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Assessing Water Quality

Guidelines for Water Quality

Introduction

Water quality in Canada is formally assessed using guidelines that form part of the broader ***Canadian Environmental Quality Guidelines***.

Canadian Environmental Quality Guidelines

The Canadian Environmental Quality Guidelines are nationally approved indicators of environmental quality, developed based on science and by the Canadian Council of Ministers of the Environment (CCME). They are mandated federally under the Canadian Environmental Protection Act (CEPA) and nationally under various federal-provincial agreements. These guidelines recommend limits (either in words or numbers) for a variety of substances and environmental quality parameters. This integrated document includes national environmental quality guidelines for air, water, soil, and sediment and tissue residue. The guidelines are updated annually. More information on the Canadian Environmental Quality Guidelines can be found at www.ccme.ca/publications/ceqg_rcqe.html or www.ec.gc.ca/ceqg-rcqe/English/.

Guidelines related to water quality are used to manage water resources in Canada. They have been subdivided into four categories:

- Guidelines for Canadian Drinking Water Quality
- Canadian Water Quality Guidelines for the Protection of Aquatic Life
- Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses
- Guidelines for Canadian Recreational Water

Guideline values are given as recommended limits (either in words or numbers) for a variety of microbial, radiological, chemical and physical parameters. Values and parameters included in the guidelines vary depending on the use of the water. Examples of guideline values for various water quality variables are shown in Table 3.1.

The federal government works with the provinces and territories to develop these voluntary guidelines for water quality. The provinces and territories use these guidelines when creating their own enforceable standards.

Current guideline values for all water quality categories in Canada can be found at:

www.ec.gc.ca/ceqg-rcqe/English/ceqg/water/default.cfm.



To be legally enforceable, the limits set in the guidelines need to be stated in a legal document such as an act, regulation, licence, statute, permit or contract.

The most relevant guidelines for northern water quality assessment are those covering (a) water used for drinking in non-urban settings where treatment is not provided, and (b) protection of aquatic life.

Further information on specific water quality standards and guidelines can be obtained from the territorial Departments of Health and Social Services in Yukon, Nunavut and Northwest Territories.

Table 3.1. Examples of guideline values for various water quality variables.

Parameter	Drinking Water ¹		Aquatic Life		Agricultural Uses	
	MAC (µg/L)	IMAC (µg/L)	Freshwater (µg/L)	Marine (µg/L)	Irrigation Water (µg/L)	Livestock Water (µg/L)
Aluminum	100		5-100		5,000	5,000
Arsenic		25	5.0	12.5	100	25
Cadmium	5		0.017	0.12	5.1	80
Chloride					100,000-700,000	
Fluoride	1500				1,000	1,000-2,000
Lead	10		1-7		200	100
Mercury	1					3
- inorganic mercury			0.026	0.016		
- Methylmercury			0.004			
Nitrate	45,000		13,000	16,000		
Nitrite	3,200		60			10,000
pH			6.5-9	7.0-8.7		
Uranium		20			10	200
Zinc			30		1,000-5,000	50,000

¹MAC = maximum acceptable concentration; IMAC = interim maximum acceptable concentration.

More information about drinking water quality is found in Chapter 7.

For more information about specific guidelines and current values, see:

www.ec.gc.ca/ceqg-rcqe/English/Ceeg/Water/default.cfm or www.ccme.ca/assets/pdf/e1_062.pdf.

Source: CCME (2003).

Guidelines for Canadian Drinking Water Quality

Health Canada has published the Guidelines for Canadian Drinking Water Quality since 1968. The guidelines, prepared by the Federal-Provincial-Territorial Committee on Drinking Water, identify microbiological, physical/chemical and radiological parameters that may be present in drinking water and are known or suspected to be harmful. Provincial and territorial agencies use these guidelines to develop drinking water objectives and water quality standards. In some instances, these guidelines are incorporated into the agencies' own regulations.

The guidelines establish the **Maximum Acceptable Concentration** (MAC) for each of a variety of substances that are permitted in drinking water. The guidelines also provide **Interim Maximum Acceptable Concentrations** (IMACs) and **Aesthetic Objectives** (AOs). Health Canada information on these guidelines and other drinking water publications can be found at:

www.hc-sc.gc.ca/hecs-sesc/water/index.htm.

The sixth edition of the Guidelines for Canadian Drinking Water Quality was published in 1996. This edition includes several new guidelines as well as revisions to previous ones. It has been expanded to include explanatory paragraphs for each of the parameters. Information on obtaining this edition can be found at

www.hc-sc.gc.ca/hecs-sesc/water/dwsixth.htm.

The summary of the guidelines for Canadian drinking water is to be used with the supporting documentation, also published by Health Canada. These reports represent the technical or scientific supporting documentation used by the Federal-Provincial-Territorial Committee on Drinking Water in developing and approving guidelines for contaminants found in drinking water. The supporting documentation can be found at www.hc-sc.gc.ca/hecs-sesc/water/dwgsup.htm.

Revisions to the guidelines are published annually in a summary table. The summary table is the most current list of approved guidelines, based on the most up-to-date scientific data available. It is updated every spring following the annual meeting of the Federal-Provincial-Territorial Committee. The table is used as a way to inform people of changes to the guidelines between the publication of new editions. The most recent summary table can be found at:

www.hc-sc.gc.ca/hecs-sesc/water/pdf/summary.pdf or
[www.hc-sc.gc.ca/hecs-sesc/water/publications/
drinking_water_quality_guidelines/toc.htm](http://www.hc-sc.gc.ca/hecs-sesc/water/publications/drinking_water_quality_guidelines/toc.htm).



Drinking water guidelines are intended to protect the health of the human population, and to make sure that water is of good aesthetic quality (taste, odour, colour, etc.). The quality of drinking water should be maintained at the highest level possible. This includes using measures to make certain that raw or source water supplies are protected against contamination. If an activity might change the quality of raw water, measures should be taken to limit the risks to human health.

Maximum Acceptable Concentration (MAC)

MACs have been established for certain substances in drinking water that are known or suspected to cause harmful effects to health. Each MAC assumes lifelong consumption of drinking water containing the substance at that concentration. The guidelines, whenever possible, consider the use of drinking water for all usual domestic purposes, including personal hygiene. The MAC levels for chemicals in the guidelines are typically 10 to 5000 times lower than levels which have harmed health during prolonged and repeated testing.

Interim Maximum Acceptable Concentration (IMAC)

IMACs have been developed for those substances in drinking water for which there are not enough data to establish a MAC. In these cases a larger safety factor is applied to compensate for the additional uncertainties. IMACs have also been established in relation to cancer risks. IMACs are reviewed when there is new information.

Aesthetic Objectives (AO)

Aesthetic considerations are those related to the taste, colour, hardness or smell of the water. AOs apply to certain substances in or features of drinking water that can affect its acceptance by consumers, or interfere with practices for supplying good quality water. For certain parameters, both AOs and health-related guidelines have been established. Where only AOs are given, the substance is not considered a health hazard. However, if a concentration in drinking water is well above an AO, there is a possibility of a health hazard.

Water Quality Guidelines for the Protection of Aquatic Life

These guidelines have been developed to protect all plants and animals that live in Canadian lakes, rivers, and oceans. The guidelines establish acceptable levels for substances or conditions that affect water quality. They are intended to protect freshwater and marine life from human-caused **stressors**, such as chemicals, or changes to physical components (e.g., pH, temperature, and debris).

The guidelines are given as numerical limits or in descriptive sentences. They are based on the most current toxicological data available. Guideline values are meant to protect all forms of aquatic life and all aspects of aquatic life cycles. This includes the most sensitive life stage of the most sensitive species over the long term. As long as conditions are within the levels established by the guidelines, there should be no negative effects on the environment.

Stressor – Something that causes a negative effect on any part of an ecosystem. The stress may be natural (e.g., wind) or caused by humans.

Care and Caution in Using the Guidelines

Water quality guidelines should be used with care. For example, in mineralized areas, the natural concentration of metals in surface waters may be higher than the established guideline. Does this indicate deteriorated water quality? Not necessarily. If it is not possible to tell the difference between natural background concentrations and increased concentrations as a result of human activities, then the water quality is acceptable.

In the case of the toxicity of metals in surface waters, guidelines are generally set for total metals. However, there is a considerable range in toxicity as a result of the nature of the metals in the water system. Total metals, bound in natural soils and sediments, will have a much lower toxic effect than a high concentration of dissolved metals due to acid drainage waters from mine tailings. The nature of the metals (e.g., dissolved versus particulate) can determine whether levels higher than the guidelines are likely to affect the water system. (More information about trace metals is provided later in this chapter.)

Natural seasonal effects, such as spring freshet with its high flows and sediment loads, can result in water quality guidelines being exceeded from time to time. The loss of oxygen in lakes due to prolonged ice cover may also produce values higher than the guidelines. This is a natural phenomenon and does not necessarily indicate deteriorated water quality. Comparison with guidelines is important, but keep in mind that the guidelines are broadly based and may not be suitable for every situation. Other information may have to be considered.





Key Parameters for Assessing Water Quality

Introduction

There are many microbial, radiological, chemical and physical parameters that can be considered in assessing or determining water quality. It is not possible to include them all in this manual. The parameters selected below are the ones that are most often monitored in the north. Some of these parameters have limits set under the Canadian Water Quality Guidelines; others do not.

Each water quality variable may be analyzed in different ways, depending on the specific application. It is important to select the right variable for your application. It is also important to make sure that variables are comparable, especially when considering such things as the relationship between current and historical data.

Microbiological Parameters

Preventing waterborne disease is a serious concern. Treated drinking water must comply with strict standards to make sure of its microbiological purity. The objective is to provide drinking water that does not contain any infectious bacteria, viruses or protozoa.

Total Coliform

Total coliform bacteria is a group of bacteria mainly found in the intestines of humans and warm-blooded animals. They are also found in soils. Total coliform is used as a general indicator of bacteriological quality. It is expressed as a count or number of living bacteria colonies on a growth medium per 100 mL of water. The Maximum Acceptable Concentration (MAC) for public, semi-public and private drinking water systems is ZERO coliforms detectable per 100 mL.

The presence of *Escherichia coli* (*E. coli*) shows recent fecal contamination. It also shows the possible presence of enteric (intestinal) pathogens that may be harmful to human health. If *E. coli* is found in a public drinking water system, it is important to contact the appropriate authorities and take corrective actions. A “boil water advisory” should be issued.

In disinfected water systems (e.g., chlorination or UV sterilization) the presence of total coliform bacteria shows a failure in the disinfecting process. In both disinfected and non-disinfected systems, total coliform detection may also indicate the presence of **biofilm** in the well or plumbing system.

Boil Water Advisory

If there is any doubt about the safety of drinking water, it should be boiled first. A rolling boil for one (1) minute is considered adequate.

Biofilm - A collection of microorganisms attached to a surface, surrounded by the slime they produce.

Total coliform bacteria found in well water (without *E. coli*) indicates the well may be infiltrated by surface water and therefore there is a risk of fecal contamination.

Protozoa

Guidelines for protozoa are currently under review by Health Canada. *Giardia lamblia* and *Cryptosporidium* are two parasites that can enter lakes and rivers through sewage and animal waste. They can also get into groundwater. In humans, *Giardia lamblia* causes gastrointestinal (stomach and intestinal) illnesses, including diarrhea, vomiting and cramps. This illness is often called “beaver fever”. *Cryptosporidium* causes cryptosporidiosis, a mild gastrointestinal disease that can be severe, and even fatal, for people with weakened immune systems.

Health Canada does not currently have numerical guidelines for these two parasites. The methods available for finding protozoan cysts and oocysts do not provide information on how long the cysts could live or how likely they are to infect people. It is important to take measures to reduce the risk of illness if human-infectious cysts or oocysts are found, or suspected, in source waters. These measures should also be taken if *Giardia* or *Cryptosporidium* has been responsible for waterborne outbreaks in a community in the past.

Viruses

There are more than 120 types of human intestinal viruses, many of which cannot be grown in a culture. Testing, if available, is complicated and expensive. Most laboratories involved in routine water quality monitoring do not have the ability to do this kind of testing. The best safeguard against these viruses is the application of adequate treatment and the absence of fecal indicator organisms such as *E. coli*. Health Canada is currently reviewing the guidelines for viruses.

Radiological Parameters

Health Canada has established radiological guidelines for drinking water to provide protection against the effects of chronic or cumulative exposure to radionuclides. Radionuclides may have natural or human origins, although in northern waters the origins are usually natural. Natural radionuclides such as uranium 238, thorium 232, potassium 40, lead 210 and radium 226 may be found in water that is in contact with bedrock and soils. Radon may also be present. Radionuclides from human activities include uranium 235, hydrogen 3 or tritium, cesium 137, strontium 90, antimony 125, lead 210 and plutonium 244.





Sievert (Sv) - the unit of radiation dose. It replaces the old unit, a "rem", where 100 rem = 1Sv. One milli-Sievert (mSv) = Sv/1000.

Water consumption results in only a portion of the possible total radiation dose, and some radionuclides are natural and therefore cannot be avoided. As a result, MACs for radionuclides in drinking water have been developed based on a dose of 0.1 milli-*Sievert* from one year's consumption of drinking water. This dose represents less than 5% of the average annual dose that is received from natural background radiation.

Mining and Radionuclides

Radiological measurements may be increased due to current or past mining activities (e.g., Ray Rock and Eldorado mines in the NWT).

Water samples were collected from the Anigaaq River near Audra Lake, and the Thelon River at the outlets of Beverly Lake and Schultz Lake, Nunavut, to assess levels of radionuclides during the early 1990s. No natural or human-caused radionuclides were found. Radionuclide analyses were also carried out during the early 1990s for the Slave River downstream from the abandoned and decommissioned Uranium City and other Saskatchewan uranium mines. No radionuclides were found, so the program was ended in the mid-1990s.

Chemical and Physical Parameters

Assessing water quality involves an understanding of many chemical and physical parameters. Guidelines are available for many of these. Other parameters such as water clarity and conductivity are important to include in water quality studies. Information about how to measure many of these parameters is provided in Chapter 5; and some values for selected northern rivers are found in Appendix B.

Water Temperature

Determining water temperature is an important first step. The temperature of the water has an effect on many different chemical, physical and biological parameters. Water density, the solubility of gases such as oxygen, the energy available for chemical reactions and the rates of chemical reactions are all affected by temperature. Water temperature can have an influence on conductivity, pH, salinity, and dissolved oxygen concentrations. Temperature can also affect biological activity and circulation in lakes by influencing density.

Water quality guidelines for temperature relate to the changes in temperature that result from thermal discharges to surface waters and are not directly quantified. An aesthetic objective (AO) limit of equal to or less than 15°C is set for drinking water.

pH

The pH is a dimensionless number that indicates the strength of an acidic or basic solution. It is reported on a scale between zero and 14, where zero is strongly acidic and 14 is strongly basic or alkaline. A neutral solution has a pH of seven.

The pH of natural fresh waters ranges from 4 to 11, with natural surface waters tending to be alkaline (i.e., pH >7.0). Groundwater is more acidic. Rainfall is naturally acidic at a pH of 5.0 to 6.5. **Acid precipitation** (caused by long-range transport of pollution) has a pH of less than 5. It is a particular concern in the northern waters of the Canadian Shield. These waters are highly sensitive because they lack the dissolved alkaline elements to offset or buffer the acid precipitation. Figure 3.1 shows the pH of a variety of liquids.

The lowering of pH in water (e.g., through **acid rock drainage**) can lead to the release of toxic concentrations of metals such as aluminum, copper and mercury. These may not otherwise be biologically available in aquatic systems. Lakes and rivers can become essentially sterile as a result of the lowering of the pH. pH should be measured in the field and confirmed in the laboratory. The average pH of northern rivers listed in Appendix B ranges from 6.8 to 8.1.

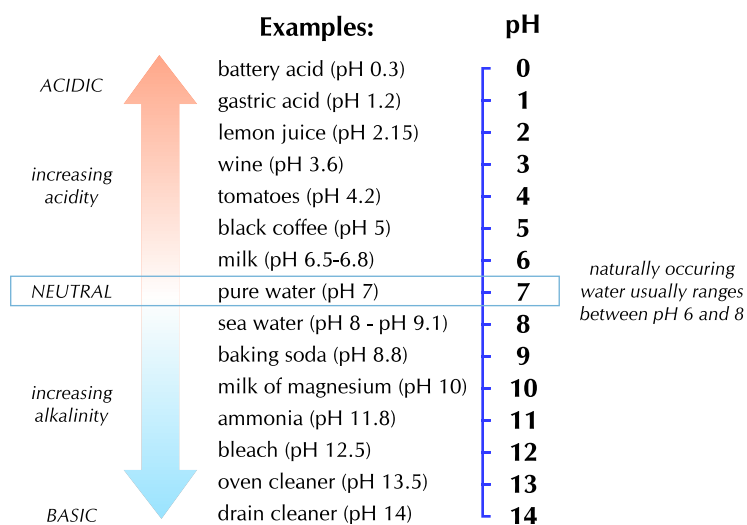
Acid precipitation -

Precipitation (rain, snow, fog) that has a lower pH (and is therefore more acidic) than unpolluted precipitation. The acids are formed when sulphur and nitrogen oxides react with water in the atmosphere.

Acid Rock Drainage (ARD) -

ARD (H_2SO_4) is the product formed by the atmospheric oxidation of the iron-sulphur minerals pyrite (FeS_2) and pyrrhotite (FeS). These relatively common minerals oxidize (or combine with water, oxygen and carbon dioxide) in the presence of bacteria (*Thiobacillus ferrooxidans*) and any other products produced because of these oxidation reactions. ARD neutralization occurs when the pH of ARD is increased by being in contact with basic minerals such as calcite ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$). ARD will also increase in a water body with an elevated pH (e.g., saltwater). Positively charged metallic cations will react to eventually form hydroxides as precipitates. (More information about ARD is provided in Chapter 7).

Figure 3.1. The pH scale and values for various liquids.





Microsiemens - A unit expressing the amount of electrical conductivity of a solution.

Conductivity

Conductivity (also referred to as conductance and specific conductance) is the measure of water's ability to conduct electrical current per unit distance. It is expressed as units of *microsiemens* (μsie) per centimetre (cm). Normally, conductivity is measured both in the field and in the laboratory. It is reported at standard temperature and pressure (25°C and 1 atmosphere).

Conductivity is affected by the types and quantities of dissolved substances in the water. It is also directly related to concentrations of total dissolved solids (TDS; see below for more details). Remote northern snow generally has a conductivity reading of less than 10 $\mu\text{sie}/\text{cm}$. Natural surface waters can range as high as 1500 $\mu\text{sie}/\text{cm}$, although the highest recorded measurement for northern rivers reported in Appendix B is 704 $\mu\text{sie}/\text{cm}$ and all average values are less than 300 $\mu\text{sie}/\text{cm}$.

Conductivity is determined by the geology, geomorphology and ecology of the drainage basin. Rivers flowing over the rocks of the Canadian Shield with little soil development tend to have low conductivity. Basins that are dominated by more soluble carbonate rocks and groundwater will have higher readings. Conductivity is inversely related to discharge. This means that, as flow increases, conductivity will decline, and vice versa.

Water Clarity

In general, water clarity (or clearness) decreases as nutrients from the surrounding watershed enter and enrich the lake, and growth of algae increases. Large amounts of algae can result in reduced water clarity. Water clearness can also be an indicator of increased sediment transport.

Water clarity is measured using a Secchi disc. When lowered into a lake, the disc provides a visual measure of the water clarity. Regular Secchi disc measurements can identify trends and detect changes or potential problems. (Chapter 5 describes how a Secchi disc is used.)

Clarity can vary according to season and geography due to a wide range of conditions. Measurements can vary from observer to observer and from day to day. Variation can depend on circumstances such as sunshine versus cloud cover, and calm versus windy conditions. High organic content can also cause abnormally low readings.

Secchi disc measurements are useful if the trophic condition of a lake or its nutrient loadings is the main concern. Lakes with low nutrient input and correspondingly low nutrient concentrations often support only small amounts of suspended algae. These are usually clear water lakes. A Secchi disc reading can indicate if a lake is eutrophic (many nutrients), mesotrophic (some nutrients), or oligotrophic (few nutrients; see also Chapter 1 and Figure 1.9).

In general, if a Secchi disc reading is 0-3 metres, the site is likely nutrient-enriched and eutrophic. If it is 3-5 metres, the site is moderately enriched and mesotrophic. More than 5 metres indicates that it is not enriched and oligotrophic.

Turbidity

Turbidity is the measurement of the **adsorption** and scattering of light in water by suspended particles (clays and silts), organic matter and other suspended matter. Turbidity should not be confused with water clarity as measured with a Secchi disc.

Turbidity is measured with a turbidimeter, usually in the field laboratory, although portable and **in situ** systems are available. The unit of measurement for the current standardized instruments is Nephelometric Turbidity Units (NTUs). These cannot be compared to older measurements reported in Jackson Turbidity Units (JTUs).

Turbidity is an indicator of suspended sediments in water and can be correlated with measurements of total suspended sediments (TSS) or non-filterable residue (NFR) measurements (see below). Since turbidity is directly correlated with TSS, it will generally increase with flow and will tend to be at a minimum under ice.

Total Suspended Solids (TSS) or Non-filterable Residue (NFR)

TSS refers to the amount of suspended matter (organic and inorganic) in the water that can be filtered or retained by a membrane filter with pore sizes of 0.45 µm. Concentrations can be extremely variable (see Appendix B) because TSS is directly related to flow and tends to peak in freshet.

Suspended sediment is important because many pollutants (e.g., pesticides, **PCBs**) stick to the surface of the sediments. Suspended matter may also contain high concentrations of contaminants (e.g., metals, phosphorus). Water quality guidelines for turbidity, TSS or NFR in freshwater and estuarine situations are given as descriptions. Other guidelines may apply to protect habitat for aquatic species, including limits to the addition of fine-grained sediments to the streambed.

Total Dissolved Solids (TDS)

TDS is the concentration of all dissolved substances in water. These substances can come from either human or natural sources. Major ions are the most important contributors. The TDS concentration is usually found by adding up the concentrations of all dissolved ions. The largest of these contributors are normally sodium, chloride and magnesium.

Adsorption versus absorption - **Adsorption** is the process by which a substance (gas, liquid or solid) adheres or sticks to the surface of a solid (e.g., PCBs adsorbed to sediment). In contrast, **absorption** involves the holding of a substance within the pores of a solid (e.g., a sponge absorbs water).

In situ - An expression meaning "in place". Some parameters need to be measured 'in place' because their readings can be easily changed or influenced if samples are removed from the site. A good example of this is water temperature.

PCBs (Polychlorinated Biphenyls) - A group of toxic chemicals used for a variety of purposes including electrical applications, carbonless copy paper, adhesives, hydraulic fluids, microscope emulsion oils, and caulking compounds. PCBs are also produced in certain combustion processes. PCBs are extremely persistent in the environment because they are very stable, non-reactive, and highly heat resistant.

Chronic exposure to PCBs is believed to cause liver damage. These chemicals are known to bio-accumulate in fatty tissues. PCB use and sale was banned in 1979 with the passage of the *Toxic Substances Control Act*.





High concentrations of TDS are a nuisance, not a hazard, as they can cause scaling in pipes and appliances. In the Arctic, high concentrations can also occur in winter as a result of freeze-out of dissolved ions from ice. This results in high concentrations in the unfrozen water. (See Chapter 1 for more details.) The highest average concentration of TDS among the rivers listed in Appendix B is 191 mg/L. This reading was taken in Liard River near the mouth.

Alkalinity

Alkalinity is a general indicator of the water's capacity to neutralize hydrogen ions. It is a measure of the water's ability to buffer or balance acid-producing substances. Alkalinity specifically represents the presence of carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), hydroxides (OH^-) and, less significantly, borates, silicates, phosphates and some organic substances. Alkalinity is affected by the bedrock, soils and vegetation of the region. Water in a watershed on bare granite generally has low alkalinity.

Dissolved Oxygen (DO)

Adequate amounts of oxygen are required to support fish and other organisms in aquatic systems. The solubility of oxygen depends on the partial pressure of oxygen in the air, water temperature, turbulence, mineral content of the water, and the ability of the water to exchange freely with the atmosphere. Oxygen is generally high in northern rivers and lakes due to low oxygen demand. There are some exceptions, such as the reduction of the levels of DO in a lake due to ice cover. Bacteria that decompose dead organic matter consume oxygen and reduce the DO in water (see eutrophication – Chapter 1).

Major Nutrients

The major aquatic nutrients include nitrogen, phosphorus and carbon. Each of these is essential for aquatic life. However, excessive nutrients can result in undesirable water quality conditions. For example, excessive growth of algae and plants can lead to a loss of oxygen when these biota die and oxygen is consumed as part of the decay process. (For more details see the description of eutrophication in Chapter 1.)

Nutrients are generally low in northern waters. Some activities, such as the use of ammonium nitrate-based explosives and aquaculture, can raise nutrient levels. Sewage effluents will also affect nutrient levels.

Nitrogen (N) is measured in a number of forms in water samples. It is measured as ammonium ion (NH_4^+), ammonia gas (NH_3), nitrate ion (NO_3^-) and nitrite ion (NO_2^-). Ammonia measurements are generally not reliable. The gas is not stable and a delay in analysis can affect the accuracy of the NH_3 measurement.

Nitrate is the principal form of combined nitrogen found in natural waters. The presence of high concentrations of nitrate and nitrite may be the result of blasting activities using ammonium nitrate. Total nitrogen (TN) is usually calculated as the sum of particulate nitrogen (i.e., it does not pass through a 0.45 μm filter) and the resultant dissolved nitrate.

Phosphorus (P) is found in a number of forms in water. It is an essential plant nutrient, often found at reduced concentrations in surface waters due to plant use. Phosphorus is considered the “limiting nutrient” because its presence or absence in the water controls the growth of aquatic vegetation.

There are numerous natural sources of total phosphorus (TP) such as soil and bedrock. However, as much of the TP associated with particulates is not biologically available, it is not always a good indicator of phosphorus pollution. Dissolved phosphorus (DP) or soluble reactive phosphorus (SRP) are accepted as better indicators of the biologically available fraction of TP. While phosphorus is not normally toxic, it can result in undesirable conditions such as eutrophication. Severe eutrophication can cause anoxia and kill fish. (For more details see Chapter 1.)

Waters on the Canadian Shield frequently have very low TP concentrations, below the analytical detection limit (usually around 0.003 mg/L). Average concentrations of TP for northern rivers summarized in Appendix B ranged from 0.01 to 0.22 mg/L. Canadian Council of Ministers of the Environment has not established water quality guidelines for TP.

Organic Carbon (C) is the total carbon in the water in dissolved and particulate forms. It can be especially high in rivers with a lot of wetlands or peat or tundra bogs, although it is generally low in most Arctic river systems. It is required as a nutrient but is not a health concern on its own.

Major Ions

Sodium (Na) is the sixth most common element in the earth’s crust. It is water-soluble and, as a result, sodium concentrations can be high due to natural sources such as salt water. They can also be raised through industrial sources, such as the pumping of concentrated brines from the subsurface to surface waters. Sodium levels can also increase seasonally as a result of freeze-out during ice formation. In general, sodium is essential for normal body functions, but high concentrations can harm those with cardiac, kidney and circulatory problems.





Potassium (K) makes up 2.5% of the earth's crust and is consequently common in surface waters. Although potassium is essential for plant and animal life, very high concentrations can be harmful to human nervous and digestive systems.

Calcium (Ca) is highly water-soluble and is common in surface waters. Calcium, along with magnesium, is the principal contributor to water hardness. Very hard water has high dissolved concentrations of calcium and magnesium. It can be a nuisance for some industrial uses and can also cause problems for domestic use. At very high concentrations calcium can restrict water use for drinking.

Magnesium (Mg) is the eighth most abundant element of the earth and is common in natural waters. As noted above, it is one of the two main components of water hardness along with calcium.

Chloride (Cl) is not generally considered a contaminant except in areas where there are increased sodium chloride (NaCl) concentrations in surface and ground waters because of the use of road salt and water softeners. Measurements are routinely done because chloride occurs naturally from the weathering of rock and soil. Chloride measurements can also be used for *mass balance* purposes, as they do not chemically transform in the water. They can be used to estimate relative discharge contributions from tributaries where flow measurements are not available. In coastal areas, chloride is an indicator of the presence of saltwater (see Chapter 2). The salinity of most seawater is 35 ppt (parts per thousand). The salinity of the Arctic Ocean is 32 ppt.

Sulphur (S) is present in the environment both in organic and inorganic forms. The most common forms are sulphate (SO_4^{2-}), sulphite (SO_3^{2-}) and sulphide (S^{2-}). Sulphate is the main oxidized form while sulphide is the most common reduced form. Sulphate concentrations can be quite high in some waters, especially in groundwater in dry regions where sulphate minerals are present. Sulphates may also be associated with acid rock drainage, while sulphides may occur in association with anoxic waters (e.g., under ice cover). High concentrations of sulphur (>500 mg/L) give water a bitter taste and may result in gastrointestinal irritation. While high concentrations can affect plumbing, they are seldom high enough to affect aquatic life.

Total hardness is the sum of calcium, magnesium and other cations including iron, aluminum and manganese. It is expressed as milligrams (mg) of CaCO_3 per litre of water. Total hardness is directly connected to the concentration of the individual major ions and to alkalinity.

Hardness inversely relates to water's ability to produce lather from soap. This means that the higher the hardness the less lather there will be. Increased hardness lowers the toxicity of heavy metals to aquatic life.

Mass balance - A mathematical relationship that shows the amount of a substance already in a body of water plus the amount entering it must equal the amount coming out plus that which stays in the system within a specified time period.

Water hardness is classified as follows:

- soft (1 to 60 mg/L)
- medium hard (61 to 120 mg/L)
- hard (121 to 180 mg/L)
- very hard (>180 mg/L)

Total hardness in rivers flowing over the Canadian Shield is typically < 60 mg/L (i.e., the water tends to be “soft”). The Camsell River at the outlet of Clut Lake, NWT (near the southeast corner of Great Bear Lake) sits on the western edge of the Canadian Shield. Its average total hardness is very close to the 60 mg/L threshold of “soft” and “medium hard” water. Hardness in a number of northern rivers is summarized in Appendix B, with average hardness varying from 5 (Coppermine River) to 160 mg/L (Flat River).

Trace Metals

Trace metals are measured and reported in a variety of ways. These are not comparable and it is essential to note the difference between samples analyzed in one way and another. Most commonly, **trace metal concentrations** will be reported as **particulate**, **dissolved**, **total** and **extractable**. As definitions and methods vary, the appropriate method of analysis should be checked with the laboratory.

Iron (Fe) is the fourth most abundant element of the earth’s crust. It is present in water in the dissolved and particulate state. Iron’s solubility increases with decreasing pH. Although iron is generally found at low concentrations, total or particulate iron may be quite high in river systems with high particulate loads. It is required for aquatic life as a micro-nutrient, but is toxic at concentrations greater than 20 mg/L. Acid rock drainage (ARD) can result in high concentrations of iron in water. Under certain conditions, precipitates of iron and other metals from ARD may form when the ARD is neutralized as a result of stream systems joining together.

Lead (Pb) is measured as total, dissolved or extractable. It has relatively low solubility and is generally found in low concentrations (<0.04 mg Pb/L). The concentration of lead is dependent on hardness, pH, alkalinity and dissolved oxygen content of the water. Human addition of lead to the environment outweighs the natural sources, especially when leaded fuels were in use (until the late 1980s). Specific limits are set for lead concentrations in water (Table 3.1) as it is toxic and accumulates in the bones and organs of humans and animals.

Trace metal concentration:

Particulate - The total metal concentration of particulates filtered from water samples that will not pass through a 0.45mm pore size filter.

Dissolved – The total concentration remaining in the water after it has been filtered as above.

Total – The sum of the particulate and dissolved fractions of metals as described above. It is normally measured as the concentration in an unfiltered water sample.

Extractable – The amount of metals detected when acid is used to extract the metals from the particulates combined with the dissolved fraction. It is often considered to be the bio-available fraction.





Manganese (Mn) is measured as total, dissolved or extractable. Manganese is a metal commonly found with iron and other metals in the earth's crust. It rarely occurs at more than 0.2 mg/L in natural surface waters. It may be higher than these concentrations if the natural sources (soils, sediments and bedrock) are enriched. Manganese is an essential micro-nutrient for life. The guidelines for manganese are largely for aesthetic purposes (it causes staining of clothing and dishes) rather than toxicity.

Mercury (Hg) is measured as total or dissolved. It may also occasionally be reported as organic (in the methyl form) or inorganic in sediments. Mercury is a trace element. It is semi-*volatile* and can be carried in the atmosphere. Industrial emissions from large-scale coal burning and cremation can release mercury that is transported long distances in the atmosphere and deposited in remote locations.

Mercury contamination in river systems in Canada has mainly been found downstream of pulp and paper mills. It has also been found in association with older gold mining operations, such as those on Bonanza Creek in the Yukon, where mercury was used in the gold refining process. Concentrations in water are generally low although sediments can have high concentrations. This is because mercury adsorbs to sediments. The most toxic form of mercury is the organic or methyl form, which can cause brain damage. Mercury *bioaccumulates* in the food chain which means that it is a major concern in the environment, especially when a particular food source such as fish form a significant portion of the diet.

A great deal of caution has to be used in sampling for mercury.

For example, people with mercury amalgam teeth fillings may contaminate a water sample by breathing onto the sample. Mercury manometers were used for years by Environment Canada as part of the water level measurement system at stream gauges. Leaks and replenishing of the reservoirs meant that the technicians were frequently in contact with mercury and could readily contaminate samples. Consequently, the number of historical analyses for mercury in northern areas is limited.

Zinc (Zn) is determined as total and extractable. It is generally plentiful in surface waters. Average concentrations of total zinc range from 0.001 to 0.033 mg/L in the rivers summarized in Appendix B. Areas with acidic waters (lower pH) have higher concentrations. Zinc, like so many other metals, is readily adsorbed to sediments. The main sources of zinc include all types of rocks. Higher levels can occur when mining activities activate metal-rich dust and fine particles. Zinc is essential for plants, animals and humans, but can be toxic to plants and fish at high concentrations.

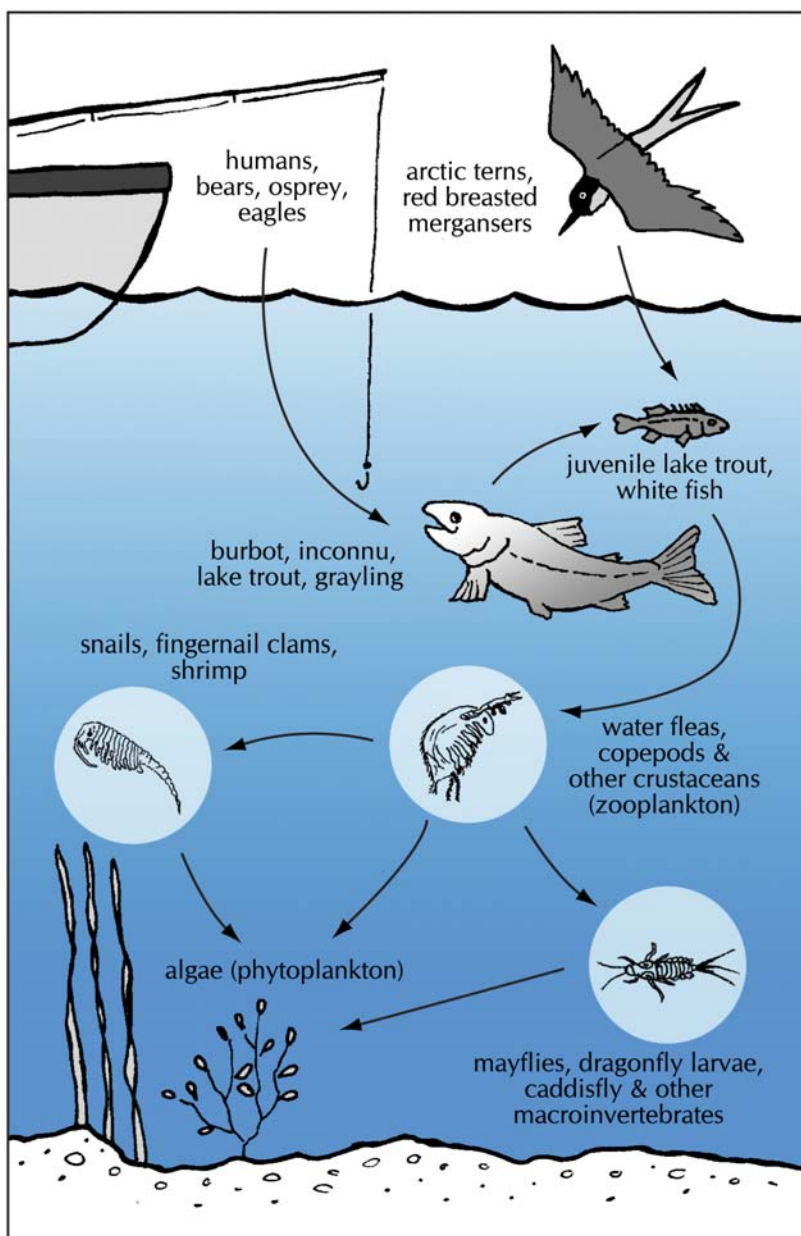
Arsenic (As) is naturally present in the environment. It enters the aquatic system from the weathering of rocks. It has been widely used in metallurgical applications, wood preservatives, herbicides,

Volatile - A compound that is easy to vaporize, even at a relatively low temperature, is said to be volatile.

Bioaccumulation - A chemical substance is said to bioaccumulate in an organism (including plants and animals) when it builds up in the tissues to higher levels than the chemical's concentration in the environment. Bioaccumulation occurs when organisms take up and store chemical components at a rate faster than they can be broken down (metabolized) or excreted. The potential of a substance to bioaccumulate is directly related to its potential toxicity. This potential is considered in the regulation of chemicals.

pharmaceuticals and glass manufacturing. It has also long been used as a poison. Levels of total arsenic in uncontaminated surface waters are generally less than 0.002 mg/L, while lake and estuarine samples in Canada usually do not exceed 0.050 mg/L. Arsenic is soluble but is readily adsorbed to suspended solids and organic matter. This is the reason why it is generally reported in water as total and/or dissolved arsenic. There is no indication that arsenic *biomagnifies*, but it is toxic at high concentrations.

Figure 3.2. Food web biomagnification.



Biomagnification - The increasing concentration of toxic substances in the body tissues of animals within each successive link of the food chain. For example, carnivores (high in the food chain) will contain more of a particular toxic substance than animals that eat plankton (low in the food chain). Food web biomagnification is illustrated in Figure 3.2. Bioaccumulation does not always result in biomagnification.



Cadmium (Cd) has many industrial applications but, because it is relatively insoluble in water, it tends to be largely associated with suspended particulates and sediments. Cadmium can enter the aquatic environment through atmospheric fallout and effluents from smelting and refining. Cadmium from river runoff is a major contributor to the concentrations found in estuarine sediment. At certain levels, cadmium is toxic to biota. The levels of toxicity form the basis of the freshwater and marine guidelines (Table 3.1). Cadmium is commonly associated with zinc in surface waters.

One of the most toxic forms of arsenic is arsenic tri-oxide dust (As_2O_3), produced by the roasting of arsenic-rich gold ores. This was the method of gold separation used at the Giant Mine in Yellowknife. Large amounts of As_2O_3 were released into the atmosphere and settled on the nearby land and water before improved scrubbing systems were installed. The improved recovery of the As_2O_3 greatly lowered the emissions but resulted in hundreds of thousands of tonnes of As_2O_3 dust being stored at the mine site. The best means of disposing of or isolating this contaminant from the environment for the long term is the subject of a major investigation. Other mining activities may release lesser amounts of arsenic from ores. Arsenic is a common concern in tailings ponds. (For more information about arsenic see Chapter 7).