Northern Waters:

A Guide to Designing and Conducting Water Quality Monitoring in Northern Canada

by the Northern Ecological Monitoring and Assessment Network (EMAN-North)

March 2005

EMAN NORTH

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Much of the original manual was re-organized, re-written and edited for a non-specialist audience by Aileen Horler. We greatly appreciate her dedication, professionalism, and perseverance, without which the project might never have been completed.

Doug Halliwell, Don Cobb, and Scott Gilbert contributed extensively to production of this manual by reviewing several versions of text and illustrations, providing editorial suggestions, and re-writing selected text. The manual has been considerably improved as a result of their efforts. Mr. Halliwell's knowledge, as well as his dedication and enthusiasm for the project, were greatly appreciated by project managers and editors.

Larry Mottle (Environment Canada, Calgary) made many valuable contributions to the original technical manual that are still present in this version.

Many illustrations have been used to help describe concepts and events. These were created, often with very little guidance from project managers, by Tanya Handley. Ms. Handley's creativity and skill at simplifying sometimes complicated concepts and events has greatly improved the manual.

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Finally, credit is collectively due to Ian McDonald, Doug Halliwell and Joan Eamer for identifying the need for a northern monitoring tool and making it happen.

Table of Contents[1]

[1] A more detailed list of chapter contents is provided at the beginning of each chapter.

[2] Terms are defined in the chapter in which they are first used, and all definitions are also provided in the Glossary.

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Preface

The northern Ecological Monitoring and Assessment Network (EMAN-North) held a special session on water monitoring at their annual meeting in November 2001. A key recommendation from that meeting was that EMAN-North should develop a basic guide for monitoring freshwater and marine water quality in northern Canada. Meeting participants saw a need for a monitoring manual written in plain language for people who are not specialists in water quality monitoring, but who have an environmental background and responsibility for designing and conducting monitoring and assessment projects.

The Northern Water Quality Manual is designed to assist with water quality and aquatic system studies in northern Canada. It provides key information that most northern personnel require to answer questions on water quality issues and to design water quality monitoring and assessment projects. The manual:

- Provides information on freshwater and marine systems, system processes, and characteristics that must be taken into consideration when designing water quality monitoring programs.
- Explains guidelines for water quality.
- Identifies key parameters for assessing water quality.
- Provides guidelines for designing monitoring programs, including the steps required and factors which should be considered.
- Includes information on field sampling techniques, handling of samples, and working with a laboratory.
- Supplies guidance for interpreting water quality data and understanding laboratory reports.
- Describes statistics for analyzing data and tools to help understand the results, such as graphs and a water quality index.
- Describes northern water quality issues including the quality of drinking water, ways to protect drinking water sources, and human activities and natural events that affect northern water quality.

Colour illustrations and examples of specific situations help to explain concepts, techniques, and issues. Definitions of terms are provided in the chapter in which they are first used. All definitions are also listed in a glossary at the back of the manual. The first time each term is used, it is italicized and bolded in blue (such as ***hydrologic cycle***) to show that a definition is provided in that section of the chapter.

We hope the Northern Water Quality Manual will help northerners monitor and protect that most precious natural resource – clean water. The manual is available on the EMAN-North website at www.emannorth.ca. Updates will be posted on the website when they are produced.

Chapter 1: Introduction to Freshwater

Introduction to Freshwater

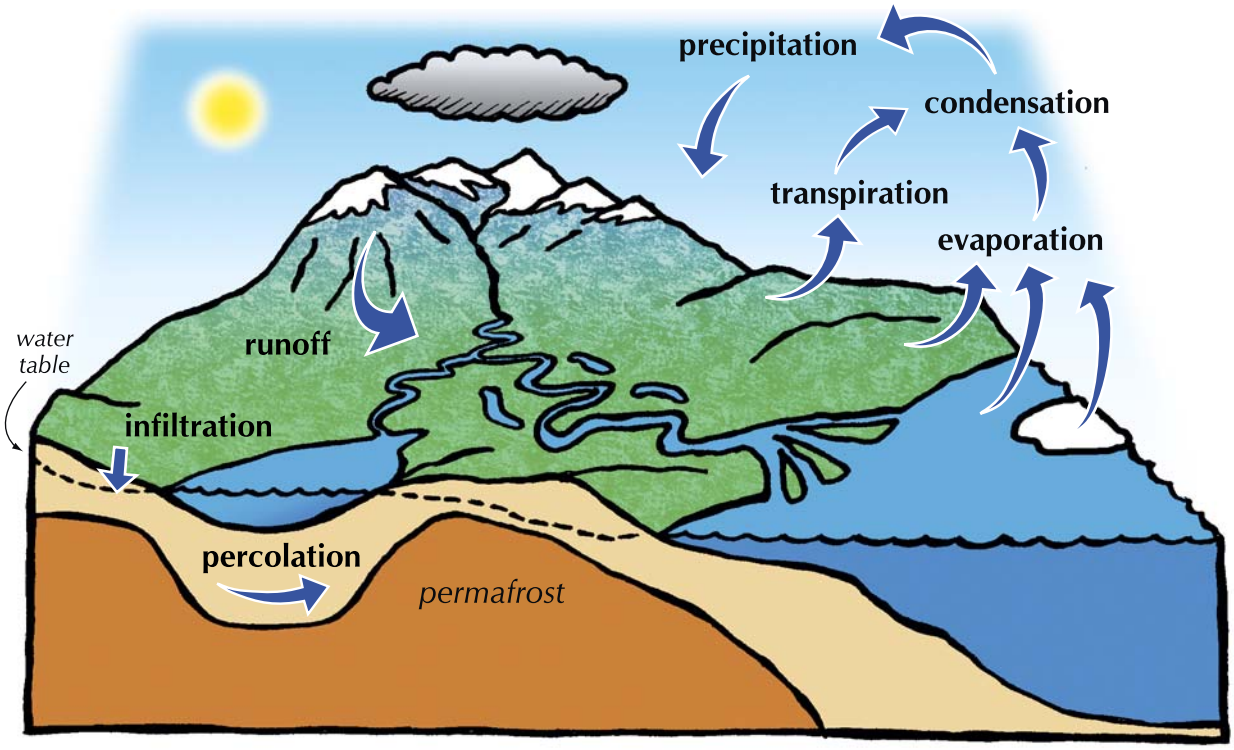
Hydrologic Cycle

The ***hydrologic cycle***[1] is the continuous circulation of water from the oceans and land to the atmosphere and back again. It is the hydrologic cycle that provides the earth with its renewed supply of purified water. There are seven primary processes that contribute to this purifying cycle (Figure 1.1).

- Evaporation
- Transpiration
- Condensation
- Precipitation
- Infiltration
- Percolation
- Runoff

Hydrologic cycle - The continuous circulation of water from the oceans and land to the atmosphere and back again.

Figure 1.1. The hydrologic cycle involves seven different processes.



[1] Italicized words throughout this document are defined in the chapter in which they are first used, and also in the Glossary.

Infiltrate - The entry of water into the ground's surface due to the combined influence of gravity and capillary forces.

Percolate - Movement of water through pores in soil or rocks to groundwater or saturated zone.

Water table - The top of the underground zone filled or saturated with water is called the water table. It can be less than half a metre below the ground's surface or it may be hundreds of metres down, and may rise or fall depending on many factors. Heavy rains or melting snow may cause the water table to rise, or an extended period of dry weather may cause the water table to fall.

Groundwater - Water that occupies pores and crevices in rock and soil, below the ground surface.

These processes happen at the same time. Evaporation occurs as water from oceans, soil, streams, rivers and lakes is heated by the sun, changes to vapour and rises into the atmosphere. Transpiration, the loss of moisture to the air through plant tissues, also releases water vapour to the atmosphere.

As water vapour rises, it cools and condenses. The condensed water particles collect to form clouds. Precipitation, in the form of rain, snow and hail, is released from clouds when they become saturated with water. Once the precipitation reaches the ground, it may run off from the land into streams and rivers, eventually reaching the sea. Water that evaporates from the land, lakes and oceans begins the cycle over again.

Water that does not run off from the surface can either ***infiltrate*** or ***percolate*** through cracks in rocks and pores in soil until it reaches the ***water table***, where it becomes ***groundwater***. Infiltrated groundwater migrates through the soil or rock, recharging surface waters. The speed at which groundwater travels depends on the size of pore spaces in the soil or fractures in the rock and how well they are connected.

On average, approximately 400,000 cubic kilometers of water are cycled through this process annually.

Information about geomorphology, geology, vegetation and climate has been synthesized to describe terrestrial eco-regions and eco-zones for Canada. See: www.ec.gc.ca/soer-ree/English/Framework/Nardesc/canada_e.cfm.

Ecosystem - A community of interacting organisms together with the chemical and physical factors that make up their environment.

Basin - Geographic land area draining into a lake or river. Also referred to as a watershed.

Hydrology - The study of water's properties, distribution and circulation on Earth. The study of moving water found in rivers, open channels and runoff moving across open land surfaces.

Aquatic Processes

Many different physical, chemical and biological processes shape aquatic ***ecosystems***. The complex interaction of the individual parts of a river ***basin*** can influence a system's ***hydrology***, water quality and biological activity. These activities and processes can occur naturally or be influenced in various ways by human behavior.

Natural physical processes include spring melt, freezing and thawing. They also include the way a drainage basin responds to precipitation and its seasonal frequency and volume. For example, how long does it take the rain from a big storm to move through a system of rivers and lakes?

Another factor influencing aquatic ecosystems is stream velocity. Velocity depends on channel steepness and the nature of the streambed itself, such as whether it is composed of rock, gravel, sand or silt. Large lakes, numerous small lakes or large wetlands can all affect the nature of surface water hydrology by increasing the storage of water within the watershed. Increased storage reduces extreme high flows and sustains low flows.

All physical processes have an influence on water chemistry. Physical features of the watershed, its geology, and its vegetation and climate, all affect water chemistry and chemical processes. Natural chemical processes are the key factors that determine ***natural water quality***. Physical and chemical processes affect the availability of nutrients in lakes and rivers, and these nutrients in turn influence the aquatic biological activity.

Natural water quality - The natural state or quality of the water (usually defined in chemical and biological terms) before any changes caused by human activities.

River System Hydrology

Water flow, also referred to as water quantity or ***discharge***, has a major effect on water quality. A graph showing river discharge over time is called a ***hydrograph***. Hydrographs can provide a lot of different information about a river system. An ***event hydrograph*** can be used to describe the way a watercourse responds to either snowmelt or a storm. An ***annual hydrograph*** shows the discharge of the river system over a year. Precipitation events, such as big storms, can cause short-term changes in the hydrograph.

Discharge - The volume of water that passes a given point in a given period of time. Also referred to as water flow or water quantity. Discharge is usually indicated by the letter "Q" in hydrologic equations and is measured in m3/sec. A simple hydrologic budget equation is represented as: $Q = P - S - E$, where P = precipitation, S = long-term storage (e.g., glaciers, lakes) and E = evaporation.

Hydrograph - A graph showing river discharge over time.

An *event hydrograph* is used to describe the way a watercourse responds to either snowmelt or a storm.

An *annual hydrograph* shows the discharge of the river system over a year.

Water flow in northern rivers varies seasonally. The lowest flows generally occur during the winter, with the ***base flow*** occurring in late winter. Many small arctic systems have no flow in the winter season. For most ice-covered rivers at northern latitudes, the spring ***freshet*** is often the largest hydrologic event of the year. The water flow recedes back from spring freshet to winter low flow during the summer - fall recession (Figure 1.2a). The peak flow of rivers fed by melting glaciers often occurs later in the season, sometime in July or August. In the winter, lakes, wetlands, and subsurface flows that don't freeze maintain the base flow of rivers. In many smaller systems, however, there is no flow during the winter because the water freezes to the bottom.

Base flow - The continuous low flow in a stream or river. The volume of flow in a stream channel that doesnot result from surface runoff from precipitation, snowmelt or a spring. Groundwater discharge is the source of base flow in most places.

Contact local representatives of the appropriate agencies to identify the locations and sampling record available for your area.

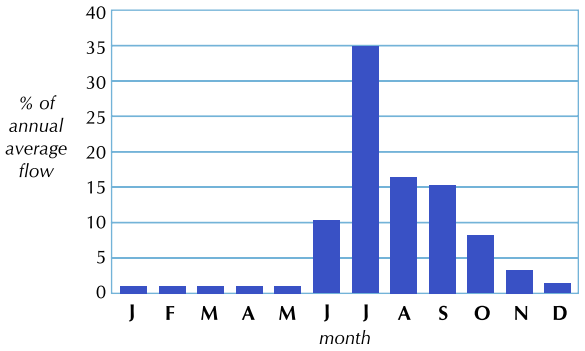
Freshet - The increased flow of water over a relatively short period of time.

Small and/or headwater river systems often show a steep peak in the hydrograph, which may reflect an event, such as snowmelt, or the flow of water for the whole year. This is because small systems respond very quickly to events. They also have little storage to help reduce the rate of runoff or to sustain flow after the event has passed. The hydrology of large watersheds with exposed bedrock will show a similar steep peak if there is little surface storage within the basin. In these systems snowmelt dominates the river hydrology because of a general lack of surface storage (lakes and wetlands) and minimal infiltration to soils.

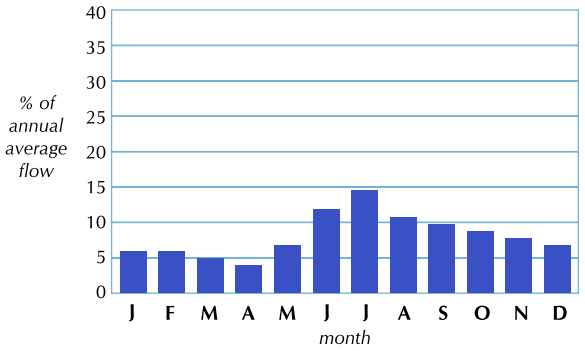
Very large, complex river systems, such as the Mackenzie, show little response to storm events. They have a broad response to snowmelt because melting occurs at various times throughout the immense

Figure 1.2. Hydrographs of two northern rivers showing different responses to events:

a) Peak flow of the Back River, Nunavut, in spring and summer followed by relatively low flows during the winter season.



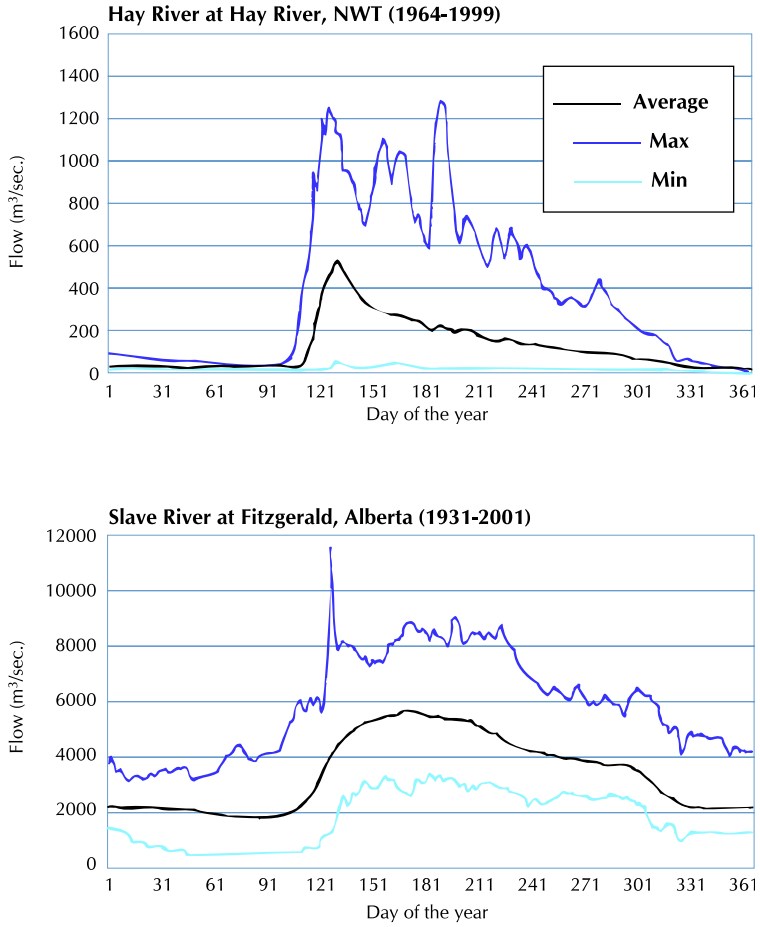
b) Broad response of the Mackenzie River, NWT, to events throughout the year.



drainage basin (Figure 1.2b). A large volume of on-line storage in the form of lakes (e.g., Bennett Dam, Lake Athabasca, Great Slave Lake, Great Bear Lake) also affects the response.

Figure 1.3 illustrates historical hydrographs for Hay River and Slave River. Hay River is typical of a natural system. This river shows a very rapid response to snowmelt about the hundredth day of the year (about mid-April), followed by a gradual decline. Peaks occur throughout the summer in response to other events, such as storms. Winter flows decline to almost zero before the spring melt begins. In contrast, the Slave River has a more gradual rise in flow in the spring. This is due to upstream storage in the Peace-Athabasca Delta, Peace and Athabasca river systems, and the controlled releases from the Bennett Dam in the headwaters of the Peace River.

Figure 1.3. Historical hydrographs for Hay River and Slave River showing variation in flow rates at different periods of the year.



As the flow varies throughout the season, the quality of the water also varies. Understanding the discharge cycle is important to understanding water quality data. Measuring flow when collecting water quality samples from a river is often essential to understand the significance of the water chemistry data. In studies where it is not feasible to measure flow, water quality samples that represent conditions throughout the range of flows may be required.

Currently, both Environment Canada (EC) and Indian and Northern Affairs Canada (INAC) measure water quantity on a periodic basis at selected sites across the north. Appendix A provides a list of these monitoring sites. The number of sites has decreased in recent years. As flows may not have changed significantly with time, historical measurements from sites that are no longer operating may still be useful, depending on the type of information required.

Water Chemistry

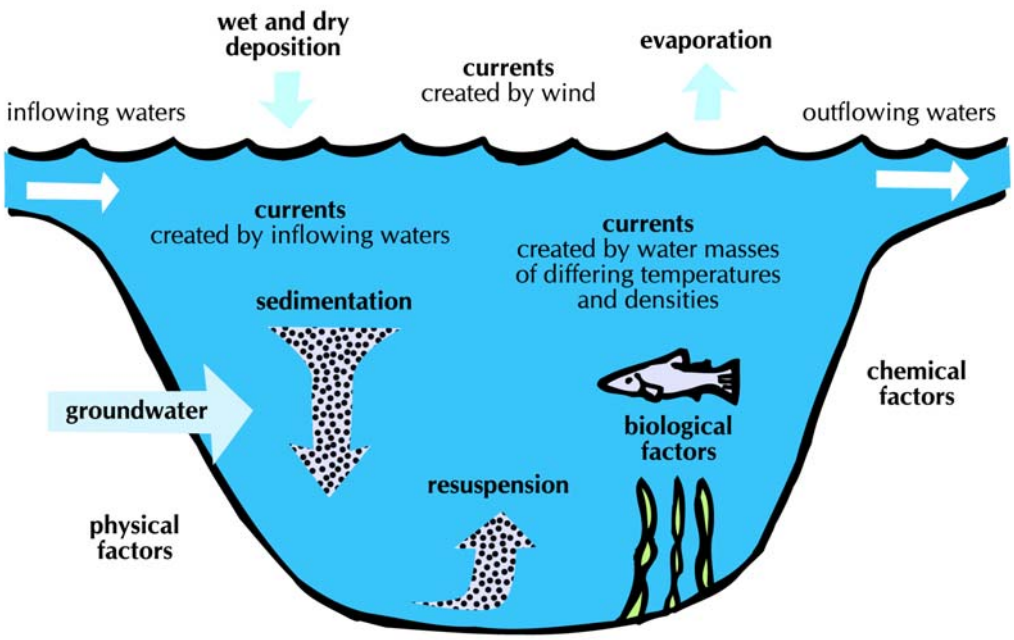
The study of water chemistry includes an examination of physical properties, such as temperature, and chemicals, such as oxygen, that are dissolved or suspended in the water. Water chemistry in lakes and rivers depends on the interaction of many biological, physical and chemical activities or processes. Human disturbance also has an impact.
The uniqueness of the chemistry of river systems declines as the systems become larger. This is because the water comes from a greater number of sources and could flow through different ecological zones.

Water chemistry is affected by the interaction of the water with the local bedrock geology, as well as by the shape of a river or lake basin, climate, soils and vegetation. Topography, such as whether an area is flat or hilly, can affect water chemistry by influencing the rate of runoff. This is because the length of time water is detained determines the level of interaction with soils, rocks, and even sunlight.

The chemistry of lake water is influenced by the water chemistry of rivers flowing into the lake. Lake water chemistry is also influenced by the material underlying the lake, how the lake was formed, the size and shape of the lake, the regional climate, and lake currents. The number of inlets and outlets associated with the lake, if any, and whether or not groundwater is moving into or out of the lake are also factors.
The processes and functions that are key to understanding factors affecting lake chemistry are illustrated in Figure 1.4.

The chemical and climate history of a lake is recorded in the sediment layers from the deep, central portions of the lake. It is also recorded in the microscopic (micro) fossils contained within those same sediment layers.

Figure 1.4. Some of the factors affecting lake chemistry.



The chemical relationship between lake water and sediments is dependent on temperature, ***pH***, ***dissolved oxygen*** levels and other conditions. Changes in these conditions move chemicals from sediments to water and vice-versa.

As already noted, river water chemistry is substantially affected by flow or discharge. In circumstances where the supply or concentration of a water quality variable is determined by the energy of the system, the concentration changes with discharge. Increases in flow affect the concentration of ***total suspended solids*** (TSS) where eroded materials have become suspended in the water column. Many metals and other parameters, such as total phosphorus and total trace metals are associated with TSS. These will also increase with flow. (More information on water quality variables can be found in Chapter 3.)

pH - The pH indicates the strength of an acid or basic solution. (More information about pH is provided in Chapter 3.)

Dissolved oxygen - The concentration of free (not chemically combined) molecular oxygen dissolved in water (DO or O2). Much of the dissolved oxygen in water is provided by photosynthesis.

Total suspended solids - Solids suspended in water that can be removed by filtration.

Very large lakes have complex water quality patterns. Great Slave Lake is a good illustration of a complicated pattern. It is caused by the many diverse and chemically distinct inflowing rivers and by the shape of the basin. The sediment-laden Slave River enters the shallow southeastern basin, while the clear rivers from the Canadian Shield enter the deep eastern and northern arms.

Water quality variables such as dissolved ions that come from interaction with bedrock and overlying material are at their highest when groundwater is the main source of flow. These variables tend to decline with increased surface water flow due to dilution effects. There are also a number of water quality measurements, such as pH, that have no real or consistent relationship with discharge and are generally controlled by other factors.

Sedimentation

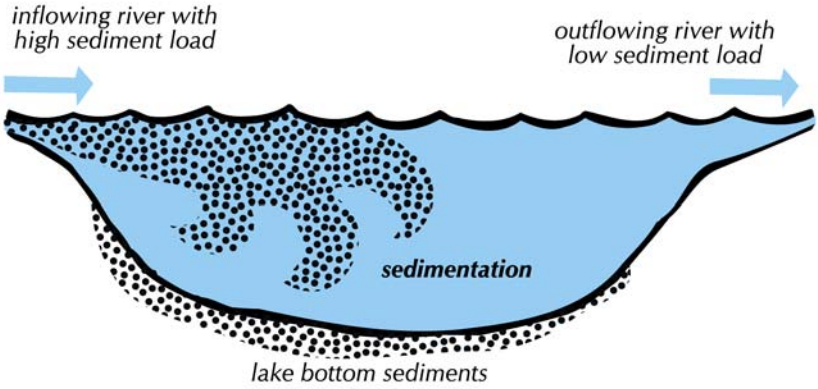
In addition to water circulation, sediments are an important indicator to consider when assessing water quality. The water flowing out of a lake may have a different chemistry than the water flowing in. When rivers enter lakes, the flow velocity and ***turbulence*** of the water is reduced. When this happens many of the sediments will settle out from the water column and fall to the bottom of the lake (Figure 1.5). Lakes can serve as permanent ***sinks*** for sediment carried into them from upstream.

Turbulence - The movement of water in an erratic fashion, often in swirling, whirlpool-like eddies. Gases such as oxygen and waters that would not normally mix due to different densities are mixed as a result of turbulence. Turbulence causes milkiness of the water as sediments from the bottom surface of the stream or river are caught up in the flow. This milkiness is measured andcalled turbidity.

Lake sediment analysis can provide an indication of the water quality because many contaminants, such as metals and trace organic contaminants, are bound to or incorporated with sediments. It normally takes a long time for lake sediments to build up, so they are not very useful for monitoring the effects of short-term developments or changes. However, like the rings of a tree, layers of lake sediment can tell a story about events and trends, such as changes in life forms and climate that have occurred over hundreds or thousands of years. In Canada's north, normal lake sediments accumulate very slowly, at rates of only 0.5 to 1.0 cm per decade. Most chemical and age-dating analyses require at least 0.5 cm, preferably 1.0 cm, of standard diameter sediment core.

Sink - A compartment or place in the environment where something is stored, for all intents and purposes permanently.

Figure 1.5. The process of sedimentation.



Thus, the shortest time interval for which lake sediment core can be sub-sampled is a decade. Forty-five cm of core overlain by the water-sediment interface and 5 cm of water from the bottom of a lake can provide up to 900 years of record. Figure 1.6 shows a lake sediment core from the northern Northwest Territories (NWT).

Rivers also deliver sediments to estuaries and deltas. This will be described further in Chapter 2.

Figure 1.6. A lake sediment core collected from Rummy Lake, Tuktut Nogait National Park, NWT.

Courtesy of: Doug Halliwell

Water Circulation in Lakes

Water circulation within a lake is a key physical process that controls the water quality. The mixing and dispersal of heat, nutrients, salts and dissolved oxygen throughout a lake is dependent on the circulation of the water. Figure 1.7 illustrates lake circulation in four seasons.

Water circulation is caused by currents from inflowing rivers and by winds. It is also influenced by differences in the density of water masses that can form in a lake.

Stratification -The separation of lake water into distinct horizontal layers.

Thermal stratification - Layering caused by the effects of temperature differences.

Thermocline - The boundary between warm and cold water in a lake (see Figure 1.7).

Hypolimnion - The lower and most dense layer of a stratified lake. It is typically the coldest layer in the summer and the warmest in the winter. It is isolated from wind mixing and typically too dark for much plant photosynthesis to occur.

Epilimnion - The upper, wind-mixed layer of a thermally stratified lake. This water is turbulently mixed throughout at least some portion of the day and, because of its exposure, can freely exchange dissolved gases (such as O2 and CO2) with the atmosphere.

Salinity - Salinity is the measure of the quantity of dissolved salts in seawater.

Halocline - The location where there is a marked change in salinity. The halocline sharply separates regions differing in salinity. Similar to a thermocline but a function of salt content as opposed to temperature differences.

Lake overturn - The circulation of water throughout the entire water column. Overturn generally occurs both in spring and fall when the temperature in a lake becomes the same at all depths.

Wind at the surface pushes the water ahead in the form of waves until they reach the edge of the lake, where the moving water either sinks or travels along the shore. Density currents can occur when river water with a high sediment load enters relatively clear lake water, or, most commonly, when water masses of different temperatures occur within the lake.

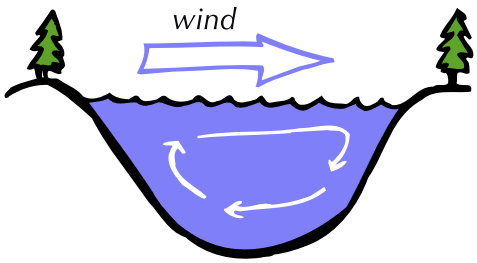
For most of the year, lake water is usually separated into distinct horizontal layers. This process is known as lake ***stratification***. Normally, lakes stratify due to differences in water density that result from the differences in water temperature. Layering caused by the effects of temperature differences is called ***thermal stratification***. Water is most dense at a temperature of 3.97 degrees Celsius. Water at this temperature sinks to the bottom, while the less dense water (water that is either cooler or warmer than 3.97^{o} C) remains near the surface or is displaced by the heavier water.

Most lakes with adequate depth are thermally stratified at some time in the year (Figure 1.7). The boundary, or gradient, between warm and cold water in a lake is called a ***thermocline***. The thermocline keeps water below this boundary, in the ***hypolimnion***, separated from the water above, in the ***epilimnion***. Smaller lakes that are constantly mixed by the wind may not stratify during the summer or may stratify temporarily. Gradients between layers, or strata, can also exist for ***salinity (halocline)***, and for dissolved oxygen and other water quality variables (chemocline).

Surface waters are warmed in the spring and cooled in the fall. When a lake is of uniform temperature because stratification has been dispersed, it will circulate throughout its entire depth. This is referred to as ***lake overturn*** and it generally occurs both in spring and fall as water warms and cools.

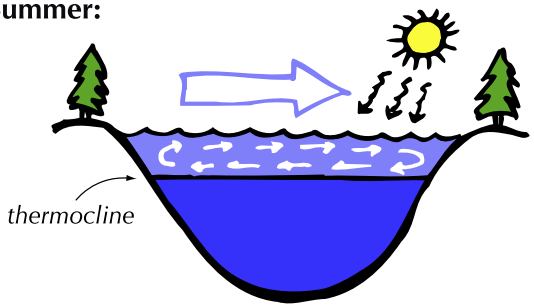
Figure 1.7. Lake circulation in four seasons.

Spring:



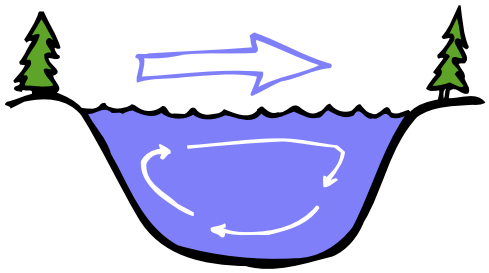
Complete mixing of water or "overturning" can occur when all water in the lake is a similar temperature. Wind helps drive this process. Water quality/chemistry should not change much with depth.

Summer:



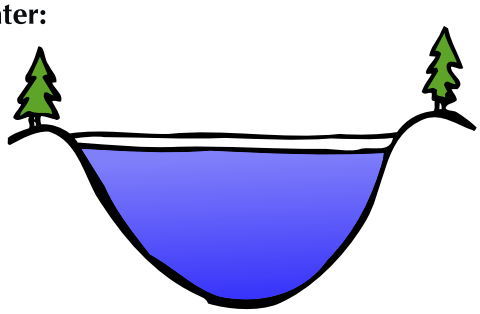
The sun warms the surface of the lake. Cold water is more dense than warm water and so forms a barrier to mixing. The lake is said to be stratified.

Fall:



The surface water cools so all the water in the lake is a similar temperature and complete mixing of oxygen and nutrients can occur again.

Winter:



During winter, ice cover prevents wind from mixing the water. The lake is once again said to be stratified.

Note: This lake stratifies twice a year. Shallow arctic lakes may only stratify during winter. Some lakes that remain open in winter can continue mixing or "overturning" year-round.

Eutrophication and Trophic State

Residence time - How long the water stays in the lake. Usually, this is calculated as the lake volume in cubic metres divided by the inflow in cubic metres per second. This figure determines the length of time that it theoretically takes for all water to be replaced in the lake. This can range from days to years and is referred to as the theoretical residence time.

The amount of biological activity in a water body is related to the amount of sunlight available and to the type and amount of major chemical nutrients present in the system. The influence of these nutrients on biological activity can be modified by many factors, such as season, temperature, nutrient loading, the ratio of nitrogen and phosphorus and the availability of dissolved oxygen. Additional factors are mixing depth, the shape of the lake bottom or riverbed, and ***residence time***, or how long the water stays in the lake.

Phytoplankton - Microscopic or small floating plants suspended in the water column of aquatic ecosystems, especially lakes.

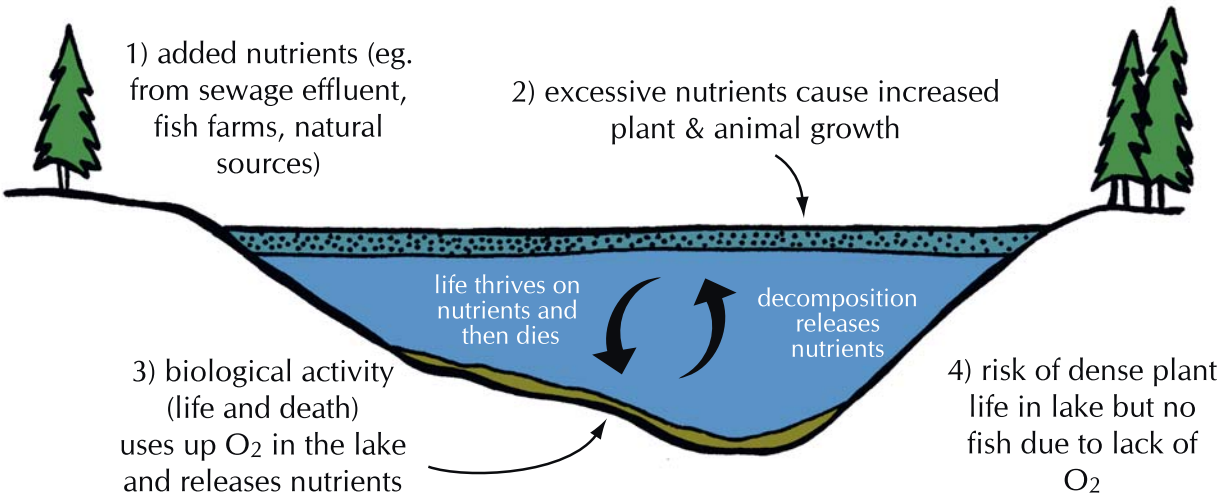
Carrying capacity - The maximum population of a particular species that a given habitat can support over a given time.

Aquatic organisms require a large number of elements for growth, including carbon, oxygen, nitrogen and phosphorus. If any one of these major elements is in limited supply, biological growth will be limited. Phosphorus most commonly limits the growth of freshwater ***phytoplankton*** in most regions, including northern lakes.

Eutrophication is the process by which lakes and rivers are enriched by nutrients. This can be a natural process that occurs over very long periods of time, or a fast-moving response to human activities. Some of the factors influencing the process of eutrophication are illustrated in Figure 1.8.

Eutrophication can both improve and degrade the aquatic habitat. The addition of nutrients, primarily phosphorus and nitrogen, can lead to higher rates of plant and animal growth. As long as this growth does not exceed the system's ***carrying capacity***, the aquatic habitat will continue to be favourable.

Figure 1.8. Some of the factors influencing the process of eutrophication.



However, the over-enrichment of a water body with nutrients can result in the excessive growth of organisms. This increase in biological activity and the subsequent die-off and decay of the plants and animals may use up the oxygen in the water. When this happens, less oxygen is available to support fish and other aquatic organisms, and the water quality can be described as degraded.

The ***trophic state*** of a water body describes the degree to which eutrophication has taken place. Scientists define the trophic state of a lake as the total weight of ***biomass*** in a water body at a specific location and time. There are three commonly described trophic states: ***oligotrophic***, ***mesotrophic*** and ***eutrophic*** (Figure 1.9). A fourth term, ***ultra-oligotrophic***, has been used to describe the trophic state of Lac de Gras, NWT, and other smaller lakes near Canada's first two diamond mines. Nutrient levels in these lakes are very low.

A typical lake that is not influenced by human activity is said to age from a young, oligotrophic lake to an older, eutrophic lake. In a natural lake, this process generally occurs over a very long period of time. The extent to which this process has occurred is reflected in a lake's trophic classification.

Eutrophication of water bodies has long been a problem in southern locations. This is mainly due to the loading of nutrients through discharges from sewage treatment plants and agricultural runoff. As populations grow in the north, eutrophication is becoming an issue around cities, smaller communities and large mines as more treated and untreated sewage is released into water systems. Activities including fish farming or aquaculture also have a high potential to contribute to eutrophication.

Trophic state (see Figure 1.9) - The total weight of living biological material in a water body at a specific location and time. The degree to which eutrophication has taken place. Most northern lakes are oligotrophic.

Oligotrophic - Very unproductive water bodies such as lakes low in nutrients and algae. Although generally considered to be young lakes, some oligotrophic lakes will never progress past this stage until environmental conditions allow increased productivity.

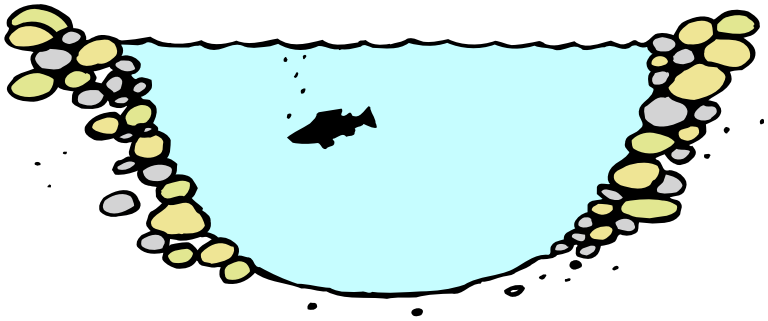
Mesotrophic - A state between oligotrophic and eutrophic. Such a lake is moderately productive and considered to be moderately fertile in terms of biomass of algae, plants, and fish.

Eutrophic - A very biologically productive water body due to relatively high rates of nutrient input. Conditions can be favourable for high fish production, but oxygen can become depleted if the demand by aquatic organisms becomes too great. There is also a risk of loss of oxygen in deeper water due to oxygen consumption by decaying vegetation.

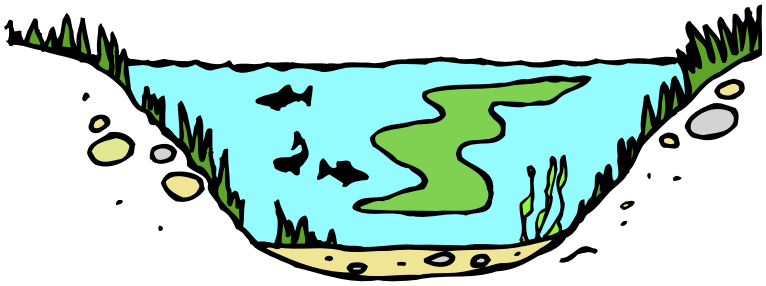
Ultra-oligotrophic - Nutrient levels lower than in oligotrophic lakes. These conditions are not common but do exist in some northern lakes.

Biomass - The weight of a living organism or assemblage of organisms.

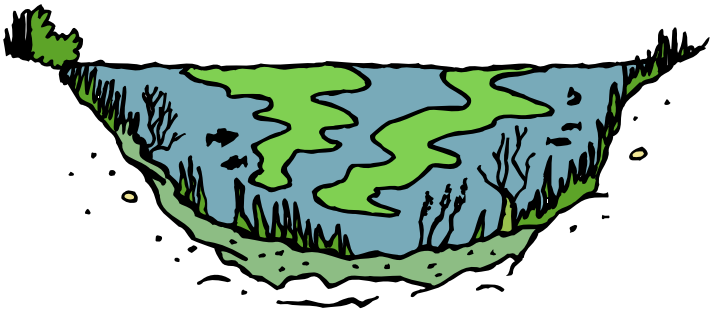
Figure 1.9. Characteristics of three trophic states.



Oligotrophic – the trophic state of most northern lakes: low productivity, low nutrient levels, low fish production, clear water; generally considered to be a desirable condition.



Mesotrophic – moderate productivity as a result of higher nutrient loadings; greater fish production and reduced water clarity; generally desirable conditions.



Eutrophic – high productivity with increased algae and plant growth, high nutrient levels, and high fish production, unless demand for oxygen becomes too great; reduced water clarity; generally not desirable aesthetically; high rate of fish production may be economically desirable.

Effect of Ice Cover

Ice plays a special role in the north. Depending upon the latitude and the nature of the river or lake system, ice can begin to form in September and remain until late into the summer. Some ice may even remain year-round. Ice generally forms later on larger lakes because the bigger water volume can store heat longer. Although ice forms later on larger lakes, it remains for just as long.

Ice cover influences northern lakes and rivers in a number of ways. Wind generates much of the water circulation during the open water season. However, once ice is formed, this cover prevents any of the lake water mixing with the air in the atmosphere. As a result, long periods of ice cover mean the loss of oxygen from rivers and lakes. This is a natural phenomenon referred to as ***anoxia***. Anoxia can be a severe problem in eutrophic lakes. If there is little or no snow cover to block sunlight, phytoplankton and ***macrophytes*** may continue to ***photosynthesize***, which can result in a small increase in dissolved oxygen just below the ice. However, micro-organisms continue to consume oxygen as they decompose material in the lower water column and in the sediments. If this decomposing activity happens when ice cover is preventing additional oxygen from entering the lake water, it causes a depletion of the dissolved oxygen.

Thick layers of ice on relatively shallow lakes can increase the concentration of dissolved solids in the unfrozen subsurface waters. This is referred to as ***cryo-concentration*** (Figure 1.10). This concentration occurs because dissolved substances are excluded from the ice during the freezing process. Cryo-concentration of dissolved salts in northern lakes is likely only to cause aesthetic concerns. However, under extreme conditions, environmental and human health issues may arise.

Anoxia - The condition of being without dissolved oxygen.

Macrophytes - Higher aquatic plants, having roots and differentiated tissues.

Photosynthesize - The process by which the energy of sunlight is captured by organisms, especially green plants, and used to manufacture organic tissue by combining the energy with carbon dioxide and water. Photosynthesis is essential in producing a lake's food base, and is an important source of oxygen for many lakes.

Cryo-concentration - The concentration of substances in a solution as a result of the lowering of temperature.

Figure 1.10. Cryo-concentration.

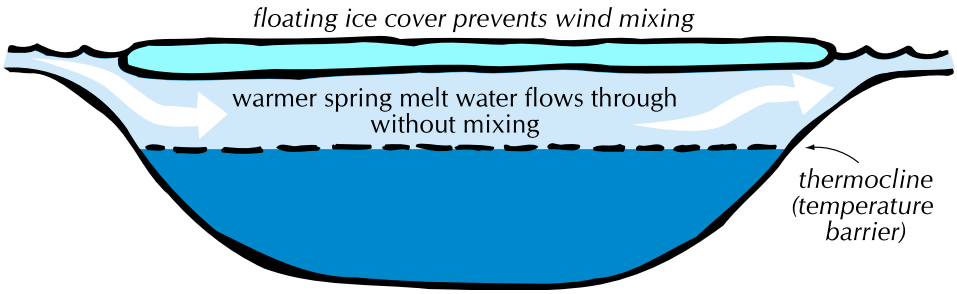
In the summer, dissolved solids are distributed throughout the lake.

In the winter, dissolved solids are concentrated in the remaining water.

Ice also plays an important role in lake circulation when the snow begins to melt in the watershed. As the inflow increases, the ice surface will tend to rise because the outflow does not increase at the same rate. Open water will appear along the shore, with floating ice still covering most of the lake. The ice remains more or less intact, preventing wind mixing of the surface waters. The inflowing river water tends to be less dense than the lake water just below the ice. This spring flush causes the river water to flow across the top of the lake water and below the ice without either water mass mixing significantly (Figure 1.11).

The spring flush of water is important from the point of view of contaminant transport and lake quality. Throughout the winter, snowfall removes contaminants from the atmosphere. These accumulate with the snow cover on the lake and within the watershed. When this contaminant-laden snow melts, the water tends to pass through the lakes quickly and is carried downstream. This means that contaminated water can reach larger downstream lakes, or even downstream marine waters and estuaries, before really mixing with large water masses and being diluted or settling out with sediment.

Figure 1.11. The spring flush of water across a lake.



Groundwater

Water returning to earth through the hydrologic cycle may remain on the surface, or it may filter into the soil and percolate to the water table, where it becomes groundwater. In streams without lake storage in their drainage basins, the base flow of water comes mainly from groundwater.

The ***recharge*** of groundwater supplies is limited by low precipitation over large areas of the Arctic. The presence of ***permafrost*** in many areas also reduces groundwater recharge by restricting the infiltration or percolation of water through the ground (Figure 1.12). Groundwater recharge increases as the ***active layer*** of the permafrost thaws. The thawing releases stored water and increases the capacity of the ground to accept recharge from summer rain. In permafrost areas, the thawing of the active layer may only happen for as little as two months of the year. Figure 1.13 shows the permafrost regions of northern Canada.

Groundwater can have an important influence on water quality. This is especially true in late winter under low or base flow conditions, when surface water contribution is minor. Ranges of physical and chemical parameters for groundwater in the permafrost region of Yukon and NWT are similar to those in non-permafrost areas. The chemical composition of ***supra-permafrost water*** in the active layer reflects the influence of rainfall, snowmelt and surface runoff (Figure 1.12). This water often has a high organic content derived from the peat layer underneath. Where there is a strong influence of ***intra-permafrost*** water and ***sub-permafrost*** water, the concentration of dissolved solids can be extremely high.

Contaminants originating from rainfall, snowmelt and surface runoff, may be present in the supra-permafrost water of the active layer. However, the transport of contaminants by drainage water is probably very limited. Hardisty et al. (1991) reported no known cases of groundwater contamination in the Canadian Arctic.

Recharge - When low groundwater supplies are filled to previous (higher) levels, they are said to be recharged.

Permafrost - A soil or rock layer that has been frozen for at least two years.

Active layer - The zone above the permafrost table that experiences seasonal freezing and thawing.

Supra-permafrost water - Drainage water within aquifers in the active layer that freezes seasonally.

Intra-permafrost water - Drainage water within aquifers in open, lateral and isolated ***talik*** zones within permafrost which is not subject to annual freezing, has relatively constant extent, and is primarily affected by long-term temperature changes.

Sub-permafrost water - Drainage water within aquifers below the permafrost, having temperatures equal to, or higher than, zero degrees Celsius.

Talik - The unfrozen area below lakes and large rivers.

The Ruggles River, which flows out of Lake Hazen on northern Ellesmere Island (82°N), remains ice free at the outlet of the lake all through the winter. This is due to relatively warm water flowing out of the lake. The water temperature in this section of the river remains at about 0°C while air temperature can be as low as -50°C. The turbulent flow, caused by the steep gradient and irregular bottom at this location, is also a factor that helps to prevent the river water from freezing.

A study of a small watershed underlain by continuous permafrost, located in Nunavut approximately 200 km south of the community of Baker Lake (62°41'N, 97°03'W), estimated that the snowmelt runoff accounts for almost 45% of the total annual runoff. This is a result of the restricted infiltration of snowmelt into the frozen active layer. Groundwater flow probably peaks by late August and slowly diminishes through September, making up about 55% or more of the average annual water balance for this site. These subsurface waters are a mixture of melting ground ice from late season rain of the previous year, rainfall from the current year and more local recharge from streams and ponds. As a result, the chemistry of these waters will be quite different from that of the snowmelt.

Figure 1.12. Permafrost restricts the percolation of water through the ground.

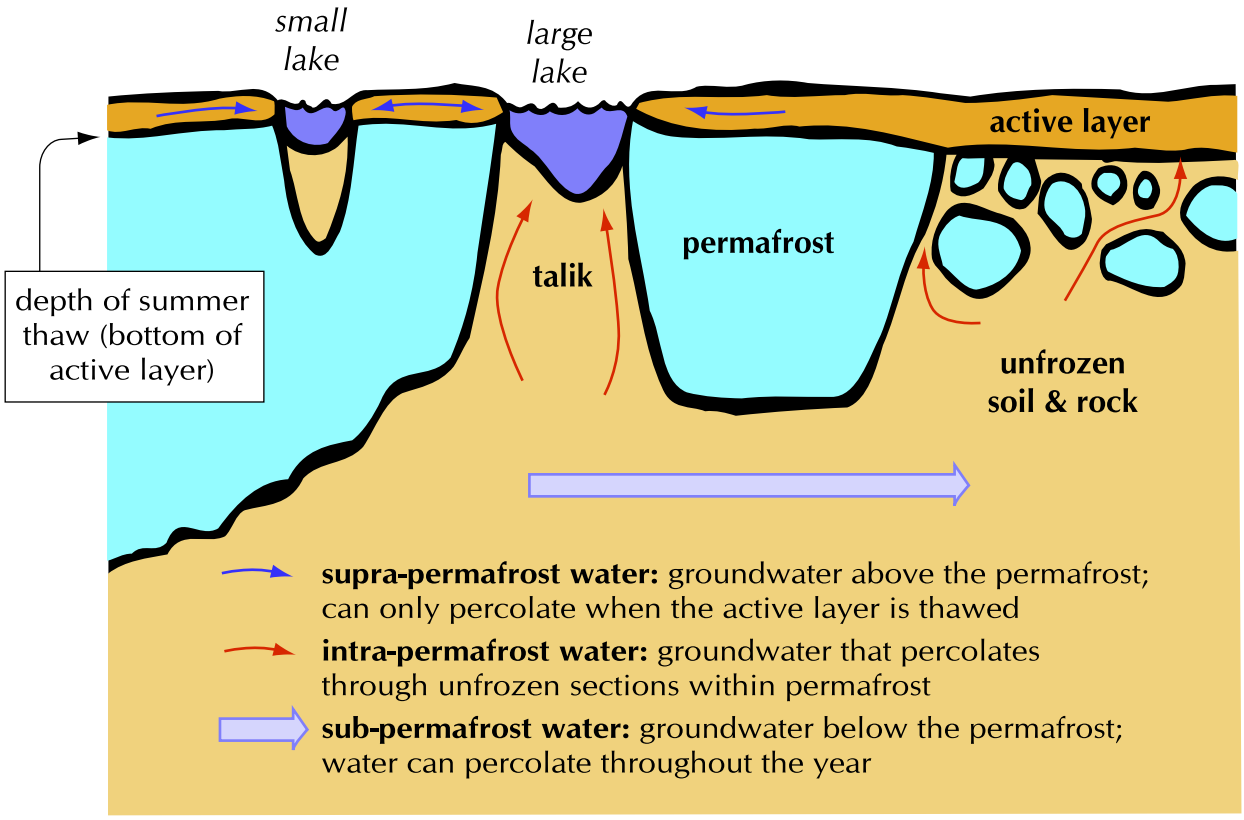
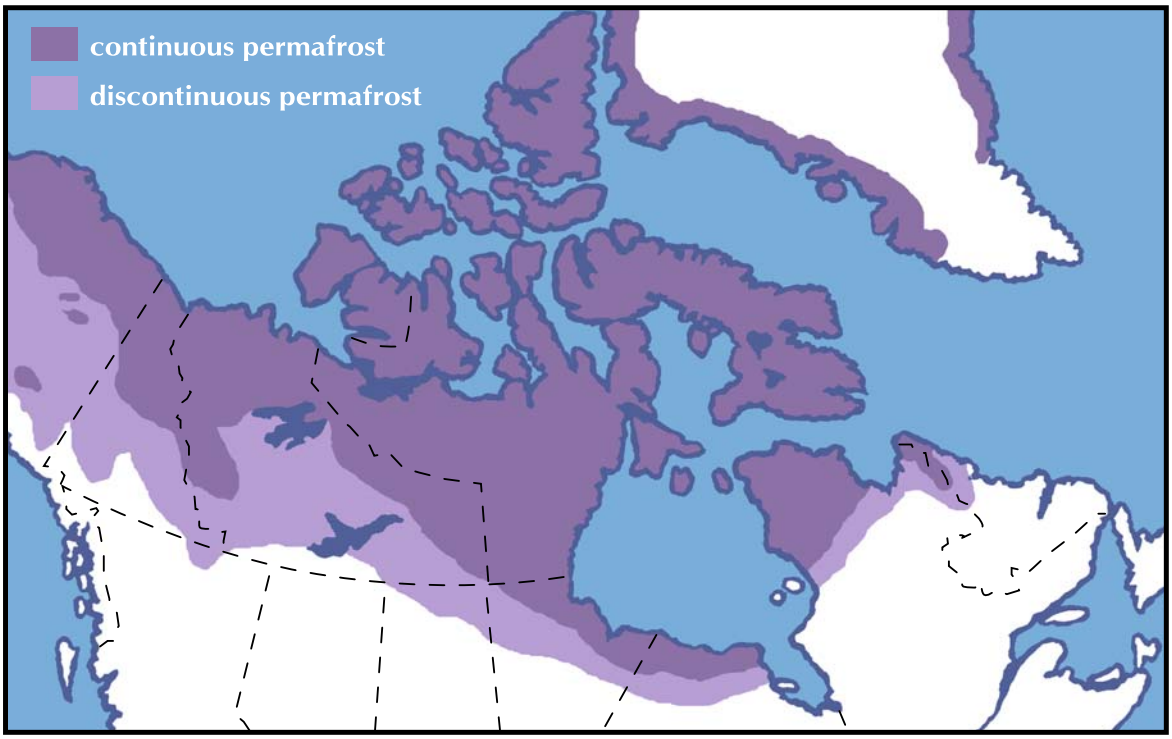


Figure 1.13. The continuous and discontinuous permafrost regions of northern Canada.



Human Impacts on Aquatic Systems

Human activity can have major effects on the hydrologic cycle and cause the deterioration of water quality. Water removed from a system and used for industrial purposes or in mining activities can be returned in a degraded quality. The release of pollutants into the atmosphere that later fall back to earth in rain, snow and dust can affect water quality as well. Figure 1.14 illustrates some of the sources that can contribute to decreasing water quality.

Leachate from landfills or from mine waste piles can contaminate groundwater. Such leachate is often highly acidic and often contains high concentrations of metals. This can result in significant changes to the chemistry of surface waters. High concentrations of metals can also be toxic to aquatic ***biota***.

Removing vegetation through forest practices, agriculture, mining, roads, housing, or other developments can reduce groundwater seepage rates and recharge. It can also contribute to soil erosion and flood risks during storms and spring melt conditions. Loss of vegetation also causes a reduction in base flow during low flow seasons.

Leachate - Material removed from a medium by the action of a percolating liquid. Contaminated water flowing out of a sewage lagoon or other source of pollution to the water.

Biota - The animal and plant life of a region or ecosystem.

Point source – A single, identifiable source of a pollutant.

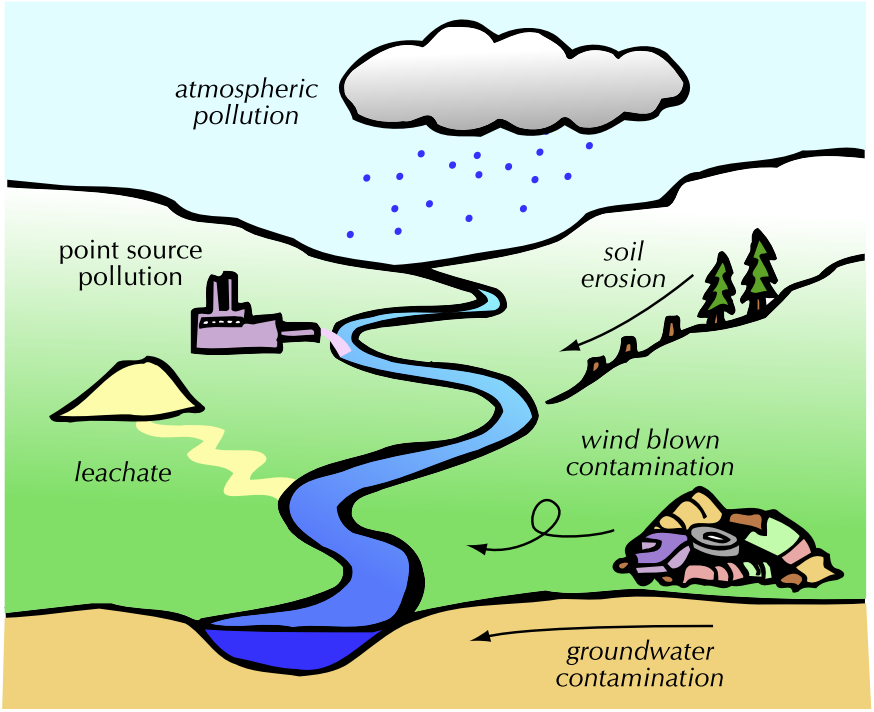
Non-point source – A source of pollution that is dispersed and often difficult to identify.

Assessing human influence on aquatic ecosystems is one of the main reasons to monitor water quality. However, even the natural chemistry of the rivers and lakes can be highly variable and complex. It can be a difficult task to isolate the effects of specific local, upstream and global human activities from natural variations in water bodies. A further complication is that changes in water quality are often cumulative in effect. A single cause, or even a major cause, cannot always be determined and can result in long delays in taking required action.

Human activities can affect an aquatic system from either a ***point*** or a ***non-point*** source. In general, it is easier to identify and resolve a problem resulting from a point source. Point sources are direct "end-of-pipe" discharges such as those from a sewage treatment plant. Industrial ***effluent*** or the release point of a mine tailings pond are also examples of point sources (Figure 1.14).

Effluent – Generally refers to wastes, treated or untreated, discharged into surface waters.

Figure 1.14. Pollution from many sources can affect water quality.



Non-point sources are much more difficult to determine and handle because they can come from a number of different places and be temporary. Examples include:

- Runoff and soil erosion from forest cutting and petroleum activities such as drilling and seismic geophysical exploration
- Runoff and leachate from mining
- Erosion from river crossings and other construction activities
- Runoff from urban streets and roads
- Discharges from sewage lagoons to wetlands or small interconnected lake systems
- Dust
- Atmospheric emissions from burning fossil fuels
- Long-range atmospheric transportation of metals, pesticides, organic contaminants and acidifying compounds to northern areas.

Chapter 7 provides more information about human impacts on aquatic systems. Issues that are discussed include drinking water quality, mining activities, petroleum development, construction activities and dams, long range atmospheric transport of contaminants and leachate from landfills.

In the north, leachate is often associated with water flowing out of a waste rock pile. The outflow becomes contaminated by metals and ions because of the slow percolation of surface and subsurface water through the waste rock. In this case, the leaching water becomes more acidic as it migrates through the rock, allowing the acidified water to dissolve metals more aggressively from the rock. (More information about this situation can be found in Chapter 7.)

Chapter 2: The Arctic Ocean and the Coastal Zone

The Arctic Ocean and the Coastal Zone

Introduction

The focus of this manual is on freshwater. However, since many northern communities are near the coastline, understanding the characteristics of the Arctic's ocean and its estuaries, deltas and associated water bodies can be useful to those working in the region. Coastal zone areas are often extremely important ecologically as well as being traditionally important to adjacent communities.

The Arctic Ocean is the smallest of the earth's oceans. The Bering Strait connects the Arctic Ocean with the Pacific Ocean. The Greenland Sea is the chief link with the Atlantic Ocean. Baffin Bay, the Beaufort Sea, the Greenland Sea, Hudson Bay, Hudson Strait and the Northwest Passage all form parts of the Arctic Ocean in Canada.

Brackish water - Brackish water contains more salts than freshwater but less than the open sea. Brackish water environments are fluctuating environments. The salinity varies depending on the tide, the amount of freshwater entering from rivers or as rain, and the rate of evaporation.

The Arctic Basin receives a large amount of freshwater from the rivers flowing from its surrounding continents. Many of these northern rivers flow into deltas. (More information on deltas is found later in this chapter.) Areas where the freshwater meets the salt water are described as estuaries and are said to contain ***brackish water***. Estuaries come in all shapes and sizes and go by many different names such as bays, lagoons, harbours, inlets, or sounds. However, not all water bodies by these names are necessarily estuaries. Some estuaries are even called brackish water lakes. These include Husky (Eskimo) Lakes on the Tuktoyaktuk Peninsula, NWT, and Ford Lake, connected at times to Wager Bay via the Reversing Falls in the new Ukkusiksalik National Park, Nunavut. Estuaries tend to be very sensitive to changes in the hydrology and/or the water quality of the inflowing rivers. Many studies of river system changes extend into the estuary where their impact may be more evident than in the river system. (More information on estuaries is provided later in this chapter.)

This chapter does not provide guidelines for the development of a coastal zone or marine water quality program. In such a case, additional expertise should be obtained to ensure validity of the design and to avoid costly mistakes.

Distinct Properties of Seawater

Seawater's main difference from freshwater is that it contains a much larger amount of salts. The average salinity of seawater is about 35 parts per thousand (ppt), or 3.5 % of its total weight. This is 220 times saltier than the freshwater found in a lake.

Approximately 85% of the salt found in the ocean is made up of sodium and chloride. Chloride salts of magnesium, sulphur, calcium, and potassium are also found.

The salinity of ocean water produces a number of physical differences between freshwater and seawater. For example, saline or salt water is denser. The average density of seawater is 1.025 g/cm^3. In comparison, the density of pure freshwater is 1.000 g/cm^3. Unlike freshwater, which reaches a maximum density at 3.97°C (approximately 4°C), seawater density increases continuously with decreasing temperature until ice forms at its maximum density.

Thermodynamic equilibrium - This occurs when the amount of heat leaving a system equals the amount of heat absorbed by the system. As a result, the overall heat remains constant with time.

Seawater is also higher in conductivity than freshwater. It has a higher boiling point and a lower freezing point. The freezing point of seawater is not fixed at approximately zero degrees Celsius, as it is for freshwater. The freezing point of seawater is the temperature at which pure ice and seawater are in ***thermodynamic equilibrium***. This temperature is variable and depends upon the salinity of the water. The greater the amount of salt in the water, the lower its freezing point; the fresher the water, the higher its freezing point. Pressure, which increases with water depth, also lowers the freezing point of seawater.

Dissolved oxygen also behaves differently in salt water, although the sources and sinks of dissolved oxygen are the same in marine and estuarine systems as they are in freshwater systems. The actual amount of dissolved oxygen in seawater is less than that in freshwater. As salinity and/ or temperature increases, the amount of oxygen that water can hold at saturation decreases. For example, freshwater (0 ppt salinity) that is 100% saturated with dissolved oxygen at 20°C contains 9.09 mg/L of dissolved oxygen. In water with 36 ppt salinity, this decreases to 7.34 mg/L. At 10°C, the dissolved oxygen level of freshwater is 11.3 mg/L, but at 36 ppt salinity it is 9.0 mg/L. As with freshwater, the amount of dissolved oxygen in estuarine waters is one of the best indicators of an estuary's health. It is an important factor controlling the presence or absence of estuarine species.

One atmosphere - The pressure of the atmosphere at sea level is one atmosphere of pressure or 760 mmHg or 101,325 Pa. The actual atmospheric pressure at a given location varies depending upon altitude and local weather conditions.

Hydrographic data from the Ross Ice Shelf in Antarctica shows the effects of pressure on the freezing point of seawater. All temperatures in a profile down to 675 m were less than -1°C. However, water between 300 and 600 m in depth had temperatures that were up to 0.07°C lower than the freezing point at the sea surface (*one atmosphere*). Water brought quickly to the surface from these depths would flash freeze, making sample collection difficult. **The effects of pressure on the freezing point should be considered when trying to obtain water samples from great depths.**

The Arctic Ocean

The oceans of the world cover 71% of the earth's surface and contain over 97% of the planet's water. The five principal oceans are the Pacific, Atlantic, Indian, Arctic and, the newly delineated Southern. Of these, the Pacific is the largest and deepest, covering approximately 166,884,000 km^2. The Atlantic and Indian oceans are each less than half the size of the Pacific, at approximately 82,841,000 and 73,710,000 km^2, respectively. The Southern Ocean is the fourth largest, covering about 20,327,000 km^2. The Arctic Ocean is the smallest, with a surface area of about 14,110,000 km^2.

The average salinity of the Arctic Ocean, however, is only about 32 ppt or 3.2 % of its total weight, slightly lower than the 35 ppt average salinity of the world's oceans. Unlike tropical oceans, which are temperature-stratified, the Arctic Ocean is ***salinity-stratified*** and has a halocline rather than a thermocline. Salinity increases slightly with depth, but increases at a higher rate somewhere between 10 and 100 m.
The presence of the halocline is important in the formation of sea ice because unlike freshwater, seawater is most dense at its freezing point. If there were no halocline, the entire Arctic Ocean would have to cool to $-1.8^{o}C$ (the average freezing point of Arctic seawater) before ice could form.

Salinity-stratified - Two or more horizontal layers formed in the water due to differing salt concentrations. Layers that are higher in salt concentration will lie at a lower depth as they have a higher density, which makes them heavier.

Continental Shelves

The broad, shallow continental shelves that surround the Arctic Ocean make up about one-third of its surface area. This is the highest percentage found in any ocean. Within the continental shelf regions, water depths are less than 200 m. Beyond the continental shelf is the continental slope, where water depth rapidly increases to 1000 m or more.

Continental shelves receive large inputs of freshwater from river inflow, ice melt, and net precipitation. This increases the stability of Arctic surface waters and promotes winter ice formation, as fresher water freezes more rapidly than saline water. As water near the shelves freezes, much of the salt is excluded, forming a cold, salt-enriched ***brine***.
This cold salty water rapidly sinks, resulting in a fresher layer of water below the surface of the ice. This process not only favours the growth of more ice but also deepens the Arctic halocline.

Brine - Water saturated with or containing large amounts of a salt, especially sodium chloride.

Continental shelves are also important sources of positive and negative buoyancy differences within the Arctic Ocean. The fresh, less dense, water floats while the denser brine-enriched water sinks.

Plume - A definable area of water that has properties that differ from the surrounding water. Most often, the difference is in the density. As a result, the water in the plume doesn't mix quickly or very much with the surrounding water.

The production of cold, salty shelf waters also triggers shelf-slope ***plumes***. These plumes are made up of cold highly saline water that sinks downwards at the shelf slope, potentially to great depths. This action further functions to cool the water in the Arctic Ocean.

The Ocean Ice

Ice in the Arctic Ocean occurs as shelves, floes, bergs and packs. An **ice shelf** is a mass of ice that floats on the surface of the ocean, but is permanently attached to an ice cap or glacier on land. There are a few small ice shelves in the Arctic, mostly around Greenland. Ice floes and icebergs are masses of ice that break off from larger ice bodies, such as ice packs and ice shelves, and float independently in the open water. A **floe** refers to a large, flat ice mass. The term **berg** is used to refer to a chunkier, more rugged piece of ice, which extends to a greater depth. Arctic ice floes and bergs may drift hundreds of kilometers toward the equator before they melt.

Pressure ridge - A pressure ridge is formed when sea ice is forced against land or another pack of sea ice.

Fast-ice - Ice anchored to the sea floor and/or the shore.

Polynyas - Areas of open water surrounded by sea ice that are caused by currents, tidal fluctuations, wind, ***upwellings***, or a combination of these factors.

Upwelling - Upwelling occurs when the surface waters are displaced and deeper waters move in to take their place. Bottom water that is colder and more nutrient-rich will flow upward to replace surface water pushed away by winds.

Flaw lead - A lead is any fracture or passageway through sea ice. Leads are generally linear in shape. A flaw lead is a lead between the fast ice and the pack ice.

The Arctic Ocean is covered by a perennial drifting polar icepack that averages about 3 meters in thickness. ***Pressure ridges*** that form on the icepack may be three times that size. Open seas surround the icepack during the summer. In winter the icepack more than doubles in size as new ice forms and the pack expands toward the encircling landmasses.

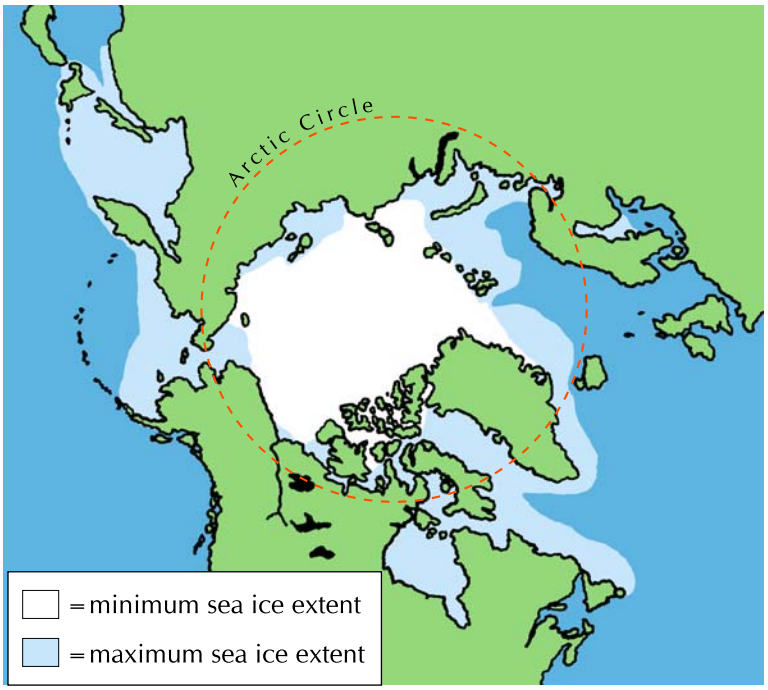
Freshwater flowing into the Arctic Basin from the surrounding continents spreads out over very large areas during the short summer. The incoming freshwater is less dense because of its low salinity. It remains near the surface and is the first to freeze in the autumn.

Much of the Arctic sea ice forms in winter in relatively shallow shelf areas. This results in the production of a band of ***fast-ice*** adjacent to the shore. There is often a region of open water, referred to as a ***polynya*** or ***flaw lead***, between the near shore zone of fast-ice and the drift ice.

Ice that does not melt after the first summer is called **second-year ice**. During the second year, additional ice is added to the underside of the floe during the winter. Ice that has survived more than two melt seasons is referred to as **multi-year ice** and is often thicker than three meters. Multi-year ice covers the central Arctic and eastern Greenland areas and is kept in continual motion by winds and ocean currents. These forces break up the ice into floes, with spaces of open water between them. Figure 2.1 shows the minimum and maximum areas covered by sea ice in the Arctic.

When sea ice forms, salt is largely excluded during the freezing process. The salinity of newly formed sea ice is approximately 5 ppt. As the ice ages, it continues to lose salts.

Figure 2.1. The maximum and minimum extent of sea ice in the Arctic Ocean.



Polynyas

Polynyas are areas of open water surrounded by sea ice. Polynyas vary in size from less than a few km^2 to immense areas, such as the North Water Polynya, that can spread to over 50,000 km^2 (Figure 2.2). The sea ice surrounding the polynya may be more than 2 m thick. Some polynyas occur at the same time and place each year. They become important to the marine mammals that have adapted to their regularity.

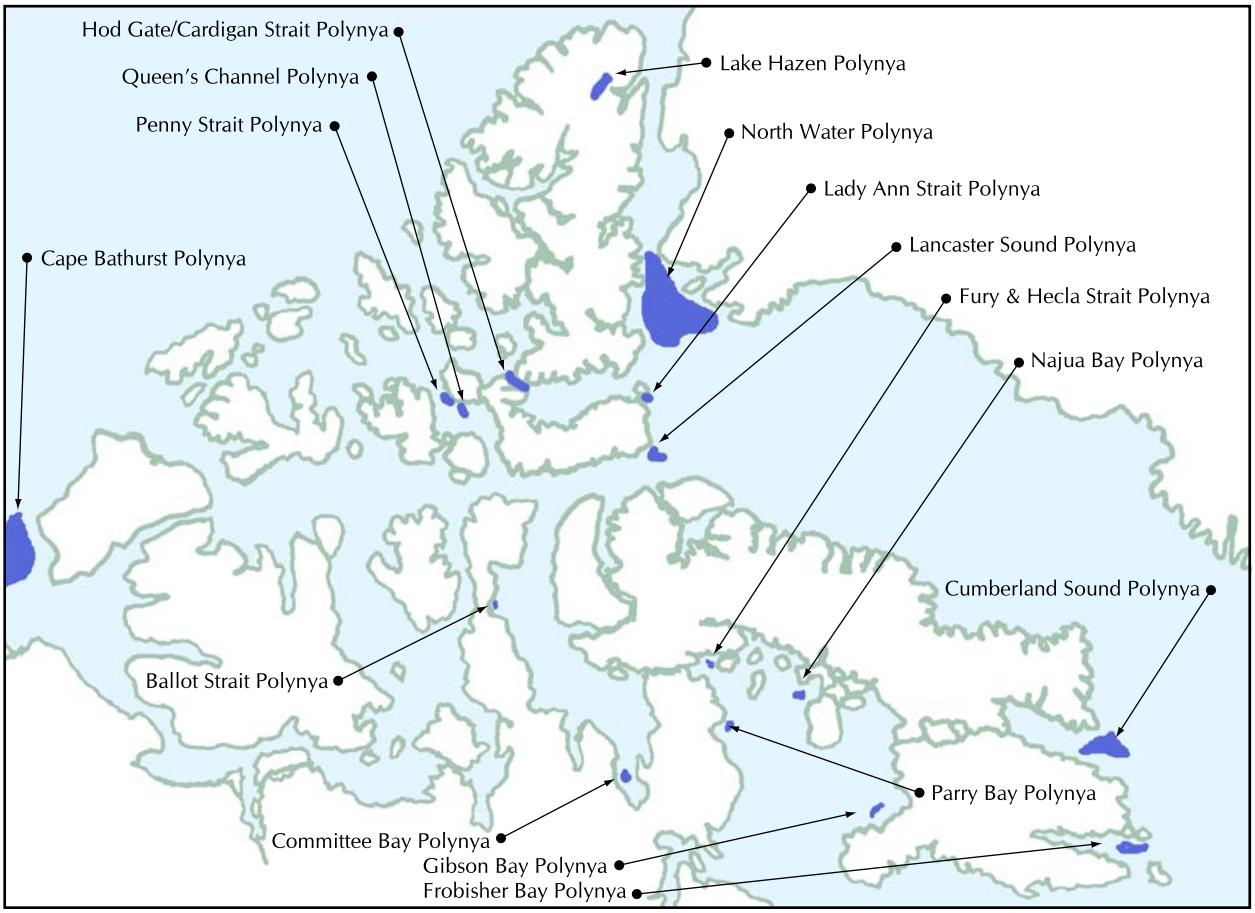
Polynyas are kept free of ice due to a number of physical processes. These processes include currents, tides, upwellings and winds. When deep, relatively warm (~ 2°C) water wells up towards the surface, replacing waters that have been pushed away from land by offshore winds, **sensible heat polynyas** are formed. Upwelling also occurs when local topography redirects a current towards the surface. This warmer water melts ice cover or prevents ice from forming.

The currents and upwellings that maintain polynyas also supply a lot of nutrients, making these waters highly productive. Polynyas are a concentration area for much of the Arctic ***food web***.

Food web/food chain - Complex network of many interconnected feeding relationships that creates many pathways for the transfer of energy through a biological community.

Latent heat polynyas form in areas where ice is moved away by winds or currents as soon as it forms, preventing it from becoming part of a local ice pack.

Figure 2.2. Location of polynyas in the Canadian Arctic.



The Movement of Water

Although largely covered by ice, the water of the Arctic Ocean is in constant circulation. The main processes that cause currents and the circulation of water are wind stresses, contrasts in water density and tidal forces. Circulation on the coastal shelf is also affected by ice formation. Ocean currents occur at all depths and may be horizontal, vertical, or sloping in their direction of flow.

Surface currents are nearly all set in motion by the frictional drag of wind moving across the surface of the ocean. Major surface currents reflect average wind conditions over a period of several years. The general circulation patterns of the ocean are similar to those of the atmosphere. On a local scale these currents can be seen affecting the distribution of surface water, resulting in coastal upwelling of colder, more saline water. Surface currents can also occur on a larger, global scale.

Deeper flows in the ocean may be set in motion by contrasts in water density associated with differences in temperature and salinity. This kind of movement is referred to as ***thermohaline circulation***. When sea ice forms, most of the salt is precipitated out. This results in the production of very saline, cold water that sinks to great depths because of its high density and causes convective currents within the water column. The production of new ice within a polynya is a significant contributor to the thermohaline processes.

Tides are caused by the gravitational pull of the moon and the sun on ocean water. There are normally two high tides and two low tides that occur in a little more than one day on each ocean coastline. ***Tidal range*** can vary depending on a number of factors. The largest tidal range occurs when the gravitational pulls of the sun and moon work together, creating maximum high and low tide levels. These tides are known as ***spring tides***. When the moon and the sun are at right angles to one another with respect to the earth, their individual gravitational pulls are in different directions. This results in lower than normal tidal ranges called ***neap tides***. The continually changing distance between the moon and the earth also affects tidal levels. Other factors include location, local wind conditions, the shape of the coastline, and the shape of the sea bottom. Tidal ranges for coastal areas in the Arctic are noted in Table 2.1.

Thermohaline circulation - Throughout the world the density of seawater is controlled by its temperature (thermo) and its salinity (haline). The difference in water densities resulting from these temperature and salinity variations creates global oceanic circulation patterns. This thermohaline circulation brings warm salty water from tropical and subtropical areas towards the poles where the water cools and sinks to great depths.

Tidal range - The maximum distance between daily high and low tides is called the tidal range.

Spring tides – Maximum high and low tide levels created when the gravitational pulls of the sun and moon work together because they pull in the same direction.

Neap tides - Lower than normal tidal ranges created when the gravitational pulls of the moon and sun are in different directions.

Table 2.1. Mean large tides and extreme tides at selected coastal locations of the Canadian Arctic.

Port	HHWLT	LLWLT	Recorded Extremes High	Recorded Extremes Low	Mean Water Level
Iqaluit	11.3 m	0.2 m	12.3 m	-0.3 m	5.9 m
Hall Beach	1.4 m	0.0 m	---	---	0.7 m
Churchill	4.5 m	-0.1 m	5.4 m	-0.8 m	2.3 m
False Strait	1.3 m	0.3 m	---	---	0.9 m
Resolute	1.9 m	-0.2 m	2.3 m	-0.4 m	0.9 m
Cambridge Bay	0.7 m	0.2 m	1.4 m	-0.8 m	0.5 m
Tuktoyaktuk	0.6 m	0.1 m	2.3 m	-0.8 m	0.3 m

HHWLT = higher high water, large tide. Average of the highest high waters, one from each of the 19 years of prediction.

LLWLT = lower low water, large tide. Average of the lowest low water, one from each of the 19 years of prediction.

Recorded Extremes = highest and lowest tides recorded at a tidal station.

MWL = mean water level. Average of all hourly water levels over the available period of record.

Source: Forrester (1983).

Two currents, the Beaufort Gyre and the Transpolar Drift Stream, are the dominant features of Arctic Ocean water circulation (Figure 2.3). An influx of cool water from the Arctic Ocean is carried into Atlantic Ocean through the Labrador Current. The Kamchatka Current carries this same cool Arctic water into the Pacific Ocean. The water in the Labrador Current is unusually fresh, especially in summer because of the influence of the melting ice. The current travels from the southern tip of Greenland southward along the coast of Newfoundland, where it deflects the warm and salty North Atlantic current in an eastward direction.

Figure 2.3. Currents that circulate Arctic Ocean water or carry Arctic water to the Atlantic and Pacific oceans.

Plankton - The collection of small or microscopic organisms, including algae and protozoans that float or drift in great numbers in fresh or salt water, especially at or near the surface, and serve as food for fish and other larger organisms.

Zooplankton - Microscopic animals living unattached in aquatic ecosystems.

Meroplankton - Meroplankton are organisms which are part of the plankton for only part of their life cycle, usually an early, larval stage. As adults the meroplankton are benthos (including intertidal organisms) or nekton (mid-water).

Life and the Marine Ice

Numerous organisms can be found within and under the sea ice. When the ice forms, small spaces filled with brine remain between the crystals. These brine channels range in diameter from a few micrometers (0.001 mm) to several centimeters and may be home to several hundred unicellular species of algae. Brine channels in the ice also offer protection from predators. Juvenile stages of ***zooplankton*** and ***meroplanktonic*** larvae of bottom-dwelling or benthic organisms are known to enter the brine channel network on shallow Arctic shelves.

Ice algal production contributes between four and twenty-six percent of the total ***primary productivity*** in seasonally ice-covered Arctic waters. Because ice significantly reduces the short-wave radiation that can penetrate the water column, this proportion may increase to fifty percent or more in permanently covered waters. While algae are present in ice from the time it forms in the fall, they become more concentrated during the spring (March to April) in response to increasing light levels. Growth of ice algae continues until late May-early June, when maximum production and abundance occurs. Because the ice algae are closer to the ice surface than the phytoplankton within the water column, they can take advantage of increased light levels. These algae can effectively limit both phytoplankton and benthic algal production by shading the communities underneath them until the break-up of ice in June.

Numerous other organisms are also present within the sea ice, including bacteria, viruses, fungi, and small zooplankton such as ***protozoans***. ***Metazoans***, such as ***tubellarians***, ***crustaceans***, and ***rotifers***, are also found. Many of these organisms feed on the ice algae and/or the dissolved organic material that they secrete.

Most ice organisms are concentrated within the lower centimeters of ice floes. During periods of complete ice coverage, there are strong interactions between ice biota and ***plankton***. ***Amphipods*** thrive at the underside of ice floes, feeding directly on the community of organisms found in the bottom of the ice. In early spring, when there is still little food to be found in the water column, copepods will migrate from deeper parts of the water column to feed on phytoplankton that accumulate just below the ice.

Primary productivity - The rate at which new plant biomass is formed by photosynthesis.

Gross primary productivity is the total rate of photosynthetic production of biomass.

Net primary productivity is gross primary productivity minus the respiration rate.

Protozoans - Small, one-celled animals including amoebae, ciliates, and flagellants.

Metazoans - Multicellular animals which have cells differentiated into tissues and organs and usually a digestive cavity and nervous system. Examples of metazoans include *tubellarians* (free-living flatworms), *crustaceans* (aquatic animals with an exoskeleton, distinct body segments with a head, thorax and abdomen, segmented appendages and antennae) and *rotifers* (very small aquatic multicellular organisms having a ciliated wheel-like organ for feeding and locomotion that form part of the plankton).

Amphipods - Small crustaceans of the order Amphipoda, such as the beach flea, which have a laterally compressed body with no carapace.

Copepods - Numerous very small marine and freshwater crustaceans of the subclass Copepoda, which have an elongated body and a forked tail.

Ice Algae in Hudson Bay

Significant quantities of ice algae have been reported in the areas of the La Grande and Grande Baleine river plumes in Hudson Bay. These algal populations can have important effects on other organisms in the food web. For example, in Manitounuk Sound and the Grande Baleine River plume, the prebreak-up bloom of ice algae triggers the reproduction of *copepods*. The eggs and young of these copepods are consumed by newly hatched fish larvae. The abundance and relative condition of larval sand lance also appear to be closely tied to the production of ice algae. The sand lance is an important food for salmon, minke whales, marine mammals, and seabirds.

The Coastal Zone

The coastal zone consists of those areas visually connected to the shoreline and forming an integral part of the coastal landscape. This includes the transitional area between coastal waters and terrestrial systems that may affect the coast or coastal resources. These are areas used for human activity related to the coast. Estuaries and deltas are key features of the coastal zone.

Estuaries

An estuary is an area where fresh and marine waters meet and mix. Local topography and the proportion of the flows of freshwater to seawater determine where and how much of this mixing occurs either in the river or in the ocean. An estuary can further be defined as the portion of a coastal river or stream that is influenced by the tide occurring in the body of water into which it is flowing. Estuaries are protected from the full force of ocean waves, winds, and storms by reefs, barrier islands, or fingers of land, mud, or sand. These features define an estuary's seaward boundary.

When freshwater and seawater meet, the two do not readily mix. The less dense freshwater tends to form an upper layer over the more dense seawater moving in from the ocean. Such stratification can significantly affect both the circulation and chemical profile of an estuary.

Estuaries are often classified into one of three types based upon the pattern of water circulation. In all cases, the temporal and spatial extent of stratification varies daily and seasonally based on tides, wind and discharge.

The tidal, sheltered waters of estuaries support unique communities of plants and animals specially adapted for life at the margin of the sea. Estuaries are typically more productive than adjacent marine waters because river inflow, runoff from the land, and upwelling of deep marine waters combine to transport nutrients into them. Phytoplankton and other microorganisms thrive in this nutrient-rich environment, forming the basis of the ***food chain*** that ends in fish, marine mammals and other predators. Many different habitat types are found in and around estuaries. These include shallow open waters, freshwater and salt marshes, sandy beaches, mud and sand flats, rocky shores, river deltas, tidal pools, sea grass and kelp beds.

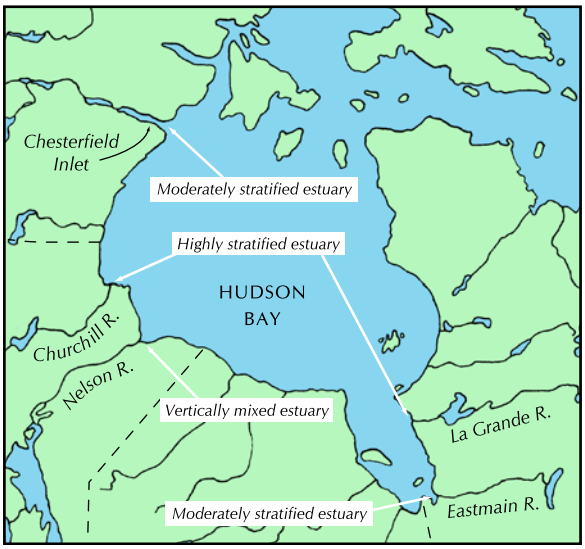
Sediments, nutrients and pollutants, carried by freshwater rivers and tributaries from upland areas, settle out of the water column when they eventually reach an estuary. Lagoons, mudflats and marshes are sites where mud and organic materials are deposited. There is a constant exchange of waters in estuaries as the freshwater flows one way and the seawater flows the other. Rather than quickly flushing out water, an

estuary often has a more lengthy retention period. Currents, generated by the ebb and flow of tides, are largely responsible for sediment transport into and out of estuaries. The net seaward flow over one complete tidal cycle may be very small.

Hudson Bay Estuaries

Hudson Bay, which drains 47% of the Canadian landmass, is ringed by estuaries (Figure 2.4). These estuaries have formed wherever the many large and small rivers empty into the bay. The three different types of estuaries are illustrated in Figure 2.5. Four of the five estuaries shown in Figure 2.4 and described below have been affected by hydroelectric development involving either an increase (Nelson and La Grande) or decrease (Churchill and Eastmain) in flow.

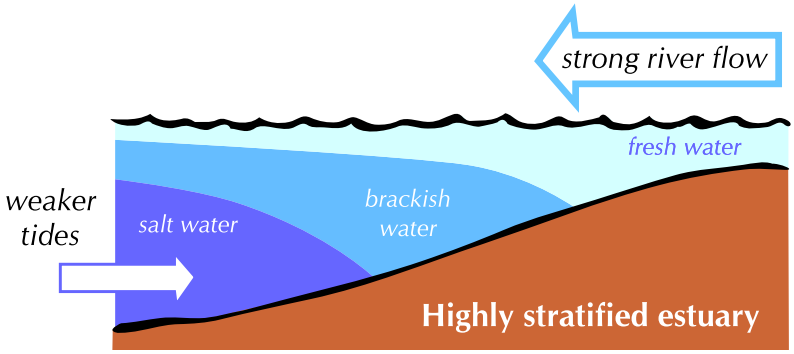
Figure 2.4. Locations of five estuaries in Hudson Bay which are examples of the three estuary types.



Highly stratified estuary (Figure 2.5a)

The estuaries of the **Churchill** and **La Grande** rivers are highly stratified. While there is some mixing of fresh and salt water, there is a notable stratification between an upper freshwater layer of water from the rivers and a lower saltwater layer. The Churchill River estuary, on the south-western coast of Hudson Bay, lies within an enclosed basin approximately 13 km long and up to 3 km wide. The low tide depth is less than 3 m, except for the lower 2 km where depths reach 21 m in the narrow passage to Hudson Bay.

Figure 2.5. Three types of estuaries: highly stratified, moderately stratified and vertically mixed.
a) Conditions that create a highly stratified estuary.



At high tide, no saline intrusion is evident in the upper 3 km. Downstream from this point bottom salinity rapidly increases to 25 ppt by kilometre 7. At low tide an irregular plume of brackish surface waters extends at least 6 km beyond the mouth of the basin. Water at the surface of the estuary is relatively fresh (only 2 to 3 ppt), while water only 2 m below the surface can be up to ten times as high (up to 26 ppt).

The La Grande River Estuary includes both a freshwater riverine portion, formed within the lowest 37 km of the La Grande River, and a large plume that extends well out into James Bay. Hydroelectric development, beginning in 1978, diverted the upper drainage basins of the Eastmain, Opinaca and Caniapiscau rivers. This resulted in an increase in the annual flow of the La Grande River from 1,700 to 3,400 m^3/sec. Winter flows in the La Grande were substantially increased and the spring freshet was eliminated. Summer flows did not change significantly from pre-development values. The combination of strong river flow and relatively weak tides (1.2 m) prevents the seawater from moving beyond the river mouth. Under present operating conditions, a minimum flow requirement of 900 m^3/sec prevents any seawater from flowing above the river mouth. River flow during all seasons is sufficient to produce a surface plume of reduced salinity over the more saline waters of James Bay. During summer, the plume is on average 1 to 2 m thick, increasing to 6 m in some areas, particularly in regions at the front. Its limits generally coincide with the coastal shelf (up to 20 m in depth) but are strongly affected by wind and tidal action. Mixing between fresh and marine waters is generally limited to the forward regions at the edge of the plume. The creation of upstream reservoirs caused an increase of 1°C in the average winter temperature and a decrease of 3 to 5°C in average summer temperature in the river. No temperature changes are noticeable at the mouth of the river. The period of ice cover in the river was also reduced from 25 to 18 weeks, though ice cover in James Bay was changed only at the river mouth.

Moderately stratified estuary (Figure 2.5b)

Moderately stratified estuaries are characterized by some mixing of fresh and salt water at all depths. The lower layer is always saltier than the upper layer. Salinities at all depths increase toward the estuary mouth. Moderate stratification can be seen in the estuaries of the **Eastmain River** and **Chesterfield Inlet**. The Eastmain River Estuary is shallow with an average depth of 3m. Even 5 km offshore depths do not exceed 10 m. In 1980, freshwater flow into the estuary was reduced by 90%, due to diversions affecting the Eastmain, Opinaca, and Petite Opinaca rivers.

The extent of mixing and vertical stratification of Chesterfield Inlet is strongly influenced by differences in the spring neap tide cycle. Vertical stratification is increased during neap tides, causing a decrease in vertical mixing and increased stability. Spring tides cause more vigorous mixing, and decreased vertical stratification and stability. These different mixing regimes can cause large changes in the concentration and distribution of nutrients and aquatic biota in the estuary.

Figure 2.5

b) Characteristics of a moderately stratified estuary.

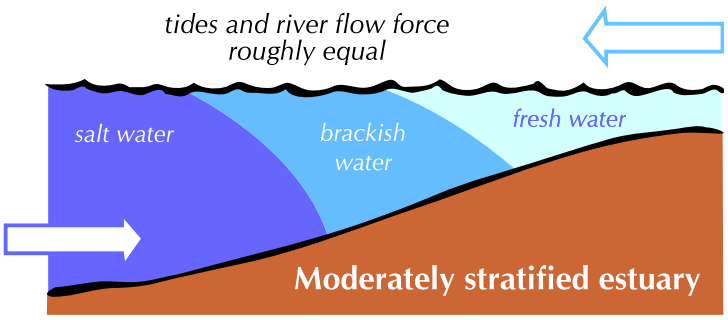
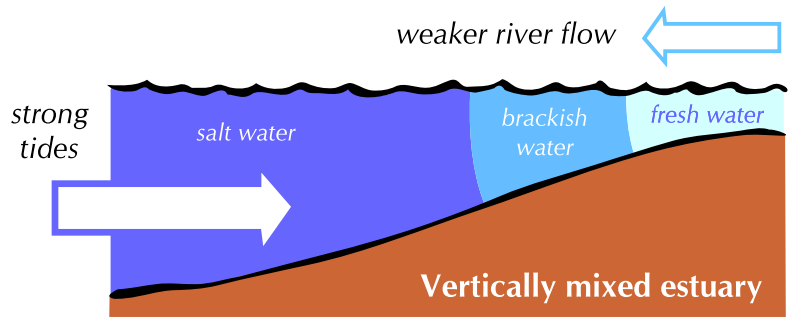


Figure 2.5

c) Conditions that produce a vertically mixed estuary.



Vertically mixed estuary (Figure 2.5c)

This type of estuary is formed by tides that powerfully mix the water, usually eliminating layering altogether. Salinity is dependent upon tidal stage. Such complete mixing is generally only observed in very small estuaries. The well-mixed estuary of the **Nelson River** has formed in the broad funnel-shaped mouth of the Nelson River where it enters southwest Hudson Bay.

Port Nelson, where the Nelson River abruptly widens, marks the upstream limit of saline intrusion, but tides affect river depth an additional 23 km upstream. A narrow, deep, central channel runs from Port Nelson well out into the estuary. On either side of this channel are extensive flats of sand and clay, which are exposed at low tide. Tides of up to 4.8 m, shallow depth, and strong winds combine to create strong onshore and offshore currents.

These strong currents vertically mix the water column to create a homogenous estuary. There is little vertical stratification except in the deep central channel. At high tide, salinity increases uniformly from zero ppt at Port Nelson to 25 ppt at 25 km offshore. At low tide, brackish inshore waters extend seaward, considerably reducing the salinity compared to the high tide condition.

Estuarine Variability

Estuaries are complex systems with a wide variety of environments. These are constantly in a state of change because of tides and the mixing of salt and freshwater.

Bathymetry - The measurement of the depth of bodies of water.

The local ***bathymetry*** at the outlet of estuaries affects the influence of tidal flow. Several studies have shown that a rapid change in water depth at the outlet reduces the tidal influence. If there is a large depression in the seabed at the mouth of an estuary, the tidal influence will not extend as far up the estuary as it would if the bathymetric elevation is relatively flat.

Wind is also a factor that influences the effects of tides on estuarine waters. If wind is blowing onshore, in the direction of the tide, the tidal influence on the estuary may be stronger. An onshore wind may also result in greater vertical mixing and a reduction in water column stratification. On the other hand, if wind is blowing offshore against the direction of the tide, the tidal influence on the estuary may be less. Offshore winds can result in greater stratification of the water column, as the force of the tide is weakened under these conditions. The effects of onshore and offshore winds on the water column are similar to the effects resulting from differences in tidal magnitude. Those differences are due to spring and neap tides, respectively.

Winds in the Mackenzie Estuary

Within the estuary of the Mackenzie River, easterly winds cause upwelling and can result in plume waters extending up to several hundred kilometers offshore. Westerly winds typically force plume waters against the coast and enhance the flow of this water along the Tuktoyaktuk Peninsula.

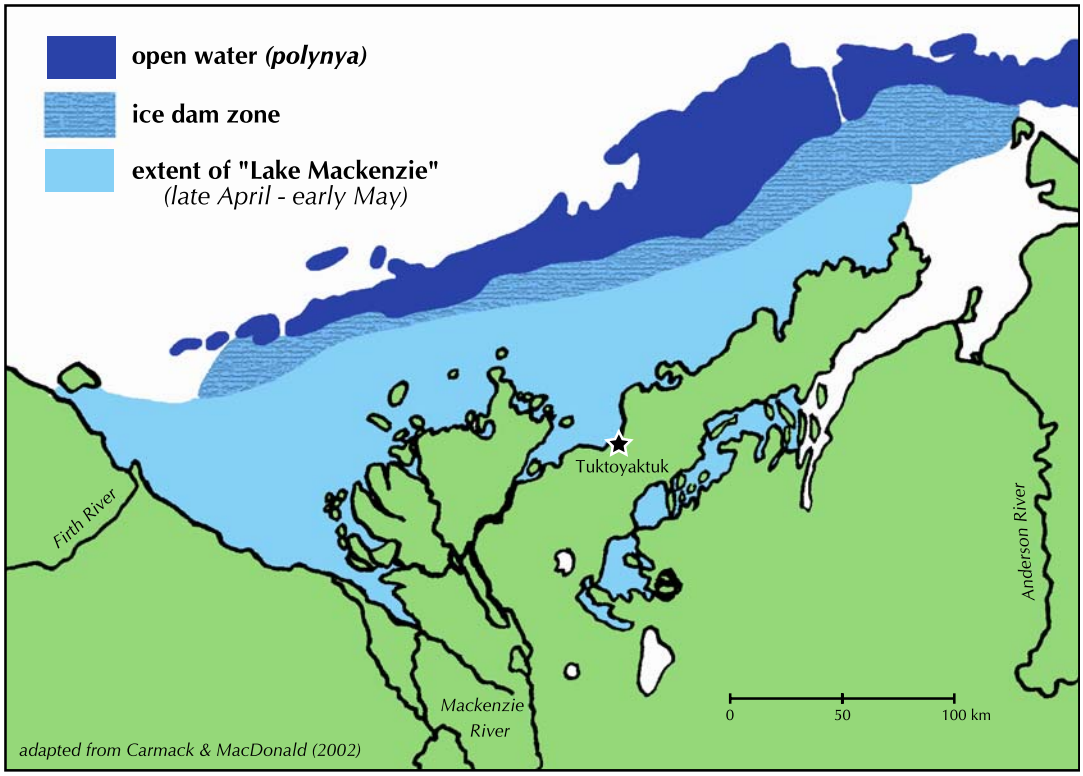
River discharge also affects tidal influences and mixing within an estuary (Figure 2.5). A very large and rapidly flowing river may not mix as readily with seawater at high tide as a smaller, slower-flowing river. A large, fast-flowing river may exert a greater freshwater influence on the ocean for a greater distance than a smaller river. Similarly, the seasonal response of rivers to snowmelt can significantly affect where freshwater and seawater meet in estuaries. If the freshwater input is large, and there is relatively little mixing due to tides or winds, a fresh or brackish plume may extend well out over the sea. The freshwater flows at the surface, away from the land. Saltwater, upwelling from deep within the ocean, flows toward land along the bottom, in proportion to the amount of freshwater outflow. Maximum mixing of these two layers occurs in frontal regions. These regions are defined as the place where the thickness of the freshwater layer abruptly changes.

Ice also affects water circulation within an estuary. For example, while the Mackenzie River discharge to the Beaufort Sea is greatest in the spring and summer, it exerts a substantial influence all year round. In the winter, freshwater from the Mackenzie gathers beneath the land-fast ice and forms a “freshwater lake” that floats above brackish and marine water. This mass of freshwater covers an area of approximately 12,000 km^2 and has a volume of about 70 km^3 (Figure 2.6). Due to differences in freezing temperatures between this freshwater and the marine water below, this is a potential site for the formation of ***frazil ice***.

Frazil ice - Small ice crystals formed in the water column that may adhere to each other to form larger masses.

These are small ice crystals that are formed in the water column. They may stick to each other to form large masses and lead to rapid cooling of the water. The dispersal of this freshwater mass influences the stability of the water column, nutrient distribution, and dispersal of organisms.

Figure 2.6. Map of "Lake Mackenzie" and the nearby polynya and ice dam zone which are formed at the end of winter.



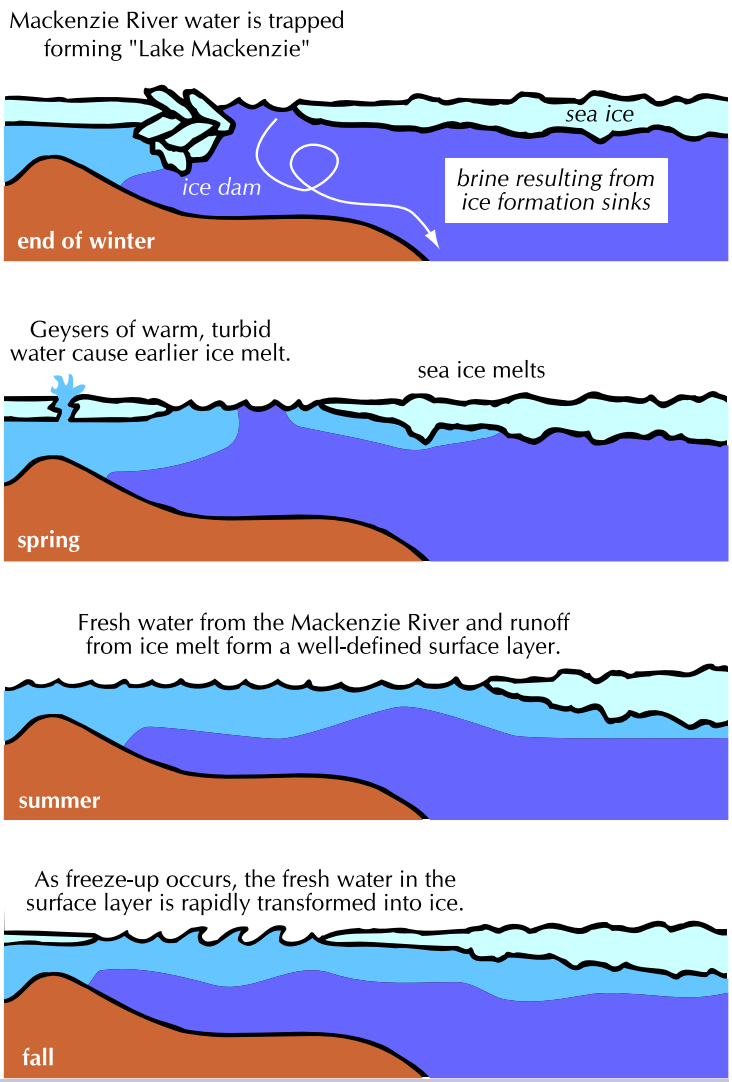
Seasonal Changes within the Mackenzie River Estuary (Figure 2.7)

By the end of winter, freshwater accumulates behind an ice dam near the mouth of the Mackenzie River (Figures 2.6 and 2.7). This results in the eventual formation of a large mass of freshwater, known locally as Lake Mackenzie, which floats above the underlying seawater further out in the estuary. Winter ice production in the seasonal ice zone results in the release of dense brine. Due to convection, the brine mixes the surface layer to a depth of 40 to 50 m as it sinks to the bottom. This mixed layer generally does not intermix with the underlying nutrient-rich waters, which originate from the Pacific Ocean.

In the spring, land-fast and bottom ice in the Mackenzie estuary and nearshore areas can block the movement of water under the ice and cause over-flooding. This results in meter-high geysers of turbid water forming at cracks and holes in the ice surface. This warmer water causes ice cover in the delta to melt about two months earlier than it would otherwise. During spring flooding, the mass of freshwater near the mouth of the Mackenzie River is displaced by turbid river water. Although sufficient nutrients are available, phytoplankton growth is restricted by lingering ice cover and high turbidity, which limits the amount of light available for photosynthesis.

In the summer, freshwater from the Mackenzie River and runoff from ice melt form a well-defined surface layer to a depth of 5 to 10 m. The transverse bar across Kittigazuit Bay usually helps to keep the sea and freshwater from mixing. On one side, the freshwater of the Mackenzie River generally remains free of salt. On the other side, toward the Beaufort Sea, a 2 to 4 m thick layer of turbid water from the Mackenzie River spreads outwards for 5 to 10 km over the denser intruding mass of seawater. The exact size and location of these water masses are influenced by wind-driven currents.

Figure 2.7. Seasonal changes in the Mackenzie River Estuary.



Before the beginning of freeze-up in mid-September, there is a 2to 4 m layer of freshwater over the Canadian shelf, resulting from ice melt and river runoff. The top 10 to 20 m of fresher water has been mixed by summer and early fall storms. The freshwater layer typically overlies a cold, saline layer, found at depths below 20 m. As freeze-up occurs, the freshwater in the surface layer is rapidly transformed into ice.

Productivity in the Estuary

The distribution of both living and non-living particles is strongly influenced by water circulation. In many estuaries this is considered to be the primary reason for the distribution of phytoplankton. However, in the Mackenzie River estuary, light penetration through the ice is thought to be the likely factor limiting primary production during spring.

The effect of freshwater input on phytoplankton growth in estuaries can be both positive and negative. Freshwater inflow brings nutrients to an estuary and increases the upwellings. This action regenerates nutrients from deep ocean waters. The most important of these nutrients are nitrogen (usually as nitrate, nitrite, urea and ammonia) and phosphorus (usually as phosphate). Additional nutrient replenishment of surface waters takes place in the winter when ice formation results in the release of cold, dense, saline water. As this water descends, it can cause convective currents that transport nutrient-rich deeper water upwards through the water column. However, high freshwater flow into stratified areas can increase the vertical layering to the extent that no mixing occurs between surface and deeper waters.

In areas where a lot of mixing occurs, phytoplankton growth is reduced because the plankton is not able to remain in the well-lit surface waters. Rapid phytoplankton growth requires a combination of conditions. Periodic mixing is needed to provide nutrients to surface waters. At the same time the stratification must be sufficient to keep phytoplankton in well-lit surface layers.

The estuaries of Hudson Bay and the surrounding area are nutrient-poor with low productivity. In contrast, the Mackenzie River is considered to be the most sediment-rich river in the Arctic. Each year it transports about 130 million tonnes of sediment into the Beaufort Sea. The distribution of nutrients in the southern Beaufort Sea is dominated by the Mackenzie River discharge. The highest concentrations of nitrates in the southeastern Beaufort Sea occur in the vicinity of the Mackenzie River outlets. Phosphate concentrations are also highest near the mouth of the Mackenzie River, but levels do not vary as greatly as for nitrates.

Collecting Samples in Salt and Estuarine Waters

There are many similarities between collecting and analyzing freshwater, estuarine and saltwater samples. For more information see Chapter 4 – Designing a Water Quality Program.

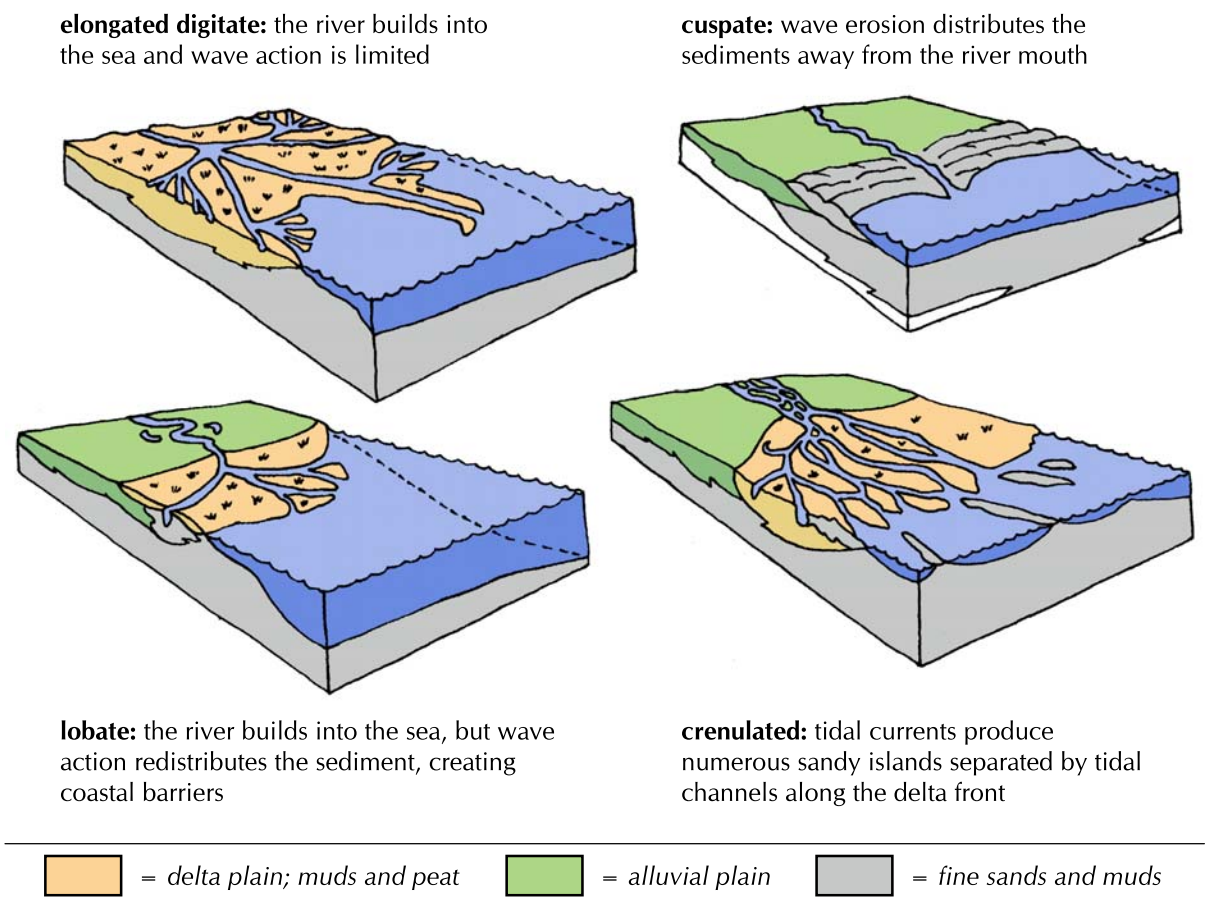
Deltas

A delta is a low, nearly flat area of land at the mouth of a river where sediments accumulate. Water channels are kept open in marine estuaries by tidal currents and river discharges. A delta is formed when there are more sediments entering an area than can be removed and redistributed by water action. Deltas come in a variety of different shapes, depending on local flows. The four more common delta formations are illustrated in Figure 2.8.

One of the best-known deltas in the Arctic is the Mackenzie Delta, located at the mouth of the Mackenzie River. This delta is approximately 13,000 km^2 in area. It is estimated that there are at least 24,000 lakes and ponds in the Mackenzie Delta.

Deltas are also found in lakes (e.g., the Slave River delta) where they play an important role in the lake system ecology.

Figure 2.8. Illustration of four different delta formations.



Human activities are having an impact on the marine and coastal environment in many areas of the Arctic:

- There is a 40-year history of oil and gas exploration in the Beaufort Sea and Mackenzie Delta. This region has a great potential for future exploitation and development of these reserves.
- There are currently a number of active mines in the Canadian Arctic, and about fifty or more active exploration projects throughout the region.
- Hydroelectric development is one the most important influences on the physical nature of the estuaries of Hudson Bay and the surrounding area. Four estuaries in Hudson Bay have been affected by hydroelectric development causing either an increase (Nelson and La Grande) or a decrease (Churchill and Eastmain) in flow.
- Contaminants originating both from local Arctic and distant sources have accumulated and affected many aspects of the environment.
- High sediment loading in estuaries, contaminated or not, can cover critical bottom habitat and smother plants and animals.
- Increased nutrient levels in estuarine regions may lead to accelerated eutrophication and associated issues of dissolved oxygen depletion within the water column.

More information on issues related to human impacts in the Arctic is provided in Chapter 7.

Chapter 3: Assessing Water Quality

Guidelines for Water Quality

Introduction

Guidelines for Canadian Drinking Water Quality

Water Quality Guidelines for the Protection of Aquatic Life

Care and Caution in Using the Guideline

Key Parameters for Assessing Water Quality

Introduction

Microbiological Parameters

Total Coliform

Protozoa

Viruses

Radiological Parameters

Chemical and Physical Parameters

Water Temperature

pH

Conductivity

Water Clarity

Turbidity

Total Suspended Solids or Non-filterable Residue

Total Dissolved Solids

Alkalinity

Dissolved Oxygen

Major Nutrients

Major Ions

Trace Metals

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

[1]MAC = 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/Ceqg/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.

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).

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.

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.

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

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.

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.

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

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.

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.

These radionuclides can be released into the environment by mining, bomb tests, crashed satellites and nuclear power plant disasters, such as the Chernobyl disaster in the Ukraine in 1986.

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 Anigaq 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.

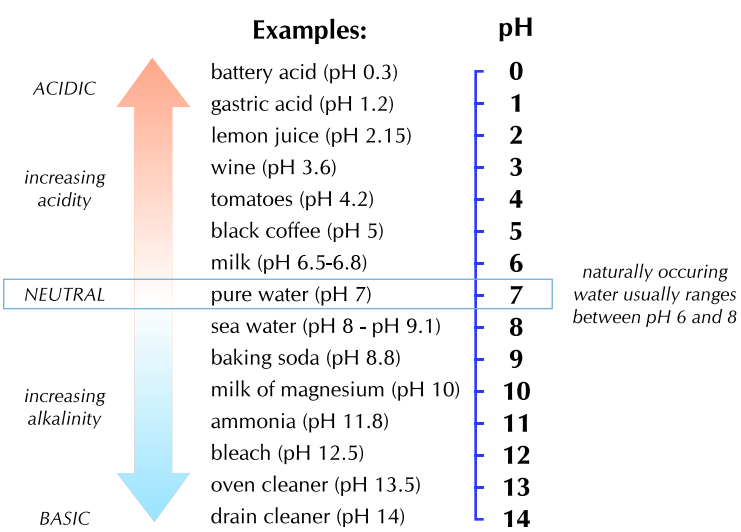
The pH of natural fresh waters ranges from 4 to 11, with natural surface waters tending to be alkaline (i.e., pH >7.0). Groundwater is more acidic. Rainfall is naturally acidic at a pH of 5.0 to 6.5. ***Acid precipitation*** (caused by long-range transport of pollution) has a pH of less than 5. It is 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.

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.

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 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 (*Thiobacillis 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.



Conductivity

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

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 µsie/cm. Natural surface waters can range as high as 1500 µsie/cm, although the highest recorded measurement for northern rivers reported in Appendix B is 704 µsie/cm and all average values are less than 300 µsie/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.

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).

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).

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.

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.

PCBs (Polychlorinated Biphenyls) - A group of toxic chemicals used for a variety of purposes including electrical applications, carbonless copy paper, adhesives, hydraulic fluids, microscope emersion 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*.

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.

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.

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.

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.

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.

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.

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.

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.

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

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.

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.

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.

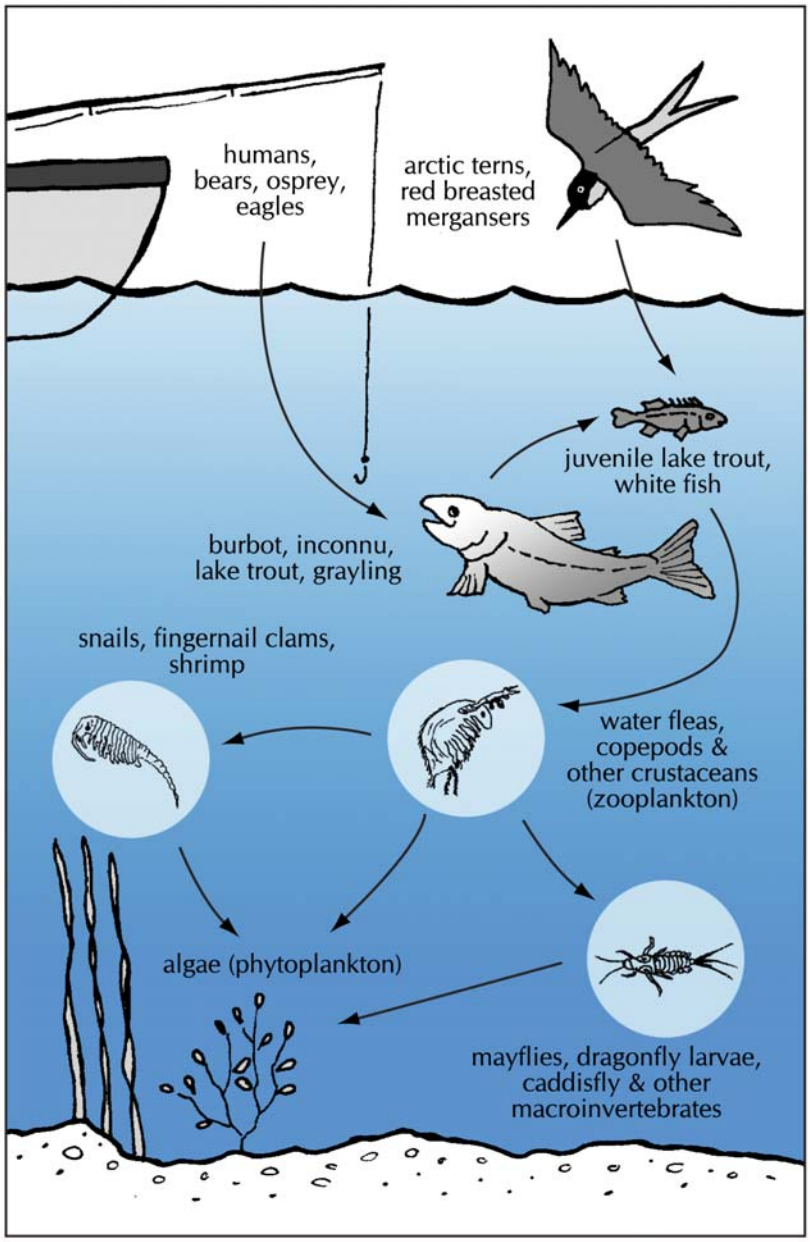
Zinc (Zn) is determined as total and extractable. It is generally plentiful in surface waters. Average concentrations of total zinc range from 0.001 to 0.033 mg/L in the rivers summarized in Appendix B. Areas with acidic waters (lower pH) have higher concentrations. Zinc, like so many other metals, is 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,

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.

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.

Figure 3.2. Food web 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).

Chapter 4: Designing a Water Quality Program

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Steps in Designing a Water Quality Program

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Establishing Baseline Conditions

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What Information Already Exists?

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What are the Components of the Sampling Program and How Will it be Conducted?

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Designing a Water Quality Program

Introduction

Water quality programs are designed to answer questions about selected chemical, physical and biological components of an aquatic system. They include monitoring programs and research projects. Water sampling can be done once or many times, and over the short or long term, depending on the objective of the program. Shorter-term research projects or studies are generally carried out to obtain baseline information about a water system.

Water quality monitoring programs are carried out for a variety of reasons. A monitoring program consists of the repeated collection of samples using the same method. Such programs are carried out in order to answer a question or a number of questions. In general, the question asked is "Has there been a change in water quality?" The length of the monitoring program is often determined by the length of time over which the change is expected to occur.

A change in water quality can be caused by a human activity such as the opening of a new mine, or a natural cause such as a landslide. Change can also occur because of seasonal variation in conditions. It can occur abruptly or over the long term.

Long versus Short Term Projects

A number of factors decide how long a water quality program lasts. These factors can include the availability of resources (such as funding and people), the objective of the program and the length of time a change in water quality is expected to take. Many monitoring projects are designed to last for a number of years or decades. They are typically designed to detect trends or subtle changes that might not be noticed in the short term. This kind of long-term monitoring requires a major commitment of personnel and resources.

Because of the high costs of long-term monitoring projects, short-term (or special) studies are becoming more common. These studies are designed to answer one or several very specific questions. Short-term projects are ideal for establishing ***baseline conditions*** as a pre-condition of a development. Baseline studies were conducted before the approval to develop the Ekati, Diavik and Snap Lake diamond mines in the NWT. Short-term projects are also a useful way to decide if there is a need for further, more specific studies.

Baseline conditions - The state of water quality (usually defined in chemical and biological terms) before a new activity occurs in the watershed that will affect water quality (e.g., mining).

They can show that an initial concern is unfounded or can help to focus the scope and nature of a longer-term project. Short-term projects always face some limitations and should never be considered as a cheap or reliable alternative to longer-term projects.

There are a number of factors to consider when deciding the timeframe of a program. For example, an effective **synoptic survey** (see program objectives below) requires an intense level of coordinated effort over a short period. This may be more difficult than organizing a lower level of effort over a longer period. Another consideration is the impact of varying natural conditions. A spring melt sampling project designed to take two weeks can extend into four because of a very prolonged melt. Alternatively, it may not happen at all because of very limited winter snow accumulation.

Steps in Designing a Water Quality Program

The development of a project design provides a detailed reference for the length of the project. All the details of the program should be written and explained in a **project design document**. This document must be understandable and should give enough detail that someone else with the appropriate knowledge and background could carry out the project.

Quantifiable - Capable of being quantified or measured.

Replicable - Capable of being repeated. If a program is fully replicable, someone else could repeat any aspect of it at another time.

Representative samples – Samples that closely reflect the actual composition or make-up of the body of water being studied.

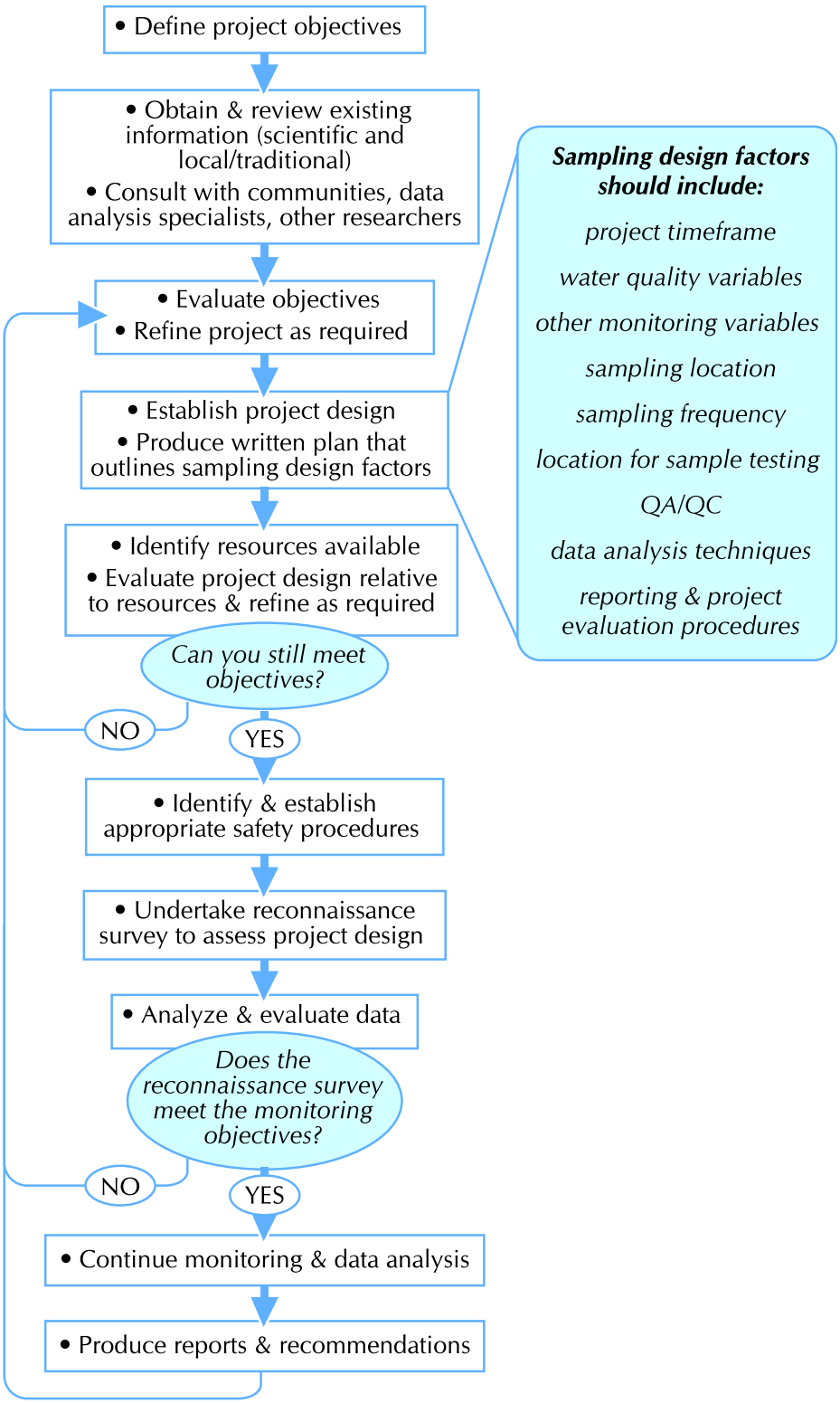
The results of any water quality program should be reliable and ***quantifiable***. If the program is properly designed and is fully ***replicable***, the data analysis will provide specific conclusions. Programs must be designed in such a way that they provide ***representative samples***. Such samples provide data about baseline conditions, natural variability over space and time, and the effect of activities on water quality.

Figure 4.1 shows the steps that should be followed when designing a water quality program. Key questions to consider are:

- What are the objectives of the program?
- What information already exists?
- What resources are available to carry out the program?
- What are the components of the sampling program and how will it be conducted?
- How can the program be pre-tested and refined?
- How will the results be analyzed?
- How will the results be reported?
- How will the program be reviewed and evaluated?

The questions do not always follow a strict order, but answering each of them is important. The information review and program objectives will help to define the sampling design factors, such as water quality variables, frequency, location, data analysis techniques, and the length of the project.

Figure 4.1. Flow chart showing the steps involved in designing, conducting and evaluating projects.



The design stage is an excellent time to consult others who have done similar work in the area. It is a good time to obtain advice from prospective laboratories and to talk with data interpretation specialists about the level of sampling effort required. Consulting local people who are familiar with the study area provides an opportunity to include local and traditional knowledge in the program. Such consultations can also help to identify possible logistical problems.

What are the Objectives of the Program?

The first step in designing any water quality program is to decide on the objectives and overall purpose of the study. The objectives should reflect both public questions and scientific and/or management needs. The more precisely the objectives are expressed, the more efficient and effective the water quality program is likely to be.

Water quality programs are generally carried out for the following reasons:

- Establishing baseline conditions
- Compliance monitoring
- Trend monitoring
- Impact assessment monitoring
- Synoptic or survey monitoring

Each of these types of monitoring is described below.

Establishing Baseline Conditions

Understanding baseline conditions is an important part of any water quality program. Baseline conditions are used as the reference point for determining the changes that might be occurring to the water system. It is very important to obtain reliable information and to allow enough time to establish these baseline conditions. Sometimes they are needed as a starting point for further study.

Baseline monitoring, also called background or ambient monitoring, is used to analyze and describe existing water quality conditions over a geographic area or specific location. The objective is usually to find out what a system's natural conditions are. Those conditions include seasonal cycles and natural variability due to ***biogeochemical cycling***. This type of monitoring is used to provide information for the comparison of conditions after some stress is imposed on the system. It is often a first step towards establishing one of the monitoring programs noted below. Baseline monitoring programs are usually short term (i.e., < 5 years), but can be medium term (i.e., 5-10 years) if natural variability is great and/or a development project is delayed.

Biogeochemical cycling - The cycling of materials through ecosystems as a result of various biological, chemical and geological processes.

Compliance Monitoring

Compliance monitoring is used to determine if the site-specific water quality objectives (see Chapter 3 - Canadian Water Quality Guidelines) or permit conditions are being met. Standards are often, but not always, site-specific and generally related to a particular effluent source. The controlling licensing or permitting authority usually sets these standards. Compliance monitoring is generally the least difficult to design and evaluate because the variables, site locations, sample frequency, and method of measurement are usually set out in the monitoring objectives. Compliance monitoring is normally conducted over the term of the licence. If the samples collected are going to be used in enforcing the water licence, there are additional considerations such as documenting the ***chain of custody*** of samples.

Chain of custody - A system to guarantee the identity and integrity of a specimen (e.g., water sample) from collection through to reporting of the test results. (More details are provided in Chapter 5).

Trend Monitoring

Trend monitoring is used to discover changes over time that may result from large-scale impacts on the environment. Examples include those caused by acid precipitation or climate change. Other impacts that can be monitored include the penetration of increased ultraviolet "B" radiation into water bodies and increases in ***ozone depletion*** in the upper atmosphere (stratosphere). Contaminants that travel over a long distance through the air, and are then deposited in snow or rain can also have an impact on the environment.

Ozone depletion - A decrease in the concentration of ozone (O_3) in the earth's upper atmosphere. Ozone depletion can cause thinning or holes in the ozone layer.

Trend monitoring is a long-term commitment, with programs generally being conducted for 5 to 10 years or longer. Cost-benefit analyses of trend monitoring show that, although it is more costly, in many cases it provides more useful and valuable information. Trend monitoring can be used for periodic reporting (including state of environment reporting) and more informed decision-making, since it provides a higher degree of certainty.

Lakes are better suited than rivers for long-term trend assessments. Lakes act as natural collectors of deposits from the atmospheric and of all upstream inputs within the watershed. Lakes also act as sinks for suspended materials. Analyses of sediments can be ideal for finding out both historical and ongoing long-term trends. Understanding lake circulation and physical processes is key to designing a sampling program for lakes.

Impact Assessment Monitoring

Impact assessment monitoring is used to measure the effects of a particular project or natural event on water quality. Projects could include mining, logging, hydropower, agriculture, construction of roads and pipelines, dams, aquaculture activities, and urban developments. Natural events include fires, floods, droughts, earthquakes and land slides. Impact assessment usually requires long-term monitoring.

An ideal impact assessment monitoring program has had baseline conditions established before the project begins. Monitoring begins before project start-up, continues while the project is underway, and extends for a defined time afterwards.

It is important to remember that impacts on surface and ground water quality may happen on a slow, geological-geochemical time-scale. The greatest impacts may happen after the project is finished.

Change is usually found in comparison with the baseline conditions. If a baseline cannot be established before a change happens, assessing an impact can be difficult. It is then essential to use a reference site or sites. A reference site can be a sampling point upstream of the specific problem or in a near-by, comparable water system. However, the information obtained through studies after change occurs is not as conclusive. These studies do not consider normal local variation as effectively as a study that includes information before change occurs.

Impact Assessment and Compliance Monitoring at a Yukon Freshwater Supply Dam

A freshwater supply dam was built as part of the original Faro Mine development in central Yukon. The reservoir behind the dam supplied water to the milling process during the mine's operation. With the closure of the mine, the dam was no longer needed and its deteriorating condition posed a very real risk to the downstream tailings infrastructure and environment. To address this risk, the dam was breached by digging out a notch in the dam at the location of the original stream channel. This was to allow the original creek, apparent from bathymetric surveys, to re-establish. To simplify water management and minimize sediment transport, construction was completed during the lowest flows of the year in late fall and winter.

To ensure that the release of sediments to the downstream environment was minimized, an **impact assessment water quality monitoring program** was developed. The design consisted of three phases of sampling: prior to construction (i.e., digging out the notch in the dam), during construction and after construction.

In the first phase (prior to construction) monitoring occurred at two sampling stations: one upstream of the reservoir and another downstream of the dam. The second phase (during construction) consisted of monitoring at six sampling stations: two upstream of the dam (with the baseline station located the furthest upstream), one immediately above the dam, another right below the dam, and two downstream of the dam.

The water quality parameters measured were total suspended solids (TSS), turbidity, metals, pH, temperature and conductivity. A small quantity of acid-generating rock was removed prior to construction and was not considered to be an issue. In some cases adaptive/mitigative measures were undertaken in response to changes in monitoring results.

Because the construction required the "right to use water" and "deposit a waste" and thus a Yukon water license, the design of the plan can also be considered a **compliance monitoring program**. The terms of the license identified the sampling locations, the timing of sampling and the water quality parameters at the sampling locations. With respect to TSS, the major water quality parameter, levels were never to be greater than 25 mg/L above the baseline station's TSS levels. The effluent standards for metal grab samples were also identified.

On two occasions during construction, total suspended sediment levels were higher than compliance allowances:

- On the first occasion in mid-November, pumping capacity was increased, problems with the generator occurred, and there was a rapid fluctuation in the reservoir's water levels. This fluctuation increased erosion of the land that was flooded, and high TSS levels were measured at a station upstream of the dam (not the baseline station), and also at the station immediately below the dam.
- In mid-December high TSS levels were measured at the same stations upstream and immediately below the dam. This was thought to be caused by erosion that occurred under the ice, a natural event that resulted when the stream channel found its natural course.

On December 15th the notch in the dam was finished and complete flow allowed. Results from the final phase of the impact assessment and compliance monitoring are not yet available.

These results will allow environmental monitors to observe if any unsatisfactory changes in TSS occur after construction. It is expected and hoped that water quality will return to levels that were measured prior to construction.

Synoptic or Survey Monitoring

Synoptic or survey monitoring is usually conducted over large areas. Such monitoring provides a "snapshot" in time of water quality conditions and the variation between different places. This kind of monitoring attempts to analyze and describe conditions in a representative sample set. It is often used to provide general information for areas where there are a large number of lakes. Government or industry geochemists might use such monitoring of stream and/or lake water and sediment for mineral exploration purposes.

There are limitations in this type of sampling. The assumption that a number of sampled water bodies represents all of the area's lakes or rivers can never really be confirmed. Nevertheless, the information can be very useful for identifying key areas for more intensive study.

Synoptic or survey monitoring lends itself to short, intensive projects. This kind of monitoring was used to evaluate the sensitivity of Keewatin District lakes to acid deposition. Surface water chemistry samples were collected at the centre of each lake over a large area in a very short time. These samples permitted the development of maps showing possible sensitivity to acidic inputs.

The loading of atmospheric contaminants such as PCBs from rivers in the NWT and in Nunavut to the Arctic Ocean was examined in a synoptic survey. Environment Canada measured the concentration of trace organic contaminants over a period of several days near the mouths of major rivers flowing into the Arctic Ocean. These measurements provided a first estimate of contaminant loadings from these rivers to the Arctic Ocean.

Another recent survey monitoring program examined the impact of the overabundance of Ross' Geese and Lesser Snow Geese on northern habitats and water quality. This study was conducted at Karrak Lake, Nunavut.

What Information Already Exists?

An important step in designing and carrying out a water quality program is to find out what information already exists. Existing information can include scientific data as well as traditional and local knowledge. Compiling and reviewing what is already known about an area gives the researcher background information on what has already been sampled, where the work was done and how it was carried out. Information gaps can then be identified. This information will help to focus the study and fine-tune the program objectives.

Historical water monitoring data might be available through Environment Canada or Indian and Northern Affairs Canada, or through other agencies such as Fisheries and Oceans Canada, territorial

governments, non-government organisations, and consultants. Useful background information can also include general basin characteristics such as drainage area, topography, and regional and climatic cycles.

A lot of information is available on the Internet, especially through the Environment Canada Green Lane site (www.ec.gc.ca/envhome.html). During 1989 and 1990, the federal government maintained 40 water quality sampling locations in the NWT and seven in the Yukon. Currently, Environment Canada has two water quality monitoring locations in Nunavut, ten in the NWT and four in the Yukon. An additional 41 stations are operated as part of programs shared by one or more government departments (e.g., Indian and Northern Affairs Canada, Fisheries and Oceans Canada, Parks Canada, Alberta Environment) in addition to Environment Canada. (Appendix A identifies these sites.)

Traditional and local environmental knowledge can be used to enhance or complement a scientific study, as well as provide information on existing conditions. Traditional and local environmental knowledge is the information and understanding held by the people who live in an area. It is also sometimes referred to as community-based knowledge. This knowledge has been gained through an individual's personal experiences and the experiences of their families and communities over time. It has often been passed down through many generations. Traditional knowledge comes in many forms, from spiritual connection to land, to classification systems and observations of change. It includes language, culture, practice and customs. This range often makes it difficult to know how to identify the available information and include it in a scientific study. Traditional and scientific knowledge should not be compared or considered equivalent. The two knowledge bases each contribute to an overall understanding in their own way.

From the beginning, the design of any new study should consider how to identify and include traditional and local knowledge. Community-based knowledge can contribute to what is known by scientists about a local area or environmental conditions. It can also be used to confirm or validate the reasons for doing a study and the conclusions that are reached. For example, aboriginal place names can reveal important information and knowledge about a particular location and the associated features of the water system. Traditional and local knowledge can be useful in providing information such as times of break-up, freeze-up, ice characteristics, and late-winter base flow where no hydrographs exist.

There are many good web sites that provide information about traditional knowledge. Some of these are listed with brief descriptions later in this manual under "References".

Arctic Borderlands Ecological Knowledge Co-op – The use of local observations to obtain information on ecological change.

Local experts from the community of Old Crow, Yukon, observed that the lakes in Old Crow Flats were drying up. Scientists followed up on (and confirmed) these observations with remote-sensing studies and ground-truthing. Further work will track this trend to see if it continues, and will look at how changes in water level influence the water quality and the lake ecology. More information on the Borderlands Co-op can be found at www.taiga.net/coop.

What Resources are Available to Carry Out the Program?

For a program to be successful, the right kind of support must be available. Resource support includes personnel, equipment, and money. Funding for training must be considered, as well as for shipping and analysis of samples, the purchase or rental of sampling equipment or field test instrumentation, and travel. Program design must include an adequate budget for all stages of a project, including data review, verification, and reporting. Estimating the funding needed for each stage and designing the sampling component are often related to each other.

Often the design of a program starts out as a stand-alone undertaking. However, as the costs and effort are identified, it frequently becomes clear that cooperation and/or co-funding are needed. Project partners can include government agencies, First Nations and other aboriginal groups, renewable resource management boards, hunter and trapper associations, and non-government organizations. Government agencies can lend equipment or provide analytical support, while local communities can provide support for operations.

What are the Components of the Sampling Program and How Will it be Conducted?

The best time to design a sampling program is after reviewing and refining objectives and after examining existing data. Sometimes only one water sample is needed to meet the project's objectives. More often a sampling program is designed to be part of an ongoing water quality monitoring program.

The most important task in designing a sampling program is to make sure that it provides a true measure of the aquatic environment under study. The key to obtaining reliable, comparable and consistent data is to collect **representative samples**. Such samples represent the population of all possible samples.

In order for a sample to be representative, the sampling must be planned carefully so it supports the project objectives. The sampling location, sampling frequency and water quality variables must provide data that meet the objectives of the project. The choice of water quality variables and sampling sites should be consistent over time. **There should be no change in any of the following:** sampling frequency, sample collection techniques, sampling devices, sample handling, sample preservation, sample identification, sample preparation and analyses, data entry and storage, and data interpretation.

If changes do occur, the effect of that change must be examined. For example, if the sampling location is changed, there must be a period of sampling at both the old and new sites. This procedure will show if the two sites are comparable, or will allow differences to be measured. Similarly, if an analytical method changes, then the old and new method must be compared.

When designing the sampling part of a water quality program, key questions are:

- Where should the sampling be done?
- How often should the sampling be done?
- What is the best location for testing the samples?
- Are there any other substances that should be sampled as part of the study?
- How is the quality of the sampling assured and controlled?
- Have baseline conditions been established?

Source: MDA Consulting Ltd. (2003)

Collecting Samples in Salt and Estuarine Waters

There are many similarities between collecting and analyzing freshwater, estuarine and saltwater samples. There are, however, some differences to note. The physical effects of salinity result in differences in some types of equipment used and the way it is maintained. Salinity is usually not measured in a freshwater environment, but should be measured at all sampling locations in an estuarine or marine environment. Usually a much larger number of samples is needed to describe an estuarine environment than a freshwater environment. Because estuaries are complex, trends for many water quality variables are hard to find until monitoring has occurred over several seasons. The more variable the habitat, the greater the number of samples required to describe the habitat with any confidence.

The number of samples required to describe baseline conditions within an estuary is often far greater than the number required in a freshwater habitat. Depending on the nature of the estuary, the water may be stratified in various ways and sampling may be required at a number of depths.

It is important to know what type of estuary is to be monitored before setting up a sampling program. (Estuary types are described in Chapter 2.) Because wind speed and direction, tides, and river discharge are important, it is essential to obtain data on these influences. All this information will help in designing a monitoring program and interpreting analytical results.

Where Should the Sampling be Done?

Choosing a location is a key factor in ensuring that the samples collected are representative. It is important to consider:

- The location of the site within the watershed (i.e., headwater stream versus confluence or river mouth, river versus lake, and stream order, with ***first-order streams*** being headwater streams).
- The potential influences of activities on the surrounding land and water.
- The physical characteristics of the watershed, including size, shape, slope, vegetation types and coverage, land use, tributary and runoff characteristics, groundwater versus surface water contributions, geology, potential sources of contamination, hydraulic conditions, climate, water depth, fluvial-sediment transport characteristics.
- The availability of historical data.

First-order stream - The smallest unbranched tributary in the headwaters of a river system.

It is very important to make sure that samples can be collected safely at any time of year during the study period. The site should also be

accessible during all seasons of the year and all flow conditions, as required. There is no point selecting a sampling site in summer if the ice at this site is unsafe all winter, making it impossible to get samples.

The number of separate sampling points chosen at any site depends on the size and the site-specific environment. A large river system, such as the Mackenzie River, usually requires more sampling points to provide representative data. Sampling snow from one location in a forest clearing or on a tundra lake is probably as representative as any other place, unless there is a significant influence from nearby activities (e.g., a mine, a dusty road, an airstrip or a community).

A sample may not be representative of a stream's water quality if it is taken from a quiet eddy at the side. A sample from the mid-point of the same stream would be more representative, although it may be more difficult to get. At some cross-sections, the water quality may be well mixed and uniform throughout (e.g., downstream of a waterfall or rapids). In other areas, such as downstream of the confluence with another river system, the water from the two rivers may remain distinct for some distance. If one of these rivers is clear and the other turbid, the absence of mixing may be easily seen. An example is the mixing of the turbid waters of the Liard River with the clearer waters of the Upper Mackenzie River near Fort Simpson, NWT (Figure 4.2). In other situations, the extent, or lack, of mixing may not be visible. In those cases, any possible differences must be examined at the sampling site under various hydrologic conditions (e.g., spring freshet, winter low flow, summer-fall recession).

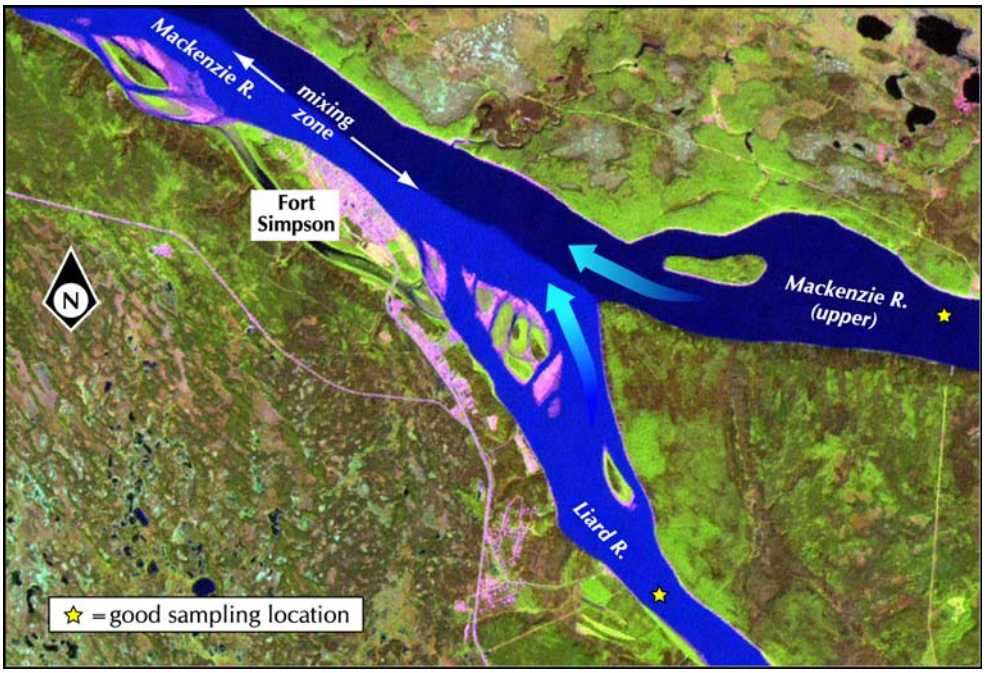
Figure 4.2 is a satellite image of the confluence of the Liard and Mackenzie rivers near Ft. Simpson, NWT. Sample locations in this area are located:

- on the Liard River upstream of the ferry crossing
- on the Upper Mackenzie River upstream of a small island

Both of these sampling locations have been selected to avoid areas where backflow and ice jams often occur.

Samples can be taken at both flowing-water and still-water sites, depending on the objectives of the program. A **flowing-water site** refers to streams or rivers or to any other surface feature in which water moves in one direction. Reservoirs and estuaries that flow in one direction, whether all or in part, are also considered to be flowing-water sites. The water can be moving fast or slow, or can be irregular, temporary, or perennial (lasting year round). A **still-water site** refers to all lakes, reservoirs, ponds, swamps, marshes, riverine backwaters, or any other bodies of surface water where water generally does not move in one direction. The parts of reservoirs that do not flow in one direction could be considered to be still water. This generally applies to large reservoirs but may not apply to small ones.

Figure 4.2. Aerial view of the confluence of the Liard and Mackenzie rivers near Ft. Simpson, NWT. Note the visible difference between the turbid waters of the Liard River (on the left) and the clearer waters of the upper Mackenzie River (on the right).



Courtesy of: Dave Taylor

A site located at or near a transect in a part of a river where other data are collected (such as data for stream flow, water levels, suspended sediment, bottom material, or biological material) will provide additional sources of information for use in the study. For example, stream flow data make it possible to find out ***constituent*** transport loads. Sites should be far enough above and below the meeting point of tributary streams, point source discharges, bridges or culverts and other structures. This is important in order to avoid sampling in a place where flows are poorly mixed or not flowing in one direction.

Constituent – The physical, chemical or biological component of water quality that is of interest in the water sample(s).

Before choosing the location of the station, it is important to make sure that the water in all sampling sections of the site is similar. This is done by using field readings for variables such as temperature, pH and conductivity. If the cross-section is well mixed, then a single vertical sample for water quality near the deepest part of the channel should be enough. This is important to make sure that all water samples are similar during different seasons and under different flow regimes. If this is not done then more sampling may be needed to get an accurate understanding of the watercourse at this location. This creates a lot of additional work and cost, and should be avoided if possible.

When choosing still-water sampling sites, the use of *in situ* field measurements (e.g., temperature, conductivity) will help to find out if the proposed locations are similar. This similarity will change seasonally. Staying away from areas near boat ramps, piers, fuel docks and ice road ramps (unless these structures are part of the study) will avoid possible local sources of contamination.

How Often Should the Sampling be Done?

The number of samples collected from a site over a certain period is the **sampling frequency**. The sampling frequency is usually decided by the study objectives. Enough samples must be taken to obtain representative data and to provide answers to the questions that form part of
the objectives.

Frequency can vary from site to site and from season to season. It must be considered carefully. For example, if a study is to be conducted over a year, one sample per month may be enough. However, it may not be possible to collect samples safely every month. In this case, the collection of twelve samples may be distributed so that more samples are obtained during key periods. If the greatest impact is expected during periods of high flows, sampling after break-up may be more important. If water quality under the ice during low or base flow conditions is a concern (e.g., active winter mineral or petroleum drilling season), winter sampling may be more important. If medium flow conditions are a concern, the summer-fall recession period may be of interest. Figure 4.3 shows timing of sampling in relation to these stream flow patterns.

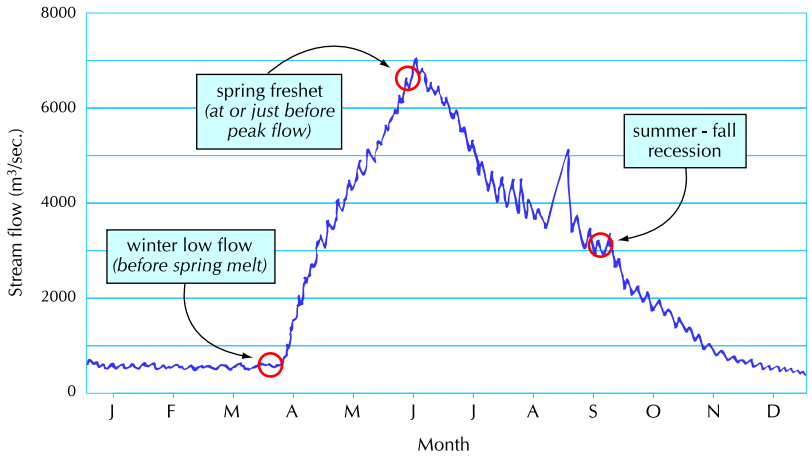
Sampling is often undertaken four times per year, or once per season. Such low-frequency sampling requires long-term monitoring in order to provide representative samples. Twelve samples per year is often a guide for many water studies at important inter-jurisdictional or international sites. However, samples are rarely collected on a monthly basis. Collecting information to find out seasonal variation is more common.

Daily or high frequency sampling is very expensive and is not usually worth doing unless specific conditions are being examined. Daily sampling may be appropriate in some cases, but it may not produce useful data in other circumstances. Water licence criteria may require monitoring of a receiving stream during the release of effluent from sewage lagoons or from mine tailings ponds. This kind of monitoring is very specialized and lasts for a relatively short term. In any situation, there needs to be a balance among the objectives of the study, its length and the available resources.

The media being sampled also need to be considered when deciding on sampling frequency. River water is probably the most dynamic medium.

It requires the greatest sampling frequency to make sure that conditions are represented adequately. However, the chemical nature of snow can be sampled once per year in late winter. Rainfall may be analyzed monthly if the samples are collected in a container that makes sure no change occurs to the sample. Lake sediment samples can be taken every ten years (represented in northern latitudes by 0.5 to 1.0 cm thick sediment slices) because they accumulate very slowly. On rare occasions, high sedimentation loads can lead to much higher sedimentation rates and even the ability to distinguish annual layers. Such lakes are extremely useful for monitoring purposes.

Figure 4.3. Water sampling is often conducted during periods of winter base flow, spring freshet, and summer-fall recession.



What is the Best Location for Testing the Samples?

Certain physical and chemical environmental variables or indicators should be measured in the field. Others should be preserved and sent off to the appropriate lab. Field testing of samples is necessary when the samples cannot be kept in their natural state for measurement later. Variables commonly measured in the field include specific conductance or conductivity, temperature, turbidity, salinity, dissolved oxygen and pH (see Chapter 3). Field-testing equipment is well developed. It is available commercially from a range of suppliers. More information on its use, maintenance and operation is given in Chapter 5.

What Else Should be Sampled as Part of the Study?

More and more water quality programs are designed to consider different aspects of the environment. Depending on the objectives, it may be appropriate to add rain, snow and sediment sampling to the collection of water samples from rivers and lakes. Special studies often include sampling of sediments and biota (e.g., invertebrates, zooplankton and fish). This makes the design of the program more complex.

Stream Sediment Sampling and Aquatic Insect Collection

The Keno Hill hard rock mine area located in the central Yukon has been influencing the South McQuesten River for nearly 100 years. Even with today's routine water chemistry monitoring there has been little evidence of impact from the many hard rock mine adits, mill or tailings pond that occur in this area. Often the only place we find proof of this is in stream sediment samples. Much of the waste water flowing into the river contains heavy metals such as arsenic, lead and zinc. Given the right circumstances, these contaminants can lead to chronic metal pollution of a stream and its inhabitants.

Sediment sampling can provide clues to where and how much heavy metals have been released into the environment. The distribution of the metals in stream sediments downstream of a suspected source can also help better understand how localized or widespread the problem might be. Sampling stream sediments combined with collecting samples of *benthic invertebrates* can provide very useful information to biologists who are providing advice to others in government and industry for making important decisions. Sediment and benthic invertebrate sampling has become an important part of many mine monitoring programs in the Yukon.

Precipitation may be a more direct way to measure the effect of a specific activity on the environment. For example, it may be useful to obtain snow and rain samples when examining the impacts of a mining activity that generates a lot of dust. Although many of the basic sampling principles are the same, the equipment is different and other important differences can happen.

Benthic invertebrates - Invertebrate animals living in the sediment at the bottom of a body of water.

Sediments should also be considered as an aspect of water quality programs, since water quality is often a function of the sediment suspended in the water. Physical and chemical analyses of bed load stream sediment, with or without related benthic invertebrate and habitat studies, can be a valuable indicator of aquatic ecosystem health.

Deep lake bottom sediments, taken from the centre of the lake, can also indicate an ecosystem's chemical and climatic conditions, integrated over time.

To a limited extent, suspended sediments are included if total concentrations (e.g., of metals in unfiltered water samples) are analyzed. However, estimating total sediment loads requires intensive sampling during the peak sediment transport periods.

Toxicological effects - The adverse effects of poisons or toxic substances, which are capable of negatively influencing the health of living organisms, usually by chemical means.

Lake sediments can be very useful in revealing time series trends. Contaminants, such as mercury and trace organic contaminants, build up in lake sediments and biological tissues such as fish muscle and organs. Contaminant concentrations in fish tissue are important in establishing ***toxicological effects***, impacts on the ecosystem and human health.

While lake sediment samples and tissue analyses are important in understanding the local environment, the techniques used are beyond the scope of this manual. However, the design of a water quality program may benefit greatly from including them. Specialized assistance is needed before doing this type of work.

Getting the Full Picture

If you were to look only at the water quality of the Mackenzie River and Delta you would not really understand what a healthy, productive system it is. Water Quality Index (WQI) values for the river are often surprisingly low ("good", "fair", or "marginal") because of the extremely high suspended sediment load and high values for turbidity, true colour, and other substances such as aluminium, copper, iron and zinc (MRBB 2003a). A "rosier" picture results from closer examination of nutrients and major ions, and assessment of other aspects of aquatic ecosystem health, such as benthic invertebrates, zooplankton, and foraging and top-predator fish species. The abundant suspended sediments in the Mackenzie River are also rich in nutrients, flora and fauna at the base of the food chain. For a northern system, the Mackenzie River and Delta is actually remarkable for its relatively mild micro-climate and relatively high biodiversity and abundance of aquatic life (MRBB 2003a). Looking at WQI values or water quality measures alone would not give you an accurate picture of the diverse, productive, and healthy Mackenzie River system.

A new protocol, the Canadian Aquatic Biomonitoring Network (CABIN) is being introduced Canada-wide. CABIN Protocols were developed for monitoring the health of fresh waters and biological ecosystems. To do so they look at benthic invertebrate community structures and their sediment habitat across various geographic regions and stream sizes. For more information see the CABIN website at: http://cabin.cciw.ca/cabin/asp/english/welcome.asp. Information about the Benthic Information System for the Yukon can be found at: www.ec.gc.ca/BISY/search_e/home_e.asp.

How is the Quality of the Sampling Assured and Controlled?

It is very important to include a field quality assurance/quality control component in a sampling program. It must be well defined and supported by accepted standardized practices. Quality assurance (QA) in the field usually refers to a broad plan for maintaining quality in all phases of a program, including how the samples are to be collected, documented and handled. Possible sources of error and of variation should be listed, as well as quality control (QC) checks for each.

QC checks can include ***field replicates***, ***laboratory blanks***, ***travel blanks*** and ***travel spiked blanks***. Procedures for collecting these samples are described in Chapter 5. The sampling program plan should state the number and type of field QA/QC checks to be included in the study. The way to document the results of these QC checks should also be stated.

Field QC procedures are not always performed at the same site. The number of QC locations should provide a general overview from all sections of the region being sampled. The total number of QC sites should be no less than 10 percent of the total number of sampling locations. This is a minimum number of QC samples needed to provide meaningful sample results. Up to as many as 30 percent is acceptable, especially at the beginning of a project.

Field QC plans should also list all field observations that are to be made at the time of sampling. These include meteorological conditions and exceptional circumstances, such as debris in a river. Field observations can be important in the interpretation of sample results.

Similar QC samples are also used in the laboratory, as well as the field. Laboratory QA/QC procedures are more elaborate and may use many spiked samples or standards.

Field replicates – Additional samples collected in the same place, at the same time (one after the other), using the same sampling and filtration procedures for each replicate. It does not mean the physical splitting of one sample into separate portions. Field replicates are used to determine how precise the sampling and laboratory analysis is. They also help to figure out contamination or analytical problems. Collecting three or four samples is better than collecting two.

Laboratory blanks – Deionized and demineralized samples of water submitted to the lab for analysis along with the genuine field samples. The lab does not know which is which. Lab blanks are used as a way to identify errors in the lab's procedures, such as bottle washing and sample handling. If the lab blanks are handled properly, all *analytes* should be reported as zero or non-detectable.

Analyte - The substance you are analysing in an experiment. For example, if you are carrying out an experiment to determine the amount of calcium in tap water, calcium is your analyte.

Travel blanks – Deionized samples of water used to identify contamination or errors in sample collection. Travel blanks will show whether samples have been altered by handling or some other process in the field. They are submitted to the lab for analysis along with the genuine field samples. The lab testing the blank does not know what it is.

Travel spiked blanks – Samples submitted to the lab for analysis that contain a known added concentration of the indicator being measured. The added amount should increase the concentration in the samples by a predictable amount. They are used to test the accuracy of the lab's analysis. Spiked blanks are not routinely used in the field, though they are routinely used in the labs.

How many replicate samples should be taken from a location?

Many water quality personnel believe that the collection of two samples from a location is enough for checking the quality of the sampling. This approach presents a problem if the two samples show considerable difference when the laboratory results come back. There is then no way of deciding which sample is right and which is wrong, unless one is so severely contaminated that it is clearly not valid. The collection of three or four samples gives a better indication of how much variation can be expected for a given aspect of water quality. More samples also help indicate how much can be attributed to sampling, handling, storage and analyses. It is also better for any statistical analysis to have more samples.

Have the Baseline Conditions been Established?

Control basin - A water basin that is believed to have the same baseline conditions as the basin under study.

Baseline conditions are used as the reference point for finding out the changes happening in the water system. Baseline conditions may have been established as part of a previous study. If it is not possible to get two to three years of baseline data before an impact or stress occurs on the system, it may be necessary to establish a ***control basin*** near the main study basin. This adds complexity to the study because it requires an understanding of two locations and the ability to compare one to the other. A control basin approach can be very effective in investigating changes over time. It is also useful in separating natural variations from water quality changes caused by some other activity in the watershed. Sometimes, a control basin turns out to be unsatisfactory, and another one may have to be chosen.

How Can the Program be Pre-tested, Evaluated and Refined?

Revisions to a program's design may be necessary at any time. From the beginning to the end, it is necessary to examine the various parts of the program to make sure the objectives are being met. It is often necessary to adapt to changing conditions, whether they are environmental, related to a new development, financial or result from changes in the program's objectives. Recognising when and how to make changes is an important part of a program's success.

A key part of the evaluation of the project plan is the ***reconnaissance survey***. A reconnaissance survey is the first full field inspection. It is conducted to evaluate the feasibility of the plan. The objective is to identify hazards and unknown problems as well as to look at the time lines. It is important to review the project plan and sampling program at this point to see if enough time has been allotted to a specific task and, in general, to find out what works and what does not. If possible, it is a good idea to carry out a reconnaissance survey before the final project plan is prepared. Changes can then be made based on the actual experience of carrying out the plan.

Reconnaissance survey - The initial field inspection or exploration of an area. It is also sometimes called an orientation survey. This survey is conducted to try out and examine various parts of the planned sampling program.

The reconnaissance survey should help to:

- evaluate the estimated time and resources required to do the sampling,
- identify specific logistical problems and hazards that need to be dealt with or eliminated,
- identify local natural conditions or human-caused activity that could affect how representative the sample is, and
- develop a better understanding of the natural processes that will affect this particular sampling site(s).

Figure 4.1 shows a number of opportunities for feedback as part of a project's ongoing evaluation. An evaluation must take place at the beginning of a project when available resources are examined. An evaluation should take place again at the end of the reconnaissance monitoring and then periodically, depending on the project. For example, if samples are being collected monthly, an evaluation of the data in connection with the project objectives should be done after the first three months, or at least after the first six months. This evaluation is done to identify problems with the sampling and to make sure that the data are being inspected carefully.

It is common to first design the best version of a program, which then turns out to be too expensive. This leads to a series of design revisions and cost re-evaluations. Alternatives may include increasing the length of time of the project to spread out the costs, or reducing the number of sampling sites to lower the costs. It may also be necessary to revise the project after the first year of field sampling, once the first results are analysed. Whatever the reason for making changes, it is important to refer back to the objectives and to make sure they can be met. It may even be necessary to adjust the program's objectives to match the available resources.

How Will the Results be Analysed and Reported?

The data must be reviewed, analyzed and compiled. This can happen at various points during the study. Results need to be summarized and reported in a timely manner, using data reports and information reports. Information on data analysis, presentation and interpretation can be found in Chapter 6.

Reporting the Results of Water Quality Monitoring

The Slave River at Fitzgerald, Alberta - One way to report the results of a long-term water quality monitoring program for public distribution is by preparing a site profile. The site profile for the Slave River at Fitzgerald near the NWT-Alberta border (Environment Canada 2001) provides a short summary of water quality monitoring results from this site, which was established in 1960 by Environment Canada and has been operated in collaboration with the governments of the Northwest Territories and Alberta. The profile provides brief descriptions of the Slave River and the monitoring site, why monitoring water quality at this site is important, and what is sampled. It also provides summaries of the information collected from the site about turbidity, nutrients, dissolved oxygen, pesticides, and micro-organisms.

Yukon Monitoring Stations – Information about four active federal water quality monitoring stations in the Yukon is available on-line at: www.waterquality.ec.gc.ca/EN/3121/search.htm. Station overviews report on each station's location and monitoring information, including type of data available (e.g., surface water, ground water), variables measured, monitoring frequency, and monitoring start and end dates. Data can be graphed on-line by selecting variables and start and end dates. The Yukon monitoring stations for which this information is available are:

- Alsek River above Bates River
- Dezadeash River at Haines Junction
- Liard River at Upper Crossing
- Porcupine River above Old Crow River.

Site Descriptions

A site sampling reference or guide should be prepared at the beginning of the project and updated following each site visit. This document should include details of location, directions for access, landmarks, special precautions and seasonal dangers. A global positioning system (GPS) should be used to confirm appropriate ***way-points*** and actual sampling locations. Photographs are useful for documenting the site and for future reference. The site guide should include descriptions of the specific locations for taking comparative photographs. Any changes seen, especially upstream, should be recorded in the site guide and evaluated for their potential impact on measurements at the site. Possible changes include water clarity, aquatic vegetation, erosion, bottom sediments and flow impediments such as landslides and fallen trees.

Way-point - A specific position along a route that is described according to a geographic coordinate system such as latitude and longitude.

A site description sheet or form should be completed during each visit so that information is collected in a consistent manner. Project specific site description forms should be developed to suit the nature of the project.

Courtesy of: Doug Halliwell

Chapter 5: Sampling for Water Quality

Sampling for Water Quality

Introduction

The objective of a sampling program is to obtain measurements for analytes you are interested in. The project design document (see Chapter 4) should provide all the information you need to know about where and what to sample. Good field practices and the development of a **consistent routine** for sampling, preservation, and analysis make sure sample integrity is maintained. This is especially true when sampling personnel may change.

A Change in Plans

It is important to note any changes to approved methods, equipment, preservatives, or analytical procedures. It is also important to note why the changes were required. Before making any changes to procedures you must test the result to make sure the changes do not affect the integrity of the data. For example, if a sampling location is going to be moved, carry out several sampling trips with replicate samples from both the old and new locations so you can find and examine any difference between the two. Relocate the sampling station only when the effect of the change is understood and noted. If you are not in control of the change and it cannot be planned for, then you should compare the data from the new site and that of the old after the change.

Working with a Laboratory

A certified analytical laboratory, carefully selected at the beginning of the project, can provide valuable advice. It can also provide some of the materials and equipment you will need to collect the samples.

Only a laboratory currently accredited and certified to analyze the parameter you are interested in should be used. This is important in order to produce high quality data that can be compared. These labs use specific procedures to provide quality data. Using the same lab for the length of the project reduces one possible source of variation in the results.

In order for procedures to be reliable, you must follow specific collection, preservation and storage requirements. Contact the lab before the sampling date to ask for sample bottles and to get information about the sampling procedures required, sample storage and delivery.

Whenever possible, clean sample bottles should be obtained from the laboratory. The laboratory will send you the bottles they require for each specific sample collection. There are various bottle shapes and sizes made from a variety of materials, depending on the analysis to be performed. The cost of the bottles is included in the price for doing the analysis. The bottles will have been thoroughly cleaned and will be ready for use. Labs run quality control checks to evaluate the bottle preparation procedures. The lab can also provide travel blanks and travel spiked blanks to accompany the samples on the field trip. (More details about this are provided later in the chapter.)

Labs can supply bottles that are treated with preservatives as required by the analysis. They will also provide a statement of the risks linked to these preservatives to ensure that you handle them safely. Alternatively, the lab can provide bulk quantities of preservative, or vials that contain the specific quantity of preservative for a single sample. The method used will depend on the laboratory you are working with, your comfort in handling preservatives which are frequently hazardous (e.g., acids or bases) and logistical difficulties in shipping hazardous goods.

The laboratory will ship bottles with chain of custody or sample submission forms (see below). The bottles will be shipped in an appropriate container such as a cooler with ice packs and with packing material to return the samples in.

It is essential to obtain detailed instructions from the laboratory about things such as rinsing the bottle with the sample, how full to fill a sample bottle for a specific parameter (some require an air space and some do not), and proper preservation techniques. You can ask for a copy of these procedures from the certified lab.

Unless you have the proper equipment and facilities to wash the bottles, order all required bottles from the certified laboratory. However, if you must use your own sample bottles, choose bottles, caps and liners that are free of contamination and suitable for the water quality parameter you are analyzing. They must be cleaned using standardized procedures to make sure the samples are the right quality. The kind of bottle or container you choose depends on what analysis is required. It is very important that the right kind of container is used. For example, samples should not be exposed to certain types of metal containers if an analysis for trace metals is being done. The requirements for the size and shape of bottle are constantly changing. These specifications also vary between different laboratories. Check with a certified laboratory for the latest up-to-date information on recommended container and washing procedures.

Sample Submission Forms

All samples must be recorded on a **field sample sheet** or **chain of custody form**. Forms used by Environment Canada in the NWT and Nunavut are shown in Figure 5.1 (Field Sample Sheet) and 5.2 (Sample Submission Form). These forms are used to record the possession, handling and analysis of the sample. These and similar forms used by other agencies can include details about the sample collection, events during transportation of the sample, and conditions at the sampling site, including weather observations. This record, depending on its purpose, can be kept from the time the sample is taken to the time analytical data are reported. Such records show who had custody or possession of the sample and where it was at any given time. The forms also provide the laboratory with information on the nature of the sample: when it was collected, for what purpose and under what conditions. All of this information is needed to check if sample integrity was maintained. If possible, these forms should be checked by a co-worker for completeness and accuracy.

Field sample sheets and chain of custody/sample submission forms are the first line of communication with the laboratory. Be sure to fill out any submission sheet in a neat, complete, and orderly manner, and keep it clean and dry. Fill out as much information as possible before leaving on the field trip. This will help to organize the trip, ensure all bottles have been packed, and allow more time in the field to enter information about significant field conditions and events. Enter comprehensive notes on the field sheet describing conditions at the time of sampling (e.g., information about whether the water level is rising or falling, plant growth, ice conditions, possible sources of contamination). It is also a good idea to maintain a log of the sampling trip identifying relevant information that does not fit onto the sample submission sheets. This material will be useful when you or someone else is inspecting the data.

A chain of custody/sample submission form is used if the project is being carried out for a legal reason (e.g., compliance monitoring). This form is critical to the validity or soundness of the project and makes sure that the sample has not been tampered with. It also makes sure that only authorized personnel handle samples, and that proper field sampling techniques for the program are used. All transfers of samples are noted on the form. Transfer procedures are also described to make sure samples are properly protected and preserved. Any changes in sampling or sample storage should be noted on the chain of custody form. The information recorded on the form should be kept on file for the project.

Figure 5.1. Environment Canada Prairie and Northern Region's Field Sample Sheet.

Environment Canada
Prairie and Northern Region

Field Sample Sheet

PROJECT Description: _____ DATE: _____

LOCATION Number: _____ SAMPLED BY: _____

Narrative: _____ Time Zone: _____

Air Temp(°C): _____ Cloud Cover (%): _____ Wind: _____ Precip: _____

Water Depth (m): _____ Ice Thickness (m): _____ % Ice cover: _____ Snow cover (cm): _____

SAMPLE Type: _____ Method: _____ Frequency: _____/YR

WATER Temp(°C): _____ pH: _____ Spec.Cond (@25 °C) _____ Cond. _____ @ _____ °C

COMMENTS: _____

TAIGA ENVIRONMENTAL LABORATORY

Container	Schema	Parameters	Preservation	Project / Time				
1L		Phys/Nutr	Cool to 4 °C					
500 mL		Phys/Nutr	Cool to 4 °C					
500 mL opaque		Cyanide	2mL 35% NaOH; Cool					
500 mL		Bacti	Cool to 4 °C					

Date Shipped: _____ Via: _____

NATIONAL LABORATORY for ENVIRONMENTAL TESTING

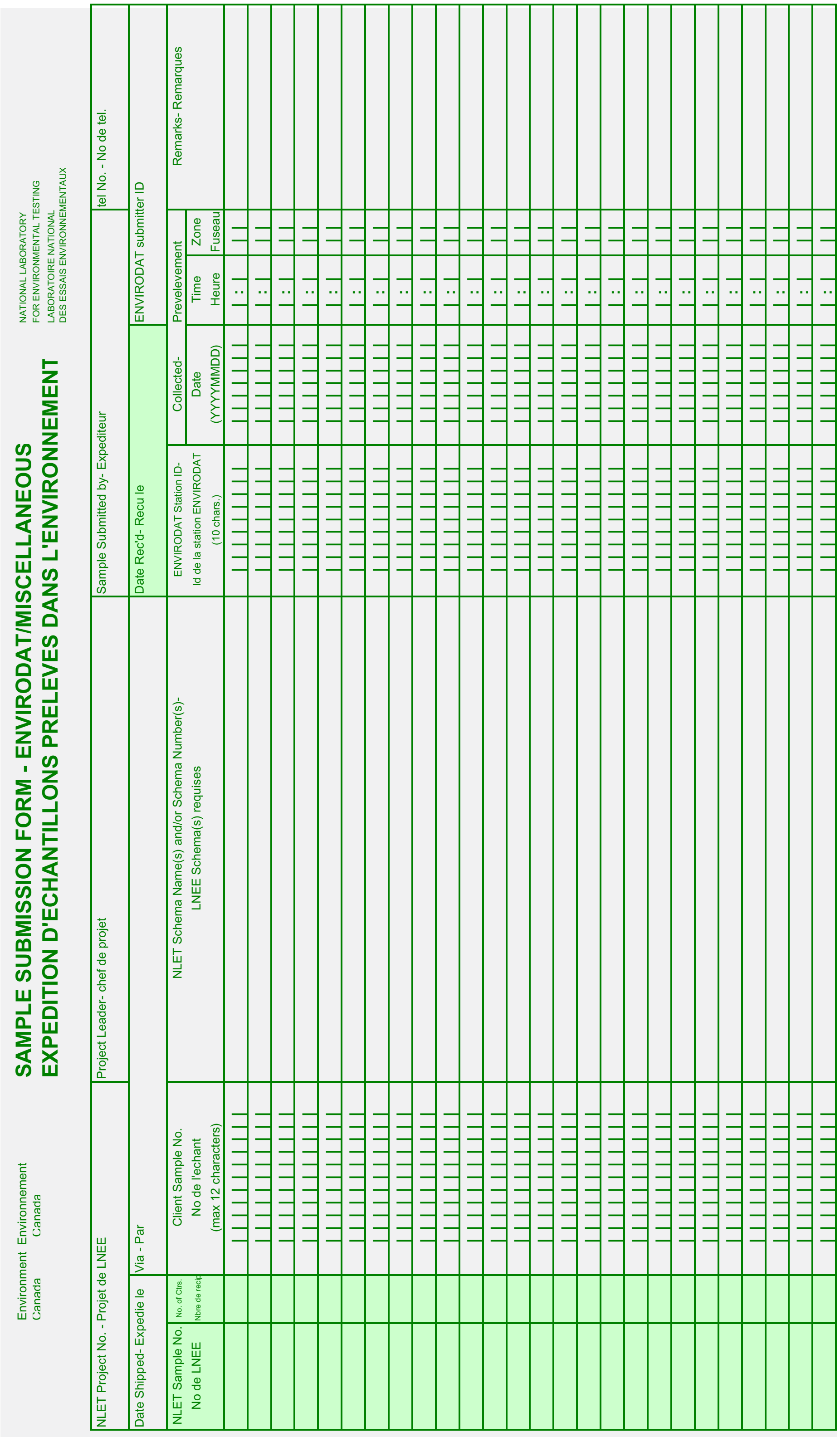
Container	Schema	Parameters	Preservation	Project / Time				
500 mL	2/3/4/5/6/7/21	Major Ions	Cool to 4 °C					
125 mL	31	Total Metals	Cool to 4 °C					
125 mL	32	Dissolved Metals	Filter; Cool to 4°C					
250 mL	33	Dissolved As Se	Cool to 4 °C					
1L Glass	61/62	Organics	Cool to 4 °C					

Date Shipped: _____ Via: _____

TEL Sample #				
EC Sample #				

WHITE COPY – ACCOMPANY SAMPLES YELLOW COPY – AHSD YELLOWKNIFE PINK COPY – FIELD OFFICE

Figure 5.2. Environment Canada’s Sample Submission Form.



Environment Canada Environnement Canada

SAMPLE SUBMISSION FORM - ENVIRODAT/MISCELLANEOUS
EXPEDITION D'ECHANTILLONS PRELEVES DANS L'ENVIRONNEMENT

NATIONAL LABORATORY FOR ENVIRONMENTAL TESTING
LABORATOIRE NATIONAL DES ESSAIS ENVIRONNEMENTAUX

NLET Project No. - Projet de LNEE	Project Leader- chef de projet	Sample Submitted by- Expediteur	tel No. - No de tel.
Date Shipped- Expedie le	Via - Par	Date Rec'd- Recu le	ENVIRODAT submitter ID

NLET Sample No. No de LNEE	No. of Ctrs. Nbre de recip	Client Sample No. No de l'echant (max 12 characters)	NLET Schema Name(s) and/or Schema Number(s)- LNEE Schema(s) requises	ENVIRODAT Station ID- Id de la station ENVIRODAT (10 chars.)	Collected- Prevelevement			Remarks- Remarques
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Field Trip Preparation

To prepare for a field trip, draw up a list of the types of samples to be collected and the field measurements to be taken. Also make a list of required equipment, supplies and materials, including bottles, extra labels, sampling equipment, sample preservative solutions (if required), travel blanks and travel spiked blanks.

Label all bottles before the sampling starts to identify the intended use. Labelling will make sure they are used for the right purpose.
Use permanent markers or special laboratory labels (e.g., peel and stick water-proof labels).

It is a good idea to prepare a checklist of all the items to be taken on the trip. This includes road maps, station location descriptions, field sampling sheets/chain of custody forms, labels, equipment manuals, personal safety equipment, and a tool box. These checklists will vary depending on the season and method of transportation. Table 5.1 and 5.2 show examples of checklists.

Reagent - A substance capable of producing a reaction with another, especially when used to detect the presence of other bodies.

Assemble the proper sampling and testing equipment. Make sure that equipment is in good working order and that spare equipment and/or parts are available for field backups. Sampling and testing equipment should be carefully packed for transportation to the field. Check that the clean sample bottles are labelled, that the caps are secure and that the bottles are safely packed for travel, usually in bubble wrap and/or polyethylene foam chips. Make sure that all chemical ***reagents*** and samples prepared by the lab are on hand for the trip and packaged safely, usually in bubble wrap and/or polyethylene foam chips.

Before leaving, write up an itinerary or trip plan that shows the sampling route and where you will be when, according to the sampling schedule. This itinerary should be left with someone who can monitor your progress to confirm that you arrive back on schedule, or who can alert authorities if problems occur.

Table 5.1. List of items recommended for a mobile laboratory. This list should be modified according to individual situations and seasons.

Samplers:

Water sample locations (lat/long)
Specialized samplers as required (Kemmerer, Alpha-bottle)
Weighted sampling line
Open bottle grab sampler
Rope or cable
Extra bolt-on weights and bolts

Preservation:

Required chemical preservatives
Disposable graduated transfer pipettes
Wash bottle
Pasteur pipettes and suction bulbs
Magnetic stirrer, stir bars, magnet

Field Filtration:

Deionized water
Silicon tubing
5% HCl
500 mL wide mouth bottle
Disposable gloves
Vacuum pump
Disposable filter units

Field Meters:

Conductivity meter
Kim wipes
Thermometer
Meter chargers, adapters, batteries
pH meter c/w buffers, electrode filling solution, electrode storage solution, ionic strength adjuster
150 mL beaker
Turbidimeter c/w cuvettes, standards
Dissolved oxygen meter
Multi-meter

Documentation and Shipping:

Extra field sheets, submission forms
Shipping labels for certified laboratories
Pens, pencils, permanent markers
Bus/plane/courier bills of lading and lot shipment stickers
Zip closure bags
"Deliver on Arrival" labels
Orientation labels
TDG documentation and labels
Cold-packs (frozen)
Insulated box(es) or cooler(s)
Masking tape
Labelling tape
Packing tape
Calculator

Clothing:

Rain gear
Rubber gloves with liners
Chest waders with belt and suspenders
Leather work gloves
Winter clothing: parka, mitts, boots, toque, snowmobile suit, snowshoes

Winter Gear:

Ice bar
Auger - hand or power type, with extra blades or cutting heads, gasoline, oil, extra spark plug, blade oil

Miscellaneous:

Broom and dustpan
Garbage bags
Camera and film
Data book for personal notes
Paper towels
Watch
Meter stick
Wire

Safety Equipment:

Satellite phone
GPS, compass, maps
Fluorescent vest
Life jacket c/w whistle
Throw bag
First aid kit
Fire extinguisher
Triangle flares
Eye-wash bottle
500 mL bottle containing baking soda
Bear spray and banger
Rifle, ammunition
Binoculars
First aid and survival manuals

Survival Kit:

Candles
Waterproof matches
Lighter
Sterno/butane stove c/w fuel
Metal cup and utensils
High calorie, non-perishable food
Needle and thread
Light rope (0.3 mm x 6 m)
Swiss army knife/uni-tool
Snare wire
Flashlight
Space blanket
Sleeping bag
Flares
Orange plastic bags
Whistle
Signal mirror c/w ground to air code
Sunglasses
Personal medical kit for allergies or medical conditions

Source: MDA Consulting Ltd. (2003).

Table 5.2. List of items to be stored in a field vehicle. This list should be modified for use in boats, planes, and snowmobiles and according to season.

Cell/satellite phone with phone list	Booster cables
Credit card	Washer fluid
Road maps	Gas line antifreeze
Transport of Dangerous Goods manifest or exemption permit	Jack and lug wrench
Travel log book	Tire chains
Tool kit	Motor oil
Duct tape	Serpentine belt
Wire	"Seal-All"
Extension cord	Transmission/Power steering fluid
Shovel	Window scraper
Axe	Fire extinguisher

Source: MDA Consulting Ltd. (2003).

Sample Testing Safety

Please refer to Canada Labour Code Part II, Water Survey Manual and Parks, Water Safety and Work Safety. The following points will help to keep everyone who conducts sample testing safe.

1) Store preservatives in a safe way when travelling to prevent upset and spillage.
2) Handle corrosive chemicals with care. Use proper personal safety equipment: goggles, gloves and lab coat (if applicable).
3) Clean up spills immediately by diluting them with large quantities of water, neutralisation, mopping up and proper disposal.
4) Avoid direct contact of skin, eye or clothing with chemicals. Rinse with large amounts of water if contact occurs.
5) Never pipette reagents by mouth.
6) Make sure adequate ventilation is provided when working with organic solvents or fuming acids. Avoid inhaling vapours.
7) Avoid rough handling of glassware.

Being Prepared and Staying Safe

A health and safety plan should be developed as part of the project for the safety of field personnel under various work conditions. The health and safety plan could require training in first aid/CPR, wilderness survival, firearm safety, Workplace Hazardous Materials Information Systems (WHMIS) and Transport of Dangerous Goods (TDG). It may also be a good idea to provide training in whitewater rescue and underwater aircraft escape.

The following points will help keep everyone involved in collecting of field samples safe:

1) Before leaving on the trip, check with RCMP, local officials, hunter and trapper associations or others regarding ice conditions at particular sites.
2) Leave your trip itinerary with your supervisor or the RCMP or someone else who can monitor your return.
3) Use proper signs, flares, vehicle warning lights, and safety vests when parking and sampling along roadways.
4) Wear an approved life jacket when sampling from boats or working over ice.
5) Use a wading stick to check for holes and unsafe footing.
6) Use suspenders and a belt on waders outside of other clothing.
7) Attach a safety rope to yourself and to a rigid, stable mooring when wading in unfamiliar areas, especially during high flow periods.
8) Carry an extra change of dry clothing with you.
9) Use an ice bar to determine the thickness and condition of the ice every few steps. Remove overlying snow as you move across the ice.
10) Never drive a vehicle over the ice except where a winter ice road exists, and then do so with caution.
11) Have at least one other person present when working from boats or over ice.
12) Carry bear repellent, bangers or a rifle, depending on the situation.

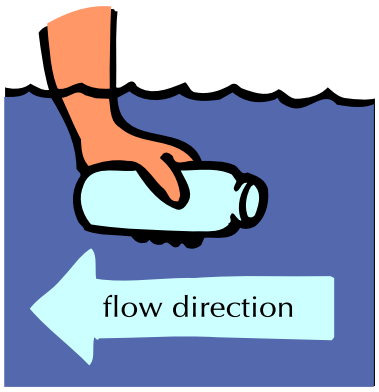
Field Sampling Techniques and Handling

How to Obtain a Water Sample

Water samples are usually taken by wading into the water or from a boat during open water seasons, or through the ice. Samples can also be taken from docks, bridges or the floats of an airplane. Some water samples are analyzed in the field at the same time they are collected, while others are collected for later analysis in a laboratory. Try to take samples from the same location each time the site is monitored, regardless of whether it is open water or ice covered. The use of a global positioning system (GPS) to identify geographic co-ordinates will make sure that the sampling site is precisely located. Note any change from the chosen location, along with the reason for the location change.

Samples near the surface can be taken by holding the collection bottle and lowering it into the water until covered, following standard procedures. This hand-held method of sampling, commonly called 'grab sampling', is the simplest way of collecting a water sample. The sample bottle should be held as show in Figure 5.3.

Figure 5.3. The technique for hand-held filling of water sample bottles.



Depth-integrated sample - A composite sample made up of water from different depths. It differs from a grab sample which is taken from only one depth. When taking a depth-integrated sample, the bottle should be lowered close to the bottom before it is raised. It should just become completely filled as it reaches the surface.

For larger, deeper river systems, use a weighted sampling device (Figure 5.4). The size of the weight required will depend on the current at the sampling point. It is important to keep the sampler vertical rather than allowing it to drift downstream. Weighted samplers are available in stainless steel or polyvinyl chloride (PVC).

When sampling rivers, a 2L sample bottle is used with the weighted sampler to collect a ***depth-integrated sample***. The actual sample bottles are filled from the larger bottle. A depth-integrated sample is taken by lowering the sample bottle to near the bottom and raising it at a constant rate so that the bottle is filled just before it breaks the surface.

For lakes, it is usually best to get both surface and subsurface water samples. Discrete depth samplers are used to collect water samples collected from below the surface. The most common sampler of this type is the Alpha water sampler (Figure 5.5). Most of these are horizontal samplers, although they are also available as vertical samplers. They are made of PVC or acrylic. A Kemmerer water sampler may be more suitable for use through ice (Figure 5.6). These can also be used in larger river systems. They are available in stainless steel or acrylic.

Figure 5.4. The stainless steel sampling iron is an example of a weighted sampling device. The sampling iron may also be painted with epoxy paint to reduce sources of metal contamination. Source: MDA Consulting Ltd. (2003)

Figure 5.5. The Alpha horizontal discrete depth sampler. Source: MDA Consulting Ltd. (2003)

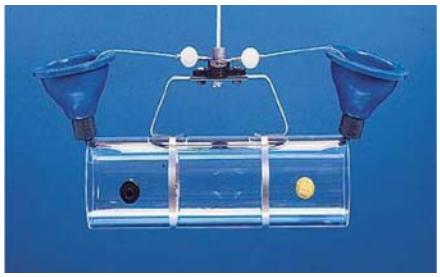


Figure 5.6. The Kemmerer discrete depth sampler capable of operation to depths of 180 m. Source: MDA Consulting Ltd. (2003)

Isokinetic Samplers

Isokinetic samplers are designed to continuously collect a representative water sample. They were developed to collect highly representative suspended sediment samples in rivers. An important feature of this type of sampler is that the speed of water approaching and entering the intake does not change. These types of samplers are not usually used for water quality sampling because of the need to clean them between each sample to reduce contamination. The samplers themselves are also a source of contamination because they are constructed of metal.

No matter how the sample is taken or for what reason, the following guidelines should be used:

- Before sample collection, rinse all sampling equipment (if appropriate) in the body of water to be sampled.
- Dispose of all rinse water downstream of the site, or in such a way that it does not contaminate or disturb the site to be sampled.
- Start sampling in areas of lowest contamination, followed by areas of highest contamination. This reduces the potential for ***cross contamination*** of samples.
- Be sure not to touch the cap liner, or the inside of the bottles. Touching may result in contamination of the sample.
- Remove all jewellery and watches. Roll up sleeves to avoid sample contamination, or wear gauntlet gloves.
- Don't smoke while taking or handling the samples.
- During sampling by hand don't use insect repellent, as this may cause sample contamination.

Cross contamination - The spreading of contaminants such as trace metals, nutrients, germs, bacteria and/or disease by carrying them from one sample to another.

Courtesy of: Doug Halliwell

Rinsing Bottles with Sample Water

Under most circumstances, bottles should be rinsed three times with the bottle mouth facing upstream. Rinse with the sample water before filling with the water to be kept for analysis. **Do not** rinse bottles that contain preservatives. **Do not** rinse bottles being used for bacteria, cyanide and synthetic organic compounds.

Rinsing Bottles at Freezing Temperatures

If the air temperature is below freezing, the rinse water will freeze to the surface of the bottle. **Do not rinse under these circumstances.** It is not effective and may do more harm than good.

New Thinking about Bottle Washing

Recent studies have indicated that properly cleaned bottles do not need to be rinsed first with the water being sampled. According to the International Organization for Standardization (ISO), rinse the sample containers only if the laboratory instructions specifically say so. Otherwise, keep the caps on the sample bottles until it is time to use them.

Sampling while Wading

Rivers and streams can be sampled by wading into the water. This kind of sampling does not work in lakes, because a sample taken near the shore will not be representative of the lake system. Sampling while wading will probably involve carrying bottles to and from shore several times.

When collecting water samples while wading:

- Wear chest waders, with a belt and suspenders, and a life jacket.
- Disturb the riverbed as little as possible to avoid contaminating the sample with sediment.
- Explore the streambed for large obstacles or holes if you don't know the stream to be sampled or if the streambed changes at times. Wade carefully into the stream with a wading stick and safety line. Once you are certain that it is safe, sampling can begin.
- Be aware of large ice pans that could knock you off balance or trap you. Also be aware of ice formation on rocks and other surfaces.

Occupational Safety and Health (OSH) Committees from federal government departments such as Environment Canada also have their own Task Hazard Analyses. Titles include "Wading Operations", "Travelling Over Ice" and "All Small Boat Operations". Task Hazard Analyses may be useful in preparing health and safety plans for specific projects.

Follow the procedures outlined below to collect the samples. All samples must be taken while **facing upstream.** This will make sure that neither your body nor your actions can affect the water being sampled (e.g., by disturbing the bottom material of sediment and biota).

1) Hold the bottle near its base and remove the bottle cap.
2) Plunge the bottle, neck downward, below the surface to a depth of about 20 cm.
3) Immediately turn the bottle until the neck points slightly upwards with the mouth directed into the current (see Figure 5.3).
4) Hold the bottle facing upstream at arm's length while it fills.
5) If conditions permit and it is appropriate, rinse all required bottles three times, following steps 1 through 4, before filling with the sample.
6) Fill all bottles with the sample water to approximately 0.5cm from the top, or as instructed by the laboratory. This allows the water to expand and/or also allows for the addition of preservatives.
7) Cap each bottle immediately after filling and place in a cooler or backpack.
8) Preserve and complete field analyses, as required, either on shore or as soon as possible.
9) Tape the lids closed on all the sample bottles so that they do not accidentally come off. Carefully re-pack the bottles so that they do not break during transport.

Sampling through Ice

Samples can be collected through the ice from both lakes and rivers at any depth. If the ice is not too thick on a river, it is possible to reach down through a hole in the ice and get a sample by hand or with the help of a sampling pole and attached container. If a sample from a greater depth is needed, use a weighted sampler. For safety reasons, any work on ice and/or in cold weather should be carried out by at least two people.

The sample site should be directly over the main flow channel of the river or stream, or over the deepest part of the lake. Ideally, this location would be the same one sampled during the open water period.

When collecting water samples through the ice:

- Wear an approved flotation or survival suit when working on ice over deep or swift water.
- Use an ice bar to test the thickness and condition of the ice to make sure that it is safe to work on it. River ice can be thin even in the Arctic if there is adequate current or warm groundwater inflow. (See Table 5.3 for a general guide to ice thickness safety.)
- Carry a couple of large nails to help in pulling yourself back onto the ice if you fall through.
- Remove overlying snow from the ice surface to provide a clean work area. An area about 1.2 metres square should be large enough.
- Drill or chop a hole through the ice, big enough for the sampler or any other equipment that will be used.
- Clear the area of ice chips, snow, slush and any substances such as grease or gasoline that could contaminate the site.

Table 5.3. General guidelines for ice strength (clear blue ice).

	Required Ice Thickness (mm)[1]			
Load	**Continuous Travel**		**Stationary Load**	
	Lake	River	Lake	River
1 person on foot	50	60	75	90
Group, single file	80	90	120	135
Passenger car (2000 kg)	180	210	300	350
Light truck (2500 kg)	200	230	340	390
Medium truck (3500 kg)	260	300	425	500

[1]Effective thickness = Thickness (clear ice) + ½ Thickness (white ice)
Where water lies between layers, use only the depth of the top layer of ice. Under thawing temperatures where average air temperature exceeds zero degrees Celsius, increase the required thickness by 20%.
Source: Alberta Occupational Health and Safety (1990).

Procedures for taking water samples through the ice are outlined below.

In shallow rivers, with water depths less than 50 cm - The sample may be collected by hand (grab sample) if the ice thickness allows. Dip and fill the bottles directly from the hole (see the method outlined above for taking samples while wading).

In deeper rivers, with water depths more than 50 cm - The sample must be collected using the proper weighted sampling device (see Figure 5.4).

1) Lower a clean, opened 2L bottle in a weighted sampler (with 2 to 3 kilograms of extra weight added) to the desired depth. If you are sampling in a current, the weight should be enough to reduce the sampler's downstream drift.
2) Lower the bottle into the river at a rate that will give a depth-integrated sample.
3) Don't let the sampler come in contact with the streambed. This may stir up bottom sediments and contaminate the water sample.
4) Raise the filled bottle from the river and use the water to rinse it, if conditions permit. If the temperature is below freezing you will not be able to rinse the bottles.
5) Repeat steps 1 through 4 until the bottle is re-filled.
6) Rinse the other bottles with the water from the 2L bottle. Swirl the 2L bottle between rinses so that each rinsed bottle receives a representative sample rinse. Leave enough water in the 2L bottle to rinse out any sediment that may have sunk to its bottom.
7) Repeat as needed to rinse out all the bottles required. One-litre bottles may be rinsed from the 2L bottle.
8) Fill bottles of 1L volume or greater by returning each one to the sampler and lowering it into the river at a rate that gives a vertically integrated sample.
9) Fill all bottles smaller than 1L from the water in the 2L bottle. Swirl the 2L bottle before filling other bottles so each container receives a representative sample and so that sediment does not settle in the 2L bottle.
10) Return to the place where preservation and field analysis of the samples will be carried out.
11) Tape the lids closed on all the sample bottles so that they do not accidentally come off. Carefully re-pack the bottles so that they do not break during transport.

In lakes - The sample must be collected using the proper weighted sampling device (see Figure 5.4). It is not necessary to rinse these samplers as sinking through the water is usually enough. It is better to take lake samples from a number of depths instead of using the depth-integrated sampling that is done in rivers. Lake samples are usually taken one to two meters below the surface and one to two meters above the bottom. The surface sample should be taken first. The same techniques are used for bottle rinsing and handling as those for deep rivers (see above). Always take care to avoid disturbing the sediments when the bottom or deep sample is collected.

Sampling from a Boat

Water samples can be taken from both lakes and rivers using a boat. Usually a sixteen-foot aluminum boat or a twelve-foot inflatable boat with 10 to 20 horsepower motors is used. Refer to the operating manual for information about the motor.

Life jackets must be worn while working from boats, as well as rubber boots/waders and rain gear. Two paddles, a bailer and an anchor must be on board. Chest waders should be worn on the **outside** of other clothing.

In moving water, always sample from the upstream side to prevent contamination of the sample from gas or oil. Grab samples can be collected while the boat is anchored or drifting along mid-channel. When using a weighted sampler in rivers or lakes, you can either anchor or keep the boat running, depending on the circumstances. For example, if there is a danger of ice floes, **do not** anchor the boat and keep the engine running to make sure that the boat can be moved out of danger. Follow the same sampling procedures as those given in the section above on sampling through ice.

Boating Safely

Be aware of other boat traffic and natural hazards. All power-driven vessels must yield the right of way to those not operating under power, such as canoes. For more information about boating regulations and safe practices, go to Transport Canada's Office of Boating Safety at www.tc.gc.ca/BoatingSafety/menu.htm.

Working from the Floats of an Aircraft

Examining water quality in remote lakes and rivers often involves flying into the site and sampling from the aircraft. Follow the same sampling procedures as you would if you were using a boat. Wear a survival suit or life jacket and waterproof chest-waders that will keep you afloat if you fall into the water. In addition, you should tie yourself to the aircraft for extra security. Straddle the floats whenever possible. The rear door of fixed-wing aircraft (e.g., the Cessna 206, with its long, broad tail section) should be tied open. This makes it easier to move the sampling equipment and bottles between the floats and the tail section of the aircraft where the samples are usually stored.

Direct or headphone communication with the pilot is essential. The pilot may need to communicate the difficulty of keeping the aircraft stable on the water, or the fact that wind, wave or fog conditions are making it too dangerous to continue with the sampling. It is much safer to have a third person to help with communication between the sampler and the pilot. A third person is also very useful to help with sample collection. Relatively busy "air traffic" in popular lakes (e.g., Rabbitkettle Lake in Nahanni NPR) may mean additional safety risks, forcing workers to work quickly and efficiently.

If you are carrying out many tasks on a large, windy lake, with a large aircraft on floats, you may have to measure a GPS location when you begin your work and when you finish. An aircraft can drift a substantial distance even when many anchors are used.

Field Measurements

There are a number of water quality measurements that can be taken in the field. The most common of these are temperature, conductivity, pH, turbidity, dissolved oxygen (DO) and water clarity. (See Chapter 3 for more information about these and other parameters.) It is very important to record measurements as soon as possible after they are taken.

Instruments designed to be used in the field are available to measure these parameters or features individually. Multi-meters that can measure more than one parameter at the same time are also available. Depending on the circumstances, measurements are taken by lowering the instrument probe directly into the water body or into a collected sample. Any probe should be triple-rinsed with the sample to be tested.

Other types of instruments can be left in place to monitor water parameters over time. The manufacturer of the field instruments will provide detailed instructions for their use.

The proper maintenance and calibration of instruments is a very important part of any water quality program. The instruments must be in good working condition in order to get accurate results. Field personnel must understand the calibration and use of any instrument they are using in the field.

Beyond Grab-sampling - Wolf Creek Research Basin

Water quality monitoring programs usually use grab sampling – fill the bottle and then analyze the water in a laboratory. This is the approach that this manual describes. Grab sampling gives you a snapshot of the water quality at one time. Of course you can repeat the sampling to get a series of snapshots.

Usually the focus of grab sampling is looking at averages, or at whether the level of something in the water exceeds a guideline. Another approach to sampling is to measure water quality parameters at frequent intervals using electronic recording systems that are left in the lake or stream. Available technology now makes this quite affordable and reliable.

In 1999 scientists at the Wolf Creek Research Basin, a mountain watershed near Whitehorse, Yukon, wanted to examine how water quality of the stream changes with weather conditions over the ice-free period. To do this, they installed electronic sensors in the stream. These sensors measured seven water parameters, including temperature, pH and dissolved oxygen, at 15-minute intervals. The results were recorded on a battery-operated data logger and accessed by cellular phone link through a modem. The entire process operated automatically.

Of course this produced a huge amount of data, and statistical techniques had to be developed to make sense of it.

From this study researchers were able to examine the water quality over the daily and seasonal cycle. The study helped them to describe how water in a mountain stream is influenced by snow-melt, by summer heating of surrounding soils, and by groundwater. This approach to water quality monitoring is best-suited to studies that are aimed at understanding dynamic processes and relationships.

Maintenance and Calibration of Instruments

The manual provided by the manufacturer for each instrument gives general maintenance and calibration instructions. Check instrument calibration before setting out for field sampling, and daily while it is being used. Doing another check when you return from field sampling will give another test of its accuracy. All instrument maintenance and calibrations should be recorded in a logbook or on designated spreadsheets.
Any maintenance or calibration, including confirmation of calibration range, time, date and person who conducted the work, should be noted.
All field meters and analytic instruments should be stored according to the manufacturer's recommendations when not in use.

Temperature

The temperature of the water you are sampling is an important first measurement. Water temperature affects many different chemical, physical and biological parameters (see below). In most cases, it is appropriate to standardize variables affected by temperature to a standard laboratory temperature of 25°C.

Temperature measurements must be taken in the field immediately upon obtaining a sample or preferably *in-situ*, by means of automated temperature probes.

Conductivity

Conductivity (also referred to as conductance and specific conductivity) is the measure of the capacity of water to conduct electrical current per unit distance (expressed as microsiemens per centimetre or µsie/cm). It is measured with a conductivity meter. The conductivity of water is temperature dependent. Conductivity probes usually include a temperature probe so that the conductivity reading can be standardized. Some conductivity meters automatically compensate for temperature. If not, the meter reading must be corrected to 25°C before reporting the conductivity.

New conductivity meters may use different types of probes. Follow the manufacturer's instructions for use. Conductivity meters are also available for "pure water" (i.e., conductivity from 0 – 100 µsie/cm) and for high conductivity waters (100 – 1000 µsie/cm). The sampling circumstances may need both ranges.

The conductivity measurement must be performed before the pH measurement because the sample may become contaminated by the potassium chloride in the pH electrode.

The procedure for measuring conductivity is as follows:

1) Shake the field sample. Rinse the conductivity cell with the shaken sample by pouring a small amount of the sample into the end of the cell and over the outside of the cell.
2) Insert the cell into the water sample and move it up and down to release any air bubbles trapped in the cell. It is important that the side vent holes remain under the surface of the sample.
3) Measure the conductivity of the sample.
4) Record this value beside the temperature of the sample on the field sheet and indicate if the meter does not automatically compensate for temperature.

Be sure to rinse the conductivity cell with deionized water before storage. Store the cell according to the manufacturer's instructions.
Some manufacturers recommend wet storage. Other cells must be stored dry.

pH

pH should be measured after the conductivity measurement. pH is measured using a pH meter.

The procedure for measuring pH is as follows:

1) Adjust the temperature reading (if needed) to the temperature of the field sample.
2) Shake the sample and rinse the electrode with sample.
3) Place the electrode in the sample.
4) Select pH measurement mode.
5) Swirl the sample and measure the pH. Allow sufficient time for the meter to stabilize.

Be sure to rinse the electrode with deionized water before storage. Store the electrode in a potassium chloride (KCl) storage solution according to the manufacturer's instructions. pH electrode sensors should be kept wet with sample water or tap water, and not in a standard solution, at all times during storage.

Turbidity

Turbidity is a measure of the amount of solid material in suspension (i.e., not dissolved) in the water. It is measured by a turbidimeter. This instrument measures the transmission of light through water across a fixed distance. The lower the light intensity, the greater the turbidity of the water. Some field multi-meters allow for turbidity measurement in the field, as long as the meter is properly calibrated for turbidity.

The procedure for measuring turbidity is as follows:

1) Fill a ***cuvette*** with shaken field sample to the line marked on the cuvette.
2) Dry the cuvette with a clean, lint-free, laboratory-grade paper towel.
3) Place the cuvette, with the orientation mark facing forward, in the chamber. Note: Handle the cuvette with care and do not touch the area of the cuvette below the line. Keep the cuvettes absolutely clean.
4) Measure the turbidity of the sample.

Cuvette - A small often transparent laboratory tube.

Rinse the cuvette with deionized water before storage.

Dissolved Oxygen

Dissolved oxygen (DO) is commonly measured *in situ* or immediately after sampling. The samples will change after collection because of ongoing oxygen demand or consumption in the sample container, so they must be measured as soon as possible.

Numerous portable DO meters are available. DO can also be measured using multi-meter DO sensors that have appropriate membranes and are properly calibrated. The meters measure the level of dissolved oxygen in both milligrams per litre and percent of oxygen saturation. Follow the manufacturer's instructions for measuring DO, calibrating the meter and keeping the probe clean.

Water Clarity

Water clarity is measured using a Secchi disc. This round, flat disc has alternating black and white quadrants or quarter-circles. When lowered into a lake it gives a visual measure of the water clarity. The depth at which a Secchi disc disappears shows the level of suspended particulate matter and algal growth in the lake.

The Secchi disc is likely the oldest water quality assessment tool still in common use. It was developed by Angelo Secchi, a Jesuit priest. In 1865, he made the first measurements of ocean transparency and colour using several weighted discs of different colours.

Water clarity measurements are made by lowering the Secchi disc slowly into the water (Figure 5.7). This is usually done from the shaded side of a boat. The depth at which the disc disappears is recorded. The rope holding the disc is marked at intervals to allow direct depth readings. Once the disc disappears, it is lowered for approximately another meter and then raised. The depth at which it first appears is recorded. The Secchi disc reading is the average of the two values recorded. The higher the Secchi disc reading, the clearer the lake. The depth at which the Secchi disc disappears or appears may vary from observer to observer and from day to day due to light conditions.

Figure 5.7. Photo showing use of a Secchi disc.
Source: MDA Consulting Ltd. (2003)

Bacterial Sample Collection

Extra care must be taken to obtain representative samples for determining if bacteria are present. Because bacterial samples are time-sensitive, it may not be possible to ship them to a laboratory for analysis. This means that local culturing and counting methods may need to be developed. Look for specific advice from local laboratories or health or environmental personnel about the best method to use.
Some community drinking water utilities carry out their own bacterial analysis on a routine basis. They may be able to help by providing analytical support to the project.

A mobile bacteriological water quality kit can be purchased from suppliers for just under $10,000. It can be used to analyze total coliform, fecal coliform, *E. coli*, and fecal streptococci. It comes with two incubators that can plug into vehicle cigarette lighters, a binocular microscope, petri dishes, squared filter paper, media, filtration equipment, sterilizing alcohol and flame.

Water samples for bacterial analysis are collected using the techniques described above. For example, in a shallow river, the 'grab sampling' method may be used. In deep water, collection is usually done using a weighted bottle holder.

Take Caution to Avoid Contamination
Contacting the sample with your hands will cause contamination of the sample. Wear disposable latex or nitex gloves.

In all cases, water samples collected for bacterial analysis must be preserved immediately after they are taken. To preserve samples, use 1.0 mL of 10% solution of sodium thiosulfate per 1L sample bottle. Or, if bottles are supplied with preservative, collect water samples in a clean bottle and transfer them directly to the analysis bottle. Leave an air space to make it easier to mix the sample with the preservative. Cap the bottle securely. To avoid any contamination of the sample, wear rubber gloves, dust masks, face masks and lab coats.

Samples should be kept out of light. Chill samples in ice between collection and filtration, but do not allow them to freeze. **Start the bacteriological analysis within one hour of getting the sample**, if possible, but not more than six hours after. This timeframe is important to prevent loss of bacteria in the sample. The process needs at least 24 hours of incubation. Colonies of bacteria can only be counted 24 hours after filtering and the start of incubation at proper temperatures.

When collecting bacterial samples from a large lake or reservoir, the 'grab sampling' method may be used. ***When sampling from rivers or streams, the following techniques should be used:***

In shallow water

- Collect the samples from a single point near the centre of flow in the stream.
- Face upstream holding the sample container near the base.
- Lower the bottle vertically under the water with the mouth directed towards the current.

Source: MDA Consulting Ltd. (2003)

In deep water

- Collect the samples from a bridge or boat using a weighted holder.
- To prevent sample contamination, first rinse the holder under the water without the bottle.
- Insert the bottle into the holder and lower the sample bottle under the water near the centre of the stream flow. Hold the collector vertically with the mouth directed toward the current. Hold the collector still to sample from one vertical point during collection.
- Leave an air space in the bottle to help mixing of the contents.

Field Quality Control Samples

Quality control (QC) is an important component of any water quality program. The number, type and location of samples collected in the field for quality control purposes are decided on as part of program design. QC checks can include ***field replicates***, ***travel blanks*** and ***travel spiked blanks***. They are used to show how accurate and precise the sampling and analysis has been.

The number of sampling bottles and the way they are prepared before the trip depends on the number of QC samples needed. A QC sample should be identified to indicate what it is, but in a way that will not advise the lab doing the analysis. This is called a blind sample. The sites to be used for QC procedures should be written down for the field sampling team.

Field Replicates

Field replicates are extra samples collected in the same place, at the same time, using the same sampling and filtration procedures. It does not mean the physical splitting of one sample into separate portions. Field replicates are used to check the precision of sampling.

Replicate samples should be taken in sequence (one after the other). Taking three (i.e., triplicate) or four replicates provides more statistical information than the use of only two (i.e., duplicate) samples, but is still cost effective. Replicate samples are all collected and processed at the same time.

A minimum of one set of replicates should be taken at each site during the project. However, the number of replicates often varies greatly. A general rule of thumb is 10% of the total number of sampling stations for each sampling project. That is, if 10 sites are being sampled, at least one site should be replicated. Stations to be replicated should be chosen from a rotational schedule set up earlier. The raw data from the “parent” sample and from each of the replicate samples should be stored within the database and identified properly. At the start of a study in an unknown area, it may be necessary to have as many as 30% of total samples as QC samples. **Do not store the average or median result of the replicates** unless the database or information system is equipped to deal with both routine and QC samples.

Travel Blanks

A travel blank is a deionized sample of water used to identify contamination or errors in sample collection and analysis. The lab testing the travel blank does not know what it is. Before leaving for the field-sampling trip, prepare one travel blank for each sample to be taken at each QC site.

The number of travel blanks prepared before the trip will depend on the number of QC samples needed. For example, if two QC sampling sites have been chosen and samples are to be collected for total metals, dissolved metals, and ammonia at each site, a minimum of six travel blanks should be prepared before leaving for the field.

Travel blanks are prepared and stored in shipping cartons containing ice packs. This keeps the sample at approximately 4°C during all steps of transport and sample collection.

Following are the steps for preparing travel blanks:

1) Use the same types of bottles for the travel blanks that you will use for field sampling.
2) Label each travel blank, identifying the sampling site location and the analysis to be carried out. Use a field code that indicates the sample is a travel blank. A code is used so that the certified lab does not know the sample is part of the QC program.
3) Fill each sample bottle with distilled, deionized water free of all analytes of interest. Leave an air gap of approximately 5cm at the top of the bottle.
4) Preserve the sample as you would for each parameter to be analyzed. For example, travel blanks for ammonia analysis will be preserved in the same way as field samples to be tested for ammonia. (See below for more details about sample preservation.)
5) Cap and shake the travel blank to mix the water with the preservative. Store it in the sample shipping box with ice packs to keep the travel blank at approximately 4°C.
6) Enter the coded travel blank on the sample submission form or chain of custody sheet.
7) When the sampling has been finished at the QC location, open the travel blank and expose it to the atmosphere for the same amount of time as it took to take the field sample.
8) Recap the exposed travel blank and returned it to the shipping container.

Travel Spiked Blanks

A travel spiked blank is used to test the accuracy of the lab's analysis. Spiked blanks are not routinely used in the field, though they are routinely used in labs. These types of blanks contain a known added amount of the analyte being measured. The added amount should increase the concentration in the sample by a predictable amount.
It is best to get spike solutions from the analytical laboratory and analyse them before use to confirm the concentration.

Preparing and handling travel and travel spiked blanks is similar.

The procedures for using travel spiked blanks are as follows:

1) Use the same type of bottles for preparing travel spiked blanks that you will use for field sampling.
2) Label each travel spiked blank, identifying the sampling site location and the analysis to be carried out. Use a field code that indicates the sample is a travel spiked blank. A code is used so that the certified lab does not know the sample is part of the QC program.
3) Fill each sample bottle with distilled, deionized water free of all analytes of interest. Leave an air gap of approximately 5 cm at the top of the bottle.
4) Mix the spiked solution and allow it to sit for about one hour before adding the sample preservative.
5) Preserve the sample as you would for each parameter to be analyzed. (See below for more details about sample preservation.)
6) Cap and shake the travel spiked blank to mix the water with the preservative. Store it in the sample shipping box with ice packs to keep the travel blank at approximately 4°C.
7) Enter the coded travel spiked blank on the sample submission form or chain of custody sheet.
8) Do not remove the travel spiked blank from the shipping container. Keep the container closed at all times during the sampling field trip.

If the lab has not supplied spiked bottles, you must spike the solution with the correct volume of concentrated stock solution. Add enough so that the final concentration of analyte is between 5 and 10 times greater than would be expected in a typical field sample at that location. For example, if the concentration of total phosphorous is expected to be 0.017 mg/L, then the total phosphorous concentration in the travel spiked blank for this QC site should be between 0.085 and 0.170 mg/L.

Sample Preservation

Physical changes and chemical and biochemical reactions may take place in the sample container between the time of sample collection and laboratory analysis. Storing samples in a cool dark shipping container, such as a cooler, helps to minimize this potential problem. However, in some cases, you may have to treat the samples with a preservative before shipping. For example, samples collected to analyze ammonia, dissolved metals, total metals, mercury and sulphides must be preserved with specific solutions.

It is important to use the same routine for the preservation and analysis of samples to make sure of sample integrity. Bottle types and preservation techniques often change, and will vary according to the

laboratory or analytical method. **Always be sure to confirm these techniques with the laboratory.** Try to keep the same techniques and bottle types for the length of the project.

Request chemical preservatives from the analytical laboratory so that they can be tested before you use them. They should be transported and added to the sample bottles with care to make sure there is no contamination. In some circumstances, it may be a good idea to get the sample bottles from the laboratory with the preservatives already added. This reduces contact and helps to prevent problems associated with shipping hazardous goods such as acids.

If the sample requires a preservation treatment, collect the sample as above and then transfer the water into the bottle containing the preservative. **Never use a bottle that contains a preservative to collect the sample.** Make sure the sample is not contaminated during the transfer step. If the laboratory has not added the preservatives to the bottles in advance, refer to Table 5.4 for proper preservatives to use.

Some accredited labs may use factory or lab-cleaned bottles that have been developed for one-time use. These bottles no longer require preservatives for dissolved or total metal samples.

Table 5.4. The appropriate volume and concentration of preservative to be used for field samples.

Parameter	Preservative
Ammonia	1 mL 10% H_2SO_4 / 125 mL
Dissolved Metals	0.5 mL concentrated HNO_3 / 250 mL
Total Metals	2 mL concentrated HNO_3 / 1000 mL
Mercury	2 mL concentrated H_2SO_4 + 5% $K_2Cr_2O_7$ solution / 100 mL
Sulphides	1 mL 2N Zn Acetate Solution / 500 mL

Source: MDA Consulting Ltd. (2003).

Sample Filtering

To find the concentration of dissolved constituents, water samples must be filtered through a 0.45 µm cellulose acetate membrane filter.
All parts of the filtration system must be washed, including the tubing, filter flasks and funnels, unless you are using disposable filter units. These disposable units will reduce sample contamination. Otherwise all filtration equipment must be washed as before leaving for the field and between filtration of each sample. The filtration equipment must be washed between replicate samples as well.

The following procedures should be used for filtering samples:

Immediately before field trips

- Clean the inside of all tubing by filling it with 5% HCl and allowing it to soak for six hours or more. Then pump approximately 500 mL of deionized water through the tubing.
- Wash filter flasks and funnels with a non-phosphate laboratory detergent (e.g., Liqui-Nox). Rinse these three times with tap water, followed by deionized water four times. Then soak the filter flasks and funnels in a 5% HCl bath overnight. After soaking, rinse four times with tap water followed by deionized water four times.

Before each filtration

- Pump approximately 250 mL of deionized water through all tubing.
- Rinse filter flasks and funnels with deionized water three times.

After each filtration

- After filtering highly turbid samples, pump about 500 mL of 5% HCl through the tubing, followed by about 200 mL of deionized water.
- Scrub and wash the filter flasks and funnels with 5% HCl. Rinse a lot with deionized water. If no sediment appears to be sticking to the filter unit, this HCl wash may be left out.
  The filtration equipment must be washed as outlined between sample replicates as well.

Use the procedure outlined below to filter samples for the analysis of dissolved nitrate/nitrite, dissolved and ortho-phosphorus, dissolved iron, manganese and boron, other dissolved metals, and dissolved arsenic and selenium. Samples for dissolved metals, dissolved trace elements, and dissolved nutrients are to be filtered on site immediately after collection. Make sure the filtering unit and tubing have been cleaned according to the standard procedures outlined above.

1) Insert a filter membrane (142 mm diameter, 0.45 µm cellulose acetate) into the funnel, using Teflon-coated or nylon forceps.
2) Pump through about 250 mL of deionized water. Run the pump until the filter is just dry.
3) Filter about 50 mL of sample, letting it run through the filter.
4) Rinse and fill each of the sample bottles with filtrate. Preserve if necessary.
5) Clean filtration unit and tubing. Between sampling sites, store the filter head in a clean plastic bag or container.

Sample Storage and Shipping

Field samples should be stored at 4°C in a mobile laboratory refrigerator, portable refrigerator, or cooler containing ice packs until they can be transferred to a temporary holding refrigerator or refrigeration facility. This will make sure that they are preserved properly and that there is no loss of sample quality. If refrigeration is not available, field activities and transportation of samples must be planned so that samples are returned quickly to the laboratory.

Samples should be shipped as soon as possible after collection. Ship samples in coolers containing enough ice packs to keep the samples at approximately 4°C for the length of the trip. Whenever possible, send samples to the laboratory the same day they were collected.

Each shipping container should contain only those bottles that are to be analyzed or cleaned by the receiving laboratory. All samples must be well sealed and packed, using foam chips or bubble wrap, to prevent spillage or breakage. The laboratory will re-wash all empty bottles. Any dirty bottles that are returned should have their lids on. Rinse old reagent bottles well before returning them.

Be sure to include a copy of the sample field sheet and/or submission form with each shipment. A chain of custody form for the samples, if required, must also be contained in each shipping container.
These forms should be placed inside a sealed plastic bag in the shipping container to protect them in case of leakage or breakage of samples.

Label all shipping containers with the address of the destination and the sender. The address labels should be bordered with red ink to highlight them and taped over with clear tape to protect against scuffing or marking. Label the top of all shipping containers with “OVER 16 KG”,

"THIS END UP" or "FRAGILE", as applicable. "DO NOT FREEZE" labels are also useful. Make sure containers are free of misleading address and warning labels. Multiple containers should be numbered in a series out of a total number (for example "3 of 6").

If a cooler is being used to ship the samples, make sure the spigot is taped over to prevent leakage. At least one piece of tape should be used over the closure clasp. Coolers should also have secure handles. Any broken handles or sharp projections should be removed.

Proper documentation or handling receipts from the trucking service or airline should be kept on file so that lost or damaged shipments can be traced.

It is very important to follow all *Transport of Dangerous Goods* regulations for packaging, labelling, and documenting sample boxes. Normally, preserved samples are not considered to be dangerous goods because of the very dilute amount of preservative. However, the shipper is responsible for the goods. You should consider becoming a certified shipper of dangerous goods in order to protect yourself and personnel who may be transporting the samples, as well as those receiving them. If you have doubts about any aspect of the regulations, contact your area Transport of Dangerous Goods Trainer or Transport Canada.

Chapter 6: Understanding the Results

Understanding the Results

Introduction

After you have returned from the field and put away your rubber boots, you can finally start working with the data you have been collecting. Previous chapters stressed the importance of collecting good quality information without making errors. This can be hard to do because water quality and quantity vary over time (i.e., temporal variability) as well as from place to place (i.e., spatial variability).

Some water quality projects start without much thought about the design. Lack of planning can result in the collection of poorly documented data that might never be analyzed. Or, if data are analyzed, they may be so limited that they provide little, if any, useful information to resource managers. Make use of the best advice you can get in order to avoid this kind of mistake.

Chapter 4 presents the steps to take when designing a water quality program. The design of the program will affect the quality of your data and the results.

There are several important things to keep in mind:

1) When a monitoring program is being developed, you need to think about **how the data will be presented and analyzed**. The design phase is the time to adjust details, such as sampling frequency, based on what the final report will require. It is very important to always think ahead. Getting good data means measuring the right variables accurately, over the right range, in the right sampling media (i.e., water, sediment, biota), and at the right sampling frequency.

2) The **target audience(s)** must be identified ahead of time. You can choose to present data in different ways to make it more understandable for different audiences. A report to a monitoring authority may be different from a report for a regulator (e.g., water board) and would certainly be different from a presentation to community leaders.

3) Look carefully at the **sample size** in the dataset and the **amount of variation** that is present in the data before making conclusions. You also need to decide **whether the samples are representative** of the system that you are trying to study. For example, it would be misleading to report a trend based on just two or three points.

It would also be misleading to report that a baseline condition has been established without representing all seasonal and flow conditions.

4) Statistics and data analysis will be carried out on the data that was collected. If your study was poorly designed, or the data was poorly collected, your data will suffer. A complicated statistical procedure will likely not help to solve the problem. **The time to start applying statistical thinking is before collecting data.** It is almost impossible to derive useful information from bad data.

This chapter looks at the steps you might follow in checking the data for errors and then analyzing the results using graphs and descriptive statistics. After reading this chapter, you should be able to check to make sure the data collected are reasonable and you should understand what the numbers and other results mean.

Preliminary Checks of Data Quality

No matter how carefully you and your co-workers collected the data, you still need to hunt carefully for mistakes and identify them. The first step is to **find out whether your data are reasonable**. Despite your best efforts, you may end up collecting incorrect data. A well-designed sampling program will expect this possibility and will guard against it at several stages. Table 6.1 presents some common sources of error in water quality sampling and suggests ways to avoid them. This topic is also discussed in more detail in Chapter 4.

There are many points in your study where errors may creep in, including during the laboratory stage when analysis is carried out. The laboratory should voluntarily provide current certification and/or accreditation information. The analytical methods and quality control (QC) protocols should be referenced to an organization with a recognized standard. The use of lab blanks as part of your quality assurance program will help to make sure that laboratory errors are identified early and, if possible, corrected so that valid data are entered into the project database. Make sure that all analyses are performed by laboratories certified and accredited to do those analyses. In Canada, the Canadian Association of Environmental and Analytical Laboratories (CAEAL) tests labs, usually every six months, and awards scores for each variable analyzed. The CAEAL test scores must be posted at every lab.

There are several organizations that have recognized standards for analytical methods and quality control (QC). Examples are the United States Environmental Protection Agency (USEPA) and American Standard Test Method (ASTM), which is the world's largest collection of technical standards.

The next step is to **check your data for completeness**. One important consideration is whether you were able to get all the samples stated in the program design. Although you would probably have a good reason why you were not able to get all the required samples, remember that incomplete field sampling may hurt your project in the long term.

Table 6.1. Common sources of error in water quality sampling and how to avoid them.

Stage	Problem	Safeguard or Solution
Field collection	Improper collection technique	Follow written protocols.
Field collection	Contamination in field	Don't wear jewelry on your sampling hand or wrist or you may inadvertently "salt" the sample.[1]
Field collection and shipping	Sample contamination	Use of quality control (QC) field replicate samples & field blanks.
Analysis	Sample contamination	Laboratory use of lab blanks, standards, spiked samples.

[1] Canada's largest gold mining company used to fire employees for wearing rings or jewelry while taking soil samples, even though soil sample analyses units of measure are parts per million (ppm). Most waters are measured at much finer levels (e.g., parts per billion, ppb), so avoiding contamination is even more important for water samples than soil samples.

(Be warned that the statisticians who might end up helping you analyze your results can be surprisingly heartless when you give them your excuse for a missing data point!)

The next question to ask is **whether all the samples you sent to the lab were analyzed**. The lab should provide a verified copy of the sample submission form to confirm they received all samples shipped. The next step is to confirm that the *Certificate of Analysis* from the lab includes all the samples, for all the variables, that were requested. If there are any differences, contact the lab to figure out what has happened. A data completeness report should be prepared each time you sample, and for the project to date for each station and for each variable.

Just as in the case of bread and milk, water quality samples have "best before" expiry dates or "holding times". Samples may eventually deteriorate due to light or darkness, heat or cold. This deterioration in turn causes chemical reactions in the water. Reputable laboratories know these "holding times" for each analysis variable and will report which samples have questionable sample results because the samples exceeded those "holding times". Delays in getting a sample analyzed can occur in the field and/or in the lab.

Next, **check to see if your data are comparable with other important datasets** (e.g., data collected in previous years). You need to make sure that the sampling techniques and sample measurements were collected using similar procedures and that the instruments have been calibrated using similar parameters (see Chapter 5). Consider the simple example of measuring the pH of a water sample. You need to make sure that the instrument was calibrated in the same manner and corrected for temperature so that samples collected in different years are comparable. If you did not consider temperature, the results will not be comparable as solution temperature affects pH. Finally, all lab and field data should be checked to ensure that they follow the sampling and analysis protocols set up for the project.

Understanding Laboratory Reports

At first glance, the report you receive from the laboratory may appear confusing. It will be easier to understand once you decipher the terms and symbols. Some of these are explained below. However, don't hesitate to ask a qualified scientist to help you interpret the results.

The example provided in Figure 6.1 is a typical analysis report from a certified northern laboratory in Yellowknife NWT. Such a report is called a ***Certificate of Analysis (C of A)***. It legally proves that the work was conducted in accordance with professional standards, accepted laboratory methods and QA/QC procedures.

Near the top of the page is the client sample identification number ("Client Sample ID"), and the corresponding laboratory sample number ("Taiga Sample ID") assigned by the certified laboratory. Results for analysis of this sample are provided for six physical parameters. The analysis date and method used for analysis are also listed for each parameter.

A comments section ("Data Qualifiers") provides key information about the data provided. In this example, a qualifier (14) indicates that they were not able to conduct the analysis for two parameters (i.e., colour and turbidity) because the amount of sample submitted to the laboratory was too small. For each parameter a detection limit is provided.

Figure 6.1. Certificate of Analysis form showing results of laboratory analyses for various parameters.

Taiga Environmental Laboratory
4601-52nd Ave., Box 1500, Yellowknife, NT. X1A 2R3
Tel: (867)-669-2788 Fax: (867)-669-2718

Standards Council of Canada Accredited Laboratory Scope of Accreditation 187
Conseil canadien des normes Laboratoire accrédité Portée d'accréditation 187 TM

- CERTIFICATE OF ANALYSIS -

Client Sample ID: 2004PN010004 **Taiga Sample ID:** 240413

Client Project: 000794
Sample Type: freshwater
Received Date: 05-Apr-04
Sampling Date: 02-Apr-04
Sampling Time: 18:10
Location: Wetboot Lake (snow)
Report Status: **AMENDED**

Approved By Helene Harper
Client Services Officer

Test Parameter	Result	Detection Limit	Units	Analysis Date	Analytical Method *	VMV Code	Qualifer
Physicals							
Colour				23-Apr-04	SM2120:B	101401	14
Conductivity, Specific	7.1	0.3	µS/cm	06-Apr-04	SM2510:B	002041	
pH	4.72	0.05	pH units	06-Apr-04	SM4500-H:B	010301	
Solids, Total Dissolved	< 10	10	mg/L	15-Apr-04	SM2540:C	010451	
Solids, Total Suspended	< 3	3	mg/L	15-Apr-04	SM2540:D	010406	
Turbidity		0.05	NTU	22-Apr-04	SM2130:B	002081	14

*** Taiga analytical methods are based on the following standard analytical methods**
SM - Standard Methods for the Examination of Water and Wastewater
EPA - United States Environmental Protection Agency

- DATA QUALIFERS -

Data Qualifier Descriptions:
14 *Insufficient sample to perform analysis*

VERIFIED
OCT 19 2004
SIG. KW

VALIDATED
OCT 19 2004
Signature:

Report Date: Thursday, October 07, 2004

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Method Detection Limit (MDL)
The MDL is a statistically defined decision point for the analytical chemist. Measured results falling at or above this point are interpreted to indicate the presence of analyte in the sample with a specific probability.
It assumes that there are no known sources of error in identification or biases in measurement.

Method Detection Limits

The Method Detection Limit (MDL) is a statistically defined decision point. Also refered to as the Limit of Detection (LOD), it is determined using a minimum of seven replicate spikes prepared at an appropriately low concentration (usually 1 to 5 times the expected MDL) and processed through the entire analytical method. The spiked matrix typically is reagent water. The MDL is provided with all laboratory data as an illustration of the lowest concentration detectable and is specific to the analytical method used.

The MDL gives us an indication of the level at which the lab can detect a substance 99 times out of 100. It is possible that the lab will make a mistake and report a substance is present when there is really nothing there. This is called a **false positive** and can occur one time out of 100. The important point is that when the lab does find a substance present in a sample, at the MDL concentration, it is likely to be a real result and not a false positive.

Table 6.2 explains what the different levels mean. Pay careful attention when comparing data from different tests or laboratories to make sure all values being compared are in the same units.

Table 6.2. Description of different method detection limits (MDL).

Term	What it means
ND	***Not Detectable*** - The lab equipment could not detect such low amounts even if present.
Trace or Tr	The lab equipment was able to detect that the substance (analyte) was present but could not put a number on the concentration (i.e., quantify it).
LDLor <MDL	***Less than Detection Limit*** - The quantity of the substance (analyte), if it was present, was less than the lab equipment could detect.
LLOD	***Lower Limit of Detection*** - This number represents the lowest concentration that can be detected.
MDL	***Method Detection Limit*** - For this particular method, this number represents the lowest concentration that can be detected.

If the values are near method detection limits (MDL), they have a higher degree of uncertainty (i.e., will be less "robust"). It is not uncommon for such values to produce confusing results. For example, results near the MDL might show that measurements of total trace metal values are slightly smaller than dissolved trace metal values for the same sample, even though that is not possible.

What do you do if you want to analyze data that includes the problematic value of "less than MDL (<MDL)"? What number would you consider replacing it with? It would be a serious mistake to use a number like 0.0 to replace <MDL when entering your lab results. A result of <MDL does not equal a concentration of zero. Rather, <MDL means that the concentration is less than the minimum analyte concentration that is detectable using a specific analytical method.

There are a number of options you might consider for replacing MDLs with real values:

1) Reporting results that are lower than the MDL as "0.0". **This approach is not realistic and should never be used**.
2) Reporting the value equal to the MDL. This creates data that are biased towards higher concentrations, as we know that some values are going to be less than the MDL.
3) Reporting the value equal to one half the MDL.
4) Reporting the concentration equal to a randomly generated number between 0.0 and the MDL.
5) Reporting the concentration as a percentage of the MDL, where the percent is based on the number of samples that are below detection limit expressed as a percentage of all samples analyzed. For example, of 30 samples collected, three (or 10%) are reported as below MDL or "non-detects." The value then used to quantify the MDL values is 90% of the MDL value for a variable with 10% non-detects.

Option 3 is likely the most frequently used technique across Canada because it is the simplest and cheapest technique. Options 1 and 2 introduce bias on the low side and high side respectively. Options 4 or 5 are acceptable, although Option 5 is most appropriate statistically.

Before making any changes to values <MDL - It is very important that you have a permanent copy of the master database **before** you make any changes to the MDL values. Any changes should be recorded on a working copy of the database. Once MDL values have been replaced on the working copy, they should be flagged appropriately to indicate the true nature of the value. As well, the MDL should be shown for each variable. Any revised database should clearly state that MDLs have been replaced and what rule was used for replacement. Finally, the method chosen for quantifying MDLs should be reported in the database and any products derived from that data.

Estimates of Precision and Accuracy

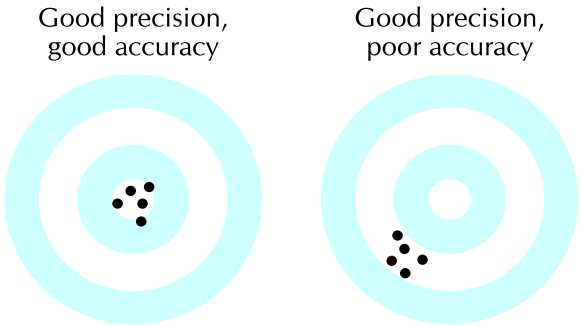
The terms accuracy and precision are used to discuss sample results. Although these terms might seem to have a similar meaning, they mean very different things when used to describe statistics.

Figure 6.2 shows results similar to those a hunter might get while sighting in their rifle. Bullets that hit the bull's eye are what a statistician would call **accurate**, or close to the true value. You may be a good shot, but if your rifle is not properly calibrated, the shots may be clumped close together but far from the target. The same is true for a field instrument. If it is not properly calibrated, the values you get may be clumped together but are not accurate. In this case you have good precision but poor accuracy, as shown in the diagram on the right.

Precision describes how well you can repeat a measurement. For example, if the pH of the same water sample was measured 10 times, you would want to see a similar result each time. If you do obtain similar numbers, you know you have a precise measurement and it is repeatable. However, you also need to calibrate your instrument to make sure it is accurate. The key point is that good hunters and scientists are always looking for both high precision and accuracy.

The lab conducting the analysis of your samples will provide a measure of precision by showing you what happened when they measured replicate samples. Usually this measure of precision is a number showing the average for the replicate samples plus or minus a percentage.

Figure 6.2. Illustration of the difference between precision and accuracy.



An Example of Accuracy and Precision

Four concurrent replicate samples were taken at a sampling station. The lab results, in µg/mL, for these four samples are:

42.80
46.60
56.00
54.10

The mean or average measure for these samples is: 49.88 µg/mL.

The reported measurement will be given as 49.88 µg/mL with a **precision** of ±12.5%. The sample concentration will fall between 43.65 and 56.10 µg/mL, 99 times out of 100 analyses.

The **accuracy** of the sampling data is calculated using a spiked blank sample. The lab does their routine analysis of this spiked blank sample and reports the concentration of the chemical that it was spiked with. The lab results are compared with the known concentration that was put in the spiked sample and expressed as a percentage.

For example, 25.00 µg/mL of analyte A was spiked into distilled water at a sampling station. Lab analysis reported the level of analyte A as 23.80 µg/mL. The accuracy or recovery (i.e., how close the analytical result is to the spiked value) is calculated to be 70.2%. This means that the analyzed result for any field sample for analyte A can be expected to be within 70.2% of the actual concentration for analyte A.

If the accuracy of the spiked blank samples is lower than prescribed in the field sampling protocol, the value should be looked at more closely. Possible causes may be a spiking error (e.g., spike was added twice or not at all) or a problem with the analytical procedure.

Checking and Recording the Data

The data should be checked as soon as you receive the results from the lab. It can be checked again as you enter it into a computer program. Once the data have been entered, graphing the results is another way to have a look at the data to find possible errors.

When you receive your data from the laboratory, you should compare it to the sample submission sheets you originally prepared. Make sure there are no missing samples or missing analyses. Look for notes from the laboratory or obviously questionable data (e.g., very high or low values that seem impossible, such as a water temperature of + 30 instead of +3). If you have any questions, contact the laboratory. Information could be missing because the samples have still not been analyzed or there could have been a problem such as a broken glass bottle. All laboratories retain samples for a time after analysis is complete. Re-analysis of the sample may be possible if you respond quickly to any analytical difficulties.

Guidelines for Accepting Analytical Results

Laboratory reports document the measured concentration of a sample parameter. To make sure results are acceptable, lab data should include the following:

1) Results of all lab QC samples applicable to the matrix and contaminant groups of interest, including method blanks, duplicates, spiked blanks, and spiked samples. These should be within the statistically determined control limits for the analysis. Any QC results which exceed these control limits should have an analyst response documenting the cause and effect on the data provided.
2) A table of precision and accuracy estimates associated with the reported results for the analysis of a standard or certified reference material.
3) A clearly identified description of any correction made to the original value of the analytical result. All analytical data should be reported without corrections. However, if an analytical error shows the value to be incorrect, then the corrected value may be added to the results table, or an amended results table may be issued. It is very important that it is clearly explained which values were changed and why.

Some common sense tests to assess water quality results:

1) Total values should theoretically equal the sum of dissolved, particulate and extractable values for the same variable and should be greater than those latter values in the same water quality sample if values aren't near MDLs. For example, **total** iron concentration should theoretically exceed **dissolved** iron or **extractable** iron concentrations, and **total** phosphorus concentrations should theoretically exceed **dissolved** phosphorus concentrations.

If values are near MDLs, uncertainties in measurements could result in dissolved phosphorous values "exceeding" total phosphorous values, which would not occur if both could be measured accurately and precisely.

2) The sum of concentrations of commonly-occurring, positively-charged cations (e.g., Na+, K+, Ca++, Mg++) should roughly equal the sum of commonly-occurring, negatively-charged anions (e.g., Cl-, SO4—, CO3—, HCO3-), to achieve **ionic balancing** (neutrality).

If the data look good, then the next step is to enter them into a database or spreadsheet, as most laboratories will not provide data electronically. Once all of the data have been entered, a second person should compare the hard copy laboratory reports to check that the information entered is correct. Ideally, the digital data system used should allow you to record the name of the person who entered the data, the person who checked the data and the date the data were entered.

Significant Figures

A lot of water quality data consist of numbers with decimal points. The figures to the right of the decimal point are referred to as the number's significant figures. How many of these figures there are in a number is important from a statistical perspective.

Scientists pay special attention to the number of significant figures in a data point. You should be careful not to change the number of significant figures in any way. It is tempting to add more decimal points when you work with the data on a computer, but this can be misleading. For example, total phosphorus (TP) data for a sample lake is reported to four decimal places (i.e., 0.0014 mg/L) but the computer calculates a mean for the data set of 0.001422. You (or your computer) have just added two more digits to this number and that implies that the original measurement was done with more precision than was the case. In fact, the last two digits are not significant and the mean should be rounded to four figures, which in this case is 0.0014 mg/L.

Chemical data, field measurements and field notes should also be entered into the electronic format, either in point form or using a coding system. For example, you could include:

- Field measurement data (i.e., field pH, field conductivity, water and air temperature, turbidity, dissolved oxygen, salinity).
- Information about any precipitation that occurred before or during the sampling.
- Lake or river water level or stage (e.g., low flow, under ice, bank full, flooding etc.).
- River flow or discharge (e.g., spring freshet or high flow, winter low flow, late winter base flow, summer-fall recession or medium flow).
- Air temperature.
- Sampling and measurement difficulties (e.g., low temperatures did not allow you to rinse your bottles, forgotten or broken sample bottles, handheld pH meter electrode frozen, you forgot the preservatives and they were not added until you returned to base).
- A forest fire in the area or construction activity begun upstream since last sample was taken.
- Potential for contamination (e.g., metal shavings off ice auger in the sample, nearby small fuel spill or fumes, nutrients bottle sample preserved with nitric acid by mistake instead of trace metals bottle sample, which would cause falsely high nitrate lab results).
- Debris or sediment plume observed in the river, caused by bank erosion or slumping.
- Recent ice jam upstream causing ice to scour river banks and high water levels washing material into rivers.
- Nearby or upstream human or animal activity (e.g., municipal/ domestic sewage, lode or placer mining, conventional and oil sands petroleum, hydropower, forestry, pulp and paper, agriculture).

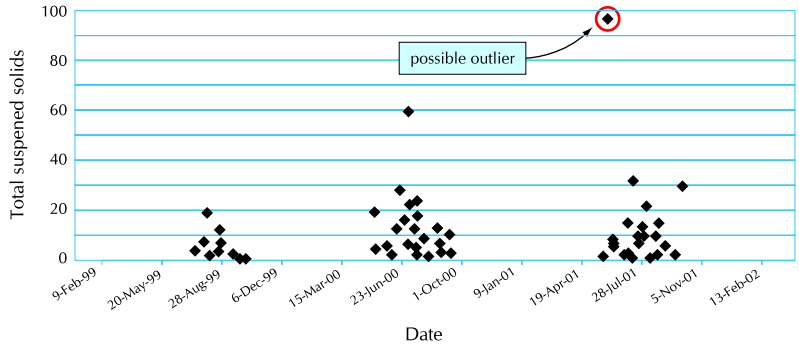
In the spring of 2004, a riverbank slump on the Yellowknife River affected the City of Yellowknife's primary water intake. The municipal water treatment plant could not deal with the increased sediment and a turbidity boil water order was issued for three weeks.

Once all of the data have been entered, you can visually inspect the data by preparing graphs. You can plot a number of variables against each other. These include:

- Concentration versus discharge for total suspended solids (TSS) or metals
- Concentration versus concentration for (a) related variables (TSS vs. metals concentrations, TSS vs. total phosphorus (TP), total nitrogen (TN) vs. dissolved nitrogen (DN), TP vs. dissolved phosphorus (DP)) and (b) selected metals vs. metals (Aluminum (Al) vs. Iron (Fe), Al vs. Manganese (Mn))
- Ratios of one variable to another (e.g., TN:TP)

Graphs are important because they allow you to identify **outliers**. An outlier is an extreme value that may represent a real but exceptional data point, or it may reflect a big mistake. You should investigate each outlier and see if there is an easy explanation. Were the data entered correctly? Was there a mistake in entering the decimal point? Did the lab give you a reason for the unusual reading? If you are convinced it is a valid point, it must be kept as part of the dataset. However, it is still appropriate to treat that point as an outlier in further interpretation. Figure 6.3 shows a graph of total suspended solids versus time, with an outlier obvious near the top right.

Figure 6.3. A plot of total suspended solids (TSS) versus time showing one possible outlier in the data set.



Analyzing Data Using Statistics

Data can be analyzed statistically in a variety of ways, depending on what you want to know. Each different kind of analysis will provide different information about your data and your samples. If the study has been designed on the basis of costs and logistical feasibility, then keep the statistical analysis within the strength and limitations of the data. Statistical methods always yield an answer, but the answer may have little meaning in the context of water quality sampling. It is very important that the specific statistical test is applied appropriately.

It is essential that a person with intimate familiarity with the data and the system understands the statistical application and conclusion. It is better for a technical specialist to carry out a simple statistical analysis than for a statistician with no knowledge of the system to undertake a complex analysis that may not be relevant to the actual situation. More computing power or more powerful statistics will not give you useful answers from limited data or data that you do not understand.

To begin an analysis of your sampling results, you need to decide on some descriptive statistics of the data. Summary statistics should be calculated during the early analysis of your data, which will provide a useful way to investigate the integrity of the data for each water quality variable.

Summary statistics you need to establish:

- *Minimum* – the lowest or smallest value
- *Maximum* - the largest or highest value
- *Range* - the difference between the minimum and maximum values
- *Sample size* - the actual number of data points you are working with, usually represented by a lowercase **n**.
- *Mean* - the **average** of the data points, usually represented by the symbol $\bar{x}$
- *Median* – the middle value. You can use the mean as one of the characteristics to describe the sample, but with some data sets this number may be misleading. The median might be a better way to describe a dataset that has many outliers in one direction (quite a few large values or quite a few low values).
- *Standard deviation* – This is the **average** variation, or difference, in a sample, usually represented by SD or a lower case **s**.
- *Variance* - The variance is the standard deviation multiplied by itself (i.e., the square of SD). Statisticians use the same symbol for the standard deviation but raised to the second power (i.e., $\mathbf{s}^2$).

Standard Deviation and Statistical Population

You need to be careful to recognize the difference between the standard deviation from a sample and what statisticians call a population. The formula used to calculate the standard deviation for a sample is different from the formula used to calculate the same measure for a statistical population. People who do field sampling will never have to calculate the standard deviation for a statistical population as all work is done with samples drawn from populations of infinite size. Most calculators and spreadsheets can calculate both types of standard deviation, so be careful to choose the correct one.

· *Coefficient of Variation* - The coefficient of variation (CV) expresses the SD as a percentage of the mean. Determining the CV provides an indication of the size of the variation and can be used to indicate relative precisions as follows:

CV (%)	General Interpretation
19 or less	Data are highly consistent
20 – 39	Data are fairly consistent
40 – 59	Data are inconsistent
60 or more	Data are highly variable and unpredictable

· *Confidence Limits* - Confidence limits place an upper and lower boundary on where the true mean is likely to be found and will help you understand how precise estimates are. Confidence limits come in a variety of sizes. You may see 90, 95 or 99% confidence limits. That number describes the likelihood that the true mean lies within the confidence limits. For example, 95% confidence limits place an upper and lower boundary on where the true mean is likely to be found 95 times out of 100 (i.e., 95% of the time). Remember that if there is a 95% chance of being right then there is also a 5% chance of being wrong. So 5% of the time the true mean of a system will “miss the mark” and lie outside the 95% confidence limits that were calculated.

It is always a good idea to look at the actual range over which the confidence limits extend. Sometimes you will find the upper and lower confidence limits are close to the sample mean. This tells you that the sample estimate is quite precise. (Either someone did lots of work to take a large number of samples or there is not much variation present in the system. Good news to a statistician in either case.)

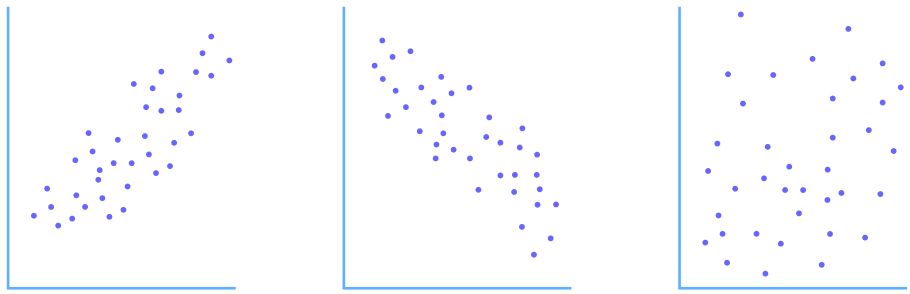
In some cases, you may find the confidence limits are huge and located a long way from either side of the sample mean. These estimates are less useful because they have lower precision, perhaps because of a small number of samples or a system that is quite variable.

Understanding Confidence Limits

While you may need to take a statistics course to learn how to calculate confidence limits, it is fairly easy to get a grasp of how to interpret them. Consider the following example. Between 1979 and 1996, there were 154 samples taken from the Flat River (near Nahanni). The average sulphate level was 29.23 mg/L and the 95% confidence limits ranged from 27.44 to 31.02 mg/L. In this case the average is a statistical estimate based on a large number of samples. The average for the true "statistical population" may not be exactly 29.23, but the sample mean is the best estimate.

· *Correlation Analysis* - This type of analysis shows the relationship between variables, using a scatter plot (Figure 6.4) to look for patterns. For example, a scatter plot can show what happens if one variable gets larger. Does the other variable get larger too or does it get smaller? The statistical tool most often used to answer this question is called correlation. Most water quality monitoring projects analyze for a wide range of chemical variables. Many of these variables are correlated.

Figure 6.4. Graphs showing different relationships that result from correlation analysis.



a) Positive relationship (slope & *r* value are positive)

b) Negative relationship (slope & *r* value are negative)

c) No relationship

The results of a correlation analysis provide a number called the **correlation coefficient**. It is represented by a lower case **r**. The value of r will range between +1 and –1 and provides two useful pieces of information:

1) The relationship between variables: A positive r value means the relationship is positive (Figure 6.4a). A negative r value means the relationship is negative (Figure 6.4b). The relationship can also be seen in the slope of the line.
2) The strength of the relationship: An r value of 1 (either +1 or –1) is a perfect correlation number and all of the points on the graph would be on a straight line. A value of zero means there is no detectable relationship (Figure 6.4c).

Statisticians will usually tell you whether the correlation is significant (or you can guess based on the size of the r value). If there is no significant correlation, then you can conclude that the scatter plot is too chaotic (Figure 6.4c) and there is no relationship.

Using Graphs to Understand Results

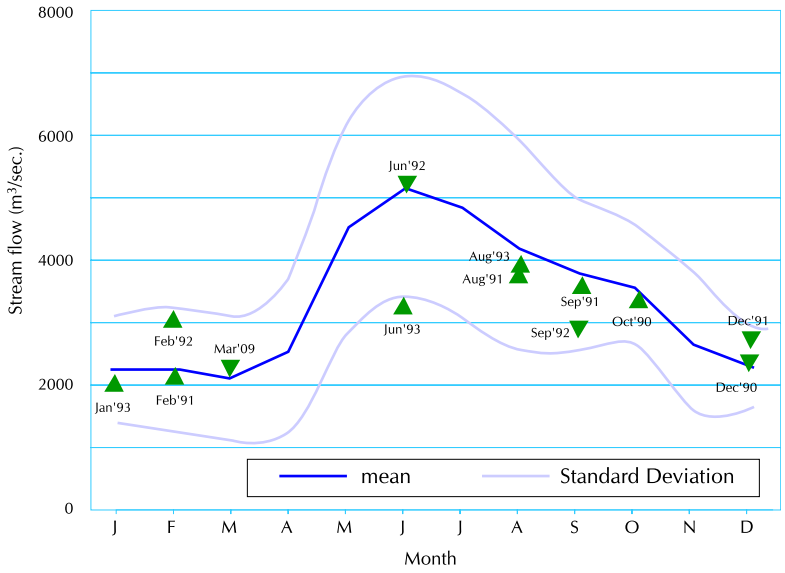
In presenting data for river systems, you should compare the date when samples were collected with the information on the seasonal state of the river stream flow or discharge (i.e., the annual hydrograph).This is relatively simple if you have an annual hydrograph, as it can show if you are missing key periods or ranges of flow. There may be good reasons why it was not possible to collect samples at a certain time of year. For example, it may be too dangerous to sample during the freshet as a result of snowmelt during the rising limb of the hydrograph.

In Figure 6.5, low flow samples during the winter season represent mean (average) flow conditions for this time of the year. However, high flow samples in June were limited and did not reflect the flows that exceeded the mean. The samples on the recession (falling) limb of the hydrograph (August through October) again were at mean flows or less.

Some water quality variables are highly influenced by flow, and you will want to make sure you have samples that represent these periods. When interpreting concentrations data, it is important to remember how water quality variables generally respond to increased river flow. Concentrations can increase, decrease, or produce no predictable response. You can usually find the responses by comparing concentrations to discharge.

Figure 6.6 shows how conductivity can vary with the amount of river discharge. However, one should be cautious before using such a plot to predict something like conductivity based on flow alone, because the relationship is often not linear. In the case illustrated by this graph, conductivity begins to decrease more slowly after about 200 m^3/sec even though flow continues to rise. If we look at two separate sets of points for flow of 0-200 m^3/sec versus flow greater than 200 m^3/sec, we see two different relationships. Figure 6.6 shows that for flows of 0-200 m^3/sec, conductivity decreases quickly as flow increases, but for flows greater than 200 m^3/sec, conductivity changes very little with increasing flow.

Figure 6.5. Example of a mean annual hydrograph for the Slave River showing sample dates for a contaminant study on the river from March, 1990 to August, 1993. The position of the triangle indicates the discharge at the time of water quality sampling.



Hysteresis

Another problem with predicting or relating water quality to flow occurs because the response on the rising limb of the hydrograph (i.e., as flow is increasing) may not be the same as that on the declining limb (as flow decreases). This is especially apparent when looking at total suspended solids (TSS) and other sediment-related variables. This phenomenon is referred to as hysteresis.

Figure 6.6. Example of conductivity declining in response to increased flow, Flat River, NWT.

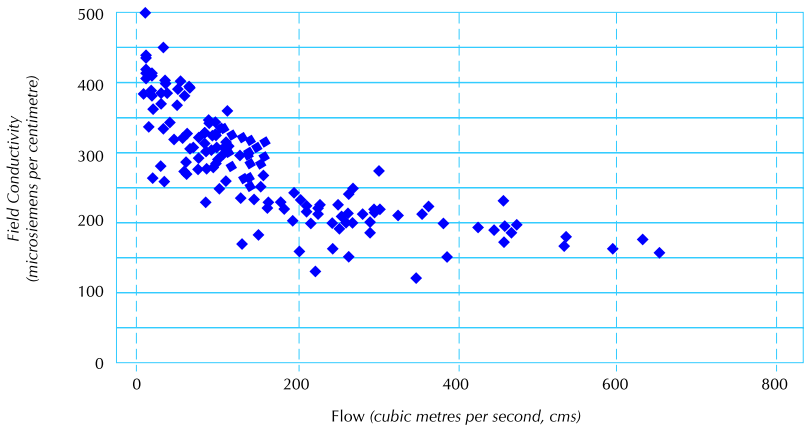
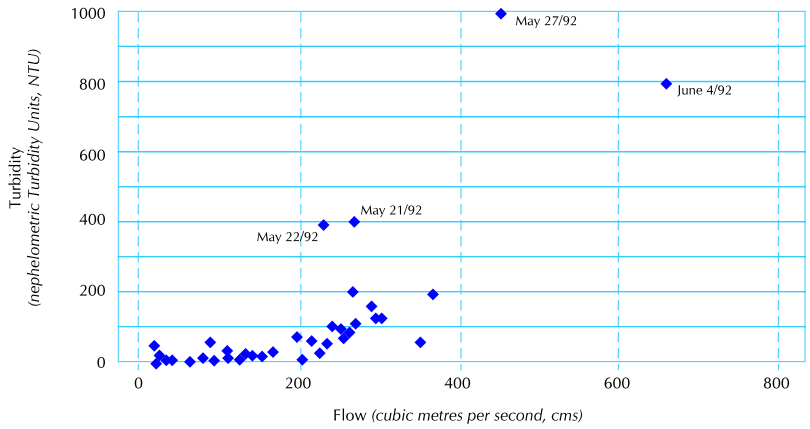


Figure 6.7 shows that variables associated with sediment can increase with flow or discharge, at least to a limit. Past that limit, there is little more sediment available for suspension and transport in this river, so turbidity does not increase much more, regardless of the flow.
For the data plotted in Figure 6.7, most turbidity values are at or below 200 NTU for flows up to 400 m^3/sec, and turbidity doesn't appear to increase at all with increasing flow from 0-200 m^3/sec.

Figure 6.7. Response of turbidity to discharge on the Flat River, NWT.



Using a Water Quality Index (WQI)

Introduction

Change is an important feature of aquatic ecosystems. Changes in aquatic ecosystem structure and function may result from storms, floods, changes in rainfall patterns, sedimentation, and other natural causes. Changes may also result from human impact such as toxic chemical inputs and nutrient enrichment.

Chapter 3 discussed the use of water quality guidelines as one management tool to keep track of undesirable changes, such as the introduction of toxic chemicals. Guidelines exist for approximately 65 water quality variables. Keeping track of them can be confusing. Usually reports are produced that describe trends and compliance with official guidelines or other objectives on a variable-by-variable basis.

Reporting the results of an environmental monitoring program to both resource managers and the general public can cause confusion. The complexity of reporting results may mean that the important messages are lost. Although there is no shortage of data, managers and the general public may lack the desire or training to study these reports in detail. As a result, some people may fail to understand the overall picture of the general health of the water system. One solution is to use a simple index, or a few sub-indices, that will mathematically combine many different water quality measures. This kind of index will provide a general and readily understood description of water.

General Description of the Index

The CCME Water Quality Index or WQI (1.0) is based on a formula developed by the British Columbia Ministry of Environment, Lands and Parks and modified by Alberta Environment. The index can be used to examine water quality relative to its desirable state, as defined by CCME Water Quality Guidelines (see Chapter 3) or site-specific water quality objectives. It can be a useful tool for describing the state of the water column, sediments, and aquatic life. It is also useful for ranking the suitability of water for use by humans, aquatic life, or wildlife. The index can be used to reflect the overall and ongoing condition of the water.

The index is based on a combination of three factors:

1) **Scope** - the number of variables whose objectives are not met
2) **Frequency** - the frequency with which the objectives are not met
3) **Amplitude -** the amount by which the objectives are not met

Calculating Index Values

Although calculation of index values can be done by hand, this is not practical for even a small number of sites, objectives, or samples. A Microsoft Excel macro that automates the process is available upon request from the CCME Water Quality Index Sub-Committee.

These factors are combined to produce a single value between zero (worst) and 100 (best) that is used to describe water quality.

Once the CCME WQI value has been determined, water quality is ranked by relating it to one of the following categories:

- **Excellent**: (CCME WQI Value 95-100) – Water quality is protected with a virtual absence of threat or impairment; conditions are very close to natural or pristine levels.

- **Good**: (CCME WQI Value 80-94) – Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

- **Fair**: (CCME WQI Value 65-79) – Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

- **Marginal**: (CCME WQI Value 45-64) – Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

- **Poor**: (CCME WQI Value 0-44) – Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

The assignment of CCME WQI values to these categories is termed **categorization** and represents a critical, but somewhat subjective, process. The categorization is based on the best available information, expert judgment, and the general public's expectations of water quality. The categorization presented here is preliminary and will no doubt be modified as the index is tested further. The specific variables, objectives, and time period used in the index are not specified and could vary from region to region, depending on local conditions and issues. Ideally there should be at least four variables sampled at least four times so that a proper index can be calculated.

The index can be very useful in tracking water quality changes at a given site over time. It can also be used to compare directly among sites that employ the same variables and objectives. However, if the variables and objectives that feed into the index vary across sites, comparing among sites can be complicated. In these cases, it is best to compare sites only as to their ability to meet relevant objectives. For example, in calculating the index for a mountain stream and a prairie river, you may need to use different nutrient objectives but the sites could still be compared as to their rank (e.g., both sites are ranked as "Good" under the index).

Data for Index Calculation

The CCME WQI provides a mathematical framework for comparing actual water quality conditions with water quality objectives. It is flexible for type and number of water quality variables to be tested, the period of application, and the type of water body (stream, river reach, lake, etc.) tested. These decisions are left to the user. Therefore, before the index is calculated, the water body, time period, variables, and appropriate objectives need to be defined.

The **body of water** to which the index will apply can be defined by one station (e.g., a monitoring site on a particular river reach) or by a number of different stations (e.g., sites throughout a lake or along a river). Individual stations work well, but only if there are enough data available for them. As more stations are combined there will be a tendency for the results to become less specific.

The **time period** chosen depends on the amount of data available and the reporting requirements of the user. A minimum period of one year is often used because data are usually collected to reflect this period (monthly or quarterly monitoring data). Data from different years may be combined, especially when monitoring in certain years is incomplete, but as with combining stations, some degree of variability will be lost. It is important to use similar number of water quality samples for each time period, or the CCME WQI value could be affected.

The calculation of the CCME WQI requires the use of **at least four variables, sampled a minimum of four times.** However, a maximum number of variables or samples is not specified. The selection of appropriate water quality variables for a particular region is necessary for the index to yield meaningful results. Choosing a small number of variables for which the objectives are not met will provide a different picture than if a large number of variables are considered, only some of which do not meet objectives. The professional judgment of the user will decide which and how many variables should be included in the CCME WQI to summarize water quality adequately in a particular region. Details regarding the development and calculation of the CCME WQI are given in CCME (2001a,b).

Use and Limitation of the Water Quality Index

The WQI can be used both for tracking changes at one site over time, and for comparisons among sites. In either case, it is important to make sure that the data are comparable and that there is a valid basis for comparison. Comparisons of data collected by different groups or agencies and over long time periods could suggest that changes in water quality do not exist. They are merely due to change in the method of analysis, change in the frequency of analysis, or change in how representative the samples are. Sites can be compared directly only if the same variables and objectives are used. Otherwise, a comparison of the sites' ability to meet relevant objectives must be made on a per-category basis.

Some general concerns with the use of the WQI are:

1) **Technical** – Using the WQI can blur information. Water quality is a blend of physical erosion, chemical dissolution, and microbial and contaminant processes. Indices that seek to average these do not provide more information. For instance, water quality could be "bad" because of either high nutrient or trace metal levels, or both. (The air quality model is somewhat better. Air quality is "bad" because the ozone/particulate matter/etc. index is high.) However, water quality sub-indices can provide more information than a single WQI value, just as report card marks for individual subjects provide a more complete picture of a student's performance than the overall average.

2) **Logical** - Using the WQI may give misinformation. For example, the validity of the index has to be questioned if pristine waters are classified as "poor quality" because the water in its natural state exceeds some of the established objectives. Water in its natural state in an ecosystem must by definition be good even if it contains sediments, metals concentrations, dissolved ions, etc., that are higher than generally accepted guidelines. Natural water should not be judged as if it was coming out of a tap.

3) **Philosophical** – WQ indices tend to focus on human use (anthropocentric) and may not adequately reflect the natural ecosystem that has adapted to that river or lake. Additionally, WQIs are often false or incomplete because monitoring agencies/ programs do not measure all variables that are required to go into an index, and therefore the index could provide misleading information. For example, it would be wrong to conclude that the water quality of a specific system is good without information on pathogens that weren't looked for.

As with most monitoring programs, an index will not usually show the effect of spills and other such one-time events unless they reoccur or are long lasting.

While indices are clearly beginning to be used to assess water quality, it is important to be careful. Like statistics, they need to be applied with full knowledge of the data and its limitations. Indices may be particularly useful in providing a relative comparison between sites that have the same information collected in the same way (e.g., upstream and downstream of a mine or a community). However, any conclusions need to be phrased carefully.

Chapter 7: Northern Water Quality Issues

The Quality of Drinking Water

Microbiological Quality of Drinking Water

Chemical Quality of Drinking Water

Protecting the Drinking Water Source

Human Activities that Affect Northern Water Quality

Mining Activities

Acid Rock Drainage

Arsenic

Petroleum Exploration, Development, Production and Transportation

Construction Activities and Power Dams

Long Range Atmospheric Transport of Contaminants

Leachate from Landfills

Natural Conditions that Affect Northern Water Quality

Oxygen Consumption and Production in Rivers and Lakes During Long Periods of Ice Cover

Anoxia

Biological Productivity

Freeze-out of Dissolved Substances during Ice Formation

Forest Fires

Radioactivity

Northern Water Quality Issues

The Quality of Drinking Water

Microbiological Quality of Drinking Water

Bacteria, viruses or protozoa carried in water can cause several kinds of diseases that affect the quality of drinking water. These organisms get into the water from a variety of sources and cause different harmful effects in humans. Although only a few of the water-borne diseases listed in Table 7.1 are found in northern Canada, they are a serious threat in other parts of the world.

Water is sometimes tested using a particular organism, or indicator organism, to see if there is potential for the presence of a disease-causing agent or pathogen. The most commonly used bacteriological indicator of water quality is the coliform organism *Escherichia coli* (*E. coli*). More specifically, we test for the presence of the fecal coliform group. We pick this group because fecal coliforms occur in large numbers in warm-blooded animal intestines and feces. Fecal coliform measurement is preferred for monitoring raw water quality. Its presence shows that pathogens can survive in the water environment being tested.
More information about microbiological parameters, such as coliforms, is found in Chapter 3.

The sampling methods and the frequency of testing depend on a number of factors. These include the source water quality, the number of water sources, the intended water use and the past frequency of unsatisfactory samples. Usually the agency responsible for looking at water quality decides how often to sample and takes local conditions into account. More information about water quality and health can be found at www.hc-sc.gc.ca/hecs-sesc/water/index.htm.

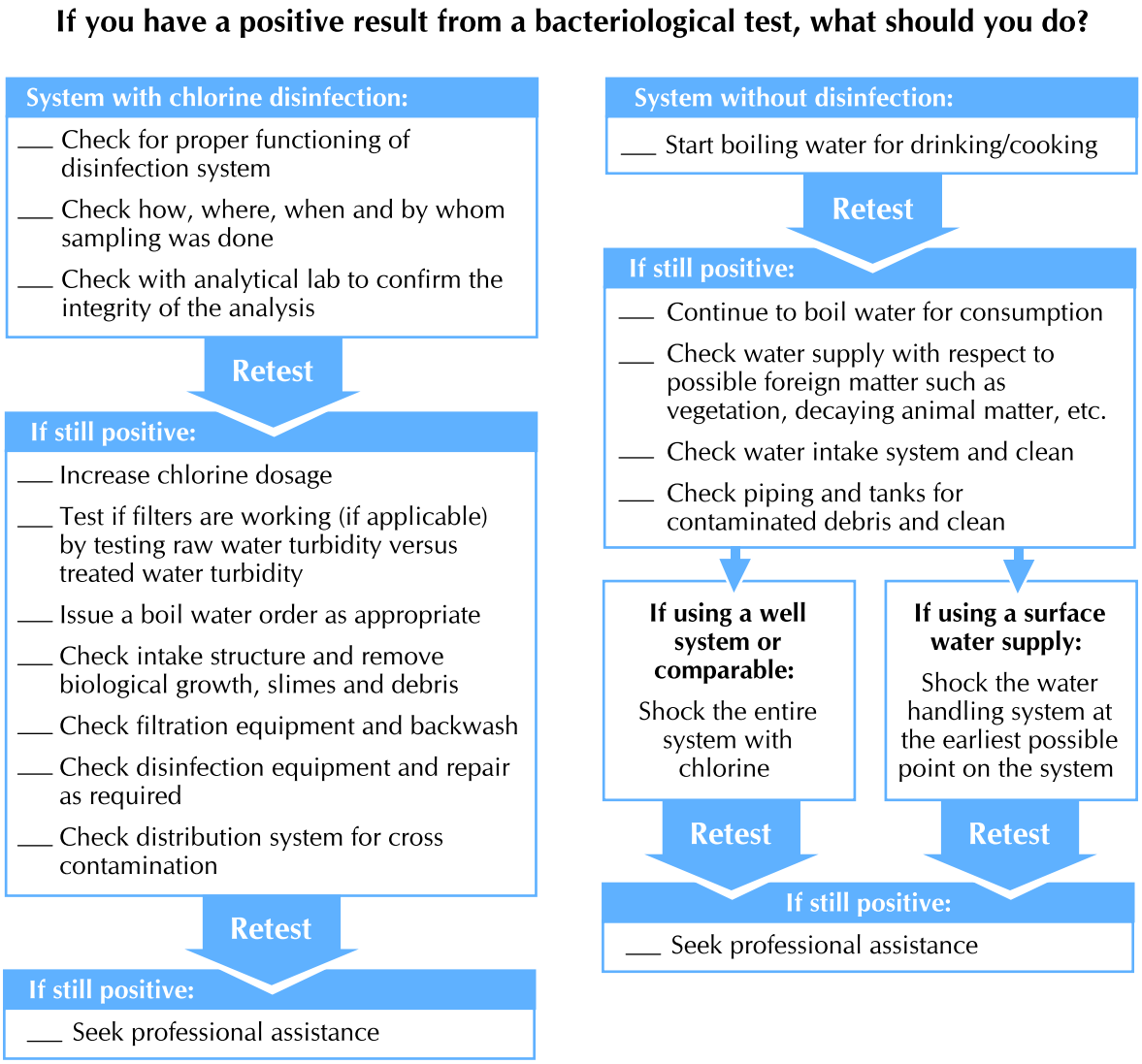
The number of samples to be tested depends on the size of the population who use the water. For example, sampling would be carried out four times a month for a user population of up to 5000. However, in the case of unregulated private wells and shared wells, or private surface water intakes, testing standards are usually not stated. Testing should be done under different environmental (hydrologic) conditions (spring high flows, summer dry periods, winter). You must test more often at the beginning of a study. If the data shows a low risk, you can test less often. Similarly, if it shows a high risk, you should test more often.

Table 7.1. Causes, sources, and symptoms of some water-borne diseases.

Water-borne Disease	Organism that Causes Disease	Source of Organism in Water	Symptoms
Gastroenteritis	Rotavirus *Salmonella* (bacterium) *Escherichia coli*	Human feces Animal or human feces Human feces	• Acute diarrhoea or vomiting • Acute diarrhoea and vomiting • Acute diarrhoea or vomiting
Typhoid	*Salmonella typhosa* (bacterium)	Human feces	• Inflamed intestine • Enlarged spleen • High temperature • Sometimes fatal
Dysentery	*Shigella* (bacterium)	Human feces	• Diarrhoea • Rarely fatal
Cholera	*Vibro comma* (bacterium)	Human feces	• Vomiting • Severe diarrhoea • Rapid dehydration • Mineral loss • High mortality
Infectious hepatitis	Hepatitis A (virus)	Human feces Shellfish grown in polluted waters	• Yellow skin • Enlarged liver • Abdominal pain • Low mortality • Lasts up to 4 months
Amoebic dysentery	*Entamoeba histolica* (protozoan)	Human feces	• Mild diarrhoea • Chronic dysentery
Giardiasis (“Beaver fever”)	*Giardia lamblia* (protozoan)	Animal or Human feces	• Diarrhoea, cramps • Nausea and general weakness • Not fatal • Lasts 1 to 30 weeks
Cryptosporidiosis	*Cryptospyridium* (protozoan)	Animal or human feces	• Diarrhoea • Stomach pain • Lasts an average of 5 days

If the sampling shows a positive result, immediately repeat the testing to make certain. A positive result in raw water means that the water must be disinfected. The disinfected water must have zero presence of the coliform group of indicator organisms before it is used for drinking. Figure 7.1 shows what steps to follow if you have a positive result from a bacteriological test.

Figure 7.1. Flow chart showing what to do if you have a positive result from a bacteriological test.



Chemical Quality of Drinking Water

In addition to the microbiological quality of water, it is important to look at the chemical quality of water used for drinking. Many chemical parameters used to assess drinking water quality are described in Chapter 3. The chemical quality of drinking water can be tested for its effects on health or for aesthetic qualities such as taste, odour or colour.

Most often, the aesthetic quality of drinking water depends on a number of factors or variables. These include total dissolved solids, colour, odour, taste, hardness, and the presence of organic compounds. While the water quality could be lessened by any one of these characteristics, the aesthetic quality of drinking water does not affect human health.

The Guidelines for Canadian Drinking Water Quality (discussed in Chapter 3) show the specific substances to be tested for. Guideline values for some substances are given in Table 7.2. Individual jurisdictions may have other guidelines.

Unlike the frequent bacteriological examination that is needed to protect drinking water supplies, the chemical characteristics can be tested less often. In general, sampling for substances that affect health should be done twice a year. Keep in mind that surface water quality, environmental conditions, and human activities around the watershed can all change with the seasons. For example, metals concentrations, turbidity, and dissolved solids will all vary by season. These changes may affect the frequency and timing of samples. Some important factors to consider are discussed in more detail in chapters 3, 4 and 5.

Chemical and bacteriological water quality results from Northwest Territories municipal laboratories since 1998, at annual and monthly sampling frequencies, respectively, can be seen at the Government of the NWT website: www.pws.gov.nt.ca\waterandsanitation\index.htm.

Table 7.2. Drinking water contaminants and possible health effects.

Contaminant	Guideline Values[1] (CCME 1999)	Possible Health Effects
Aluminum	0.1 mg/L (limit is only an operational guideline)	irritation of gastrointestinal tract rickets skeletal pain muscle weakness death
Arsenic	0.025 mg/L (IMAC)	malignant tumour to skin & lungs cramps spasms effects to nervous system
Copper	≤ 1.0 mg/L – aesthetic objective	gastrointestinal tract irritant
Mercury	0.001 mg/L (MAC)	kidney impairment possible death
Nitrate/nitrite	45 mg/L (MAC)	potential poisoning of infants methemoglobinemia – "blue baby syndrome"
Lead	0.01 mg/L (MAC at the point of consumption)	damage to nervous system, kidneys, reproductive system cancer (in rats)
Selenium	0.01 mg/L (MAC)	carcinogen irritation to mucous membrane dermatitis

[1]IMAC = Interim Maximum Acceptable Concentration; MAC = Maximum Acceptable Concentration. More information about drinking water quality guidelines is provided in Chapter 3.

Protecting the Drinking Water Source

The best ways of protecting a drinking water source is the use of "multiple barriers". Multiple barriers in the water system make sure that our water is free from all harmful substances and is safe to drink from source to tap. For example, limiting activities in the nearby area can protect the water source. This is true for both surface waters and groundwater from wells.

Proper well construction is another barrier. If a well is properly sealed, pathogens present in surface waters can be prevented from entering the groundwater. However, the well must not be connected to a surface water source. This was the original cause of the problem at Walkerton, Ontario.

Where surface water is used as a drinking water source, the location of the water intake represents the first barrier. Since low and high flow conditions will influence the water quality, they must be considered when deciding on the location of the intake. The next barrier is filtration. Filtration removes particles, although the size of the particles that are removed will depend on the treatment process. Organisms have the ability to attach themselves to particles, so if these are not removed they will escape disinfection. Popular methods of disinfection include chlorine, ultraviolet light, or a combination of the two.

Whether the source is groundwater or surface water, a clean distribution system is necessary to make sure of protection. Often, even after all safeguards are in place, contamination happens because of lack of cleanliness in the home, restaurant or elsewhere. Faucets and utensils must be properly handled and cleaned.

How Do I Know if My Water is "Safe" or "Good" to Drink?

The definitions of **safe water** and **good water** are not always the same. "Safe water" usually means water that is free of bacteria and viruses and that will not make people sick. Chlorinated waters used in most municipal water supply systems in Canada are usually considered "safe". However, many people do not consider chlorinated water to be "good" because of its taste and odour.

In 1988, a public working group met near Whitehorse to discuss the question "What is good water?" The group decided on an objective for water quality of: "All water in the Yukon should be safe to drink".

However, it is not possible to meet this objective for a number of reasons. For example, some waters, through natural processes, are not safe to drink without treatment. Wells cannot be used for drinking water in certain places in the Yukon because the groundwater contains too much natural arsenic from the surrounding rock. Sometimes iron and other metals make the water taste bad even though it may be safe to drink. Water may also be unsafe to drink because of the presence of pathogens such as giardia from the feces of wild animals. These can make people sick unless the water is treated.

There may be uses of the water that are more sensitive than drinking water. For example, mining can introduce high levels of zinc to streams. This is not a problem for people drinking the water, but these levels may be toxic to fish and aquatic plants.

Drinking water may require treatment to ensure safety. The need for treatment does not necessarily mean a failure to protect the resource. Many groundwater sources (wells and springs) remain pure enough to drink safely. So do snow and ice melt from areas beyond normal human and animal ranges (glaciers and icebergs). If you are not sure, boil the water for a minimum of one minute to kill any disease-causing organisms.

What Can I Do to Make My Water Safe to Drink?

The most common worry about safety is the presence of pathogens or microorganisms in the water. Boiling the water for at least one minute is a good short-term solution. However, longer-term solutions are also available.

Chlorine, for example, is a common way to control microorganisms. The chlorine must be in contact with the water for at least 30 minutes to make sure it is disinfected. Chlorine works by killing an organism or damaging its cell wall. But because cells have the capacity to repair themselves (regrowth) disinfecting with chlorine is not always a complete solution. Also parasites can be resistant to chlorine and disinfection by-products may be created. This is especially true in the case of waters with high organic matter from nutrient-rich lakes or wetlands.

Ultraviolet treatment is becoming increasingly popular in homes and small systems (e.g., campgrounds, communal wells, etc.). The process imitates the action of ultraviolet (UV) rays from the sun. A light tube similar to a fluorescent light is used so that the UV light is in contact with the water containing the microorganisms. The UV rays pass through the cell wall of the organism and disrupt the cells' DNA structure. The cell is then no longer able to reproduce. The manufacturer's instructions about installing and operating these systems must be followed to make sure they are used safely and effectively.

Human Activities that Affect Northern Water Quality

Many human activities may affect water quality. The activities that most often affect northern water quality are described below.

Mining Activities

Water quality tests are often done as part of the water licensing process before any new mining activity begins. A complete baseline study should be done before any activity starts to identify pre-disturbance conditions.

Water licences currently require aquatic quality sampling and monitoring during the environmental impact assessment, construction and operational phases of a mine. Any effects connected with the mining and milling process are studied. While these studies vary in quality, many are very good. Results should be examined to see how they could be used in another water quality monitoring activity. You can also use existing studies to identify any limitations and weaknesses in the project design or monitoring methods.

The exploration and construction phases may cause the exposure of acid-generating rocks, loss of vegetation, and increased runoff and erosion. All of these changes can affect water quality, especially the pH and ion and metal concentrations. Another environmental issue that should be tested or monitored includes the possible effects of the mining activities on permafrost. These effects may change water quality and the requirements for safe storage of materials.

The North has many mines that have been abandoned and not properly reclaimed. The problems left behind include abandoned fuel caches and equipment used during preliminary exploration and the effects of mines abandoned after decades of production. Figures 7.2, 7.3 and 7.4 show examples of some of these problems.

Figure 7.2. Tailings pond from an abandoned gold mine site. Water and sediments may contain high concentrations of heavy metals and cyanide used in the separation process.
Source: MDA Consulting Ltd. (2003)

Figure 7.3. Example of an abandoned mine/exploration site showing abandoned buildings and equipment. Stream banks were greatly disturbed and crossed in a number of areas. The vegetation was destroyed resulting in gullying and erosion.
Source: MDA Consulting Ltd. (2003)

Figure 7.4. Threats to aquatic systems at a northern mine site: (a) leaking fuel tanks and (b) piping lying across the creek bed.

Courtesy of: Steve Matthews

Mining and Protected Areas – Achieving Environmental Protection through Water Quality Sampling

"Green" Mine – This *base metal* mine had been shut down for years. It was recently reopened in response to increased metal prices. There are several old buildings located at the mine site. This mine has an acid rock drainage (ARD) problem, which makes associated waters acidic and raises levels of dissolved trace metals. (More details about the causes and effects of ARD are provided below.) Green Mine is located near the Green River, and has a recent history of fuel spills.

Base metal - Any alloy or pure metal of relatively low value. The term "base" either refers to the metal as basic or low-value, or to the practice of using a higher value metal, such as gold or silver, to coat or "plate" over a base of the lower value metal. Common base metals include brass, bronze, and copper.

"Blue" Mine – This mine was constructed as a *precious metal* mine but it was never opened. There is now a proposal to open it for base metal mining. New operations would require new infrastructure and a new access road. Blue Mine also has ARD problems and a history of fuel spills. It is also close to fish-spawning habitat in Blue Creek and is upstream from a protected area. An earthquake or landslide in this mountainous area could damage or destroy the tailings pond and buildings, resulting in serious environmental damage. Scientists and managers of a protected area downstream of the site are also concerned about the quality of the water and the type of suspended sediments in Blue Creek. Blue Creek typically has very low stream flow (i.e., less than 20 cubic metres per second).

Precious metal – A metal that is relatively scarce, highly corrosion-resistant, and valuable, including, silver, platinum, and gold.

Bed-load sediments - Sediments found at the bottom of a stream in a streambed.

A four-year study was designed to find out about baseline water quality. Sites were set up in the protected area on Green River and Blue Creek as well as on the larger river they drain into. Water quantity was measured as well as fine-grained sediments. The concentration of water quality variables like pH, total dissolved solids, total suspended solids, nutrients, major ions and trace metals were also measured. Streambeds were also sampled for trace metals and other things found in *bed-load sediments*.

In mountainous rivers and streams, the quality of the water is greatly affected by how much water there is, so samples were collected during high stream flows (freshet), medium flows (summer-fall recession) and at low flows (under-ice).

Sampling over several years at different times showed the patterns of change by season and among different sites. These measurements were compared to the appropriate water and sediment quality guidelines (CCME Canadian Water Quality Guidelines, and CCME Interim Sediment Quality Guidelines for freshwater).

Naturally elevated levels of metals, including aluminum, cadmium, copper and zinc, were found in the water. The natural ecosystem already looked "stressed" without the mines being in operation. This result suggested that any additional loading might be the "push over the edge" for aquatic life.

Based on the data obtained for each water system during the baseline studies, water quality guidelines were developed specifically for Blue Creek and Green River. These guidelines are intended for use in setting water licence regulations for Green Mine and Blue Mine.

In part as a result of the aquatic sampling work, the aquatic ecosystems can be protected through appropriate mine effluent regulations. Mine operators know the requirements up front, and the ecological integrity of the protected area can be maintained.

Lessons learned:

1) Baseline data permitted the development of water quality standards for use in the water licence that would help protect the protected area.
2) Hydrocarbons were overlooked as a source of pollution in the initial sampling program, but need to be considered as a part of any industrial activity.
3) Acid rock drainage, and possibly other effluent discharge, was already occurring from at least one of the dormant sites when the sampling program was begun. Without adequate upstream sampling even the baseline stream data are not truly pristine.

Acid Rock Drainage

For hundreds of years, prospectors who looked for potential mineral deposits around rust-coloured rocks or waters were seeing the visual effects of naturally occurring acid rock drainage (ARD). ARD is the result of the physical and chemical weathering of rocks that contain metal-sulphide minerals. When sulphide materials are exposed to air and water, they chemically react to produce acid. This acid can then dissolve the metals they contain. This process can be speeded up by activities such as road building, land clearing, and mine development.

ARD is a major environmental issue for the mining industry, as metal and coal deposits can be rich in sulphide materials. The runoff and seepage from waste rock and tailings sites can contaminate watercourses and harm aquatic life. Figures 7.5 and 7.6 illustrate how an ARD situation develops at a mine site.

Contact with ARD will decrease the water quality of streams, lakes, wetlands and other water bodies. ARD creates two different environmental problems:

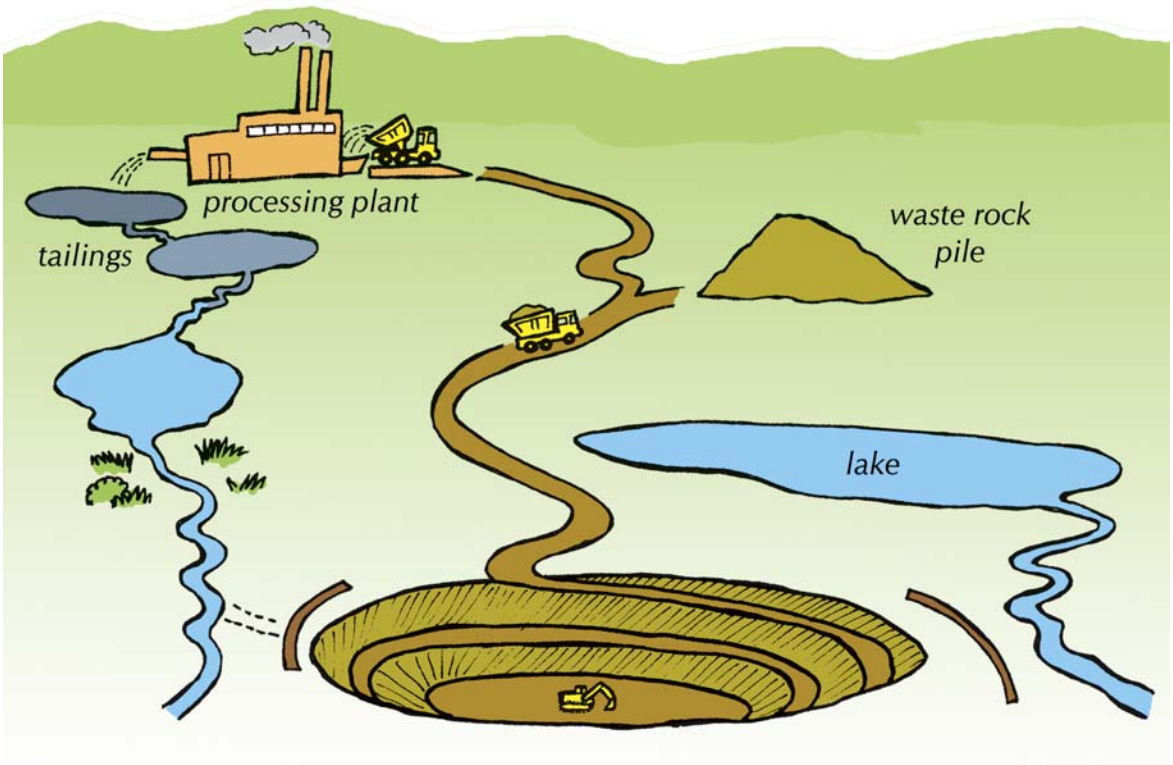
- The sulphuric acid released from the rock lowers pH and makes conditions more acidic.
- Low pH conditions can help dissolve trace metals. These metals may become mobilized and be taken up by organisms.

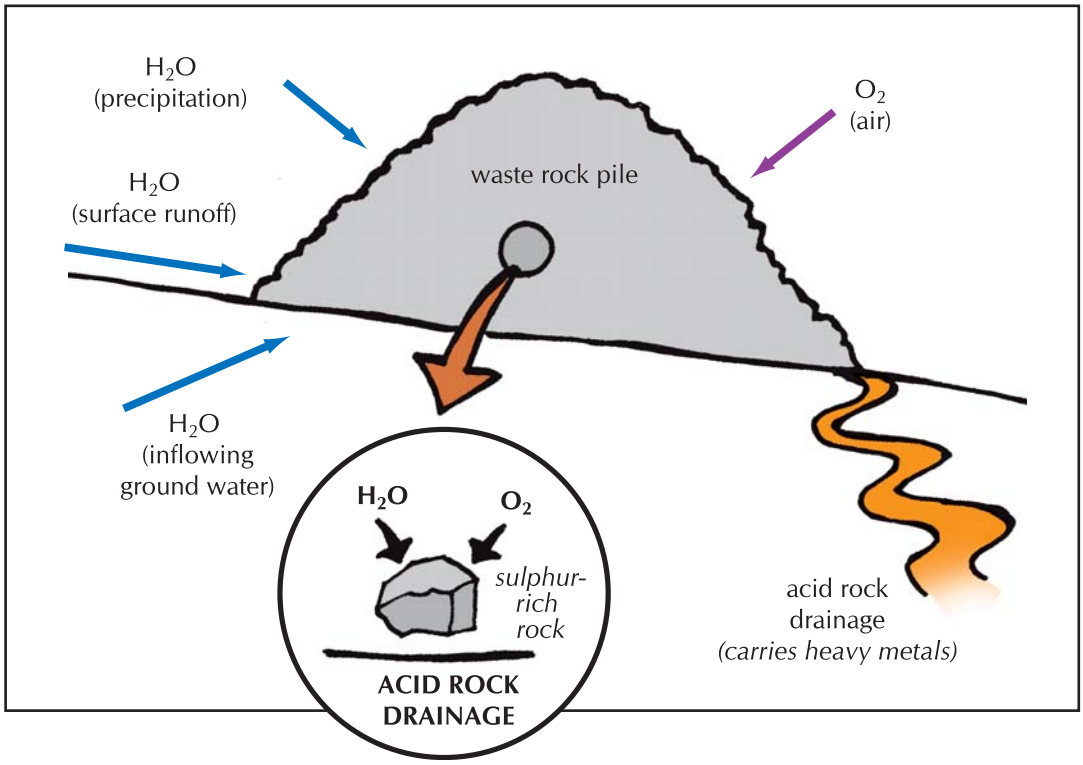
The two effects should be recognized as separate, with different consequences to aquatic ecosystems.

Figure 7.5. A waste rock pile and potential ARD source next to a water body at a northern mine site.

Courtesy of: Steve Matthews

Figure 7.6. Acid rock drainage resulting from a mine.





There are two approaches to managing ARD. One is to deal with the root cause. Limiting or reducing the exposure of the sulphide minerals to air and water can prevent ARD. For example, you can plant vegetation in a soil layer covering the sulphide-bearing rock, or place sulphide-bearing rock wastes under water. The second approach would be to deal with the symptoms by neutralizing the acid. The acid-generating rock can be mixed with naturally occurring rocks that are basic (high pH). Where this is not practical, a combined collection and water treatment system can be put in place.

The rates at which ARD generation and ARD neutralizing chemical reactions occur are not easy to predict. Each place is different because of the multiple chemical reactions involved and the effects of temperature. Reaction rates also vary with rock types. During environmental impact assessments (EIAs), mining companies are often required to use geochemical mathematical models. These models try to predict what pH and trace metal concentrations will be during the construction, production and post-production phases of mining and milling, in both surface and ground waters.

The natural and sometimes frequent occurrences of coloured *gossans* have resulted in names for rock formations, such as the 'Sunblood' formation in Nahanni National Park Reserve. These gossans are reddish-brown to yellow-ochre. Such natural occurrences are well known to First Nations who use the gossans to paint their bodies. Iron hydroxides are still principal ingredients in some modern-day cosmetics.

Gossan - The familiar rust-colored stain in rock associated with ARD.
At pHs higher than 3.0, ferric iron reacts with oxide (O_2-) hydroxide ions (OH-) to form ferric hydroxide, Fe $(OH)_3$, which precipitates as gossan.

Does an Abandoned Mine Affect Water Quality?

Abandoned mines often affect water quality close to the mine site. The most common cause is the release of acid rock drainage (ARD) from mine tailings and mine works. ARD can lower the pH of the water, especially in poorly buffered waters common to the Canadian Shield. This lower pH can in turn make the water too acidic for aquatic plants and biota to survive. The acid water may also contain high concentrations of dissolved metals that could be toxic to aquatic species. If something is not done to prevent it, ARD can continue to affect water quality for many decades.

Many abandoned mines may have used ponds to allow tailings to settle from water slurries. These artificially created ponds and small lakes may release sediments and water downstream during freshet. If the earthen dams that usually enclose the ponds are not kept up, a catastrophic release of water and sediments can result. These contaminated sediments could smother spawning areas and other important aquatic habitats. Many years of natural flushing would occur before the site is returned to pre-mine conditions.

Arsenic

Arsenic is a natural element found in arsenopyrite-bearing rocks that contain minerals we mine (e.g., gold). It may be naturally higher near ore bodies. Arsenic in drinking water is currently a major issue internationally. Extensive research is underway regarding acceptable guidelines and criteria.

Arsenic exists in several forms. Arsenic trioxide is generally the most toxic and most mobile in the environment. Arsenic is toxic to aquatic biota and humans, though it does not bioaccumulate to a great degree. However, it can be concentrated to some extent in food, especially in plants grown on arsenic-enriched or contaminated soils. Arsenic can get into the aquatic system when tailings ponds overflow or fail to operate correctly. Arsenic can also be dispersed into the atmosphere during mineral processing. It is deposited on the ground, and eventually reaches the aquatic system.

The Canadian Drinking Water Quality Guideline for arsenic is 25 µg/L (or 25 ppb; CCME 2003). The Environmental Protection Agency in the United States has recently adopted a more stringent level of 10 ppb in drinking water. For more information about the Canadian guideline for arsenic in drinking water see:
www.hc-sc.gc.ca/hecs-sesc/water/pdf/dwg/arsenic.pdf and
www.hc-sc.gc.ca/english/iyh/environment/arsenic.html.

Arsenic and the Giant Mine in Yellowknife

More than 237,000 tonnes of arsenic trioxide dust is being stored at the former Giant Mine near Yellowknife, waiting for a permanent disposal solution. The arsenic trioxide dust was produced by the gold mine from 1951 to 1999, when the mining company went bankrupt. When production ended, the federal government inherited the abandoned mine and its arsenic problem.

The release of arsenic from the mine's roaster stack and the difficulty storing arsenic trioxide dust have been thoroughly investigated. These investigations have looked at the risk of arsenic in the environment and the best practices for long-term management of the arsenic-laced dust. In the case of Giant Mine, arsenic is a natural product in the ore. During the roasting process sulphur dioxide and arsenic vapour are released. The arsenic vapour collected on dust collectors installed on the roaster rack and produced arsenic trioxide dust.

Current research indicates that the arsenic in soil in the Yellowknife area is not having an ecological impact. Yellowknife obtains its drinking water from upstream of the area where arsenic has been released. As a result, drinking water consistently tests at concentrations of less than 1 µg/L of arsenic. This level is well below the Canadian Drinking Water Guideline and not a direct threat to human health.

Petroleum Exploration, Development, Production, and Transportation

The effects of petroleum (oil and gas) exploration, development, production and transportation are generally well known in southern Canada and around the world. Both water quality and aquatic ecosystem health are affected by petroleum development, including extraction from oil sands deposits. The effects are less well known in the north because they were not examined in the past (e.g., the 1940s Norman Wells to Whitehorse CANOL Pipeline). Other impacts were mainly looked at after construction (e.g., the 1977 Alyeska Oil Pipeline in Alaska, the 1985 Enbridge Oil Pipeline from Norman Wells). The effects of petroleum projects on aquatic ecosystem health, including effects on fish and wildlife and their habitats, are now becoming better understood in the north. This is a result of recent environmental impact assessments for several northern projects.

What factors influence the effects of petroleum activities on aquatic ecosystem health?

The effects of petroleum activities on aquatic ecosystem health depend upon the size of the project, the geographic area it covers, and the time over which activities occur. A permanent, large camp has a potentially greater impact on nutrient and bacteriological water quality values in nearby water bodies than a small, temporary camp. For example, the proposed Mackenzie Gas Project (MGP) is more likely to have significant effects than the 50 km Ikhil natural gas pipeline near Inuvik. The MGP includes a pipeline and many associated activities stretching from the Beaufort Sea (Arctic Ocean) to northwestern Alberta.

In general, development activities that occur over a long time cause greater environmental changes than similar activities that occur over a shorter time. However, the construction phase of the MGP would be more likely to cause significant changes to the aquatic ecosystem even though it would be much shorter (two to three years) than the operation and production phases (30 years). These changes are caused by the nature of construction activities and the long period over which their effects last.

Some oil sands activities could affect water quality and aquatic ecosystem health in a way that may last for decades, or even centuries. Oil sands developments may result in the introduction of toxic chemicals to groundwater in ancient sand channels and, eventually, to surface waters in major rivers.

Some of the petroleum activities that can cause serious harm to water quality and aquatic ecosystem health are:

- Development and use of seismic ground geophysical survey lines and helipads.
- Access road construction and use.
- Drill pad construction.
- Transportation of fuel and potential spills.
- Channel dredging for barge operation.
- Channel straightening to avoid ice jams.
- Down hole geophysical surveys (measurements made by lowering probes down wells to find how deep and how thick rocks are and whether there is oil, natural gas or water in the reservoir rocks).
- Drill wells that require cementing.
- Drilling activities that involve: the use of salts, metals and other drilling mud additives to cool drill bits; disposal of drill cuttings and bent, non-usable drill rods; addition or removal of formational ground waters (when wells intersect underground faults and/or taliks near large lakes); related events such as oil blowouts and well fires.

- Disposal of hazardous wastes.
- Removal of natural gas from shallow rock formations, which can cause land to sink and flood more frequently.
- Removal of surface and groundwater for camp use, drilling, and winter road construction, which can cause water levels to be "drawn down" to very low levels.
- Camp operations, such as water and sewage treatment plants, that may affect nutrients and bacteriological levels of water quality in nearby water bodies.
- Explosives storage and potential pollution of nearby water bodies from leakage of nutrient and fuel oil ingredients.
- Long-term compressor station operation and potential acidification of nearby downwind water bodies.
- The effects of construction and operation of buried pipelines on permafrost, including (i) melting of permafrost, which may worsen the melting that is occurring as a result of climate change, and (ii) creating new local areas of permafrost, which may block stream flow and affect water levels, fish and fish habitat.
- Potential over-fishing by many thousands of pipeline construction personnel over several years.

Construction Activities and Power Dams

Activities such as bridge construction, pipeline crossings of watercourses and power dams are all expected to increase in the north in the future. Exploration and development will need new and expanded resources and will bring more people into the area.

Construction activities in and near watercourses can have an important impact on aquatic quality. Power dams can also affect water quality. A number of factors, including permafrost and the slow rate of revegetation, can work together to increase these effects.

The main effects of construction projects on rivers include:

- Erosion during construction.
- Increased downstream turbidity.
- Smothering of important habitat for aquatic organisms with fine materials.
- Ongoing erosion of riverbanks and nearby areas due to a slow rate of revegetation.
- Exposure of permafrost which could melt, resulting in a continuing cycle of erosion and melting.
- Changes in downstream habitats as a result of changes in the water system.
- Potential harm to water source due to disposal of waste materials.

Planning for new projects, including environmental impact assessments, should take possible aquatic system effects into account. It may be necessary to monitor effects and the methods used to lessen them. Pre- and post-construction monitoring is the best. This monitoring usually involves field analysis, including turbidity, dissolved oxygen (especially under ice), conductivity and pH. Laboratory analysis can target major ions and metals. Chemical monitoring would likely be combined with a biological monitoring program (e.g., fish, invertebrates, aquatic vegetation).

Short-term projects can be monitored afterwards to see if conditions have returned to the state they were in before the project. Hydro development projects tend to have major long-term effects on the aquatic environment. Monitoring also requires investigations beyond water quality measurements, sampling other media like sediment and biota.

Assessing the Effects of Dams on Estuaries - Case Study of the Nelson River Estuary

Estuaries are affected by the tides and are highly changeable in their physical, chemical, and biological properties. Freshwater inflow is the most important factor because it affects total salinity, ice formation, accumulation of nutrients and organic substances, and water circulation and residence time.

The Nelson River Estuary is the major estuary in western Hudson Bay. Its system is partially to completely mixed because it has a large tidal range, shallow depth, and a large ratio of tide to river volume. These factors combine to produce strong currents that mix the water vertically and laterally. They also cause the plume of estuarine water to be compressed and extended with each flood and ebb tide.

Before the late 1980s, the estuary was virtually unstudied even though a number of hydroelectric developments had the potential to affect it. These included dams and generating stations constructed in the 1960s. The Churchill River Diversion moved approximately 80% of the flow from the Churchill River into the Burntwood and Nelson rivers. The regulation of Lake Winnipeg in the mid-1970s also had the potential to affect the estuary.

Multidisciplinary biological studies were carried out on the Nelson River Estuary in the late 1980s and early 1990s. A multi-year monitoring program was started in 1995. This program established an environmental database that could be used to study the continued effects of development and examine the effects from future developments. A pilot study conducted in 1995 looked at various sampling techniques. It also identified the elements to be studied in the estuary and set up a regular plan for data collection.

Between 1996 and 1999 the Nelson River estuary monitoring program examined:

- water depth
- water velocity
- water transparency
- temperature
- dissolved oxygen and salinity profiles
- water chemistry including conductivity, nitrate and nitrite-nitrogen, ammonia-nitrogen, total dissolved nitrogen, suspended nitrogen, total dissolved phosphorus, suspended phosphorus, dissolved organic carbon, dissolved inorganic carbon, suspended carbon, total suspended solids, chloride, sulphate, sodium, potassium, magnesium, calcium, and iron.

Not all parameters were assessed each year. Biological investigations included phytoplankton abundance assessed by chlorophyll *a,* phytoplankton species composition and abundance, and zooplankton and benthic invertebrate composition and abundance.

The researchers collected water samples from sites that represented four estuary zones. They also collected sub-surface water samples from each zone in the Nelson River Estuary. Beginning in 1995, samples were taken during both high and low tides, and from surface and deep (> 10 m) water.

Lessons learned:

1) In a complex estuarine environment, one or more years of study may be needed to identify the right sampling methods. The same is true for the features to be sampled and the sample collection times and depths.
2) In an estuary where almost nothing is known, it is important to choose a broad range of chemical analyses to adequately describe the estuary.
3) It is necessary to know tide heights and times and to be prepared to work quickly for short periods to “catch the tide”.

Long-Range Atmospheric Transport of Contaminants

DDT (Dichlorodiphenyltrichloroethane) - A colourless crystalline compound made by the reaction of trichloromethanal with chlorobenzene. The compound is stable, accumulates in the soil, and concentrates in fatty tissue, reaching dangerous levels in carnivores high in the food chain.

HCH (Hexachlorocyclohexane) - This chemical has been produced since the Second World War. It is one of the few organochlorine insecticides used on a large scale. Its compounds vaporize easily and are transported to the Arctic through the air.

The most common contaminants or impurities brought to the north through the atmosphere include PCBs and organochlorine pesticides (e.g., ***DDT*** and ***HCH***). Some metals, including mercury, as well as other industrial chemicals such as brominated flame-retardants and agricultural herbicides are also transported long distances to the north (Figure 7.7).

These contaminants have several chemical properties that are a concern for the health of the environment:

- They maintain their properties as compounds and do not break down under normal conditions.
- They are toxic to many organisms at low concentrations.
- They are fat-soluble and may bioaccumulate in the fatty tissues of organisms.
- They may reach high concentrations in top predators after passing up a food chain/web from one organism to another (Figure 3.2).

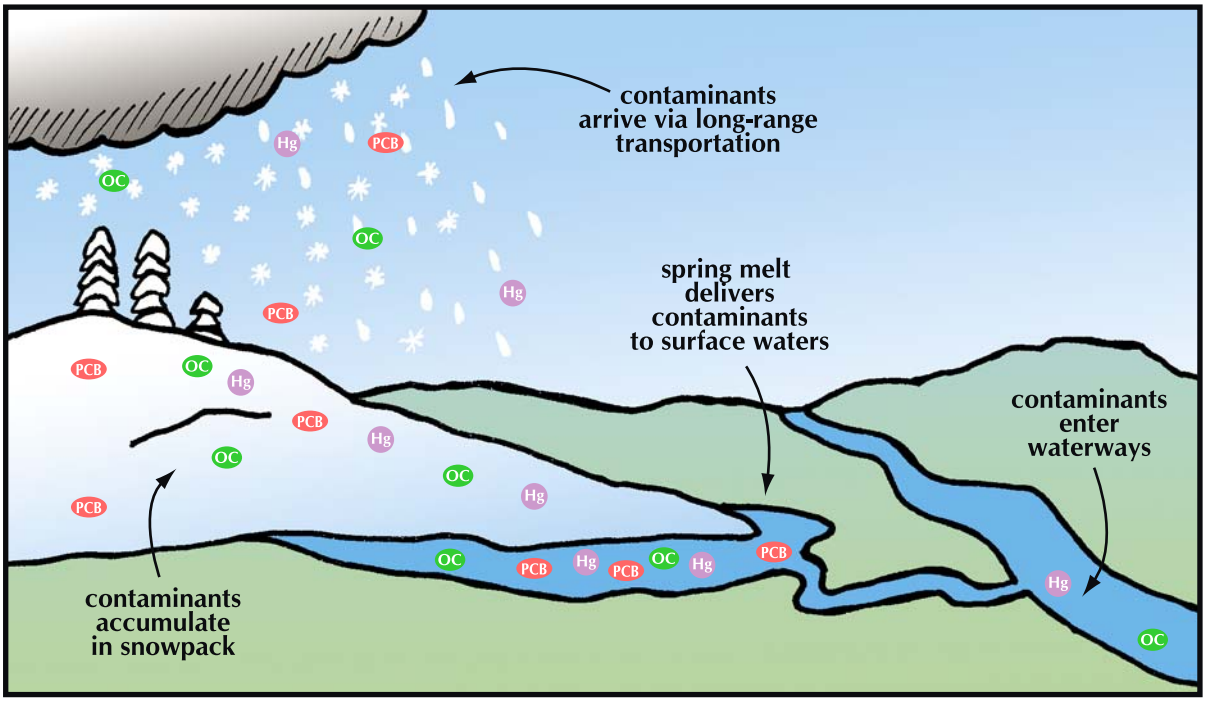
These compounds are semi-volatile. If free in the environment they can get into the atmosphere and travel long distances until they reach the Arctic. Cold temperatures make these contaminants return to the ground attached to dust particles or in rain and snow. They reach the aquatic system through snowmelt as well as directly with rainfall. The cold temperatures also make it unlikely that these compounds will vaporize again from the snow and other surfaces into the atmosphere.

Figure 7.7. Long-range transport of contaminants to the Canadian Arctic.

Large quantities of contaminants can build up in snowpacks and be released to the aquatic system during snowmelt (Figure 7.8). A quick snowmelt in spring may cause a rapid release of contaminants, known as a pulse loading, to the aquatic environment. This leads to build-up in the aquatic food chain, which can be measured in the sediments of many northern lakes and in fish tissue. The key contaminants listed above bioaccumulate and biomagnify up the food chain/web (Figure 3.2). They may cause cancer and have other effects on the organisms that collect them. This means aquatic life and humans that eat large quantities of fish with these contaminants may be harmed.

The atmospheric pathways of these contaminants to the north are greater in the winter season (Figure 7.9). The direct pathways from industrial and agricultural areas in Eurasia are especially important sources to the Canadian North. North American sources are believed to be less important.

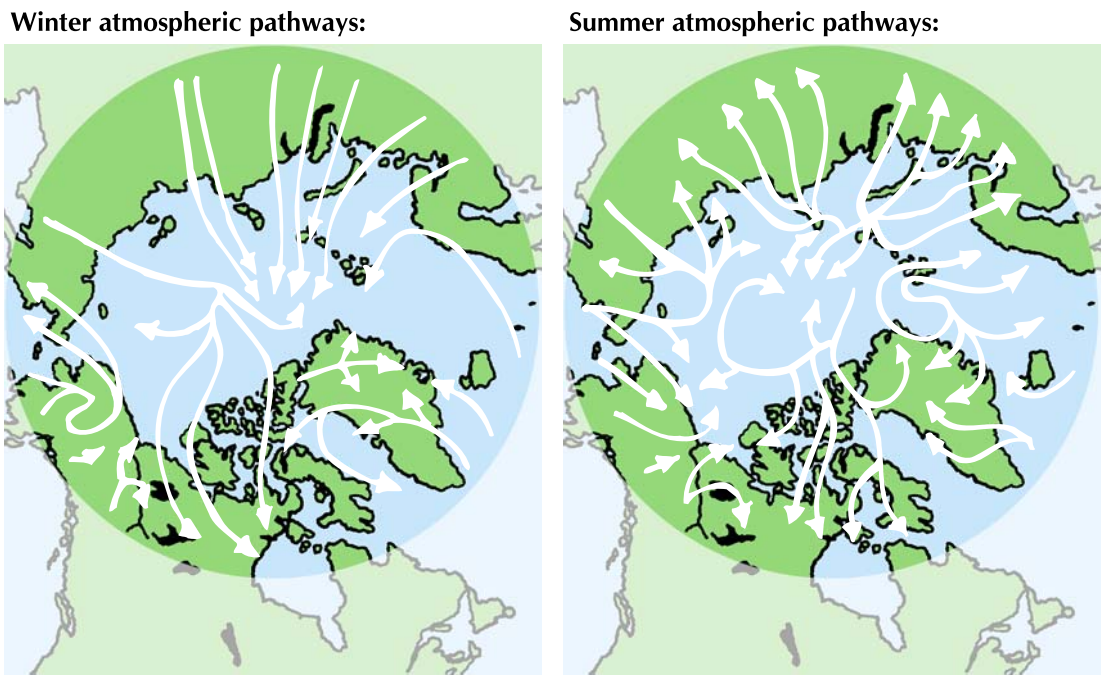
Figure 7.8. Release of contaminants from snowpacks to water bodies during snowmelt.



Does the Long-range Transport of Contaminants through the Atmosphere Affect Drinking Water?

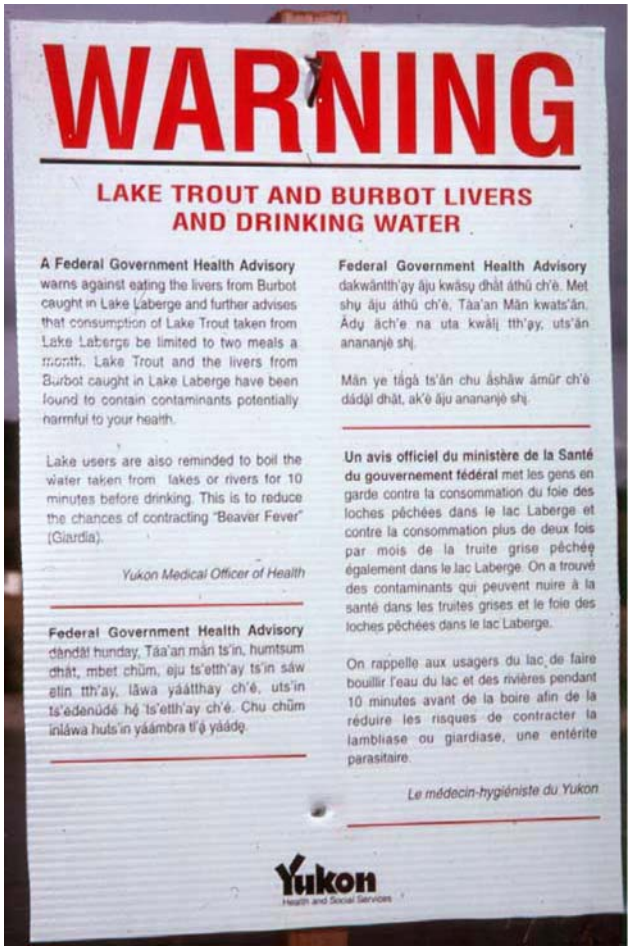
Trace metals (e.g., mercury, lead) and Persistent Organic Pollutants (POPs), such as pesticides and other contaminants, are being transported in the air to all parts of the world, including even remote northern areas. These contaminants are removed from the atmosphere by rain and snow and can then get into surface water. Many of the contaminants are eventually removed from the water through sedimentation and building up in biological material such as vegetation and fish. Melting snow and snowmelt water, however, remain safe to drink, as their concentrations are well below drinking water quality guidelines.

Figure 7.9. Generalized wind fields showing atmospheric pathways to the Arctic primarily from Eurasia during the winter contrasted with average summer wind fields.



Although the concentrations of these contaminants tend to be low, there is the possibility of long-term accumulation in lake sediments, marine sediments, and glaciers and ice caps. Annual snowmelt will continue to release fresh contaminants to the aquatic system. Retreat of glaciers and ice caps may also cause release, although this release is likely to be very small by comparison. The glaciers and ice caps represent thousands of years of built-up snow and ice, but the portion with contaminants has only recently accumulated (e.g., in the last 40 or 50 years). Nevertheless, there is build-up in freshwater and marine systems, and the bioaccumulation of contaminants in the food chain can affect the safety of country foods (Figure 7.10).

Figure 7.10. Warning sign on the Yukon River advising against eating Lake Trout and Burbot livers from the Yukon River as a result of contaminants in the aquatic system that have accumulated in the food chain. Source: MDA Consulting Ltd.(2003)

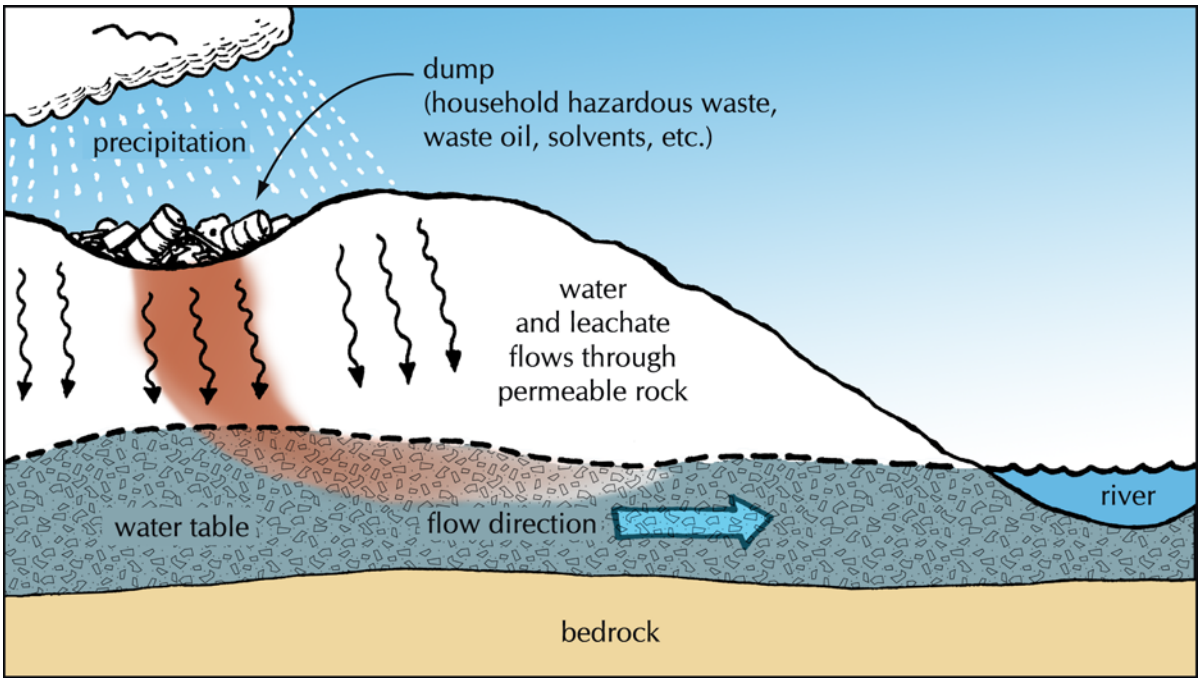


Leachate from Landfills

Leachate from landfills can contaminate groundwater and surface waters (Figure 7.11). This leachate is often highly acidic and often contains high concentrations of metals. It can result in significant changes to the chemistry of the water.

There are a number of things to consider when examining the environmental effects of leachate. It is important to know where to look for information and whom to ask. For instance, is the area of interest a military site, or an industrial site used for mining or exploration? Is there surface storage or a subsurface disposal site? These are important considerations because they can have different effects on the environment. The age of a landfill is also important, as older landfills received materials (e.g., contaminants such as PCBs) that are no longer accepted. As time progresses, however, the biodegradable part of the waste is consumed, resulting in reduced oxygen demand of the leachate. As more of the biological material in the landfill is used up, then the oxygen demand will lessen and the leachate quality should improve.

Figure 7.11. Water and leachate can flow through landfills and permeable rock to the water table.



Old, abandoned or closed landfills are a problem due to past disposal methods and the lack of modern design plans. Many older landfills were convenient cliffs along eroding river sections or depressions such as gravel pits where material was dumped. These are likely the worst places for landfills, as leachate could easily reach the aquatic environment and enter the groundwater as seen in Figure 7.12.

Modern landfills use low permeability soil liners, sorting of material, leachate collection/treatment systems, gas recovery/treatment systems and proper capping with low permeability to minimize infiltration of rainfall and snow melt. The presence of permafrost must also be considered in the design and operation of landfills in northern locations.

Figure 7.12. Photograph of the old Whitehorse dump next to a water body.

Courtesy of: Bob Truelson

Natural Conditions that Affect Northern Water Quality

Some important natural conditions that may affect water quality in the north are described below. Human activities can influence these conditions and indirectly raise or lessen their effects on water quality. For instance, climate change due to human activities can increase the numbers of forest fires in some areas, and shorten the period of ice cover in others. Uranium mining can increase the levels of radioactivity in the environment.

Oxygen Consumption and Production in Rivers and Lakes during Long Periods of Ice Cover

Anoxia

Long periods of ice cover on northern rivers and lakes can result in severe dissolved oxygen (DO) loss. This is a natural phenomenon referred to as anoxia (see also Chapter 1). DO is essential for fish habitat and can have an effect on water chemistry. Misinterpretation of the cause of the anoxia can happen unless this phenomenon is understood. Anoxia can result in temporarily high metal concentrations due to chemical reactions in the water and the sediments. In extreme cases, anoxia can result in fish kills, bad tastes and odours. Systems can be affected by naturally low DO conditions during certain times of the year. It is important to thoroughly understand conditions in river systems in order to avoid concluding that the problem has another cause. Recovery from low DO is rapid with ice break-up.

Biological Productivity

Biological productivity under ice has also been indirectly measured by DO concentrations in both Arctic rivers and lakes. Biological productivity in natural Arctic lakes is controlled by light. The highest productivity usually occurs in the spring, after snowmelt but still under ice cover. It is important to be careful in predicting the response of Arctic lakes to nutrient inputs (i.e., eutrophication) from the release of sewage or from other activities such as aquaculture. The total phosphorus and chlorophyll relationships used for predicting trophic state may not apply in the north. See Chapter 1 for additional information about eutrophication and trophic state.

In some situations, where the lake is more productive because of increased nutrient loads, surface snow may be blown off the ice. This allows algal growth to occur with sun-up and result in algal blooms beginning earlier in the year.

If the algal blooms are large, the ice is still intact, and there is no regeneration of oxygen, low oxygen or anoxic conditions may occur and stay for a long period once the decaying algal bloom begins to consume the oxygen.

If the spring overturn occurs late in the season, it can take some time for oxygen to return to the bottom waters of a lake. It is important to understand the mixing patterns of inflowing waters in a lake to order to find out why oxygen is slow to return. The volume of the anoxic water can vary seasonally and annually depending on conditions. Water circulation in lakes is discussed in Chapter 1.

How to Investigate Anoxia

If anoxia is suspected, you should measure DO, conductivity and temperature at appropriate places over a period. Begin the measurements after ice forms and as soon as it is safe to travel over. The simplest way to get these measurements is to drill a small diameter hole through the ice. Use a continuous reading oxygen probe on a cable to get an oxygen profile for the full depth of the water body. You can also use a multi-metre that will give you readings of DO, conductivity, and temperature all at once.

In non-flowing waters, it is especially important not to disturb the bottom sediments, as this could affect DO and other water quality readings. If possible, use a depth sounder to find out the depth of water in advance of profiling or sampling. Show graduations on the security line for the probe or multi-meter at 0.5 m intervals at a minimum.

Repeat these measurements at least once a month at the same location the whole winter season. Begin to take measurements more often (e.g., weekly) if a downward trend is observed in the DO readings.

Site selection is critical. If known, the deepest point of the lake is the best location. Usually the centre of the lake is best. It may be necessary to sample large lakes and rivers at several locations to determine the scale of the problem (for example, is it local or large-scale).

Continue sampling until DO levels have returned to normal. Once anoxia has been identified, it is a good idea to find out whether the cause is natural or human. If it is natural, little can be done. If the cause is human activity, you can consider ways to correct the problem.

Dissolved Oxygen and Chlorophyll Levels under Ice

Investigations on the Swift River and the Ogilvie River in Yukon from fall 1977 to spring 1978 demonstrated anoxia. This study confirmed severe DO depressions throughout the basins, with lowest levels in late winter. Open water sections of the river did not necessarily bring in more oxygen during winter because these rivers were linked to groundwater inflows that also had low oxygen concentrations.

Studies of DO under ice were conducted on two Yukon rivers - the Takhini, a groundwater dominated system, and the Nordenskiold, a river rich in organics and with many bogs and marshes. DO decreased very rapidly in November and continued to decline in both rivers until February or March. The Nordenskiold had lower levels than the Takhini. Both rivers showed DO recoveries during April under full ice cover. This increase in DO under ice is probably due to the rise in micro-algal and bacterial biomasses that produce oxygen. These organisms respond to the increased light and dissolved organic carbon.

Lakes also show the influence of ice and snow cover on light levels in the water and the resulting DO levels. Snow cover lessens the amount of light that can reach the water much more than either black or white ice. Chlorophyll levels were observed to be higher under ice than average summer chlorophyll in 5 of 10 lakes sampled in one study.

Freeze-out of Dissolved Substances during Ice Formation

Large amounts of dissolved solids can be released into the subsurface waters when large shallow lakes are covered with layers of ice more than a meter thick. This is referred to as cryo-concentration (also see Chapter 1). It occurs because dissolved substances are released from the ice during the freezing process. The water level can be lowered by 25% or more in very shallow lake systems. This cryo-concentration of dissolved substances can result in very high concentrations in winter, if the groundwater inflow contains high levels of dissolved solids.

Cryo-concentration of dissolved salts in northern lakes is mainly an aesthetic concern because the water can have an unpleasant odour or taste. However, under extreme conditions, environmental and human health issues can happen.

Several Arctic lakes on Cornwallis Island near Resolute Bay, Nunavut show reduced volumes and poor water quality due to cryo-concentration. Cryo-concentration has been extensively investigated at Char Lake. Conductivity measurements at the beginning of the ice season were vertically uniform in the lake at 200 µmho/cm^2. During the period of active freezing, there were two areas showing high conductivity readings: immediately below the ice layer and near the bottom (the higher reading). Peak conductivity measurements were 280 µmho/cm^2.

Forest Fires

Wildland fire is a serious and growing hazard over much of northern Canada. It poses a great threat to life and can cause changes to the environment. However, wildland fire is also a natural process. We now understand that controlling these natural fires for many years can cause a larger fire hazard. This is because live and dead vegetation builds up in areas where no fires are allowed to burn. The absence of fire also changes or disrupts the cycle of natural plant succession and wildlife habitat. Management agencies are trying to find ways to reintroduce fire into natural ecosystems through ***prescribed burning.*** However, fire fighting and control are still important.

Prescribed burning - This is a technique used for management of forests, shrublands, and grasslands in which vegetation is burned on purpose to get rid of flammable materials that build up and to encourage specific types of vegetation to grow.

Wildfires can cause problems long after they have been put out. Wildfires on steep slopes can result in land slides and severe erosion because of the loss of vegetation. During an intense wildfire, all vegetation may be destroyed. The organic material in the soil may be burned away, or it may decompose into water-repellent substances that prevent water from seeping into the soil. As a result, even normal rainfall may cause unusual erosion or flooding from a burned area. Heavy rain can cause destructive debris flows and snowmelt can produce excessive erosion. Both debris flows and erosion will cause increases in the turbidity and sediment load of receiving streams. Severe or large slides can cause stream re-alignment, the temporary holding of water in an area or other changes in water movement.

The loss of ground-surface cover in a fire, such as needles from trees, low shrubs and other plants, also affects the water supply. The chemical transformation of burned soils makes watersheds more likely to erode during rainstorms. Such erosion causes increased phosphorus loads in receiving waters, as well as higher levels of manganese and other metals, which were previously bound to sediments and organic matter. Even after two years of natural revegetation, the burned hill slopes can still show major erosion. The transport of sediments can affect water chemistry and can bury sensitive habitats with fresh sediment.

Radioactivity

Exposure to radiation is impossible to avoid. The source may be from naturally occurring radionuclides in air, water or food, from gamma radiation in rocks and soil, or from sources in space. The degree of exposure to natural radioactivity depends largely on the nature of the rocks and soil where you live. The most common elements in the Earth's crust that give off gamma radiation are potassium, uranium and thorium. Radon gas is an abundant source of natural alpha particles from radioactive elements.

The typical annual dose per person from natural sources in Canada is estimated at 2,000 microsieverts per year (µSv/a). Natural background levels of radiation are thought to be only a small factor in cancer rates. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1994) reports that populations living in areas of higher natural radiation exposure have no identifiable increase in deaths from cancer.

Gamma radiation is given off when uranium decays as part of a natural process. The typical level of gamma radiation from sources in the earth is 350 microsieverts per year (µSv/a). The acceptable dose depends on exposure conditions. As a result, allowable gamma exposure levels vary from site to site. The ways to deal with levels that are considered too high also vary.

Exposure to manufactured sources in Canada, excluding medical diagnoses and treatments, averages an additional 620 µSv/a. Current radiation doses from nuclear facilities are 1000 µSv/a for members of the public and 50,000 µSv/a for workers.

The basic principles of radiological protection for non-military uses are followed in most countries. In order to limit the environmental effects of any operations that use radionuclides, most countries carry out:

- a study of radiation sources before licensing
- a study of radiation sources and monitoring during operation
- a study of the effects of different doses after an accident.

Sampling for radionuclides is usually only done by specialists in the measurement and study of low-level radiation.

Climate Change and Northern Waters

The term "climate change" has been used to describe changes in the "average weather" for a region. Today, however, "climate change" is usually used to describe changes in climate caused by human activities: changes that are over and above those from natural causes.

Both scientific and Aboriginal traditional ecological knowledge indicate that weather patterns change from year to year, and that adapting to these changes is a normal part of life. However, the earth's climate has been warmer and more stable for the last 10,000 years. This has allowed humans to prosper. It will be difficult for people to adapt to dramatic changes in climate that occur over a short period of time. These rapid changes will cause problems for northern ecosystems, which are adapted to seasonal patterns of temperature, snow and ice melt, ice formation and precipitation.

Over the past few decades, the Arctic's annual average temperature has increased at nearly twice the rate of the rest of the world. The Arctic Climate Impact Assessment (ACIA 2004) predicts that annual average temperatures in the western Arctic and sub-arctic regions will increase by 3 to 5° C over land and up to 7° C over the oceans during this century. In most places, winter temperatures are increasing faster than summer temperatures. For instance, in Alaska and the western Canadian Arctic, winter temperatures have increased by up to 3-4° C in the past 50 years. Although the Arctic as a whole is warming, there are regional variations. In the eastern Canadian Arctic a cooling trend has started and is expected to continue.

Climate change is causing changes in northern water resources. The Mackenzie River Basin Board reached the following conclusions about climate change in the Mackenzie River basin's aquatic ecosystem:

> Climate change has brought a warming trend and altered precipitation across the basin, affecting river flows, lake levels, habitats, pollutant concentrations, and transportation routes and subsistence lifestyles. All governments should intensify research and cooperation to help us understand and prepare for climate change (MRRB 2003b: 3).

Other impacts of this warming trend on aquatic systems – some of which are already being observed – include: increased thawing of permafrost, melting glaciers, drying of marshes and deltas, less ice formation on lakes and rivers, and warmer lake temperatures.

Earlier spring melting, longer ice-free seasons and changes in the timing and amount of ice jams on rivers in the spring have also been observed. Changes observed and expected for the Arctic coastal zone include changes to sea ice (e.g., thinner and covering less area), shorefast ice, polynyas, and the stability of coastal areas.

How will these and other results of climate change affect northern water quality?
Climate change will have the greatest impact on water quality when it increases the effects that natural conditions and other human activities have on water (see descriptions earlier in this chapter). For instance, increased thawing of permafrost will result in increased erosion and more landslides. This could lead to higher sediment loads in aquatic ecosystems that may cause problems for biota and drinking water. Changes in the timing and extent of major events in the annual water cycle - such as spring melt, runoff, and floods resulting from ice jams - will also affect water quality. These changes could affect the structure of aquatic ecosystems and the way they function, which will in turn influence water quality. In addition, they could increase the flow of sediments, nutrients, and contaminants into the ecosystem, which would affect water quality in various ways.

Climate change poses a large challenge for the north. We know that the global climate is becoming more variable and less predictable, and that shifting weather patterns in many northern regions will result in warmer temperatures and more precipitation. But it is difficult to forecast how much change will occur in specific regions, and what effects these changes will have on those ecosystems, their watersheds, and water quality.

Dealing with climate change in the north will be difficult. The causes of climate change are global, and much of the human activities that create these changes cannot be controlled by northern people or governments. Because people need to adapt to climate change effects at both the regional level (e.g., coastlines) and local level (e.g., communities), adaptation strategies are complicated and will take time to develop.

Glossary

Absorption involves the holding of a substance within the pores of a solid (e.g., a sponge absorbs water).

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 (*Thiobacillis 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.

Active layer - The zone above the permafrost table that experiences seasonal freezing and thawing.

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).

Amphipod - A small crustacean of the order Amphipoda, such as the beach flea, which has a laterally compressed body with no carapace.

Analyte - The substance you are analysing in an experiment. For example, if you are carrying out an experiment to determine the amount of calcium in tap water, calcium is your analyte.

Annual hydrograph – a graph that shows the discharge of the river system over a year.

Anoxia - The condition of being without dissolved oxygen.

Base flow – The continuous low flow in a stream or river. The volume of flow in a stream channel that does not result from surface runoff from precipitation, snowmelt or a spring. Groundwater discharge is the source of base flow in most places.

Base metal - Any alloy or pure metal of relatively low value. The term “base” either refers to the metal as basic or low-value, or to the practice of using a higher value metal, such as gold or silver, to coat or “plate” over a base of the lower value metal. Common base metals include brass, bronze, and copper.

Baseline conditions - The state of water quality (usually defined in chemical and biological terms) before a new activity occurs in the watershed that will affect water quality (e.g., mining).

Basin - Geographic land area draining into a lake or river. Also referred to as a watershed.

Bathymetry - The measurement of the depth of bodies of water.

Bed-load sediments - Sediments found at the bottom of a stream in a streambed.

Benthic invertebrates - Invertebrate animals living in the sediment at the bottom of a body of water.

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.

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

Biogeochemical cycling - The cycling of materials through ecosystems as a result of various biological, chemical and geological processes.

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). *Bioaccumulation* does not always result in biomagnification.

Biomass - The weight of a living organism or assemblage of organisms.

Biota - The animal and plant life of a region or ecosystem.

Brackish water - Brackish water contains more salts than freshwater but less than the open sea. Brackish water environments are fluctuating environments. The salinity varies depending on the tide, the amount of freshwater entering from rivers or as rain, and the rate of evaporation.

Brine - Water saturated with or containing large amounts of a salt, especially sodium chloride.

Carrying capacity - The maximum population of a particular species that a given habitat can support over a given time.

Chain of custody - A system to guarantee the identity and integrity of a specimen (e.g., water sample) from collection through to reporting of the test results.

Constituent – The physical, chemical or biological component of water quality that is of interest in the water sample(s).

Control basin - A water basin that is believed to have the same baseline conditions as the basin under study.

Copepods - Numerous very small marine and freshwater crustaceans of the subclass Copepoda, which have an elongated body and a forked tail.

Cross contamination - The spreading of contaminants such as trace metals, nutrients, germs, bacteria and/or disease by carrying them from one sample to another.

Cryo-concentration - The concentration of substances in a solution as a result of the lowering of temperature.

Cuvette - A small often transparent laboratory tube.

DDT (Dichlorodiphenyltrichloroethane) - A colourless crystalline compound made by the reaction of trichloromethanal with chlorobenzene. The compound is stable, accumulates in the soil, and concentrates in fatty tissue, reaching dangerous levels in carnivores high in the food chain.

Depth-integrated sample - A composite sample made up of water from different depths. It differs from a grab sample which is taken from only one depth. When taking a depth-integrated sample, the bottle should be lowered close to the bottom before it is raised. It should just become completely filled as it reaches the surface.

Discharge - The volume of water that passes a given point in a given period of time. Also referred to as water flow or water quantity. Discharge is usually indicated by the letter "Q" in hydrologic equations and is measured in m^3/sec. A simple hydrologic budget equation is represented as: $Q = P - S - E$, where P = precipitation, S = long-term storage (e.g., glaciers, lakes) and E = evaporation.

Dissolved oxygen - The concentration of free (not chemically combined) molecular oxygen dissolved in water (DO or O_2). Much of the dissolved oxygen in water is provided by photosynthesis.

Ecosystem - A community of interacting organisms together with the chemical and physical factors that make up their environment.

Effluent – Generally refers to wastes, treated or untreated, discharged into surface waters.

Epilimnion - The upper, wind-mixed layer of a thermally stratified lake. This water is turbulently mixed throughout at least some portion of the day and, because of its exposure, can freely exchange dissolved gases (such as O_2 and CO_2) with the atmosphere.

Eutrophic - A very biologically productive water body due to relatively high rates of nutrient input. Conditions can be favourable for high fish production, but oxygen can become depleted if the demand by aquatic organisms becomes too great. There is also a risk of loss of oxygen in deeper water due to oxygen consumption by decaying vegetation.

Event hydrograph – a graph used to describe the way a watercourse responds to either snowmelt or a storm.

Fast-ice - Ice anchored to the sea floor and/or the shore.

Field replicates – Additional samples collected in the same place, at the same time (one after the other), using the same sampling and filtration procedures for each replicate. It does not mean the physical splitting of one sample into separate portions. Field replicates are used to determine how precise the sampling and laboratory analysis is. They also help to figure out contamination or analytical problems. Collecting three or four samples is better than collecting two.

First-order stream - The smallest unbranched tributary in the headwaters of a river system.

Flaw lead - A lead is any fracture or passageway through sea ice. Leads are generally linear in shape. A flaw lead is a lead between the fast ice and the pack ice.

Food web/food chain - Complex network of many interconnected feeding relationships that creates many pathways for the transfer of energy through a biological community.

Frazil ice - Small ice crystals formed in the water column that may adhere to each other to form larger masses.

Freshet - The increased flow of water over a relatively short period of time.

Gossan - The familiar rust-colored stain in rock associated with ARD. At pHs higher than 3.0, ferric iron reacts with oxide (O_2-) hydroxide ions (OH-) to form ferric hydroxide, Fe $(OH)_3$, which precipitates as gossan.

Gross primary productivity - The total rate of photosynthetic production of biomass.

Groundwater - Water that occupies pores and crevices in rock and soil, below the ground surface.

Halocline - The location where there is a marked change in salinity. The halocline sharply separates regions differing in salinity. Similar to a thermocline but a function of salt content as opposed to temperature differences.

HCH (Hexachlorocyclohexane) - This chemical has been produced since the Second World War. It is one of the few organochlorine insecticides used on a large scale. Its compounds vaporize easily and are transported to the Arctic through the air.

Hydrograph - A graph showing river discharge over time. (See also *annual* and *event hydrograph*.)

Hydrologic cycle - The continuous circulation of water from the oceans and land to the atmosphere and back again.

Hydrology - The study of water's properties, distribution and circulation on Earth. The study of moving water found in rivers, open channels and runoff moving across open land surfaces.

Hypolimnion - The lower and most dense layer of a stratified lake. It is typically the coldest layer in the summer and the warmest in the winter. It is isolated from wind mixing and typically too dark for much plant photosynthesis to occur.

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.

Infiltrate - The entry of water into the ground's surface due to the combined influence of gravity and capillary forces.

Intra-permafrost water - Drainage water within aquifers in open, lateral and isolated talik zones within permafrost which is not subject to annual freezing, has relatively constant extent, and is primarily affected by long-term temperature changes.

Laboratory blanks – Deionized and demineralized samples of water submitted to the lab for analysis along with the genuine field samples. The lab does not know which is which. Lab blanks are used as a way to identify errors in the lab's procedures, such as bottle washing and sample handling. If the lab blanks are handled properly, all analytes should be reported as zero or non-detectable.

Lake overturn - The circulation of water throughout the entire water column. Overturn generally occurs both in spring and fall when the temperature in a lake becomes the same at all depths.

Leachate - Material removed from a medium by the action of a percolating liquid. Contaminated water flowing out of a sewage lagoon or other source of pollution to the water.

Macrophytes - Higher aquatic plants, having roots and differentiated tissues.

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.

Meroplankton - Meroplankton are organisms which are part of the plankton for only part of their life cycle, usually an early, larval stage. As adults the meroplankton are benthos (including intertidal organisms) or nekton (mid-water).

Mesotrophic - A state between oligotrophic and eutrophic. Such a lake is moderately productive and considered to be moderately fertile in terms of biomass of algae, plants, and fish.

Metazoans - Multicellular animals which have cells differentiated into tissues and organs and usually a digestive cavity and nervous system. Examples of metazoans include ***tubellarians*** (free-living flatworms), ***crustaceans*** (aquatic animals with an exoskeleton, distinct body segments with a head, thorax and abdomen, segmented appendages and antennae) and ***rotifers*** (very small aquatic multicellular organisms having a ciliated wheel-like organ for feeding and locomotion that form part of the plankton).

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

Natural water quality - The natural state or quality of the water (usually defined in chemical and biological terms) before any changes caused by human activities.

Neap tides - Lower than normal tidal ranges created when the gravitational pulls of the moon and sun are in different directions.

Net primary productivity - Gross primary productivity minus the respiration rate.

Non-point source – A source of pollution that is dispersed and often difficult to identify.

Oligotrophic - Very unproductive water bodies such as lakes low in nutrients and algae. Although generally considered to be young lakes, some oligotrophic lakes will never progress past this stage until environmental conditions allow increased productivity.

One atmosphere - The pressure of the atmosphere at sea level is one atmosphere of pressure or 760 mmHg or 101,325 Pa. The actual atmospheric pressure at a given location varies depending upon altitude and local weather conditions.

Ozone depletion - A decrease in the concentration of ozone (O_3) in the earth's upper atmosphere. Ozone depletion can cause thinning or holes in the ozone layer.

PCBs (Polychlorinated Biphenyls) - A group of toxic chemicals used for a variety of purposes including electrical applications, carbonless copy paper, adhesives, hydraulic fluids, microscope emersion 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*.

Percolate - Movement of water through pores in soil or rocks to groundwater or saturated zone.

Permafrost - A soil or rock layer that has been frozen for at least two years.

pH - The pH indicates the strength of an acid or basic solution.

Photosynthesize - The process by which the energy of sunlight is captured by organisms, especially green plants, and used to manufacture organic tissue by combining the energy with carbon dioxide and water. Photosynthesis is essential in producing a lake's food base, and is an important source of oxygen for many lakes.

Phytoplankton - Microscopic or small floating plants suspended in the water column of aquatic ecosystems, especially lakes.

Plankton - The collection of small or microscopic organisms, including algae and protozoans that float or drift in great numbers in fresh or salt water, especially at or near the surface, and serve as food for fish and other larger organisms.

Plume - A definable area of water that has properties that differ from the surrounding water. Most often, the difference is in the density. As a result, the water in the plume doesn't mix quickly or very much with the surrounding water.

Point source – A single, identifiable source of a pollutant.

Polynyas - Areas of open water surrounded by sea ice that are caused by currents, tidal fluctuations, wind, upwellings, or a combination of these factors.

Precious metal – A metal that is relatively scarce, highly corrosion-resistant, and valuable, including, silver, platinum, and gold.

Prescribed burning - This is a technique used for management of forests, shrublands, and grasslands in which vegetation is burned on purpose to get rid of flammable materials that build up and to encourage specific types of vegetation to grow.

Pressure ridge - A pressure ridge is formed when sea ice is forced against land or another pack of sea ice.

Primary productivity - The rate at which new plant biomass is formed by photosynthesis. (See also *gross primary productivity* and *net primary productivity*.)

Protozoans - Small, one-celled animals including amoebae, ciliates, and flagellants.

Quantifiable - Capable of being quantified or measured.

Reagent - A substance capable of producing a reaction with another, especially when used to detect the presence of other bodies.

Recharge – When low groundwater supplies are filled to previous (higher) levels, they are said to be recharged.

Reconnaissance survey - The initial field inspection or exploration of an area. It is also sometimes called an orientation survey. This survey is conducted to try out and examine various parts of the planned sampling program.

Replicable - Capable of being repeated. If a program is fully replicable, someone else could repeat any aspect of it at another time.

Representative samples – Samples that closely reflect the actual composition or make-up of the body of water being studied.

Residence time - How long the water stays in the lake. Usually, this is calculated as the lake volume in cubic metres divided by the inflow in cubic metres per second. This figure determines the length of time that it theoretically takes for all water to be replaced in the lake. This can range from days to years and is referred to as the theoretical residence time.

Salinity - Salinity is the measure of the quantity of dissolved salts in seawater.

Salinity-stratified - Two or more horizontal layers formed in the water due to differing salt concentrations. Layers that are higher in salt concentration will lie at a lower depth as they have a higher density, which makes them heavier.

Sievert (Sv) - the unit of radiation dose. It replaces the old unit, a “rem”, where 1 rem=0.01 Sv. One milli-Sievert (mSv) = Sv/1000.

Sink - A compartment or place in the environment where something is stored, for all intents and purposes permanently.

Spring tides – Maximum high and low tide levels created when the gravitational pulls of the sun and moon work together because they pull in the same direction.

Stratification -The separation of lake water into distinct horizontal layers.

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.

Sub-permafrost water - Drainage water within aquifers below the permafrost, having temperatures equal to, or higher than, zero degrees Celsius.

Supra-permafrost water - Drainage water within aquifers in the active layer that freezes seasonally.

Talik - The unfrozen area below lakes and large rivers.

Thermal stratification - Layering caused by the effects of temperature differences.

Thermocline - The boundary between warm and cold water in a lake.

Thermodynamic equilibrium - This occurs when the amount of heat leaving a system equals the amount of heat absorbed by the system. As a result, the overall heat remains constant with time.

Thermohaline circulation - Throughout the world the density of seawater is controlled by its temperature (thermo) and its salinity (haline). The difference in water densities resulting from these temperature and salinity variations creates global oceanic circulation patterns. This thermohaline circulation brings warm salty water from tropical and subtropical areas towards the poles where the water cools and sinks to great depths.

Tidal range - The maximum distance between daily high and low tides is called the tidal range.

Total suspended solids - Solids suspended in water that can be removed by filtration.

Toxicological effects - The adverse effects of poisons or toxic substances, which are capable of negatively influencing the health of living organisms, usually by chemical means.

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.

Travel blanks – Deionized samples of water used to identify contamination or errors in sample collection. Travel blanks will show whether samples have been altered by handling or some other process in the field. They are submitted to the lab for analysis along with the genuine field samples. The lab testing the blank does not know what it is.

Travel spiked blanks – Samples submitted to the lab for analysis that contain a known added concentration of the indicator being measured. The added amount should increase the concentration in the samples by a predictable amount. They are used to test the accuracy of the lab's analysis. Spiked blanks are not routinely used in the field, though they are routinely used in the labs.

Trophic state - The total weight of living biological material in a water body at a specific location and time. The degree to which eutrophication has taken place. Most northern lakes are oligotrophic.

Turbulence - The movement of water in an erratic fashion, often in swirling, whirlpool-like eddies. Gases such as oxygen and waters that would not normally mix due to different densities are mixed as a result of turbulence. Turbulence causes milkiness of the water as sediments from the bottom surface of the stream or river are caught up in the flow. This milkiness is measured and called turbidity.

Ultra-oligotrophic - Nutrient levels lower than in oligotrophic lakes. These conditions are not common but do exist in some northern lakes.

Upwelling - Upwelling occurs when the surface waters are displaced and deeper waters move in to take their place. Bottom water that is colder and more nutrient-rich will flow upward to replace surface water pushed away by winds.

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

Water table - The top of the underground zone filled or saturated with water is called the water table. It can be less than half a metre below the ground's surface or it may be hundreds of metres down, and may rise or fall depending on many factors. Heavy rains or melting snow may cause the water table to rise, or an extended period of dry weather may cause the water table to fall.

Way-point - A specific position along a route that is described according to a geographic coordinate system such as latitude and longitude.

Zooplankton - Microscopic animals living unattached in aquatic ecosystems.

References and Recommended Reading

Demayo, A. and Watt, E. 1993. Glossary of water terms: English-French. Canadian Water Resources Association. 49 p.

MDA Consulting Limited. 2003. A manual for designing and implementing water quality investigations in northern Canada – Draft 2003-2. Prepared for Environment Canada, Whitehorse Yukon. March 2003. 202 p.

Chapter 1

Environment Canada. Narrative descriptions of terrestrial ecozones and ecoregions of Canada. www.ec.gc.ca/soer-ree/English/Framework/Nardesc/canada_e.cfm

Gray, D.M. 1970. Handbook on the principles of hydrology. Canadian National Committee for the International Hydrological Decade, National Research Council of Canada, Ottawa, ON. 625 p.

Hardisty, P., Schilder, V., Dabrowski, T., and Wells, J. 1991. Yukon and Northwest Territories ground-water data base. Pages 465-482 IN: Prowse, T.D., and Ommaney, C.S.L. (eds.) Northern Hydrology: Selected Perspectives. NHRI Symposium no. 6, Environment Canada, Saskatoon, SK.

Janus, L. L. and Vollenweider, R.A. 1981. Summary report. The OECD Cooperative Programme on Eutrophication, Canadian Contribution. Scientific Series No. 131. National Water Research Institute, Inland Waters Directorate, Canada Centre for Inland Waters, Burlington, Ontario.

Prowse, T. D. and R. L. Stephenson, 1986. The relationship between winter lake cover, radiation receipts and the oxygen deficit in temperate lakes. Atmosphere-Ocean 24(4): 386-403.

Ryding, S.-O. and Rast, W. (eds.) 1989. The control of eutrophication of lakes and reservoirs. Man and the Biosphere Series no. 1, UNESCO, Paris and Parthenon Publishing, Carnforth. 314 p.

Van Everdingen, R.O. 1990. Ground-water hydrology. Pages 77-101 IN: Prowse, T.D., and Ommaney, C.S.L. (eds.) Northern Hydrology: Canadian Perspectives. NHRI Science Report no. 1. Environment Canada, Saskatoon, SK.

Ward, R., and Robinson, M. 1999. Principles of hydrology (4th edition). McGraw Hill. 365 p.

Chapter 2

Aagaard, K., and Carmack, E.C. 1989. The role of sea ice and other fresh water in the arctic circulation. Journal of Geophysical Research. 94: 14,485-14,498.

Baker, R.F. 1989. An environmental assessment and biological investigation of the Nelson River estuary. Report prepared for Manitoba Hydro by North-South Consultants Inc.179 p.

Carmack, E.C., and Macdonald, R.W. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: A setting for marine life. Arctic 55(1): 29-45.

Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C., and Vincent, M. 2001. (eds.) Marine monitoring handbook. Joint Nature Conservation Committee. 405 p.

DOME Petroleum Ltd., ESSO Resources Canada Ltd., and GULF Canada Resources Inc. 1982. Environmental impact statement for hydrocarbon development in the Beaufort Sea-Mackenzie Delta region. Volume 3A: Beaufort Sea-Delta Setting.

Forrester, W. D. 1983. Canadian tidal manual. Dept. of Fisheries and Oceans, Canadian Hydrographic Service, Ottawa, ON.

Gradinger, R. 2002. National Oceanic and Atmospheric Administration Ocean Explorer:Arctic exploration. http://oceanexplorer.noaa.gov/explorations/02arctic/background/sea_ice/sea_ice.html

Hopky, G.E., Chiperzak, D.B., and Lawrence, M.J. 1988a. Salinity, temperature and density data for the Canadian Beaufort Sea Shelf, March 1987. Canada. Dat. Rep. Fish. Aquatic. Science. No. 685. 162 p.

Horner, R., and Shrader, G.C. 1982. Relative contributions of ice algae, phytoplankton, and benthic micro-algae to primary production in near shore regions of the Beaufort Sea. Arctic 35(4): 485-503.

Ingram, R.G. 1982. Mean and tidal circulation of the East Main River (James Bay). Nature Canada 109:733-743.

Ketchum, B.H. 1983. Estuarine characteristics. Pages 1-14 IN: Ketchum, B.S. (ed.) Estuaries and enclosed seas. Elsevier Scientific Publishing Co. Amsterdam.

Linacre, E., and Geerts, B. 1998. The Arctic: the ocean, sea ice, icebergs, and climate. www-das.uwyo.edu/~geerts/cwx/notes/chap17/arctic.html

McLusky, D. 1981. The estuarine ecosystem. John Wiley and Sons, New York. 143 p.

Murray, J.W. 2001. University of Washington Oceanography 400 - Chemical Oceanography Chapter 3: Properties of water and seawater. www.ocean.washington.edu/courses/oc421/Lecture_Notes/CHPT3.pdf

North-South Consultants Inc. 2001. Overview of the coastal marine ecosystem of the southeastern Beaufort Sea in the vicinity of the Mackenzie River Estuary. A report prepared for the Department of Fisheries and Oceans. 138 p.

North-South Consultants Inc. 1993. Churchill River Estuary biological and oceanographic survey progress report. A report prepared for Manitoba Hydro. 18 p.

NOW (International North Water Polynya Study). 2003. What's a polynya? www.fsg.ulaval.ca/giroq/now/what.htm

Schneider-Vieira, F., Baker, R., and Lawrence, M. 1993. The estuaries of Hudson Bay. A case study of the physical and biological characteristics of selected sites. A report prepared for the Hudson Bay Program by North-South Consultants Inc. 26 p.

Swensen, H. 2003. Why is the Ocean Salty? U.S. Geological Survey Publication. http://publish.uwo.ca/~wrchurch/sea/tidbits.htm

United States Environmental Protection Agency (EPA) 2002. National Estuary Program. Volunteer estuary monitoring: A methods manual. www.epa.gov/owow/estuaries/monitor/

University of Washington Fisheries-Oceanography Library. www.lib.washington.edu/fish/

Chapter 3

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.

CCME. 2003. Summary of existing Canadian Environmental Quality Guidelines. Summary table. December 2003. www.ccme.ca/assets/pdf/e1_062.pdf

CCME. Canadian Environmental Quality Guidelines. www.ccme.ca/publications/ceqg_rcqe.html

Cavanagh, N.S., Nordin, R.N., Swain, L.G., and Pommen, L.W. 1994. Ambient fresh water and effluent sampling manual. British Columbia Ministry of Environment, Lands and Parks.

Demayo, A., and Watt, E. 1993. Glossary of water terms. English – French. Canadian Water Resources Association. 49 p.

Environment Canada. Canadian Environmental Quality Guidelines. www.ec.gc.ca/ceqg-rcqe/English/

Environment Canada. Canadian Water Quality Guidelines.
www.ec.gc.ca/ceqg-rcqe/English/ceqg/water/default.cfm

Gregor, D.J. 1990. Water quality research. Pages 163-186 IN: Prowse, T.D., and Ommaney, C.S.L. (eds.) Northern hydrology: Canadian perspectives. NHRI Science Report no. 1. Environment Canada, Saskatoon, SK.

Health Canada. 1996. Guidelines for Canadian drinking water quality. (6th Ed.) (Information about this publication and how to obtain copies)
www.hc-sc.gc.ca/hecs-sesc/water/dwsixth.htm

Health Canada. 2004. Summary of guidelines for Canadian drinking water quality. Prepared by the Federal-Provincial-Territorial Committee on Drinking Water of the Federal-Provincial-Territorial Committee on Environmental and Occupational Health. April 2004.
www.hc-sc.gc.ca/hecs-sesc/water/pdf/summary.pdf
www.hc-sc.gc.ca/hecs-sesc/water/publications/drinking_water_quality_guidelines/toc.htm

Health Canada. Water quality and health.
www.hc-sc.gc.ca/hecs-sesc/water/index.htm

Health Canada. Water quality and health. Guidelines for Canadian drinking water quality - Supporting documents.
www.hc-sc.gc.ca/hecs-sesc/water/dwgsup.htm

Runnells, D.D., Shepherd, T.A., and Angino, E.E. 1992. Metals in water, determining natural background concentrations in mineralized areas. Environmental Science & Technology 62(12): 2316-2323.

Chapter 4

(See also “Traditional Knowledge Web Sites” below.)

Arctic Borderlands Ecological Knowledge Co-op.
www.taiga.net/coop

Cizek, P., Barnaby, J., Saxena, A., Bentz, J., Brockman, A., Legat, A., and Little, L. 1995. Inventory of existing environmental, Traditional Ecological Knowledge, and socioeconomic information in the West Kitikmeot/Slave Geological Province. Vol. I. Data Overview, Data Gaps, and Directions for Further Research.

Cohen, S.J. 1997. Results and reflections from the Mackenzie Basin Impact Study. Pages 25-42 IN: Mackenzie Basin Impact Study Final Report. Cohen, S. (ed.) Environment Canada, Environmental Adaptation Research Group, Climate and Atmospheric Research Directorate, Atmospheric Environmental Service.

Davidge, D. 2001. A summary or current and historic benthic invertebrate and stream sediment metals data, 1974 to 2000. Environmental Protection Branch, Environment Canada, Whitehorse, Yukon. February 2001.

Environment Canada. 2001. Monitoring water quality: Slave River at Fitzgerald water quality site profile. March 2001. Environment Canada and Alberta Environment. 4 p.

Environment Canada. Benthic Information System for the Yukon.
www.ec.gc.ca/BISY/search_e/home_e.asp

Environment Canada. Canadian Aquatic Biomonitoring Network.
http://cabin.cciw.ca/cabin/asp/english/welcome.asp

Environment Canada. The Green Lane.
www.ec.gc.ca/envhome.html

Environment Canada. Pacific/Yukon Water Quality Monitoring Program. Data online.
www.waterquality.ec.gc.ca/EN/3121/search.htm

Gray, D.M. 1970. Handbook on the principles of hydrology. Canadian National Committee for the International Hydrological Decade, National Research Council of Canada, Ottawa, ON. 625 p.

Mackenzie River Basin Board (MRRB). 2003. Mackenzie River Basin state of the aquatic ecosystem report 2003. 213p.

Sly, P.G., Little, L., Hart, E., and McCullum, J. 1999. State of knowledge report - West Kitikmeot/Slave Study Area. West Kitikmeot/Slave Study Society.

Sly, P.G., Little, L., Freeman, R., and McCullum, J. 2001. Updated state of knowledge report - West Kitikmeot and Slave Study Area. West Kitikmeot/Slave Study Society.

Ward, R., and Robinson, M. 1999. Principles of hydrology (4th edition). McGraw Hill, 365 p.

Chapter 5

Alberta Occupational Health and Safety. 1990. Bulletin OHS-126 Jan 1990.

Canada Labour Code Part II. Parks, water safety and work safety.
http://laws.justice.gc.ca/en/L-2/

Quilty, E.J., and Whitfield, P. H. 2001. Assessing continuous water quality data from Wolf Creek, Yukon Territory. Changing Water Environments: Research and Practice. CWRA May 2001 pg WQ-11-19.

Shugar, G.J., and Ballinger, J.T. 1996. Chemical technicians' ready reference handbook (4th Ed.)

Skoog, D.A., and West, D.M. 1979. Analytical chemistry. (3rd Ed.) Saunders College.

Transport Canada. Office of Boating Safety.
www.tc.gc.ca/BoatingSafety/menu.htm

U.S. Geological Survey. (variously dated) National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations. Book 9, chaps. A1-A9 available online at
http://pubs.water.usgs.gov/twri9A
Chapter A1. Preparation for water sampling.
Chapter A2. Selection of equipment for water sampling.
Chapter A3. Cleaning of equipment for water sampling.
Chapter A4. Collection of water samples.
Chapter A5. Processing of water samples.
Chapter A6. Field measurements.
Chapter A9. Safety in field activities.
See also: http://water.usgs.gov/owq/FieldManual/

Workers Compensation Board, NWT and Nunavut.
www.wcb.nt.ca

Yukon Workers Compensation Health and Safety Board
www.wcb.yk.ca/

Chapter 6

Canadian Council of Ministers of the Environment (CCME). 2001a. Canadian Water Quality Index 1.0 – Technical report. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Canadian Environmental Quality Guidelines. 13 p.

CCME. 2001b. Canadian Water Quality Index 1.0 - User's manual. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Canadian Environmental Quality Guidelines. 5 p.

Cavanagh, N.S., Nordin, R.N., Pommen, L.W., and Swain, L.G. 1998. Guidelines for interpreting water quality data. British Columbia Ministry of Environment, Lands and Parks.

Chapter 7

Arctic Climate Impact Assessment (ACIA). 2004a. Impacts of a warming Arctic: Arctic climate impact assessment. Cambridge University Press. 139 p.
www.acia.uaf.edu

ACIA. 2004b. Impacts of a warming Arctic: Arctic climate impact assessment – Highlights. 20pp. Available at: www.iasc.no

Arctic Monitoring and Assessment Programme (AMAP). 1998. AMAP assessment report. Arctic pollution issues. Oslo, Norway. 859 p.

AMAP. 1998. AMAP Assessment Report: Arctic Pollution Issues. Chapter 8: Radioactivity. Oslo, Norway. pp. 525-620.

Atomic Energy Control Board (AECB) and Canadian Nuclear Services. 1995. Canada: Living with radiation.

Barrie, L., Macdonald, R., Bideleman, T., Diamond, M., Gregor, D., Semkin, R., Strachan, W., Alaee, M., Backus, S., Bewers, M., Gobeil, C., Halsall, C., Hoff , J., Li ,A., Lockhart, L., Mackay, D., Muir, D., Pudykiewicz. J., Reimer, K., Smith, J., Stern, G., Schroeder, W., Wagemann, R., Wania, F., and Yunker , M. 1997. Chapter 2: Sources, occurrence and pathways. Pages 25-182 IN: Jensen, J., Adare, K., and Shearer, R. (eds.) Canadian Arctic contaminants assessment report. Indian and Northern Affairs Canada, Ottawa.

CCME. 2003. Summary of existing Canadian Environmental Quality Guidelines. Summary table. December 2003. http://www.ccme.ca/assets/pdf/e1_062.pdf

Cohen, S.J. 1997. What if and so what - Northwest Canada: Could climate make a difference to the future of the Mackenzie Basin? Arctic 50(4): 293-307.

Government of the Northwest Territories. Public Works and Services. Water and Sanitation. www.pws.gov.nt.ca\waterandsanitation\index.htm

Health Canada. 1989. Guidelines for Canadian Drinking Water Quality: Arsenic. February 1989. ww.hc-sc.gc.ca/hecs-sesc/water/pdf/dwg/arsenic.pdf

Health Canada. 2004. Summary of guidelines for Canadian drinking water quality. April 2004. www.hc-sc.gc.ca/hecs-sesc/water/pdf/summary.pdf

Health Canada. Water Quality and Health. www.hc-sc.gc.ca/hecs-sesc/water/index.htm

Health Canada. It's your health. Arsenic in drinking water. www.hc-sc.gc.ca/english/iyh/environment/arsenic.html

Indian and Northern Affairs Canada, 2003. Canadian Arctic contaminants assessment report II – Sources, occurrence, trends and pathways in the physical environment. Indian and Northern Affairs Canada, Ottawa. 332 p.

Jensen, J., K. Adare and Shearer, R. (eds.), 1997. Canadian Arctic contaminants assessment report. Department of Indian and Northern Affairs, Ottawa, Canada.

Lui, H.F., and Liptak, B.G. 2000. Ground and surface water pollution. Lewis Publishers.

Macdonald, R.W., Barrie, L.A., Bidelman, T.F., Diamond, M.L., Gregor, D.J., Semkin, R.G., Strachan, W.M.,J., Li, Y.F., Wania, F., Alaee, M., Alexeeva, L.B., Backus, S.M., Bailey, R., Bewers, J.M., Goebeil, G., Halsall, C.J., Harner, T., Hoff, J.T., Jantunen, L.M.M., Lockhart, W.L., Mackay, D., Muir, D.C.G., Pudykiewicz, J., Reimer, K.J., Smith, J.N., Stern, G.A., Schroeder, W.H., Wagemann, R., and Yunker, M.B. 2000. Contaminants in the Canadian Arctic: 5 years of progress in understanding sources, occurrence and pathways. Science Total Environment 254: 93-234.

Mackenzie River Basin Board (MRRB). 2003a. Mackenzie River Basin state of the aquatic ecosystem report 2003. 213 p.

MRRB. 2003b. Highlights of the Mackenzie River Basin Board's state of the aquatic ecosystem report 2003. 10pp. Available at: www.mrbb.ca.

Morin, K. A, and Hutt, N. M. 1997. Environmental geochemistry of minesite drainage: Practical theory and case studies. Minesite Drainage Assessment Group (MDAG) Publishing, Surrey, B.C. 333 pp. www.mdag.com/index-mine.html

Northern Climate Exchange. 2003. Weathering change: Newsletter of the Northern Climate Exchange. Summer-fall 2003. 8pp. Available on-line at: http://yukon.taiga.net/knowledge/initiatives/NCE_Newsletter_Summer2003.pdf

Northern Climate Exchange. 2005. Why is climate changing now? From the Northern Climate Exchange (NCE) Knowledge Site on the NCE website: http://yukon.taiga.net/knowledge/resources/why.html

Prowse, T. D. and Stephenson, R. L. 1986. The relationship between winter lake cover, radiation receipts and the oxygen deficit in temperate lakes. Atmosphere-Ocean 24(4): 386-403.

Schreier, H., W. Erlebach and Albright, L.J. 1980. Variations in water quality in two Yukon rivers with emphasis on dissolved oxygen concentration. Water Research 14(9): 1345-1351.

SRK Consulting Engineers & Scientists, 2001. Study of management alternatives – Giant Mine arsenic trioxide dust. Indian Affairs and Northern Development,Yellowknife. 79 p.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1994. Sources and effects of ionizing radiation. Volume I Sources, Volume II Effects. Report E.00IX.4, New York.

Whitfield, P. H. 1983. Evaluation of water quality sampling locations on the Yukon River. Water Resources Bulletin 19(1): 115-121.

Whitfield, P. H. and McNaughton, B. 1986. Dissolved oxygen depressions under ice cover in two Yukon rivers. Water Resources Research 22(12): 1675-1679.

Whitfield, P. H. and Whitley, W. G. 1986. Water quality-discharge relationships in the Yukon River Basin, Canada. Pages 149-156 IN: D. L. Kane (ed.) Proceedings of the symposium: Cold Regions Hydrology, 22-25 July 1986, Fairbanks, Alaska. American Water Resources Association Technical Publication Series No. TPS-86-1, Bethesda, Maryland.

Traditional Knowledge Web Sites

1) Indigenous Knowledge and Development Monitor
www.nuffic.nl/ciran/ikdm/index.html
- for those with an interest in the role of indigenous knowledge (local or traditional knowledge) in participatory approaches to sustainable development; provides an overview of activities in the field of indigenous knowledge and sustainable development.

2) Indigenous knowledge in the Arctic: a review of research and applications - article by Huntington and Ferandez-Gimenez (1999)
www.nuffic.nl/ciran/ikdm/7-3/hunt.html
- the authors first present an overview of how IK (indigenous knowledge) is being approached in the Arctic, and then indicate ways in which such knowledge might be used in the future, not only for research purposes, but also within the community.

3) Beluga Whale Traditional Ecological Knowledge (TEK) – Smithsonian National Museum of Natural History, Arctic Studies Center
www.mnh.si.edu/arctic/html/tek.html
- an indigenous knowledge pilot project in the Chukchi and Northern Bering Seas

4) Traditional Knowledge Online
www.traditionalknowledge.info/about.php
- allows you to search for TK related web sites; brings together information available on the web to help better understanding and study of traditional knowledge.

5) TEK Prior Art Database
http://ip.aaas.org/tekindex.nsf
- a searchable archive of traditional knowledge documentation.

6) Ecology and Society: Traditional Knowledge in Social-Ecological Systems
www.ecologyandsociety.org/viewissue.php?id=45
- an electronic, peer-reviewed, multi-disciplinary journal devoted to making information about current research widely and quickly available.

7) Gwich'in Social and Cultural Institute
www.gwichin.ca/Research/research.html
- describes the research carried out since 1993 on the people of the Gwich'in nation and their traditions and uses of the land.

8) Alaska Traditional Knowledge and Native Foods Database
www.nativeknowledge.org/login.asp
- the goal of the project is to build capacity among Alaska Tribes to take effective action to clearly identify and address their concerns about radio nuclides, other types of contamination, and adverse changes in the environment.

9) Parks Canada on Traditional Knowledge
www.pc.gc.ca/docs/r/pca-acl/sec1/sec1b_e.asp
- An Approach to Aboriginal Cultural Landscapes – Aboriginal World Views

10) Canadian Federal Government – Aboriginal Canada Portal
www.aboriginalcanada.gc.ca/acp/site.nsf/en/ao27021.html
- a site where people may locate, discuss and share information, views, services, successes and to act as a central gateway to increase the awareness of Aboriginal Peoples history, heritage, traditions and Aboriginal community successes among Aboriginal Peoples and non-Aboriginal Canadians.

11) University of Guelph Traditional Knowledge site
www.polarlife.ca/Traditional/traditional_frame.htm
- information about Inuit Traditional Knowledge

APPENDICES

Appendix A. Hydrometric and water quality stations operated in northern Canada in 2002/03. (Source: MDA Consulting Ltd. 2003)

Table A-1. Hydrometric and water quality stations operated in the Yukon in 2002/03 (N=49). Highlighted stations (N=4) operated as water quality stations during 2002/03.

Table A-2. Hydrometric and water quality stations operated in the Northwest Territories in 2002/03 (N=73). Highlighted stations (N=18) operated as water quality stations during 2002/03.

Table A-3. Hydrometric stations operated in Nunavut in 2002/03 (N=21).

Appendix B. Water quality values for selected northern rivers.

Appendix A. Hydrometric and water quality stations operated in northern Canada in 2002/03. (Source: MDA Consulting Ltd. 2003)

Table A-1. Hydrometric and water quality stations operated in the Yukon Territories in 2002/03 (N=49). Highlighted stations (N=4) operated as water quality stations during 2002/03.

Station No.	Station Name	Location (Latitude_ Longitude)
08AA003	Dezadeash River at Haines Junction	60.74833 -137.5053
08AA005	Aishihik Lake near Whitehorse	61.19806 -136.9981
08AA007	Sekulmun Lake near Whitehorse	61.53611 -137.5903
08AA008	Sekulmun River at outlet of Sekulmun Lake	61.56389 -137.5325
08AA009	Giltana Creek near the mouth	61.19667 -136.9872
08AA010	Aishihik River below Aishihik Lake	61.18444 -136.99
08AA012	Aishihik Lake near Aishihik	61.59028 -137.4111
08AB001	Alsek River above Bates River	60.11917 -137.9742
08AC001	Takhanne River at Km 167 Haines Highway	60.09722 -136.9167
08AC002	Tatshenshini River near Dalton Post	60.11833 -137.0875
09AA004	Bennett Lake at Carcross	60.16389 -134.7075
09AA012	Wheaton River near Carcross	60.13472 -134.8958
09AA017	Tagish Lake at 10 Mile Road	60.15944 -134.3755
09AB001	Yukon River at Whitehorse	60.71389 -135.0431
09AB004	Marsh Lake near Whitehorse	60.53056 -134.3653
09AB010	Lake Laberge near Whitehorse	61.09028 -135.1992
09AC001	Takhini River near Whitehorse	60.85222 -135.7392
09AC007	Ibex River near Whitehorse	60.72667 -135.485
09AE002	Teslin Lake at Teslin	60.15833 -132.7075
09AE006	Morely River at Km 1251 Alaska Highway	60.00694 -132.1444
09AH003	Big Creek near the mouth	62.56861 -137.0161
09AH004	Nordenskiold River below Rowlinson Creek	62.05 -136.2792
09AH005	Drury Creek at Km 469 Robert Campbell Highway	62.20833 -134.3861

Station No.	Station Name	Location
09BA001	Ross River at Ross River	61.99445 -132.3778
09BC001	Pelly River at Pelly Crossing	62.82972 -136.5806
09BC004	Pelly River below Vangorda Creek	62.22222 -133.3778
09CA001	Kluane Lake near Burwash Landing	61.055 -138.5033
09CA004	Duke River near the mouth	61.36028 -139.1564
09CA006	Nisling River below Onion Creek	62.20806 -139.0486
09CB001	White River at Kilometre 1881.6 Alaska Highway	61.98667 -140.5531
09CD001	Yukon River above White River	63.08389 -139.4944
09DB001	Beaver River below Matson Creek	64.015 -134.1392
09DC004	Wareham Lake at Headgate	63.65667 -135.9172
09DC005	Mayo Lake near the outlet	63.77333 -135.3881
09DC006	Stewart River near Mayo	63.59056 -135.8967
09DD003	Stewart River at the mouth	63.28194 -139.2489
09DD004	McQuesten River near the mouth	63.61111 -137.2694
09EA003	Klondike River above Bonanza Creek	64.04278 -139.4078
09EA004	North Klondike River near the mouth	64.02111 -138.5828
09EB003	Indian River above the mouth	63.77111 -139.6292
09EB004	Sixty Mile River near the mouth	63.69028 -140.1633
09FC001	Old Crow River near the mouth	67.63445 -139.6964
09FD002	Porcupine River Near International Boundary	67.42416 -140.8911
10AA001	Liard River at Upper Crossing	60.05 -128.9
10AA004	Rancheria River near the mouth	60.20972 -129.55
10AA005	Big Creek at Km 1084.8 Alaska Highway	60.15833 -129.7028
10AB001	Frances River near Watson Lake	60.47389 -129.1189
YT10MB006	Bonnet Plume R. above mouth (water quality only)	65.425 -134.83056
YT09FB0003	Porcupine R. above Old Crow (water quality only)	67.57972 -13978194

Table A-2. Hydrometric and water quality stations operated in the Northwest Territories in 2002/03 (N=73). Highlighted stations (N=18) operated as water quality stations during 2002/03.

Station No.	Station Name	Location (Latitude_ Longitude)
10NC001	Anderson River below Carnwath River	68.643889 -128.425
10LA002	Arctic Red River near the mouth	66.788333 -133.07944
07SB013	Baker Creek at outlet of Lower Martin Lake	62.512778 -114.40333
10ED003	Birch River at Highway No. 7	61.336667 -122.08667
10ED007	Blackstone River at Highway No. 7	61.060833 -122.89444
07SB015	Bluefish Lake near Yellowknife	62.679167 -114.26444
07SB010	Cameron River below Reid Lake	62.994444 -113.28472
10JA002	Camsell River at outlet of Clut Lake	65.606667 -117.76528
10KB001	Carcajou River below Imperial River	65.297778 -127.68444
10LC007	Caribou Creek above Highway No. 8 (Dempster Highway)	68.089444 -133.49
10PB001	Coppermine River at outlet of Point Lake	65.413056 -114.00389
10PA001	Coppermine River below Desteffany Lake	64.615556 -111.95444
07SB012	Duncan Lake near Yellowknife	62.85 -113.96667
10MD001	Firth River near the mouth	69.313611 -139.56694
10EA003	Flat River at the mouth	61.530833 -125.40694
10JE002	Great Bear Lake at Hornby Bay	66.599722 -117.61917
10JC003	Great Bear River at outlet of Great Bear Lake	65.134722 -123.51806
07OB002	Great Slave Lake at Hay River	60.85 -115.79972
07SB001	Great Slave Lake at Yellowknife Bay	62.441667 -114.34972
06JB001	Hanbury River above Hoare Lake	63.601667 -105.13083
10ND004	Hans Creek above Eskimo Lakes	68.870556 -133.57833
10LC017	Havikpak Creek near Inuvik	68.314444 -133.52083
07OB008	Hay River near Alberta/NWT Boundary	60.004444 -116.96889
07OB001	Hay River near Hay River	60.744722 -115.85972
10OB001	Hornaday River near the Park Boundary	69.175833 -123.25139

Station No.	Station Name	Location
07SA004	Indin River above Chalco Lake	64.388611 -115.02083
10FB005	Jean-Marie River at Highway No. 1	61.445556 -121.24083
10HA004	Keele River above Twitya River	64.099722 -128.15
07TA001	La Martre River below outlet of Lac La Martre	63.109722 -116.97194
10ED001	Liard River at Fort Liard	60.243056 -123.47917
10ED002	Liard River near the mouth	61.746944 -121.22361
07RD001	Lockhart River at Outlet of Artillery Lake	62.896667 -108.47139
10LC013	Mackenzie River (East Channel) above Kittigazuit Bay	69.305556 -133.89278
10LC002	Mackenzie River (East Channel) at Inuvik	68.375556 -133.76278
10LC016	Mackenzie River (East Channel) at Tununuk Point	69.166667 -134.63333
10LC019	Mackenzie River (Kumak Channel) below Middle Channel	68.316389 -135.23222
10LC012	Mackenzie River (Middle Channel) at Tununuk Point	69.015556 -134.69222
10MC008	Mackenzie River (Middle Channel) below Raymond Channel	68.293056 -134.42222
10MC023	Mackenzie River (Napoiak Channel) above Shallow Bay	68.638056 -134.97917
10MC003	Mackenzie River (Peel Channel) above Aklavik	68.213889 -135.11389
10MC011	Mackenzie River (Reindeer Channel) at Ellice Island	69.020556 -135.55417
10MC015	Mackenzie River (Reindeer Channel) below Louis Channel	68.883333 -135.01667
10LC014	Mackenzie River at Arctic Red River	67.458056 -133.74444
10LD001	Mackenzie River at Fort Good Hope	66.253889 -128.63306
10GC001	Mackenzie River at Fort Simpson	61.868611 -121.35694
10KA001	Mackenzie River at Norman Wells	65.272222 -126.88333
10KD001	Mackenzie River at Sans Sault Rapids	65.765 -128.75056
10FB006	Mackenzie River at Strong Point	61.817778 -120.79
10LC015	Mackenzie River below Confluence East Channel	67.794444 -134.12972
10MC010	Mackenzie River Outflow Middle Channel below Langley Island	69.077778 -135.12528
10GC003	Martin River at Highway No. 1	61.897222 -121.6075
07QD002	Nonacho Lake near Lutselk'e (Snowdrift)	61.730278 -109.67083
07KC001	Peace River at Peace Point (Alberta)	59.113889 -112.42639

Station No.	Station Name	Location
10MC002	Peel River above Fort McPherson	67.236111 -134.9075
10MC022	Peel River at Frog Creek	67.614444 -134.67306
07SB017	Prelude Lake near Yellowknife	62.583639 -113.9735
07SB014	Prosperous Lake near McMeekan Bay	62.5225 -114.15889
10HB005	Redstone River 63 km above the mouth	63.925278 -125.30056
10LC003	Rengleng River below Highway No. 8 (Dempster Highway)	67.755833 -133.84417
10GA001	Root River near the mouth	62.475833 -123.43
10ED009	Scotty Creek at Highway No. 7	61.413889 -121.45556
07NB001	Slave River at Fitzgerald (Alberta)	59.872222 -111.58333
07SA002	Snare River below Ghost River	63.975 -115.43361
07SA008	Snare River near inlet to Indin Lake	64.200278 -114.96694
10EB001	South Nahanni River above Virginia Falls	61.642222 -125.80333
07QD007	Taltson River below Hydro Dam	60.5 -111.5
10ND002	Trail Valley Creek near Inuvik	68.738056 -133.44056
10FA002	Trout River at Highway No. 1	61.139722 -119.83556
10GB006	Willowlake River above Metahdali Creek	62.650278 -122.89722
10PA002	Yamba River at outlet of Daring Lake	64.806667 -111.67806
07SB003	Yellowknife River at inlet to Prosperous Lake	62.669167 -114.2625
07SB019	Yellowknife River at outlet of Lower Carp Lake	63.555833 -113.98
07SB002	Yellowknife River at outlet of Prosperous Lake	62.491389 -113.52472

Table A-3. Hydrometric stations operated in Nunavut in 2002/03 (N=21).

Station No.	Station Name	Location (Latitude_ Longitude)
10RC001	Back River above Hermann River	66.08583333 -96.50388889
10RA001	Back River below Beechy Lake	65.1925 -106.0769444
10RA002	Baillie River near the mouth	65.04416667 -104.5125
10QC004	Burnside River at outlet of Contwoyto Lake	66.07222222 -111.2169444
10QC001	Burnside River near the mouth	66.73611111 -108.8188889
10QC003	Contwoyto Lake at Lupin Mine	65.76638889 -111.2291667
10PC004	Coppermine River above Copper Creek	67.22805556 -115.8877778
06KC003	Dubawnt River at outlet of Marjorie Lake	64.23083333 -99.47666667
10QD001	Ellice River near the mouth	67.71166667 -108.1405556
06LA003	Ennadai Lake near Ennadai, Site No. 2	61.13305556 -100.9
10PC005	Fairy Lake River near outlet of Napaktulik Lake	66.25194444 -113.9852778
10TF001	Freshwater Creek near Cambridge Bay	69.13083333 -104.9905556
10QB001	Hood River near the mouth	67.34166667 -108.9269444
06LC001	Kazan River above Kazan Falls	63.65277778 -95.855
06LA001	Kazan River at outlet of Ennadai Lake	61.25361111 -100.9738889
10PC001	Kendall River near Dismal Lakes	67.20861111 -116.5722222
10VK001	Ruggles River at outlet of Lake Hazen	81.79416667 -70.44027778
06JC002	Thelon River above Beverly Lake	64.53111111 -101.3647222
06MA006	Thelon River below Outlet of Schultz Lake	64.77305556 -97.0675
06HB002	Thlewiaza River above Outlet Sealhole Lake	60.78361111 -98.7775
10QA001	Tree River near the mouth	67.63416667 -111.9088889

Appendix B. Water quality values for selected northern rivers[1].

Variable (units)	Statistic	Sampling Sites[2]						
		Northwest Territories Sites					Nunavut Sites	
		Flat River near the mouth	Great Bear River at outlet of Great Bear Lake	Liard River near the mouth	Mackenzie River above Arctic Red River	Yellowknife River upstream of Yellowknife Bay	Coppermine River at outlet of Point Lake	Thelon River at outlet of Schultz Lake
pH (pH units)	Mean	8.1	7.6	8.0	7.8	7.2	7.0	6.8
	Minimum	6.9	6.2	7.0	6.5	6.0	5.8	5.2
	Maximum	8.9	8.7	9.3	9.0	8.4	8.6	7.9
	No. Samples	152	112	186	205	140	51	29
	Sampling period	1973-2003	1971-2003	1972-2003	1972-2003	1972-2001	1973-2000	1978-2001
Field Conductivity (µsie /cm)	Mean	268.6	151.7	286.5	253.2	41.7	12.7	35.0
	Minimum	80.0	70.0	130.0	59.6	10.0	4.6	10.0
	Maximum	496.0	380.0	704.5	423.0	90.0	23.0	90.0
	No. Samples	166	117	187	198	120	60	31
	Sampling period	1972-2003	1971-2003	1972-2003	1972-2003	1987-2001	1973-2000	1979-2001
Total Suspended Solids (mg/L)	Mean	85.2	6.4	210.8	120.1	17.2	2.4	2.6
	Minimum	L1.0	0.5	L1.0	L1.0	L1.0	L1.0	1.0
	Maximum	1,624.0	183.0	3,627.0	1,385.0	308.0	12.0	9.0
	No. Samples	153	146	210	236	143	91	34
	Sampling period	1972-2003	1969-2002	1962-2002	1966-2002	1973-1999	1979-1998	1979-1998
Total Dissolved Solids (mg/L)	Mean	174.8	85.7	190.7	184.9	23.2	7.1	120.7
	Minimum	85.0	5.0	5.0	113.0	1.0	4.0	12.0
	Maximum	256.0	150.0	400.0	264.0	42.0	12.0	1,040.1
	No. Samples	60	58	86	83	100	62	20
	Sampling period	1980-1994	1969-2002	1993-2002	1993-2002	1987-1996	1980-1996	1980-1988

[1] Adapted from MDA Consulting Ltd. (2003); based on data available to March 2003.
[2] Locations of stations are provided in Appendix A.

Variable (units)	Statistic	Sampling Sites[2]						
		Northwest Territories Sites					Nunavut Sites	
		Flat River near the mouth	Great Bear River at outlet of Great Bear Lake	Liard River near the mouth	Mackenzie River above Arctic Red River	Yellowknife River upstream of Yellowknife Bay	Coppermine River at outlet of Point Lake	Thelon River at outlet of Schultz Lake
Total Phosphorus (mg/L)	Mean	0.1209	0.0117	0.2200	0.1314	0.0127	0.0099	0.021
	Minimum	0.0020	L0.0010	L0.0020	0.0025	L0.0020	L0.0020	0.003
	Maximum	4.1000	0.3630	10.6000	1.5380	0.2000	0.1000	0.16
	No. Samples	57	119	231	206	86	85	28
	Sampling period	1973-1995	1969-2002	1960-2002	1960-2002	1991-1999	1973-1998	1975-1998
Total Hardness (mg/L)	Mean	159.9	70.1	156.8	125.7	18.2	4.6	29.8
	Minimum	73.8	30.4	71.6	60.1	0.7	0.7	8.9
	Maximum	225.5	89.3	248.6	205.0	42.9	8.0	193.5
	No. Samples	59	114	168	195	100	63	21
	Sampling period	1980-1994	1969-1996	1969-1996	1967-1996	1987-1996	1980-1996	1980-1988
Total Zinc (mg/L)	Mean	0.0328	0.0014	0.0225	0.0140	0.0027	0.0024	0.0103
	Minimum	0.0008	L0.0005	L0.0001	L0.0005	L0.0002	L0.0002	L0.0002
	Maximum	0.4268	0.0176	0.3830	0.1850	0.0284	0.0197	0.0620
	No. Samples	146	110	171	185	113	67	21
	Sampling period	1984-2002	1983-1998	1983-2002	1980-2003	1987-1998	1984-1998	1984-1998