GROUNDWATER QUALITY IN NOVA SCOTIA

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Abstract

Groundwater is an important resource in Nova Scotia, with about 46% of the population relying on groundwater for their water supply. Groundwater quality has been assessed in various parts of the province during provincial water resource evaluations, and several province-wide studies have been carried out to assess specific chemicals in groundwater, such as arsenic and uranium. However, to date there has not been a province-wide quantitative analysis of the general chemical quality of groundwater. Nova Scotia Environment and Labour (NSEL) has compiled a database of registered and municipal water supplies across the province, and this represents a good opportunity to complete a quantitative assessment of groundwater quality.

Water is called the universal solvent. As groundwater passes through geologic materials, it participates in various chemical processes. The resulting water chemistry will vary with geology and contact time. Groundwater regions in Nova Scotia can be broken down into five major hydrostratigraphic units: igneous, metamorphic, sedimentary, carbonate and evaporite, and surficial aquifers.

This report reviews groundwater chemical results, especially trace metals, from about 1000 samples from the NSEL database. A typical water quality report includes major and minor ions, physical properties, trace metals, total dissolved solids and pH. The various individual parameters are compared to the Guidelines for Canadian Drinking Water Quality, which are based on both health and aesthetic considerations.

Nova Scotia's drinking water is generally of good chemical quality when compared to the Guidelines. There are some exceedances of guidelines in parameters such as chloride, fluoride, arsenic, uranium, pH, colour, turbidity, iron and manganese. Conventional treatment, either point-of-entry or point-of-use, is available to reduce both health risks and aesthetic concerns to consumers.

This study represents a 'first cut', one point in time, approach to assess groundwater quality on a province-wide scale. Further work could involve more detailed resolution of data issues, use of more sophisticated statistical software tools, additional sampling to ensure adequate coverage of hydrostratigraphic units and geographical areas, analysis of seasonal variations in water quality, and location of data points for a GIS-based database.

To my parents, Joan and Ted, as well as my big brother, Doug.
For always being there pushing me to succeed.

To my friends who have seen me through the good and the bad that is often associated
with a research project.

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Sodium
Potassium
Calcium
Magnesium
Hardness
Alkalinity
Sulfate
Chloride
Fluoride
Silica
Nitrate-Nitrite-Nitrogen
Ammonia-Nitrogen
Total Dissolved Solids
Colour
Turbidity
Conductivity
TDS/Conductivity Ratio
pH
Total Organic Carbon
Aluminum
Arsenic
Barium
Boron
Copper
Iron
Lead
Manganese
Molybdenum
Strontium
Uranium
Zinc

Terminology and Abbreviations

Terminology

Aquifer is a saturated permeable geologic unit that will yield water in a usable quantity to a well or spring under ordinary hydraulic gradients.

Groundwater is all water naturally occurring under the ground surface (as defined in the Nova Scotia Environment Act). Watson and Burnett (1995) give a more detailed definition: Groundwater may be described as subsurface water in a state of temporary storage in earth materials. Its movement and chemistry are intimately influenced by the nature of sediments and rock within which it is found. Geology, therefore, dominates the study of groundwater. Where groundwater is present within a mappable zone of geologic materials in sufficient quantities to be economically useful, that subsurface zone is referred to as an aquifer.

Hydrochemical Facies is the diagnostic chemical character of water solutions in hydrologic systems. The hydrochemical facies of the water (solution) reflects the effects of chemical processes occurring between the minerals within the lithologic framework (solute) and the groundwater (solvent). Groundwater flow patterns modify the facies and control their distribution.

Hydrostratigraphic unit (HU) is a body of rock distinguished and characterized by its porosity and permeability, ie. it is a group of geologic materials with similar water-bearing properties. A geologic formation or group, or several formations or groups may comprise a hydrostratigraphic unit (e.g. the Halifax and Goldenville Formations in Nova Scotia are one HU).

Permeability reflects the water transmitting capability of a formation or aquifer, and is the volume of water transmitted through a unit cross sectional area in a certain time. The newer term is *hydraulic conductivity (K)*, but the term permeability is still frequently used.

Porosity (n) is the ratio of the volume of voids (V_v) to the total volume (V_t) of aquifer or sample (V_t is V_v plus the volume of solids V_s):

$$n = (V_t - V_s) / V_t = V_v / V_t$$

Porosity is related to the storage characteristics of an aquifer.

Public Drinking Water Supply (water supply) means a water supply system, including any source, intake, treatment, storage, transmission or distribution, that is intended to provide the public with potable, piped water and that:

    i)   has at least 15 service connections; or

    ii)   regularly serves 25 or more persons per day at least 60 days of the year.

There are two types of public drinking water supplies:

    i)   approved water supplies, which hold a municipal water works approval; and

    ii)   registered water supplies, which hold a registration with NSEL.

Examples of registered water supplies include: trailer parks, apartment buildings, rural developments, schools, day cares, nursing homes, industrial or commercial buildings, eating establishments, fixed roof accommodations, recreational facilities, campgrounds, etc. that are not connected to a municipal water works. All public drinking water supplies must be monitored, as required by the Guidelines for Monitoring Public Drinking Water Quality under the Environment Act.

Safe Drinking Water means water that meets the health-related criteria for substances specified in the most recent version of Health Canada's Guidelines for Canadian Drinking Water Quality, as amended from time to time.

Abbreviations

Al:	aluminum
Alk:	alkalinity
Ag:	silver
AO:	aesthetic objective
As:	arsenic
B:	boron
Ba:	barium
Be:	beryllium
Bi:	bismuth
Br:	bromide
Ca:	calcium
Cd:	cadmium
Cl:	chloride
Co:	cobalt
CO3:	carbonate
Cond:	conductivity
Cr:	chromium
Cu:	copper
EQG:	environmental quality guideline
F:	fluoride
Fe:	iron
Hard:	hardness
HCO3:	bicarbonate
Hg:	mercury
IMAC:	interim maximum acceptable concentration
K:	potassium
Li:	lithium
MAC:	maximum acceptable concentration
Mg:	magnesium
Mn:	manganese
Mo:	molybdenum
N:	nitrogen
Na:	sodium
Ni:	nickel
NO2:	nitrite

NO3:   nitrate
Pb: lead
S: sulfur
Sb: antimony
Se: selenium
SiO2:   silica
Sn: tin
SO4:   sulfate
Sr: strontium
TDS: total dissolved solids
Ti: titanium
Tl: thallium
U: uranium
V: vanadium
Zn: zinc

Acknowledgements

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I would also like to thank my research project supervisor, Heather Cross, for all the time and effort she put into supervising this report.

Chapter 1 Introduction

1.1 Purpose and Scope

Groundwater chemical quality reflects the dissolved minerals in the water. The purpose
of this report is to review groundwater chemical quality, especially trace metals, from
registered and municipal public drinking water supplies across Nova Scotia. The data was
kindly supplied by Nova Scotia Environment and Labour (hereafter referred to as NSEL)
from various databases, under a Data Sharing Agreement.

This data was assessed statistically, and related to major hydrogeological regions. The
data was also compared to the Guidelines for Canadian Drinking Water Quality
(GCDWQ), for any exceedances. Both health and social implications of any exceedances
will be discussed.

1.2 Importance of Study

There has not been a major quantitative analysis of groundwater quality in the province to
date, although a number of regional water resources studies have been conducted. There
have also been smaller local studies, and/or private client-confidential studies, but the
latter data are not readily available to the general public. Most homeowners know little of
groundwater quality except for that available to them via public school education,
pamphlets and the internet. Society and industry require knowledge of water supplies,
from small-scale domestic users to large-scale industrial and municipal users.

This report will be beneficial for those concerned with the groundwater quality, especially for human consumption uses. This report will also be used as a base for an interpretive booklet on groundwater quality and treatment planned by Heather Cross (thesis supervisor).

1.3 <u>Organization of Report</u>

The report is divided into six chapters, each of which is subdivided into further topics based on the subject matter. Chapters 1 to 3 introduce background information, Chapters 4 to 6 discuss methodology, results, and conclusions and recommendations. Chapter 1 provides an Introduction. Chapter 2 discusses the Geology of the Study Region, using a breakdown into five broad groundwater regions in Nova Scotia: igneous rocks, metamorphic rocks, sedimentary rocks, carbonate and evaporite rocks, and surficial deposits.

Chapter 3 provides an overview of Groundwater Quality, including various factors affecting the development of groundwater chemistry, guidelines put in place to regulate the quality for different uses, natural and anthropogenic 'contaminants' that commonly occur in Nova Scotia, and their importance. Chapter 4 describes the source of the water quality data used for this study, issues found in the data and the methods used for analysis. Chapter 5, Discussion of Results, contains the geological distribution of the chemical parameters studied, as well as any guideline exceedances. Chapter 6, Conclusions and Recommendations, contains a brief summary of the study, including

recommendations for further work in the province. Data is included in the appendices at

the end of the report.

Chapter 2 Hydrogeology of the Study Region

Groundwater occurrence in Nova Scotia can be divided into regions based on hydrostratigraphic units (HUs). HUs have similar water-bearing properties with respect to occurrence and movement of groundwater, as noted in the Terminology section earlier. Individual HUs may be comprised of various rock lithologies, which may have different ages and origins, but still have similar water-bearing properties. Two of these properties are porosity and permeability, which are defined in the Terminology section. Porosity is both primary (formed during deposition) and secondary (formed later through fracturing and other processes), and both types can occur simultaneously in a rock type. Porosity may also decrease due to cementation. Table 2.1 shows examples of types of porosity in different rock types.

In Nova Scotia, the various geologic units can be broadly grouped into the following groundwater regions or HUs (after Shawinigan, 1980): igneous rocks, metamorphic rocks, carbonate and evaporite rocks, all other sedimentary rocks, and surficial deposits, as shown in Figures 2.1 and 2.2.

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Figure 2.1: Groundwater regions (HUs) of Nova Scotia (Shawinigan, 1980)
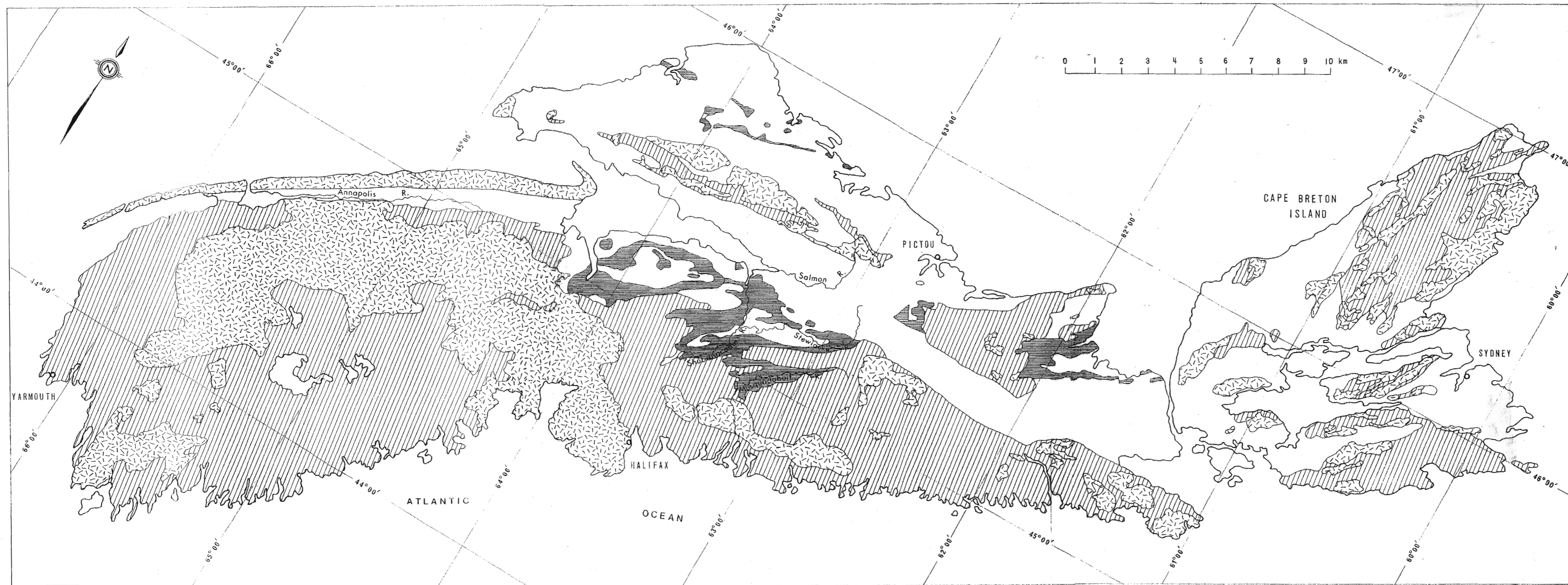
GROUNDWATER REGION 1. IGNEOUS AND METAMORPHIC ROCKS

SUB-REGION 1A

IGNEOUS ROCKS

SUB-REGION 1B

METAMORPHIC ROCKS

GROUNDWATER REGION 2. SEDIMENTARY ROCKS

SUB-REGION 2A
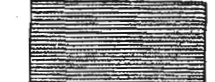
CARBONATE ROCKS

SUB-REGION 2B

ALL OTHER SEDIMENTARY ROCKS

GROUNDWATER REGION 3. DEPOSITS

SURFICIAL DEPOSITS IN REGIONS 1 AND 2

SOURCE: GEOLOGIC MAP OF THE PROVINCE OF NOVA SCOTIA
DEPARTMENT OF MINES AND ENERGY
COMPILED BY J.D. KEPPIE, 1979

SIMPLIFIED SURFICIAL GEOLOGY

LEGEND

bedrock, thin - discontinuous veneer of till, residuum, colluvium

GLACIAL ADVANCE DEPOSITS

stony - silty till (includes drumlin facies)

GLACIAL RETREAT AND STREAM SEDIMENT DEPOSITS
(major sources of sand and gravel)

mixture may include ablation till, glaciofluvial deposits (eskers, kames, hummocks, outwash fans, deltas), and alluvium (stream sediment deposits)

esker

hummocks

Figure 2.2: Simplified surficial geology of Nova Scotia (prepared by J. Drage, Nova Scotia Environment and Labour)

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Type of porosity	Sedimentary		Igneous and Metamorphic	Volcanic	
	Consolidated	Unconsolidated		Consolidated	Unconsolidated
Intergranular		Gravelly sand, Clayey sand, Sandy clay	Weathered zone of granite-gneiss	Weathered zone of basalt	Volcanic ejecta, blocks, and fragments; Ash
Intergranular and fracture	Breccia, Conglomerate, Sandstone, Shale		Zoogenic limestone, Oolitic limestone, Calcareous grit	Volcanic tuff, Cinder, Volcanic breccia, Pumice	
Fracture	Limestone, Dolomite, Dolomitic limestone		Granite, Gneiss, Gabbro, Quartzite, Diorite, Schist	Basalt, Andesite, Rhyolite	

Table 2.1: Examples of porosity in different rock types (modified from van der Leeden et al, 1990)

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2.1 Igneous and Metamorphic Hydrostratigraphic Units

In igneous and metamorphic rocks, groundwater occurs primarily in fractures. Fractures are discontinuities in the rock originating from various processes such as folding, regional deformation, and faulting. Fractures may vary from local to regional joint sets, to distinct faults and shear zones. From the point of view of groundwater occurrence, there is no significant distinction between igneous and metamorphic rocks, or between metamorphic rocks of sedimentary or igneous origin. The difference between the latter two origins has little or no bearing on groundwater occurrence once the rocks have been metamorphosed. To maximize the probability of sufficient groundwater for regular domestic use in these HUs, drilling to depths of 75-90 m is often required.

Igneous and metamorphic rocks underlie almost the entire western, and the majority of the southeastern, portions of the Southern Mainland of Nova Scotia (Figure 2.1). In the Northern Mainland of Nova Scotia, the western-central section is underlain by igneous plutonic rocks, which are bordered on the southern edge by metamorphic rocks. In Cape Breton, the highlands and southern part of the island are composed of igneous and metamorphic rocks. (Figure 2.1).

Although igneous and metamorphic rocks have similar water-bearing properties, the water quality or hydrochemical facies often differs between metamorphic rocks, plutonic igneous rocks, and volcanic igneous rocks. For this reason, they are considered as three separate HUs in this project.

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2.2 Sedimentary Hydrostratigraphic Unit

Sedimentary rocks may have both intergranular and fracture porosity and permeability. The degree of consolidation is an important consideration in intergranular permeability. Where sedimentary rocks are partially consolidated, precipitation of cementing agents such as silica or calcium carbonate may fill some, but not all, of the pore spaces between the grains. The resulting permeability depends on how many interconnected voids are left in the rock. Coarse-grained sediments and conglomerates generally have high intergranular permeability and groundwater storage capacity (porosity). Sedimentary rocks may also allow groundwater movement along fractures, joints, and fault zones similar to igneous and metamorphic rocks. Groundwater movement along bedding planes is also common.

Sedimentary rocks underlie the majority of the Northern Mainland of Nova Scotia (Figure 2.1). They are also found along a narrow northern edge of the western portion of the Southern Mainland and the same northern edge of the eastern portion. The southwestern parts of Cape Breton Island, as well as the central and northeastern parts, are underlain by sedimentary rocks (Figure 2.1).

2.3 Carbonate and Evaporite Hydrostratigraphic Unit

The porosity and permeability of carbonate and evaporite rocks ranges from low values where the rocks are only slightly fractured, to high values in areas of dense fracturing and solution channels. Where highly fractured rocks outcrop at the surface, where weathering increases permeability at the surface, or where karst or sinkhole features occur, the

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aquifers may be vulnerable to contamination from surface and near-surface sources. The larger fractures may allow rapid access of contaminants into the subsurface, with very little time for natural filtration to occur.

Carbonate and evaporite rocks often occur together in Nova Scotia, and have been grouped as a single HU. The occurrence of this HU (Figure 2.1) often coincides with a particular geologic unit, the Windsor Group, or in other units influenced by the Windsor Group.

2.4 Surficial Hydrostratigraphic Unit

Figure 2.2 shows a simplified surficial geology map of the province. Glacially deposited sediments overlie the bedrock throughout much of the province. During the ice age, glaciers extended out to the continental shelf, with repeated glacial events eroding soil and bedrock. This eroded material, composed of particles of various sizes, was incorporated into the ice, and when the ice melted, it was deposited in place or carried further by meltwater and deposited later.

Till is glacial sediment deposited directly beneath or in front of a glacier (Grant, 1994). Glacial till deposits are largely unsorted and generally have low permeability and relatively low groundwater yields. Granular tills occur in some areas. In Figure 2.2, for simplicity, all till types are grouped together.

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Glaciofluvial deposits are sediments transported and laid down by glacial meltwater, either beneath, within, or in front of the glacier as ice-contact stratified drift, or beyond the glacier as proglacial outwash (Grant, 1994). Glaciofluvial deposits are generally better sorted and more permeable than tills, and may form good aquifers, for example in the Annapolis Valley where extensive outwash sand and gravel deposits occur (Trescott, 1969). Along some river systems, glaciofluvial deposits have been reworked by more recent alluvial processes.

Where fine-grained glacial material was deposited in lakes, or in an ice-dammed valley, low permeability deposits can be found.

Other types of surficial deposits not of glacial origin may include alluvial, beach and talus deposits. These are often permeable and may form aquifers if there is sufficient saturated thickness. Generally, surficial deposits of glacial and non-glacial origin have intergranular rather than fracture permeability with respect to groundwater movement.

The majority of the province is covered by till that is relatively thin (less than 6 meters) but in some areas can exceed 30 meters. The main glacial outwash sand and gravel aquifers are located in the valleys of larger river systems, such as the Annapolis River, the Musquodoboit River, the Salmon River (near Truro) and various other locations (Figure 2.2). These deposits are generally good aquifers where they are not limited by factors such as areal extent, saturated thickness, and fine-grained interbeds (Shawinigan, 1980).

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2.5 Groundwater Recharge

Groundwater is part of the hydrologic cycle. The main source for groundwater recharge is precipitation. In Nova Scotia, the mean annual total precipitation ranges from 1270 mm in the Southern Mainland, to 1140 mm in the Northern Mainland, to 1520 mm in parts of Cape Breton (Shawinigan, 1980).

The minimum annual groundwater recharge is estimated to be between 125 mm and 150 mm, or approximately 10 percent of the mean annual precipitation (Shawinigan, 1980). Peak periods of recharge occur in the spring from snow melt and in late fall from fall rains. During the summer months, the groundwater recharge is at a minimum due to generally low precipitation and high evapotranspiration. Groundwater levels usually start to lower between April and mid-June, and this recession continues until late September to early October. Groundwater recharge can also occur during mid-winter thaws and as a result, groundwater recharge is not necessarily limited to any one season in Nova Scotia.

Chapter 3 Groundwater Quality

3.1 Development of Groundwater Quality

Water is called the universal solvent. Dissolved components in groundwater can be viewed as

$$SOLUTE + SOLVENT = SOLUTION$$

where the solute is the earth material, the solvent is water, and the resulting solution is groundwater. The water quality from natural water sources depends partly on the solubility of the rock and soil types that the water passes through and with which it interacts. Contaminant hydrogeology deals with water sources that have been affected by anthropogenic sources and/or wastes as well as natural geological factors. This project will focus on the natural geological factors.

Water enters the subsurface via the unsaturated zone into the saturated zone (recharge). Depending on climatic, topographic and geologic conditions, water entering the groundwater system may follow a local pathway that brings it back to the surface in a short distance, or a regional pathway that takes it deeper within the earth to resurface a long distance away. Groundwater residence times in the subsurface may vary from days to millennia (Figure 3.1). Groundwater quality depends partly on the contact time of the water with the geologic materials in the subsurface.
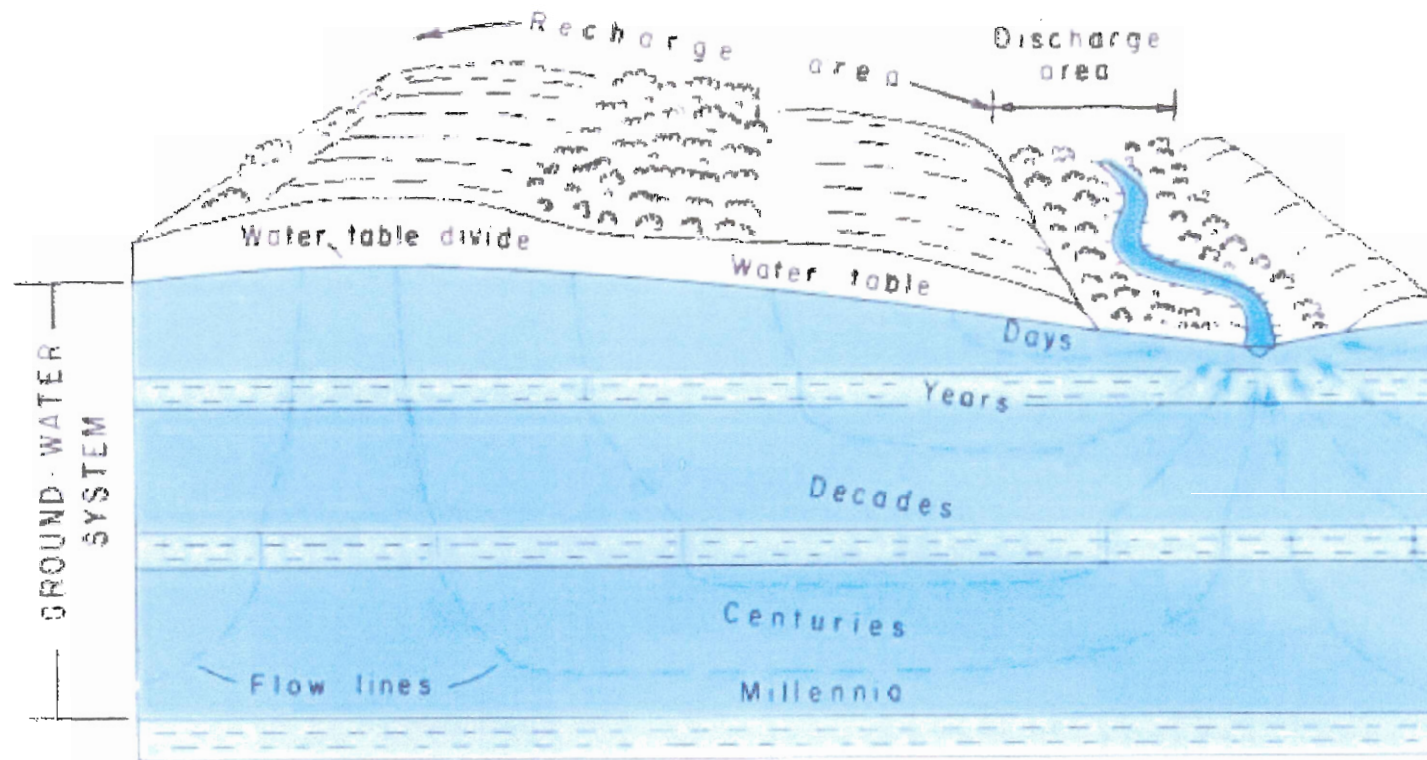
Figure 3.1: Examples of various groundwater flowpaths and residence times (Heath, 1983)

One indicator of overall dissolved mineral content of a water is total dissolved solids (TDS). Typically, TDS increases as groundwater moves through the hydrologic cycle, and as residence time increases. As a very general example of order-of-magnitude changes, TDS ranges may be as follows (H. Cross and R. McCurdy, Groundwater Chemical Quality course notes):

- rain 1-10 mg/L
- surface water 10-20 mg/L
- groundwater
  - shallow 50-100 mg/L
  - intermediate100-1000 mg/L
  - deep1000-10000 mg/L
- sea water ~50000-100000 mg/L
- deep brines ~50000-100000$^+$ mg/L (may be in a similar range to, or more concentrated than, sea water).

3.1.1 Geological Influences

Chebotarev (1955) was one of the earlier authors who recognized the evolution of groundwater quality as the water interacts with the surrounding geologic materials. He proposed that the water theoretically evolves from a bicarbonate type in the recharge area to a chloride type in the discharge area. This series of anion changes is shown below. Note that where there is more than one anion (such as $HCO_3^- + SO_4^=$), the first one is predominant.

$$HCO_3^- \rightarrow HCO_3^- + SO_4^= \rightarrow SO_4^= + HCO_3^- \rightarrow SO_4^= \rightarrow SO_4^= + Cl^- \rightarrow Cl^- + SO_4^= \rightarrow Cl^-$$
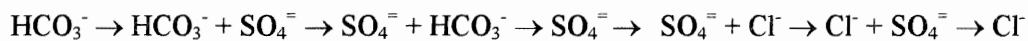
This anion-evolution sequence can be explained in terms of mineral availablity and solubility. The HCO_3^- content is usually derived from dissolution of limestone and dolomite by carbonic acid (from soil zone carbon dioxide and water), and bicarbonate is

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nearly always the dominant anion in recharge areas. If there is a source chemical missing in this link, then the water cannot evolve past the state it is in until the mineral or rock containing those ions is met on the flowpath. For example, if gypsum or anhydrite are present in only trace amounts, a source of sulfate may not be available, and it may take a longer time and distance for the above evolution of water to be completed, or the evolution may end before full completion. Thus mineral availability along the flowpath affects the evolution of groundwater quality.

Hounslow (1995) suggested that different rock types produce waters characterized by dominant ions, TDS, pH and silica content as shown in Table 3.1.

Another important factor in the evolution of groundwater quality in mixed or layered geological sequences is the order of encounter, that is, the order in which various rock types are encountered by the water as it moves through the flow system. Table 3.2 shows an example of the final groundwater quality after flow through a hypothetical sequence of soil, limestone, gypsum, sandstone, and shale (sequence 1), and the same layers in a different order of soil, sandstone, shale, limestone, gypsum (sequence 2) (Freeze et al, 1979). Reactions modelled in the sequence included mineral dissolution, precipitation and ion exchange.

Rock type	Dominant ions	TDS	pH range	SiO_2 content
Granite, rhyolite	Na, HCO_3	Low	6.3-7.9	moderate to high
Gabbro, basalt	Ca, Mg, HCO_3	Moderate	6.7-8.5	High
sandstone, arkose, greywacke	Ca, Mg, Na, HCO_3	High	5.6-9.2	low to moderate
Siltstone, clay, shale	Na, Ca, Mg, HCO_3, SO_4, Cl	High	4.0-8.6	low to moderate
limestone, dolomite	Ca, Mg, HCO_3	High	7.0-8.2	Low
slate, schist, gneiss	HCO_3, Ca, Na	low to moderate	5.2-8.1	Low

Table 3.1: Characterization of water quality from different rock types (Hounslow, 1995)

Groundwater chemistry at $25°C$ (1)						
Sequence	Na	Ca	HCO3	SO4	TDS	pH
1	725	20	140	1400	2350	6.7
2	3.9	600	31	1440	2100	8.9

(1) Concentrations expressed in mg/L except for pH

Table 3.2: Example of the effect of order of encounter on groundwater quality (abbreviated from Freeze and Cherry, 1979)

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3.1.2 Individual Parameters

All chemicals dissolved by the 'solvent' water may be found in major, minor or trace amounts. Major chemicals (generally >5 mg/L) found in groundwater include: sodium, calcium, magnesium, bicarbonate, sulfate, chloride, and silica. Minor chemicals (0.1-5 mg/L) include: potassium, ortho-phosphate, carbonate, nitrate- plus nitrite-nitrogen, ammonia-nitrogen, iron, and fluoride. Trace chemicals, many of which are trace metals, are those that, if detectable by analytical methods, are usually present in amounts <0.1mg/L. Some examples of trace chemicals are aluminum, antimony, arsenic, barium, beryllium, bismuth, boron, bromide, cadmium, chromium, cobalt, copper, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, tin, titanium, tungsten, uranium, vanadium, zinc, and a number of rare earth elements. Whether a chemical is determined to be major, minor or trace depends on the geology of the aquifer. In Nova Scotia, a number of the normally trace chemicals are usually found in minor quantities.

Additional parameters usually included in a water analysis include colour, turbidity, suspended solids, total dissolved solids and pH. These parameters do not necessarily impact the health of the consumer of the drinking water, but may affect the aesthetics of the water and make it less pleasing to the user. In addition, turbidity may compromise the integrity of some disinfection processes (such as ultraviolet light).

Additional parameters not routinely analyzed in a complete water analysis for domestic uses, but which may be important in certain environments, may include natural organic compounds (humic substances, tannins, lignins, carbohydrates, amino acids,

hydrocarbons), gases (carbon dioxide, hydrogen sulfide, methane, nitrogen), radionuclides (gross alpha and beta, radium, radon, lead-210), and isotopes (deuterium, oxygen-18, tritium, carbon-14).

3.2 Guidelines for Water Quality in Canada

The Canadian Council of Ministers of the Environment (CCME), formerly the Canadian Council of Resource and Environment Ministers (CCREM), released Canadian Water Quality Guidelines in 1987. These guidelines indicate optimum water quality for various uses, such as drinking water, freshwater aquatic life, agriculture, recreation, and industrial water supplies (CCME, 1999). These water quality guidelines are regularly updated as new information becomes available.

Guidelines for water quality are essential, especially as environmental concerns and awareness have risen over the years. As well, increased human knowledge of health and ecology has necessitated a set of guidelines to determine water quality for different types of water usage. Environmental Quality Guidelines (EQGs) are also useful in the management of water supplies, in environmental assessment, and in management strategies. The applications of EQGs include (CCME Introduction, 1999):

- national benchmarks to assess potential or actual impairment of socially relevant resource uses
- the scientific basis for the development of site-specific criteria, guidelines, objectives, or standards
- indicators for state-of-the-environment reporting
- science-based goals or performance indicators for regional, national, or international management strategies for toxic substances
- interim management objectives for persistent, bioaccumulative, and toxic substances to track progress toward their virtual elimination

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- scientific tools for assessing risks associated with existing concentrations of persistent, bioaccumulative, and toxic substances in the ambient environment
- indicators of ecotoxicologically relevant concentrations of persistent, bioaccumulative, and toxic substances for the purposes of improving analytical detection and quantification capabilities
- tools to evaluate the effectiveness of point-source controls
- the scientific basis for environmental regulations
- scientific benchmarks or targets in the assessment and remediation of contaminated sites
- science-based assessments and tools for consideration in the development of Canada-wide standards under the Canada-wide Accord on Environmental Harmonization.

Provincial and territorial governments may adopt the EQGs entirely, or use them to develop their own set of guidelines.

3.2.1 Development of the Guidelines

During the development of the guidelines, different aspects of water quality are considered, such as health, safety, aesthetics, and water use. For recreational water use, water must be free from microbiological, chemical and physical hazards. Also included in recreational water guidelines is the quality of the environment surrounding the water body in question. Industry, logging, mining and land erosion can all effect the enjoyment of surface water for recreational purposes.

Guidelines for freshwater aquatic life (FWAL) are intended to protect such life from anthropogenic stressors such as chemical inputs or changes to physical factors such as pH, temperature and debris. Guideline values are meant to protect all forms of aquatic life and all aspects of the aquatic life cycles, including the most sensitive life stage of the most sensitive species over the long term.

Parameter	Units	Potable water		Fresh water aquatic life	Irrigation water	Livestock
Sodium (Na)	mg/L	<=200	AO			
Potassium (K)	mg/L					
Calcium (Ca)	mg/L					1000
Magnesium (Mg)	mg/L					
Hardness (as CaCO3)	mg/L					
Alkalinity (as CaCO3)	mg/L					
Sulphate (SO4)	mg/L	<=500	AO			1000
Chloride (Cl)	mg/L	<=250	AO		100-700	
Fluoride (F-)	mg/L	1.5	MAC	0.12	1.0	1.0-2.0
Reactive Silica (SiO2)	mg/L					
Nitrate + Nitrite (N)	mg/L	10	MAC			22.6
Nitrate (N)	mg/L	10	MAC	2.94		
Nitrite (N)	mg/L	1	MAC	0.02		3.0
Ammonia (N)	mg/L			depends on pH and temperature		
Orthophosphate (P)	mg/L					
Phosphorus (P)	mg/L					
Total Dissolved Solids	mg/L	<=500	AO		500-3500	3000
Colour	TCU	<=15	AO			
Turbidity	NTU	see Section 5.1-15				
Conductivity	uS/cm					
PH		6.5-8.5	AO	6.5-9.0		
Organic Carbon (C)	mg/L					
Cation Sum	meq/L					
Anion Sum	meq/L					
Ion Balance (% Difference)	%	Should be within +/- 5%				
Bicarbonate Alkalinity (calc. as CaCO3)	mg/L					
Carbonate Alkalinity (calc. as CaCO3)	mg/L					
Langelier Index (@ 4C)						
Langelier Index (@ 20C)						
Saturation pH (@ 4C)						
Saturation pH (@						

20C)						
Aluminum (Al)	mg/L	0.1/0.2 (operational value)		0.005-0.1, depends on pH, Ca, DOC	5.0	5.0
Antimony (Sb)	mg/L	0.006	IMAC			
Arsenic (As)	mg/L	0.025	MAC	0.005	0.1	0.025
Barium (Ba)	mg/L	1.0	MAC			
Beryllium (Be)	mg/L				0.1	0.1
Bismuth (Bi)	mg/L					
Boron (B)	mg/L	5.0	MAC		0.5-6.0	5.0
Cadmium (Cd)	mg/L	0.005	MAC	formula; depends on hardness	0.0051	0.08
Chromium (Cr)	mg/L	0.05	MAC	0.0089(III), 0.001(VI)	0.0049(III), 0.008(VI)	0.05(CrIII), 0.05(CrVI)
Cobalt (Co)	mg/L				0.05	1.0
Copper (Cu)	mg/L	<=1.0	AO	0.002-0.004, depends on hardness	0.2-1.0	0.5-5.0
Iron (Fe)	mg/L	<=0.3	AO	0.3	5.0	
Lead (Pb)	mg/L	0.01	MAC	0.001-0.007, depends on hardness	0.2	0.1
Manganese (Mn)	mg/L	<=0.05	AO		0.2	
Molybdenum (Mo)	mg/L			0.073	0.01-0.05	0.5
Nickel (Ni)	mg/L			0.025-0.15, depends on hardness	0.2	1.0
Selenium (Se)	mg/L	0.01	MAC	0.001	0.02-0.05	0.05
Silver (Ag)	mg/L			0.0001		
Strontium (Sr)	mg/L					
Thallium (Tl)	mg/L			0.0008		
Tin (Sn)	mg/L					
Titanium (Ti)	mg/L					
Uranium (U)	mg/L	0.02	IMAC		0.01	0.2
Vanadium (V)	mg/L				0.1	0.1
Zinc (Zn)	mg/L	<=5.0	AO	0.03	1.0-5.0	50
Total coliform	cfu/100 mL	0	MAC		1000	
Faecal coliform	cfu/100 mL	0	MAC		100	
E. coli	cfu/100 mL	0	MAC			

Table 3.3: Summary of Selected Canadian Water Quality Guidelines (adapted from CCME, 1999)
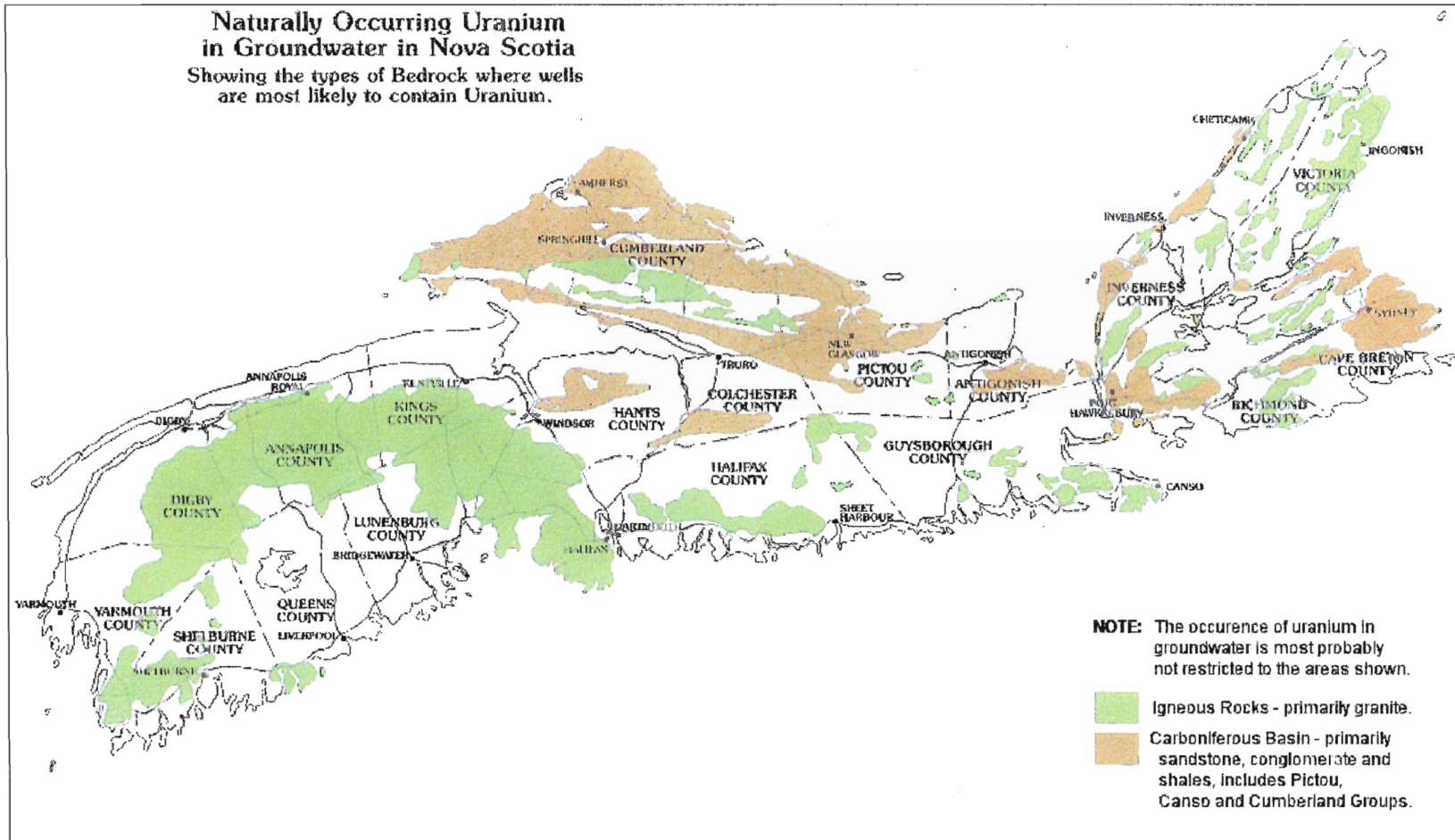
Figure 3.3: Distribution of naturally occurring uranium in groundwater in Nova Scotia (NS Department of Health, no date)

3.3.2 **Anthropogenic Contaminants**

Humans and their activities can impact the water quality of both groundwater and surface waters. A few examples of contaminant sources include:

- industrial and municipal wastes
- underground storage tanks and other petroleum products
- domestic sewage
- road salt
- agricultural activities (fertilizers, manure, pesticides)

In some cases, an aquifer may be contaminated by surface water, human or animal waste, or other sources of bacteria. However, it is more common to find an individual well or water supply affected by a localized source of contamination. To protect wells from potential sources of anthropogenic contamination, some recommendations include: place wells at higher elevations than sources of contamination, prevent ponding of water around the well, and keep the well properly capped or covered to protect it from vermin, insects, and animals. In general, drilled wells are less susceptible to surface sources of contamination than dug wells. (NSEL Water Wisdom Fact Sheet)

3.4 Importance of Groundwater Quality

3.4.1 **Health Considerations**

Drinking water guidelines for bacterial and chemical quality are established to protect human health. With respect to bacterial quality, coliform bacteria themselves may not be harmful, but may be indicative of a more serious problem (CCME, 1999).

The presence of E. coli indicates that the source has been impacted by recent faecal contamination and therefore the water is unsafe to drink. The presence of total coliform in

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a non-disinfected well means that the well is prone to surface water infiltration and is therefore at risk of faecal contamination. The presence of total coliform in a disinfected system means the disinfection process has failed or has been overwhelmed. In these cases, the water is considered unsafe to drink until the situation is remediated.

Bacterial contamination may be due to surface water influence on water supplies. In general, groundwater supplies are often safer than surface water because of the natural filtration and sorption which occurs in soil and sediments. The distance required for removal of all bacteria by filtration depends on the permeability, sorting, cementation, adsorptive capacity and other properties of the sediments through which the water travels (Yates et al, 1988). Table 3.4 shows a wide range of distances for bacteria migration, depending on soil and bedrock type.

When bacteria are found in a water supply, it is important to identify the cause of contamination and correct the problem at the source if possible. If this is not possible, well reconstruction or replacement may be necessary. Some health considerations related to bacteria are summarized in Table 3.5. Without proper attention to water quality, the health implications of contaminated drinking water can result in severe illness or, in severe cases, death, as occurred in Walkerton, Ontario (O'Connor, 2002)..

Microorganism	Medium	Maximum distance travelled (m)	
		Vertical	**Horizontal**
Bacteria	fine sand		457
	medium to coarse sand		21
	alluvial gravel		90
	pea gravel + sand		30
	coarse gravels		457
	Gravel		920
	sandy clay		15.25
	fine to coarse sand		30.5
	fine to medium sand		6.1
Coliforms	sand + gravel	10-12	850
	fine sandy loam	4	1.2
	fine sand	4	2
	Pebbles		850
	Weathered limestone		1000
	stony clay + sand	0.91	
	stone + clay	0.61	
	firm clay	0.3	
	coarse sand + gravel		55
	sandy clay loam	2	6.1
	sandy clay loam	4.3	13.5
	sandy loam	0.64	28
E. coli	Sand		3.1
	fine + coarse sand	4	24.4
	fine + medium sand	0.15	
	fine + medium sand		3.1
	sand + sandy clay	1.5	10.7
	silt loam		3
	silty clay loam		1.5
	medium sandy gravel		125
	fine sandy gravel with cobbles		50
	silty clay loam	1	15
	fine sand		19.8
	fine sand	0.3	70.7
Faecal coliforms	fine loamy sand + gravel		9.1
	stony silt loam		900
	fine to medium sand		2.4
	gravel with sand + clay		9
	Saturated gravels		42
	sandy clay + clay	0.85	
	sandy clay	1.2	

Table 3.4: Migration of bacteria in the subsurface (adapted from Yates and Yates, 1988)

Bacteria/ protozoa	Possible infection/ disease
Escherichia coli	urinary tract infections, diarrhea in some individuals
Pseudomona aeruginosa	otitis externa (swimmer's ear)
Salmonella, various types	effects range in severity from typhoid fever, to the common acute intestinal upsets formally known as "ptomaine poisoning"
Klebsiella pneumoniae	may cause a highly fatal type of pneumonia which accounts for 3% of bacteria pneumonia
Bacillus anthracis	causes anthrax in animals which can then be transmitted to humans
Clostridium tetani	if spores introduced into deep wounds during bathing can cause tetanus
Vibrio cholerae	cholera, organism may persist for weeks in either very clean or very turbid water
Shigella, various types	acute diarrhea
Vyersinia tularensis	Gastroenteritis
Francisella tularensis	tularemia, spread via drinking water contaminated by wild animals in rural areas
Entamoeba histolytica	amoebic dysentery
Glardia lamblia	recurring diarrhea

Table 3.5: Possible bacteria and protozoa found in source water with potential health implications (McLeod et al, 1986)

With respect to chemical quality, health considerations vary with the particular parameter. Some of the parameters which may exceed health-based guidelines in some areas of the province, depending on geology, are arsenic, uranium, fluoride, nitrate, turbidity, and radionuclides such as lead-210. Nitrate is usually related to land use.

The registered water supply database used for this project is from various provincial government agencies with registered water supplies, and from selected non-government supplies where data was requested by NSEL. Some of the data was from a database maintained by Nova Scotia Transportation and Public Works.

4.1.3 Pumping Test Chemistry Data

NSEL has maintained an electronic database of pump tests since the 1980's. Pump tests of 72 hour duration are currently required under the Well Construction Regulations for water supplies for purposes other than single family dwellings, independent of the amount of water to be used. This database originally did not include water quality data (other than qualitative comments), but recent enhancements for internal use have included available chemistry data from newer entries where available. For the most part, older tests have not been pulled from the files to add chemical data. Past practice by industry was to collect 2 to 3 samples for chemical and bacterial quality during a 72 hour pump test, although there was no regulatory mandate to do so.

In May 2004, NSEL introduced the Guide to Groundwater Withdrawal Approvals for withdrawals exceeding 23000 litres per day (5000 gallons per day). Part of the required information includes 72 hour pump tests, and water quality data must be collected from each pumping well during the pumping test, including the collection of water quality samples and measurement of field parameters (NSEL, 2004). A water quality sample must be collected near the end of the pumping period for laboratory analysis, including at a minimum, bacteria, general chemistry, metals, and fluoride. The guide notes that 'It

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may also be useful during the 72 hour pumping test to collect additional samples for evaluation. Often three sets of samples are collected (3 samples for bacterial quality and 3 samples for chemical quality). One sample should be collected in the first hour, one sample between 24 and 36 hours, and one sample during the last hour of the pumping test.'

If the water is for a public drinking water supply, parameters must include, at a minimum, those specified in the GMPDWS, following the recommended sampling protocols in that document. Additional parameters may be required, depending on site-specific details. All water quality analysis must be conducted at an accredited laboratory.

4.1.4 Municipal Water Supply Data (parts A and B)

About 62% of Nova Scotians rely on municipal rather than private wells for their water supply. There are 86 municipal supplies in Nova Scotia. Of these, 33 are groundwater, 49 are surface water, and 4 are combined surface water and groundwater (J. Drage, NSEL, personal communication). Note that the latter percentages refer to municipal units rather than population. Municipal water supplies are regulated as noted in Section 4.1.1. NSEL also conducts periodic audits by collecting their own samples in addition to those taken by the municipal units.

4.1.5 Groundwater Monitoring Well Data

NSEL maintains a groundwater observation well network which has been in operation since about 1965. The primary purpose of this network is to measure groundwater levels

to determine short and long term fluctuations and trends. Originally there were in the order of 40 wells with chart recorders, but over time this number has decreased for various reasons (vandalism, cost, etc.).

There are currently 13 observation well sites across the province. These sites have modern telemetric systems for remote data retrieval. Water samples were collected in 2004-2005 from the 13 sites, although not all data is currently available. The number of sites is to be expanded to 22 during 2006.

4.2 Data Issues

4.2.1 **Background**

The 5 separate files provided were all in Microsoft Excel. The original paper data was not readily available since there were several data sources, not all held by NSEL. There was insufficient time during this project to attempt to collect and compile the original data to resolve any data issues. The following sections describe some of the data issues in each file, and the steps taken by H. Cross to prepare a working file for use for this project. Seven different stages of work were carried out, as listed below.

1. The separate files were combined into one Excel workbook as separate worksheets (file chemworking1). Each worksheet was then assessed and corrections started.

2. The 5 original files were in different formats with respect to order of parameters, rows/columns transposed in reporting, reporting of non-detects as "nd" or less than a

particular detection limit where one was given, and different metals units (milligrams per litre or micrograms per litre). Each file (worksheet) was modified so that row/column, and order of parameters in rows and columns, were essentially in the same format as NSEL's water quality database (file chemworking2). Other changes included:

- Addition of 2 extra columns for regional HU and one for total coliform. The original NSEL database had a column for total coliform, faecal coliform, and E. coli, while one of the new files had 2 columns for total coliform, one for MPN, one for P/A).
- Some nd's were changed to less than the detection limit value.
- Metal concentrations in ug/L were changed to mg/L since the GCDWQ use mg/L.

3. The following changes were made in file chemworking3:

- Total metals (As, Fe, Mn, Pb, Cu, Zn) were moved to dissolved where there were no values in the dissolved metals.
- Aluminum HGA and Aluminum were combined. In the few cases where there were values for both, the HGA value was used (lower detection level).
- A number of 'nds' were found in the pump test file; these were changed to the most probable 'less than' values.
- A number of 'less than' numbers were found to have a space between the '<' sign and the first number in the value.

4. The 5 worksheets were amalgamated into one (file chemworking4), with several worksheets.

- In edit1, samples were sorted by MWS ID# (registration #), station no., and date, then reviewed to determine duplicates, and if so, which ones to delete/use. After discussion with NSEL, it was decided to use the most recent sample (unless treated).
- In edit2, an HU of MM (metamorphic), IG/GT (igneous/granite), IG/BA (igneous/basalt), SED (sedimentary), CO3 (carbonate and evaporite), or Q (surficial) was assigned to the sample, based on one of the following:
  a. Samples with geologic formations given were changed to HUs based on the map book originally used to classify the data.
  b. Where no geologic formations were given (majority of samples), HU's were determined from community by comparison to the above map book.
  c. Where data indicated water source as dug wells, the HU was classed as Q.

Although there are no doubt some errors in classification, this study can be considered a first approximation until better location control is available to relate sample location by GPS to geology using geographic information system technology.

In edit2, additional errors/changes were made, such as:

- County names written in full were changed to 3 letters.
- Some individual data were changed, such as: Reg671 spelling error in community name; Reg824, 876, 1061, 1187, 1188 postal codes and community reversed; Reg824 county ANT not ANN; Reg893 Brookside in LUN incorrect county (HAL and COL have Brookside), so deleted since actual county unknown; Reg303 no Cape St. Marys in QUE, so assumed YAR; Reg1120 Port Howe in CUM; Reg524 pH and conductivity were the same, so cond deleted; Reg1204 cond 3.16 thought to be decimal error and changed to 316.
- Each column was sorted to find cells that appear empty but are read by Excel as non-blank.
- Cells in various columns such as pH, Langelier Indicers, and saturation pHs had what appeared to be a blank at the end of the cell. These cells were not counted as numeric, nor could the number of decimal places be changed. Efforts were made to correct this by searching for blanks, using the trim function, changing to text and searching for blanks, etc. All were unsuccessful. The blank was thus not considered blank, and had to be manually removed in the affected cells.
- Carbonate values of 0 were changed to <0.01.
- Two pump test TDS/cond ratios were still as formulas; these were changed to values.
- During the column sorts, decimal places were made more consistent, eg. where <0.10 and <0.1, changed to <0.1.
- Total coliform by MPN had only 6 values; these were changed to present/absent and the MPN column was deleted.
- Various columns were deleted in edit 2, where there were no data (eg. faecal coliform and E. coli), or data which would likely not be used for this project (such as various organics); a total of 58 columns were deleted in edit 2 worksheet. The apparent blanks in these deleted columns were not checked for formatting.
- Colour was changed in 2 samples which were inconsistent with other values in the data: Reg596 <50 to <5, Ptest138 <20 to <2 (NTU).
- Columns were aligned and decimal places in numeric values made consistent.
- TDS/conductivity was calculated where data were available.
- Acceptability was assessed where data were available.

5. In chemworking5, the data from edit2 were transferred to 'working_all', and columns to be used for data analysis were highlighted.

- In all_edit1, all data with reasons for non-use were removed, which decreased the number of samples from 2581 to 1069. The data were sorted by HU, and any questionable HUs were reviewed and classified where possible, or deleted if not possible.
- The data were then separated into different worksheets by HU (working_HU. The number of numeric and non-detects were calculated in individual worksheets, then compiled in 'datacheck' to determine possible methods to handle the data.

Some suggested methods where some data is censored (non-detect) are shown in Tables

4.1 and 4.2.

Percentage of Nondetects	Statistical Analysis Method
<15%	Replace nondetects with 1/2 the detection limit, the detection limit itself, or a very small number
15%-50%	Trimmed mean, Cohen's adjustment, Winsorized mean, and standard deviation
>50%-90%	Use tests for proportions

Table 4.1: Suggested statistical analysis methods for non-detects (USEPA, 2000)

Percentage of Nondetects	Statistical Analysis Method
up to 90%	When at least 10% of the samples have measurable values, approximate mean and variance by method in Aitchison (1955)
90-99%	When 1 to 10% of the samples have measurable values, use tolerance and prediction limits bsed on the Poisson distribution described in Gibbons (1987)
100%	When all samples have non-detect values, it is possible to use method detection limit based on 'spiked' calibration samples.

Table 4.2. Suggested statistical analysis methods for non-detects (Nielsen, 1991)

Some of the methods In Tables 4.1 and 4.2 were attempted in a 'test run' of one parameter, but found to be too complex and time-consuming without the use of more sophisticated and costly software such as WQStat and SANITAS. Where non-detects were found, there were often multiple detection limits, with actual values in between the different detection limits. This posed a significant data issue. For example, censoring the data at the highest detection limit would have rendered the data essentially useless in many cases.

Although it is recognized that there are many other approaches to statistical treatment of censored data, depending on the proportion of non-detects, the methodology is complex and beyond the time and scope of this project. Therefore, it was decided to use methods which could be performed relatively simply in an Excel spreadsheet, following some methods suggested in Helsel and Hirsch (1993).

6. In chemworking6, the following work was carried out.

- Parameters with 3 or more HUs with >90% non-detects were eliminated from the study due to time constraints and limited usefulness of the data.
- Data with <15% non-detects were changed so that nd was replaced by half the detection limit, then analyzed to find median and percentiles (5, 25, 75, 95); the data were then plotted as quantiles (actual and log-transformed data) and modified box and whisker (B&W) plots.
- Data with >15% up to 90% non-detects were plotted as histograms of detected values alone and non-detects alone, then as a B&W of median and quartiles of detected and non-detected values.
- Although geomean was not plotted, it was calculated for the data. In some cases, where parameters with larger values were present in higher number (such as sodium in the SED HU), geomean was beyond the capability of Excel, and was thus calculated manually by the use of logs.

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The quantile plots basically represent percent probability of occurrence. The plotting

position on the x-axis is the probability of occurrence, plotted as a fraction from 0.0-1.0

(0-100 percent). When plotted on probability paper (not available in Excel), such plots

can be used to compare data to a normal distribution. A number of formulae are available

to calculate plotting positions (Table 4.3). Helsel and Hirsch (1993) and ASTM (2000)

use the Cunnane formula, while EPA (2000) uses the Hazen formula. The Weibull

formula is commonly used for flow-duration and flood-frequency curves. Several checks

were made, and there was no significant difference in the plots, thus it was decided to use

the Hazen formula, as used by USEPA (2000).

Method	Value of a	Formula*	Comments
Weibull	0	$i/(n+1)$	Long used by United States hydrologists for plotting flow-duration and flood-frequency curves
Blom	0.375	$(i-0.375)/(n+0.25)$	Good for comparing data quantiles to those of a normal distribution on probability plots (all formulas except Weibull can be used for this)
Cunnane	0.4	$(i-0.4)/(n+0.2)$	Close to Blom formula; used by Canadian and European hydrologists for plotting flow-duration and flood-frequency curves
Gringorten	0.44	$(i-0.44)/(n+0.12)$	
Hazen	0.5	$(i-0.5)/(n)$	Used for comparing 2 or more data sets using quantile-quantile plots

Table 4.3. Commonly used plotting position formulas (Helsel and Hirsch, 1993)

* The general formula is $p = (i-a)/(n+1-2a)$, where
p = probability of occurrence of a particular value, as a fraction between 0.0 and 1.0
i = position of the value in a list ordered from smallest (i = 1) to largest (i = n)
n = number of values
a = numeric value from 0 to 0.5

When plotting the histograms, because of the large range in values of parameters such as metals, the range on the x-axis was a pseudo-logarithmic rather than an arithmetic scale. As an example, in order to use typical parameter values, a concentration range of 0.001 to 0.01 mg/L was given range boundaries of:

0.001-0.002 (log is -3.00 to -2.70) mg/L
0.002-0.003 (log is -2.70 to -2.52) mg/L
0.003-0.006 (log is -2.52 to -2.22) mg/L
0.006-0.01 (log is -2.22 to -2.00) mg/L.

As noted in brackets, the log values are close to being arithmetically scaled, though not exactly, so that data values could be better matched. Plotting in this way produced a much better picture of the distribution without large gaps, and also showed actual concentrations without transforming the data to logs.

7. In the chemworking6 files, an error occurred in Excel related to the number of graphs on individual worksheets and eventually to the total in the workbook. Because of this, the chemworking6 files were separated into 5 'final' files:

- Chem_final1[date].xls: contains the HU data, and parameters Na, K, Ca, Mg, hard, alk, SO4, Cl, SiO2, TDS, pH.
- Chem_final2[date].xls: contains the HU data, and parameters F, TOC, Al, As, Ba, B.
- Chem_final3[date].xls: contains the HU data, and parameters Cu, Fe, Pb, Mn, Mo, U.
- Chem_final4[date].xls: contains the HU data, and parameters Sr, Zn, cond, TDS/cond ratio.
- Chem_final5[date].xls: contains the HU data, and parameters NO3+NO2-N, NH3-N, colour, turbidity; this file has the most up-to-date HU and datacheck information.

During work in the final files, additional errors were found and fixed, such as:

- Reg696 had an iron value of 1458 mg/L, which was extremely high and inconsistent with colour and turbidity in the sample; it was deleted.

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- Reg635 had a sulfate value of 1400 mg/L, listed as Brooklyn, Queens County, and was classed as MM HU originally. The sample is likely from Brooklyn in Hants County, and was reclassified as CO3 HU.

Some specific issues associated with the 5 individual data files are discussed in Sections 4.2.2 to 4.2.6 below.

4.2.2 Registered Public Drinking Water Data

The two most serious issues with these data were:

1. About 100 samples appeared to be "double corrected" for trace metals when converting units from ug/L to mg/L, eg. columns BA, BD, rows 13, 27, 32. To resolve this, the metals were sorted one column at a time, and unreasonably low values were multiplied by 1000, then the column was sorted back to its original order. After all columns were fixed individually, they were compared by rows to check for consistency in samples changed.

2. Most of the problems related to pH, Langelier Index and saturation pH noted above were in this database.

Several minor issues were:

- Cell Y236 showed ion balance as #value; it was deleted.
- Some well depths were stored as text rather than numbers; this was changed.
- A few county codes were inconsistent, eg. HA and HX for Halifax, QU and QE for Queens. Also, some of these codes coincided with geology codes in the NSEL water quality and pump test databases, eg. HX for Halifax County and Halifax Formation. To resolve these issues and avoid confusion, county codes were all changed to 3 letters (the first 3 of the county name), to be consistent with the NSEL water quality, well log and pump test databases.
- A couple of strontium values seemed incorrect, eg. one given as 830 mg/L was assumed to be 0.83 mg/L.
- There were 2 incorrect manganese values (with spaces) which were noted during sorting, eg. 0 .09 mg/L changed to 0.09 mg/L.

In general, this database had poor documentation of many samples as to treatment (or lack of) on each sample taken. In some cases, treatment of the system was given, but it

was evident that the sample itself was untreated. There were a number of multiple samples taken the same date with no explanation of the difference and no evident (or significant) difference in water quality; some were possibly field or lab duplicates.

4.2.3 Pumping Test Chemistry Data

This file was already in the same format as the NSEL water quality database, so little change was needed. The file contained geology codes already; these were converted to one of the HUs defined for this project. A number of 'nds' were found in the pump test file (rows 79,80,83,84, or sorting nos. Ptest74,75,78,79). These were entered from tables in pump test reports when either only part of the report was available, or the consultant had not included the original lab certificates with the estimated quantitation limits linked to the 'nd'. The nds were changed to the most probable 'less than' values in mg/L as follows:

Al <0.005	o-PO4 <0.02
NO3+NO2-N and NH3-N <0.05	Cu <0.01
colour <5	turbidity <0.1
TOC <0.5	F <0.1
Sb, As, Bi, Cr, Mo, Ni, Se, Sn, V <0.002	Be <0.005
Cd, Pb <0.0003	Co <0.001
Tl <0.0002	Hg <0.0001.

4.2.4 Municipal Water Supply Data Part A

This file was originally in Quattro Pro and had been converted to Microsoft Excel some time ago. The Excel file had been modified as part of a database enhancement project in 2003, so permission was received to use the modified file. Some of the changes made to the original file were:

- There were many 'zero' values for unanalyzed or uncalculated parameters; these were deleted and left as blanks.
- There were a number of places where numbers were stored as text rather than numbers, especially in conductivity, pH, Langelier Index and saturation pH data.

The modified file contained ~3250 analyses in the original file, of which 969 were groundwater. This file was then edited to remove confidential data and information.

4.2.5 Municipal Water Supply Data Part B

This file contained 363 analyses of auditing data collected since the data analysis included in the part A file. After removing surface water samples, there were 155 that were most probably groundwater. Further editing (deleted treated samples and cells where ranges of values rather than a specific value were given) reduced the number of samples to 120. Additional editing included:

- Various organic parameters were deleted, leaving normal general chemistry and metals scan parameters;
- Results of 2 columns for silica and reactive SiO_2 were combined into one;
- There were 2 columns NO_3 as N and as NO_3; the latter was deleted as there were no values;
- Results of 2 columns SS and TSS were combined into one;
- Results of 3 columns for organic carbon TOC by IR (no values), TOC by UV, and DOC were combined into one*.
  * In groundwater, TOC and DOC are usually the same. The lab analytical method was essentially the same, but reported differently with time.

4.2.6 Observation well data

The main change required in this file, other than order and transposition, was conversion of metals units from ug/L to mg/L. Based on geological information, an HU was assumed.

4.3 Methods of Data Analysis

Once the file issues were resolved, the remaining data was sorted into different

hydrostratigraphic units for statistical analysis. Water resources data often have the

following characteristics (Helsel and Hirsch, 1993):

1. A lower bound of zero. No negative values are possible.
2. Presence of 'outliers', observations considerably higher or lower than most of the data, which infrequently but regularly occur. Outliers on the high side are more common in water resources.
3. Positive skewness, due to items 1 and 2. Skewness can be expected when outlying values occur in only one direction.
4. Non-normal distribution of data, due to items 1 - 3 above. While many statistical tests assume data follow a normal distribution, water resources data often look more like a lognormal distribution. However, symmetry does not guarantee normality.
5. Data reported only as below or above some threshold (censored data). Examples include concentrations below one or more detection limits.
6. Seasonal patterns. Values tend to be higher or lower in certain seasons of the year.
7. Autocorrelation. Consecutive observations tend to be strongly correlated with each other. For the most common kind of autocorrelation in water resources (positive autocorrelation), high values tend to follow high values and low values tend to follow low values.
8. Dependence on other uncontrolled variables. Values strongly covary with water discharge, hydraulic conductivity, sediment grain size, or some other variable.

An additional factor that may affect results, especially those of trace metals, is the

sampling protocol. Some items involved in sampling protocol include amount of prior

use, sample run time, sample location, distribution system effects (such as material, size

of building, etc.), sample filtration or non-filtration, treatment units (some obvious such

as softeners, others not such as particulate filters, ultraviolet light, etc.), sample

containers, sample preservation, sample handling and sample storage and holding times.

Chapter 5 Discussion of Results

The results will be discussed both by individual parameters and by hydrostratigraphic units. For individual parameters, modified box and whisker plots are used to show the concentrations. Where the percentage of non-detect values is less than 15%, the percentiles shown are 5, 25, 50 (median), 75 and 95. Where the percentage of non-detect values is greater than 15%, only the median and interquartile percentiles of 25, 50 and 75 are shown, for detects and non-detects, since the higher and lower ends are less meaningful.

Use of detectable values only tends to bias results high, but the use of detects and non-detects combined on the plots does not take into account the wide range of non-detect values. To provide some appreciation of the range of non-detects in the analyses, they were converted to numbers and treated statistically as values, then plotted in a similar way to detected values.

Data for each parameter is also summarized in tables, giving the median, interquartile values, and percent of detect values (det), and of detect and non-detect values (det+nd) values that exceed the GCDWQ (where applicable).

5.1 Individual Parameters

5.1.1 Sodium

Major sources of sodium in groundwater are atmospheric (sea spray and dry fallout) and geological. Sodium in igneous rocks is commonly from feldspars such as albite, with minor amounts from sodium that is substituting for potassium in orthoclase and microcline. In sedimentary rocks, sodium may be found in a cement, or in crystals deposited with the sediments, or in residual saline water from the time of deposition. In carbonate and evaporites, halite is the common mineral (rock salt). In some areas, wells may not be drilled into halite, but may be affected by saline waters channeled by faults or fractures. Other sources of sodium include salt water intrusion, water softeners, road salt, and waste disposal.

Sodium is an essential nutrient, necessary for nerve impulses. The 200 mg/L guideline for sodium in water has been established to protect individuals with a history of cardiovascular problems. Individuals on a medically supervised salt restricted diet may need to limit their intake of water that exceeds 20 mg/L of sodium, but should consult with their physician in such matters. If a water softener is used, it removes the calcium and magnesium from the raw water and replaces it with sodium. This increase in the natural sodium level should be checked. Health Canada recommends that where water is softened by sodium ion exchange, it is recommended that a separate, unsoftened supply be retained for culinary and drinking purposes.

In Nova Scotia, sodium (Figure 5.1 and Table 5.1) is generally highest in the CO3 HU as a result of the influence of evaporites within the HU. This HU has the highest exceedance for sodium (20%). Sodium in the SED HU is likely from saline formation water and or natural softening. In the Q HU, the median value is low, but the upper quartile is slightly higher than the remaining bedrock HUs; this is most likely due to influences such as road salt.

5.1.2 Potassium

The major sources of potassium in groundwater are geological. In igneous rocks, potassium is often found in the feldspars orthoclase and microcline, the micas and the feldspathoid leucite. The feldspars are more resistant to chemical breakdown by groundwater, but may still dissolve at a faster rate than some other ions. In sediments, potassium is often found in unaltered feldspar or mica particles, and in illite or other clay minerals. In the evaporites, the potassium source may be localized beds of potassium salts. In agricultural areas, potassium may be derived from fertilizers and manures.

Potassium is an essential element, necessary for nerve impulses. There is no guideline but elevated concentrations may be harmful to the nervous and digestive systems. The concentration in natural waters seldom reaches 20 mg/L, probably due to removal by biological and ion exchange mechanisms. Concentrations >20 mg/L may occur in treated waters softened by ion exchange, using potassium chloride for regeneration.
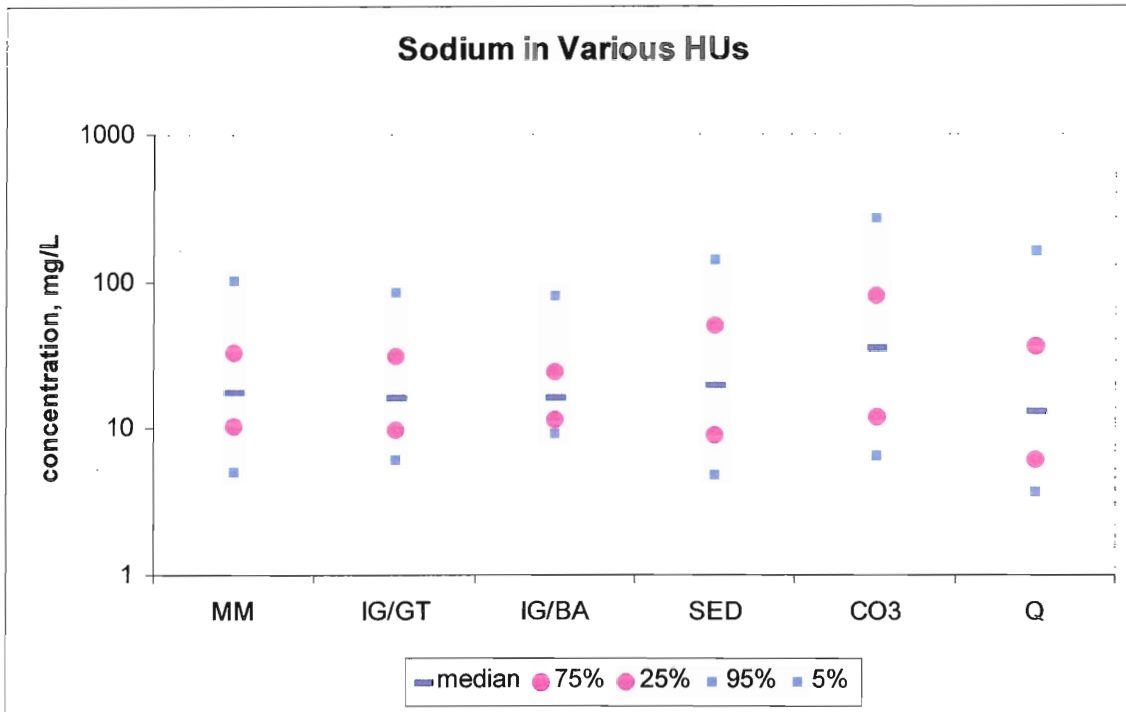
Figure 5.1: Distribution of sodium in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	17.5	33.2	10.3	179	0.0	N/A
IG/GT	16.4	30.8	9.8	65	0.0	N/A
IG/BA	15.9	24.0	11.5	23	0.0	N/A
SED	19.6	50.2	8.9	529	3.0	N/A
CO3	35.4	78.7	11.9	79	20.3	N/A
Q	12.9	36.4	6.1	139	2.9	N/A

Table 5.1: Median and quartile values of sodium in various HUs in Nova Scotia

In Nova Scotia drinking water (Figure 5.2 and Table 5.2), potassium occurs at relatively low levels in all HUs, with the SED and CO3 HUs being highest. The IG/BA HU has the lowest concentration of all the HUs, and was the only HU that contained non-detects. This is because feldspars and micas containing potassium are not usually found in basaltic rocks. The small number of sample analysis from basaltic rocks may also bias the results.

Figure 5.2: Distribution of potassium in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	1.20	1.80	0.80	171	N/A	N/A
IG/GT	1.40	2.20	0.90	65	N/A	N/A
IG/BA	0.20	0.70	0.15	15	N/A	N/A
SED	1.70	2.60	0.90	487	N/A	N/A
CO3	1.80	3.13	1.00	76	N/A	N/A
Q	1.40	2.00	0.81	131	N/A	N/A

Table 5.2: Median and quartile values of potassium in various HUs in Nova Scotia

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5.1.3 Calcium

The major sources of calcium in groundwater are geological. Calcium is found in calcite, aragonite, gypsum, and anhydrite. Calcium carbonate is also a common cement between grains in sedimentary rocks. In igneous rocks, calcium is found in large quantities in pyroxenes, amphiboles and the feldspars. Road salting, dust control, agricultural liming and other anthropogenic influences may also contribute calcium to waters.

Calcium is an essential element, for bones, teeth, etc. Calcium and magnesium contribute to water hardness causing aesthetic concerns such as taste, scale, excessive soap consumption, bathtub ring, and grayish laundry. There is no evidence of adverse health effects specifically attributable to calcium in drinking water. Undesirable effects due to the presence of calcium in drinking water may result from its contribution to hardness. A separate maximum acceptable concentration for calcium has, therefore, not been specified. Calcium can be easily removed with a water softener by ion exchange, with the calcium being replaced normally by sodium or potassium.

In Nova Scotia (Figure 5.3 and Table 5.3), calcium is elevated in the SED and CO3 HUs as expected, and relatively lower in the IG/BA HU than other HUs.

Figure 5.3: Distribution of calcium in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	20.3	28.5	13.6	179	N/A	N/A
IG/GT	17.0	28.8	10.0	65	N/A	N/A
IG/BA	13.0	18.8	10.4	23	N/A	N/A
SED	34.2	52.3	22.3	530	N/A	N/A
CO3	46.7	89.9	26.0	79	N/A	N/A
Q	17.1	32.7	7.7	140	N/A	N/A

Table 5.3: Median and quartile values of calcium in various HUs in Nova Scotia

5.1.4 Magnesium

Magnesium is typically a major part of dark-coloured ferromagnesian minerals found in igneous rocks. These minerals can include olivine, the pyroxenes, amphiboles, and dark-coloured micas. In metamorphic and altered rocks magnesium occurs in chlorite and serpentine. Carbonates such as magnesite and hydromagnesite also contain larger amounts of magnesium. Dolomite has a crystal structure where calcium and magnesium are present in equal amounts.

Magnesium is an essential element, beneficial for heart and nervous system. Magnesium is one of the major contributors to water hardness, and may also contribute undesirable tastes to drinking water. The taste threshold has been reported to be 100 mg/L for sensitive individuals and about 500 mg/L for the average person. These levels are well above the magnesium concentrations encountered in Nova Scotia drinking waters.

There is no evidence of adverse health effects specifically attributable to magnesium in drinking water, although undesirable effects may result indirectly from the laxative effect of magnesium in association with the sulphate ion. Therefore, a maximum concentration for magnesium has not been specified.

In Nova Scotia, the occurrence of magnesium in drinking water (Figure 5.4 and Table 5.4) is relatively consistent for all HUs, with the highest concentration in the CO3 HU. This occurrence in the CO3 HU is likely from dolomite.
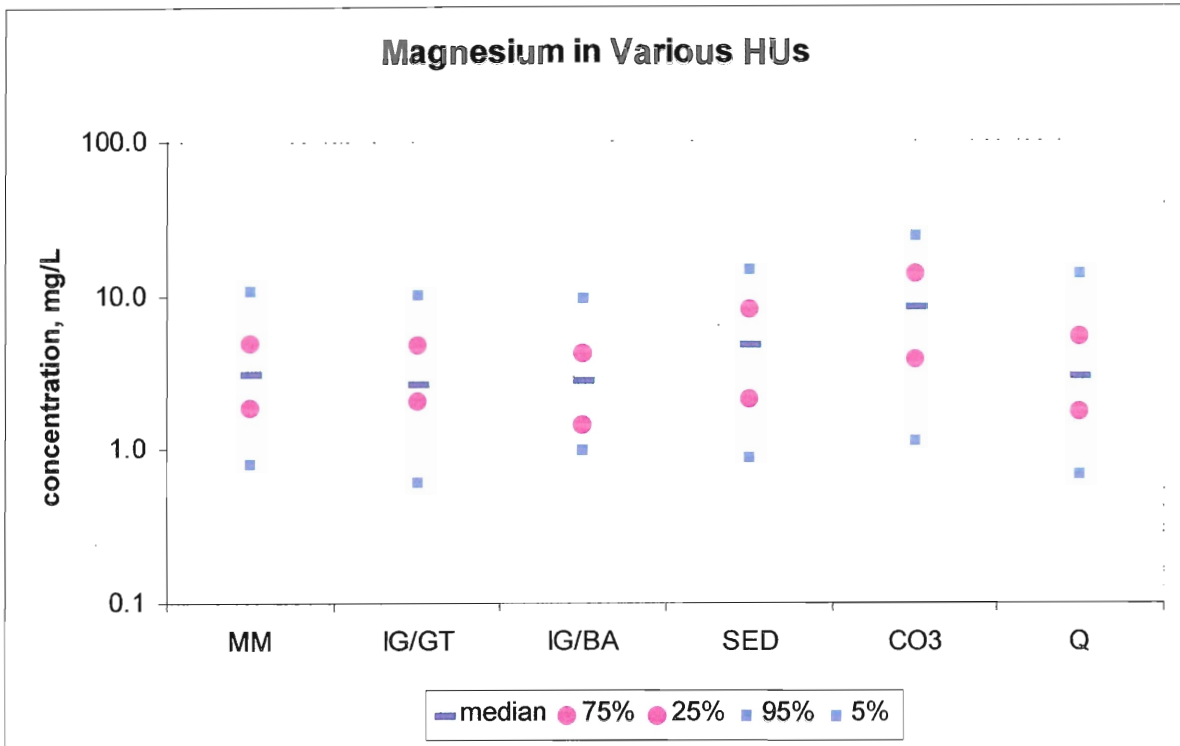
Figure 5.4: Distribution of magnesium in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	3.10	5.05	1.90	179	N/A	N/A
IG/GT	2.70	4.80	2.10	65	N/A	N/A
IG/BA	2.80	4.29	1.49	23	N/A	N/A
SED	4.80	8.20	2.16	526	N/A	N/A
CO3	8.42	13.85	3.89	79	N/A	N/A
Q	3.05	5.40	1.78	138	N/A	N/A

Table 5.4: Median and quartile values of magnesium in various HUs in Nova Scotia

5.1.5 Hardness

Hardness in drinking water is directly related to calcium and magnesium concentrations. In Nova Scotia (Figure 5.5 and Table 5.5a), hardness is higher in both the SED and CO3 HUs than in the igneous, metamorphic and surficial sediments. In comparing this with the calcium (Figure 5.3) and magnesium (Figure 5.4) graphs, it is evident that there is a direct contribution from calcium and magnesium to the hardness of Nova Scotia groundwaters.

There is no guideline for hardness, and public acceptance varies widely. Generally, hardness levels between 80 and 100 mg/L (as CaCO3) are considered acceptable; levels greater than 200 mg/L are considered poor but can be tolerated; those in excess of 500 mg/L are normally considered unacceptable. Where water is softened by sodium ion exchange, Health Canada recommends that a separate, unsoftened supply be retained for culinary and drinking purposes.

The main concerns with hardness are incrustation on pipes, kitchen utensils and tubs as well as excessive soap consumption. Hard waters, when heated, have a tendency to form scale deposits. Soft waters, on the other hand, have a tendency to corrode water pipes. Health Canada suggests that the degree of hardness of drinking water may be classified in terms of its calcium carbonate concentration as follows: soft, 0 to <60 mg/L; medium hard, 60 to <120 mg/L; hard, 120 to <180 mg/L; and very hard, 180 mg/L and above. Table 5.5b shows that the hardest waters, as expected, are those from the CO3 HU.

Figure 5.5: Distribution of hardness in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det >200 mg/L
MM	65.2	92.7	43.6	178	N/A	3.4
IG/GT	54.0	96.3	35.7	64	N/A	3.1
IG/BA	46.7	59.2	35.2	23	N/A	0.0
SED	112.0	163.0	71.7	528	N/A	16.7
CO3	170.0	293.5	98.0	76	N/A	40.8
Q	54.3	100.2	27.1	135	N/A	10.4

Table 5.5a: Median and quartile values of hardness in various HUs in Nova Scotia

HU	Percent soft	Percent med hard	Percent hard	Percent v. hard	>50% of samples are
MM	45.5	38.8	10.1	5.6	soft to moderately hard
IG/GT	57.8	21.9	15.6	4.7	soft
IG/BA	73.9	17.4	8.7	0.0	soft
SED	18.2	36.2	24.8	20.8	soft to moderately hard
CO3	17.1	11.8	27.6	43.4	hard to very hard
Q	52.6	26.7	6.7	14.1	soft

Table 5.5b. Classification of hardness in various HUs in Nova Scotia

5.1.6 Alkalinity

Alkalinity is the measure of water's capacity to neutralize an acid. Waters with high alkalinity, when boiled over an extended period of time, tend to form a deposit or unpleasant taste. Waters with very low alkalinity tend to corrode pipes and plumbing. The main source of alkalinity in groundwater is bicarbonate and carbonate derived from carbon dioxide (atmospheric and bacterially-mediated) and carbonate rocks/minerals such as limestone, dolomite and calcite. Anions of weak acids of boron, silica, phosphorus, and organic acids may also contribute to the alkalinity.

There is no guideline for alkalinity, but concentrations in the range of 30 to 500 mg/L are generally acceptable, to allow water treatment plants to maintain chemical balance of water to prevent excessive incrustation or corrosion.

The alkalinity of Nova Scotia water (Figure 5.6 and Table 5.6) is highest in the SED and CO3 HUs, as expected because they tend to contain higher concentrations of carbonate minerals. The lowest values occur in the Q HU unit since its waters tend to be lower in carbonate minerals, less buffered and less evolved from rainwater.
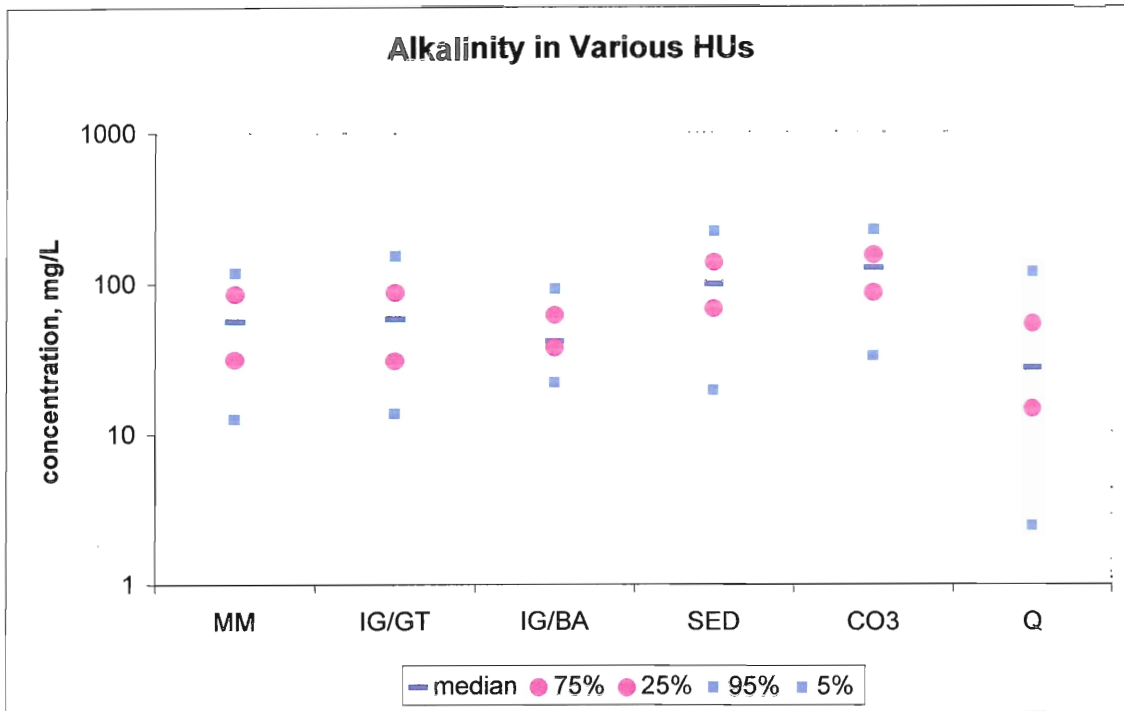
Figure 5.6: Distribution of alkalinity in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	57.0	87.0	32.0	178	N/A	N/A
IG/GT	59.0	88.8	31.3	62	N/A	N/A
IG/BA	41.9	62.5	38.0	23	N/A	N/A
SED	100.0	139.5	69.0	495	N/A	N/A
CO3	130.0	158.0	89.0	71	N/A	N/A
Q	28.0	55.0	15.0	135	N/A	N/A

Table 5.6: Median and quartile values of alkalinity in various HUs in Nova Scotia

5.1.7 Sulfate

Major sources of sulfate in groundwater are geological and industrial discharge; wet and dry deposition from the air contains sulfates from burning fossil fuels (eg. coal). Common geologic sources include gypsum, anhydrite, and sulfide minerals. Sulfur is well distributed in reduced form (sulfide) in igneous and sedimentary rocks. When the sulfide is weathered in contact with oxygenated water, the sulfide is oxidized into sulphate. Pyrite is a common sulfide mineral, but in Nova Scotia pyrrhotite is also a major contributor in sulphidic slates offender (Fox, 1999).

Individuals who complain of a sulfur or rotten egg odour from their water often have a hydrogen sulfide problem. Such water is usually low in sulfate since any sulfur present tends to be in reduced form as hydrogen sulfide gas.

The guideline of 500 mg/L for sulfate has been established for health and aesthetic reasons. The major physiological effect from ingestion of water containing sulfate at concentrations in excess of this limit is catharsis (laxative effect) and gastrointestinal irritation. The presence of sulfate may also result in noticeable taste.

In Nova Scotia (Figure 5.7 and Table 5.7), the highest sulfate concentrations are found in the CO3 HU due to gypsum. Sulfate is higher in the SED HU than in the MM, IG and Q HUs. This may be due to gypsum in some sedimentary units such as the Blomidon Formation, or association of sedimentary units with evaporite sequences. The CO3 HU shows the highest percentage of sulfate exceedances.
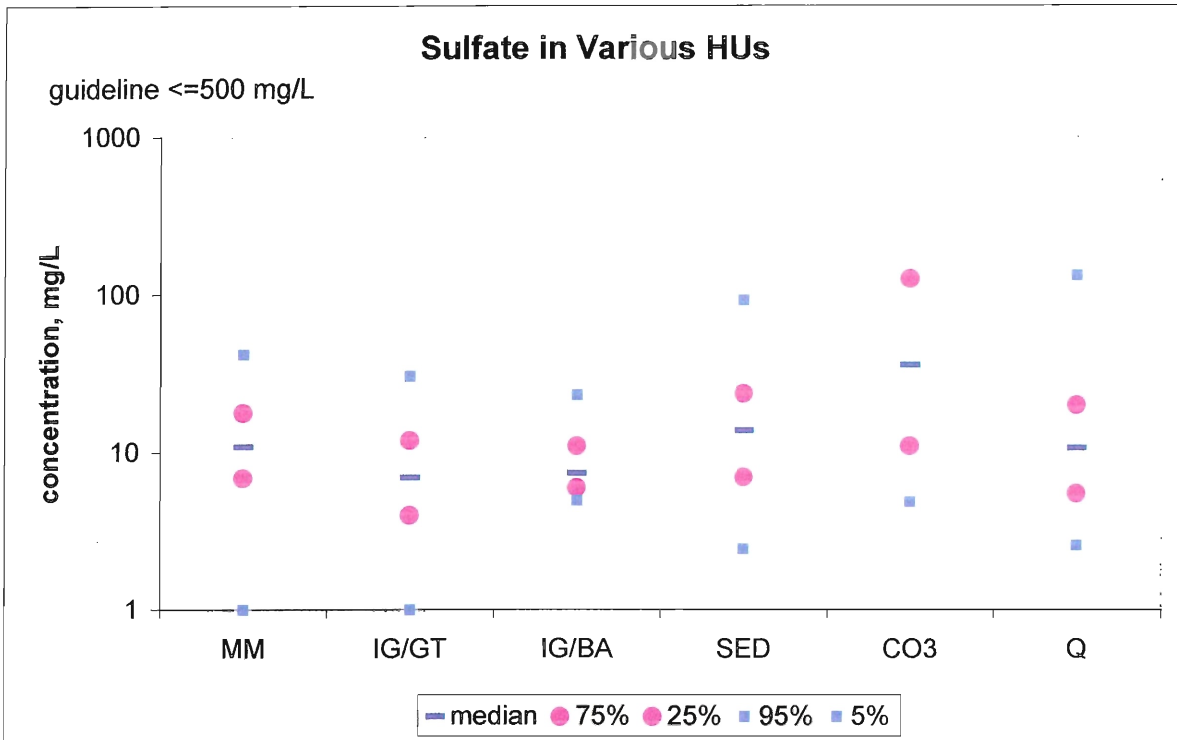
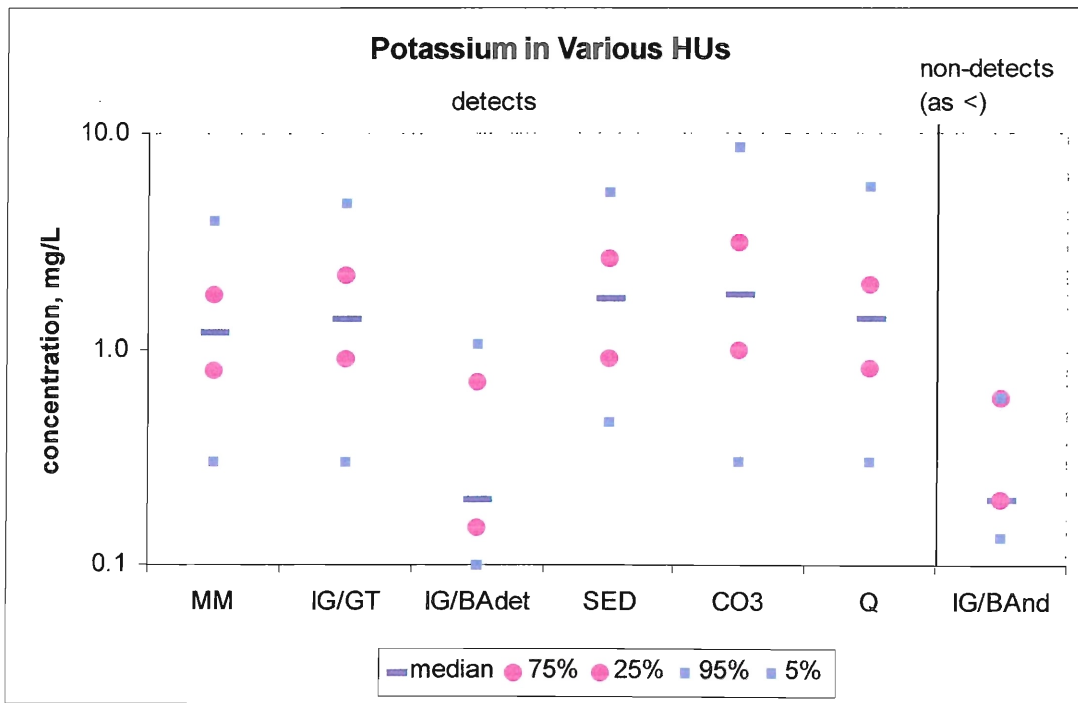Note: 95% percentile off scale for CO3 HU at 1100 mg/L

Figure 5.7: Distribution of sulfate in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	11.0	18.0	7.0	179	1.1	N/A
IG/GT	7.0	12.0	4.1	63	0.0	N/A
IG/BA	7.4	11.0	6.0	23	0.0	N/A
SED	13.8	23.6	7.0	533	0.9	N/A
CO3	35.9	126.0	11.0	77	10.4	N/A
Q	10.7	20.0	5.5	137	0.7	N/A

Table 5.7: Median and quartile values of sulfate in various HUs in Nova Scotia

5.1.8 Chloride

The major geologic source of chloride is natural salt deposits. Chloride often occurs in groundwater in sedimentary rocks, through the deposition of sediments in a closed basin system with saline formation water. Chloride can also show variances in surface water composition from snow and rain that is influenced by marine solutes (atmospheric input). Other sources (usually local) include salt water intrusion, road salt, septic tank systems, and industrial wastes.

Chloride above the guideline of 250 mg/L imparts an undesirable salty taste to the water. The normal range in drinking water is 5 to 20 mg/L, although in Nova Scotia, background in coastal areas is usually considered as <50 mg/L. Levels above this may be an early indicator of contamination. Chloride contributes to TDS, which is a factor is the corrosive tendency of a water to metals in the distribution system.

In Nova Scotia, the median chloride in drinking water supplies (Figure 5.8 and Table 5.8) is almost the same in all HUs. However, there is a larger variance in the 95th percentile concentrations in the different HUs. The SED and CO3 HUs are highest, as expected based on probable geologic origin. In the remaining HUs, especially the Q HU, chloride is likely related to other sources such as road salt or seawater intrusion.
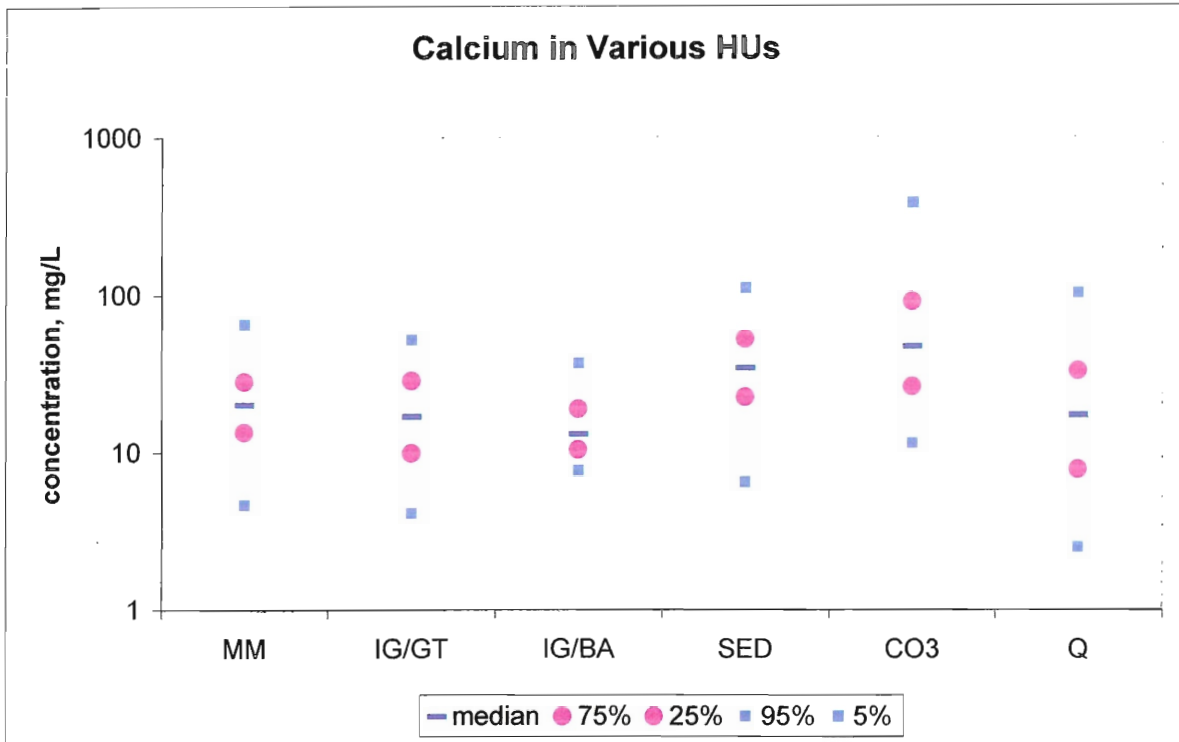
Figure 5.8: Distribution of chloride in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	20.0	53.0	9.0	179	2.8	N/A
IG/GT	24.0	45.3	10.0	63	0.0	N/A
IG/BA	22.2	38.7	9.0	23	0.0	N/A
SED	26.8	64.0	10.4	533	3.6	N/A
CO3	32.0	88.3	13.1	77	9.1	N/A
Q	28.0	68.0	9.2	137	3.6	N/A

Table 5.8: Median and quartile values of chloride in various HUs in Nova Scotia

5.1.9 Fluoride

Fluoride is most commonly found in waters from igneous and sedimentary rocks. The major mineral sources include apatite and fluorite; however amphiboles (such as hornblende) and micas may have fluoride that replaced hydroxide in their crystal structure.

The guideline of 1.5 mg/L has been established for health reasons. Fluoride is added to many central water supplies. Health Canada suggests that the optimum range to control dental caries is 0.8 to 1.0 mg/L. Fluoride in excess of 1.5 mg/L may produce mottling of tooth enamel.

The highest concentration of fluoride in Nova Scotia (Figure 5.9 and Table 5.9) is found in the MM and IG/GT HUs. These concentrations are significantly higher than those found in other HUs. Fluorite mineralization is common in some areas of granitic rocks. Elevated fluoride in the MM HU is more commonly associated with the Halifax Formation than the Goldenville Formation (H. Cross, pers.comm.).
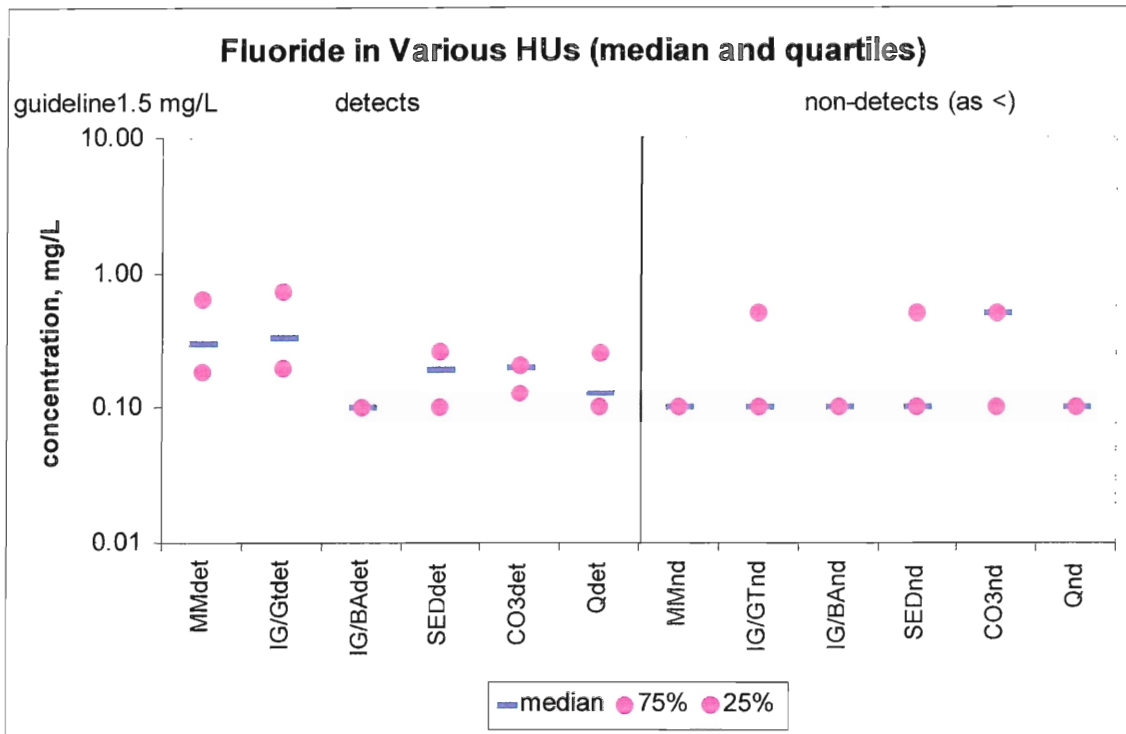
Figure 5.9: Distribution of fluoride in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.30	0.65	0.19	72	4.2	2.5
IG/GT	0.34	0.73	0.20	32	9.4	6.5
IG/BA	0.10	0.10	0.10	6	0.0	0.0
SED	0.20	0.26	0.10	156	0.0	0.0
CO3	0.20	0.21	0.13	25	0.0	0.0
Q	0.13	0.25	0.10	15	0.0	0.0

Table 5.9: Median and quartile values of fluoride in various HUs in Nova Scotia

5.1.10 Silica

Silica is most common as quartz, but because of the hardness of quartz, it is very resistant to chemical breakdown by water. Major sources of silica in groundwater are geological, mainly feldspars, ferromagnesian and clay minerals, and minor amorphous silica such as chert and opal. Silica results from the chemical breakdown of silicate minerals during weathering processes.

There is no guideline for silica, but natural concentrations usually range from 1 to 30 mg/L. In the presence of calcium and magnesium, silica may form a scale on boiler walls and on steam turbine blades that retards heat transfer; the scale is difficult to remove. Silica is sometimes added to soft water to inhibit corrosion of iron pipes.

The silica concentrations are highest in the IG HUs (Figure 5.10 and Table 5.10), due to weathering of feldspars and ferromagnesian minerals. The CO3 and Q HUs have the lowest concentrations of silica. There is generally little silica in the CO3 HU. In the Q HU, the silica would likely be derived mainly from quartz, which is more resistant to weathering.
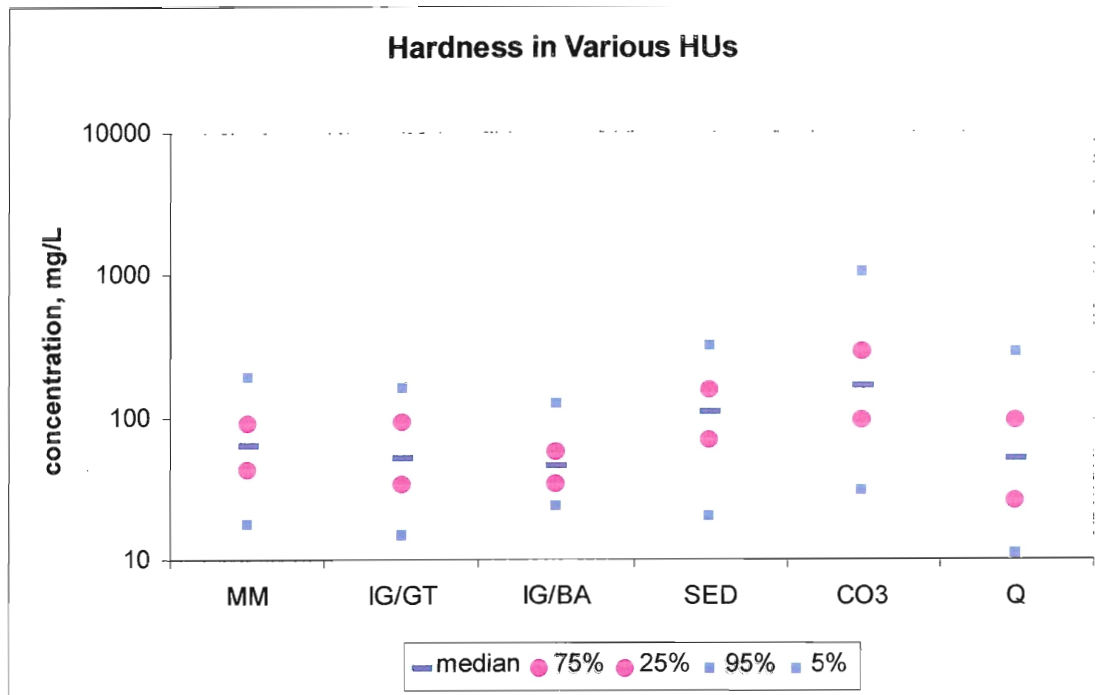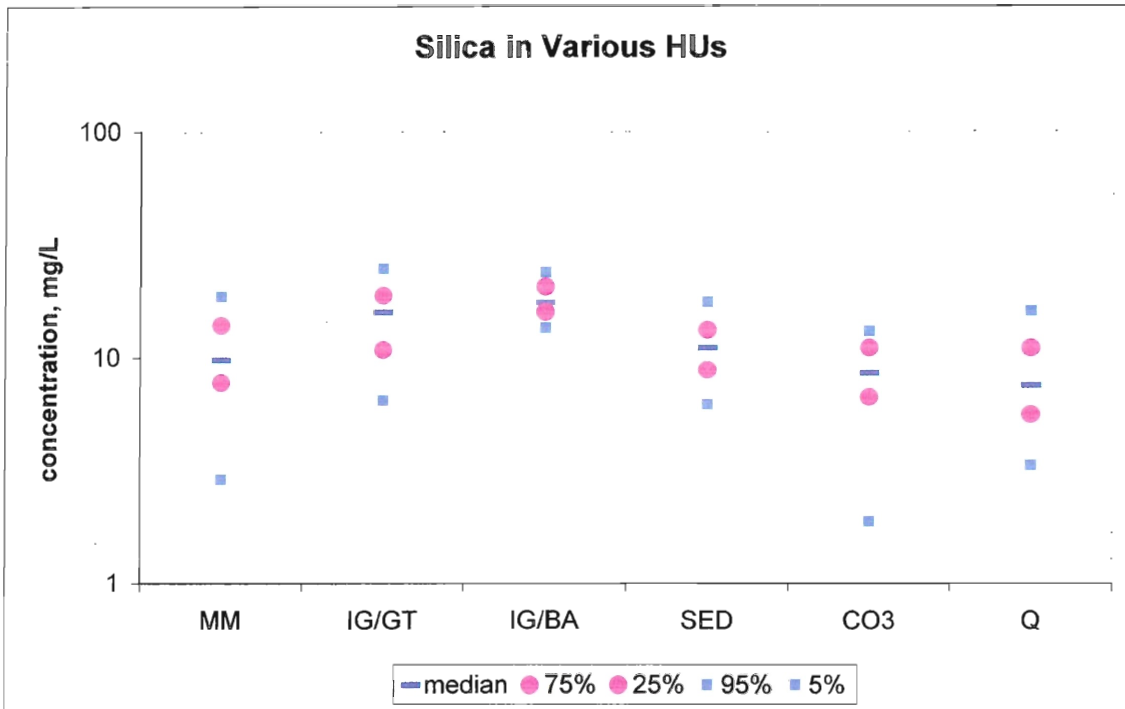
Figure 5.10: Distribution of silica in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	9.8	14.0	7.8	119	N/A	N/A
IG/GT	16.0	19.0	11.0	56	N/A	N/A
IG/BA	17.5	20.6	16.0	20	N/A	N/A
SED	11.0	13.2	8.8	384	N/A	N/A
CO3	8.5	11.0	6.7	66	N/A	N/A
Q	7.5	11.0	5.6	109	N/A	N/A

Table 5.10: Median and quartile values of silica in various HUs in Nova Scotia

5.1.11 Nitrate+Nitrite-Nitrogen

Nitrate and nitrite are naturally occurring inorganic compounds of nitrogen found widespread in the environment. Nitrogen comprises about 78% of the earth's atmosphere. Bacteria found in the soil convert nitrogen into nitrate and nitrite. Nitrates are also used widely as fertilizers. Nitrites are used as food preservatives, especially in cured meats.

In water supplies, particularly groundwater, the origin of nitrate may be from the atmosphere, decaying plant or animal material, agricultural fertilizers, manure, and domestic sewage. Most, however, is generated by the decay of organic matter and agricultural chemicals. For this reason, higher values in Nova Scotia groundwaters tend to occur in areas of intensive agriculture such as the Annapolis-Cornwallis Valley. Wells most likely to be affected are dug wells, drilled wells with short casing, in areas with shallow water table and permeable surficial material.

Nitrate values may also be elevated where surface water, or shallow groundwater affected by surface or near-surface processes (such as animal waste or on-site sewage disposal), influence a well (dug or drilled).

The GCDWQ have set a MAC for nitrate-nitrogen of 10 mg/L. If exceeded, nitrogen has been known to cause 'blue baby' syndrome in infants under six months old, and occurs when the blood stream is unable to carry sufficient oxygen to organs and body tissues. Consuming water with nitrate levels near the guideline does not normally affect older

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children and adults. However, there is some concern about an increased risk of gastric

cancer in humans from the ingestion of nitrate/nitrite in drinking water. Scientifically the

evidence is weak.

In Nova Scotia (Figure 5.11 and Table 5.11), median values for nitrogen in the various

HUs are just slightly less than 1.0 mg/L. Some exceedances occur in the SED HU, likely

related to farming areas such as the Annapolis Valley as noted above.

5.1.12 Ammonia-Nitrogen

Natural levels of ammonia in groundwater are often below 0.2 mg/L. Higher

concentrations may be an early indicator of contamination, either surface water or

domestic wastewater. If ammonia exceeds 0.1 to 0.2 mg/L, the possibility and type of

contamination should be investigated. Ammonia is sometimes corrosive to copper and its

alloys and may thus corrode pipes, may promote the growth of organisms, and may

reduce the disinfection capacity of chlorine. Cement mortar used to coat the inside of

pipes may also release ammonia into drinking water.

Ammonia at concentrations expected in drinking water is not harmful to humans or

animals and is therefore a guideline has not been established (a value of 0.5 mg/L from

older drinking water guidelines from the 1970's is sometimes quoted). In Nova Scotia,

median concentrations of detectable levels of ammonia (Figure 5.12 and Table 5.12) are

generally below the 0.2 mg/L expected to occur naturally.

Nitrate+nitrite-N in Various HUs (median and quartiles)
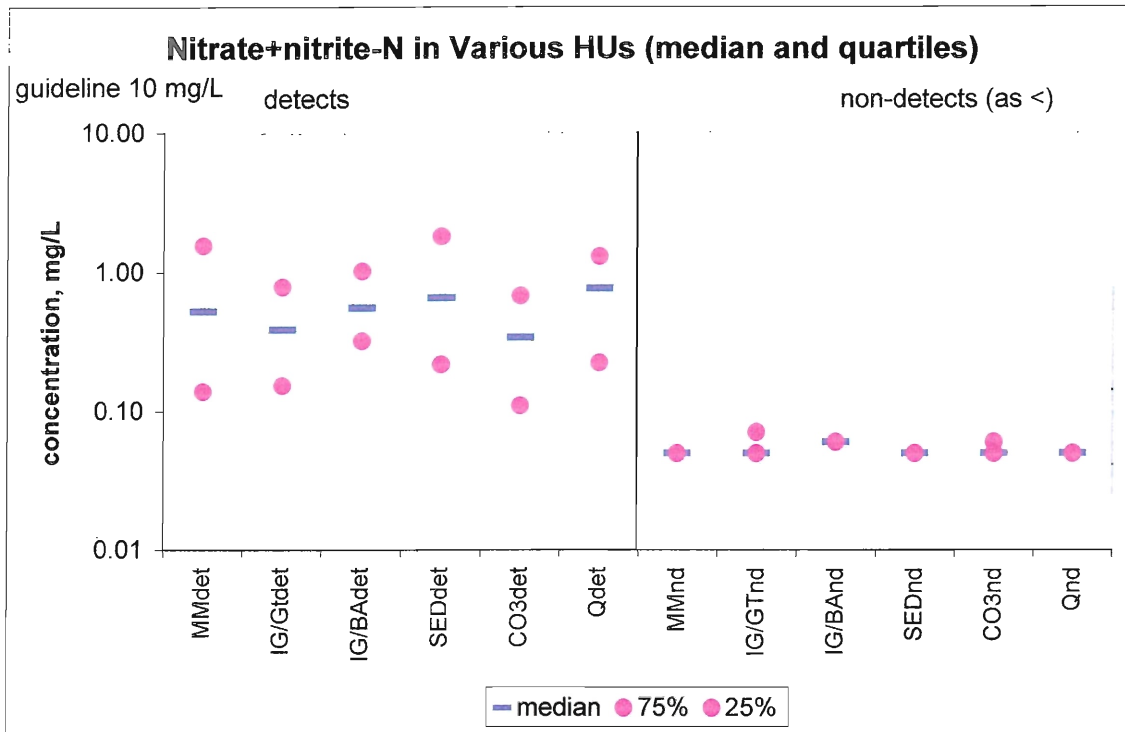
Figure 5.11: Distribution of nitrate+nitrite-N in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.53	1.55	0.14	72	0.0	0.0
IG/GT	0.39	0.79	0.16	27	0.0	0.0
IG/BA	0.56	1.02	0.33	19	0.0	0.0
SED	0.66	1.80	0.22	302	2.6	1.7
CO3	0.34	0.68	0.11	43	0.0	0.0
Q	0.77	1.30	0.23	106	0.0	0.0

Table 5.11: Median and quartile values of nitrate+nitrite-N in various HUs in Nova Scotia

Figure 5.12: Distribution of ammonia-N in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.08	0.15	0.06	28	N/A	N/A
IG/GT	0.13	0.31	0.07	7	N/A	N/A
IG/BA	0.15	0.15	0.15	1	N/A	N/A
SED	0.11	0.23	0.08	68	N/A	N/A
CO3	0.12	0.14	0.07	15	N/A	N/A
Q	0.13	0.24	0.08	14	N/A	N/A

Table 5.12: Median and quartile values of ammonia-N in various HUs in Nova Scotia

5.1.13 Total Dissolved Solids

Total dissolved solids (TDS) in drinking water sources is made up of all the dissolved

minerals in the water, such as sodium, potassium, calcium, magnesium, bicarbonate,

sulfate, chloride, fluoride and nitrate. This parameter is calculated from the analytical

results. Various labs use different formulas. For example, one local lab currently uses:

TDS = sodium + potassium + calcium + magnesium + (total alkalinity as calcium carbonate* 0.6) + sulfate + chloride + fluoride + silica + nitrate + ammonia + phosphate + iron + manganese (all concentrations in mg/L).

Theoretically, TDS is proportional to electrical conductivity. Conductivity is a separate

measurement and is discussed in Section 5.1.16.

The guideline for TDS is 500 mg/L, to prevent taste, corrosion, scaling and laxative

effect. In Nova Scotia, the highest concentration of TDS (Figure 5.13 and Table 5.13) is

found in the CO3 HU, related to gypsum, halite, calcium carbonate and other soluble

minerals. This unit has a much greater percentage of exceedances than all the other HUs.

The second highest is the Q HU, likely related to anthropogenic influences such as road

salt and nitrates.
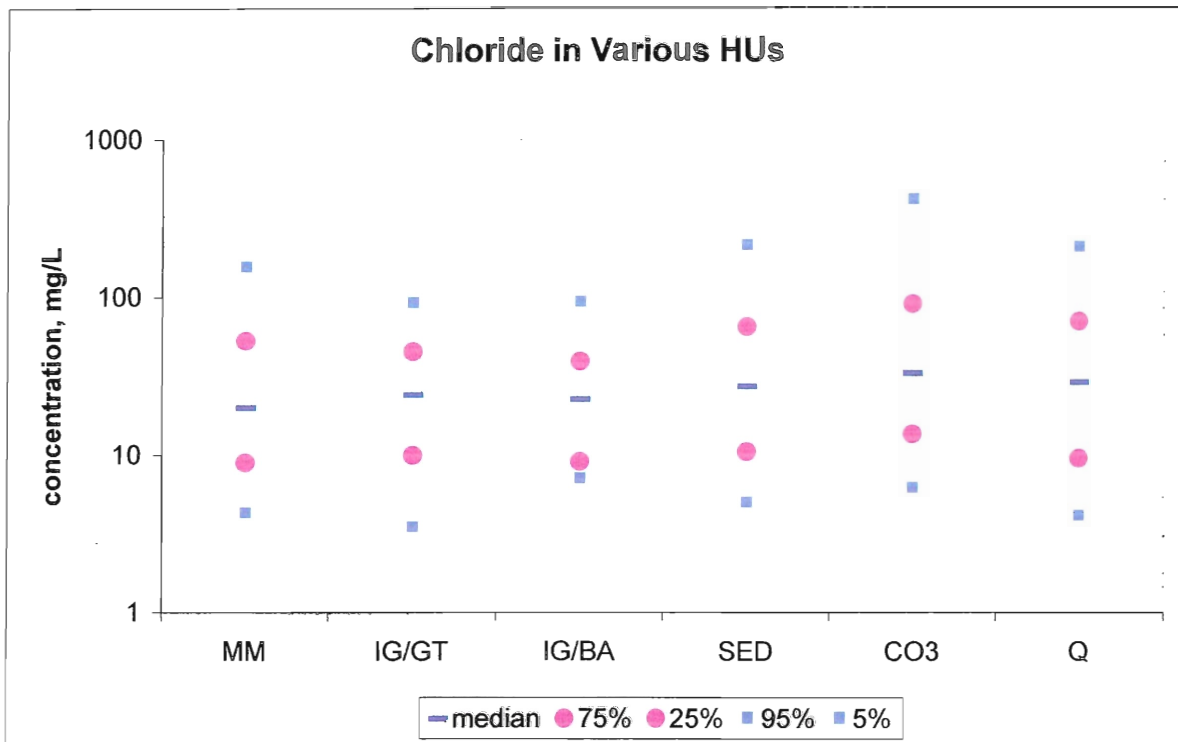
Total Dissolved Solids in Various HUs
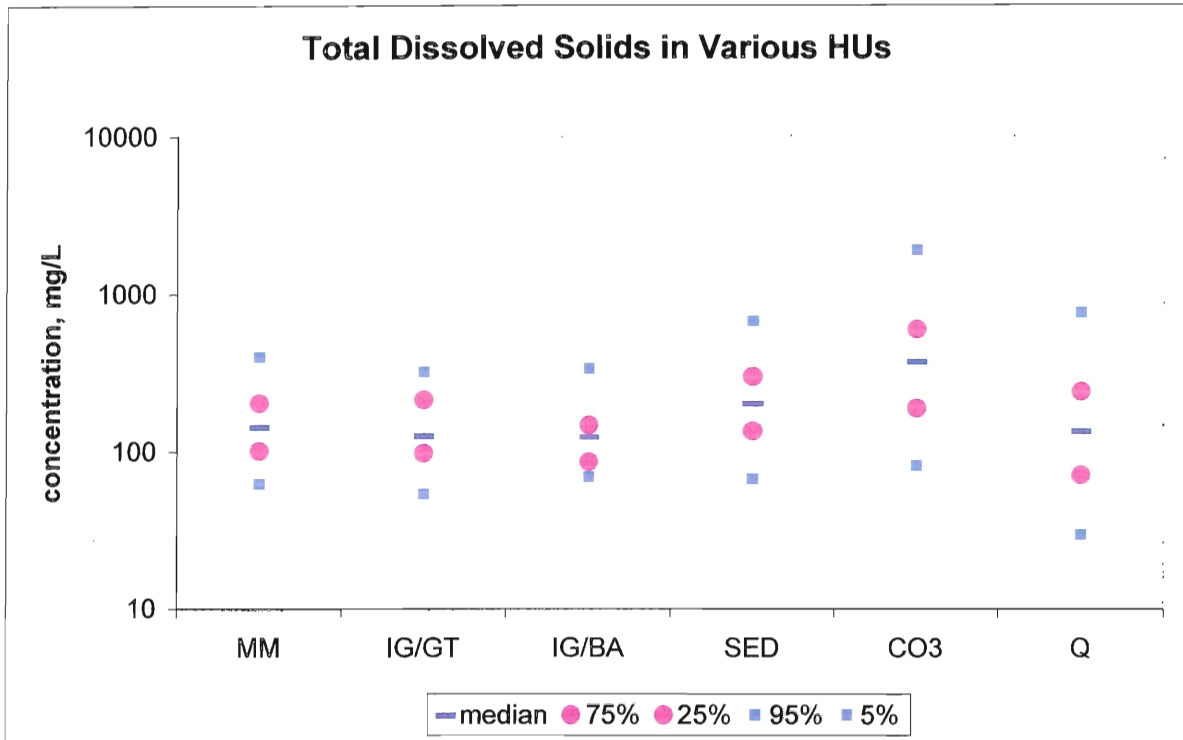
Figure 5.13: Distribution of TDS in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	144.0	206.0	102.5	159	3.8	N/A
IG/GT	126.3	215.5	99.0	55	1.8	N/A
IG/BA	123.4	146.8	85.9	22	0.0	N/A
SED	199.0	295.3	134.0	473	7.8	N/A
CO3	365.1	587.2	185.8	72	33.3	N/A
Q	132.1	237.5	70.0	118	10.2	N/A

Table 5.13: Median and quartile values of TDS in various HUs in Nova Scotia

5.1.14 Colour

Colour in drinking water has no direct chemical basis and is not considered to be a health problem. Colour can vary from a light yellow to a dark brown. It is measured by visual comparison to a series of standard solutions. High colour is a possible indication of pollution, aesthetically unpleasing, and stains clothing, food and plumbing fixtures. It is caused primarily by dissolved organic matter (humic substances, tannins, lignins) and inorganic material (iron, manganese). True colour is measured in a sample from which particulate matter is removed by centrifugation. Apparent colour includes colour due to suspended matter (turbidity). True colour is generally less than apparent colour.

The aesthetic objective for colour in the GCDWQ is 15 TCU. Colour below 10-15 units is barely noticeable to the consumer. At about 100 TCU, the water appears to be the colour of tea.

In Nova Scotia drinking waters (Figure 5.14 and Table 5.14), the median TCU in all HUs is generally less than 10. In the MM HU, the colour is a little more noticeable than in the other HUs. Table 5.14 indicates that exceedances occur in all HUs. This may be at least partly due to the widespread occurrence of iron and manganese in Nova Scotia groundwater, and the presence of some naturally occurring suspended solids in some formations such as shales and mudstones.
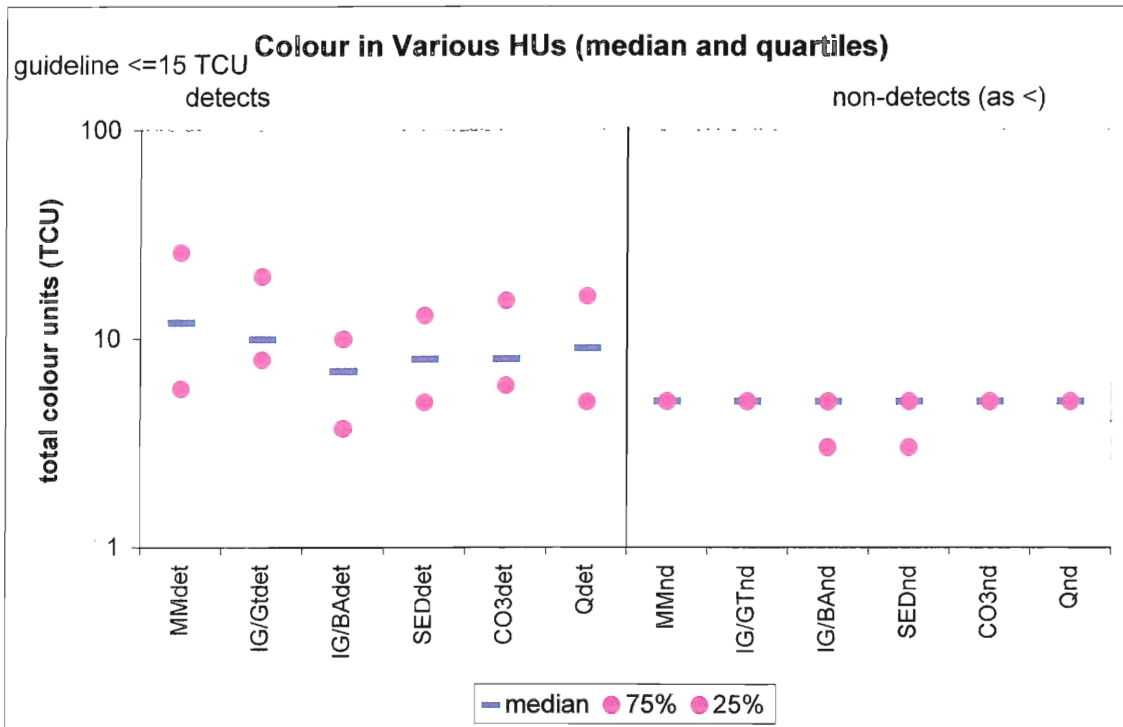
Figure 5.14: Distribution of colour in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	12.0	26.0	5.8	73	38.4	16.6
IG/GT	10.0	20.0	8.0	29	34.5	15.9
IG/BA	7.0	10.0	3.8	11	9.1	4.3
SED	8.0	13.0	5.0	158	21.5	7.0
CO3	8.0	15.3	6.0	32	25.0	11.0
Q	9.0	16.0	5.0	52	26.9	10.9

Table 5.14: Median and quartile values of colour in various HUs in Nova Scotia

5.1.15 Turbidity

Turbidity is measured in Nephelometric turbidity units, or NTU, using a device called a turbidimeter. Turbidity is a measure of the cloudiness of water and indirectly of the suspended material. It is usually caused by suspended particles such as silt, clay, algae, and detritus. Surface waters may range from 0-100 NTU, groundwaters near 0 NTU. Turbidity may reduce the effectiveness of disinfection (chlorination and ultraviolet light) treatment by shielding microorganisms, which may then reach the consumer.

Until 2005, the health-based guideline for turbidity was 1 NTU, the aesthetic objective 5 NTU. A new guideline document was issued in 2005. It states:

> 'While turbidity may be measured in secure groundwater supplies (i.e., not under the direct influence of surface water), it is not a concern in treated water from these sources provided it does not hinder disinfection. It is good practice to ensure that water entering the distribution system from a secure groundwater supply has a low turbidity level around 1.0 NTU. ...' 'Turbidity measured to be less than 5.0 NTU is not discernible to the naked eye, but at higher levels the particulate matter in water may cause colour, taste and odour concerns for consumers. For this reason, utilities should try to maintain the level of turbidity in the distribution system to below 5.0 NTU. An aesthetic objective has not been set in order to avoid confusion with the health-related guideline.'

Although the new guideline is somewhat confusing, the results in this study are compared to 1 and 5 NTU. In Nova Scotia, Figure 5.15 and Table 15.5 show that turbidity is lowest in the IG/BA HU, which may be partly a function of the smallest number of samples in this HU. Median turbidity values in the other HUs are generally less than 1-2 NTU. The highest 75 percentile values are in the MM, IG/GT and CO3 HUs where fracture flow predominates. In fracture flow, there is usually less opportunity for filtration compared to intergranular flow.

Figure 5.15: Distribution of turbidity in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ (1 NTU)	Percent of det+nd >GCDWQ (1 NTU)	Percent of det >GCDWQ (5 NTU)	Percent of det+nd >GCDWQ (5 NTU)
MM	1.10	6.58	0.40	144	50.7	42.7	27.1	22.8
IG/GT	1.20	5.46	0.30	51	52.9	40.9	25.5	19.7
IG/BA	0.45	1.70	0.21	18	27.8	21.7	11.1	8.7
SED	0.90	2.80	0.38	381	46.5	34.9	14.2	10.7
CO3	1.08	4.15	0.40	64	51.6	40.7	21.9	17.3
Q	0.70	2.10	0.30	107	42.1	35.2	11.2	9.4

Figure 5.15: Distribution of turbidity in various HUs in Nova Scotia

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5.1.16 Conductivity and TDS/Conductivity Ratio

Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of dissolved ions; on their total concentration, mobility, and valence; and on the temperature at the time of measurement. As noted in section 5.1.13, conductivity is related to TDS, thus conductivity results in Figure 5.16 and Table 5.16 show similar relationships to those for TDS (Figure 5.13 and Table 5.13)..

The general relationship between conductivity and TDS is:

conductivity (in umhos/cm or uS/cm) x factor (0.55 to 0.7) = TDS (in mg/L),

which means that the ratio of TDS/cond is theoretically in the range of 0.55 to 0.7. This relationship generally holds true in Nova Scotia (Figure 5.17 and Table 5.17), although the median values tend to be in the lower part of the range.
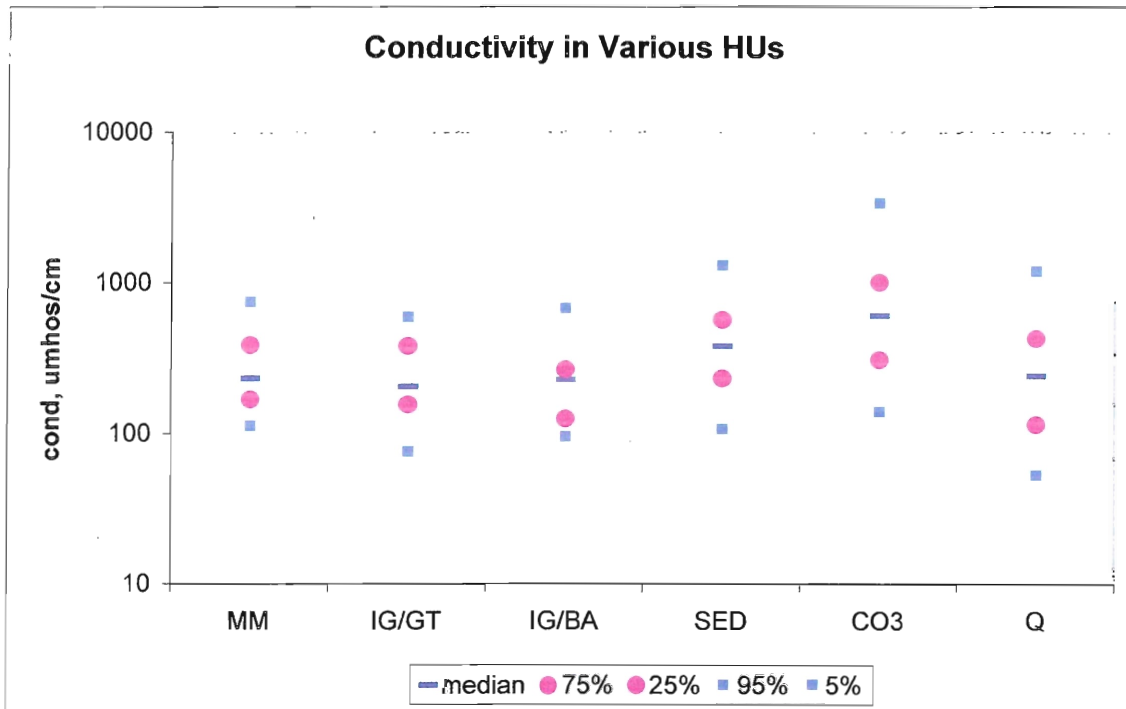
Figure 5.16: Distribution of conductivity in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	233.0	386.5	170.0	179	N/A	N/A
IG/GT	204.0	379.0	156.0	63	N/A	N/A
IG/BA	225.0	263.0	124.5	23	N/A	N/A
SED	375.0	559.5	230.0	527	N/A	N/A
CO3	597.0	992.0	305.0	77	N/A	N/A
Q	234.5	414.8	111.8	134	N/A	N/A

Table 5.16: Median and quartile values of conductivity in various HUs in Nova Scotia
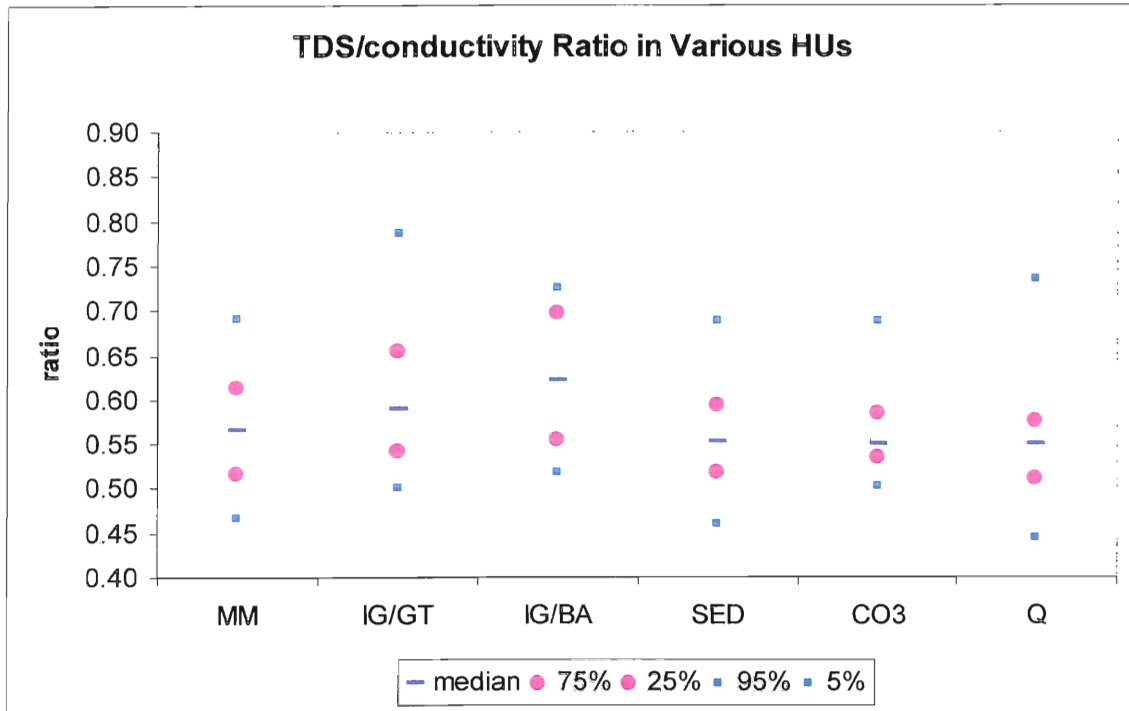
Figure 5.17: Distribution of TDS/conductivity in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.56738	0.61411	0.51809	165	N/A	N/A
IG/GT	0.59167	0.65539	0.54426	63	N/A	N/A
IG/BA	0.62288	0.69801	0.55601	23	N/A	N/A
SED	0.55509	0.59482	0.52105	480	N/A	N/A
CO3	0.55224	0.58590	0.53750	73	N/A	N/A
Q	0.55177	0.57911	0.51466	120	N/A	N/A

Table 5.17: Median and quartile values of TDS/conductivity in various HUs in Nova Scotia

5.1.17 pH

pH is a measure of the hydrogen concentration in drinking water sources. In Nova Scotia (Figure 5.18 and Table 5.18), the drinking water sources tend to be neutral to alkaline. The most alkaline water comes from the SED and CO3 HUs, the most acidic from the Q HU. The pH is controlled primarily by the carbonate equilibria, but microbial reactions can also play a significant role in some cases. The Q HU is likely closest to rainwater, with an acidic pH, unless the water has contacted carbonate material.

An acceptable pH range for drinking water is 6.5-8.5. One of the main objectives in controlling pH is to produce water that minimizes corrosion or incrustation. Low pH is a contributing factor to corrosion of water distribution systems, while high pH is a contributing factor to incrustation of pipes.
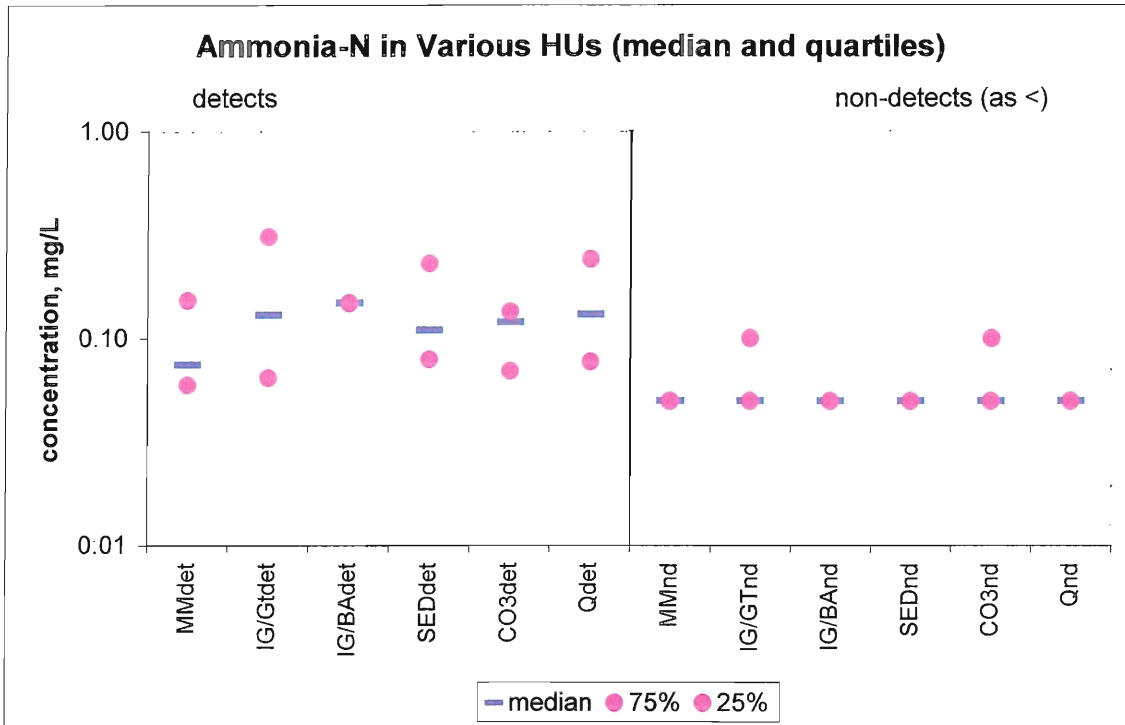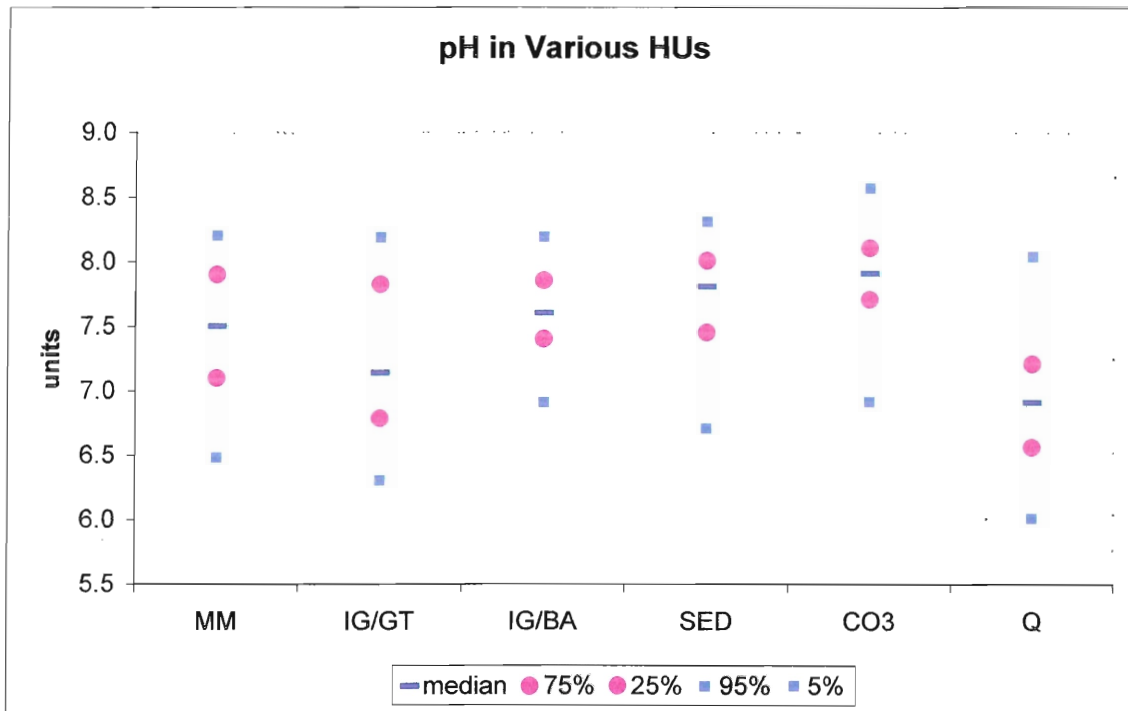
Figure 5.18: Distribution of pH in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No.	Percent of det <>GCDWQ	Percent of det+nd <>GCDWQ
MM	7.50	7.90	7.10	181	6.6	N/A
IG/GT	7.14	7.83	6.79	64	10.9	N/A
IG/BA	7.60	7.85	7.40	23	4.3	N/A
SED	7.80	8.00	7.45	531	4.5	N/A
CO3	7.90	8.10	7.70	77	7.8	N/A
Q	6.90	7.20	6.56	135	19.3	N/A

Table 5.18: Median and quartile values of pH in various HUs in Nova Scotia

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5.1.18 Total Organic Carbon

Total organic carbon (TOC) in drinking water includes all forms of organic matter (living microorganisms, suspended particles, dissolved molecules), but is most commonly composed of humic substances such as humic and fulvic acids. It considers both dissolved organic carbon and suspended organic carbon, and is determined by converting all carbon species present to CO_2 and correcting for any dissolved CO_2 species that were initially present. TOC is generally higher in surface water supplies than in groundwater. TOC in natural waters generally ranges from 1 to 30 mg/L. TOC in groundwater is generally within the range of 1 to 10 mg/L, though usually <4 to 5 mg/L.

There is no guideline for TOC. However it may contribute to colour and taste, and to the formation of trihalomethanes during disinfection with chlorine. In Nova Scotia (Figure 5.19 and Table 5.19), TOC is relatively consistent in all the HUs.
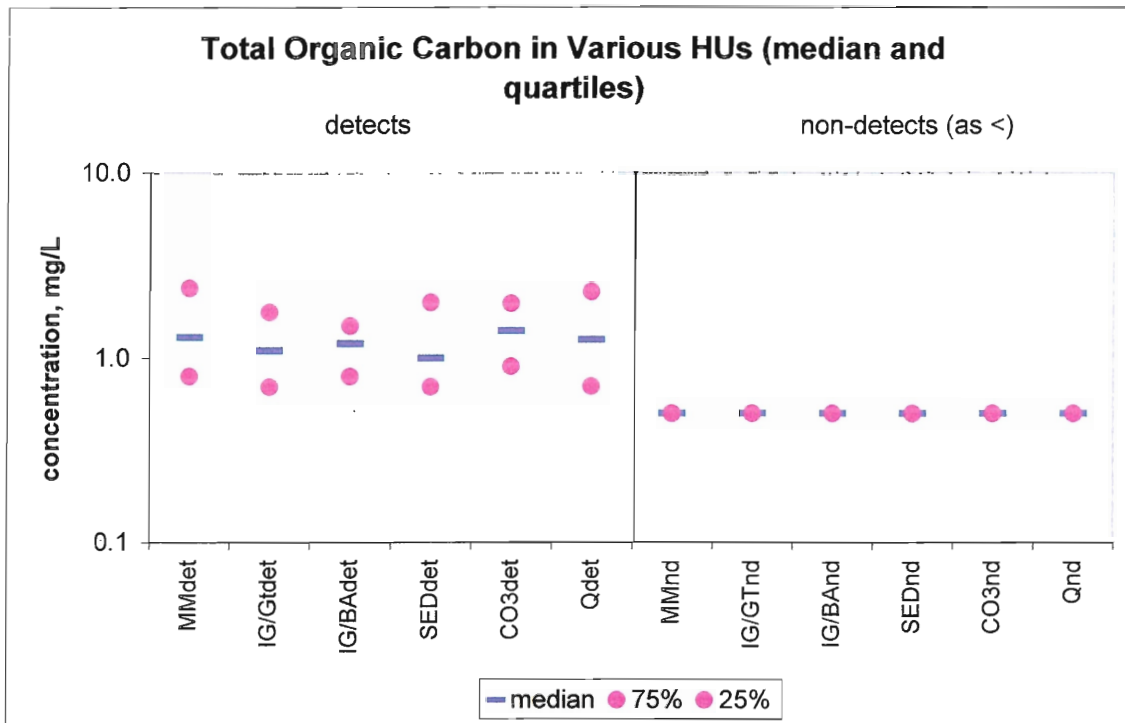
Figure 5.19: Distribution of TOC in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No.	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	1.30	2.40	0.80	83	N/A	N/A
IG/GT	1.10	1.78	0.70	34	N/A	N/A
IG/BA	1.20	1.50	0.80	13	N/A	N/A
SED	1.00	2.00	0.70	222	N/A	N/A
CO3	1.40	1.98	0.90	42	N/A	N/A
Q	1.25	2.28	0.70	78	N/A	N/A

Table 5.19: Median and quartile values of TOC in various HUs in Nova Scotia

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5.1.19 Aluminum

Aluminum is most commonly found in silicate igneous rocks as feldspars, feldspathoids, micas and the amphiboles. In low pH environments, the aluminum may be precipitated out in the form of an aluminum hydroxysulfate. In sedimentary rocks, the most common form of aluminum is found in clays. Clay minerals have a layered structure in which aluminum coordinated with oxide or hydroxide ions will form one layer while silicon with oxide will form the second layer. These clays will alternate with Si-O-Al bonds between the layers.

There is no consistent, convincing evidence that aluminum in drinking water causes adverse health effects in humans, and aluminum does not affect the acceptance of drinking water by consumers or interfere with practices for supplying good water. Therefore, a health-based guideline or aesthetic objective has not been established for aluminum in drinking water. However, operational guidelines have been established for treated water from water treatment plants using aluminum-based coagulants. Health Canada recommends an operational guidance values of less than 0.1 mg/L total aluminum for conventional treatment plants, and less than 0.2 mg/L total aluminum for other types of treatment systems (e.g., direct or in-line filtration plants, lime softening plants).

The operational guidance relates to recognition of advancing research into the health effects of aluminum and in an exercise of the precautionary principle, since there has

been some suggestion that aluminum may be a causal factor in the onset of Alzheimer's disease.

The interquartile range for aluminum in Nova Scotia drinking water (Figure 5.20 and Table 5.20) is below the operational guidelines set by Health Canada in all HUs. There are a few exceedances in all HUs except IG/BA, but as noted above, the guideline is for water treatment plants. Since the analytical results are for total metals, small amounts of suspended solids or colloidal material containing aluminium (such as clay minerals) may be dissolved during the acidification of the sample.

Figure 5.20: Distribution of aluminum in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ (0.1)	Percent of det+nd >GCDWQ (0.1)	Percent of det >GCDWQ (0.2)	Percent of det+nd >GCDWQ (0.2)
MM	0.02650	0.06000	0.00975	68	13.2	5.6	8.8	3.7
IG/GT	0.02300	0.05500	0.01300	27	7.4	3.5	7.4	3.5
IG/BA	0.01750	0.05025	0.01100	6	0.0	0.0	0.0	0.0
SED	0.01400	0.03400	0.01000	151	9.9	3.4	6.6	2.3
CO3	0.03000	0.08750	0.02150	14	21.4	4.4	7.1	1.5
Q	0.03000	0.08750	0.01550	62	16.1	10.2	9.7	6.1

Table 5.20: Median and quartile values of aluminum in various HUs in Nova Scotia

5.1.20 Arsenic

Arsenic is a naturally occurring earth element and as a result is present in trace amounts in living matter and is widely distributed through the earth's crust. Arsenic has also been used as a component in pesticides and wood preservatives. It is also a component of fossil fuels including oil, gasoline, coal and wood. When these fuels are burned, arsenic is released into the air.

The major source of arsenic in Nova Scotia groundwater is from mineral dissolution (arsenopyrite). Wells most likely to have elevated levels of arsenic are those underlain by slates, quartzites, and greywackes of the Meguma Group (Halifax and Goldenville Formations) and their more highly metamorphosed equivalents (schist and gneiss). Less commonly, elevated levels may occur in areas underlain by granite and sandstone. Elevated arsenic levels in drinking water are most often found in drilled wells. Dug well water and surface water usually contain barely detectable levels of arsenic unless affected by contamination from mine waste, acid rock drainage, or arsenic-containing waste chemicals.

The current guideline for arsenic is 0.025 mg/L. In Nova Scotia (Figure 5.21 and Table 5.21), the IG/GT, IG/BA and SED HUs of this data did not exceed this guideline. In the remaining HUs, the highest concentrations of arsenic are in the MM HU, with about 4.3% exceedances. Health Canada is considering lowering the guideline for arsenic to 0.01 mg/L, similar to the United States. Should this occur, it could approximately double the exceedances in the MM HU (prop 0.01 (proposed 0.01 mg/L) in Table 5.21).
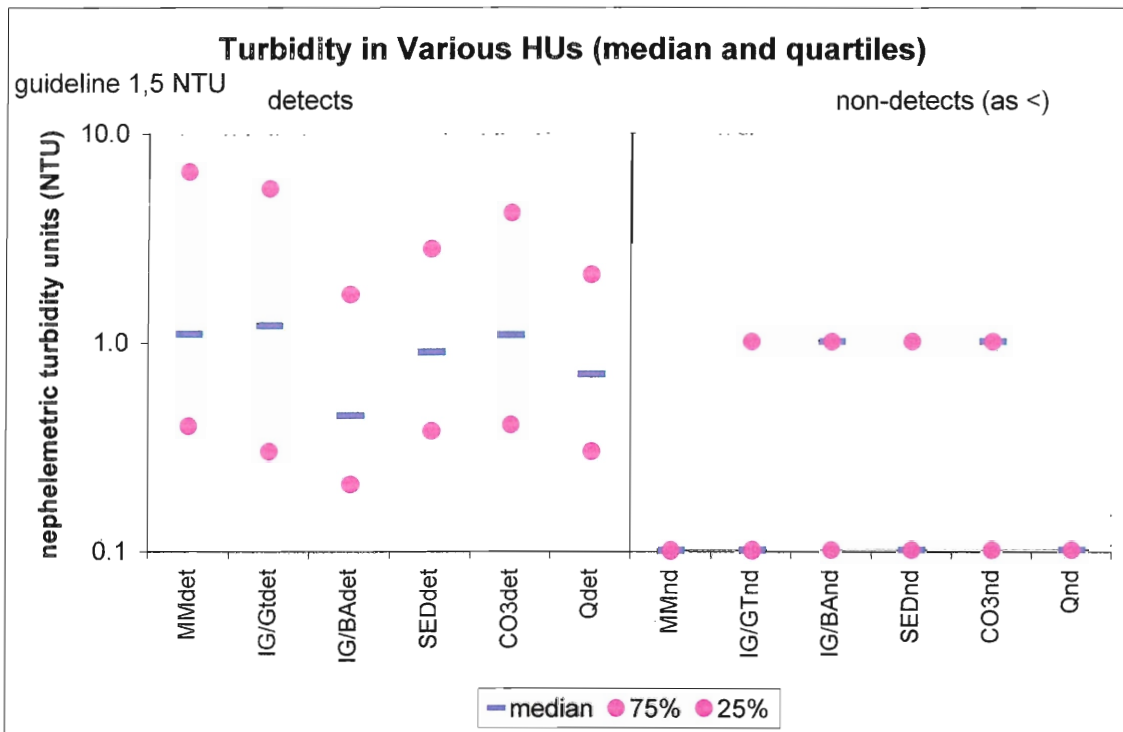
Figure 5.21: Distribution of arsenic in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ	Percent of det >prop 0.01	Percent of det+nd >prop 0.01
MM	0.00420	0.01550	0.00200	51	13.7	4.3	31.4	9.8
IG/GT	0.00300	0.00475	0.00200	27	0.0	0.0	11.1	4.8
IG/BA	0.00160	0.00200	0.00105	4	0.0	0.0	0.0	0.0
SED	0.00300	0.00500	0.00200	221	0.0	0.0	5.0	2.2
CO3	0.00480	0.00700	0.00200	33	3.0	1.3	15.2	6.4
Q	0.00150	0.00200	0.00065	15	6.7	0.9	6.7	0.9

Table 5.21: Median and quartile values of arsenic in various HUs in Nova Scotia

5.1.21 Barium

Barium is found in igneous, sedimentary and carbonate rocks. It most commonly occurs as a carbonate (witherite) and sulfate (barite). Hem (1985) suggests that the solubility of barite is a likely control over the concentration of barium in natural water.

A MAC for barium has been set at 1.0 mg/L. It is not considered to be an essential element for human nutrition. It is absorbed through the lungs and gastrointestinal tract, and is deposited mainly in the bone. There is inadequate data to evaluate barium as a carcinogen. Although there has been some suggestion that small increases in blood pressure due to barium may result in increased coronary heart disease, this has not been observed in epidemiological studies to date (GCDWQ supporting documentation for barium).

In Nova Scotia (Figure 5.22 and Table 5.22), all HUs have 95 percentile values less than the guideline. There is a large variance between igneous and metamorphic rocks and the sedimentary-based units. The IG/BA HU shows little variance in concentration with percentiles being very close range to the median value. All other HUs show a wider range of values for barium concentrations, with the SED and CO3 HU's being highest. The CO3 HU shows a small proportion of exceedances (Table 5.22).

Figure 5.22: Distribution of barium in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.01020	0.03175	0.00600	115	0.0	0.0
IG/GT	0.01400	0.05900	0.00800	45	0.0	0.0
IG/BA	0.00650	0.00828	0.00308	6	0.0	0.0
SED	0.08600	0.15000	0.03205	454	0.2	N/A
CO3	0.06450	0.11500	0.02455	75	2.7	N/A
Q	0.03100	0.07800	0.01500	97	0.0	N/A

Table 5.22: Median and quartile values of arsenic in various HUs in Nova Scotia

5.1.22 Boron

Boron is ubiquitous in the environment, but is most commonly found in igneous rocks in the mineral tourmaline. Tourmaline is resistant to weathering by water and as a result, boron may not be found in high concentrations in groundwater. Boron may also be present as an accessory constituent of biotite and the amphiboles in igneous rocks. It may also be found in evaporite deposits of certain closed basins in the form of colemanite and kernite. Boron compounds, such as boric acid and borax, are used is used in the manufacture of borosilicate glass, insecticides, and enamels, and in industries such as cosmetics, leather, textile, paint, and wood-processing. Borax is used extensively as a cleaning compound.

In Nova Scotia (Figure 5.23 and Table 5.23), boron is fairly consistent in all HUs except for the CO3 HU. In carbonate rocks, the median boron concentration is approximately 0.1 mg/L, about five times that in the other HUs. None of the HUs in this study indicated boron concentrations greater than the drinking water guideline of 5.0 mg/L.

Figure 5.23: Distribution of boron in various HUs in Nova Scotia

B detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.01600	0.03500	0.01000	121	0.0	0.0
IG/GT	0.01900	0.03100	0.01000	37	0.0	0.0
IG/BA	0.01750	0.02800	0.01025	14	0.0	0.0
SED	0.02100	0.06075	0.01000	262	0.0	0.0
CO3	0.10000	0.19000	0.03600	49	0.0	0.0
Q	0.01700	0.03250	0.00900	59	0.0	0.0

Table 5.23: Median and quartile values of boron in various HUs in Nova Scotia

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5.1.23 Copper

The most common source of copper in drinking water is from corrosion of copper pipes within the home. When water remains in contact with the pipes for long periods of time, it dissolves copper from the pipes. When this water contacts soaps or detergents, the copper precipitates from the water as a turquoise-blue sediment. Flushing the lines prior to using the water will help to minimize such problems. Major sources of copper in natural waters are industrial/manufacturing, smelters, acid mine drainage, and agricultural fungicides/pesticides.

The guideline for copper of 1.0 mg/L is based on aesthetic considerations of taste and staining characteristics. It is an essential nutrient for human nutrition and is required in many enzyme functions. Although the intake of large doses of copper has resulted in adverse health effects (liver damage), the levels at which this occurs are much higher than the maximum acceptable concentration.

Copper levels in Nova Scotia drinking water (Figure 5.24 and Table 5.24) show a median range of 0.01 mg/L to 0.10 mg/L. A very small percentage of HUs have exceedances with the IG/GT HU having the highest proportion at 5.5%.
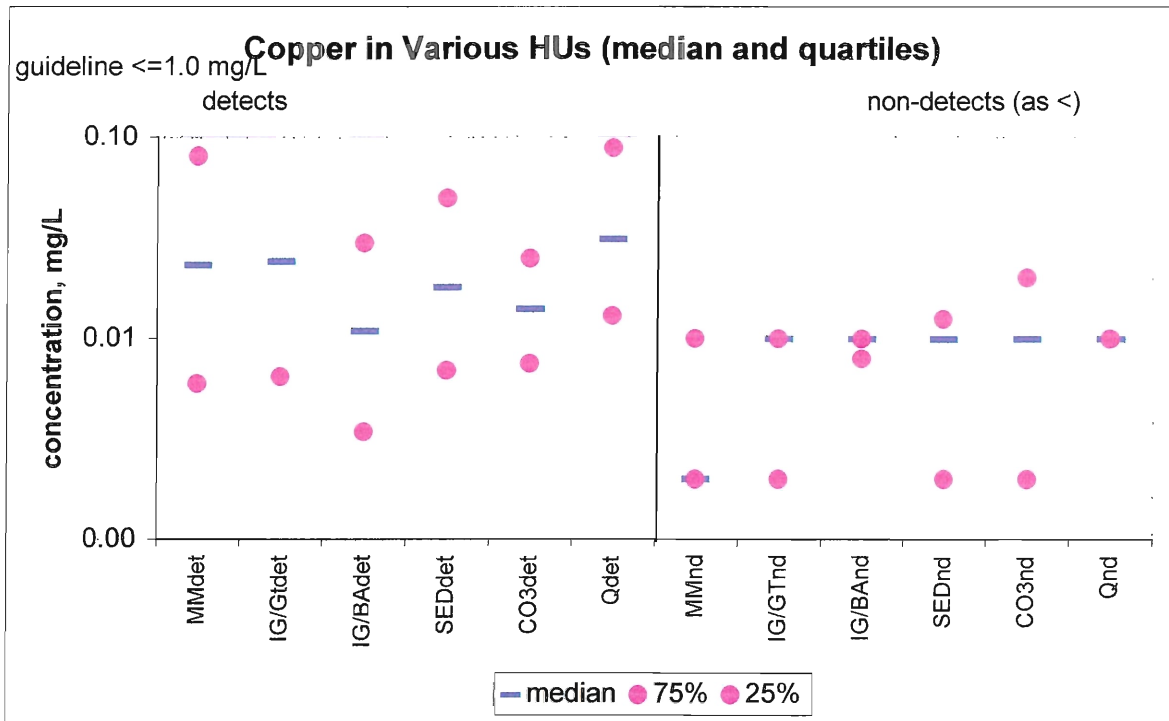
Figure 5.24: Distribution of copper in various HUs in Nova Scotia

Note: 75th percentile for IG/GT just off scale at 0.1185 mg/L

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.02300	0.08100	0.00600	135	2.2	1.7
IG/GT	0.02400	0.11850	0.00650	55	5.5	4.5
IG/BA	0.01100	0.03000	0.00350	15	0.0	0.0
SED	0.01800	0.04975	0.00700	274	1.1	0.6
CO3	0.01400	0.02500	0.00750	48	0.0	0.0
Q	0.03100	0.08775	0.01300	100	1.0	0.7

Table 5.24: Median and quartile values of copper in various HUs in Nova Scotia

5.1.24 Iron

Natural geological sources include amphiboles, ferromagnesian micas, iron sulfides, magnetite, oxides, carbonates and iron clay minerals. Iron may also be complexed with organic acids. Manmade sources include well casing, piping, pump parts, storage tanks, and other objects of cast iron or steel which may be in contact with the water, as well as industrial wastes.

Iron is an essential element in human nutrition. Toxic effects have resulted from the ingestion of large quantities of iron, but there is no evidence to indicate that concentrations of iron commonly present in food or drinking water constitute any hazard to human health. Therefore, a maximum acceptable concentration has not been set.

The guideline of 0.3 mg/L has been established on the basis of aesthetic considerations. Above this level, iron may stain laundry and plumbing fixtures, and cause undesirable tastes in beverages. When exposed to the air, dissolved iron precipitates and imparts a reddish-brown colour to the water. Even at concentrations of less than 0.3 mg/L, taste may be affected under some conditions. The presence of iron may promote the growth of certain microorganisms, leading to the deposition of a slimy coat in pipes.

In Nova Scotia drinking water (Figure 5.25 and Table 5.25), the highest concentrations for iron are in the IG/GT and SED HUs. However, the MM and CO3 HUs show the highest percentages of detects above the guideline. Overall, iron concentrations tend to be

elevated across the province in all HUs, with the percentage exceedance varying from 13 to 31% of the samples (detects+nds).
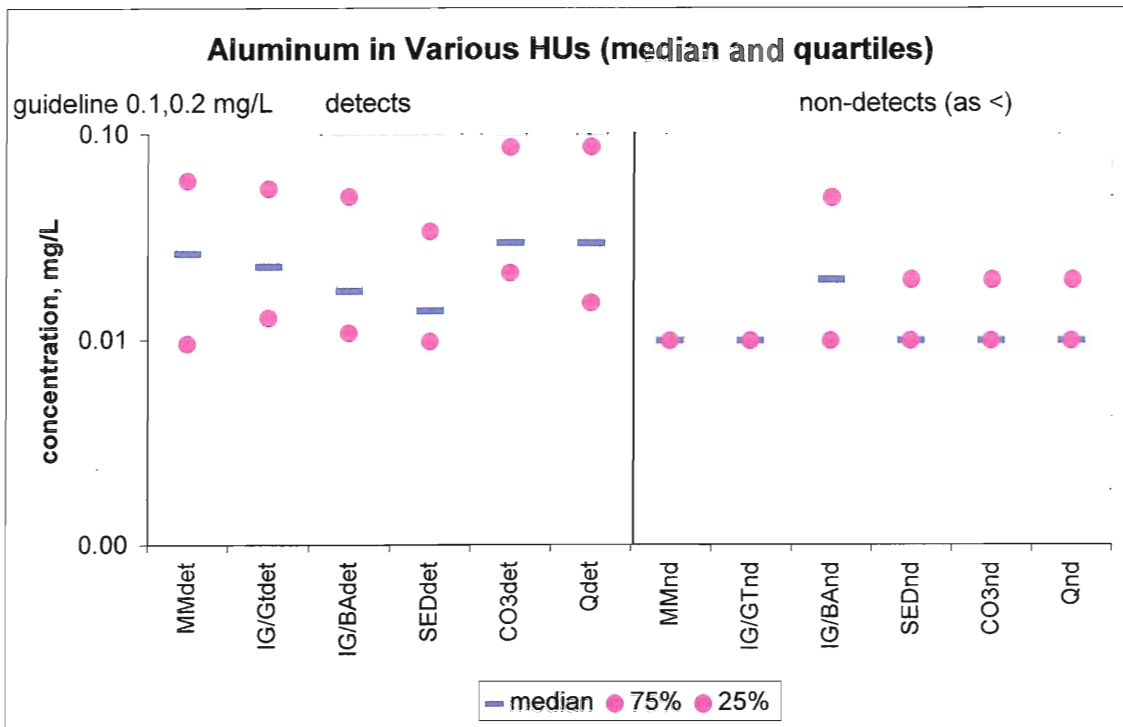

Figure 5.25: Distribution of iron in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.24000	1.66675	0.08950	116	47.4	30.7
IG/GT	0.26000	0.80000	0.09000	41	39.0	24.2
IG/BA	0.18000	0.28500	0.03000	11	27.3	13.0
SED	0.16000	0.46000	0.06000	281	33.8	17.7
CO3	0.24000	0.84000	0.10000	43	44.2	24.1
Q	0.11000	0.39000	0.04350	83	32.5	19.1

Table 5.25: Median and quartile values of iron in various HUs in Nova Scotia

5.1.25 Lead

Lead is widespread in the environment through human use. It is found in lead-based paints, soil and dust, and vehicle emissions. The primary source of lead in drinking water is from the corrosion of piping within the consumer's distribution system. Lead is found in solder used to join copper pipes, and in some older systems, lead pipes were used, although these are rare in newer household systems. Where the plumbing system contains lead, the first drawn water should be discarded. High levels of lead can be found in corrosive water that has been allowed to sit in the pipes without flushing or use for long periods of time.

The guideline of 0.01 mg/L has been established on the basis of toxicological considerations. Lead has long been recognized as a general metabolic poison which causes a variety of human disorders. It can be absorbed by the body through inhalation, ingestion, dermal contact (mainly as a result of occupational exposure) or transfer via the placenta. Children are more susceptible to the effects of lead poisoning than adults since lead has cumulative effects.

Nova Scotia drinking water (Figure 5.26 and Table 5.26) has relatively low concentrations of lead in all HUs. The percentage exceedances are relatively low. However, the HUs with the highest percentages (IG/GT, IG/BA, and Q) are those which tend to have less buffering capacity and other factors such as low pH, hardness, and alkalinity which are all factors affecting the corrosivenss of the water.
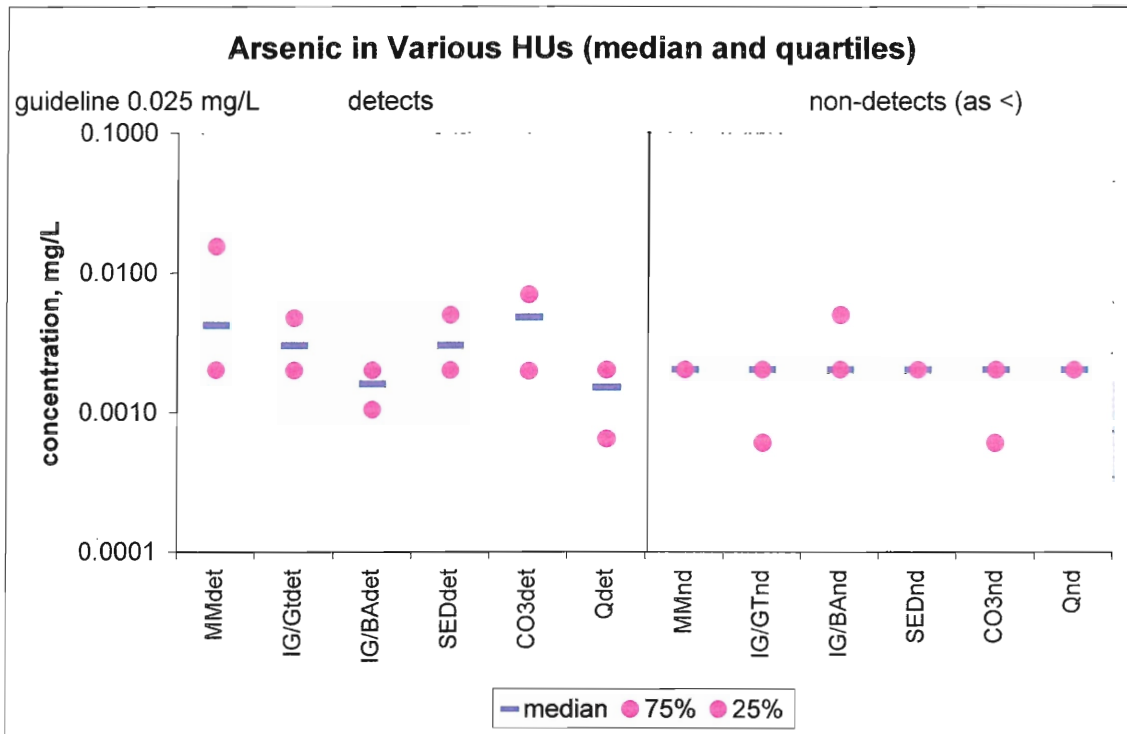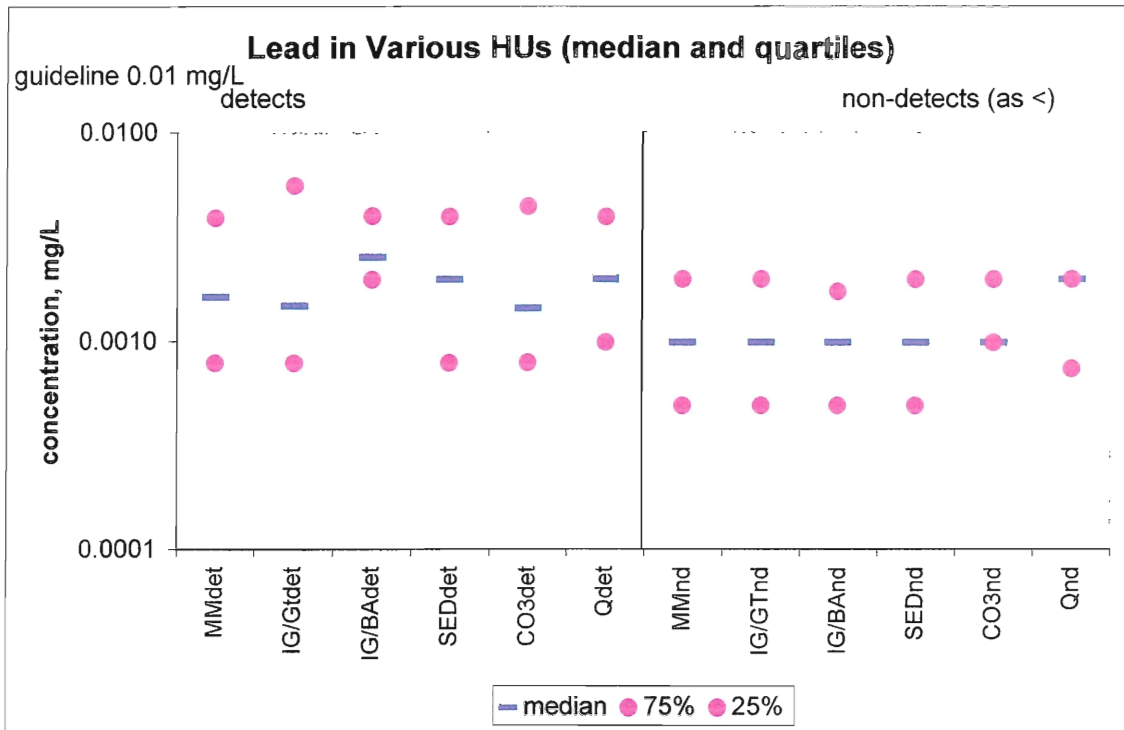
Figure 5.26: Distribution of lead in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.00165	0.00393	0.00080	74	5.4	2.4
IG/GT	0.00150	0.00560	0.00080	33	12.1	6.3
IG/BA	0.00255	0.00403	0.00200	8	12.5	4.5
SED	0.00200	0.00400	0.00080	144	6.9	2.0
CO3	0.00145	0.00445	0.00080	26	0.0	0.0
Q	0.00200	0.00398	0.00100	70	7.1	4.4

Table 5.26: Median and quartile values of lead in various HUs in Nova Scotia

5.1.26 Manganese

Manganese is not an essential constituent of the silicate rock materials but can substitute for iron, magnesium, or calcium in silicate structures. It is found in significant quantities in basalt rocks and in many olivines, pyroxenes and amphiboles. If in contact with the atmosphere, it will precipitate forming a layer of Mn^{4+}. These layers usually contain iron and sometimes cobalt, lead, zinc, copper, nickel and barium. There are manganese deposits in Nova Scotia, and elevated groundwater values have been reported in some (for example, in Hennigar, 1972).

The guideline of 0.05 mg/L for manganese has been established for aesthetic reasons. It is an essential nutrient for humans. Manganese in water supplies stains plumbing fixtures and laundry, causes undesirable tastes in beverages and may form coatings on pipes, which may slough off as a black precipitate. Iron and manganese often tend to occur together.

Manganese in Nova Scotia drinking water (Figure 5.27 and Table 5.27) exceeds its guidelines in all HUs. Median values are below the guideline in the IG/BA, CO3 and Q HUs. The lower percentage exccedance in the IG/BA HU may be in part due to the smaller sample size. Overall, manganese concentrations tend to be elevated across the province in all HUs, with the percentage exceedance varying from 9 to 44% of the samples (detects+nds); this range increases to 22 to 44% if the IG/BA HU is ignored.
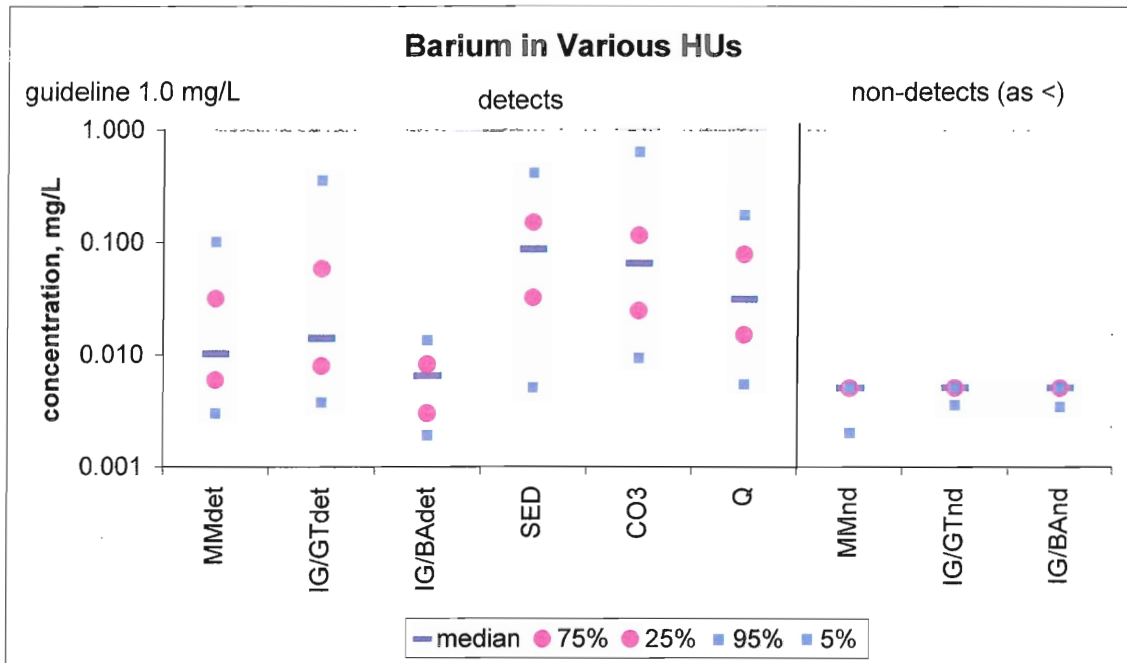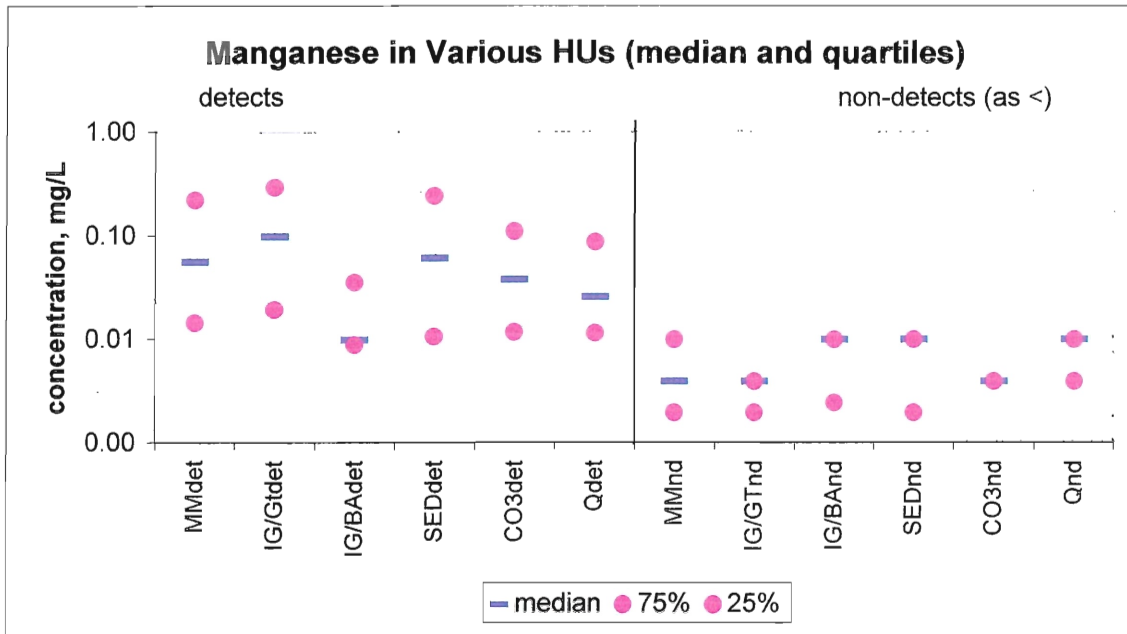
Figure 5.27: Distribution of manganese in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.05600	0.22000	0.01475	144	51.4	42.3
IG/GT	0.10000	0.29800	0.02000	49	59.2	43.9
IG/BA	0.01000	0.03600	0.00900	9	22.2	8.7
SED	0.06200	0.24500	0.01100	291	52.2	28.3
CO3	0.03800	0.11000	0.01200	53	43.4	29.1
Q	0.02600	0.08700	0.01175	84	35.7	21.6

Table 5.27: Median and quartile values of manganese in various HUs in Nova Scotia

5.1.27 Molybdenum

Molybdenum is not a common earth element and as a result may or may not be present in drinking water. Molybdenum is most often found in molybdenite and other metal molybdates; it is also present in fossil fuels. Molybdenum has a generally high geochemical mobility and a tendency to enter into solution in water under normal earth surface conditions (Hem, 1985).

Molybdenum in Nova Scotia (Figure 5.28 and Table 5.28) has very low concentrations in all HUs, with the 75 percentile rarely more than 0.01mg/L. There were no analyses of molybdenum available from the IG/BA HU.
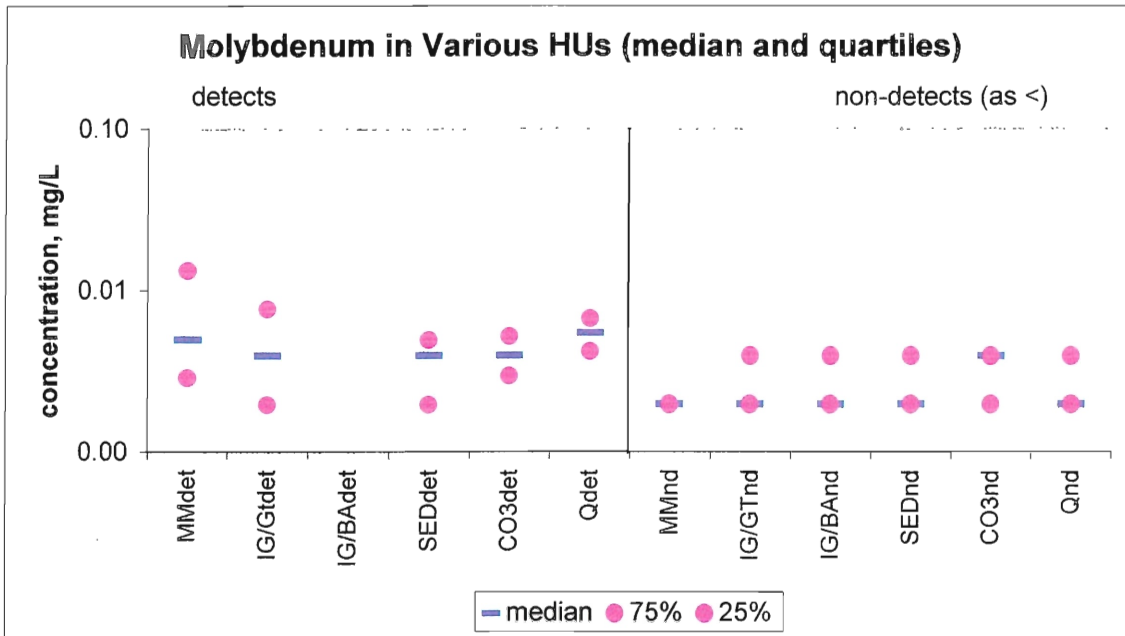
Figure 5.28: Distribution of molybdenum in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.00500	0.01325	0.00293	24	N/A	N/A
IG/GT	0.00400	0.00775	0.00200	10	N/A	N/A
IG/BA				0	N/A	N/A
SED	0.00400	0.00500	0.00200	51	N/A	N/A
CO3	0.00400	0.00525	0.00300	12	N/A	N/A
Q	0.00550	0.00675	0.00425	6	N/A	N/A

Table 5.28: Median and quartile values of molybdenum in various HUs in Nova Scotia

5.1.28 Strontium

Strontium is a common element, often replacing calcium or potassium in igneous rocks in minor amounts, mainly in igneous rocks of granitic or syenitic composition rather than those of basaltic composition. In sedimentary rocks, strontium is often found as a carbonate (strontianite) or sulfate (celesite). Strontium is generally less abundant in igneous rocks, but more abundant in carbonate rocks, than barium (Hem, 1985).

There is no guideline for Sr in drinking water in Canada or in USEPA guidelines. Minnesota Department of Health established a health risk limit of 4.0 mg/L based on daily ingestion over a lifetime, considering the bone system. The body views Sr as a replacement for Ca but uses and retains Sr less effectively than Ca.

Median strontium levels in Nova Scotia drinking water (Figure 5.29 and Table 5.29) are in the order of approximately 0.10 mg/L in all HUs except the CO3 and IG/BA HUs. Strontium is high in the CO3 HU as it is chemically similar to calcium. R. Ryan (DNR, personal communication) indicated that gypsum and anhydrites in the Windsor Group (CO3 HU) are often high in Sr (~200 to several thousand ppm in the rock).
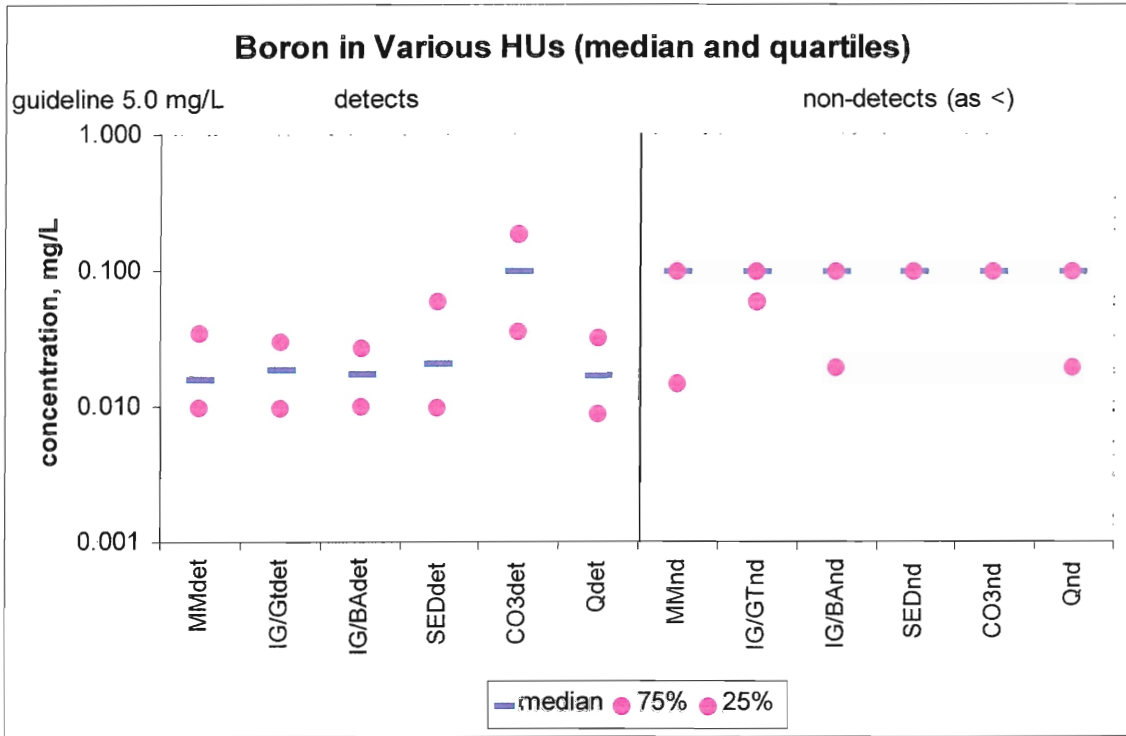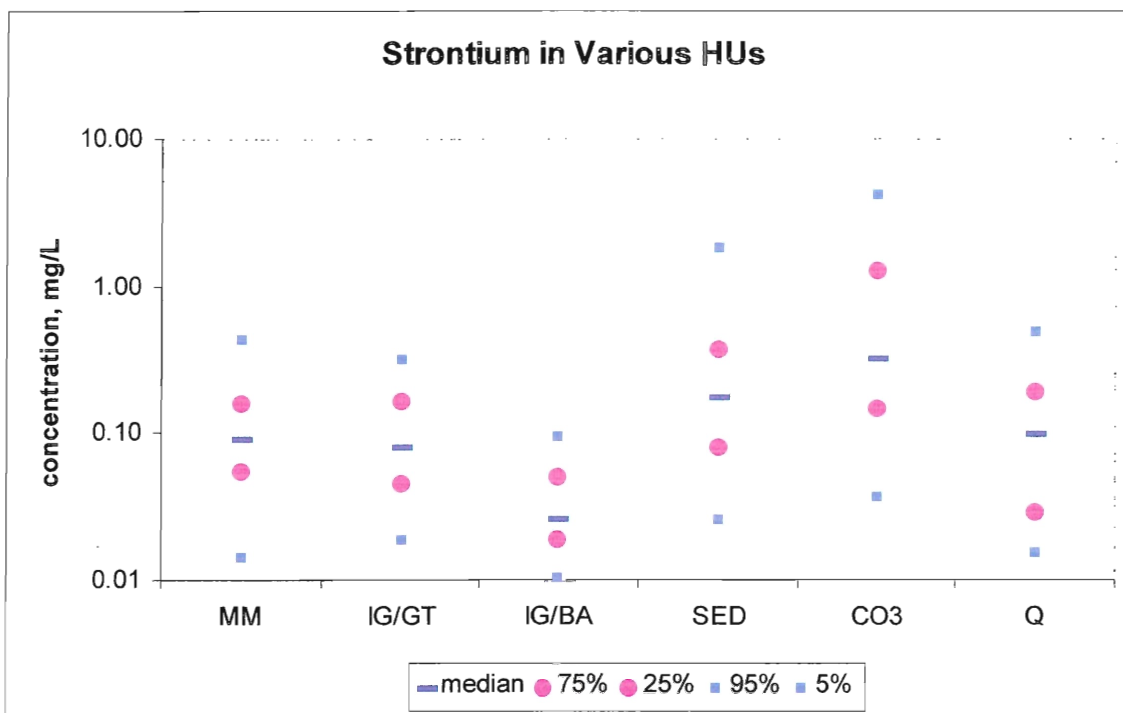
Figure 5.29: Distribution of strontium in various HUs in Nova Scotia

HU	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.09300	0.16000	0.05500	117	N/A	N/A
IG/GT	0.08150	0.16850	0.04675	48	N/A	N/A
IG/BA	0.02600	0.05100	0.01925	12	N/A	N/A
SED	0.18000	0.37000	0.08200	303	N/A	N/A
CO3	0.33000	1.30000	0.15300	57	N/A	N/A
Q	0.10200	0.19600	0.03000	77	N/A	N/A

Table 5.29: Median and quartile values of strontium in various HUs in Nova Scotia

5.1.29 Uranium

Uranium occurs as a number of isotopes of which uranium-238 is predominant. It is found in many minerals including uraninite, autunite, uranophane, torbernite, and coffinite (Wikipedia, 2006). Uranium can also be found in phosphate rock deposits.

The amount of uranium in well water throughout Nova Scotia varies with the concentration of uranium in the bedrock. Wells most likely to have high levels of uranium are those in areas with granite or alkaline sandstone and shale bedrock. Large areas of mainland Nova Scotia have granite bedrock; the northwestern part of the province has alkaline sandstone and shale. Elevated levels of uranium are more likely to be found in drilled wells than in dug wells or surface water supplies.

The drinking water guideline for uranium is 0.02 mg/L. Although ubiquitous in the environment, uranium has no known metabolic function in animals and is currently regarded as non-essential. Absorption of uranium from the gastrointestinal tract depends upon the solubility of the uranium compound and other factors, but nephritis is the primary chemically induced effect of uranium in animals and humans. Little information is available on the chronic health effects of exposure to environmental uranium in humans (GCDWQ supporting documentation for U).

In Nova Scotia drinking water (Figure 5.30 and Table 5.30), there is wide variance in amounts of uranium throughout the HUs of Nova Scotia, varying by an order of magnitude. The highest median values occur in the IG/GT and SED HUs. Exceedances

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are highest in the IG/GT HU as expected (Table 5.30), followed by the SED and MM
HUs.
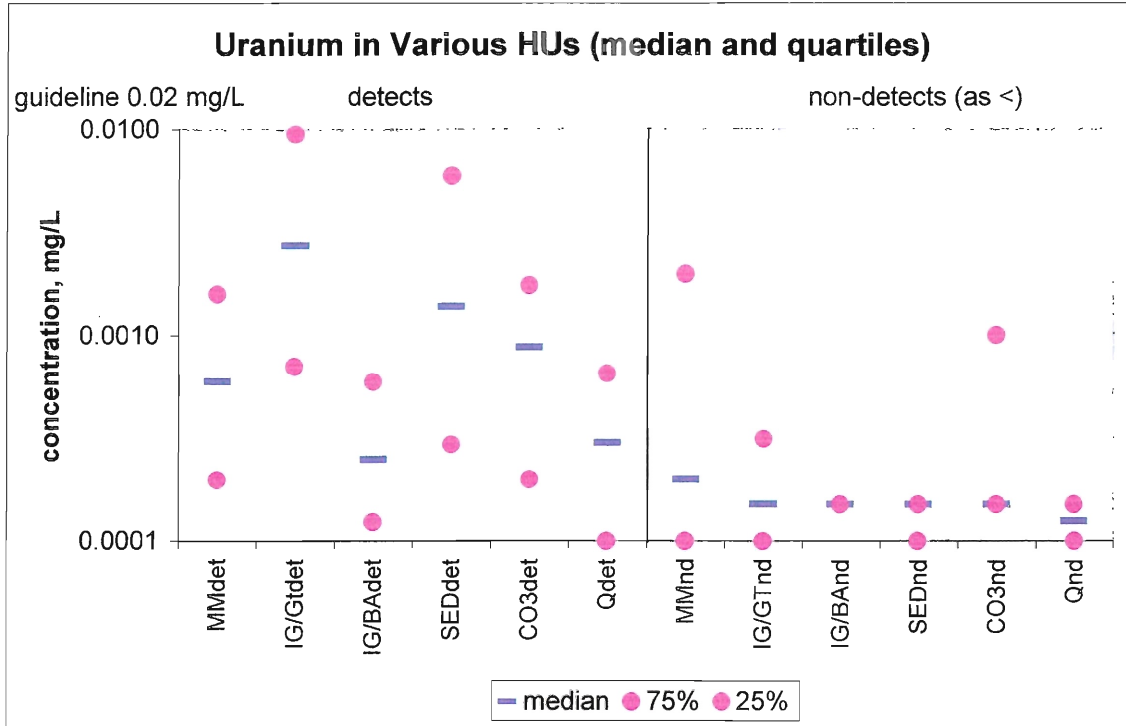
Figure 5.30: Distribution of uranium in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.00060	0.00160	0.00020	71	7.0	3.2
IG/GT	0.00276	0.00954	0.00071	46	8.7	7.4
IG/BA	0.00025	0.00060	0.00013	6	0.0	0.0
SED	0.00140	0.00600	0.00030	267	4.5	3.3
CO3	0.00087	0.00175	0.00020	52	1.9	1.4
Q	0.00030	0.00065	0.00010	38	0.0	0.0

Table 5.30: Median and quartile values of strontium in various HUs in Nova Scotia

5.1.30 Zinc

The most likely source of zinc in drinking water is from corrosion of the distribution system (eg. galvanized fittings). Other sources include industry, lead-zinc smelters and geological. Zinc is fairly common and has the same abundance as copper or nickel. It tends to be more soluble in water than either Cu or Ni.

Zinc is an essential element for all living things, with zinc-containing proteins and enzymes involved in every aspect of metabolism. Long-term ingestion of quantities considerably in excess of required amounts has not resulted in adverse effects. Also, because of efficient homeostatic control mechanisms, the occurrence of chronic zinc toxicity is extremely unlikely. Thus a MAC for zinc in drinking water has not been set.

The guideline of 5.0 mg/L for zinc is based on aesthetic considerations. Water containing zinc at levels above 5.0 mg/L tends to appear milky, develops a greasy film when boiled, and has an undesirable metallic or astringent taste.

In Nova Scotia (Figure 5.31 and Table 5.31), levels of zinc are well below drinking water guidelines, with a median concentration of 0.02-0.03 mg/L. The only HU to have any exceedances was the IG/GT HU, with only 1.9% of detects exceeding the 5 mg/L guideline.
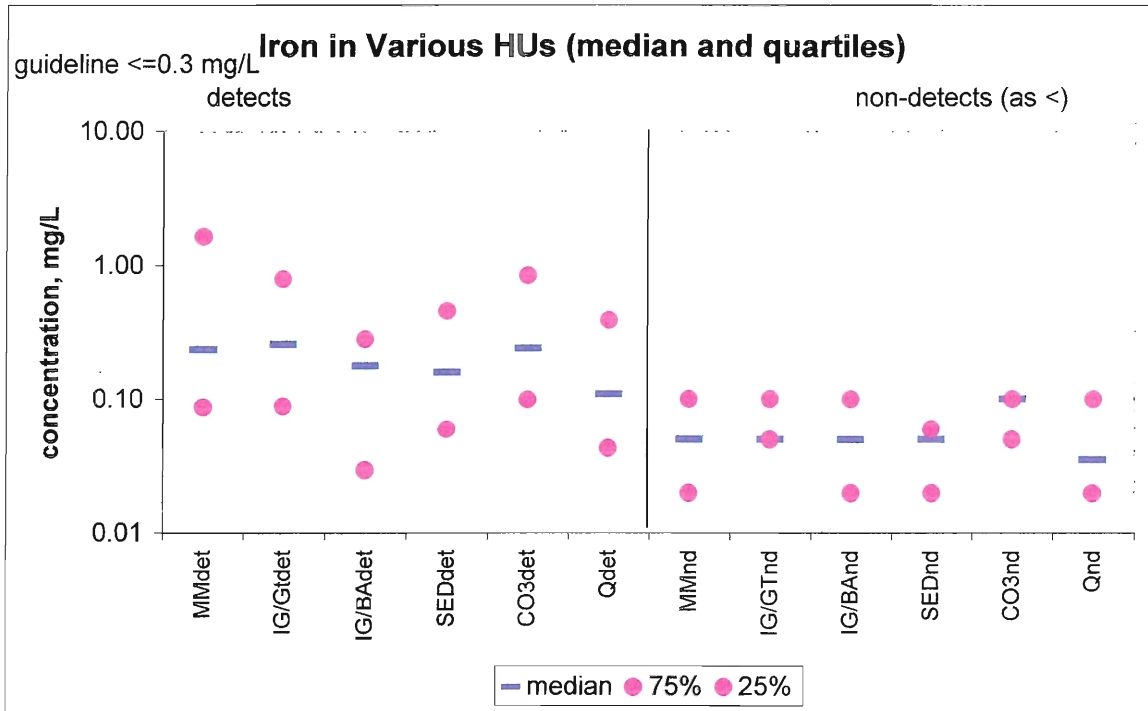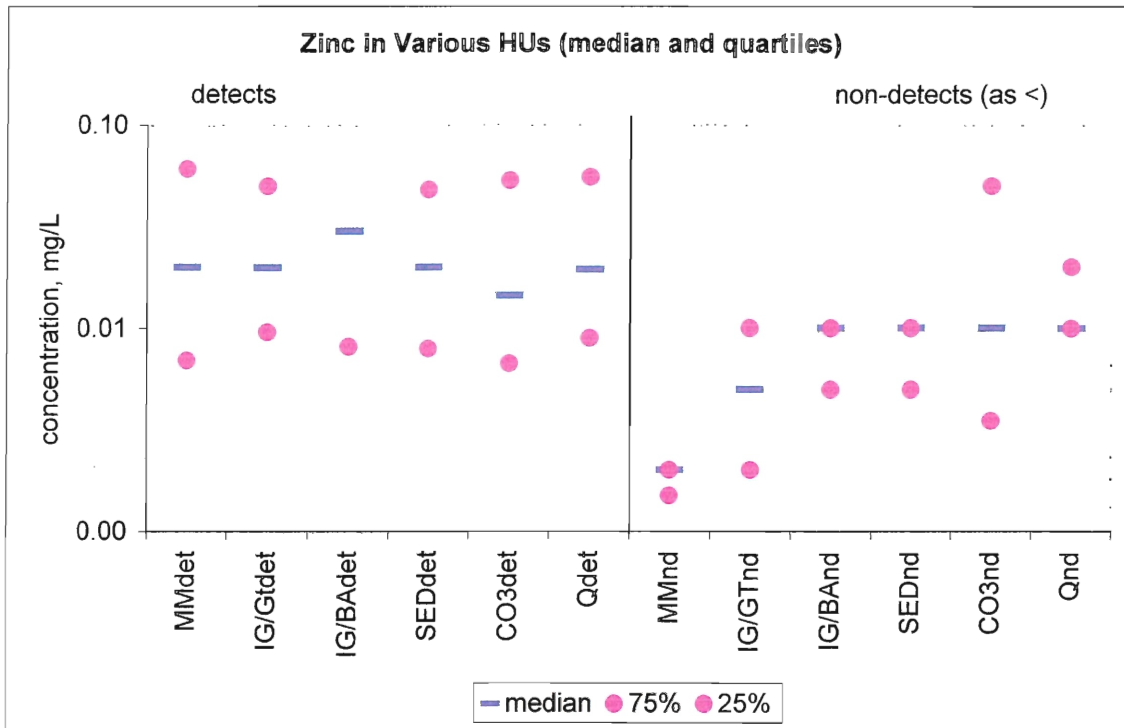
Figure 5.31: Distribution of zinc in various HUs in Nova Scotia

HU detects	Median	75th Percentile	25th Percentile	No. samples	Percent of det >GCDWQ	Percent of det+nd >GCDWQ
MM	0.02000	0.06100	0.00700	152	0.0	0.0
IG/GT	0.02000	0.05050	0.00968	52	1.9	1.5
IG/BA	0.03000	0.13000	0.00825	18	0.0	0.0
SED	0.02000	0.04800	0.00800	344	0.0	0.0
CO3	0.01450	0.05308	0.00675	64	0.0	0.0
Q	0.01950	0.05550	0.00900	96	0.0	0.0

Table 5.31: Median and quartile values of zinc in various HUs in Nova Scotia

5.2 Hydrostratigraphic Units

In this section, exceedances will be discussed briefly based on hydrostratigraphic units rather than individual parameters as outlined in Section 5.1. The data for percentage exceedances of various health- and aesthetic-related parameters are presented in Tables 5.32 and 5.33, which are located at the end of this section. Additional data can be found in Appendix A.

Median values for parameters from the various HUs from this study were found to be consistent with those reported in the literature from other studies, as shown in the summary comparison table in Appendix B.

5.2.1 **Metamorphic HU**

The MM HU generally has few exceedances for health-related parameters (Table 5.32). Less than 5% of all samples taken for arsenic exceed the current guidelines of 0.025 mg/L, although this may approach 10% if the guideline is lowered to 0.01 mg/L. Ingestion of drinking water that has high concentrations of arsenic over a short period of time can cause sickness including nausea, diarrhea and muscle pain. Over the long term, exposure to low levels of arsenic may cause certain types of cancer (NSEL water website, www.gov.ns.ca/enla/water/arsenic.asp).

More than 5% of all samples in the MM HU may exceed 0.1 mg/L of aluminum. However, there is no consistent, convincing evidence that aluminum in drinking water causes adverse health effects in humans, and aluminum does not affect the acceptance of

drinking water by consumers or interfere with practices for supplying good water (GCDWQ supporting documentation for aluminum). The guideline is set as an operational guidance for water treatment plants in recognition of advancing research into the health effects of aluminum and in an exercise of the precautionary principle.

For aesthetic-related parameters, the MM HU has some exceedances (Table 5.33), the most noticeable being iron, manganese and turbidity. Iron and manganese can cause red to brown staining on porcelain fixtures, dishes and flatware. Elevated levels of turbidity can cause water to take on a cloudy appearance. Also notable in the MM HU are elevated levels of colour, and pH outside the recommended range (generally lower rather than higher).

5.2.2 Igneous/Granite HU

The IG/GT HU shows exceedances in the health-related parameters fluoride, lead and uranium (Table 5.32), with 5% or more of all samples being above their guidelines. Fluoride in excess can cause bone disease, and in children can cause a mottled appearance of teeth. Lead can cause delays in physical or mental development of children. Children could also show slight deficits in attention and learning. Adults ingesting elevated levels of lead can experience kidney problems and high blood pressure. Uranium may cause kidney toxicity.

The IG/GT HU has the same exceedances as the MM HU in terms of aesthetic objectives (Table 5.33). Higher levels of turbidity, iron, manganese and colour are noted.

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5.2.3 Igneous/Basalt HU

There are no exceedances for health-related parameters exceeding >5% of samples taken in the IG/BA HU (Table 5.32). Included in the <5% exceedances are fluoride, nitrate-nitrite-N, aluminum, arsenic, barium, boron, lead, and uranium. Water with elevated nitrate may result in blue-baby syndrome and shortness of breath in infants below six months.

The IG/BA HU shows no large exceedances of turbidity, iron or manganese compared to the previous HUs (Table 5.33). Iron exceeds guidelines set in 10-20% of samples taken. Turbidity and manganese exceed guidelines in 5-10% of samples taken from this HU. Statistical analyses of samples from this HU are not considered as reliable as the other HUs due to the lower number of samples available (number varies for each individual parameter).

5.2.4 Sedimentary HU

The health-related parameters in the SED HU are all at <5% in the samples taken (Table 5.32). Specifically, fluoride, nitrate-nitrite-N, aluminum, arsenic, barium, boron, lead and uranium are shown to exceed their guidelines in <5% of samples. Health issues related to fluoride and aluminum are discussed in Section 5.2.3.

The SED HU shows elevated levels of manganese, turbidity and iron (Table 5.33). These can cause staining and a cloudy appearance of drinking water.

5.2.5 Carbonate/Evaporite HU

The only health-related parameter showing exceedances in >5% of samples taken is arsenic (Table 5.32). Health effects associated with arsenic were discussed previously in section 5.2.1.

The CO3 HU shows elevated levels of sodium, sulfate and chloride that separate it from the other HUs (Table 5.33). All three of these exceedances can impart a salty taste or undesirable appearance and smell to the water. These parameters are due to the presence of evaporites such as gypsum and rock salt that the groundwater has encountered in this HU. Also exceeding its guideline is TDS, which reflects higher dissolved mineral content such as sulfate and chloride.

5.2.6 Surficial HU

This HU is the only one which shows exceedances in more than 10% of samples for health-related parameters (Table 5.32). However, this exceedance is for aluminum, which is discussed in Sections 5.1.19 and 5.2.1.

The Q HU has some elevated levels of TDS, colour, pH, iron and manganese (Table 5.33). Elevated TDS is most likely associated either with surficial deposits influenced by the CO3 HU, or with anthropogenic inputs such as road salt. Colour may be due to iron and manganese, and possibly in some cases to dissolved organic matter such as humic substances.

Percentage	<5%	>=5 to 10%	>=10 to 20%	>=20%
HU				
MM	fluoride, nitrate+nitrite-N, aluminum >0.2, arsenic >0.025, barium, boron, lead, uranium	arsenic >0.01, aluminum >0.1		turbidity >1
IG/GT	nitrate+nitrite-N, turbidity >1, aluminum >0.1 and 0.2, arsenic >0.025, arsenic >0.01, barium, boron	fluoride, lead, uranium		turbidity >1
IG/BA	fluoride, nitrate+nitrite-N, aluminum >0.1 and 0.2, arsenic >0.025, arsenic >0.01, barium, boron, lead, uranium			turbidity >1
SED	fluoride, nitrate+nitrite-N, aluminum >0.1 and 0.2, arsenic >0.025, arsenic >0.01, barium, boron, lead, uranium			turbidity >1
CO3	fluoride, nitrate+nitrite-N, aluminum >0.1 and 0.2, arsenic >0.025, barium, boron, lead, uranium	arsenic >0.01		turbidity >1
Q	fluoride, nitrate+nitrite-N, turbidity >1, arsenic >0.025, arsenic >0.01, barium, boron, lead, uranium	aluminum >0.2	aluminum >0.1	turbidity >1

Table 5.32: Summary of exceedances (detects+nds) by percentage of samples, health-related parameters

Percentage	<5%	>=5 to 10%	>=10 to 20%	>=20%
HU				
MM	sodium, sulfate, chloride, TDS, copper, zinc	pH	Colour	turbidity >5 NTU, iron, manganese
IG/GT	sodium, sulfate, chloride, TDS, pH, copper, zinc		Colour	turbidity >5 NTU, iron, manganese
IG/BA	sodium, sulfate, chloride, TDS, colour, pH, copper, zinc	turbidity, manganese	Iron	
SED	sodium, sulfate, chloride, pH, copper, zinc	TDS, colour	turbidity, iron	manganese
CO3	copper, zinc	chloride, pH	sulfate, colour, turbidity	sodium, TDS, iron, manganese
Q	sodium, sulfate, chloride, copper, zinc	turbidity	TDS, colour, pH, iron	manganese

Table 5.33: Summary of exceedances (detects+nds) by percentage of samples, aesthetic-related parameters

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Chapter 6 Conclusions and Recommendations

6.1 Water Quality and Exceedances

This section will briefly discuss some of the parameters assessed in section 5.1.

Water quality in Nova Scotia differs greatly depending on the HU in which the well is completed, because the different HUs represent different lithologies and therefore different source rocks and minerals. The distribution of individual parameters also varies within the various HUs.

The data set used for this study suggest that the most common parameters exceeding the guidelines of the GCDWQ are chloride, fluoride, colour, turbidity, arsenic, iron, manganese and uranium. Of the parameters assessed, only boron had no exceedances in any HU. Although hardness has no 'official' guideline, there are exceedances of 200 mg/L, which are considered poor water quality.

The percentages of exceedances for most parameters are generally low, and conventional treatment is generally available for these parameters, either point-of-entry (POE) or point-of-use (POU). Overall, Nova Scotia drinking water is of good quality and there is no need for undue public concern. However, private well owners should be encouraged to test their well water regularly for both chemical and bacterial quality.

6.2 Health and Social Implications

Where chloride is elevated due to the lithology (such as evaporite sequences) or to formation salt, the salty taste of the water may be displeasing to consumers. Chloride may be removed by reverse osmosis or distillation, which is most practical at POU.

The guideline for fluoride has been set at a level that is beneficial to healthy teeth and bones. Higher concentrations may be detrimental to teeth and long-term exposure to elevated levels of fluorides may be associated with skeletal fluorosis. This is a progressive, non-life-threatening condition in which the bones increase in density and gradually become more brittle. If necessary, elevated fluoride can be removed by processes such as reverse osmosis.

Levels of pH in the CO3 and Q HUs tend to be above or below the recommended range of 6.5 to 8.5, which may contribute either to incrustation or corrosion of water pipes in the distribution system. Treatment for pH adjustment is available at POE.

The guideline for aluminium is an operational guideline for water treatment plants using aluminium-based coagulants. Since there is no consistent, convincing evidence that aluminum in drinking water causes adverse health effects in humans, a health-based guideline or aesthetic objective has not been established. Despite this, in industry practice, most drinking waters are still compared to the operational guidelines as a precautionary principle.

Arsenic levels in the MM HU tend to be higher than other HUs. This issue was first documented in Nova Scotia in the mid-1970s (Grantham et al, 1977). Arsenic is a known human poison and carcinogen. As a result, arsenic is now routinely tested during most real estate transactions and is required by many lending institutions. Domestic treatment is typically POU, either by distillation or reverse osmosis. There may be a potential future concern if the arsenic guideline is lowered to 0.01 mg/L, as the number of exceedances could potentially double based on the data used for this study. The IG/BA HU showed no exceedances of arsenic, but the data set for this HU had only 4 samples for arsenic and so may not be representative.

High levels of iron in drinking water may cause a red staining in bathtubs and sinks. It can also appear on clothes that are washed in iron rich water. Iron has no health implications except in extreme conditions. Where staining, odor and taste are offensive, iron can be removed from water by various methods depending on the overall water chemistry. Examples of treatment methods include oxidation filters, particulate filters and ion exchange.

At levels normally found in drinking water, manganese has no known health considerations. Even in small concentrations, manganese can produce an unpleasant taste and odor in water. Brownish-black stains may also be noticeable on laundry, dishes, porcelain fixtures and glassware. Once these stains are present, they are difficult to remove; soaps are not useful, and the use of bleach may intensify the coloration. To

remove relatively low levels of manganese, ion exchange may work. For higher concentrations, a professional assessment of the optimum treatment is recommended.

Uranium exceeds its guideline primarily in the IG/GT HU. Its guideline is based on chemical toxicity to the kidney rather than radioactivity. However, other parameters such as lead-210 and radon may also be associated with groundwaters from granitic rocks. To date, data has not indicated a significant problem with lead-210 once an appropriate sampling protocol was established (Drage et al, 2004). There is no drinking water guideline at present for radon, since the risk from ingestion is considered insignificant compared with the risk of lung cancer from inhalation (GCDWQ supporting documentation for radon).

Colour of drinking water in Nova Scotia tends to be elevated in some samples, although it may still be considered undetectable to the human eye. Colour may be aesthetically displeasing to the consumer. If colour is due to inorganic parameters such as iron, it can be removed by filtration or other means. However, if due to dissolved organic matter, such as humic substances, colour is difficult to remove and may affect the efficiency of various types of treatment units (H. Cross, personal communication).

The guideline for turbidity is more for treated waters than for untreated groundwaters, as discussed earlier in Section 5.1.29. Turbidity may be of concern aesthetically, but is especially critical in water treated by disinfection since it may shield microorganisms from the disinfection process. Pre-treatment to remove turbidity may be necessary to ensure that disinfection is not compromised.

6.3 <u>Recommendations for Further Work</u>

This project was a 'first cut' attempt to characterize the water quality from various HUs across the province, with limited time, and budget constraints. Many improvements could be made in the future, related to data issues identified during the study, methods of data analysis, collection of additional data, analysis of seasonal variations, and more detailed refinement of various HUs.

With respect to data issues, better documentation on sampling protocol, whether the sample was raw or treated, type of treatment at the particular sample site (if applicable), and well data (including well log) would be helpful.

Data analysis could be improved by the use of more sophisticated software to handle large volumes of data and parameters, especially with respect to data with varying proportion of non-detects (censored data) and varying detection limits for individual parameters. Such software could also be used to assess analysis of variance between different parameters in different HUs, to determine which parameters differ significantly. Data analysis could also be improved by the use of various types of graphical plots, such as those in ASTM (2000).

Collection of additional data could be considered where sample numbers are limited. In this study, the IG/BA HU had very few samples compared to other HUs, thus it cannot be determined with certainty whether the observed differences are significant, and whether observed exceedances (or lack of) are reliable. Additional work could include statistical analysis to determine if there is a significant difference between the IG/GT and IG/BA HUs

to warrant separate groupings, and to determine the minimum number of samples needed for statistically significant results. Data gaps should also be identified from a geographic standpoint.

This study considered data collected at one point in time. Some sample sites have data over longer periods. Where such data is available, it would be useful to assess seasonal and long term trends in groundwater quality in different HUs and in different well types (such as drilled and dug wells) and geographical areas.

Due to time constraints and data limitations, the grouping of HUs was highly simplified. If information is available, it may be useful to separate the HUs in this study into more sub-units. For example, various igneous bodies may differ in composition depending on rate of cooling and depth of intrusion. Metamorphic rocks may vary in composition depending on original lithology, heat and pressure. The carbonate HU in this study could be further broken down into waters affected by sulfates, carbonates and halite. In the future, a study based more on geological formations rather than regional HUs could be considered if sufficient data is available. Such a study would require considerably more time and funding than was available for this project.

Once some of the above issues are resolved, it would be desirable for sample data points to be accurately located so that the water quality data can be presented in a geographic information system format.

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Summary of Exceedances by HU, Percent of Samples, Health-related Parameters

Parameter	Fluoride		Nitrate+nitrite-N		Turbidity >1 NTU*		Aluminum >0.1*		Aluminum >0.2*		Arsenic >0.025		Arsenic >0.01**		Barium		Boron		Lead		Uranium	
HU	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds
MM	4.2	2.5	0.0	0.0	50.7	42.7	13.2	5.6	8.8	3.7	13.7	4.3	31.4	9.8	0.0	0.0	0.0	0.0	5.4	2.4	7.0	3.2
IG/GT	9.4	6.5	0.0	0.0	52.9	40.9	7.4	3.5	7.4	3.5	0.0	0.0	11.1	4.8	0.0	0.0	0.0	0.0	12.1	6.3	8.7	7.4
IG/BA	0.0	0.0	0.0	0.0	27.8	21.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	4.5	0.0	0.0
SED	0.0	0.0	2.6	1.7	46.5	34.9	9.9	3.4	6.6	2.3	0.0	0.0	5.0	2.2	0.2	N/A	0.0	0.0	6.9	2.0	4.5	3.3
CO3	0.0	0.0	0.0	0.0	51.6	40.7	21.4	4.4	7.1	1.5	3.0	1.3	15.2	6.4	2.7	N/A	0.0	0.0	0.0	0.0	1.9	1.4
Q	0.0	0.0	0.0	0.0	42.1	35.2	16.1	10.2	9.7	6.1	6.7	0.9	6.7	0.9	0.0	N/A	0.0	0.0	7.1	4.4	0.0	0.0

*in treated waters   *operational guidance   *operational guidance   **proposed guideline

Summary of Exceedances by HU, Percent of Samples, Aesthetic-related Parameters

Parameter	Sodium	Sulfate	Chloride	Total Dissolved Solids	Colour		Turbidity >5 NTU		pH	Aluminum >0.1*		Aluminum >0.2*		Copper		Iron		Manganese		Zinc	
HU	detects	detects	detects	detects	detects	detects+nds	detects	detects+nds	detects <>	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds	detects	detects+nds
MM	0.0	1.1	2.8	3.8	38.4	16.6	27.1	22.8	6.6	13.2	5.6	8.8	3.7	2.2	1.7	47.4	30.7	51.4	42.3	0.0	0.0
IG/GT	0.0	0.0	0.0	1.8	34.5	15.9	25.5	19.7	10.9	7.4	3.5	7.4	3.5	5.5	4.5	39.0	24.2	59.2	43.9	1.9	1.5
IG/BA	0.0	0.0	0.0	0.0	9.1	4.3	11.1	8.7	4.3	0.0	0.0	0.0	0.0	0.0	0.0	27.3	13.0	22.2	8.7	0.0	0.0
SED	3.0	0.9	3.6	7.8	21.5	7.0	14.2	10.7	4.5	9.9	3.4	6.6	2.3	1.1	0.6	33.8	17.7	52.2	28.3	0.0	0.0
CO3	20.3	10.4	9.1	33.3	25.0	11.0	21.9	17.3	7.8	21.4	4.4	7.1	1.5	0.0	0.0	44.2	24.1	43.4	29.1	0.0	0.0
Q	2.9	0.7	3.6	10.2	26.9	10.9	11.2	9.4	19.3	16.1	10.2	9.7	6.1	1.0	0.7	32.5	19.1	35.7	21.6	0.0	0.0

Median values (detects only)

Hydrostratigraphic unit	Sodium, mg/L	Potassium, mg/L	Calcium, mg/L	Magnesium, mg/L	Hardness, mg/L as CaCO3	Alkalinity, mg/L as CaCO3	Sulfate, mg/L	Chloride, mg/L	Fluoride, mg/L	Silica, mg/L	Nitrate+nitrite-N, mg/L	Ammonia-N, mg/L	TDS, mg/L	Colour, TCU	Turbidity, NTU	Conductivity, uS/cm	pH	Total Organic Carbon, mg/L	TDS/Cond ratio	Aluminum, mg/L	Arsenic, mg/L	Barium, mg/L	Boron, mg/L	Copper, mg/L	Iron, mg/L	Lead, mg/L	Manganese, mg/L	Molybdenum, mg/L	Strontium, mg/L	Uranium, mg/L	Zinc, mg/L	Water type	Information Source
Metamorphic HU																																	
MM (this study)	17.50	1.20	20.30	3.10	65.16	57.00	11.00	20.00	0.30	9.80	0.53	0.08	144.00	12.00	1.10	233.00	7.50	1.30	0.57	0.02650	0.00420	0.01020	0.01600	0.02300	0.24000	0.00165	0.05600	0.00500	0.09300	0.00080	0.02000	CaNaHCO3	This study
MM (Goldenville Formation)	26.30	2.80	27.50	5.10	84.30	66.10	16.90	13.90	<0.1		0.40	<0.05	191.00	13.60	2.80	299.60	7.40				0.00500			0.03000	0.34000	0.00500	0.19000			0.20000			Porter (1982)
MM (metamorphic rocks)	8.28		15.60	3.60	57.00	41.00	8.30	23.80			1.26		100.00			190.00	6.60					0.33480					0.09000						Trescott (1968)
MM (metamorphosed sedimentary and volcanic rocks)					15-133	7-123							38-225				7.2-8.3	<0.5-1.5							<0.5-0.26		<0.05-0.56					mainly CaHCO3 type with some mixed CaNa-HCO3Cl	Baechler & Baechler (2005)
Igneous/granite HU																																	
IG/GT (this study)	16.40	1.40	17.00	2.70	54.00	59.00	7.00	24.00	0.34	16.00	0.39	0.13	126.25	10.00	1.20	204.00	7.14	1.10	0.59	0.02300	0.00300	0.01400	0.01900	0.02400	0.26000	0.00150	-0.10000	0.00400	0.08150	0.00276	0.02000	CaNaHCO3	This study
IG/GT (granites)	32.10	1.70	9.60	2.90	36.30	60.30	6.10	31.40	0.90	18.00	<0.05	0.07	147.30	18.20	6.10	213.50	7.14				0.00500			0.06000	0.62000	0.01000	0.10000			0.04000			Porter (1982)
IG/GT (granite)	4.83		37.60	3.60	109.00	79.00	15.70	7.50			0.70		160.00			280.00	6.90								0.93000		<0.01						Trescott (1968)
Igneous/basalt HU																																	
IG/BA (this study)	15.90	0.20	13.00	2.80	46.70	41.90	7.40	22.20	0.10	17.50	0.56	0.15	123.35	7.00	0.45	225.00	7.60	1.20	0.62	0.01750	0.00160	0.00650	0.01750	0.01100	0.18000	0.00255	0.01000		0.02600	0.00025	0.03000	NaCaHCO3	This study
IG/BA (North Mountain basalt)	9.66		20.20	3.60	66.00	52.00	8.40	15.70			2.44		110.00			200.00	7.10					0.05580					0.01000						Trescott (1968)
Sedimentary HU																																	
SED (this study)	19.60	1.70	34.20	4.80	112.00	100.00	13.80	26.80	0.20	11.00	0.66	0.11	199.00	8.00	0.90	375.00	7.80	1.00	0.56	0.01400	0.00300	0.08800	0.02100	0.01800	0.16000	0.00200	0.06200	0.00400	0.18000	0.00140	0.02000	CaHCO3	This study
SED (Biomidon Formation)	17.94		103.80	8.88	268.00	105.00	137.00	27.90			2.44		310.00			560.00	7.40								0.39060		0.07000						Trescott (1968)
SED (Wolfville Formation)	21.85		41.40	3.96	117.00	79.00	20.00	33.70			2.17		190.00			350.00	7.60								0.22320		0.02000						Trescott (1968)
SED (Horton Group)	20.24		39.80	11.84	149.00	93.00	13.40	59.70			0.75		210.00			380.00	7.60								0.05580		0.02000						Trescott (1968)
SED (Canso Group)	20.40	3.30	27.20	7.30	98.80	101.00	14.30	21.00	0.18	8.80	0.13	0.10	187.60	14.00	1.52	254.00	7.40							0.09000	1.60000	0.01000	0.82000		0.05000			Na and Ca, Cl and HCO3	Gibb et al (1980)
SED (Riversdale Group)	57.10	2.90	33.40	4.60	103.00	108.00	18.10	100.00	0.03	8.30	2.35	0.19	301.60	27.10	17.60	421.00	8.10				0.00500			0.17000	0.40000	0.01000	0.08000		0.12000			NaCl and HCO3	Gibb et al (1980)
SED (Cumberland Group)	89.90	1.90	24.80	1.10	77.20	187.00	37.60	40.50	0.63	6.70	0.13	0.19	360.00	27.00	10.50	497.00	8.20				0.00500			0.04000	0.17000	0.01000	0.02000		0.10000				Gibb et al (1980)
SED (Stellarton Series)	153.90	7.40	35.90	8.30	130.00	280.00	32.40	96.50	0.36	7.10	7.84	0.39	581.00	16.30	49.00	611.00	7.80							0.05000	3.20000	0.02000	0.27000		0.02000				Gibb et al (1980)
SED (Pictou Group)	25.90	3.00	37.60	8.30	129.00	140.00	18.50	21.00	0.30	10.10	0.28	0.10	222.00	13.00	7.10	311.00	7.30				0.00500			0.05000	0.26000	0.01000	0.27000		0.12000			CaHCO3 and CaSO4	Gibb et al (1980)
SED (Lower Morien HU)					10-160								51-244				6.2-8.1	1-10				0.02-0.33			<0.01-0.25		<0.01-8.6		<0.005-0.24			mainly CaHCO3; also mixed NaCaClHCO3, and NaHCO3	Baechler (1986)
SED (Upper Morien HU)					90-220								150-250				7.0-7.8	1-4				0.06-0.25					<0.02-1.0		<0.1-2.4			mainly CaHCO3; also mixed NaCaClHCO3, and NaHCO3	Baechler (1986)
SED (Upper Windsor HU)					73-140								77-370				6.5-8.0	<5				0.01-0.39	0.02-0.15	<0.005-0.06	<0.02-1.0		<0.02-0.06				<0.01-0.19	mainly CaHCO3; also CaSO4 and NaCl from evaporites	Baechler (1986)
SED (Horton HU)					32-240	30-230				3.5-9.5			57-582				7.0-8.8	<0.5-5.7							<0.01-0.21		<0.01-0.172	<0.0001-0.0022				CaHCO3, NaHCO3, mixed NaCa-HCO3Cl	Baechler & Baechler (2005)
SED (Cumberland Group)	11.6+/-9.7	25.4+/-11.0			88.1+/-38.8	82.2+/-37.2	11.8+/-12.1	13.8+/-6.7	0.02	8.4+/-2.7			129+/-45.2				6.3-8.1	1.95+/-2.1				0.102+/-0.067	0.022+/-0.020		0.8+/-1.9		0.491+/-0.946					mainly CaHCO3 type; +/- is 1 standard deviation	Baechler & Baechler (2005)
Carbonate/evaporite HU																																	
CO3 (this study)	35.40	1.80	46.70	8.42	170.00	130.00	35.93	32.00	0.20	8.50	0.34	0.12	365.08	8.00	1.08	597.00	7.90	1.40	0.55	0.03000	0.00480	0.06450	0.10000	0.01400	0.24000	0.00145	0.03800	0.00400	0.33000	0.00087	0.01450	CaHCO3	This study
CO3 (Windsor Group)	261.00	5.00	92.40	16.40	270.00	123.00	320.00	235.00	0.34	9.50	0.38	0.10	102.30	15.60	6.46	1080.00	7.80							0.02000	0.25000	0.00500	0.12000		0.04000				Gibb et al (1980)
CO3 (Windsor Group)					23-1590	15-215				1-11			77-50000				6.5-8.7	<0.5-22							<0.2-2.7		0.01-2.5					CaSO4, NaCl, CaHCO3	Baechler & Baechler (2005)
CO3 (Windsor-Mabou)																												0.00011-0.0022					Baechler & Baechler (2005)
Surficial HU																																	
Q (this study)	12.90	1.40	17.05	3.05	54.26	28.00	10.68	28.00	0.13	7.50	0.77	0.13	132.07	9.00	0.70	234.50	6.90	1.25	0.55	0.03000	0.00150	0.03100	0.01700	0.03100	0.11000	0.00200	0.02600	0.00550	0.10200	0.00030	0.01950	CaCl	This study
Q (sand and gravel)	12.19		18.60	3.60	62.00	41.00	11.70	19.20			1.74		120.00			210.00	6.80								0.29760		0.04000						Trescott (1968)
Q (sand and gravel)					21-1700								213-1447				7.0-8.5															CaHCO3SO4	Baechler (1986)
Q (Sand and gravel)					112+/-48.1	98.7+/-39.8			<0.1-0.3	7.3+/-2.1			157+/-55.2				6.9-8.1								<0.1-3.4		<0.1-1.1					mainly CaHCO3	Baechler & Baechler (2005)
Q (all tills)	10.81		17.80	3.96	62.00	47.00	10.50	18.60			1.47		110.00			210.00	6.80								0.35340		0.03000						Trescott (1968)
Q (glacial till)					40-430	38-279			<0.1-1	4.8-16.9			91-291				7.1-8.2	1-19, mainly <5							0.02-1.12		<0.01-2.2					mainly CaHCO3 type	Baechler & Baechler (2005)
Q (Basal till HU)					64-437								106-632				7.4-7.9	<5				0.07-0.17			0.03-0.55		0.01-0.17		0.01-0.26			CaHCO3SO4	Baechler (1986)

Na_MM, Quantile Plot

Na_SED, Quantile Plot
n=529

Na_IG/GT, Quantile Plot
n=65

Na_CO3, Quantile Plot
n=79

Na_IG/BA, Quantile Plot
n=23

Na_Q, Quantile Plot
n=139

K_MM, Quantile Plot

n=171

K_SED, Quantile Plot

n=487

K_IG/GT, Quantile Plot

n=65

K_CO3, Quantile Plot

n=76

K_Q, Quantile Plot

n=131

K in detects in IG/BA

n=15

K in non-detects in IG/BA

n=8

Ca_MM, Quantile Plot

n=530 Ca_SED, Quantile Plot

n=65 Ca_IG/GT, Quantile Plot

n=79 Ca_CO3, Quantile Plot

n=23 Ca_IG/BA, Quantile Plot

n=140 Na_Q, Quantile Plot

Mg_MM, Quantile Plot

n=526 Mg_SED, Quantile Plot

n=65 Mg_IG/GT, Quantile Plot

n=79 Mg_CO3, Quantile Plot

n=23 Mg_IG/BA, Quantile Plot

n=138 Mg_Q, Quantile Plot

Hard_MM, Quantile Plot

n=528 Hard_SED, Quantile Plot

n=64 Hard_IG/GT, Quantile Plot

n=76 Hard_CO3, Quantile Plot

n=23 Hard_IG/BA, Quantile Plot

n=135 Hard_Q, Quantile Plot

Alk_MM, Quantile Plot

n=495 Alk_SED, Quantile Plot

n=62 Alk_IG/GT, Quantile Plot

n=71 Alk_CO3, Quantile Plot

n=23 Alk_IG/BA, Quantile Plot

n=135 Alk_Q, Quantile Plot

SO4_MM, Quantile Plot

n=533 — SO4_SED, Quantile Plot

n=63 — SO4_IG/GT, Quantile Plot

n=77 — SO4_CO3, Quantile Plot

n=23 — SO4_IG/BA, Quantile Plot

n=137 — SO4_Q, Quantile Plot

Cl_MM, Quantile Plot

n=533 Cl_SED, Quantile Plot

n=63 Cl_IG/GT, Quantile Plot

n=77 Cl_CO3, Quantile Plot

n=23 Cl_IG/BA, Quantile Plot

n=137 Cl_Q, Quantile Plot

n=72 — F in detects in MM

n=49 — F in non-detects in MM

n=32 — F in detects in IG/GT

n=14 — F in non-detects in IG/GT

n=6 — F in detects in IG/BA

n=10 — F in non-detects in IG/BA

n=156

F in detects in SED

n=201

F in non-detects in SED

n=25

F in detects in CO3

n=35

F in non-detects in CO3

n=15

F in detects in Q

n=64

F in non-detects in Q

SiO2_MM, Quantile Plot

n=384 SiO2_SED, Quantile Plot

n=56 SiO2_IG/GT, Quantile Plot

n=66 SiO2_CO3, Quantile Plot

n=20 SiO2_IG/BA, Quantile Plot

n=109 SiO2_Q, Quantile Plot

n=72
NOx-N in detects in MM

n=85
NOx-N in non-detects in MM

n=27
NOx-N in detects in IG/GT

n=36
NOx-N in non-detects in IG/GT

n=19
NOx-N in detects in IG/BA

n=2
NOx-N in non-detects in IG/BA

n=302

NOx-N in detects in SED

n=169

NOx-N in non-detects in SED

n=43

NOx-N in detects in CO3

n=35

NOx-N in non-detects in CO3

n=106

NOx-N in detects in Q

n=26

NOx-N in non-detects in Q

NH3-N in detects in MM (n=28)

NH3-N in non-detects in MM (n=139)

NH3-N in detects in IG/GT (n=7)

NH3-N in non-detects in IG/GT (n=55)

NH3-N in detects in IG/BA (n=1)

NH3-N in non-detects in IG/BA (n=21)

NH3-N in detects in SED

NH3-N in non-detects in SED

NH3-N in detects in CO3

NH3-N in non-detects in CO3

NH3-N in detects in Q

NH3-N in non-detects in Q

TDS_MM, Quantile Plot

n=473   TDS_SED, Quantile Plot

n=55   TDS_IG/GT, Quantile Plot

n=72   TDS_CO3, Quantile Plot

n=22   TDS_IG/BA, Quantile Plot

n=118   TDS_Q, Quantile Plot

n=73 — Color in detects in MM

n=96 — Color in non-detects in MM

n=29 — Color in detects in IG/GT

n=34 — Color in non-detects in IG/GT

n=11 — Color in detects in IG/BA

n=12 — Color in non-detects in IG/BA

n=158 — Color in detects in SED

n=330 — Color in non-detects in SED

n=32 — Color in detects in CO3

n=41 — Color in non-detects in CO3

n=52 — Color in detects in Q

n=77 — Color in non-detects in Q

n=144
Turbidity in detects in MM

n=27
Turbidity in non-detects in MM

n=51
Turbidity in detects in IG/GT

n=15
Turbidity in non-detects in IG/GT

n=18
Turbidity in detects in IG/BA

n=5
Turbidity in non-detects in IG/BA

n=381

Turbidity in detects in SED

n=126

Turbidity in non-detects in SED

n=64

Turbidity in detects in CO3

n=17

Turbidity in non-detects in CO3

n=107

Turbidity in detects in Q

n=21

Turbidity in non-detects in Q

Cond_MM, Quantile Plot

Cond_SED, Quantile Plot (n=527)

Cond_IG/GT, Quantile Plot (n=63)

Cond_CO3, Quantile Plot (n=77)

Cond_IG/BA, Quantile Plot (n=23)

Cond_Q, Quantile Plot (n=134)

TDS/cond_MM, Quantile Plot

TDS/cond_SED, Quantile Plot — n=480

TDS/cond_IG/GT, Quantile Plot — n=63

TDS/cond_CO3, Quantile Plot — n=73

TDS/cond_IG/BA, Quantile Plot — n=23

TDS/cond_Q, Quantile Plot — n=120

pH_MM, Quantile Plot

n=531 pH_SED, Quantile Plot

n=64 pH_IG/GT, Quantile Plot

n=77 pH_CO3, Quantile Plot

n=23 pH_IG/BA, Quantile Plot

n=135 pH_Q, Quantile Plot

n=83 — TOC in detects in MM

n=78 — TOC in non-detects in MM

n=34 — TOC in detects in IG/GT

n=19 — TOC in non-detects in IG/GT

n=13 — TOC in detects in IG/BA

n=9 — TOC in non-detects in IG/BA

n=222

TOC in detects in SED

n=241

TOC in non-detects in SED

n=42

TOC in detects in CO3

n=30

TOC in non-detects in CO3

n=78

TOC in detects in Q

n=35

TOC in non-detects in Q

n=68

Al in detects in MM

n=93

Al in non-detects in MM

n=27

Al in detects in IG/GT

n=30

Al in non-detects in IG/GT

n=6

Al in detects in IG/BA

n=14

Al in non-detects in IG/BA

n=151

Al in detects in SED

n=292

Al in non-detects in SED

n=14

Al in detects in CO3

n=54

Al in non-detects in CO3

n=62

Al in detects in Q

n=36

Al in non-detects in Q

n=51

As in detects in MM

frequency / concentration in mg/L

n=113

As in non-detects in MM

frequency / concentration in mg/L

n=27

As in detects in IG/GT

frequency / concentration in mg/L

n=35

As in non-detects in IG/GT

frequency / concentration in mg/L

n=4

As in detects in IG/BA

frequency / concentration in mg/L

n=17

As in non-detects in IG/BA

frequency / concentration in mg/L

n=221 — As in detects in SED

n=270 — As in non-detects in SED

n=33 — As in detects in CO3

n=45 — As in non-detects in CO3

n=15 — As in detects in Q

n=101 — As in non-detects in Q

Ba_SED, Quantile Plot (n=454)

Ba_CO3, Quantile Plot (n=75)

Ba_Q, Quantile Plot (n=97)

n=262 — B in detects in SED

n=196 — B in non-detects in SED

n=49 — B in detects in CO3

n=26 — B in non-detects in CO3

n=59 — B in detects in Q

n=38 — B in non-detects in Q

n=274 — Cu in detects in SED

n=260 — Cu in non-detects in SED

n=48 — Cu in detects in CO3

n=31 — Cu in non-detects in CO3

n=100 — Cu in detects in Q

n=37 — Cu in non-detects in Q

Fe in detects in MM (n=116)

Fe in non-detects in MM (n=63)

Fe in detects in IG/GT (n=41)

Fe in non-detects in IG/GT (n=25)

Fe in detects in IG/BA (n=11)

Fe in non-detects in IG/BA (n=12)

n=281 — Fe in detects in SED

n=257 — Fe in non-detects in SED

n=43 — Fe in detects in CO3

n=36 — Fe in non-detects in CO3

n=83 — Fe in detects in Q

n=58 — Fe in non-detects in Q

Mn in detects in MM (n=144)

Mn in non-detects in MM (n=31)

Mn in detects in IG/GT (n=49)

Mn in non-detects in IG/GT (n=17)

Mn in detects in IG/BA (n=9)

Mn in non-detects in IG/BA (n=14)

n=291 — Mn in detects in SED

n=247 — Mn in non-detects in SED

n=53 — Mn in detects in CO3

n=26 — Mn in non-detects in CO3

n=84 — Mn in detects in Q

n=55 — Mn in non-detects in Q

n=24

Mo in detects in MM

n=94

Mo in non-detects in MM

n=10

Mo in detects in IG/GT

n=38

Mo in non-detects in IG/GT

n=0

Mo in detects in IG/BA

n=12

Mo in non-detects in IG/BA

n=51 — Mo in detects in SED (frequency vs concentration in mg/L)

n=223 — Mo in non-detects in SED (frequency vs concentration in mg/L)

n=12 — Mo in detects in CO3 (frequency vs concentration in mg/L)

n=44 — Mo in non-detects in CO3 (frequency vs concentration in mg/L)

n=6 — Mo in detects in Q (frequency vs concentration in mg/L)

n=65 — Mo in non-detects in Q (frequency vs concentration in mg/L)

Sr_MM, Quantile Plot

Sr_SED, Quantile Plot
n=303

Sr_IG/GT, Quantile Plot
n=48

Sr_CO3, Quantile Plot
n=57

Sr_IG/BA, Quantile Plot
n=12

Sr_Q, Quantile Plot
n=77

U in detects in MM (n=71)

U in non-detects in MM (n=85)

U in detects in IG/GT (n=46)

U in non-detects in IG/GT (n=8)

U in detects in IG/BA (n=6)

U in non-detects in IG/BA (n=5)

n=267 — U in detects in SED

n=100 — U in non-detects in SED

n=52 — U in detects in CO3

n=17 — U in non-detects in CO3

n=38 — U in detects in Q

n=48 — U in non-detects in Q

Zn in detects in MM (n=152)

Zn in non-detects in MM (n=22)

Zn in detects in IG/GT (n=52)

Zn in non-detects in IG/GT (n=13)

Zn in detects in IG/BA (n=18)

Zn in non-detects in IG/BA (n=5)

n=344
Zn in detects in SED

n=183
Zn in non-detects in SED

n=64
Zn in detects in CO3

n=15
Zn in non-detects in CO3

n=96
Zn in detects in Q

n=40
Zn in non-detects in Q