrian aquifers.
4. Concentrations of most chemicals in buried artesian aquifers (QBAA) were intermediate between concentrations in other aquifers. QBAA aquifers showed low concentrations of oxygen and nitrate. Buried artesian aquifers may be well protected in Region 2, but there is no evidence of elevated concentrations of sodium and chloride, as might be expected for older ground water. This may be related to chemistry of the glacial materials and will be discussed further in the next section.
5. Eh, and concentrations of calcium, nitrate, and sulfate were higher in the unconfined buried drift aquifers compared to most aquifers. These aquifers also had elevated concentrations of DO and chloride and low concentrations of iron. Water quality in the unconfined aquifers suggests some influence of human activities and direct recharge from the soil zone.

6. Eh and concentrations of barium, nitrate, calcium, and selenium were higher in the water table aquifers (QWTA) compared to most other aquifers. Concentrations of many trace chemicals such as boron, aluminum, copper, and zinc were lower in these aquifers compared to other aquifers. QWTA aquifers also showed elevated concentrations of DO and chloride, indicative of influences from human activities and from soil water recharge. Concentrations of sodium, strontium, and fluoride were low in the QWTA aquifers.

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. 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 1,000 ug/L or higher, the drinking criteria for manganese used in this report is modified from the HRL (Minnesota Department of Health, 1997)**. Sample size was not sufficient for several of the Cambrian (CFIG, CFRN, and CIGL) and Precambrian aquifers (PMFL, PMHN, and PMUD) to provide meaningful results. No chemical appeared to represent a significant potential risk in any aquifer. Boron and beryllium showed a relatively high frequency of exceeding drinking criteria in the crystalline Precambrian and North Shore Volcanic aquifers, but sample sizes were small for these aquifers. Three percent of samples exceeded the HRL for boron in buried artesian drift aquifers, but this is less than half the statewide exceedance rate of 7.7 percent. Nitrate exceeded its HRL in 9 and 4 percent of buried unconfined and surficial drift aquifers, both of which exceed the statewide exceedance rate of 3.2 percent. Manganese exceeded 1,000 ug/L in 7 percent of surficial drift samples, which is higher than the statewide rate of 4 percent.

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 MCL and SMCL. Iron exceeded its SMCL in 70, 60, 53, 36, 56, and approximately 50 percent of the sampled wells in the CMSH-CMTS, KRET, QBAA, QBUA, QWTA, and Precambrian aquifers respectively. The incidence of other exceedances was low.

Some chemicals have the same toxic endpoint. For example, Table A.21 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. To make this calculation, a hazard index (HI) is used to add the contribution of each chemical with similar endpoints

$$[\mathrm{HI}_{\mathrm{endpoint}} = \mathrm{C}_{\mathrm{chemical\ 1}}/\mathrm{HRL}_{\mathrm{chemical1}} + \mathrm{C}_{\mathrm{chemical\ 2}}/\mathrm{HRL}_{\mathrm{chemical2}} + \ldots + \mathrm{C}_{\mathrm{chemical\ n}}/\mathrm{HRL}_{\mathrm{chemicaln}}]$$

where C represents the concentration ug/L of a chemical. If the HI exceeds 1.0 in an individual well, 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. The calculations would therefore be potentially misleading. These calculations were made for statewide data and are reported in MPCA, 1998a.

3.4. Discussion of Individual Chemicals and Chemical Parameters

Water quality of most aquifers in Region 2 is good. Isolated instances of drinking water exceedances occurred, but in only a few cases did there appear to be aquifer-wide concerns. Some trace inorganic chemicals were a potential concern in the Precambrian aquifers, particularly the North Shore Volcanics. Boron, iron, manganese, nitrate, and aluminum were the primary chemicals of potential concern in these aquifers. Except for nitrate, these are chemicals which reflect dissolution of the parent rock in which the aquifer occurs. The concentration and distribution of these chemicals is largely controlled by natural factors. These chemicals will be of greatest concern in those areas where parent materials are enriched in the chemicals and residence times are sufficient for dissolution of parent material to occur. A number of geochemical models can be used to relate ground water chemistry to chemistry of parent material. This may be useful when attempting to predict water quality of an aquifer prior to well completion.

Nitrate and VOCs are exceptions to the above conditions. The distribution of nitrate concentrations was correlated with oxidation-reduction conditions within an aquifer. This section focuses on more detailed examination of nitrate and VOCs. Information on oxidation-reduction potential is included.

3.4.1. Nitrogen

Understanding the distribution of nitrate in ground water requires a fundamental understanding of nitrogen and how it behaves in the environment. Nitrogen is a nonmetal which can have many different redox forms. Humans have dramatically altered the nitrogen cycle through soil cultivation, burning of fossil fuels, fertilization, and waste management. Nitrate is an oxidized form of nitrogen and is by far the most important chemical of concern in ground water impacted by humans, excluding isolated instances of aquifer contamination with synthetic organic chemicals.

Nitrogen may be introduced into ground water in many forms - as ammonia from animal and human waste, through interaction with the atmosphere (deposition of nitrogen with precipitation or gas exchange at the surface of an aquifer), with organic matter, or as nitrate from animal waste or fertilizer. Once in ground water, the form, in which nitrogen exists, is a function of redox conditions within the aquifer. Reduced forms will be oxidized to nitrate above Eh values of about 200 to 250 mV. Nitrate present at higher Eh values will be stable. Nitrate is therefore a conservative chemical within oxidized ground water. Once oxygen is depleted, nitrate will be used by microbes. Microbes convert nitrate to nitrogen gas through a process called denitrification. Once nitrate is consumed, manganese and then iron enter into solution as these metals undergo reduction reactions.

In Region 2, inputs of nitrogen to the water table are highly varied. There are many areas of intense agriculture, including many irrigated areas. Conversely, there are many wooded areas which should receive minimal inputs of nitrogen from human activity. This makes interpretation of the regional data potentially difficult, since the reporting limit of 500 ug/L may exceed natural background concentrations of nitrate, even in aquifers in which nitrate will be stable (not denitrified).

To better understand the distribution of nitrate in ground water of north central Minnesota, the data were divided into samples where nitrate will be stable and samples where nitrate will not be stable (will be denitrified). The following methods were used to divide the data into these two groups.

1. Nitrate stable waters are those in which the concentration of DO is higher than 300 ug/L (the precision of the field instrument), Eh values are greater than 200 mV, and total iron concentrations are less than 1,000 ug/L.
2. Nitrate unstable waters are those in which the concentration of DO is less than 3 00 ug/L, Eh values are less than 200 mV, and the concentration of total iron is higher than 1,000 ug/L.

Using these two groups of data, minimum, median, maximum, and 25th and 75th quartile nitrate concentrations are illustrated in Table A.26. Data which did not fit either of these classification groups were included as a separate group which cannot be related to nitrate stability. The results are striking, with redox conditions in ground water having a major impact on the distribution of nitrate. No sample exceeded the reporting limit of 500 ug/L in samples from nitrate unstable waters, while nearly half of the samples from nitrate-stable waters exceeded 1,000 ug/L. The value of 1,000 ug/L is often considered representative of waters impacted by human activity. The results indicate that nitrogen inputs in Region 2 are significant, but much less than some of the more intensively farmed areas of Minnesota where median concentrations in nitrate-stable wells exceed 1,000 ug/L (MPCA, 1998d). If a source of nitrogen existed for all nitrate-stable wells sampled, nitrate should have been found in every well. Since it was not, either nitrate sources were not present for the wells with low concentrations, there was some process of nitrate removal occurring in those wells, or the field measurements for DO or Eh may have been in error. Land use was not determined for the area surrounding the sampled wells, so potential nitrogen inputs could not be correlated with nitrate concentrations. The data in Table A.26 also indicate nitrate concentrations will be very low in certain geochemical environments, regardless of which aquifer is being sampled. This means that geochemical sensitivity of ground water can be used as an important management tool for nitrates. Simple field assessments can be made to make this determination, including measurement of DO, oxidation-reduction potential, dissolved iron, and dissolved manganese. These are discussed in Sections 3.4.3 and 4.3.

There were no strong correlations between nitrate and other parameters for nitrate-stable samples. This makes sense since the primary control on concentration of nitrate in nitrate-stable ground water will be the quantity of nitrogen available for being leached to the water table, and this was not considered during the baseline study. Presence of a VOC in a sample is an indication of human activity, and concentrations of nitrate in wells with a detectable VOC were 1,900 ug/L, compared to 500 ug/L in wells with no detectable VOC. This suggests there is an effect of land use on nitrate concentrations in ground water.

3.4.2. Volatile Organic Compounds

VOC results are summarized in Table A.27. The distribution of VOC samples and detections are illustrated in Figure B.7. There were 25 wells in which a VOC was detected. This represents 11 percent of the sampled wells, which is equal to the overall statewide rate of 11 percent. There were four wells in which more than one VOC was detected. Fifteen of the 37 total detections were compounds which are generally associated with fuel oil leaks or spills, such as benzene, toluene, ethylbenzene, and xylene. Thirteen compounds were trihalomethane compounds, primarily chloroform, which have historically been considered to result from well disinfection but may also be naturally-occurring. Concentrations of the trihalomethane compounds were near the reporting limits.

Nine of the 25 wells with VOC detections were in the QBUA aquifer and eight were in the QWTA aquifer. The occurrence of VOCs was associated with high concentrations of chloride and DO and detectable tritium, while wells with no VOCs had higher concentrations of iron, boron, manganese, arsenic, and barium and a low rate of tritium detection compared to wells having detectable VOCs. The median well depth in wells with VOCs was 62 feet, compared to 80 feet for wells with no detectable VOCs. These results suggest surficial aquifers in Region 2 are susceptible to contamination with VOCs. However, the roles of recharge from the soil zone and geochemistry are unclear for VOCs. Halogenated compounds, such as chloroform and trichloroethene, are mobile in soil and are persistent in oxygenated ground water, while fuel-related compounds are also mobile in soil, but will be degraded in the presence of oxygen in ground water. Consequently, well depth alone is insufficient to predict aquifer sensitivity to contamination with VOCs.

There were two exceedances of drinking criteria. Benzene was detected in one well at a concentration of 22 ug/L (HRL = 10 ug/L), and tetrachloroethene was detected in another well at a concentration of 8.6 ug/L (HRL = 7 ug/L). Although surficial aquifers are sensitive to contamination with VOCs, VOCs do not represent a drinking water concern in Region 2, except in isolated cases of contamination.

3.4.3. Oxidation-reduction Potential

When microbes consume organic matter for food, the organic matter is oxidized. If organic matter is being oxidized, another chemical must be reduced. Chemicals available for reduction are oxygen, nitrate, manganese, iron, sulfate, and carbon dioxide. These redox chemicals are in a sense independent of each other, since nitrate will not be utilized until most of the oxygen is used, manganese will not be utilized until most of the nitrate is used, and so on. This is important, since the boundaries at which these chemicals become important are fairly well defined. The oxidation-reduction (redox) potential provides an indication of which chemical is likely to be involved in these redox reactions. Most chemicals are affected by redox conditions in ground water, either because they directly undergo redox reactions or because they are associated with one of the redox chemicals discussed above. For example, arsenic undergoes redox reactions and is therefore directly related to redox potential. Boron is not redox-sensitive but shows a correlation with redox potential because it is strongly associated with iron and manganese, both of which are redox-sensitive.

Eh is a unit of measurement which defines the redox status of ground water. Understanding redox reactions is very complex, partly because of the number of redox reactions that occur in ground water but also because it is very difficult to accurately measure the redox status of ground water. Figure B.8 schematically portrays redox boundaries and chemicals which will be of concern within each boundary. When looking at this figure, it should be clear why it is so important to attempt to determine the redox status of an aquifer. In particular, the redox status will change not only in an aquifer system but within even a single aquifer.

There has been considerable discussion in this report describing the importance and role of redox conditions on the distribution of chemicals in ground water. The following measurements can be conducted in the field and will provide a quick assessment of the redox status of ground water.

1. DO is measured in the field either with a probe or with the Winkler (wet chemistry) method. The Winkler method is more precise but can be difficult to use in some field situations. Precision of the DO measurement is 100 ug/L for the Winkler method and 300 ug/L for a probe. If oxygen concentrations are less than 500 ug/L, the sample can be considered anaerobic. The measurement of DO in the field is subject to numerous sources of error, particularly in the sampling equipment, and DO should never be used as the only indicator of ground water redox conditions.
2. Measurement of oxidation-reduction potential (ORP or redox) is accomplished with a redox probe. The measurement must be converted to Eh. This conversion varies with the type of probe and is about 200 mV. A temperature correction is also required and

this will be described in the manual for the probe. The redox probe provides a measure of the dominant redox couple operating in a sample. It is therefore only an approximation of the overall redox condition within the aquifer. The redox probe is subject to drift (reading does not stabilize), particularly in reducing ground water. If possible, the instrument should be allowed to stabilize to within about 10 mV for three successive readings. The accuracy of the probe varies, but for practical purposes it probably provides an estimate of redox within 25 to 50 mV of the true value in the aquifer.

3. Measurement of dissolved iron and manganese can be conducted directly in the field, usually with color wheels. These instruments measure reduced forms of iron and manganese, which are the desired forms in evaluating redox. These instruments do not measure low level concentrations and the test is primarily to determine if reduced manganese or iron are present. If they are present, nitrate and DO should be very low and Eh will be less than 200 mV.
4. Nitrate measurement in the field is measured in a variety of ways. Most will provide measurements down to about 1,000 ug/L. Turbid samples should be filtered. The field test is simple but can be imprecise.

In strongly reducing environments, carbon dioxide, hydrogen sulfide, and ammonia can also be tested. Carbon dioxide will be absent in strongly reducing environments, while hydrogen sulfide and ammonia may be present in those environments. Interpretation of redox conditions should be done carefully, but Figure B.8 will provide a useful starting point in interpretations.

3.5. Aquifers

The hydrology and geology of Region 2 is described in numerous reports, although there is no specific report which encompasses the entire area. The Hydrologic Investigations Reports for the Mississippi and Sauk River (Helgeson et al., 1975), Crow Wing River (Lindholm et al., 1972), Lower St. Croix River (Lindholm et al., 1974), and Mississippi Headwaters (Oakes and Bidwell, 1968) watersheds provide information about climate, the water budget, surface water, and ground water. Precipitation across the region varies from about 28 inches in the east to 24 inches in the west. Annual recharge across the region averages more than eight inches in the east and less than six inches in the west, but will vary widely with location and annual precipitation. Most of the major rivers in the region are gaining streams in that they have a baseflow component (ground water discharges to them).

The hydrogeology of Region 2 is dominated by glacial deposits. Surficial geology may be associated with the Wadena, Rainy, Superior, or Des Moines lobes, or consist of peat or river terrace deposits. Deposits associated with the Wadena Lobe occur in the northwest portion of Region 2. The area consists predominantly of outwash and drumlin fields. These deposits are gray, calcareous, and contain small amounts of shale. Deposits associated with the Rainy Lobe are brown or gray and noncalcareous and are found between Mill Lacs Lake and the Wadena Lobe deposits. This area also is comprised of outwash deposits and some drumlin fields. Superior Lobe deposits occur in the east central portion of Region 2. These deposits are red-brown, noncalcareous, and relatively coarse textured compared to other glacial deposits. Superior Lobe material was deposited predominantly as ground moraine and there are few areas where surficial and buried outwash occur. Des Moines Lobe deposits cover the southern and southwestern portion of Region 2. These deposits are gray, calcareous, and finer-textured than other glacial deposits. However, much of the area consists of outwash, particularly east of the Mississippi River. West of the Mississippi River, scattered outwash deposits occur along rivers with the remainder of the area consisting of ground and stagnation moraines. During the various glacial advances and retreats, materials from each of these lobes may have been buried under new glacial material (Hobbs and Goebel, 1982).

Cretaceous bedrock deposits underlie the glacial deposits in the extreme southwestern portion of Region 2. Cambrian-age deposits include the Franconia, Ironton, and Galesville formations, which are limited to the southeastern portion of the study area, and the Mt. Simon aquifer, which extends throughout most of the eastern portion of Region 2. The Mt. Simon aquifer is often associated with the Hinckley aquifer, which is a Precambrian-age deposit. Precambrian deposits underlie the entire region but are locally important as aquifers only in the east-central portion of Region 2. This is an area where there are few surficial drift aquifers and only scattered buried drift aquifers. More typically, Precambrian rocks form a nearly impermeable boundary to ground water flow and have a minor impact on ground water chemistry because they are resistant to weathering. The location of wells sampled from the surficial and buried drift, Cretaceous, Franconia-Ironton-Galesville, and Mt. Simon-Hinckley aquifers are illustrated in Figures B.3, B.4, and B.6.

The outwash sands, located throughout Region 2, are the most important hydrologic feature within the study area (Figure B.9). These deposits are often referred to as the central sands and they extend northwest and southeast beyond the boundaries of Region 2. The Anoka Sand Plain Aquifer is a large surficial aquifer covering much of the southern and central portion of Region 2. Similar aquifers, although smaller in size, extend east and northwest of the Anoka Sand Plain Aquifer. Some of these sand plain aquifers are described in reports (Anderson, 1993; Myette, 1982; Lindholm, 1980).

Ground water primarily originates as precipitation which percolates through the soil and vadose zone and into the saturated zone (ground water). Most recharge occurs in March and April following snowmelt and prior to crop growth. The water table generally reflects, in a subdued way, surface topography. The regional direction of ground-water flow is from topographic highs to the major rivers in the study area, such as the Mississippi, Sauk, Rum, Snake, Kettle, St. Croix, and Crow Wing Rivers. The sub-regional water-table aquifer therefore has relatively shorter travel paths and shorter ground water residence times within the surficial system. Buried outwash deposits, although extensive across most of the study area, are hydrologically not continuous. Taken as a whole, the buried drift system behaves as a buried regional system in which travel path lengths and residence time may be long (Minnesota Department of Natural Resources, 1993). The Mt. Simon and Hinckley aquifers may behave as a regional aquifer, but there is limited information on the origin and development of flow within this system. These aquifers are important where surficial and buried drift aquifers are absent and where they are near the land surface. Precambrian aquifers may also be important locally when they are close to the land surface and can store and transmit water at a rate sufficient for domestic use.

There has been no systematic effort to map the surficial regional flow system. Because of the nature of recharge and discharge to the surficial system, research has focused on portions of the surficial system. Ground water flow models have been applied over large portions of the study area (Lindholm, 1980; Myette, 1986). A regional hydrologic investigation of the Anoka Sand Plain was completed by the Minnesota Department of Natural Resources (1993). Regional water quality studies have been conducted by Anderson (1993) and Myette (1982). Because of increased awareness of ground water quality issues such as nitrate concentrations in shallow ground water, and because of changing land use, there have been increased efforts in recent years to improve the understanding of regional ground water flow in the central sands area of Minnesota.

Surficial and buried drift aquifers comprise the most important source of ground water in North Central Minnesota. Locally, the Mt. Simon aquifer and Precambrian aquifers are important sources of drinking water. Less important are the Franconia-Ironton-Galesville and Cretaceous aquifers. Surficial drift, buried drift, Cretaceous, Precambrian, and Mt. Simon-Hinckley aquifers are discussed in this report.

3.5.1. Surficial Drift Aquifers

Well-sorted sand and gravel were deposited as outwash plains by advancing and retreating glaciers. These outwash deposits occur at the land surface over about 35 percent of the study area. Crevasse fillings and terrace gravel deposited in networks of long and narrow melt-water channels, commonly followed by present stream courses, are also present in the study area, particularly west of the Mississippi River. These surficial sand and gravel deposits comprise aquifers which contain sufficient saturated material to yield large quantities of water. They are unconfined and hydraulically connected to streams. They are also vulnerable to contamination from human activity at the land surface. Extensive hydrologic information, including climatic data and both surface and ground water data, can be found in the USGS watershed reports for the area (Helgeson et al., 1975; Lindholm et al., 1972; Lindholm et al., 1974; Oakes and Bidwell, 1968) and in Lindholm (1980), Myette (1982; 1986) and Anderson (1993).

Using the CWI nomenclature, the surficial drift group is comprised of water-table wells (QWTA). These aquifers have less than 10 feet of confining material between the land surface and well screen. There was no attempt to identify the extent of confinement, well screen depth, and depth to the water table in the wells sampled as part of the baseline analysis.

Water quality information for surficial drift aquifers in Region 2 is illustrated in Table A.17. These aquifers generally are oxygenated, have relatively high oxidation-reduction potentials, and have relatively low concentrations of iron, manganese, and total dissolved solids compared to buried drift aquifers. The water quality of surficial drift aquifers in Region 2 differs slightly compared to similar aquifers in other areas of the state. Concentrations of chloride, chromium, DO, lead, selenium, sulfate, and phosphate, and oxidation-reduction potential are slightly higher in Region 2 compared to similar aquifers in the remainder of the state, while concentrations of most other parameters are lower. These parameters reflect the impact of soil water recharge on water quality of surficial aquifers in Region 2.

Water quality information from other studies conducted in Region 2 is illustrated in Table A.28. The data indicate water quality differences between GWMAP data and wells sampled for other studies conducted in Region 2. Concentrations of calcium, total dissolved solids, sodium, phosphorus, fluoride, and bicarbonate are higher in GWMAP wells, while temperature and concentrations of chloride are lower. The most probable explanation for these differences is that data collected for other studies are predominantly from shallow wells, primarily for purposes of assessing water quality near the water table. For example, the median well depth in the study by Myette (1982) was 25 feet, compared to a median depth of 56 feet in GWMAP wells. Ground water recharged by percolation of soil water should more closely reflect impacts from the land surface and the unsaturated zone.

GWMAP baseline data are not well suited to understanding vertical differences in water quality within surficial aquifers. Consequently, correlations between concentrations of chemical parameters and factors such as geographic location, well depth, and static water level were insignificant (Table A.25). Anderson (1993) presents some discussion of vertical differences in water quality within the surficial aquifers of Region 2. Information collected for the St. Cloud land use study (MPCA, 1998c) also provides some of this information and serves as a link to understanding differences observed between shallow ground water and wells sampled as part of the baseline study.

Wells from the surficial drift were associated with one of five outwash units shown in Figure B.9. Comparisons of water quality data from each of the five geologic units revealed significant differences in the redox status of the units (Figure B.10). Wells completed in surficial deposits from the Rainy and Superior lobes had high oxidation-reduction (Eh) potentials, high concentrations of DO, and low concentrations of iron, reflecting oxygenated ground water. Nitrate concentrations in wells completed in the Rainy and Superior lobe deposits were higher than in the remaining three outwash deposits, although the overall median nitrate concentrations in all geologic units were low. Wells completed in outwash from the Des Moines Lobe had lower redox potentials, lower concentrations of DO, higher concentrations of iron, and lower concentrations of nitrate. Reasons for these differences were not explored but may be related to the permeability or chemistry of these different geologic units. Wells sampled from the Wadena Lobe were intermediate in redox status and in nitrate concentration, although the wells indicated a redox condition which was conducive to denitrification. Data from river terrace deposits was mixed. The results indicate that aquifers associated with outwash from the Rainy and Superior Lobes may be more sensitive to nitrate contamination than aquifers from the Des Moines and Wadena Lobes.

Water quality of water-table aquifers in Region 2 is generally very good (Table A.17). There are occasional high concentrations of nitrate, iron, and manganese which exceed the drinking water criteria for these chemicals. In addition, maximum concentrations of chloride and lead exceeded drinking water criteria. Nitrate, manganese, iron, lead, and chloride are discussed below.

Nitrate

Although the mean and median concentrations of nitrate in surficial drift aquifers were 440 and < 500 ug/L, respectively, 28 percent of the sampled wells exceeded a concentration of 1,000 ug/L, which is a concentration often associated with human impacts. Ten, five, and two samples exceeded concentrations of 3,000, 5,000, and 10,000 ug/L, respectively.

Correlation tests were conducted between nitrate concentration and other sampled parameters. A correlation test relates the probability nitrate concentration is correlated with another parameter and quantifies the amount of variability in nitrate concentration accounted for by the other variable. For example, if the p-value (probability that the two parameters are not correlated) and R^2 (correlation coefficient) for a nitrate-sulfate correlation are 0.04 and 0.50, respectively, then the probability that the two are correlated is 96 percent (1-0.04) and 50 percent (0.50) of the variability in nitrate concentration is accounted for by variability in the concentration of sulfate. Thus, a correlation between two parameters may be statistically significant (generally if the p-value is less than 0.05) while the correlation can be weak. A strong correlation is generally considered to be greater than 0.60 or less than -0.60.

Nitrate concentration was most strongly correlated with redox parameters - DO, iron, and manganese (Table A.27). The median concentration of nitrate in wells in which nitrate is considered to be thermodynamically stable (Eh > 200 mV, DO > 500 ug/L, and total iron < 1,000 ug/L) was 1,400 ug/L, while the median concentration in the remaining wells was below the reporting limit of 500 ug/L. All but six sampled wells were screened at depths greater than 30 feet and only nine wells represented conditions in which nitrate would be expected to be stable (not denitrified). Consequently, nitrate was only weakly correlated with well depth (-0.282), with concentrations decreasing as well depth increased. Nitrate was weakly correlated with total organic carbon (-0.350), with nitrate concentration decreasing as carbon content increased. When only nitrate stable conditions were considered, this correlation strengthened to -0.570. When a food source is not available for bacteria, nitrate will be more persistent in ground water.

There was no correlation between nitrate and geographic location (UTM coordinates), static water level, sampling year, or occurrence of volatile organic compounds. The primary factors controlling distribution of nitrate in surficial drift aquifers appear to be availability of nitrogen for leaching and the geochemical conditions within the aquifer.

Manganese

The mean and median concentrations of manganese were 116 and 177 ug/L, respectively. These concentrations exceed the current HRL (100 ug/L) for manganese, although the HRL is expected to be modified to a value of 1,000 ug/L or more (MDH, 1997). There were three wells in which a concentration of 1,000 ug/L was exceeded. The strongest correlations for manganese were with total organic carbon (0.575), total suspended solids (0.538), dissolved oxygen (-0.523), and arsenic (0.502). Other significant correlations were with nitrate (-0.413), Eh (-0.323), static water elevation (-0.317), and UTM-north coordinate (-0.302). The distribution of manganese in ground water is initially dependent on geochemical conditions, more specifically the absence of nitrate and DO. Once these conditions are achieved within an aquifer, the distribution of manganese is affected by dissolved solids, particularly organic material, within the aquifer.

Iron

The mean and median concentrations of iron were 145 and 344 ug/L, respectively. These represent total iron concentrations, since samples were not filtered. The SMCL for iron is 300 ug/L, with the primary effect of iron being the staining of plumbing pipes and fixtures. The SMCL was exceeded in 26 wells, which is 56 percent of the wells sampled. The strongest correlations for iron were with nitrate (-0.643), total suspended solids (0.642), phosphorus (0.639), and Eh (-0.558). Other significant correlations for iron were with arsenic (0.498), manganese (0.491), dissolved oxygen (-0.468), total organic carbon

(0.448), sulfate (-0.425), and barium (0.416). These results indicate two effects on the distribution of iron in ground water. As ground water becomes more reducing, particularly once oxygen and nitrate are depleted in the aquifer, iron concentrations increase. However, most of the iron in ground water is associated with suspended material, including organic carbon. Since dissolved concentrations of iron are the species of concern for staining, additional work is needed to determine concentrations of dissolved iron as Eh changes, particularly at Eh values below 200 mV (where nitrate and oxygen should be absent).

Chloride

The mean and median concentrations for chloride in QWTA wells were 4,240 and 6,030 ug/L, respectively. These concentrations are similar to the overall statewide median concentration of 5,810 ug/L for QWTA wells and well below SMCL of 250,000 ug/L. There was one exceedance of the SMCL and another value of 172,450 ug/L, but the remaining values were less than 100,000 ug/L. Chloride, which can impart a bad taste to water, does not represent a drinking water concern in QWTA aquifers in Region 2. However, chloride can be a useful tracer of anthropogenic sources, such as from road de-icing, fertilizer, and animal or septic waste.

Lead

The mean and median concentrations of lead were 0.26 and 0.22 ug/L, respectively, which are well below the drinking criteria (an action level) of 15 ug/L. There was one well with a lead concentration of 162 ug/L, but the remaining samples had concentrations less than 3.5 ug/L. The single exceedance of the drinking water criteria was from a well with a very high concentration of suspended solids and iron, and filtering of water in this well may dramatically improve water quality. Lead does not represent a health concern in QWTA wells in Region 2.

3.5.2. Buried Drift Aquifers

Many sand and gravel deposits similar to the surficial deposits described in the previous section have been covered by till, loess, or alluvial material as a result of subsequent geologic events. These sand and gravel deposits constitute aquifers and serve as the most important source of ground water in Region 2. Water within these deposits is considered to be buried and may be under confined conditions. Two aquifers make up the buried drift aquifer group. These are buried, confined drift aquifers (QBAA) and buried unconfined drift aquifers (QBUA). A third aquifer group, the buried undifferentiated aquifers (QBUU) are not considered in this analysis because there was only one sample collected from the aquifer group.

Buried sand and gravel deposits act as independent aquifers. However, taken as a whole, these buried aquifers form a regional hydrologic system in which water moves vertically and horizontally in response to differences in hydraulic potential. Ground water movement within the deeper portions of this system is slow. Ground water more than 100 feet below the land surface rarely contains tritium, which is reflective of post-1953 water.

Ground water flow in the buried drift system of Region 2 is similar to the surficial system. In general, the buried aquifer system is less responsive to recharge, and travel paths are longer compared to the surficial system. These differences result in significant differences in water quality compared to the surficial system. Data from various reports are summarized in Table A.30. Data from the GWMAP baseline study is included. Median concentrations are provided. GWMAP data are intermediate between data from the other studies. However, there appear to be significant differences in the water quality of QBUA and QBAA wells. The QBUA aquifer has higher concentrations of chloride, DO, lower concentrations of iron, and higher oxidation-reduction potential compared to the QBAA aquifer. The QBAA aquifer has higher concentrations of most dissolved chemicals. Statistical analysis revealed that concentrations of nitrate, chloride, DO, tritium, and oxidation-reduction potential were equal in QWTA and QBUA wells and significantly different from QBAA wells. These results indicate that wells classified as QBUA in Region 2 behave similarly to wells classified as QWTA. This makes physical sense because the difference in the two designations is based on total thickness of confining units (10 feet is the cutoff) and not on hydrologic properties of the aquifer or vadose zone materials. Chemicals such as oxygen (dissolved), nitrate, chloride, VOCs, and hydrogen (tritium) tend to be conservative in the unsaturated zone, regardless of travel time.

Considering just QBAA wells, concentrations of most parameters were well below drinking water criteria. Mean concentrations of iron exceeded the SMCL of 300 ug/L. Maximum concentrations of arsenic, beryllium, boron, nitrate, and sulfate exceeded drinking criteria. These chemicals are discussed below. Results of correlation analysis for these chemicals are illustrated in Table A.31.

Iron

The mean and median concentrations for iron were 422 and 657 ug/L, respectively. The strongest correlations for iron were with total suspended solids (0.809), Eh (-0.542), and a number of chemicals which are indicative of increased residence time (barium, calcium, potassium, strontium, nickel, titanium, and vanadium). At the Eh values typical for these aquifers (median Eh = 195 mV), dissolved iron concentrations will exceed the drinking water criteria unless parent materials have very low iron concentrations. As residence time increases, more iron is brought into solution. Filtration may reduce iron concentrations, but not below the SMCL of 300 ug/L.

Arsenic

The mean and median concentrations of arsenic were 1.4 and 1.6 ug/L, respectively. One well had a concentration of 56 ug/L, which exceeds the MCL of 50 ug/L. An additional seven samples exceeded 10 ug/L. There were no strong correlations between arsenic and other parameters, although there was a tendency for higher arsenic concentrations in ground water with higher concentrations of dissolved solids. There was no correlation between arsenic concentration and oxidation-reduction potential, and the median Eh of 195 mV is well above the redox “window” of -100 to 0 mV in which arsenic activity is considered to be greatest. There were also no significant relationships between arsenic and other parameters for the higher concentrations of arsenic (> 1 ug/L).

Arsenic concentrations differed between glacial deposits for both surficial and buried drift wells, as illustrated in Figure B.11. Arsenic concentrations in surficial wells were higher in undifferentiated Des Moines Lobe deposits compared to surficial wells from the Itasca and Alexandria moraines (both associated with the Wadena Lobe) and from the Mille Lacs-Highland Moraine Association (Superior Lobe). However, arsenic concentrations in surficial wells from the Altamount Moraine Association, another deposit associated with the Des Moines Lobe, were also less than in wells from the undifferentiated Des Moines Lobe deposits. For buried wells, concentrations of arsenic were also low in areas where surficial deposits are associated with the Wadena Lobe (Itasca and Alexandria Moraine Associations). Concentrations of arsenic were elevated in areas associated with the Des Moines Lobe.

Understanding the distribution of arsenic is difficult based on the existing data. If the drinking water criteria for arsenic is lowered to less than 10 ug/L, arsenic will become a significant concern in buried artesian aquifers of Region 2.

Beryllium

The mean and median concentrations of beryllium were 0.0020 and < 0.010 ug/L, respectively, which are well below the HRL of 0.08 ug/L. Only one well, with a concentration of 0.19 ug/L, exceeded the HRL. There were no significant correlations between beryllium and other parameters. Beryllium does not represent a drinking water concern in Region 2.

Boron

The mean and median concentrations of boron were 25 and 21 ug/L, respectively. These are well below the HRL of 600 ug/L. Three wells had boron concentrations higher than the HRL and two additional wells had concentrations higher than 300 ug/L. Boron concentrations were most strongly correlated with chemicals which reflect increased residence time in ground water, such as strontium (0.778), sodium (0.736), potassium

(0.665), and fluoride (0.520). Boron concentrations, in general, do not represent a potential health impact to drinking water receptors.

Nitrate

The mean and median nitrate concentrations were 28 and < 500 ug/L, respectively. These are well below the HRL of 10,000 ug/L. Only one sample, with a concentration of 16,800 ug/L, exceeded the HRL, while one additional sample had a concentration of 6400 ug/L. The strongest nitrate correlation was with tritium (0.627). Tritium concentrations in excess of about 10 tritium units are considered to represent post-1953 water. Three wells had concentrations exceeding this value. Two of these wells had nitrate concentrations higher than 1,000 ug/L, while the third well had no detectable nitrate. Tritium is a useful tool for identifying ground water potentially sensitive to nitrate contamination, but when tritium is detected in ground water, additional chemical analysis is warranted to evaluate nitrate sensitivity.

Sulfate

Mean and median sulfate concentrations were 6,432 and 8,355 ug/L, respectively. These are well below the MCL of 500,000 ug/L. There were two exceedances of the MCL and another well with a concentration of 484,000 ug/L. The strongest correlations for sulfate were with calcium (0.652), magnesium (0.498), and chloride (0.394), and sulfate was significantly correlated with tritium (0.889). These results suggest an effect of parent material on sulfate concentration, but the relationships with calcium and magnesium did not hold for sulfate concentrations in excess of 100,000 ug/L. This is well below the maximum solubility of calcium- and magnesium-sulfates. Sulfate concentrations are very low in most buried artesian aquifers, and sulfate does not represent a drinking water concern in these aquifers.

3.5.3. Cretaceous Aquifers

Cretaceous deposits are limited to the southwestern portion of Region 2. They are used as a source of ground water only when glacial sand and gravel aquifers are absent. Only five samples were collected from Cretaceous aquifers.

Water quality from Cretaceous wells in Region 2 was much better than the statewide water quality of Cretaceous wells (Table A.8; Table A.32). Concentrations of boron, manganese, and sulfate were well below statewide medians, and these are three chemicals which often exceed drinking water criteria in Cretaceous wells. Eh and concentrations of DO and selenium were higher in Region 2 than in Cretaceous aquifers statewide. The water quality of Cretaceous aquifers in Region 2 is not typical of Cretaceous aquifers statewide, since concentrations of dissolved solids, particularly sodium, chloride, and potassium are relatively low.

Concentrations of beryllium, iron, and thallium exceeded their drinking criteria in at least one sample. The distribution of these chemicals in Cretaceous aquifers is discussed below. Results of correlation analysis for these chemicals is illustrated in Table A.33.

Beryllium

Concentrations of beryllium were below the reporting limit of 0.010 ug/L in all but one sample, but the concentration of 0.14 ug/L exceeded the HRL (0.08 ug/L) in the one well where beryllium was detected. Beryllium does not appear to be a health concern in Cretaceous aquifers from Region 2.

Iron

The mean and median concentrations of iron were 1,313 and 2,509 ug/L, respectively. These exceed the SMCL of 300 ug/L. Three of the five samples exceeded the drinking water criteria. Iron was most strongly correlated with manganese (0.821) and nitrate (-0.802), both of which are redox-sensitive parameters. Three of the sampled wells had Eh values higher than 250 mV, while the remaining wells had Eh values below 101 mV. The average well depth for the wells with higher Eh values was 111 feet, compared to 257 feet for the remaining wells. This effect of well depth on water quality of Cretaceous aquifers is similar to results from other parts of the state (MPCA, 1998d). Iron will exceed the drinking water criteria in deeper Cretaceous wells.

Thallium

The mean concentration for thallium of 0.0010 ug/L is well below the HRL of 0.6 ug/L. One well had a concentration of 43 ug/L, but this well also had a very high concentration of total suspended solids (56,000 ug/L). All other wells had thallium concentrations less than 0.050 ug/L. Thallium does not represent a drinking water concern in Region 2.

3.5.4. Precambrian Aquifers

Although Precambrian deposits underlie the entire region, they are only used as a source of drinking water in the northeast and central part of Region 2 (Figure B.5). This is an area in which overlying glacial deposits are thin or sand and gravel outwash is absent. The North Shore Volcanic samples were restricted to the extreme northeastern part of the region. There was little water quality information in the literature for comparison with the baseline data.

Sample sizes were small for the Precambrian aquifers. The Hinckley sandstone aquifer is grouped with the Mt. Simon samples and are discussed in Section 3.5.5. The water quality of the North Shore Volcanics aquifers appeared to be poor. However, closer examination of the data revealed one well with particularly poor water quality. This well had a total suspended solids concentration of 1732000 ug/L, with resulting high concentrations of most trace inorganic chemicals, particularly aluminum, arsenic, beryllium, boron, copper, cobalt, iron, lead, nickel, vanadium, and zinc. Excluding this one well, water quality in North Shore Volcanics was similar to statewide results. Water quality in undifferentiated Precambrian formations was similar to statewide results, except that iron, magnesium, and sulfate concentrations were higher. In general, water from the Precambrian aquifers in Region 2 contains slightly higher concentrations of most dissolved solids compared to statewide data. This may reflect greater thickness of overlying soil and glacial material, and hence, residence time, compared to the northeastern part of the state, where these aquifers are most common. Iron, boron, beryllium, aluminum, and manganese can represent potential drinking water concerns in isolated areas.

3.5.5. Mt. Simon and Hinckley Aquifers

In terms of water quality, the Mt. Simon and Hinckley aquifers can be treated as a single aquifer. Concentrations of chemicals in the Mt. Simon and Mt. Simon-Hinckley aquifers were compared, and only thallium, temperature, nickel, and lithium differed between the two aquifers. The Mt. Simon and Hinckley aquifers are not important aquifers in Region 2 except in some locations in the northeastern portion of the study area where glacial deposits are thin or sand and gravel outwash is absent.

Twenty of the 26 samples collected statewide for this aquifer were in Region 2. Concentrations of most dissolved solids and total suspended solids were slightly lower in Region 2 compared to statewide data, but the differences were not appreciable. There were exceedances of drinking water criteria for iron, manganese, and nitrate. The distribution of these three chemicals in the Mt. Simon-Hinckley aquifer are discussed below.

Iron

The mean concentrations of 360 and 917 ug/L for the Mt. Simon and Mt. Simon-Hinckley aquifers exceeded the SMCL for iron of 300 ug/L. Fourteen of the 20 samples exceeded the drinking water criteria. There were many strong correlations between iron and other chemical parameters, including beryllium (0.959), strontium (0.915), total organic carbon (0.982), total suspended solids (0.969), and several trace metals (barium, cadmium, chromium, and vanadium). These results indicate the influence of parent material, residence time, and suspended solids, particularly organic carbon, on the distribution of iron. Iron concentrations were not correlated with well depth, static water elevation, or UTM coordinates. In general, iron concentrations in the Mt. Simon-Hinckley aquifer are very high compared to most aquifers in the state, and iron represents a concern in wells completed in this aquifer. The primary effect of iron is the staining of pipes and plumbing fixtures.

Manganese

The mean concentration of manganese in both the Mt. Simon and Mt. Simon-Hinckley aquifer was less than 130 ug/L, well below the drinking water criteria of 1,000 ug/L used in this report. There was just one exceedance of the 1,000 ug/L value, with the remaining samples being less than 600 ug/L. Manganese was not well correlated with most chemical parameters. Manganese does not appear to represent a drinking water concern for Region 2.

Nitrate

The median concentration of nitrate was less than the reporting limit of 500 ug/L. However, there was considerable variability in the data as reflected by the Upper Confidence Limit concentration of 12,036 ug/L for the CMSH aquifer. The HRL was not exceeded in any sample and nitrate does not appear to be a drinking water concern in the Mt. Simon-Hinckley aquifer, despite the large variability in the data. As with many aquifers statewide, nitrate is at very low concentrations in the Mt. Simon-Hinckley aquifer, but when present, often exceeds concentrations of 1,000 ug/L. The clearest indication of this is illustrated by considering nitrate stability. Nitrate was detected in five wells, and in each of these wells iron concentrations were less than 1000 ug/L, Eh was higher than 250 mV, and DO was higher than 1,000 ug/L. In the remaining wells, iron concentrations were higher than 1,000 ug/L, DO concentrations were less than 1,000 ug/L, and Eh was less than 250 mV.

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 2 in north central Minnesota. Sample size was sufficient for the Mt. Simon-Hinckley (CMSH), Mt. Simon (CMTS), Precambrian crystalline (PCCR), buried artesian drift (QBAA), buried unconfined drift (QBUA), and surficial drift (QWTA) aquifers so that these values may serve as background concentrations for the aquifers in Region 2.
2. There were differences in concentrations of many chemicals between different aquifers. Surficial and unconfined drift aquifers had higher Eh and concentrations of chloride, calcium, and sulfur compared to other aquifers. Buried drift and Mt. Simon-Hinckley aquifers had concentrations intermediate between other aquifers. Concentrations of aluminum, beryllium, boron, fluoride, sodium, and strontium were higher in Precambrian aquifers compared to most other aquifers. Concentrations of bicarbonate, boron, chloride, copper, manganese, potassium, and sodium were higher in Cretaceous aquifers compared to other aquifers. These results reflect the importance of recharge in surficial aquifers and parent material in buried aquifers as controls on water quality.
3. Health-based drinking standards (HRL or HBV) were exceeded for the following compounds:
    - Manganese - 9 exceedances, primarily in drift aquifers;
    - nitrate - 9 exceedances, primarily in surficial and unconfined drift aquifers;
    - boron - 6 exceedances in Precambrian and buried drift aquifers;
    - beryllium - 4 exceedances, primarily in Precambrian aquifers;
    - thallium - 2 exceedances;
    - nickel - 1 exceedance;
    - vanadium - 1 exceedance; and
    - selenium - 1 exceedance.
4. Non-health based standards (MCL or SMCL) were exceeded for the following compounds:

- Iron - 135 exceedances, scattered among all aquifers;
- aluminum - 9 exceedances, primarily in Precambrian aquifers;
- sulfate - 3 exceedances, primarily in buried drift aquifers;
- chloride - 2 exceedances;
- sodium - 1 exceedances;
- arsenic - 1 exceedance; and
- lead - 1 exceedance of the action level of 15 ug/L.

5. Median concentrations of most chemicals in all aquifers of Region 2 were similar to or less than statewide median concentrations for similar aquifers. Other than iron, there were no chemicals of potential concern in any aquifer, although there were multiple exceedance rates of drinking water criteria for boron and beryllium in the North Shore Volcanics aquifers, nitrate in the buried unconfined aquifer, and aluminum in Precambrian aquifers. The primary control on concentrations of boron, aluminum, and beryllium appears to be parent material.
6. Nitrate inputs are likely to vary widely across Region 2. There is intensive irrigated agriculture in many areas of surficial outwash, but there are also numerous tracts of forested land. Consequently, nitrate was prevalent in well-oxygenated surficial aquifers, but the median concentration was only 800 ug/L. Nitrate was below the reporting limit of 500 ug/L in all wells in which nitrate will be denitrified. The primary control on the presence and concentration of nitrate in ground water is the quantity of nitrogen available for leaching. This includes physical factors which enhance nitrate leaching, such as increasing recharge and low soil organic matter content.
7. VOCs were detected in 25 wells or 11 percent of the samples. Trihalomethane compounds, primarily chloroform, were the most common VOC found. Fuel oil compounds were detected next most frequently. The HRL for benzene (10 ug/L) was exceeded in one well (22 ug/L) and the HRL for tetrachloroethene (7 ug/L) was exceeded in one well (8.7 ug/L).

4.2. Research Recommendations

The objective of research is to provide information relating physical processes with water quality. Although research is typically conducted at small scales, results should have widespread application. GWMAP conducts research related to impacts of human activity on ground water quality. Research recommendations for Region 2 are discussed below.

1. This report provides a general overview of water quality in Region 2. Data interpretation is based on a classification well system (CWI). There is no consideration of water quality in individual aquifers or aquifer systems. While water quality appears to differ substantially between these broad aquifer classifications, it will also differ between individual aquifers. Processes such as recharge, discharge, surface water-ground water interaction, and chemistry of aquifer material should be investigated in regional hydrologic assessments.
2. The relationship between water quantity and quality is unclear. Aquifer sustainability applies to both quantity and quality. As water demands increase in Region 2, particularly for surficial aquifers, aquifer sustainability needs to be considered. Consequently, additional hydrologic investigations should couple aquifer sensitivity with potential supply.
3. Land use information needs to be collected along with additional nitrate information for shallow, oxygenated ground water. These are predominantly the aquifers found in surficial outwash deposits. Information published by Anderson (1993) and by MPCA (1998c) indicates land use has a significant impact on water quality of water table aquifers. It is unclear how widely applicable this information is.
4. Additional work should be conducted to determine geochemical conditions within the upper portion of surficial outwash aquifers, particularly with respect to nitrate. Redox conditions should be established within portions of aquifers in which nitrate is stable.
5. Computer models should be developed to allow resource managers to predict the effects of different land uses or changes in land use. Increased irrigation and development of unsewered residential areas are the two land uses of greatest concern for nitrate.

6. Pesticide and VOC information collected for the baseline study are not adequate for assessing water quality of surficial aquifers under conditions in which these organic chemicals are most likely to be found. Additional research should focus on sampling for these chemicals within the upper few feet of surficial aquifers in appropriate land use settings.

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 2 are discussed below.

1. Baseline data: the baseline data for the buried confined drift (QBAA), buried unconfined drift (QBUA), surficial drift (QWTA), and Mt. Simon-Hinckley (CMSH, CMTS, and PMHN) aquifers is sufficient to be considered representative of background. These data can simply be updated over time. Data bases for the Precambrian and Cretaceous aquifers should be expanded and the data reanalyzed 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. The following specific recommendations are made for baseline enhancement.
    - Establish a central database for surficial outwash aquifers in Region 2. The primary fields in this database are CWI unique number, UTM coordinates, four-letter aquifer code, source of the data (e.g. MPCA, USGS, etc.), chemical concentrations, and land use. Other information may be added but is difficult to standardize.
    - Expand the database for PCCR, PMNS, and KRET aquifers by about ten wells each. Wells selected for sampling should have well logs and would preferably be grouted and finished below the middle of the aquifer. The wells do not

need to be located within GWMAP grid cells. The parameter list includes major cations and anions and the inorganic trace elements.

- Sample for VOCs and pesticides in approximately 100 shallow water table wells across Region 2.
- Analysis of the data should be conducted at approximately five to ten year intervals, provided data have been collected during this period. Analysis methods similar to those employed by GWMAP should be used.
- Data from other studies can be incorporated into the baseline data base. Field sampling methods must be documented and meet standard QA/QC protocol.

2. Ambient monitoring: ambient monitoring is needed in aquifers impacted by humans. These will be surficial aquifers. Nitrate and possibly VOCs and pesticides are chemicals of concern associated with human activity. The objective of ambient sampling is to conduct a trend analysis to determine if ground water quality is changing and to assess the variability in water quality with time and location. The type of ambient monitoring program that could be established varies widely, but some recommendations are listed below.
    - Set up a shallow ground water monitoring network across the surficial sands in Region 2. The network would consist of 100 to 200 wells screened at the water table. Many existing wells from previous studies could be incorporated into this network. The network should be designed to incorporate a sufficient number of samples for analysis based on hydrologic regimes. For example, Shmagin and Kanivetsky (1998) have identified four types of ground water regimes for the Rum River watershed. Additional analysis of data or hydrologic studies would be needed to properly set up an ambient network based on hydrologic regimes. Establishment of networks based on hydrologic regimes would also allow spatial analysis. Well nests may be added to the network after approximately one year of sampling. The objective of installing deeper wells would be to determine if there is a correlation between water quality at the water table and water quality deeper in the surficial system or in underlying buried aquifers.

- Sampling parameters for laboratory analysis would include just nitrate initially, but may be expanded to included VOCs, pesticides, and redox-related parameters (dissolved iron, dissolved manganese, and dissolved organic carbon).
- Field analysis should include specific conductance, redox potential DO, dissolved iron, temperature, pH, and alkalinity. The field kits discussed in Section 3.5.3 could also be used.
- Approximately ten percent of the wells should be nested approximately 15 feet below the top of the water table. Existing wells may be used if samples meet quality assurance/quality control requirements.
- Sampling should be conducted quarterly on approximately March 15, June 1, August 15, and November 1.
- Quarterly sampling should be conducted for a minimum of four years, after which time sampling may be reduced to once a year.

3. Sampling, data management, and data analysis protocols should be established and documented. Protocols developed by other agencies or ground water groups can be utilized.

References

Anderson, H.W. 1993. *Effects of Agricultural and Residential Land Use on Ground-Water Quality, Anoka Sand Plain Aquifer, East-Central Minnesota*. United States Geological Survey Water-Resources Investigations Report 93-4074. 62 p.

Helgeson, J.O., D.W. Ericson, and G.F. Lindholm. 1975. W*ater Resources of the Mississippi and Sauk Rivers Watershed, Central Minnesota*. United States Geological Survey Hydrologic Investigations Atlas HA-534. 3 plates.

Hobbs, H.C., and J.E. Goebel. 1982. *Geologic map of Minnesota, Quaternary Geology*. Minnesota Geological Survey. St. Paul, MN. 1 plate.

Lindholm, G.F. 1980. Ground-Water Appraisal of Sand Plains in Benton, Sherburne, Stearns, and Wright Counties, Central Minnesota. United States Geological Survey Water-Resources Investigations, Open-file report 80-1285. 103 p. and 4 plates.

Lindholm, G.F., J.O. Helgeson, W.L. Broussard, and D.F. Farrell. 1974. *Water Resources of the Lower St. Croix River Watershed, East-Central Minnesota.* United States Geological Survey Hydrologic Investigations Atlas HA-490. 3 plates.

Lindholm, G.F., E.L. Oakes, D.W. Ericson, and J.O. Helgeson. 1972. *Water Resources of the Crow Wing River Watershed, Central Minnesota*. United States Geological Survey Hydrologic Investigations Atlas HA-380. 4 plates.

Minnesota Department of Health. 1997. *Health Based Value for Manganese.* Office Memorandum by Larry Gust, Supervisor, Health Risk Assessment Unit. Minneapolis, MN. 1 p.

Minnesota Department of Natural Resources. 1993. *Regional Hydrogeologic Assessment - Anoka Sand Plain*. Regional Hydrogeologic Assessment RHA-1. St. Paul, MN. 3 plates.

Minnesota Pollution Control Agency. 1994. *Ground Water Monitoring and Assessment Program (GWMAP) Annual Report.* St. Paul, MN. 182 p.

Minnesota Pollution Control Agency. 1995. *Ground Water Monitoring and Assessment Program (GWMAP) Annual Report.* St. Paul, MN. 116 p.

Minnesota Pollution Control Agency. 1996. *GWMAP Field Guidance Manual*. St. Paul, MN. 42p.

Minnesota Pollution Control Agency. 1998a. *Baseline Water Quality of Minnesota's Principal Aquifers.* St. Paul, MN. 145p. and appendices.

Minnesota Pollution Control Agency. 1998b. *Data Analysis Protocol for the Ground Water Monitoring and Assessment Program (GWMAP).* Draft in review.

Minnesota Pollution Control Agency. 1998c. *Effects of Land Use on Ground Water Quality, St. Cloud Area, Minnesota. 1997 Results*. St. Paul, MN. 59 p.

Minnesota Pollution Control Agency. 1998d. *Baseline Water Quality of Minnesota's Principal Aquifers - Southwest Region.* St. Paul, MN. 83p.

Myers, Georgianna, S. Magdalene, D. Jakes, E. Porcher. 1992. *The Redesign of the Ambient Ground Water Monitoring Program*. Minnesota Pollution Control Agency. St. Paul, MN. 151 p.

Myette, C.F. 1982. *Baseline Water-Quality Data for Sand-Plain Aquifers in Hubbard, Morrison, Otter Tail, and Wadena Counties, Minnesota*. United States Geological Survey Open-File Report 82-909. 112 p.

Myette, C.F. 1986. *Hydrogeology of Sand-Plain Aquifers in Carlton, Kanabec, and Pine Counties, East-central Minnesota*. United States Geological Survey Water Resources Investigations Report 85-4334. 66 p and 4 plates.

Oakes, E.L., and L.E. Bidwell. 1968. *Water Resources of the Mississippi Headwaters Watershed, North-Central Minnesota*. United States Geological Survey Hydrologic Investigations Atlas HA-488. 4 plates.

Shmagin, B.A., and R. Kanivetsky. 1998. *Quantitative Mapping of Ground-Water Resources in Rum River Watershed, Minnesota*. Minnesota Water '98. University of Minnesota. Collection of Abstracts. p. 103.

Wahl, T. E., and R. G. Tipping. 1991. *Ground-Water Data Management - The County Well Index*. Minnesota Geological Survey. Minneapolis, MN. 38 p.

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.
3. Descriptive statistics for Franconia-Ironton Galesville Formation (CFIG).
4. Descriptive statistics for Franconia Formation (CFRN).
5. Descriptive statistics for Ironton-Galesville Formation (CIGL).
6. Descriptive statistics for Mount Simon-Hinckley Formation (CMSH).
7. Descriptive statistics for Mount Simon Formation (CMTS).
8. Descriptive statistics for Cretaceous Sandstones (KRET).
9. Descriptive statistics for undifferentiated Precambrian formations (PCCR).
10. Descriptive statistics for the Mount Simon-Fon du Lac Formation (PMFL).
11. Descriptive statistics for the Mount Simon-Hinckley Sandstone Formation (PMHN).
12. Descriptive statistics for the North Shore Volcanics group (PMNS).
13. Descriptive statistics for undifferentiated Middle Proterozoic Metasedimentary units (PMUD).
14. Descriptive statistics for buried Quaternary artesian aquifers (QBAA).
15. Descriptive statistics for unconfined buried Quaternary aquifers (QBUA).
16. Descriptive statistics for buried undifferentiated Quaternary aquifers (QBUU).
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 parameters for each of the major aquifers. The p-value indicates the probability that aquifers have equal concentrations.
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.
26. Summary statistics for different nitrate stability groups.
27. Summary information for VOCs detected in Region 2. Wells have been assigned arbitrary values to replace CWI unique numbers.
28. Comparison of water quality data for surficial drift aquifers from different literature sources for North Central Minnesota. Concentrations represent median values, in ug/L (ppb), except where indicated.
29. Summary of correlation coefficients between chemicals of concern and sampled parameters for water-table drift aquifers (QWTA).
30. Comparison of water quality data for buried drift aquifers from different literature sources for North Central Minnesota. Concentrations represent median values, in ug/L (ppb), except where indicated.

31. Summary of correlation coefficients between chemicals of concern and sampled parameters for buried drift aquifers (QBAA and QBUA).
32. Comparison of water quality data for Cretaceous aquifers from different literature sources for North Central Minnesota. Concentrations represent median values, in ug/L (ppb), except where indicated.
33. Summary of correlation coefficients between chemicals of concern and sampled parameters for Cretaceous aquifers (KRET).

Table A.1: Distribution of samples, by aquifer.

Aquifer	Number of Samples
Franconia-Ironton-Galesville (CFIG)	2
Franconia (CFRN)	3
Ironton-Galesville (CIGL)	2
Mount Simon-Hinckley (CMSH)	9
Mount Simon (CMTS)	9
Cretaceous (KRET)	5
Precambrian Crystalline (PCCR)	8
Fond du Lac (PMFL)	1
Hinckley (PMHN)	2
North Shore Volcanics (PMNS)	5
Precambrian undifferentiated (PMUD)	3
Quaternary buried artesian aquifer (QBAA)	90
Quaternary buried unconfined aquifer (QBUA)	52
Quaternary buried unconfined undifferentiated (QBUU)	1
Quaternary water table aquifer (QWTA)	46

Table A.2: Summary information for all chemical parameters. Censoring values were established just below the maximum reporting limit.

Parameter	No. of samples	No. of missing	Maximum reporting limit (ug/L)	No. detections above censoring value	No. censored values
Alkalinity	235	3	nnd[1]	235	0
Aluminum (Al)	238	0	0.060	163	75
Antimony (Sb)	238	0	0.008	140	98
Arsenic (As)	238	0	0.060	219	19
Barium (Ba)	238	0	1.4	237	1
Beryllium (Be)	238	0	0.010	51	187
Bismuth (Bi)	67	171	0.040	0	74
Boron (B)	238	0	13	191	47
Bromide (Br)	236	2	0.20	5	231
Cadmium (Cd)	238	0	0.020	84	154
Calcium (Ca)	238	0	nnd	238	0
Cesium (Cs)	67	171	0.030	6	61
Chromium (Cr)	238	0	0.050	238	0
Chloride (Cl)	238	0	200	209	29
Cobalt (Co)	238	0	0.0020	238	0
Copper (Cu)	238	0	5.5	91	147
Dissolved Oxygen	238	0	nnd	107	131
Eh	238	0	nnd	238	0
Fluoride (F)[2]	149	89	[2]	60	89
Iron (Fe)	238	0	3.2	234	4
Lead (Pb)	237	1	0.03	232	5
Lithium (Li)	238	0	4.5	116	122
Magnesium (Mg)	238	0	nnd	238	0
Manganese (Mn)	238	0	0.90	213	25
Mercury (Hg)	107	131	0.10	14	93
Molybdenum (Mo)	238	0	4.2	29	209
Nickel (Ni)	238	0	6.0	39	199
Nitrate-N (NO_3-N)	238	0	500	51	187
pH	238	0	nnd	238	0
Phosphorus$_{total}$	238	0	14.9	212	26
Potassium (K)	238	0	118.5	238	0
Redox	238	0	nnd	238	0
Rubidium (Rb)	238	0	555.3	14	224
Selenium (Se)	238	0	1.0	205	33
Silicate (Si)	238	0	nnd	238	0
Silver (Ag)	238	0	0.0090	94	144
Sodium (Na)	238	0	nnd	238	0
Specific conductance	238	0	nnd	238	0
Strontium (Sr)	238	0	0.60	236	2
Sulfate	238	0	300	212	26
Sulfur (S)	238	0	21.8	238	0
Temperature	238	0	nnd	238	0
Thallium (Tl)	238	0	0.0050	82	156
Tin (Sn)	67	171	0.040	54	13
Titanium (Ti)	238	0	0.0035	31	207
Total dissolved solids	238	0	nnd	238	0
Total organic carbon	237	1	500	230	7
Total phosphate	238	0	20	200	38
Total suspended solids	238	0	nnd	238	0
Vanadium (V)	238	0	4.7	87	151
Zinc (Zn)	238	0	2.7	212	26
Zirconium (Zr)	67	171	0.030	21	46

Table A.2 Continued

Parameter	No. of samples	No. of missing	Maximum reporting limit (ug/L)	No. detections above censoring value	No. censored values
1,1-Dichloroethane	238	-	0.2	-	-
1,1-Dichloroethene	238	-	0.5	-	-
1,1-Dichloropropene	238	-	0.2	-	-
1,1,1-Trichloroethane	238	-	0.2	-	-
1,1,1,2-Tetrachloroethane	238	-	0.2	-	-
1,1,2-Trichloroethane	238	-	0.2	-	-
1,1,2,2-Tetrachloroethane	238	-	0.2	-	-
1,1,2-Trichlorotrifluoroethane	238	-	0.2	-	-
1,2-Dichlorobenzene	238	-	0.2	-	-
1,2-Dichloroethane	238	-	0.2	-	-
1,2-Dichloropropane	238	-	0.2	-	-
1,2,3-Trichlorobenzene	238	-	0.5	-	-
1,2,3-Trichloropropane	238	-	0.5	-	-
1,2,4-Trichlorobenzene	238	-	0.5	-	-
1,2,4-Trimethylbenzene	238	-	0.5	-	-
1,3-Dichlorobenzene	238	-	0.2	-	-
1,3-Dichloropropane	238	-	0.2	-	-
1,3,5-Trimethylbenzene	238	-	0.5	-	-
1,4-Dichlorobenzene	238	-	0.2	-	-
2,2-Dichloropropane	238	-	0.5	-	-
2-Chlorotoluene	238	-	0.5	-	-
4-Chlorotoluene	238	-	0.5	-	-
Acetone	238	-	20	-	-
Allyl chloride	238	-	0.5	-	-
Bromochloromethane	238	-	0.5	-	-
Bromodichloromethane	238	-	0.2	-	-
Benzene	238	-	0.2	-	-
Bromobenzene	238	-	0.2	-	-
Bromoform	238	-	0.5	-	-
Bromomethane	238	-	0.5	-	-
cis-1,2-Dichloroethene	238	-	0.2	-	-
cis-1,3-Dichloropropene	238	-	0.2	-	-
Carbon tetrachloride	238	-	0.2	-	-
Chlorodibromomethane	238	-	0.5	-	-
Chlorobenzene	238	-	0.2	-	-
Chloroethane	238	-	0.5	-	-
Chloroform	238	-	0.1	-	-
Chloromethane	238	-	0.5	-	-
1,2-Dibromo-3-chloropropane	238	-	0.5	-	-
Dibromomethane	238	-	0.5	-	-

Table A.2 Continued

Parameter	No. of samples	No. of missing	Maximum reporting limit (ug/L)	No. detections above censoring value	No. censored values
Dichlorodifluoromethane	238	-	0.5	-	-
Dichlorofluoromethane	238	-	0.5	-	-
1,2-Dibromoethane	238	-	0.5	-	-
Ethylbenzene	238	-	0.2	-	-
Ethyl ether	238	-	2	-	-
Hexachlorobutadiene	238	-	0.5	-	-
Isopropylbenzene	238	-	0.5	-	-
Methylene chloride	238	-	0.5	-	-
Methyl ethyl ketone	238	-	10	-	-
Methyl isobutyl ketone	238	-	5	-	-
Methyl tertiary butyl ether	238	-	2	-	-
n-Butylbenzene	238	-	0.5	-	-
Naphthalene	238	-	0.5	-	-
n-Propylbenzene	238	-	0.5	-	-
o-Xylene	238	-	0.2	-	-
p&m-Xylene	238	-	0.2	-	-
p-Isopropyltoluene	238	-	0.5	-	-
sec-Butylbenzene	238	-	0.5	-	-
Styrene	238	-	0.5	-	-
tert-Butylbenzene	238	-	0.5	-	-
trans-1,2-Dichloroethene	238	-	0.1	-	-
trans-1,3-Dichloropropene	238	-	0.2	-	-
Trichloroethene	238	-	0.1	-	-
Trichlorofluoromethane	238	-	0.5	-	-
Tetrachloroethene	238	-	0.2	-	-
Tetrahydrofuran	238	-	10	-	-
Toluene	238	-	0.2	-	-
Vinyl chloride	238	-	0.5	-	-

[1] nnd = no samples were below the maximum reporting limit

[2] 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 Franconia-Ironton Galesville Formation (CFIG). ins=insufficient sample size.

Parameter	No. of samples	No.values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	2	0	ins	ins	ins	287000	ins	244000	330000	330000
Aluminum	2	0	ins	ins	ins	54	ins	3.4	105	2.9
Antimony	2	0	ins	ins	ins	0.023	ins	0.015	0.030	0.017
Arsenic	2	1	ins	ins	ins	0.75	ins	< 0.060	1.4	0.99
Barium	2	0	ins	ins	ins	33	ins	24	43	35
Beryllium	2	1	ins	ins	ins	0.013	ins	< 0.010	0.020	< 0.010
Boron	2	0	ins	ins	ins	17	ins	17	17	113
Bromide	2	2	ins	ins	ins	< 0.20	ins	< 0.20	< 0.20	< 0.20
Cadmium	2	1	ins	ins	ins	0.030	ins	< 0.020	0.050	0.040
Calcium	2	0	ins	ins	ins	74571	ins	60161	88981	99107
Chloride	2	0	ins	ins	ins	1760	ins	1460	2060	1310
Chromium	2	0	ins	ins	ins	0.13	ins	0.080	0.18	0.27
Cobalt	2	0	ins	ins	ins	0.99	ins	0.57	1.4	0.55
Copper	2	2	ins	ins	ins	< 5.5	ins	< 5.5	< 5.5	< 5.5
Dissolved oxygen	2	2	ins	ins	ins	< 300	ins	< 300	< 300	< 300
Eh	2	0	ins	ins	ins	173	ins	146	201	140
Fluoride	1	0	ins	ins	ins	300	ins	-	-	325
Iron	2	0	ins	ins	ins	549	ins	221	876	876
Lead	2	0	ins	ins	ins	0.19	ins	0.070	0.30	0.20
Lithium	2	1	ins	ins	ins	7.3	ins	< 4.5	10	6.2
Magnesium	2	0	ins	ins	ins	26956	ins	24077	29836	36044
Manganese	2	0	ins	ins	ins	572	ins	123	1022	53
Molybdenum	2	2	ins	ins	ins	< 4.2	ins	< 4.2	< 4.2	< 4.2
Nickel	2	2	ins	ins	ins	< 6.0	ins	< 6.0	< 6.0	< 6.0
Nitrate-N	2	2	ins	ins	ins	< 500	ins	< 500	< 500	< 500
pH	2	0	ins	ins	ins	7.2	ins	7.2	7.2	7.2
Phosphorus	2	0	ins	ins	ins	73	ins	26	119	33
Potassium	2	0	ins	ins	ins	1381	ins	1280	1482	4099
Redox	2	0	ins	ins	ins	-46	ins	-74	-18	-74
Rubidium	2	2	ins	ins	ins	< 556	ins	< 556	< 556	< 556
Selenium	2	1	ins	ins	ins	2.5	ins	<1.0	4.0	2.9
Silicate	2	0	ins	ins	ins	11542	ins	9127	13957	6233
Silver	2	1	ins	ins	ins	0.0095	ins	< 0.0090	0.011	< 0.0090
Sodium	2	0	ins	ins	ins	3906	ins	3387	4426	10760
Specific conductance	2	0	ins	ins	ins	520	ins	400	630	700
Strontium	2	0	ins	ins	ins	112	ins	93	132	363
Sulfate	2	2	ins	ins	ins	7485	ins	5190	9780	24330
Sulfur	2	0	ins	ins	ins	2842	ins	2037	3647	23426
Temperature	2	0	ins	ins	ins	9.3	ins	9.0	9.5	9.7
Thallium	2	1	ins	ins	ins	0.081	ins	<0.0050	0.16	< 0.0050
Titanium	2	1	ins	ins	ins	0.0043	ins	< 0.0035	0.0052	0.14
Total dissolved solids	2	0	ins	ins	ins	315000	ins	270000	360000	428000
Total organic carbon	2	1	ins	ins	ins	700	ins	< 500	1000	1000
Total phosphate-P	2	1	ins	ins	ins	50	ins	< 20	90	< 20
Total suspended solids	2	0	ins	ins	ins	6000	ins	2000	10000	6000
Vanadium	2	0	ins	ins	ins	5.3	ins	4.9	5.6	4.9
Zinc	2	0	ins	ins	ins	24	ins	9.7	39	39

Table A.4: Descriptive statistics for Franconia Formation (CFRN).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	3	0	ins	ins	ins	203000	ins	148000	416000	270000
Aluminum	3	1	ins	ins	ins	0.83	ins	< 0.060	3.1	1.5
Antimony	3	3	ins	ins	ins	< 0.0080	ins	< 0.0080	< 0.0080	0.012
Arsenic	3	1	ins	ins	ins	11	ins	< 0.060	16	0.68
Barium	3	0	ins	ins	ins	15	ins	9.1	159	48
Beryllium	3	2	ins	ins	ins	< 0.010	ins	< 0.010	0.020	< 0.010
Boron	3	0	ins	ins	ins	23	ins	20	97	28
Bromide	3	3	ins	ins	ins	< 0.20	ins	< 0.20	< 0.20	< 0.20
Cadmium	3	2	ins	ins	ins	< 0.020	ins	< 0.020	0.030	0.055
Calcium	3	0	ins	ins	ins	59803	ins	28627	90450	69745
Chloride	3	0	ins	ins	ins	740	ins	560	3750	1030
Chromium	3	0	ins	ins	ins	1.9	ins	0.080	2.3	0.29
Cobalt	3	0	ins	ins	ins	0.61	ins	0.36	1.2	0.58
Copper	3	2	ins	ins	ins	< 5.5	ins	< 5.5	14	< 5.5
Dissolved oxygen	3	2	ins	ins	ins	< 300	ins	< 300	4700	< 300
Eh	3	0	ins	ins	ins	63	ins	25	219	213
Fluoride	2	0	ins	ins	ins	280	ins	280	280	280
Iron	3	0	ins	ins	ins	1138	ins	13	4084	856
Lead	3	0	ins	ins	ins	0.20	ins	0.070	0.46	0.23
Lithium	3	0	ins	ins	ins	7.3	ins	4.9	8.8	5.1
Magnesium	3	0	ins	ins	ins	21313	ins	15915	39993	30514
Manganese	3	0	ins	ins	ins	126	ins	3.4	299	47
Mercury	1	0	ins	ins	ins	< 0.10	ins	-	-	< 0.10
Molybdenum	3	1	ins	ins	ins	4.2	ins	< 4.2	6.5	< 4.2
Nickel	3	2	ins	ins	ins	< 6.0	ins	< 6.0	8.6	< 6.0
Nitrate-N	3	2	ins	ins	ins	< 500	ins	< 500	2300	< 500
pH	3	0	ins	ins	ins	7.4	ins	7.4	7.7	7.3
Phosphorus	3	0	ins	ins	ins	28	ins	20	196	29
Potassium	3	0	ins	ins	ins	1716	ins	1558	2399	1691
Redox	3	0	ins	ins	ins	-156	ins	-195	0	0
Rubidium	3	3	ins	ins	ins	< 556	ins	< 556	< 556	< 555
Selenium	3	1	ins	ins	ins	1.6	ins	< 1.0	6.7	1.0
Silicate	3	0	ins	ins	ins	9649	ins	5690	10783	8291
Silver	3	1	ins	ins	ins	0.010	ins	< 0.0090	0.023	< 0.0090
Sodium	3	0	ins	ins	ins	3534	ins	2434	12932	4997
Specific conductance	3	0	ins	ins	ins	460	ins	270	730	510
Strontium	3	0	ins	ins	ins	92	ins	88	390	110
Sulfate	3	1	ins	ins	ins	7350	ins	< 300	13020	6330
Sulfur	3	0	ins	ins	ins	2895	ins	51	4834	6948
Temperature	3	0	ins	ins	ins	9.3	ins	8.9	9.8	9.8
Thallium	3	2	ins	ins	ins	< 0.0050	ins	< 0.0050	2.4	< 0.0050
Titanium	3	2	ins	ins	ins	< 0.0035	ins	< 0.0035	0.0047	< 0.0035
Total dissolved solids	3	0	ins	ins	ins	296000	ins	150000	420000	339000
Total organic carbon	3	0	ins	ins	ins	2000	ins	500	3100	2900
Total phosphate-P	3	1	ins	ins	ins	20	ins	<20	240	20
Total suspended solids	3	0	ins	ins	ins	5000	ins	1000	10000	3500
Vanadium	3	2	ins	ins	ins	< 4.6	ins	< 4.6	7.5	< 4.7
Zinc	3	0	ins	ins	ins	79	ins	7.7	130	88

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

Parameter	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	2	0	ins	ins	ins	235000	ins	136000	334000	353500
Aluminum	2	0	ins	ins	ins	16	ins	1.7	29	2.1
Antimony	2	1	ins	ins	ins	0.013	ins	< 0.0080	0.018	0.019
Arsenic	2	0	ins	ins	ins	0.59	ins	0.45	0.72	0.65
Barium	2	0	ins	ins	ins	16	ins	5.6	26	47
Beryllium	2	1	ins	ins	ins	0.0075	ins	< 0.010	0.010	0.010
Boron	2	1	ins	ins	ins	19	ins	< 13	27	59
Bromide	2	2	ins	ins	ins	< 0.20	ins	< 0.20	0.10	< 0.20
Cadmium	2	0	ins	ins	ins	0.07	ins	0.070	0.070	0.090
Calcium	2	0	ins	ins	ins	63680	ins	41057	863034	89046
Chloride	2	0	ins	ins	ins	1295	ins	1210	1380	1310
Chromium	2	0	ins	ins	ins	14	ins	0.070	28	0.27
Cobalt	2	0	ins	ins	ins	0.91	ins	0.36	1.5	0.72
Copper	2	0	ins	ins	ins	76	ins	35	118	10
Dissolved oxygen	2	2	ins	ins	ins	< 300	ins	< 300	290	< 300
Eh	2	0	ins	ins	ins	191	ins	33	349	207
Iron	2	0	ins	ins	ins	550	ins	31	1068	1005
Lead	2	0	ins	ins	ins	1.4	ins	0.75	2.1	0.88
Lithium	2	1	ins	ins	ins	7.5	ins	< 4.5	11	10
Magnesium	2	0	ins	ins	ins	20700	ins	11370	30030	32668
Manganese	2	0	ins	ins	ins	440	ins	162	717	136
Molybdenum	2	2	ins	ins	ins	< 4.2	ins	< 4.2	4.1	< 4.2
Nickel	2	2	ins	ins	ins	< 6.0	ins	< 6.0	5.9	< 6.0
Nitrate-N	2	2	ins	ins	ins	< 500	ins	< 500	490	< 500
pH	2	0	ins	ins	ins	7.64	ins	7.33	7.95	7.27
Phosphorus	2	0	ins	ins	ins	143	ins	140	147	57
Potassium	2	0	ins	ins	ins	1316	ins	976	1657	2564
Redox	2	0	ins	ins	ins	-28	ins	-187	131	-5
Rubidium	2	2	ins	ins	ins	< 556	ins	< 556	< 556	< 555
Selenium	2	2	ins	ins	ins	< 1.0	ins	< 1.0	0.90	< 1.0
Silicate	2	0	ins	ins	ins	10752	ins	7066	14437	7059
Silver	2	2	ins	ins	ins	< 0.0090	ins	< 0.0090	< 0.0090	0.025
Sodium	2	0	ins	ins	ins	3840	ins	3405	4274	9965
Specific Conductance	2	0	ins	ins	ins	462	ins	298	625	651
Strontium	2	0	ins	ins	ins	113	ins	101	126	224
Sulfate	2	0	ins	ins	ins	9270	ins	7320	11220	8155
Sulfur	2	0	ins	ins	ins	3460	ins	2786	4133	8333
Temperature	2	0	ins	ins	ins	9.5	ins	8.9	10.1	10.3
Thallium	2	1	ins	ins	ins	0.042	ins	< 0.0050	0.080	0.027
Titanium	2	2	ins	ins	ins	< 0.0035	ins	< 0.0035	< 0.0035	< 0.0035
Total dissolved solids	2	0	ins	ins	ins	275000	ins	194000	356000	373000
Total organic carbon	2	0	ins	ins	ins	1250	ins	1100	1400	1650
Total phosphate-P	2	0	ins	ins	ins	125	ins	100	150	30
Total suspended solids	2	0	ins	ins	ins	5000	ins	1000	9000	5000
Vanadium	2	1	ins	ins	ins	6.7	ins	< 4.7	8.7	6.7
Zinc	2	0	ins	ins	ins	25	ins	22	28	56

Table A.6: Descriptive statistics for Mount Simon-Hinckley Formation (CMSH).

Parameter	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	9	0	normal	162889	249109	126000	ins	13000	399000	132500
Aluminum	9	0	log-normal	1.8	4.0	1.3	ins	0.83	23	1.2
Antimony	9	4	log-censored	0.015	0.19	0.010	ins	< 0.0080	0.090	0.010
Arsenic	9	3	log-censored	0.44	11	0.64	ins	< 0.060	4.1	0.86
Barium	9	0	normal	66	111	50	ins	7.6	200	57
Beryllium	9	8	ins	ins	ins	< 0.010	ins	< 0.010	0.07	< 0.010
Boron	9	3	log-censored	21	145	22	ins	< 13	106	23
Bromide	9	9	ins	ins	ins	< 0.20	ins	< 0.20	< 0.20	< 0.20
Cadmium	9	6	log-censored	0.010	0.73	< 0.020	ins	< 0.020	0.22	< 0.020
Calcium	9	0	log-normal	36889	77002	48425	ins	5032	157955	43648
Chloride	9	0	normal	2458	4128	1320	ins	370	6530	2135
Chromium	9	4	log-censored	0.16	26	0.060	ins	< 0.050	4.2	0.25
Cobalt	9	0	normal	0.50	0.78	0.52	ins	0.090	1.1	0.41
Copper	9	4	log-censored	6.6	25	6.0	ins	< 5.5	16	5.7
Dissolved oxygen	9	3	log-censored	840	35476	930	ins	< 300	10910	630
Eh	9	0	normal	212	249	219	ins	102	260	212
Fluoride	9	0	normal	236	271	220	ins	200	310	225
Iron	9	0	log-normal	917	5335	431	ins	20	62577	387
Lead	9	0	log-normal	0.21	0.51	0.18	ins	0.050	1.8	0.17
Lithium	9	3	log-censored	7.0	55	7.4	ins	< 4.5	48	7.0
Magnesium	9	0	log-normal	12419	24581	13870	ins	1889	49440	13269
Manganese	9	1	log-censored	49	15818	53	ins	< 0.90	1856	44
Mercury	1	0	ins	ins	ins	0.09	ins	-	-	< 0.10
Molybdenum	9	6	log-censored	4.4	9.0	< 4.2	ins	< 4.2	7.5	< 4.2
Nickel	9	5	log-censored	5.5	20	< 6.0	ins	< 6.0	14	< 6.0
Nitrate-N	9	6	log-censored	159	12036	< 500	ins	< 500	4000	< 500
pH	9	0	normal	7.1	7.7	7.3	ins	5.3	7.8	7.3
Phosphorus	9	2	log-censored	43	853	34	ins	< 15	721	34
Potassium	9	0	normal	1526	2285	1193	ins	525	3799	1292
Redox	9	0	normal	-8	29	-1	ins	-118	40	-3
Rubidium	9	7	log-censored	575	759	< 556	ins	< 556	710	< 555
Selenium	9	2	log-censored	1.8	10	1.8	ins	< 1.0	5.9	1.6
Silicate	9	0	log-normal	10970	15474	11850	ins	6156	29313	10894
Silver	9	7	log-censored	0.0090	0.11	< 0.0090	ins	< 0.0090	0.051	< 0.0090
Sodium	9	0	normal	4269	5859	3545	ins	1870	7879	3823
Specific Conductance	9	0	normal	400	640	330	ins	60	1100	304
Strontium	9	0	log-normal	84	186	104	ins	20	510	109
Sulfate	9	3	log-censored	2836	349326	2820	ins	< 300	216780	1735
Sulfur	9	0	log-normal	1332	6131	1222	ins	176	76310	1948
Temperature	9	0	normal	8.8	9.2	8.5	ins	8.0	9.5	8.7
Thallium	9	9	ins	ins	ins	< 0.0050	ins	< 0.0050	< 0.0050	< 0.0050
Titanium	9	5	log-censored	0.0039	0.011	< 0.0035	ins	< 0.0035	0.0082	< 0.0035
Total dissolved solids	9	0	log-normal	195254	354242	214000	ins	60000	874000	218000
Total organic carbon	9	1	log-censored	1803	19504	2100	ins	< 500	18500	1850
Total phosphate-P	9	3	log-censored	20	1257	20	ins	< 20	720	20
Total suspended solids	9	0	log-normal	7940	24110	6000	ins	2000	206000	5000
Vanadium	9	4	log-censored	6.0	32	5.1	ins	< 4.7	20	4.9
Zinc	9	1	log-censored	14	140	13	ins	< 2.7	127	12

Table A.7: Descriptive statistics for Mount Simon Formation (CMTS).

Parameter	No. of samples	No.values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	9	0	normal	237600	382030	216000	ins	143000	440000	257000
Aluminum	9	4	log-censored	0.57	273	0.53	ins	< 0.060	44	0.53
Antimony	9	3	log-censored	0.012	0.092	0.013	ins	<0.0080	0.058	0.016
Arsenic	9	1	log-censored	0.65	20	1.6	ins	< 0.060	4.5	1.6
Barium	9	0	log-normal	47	91	44	ins	13	183	57
Beryllium	9	6	log-censored	0.0060	0.027	< 0.010	ins	< 0.010	0.020	< 0.010
Boron	9	0	normal	24	34	20	ins	14	41	33
Bromide	9	6	ins	ins	ins	< 0.20	ins	< 0.20	0.10	< 0.20
Cadmium	9	6	ins	ins	ins	< 0.020	ins	< 0.020	0.050	< 0.020
Calcium	9	0	normal	60646	91203	59094	ins	37694	102162	76615
Chloride	9	0	normal	1714	3752	900	ins	310	56740	1010
Chromium	9	1	log-censored	0.48	7.2	0.31	ins	< 0.050	2.8	0.31
Cobalt	9	0	normal	0.60	1.2	0.50	ins	0.30	1.5	0.60
Copper	9	6	log-censored	3.3	79	< 5.5	ins	< 5.5	30	< 5.5
Dissolved oxygen	9	7	log-censored	315	27121	< 300	ins	< 300	9410	< 300
Eh	9	0	normal	168	287	84	ins	1.9	266	79
Fluoride	5	0	normal	266	343	230	ins	220	360	280
Iron	9	1	log-censored	360	23753	1249	ins	< 3.2	4733	1259
Lead	9	0	log-normal	0.29	0.86	0.20	ins	0.080	3.4	0.20
Lithium	9	8	ins	ins	ins	< 4.5	ins	< 4.5	7.7	< 4.5
Magnesium	9	0	normal	20202	33023	18413	ins	9553	37464	26883
Manganese	9	3	log-censored	130	728	131	ins	< 0.90	531	100
Mercury	4	4	ins	ins	ins	0.090	ins	< 0.10	0.090	< 0.10
Molybdenum	9	9	ins	ins	ins	< 4.2	ins	< 4.2	< 4.2	< 4.2
Nickel	9	9	ins	ins	ins	< 6.0	ins	< 6.0	< 6.0	< 6.0
Nitrate-N	9	7	log-censored	834	1492	< 500	ins	< 500	1300	< 500
pH	9	0	normal	7.3	7.5	7.3	ins	7.2	7.6	7.3
Phosphorus	9	0	log-normal	76	149	69	ins	35	468	64
Potassium	9	0	normal	1513	2012	1650	ins	799	1983	1700
Redox	9	0	normal	-50	68	-136	ins	-217	46	-132
Rubidium	9	9	ins	ins	ins	< 556	ins	< 556	< 556	< 555
Selenium	9	2	log-censored	2.6	10	2.7	ins	< 1.0	5.6	2.4
Silicate	9	0	normal	9623	12882	9618	ins	6951	13086	8567
Silver	9	7	log-censored	0.0040	0.039	< 0.0090	ins	< 0.0090	0.023	< 0.0090
Sodium	9	0	normal	5970	9001	5327	ins	3007	23912	8085
Specific	9	0	normal	450	680	420	ins	270	760	661
Strontium	9	0	normal	138	266	88	ins	63	310	159
Sulfate	9	1	log-censored	3128	52493	2160	ins	< 300	25020	2450
Sulfur	9	0	normal	2563	6760	1021	ins	352	8354	2732
Temperature	9	0	normal	9.7	11	9.6	ins	8.6	11	9.6
Thallium	9	5	log-censored	0.0060	0.029	< 0.0050	ins	< 0.0050	0.013	0.0060
Titanium	9	8	ins	ins	ins	< 0.0035	ins	< 0.0035	0.0064	< 0.0035
Total dissolved	9	0	normal	279200	428413	272000	ins	130000	444000	374000
Total organic carbon	9	0	normal	1420	2202	1300	ins	700	2100	2000
Total phosphate-P	9	1	log-censored	61	1163	50	ins	< 20	680	40
Total suspended	9	0	normal	5200	11675	2000	ins	2000	15000	5000
Vanadium	9	7	log-censored	2.4	13	< 4.7	ins	< 4.7	8.6	< 4.7
Zinc	9	0	log-normal	14	48	14	ins	3.1	242	14

Table A.8: Descriptive statistics for Cretaceous Sandstones (KRET).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	5	0	ins	ins	ins	294000	ins	204000	534000	356000
Aluminum	5	0	ins	ins	ins	2.3	ins	0.17	617	1.5
Antimony	5	2	ins	ins	ins	0.024	ins	< 0.0080	0.043	0.025
Arsenic	5	0	ins	ins	ins	0.52	ins	0.090	3.5	1.3
Barium	5	0	ins	ins	ins	119	ins	59	268	20
Beryllium	5	4	ins	ins	ins	< 0.010	ins	< 0.010	0.14	< 0.010
Boron	5	1	ins	ins	ins	43	ins	< 13	290	410
Bromide	5	5	ins	ins	ins	< 0.20	ins	< 0.20	0.10	< 0.20
Cadmium	5	2	ins	ins	ins	< 0.020	ins	< 0.020	0.47	0.050
Calcium	5	0	ins	ins	ins	70898	ins	61147	93090	132699
Chloride	5	0	ins	ins	ins	3090	ins	830	32060	5840
Chromium	5	0	ins	ins	ins	1.1	ins	0.81	3.2	0.14
Cobalt	5	0	ins	ins	ins	0.51	ins	0.44	0.94	0.60
Copper	5	2	ins	ins	ins	13	ins	< 5.5	23	13
Dissolved oxygen	5	2	ins	ins	ins	3010	ins	< 300	17460	< 300
Eh	5	0	ins	ins	ins	277	ins	63	286	144
Fluoride	4	0	ins	ins	ins	280	ins	200	390	430
Iron	5	0	ins	ins	ins	1235	ins	25	2716	1514
Lead	5	0	ins	ins	ins	0.60	ins	0.050	5.8	0.45
Lithium	5	2	ins	ins	ins	5.3	ins	< 4.5	23	35
Magnesium	5	0	ins	ins	ins	26864	ins	18414	33289	51635
Manganese	5	0	ins	ins	ins	49	ins	8.5	150	112
Mercury	5	5	ins	ins	ins	< 0.10	ins	< 0.10	< 0.10	< 0.10
Molybdenum	5	5	ins	ins	ins	< 4.2	ins	< 4.2	< 4.2	< 4.2
Nickel	5	4	ins	ins	ins	< 6.0	ins	< 6.0	9.5	< 6.0
Nitrate-N	5	3	ins	ins	ins	< 500	ins	< 500	1100	< 500
pH	5	0	ins	ins	ins	7.15	ins	6.8	7.36	7.0
Phosphorus	5	0	ins	ins	ins	115	ins	19	234	140
Potassium	5	0	ins	ins	ins	2554	ins	1347	3527	5474
Redox	5	0	ins	ins	ins	57	ins	-157	63	-75
Rubidium	5	1	ins	ins	ins	< 556	ins	< 556	893	< 555
Selenium	5	1	ins	ins	ins	5.2	ins	< 1.0	11	1.5
Silicate	5	0	ins	ins	ins	11645	ins	7106	12123	10955
Silver	5	0	ins	ins	ins	0.095	ins	< 0.0090	0.34	< 0.0090
Sodium	5	0	ins	ins	ins	9815	ins	4074	22583	76187
Specific Conductance	5	0	ins	ins	ins	617	ins	440	0.69	1436
Strontium	5	0	ins	ins	ins	279	ins	72	747	754
Sulfate	5	1	ins	ins	ins	10080	ins	< 300	14400	420390
Sulfur	5	0	ins	ins	ins	3112	ins	356	5262	162675
Temperature	5	0	ins	ins	ins	8.7	ins	6.5	10	10
Thallium	5	4	ins	ins	ins	< 0.0050	ins	< 0.0050	43	< 0.0050
Titanium	5	5	ins	ins	ins	< 0.0035	ins	< 0.0035	< 0.00354	< 0.0035
Total dissolved solids	5	0	ins	ins	ins	374000	ins	268000	390000	1110000
Total organic carbon	5	0	ins	ins	ins	1500	ins	1300	2600	2800
Total phosphate-P	5	1	ins	ins	ins	50	ins	< 20	380	50
Total suspended solids	5	0	ins	ins	ins	4000	ins	2000	56000	8000
Vanadium	5	3	ins	ins	ins	< 4.7	ins	< 4.7	12	7.2
Zinc	5	0	ins	ins	ins	15	ins	< 2.7	449	26

Table A.9: Descriptive statistics for undifferentiated Precambrian formations (PCCR).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	8	0	normal	253125	354869	233000	ins	33000	434000	211000
Aluminum	8	2	log-censored	3.8	10148	8.1	ins	< 0.060	1396	9.4
Antimony	8	3	log-censored	0.014	0.20	0.013	ins	< .00080	0.071	0.014
Arsenic	8	1	log-censored	0.61	7.2	0.56	ins	< 0.060	3.7	0.64
Barium	8	0	normal	38	47	40	ins	21	57	39
Beryllium	8	4	log-censored	0.019	0.069	0.013	ins	< 0.010	0.050	0.020
Boron	8	0	log-normal	91	339	90	ins	13	2013	55
Bromide	8	8	ins	ins	ins	< 0.20	ins	< 0.20	< 0.20	< 0.20
Cadmium	8	4	log-censored	0.050	0.17	0.030	ins	< 0.020	0.11	0.020
Calcium	8	0	normal	50693	69894	43209	ins	30851	93660	38909
Chloride	8	0	log-normal	2549	8.0	2030	ins	580	22500	2680
Chromium	8	1	log-censored	0.98	17	0.72	ins	< 0.050	20	0.61
Cobalt	8	0	normal	0.51	0.80	0.45	ins	0.19	1.3	0.37
Copper	8	4	log-censored	7.2	51	6.2	ins	< 5.5	28	7.3
Dissolved oxygen	8	4	log-censored	933	30962	545	ins	< 300	10520	735
Eh	8	0	normal	193	251	184	ins	80	296	217
Fluoride	8	0	normal	575	810	480	ins	330	1010	490
Iron	8	0	log-normal	547	2008	586	ins	95	82554	205
Lead	8	0	normal	1.3	2.5	0.75	ins	0.090	3.7	0.50
Lithium	8	3	log-censored	6.1	22	6.9	ins	< 4.5	20	6.5
Magnesium	8	0	normal	20915	32053	18047	ins	7837	44780	13501
Manganese	8	0	log-normal	94	273	125	ins	14	749	102
Mercury	5	5	ins	ins	ins	< 0.10	ins	< 0.10	0.090	< 0.10
Molybdenum	8	5	log-censored	3.7	38	< 4.2	ins	< 4.2	21	< 4.2
Nickel	8	5	log-censored	5.8	15	< 6.0	ins	< 6.0	12	< 6.0
Nitrate-N	8	7	ins	ins	ins	< 500	ins	< 500	16700	< 500
pH	8	0	normal	7.4	7.7	7.4	ins	6.6	7.8	7.4
Phosphorus	8	2	log-censored	47	428	54	ins	< 15	180	31
Potassium	8	0	normal	2285	3139	1821	ins	1156	4339	2007
Redox	8	0	normal	-27	31	-37	ins	-140	76	3
Rubidium	8	8	ins	ins	ins	< 556	ins	< 556	< 556	< 555
Selenium	8	0	normal	4.7	7.4	4.4	ins	1.2	8.6	2.0
Silicate	8	0	normal	8577	10266	8312	ins	5850	11934	8567
Silver	8	3	log-censored	0.018	0.94	0.025	ins	< 0.0090	0.66	0.0090
Sodium	8	0	log-normal	14666	36915	11797	ins	3696	131300	9821
Specific Conductance	8	0	normal	430	600	410	ins	110	730	300
Strontium	8	0	log-normal	214	362	179	ins	118	822	197
Sulfate	8	0	log-normal	9403	22798	10890	ins	1170	52650	3410
Sulfur	8	0	log-normal	3546	7558	3956	ins	652	16210	3721
Temperature	8	0	normal	8.9	9.3	8.8	ins	8.4	10	8.5
Thallium	8	4	log-censored	0.0060	0.034	0.0060	ins	< 0.0050	0.025	< 0.0050
Titanium	8	4	log-censored	0.0031	0.013	0.0038	ins	< 0.0035	0.010	< 0.0035
Total dissolved solids	8	0	normal	312625	393210	272000	ins	218000	442000	257000
Total organic carbon	8	0	normal	1850	2606	1700	ins	800	3800	2100
Total phosphate-P	8	3	log-censored	41	580	40	ins	< 20	190	< 20
Total suspended solids	8	0	normal	3500	5172	4000	ins	1000	6000	4000
Vanadium	8	4	log-censored	4.1	25	4.7	ins	< 4.7	17	5.1
Zinc	8	1	log-censored	18	104	17	ins	< 2.7	78	15

Table A.10: Descriptive statistics for the Mount Simon-Fond du Lac Formation (PMFL).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	1	0	ins	ins	ins	133000	ins	-	-	ins
Aluminum	1	0	ins	ins	ins	6.8	ins	-	-	ins
Antimony	1	0	ins	ins	ins	0.019	ins	-	-	ins
Arsenic	1	0	ins	ins	ins	0.26	ins	-	-	ins
Barium	1	0	ins	ins	ins	29	ins	-	-	ins
Beryllium	1	0	ins	ins	ins	< 0.010	ins	-	-	ins
Boron	1	0	ins	ins	ins	14	ins	-	-	ins
Bromide	1	1	ins	ins	ins	< 0.20	ins	-	-	ins
Cadmium	1	1	ins	ins	ins	< 0.020	ins	-	-	ins
Calcium	1	0	ins	ins	ins	37244	ins	-	-	ins
Chloride	1	0	ins	ins	ins	850	ins	-	-	ins
Chromium	1	0	ins	ins	ins	0.87	ins	-	-	ins
Cobalt	1	0	ins	ins	ins	0.68	ins	-	-	ins
Copper	1	1	ins	ins	ins	< 5.5	ins	-	-	ins
Dissolved oxygen	1	0	ins	ins	ins	800	ins	-	-	ins
Eh	1	0	ins	ins	ins	294	ins	-	-	ins
Iron	1	0	ins	ins	ins	219	ins	-	-	ins
Lead	1	0	ins	ins	ins	0.40	ins	-	-	ins
Lithium	1	0	ins	ins	ins	6.2	ins	-	-	ins
Magnesium	1	0	ins	ins	ins	11902	ins	-	-	ins
Manganese	1	0	ins	ins	ins	243	ins	-	-	ins
Molybdenum	1	1	ins	ins	ins	< 4.2	ins	-	-	ins
Nickel	1	1	ins	ins	ins	< 6.0	ins	-	-	ins
Nitrate-N	1	1	ins	ins	ins	< 500	ins	-	-	ins
pH	1	0	ins	ins	ins	7.4	ins	-	-	ins
Phosphorus	1	0	ins	ins	ins	16	ins	-	-	ins
Potassium	1	0	ins	ins	ins	723	ins	-	-	ins
Redox	1	0	ins	ins	ins	72	ins	-	-	ins
Rubidium	1	1	ins	ins	ins	< 556	ins	-	-	ins
Selenium	1	1	ins	ins	ins	< 1.0	ins	-	-	ins
Silicate	1	0	ins	ins	ins	11938	ins	-	-	ins
Silver	1	0	ins	ins	ins	0.0090	ins	-	-	ins
Sodium	1	0	ins	ins	ins	3250	ins	-	-	ins
Specific Conductance	1	0	ins	ins	ins	280	ins	-	-	ins
Strontium	1	0	ins	ins	ins	41	ins	-	-	ins
Sulfate	1	0	ins	ins	ins	7650	ins	-	-	ins
Sulfur	1	0	ins	ins	ins	2803	ins	-	-	ins
Temperature	1	0	ins	ins	ins	7.6	ins	-	-	ins
Thallium	1	0	ins	ins	ins	0.0070	ins	-	-	ins
Titanium	1	1	ins	ins	ins	< 0.0035	ins	-	-	ins
Total dissolved solids	1	0	ins	ins	ins	186000	ins	-	-	ins
Total organic carbon	1	0	ins	ins	ins	1600	ins	-	-	ins
Total phosphate-P	1	0	ins	ins	ins	30	ins	-	-	ins
Total suspended solids	1	0	ins	ins	ins	2000	ins	-	-	ins
Vanadium	1	0	ins	ins	ins	6.2	ins	-	-	ins
Zinc	1	0	ins	ins	ins	3.3	ins	-	-	ins

Table A.11: Descriptive statistics for the Hinckley Sandstone Formation (PMHN).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	2	0	ins	ins	ins	100500	ins	91000	110000	110000
Aluminum	2	0	ins	ins	ins	2.0	ins	0.74	3.2	3.2
Antimony	2	1	ins	ins	ins	0.069	ins	< 0.0080	0.13	0.030
Arsenic	2	0	ins	ins	ins	2.2	ins	1.1	3.3	2.7
Barium	2	0	ins	ins	ins	33	ins	32	33	33
Beryllium	2	1	ins	ins	ins	0.018	ins	<0.010	0.030	< 0.010
Boron	2	2	ins	ins	ins	< 13	ins	< 13	< 13	< 13
Bromide	2	2	ins	ins	ins	< 0.20	ins	< 0.20	< 0.20	< 0.20
Cadmium	2	2	ins	ins	ins	< 0.020	ins	< 0.020	< 0.020	< 0.020
Calcium	2	0	ins	ins	ins	24018	ins	21864	26173	26173
Chloride	2	0	ins	ins	ins	2175	ins	1660	2690	1660
Chromium	2	1	ins	ins	ins	1.2	ins	<0.050	2.3	0.15
Cobalt	2	0	ins	ins	ins	2.4	ins	0.99	3.8	0.99
Copper	2	2	ins	ins	ins	< 5.5	ins	< 5.5	< 5.5	< 5.5
Dissolved oxygen	2	2	ins	ins	ins	< 300	ins	< 300	< 300	< 300
Eh	2	0	ins	ins	ins	207	ins	166	248	160
Fluoride	2		ins	ins	ins	200	ins	200	200	200
Iron	2	0	ins	ins	ins	8572	ins	1634	15511	1634
Lead	2	0	ins	ins	ins	0.70	ins	0.060	1.3	0.45
Lithium	2	2	ins	ins	ins	< 4.5	ins	< 4.5	< 4.5	< 4.5
Magnesium	2	0	ins	ins	ins	9072	ins	8925	9220	8925
Manganese	2	0	ins	ins	ins	322	ins	139	505	139
Molybdenum	2	2	ins	ins	ins	< 4.2	ins	< 4.2	< 4.2	<4.2
Nickel	2	2	ins	ins	ins	< 6.0	ins	< 6.0	< 6.0	<6.0
Nitrate-N	2	2	ins	ins	ins	< 500	ins	< 500	< 500	< 500
pH	2	0	ins	ins	ins	6.5	ins	6.2	6.8	6.8
Phosphorus	2	0	ins	ins	ins	89	ins	19	160	43
Potassium	2	0	ins	ins	ins	601	ins	525	677	677
Redox	2	0	ins	ins	ins	-14	ins	-55	28	-55
Rubidium	2	2	ins	ins	ins	< 556	ins	< 556	< 556	< 555
Selenium	2	1	ins	ins	ins	3.7	ins	< 1.0	6.5	< 1.0
Silicate	2	0	ins	ins	ins	13511	ins	11996	15026	11996
Silver	2	2	ins	ins	ins	< 0.0090	ins	< 0.0090	< 0.0090	< 0.0090
Sodium	2	0	ins	ins	ins	3907	ins	3718	4096	4096
Specific Conductance	2	0	ins	ins	ins	240	ins	230	250	248
Strontium	2	0	ins	ins	ins	40	ins	35	45	45
Sulfate	2	0	ins	ins	ins	6825	ins	6120	7530	2040
Sulfur	2	0	ins	ins	ins	2447	ins	2200	2695	2200
Temperature	2	0	ins	ins	ins	8.2	ins	7.8	8.5	7.8
Thallium	2	2	ins	ins	ins	< 0.0050	ins	< 0.0050	< 0.0050	< 0.0050
Titanium	2	2	ins	ins	ins	< 0.0035	ins	< 0.0035	< 0.0035	< 0.0035
Total dissolved solids	2	0	ins	ins	ins	146000	ins	142000	150000	150000
Total organic carbon	2	0	ins	ins	ins	4350	ins	1500	7200	2700
Total phosphate-P	2	1	ins	ins	ins	65	ins	<20	120	20
Total suspended solids	2	0	ins	ins	ins	6000	ins	4000	8000	4000
Vanadium	2	1	ins	ins	ins	5.4	ins	< 4.7	6.1	6.1
Zinc	2	0	ins	ins	ins	9.5	ins	2.8	16	16

Table A.12: Descriptive statistics for the North Shore Volcanics group (PMNS).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	4	0	ins	ins	ins	155000	ins	94000	194000	125500
Aluminum	5	0	ins	ins	ins	28	ins	3.0	2179	37
Antimony	5	0	ins	ins	ins	0.022	ins	0.010	0.20	0.040
Arsenic	5	0	ins	ins	ins	1.1	ins	0.30	4.4	0.98
Barium	5	0	ins	ins	ins	28	ins	5.6	153	7.0
Beryllium	5	2	ins	ins	ins	0.010	ins	< 0.010	0.31	0.020
Boron	5	0	ins	ins	ins	122	ins	39	3524	129
Bromide	5	4	ins	ins	ins	< 0.20	ins	< 0.20	1.5	< 0.20
Cadmium	5	2	ins	ins	ins	0.090	ins	< 0.020	1.0	0.030
Calcium	5	0	ins	ins	ins	32551	ins	1298	43578	26763
Chloride	5	0	ins	ins	ins	1880	ins	440	231230	1880
Chromium	5	0	ins	ins	ins	1.4	ins	0.11	92	0.66
Cobalt	5	0	ins	ins	ins	0.36	ins	0.084	49	0.29
Copper	5	1	ins	ins	ins	12	ins	< 5.5	450	12
Dissolved oxygen	5	2	ins	ins	ins	4550	ins	< 300	5780	< 300
Eh	5	0	ins	ins	ins	179	ins	16	253	173
Fluoride	5		ins	ins	ins	270	ins	230	560	430
Iron	5	0	ins	ins	ins	265	ins	20	123730	238
Lead	5	0	ins	ins	ins	0.38	ins	0.18	14	0.38
Lithium	5	0	ins	ins	ins	12	ins	6.0	75	11
Magnesium	5	0	ins	ins	ins	14858	ins	409	76379	11528
Manganese	5	0	ins	ins	ins	13	ins	3.0	1116	28
Molybdenum	5	2	ins	ins	ins	7.2	ins	< 4.2	13	< 4.2
Nickel	5	1	ins	ins	ins	13	ins	< 6.0	234	< 6.0
Nitrate-N	5	4	ins	ins	ins	< 500	ins	< 500	3900	< 500
pH	5	0	ins	ins	ins	7.9	ins	6.9	9.4	8.0
Phosphorus	5	1	ins	ins	ins	39	ins	< 15	1566	23
Potassium	5	0	ins	ins	ins	1720	ins	731	6408	776
Redox	5	0	ins	ins	ins	-42	ins	-204	32	-42
Rubidium	5	4	ins	ins	ins	< 556	ins	< 556	589	< 555
Selenium	5	2	ins	ins	ins	1.7	ins	< 1.0	5.0	1.7
Silicate	5	0	ins	ins	ins	9590	ins	5665	53216	9039
Silver	5	2	ins	ins	ins	0.010	ins	< 0.0090	0.061	0.013
Sodium	5	0	ins	ins	ins	14043	ins	8204	169770	17890
Specific Conductance	5	0	ins	ins	ins	360	ins	180	1000	339
Strontium	5	0	ins	ins	ins	179	ins	23	508	121
Sulfate	5	0	ins	ins	ins	8790	ins	1740	35460	2930
Sulfur	5	0	ins	ins	ins	3390	ins	698	12144	3390
Temperature	5	0	ins	ins	ins	8.8	ins	8.1	12	7.8
Thallium	5	3	ins	ins	ins	< 0.0050	ins	< 0.0050	0.42	< 0.0050
Titanium	5	0	ins	ins	ins	0.0075	ins	0.0047	0.022	0.0050
Total dissolved solids	5	0	ins	ins	ins	254000	ins	158000	604000	238000
Total organic carbon	5	0	ins	ins	ins	2200	ins	1800	3700	1300
Total phosphate-P	5	2	ins	ins	ins	20	ins	< 20	1660	< 20
Total suspended solids	5	0	ins	ins	ins	4000	ins	2000	1732000	4000
Vanadium	5	1	ins	ins	ins	8.0	ins	< 4.7	112	6.5
Zinc	5	1	ins	ins	ins	16	ins	< 2.7	1078	13

Table A.13: Descriptive statistics for undifferentiated Middle Proterozoic Metasedimentary units (PMUD).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	3	0	ins	ins	ins	102000	ins	98000	285000	159500
Aluminum	3	1	ins	ins	ins	1.2	ins	< 0.060	7.6	3.9
Antimony	3	3	ins	ins	ins	< 0.0080	ins	< 0.0080	< 0.0080	0.010
Arsenic	3	1	ins	ins	ins	0.79	ins	< 0.060	1.1	1.1
Barium	3	0	ins	ins	ins	62	ins	59	209	42
Beryllium	3	3	ins	ins	ins	< 0.010	ins	< 0.010	< 0.010	< 0.010
Boron	3	1	ins	ins	ins	18	ins	< 13	49	36
Bromide	3	3	ins	ins	ins	< 0.20	ins	< 0.20	< 0.20	< 0.20
Cadmium	3	2	ins	ins	ins	< 0.020	ins	< 0.020	0.030	< 0.020
Calcium	3	0	ins	ins	ins	65558	ins	26601	86947	31704
Chloride	3	0	ins	ins	ins	870	ins	320	132100	1850
Chromium	3	1	ins	ins	ins	1.1	ins	< 0.050	1.5	0.28
Cobalt	3	0	ins	ins	ins	0.26	ins	0.18	0.97	0.22
Copper	3	2	ins	ins	ins	< 5.5	ins	< 5.5	10	6.8
Dissolved oxygen	3	2	ins	ins	ins	< 300	ins	< 300	34100	< 300
Eh	3	0	ins	ins	ins	221	ins	216	332	216
Fluoride	3		ins	ins	ins	200	ins	200	310	350
Iron	3	0	ins	ins	ins	39	ins	13	484	209
Lead	3	0	ins	ins	ins	0.47	ins	0.050	0.71	0.47
Lithium	3	2	ins	ins	ins	< 4.5	ins	< 4.5	18	5.0
Magnesium	3	0	ins	ins	ins	21956	ins	8895	26655	13317
Manganese	3	1	ins	ins	ins	33	ins	< 0.90	153	65
Mercury	2	1	ins	ins	ins	0.13	ins	< 0.10	0.17	ins
Molybdenum	3	2	ins	ins	ins	< 4.2	ins	< 4.2	7.4	< 4.2
Nickel	3	3	ins	ins	ins	< 6.0	ins	< 6.0	< 6.0	< 6.0
Nitrate-N	3	1	ins	ins	ins	900	ins	< 500	8100	< 500
pH	3	0	ins	ins	ins	7.2	ins	6.8	8.1	7.6
Phosphorus	3	0	ins	ins	ins	38	ins	38	71	35
Potassium	3	0	ins	ins	ins	1997	ins	673	3811	1540
Redox	3	0	ins	ins	ins	-1.0	ins	-3.0	113	-1.0
Rubidium	3	3	ins	ins	ins	< 556	ins	< 556	< 556	< 555
Selenium	3	0	ins	ins	ins	2.5	ins	1.7	5.6	2.1
Silicate	3	0	ins	ins	ins	6744	ins	6442	9902	8688
Silver	3	2	ins	ins	ins	< 0.0090	ins	< 0.0090	0.0090	< 0.0090
Sodium	3	0	ins	ins	ins	16937	ins	3623	17641	10241
Specific Conductance	3	0	ins	ins	ins	520	ins	220	780	330
Strontium	3	0	ins	ins	ins	158	ins	78	188	125
Sulfate	3	0	ins	ins	ins	5850	ins	2910	24750	1950
Sulfur	3	0	ins	ins	ins	8814	ins	1004	14155	2374
Temperature	3	0	ins	ins	ins	9.4	ins	7.6	9.8	7.7
Thallium	3	2	ins	ins	ins	< 0.0050	ins	< 0.0050	0.035	< 0.0050
Titanium	3	3	ins	ins	ins	< 0.0035	ins	< 0.0035	< 0.0035	< 0.0035
Total dissolved solids	3	0	ins	ins	ins	324000	ins	172000	664000	222000
Total organic carbon	3	1	ins	ins	ins	1100	ins	< 500	1700	1700
Total phosphate-P	3	0	ins	ins	ins	40	ins	20	70	20
Total suspended solids	3	0	ins	ins	ins	2000	ins	2000	4000	4000
Vanadium	3	3	ins	ins	ins	< 4.7	ins	< 4.7	< 4.7	< 4.7
Zinc	3	1	ins	ins	ins	5.0	ins	<2.7	92	11

Table A.14: Descriptive statistics for buried Quaternary artesian aquifers (QBAA).

Parameters	No. of samples	No.values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	89	0	normal	266328	287125	248000	401600	81000	446000	328000
Aluminum	90	34	log-censored	0.53	21	0.49	11	< 0.060	334	0.88
Antimony	90	37	log-censored	0.012	0.090	0.013	0.064	< 0.0080	0.13	0.011
Arsenic	90	4	log-censored	1.4	28	1.2	15	< 0.060	56	2.6
Barium	90	0	no distribution	-	-	60	288	1.5	351	61
Beryllium	90	73	log-censored	0.0020	0.053	< 0.010	0.030	< 0.010	0.19	< 0.010
Boron	90	16	log-censored	25	324	18	388	12	1485	98
Bromide	90	92	ins	ins	ins	< 0.20	< 0.20	< 0.20	0.37	< 0.20
Cadmium	90	61	log-censored	0.020	0.19	< 0.020	0.17	< 0.020	0.18	< 0.020
Calcium	90	0	normal	63966	70008	75444	112572	30	193220	79537
Chloride	90	0	no distribution	-	-	5950	53033	320	185050	2320
Chromium	90	14	log-censored	0.65	5.0	1.1	2.6	< 0.050	5.9	0.49
Cobalt	90	0	no distribution	-	-	0.43	1.0	0.010	5.1	0.46
Copper	90	65	log-censored	4.5	18	< 5.5	14	< 5.5	23	< 5.5
Dissolved oxygen	90	55	log-censored	260	14359	< 300	8538	< 300	13840	< 300
Eh	90	0	normal	188	210	238	302	-37	424	158
Fluoride			no distribution	-	-	280	512	200	730	380
Iron	90	1	log-censored	422	22846	137	6927	< 3.2	17963	1179
Lead	90	4	log-censored	0.22	3.3	0.19	2.6	< 0.030	12	0.18
Lithium	90	48	log-censored	3.5	80	4.9	58	< 4.5	161	14
Magnesium	90	0	normal	21433	23798	23421	42210	59	64210	30515
Manganese	90	9	log-censored	114	1251	142	837	< 0.90	1145	131
Mercury		34	log-censored	0.080	0.18	< 0.10	0.17	< 0.10	0.18	< 0.10
Molybdenum	90	78	log-censored	2.4	9.9	< 4.2	8.3	< 4.2	14	< 4.2
Nickel	90	81	log-censored	3.8	12	< 6.0	11	< 6.0	17	< 6.0
Nitrate-N	90	83	log-censored	28	4801	< 500	1450	< 500	16800	< 500
pH	90	0	no distribution	-	-	7.30	8.1	6.6	8.20	7.3
Phosphorus	90	2	log-censored	82	421	53	326	< 15	554	102
Potassium	90	0	log-normal	1635	1898	1555	5905	246	5462	3068
Redox	90	0	normal	-32	-10	18	80	-258	202	-56
Rubidium	90	86	log-censored	318	750	< 556	679	< 556	863	< 555
Selenium	90	12	log-censored	3.1	19	3.4	13	< 1.0	31	2.4
Silicate	90	0	log-normal	9777	10397	10209	14854	4331	17430	11914
Silver	90	56	log-censored	0.0060	0.49	< 0.0090	0.38	< 0.0090	0.68	< 0.0090
Sodium	90	0	no distribution	-	-	6201	126916	1597	213087	18812
Specific Conductance	90	0	normal	440	490	0.5	1100	84	6900	619
Strontium	90	1	log-censored	127	689	99	620	< 0.60	595	304
Sulfate	90	13	log-censored	6432	265944	14970	204375	< 300	253830	7300
Sulfur	90	0	log-normal	2252	3273	5358	69578	100	88015	8110
Temperature	90	0	normal	8.7	8.9	9.0	10	7.2	11.0	8.9
Thallium	90	68	log-censored	0.0020	0.047	< 0.0050	0.026	< 0.0050	0.15	< 0.0050
Titanium	90	85	log-censored	0.00080	0.0082	< 0.0035	0.0060	< 0.0035	0.017	< 0.0035
Total dissolved solids	90	0	log-normal	300538	327567	328000	762500	114000	962000	430000
Total organic carbon	89	2	log-censored	1990	7356	1600	6310	< 500	18100	2600
Total phosphate-P	90	7	log-censored	79	840	40	528	< 20	1440	60
Total suspended solids	90	0	no distribution	-	-	2000	14500	1000	78000	5000
Vanadium	90	68	log-censored	3.3	13	4.6	11	< 4.7	15	<4.7
Zinc	90	10	log-censored	14	210	10	208	< 2.7	595	13

Table A.15: Descriptive statistics for unconfined buried Quaternary aquifers (QBUA).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	52	0	normal	258821	300936	250500	475350	59000	515000	281000
Aluminum	52	20	log-censored	0.41	10	0.50	3.7	< 0.060	65	0.91
Antimony	52	20	log-censored	0.015	0.15	0.015	0.12	< 0.0080	0.20	0.016
Arsenic	52	2	log-censored	1.3	15	1.2	12	< 0.060	16	1.9
Barium	52	0	log-normal	64	94	59	392	1.8	458	71
Beryllium	52	45	log-censored	0.0030	0.026	< 0.010	0.024	< 0.010	0.030	< 0.010
Boron	52	11	log-censored	19	106	18	123	< 13	521	23
Bromide	52	51	ins	ins	ins	< 0.20	0.10	< 0.20	0.20	< 0.20
Cadmium	52	34	log-censored	0.020	0.10	< 0.020	0.080	< 0.020	0.090	< 0.020
Calcium	52	0	normal	72100	85349	75466	155929	42	169299	78821
Chloride	52	0	log-normal	4163	7861	6075	73094	410	296800	3625
Chromium	52	7	log-censored	0.60	6.4	1.0	2.9	< 0.050	3.4	0.69
Cobalt	52	0	log-normal	0.37	0.50	0.44	1.2	0.020	1.6	0.46
Copper	52	28	log-censored	5.3	34	< 5.5	28	< 5.5	46	< 5.5
Dissolved oxygen	52	25	log-censored	1054	33047	675	16916	< 300	23000	< 500
Eh	52	0	normal	223	250	239	354	-10	398	220
Fluoride	28	0	log-normal	282	314	280	582	200	600	305
Iron	52	2	log-censored	117	12021	118	5070	< 3.2	22451	367
Lead	52	0	log-normal	0.19	0.28	0.20	0.98	0.030	2.2	0.19
Lithium	52	24	log-censored	4.3	38	5.0	29	< 4.5	80	7.1
Magnesium	52	0	normal	25421	31023	23483	57497	70	75489	26539
Manganese	52	8	log-censored	70	2023	138	553	< 0.90	1311	152
Mercury	28	26	log-censored	0.040	0.17	< 0.10	0.16	< 0.10	0.18	< 0.10
Molybdenum	52	47	log-censored	1.8	9.5	< 4.2	8.1	< 4.2	11	< 4.2
Nickel	52	43	log-censored	5.5	12	< 6.0	11	< 6.0	12	< 6.0
Nitrate-N	52	33	log-censored	200	34743	< 500	12770	< 500	47900	< 500
pH	52	0	normal	7.3	7.4	7.3	8.0	6.4	8.1	7.2
Phosphorus	52	10	log-censored	49	273	54	265	< 15	340	57
Potassium	52	0	log-normal	1493	1892	1561	5221	313	94813	1796
Redox	52	0	normal	4.0	31	20	135	-230	178	5.0
Rubidium	52	47	log-censored	342	726	< 556	676	< 556	798	< 555
Selenium	52	3	log-censored	4.1	36	3.8	28	< 1.0	613	3.2
Silicate	52	0	normal	10621	11422	10230	13817	3878	14486	10867
Silver	52	31	log-censored	0.0050	0.73	< 0.0090	0.34	< 0.0090	0.80	< 0.0090
Sodium	52	0	no distribution	-	-	6213	87652	2352	206307	5906
Specific Conductance	52	0	normal	540	670	530	1400	98	1900	533
Strontium	52	0	no distribution	-	-	101	373	0.70	717	112
Sulfate	52	2	log-censored	14487	191438	15345	142559	< 300	709770	5280
Sulfur	52	0	normal	7414	9885	5648	48378	128	218984	5406
Temperature	52	0	normal	9.0	9.3	9.0	10	7.0	11	8.8
Thallium	52	32	log-censored	0.0040	0.020	< 0.0050	0.015	< 0.0050	0.037	< 0.0050
Titanium	52	47	log-censored	0.0019	0.0061	< 0.0035	0.0060	< 0.0035	0.0065	< 0.0035
Total dissolved solids	52	0	log-normal	321218	385035	329000	999400	132000	1512000	350000
Total organic carbon	52	2	log-censored	1744	6744	1700	6175	< 500	8200	1900
Total phosphate-P	52	10	log-censored	38	358	40	275	< 20	420	40
Total suspended solids	52	0	no distribution	-	-	2000	12100	1000	44000	2000
Vanadium	52	28	log-censored	4.5	14	< 4.7	12	< 4.7	14	< 4.7
Zinc	52	5	log-censored	11	86	9.9	57	< 2.7	163	12

Table A.16: Descriptive statistics for buried undifferentiated Quaternary aquifers (QBUU).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	1	0	ins	ins	ins	328000	ins	-	-	385000
Aluminum	1	1	ins	ins	ins	< 0.060	ins	-	-	0.36
Antimony	1	1	ins	ins	ins	< 0.0080	ins	-	-	0.056
Arsenic	1	0	ins	ins	ins	1.2	ins	-	-	2.8
Barium	1	1	ins	ins	ins	< 1.4	ins	-	-	52
Beryllium	1	1	ins	ins	ins	< 0.010	ins	-	-	< 0.010
Boron	1	0	ins	ins	ins	38	ins	-	-	279
Bromide	1	1	ins	ins	ins	< 0.20	ins	-	-	< 0.20
Cadmium	1	1	ins	ins	ins	< 0.020	ins	-	-	0.13
Calcium	1	0	ins	ins	ins	371	ins	-	-	114917
Chloride	1	0	ins	ins	ins	105610	ins	-	-	2185
Chromium	1	0	ins	ins	ins	1.7	ins	-	-	0.060
Cobalt	1	0	ins	ins	ins	0.33	ins	-	-	0.99
Copper	1	1	ins	ins	ins	< 5.5	ins	-	-	< 5.5
Dissolved oxygen	1	0	ins	ins	ins	3710	ins	-	-	< 500
Eh	1	0	ins	ins	ins	226	ins	-	-	261
Fluoride	1		ins	ins	ins	310	ins	-	-	330
Iron	1	0	ins	ins	ins	46	ins	-	-	2080
Lead	1	0	ins	ins	ins	1.4	ins	-	-	0.27
Lithium	1	1	ins	ins	ins	< 4.5	ins	-	-	36
Magnesium	1	0	ins	ins	ins	160	ins	-	-	42087
Manganese	1	0	ins	ins	ins	1.8	ins	-	-	205
Mercury	1	1	ins	ins	ins	< 0.10	ins	-	-	< 0.10
Molybdenum	1	1	ins	ins	ins	< 4.2	ins	-	-	< 4.2
Nickel	1	1	ins	ins	ins	< 6.0	ins	-	-	< 6.0
Nitrate-N	1	1	ins	ins	ins	< 500	ins	-	-	< 500
pH	1	0	ins	ins	ins	7.2	ins	-	-	7.1
Phosphorus	1	1	ins	ins	ins	< 15	ins	-	-	80
Potassium	1	0	ins	ins	ins	764	ins	-	-	4960
Redox	1	0	ins	ins	ins	10	ins	-	-	49
Rubidium	1	1	ins	ins	ins	< 556	ins	-	-	< 555
Selenium	1	0	ins	ins	ins	5.1	ins	-	-	1.8
Silicate	1	0	ins	ins	ins	9102	ins	-	-	13548
Silver	1	1	ins	ins	ins	< 0.0090	ins	-	-	< 0.0090
Sodium	1	0	ins	ins	ins	211425	ins	-	-	47568
Specific Conductance	1	0	ins	ins	ins	940	ins	-	-	955
Strontium	1	1	ins	ins	ins	< 0.60	ins	-	-	561
Sulfate	1	0	ins	ins	ins	23190	ins	-	-	42390
Sulfur	1	0	ins	ins	ins	12891	ins	-	-	43256
Temperature	1	0	ins	ins	ins	12	ins	-	-	10
Thallium	1	0	ins	ins	ins	0.043	ins	-	-	0.011
Titanium	1	1	ins	ins	ins	< 0.0035	ins	-	-	< 0.0035
Total dissolved solids	1	0	ins	ins	ins	552000	ins	-	-	608000
Total organic carbon	1	0	ins	ins	ins	1000	ins	-	-	3400
Total phosphate-P	1	0	ins	ins	ins	20	ins	-	-	50
Total suspended solids	1	0	ins	ins	ins	1000	ins	-	-	7000
Vanadium	1	1	ins	ins	ins	< 4.7	ins	-	-	5.1
Zinc	1	1	ins	ins	ins	< 2.7	ins	-	-	25

Table A.17: Descriptive statistics for Quaternary water table aquifers (QWTA).

Parameters	No. of samples	No. values censored	Distribution	Mean	UCL mean	Median	95th percentile	Min	Max	State Median
						ug/L				
Alkalinity	45	0	normal	258191	282377	235500	341300	43000	362000	237500
Aluminum	46	13	log-censored	0.57	45	0.74	15	< 0.060	414	1.2
Antimony	46	20	log-censored	0.014	0.13	0.013	0.098	< 0.0080	0.17	0.017
Arsenic	46	5	log-censored	0.74	11	0.85	5.9	< 0.060	9.2	1.3
Barium	46	0	normal	107	145	73	301	5.4	349	85
Beryllium	46	30	log-censored	0.0040	0.072	< 0.010	0.042	< 0.010	0.14	< 0.010
Boron	46	12	log-censored	19	62	18	51	< 13	84	24
Bromide	44	45	ins	ins	ins	< 0.20	< 0.20	< 0.20	0.10	< 0.20
Cadmium	46	28	log-censored	0.030	0.20	< 0.020	0.14	< 0.020	0.16	< 0.020
Calcium	46	0	normal	77297	85781	71209	110649	12386	121131	74237
Chloride	46	0	log-normal	4240	9101	6030	142370	260	357830	5810
Chromium	46	2	log-censored	0.76	5.8	0.97	4.7	< 0.050	5.7	0.55
Cobalt	46	0	log-normal	0.48	0.59	0.48	1.1	0.11	1.5	0.48
Copper	46	26	log-censored	6.6	25	< 5.5	24	< 5.5	33	6.3
Dissolved oxygen	46	21	log-censored	975	22339	730	10072	< 300	12260	< 500
Eh	46	0	normal	224	250	233	287	62	317	187
Fluoride	21	0	no distribution	-	-	235	829	200	910	300
Iron	46	0	log-normal	145	415	344	14646	5.2	15824	811
Lead	45	1	log-censored	0.26	3.5	0.22	2.8	0.030	162	0.18
Lithium	46	27	log-censored	4.1	16	< 4.5	14	< 4.5	19	5.7
Magnesium	46	0	normal	20709	23016	19185	30576	2278	36817	22224
Manganese	46	5	log-censored	116	3233	177	1265	< 0.90	1750	176
Mercury	19	14	log-censored	0.090	0.17	0.090	0.16	< 0.10	0.16	< 0.10
Molybdenum	46	45	log-censored	5.5	5.9	< 4.2	5.2	< 4.2	6.0	< 4.2
Nickel	46	36	log-censored	4.8	12	< 6.0	10	< 6.0	15	< 6.0
Nitrate-N	46	31	log-censored	440	20751	< 500	12318	< 500	22300	< 500
pH	46	0	normal	7.2	7.4	7.1	7.7	5.7	8.1	7.2
Phosphorus	46	8	log-censored	51	321	56	201	< 15	488	56
Potassium	46	0	log-normal	1464	1858	1407	4136	469	4887	1766
Redox	46	0	normal	3.0	29	13	67	-158	96	-24
Rubidium	46	43	log-censored	368	821	< 556	801	< 556	868	< 555
Selenium	46	5	log-censored	2.8	15	3.3	10	< 1.0	21	2.1
Silicate	46	0	normal	8997	9911	9439	15348	5480	16823	10819
Silver	46	28	log-censored	0.0080	0.65	< 0.0090	0.49	< 0.0090	0.65	< 0.0090
Sodium	46	0	no distribution	-	-	4243	97828	1746	180065	4986
Specific Conductance	46	0	no distribution	-	-	480	950	55	1600	465
Strontium	46	0	log-normal	108	132	90	195	32	484	105
Sulfate	46	5	log-censored	7094	95975	8790	48834	< 300	69600	4250
Sulfur	46	0	log-normal	2707	4225	3415	16477	244	25144	4603
Temperature	46	0	no distribution	-	-	8.7	11	7.2	12	8.8
Thallium	46	23	log-censored	0.0060	0.035	0.0050	0.038	< 0.0050	0.040	< 0.0050
Titanium	46	39	log-censored	0.0018	0.0080	< 0.0035	0.0060	< 0.0035	0.012	< 0.0035
Total dissolved solids	46	0	log-normal	337598	393913	320000	569600	100000	1020000	340000
Total organic carbon	46	0	log-normal	1906	2699	2000	14620	500	17600	2400
Total phosphate-P	46	8	log-censored	50	609	60	412	< 20	460	40
Total suspended solids	46	0	log-normal	3511	5591	4000	30800	1000	42000	4000
Vanadium	46	26	log-censored	4.9	17	< 4.7	13	< 4.7	18	5.4
Zinc	46	5	log-censored	13	175	9.9	117	< 2.7	1250	12

Table A.18: Coefficients for log-censored data from analysis of descriptive statistics, for each aquifer and chemical. See MPCA, 1998a, for application of these coefficients.

Chemical Parameter	**CMSH**		**CMTS**		**PCCR**	
	a	**b**	**a**	**b**	**a**	**b**
Aluminum (Al)	-	-	-0.563	3.149	1.336	4.025
Antimony (Sb)	-4.186	1.29	-4.371	1.011	-4.268	1.349
Arsenic (As)	-0.82	1.618	-0.431	1.738	-0.494	1.262
Beryllium (Be)	-	-	-5.166	0.793	-3.955	0.652
Boron (B)	3.048	0.984	-	-	-	-
Bromide (Br)	-	-	-	-	-	-
Cadmium (Cd)	-4.218	1.992	-	-	-2.926	0.574
Chloride (Cl)	-	-	-	-	-	-
Chromium (Cr)	-1.816	2.594	-0.728	1.377	-0.018	1.465
Cobalt (Co)	-	-	-	-	-	-
Copper (Cu)	1.882	0.674	1.194	1.621	1.978	0.998
Dissolved Oxygen	6.733	1.91	5.753	2.273	6.838	1.787
Iron (Fe)	-	-	5.885	2.138	-	-
Lead (Pb)	-	-	-	-	-	-
Lithium (Li)	1.943	1.054	-	-	1.81	0.644
Manganese (Mn)	3.883	2.952	4.869	0.878	-	-
Mercury (Hg)	-		-	-	-	-
Molybdenum (Mo)	1.486	0.365	-	-	1.301	1.187
Nickel (Ni)	1.697	0.673	-	-	1.759	0.466
Nitrate (NO3)	5.068	2.208	6.726	0.297	-	-
Phosphorus$_{total}$	3.765	1.522	-	-	3.843	1.131
Rubidium (Rb)	6.355	0.141	-	-	-	-
Selenium (Se)	0.615	0.867	0.937	0.699	-	-
Silver (Ag)	-5.463	1.664	-5.501	1.156	-4.04	2.03
Sulfate (SO_4)	7.95	2.456	8.048	1.439	-	-
Thallium (Tl)	-	-	-5.153	0.822	-5.051	0.851
Titanium (Ti)	-5.549	0.545	-	-	-5.769	0.719
Total organic carbon	7.497	1.215	-	-	-	-
Total phosphate	2.987	2.117	4.113	1.503	3.719	1.349
Vanadium (V)	1.786	0.863	0.866	0.86	1.413	0.926
Zinc (Zn)	2.641	1.174	-	-	2.894	0.895

Table A.18 continued

Chemical Parameter	QBAA		QBUA		QWTA	
	a	b	a	b	a	b
Aluminum (Al)	-0.639	1.880	-0.883	1.639	-0.564	2.233
Antimony (Sb)	-4.41	1.019	-4.208	1.19	-4.303	1.164
Arsenic (As)	0.349	1.528	0.27	1.229	-0.306	1.378
Beryllium (Be)	-6.008	1.567	-5.935	1.174	-5.587	1.508
Boron (B)	3.23	1.302	2.93	0.882	2.923	0.611
Cadmium (Cd)	-3.907	1.149	-3.772	0.769	-3.52	0.961
Chromium (Cr)	-0.424	1.042	-0.512	1.211	-0.271	1.034
Cobalt (Co)	-	-	1.676	0.95	-	-
Copper (Cu)	1.511	0.691	1.676	0.95	1.893	0.685
Dissolved Oxygen	5.56	2.047	6.96	1.758	6.882	1.598
Iron (Fe)	6.044	2.037	4.761	2.364	-	-
Lead (Pb)	-1.509	1.377	-	-	-1.354	1.329
Lithium (Li)	1.261	1.589	1.465	1.106	1.408	0.688
Manganese (Mn)	1.7362	1.222	1.245	1.718	4.757	1.696
Mercury (Hg)	-2.58	0.451	-3.217	0.747	-2.381	0.299
Molybdenum (Mo)	0.883	0.719	0.576	0.854	1.698	0.042
Nickel (Ni)	1.322	0.612	1.706	0.4	1.565	0.481
Nitrate (NO3)	3.316	2.633	5.297	2.632	6.087	1.966
$\text{Phosphorus}_{\text{total}}$	4.411	0.832	3.894	0.875	3.926	0.942
Rubidium (Rb)	5.761	0.438	5.835	0.384	5.909	0.409
Selenium (Se)	1.117	0.918	1.405	1.108	1.022	0.863
Silver (Ag)	-5.095	2.237	-5.301	2.543	-4.884	2.268
Strontium (Sr)	4.846	0.862	-	-	-	-
Sulfate (SO_4)	8.769	1.899	9.581	1.317	8.867	1.329
Thallium (Tl)	-6.439	1.728	-5.623	0.874	-5.191	0.939
Titanium (Ti)	-7.115	1.177	-6.269	0.596	-6.328	0.765
Total organic carbon	7.596	0.667	7.464	0.69	-	-
Total phosphate	4.366	1.208	3.632	1.147	3.921	1.271
Vanadium (V)	1.193	0.707	1.5	0.569	1.587	0.63
Zinc (Zn)	2.617	1.391	2.408	1.045	2.527	1.345

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.

Chemical Parameter	CMSH		CMTS		PCCR	
	std. dev.	n	std. dev.	n	std. dev.	n
Aluminum (Al)	0.4473	9	-	-	-	-
Arsenic (As)	-	-	-	-	-	-
Barium (Ba)	-	-	0.3731	9	-	-
Boron (B)	-	-	-	-	0.6844	8
Calcium (Ca)	0.4157	9	-	-	-	-
Chloride (Cl)	-	-	-	-	0.5316	8
Iron (Fe)	0.9951	9	-	-	0.6760	8
Lead (Pb)	0.4945	9	0.6164	9	-	-
Magnesium (Mg)	0.3857	9	-	-	-	-
Manganese (Mn)	-	-	-	-	0.5516	8
Phosphorus (P)	-	-	0.3799	9	-	-
Silicate (Si)	0.1944	9	-	-	-	-
Sodium (Na)	-	-	-	-	0.4796	8
Strontium (Sr)	0.4509	9	-	-	0.2730	8
Sulfate (SO4)	-	-	-	-	0.4600	8
Sulfur (S)	0.8624	9	-	-	0.3931	8
Total dissolved solids	0.3365	9	-	-	-	-
Total suspended solids	0.6277	9	-	-	-	-
Zinc (Zn)	-	-	0.6876	9	-	-

Table A.19 continued

Chemical Parameter	QBAA		QBUA		QWTA	
	std. dev.	n	std. dev.	n	std. dev.	n
Barium (Ba)	-	-	0.4311	52	-	-
Chloride (Cl)	-	-	0.6911	52	0.6584	47
Cobalt (Co)	-	-	0.3090	52	0.2187	47
Fluoride (F)	-	-	0.1220	52	-	-
Iron (Fe)	-	-	-	-	1.0397	47
Lead (Pb)	-	-	0.4238	52	-	-
Potassium (K)	0.2840	94	0.3592	52	0.2391	47
Silicate (Si)	0.1239	94	-	-	-	-
Strontium (Sr)	-	-	-	-	0.2017	47
Sulfur (S)	0.7419	94	-	-	0.5255	47
Total dissolved solids	0.2035	94	0.2339	52	0.1762	47
Total organic carbon	-	-	-	-	0.3660	47
Total suspended solids	-	-	-	-	0.4595	47

Table A.20: Median concentrations, in ug/L, of sampled parameters for each of the major aquifers. The p-value indicates the probability that aquifers have equal concentrations.

Parameter	p-value	CMSH	CMTS	KRET	PCCR	QBAA	QBUA	QWTA
		ug/L						
Alkalinity	0.007	126000	216000	294000	233000	257000	250500	235500
Aluminum	0.001	1.3	0.53	2.3	8.1	0.75	0.50	0.74
Antimony	0.710	0.010	0.013	0.024	0.013	0.01	0.015	0.013
Arsenic	0.100	0.64	1.6	0.52	0.56	1.6	1.2	0.85
Barium	0.206	50	44	119	40	70	59	73
Beryllium	0.047	< 0.010	< 0.010	< 0.010	0.013	< 0.010	< 0.010	< 0.010
Boron	< 0.001	22	20	43	90	21	18	18
Bromide	-	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20
Cadmium	0.567	< 0.020	< 0.020	< 0.020	0.030	< 0.020	< 0.020	< 0.020
Calcium	0.001	48425	59094	70898	43209	64284	75466	71209
Chloride	0.002	1320	900	3090	2030	1635	6075	6030
Chromium	0.749	0.060	0.31	1.1	0.72	0.85	1.0	0.97
Cobalt	0.648	0.52	0.50	0.51	0.45	0.40	0.44	0.48
Copper	0.030	6.0	< 5.5	13	6.2	< 5.5	< 5.5	< 5.5
Dissolved oxygen	0.216	930	< 300	3010	545	< 300	675	730
Eh	0.032	219	84	277	184	195	239	233
Fluoride	0.001	220	230	280	480	270	280	235
Iron	0.096	431	1249	1235	586	657	118	344
Lead	0.155	0.18	0.20	0.60	0.75	0.20	0.20	0.22
Lithium	0.013	7.4	< 4.5	5.3	6.9	< 4.5	5.0	< 4.5
Magnesium	0.043	13870	18413	26864	18047	20253	23483	19185
Manganese	0.352	53	131	49	125	133	138	177
Mercury	0.188	0.09	0.090	< 0.10	< 0.10	0.090	< 0.10	0.090
Molybdenum	0.002	< 4.2	< 4.2	< 4.2	< 4.2	< 4.2	< 4.2	< 4.2
Nickel	0.001	< 6.0	< 6.0	< 6.0	< 6.0	< 6.0	< 6.0	< 6.0
Nitrate-N	0.020	< 500	< 500	< 500	< 500	< 500	< 500	< 500
pH	0.003	7.3	7.3	7.15	7.4	7.4	7.3	7.1
Phosphorus	0.011	34	69	115	54	80	54	56
Potassium	0.046	1193	1650	2554	1821	1524	1561	1407
Rubidium	0.721	< 556	< 556	< 556	< 556	< 556	< 556	< 556
Selenium	0.070	1.8	2.7	5.2	4.4	3.3	3.8	3.3
Silicate	0.593	11850	9618	11645	8312	9947	10230	9439
Silver	0.129	< 0.0090	< 0.0090	0.095	0.025	< 0.0090	< 0.0090	< 0.0090
Sodium	< 0.001	3545	5327	9815	11797	7010	6213	4243
Specific Conductance	0.139	330	420	617	410	470	530	480
Strontium	0.002	104	88	279	179	123	101	90
Sulfate	0.027	2820	2160	10080	10890	8355	15345	8790
Sulfur	0.047	1222	1021	3112	3956	3464	5648	3415
Temperature	0.504	8.5	9.6	8.7	8.8	8.8	9.0	8.7
Thallium	0.039	< 0.0050	< 0.0050	< 0.0050	0.0060	< 0.0050	< 0.0050	0.0050
Titanium	< 0.001	< 0.0035	< 0.0035	< 0.0035	0.0038	< 0.0035	< 0.0035	< 0.0035
Total dissolved solids	0.064	214000	272000	374000	272000	301000	329000	320000
Total organic carbon	0.350	2100	1300	1500	1700	1900	1700	2000
Total phosphate-P	0.027	20	50	50	40	70	40	60
Total suspended solids	0.074	6000	2000	4000	4000	4000	2000	4000
Vanadium	0.930	5.1	< 4.7	< 4.7	4.7	< 4.7	< 4.7	< 4.7
Zinc	0.021	13	14	15	17	13	9.9	9.9

[1] Eh is in mV, Specific Conductance in mmhos/cm, Temperature in °C, and pH in pH units

Table A.21: Summary of water quality criteria, basis of criteria, and endpoints, by chemical parameter.

Parameter	Criteria (ug/L)	Basis of criteria	Endpoint
Alkalinity	-	-	-
Aluminum (Al)	50	MCL	-
Antimony (Sb)	6	HRL	-
Arsenic (As)	50	MCL	Cancer
Barium (Ba)	2000	HRL	Cardiovascular/blood
Beryllium (Be)	0.08	HRL	Cancer
Boron (B)	600	HRL	Reproductive
Bromide (Br)	-	-	-
Cadmium (Cd)	4	HRL	Kidney
Calcium (Ca)	-	-	-
Chloride (Cl)	250000	SMCL	-
Chromium (Cr)	20000[1]	HRL	-
Cobalt (Co)	30	HBV	-
Copper (Cu)	1000	HBV	-
Dissolved Oxygen	-	-	-
Fluoride (F)	4000	MCL	-
Iron (Fe)	300	SMCL	-
Lead (Pb)	15	Action level at tap	-
Lithium (Li)	-	-	-
Magnesium (Mg)	-	-	-
Manganese (Mn)	100 (1000)[2]	HRL	Central nervous system
Mercury (Hg)	2	MCL	-
Molybdenum (Mo)	30	HBV	Kidney
Nickel (Ni)	100	HRL	-
Nitrate-N (NO_3-N)	10000	HRL	Cardiovascular/blood
Ortho-phosphate	-	-	-
pH	-	-	-
$\text{Phosphorus}_{\text{total}}$	-	-	-
Potassium (K)	-	-	-
Redox/Eh	-	-	-
Rubidium (Rb)	-	-	-
Selenium (Se)	30	HRL	-
Silicate (Si)	-	-	-
Silver (Ag)	30	HRL	-
Sodium (Na)	250000	SMCL	-
Specific conductance	-	-	-
Strontium (Sr)	4000	HRL	Bone
Sulfate (SO_4)	500000	MCL	-
Sulfur (S)	-	-	-
Temperature	-	-	-
Thallium (Tl)	0.6	HRL	Gastrointestinal/liver
Titanium (Ti)	-	-	-
Total dissolved solids	-	-	-
Total organic carbon	-	-	-
Total phosphate	-	-	-
Total suspended solids	-	-	-
Vanadium (V)	50	HRL	-
Zinc (Zn)	2000	HRL	-

Table A.21 continued

Parameter	Criteria (ug/L)	Basis of criteria	Endpoint
1,1,1-trichloroethane	600	HRL	gi/liv
1,1-dichloroethane	70	HRL	kid
1,1-dichloroethene	6	HRL	gi/liv
1,2-dichloroethane	4	HRL	cancer
1,2-dichloropropane	5	HRL	cancer
acetone	700	HRL	cv/bld; liv
benzene	10	HRL	cancer
bromodichloromethane	6	HRL	cancer
chlorodibromomethane	-	-	-
chloroform	60	HRL	cancer
dichlorodifluoromethane	1000	HRL	body weight
dichlorofluoromethane	-	-	-
ethyl ether	1000	HRL	body weight
isopropylbenzene	-	-	-
xylene	10000	HRL	cns/pns
methyl ethyl ketone	4000	HRL	repro
methylene chloride	50	HRL	cancer
naphthalene	300	HRL	cv/bld
tetrachloroethene	7	HRL	cancer
tetrahydrofuran	100	HRL	gi/liv
toluene	1000	HRL	kid; gi/liv
trichloroethene	30	HRL	cancer
1,2,4-trimethylbenzene	-	-	-
1,3,5-trimethylbenzene	-	-	-
cis-1,2 dichloroethene	70	HRL	cv/bld
ethyl benzene	700	HRL	kid; gi/liv
n-butylbenzene	-	-	-
n-propyl benzene	-	-	-
p-isopropyltoluene	-	-	-
styrene	-	-	-
trichlorofluoromethane	-	-	-

[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.

	No. exceedances of criteria								
Parameter	CFIG	CFRN	CMSH	KRET	PCCR	PMNS	QBAA	QBUA	QWTA
Beryllium (Be)	-	-	-	1	-	2	1	-	1
Boron (B)	-	-	-	-	1	2	3	-	-
Manganese (Mn)	1	-	1	-	-	1	2	1	3
Molybdenum (Mo)	-	-	-	-	-	-	-	-	-
Nickel (Ni)	-	-	-	-	-	1	-	-	-
Nitrate (NO3)	-	-	-	-	1	-	1	5	2
Selenium (Se)	-	-	-	-	-	-	-	1	-
Thallium (Tl)	-	1	-	1	-	-	-	-	-
Vanadium (V)	-	-	-	-	-	1	-	-	-

Table A.23: Percentage of samples exceeding health-based water quality criteria, by aquifer.

	% exceedances of criteria								
Parameter	CFIG	CFRN	CMSH	KRET	PCCR	PMNS	QBAA	QBUA	QWTA
Beryllium (Be)	-	-	-	20	-	40	1	-	2
Boron (B)	-	-	-	-	13	40	3	-	-
Manganese (Mn)	50	-	11	-	-	20	2	2	7
Molybdenum (Mo)	-	-	-	-	-	-	-	-	-
Nickel (Ni)	-	-	-	-	-	20	-	-	-
Nitrate (NO3)	-	-	-	-	13	-	1	9	4
Selenium (Se)	-	-	-	-	-	-	-	2	-
Thallium (Tl)	-	33	-	20	-	-	-	-	-
Vanadium (V)	-	-	-	-	-	20	-	-	-

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

	No. exceedances of criteria												
Parameter	CFIG	CFRN	CIGL	CMSH	CMTS	KRET	PCCR	PMHN	PMNS	PMUD	QBAA	QBUA	QWTA
Aluminum (Al)	1	-	-	-	-	1	2	-	2	-	1	1	1
Arsenic (As)	-	-	-	-	-	-	-	-	-	-	1	-	-
Chloride (Cl)	-	-	-	-	-	-	-	-	-	-	-	1	1
Iron (Fe)	1	2	1	7	6	3	5	2	2	1	60	19	26
Lead (Pb)	-	-	-	-	-	-	-	-	-	-	-	-	1
Sodium (Na)	-	-	-	-	-	-	-	-	-	-	1	-	-
Sulfate (SO_4)	-	-	-	-	-	-	-	-	-	-	2	1	-

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

	% exceedances of criteria												
Parameter	CFIG	CFRN	CIGL	CMSH	CMTS	KRET	PCCR	PMHN	PMNS	PMUD	QBAA	QBUA	QWTA
Aluminum (Al)	50	-	-	-	-	20	25	-	40	-	1	2	2
Arsenic (As)	-	-	-	-	-	-	-	-	-	-	1	-	-
Chloride (Cl)	-	-	-	-	-	-	-	-	-	-	-	2	2
Iron (Fe)	50	33	50	78	67	60	63	100	40	33	53	36	56
Lead (Pb)	-	-	-	-	-	-	-	-	-	-	-	-	2
Sodium (Na)	-	-	-	-	-	-	-	-	-	-	1	-	-
Sulfate (SO_4)	-	-	-	-	-	-	-	-	-	-	2	2	-

Table A.26: Summary statistics for different nitrate stability groups.

Nitrate stability	No. samples	Median (ug/L)	Q75 (ug/L)	Maximum (ug/L)	No. > 1000 ug/L	No. > HRL (10000 ug/L)
Stable	78	800	3975	47900	36	7
Not stable	35	< 490	< 490	< 490	0	0
Unknown	132	< 490	< 490	22300	3	2

Table A.27: Summary information for VOCs detected in Region 2. Wells have been assigned arbitrary values to replace CWI unique numbers.

Unique No.	PARAMETER	Concentration (ug/L)	Chemical Class
1	benzene	3.2	BTEX
2	toluene	0.3	BTEX
3	chloroform	0.1	Trihalomethane
4	chloroform	1.3	Trihalomethane
5	toluene	0.3	BTEX
6	xylene	0.2	BTEX
6	methyl ethyl ketone	51	Ketone
6	tetrahydrofuran	19	Ether
7	chloroform	0.2	Trihalomethane
8	dichlorodifluoromethane	1.3	Chlorofluorocarbon
8	trichlorofluoromethane	1.9	Chlorofluorocarbon
9	toluene	0.3	BTEX
10	trichloroethene	0.1	Halogenated aliphatic
11	toluene	0.3	BTEX
12	acetone	20	Ketone
13	toluene	0.3	BTEX
14	toluene	0.2	BTEX
15	chloroform	0.5	Trihalomethane
16	chloroform	0.2	Trihalomethane
17	chloroform	0.8	Trihalomethane
18	trichloroethene	0.1	Halogenated aliphatic
18	tetrachloroethene	8.6	Halogenated aliphatic
18	chloroform	0.2	Trihalomethane
19	chloroform	0.9	Trihalomethane
20	chloroform	0.2	Trihalomethane
21	chloroform	0.3	Trihalomethane
22	chloroform	0.1	Trihalomethane
23	chloroform	0.3	Trihalomethane
24	chloroform	0.3	Trihalomethane
25	benzene	22	BTEX
25	xylene	2.2	BTEX
25	ethylbenzene	0.7	BTEX
25	toluene	3.3	BTEX
25	1,3,5-trimethylbenzene	0.5	BTEX
25	isopropylbenzene	0.5	BTEX
25	1,2,4-trimethylbenzene	1.1	BTEX
25	naphthalene	1.2	PAH

Table A.28: Comparison of water quality data for surficial drift aquifers from different literature sources for North Central Minnesota. Concentrations represent median values, in ug/L (ppb), except where indicated.

Parameter	Myette, 1986	Myette, 1982	Lindholm, 1980	Anderson, 1993	GWMAP
No. of Samples	32	93	32	70 to > 200	47
Bicarbonate	67000	200000	230000	219000	235500
Boron	20	5	20	20	18
Calcium	18000	62000	68000	57000	71209
Chloride	7000	7100	7900	12000	6030
Dissolved Oxygen	-	-	-	-	730
Fluoride	< 100	100	100	100	235
Hardness (as $CaCO_3$)	73000	99500	-	210000	-
Iron	1200	40[1]	550	20[1]	344
Magnesium	6100	16500	21000	17000	19185
Manganese	120	50[1]	110	30[1]	177
Nitrate	110	2100	2550	2800	< 500
pH	6.6	7.45	7.6	7.6	7.1
Phosphorus	< 10	10	40	10	56
Potassium	900	1050	1600	1000	1407
Silica	18000	14000	19000	18000	9439
Sodium	3900	3350	3200	3900	4243
Sulfate	8000	10400	19000	17000	8790
Temperature (^{o}C)	10	9	12	9.0	8.7
Total dissolved solids	117000	273000	301500	240000	320000
Total organic carbon	-	-	2700	1400	2000

[1] Dissolved Iron

Table A.29: Summary of correlation coefficients between chemicals of concern and sampled parameters for water-table drift aquifers (QWTA).

Chemical	Alkalinity	Barium	Calcium	Chloride	Magnesium	Potassium	Sodium	Strontium
Iron	ns	0.416	ns	ns	ns	0.262[1]	ns	ns
Manganese	ns	0.429	ns	0.260[1]	ns	0.299	ns	0.359
Nitrate	ns	ns	ns	0.350	ns	-0.279[1]	ns	ns
Chloride	ns	ns	0.340	-	0.316	ns	0.349	ns
Lead	ns	-0.279[1]	ns	ns	ns	ns	ns	ns
	Dissolved Oxygen	**Eh**	**TDS**	**Tritium[3]**	**UTM-e**	**UTM-n**	**Well depth**	**Well diameter**
Iron	-0.468	-0.558	ns	-	ns	-0.291	ns	ns
Manganese	-0.523	-0.323	ns	-	ns	-0.302	ns	ns
Nitrate	0.488	0.297	0.254[1]	-	-0.420	ns	-0.282[1]	ns
Chloride	ns	ns	0.487	-	ns	-0.414	ns	ns
Lead	0.430	ns	ns	-	ns	ns	ns	ns

[1] Significant at the 0.10 level but not at the 0.05 level.
[2] ns = Not significant at the 0.10 level.
[3] Tritium was sampled in only 2 water table aquifers

Table A.30: Comparison of water quality data for buried drift aquifers from different literature sources for North Central Minnesota. Concentrations represent median values, in ug/L (ppb), except where indicated.

Parameter	Stearns County data	DNR Atlas - Stearns County	Lindholm, 1980	Anderson, 1993	GWMAP Baseline - QBUA	GWMAP Baseline - QBAA
No. samples	19	28	5	16	52	94
Bicarbonate	313000	350000	220000	200000	281000	328000
Boron	43	-	30	< 20	23	98
Calcium	80000	91050	62000	44000	78821	79537
Chloride	510	2875	9000	1300	3625	2320
Conductivity (umhos/cm)	642	473	550	350	533	619
Fluoride	300	180	100	100	305	380
Hardness (as $CaCO_3$)	-	371570	230000	170000	-	-
Iron	1150	1430	1450	230	367	1179
Magnesium	270	32750	19000	15000	26539	30515
Manganese	30700	121	40	86	152	131
Nitrate	< 100	315	1000	< 100	< 500	< 500
pH	7.45	7.3	7.6	7.5	7.2	7.3
Phosphorus	-	85	35	50	57	102
Potassium	2300	2340	1400	1000	1796	3068
Redox (mV)	-	17.5	-	-	5	-56
Silica	21700	12400	19000	16000	10867	11914
Sodium	5640	15760	3200	5400	5906	18812
Strontium	170	281	-	-	112	304
Sulfate	25500	26300	17000	3700	5280	7300
Temperature (^oC)	9.15	8.8	1.3	9.5	8.8	8.9
Total dissolved solids	385000	382814	267000	200000	350000	430000
Total organic carbon	2150	-	400	1200	1900	2600

Table A.31: Summary of correlation coefficients between chemicals of concern and sampled parameters for buried drift aquifers (QBAA and QBUA).

QBAA

Chemical	Alkalinity	Barium	Calcium	Chloride	Magnesium	Potassium	Sodium	Strontium
Arsenic	0.348	ns	0.269	ns	0.367	0.412	0.279	0.390
Beryllium	ns[2]	ns	ns	ns	ns	ns	ns	ns
Boron	0.528	0.311	ns	ns	0.431	0.665	0.736	0.778
Iron	0.371	0.524	0.411	ns	ns	0.333	ns	0.313
Manganese	ns	ns	0.331	ns	ns	ns	ns	ns
Nitrate	ns	ns	ns	ns	ns	ns	ns	ns
Sulfate	ns	ns	0.487	0.594	0.467	ns	ns	ns
	Dissolved Oxygen	**Eh**	**TDS**	**Tritium**	**UTM-e**	**UTM-n**	**Well depth**	**Well diameter**
Arsenic	ns	ns	0.269	ns	0.367	0.412	0.279	0.390
Beryllium	ns	ns	ns	ns	ns	ns	ns	ns
Boron	ns	-0.279	0.449	-0.701	ns	-0.350	ns	ns
Iron	ns	-0.542	0.294	ns	ns	ns	ns	ns
Manganese	ns	ns	ns	-0.322	ns	ns	ns	ns
Nitrate	0.327	0.278	ns	0.632	ns	ns	ns	ns
Sulfate	0.255	ns	0.519	0.446	ns	-0.355	ns	0.425

QBUA

Chemical	Alkalinity	Barium	Calcium	Chloride	Magnesium	Potassium	Sodium	Strontium
Chloride	ns	ns	0.482	-	0.508	ns	0.383	ns
Iron	ns	0.488	ns	ns	0.680	ns	ns	ns
Manganese	0.248[1]	0.427	ns	-0.236[1]	ns	0.308	ns	0.393
Nitrate	-0.237[1]	-0.374	ns	0.383	ns	0.264[1]	ns	ns
Selenium	ns	ns	ns	0.317	ns	ns	ns	ns
Sulfate	0.432	0.243[1]	0.692	0.703	0.695	0.342	ns	0.397
	Dissolved Oxygen	**Eh**	**TDS**	**Tritium**	**UTM-e**	**UTM-n**	**Well depth**	**Well diameter**
Chloride	0.402	ns	0.568	-	ns	ns	-0.327	ns
Iron	-0.539	-0.493	ns	-	ns	ns	ns	ns
Manganese	-0.489	-0.284	ns	-	ns	ns	ns	ns
Nitrate	0.655	0.355	ns	-	ns	ns	ns	ns
Selenium	0.353	0.267	ns	-	ns	-0.303	ns	ns
Sulfate	ns	ns	0.720	-	ns	-0.532	ns	0.279

[1] significant at the 0.10 level but not at the 0.05 level.

[2] ns = Not significant at the 0.10 level.

Table A.32: Comparison of water quality data for Cretaceous aquifers from different literature sources for North Central Minnesota. Concentrations represent median values, in ug/L (ppb), except where indicated.

Parameter	Stearns County	DNR Atlas - Stearns County	GWMAP
No. of Samples	6	5	7
Bicarbonate	336000	294000	356000
Boron	654	43	410
Calcium	50500	70898	132699
Chloride	4800	3090	5840
Conductivity (umhos/cm)	682	-	1436
Dissolved oxygen	1215	3010	< 300
Fluoride	725	-	430
Hardness	-	617000	1514
Iron	545	1235	-
Magnesium	30500	26864	51635
Manganese	25	49	112
Nitrate	100	500	< 500
pH	7.59	7.15	7.0
Potassium	5650	2554	5474
Redox (mV)	-	57	-75
Silica	10600	-	10955
Sodium	29150	9815	76187
Strontium	655	-	754
Sulfate	32000	3360	420390
Temperature (^oC)	9.6	-	10
Total dissolved solids	406500	374000	1110000
Total organic carbon	2300	1500	2800
Total phosphorus	-	50	140

Table A.33: Summary of correlation coefficients between chemicals of concern and sampled parameters for Cretaceous aquifers (KRET).

Chemical	**Alkalinity**	**Barium**	**Calcium**	**Chloride**	**Magnesium**	**Potassium**	**Sodium**	**Strontium**
Beryllium	ns	ns	ns	ns	ns	ns	ns	ns
Iron	ns	ns	ns	ns	ns	ns	ns	ns
Thallium	ns	ns	ns	0.788	ns	0.749	ns	ns
	Dissolved Oxygen	**Eh**	**TDS**	**Tritium[3]**	**UTM-e**	**UTM-n**	**Well depth**	**Well diameter**
Beryllium	0.676[1]	ns	ns	-	ns	ns	ns	ns
Iron	ns	ns	ns	-	ns	ns	ns	ns
Thallium	ns	ns	ns	-	ns	ns	ns	ns

[1] Significant at the 0.10 level but not at the 0.05 level.

[2] ns = Not significant at the 0.10 level.

[3] Tritium was not sampled in Cretaceous aquifers

Appendix B - Figures

Figure B.1: Location of Region 2

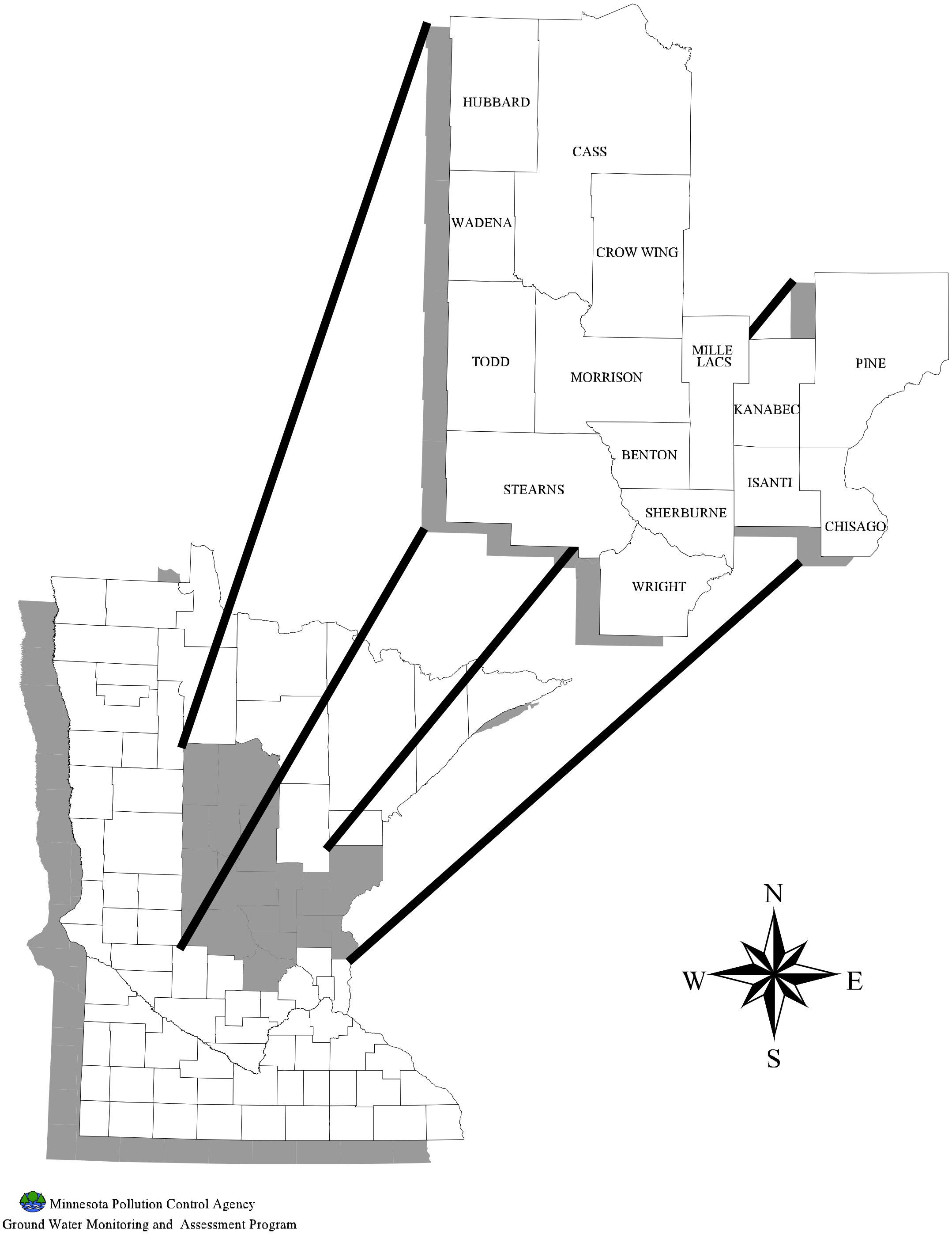


Figure B.2: Location of sampled wells from surficial Quaternary (drift) aquifers.

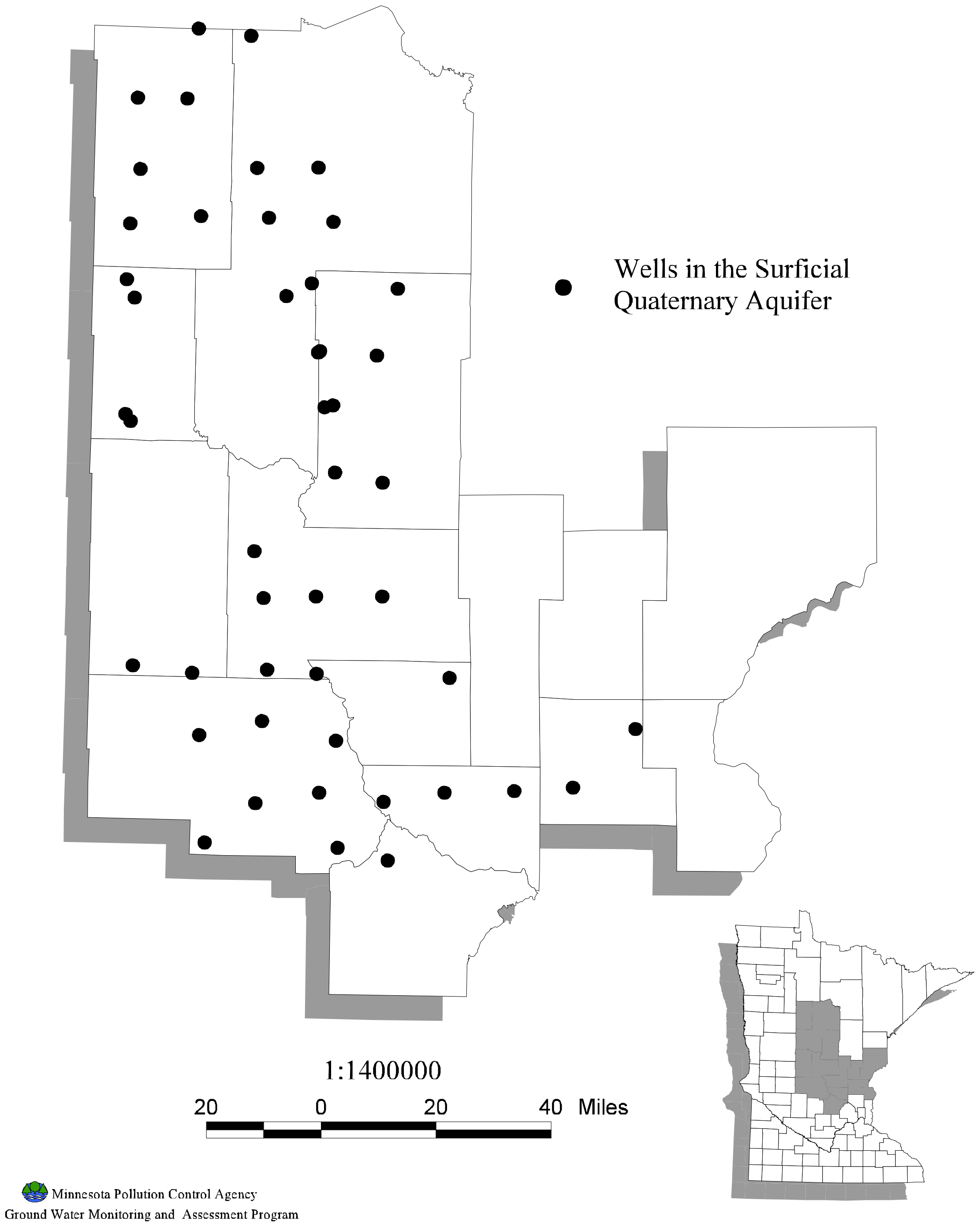


Figure B.3: Location of sampled wells from buried drift aquifers.

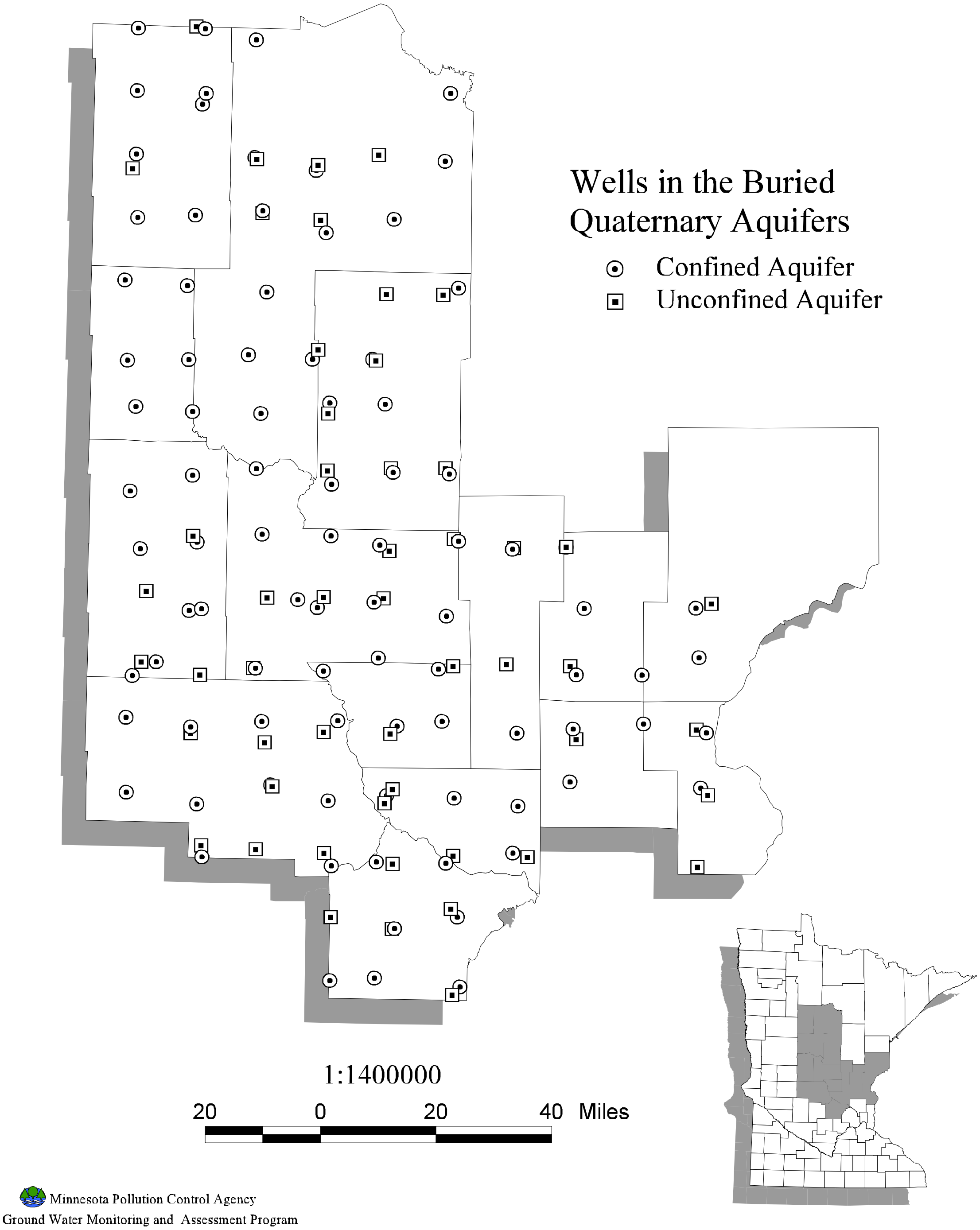


Figure B.4: Location of sampled wells from Cretaceous aquifers.

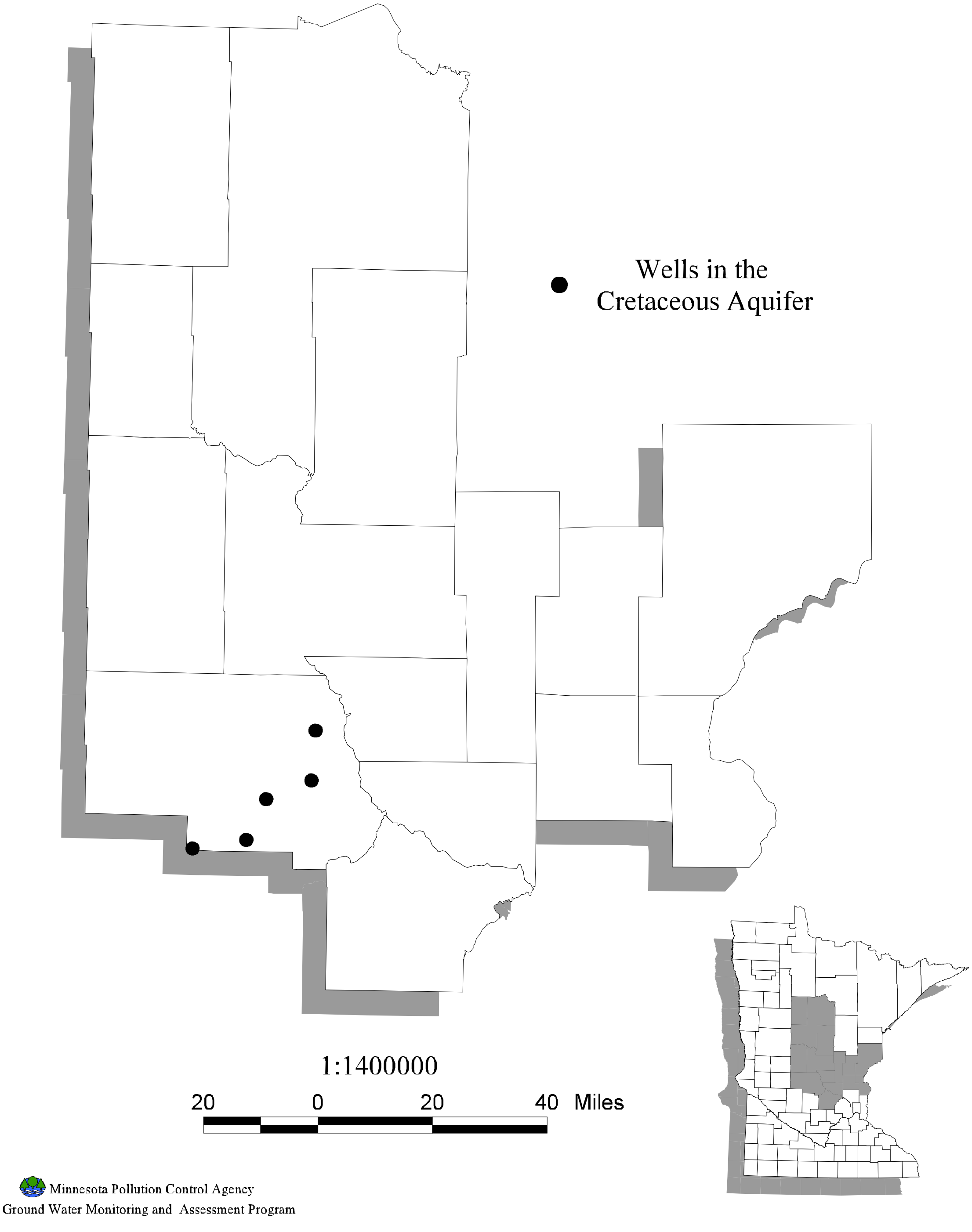
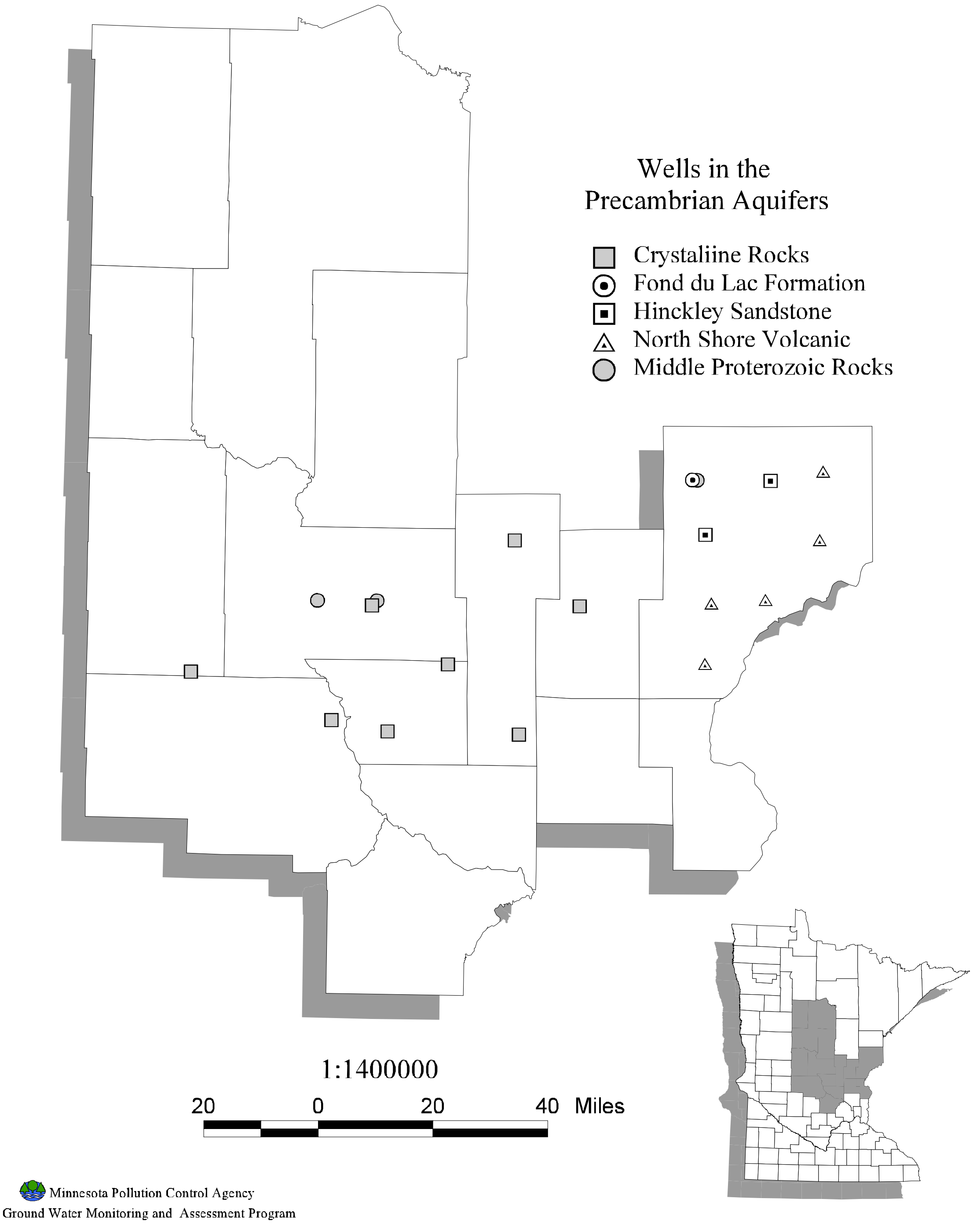


Figure B.5: Location of sampled wells from Precambrian aquifers.



B.6: Location of sampled wells from Cambrian aquifers.

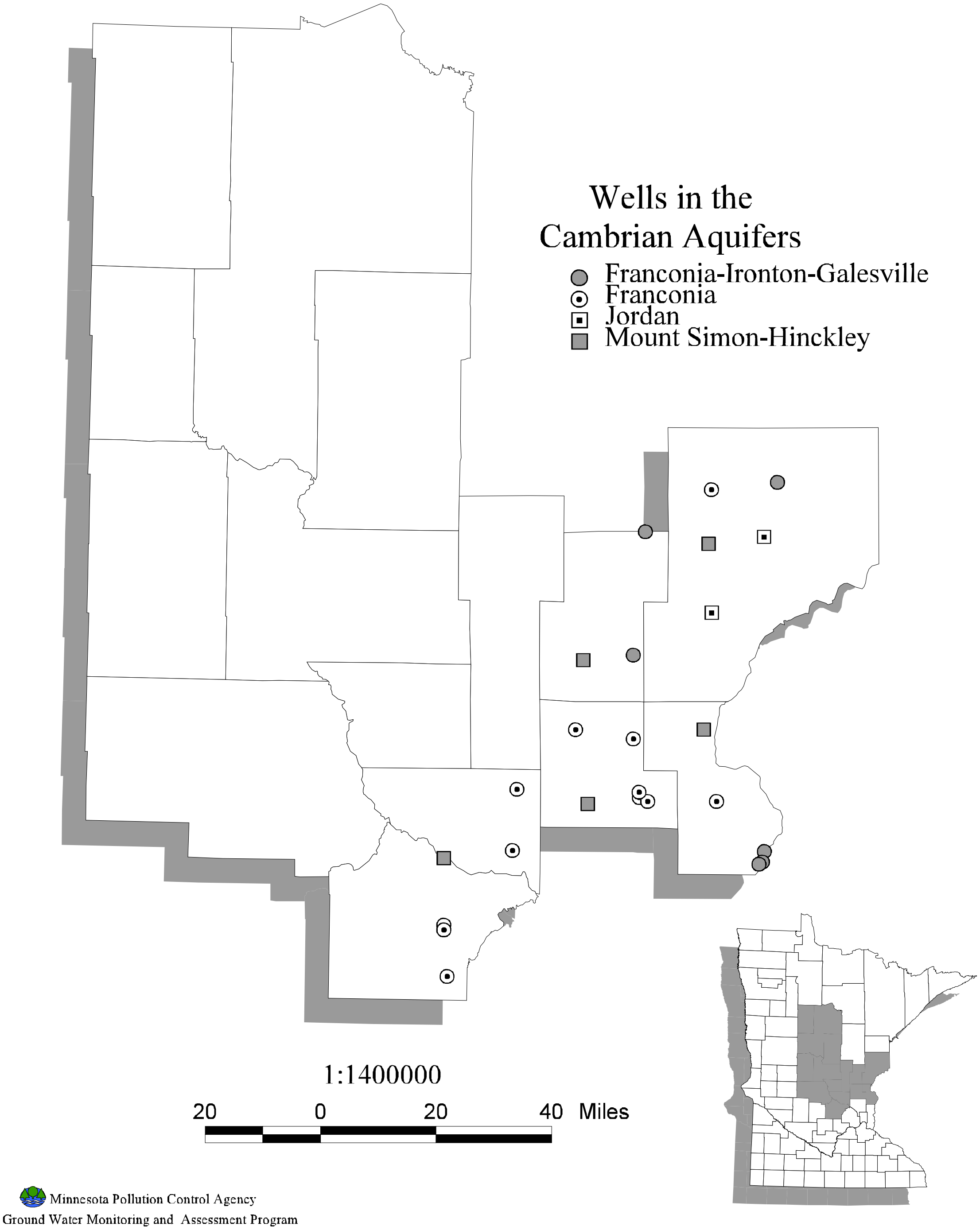


Figure B.7: Distribution of VOCs in Region 2.

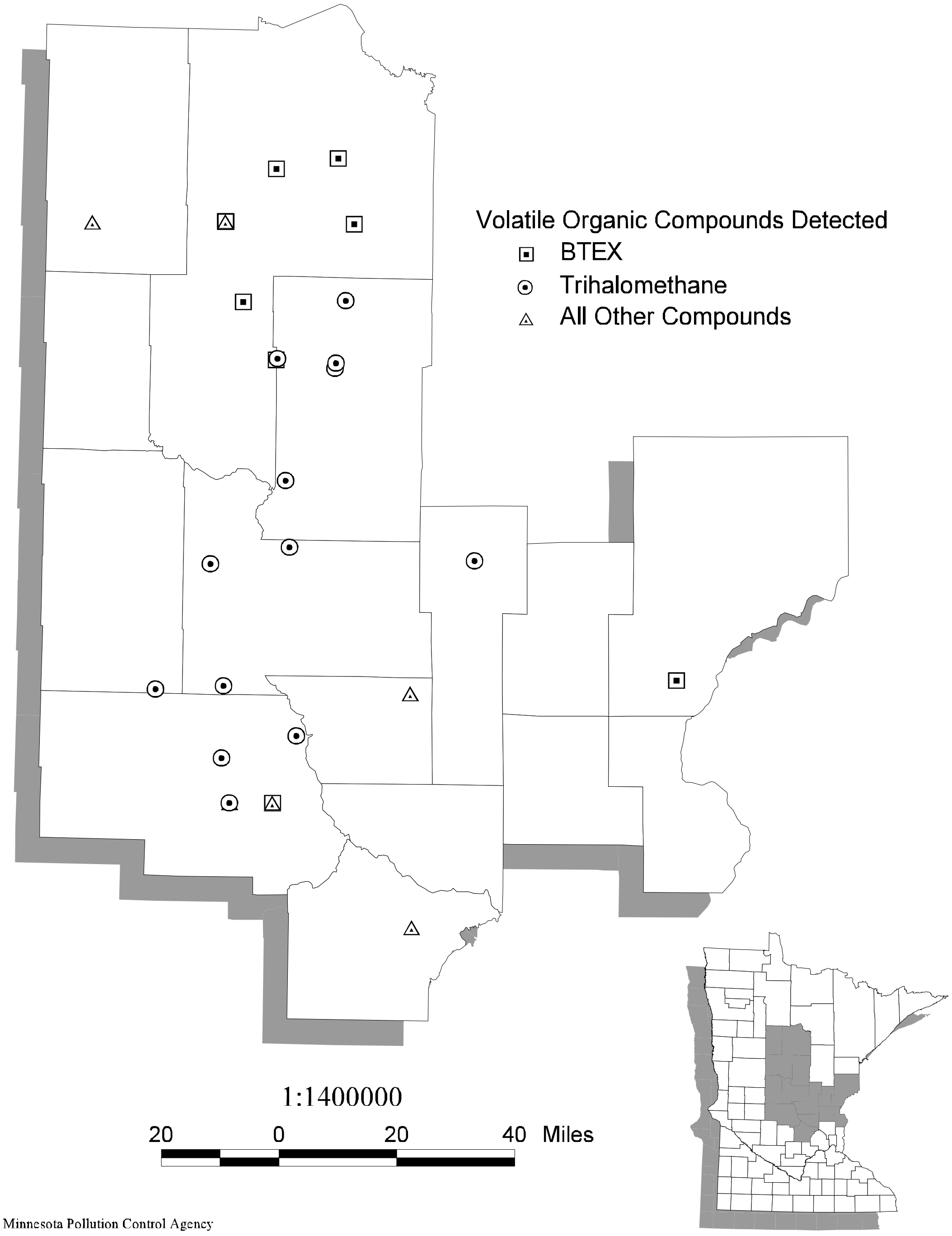


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Figure B.8: Illustration of redox boundaries for some chemicals of potential concern. Also illustrated are chemicals which are likely to interact with the redox-sensitive chemicals.

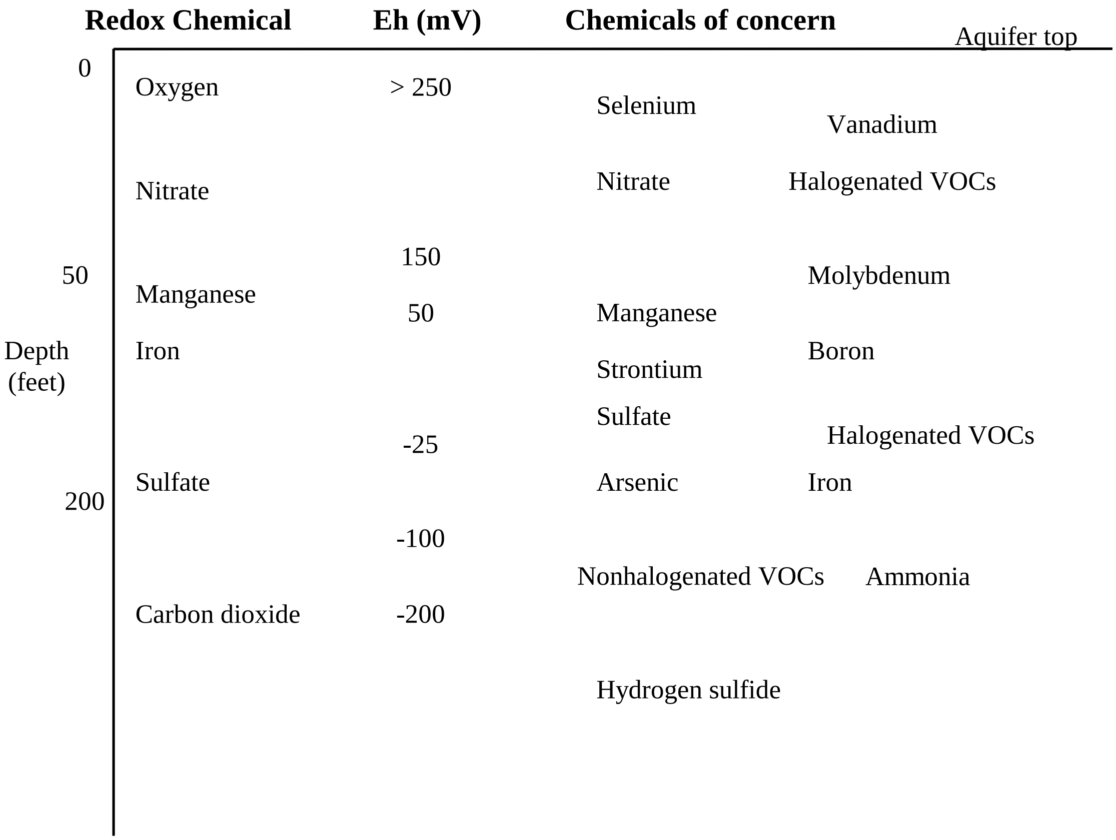

Figure B.9: Location of surficial outwash in Region 2.

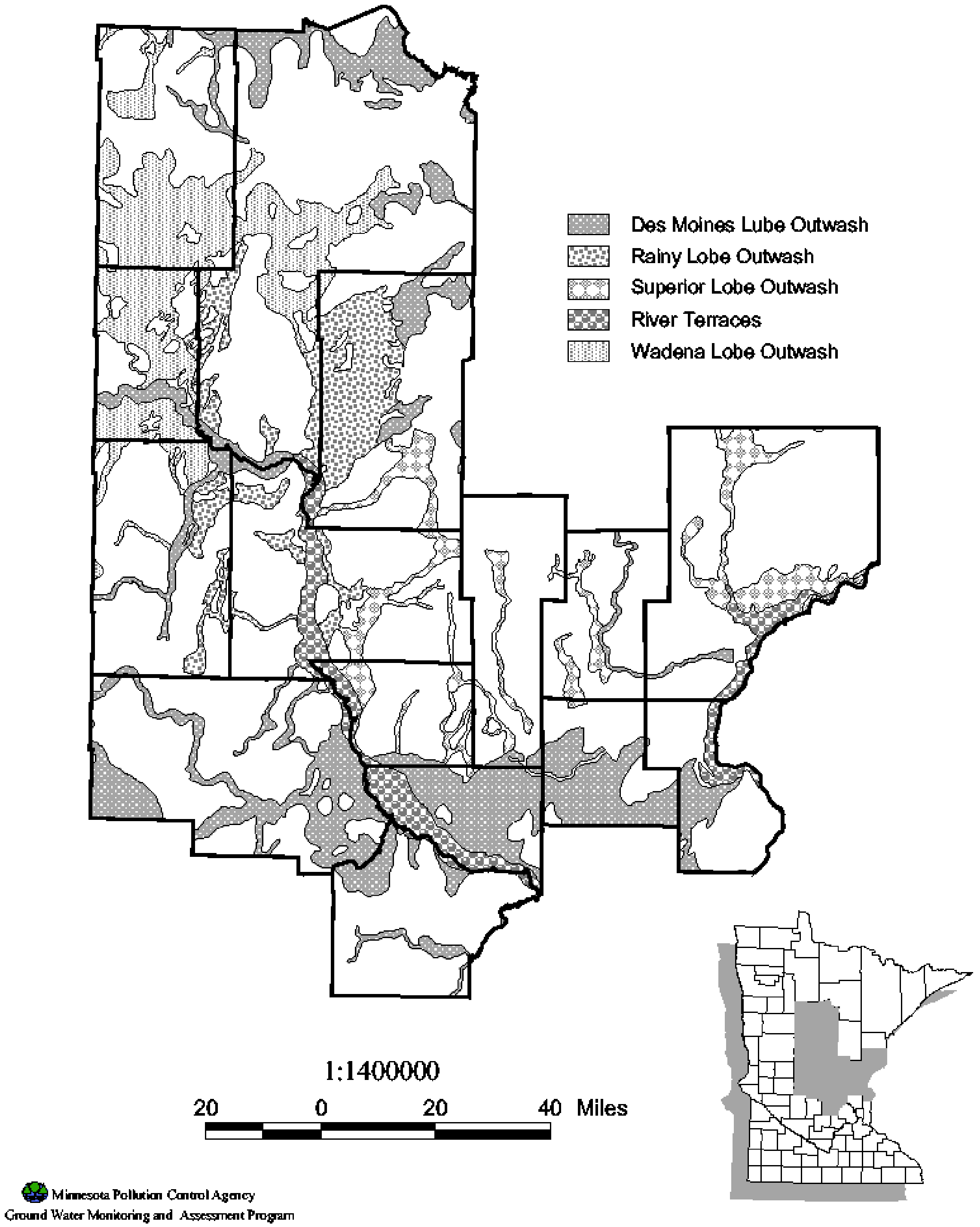

Figure B.10: Comparison of dissolved oxygen concentration, Eh, and iron concentration in the five surficial outwash deposits of Region 2.

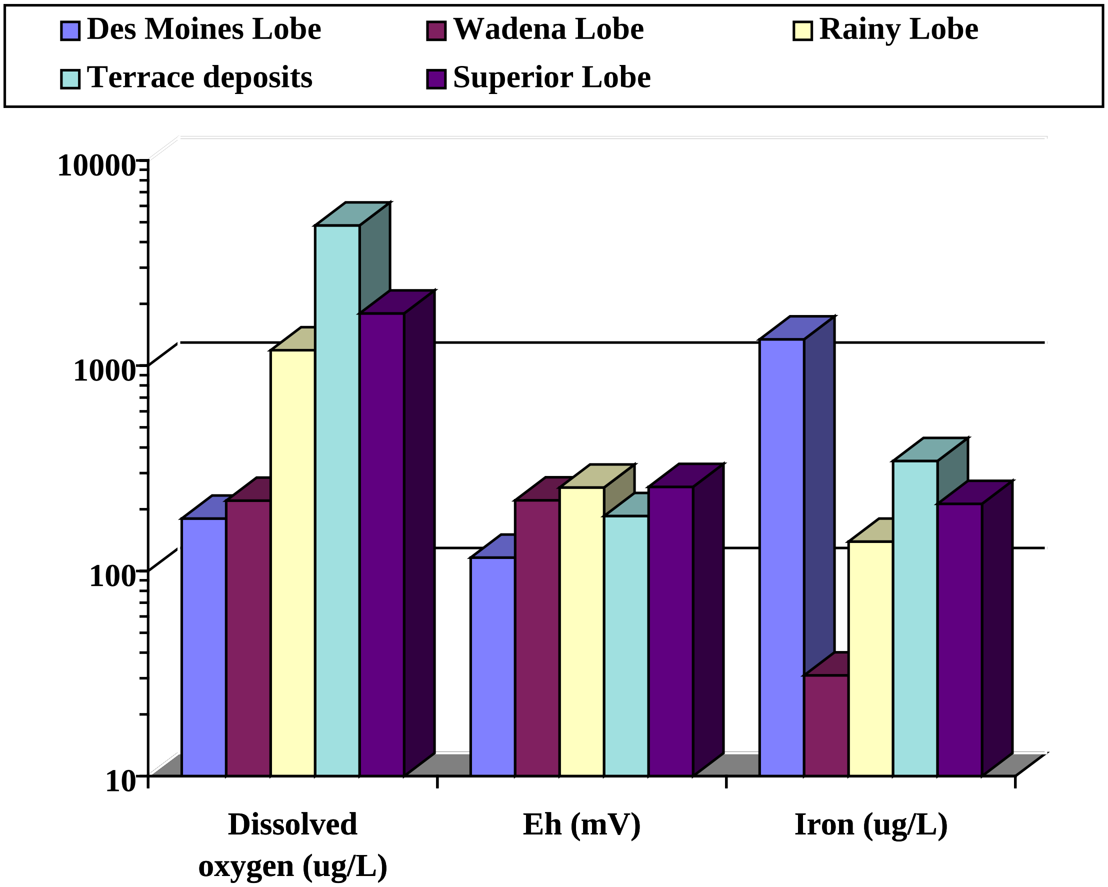

Figure B.11: Arsenic concentrations in wells associated with different surficial deposits.