LAKEKEEPERS MANUAL

A GUIDE TO LAKE STEWARDSHIP AND ECOLOGY IN BRITISH COLUMBIA

THE BC LAKE STEWARDSHIP SOCIETY

Published July 2022, Vancouver, British Columbia, Canada.

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Cover photo: Green Lake, Whistler. Source: Marie McCallum.

WELCOME TO LAKEKEEPERS!

The 2022 edition of the LakeKeepers manual was produced by the Board of Directors and staff of the BC Lake Stewardship Society (BCLSS) for individuals and groups interested in protecting and preserving lake habitats in British Columbia.

The LakeKeepers manual is a comprehensive document that is equally an educational resource, lake monitoring training guide, and toolkit for developing successful community lake stewardship initiatives. LakeKeepers strives to outline basic concepts of lake structures and functions and presents detailed modules for effective lake monitoring.

Limnology, the study of freshwater systems, is a fascinating and diverse discipline. Lakes are complex freshwater systems and key components of the natural environment. They rise, fall, freeze, and thaw with the seasons. They receive, store, and discharge water, sediments, and contaminants. Lakes vary greatly in quality and appearance. They can range in colour & odour and may support a wide range of aquatic species or be largely inhospitable.

Most British Columbians expect lakes to provide scenic beauty, habitat for wildlife, drinking water, energy, and recreational opportunities. Lakes also have important cultural, heritage, and ceremonial values for Indigenous Peoples. When lake conditions change, or unusual lake characteristics are observed, concern may develop and lead to questions: *Why is the lake water cloudy? Is the lake experiencing increased algae blooms? Are there changes in the aquatic plants in the lake?* The LakeKeepers manual seeks to play a part in analyzing and addressing these sorts of questions.

While LakeKeepers focuses on water quality, the management of nearshore and riparian environments is also of critical importance. Shoreline stewardship is thus a key component of any lake management strategy. The watershed of a lake and the activities within the watershed determine in large part what the lake characteristics are.

The BCLSS invites all groups and individuals in British Columbia with an interest in lake conservation to become a member of our society. Let's work together towards improved lake health and protect lake environments in the province.

BCLSS

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ACKNOWLEDGMENTS

Producing the LakeKeepers manual is the result of hundreds of volunteer hours. The 2004 version of LakeKeepers was composed by, Bruce Carmichael (Senior Author and Primary Editor), Bonnie Winter, Brian Nickurak, Bob Grace, Todd French, Irene Calbick, Eric Bonham, Dawn Roumieu, Heidi Hicks, Angie Cleveland, Norm Zirnhelt, Rick Nordin, and Keith Carlson. This updated version of LakeKeepers was completed by Norm Zirnhelt, Dawn Roumieu, Marie McCallum, Emily Gutenberg, Rick Nordin, and Chris Swan.

Producing this 2022 edition of the LakeKeepers manual would not have been possible without the generous support of the BC Ministry of Municipal Affairs. Thank you for your contribution to lake education and conservation in British Columbia!

Special thanks go out to all BCLSS lake groups, environmental stewardship organizations, and individual volunteers who have contributed their time and efforts to conserving, protecting, and enhancing lake habitats in BC.

The BCLSS recognizes that our lake stewardship activities take place on the traditional territories of Indigenous peoples, who have stewarded the water since time immemorial.

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Gavin Lake. Source: Marie McCallum.

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"There is power in local ownership of problems and solutions, and strength in a sense of responsibility derived from identification with a place."
-Yaffe

Okanagan Lake. Source: Emily Gutenberg.

Chapter Contents

1.1 THE VALUE OF STEWARDSHIP

A **steward** is a person entrusted with the care of something that requires support and attention in order to thrive, such as a living thing, natural resource, or shared community experience. **Stewardship** is the translating of this care into action through careful planning and responsible management. **Environmental stewardship** is stewardship that is concerned with the **biotic** (living) and **abiotic** (non-living) components of our natural environment. Environmental stewardship includes a wide range of actions such as education, public engagement, political advocacy, habitat remediation, land management, and environmental monitoring, all in pursuit of enhancing, restoring, and conserving natural resources, ecosystems, and the species associated with them. Environmental stewardship is important because it inherently recognizes the many values of nature, including:

- Cultural value (traditional or spiritual relationships between people and the land)
- Recreational value (the use of natural landscape features for hiking, swimming, exploring)
- Medicinal value (traditional Indigenous or Western uses of natural items for health and wellness)
- Educational value (opportunities for others to learn about the world from nature)
- Economic value (businesses using natural resources to create in-demand items or services)
- Intrinsic value (the unique worth of species that originates within itself)

Stewardship provides the link between community members and the areas of a watershed that need attention and support. Without stewardship, the local environment may become degraded, the health of fish, wildlife, and humans may be impacted, cultural practices may be lost, and economic welfare may be compromised, and even a direct impact to personal health. This is why stewardship and volunteer monitoring are essential. Taking responsibility on a personal level and connecting with other concerned community members are important steps of effective stewardship.

Indigenous knowledge and culture are critical components of effective environmental stewardship. Michele Sam (2018) of the Ktunaxa First Nation has provided this perspective on stewardship as part of An Integrated Lake Monitoring Framework for British Columbia (2018):

"Our relationship with our lands, territories and water is the fundamental physical cultural and spiritual basis for our existence. This relationship to our Mother Earth requires us to conserve our freshwaters and oceans for the survival of present and future generations. We assert our role as caretakers with rights and responsibilities to defend and ensure the protection, availability, and purity of water. We stand united to follow and implement our knowledge and traditional laws and exercise our right of self-determination to preserve water, and to preserve life."

KEY TERMS

Steward: A person entrusted with the care of something that requires support and attention in order to thrive.

Stewardship: The act of caring for something through dutiful planning and conscientious management.

Environmental Stewardship: Stewardship concerned with the biotic and abiotic components of our natural environment in pursuit of enhancing, restoring, and conserving natural resources, ecosystems, and the species associated with them.

Biotic Components: Living components of our natural environment, such as people, plants, animals, fungi, and microorganisms.

Abiotic Components: Non-living components of our natural environment, such as sunlight, water, oxygen, minerals, and temperature.

Comox Lake. Source: Marge Sidney.

1.2 GETTING INVOLVED

Environmental stewardship can be a source of empowerment for individuals concerned with environmental issues. There are many ways that humans impact lakes. These include improper land development and dock construction, inadequate maintenance of septic systems, and poor boating practices. Altering the waterfront with lawns, docks, and/or retaining walls can increase erosion to the shoreline, reducing habitat and increasing sediment deposition into the lake (Federation of Ontario Cottagers' Associations, n.d.). Excessive nutrients, namely phosphorus, can be transported into water due to runoff from several sources including fertilized lawns and septic systems that are not maintained properly. This may result in algal blooms, excessive growth of aquatic plants, decrease in water clarity, lower levels of dissolved oxygen, and increased levels of coliform and *E. coli* bacteria (Federation of Ontario Cottagers' Associations, n.d.). Building a dock can impact shoreline habitat, cause erosion, remove vegetation, and even introduce unwanted substances to a lake if improper building materials are used. Poor boating practices can result in damaging wake effects, disturbance to wildlife, excessive noise, and pollution.

Taking action is important if issues are observed at local lakes. It only takes one individual to establish a call to action that will draw others to community stewardship. If an individual is concerned about the state of their local lake, stream, park, or forest, it is likely that others in the area are too.

1.3.1 STEWARDSHIP IN THE COMMUNITY

Stewards can take on many roles. These include:

- Being the voice for their favourite lake(s)
- Developing a communications network for sharing lake news
- Raising awareness of lake issues in the community
- Raising funds
- Acting as a support group for members
- Gaining strength in numbers
- Gathering information and educational materials
- Conducting data collection on a broad range of lake concerns (water quality, development, lake use conflicts)
- Gaining a historical perspective from long-time residents
- Networking with other lake organizations
- Learning from Indigenous knowledge keepers

(Adapted from Greater Sudbury, 2022)

Citizen monitoring

Due to a lack of resources, government agencies are unable to routinely sample or monitor every lake. Volunteer groups can play an important role in protecting and managing lakes by taking on a citizen science role and monitoring them. By collecting essential data, observing trends, and reporting findings, stewardship groups can provide vital information to the government and the community. Stewards can make a positive and effective contribution to managing the lake or lakes they are passionate about.


Source: BCLSS Files.

The BCLSS and the BC Ministry of Environment can assist with developing a detailed plan based on monitoring objectives to ensure that high quality, reliable results are being collected. As indicated by Fisher (2017), sampling should always be completed following provincial protocols so that the data can be used by government agencies when making decisions about activities in watersheds. Standard methods also allow data to be compared across watersheds.

Advocacy

Advocacy is a key community service provided by stewardship groups. Stewardship group members can campaign for their group's ideas, mandate, and ongoing initiatives. Advocacy can take shape through speaking with neighbours to gauge local concerns, by attending local government meetings to stay current with local policies, urban plans, and upcoming bylaw changes, by hosting events to inform and educate the community of your group's cause, or by writing letters to political representatives to generate change. Elected officials may realize the potential of volunteers to make a positive and effective contribution to the community if approached by a well-organized community group.

Shoreline Stewardship

Shorelines are unique, ecologically significant, sensitive environments. Along with the riparian area, they are essential for soil stabilization, erosion reduction, filtering surface runoff, and maintaining or improving water quality. Lakeshore property owners often wish to make changes to these sensitive foreshore areas of their properties (Habitat Conservation Fund, n.d.). Common changes such as clearing land, adding fill, and putting up retaining walls may negatively affect the lake and its inhabitants. In addition, there is a cumulative effect of all the changes along a lakeshore and within the watershed.

Williams Lake. Source: Chris Swan.

Lake stewards with shoreline property can plan development to conserve natural vegetation and, where necessary, consider taking on restoration projects to replace lost habitat. Stewards can also notify local government if you observe others making changes to their property that may be harmful to the lake and surrounding area.

Resources to help understand and evaluate your shoreline include:
How Healthy is My Shoreline?, **Waterfront Living**, **Lake Protection Workbook**, and **A Shoreline Owner's Guide to Healthy Waterfronts**

Education

Stewardship groups can also provide education and cooperate with the local community to promote a shared responsibility for the lake (Habitat Conservation Fund, n.d.). There is a variety of lake stewardship resources available, many of which can be found in the *Resources* list at the end of this document and on the **BCLSS website**.

The following educational information on how to keep your lake healthy can be shared with waterfront communities.

Tips for Keeping Your Lake Healthy

The following tips are adapted from the fact sheet *Some Guiding Principles to Lakeshore Living in Relation to Water Quality* (Ministry of Water, Land, and Air Protection Cariboo Region, n.d.) and BCLSS lake reports which can be found in the library at **www.bclss.org**.

Landscaping and Gardening

- Using native plant species means minimal maintenance, including less watering, fertilizing, and pesticides. Fertilizers can be carried by runoff to nearby waterbodies, causing an increase in nutrients and possible decline in water quality.
- Keep existing trees and shrubs where possible and plant trees and shrubs in open areas to help prevent erosion and lessen runoff.
- Mulch grass trimmings to promote recycling of nutrients and moisture back into the existing lawn. This also reduces the need for watering and fertilizer application.
- Check the weather to avoid over-watering your lawn or garden as this can increase movement of phosphorus in the soil towards nearby waterbodies.
- Clean up after pets and domestic animals. Waste can be transported by runoff causing fecal contamination and phosphorus input to nearby water.

Source: Pixabay.

- Dispose of yard debris, or compost it, away from lakes or streams while avoiding natural runoff channels. This will prevent the compost from contributing phosphorus to the lake.
- Maintain vegetation near the shoreline to filter and absorb runoff, to provide shoreline stabilization, and to discourage waterfowl from frequenting. Waterfowl can contribute considerable levels of fecal coliforms and phosphorus.
- Use wood, bricks, interlocking stones, or gravel for pathways and driveways instead of cement or tarmac, which prevents water from filtering into the ground. Impermeable surfaces create surface runoff, which can initiate erosion and nutrient transport.
- Create small gravel receptacles or trenches where water collects to allow for filtering into the ground and to prevent soil erosion. Movement of sediment to water bodies can increase turbidity and nutrients, which decreases water quality.

- Many lakeshore erosion protection options are available, including planting of native trees and shrubs, planting of native trees and shrubs through a biodegradable erosion control blanket, planting of native trees and shrubs within the joints of a rock matrix and hard armoring techniques. Additional information is provided in the BC Ministry of Environment and Climate Change Strategy report titled *Best Management Practices for Lakeshore Stabilization* in the resource section at the end of this document.

Septic Systems

- Inspect your septic system annually and pump it out regularly. Every three to five years for the average home with a 1000-gallon tank; smaller tanks should be pumped out more often.
- Do not use septic system additives, as there is no scientific evidence they help. Some additives can be detrimental to the septic system or can contaminate groundwater.
- Avoid using toilets for garbage disposal and minimize the use of sink garbage disposals. This adds solids to your septic system, which will then require more frequent pumping or could clog your drain field. Compost instead.
- Use phosphate-free detergents and cleaning agents as it reduces the strain on your septic system and minimizes phosphorus movement through soil to the lake. Most major commercial brands of detergents and cleaning products are phosphate free. Read the label.

Water Conservation

- Minimal use of water means less wear and tear on the septic system, less chance of septic seepage into surrounding soils, less runoff and therefore less movement of nutrients, fecal material, and chemicals to nearby water bodies and finally more water in the soil for surrounding vegetation.
- If possible, use low-flow faucets, showerheads, reduced-flow toilet flushing equipment, and newer water saving appliances for clothes and dishes. They decrease the volume of wastewater going to the septic system and extend the interval between pumping.
- Repair any leaking faucets, toilets, and pumps. This prevents water being wasted.
- Avoid leaving water running while doing other activities such as when brushing teeth, washing and rinsing dishes, and washing the car. Excess water ends up either in the septic system or as unnecessary runoff.
- Try slow-watering techniques such as trickle irrigation or soaker hoses, which are more effective than sprinklers, and water in the evening to minimize evaporation. This will lessen runoff and minimize water use.
- Avoid cleaning your driveway, pathways, decks, or docks by hosing them down. This practice wastes water and can create surface runoff and can transport contaminants and chemicals to the lake.

Household Chemicals

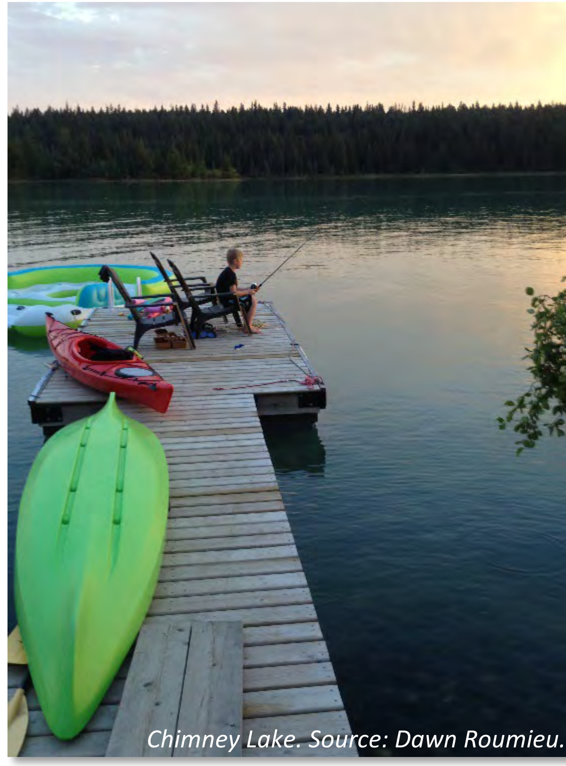
- Use water-based and/or low phosphate or phosphate-free products if available. High phosphorus loading to aseptic system can cause movement of phosphorus through soil, which can lead to decreased water quality.
- Buy the amount of product you are planning to use and apply as directed; more is not necessarily better. Using more than required may result in additional product in the septic system or spillage on the ground, both of which could result in soil or water contamination.
- Take unwanted chemical products to proper collection and disposal centres; do not pour them down the drain or on the ground. Soil cannot eliminate most chemicals and they may end up in the runoff.

Boating

- Use 4 stroke engines, which are less polluting than 2 stroke engines, whenever possible.
- Use an electric motor where practical.
- Watch your speed. Motors can stir up sediments releasing nutrients that lead to water quality deterioration. Increased wake action can also disturb shorelines.
- Do not throw trash overboard or use lakes or other water bodies as toilets.
- Conduct major maintenance chores on land. This prevents water contamination.
- Keep motors well maintained and tuned to prevent fuel and lubricant leaks.
- Use absorbent bilge pads for minor leaks or spills.
- Recycle used lubricating oil and leftover paints.
- Clean, Drain, Dry your boat. Aquatic invasive species are a threat to BC lakes. Follow the **Invasive Species Council of BC best management practices for boating**.

Chimney Lake. Source: Dawn Roumieu.

Docks


Chimney Lake. Source: Dawn Roumieu.

- Do not use metal drums in dock construction. They rust, sink, and become unwanted debris.
- Do not use pressure treated wood. To avoid water contamination, use unpainted and unstained preferred dock woods such as red cedar, redwood, cypress, or plastic decking and floats that maximize light penetration (Shoreline Management Guidelines – Kootenay Lake, 2018).
- Do not use non-encapsulated Styrofoam as this material breaks up, littering beaches and is often consumed by fish and other wildlife who mistake it for food (Shoreline Management Guidelines – Kootenay Lake, 2018).
- Use only encapsulated Styrofoam or washed plastic barrel floats.
- All floats should be labelled with the owner's name, phone number, and confirmation that barrels have been properly maintained.

1.2 FORMING A STEWARDSHIP GROUP

Individuals can be outstanding environmental stewards but by coming together as a group, each member's passion can be harnessed and put collective action to work in order to come up with the ideas, energy, technical expertise, and financial resources necessary to solve environmental problems. It is important to determine if there is any other local group that is already focusing on the issues of concern. Groups such as water use committees or neighbourhood associations may already exist in the community and may already be working on the same issue. There may also be groups that have related interests in the general area but are not focused solely on local lakes (e.g., naturalist clubs, sailing and boating associations, other environmental organisations).

Joining an existing group with an established membership may develop momentum for lake management and may increase the cost effectiveness of lake stewardship projects and initiatives. Before joining an existing group, it is important to determine their interest in carrying out aspects of lake stewardship. If personal interest and goals do not align with an established group, a new stewardship group can be established while maintaining a positive working relationship with those that already exist in order to maximize impact. It is also important to ensure that your purpose, goals, and efforts will complement, rather than compete with these other community groups and their initiatives. Collaboration between groups can strengthen success in the community.

Forming and sustaining a lake stewardship group involves a significant amount of ongoing volunteer work and commitment but can produce invaluable environmental achievements and community legacies. By creating a stewardship group motivated by lake conservation, others with similar interests and values can participate in the cause. Not only does environmental stewardship offer the opportunity to have fun, engage in outdoor recreation, and learn new skills, but it can also provide a sense of fulfillment and pride from contributing to the well-being of your community.

By increasing community awareness about the needs of a lake environment, responsible citizenship can be established to lay the foundation of participation for future generations. A lake-based stewardship group can undertake a number of activities to generate community awareness, such as storm drain marking, information campaigns, public workshops, lake events, or school presentations. For example, the BC Lake Stewardship Society (BCLSS) organizes the annual Secchi Dip-In, an event that takes place during Lakes Appreciation Month, that encourages British Columbians to participate in citizen science and submit a snapshot of water-clarity data from their local lake (see Section 3.1. Water Clarity). More information on the Secchi Dip-In can be found on our website **here**.

Source: BCLSS Files

1.3.2 MEMBERSHIP

Prior to recruitment, it is important to clearly define the benefits to, and expectations of, stewardship group members. Assembling a team that understands their call-to-action and responsibilities will ensure success. Members of a stewardship group can contribute their time and a wide range of valuable assets including technical skills and traditional or historical knowledge of the community. Volunteers are invaluable when pursuing physically demanding projects, rallying for public support, or providing administrative support. A diversified membership base can also invite new ideas and insights to a group, creating an innovative approach to shared challenges and aspirations. Members may also recruit other individuals and bridge unique community connections by tapping into their existing social or professional networks. Several actions can be taken to connect with and recruit potential group members, such as:

- Approaching personal contacts (friends, family, co-workers, affiliated organizations)
- Contacting similar organizations or local businesses to explore partnership opportunities
- Advertising on social media in local newspapers or community bulletins
- Creating a website with group information

Stewardship groups in need of specific skillsets to reach their goals can solicit volunteers with those desired abilities. Lake stewardship groups can recruit a diverse team of members such as:

- Private landowners that reside in the lake watershed
- Indigenous community members
- Farmers, land developers, and foresters
- Fishermen and boaters
- Industries and utilities that operate within the watershed
- School, college, and university instructors and their students
- Community and tourism groups (non-government organizations), and
- Government agents with responsibility for lake management

The size of a stewardship group's membership base depends on the scale of its work, the size of the community it serves, and the opportunities available. Too few or too many members may create challenges in a group.

Too few group members may not be conducive to taking on large projects or may result in a lack of skills diversity. Too few members can also lead to **volunteer burnout**, when a small number of volunteers are constantly called upon for their time and become fatigued or disinterested. To minimize the likelihood of burnout, volunteers can be rotated through specific positions.

Too many group volunteers may make the coordinating of activities difficult and can lead to **volunteer saturation**. To mitigate this issue, volunteers can be divided into groups to be assigned specific tasks or projects that align with their skills or interests.

KEY TERMS

Volunteer Burnout: A situation that arises when a volunteer group has too few members, resulting in the overworking of a small pool of volunteers who may become fatigued or disinterested in the group over time.

Volunteer Saturation: A situation that arises when a volunteer group has too many members, resulting in stress for group managers to coordinate, and insufficient opportunities for a large group of volunteers such that they may become disinterested in the group over time.

1.4 SOCIETIES & CHARITABLE STATUS

1.4.1 BECOMING A SOCIETY

In British Columbia, non-profit organizations are known as societies. Societies are independent, democratic organizations that are required to comply with the **Societies Act** and their own constitution and bylaws (Government of BC, 2022). Societies may be formed for any lawful purpose(s), including artistic, charitable, political, recreational, scientific, or social (Government of BC, 2022).

> **Did you know?**
> Information on how to apply for charitable registration can be found here: **Registering for charitable or qualified donee status - Canada.ca**.
>
> Canada Revenue Agency also provides information to help you decide if registration is right for your stewardship group.

The new *Societies Act* came into effect in November 2016 and governs how societies are created and run in BC. The *Act* includes significant updates to allow for more flexibility in how societies operate, while still protecting the public interest (Government of BC, 2018). The filing requirements of a society can now be easily completed at **Societies Online**. This includes submitting Annual Reports and changes of address, directors, or bylaws, and paying associated fees.

There are many aspects that need to be considered when starting a society. These include:

- Defining the purpose of the society
- Designating directors
- Establishing bylaws
- Maintaining the society (administration, etc.)
- Incorporating

Although incorporation of a society is not required, it has advantages. If a society plans to pursue funding, grants, or charitable status, incorporation should be considered. Incorporation also gives a society the rights of an individual, and independent existence separate and distinct from its members, and unlimited life expectance (Government of BC, 2022).

More information on not-for-profit organizations, including starting a society, can be found on the **Government of BC website**.

1.4.2 CHARITABLE STATUS

Societies may be eligible to register for **charitable status** through the Canada Revenue Agency (CRA). Charitable status enables access to a wider variety of grants and funding sources and allows for the issue of official tax receipts for donations received. Registered charities are also exempt from paying income tax, exempt from charging GST/HST on many goods and services, and can also claim a partial rebate for GST/HST paid. Charitable status may also provide credibility to an organization.

However, maintaining charitable status in Canada requires increased administrative efforts. Obligations are outlined on the CRA website and include filing a Registered Charity Information Return (Form T3010), issuing accurate donation receipts, and keeping reliable books and records. If obligations are not met, charities may be subject to a penalty and have their registered status revoked.

> **Charity Central Fast Facts**
>
> **Registered Charity vs. Non-Profit Organization**

The Government of Canada CRA website has comprehensive information, resources, and checklists to assist with charity registration. In addition, the following websites have been developed in partnership with the Canada Revenue Agency to provide education and training on registration.

- **Centre for Public Legal Education Alberta**
- **Educaloi**

In addition, **Charity Central** houses a Learning Centre and provides modules containing information on the definition of a registered charity, the rules regarding provincial legislation, how to apply to become a registered charity, and documentation required.

KEY TERMS

Society: An independent, democratic organization that is governed by the Societies Act and the society's own constitution and bylaws.
Charitable Status: A status obtained by legally registering a stewardship or volunteer group as a charity with Canada Revenue Agency (Government of Canada, 2021).

1.5 BOARD OF DIRECTORS AND COMMITTEES

1.5.1 BOARD OF DIRECTORS

An active and dedicated **Board of Directors** helps to coordinate the activities and operations of a stewardship organization. The board leads the organization toward the group's vision. Most of the time, a board has a chair or president, a vice-chair or vice-president, a secretary, and a treasurer. There are two common kinds of boards; one is a policy or governance board the other is a working or administrative board (The Calgary Foundation, 2021). A small group with no paid staff usually has a working or administrative board. This means the board does all the work of the group, volunteering time above and beyond meeting time. A policy or governance board is typical for groups with paid staff. In this case, the boards' role is to do the strategic planning for the group. The BCLSS Board of Directors is listed **here**.

An effective Board of Directors has a clear understanding of its roles and responsibilities, which include three main areas (Davidson, 2014):

1. Governance: The board develops policies that give direction to the organization
2. Management: The board takes actions and makes decisions to ensure that there are sufficient and appropriate human and financial resources for the organization to accomplish its work
3. Operations: The Activities related to the delivery of programs or services of the organization

Additional Board of Director responsibilities include:

- Creating and putting into action the group's purpose or mission. Setting long and short-term goals for the group. Keeping track of the organization's progress
- Knowing what resources the group has and needs. Balancing needs against resources. Taking part in fundraising
- Making policies for how the group runs
- Knowing and following the organizations bylaws

Resources for forming an effective Board of Directors can be found at the end of Section 1.5.2.

1.5.2 COMMITTEES

Committees are smaller groups, consisting of volunteers, staff, and board members, that focus on one aspect or program of the non-profit. Committees are a way to leverage the knowledge of a larger group of people to help the board make decisions and plan efficiently. They also allow necessary work to be evenly distributed throughout the board.

Benefits of forming committees (Clark, 2020):

- Clearly define responsibilities for specific members
- Empower committee members to work at their own pace
- Put the skills and talents of your board members to the best use
- Research, make recommendations, and present option to the board at large

Examples of committees (Clark, 2020):

1. Executive / Steering Committee: create agenda for the organization
2. Standing Committee: Monitor progress, make plans and often cover finance, marketing, communications, and budgets
3. Ad-hoc Work Committee: Shorter term committee that can be useful in planning fundraisers, galas, volunteer gatherings, or other events
4. Fundraising Committee: Focuses on donor appreciation activities, fundraising campaigns, corporate sponsorship, or donation procurement
5. Finance Committee: Support's the board's fiduciary oversight and planning by focusing on longer-term projects like investments, capital campaigns, and reserve funds
6. Governance and nominating Committees: Nominate new board members, review bylaws, oversee executive director employment, and lead board evaluations
7. Communications and public relations committees: Provide internal communication, help produce newsletters and official statements, manage social media, and act as the contact point for any media requests
8. Audit Committee: Conducts an annual review of all the nonprofit's finances and ensures the board is ready to answer any regulatory questions accurately

The number and type of committees for a stewardship organization depend on the group's goals, the number of board members, and resources available. There are many engaging activities that a Board of Directors can facilitate. Examples are provided below.

Examples of engaging activities:

- **The BCLSS LakeKeepers Manual**
- **The Secchi Dip-In**
- **United Nations World Water Day (March 22 every year)**
- **World Wetlands Day**
- **Earth Day**
- **North American Lake Management Society Symposium**
- **Lakes Appreciation Month**
- **Great Canadian Shoreline Cleanup**
- Educational events for youth and families (e.g., NatureKids, Water Rangers, Lake Blitz)
- Signage projects

- Restoration projects
- Lake monitoring

The following resources contain additional information about creating a board of directors and committees:

Guide for Successful Groups
Board Governance Resource Guide

1.5.3 LIABILITY INSURANCE

Directors and officers have a duty to exercise due diligence in overseeing the management of the organization that they serve. This involves 3 basic duties (Insurance Bureau of Canada, 2022):

1. Duty of Diligence (Duty of Care): Act reasonably, in good faith and in the organization's best interest
2. Duty of Loyalty: Place the interest of the organization before your own
3. Duty of Obedience: Act within the scope of applicable bylaws

Liability Insurance for boards is known as Director's and Officer's (D&O) Insurance. This insurance covers the legal costs that an organization is responsible for if liabilities have occurred. While D&O Insurance is not required under the Canada Corporations Act, some funders require it before granting money to the organization and some organization have this written into their bylaws and policies (Davidson, 2014).

D&O Insurance covers situations such as (APOLLO, 2021):

- Improper employment or human resource practices such as wrongful dismissal, discrimination, harassment, or unsafe practices
- If there is a belief by donors that funds are being mismanaged
- Defamation
- Breach of fiduciary duties or issues related to a conflict of interest

KEY TERMS

Board of Directors: Individuals within a stewardship group who are key decision-makers and coordinate the activities and operations of a group.

Liability Insurance (D&O Insurance): Covers the legal costs that an organization is responsible for if liabilities have occurred.

1.6 STRATEGIC PLANNING

Strategic planning sets the foundation for your stewardship group. Developing a plan assists with setting goals, determining objectives, allowing for progress assessment, and facilitating growth. It may also help your group stay focused.

Basic components of a plan:

1. **Purpose**

   You can define your group's purpose by developing clear statements of what the group wants to do. For example, the purpose of the BCLSS is as follows:

   - Provide lake stewardship education and training opportunities through a variety of programs
   - Provide support and foster communication, linkage, and networking for lake protection groups throughout BC
   - Offer and participate in conferences, courses, seminars, and events throughout BC.
   - Organize and participate in environmental projects
   - Provide tools and resource materials to community members on lake related issues

2. **Vision and Mission:**

   A **vision** is a simple inspirational statement that outlines an ideal that the group aspires to. For example, as a lake stewardship group, identify what you would like for your lake in the future. The BCLSS vision statement is:

   Clean, healthy lakes that provide quality habitat for aquatic life, wildlife, and people throughout British Columbia.

   A **mission statement** is a clear and concise description of your group's reason for being. The BCLSS's mission is to act as a resource, communication, and information network among scientists, environmental professionals, First Nations, stewardship groups, lakeshore residents, the general public, and government agencies to preserve, protect, and restore lakes in British Columbia. Our vision is clean, healthy lakes that provide habitat for wildlife, drinking water, recreational opportunities, scenic beauty, and connection to the natural world.

   It is important to keep your purpose and statements general enough to encourage widespread support, but specific enough so the group can measure progress and clearly identify goals and activities. Make sure all partners are involved in developing the statement and that it accurately reflects what the group plans to accomplish. Review the statement, to make sure everyone is willing to commit to it. This process may not be easy, but it will be time well spent (Alberta Agriculture and Forestry, 2001).

3. Goals and Objectives

A goal is an achievable outcome that is broad and longer term. They are developed to fulfill the vision and mission. Objectives are the specific actions to achieve the goal. It is important that your goals follow the **SMART principle**.

4. Resource Assessment

Identify the group's strengths, weaknesses, opportunities, and threats (**SWOT analysis**) as well as the benefits and the potential costs associated with accomplishing goals. Identify what information has already been collected, including reports and planning documents, and any related activities that are ongoing. Possible contacts for this information are the Ministry of Environment and Climate Change Strategy, Department of Fisheries and Oceans, Ministry of Forests, Lands, Natural Resource Operations & Rural Development, Regional Districts, fish and game clubs, etc.

5. Plan of Action

After stating what needs to be accomplished through your objectives, identify the specific tasks, activities, and/or projects that are involved. Arrange the tasks by priority and fit them into a realistic timeline based on available resources. Include planning for fundraising, training, communication, administration, and other related activities. Determine how the success of activities will be determined and measured.

6. Budget

A detailed budget will reveal the areas in which assistance will be needed. Budgets also help determine if your goals are realistic, given available resources. See Appendix 1.1: Annual Lake Society Budget.

The following resources contain additional information on strategic planning for your organization:

Guide for Successful Groups

Nonprofit SWOT Analysis: A Strategic Management Tool

The Stewardship Toolbox

KEY TERMS

Mission statement: A clear and concise description of your organization's reason for being.
Vision: A simple inspirational statement that outlines and ideal that your organization aspires to.
SMART goal: A specific, measurable, achievable, relevant, and time-delineated goal.
SWOT analysis: An exploration undertaken by an organization to identify its strengths, weaknesses, opportunities, and threats.

Big Bar Lake. Source: Marge Sidney.

1.7 FACILITATION

While meetings are an important component of every organization, it is important to make sure that they are effective to encourage member participation and involvement. There are many ways to host meetings and it is important to consider the goal of the meeting when deciding on a venue or platform. The first step in planning a meeting is to list the goals and determine who should attend. As the meeting host or facilitator, you are responsible for more than just moving the group through the agenda; you are also responsible for the well-being of the attendees (Community Tool Box, N.D.). The following outlines some steps to take to run an effective meeting. Additional resources are provided in section 1.7.3.

Running an effective meeting:

1. **Plan the meeting:** Define goals and create an agenda
2. **Set up the meeting:** Decide on meeting format (online or in person), start and end on time, keep track of who is attending, create a welcoming and safe space
3. **Run the meeting:** Do introductions, run through agenda and meeting rules, keep discussion on track
4. **Follow up on the meeting:** Gather feedback from the group, follow up with calls or emails, summarize the meeting

1.7.1 CREATING A COLLABORATIVE ENVIRONMENT

Open communication and the sharing of information are essential factors to build trust in the organization, as is the need to seek cooperation, share authority and build teamwork. One way to prevent conflict is to establish a community agreement. This provides everyone with an opportunity to express what they need to feel comfortable in the space and to encourage positive and constructive interactions. Cultural safety training is also an important component of a stewardship organization to ensure that all members understand cultural protocols, empathy, and safety; an important step when working towards reconciliation. Links to resources are provided in section 1.7.3. The following are important for establishing a respectful and collaborate stewardship group.

Creating a respectful collaborative environment (BC Government, N.D.):

- Ensure inclusivity
- Value diversity
- Clearly communicate expectations around behaviour
- Promote health and safety of volunteers, members, and staff

- Provide resources and training to resolve disputes
- Strive for improvement
- Maintain open channels of communication

1.7.2 CONFLICT RESOLUTION

Although members of a stewardship group can share the same vision, conflicts may arise in response to differing beliefs, attitudes, personalities, or needs. Conflict is not always negative, and when effectively managed, can lead to growth and innovation. Given that every group member brings unique qualities that benefit the group, conflict resolution should be a priority. Below, we highlight some steps that can be taken to resolve conflict within a stewardship group.

Steps in conflict resolution:

1. Call a conflict resolution meeting to address the issue
2. Find a facilitator or negotiator who can stay calm and has an objective view of the situation.
3. Be clear about the problem
4. Find common ground
5. Discuss the problem, allow everyone to share
6. Brainstorm options to resolve or manage the problem
7. Choose an option that is best for everyone
8. Develop plan for how to put it into action

1.7.3 FACILITATION RESOURCES

Meetings & Conflict Management
Community Tool Box: Conducting Effective Meetings
The Calgary Foundation: Guide for Successful Groups
Land Stewardship Centre: The Stewardship Toolbox

Establishing a respectful working environment
Nahanee Creative: Cultural Safety Training
Government of BC: Respectful workplace

1.8 FUNDING

Many groups work with limited financial resources and depend on the in-kind contributions of dedicated members and supporters. While these efforts are very valuable and can result in substantial progress, a lack of funds can limit the goals and achievements of a stewardship group. Securing financial support can increase the capacity of a group.

Before seeking funding for a project, a budget should be established to outline the financial need. This may include hiring consultants and staff, purchasing necessary equipment and supplies, enlisting professional services, and any administrative costs.

When the budget has been established, relevant funding sources can be identified and solicited. A variety of funding options exist:

- Members - collect membership dues and donations
- Sponsors - company logos or web links on website or printed material
- Fundraising events - silent auctions, raffles, lake-themed events
- Businesses and corporations - request donations including goods or services (e.g., skilled labour)
- Grants
    - Foundations in Canada, the USA, and international
    - Government agencies – local, provincial, and federal

Grants are an excellent funding option but can be very competitive and the applications can involve significant time and information. Application requirements vary depending on the funder, so it is important to carefully consider:

- If the criteria set out by the funding agency align with the group's eligibility
- How the project goals meet the funding objectives
- If the grant deadline, acceptance, and disbursement schedule align with the project timeline

Many funding agencies indicate that they will not provide the sole source of funding for a project. Applicants that can supply partial funding, through in-kind support and/or matching funds, may be eligible for more opportunities and have more success. Securing financial resources through membership dues, community support, and other grants are very important to show that your group has more than one financial source in place. Therefore, it is recommended to apply to several funding agencies.

Funders receive a high number of applications, so it is important to have a strong, succinct, and persuasive application. Many have standardized online applications, while some invite letters of intent and written proposals.

Key Elements of an Effective Proposal

- Strong summary
- Demonstrate need
- Clearly stated goals & objectives
- Methods and strategies outlined
- Compelling narrative
- Budget
- Partners
- Sustainability
- Evaluation Plan

Opheim Lake. Source Norm Zirnhelt.

For a sample of a general proposal, see Appendix 1.2: Example Proposal – Hardy Lake System Project.

Some General Funding Sources for Water-Related Projects:

BC Conservation & Biodiversity Awards
Community Gaming Grants
Donner Canadian Foundation
Environment and Climate Change Canada
Gordon and Betty Moore Foundation
Habitat Conservation Trust Foundation
MakeWay
RBC Foundation
Real Estate Foundation of BC
Sitka Foundation
TD Friends of the Environment Foundation
The McLean Foundation
Vancouver Foundation

Other listings can be found at:

BC Water Funders Collaborative
Canadian Foundations
GrantStation (subscription required)

More information on how to fundraise can be found at **Charity Village.**

The BC Lake Stewardship Society shares funding opportunities through our monthly newsletter and can help identify suitable funding sources if you contact the office directly. BCLSS also offers assistance with funding proposals to our members, can provide letters of support, and considers partnerships on projects that meet our vision of clean, healthy lakes.

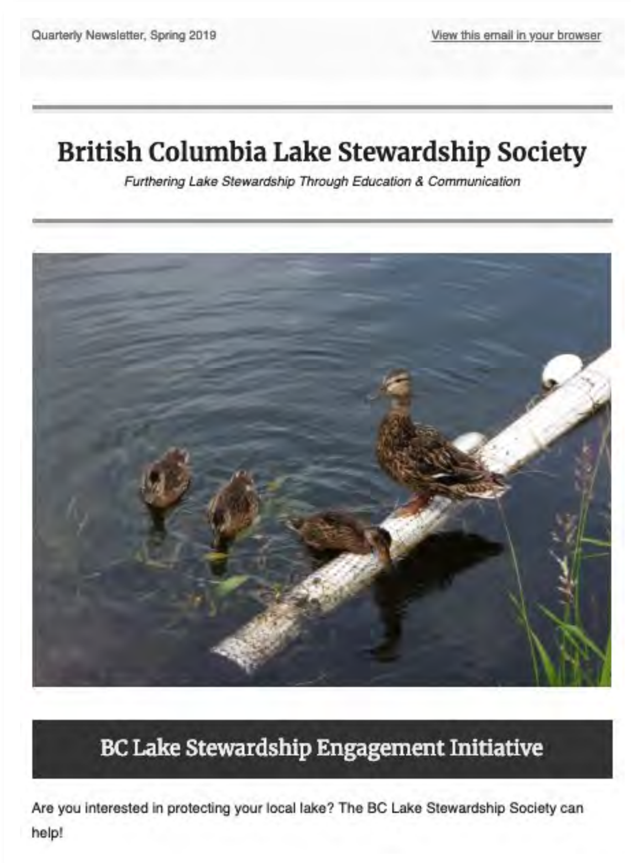

Source: MindfulChar from Pixabay.

1.9 RAISING AWARENESS

Promoting stewardship group activities using available media outlets will help to increase community awareness. It may also attract volunteers and document an ongoing project that can be used in subsequent funding or grant applications. Examples include:

- Set up a website, blog, or social media platform such as Facebook, Twitter, Instagram, or Tik Tok
- Approach your own personal contacts: friends, family, neighbours, co-workers, other community groups
- Connect with local Indigenous peoples regarding stewardship and Traditional Knowledge
- Arrange a meeting and invite people from other organizations such as environmental or boating groups, chambers of commerce, and fish, game, naturalist, and recreation clubs
- Organize a summer social with lakeshore neighbours
- Connect with local businesses that may be interested in the lake such as resorts, marinas, boat companies and tackle stores

- Distribute information to those who own lakefront property, live in the watershed, or use public recreational facilities
- Advertise in local newspapers with announcements and post bulletins or posters around your community
- Radio and television stations usually reserve space for public service announcements
- Media releases (e.g., **Provincial lake monitoring programs ensure B.C.'s lakes stay healthy | BC Gov News**)
- Join the BCLSS and receive monthly newsletters (shown at right) which contain information about ongoing lake-related initiatives and about like-minded BC lake groups



- BCLSS accepts articles for distribution in newsletter
- BCLSS promotes group members on our website, newsletters, and direct contact

1.10 INDIGENOUS PEOPLES

Indigenous knowledge and culture in Canada include a way of life rich with songs, stories, ceremonies, values, beliefs, and languages. Collaborating with local and regional Indigenous communities is critical to a holistic lake stewardship ethic. Each Indigenous Nation has a unique relationship to the land and watershed, as well as distinct Traditional Knowledge and protocols. Contacting the Nation, band office, or local governing body of the traditional territory is the first step when considering water stewardship projects. Local and Traditional Knowledge provide key insights and observations to lake water quality monitoring and stewardship including historical and current land uses.

There are many resources available for identifying relative locations of traditional territories including **Native Land Digital** and **INAC First Nations Profile Interactive Map**. The Centre for Indigenous Environmental Resources (CIER) released a series of **Watershed Planning Guidebooks** for collaborating with local First Nations around watershed planning and management. Many Nations also have toolkits or guidebooks prepared for their community to understand governance, roles, rights, and responsibilities that provide important background information for developing a foundation of trust and understanding. Other important background information to include are the **Truth and Reconciliation Calls to Action** and Canada's commitment to the **United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).** This information is to be used as a framework to reach true reconciliation through the help of initiatives like **#Next150**.

Indigenous Corporate Training offers **3 Rs of engagement** to develop trusting relationships with local Indigenous communities. The first is **research** which emphasizes the importance of doing your own due diligence to develop a holistic understanding of the community before you interact with them. The second is **respect**. As settlers, it is important to understand the history and impacts of colonialism on First Nations communities and to respect the relationship that the community has with the land around them. The final step is to provide **recognition** and **regard** for the rights of Indigenous Peoples. It is important to develop an understanding of the Constitution Act and to recognize the immense work that Indigenous peoples took on in order to have their rights recognized in the Constitution (**Indigenous Corporate Training INC, n.d.**).

Pitt Lake. Source: James Wheeler from Pixabay.

It is recommended to engage with First Nations as early as possible in the planning stages of a project to build relationships before commitments are required (BC Government, 2021). The BC Government has created a **document** that focuses on building relationships with First Nations from a business lens.

Some additional resources to support the engagement process are:

- **First Nations Consultation Guidelines – Indigenous Corporate Training Inc.**
- **Compilation of Resources for Indigenous Consultation – Indigenous Corporate Training Inc.**
- **Growing Indigenous Inclusion and Engagement – Nature Canada**
- **Building Relationships and Advancing Reconciliation through Meaningful Consultation – Government of Canada**
- **First Nation Profiles Interactive Map – Government of Canada**
- **Reconciliation Canada**

1.11 GOVERNMENT AGENCIES AND LEGISLATION

There are a number of government agencies involved with the management of water and habitat. The following pages include brief descriptions of the various roles and responsibilities of those agencies involved in managing many aspects of lakes located in BC. A lake stewardship group should develop a working relationship with government staff in these various agencies as a means of bringing group concerns to government attention or requesting technical and/or financial support to ensure that the group's actions will not violate various environmental legislation.

Local Government (Regional & Municipal)

Municipal or regional district governments may have land use plans (e.g., Official Community Plans) and bylaws relating to foreshore development and planning, riparian or streamside buffer zones, or other issues relevant to your lake. Additionally, these governments may have engineering, parks, public works, or planning departments responsible for managing lake-related issues.

BC Provincial Government

Various BC provincial government ministries deal with water related issues. Table 1.0: Water-Related Responsibilities of Government Agencies in BC, presents a brief summary of these ministries and their water-related responsibilities. You can request the number for any provincial government office within BC by contacting **Service BC**. Pollution can be reported to the **Report All Poachers and Polluters (RAPP)** hotline at 1-877-952-RAPP (7277). In addition, algae observations can be reported through **Algae Watch**, a citizen science data program to help people recognize and identify algae blooms in B.C. lakes.

Since the 1990s, the Ministry of Environment and Climate Change Strategy (ENV) has aided in the creation and operation of stewardship groups predominantly through funding and sharing expertise (Fisher, 2017). The BC Ministry of Environment aims to provide accessible and consistent guidance for water quality monitoring for BC stewardship groups to enable them to collect scientifically defensible data that inform decision makers within government, industry, and the public. It is also imperative to develop and maintain partnerships with stewardship groups and other programs in order to provide a strategic coordinated approach to provincial water quality sampling.

Federal Government, Fisheries and Oceans Canada (DFO): Fisheries and Oceans Canada is primarily responsible for the protection of salmon stocks and their related marine and freshwater habitats. This responsibility is addressed through application of the Fisheries Act in cases where 1) sediment (a deleterious substance) is introduced to streams or lakes inhabited by fish; and 2) where the introduction of a deleterious substance has caused harmful alteration of habitat. The Fisheries Act is designed to protect both sport and non-sport fish species. Other DFO activities include the regulation and management of commercial, First Nations, and recreational salmon and marine fishing activities and the application of watershed stewardship programs throughout the province.

Federal Government, Environment Canada (EC): Although DFO is the primary agency for administering the Fisheries Act, Environment Canada is the lead agency that enforces the pollution portion of this Act. This includes 1) responding to incidents of deposits, into waters inhabited by fish, of substances that are harmful to fish (deleterious substances); and 2) enforcement of regulations. While the provincial government takes a lead role in water quality protection and monitoring in British Columbia, Environment Canada is active in 1) environmental effects monitoring related to major pulping and mining operations; 2) environmental enforcement under the Fisheries Act; 3) stream flow and lake level measurement; and 4) long term water quality trend assessment.

Table 1.0: Water-Related Responsibilities of Government Agencies in BC

Ministry/Agency	**Related Responsibilities**
Ministry of Environment and Climate Change Strategy (ENV)	- Pollution control protection land, water, and air
	- Monitoring of land, water, and air quality
	- Environmental emergencies (spills)
	- Legal enforcement (pollution, habitat, fish, wildlife)
	- Fish and wildlife habitat and species protection
	- Recreational fish and wildlife management
	- Parks and Protected Area Strategies
	- Flood plain management
	- Environmental assessment of major projects
	- Works that encroach below the lake high water line (Water Act)
	- Consumptive use - water and outlet controls structures (Water Act)
Ministry of Land, Water and Resource Stewardship	- Objective setting for land and marine environments
	- Effectively managing cumulative effects
	- Advancing reconciliation with Indigenous Peoples

Integrated Land & Resource Registry	- Mapping and database management
	- Strategic land and resource planning
	- Facilitating coordinated access to crown land and its resources
	- Lake shore property tenure, leases, and fee simple (Lands Act)
Ministry of Health	- Primary responsibility for drinking water quality
	- Residential sewage treatment
	- Public health related issues
	- Works in and around streams
Ministry of Forests, Lands, Natural Resource Operations and Rural Development	- Timber supply management
	- Reforestation, silviculture, and research
	- Forest recreation
	- Pest control
	- Fire protection
	- Livestock range management
	- BC Timber Sales (Small Business)
Ministry of Agriculture	- Environmental sustainability and resource management
	- Promoting environmental stewardship through the Agriculture Environment Partnership Initiative.
	- Livestock management, pest management, invasive species
Local Regional Districts	- Development permits
	- Growth strategies
	- Community planning, zoning, and land use
	- Sewer systems, water systems, drainage plans

1.12 THE BC LAKE STEWARDSHIP SOCIETY (BCLSS)

The BC Lake Stewardship Society was created in 1997 to provide support and information to concerned citizens interested in preserving the water quality of lakes throughout British Columbia. An affiliate of the North American Lake Management Society (NALMS), the BCLSS was formed to provide high quality information on provincial lakes.

The purpose of the BCLSS is:

- Provide lake stewardship education and training opportunities through a variety of programs
- Provide support and foster communication, linkage, and networking for lake protection groups throughout BC
- Offer and participate in conferences, courses, seminars, and events throughout BC
- Organize and participate in environmental projects
- Provide tools and resource materials to community members on lake related issues

Overall, the BCLSS aims to promote stewardship, understanding, and comprehensive management of lakes, reservoirs, and watersheds.

The objectives of the Society are accomplished by working with our members and project partners. The information and training provided by the BCLSS has enabled many volunteers around BC to become stewards and advocate for their lake.

BCLSS staff and directors work to expand and strengthen the lake stewardship sector throughout the province. BCLSS addresses many inquiries about water quality, algae blooms, pollution, development, boating, and overall lake and watershed uses and issues. BCLSS has established regional representation through the province in its Board of Directors, which is available to assist citizen lake questions and the needs of lake-based stewardship groups.

The BCLSS produces an informative **monthly newsletter** that includes articles from professionals, volunteers, and lake groups. It illustrates the strong network between concerned citizens, lake groups, the scientific community, BCLSS staff, and directors, which allows for sharing of lake information and solutions to lake issues. **Sign up for the newsletter here**.

We encourage lake users to become committed members of the BC Lake Stewardship Society. With growing concerns over deteriorating water quality, increases in harmful algal blooms, increased lake usage, effects of climate change, and strains on government resources, community education and citizen science are critical to the protection of lake water quality throughout the province.

It is through the support of our members that we can continue to provide essential education and services. The cost of becoming an annual BCLSS member is minimal but the value of protecting water is priceless! Membership also fosters networking among lake groups with similar concerns and enables learning from one another's successes.

BCLSS Contact Information

1-877-BCLAKES (toll free) or 604-474-2441
www.bclss.org
info@bclss.org

RESOURCES

- **BC Registries and Online Services**

  https://www.bcregistry.ca/societies/
- **British Columbia Lake Stewardship Society (BCLSS)**

  www.bclss.org | 1-877-225-2537 | info@bclss.org
- **Canada Earth Day**

  www.earthday.ca
- **Centre for Indigenous and Environmental Resources (CIER)**

  www.yourcier.org | 204-956-0660
- **Crown - Indigenous Relations & Northern Affairs Canada (CIRNAC)**

  https://www.rcaanc-cirnac.gc.ca
- **Ducks Unlimited Canada**

  www.ducks.ca
- **Great Canadian Shoreline Cleanup**

  www.shorelinecleanup.ca
- **Native Land Digital**

  https://native-land.ca/
- **North American Lake Management Society (NALMS) Conference**

  www.nalms.org
- **Report a Fisheries Violation**

  https://www.dfo-mpo.gc.ca/contact/report-signaler-eng.htm | 1-800-465-4336
- **Report All Polluters and Polluters**

  Report an Environmental Concern - Province of British Columbia (gov.bc.ca) | 1-877-952-RAPP (7277)
- **Stewardship Centre for BC**

  stewardshipcentrebc.ca
- **The Secchi Dip-In**

  www.nalms.orgUnited Nations World Water Day

  www.worldwaterday.org
- **Volunteer Canada**

  https://volunteer.ca/index.php
- **World Wetlands Day**

  www.worldwetlandsday.org

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Loon Lake. Source: Dawn Roumieu.

PART B: LAKE ECOLOGY AND MONITORING

Slocan Lake. Source: Marie McCallum.

CHAPTER ONE:
AN INTRODUCTION TO LAKES

"We forget that the water cycle and the life cycle are one."
- Jacques Cousteau

Campbell Lake. Source: Emily Gutenberg.

Chapter Contents

Chapter 1 of LakeKeepers introduces the science of **limnology** – the study of inland freshwater systems including lakes & reservoirs, rivers, creeks and streams, groundwater, and wetlands. From wave action to water chemistry, oxygen patterns to algal blooms, limnology enhances our shared knowledge of freshwater systems. This section presents the hydrologic cycle, physical characteristics of lakes including nutrients and biological production, and human impacts on watersheds.

K E Y T E R M S

Limnology: The scientific study of inland freshwater systems including lakes & reservoirs, rivers, creeks & streams, groundwater, and wetlands.

1.1 WATER FUNDAMENTALS

1.1.1 GLOBAL WATER COMPARTMENTS

Our planet's water is contained in five main compartments: oceans, atmosphere, snow and ice packs, surface water, and groundwater. The largest portion of the earth's water is found in its oceans. On a continental scale, the oceans are the main source of water that, through evaporation, charge the atmosphere. Most cloud formation occurs at the interface between the oceans and land masses. Oceans also tend to be the final resting place for many of our industrial and municipal wastes. Some of the world's water is bound in snowpacks, glaciers, and polar ice caps. In its frozen state, this trapped water largely is unavailable to the other compartments. As the climate warms, less water will be bound in frozen states.

Water is present as vapour in the earth's atmosphere. This vapour forms clouds and eventually falls to earth, commonly as rain or snow. Fresh surface water is found in lakes, streams, and reservoirs and makes up much of the water supply for humans and wildlife, as well as habitat for fish and other freshwater aquatic life. The final compartment, groundwater, is located in underground aquifers that may be shallow and unconfined or hidden deep under impervious layers of clay and/or bedrock. Shallow aquifers provide a large reservoir of water that is slowly released into watercourses and during dry periods comprises the majority of a stream's base flow.

1.1.2 THE HYDROLOGIC CYCLE

The circulation of water between the five global water compartments forms the **hydrologic cycle**. This cycle transfers fresh water through most of the world and, while doing so, provides for its filtration and this can provide purification. Five major processes comprise the hydrologic cycle: **condensation, precipitation, infiltration, surface runoff**, and **evapotranspiration (evaporation)** as illustrated in Figure 1.1.

Condensation occurs when ambient air temperature decreases to the dew point such that water vapour adsorbs onto airborne particulates and forms clouds. Wind moves these clouds across the earth's surface, spreading water vapour (and pollutants) to different areas in varying amounts. Eventually, the moisture content of these clouds reaches saturation and precipitation occurs, usually as rain or snow.

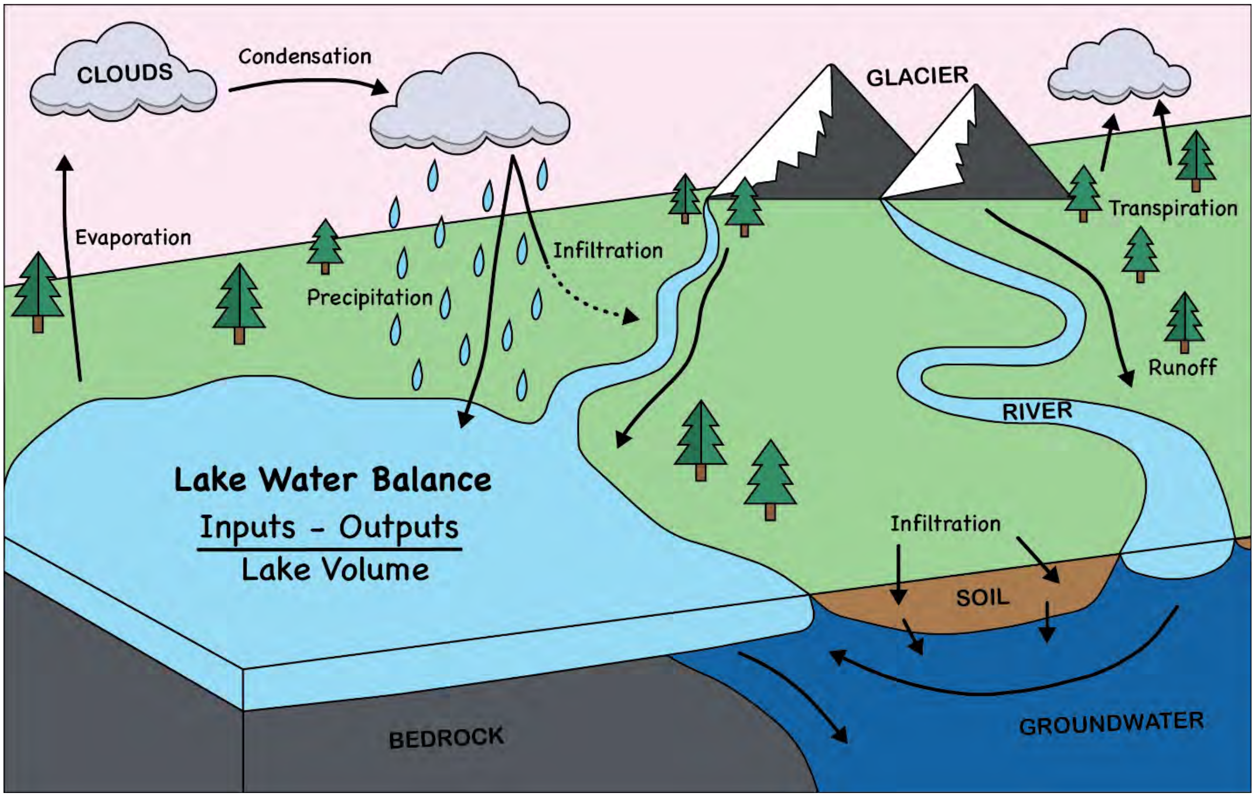


Figure 1.1 Hydrologic Cycle

Infiltration follows when this precipitation seeps into the ground. The degree of infiltration depends on how easily the water is able to seep through the soil (permeability). Runoff will occur if a surface is impermeable (especially artificial surfaces such as pavement or roofs) or if the rate of precipitation exceeds that of infiltration (rock, hard packed soil, or frozen ground in the spring). High levels of ground saturation will also encourage runoff. Runoff water flows directly into streams, rivers, and lakes. Infiltrated water seeps into groundwater, some of which will eventually end up in streams and lakes as base flow.

While precipitation, runoff and infiltration are distributing water across the earth's surface, evapotranspiration returns some of that water to the atmosphere. Heat energy from the sun drives this portion of the hydrologic cycle by changing surface water into air vapour through evaporation. Plants also contain water absorbed from local soils. Solar radiation causes the loss of some of this water from plant leaves to the atmosphere through a process called transpiration. Evapotranspiration is a term commonly used to incorporate both functions. This atmospheric moisture eventually condenses, forming clouds, and the cycle continues.

KEY TERMS

Hydrologic Cycle: The natural movement of water on earth between condensation, precipitation, infiltration, runoff, and evapotranspiration.
Condensation: The change in state of water from a vapour to a liquid.
Precipitation: The movement of water from the atmosphere to the earth's surface.
Infiltration: The movement of water below the earth's surface.
Runoff: The movement of water across the earth's surface.
Evaporation: The movement of water from liquid to vapour due to physical processes (heat primarily).
Evapotranspiration: Transfer of water from liquid to vapour due to the biological processes of trees and other vegetation.

1.1.3 WATERSHEDS AND LAKES

On a smaller scale, the hydrologic cycle is considered in terms of watershed areas. A watershed, or drainage basin, can be defined as the entire area of land that moves the water it receives to a common water body. It is physically confined by its surrounding height of land. The term watershed is misused if it describes only the land immediately surrounding a water body or the water body itself. The true definition (described above) represents a much larger land area than most people normally consider. A watershed is where much of the ongoing hydrological cycle takes place, and it plays a crucial role in the purification of water.

Water is cleansed through its continuous natural cycling through watershed compartments (e.g., vegetation and soils) and the atmosphere. Lakes are the product of the watersheds in which they exist. They are long-term sinks that collect watershed runoff, including that from human land-use practices. Factors such as watershed size, geology, soil, and vegetation, as well as lake size, depth, shape, and biological productivity contribute to the initial character of a lake. Lakes provide a variety of functions including water and nutrient storage and freshwater habitat maintenance. Depending on the extent of land use development and the type of human practices within a watershed, the ability of the watershed and/or the lake to meet these expectations may become compromised.

1.2 PHYSICAL CHARACTERISTICS OF LAKES

Learning about processes related to lake **morphometry** (shape), temperature, and dissolved oxygen can create a better understanding of how human activities can modify a lake.

1.2.1 LAKE SIZE

The land mass that we refer to as British Columbia has undergone extensive geological processing, mainly by tectonic plate movement and glaciation, followed by subsequent erosion that has created abundant mountains, valleys, and lakes. Most of the province's interior lakes were formed after the recession of the continental glacial sheet, approximately 12,000 years ago.

The height of land around a water body (the drainage divide) identifies its watershed boundary. Within many of these boundaries, lakes provide the storage of variable amounts of water. Lakes in British Columbia range in size from 0.1 hectares (ha)[1], such as Hidden Lake in the Lower Mainland to Babine Lake in the Skeena watershed, which is over 46, 500 ha, and even up to the man-made Williston Reservoir of 160,000 ha, located in the northern interior. While size is one of many morphometric parameters used to describe lakes, some important relationships are based on this measure.

Lake Volume to Watershed Size

The relationship between lake volume and watershed size can help determine the potential for a lake to fill with sediment or to be affected by inflowing nutrients. Sediments, nutrients, and pollutants accumulate in water as it flows through a watershed either by erosion, runoff, or intentional waste discharge. In general, the larger the watershed, the greater the potential for this accumulation. Given two similar watersheds, a smaller lake will generally experience a greater sediment and pollutant impact than a larger lake due to the smaller ratio of lake volume to watershed size (see Figure 1.2).

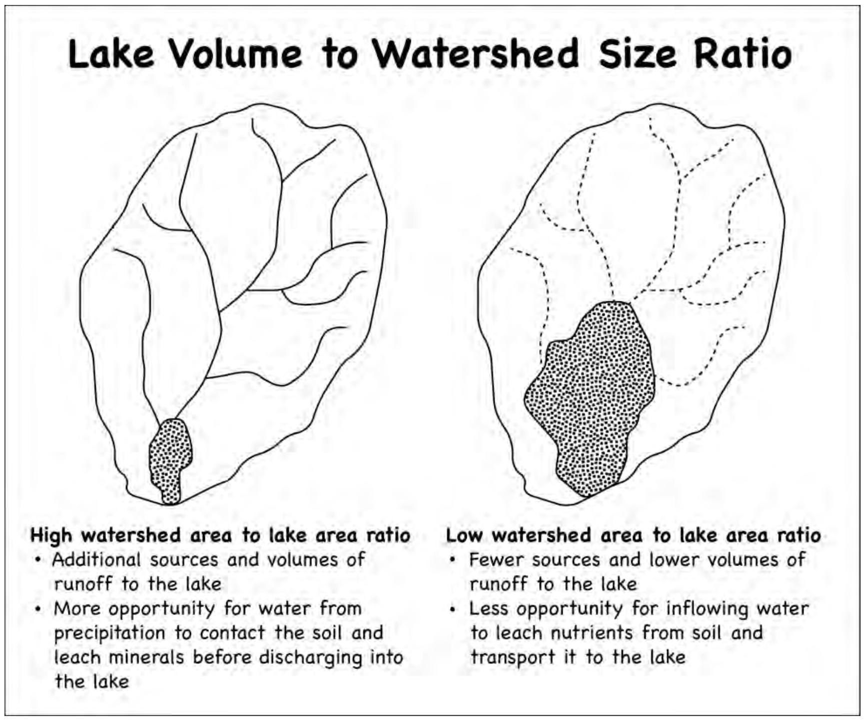


Figure 1.2 Lake volume to watershed size ratio

Lake Water Balance

Lake water balance comes into consideration when precipitation is added to lake volume and watershed size. Knowledge of a lake's water balance is critical to understanding local chemical and biological cycling. If the condition of a lake appears degraded, understanding its water balance is a necessary for effective restoration. This is because water balance influences the capacity of a lake to deal with the incoming nutrients that promote the growth of algae and aquatic plants. If abundant in a lake, algae can develop into unsightly surface blooms and aquatic plants can form thick mats.

[1] See Appendix 1.1 for useful conversions that are helpful in understanding lakes

Water storage is determined by dividing the volume of water delivered to a lake through inputs (surface inflows, groundwater, and direct precipitation) by water outputs (via outlet flows, consumptive uses, and evapotranspiration) and using the lake volume itself. A lake's water balance is most often thought of in terms of its water exchange rate by incorporating lake volume. **Water exchange rate** can be defined as the rate of water replacement or the number of times the lake water volume is replaced each year. Its unit of measure is times/year. Conversely, **retention time** is the duration that the lake-volume equivalent of water remains in the lake and is measured in years.

Depending on the lake, retention may be a few days or many years. Lakes that flush rapidly usually have large inflowing and outflowing rivers. These rapidly flushing lakes are often just enlarged sections of a river. Slower flushing lakes are large relative to their inflows and/or may rely primarily on direct input from precipitation and groundwater seeps. Fraser Lake in the BC's central interior has a high flushing rate of 1.6 times per year. Near the other extreme, Okanagan Lake has a rate of 0.017 times per year. Their respective retention times are 0.6 and 60 years.

The flushing rate of a lake is one of the important factors influencing water quality. If a lake flushes rapidly, pollutants may be removed before they are incorporated into long term cycling within the lake where they can substantially impair water quality. With a slow flushing rate, internal cycling becomes a much larger factor in determining water quality.

Lake Shoreline Length to Surface Area

The ratio of lake shoreline length to lake surface area (the **shoreline development ratio**, D_L) is of interest because it suggests the degree to which biological development within the productive near-shore zone

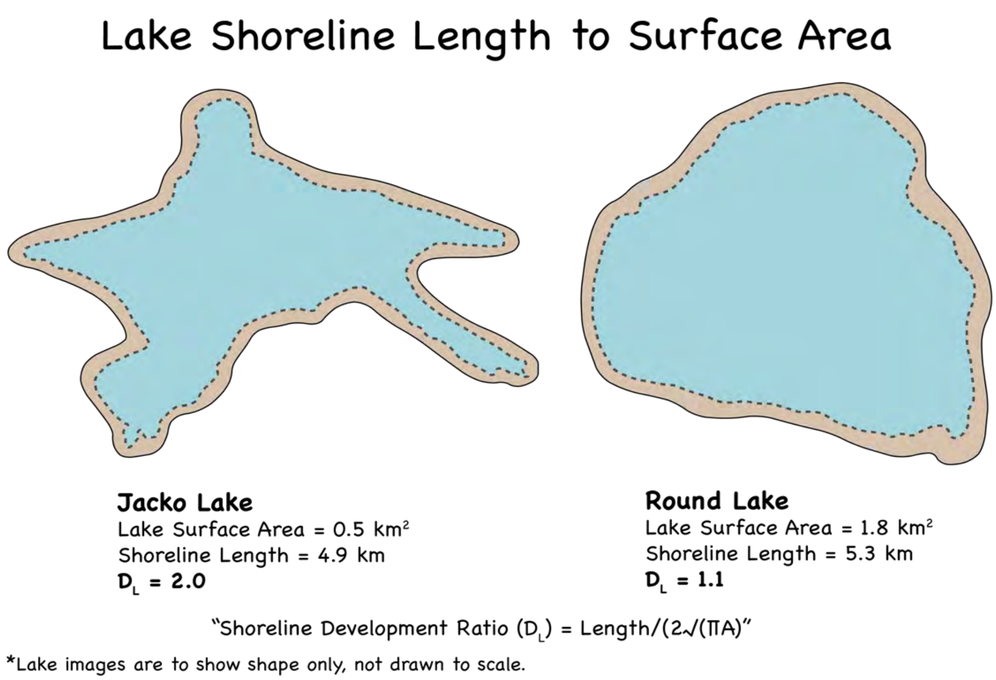


Figure 1.3 Lake shoreline length to surface area

will contribute to overall lake productivity. A lake with a long shoreline relative to lake surface area (i.e., one with many points and bays) contains proportionally more shallow water habitat than a simple circular water body. More habitat implies more biological (including fish) production. Figure 1.3 illustrates the effect of shoreline and surface area on the shoreline development ratio.

Lakes with high shoreline development ratios may appear able to accommodate relatively high amounts of shoreline cottage development. In fact, their abilities to assimilate pollutants may be similar to a circular lake where less development may be permitted from a visual point of view.

KEY TERMS

Morphometry: Referring to the size and shape of a lake.
Water Exchange Rate: The amount of water replaced in a lake over a period of time.
Retention Time: The number of years that a lake-volume equivalent of water remains in a lake.
Shoreline Development Ratio (or Index): A number that relates the measured shoreline length of a given lake to the shoreline length of a perfectly circular lake of equal area.

1.2.2 WATER DENSITY & LAKE TEMPERATURE

BC lakes can show a variety of annual temperature patterns depending on their location within the province, their altitude, and their basin morphometry. Most of our lakes form layers (stratify) on a seasonal basis with the coldest summer water near the bottom (Figure 1.4-A). Temperature stratification patterns are very important to lake water quality. They determine much of the seasonal oxygen and algal conditions within the lake. When abundant, algae can create problems for lake users.

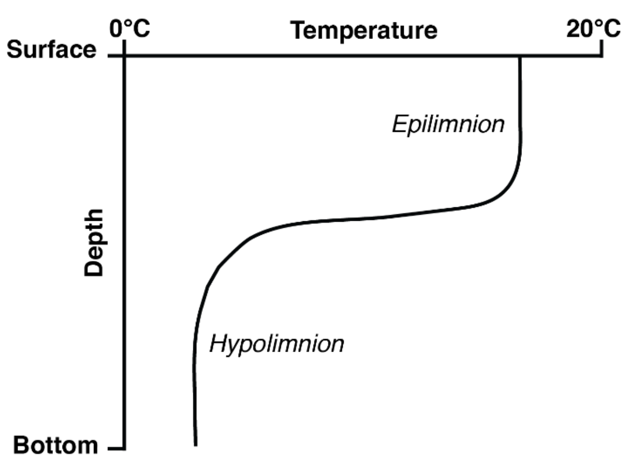


Figure 1.4-A Summer temperature profile

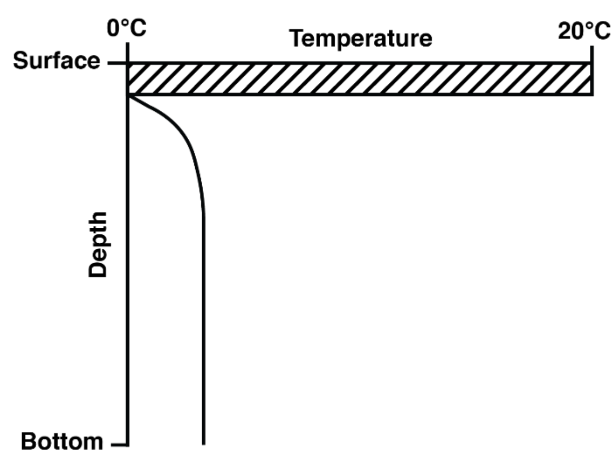


Figure 1.4-B. Winter temperature profile

Thermal stratification is a physical response to the effect of solar heating to water's properties of temperature and density. Water is most dense or heaviest at 4°C. Generally, water density *decreases* as temperature *increases* as seen in Figure 1.5. Warm water is less dense than cold water, so it tends to overlay cold water. But as we all know when we walk on a frozen lake, this relationship cannot hold across the entire temperature range. If it did, ice would form on the bottom of lakes.

Ice floats due to the expanded volume of water molecules when in the solid, crystal phase. Together, these molecules cause water to actually expand as it freezes. Ice is slightly less dense and thus a bit lighter than water. As noted above, water is most dense at 4°C – not at 0°C when it freezes. Accordingly, the bottom water temperature of most lakes should not decrease below this 4°C minimum and overlying water should be either warmer (in summer) or colder (in winter) (Figure 1.4-A & B). Water density decreases as temperature increases for temperatures exceeding 4°C.

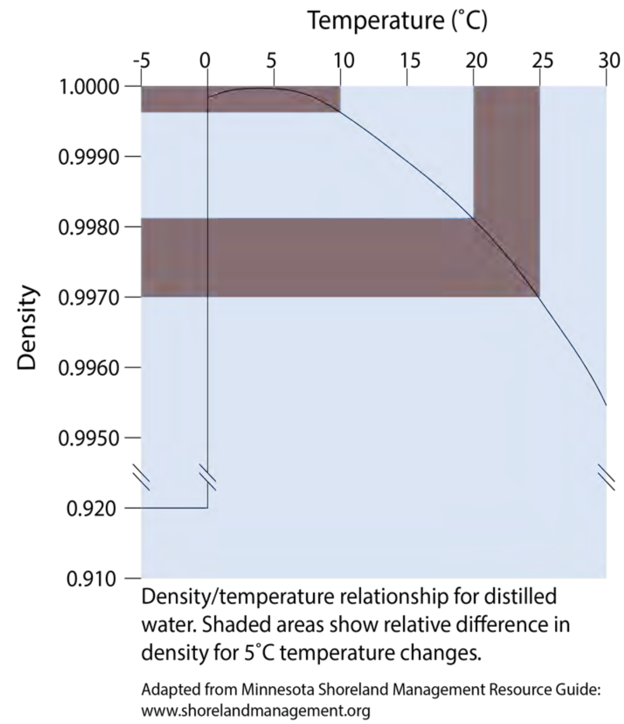


Figure 1.5 Density changes in water *Source: Minnesota Shoreland Management Resource Guide, retrieved April 2019 from* **www.shorelandmanagement.org**

1.2.3 LAKE TEMPERATURE PATTERNS

Let's consider how this temperature/density relationship functions on a seasonal basis. Refer to the related figures on the following pages.

Duncan Lake. Source: Emily Gutenberg.

Spring

During the spring season, lakes lose their ice cover with the onset of solar heating. Soon after this loss of ice, lakes become completely mixed as wind energy overcomes the reduced temperature and density differences between surface and bottom waters. Water temperature and density are similar throughout the lake depth (**isothermic**) and a complete mixing of water, oxygen, and nutrients can occur. This replenishing of the lake water is known as **spring overturn**. Depending on the **lake fetch** (alignment and exposure to dominant wind direction), wind strength, rate of solar heating, and lake depth, overturn may last from days to weeks. Figure 1.6 shows a typical spring overturn, where nutrients from land carried by water to the lake, and nutrients from the bottom are all mixed throughout the water column by wind. The typical spring and fall temperature profile is shown in Figure 1.7. These conditions also occur in the fall as will be discussed further on.

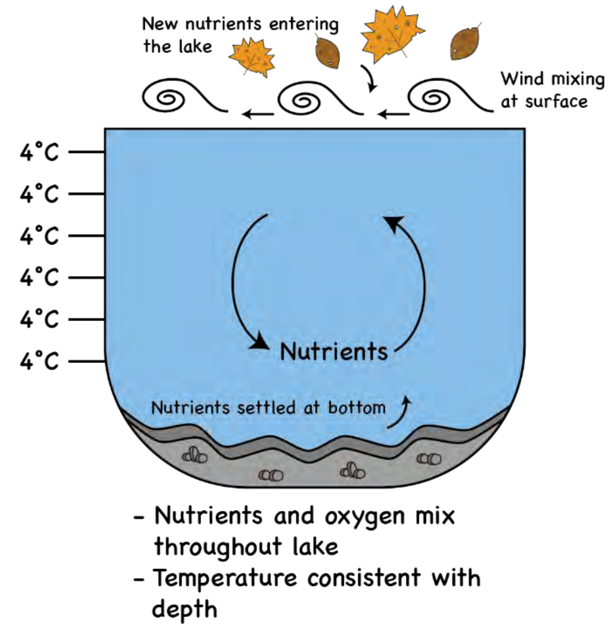


Figure 1.6 Spring (or fall) overturn in a lake

As solar heating continues to warm the lake surface, density differences between surface and bottom waters eventually overcome the energy necessary to mix colder, denser water from the lake bottom up to the surface. At this time, the lake separates into layers based on the temperature/density relationship, and **summer stratification** is said to begin. In years when hot weather onsets quickly in the spring, solar heating can result in incomplete mixing of nutrients and no re-oxygenation of bottom waters.

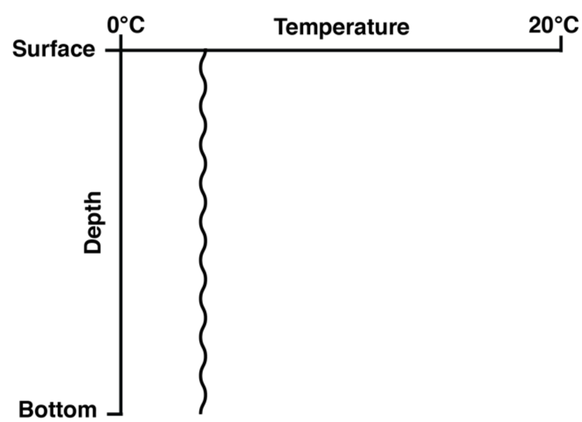


Figure 1.7 Spring and fall temperature profile

Summer

This stratification, which is usually quite well defined in medium to deep lakes, involves three layers. The top layer, known as the epilimnion, is comprised of relatively warm, well mixed water in direct contact with the atmosphere. The middle **thermocline**, or **metalimnion**, is defined by a temperature change of at least 1°C per vertical meter and marks the transition between the top and bottom layers. This temperature/density gradient can be very sharp and can effectively prevent the mixing of the top and bottom layers. The bottom layer, the hypolimnion, is comprised of uniformly cold (as low as 4° C) and relatively undisturbed water that is not exposed to the atmosphere.

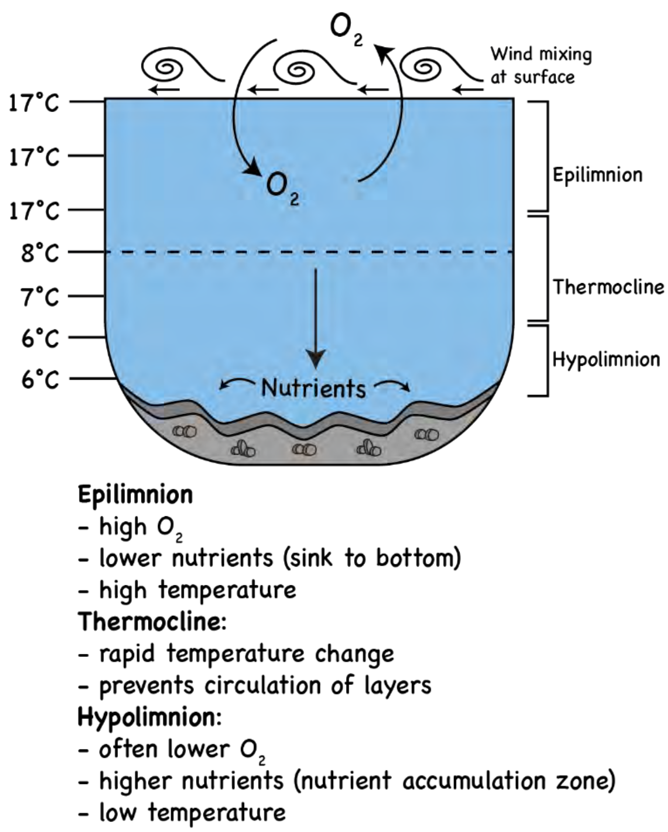


Figure 1.8 Summer thermal stratification in a lake

Stratification in moderately deep and deep lakes will be maintained through the summer, with the thermocline often reaching a depth of six to nine metres in medium sized BC lakes. In large lakes (e.g., Okanagan Lake) the thermocline can be 20 to 40 metres deeps. Wind circulates the waters of the epilimnion during this period. Deeper, cold water will not mix and remains isolated from the atmosphere until the fall overturn. Figure 1.8 shows a typical summer thermal stratification for moderate to deep lakes.

Shallow lakes, less than six metres deep, can remain completely mixed through the summer depending on wind strength and surrounding topography. Lakes of up to nine metres depth may de-stratify for short periods during summer wind events. This can have particular influence on **nutrient cycling** in such lakes.

Fall

During the fall, with its shorter days and reduced solar energy, the **epilimnion** cools so that the temperatures of this and the hypolimnion approach uniformity. At this time, wind energy once again overcomes whatever minor density differences exist and the entire lake volume will mix. Fall overturn is typically longer than the spring overturn, lasting from the point at which epilimnion and **hypolimnion** temperatures converge, gradually decreasing to a uniform 4 °C to 8°C, and in the interior, to the start of winter stratification. Figure 1.6 shows a typical fall (or spring) overturn with vertical mixing.

Winter

In winter, the ice that typically covers most interior BC lakes will prevent wind from mixing lake water. To follow from our discussion on water density, water that is at 4°C will occupy the bottom of the lake. A narrow layer of overlying water, just beneath the 0°C ice, will be similar to the ice temperature. This reverse stratification sees warmer water near the bottom. The density gradient formed by the ice at 0°C at the top progressing to water at 4°C near the bottom prevents mixing from occurring (known as winter stagnation). Figure 1.9 displays the winter conditions of an ice-covered lake. The winter pattern of shallow lakes tends to be similar to that of deeper lakes. Coastal lakes that lack ice cover will maintain the fall overturn thermal structure and remain mixed through the winter period. In summary, the annual thermal stratification cycle of a moderate to deep BC interior lake is presented in Figure 1.10.

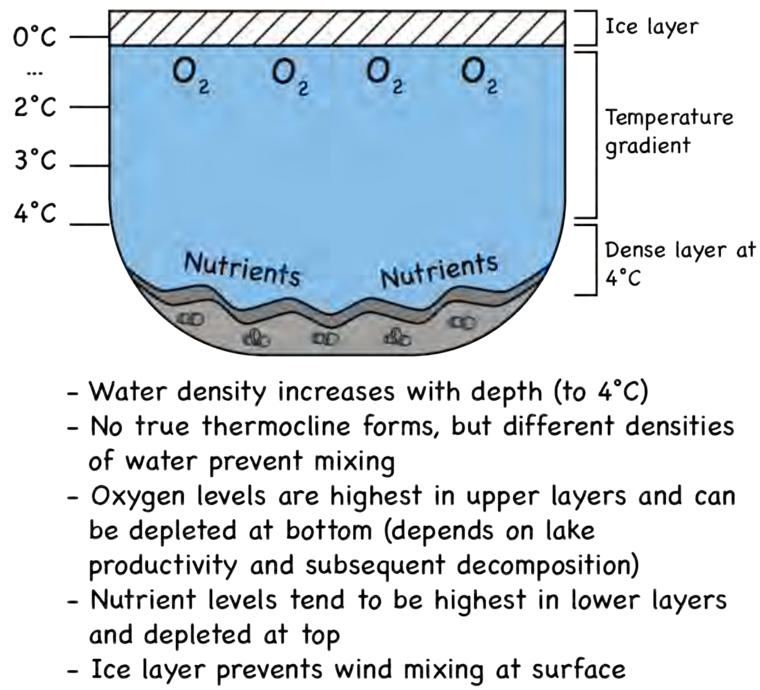


Figure 1.9 Winter thermal stratification in a lake.

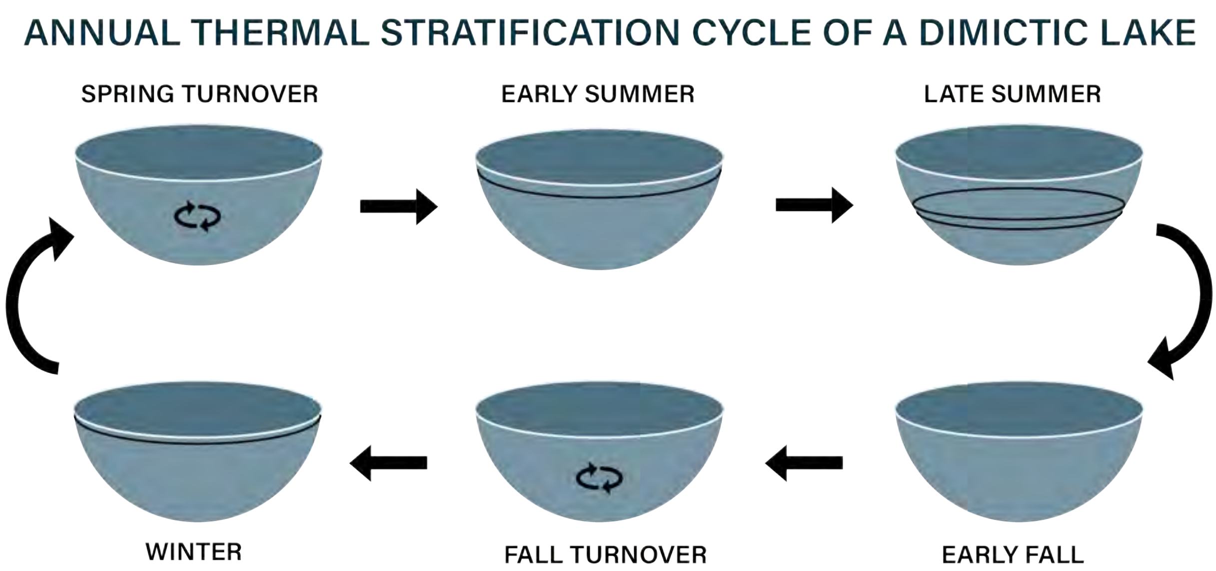


Figure 1.10 Annual thermal stratification cycle of a dimictic lake

Seiche waves can also result in lake mixing as underwater currents are generated which can cause bottom water to come to the surface and can mobilize lake sediments and carry them into the water. See Appendix 1.2 for more information on seiches.

KEY TERMS

Isothermic: Lake conditions that present consistent or similar water temperatures at varying depths.
Spring Overturn: Seasonal springtime mixing of lake layers separated by density due to temperature.
Lake Fetch: A lake's position relative to wind direction and flow defined as the surface area of a lake over which the wind blows constantly, generating waves.
Summer Stratification: Seasonal summertime separation of lake water into layers based on density due to temperature.
Epilimnion: The upper, well-mixed, well-illuminated, nearly isothermal region of a typical stratified lake. Above the metalimnion (thermocline).
Thermocline/ Metalimnion: The zone in which the largest relative temperature change occurs with depth during lake thermal stratification.
Hypolimnion: Lowermost, noncirculating layer of cold water in a typical, thermally stratified lake, usually deficient in oxygen. Lies below the thermocline.
Nutrient Cycling: The movement of inorganic compounds from nutrient reservoirs through trophic levels and abiotic components.
Seiche: Standing or oscillating wave in an enclosed or partially enclosed body of water.

Horn Lake. Source: Chris Swan

1.2.4 LAKE STRATIFICATION SCHEMES

Lakes can be classified based on their annual stratification patterns. Stratification is affected by the interaction of climate, latitude, altitude, and lake morphometry. Stratification is a key factor in determining the **biological productivity** in a lake. The following classification system was introduced by Hutchinson and Loffler in 1956 and is widely used today. Table 1.1 outlines definitions of lake types in BC.

Table 1.1 Defining lake types	
Lake Type	**Definition**
Amictic Lake	Amictic lakes are sealed off perennially by ice due to low temperatures. These lakes are rare and are mainly found in Antarctica or on very high mountains. The heating of these lakes comes from light transmission through ice and conduction of heat through sediments.
Cold Monomictic Lake	Cold monomictic lakes have a water temperature that never exceeds 4°C and a period of circulation in the summer. These lakes are mainly found in the Arctic mountains and usually have some contact with glaciers or permafrost.
Warm Monomictic Lake	Warm monomictic lakes have temperatures that do not fall below 4°C. They do not freeze, circulating freely in the winter at or above 4°C, and stratify directly in the summer. They are found mostly in warm regions of temperate zones. BC coastal lakes are usually warm monomictic.
Dimictic Lake	Dimictic lakes circulate in the spring and fall and stratify in the summer due to solar heating and in winter due ice cover. This is the most common type of lake in the interior of BC.
Oligomictic Lake	Oligomictic lakes are characterised by a rare circulation at irregular intervals and have a temperature that is always above 4°C. This type of lake is primarily found in the tropics, but there are examples in BC.
Polymictic Lake	Polymictic lakes have frequent and continuous circulation. These lakes can be classified as cold or warm. Cold polymictic lakes circulate continually at temperatures near 4°C and are usually large in size and moderately deep. Warm polymictic lakes circulate frequently at temperatures well above 4°C. These lakes are usually tropical.
Meromictic Lake	Meromictic lakes do not undergo complete circulation. The primary water mass does not mix with a lower portion. The deeper layer of water is perennially isolated. The upper layer of water mixes periodically. These two layers are separated by a steep salinity gradient. Examples in BC include Sakinaw Lake and Powell Lake on the coast, and Mahoney Lake and Lyons Lake in the interior.

KEY TERMS

Biological Productivity: The total amount of organic matter or equivalent in energy accumulated in an ecosystem.

1.2.5 DISSOLVED OXYGEN PATTERNS

Oxygen is essential to life in lakes. Given that fish breathe oxygen dissolved in water (referred to as dissolved oxygen or DO), the sport fisheries that many of us enjoy are absolutely dependent on water having an adequate supply of this substance. Its concentration also has a great effect on the biochemical nature of a lake. Long term changes in oxygen concentration, especially at the lake bottom, can markedly affect nutrient availability and alter the productivity of the entire lake. As such, oxygen is one of the most important resources influencing lake management. Its measurement should be part of any lake sampling program.

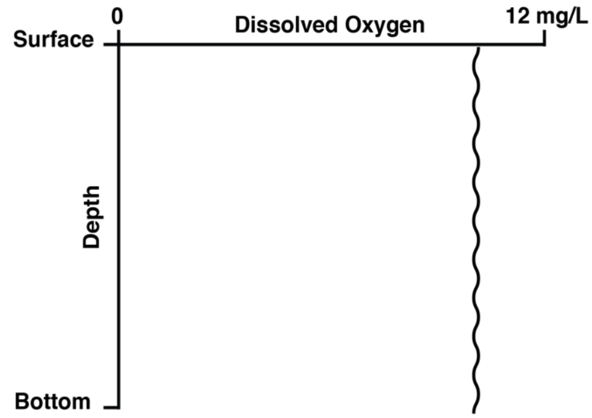


Figure 1.11 Spring & fall dissolved oxygen profile

Spring & Fall

Oxygen concentration and cycling are mainly dependent on lake thermal stratification patterns, and like temperature, are seasonally variable. During both spring and fall overturn, oxygen in the water column is brought close to equilibrium with atmospheric concentrations by diffusion across the water surface. If the duration of a lake's overturn is long enough, water at all depths will become saturated with oxygen. A vertical oxygen profile at this time would show similar concentrations from surface to bottom. Figure 1.11 to shows a typical spring or fall oxygen profile for BC lakes.

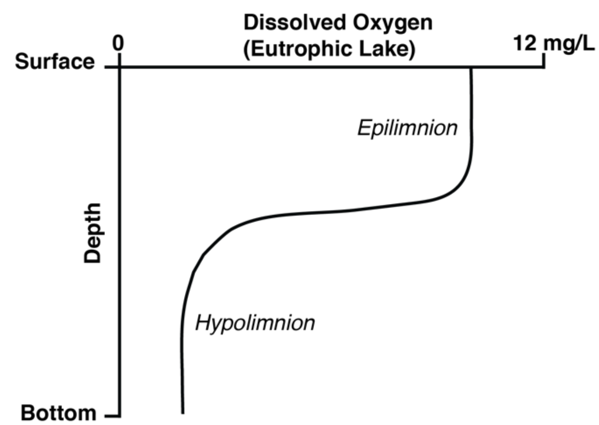


Figure 1.12 Summer dissolved oxygen profile – eutrophic lake

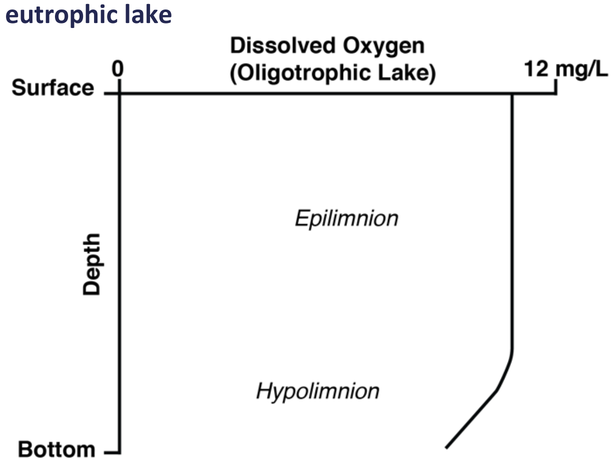


Figure 1.13 Summer & winter dissolved oxygen profile – oligotrophic lake

Summer

With the onset of summer stratification, the lake's vertical oxygen profile will begin to change. Epilimnion waters have surface contact with atmospheric oxygen, allowing diffusion into the water, and also receive light, allowing oxygen production by the photosynthetic action of rooted aquatic plants and suspended algae. Oxygen in this surface layer will remain abundant through periods of stratification. It will not, however, be available to underlying waters. The thermocline typically marks the depth at which oxygen concentrations may begin to decrease, with the decline often being dramatic in eutrophic lakes. Waters of the hypolimnion have no contact with atmospheric oxygen during summer and winter and are too dark to support most photosynthetic algae. The oxygen supply here is seasonally limited. Figure

1.12 shows a typical summer oxygen profile for a eutrophic BC lake and Figure 1.13 shows a typical oxygen profile for an oligotrophic lake in summer or winter[2].

The breakdown of organic (plant and animal) matter is ongoing and is carried out mainly in the hypolimnion and particularly in the lake sediments. Because this decomposition is performed by aerobic bacteria (using respiration), oxygen loss can occur. Aerobic breakdown of large amounts of organic matter could eventually render the entire hypolimnion devoid of oxygen if demand outstrips the limited supply. This depends on the volume of the hypolimnion, the duration of stratification and the amount of organic matter loaded to that zone annually.

Winter

Winter thermal stratification is less evident than that of the summer because temperatures range from only 0°C at the surface to roughly 4°C near bottom. However, the supply of oxygen to the deep water may be even more limited than during summer because of the impermeable layer of surface ice, which isolates the entire lake from atmospheric exchange. With protection from wind, subsurface currents can be minimal, slowing oxygen supply to the deep water. Oxygen depletion in the hypolimnion of ice-covered lakes can develop and may be extreme during late winter. Lakes that are clear and biologically unproductive will have sufficient oxygen to support life at all depths through periods of stratification. However, as lakes become more productive and increasing quantities of plants and animal life such as zooplankton respire and decay, more oxygen consumption occurs, especially near the bottom where dead organisms accumulate. Figure 1.13 to shows a typical oxygen profile for an oligotrophic lake in summer or winter[2], and Figure 1.14 shows a typical winter profile for a eutrophic lake.

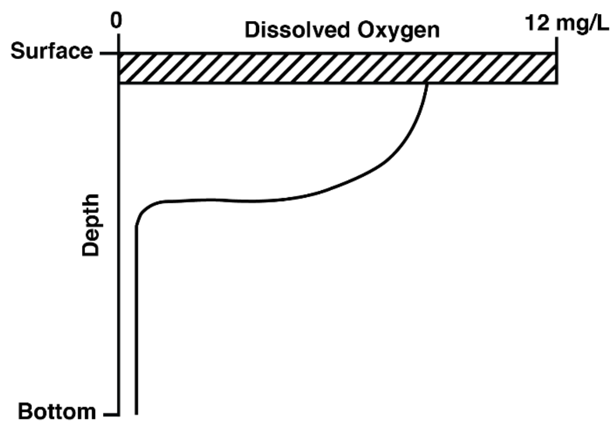


Figure 1.14 Winter dissolved oxygen profile – eutrophic lake

In productive lakes, oxygen in the isolated bottom layer may decrease rapidly, forcing fish to move into the upper layer (this because fish are stressed when oxygen falls below about 20% saturation). Fish kills can occur when decomposing or respiring algae use up the oxygen. In summer or fall, this can happen on calm nights after an algal bloom, but most fish kills occur during late winter or at initial spring mixing.

K E Y T E R M S

Oligotrophic: The condition of having a relatively low concentration of nutrients.
Eutrophic: The condition of having a relatively high concentration of nutrients.

[2] Actual dissolved oxygen may be lower in winter but the profile pattern would be similar in summer & winter with only a slight decrease in dissolved oxygen near the bottom in oligotrophic lakes

1.3 LAKE NUTRIENT DYNAMICS & BIOLOGICAL PRODUCTION

The next few discussions address concepts of biological production, oxygen concentration and phosphorus.

1.3.1 TROPHIC LEVELS

Biological systems are made of two basic food levels, or **trophic levels**: producers and consumers. Producers are organisms that create organic matter. Through **photosynthesis**, primary producers (e.g., algae and plants) convert carbon dioxide, water, and sunlight into organic matter. Consumers utilize this organic matter. **Herbivorous** animals, some types of insect larvae, zooplankton, and fish, consume algae and plants. **Carnivores**, many amphibians, fish and birds for example, feed on these herbivores. The lake trout is a good example of a peak consumer, living at the top of the BC freshwater food chain.

Another type of consumer includes **detritus**-eating snails, insects, and worms, and the **decomposers**, namely bacteria and fungi. Decomposition, the breakdown of organic matter to its various chemical constituents, is preferentially aerobic, but can occur more slowly without oxygen. This decomposition is important in recycling nutrients back into the lake system. Together, all these organisms take part in the unique chemical and biological cycles of a lake and play a vital role in producing, consuming, and recycling

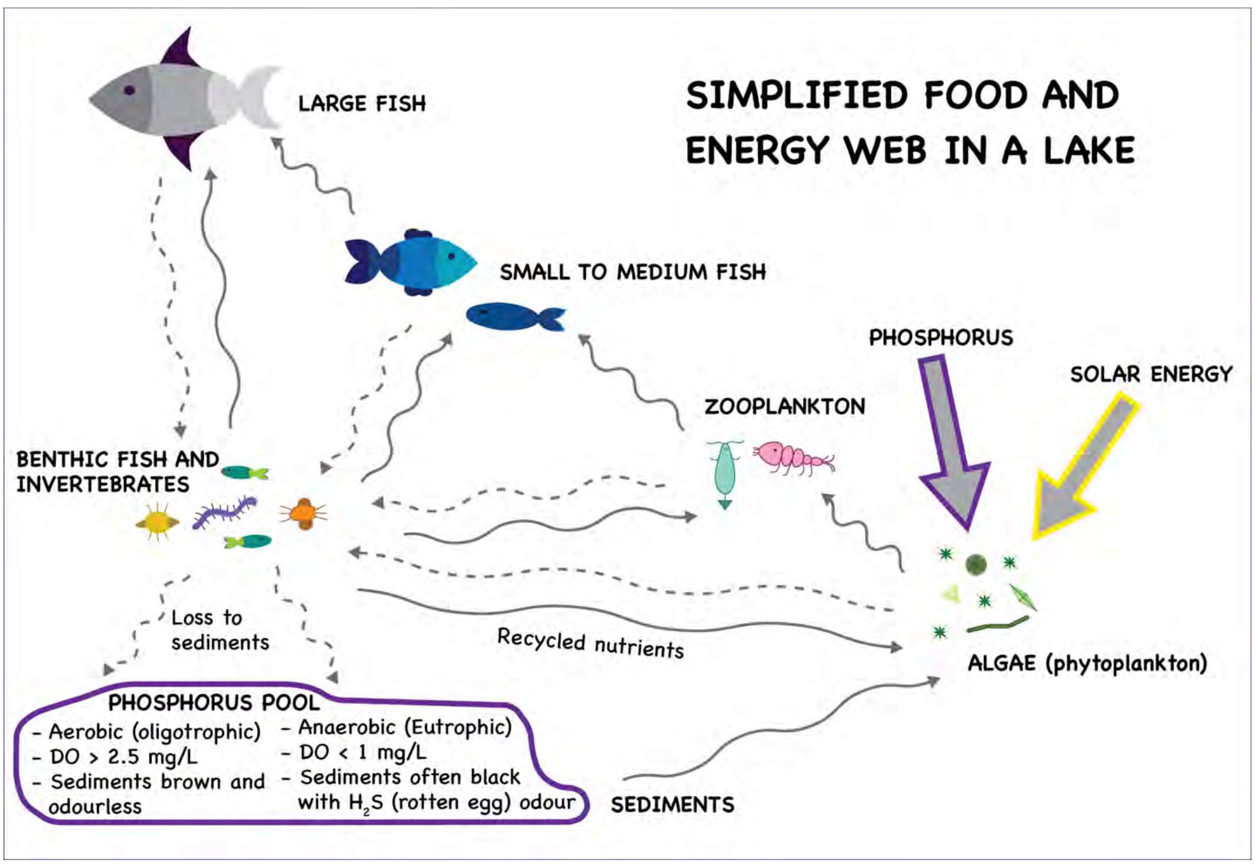


Figure 1.15 Lake food web example

nutrients and organic matter. Food chains and food webs are two types of diagrams representing feeding relationships between organisms. A food chain shows a single pathway of energy, whereas a more complex food web shows multiple pathways between organisms at different trophic levels. Figure 1.15 presents a lake food web example. In Figure 1.15, solid arrows represent energy moving to higher trophic levels (such as zooplankton consuming algae) and broken arrows represent energy moving to lower trophic levels in the form of detritus (such as dead or decaying fish).

KEY TERMS

Trophic Levels: Positions in a food web occupied by a group of organisms with similar feeding modes
Photosynthesis: The chemical process by which plants convert sunlight, carbon dioxide, and water to energy (sugars) to live and grow.
Herbivore: An animal that obtains its energy from consuming plants.
Carnivore: An animal that obtains its energy from consuming other animals.
Detritus: Material that consists of decaying, decomposing organic matter (often dead plants or animals).
Decomposer: An animal that obtains its energy from consuming dead or decaying matter.

1.3.2 LAKE ZONES

A lake can be divided into three main zones based on light penetration and biological productivity. These are the **littoral, pelagic** and **profundal** zones. Figure 1.16 portrays typical lake zones.

The **littoral zone** is typically that part of a lake between the shoreline and the maximum depth to which rooted aquatic plants grow. It is the zone where sunlight reaches the bottom in sufficient amounts to

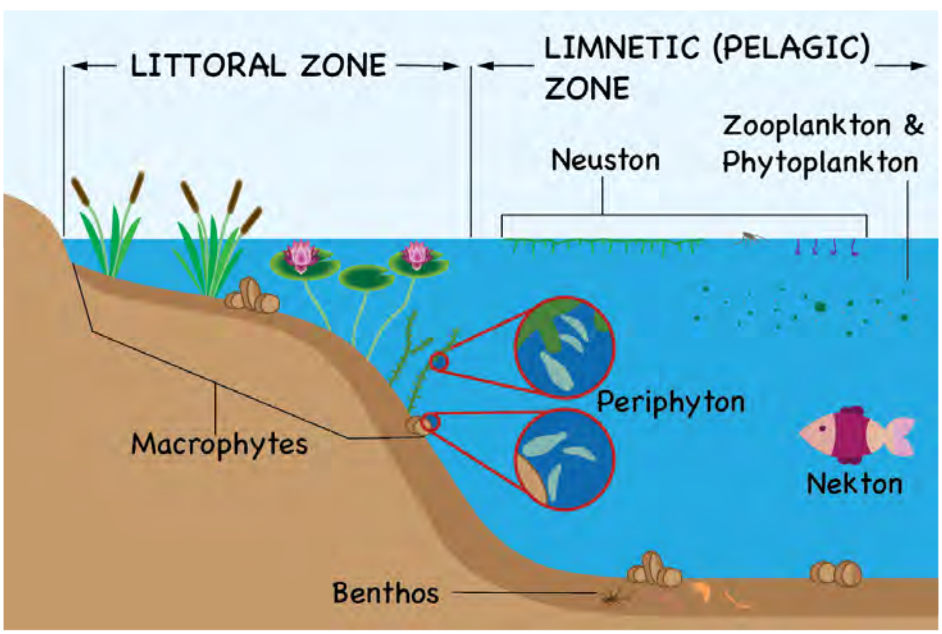


Figure 1.16 Lake zones

promote plant growth, however in very clear lakes, pressure may limit rooted aquatic plant growth. The littoral zone may include shallows that extend for a considerable distance from shore. The depth of this zone depends largely on water clarity. Turbidity, highly-coloured water or dense algal blooms will limit the depth to which sunlight penetrates, and thus the depth of macrophyte growth. Figure 1.17 presents plant types around and in the littoral zone.

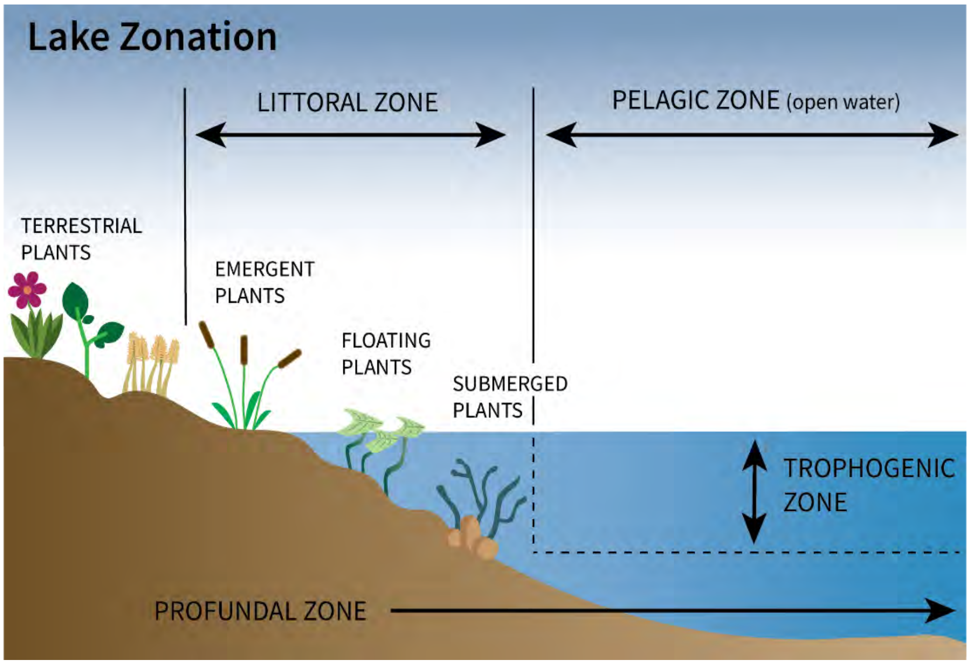


Figure 1.17 Plants and the littoral lake zone

The littoral zone contains *producers* of organic matter that include rooted plants and those algae (periphyton) attached either to plant surfaces or to the shallow lake bottom. Aquatic plants may be emergent (rooted but with part of their structure above the water surface, such as cattails) or rooted and submerged (e.g., milfoils and pondweeds). Most aquatic plants derive their nutrition from the substrate into which they are rooted. Periphyton (and some aquatic plant species) on the other hand, derive nutrition from the surrounding waters. Littoral *consumers* of organic matter include zooplankton, flat worms, insect larvae, snails, amphibians, fish, and humans. Much of a lake's fish production can be determined by the extent of its littoral zone.

The **profundal (benthic) zone** is the main sediment zone of a lake, or simply the lake bottom that exists beyond the littoral zone. It is that portion of the lake bottom sediment that, because of lack of light and pressure with depth, is free of rooted vegetation. Organic producers are generally absent from the profundal zone. Consumers are represented by a variety of worms, insect larvae, fungi, and bacteria. These organisms decompose organic matter that settles to the bottom sediments, releasing inorganic nutrients and carbon dioxide (CO_2), and if oxygen is lacking, methane (CH_4) and hydrogen sulphide (H_2S).

The **pelagic (limnetic) zone** is the main open water portion of a lake, beyond the extent of rooted vegetation and above the profundal sediments. **Phytoplankton** (algae that live in the water column) are the main organic producers of this zone. Consumers include **zooplankton** (e.g., the water flea *Daphnia*), swimming insects, fish, and humans. Depending on the fish species, they may feed entirely within the **pelagic** zone (e.g., kokanee strain zooplankton from the pelagic waters) or may preferentially feed along the weedy margins of the littoral zone (rainbow trout search out insects as they "emerge" from the shallow muds). As with plants in the littoral zone, algal production within the pelagic zone will be determined primarily by water clarity and nutrient availability. The **trophogenic zone (or photic zone)** is the portion of the upper pelagic zone where light is adequate to support the photosynthesis of planktonic algae.

Riparian zones are the transition areas between aquatic and dry, upland habitats and are seasonally inundated with water. They are also very important areas to lakes and are illustrated in Figure 1.18.

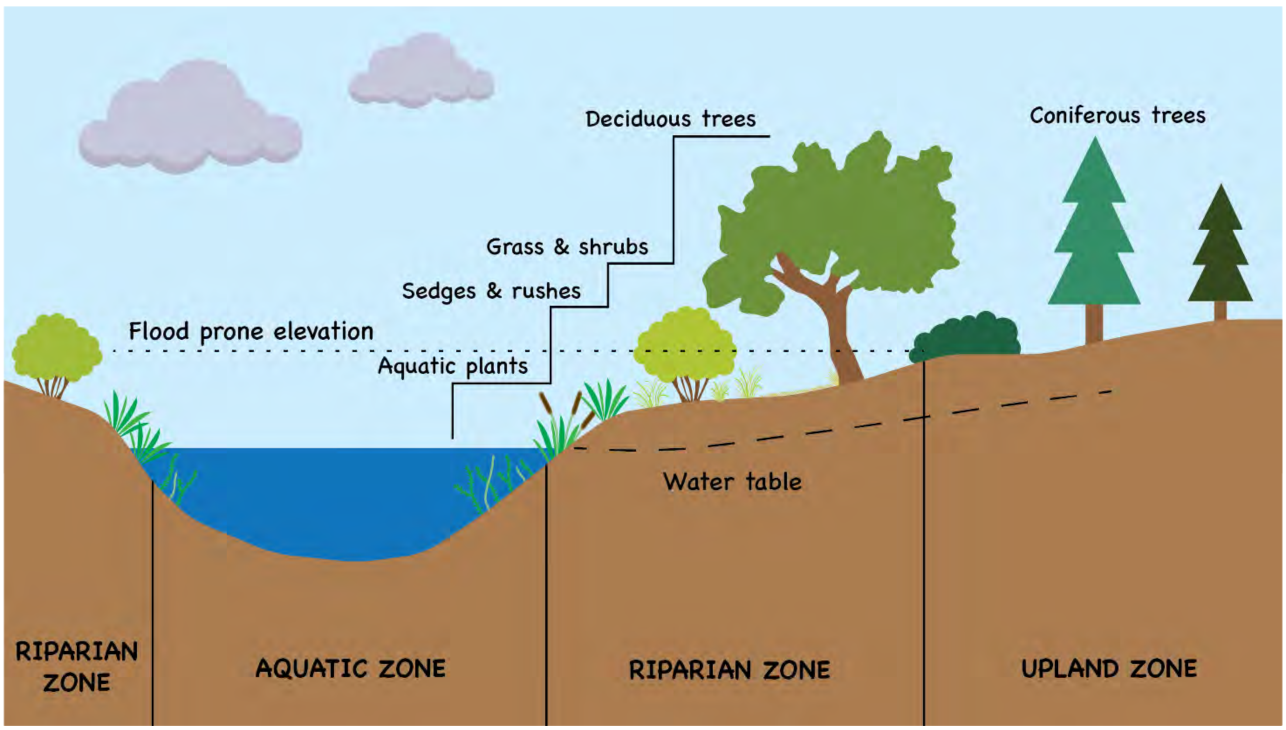


Figure 1.18 Lake riparian zone

KEY TERMS

Littoral Zone: The lake zone between the shoreline and maximum depth aquatic plants can grow.

Profundal (Benthic) Zone: The bottom zone of a lake.

Pelagic (Limnetic) Zone: The middle, open-water zone of a lake.

Riparian Zone: The area of land bordering streams, lakes, and rivers containing moist soils and moisture-loving plants that is seasonally inundated with water.

Phytoplankton: Algae that live in the water column.

Zooplankton: Microscopic animals that live in the water column and feed on phytoplankton.

Trophogenic zone: The zone of a lake where sunlight reaches so photosynthesis/algae growth can occur. In this zone, the rate of photosynthesis is greater than the rate of respiration by phytoplankton. Also referred to as the photic zone.

Cyanobacteria: Known as blue-green algae that are bacteria with a simple cell structure. They are distinguished from other bacteria by the presence of chlorophyll-a and their ability to photosynthesize like plants in the aquatic system.

Periphyton: Microbial growth upon substratum including living or dead, plant, animal, or non-living.

Nekton: Animals capable of swimming independently of turbulence

Neuston: Microscopic organisms adapted to living on the upper surface and underside of the surface film on the air-water interface.

Alouette Lake. Source: BCLSS Files.

1.3.3 LAKE TROPHIC STATUS & PHOSPHORUS

The term **trophic status** is used to describe a lake's level of productivity. It depends on the amount of nutrient available for plant growth, both of floating algae (phytoplankton) and rooted plants (macrophytes). Algae are important to the overall ecology of a lake because they use nutrients to produce organic matter, and because they are consumed by zooplankton, which in turn are food for other organisms, including fish. **Macrophytes** provide important habitat to many fish species and are the base of littoral zone production.

In most BC lakes, phosphorus is the nutrient in shortest supply relative to need and thus acts to limit the production of aquatic life although nitrogen may also be important in some lakes. When in excess, phosphorus accelerates plant growth and may artificially age a lake. Total phosphorus (TP) in a lake can be greatly influenced by human activities. Refer to Chapter 3 (S.3.4) for more information on phosphorus. Lakes of low biological productivity are referred to as **oligotrophic**, meaning they are typically clear water lakes with low nutrient levels (1-10 µg/L TP**) (**Appendix 1.1), sparse plant life (0 - 2 µg/L of algal chlorophyll a), and low fish production. Lakes of high productivity are **eutrophic**. They have abundant plant life (>7 µg/L algal chlorophyll a), including algae in dense surface blooms, because of the higher phosphorus concentrations (>30 µg/L TP).

These lakes may experience water quality problems that result in oxygen depletion, fish kills, and toxic algal blooms. Lakes with an intermediate productivity are called **mesotrophic** (10- 30 µg/L TP and 2-7 µg/L chlorophyll a) and generally combine the qualities of oligotrophic and eutrophic lakes. These lakes may experience occasional algal blooms.

Figuratively, over the physical life of a lake, oligotrophy could be considered as childhood and eutrophy as old age. Young lakes are often deep, with low nutrient concentrations and high clarity, while very old lakes are often shallow and, because of increased nutrient levels, prone to very high algae and/or plant densities. The foregoing is a generality, and the ontogeny of lake ecosystems is complex and not defined by years.

Lakes can also age artificially by **nutrient pollution**. This can increase replace the effect of natural shallowing and littoral development that is caused by inflowing sediments with phosphorus induced biological production within the trophogenic zone. Natural eutrophication may be macrophyte dominated because of increased littoral sedimentation and shallowing. Artificial or cultural eutrophication may be algal dominated due to the influence of biologically available nutrients transported via wastewater.

The trophic status of a lake can be determined by measuring its biological productivity. The more productive a lake is, the greater its algal growth will be and the less clear its waters become. Water clarity is measured using a **Secchi disk**. Productivity can also be determined by measuring nutrient levels and **chlorophyll** (the green photosynthetic pigment of algae). More can be learned about these measurements in Chapters 3 (S.3.1 and S.3.6).

As illustrated in Figure 1.19, fish production also varies between eutrophic and oligotrophic lakes.

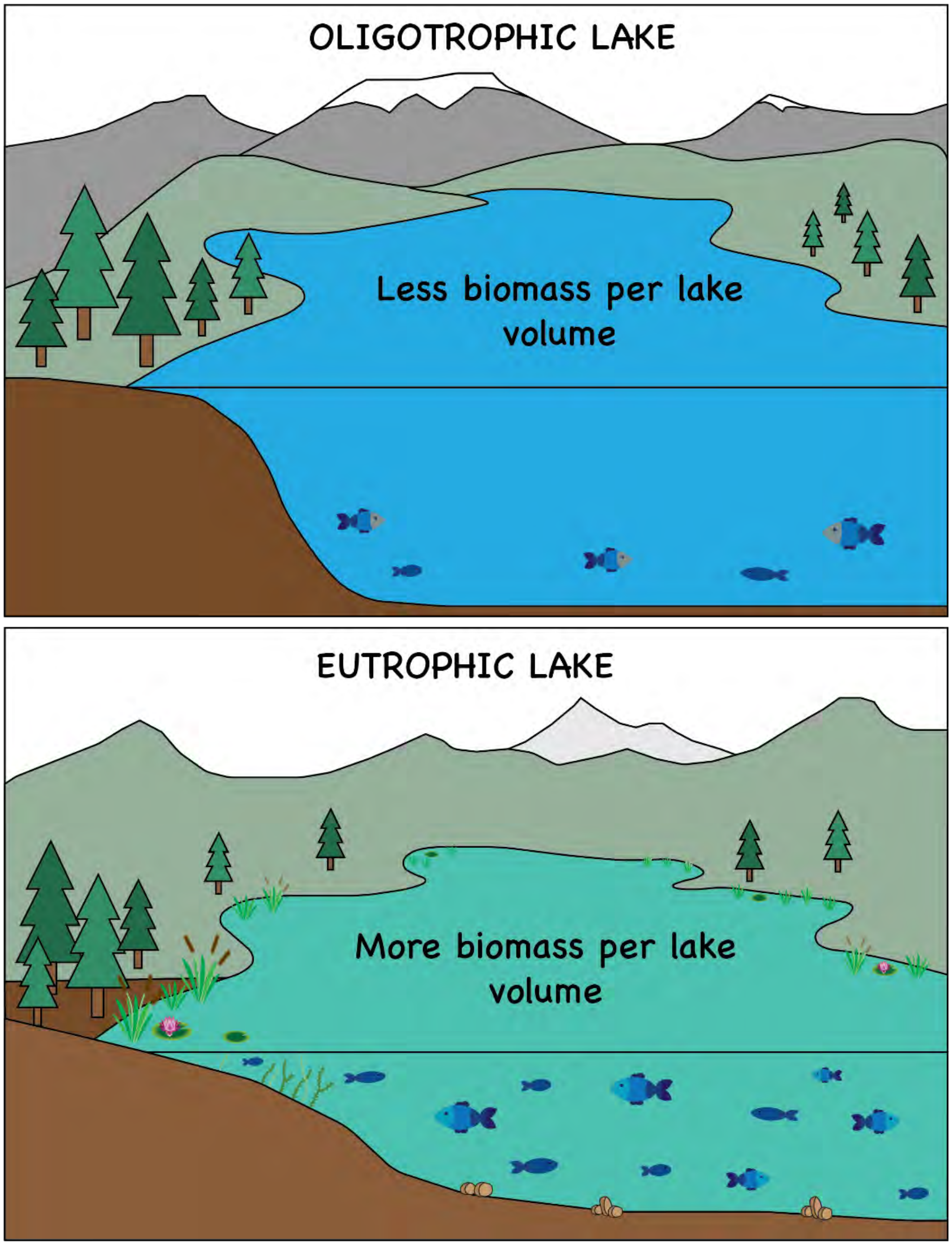


Figure 1.19 Fish production in lakes

K E Y   T E R M S

Trophic Status: the relative biological (algal) productivity of a water body usually assessed by measurement of specific quality parameters including chlorophyll a concentration, water clarity and rate of loss of oxygen from profundal waters.
Macrophytes: Rooted aquatic plants found in the littoral zone of a lake.
Oligotrophic: Relatively low productivity lakes due to low nitrogen and phosphorus levels. Waters of these lakes are usually quite clear due to limited algae and plant growth.
Mesotrophic: The condition of have a moderate amount of nutrients.
Eutrophic: Lakes that have high levels of biological productivity. An abundance of plants is supported by having high levels phosphorus and nitrogen.
Nutrient Pollution: The negative effects in lakes brought on by an excess of nitrogen and/or phosphorus, resulting in exponential algae growth.
Secchi Disk: A marked instrument used for measuring water clarity. The Secchi Disk is usually black and white, and lowered slowly into water and it is noted at what depth it is no longer visible from the surface.
Chlorophyll: The green pigment in plants and algae.

1.3.4 TROPHIC STATUS & OXYGEN

Patterns of seasonal dissolved oxygen are present in every lake. In low productivity lakes, dissolved oxygen remains abundant throughout the lake all year round primarily due to the low amount of organic matter decomposing in the bottom waters. In high productivity lakes, oxygen below the thermocline can decline to the point of **anoxia** (no oxygen), in this case due to a high organic matter content. The implication of this loss of oxygen is discussed in the following section.

K E Y   T E R M S

Anoxia: Water conditions where dissolved oxygen is depleted (insufficient available oxygen is present).

1.3.5 LAKE SEDIMENT & PHOSPHORUS

Energy and nutrients (mainly phosphorus and nitrogen) are used and recycled by life forms ranging from primary producers (algae and rooted plants) to higher level consumers (fish and fish-eating animals, including humans). Note that the major loss of nutrients and biomass (plant and animal wastes and dead organisms) is to the lake outlet and/or to lake sediments.

Following from Section 1.2.1, the portion lost to the outlet is a function of flushing rate, with more nutrients being lost to the outlet in the case of high flushing rate. Most of the biomass and some amount of phosphorus will nonetheless be lost to the bottom sediments. In oligotrophic or mesotrophic lakes, this phosphorus will be stored in the sediments indefinitely, in most cases by way of chemical binding to sediment metals, such as iron, calcium, or aluminum.

To take this situation a step further, lake sediments can themselves be a major source of phosphorus. If deep-water oxygen becomes depleted to an anaerobic condition (anoxia), a chemical shift occurs in bottom sediments. The shift causes sediment iron (or perhaps calcium or aluminum, depending on the lake) to release phosphorus back to overlying waters. This internal loading of phosphorus can be natural but can also be the result of phosphorus pollution and the anoxic conditions that dense algal blooms or beds of aquatic plants can promote. Lakes displaying internal loading are usually of the eutrophic class, have elevated algal levels and generally lack recreational appeal.

In S.1.2.3 it was explained that 9 m lakes discussed above occasionally de-stratify because of wind-induced vertical mixing. In shallow eutrophic lakes, this mid-summer mixing may disrupt conditions of deep-water anoxia where internal phosphorus loading is active. The temporary overturn will transfer hypolimnetic phosphorus up into the productive trophogenic zone where solar radiation at the height of summer is sufficient to allow algae to utilize that phosphorus for its own exponential growth. The result can be massive blooms of algae or cyanobacteria, not just at the normal fall overturn, but also during the mid-summer peak recreational period.

It can now be appreciated that that a lack of dissolved oxygen in a lake's deeper water can cause an increase in phosphorus into the lake's water column and lead to shifts in both lake trophic status and recreational water quality. A great deal can be learned about the health of a lake by studying lake temperature, oxygen, and phosphorus dynamics.

1.4 HUMAN IMPACTS ON WATERSHEDS

Habitat destruction and water pollution are two problems commonly faced by watersheds and the lakes within them. Habitat destruction can occur with any addition to, subtraction from or alteration of features within the lake or streamside (riparian) environment. These alterations can result from trampling, illegal dumping or removal of important habitat features such as vegetation or large woody debris.

There are two primary categories of water pollution: point source and non-point source. Point source pollution originates from a discrete source where discharge is often happening through a pipe or ditch, for example municipal or industrial effluent outfalls. Conversely, non-point source (NPS) water pollution is a more gradual release of pollutants from a variety of diffuse sources, which are largely unregulated, and associated with urbanization, agriculture, forestry, and other forms of land development. Point source pollution is much easier to manage and regulate compared to NPS, and as a result point sources have largely been controlled in North America and many parts of the world.

Non-point source (NPS) pollution is the opposite of point-source pollution, with pollutants released in a wide area. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants from a variety of diffuse sources, finally depositing them into lakes, rivers, wetlands, coastal waters, and ground waters. See the following link for further information **https://www.epa.gov/nps**.

One of the most detrimental effects of NPS pollution is nutrient loading to water bodies. Phosphorus is a key nutrient for plant life, but excess amounts can decrease water quality and pollute lakes. The amount of total phosphorus (TP) in a lake can be greatly influenced by human activities, and if watershed soils and vegetation do not retain this phosphorus, it will enter watercourses and may cause increased algal growth. Following are some common types of non-point source pollution.

Stormwater Runoff

Lawn and garden fertilizer, sediment eroded from modified shorelines or infill projects, oil and fuel leaks from vehicles, snowmobiles and boats, road salt, and litter can all be washed by rain and snowmelt from properties and streets into watercourses. Phosphorus and sediment are of greatest concern, providing nutrients and/or a rooting medium for aquatic plants and algae. Paved surfaces prevent water infiltration to soils, and are potential sources of hydrocarbon and metal contamination, which can runoff into lakes during storm events.

Boating

Oil and fuel leaks are the main water quality concerns of boat operation on lakes. However, boating activities can also cause shoreline erosion from large wakes and churn up sediment and nutrients in shallow water from propeller wash. Other problems include the spread of aquatic invasive plants/animals and the dumping of litter.

Disturbance of sediments from boats in shallow water, in particular wake boats, can dislodge sediment bound pollutants and increase phosphorus and suspended sediment.

Forestry

Timber harvesting can include clear cutting, road building, and land disturbances, which alter water flow and the ability for nutrients to remain stored (sequestered) in soil, potentially increasing sediment and phosphorus inputs to water bodies.

Wildfires

Wildfires can impact water sources such as streams, rivers, and lakes. Potential impacts include changes in the amount and timing of snowmelt and runoff from storms, changes in water quality from build-up of ash, soil erosion, and fire debris. An increase in nutrient loading is typical after wildfires because of increased sedimentation in receiving surface water bodies contributing to eutrophication. There may also be increases in water temperatures due to canopy removal from contributing streams. If fire retardant is present, there may be a possible rise in soil and water chemical levels such as phosphorus (HealthLink BC, 2021).

Recreation

Backcountry activities such as camping, ATV use, fishing and hunting may occur at various times of the year throughout the watershed. Recreational activities can affect water quality in several ways. Erosion associated with 4-wheel drive and ATV vehicles, direct contamination of water from vehicle fuel, and fecal contamination from human and domestic animal wastes (e.g., dogs or horses) are typical examples of potential effects These land-based activities also increase the risk of forest fires within the watershed.

Atmospheric Deposition

Gases and particulates released to the atmosphere from combustion sources such as motor vehicle emissions, slash burning, wildfires, and industrial sources contain nitrogen, sulphur, and metal compounds which eventually settle to the ground as dust or fall to the earth in rain and snow. These contaminants can fall directly into a waterbody, filter slowly into groundwater, or be washed into surface waters with runoff.

Onsite Septic Systems and Grey Water

Onsite septic systems can effectively treat human wastewater and wash water (grey water) if they are properly located, designed, installed, and maintained. When these systems fail, they can become significant sources of nutrients and pathogens to water bodies. Poorly located or maintained pit privies, used for the disposal of human waste and grey water, can also be significant contributors.

Agriculture

Agricultural production of crops and livestock, along with mixed farming activities, can alter water flow and increase sediment and chemical/bacterial/parasitic input into water bodies. Potential sources of nutrients (nitrogen & phosphorus) include chemical fertilizers, manure, and improperly situated winter-feeding areas. Significant amounts of total phosphorus can be transported by sediment inputs when riparian areas are not well maintained near agricultural activities and become degraded. The Code of Practice for Agricultural Environmental Management outlines requirements to minimize the impacts of agriculture on local waterways, including the distances structures and agricultural activities should be kept away from a watercourse (BC ENV, 2020) and should be complied with by farmers and ranchers.

Invasive Species

Plants, fish, and other aquatic organisms that are introduced to new areas often thrive in the new environments where there is a lack of environmental limits or familiar predators. These organisms have the potential to reduce or eliminate native species populations through predation, competition for habitat or resources, or by altering the habitat (Ministry of Environment, 2022). Some common aquatic invasive species in BC include largemouth and smallmouth bass and Eurasian milfoil. Boats and other watercraft, including kayaks and canoes, easily and frequently carry invasive species from one water body to another (ISCBC, 2022). Boaters, anglers, and other recreational users are encouraged to stop the spread by practicing Clean Drain Dry. **Learn more from the Invasive Species Council of BC**.

Humans can impact watersheds in a variety of ways and the following table gives some relevant examples.

Table 1.2: Examples of impacts of human activities on watershed environments	
Habitat Destruction	Pollution
Urban	
Recreation: Trampling and removal of natural features through abuse of wilderness areas (soil, land, water, riparian).	Pollutants deposited directly into the environment through motorized vehicles (cars, boats) soil erosion and sediment deposition at watercourses.
House & Yard Care: Removal of natural vegetation and addition of non-porous surfaces resulting in altered flow patterns and excessive runoff.	Run-off of household chemicals, pesticides, fertilizers, car fluids (oil, gas, antifreeze, and washer fluid), human sewage (from improperly serviced septic tanks) and pet excrement.
Agricultural	
Trampling by livestock with uncontrolled access to stream and lake shores causing damage to vegetation, soil erosion, and deposition of manure.	Run-off of pesticides, fertilizer, and manure, or drugs used to treat livestock. Food processing wastes such as dairy effluent, silo seepage or blood.
Forestry	
Loss of riparian vegetation, building of fish migration barriers at stream crossings, deposition of sediment on spawning habitats.	Erosion of sediments and runoff of pollutants from forest roads and altered habitats (nutrients, pesticides) changes to stream runoff flow patterns.
Industry	
Reduction in plant cover and the addition of non-porous surfaces resulting in excessive run-off.	Point source sediment and chemical discharges and leachates, non-point source run-off. Air pollutants that enter the water system via precipitation.

1.5 LAKES AND CLIMATE CHANGE

Globally, there are more than 100 million lakes, holding 87% of Earth's liquid surface freshwater. The changing climate has impacts on lakes and threatens this important resource. Some of the most pervasive and concerning consequences of climate change on lakes include the loss of ice cover, changes in evaporation and the amount of water available, warming surface water temperature and alterations in mixing regimes. Some of the impacts of these consequences are highlighted below.

1.5.1 IMPACTS OF CLIMATE CHANGE ON LAKES

Decreasing Lake Ice

- Larger lakes with a longer fetch (the maximum distance across a lake where wind can travel without stopping) tend to freeze later, as they are more sensitive to increased wind action breaking up the initial thin layer of ice on the lake surface. Under predicted scenarios of climate warming, deeper lakes with larger fetch are expected to be more susceptible to losing ice cover than shallower lakes within the same region (Woolway et al., 2020).
- Water temperatures in late winter and early spring have been associated with earlier ice break-up for lakes in temperate zones (Woolway et al., 2020).
- With continued climate warming, lake ice break-up is expected to happen earlier. For example, ice break-up is projected to be 10-30 days earlier across the Northern Hemisphere by mid-century (Woolway et al., 2020).
- Earlier ice break-up has already been documented around the world. For example, lakes in Madison Wisconsin have statistics on ice cover that date back to the 1850s. Overall, the average number of days of ice cover on Lake Menona and Lake Mendota has decreased by around 29-35 days over the past 150 years (Climate Wisconsin, 2019).
- Figure 1.20-A and 1.20-B show the duration of ice on two lakes in Madison that have been extensively studied since the 19th century.

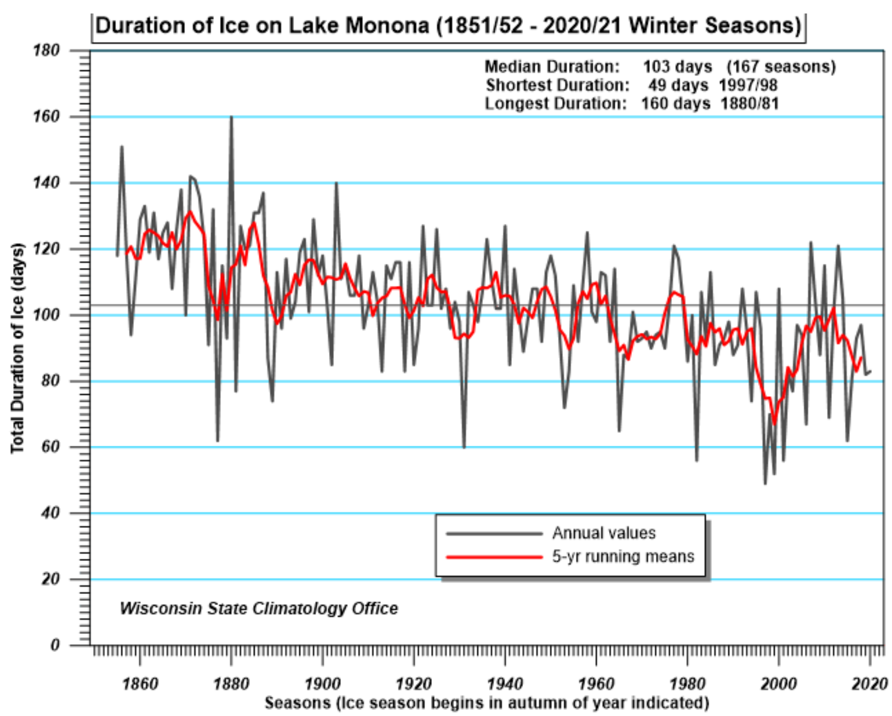


Figure 1.20-A Lake Monona ice duration from 1851 to 2021.

Source: Wisconsin State Climatology Office. Accessed January 11, 2022 from **http://www.aos.wisc.edu/~sco/lakes/msnicesum.html**

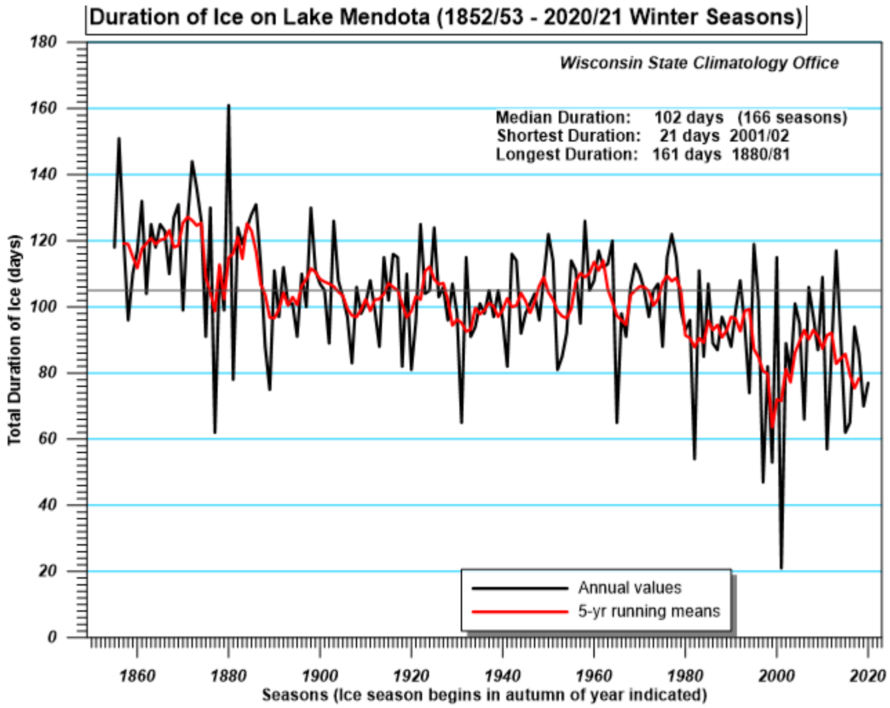


Figure 1.20-B Lake Mendota ice duration from 1852 to 2021.

Source: Wisconsin State Climatology Office. Accessed January 11, 2022 from **http://www.aos.wisc.edu/~sco/lakes/msnicesum.html**

- The decrease in duration of lake ice can be linked to the warming air temperature. On average, the Madison winter has warmed, on average, 2.4°F (1.3°C) since 1940. The warming is even more pronounced in winter than in summer, as seen in Figure 1.21 below with an average increase of 0.04°C per decade in the summer and 0.2°C per decade winter (Gloege, 2021).

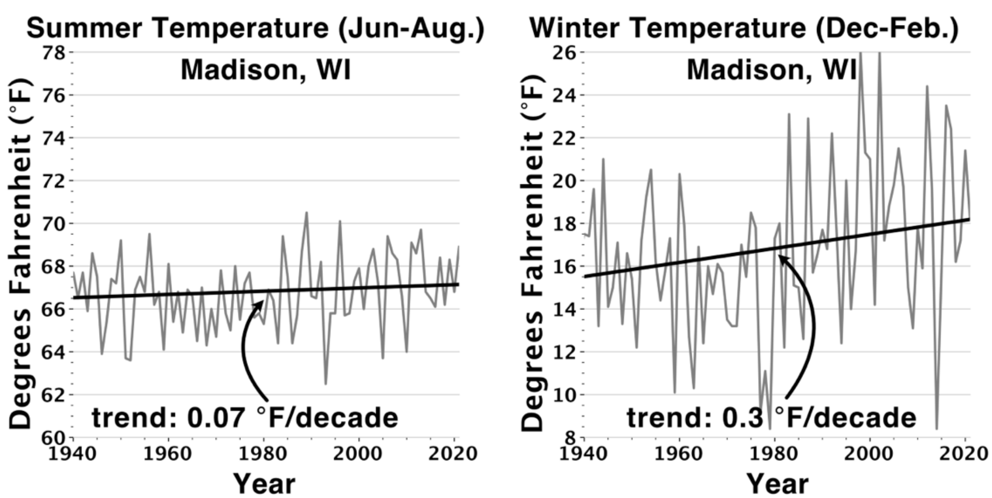


Figure 1.21 Summer and winter temperature trends in Madison, WI.

Source: Climate Conscious, Gloege (2021). Retrieved January 13, 2022 from **https://medium.com/climate-conscious/climate-change-in-madison-wi-f9800d6461ab**

- In the northern hemisphere, ice duration is now 19 days shorter per century on average (Woolway et al., 2020).
- Ice safety is becoming an issue with warmer winter temperatures and less predictability. Ice roads across lakes are a vital transportation link for many northern Canadian communities in the winter.

Warming Lake Surface Waters

- It has been found that lakes around the world with cold winters, where the mean air temperature is less than -0.4°C, are warming more rapidly than lakes in regions with warm winters, which partially reflects the more rapid warming in regions towards the poles (Woolway et al., 2020).
- For many mid-latitude, **dimictic lakes** (lakes that experience two mixing events per year, one typically following the summer stratification period and the other following the inversely stratified winter period), the warm-season lake surface water temperature trends are primarily the result of earlier stratification, where the lake separates into layers, and a prolonged stratification period in the summer (Woolway et al., 2020).
- Monomictic lakes tend to stay stratified longer, reducing the period for oxygen replenishment to bottom waters.

Increasing Lake Evaporation

- Globally, lake evaporation is expected to increase by 16% on average by 2100 (Woolway et al., 2020).
- Evaporation rates are influenced by reduced snow and ice cover during warming winters, as well as earlier summer stratification. With less snow and ice cover during the winter, there is less light reflected and more solar radiation is absorbed, resulting in a higher rate of evaporation (Woolway et al., 2020).

Wetting and Drying Trends

- There is evidence for a wet gets wetter signal over water sufficient lands such as Canada (Woolway et al., 2020).
- Unusually high precipitation from months to decades can lead to significant impacts on even the largest of lake systems, including regional flooding and rapid lake level rise, and increased delivery of nutrients, sediments, pollutants, and dissolved organic matter to lakes (Woolway et al., 2020).

Changing Lake Water Storage

- The amount of water stored in specific lakes may increase, decrease, or experience no substantial cumulative change in a warming climate. This uncertainty is largely due to the impact of human water withdrawal (Woolway et al., 2020).
- Until the influence of climate change on all water inputs and outputs relevant to lake water budgets such as precipitation, evapotranspiration, and runoff, can be adequately resolved, the

magnitude of climate change effects on global lake water storage will remain highly uncertain, particularly with interannual climate variability (Woolway et al., 2020).

Altered Lake Mixing Regimes

- Mixing regimes of lakes are projected to change through time, in response to climate-induced variations in lake surface conditions. This can have numerous consequential implications for lake ecosystems (Woolway et al., 2020).
- The most common expected change is from dimictic (two mixing events per year) to **monomictic** (one vertical mixing event per year) with approximately 17% of all lakes likely to experience this mixing regime alteration by 2080-2099. Warming winters, a loss of ice cover, and warmer winter surface waters will result in lakes no longer typically experiencing an inversely stratified winter period. Rather, they will remain vertically mixed from autumn (following the fall mixing regime) until stratification onset in the spring (Woolway et al., 2020).
- Many lakes will have longer summer stratification and increasing hypolimnetic oxygen depletion, fish and benthic habitat loss, and internal loading rates.
- Another commonly identified alteration in lake mixing regimes is a change from monomictic to **oligomictic** (lakes that are persistently stratified in most years yet mix fully in others) and/or **meromictic** (lakes that are persistently stratified, often owing to their great depths or to the presence of a chemical gradient). An increase in winter lake surface water temperature is a key driver of change from monomictic to oligomictic and/or meromictic conditions. In particular, if the surface temperature of deep lakes no longer falls to 4°C, stratification can persist from one summer to the next without interruption, inhibiting complete turnover (Woolway et al., 2020).
- Lakes that are the most susceptible to changes in mixing regime are those that are **marginal**, meaning they historically transition between two mixing classes and often experience unusual mixing behaviour relative to their dominant mixing classification (Woolway et al., 2020).
- Mixing regimes of marginal lakes have been described to be very sensitive to changes in water clarity. A browning of lake surface waters, due mainly to terrestrial inputs of dissolved organic matter, affects the depth at which sunlight can penetrate in a lake. The browning has a significant impact on the vertical thermal structure of a lake, and it can determine whether a lake mixes regularly or stratifies continuously throughout the summer period (Woolway et al., 2020).
- Figure 1.22 shows that there will be minimum of a 30% increase in the mobilization of dissolved organic carbon from soils to freshwater with a 10% increase in precipitation. This study is based on data from 290 lakes and 184 running waters in Fennoscandia, the geographical peninsula comprising the Scandinavian and Kola Peninsulas, mainland Finland, and Karelia (Wit et al., 2016).

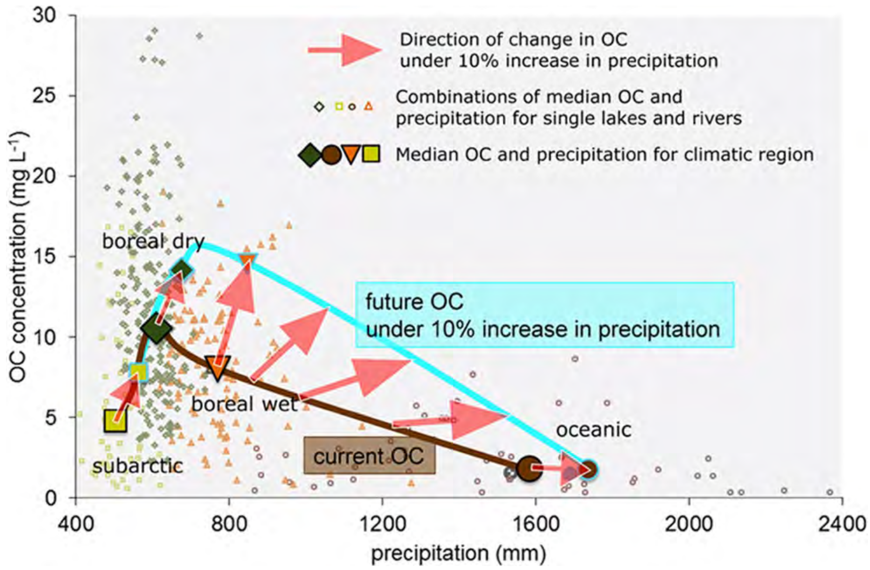


Figure 1.22 Projections of organic carbon concentrations in a wetter climate in Fennoscandia.

Source: "The Current Browning of Surface Waters Will Be Further Promoted by Wetter Climate" by Wit et al. (2016). Retrieved January 14, 2022, from **https://pubs.acs.org/doi/pdf/10.1021/acs.estlett.6b00396**

- Some lakes may experience fewer continuous periods of stratification as a result of a local increase in near-surface wind speeds. An increase in wind mixing could push a lake to a less stable regime and result in a lake transitioning from a dimictic to a polymictic (permanently or frequently mixed lakes) (Wit et al., 2016).
- The interactions among decreasing water transparency, vertical thermal structure and shifting lake mixing regimes are expected to be the most important in historically clearer lakes (Wit et al., 2016).
- Future research should aim to expand on previous work and investigate mixing regimes at a truly global scale (such as across climatic gradients, including lakes that are covered in ice for more than one year), and include both freshwater and saline lakes (Wit et al., 2016).
- See Chapter 1 (S.1.2.4) for more information on lake stratification schemes in BC.

Increasing Algal Blooms

- Warmer water temperatures can result in increased frequency and duration of blue green algae (cyanobacteria). See Chapter 3 (S.3.7) for further discussion on cyanobacteria.
- Worldwide, the occurrence and severity of algal blooms are expected to increase in response to ongoing human-driven nutrient loading and climate change (Janssen et al., 2019).
- Algal blooms are triggered by excess nutrient loads and further promoted by relative high-water temperatures (Janssen et al., 2019).
- Future climate projections indicate there will be more extreme precipitation events. This will cause higher rates of runoff that carry excess fertilizers and other sources of nutrients into water

bodies. This combined with warmer conditions increases the likelihood for algal blooms to form (Chapra et al., 2017).

- Changes in climate variability such as a drought period following an intense precipitation event, result in longer residence times in lakes, allowing for more time for bloom formation (Chapra et al., 2017).

Most global studies of lakes surface water temperature responses to climate change focus on summer observation. This misses important changes that are taking place in other seasons, which merits future study (Woolway et al., 2020).

1.5.2 MONITORING LAKES FOR CLIMATE IMPACTS

Dissolved Oxygen and Temperature Profiles

- By taking profiles of a lake, it may be possible to detect changes to the depth of the thermocline, or changes in the time of lake turnover, which can have marked effects on DO and nutrient cycling. Due to the sensitivity of lakes and lake ecosystems to climate change, it is important that proactive measures be taken in order to better predict how lakes throughout BC will respond. The more lakes that provide temperature and DO profiles, the more data points there are for different regions and lake characteristics so that steps can be taken to mitigate impacts or provide information in advance of an extreme shift.
- The best way to measure DO and temperature in a water column is to use an oxygen meter which measures the amount of dissolved oxygen in an aqueous solution and has a built-in thermistor so that temperature can be recorded with every DO reading.

Figure 1.23 YSI ProSolo

Source: YSI Inc. 2021
https://www.ysi.com/prosolo

- A probe such as the YSI ProSolo, as seen in Figure 1.23, collects reliable data with a reasonable amount of ease.
- Profiles should be collected at regular intervals, every 1 or 2 weeks during ice-free periods.
- The limitations of dissolved oxygen and temperature profiles are that it can be time consuming to do multiple locations on a lake and it is more difficult to do during the winter.

Measuring Surface Temperature (Mulder-Hardenberg Group, 2013)

- Continuous temperature data is important as real-time data is collected and changes can be detected rapidly.
- Probes such as the HOBO Water Temperature Pro v2 Data Logger (Figure 1.24) can be attached to buoys and suspended at various depths throughout the water column, collecting continuous temperature data.

Figure 1.24 HOBO Water Temperature Pro v2 Data Logger

Source: Mulder-Hardenberg Group, 2013. Retrieved from **https://bit.ly/3sirB2H**

Multi-Parameter Sondes (Fondriest, 2015)

- Multi-parameter sondes (Figure 1.25) usually feature an array of ports for attaching dissolved oxygen, temperature, depth, conductivity, pH, and other sensors.
- Most sondes contain an internal battery and memory so they can be deployed for long periods without regular attendance. Data logger and external power connectivity allow for even longer deployments on certain sondes.
- For applications in lakes, it's common to mount multi-parameter sondes in a buoy along with a data logger. The sondes can be deployed at multiple depths and can have Bluetooth connectivity.

Figure 1.25 YSI EXO Multi-Parameter Water Quality Sonde

Source: Fondriest Environmental Learning Center, 2015. Retrieved from **https://bit.ly/3gkH4tg**

Measuring Photosynthetically Active Radiation (Fondriest, 2015)

- Solar radiation that falls between 400 and 700 nm is known as PAR. This is an important parameter for freshwater lakes as it is a determining factor of aquatic productivity. Plants rely on PAR for growth but so do a number of other vital organisms at the base of the food chain.
- Each PAR is rated for use up to a certain depth or pressure. Some measure radiation in one direction, others, such as the one shown in Figure 1.26, can sense it in all directions.

Figure 1.26 LI-COR LI-192 Underwater PAR Sensor

Source: Fondriest Environmental Learning Center, 2015. Retrieved from **https://bit.ly/3gkH4tg**

Remote Sensing (Altaweel, 2020)

- Used to monitor lake level, chlorophyll-*a*, clarity.
- Satellite remote sensing provides global, timely, consistent observations.
- Remote sensing allows for more lakes to be monitored.
    - Some lakes are remote and difficult to access on land, some regions have so many lakes that it can take a lot of effort and money to monitor them.
- Using sensors such as the Thermal Infra-Red Scanner and the Operation Land Image allow for changes in lake temperature to be captured. Using these two sensors allows relative lake temperature, and temperature fluctuations.
- It is important to use ground-based sensors to calibrate and check the quality of satellite-based results.
- Algal blooms can be monitored by using sensors that detect light wave absorption between 440 and 560 nm to measure Chlorophyll-a content.
- Limitations: Satellites only provide information about shallow waters. Toxin concentrations cannot be estimated. Species of algae cannot be distinguished.

KEY TERMS

Fetch: The maximum distance across a lake where wind can travel without stopping.
Dimictic Lakes: Lakes that experience two mixing events per year, one typically following the summer stratification period and the other following the inversely stratified winter period.
Monomictic Lakes: One vertical mixing event per year.
Oligomictic Lakes: Lakes that are persistently stratified in most years yet mix fully in others.
Meromictic Lakes: Lakes that are persistently stratified, often owing to their great depths or to the presence of a chemical gradient.
Marginal Lakes: Lakes that historically transition between two mixing classes and often experience unusual mixing behaviour relative to their dominant mixing classification.
Polymictic Lakes: Permanently or frequently mixed lakes.

CHAPTER TWO:
DEVELOPING A LAKE SAMPLING PROGRAM

"We must conceive stewardship not simply one individual's practice, but rather as the mutual and intimate relationship, extending across the generations, between a human community and it's place on earth."

- John Elder

Buntzen Lake. Source: Emily Gutenberg.

Chapter Contents

Understanding lake theory and the complex processes underway below the surface is important. But assessing whether lake conditions are normal or a response to human activity is a critical part of lake management. Achieving this understanding can be accomplished through lake sampling. British Columbians expect lakes to provide world-class water quality, aesthetics, and recreational opportunities. However, when these characteristics suffer, it can spark concern, curiosity, and action amongst citizens.

The BC Lake Stewardship and Monitoring Program (BCLSMP) is designed to facilitate lake sampling in the province. Through regular water sample collections, we can come to understand a lake's current water quality, identify the preferred uses for a given lake, and monitor water quality changes resulting from land development within the lake's watershed. Lake water quality monitoring data is also valuable information to help us understand the impacts of climate change. Through regular status reports, these programs can provide communities with monitoring results and assessments specific to their local lake and with educational material on lake and watershed protection issues in general. This useful information can help communities play an active role in the protection of the lake resource. Finally, these programs allow the provincial government to use its limited resources efficiently thanks to the help of lake volunteers and the BC Lake Stewardship Society.

Monitoring lake water quality can be relatively simple and can provide valuable information to characterize current conditions and track changes in the lake over time. Time is an important factor here: lake water quality changes both seasonally and, if affected by human activity, over the long term. A good program may require repeated sampling visits at several depths over many years.

Chapter three of LakeKeepers will assist with constructing a successful lake sampling program and will provide techniques for collecting water quality samples. These techniques should ensure that the resulting data will be accurate and can be used to identify and hopefully assist in resolving water quality problems.

Spruce Lake. Source: Marie McCallum.

2.1 DESIGN BASICS

Sampling programs should be developed to address problems that are specific to each lake. They should be guided by the goals and visions of the interested lake group and put into practice based on the skills of group members, equipment, and financial resources available to the program.

The BCLSS volunteer lake sampling program has identified three levels of lake monitoring and assessment that can be undertaken by lake stewards (Figure 2.1):

Level 1: Weekly summer water clarity (Secchi transparency) and surface (0.5 m) water temperature readings and may include weekly temperature and dissolved oxygen profiles. Provides a minimum level of baseline information for a lake and it is valuable to obtain this data for a large number of lakes from different biogeoclimatic zones for climate and eutrophication research. This level of program can be coordinated by the BCLSS without ENV involvement.

Level 2: Spring overturn and late summer water chemistry at surface, complemented by weekly summer water clarity and surface water temperature readings. Regular temperature and dissolved oxygen profiles may be included. Level 2 programs generally have Ministry of Environment and Climate Change Strategy (ENV) involvement as part of the BC Long Term Lakes Trend Program. At this level, sampling is required in the spring and late summer.

Level 3: Similar to Level 2 in that water chemistry is collected, but adding multiple depth water chemistry and biological sampling on alternate weeks through the open water period. Sampling parameters will vary based on study design. This level provides more detailed information on the lake such as possible summer oxygen depletion and internal nutrient loading. This level can also be complemented by a sediment core which provides insight into historic water quality to assess whether the lake has changed over time. ENV involvement is required at this level and significantly higher costs and effort are involved.

Level 4: Adds a complete watershed study. This level provides relative magnitudes of potential effects of different land uses and is of great value in prioritizing management efforts. This level is considerably more expensive and requires the services of a consultant, with involvement by ENV and local stewardship groups.

Level 5: Adds inflow stream monitoring. This is the highest level of study and is very expensive and time consuming. It is not practical or necessary for every watershed.

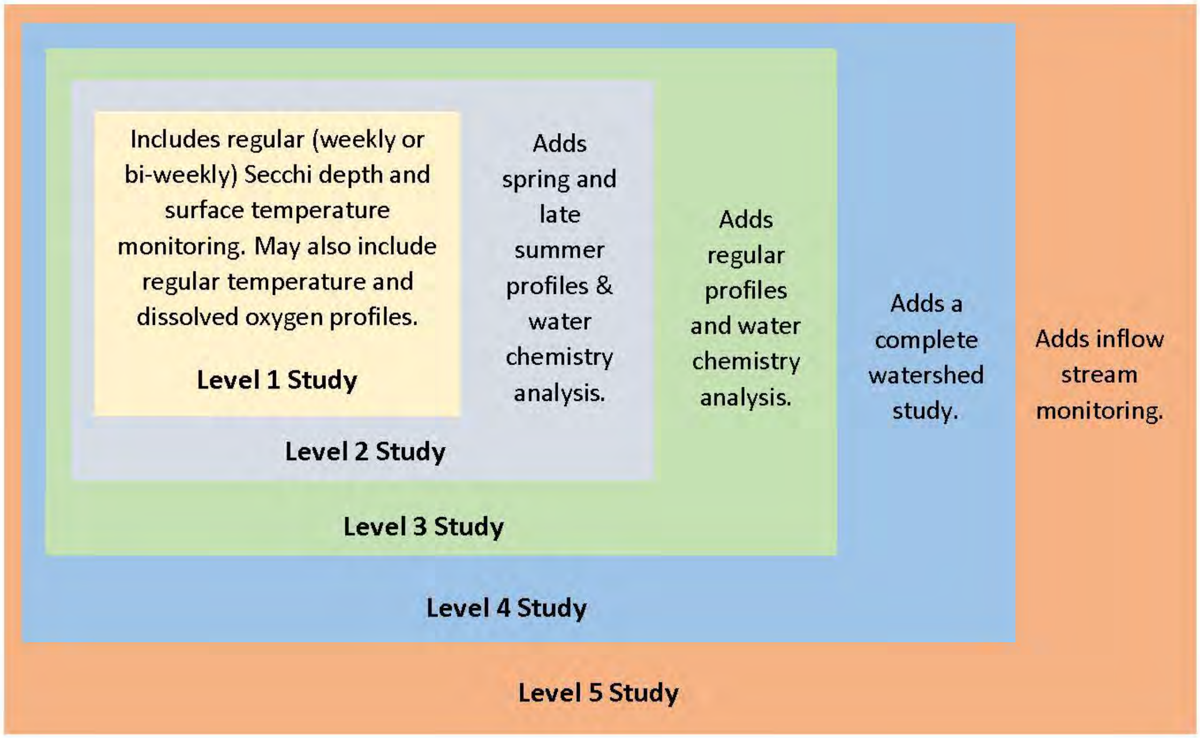


Figure 2.1 Lake monitoring levels

Image adapted from ENV Volunteer Lake Monitoring Program **website**.

Appendix 2.1 provides examples of the types of data bases that could be generated for each of these assessment levels.

2.1.1 SETTING STUDY OBJECTIVES

Before beginning a sampling program, it is necessary to identify lake-specific questions and problems related to the lake you are concerned with. To identify potential objectives of a lake study, it may be useful to find out the following information:

1) Current water quality or trophic status of a lake

Is there water quality data available for the lake or inflow and outflow streams? When does the lake stratify? Are low dissolved oxygen concentrations a problem in late summer or under ice cover? What is the spring phosphorus concentration or the average summer algal chlorophyll concentration or Secchi transparency?

2) Whether trophic status has changed with cottage or other land development

Do we have sufficient limnological data to identify any trends in water quality? Are there any historical reports on the lake? How many years of monitoring are recommended to assess changes in water quality? Should a lake sediment core, that provides good historical data of lake quality, be collected?

3) Lake phosphorus dynamics

Phosphorus usually drives the biological productivity of a lake, but where is the phosphorus coming from? Which tributaries are main contributors? Is there potential for development upstream from the lake to be contributing to its current condition? How important are the lake's bottom sediments in terms of internal phosphorus loading and algal blooms?

4) Lake drinking water quality

What is the chemical, bacterial, or parasitic risk of drinking this lake water? (Note that all surface water should be disinfected before consumption).

5) Potential effects of future land use development

How much more, or what types of land development are acceptable now and in the future? When will water quality (including water clarity) become affected?

These are some of the possible objectives that can help a lake group determine the type of monitoring program to conduct. Be sure to have the objectives clearly identified before beginning the program design stage.

2.1.2 FIELD SAFETY

Before program design is discussed, field safety needs to be considered. Safety should be the first and foremost priority of any sampling trip. Lake sampling can be inherently dangerous; the need for safe operation on water cannot be overstated. Lake sampling during the spring mixing, within two weeks following "ice off", is one of the single most useful times for limnological data collection. It is a normal part of a volunteer program, but typical lake water may be only 4°C during this period, cold enough to kill a person immersed in it for even a short period of time, regardless of the use of typical floatation life jackets. Appendix 2.2 provides information on cold water exposure risks.

Always take a partner when sampling from a boat and always notify someone on shore of where and when you are sampling and at what time you expect to return to shore. If you are using a boat to collect samples, ensure that the driver of the boat has all required certification for that particular boat. Never jeopardize your personal safety by venturing onto a wind-blown, rough lake, particularly when the water is cold. If available, wear a floater jacket or specially designed suit that would improve survival in cold water. Standard life jackets may be suitable during the summer when the lake water is warm.

Appendix 2.3 shows ice thicknesses required for safety. **Special note: With recent warming trends, many BC lakes do not freeze as solidly as they have in the past, and this must be considered for both lake sampling and recreation.**

Never work or travel on frozen lakes without a partner. At minimum, wear a floater jacket, but a survival suit is preferable, and each person should have a **pair of retractable ice picks**. Always ensure that the ice can support your weight by testing its strength before stepping on it. Always use a weighted and sharpened long handled ice chisel to check the safety of the ice in front of you. If the chisel can break through the ice, so might you. The lead person should wear an appropriate (climbing) harness and be roped to the field assistant who will not stray from the foot path confirmed safe by chisel testing. The assistant should carry an **ice anchoring screw** that can be driven into the ice to provide a solid anchor should the lead person break through. Always carry a first aid kit (containing dressings and bandages to be used in the event that a cut is received from an auger blade) and know how to use it. As with summer sampling, ensure that someone on shore knows your intended location and schedule. BCLSS recommends that anyone working on ice complete the **Ice Safety Technician course** offered by Rescue Canada.

Charlie Lake. Source: Bruce Kosugi.

Any volunteer lake sampling program should include a notification of risk to personal safety. Volunteers under the BCLSMP are given basic safety instruction, and then must sign a waiver of liability for the BCLSS. Appendix 2.4 contains an example of a volunteer notification of risk and responsibility and waiver.

2.2 QUALITY CONTROL & QUALITY ASSURANCE

A basic principle of sampling is that information needs to be collected at the same place using the same high-quality technique over a period of time. A good adage for lake sampling might be: "Have the same people do the same quality assured sampling at the same place on a regular, repeated basis." Once this standard has been achieved, program data should be of good quality (i.e., accurate and precise) and can be used to understand the lake and make good decisions about its management. Quality Control (QC) can be defined as sampling cleanly. Quality Assurance (QA) provides the proof. Sampling programs must make use of quality control and quality assurance (the so-called QA/QC) to maximize data value.

KEY TERMS

Quality Assurance: A variety of strategic, careful actions taken to ensure to the highest reasonable degree that methods are sound and followed correctly.

Quality Control: A specific system of maintaining conditions such that results are reliable.

2.2.1 FIELD QUALITY CONTROL

When carrying out a sampling program, you want to ensure a high degree of confidence in the data being collected. Poor quality data does not provide sufficient information to understand a problem. It is not useful to conduct expensive, time consuming lake management initiatives when they are based on low quality information.

Quality information can be gained by practicing good quality control (QC) in the field, which includes specific steps, procedures, and practices. Laboratories also follow strict procedures to minimize the likelihood that QC problems will occur during sample handling and analysis.

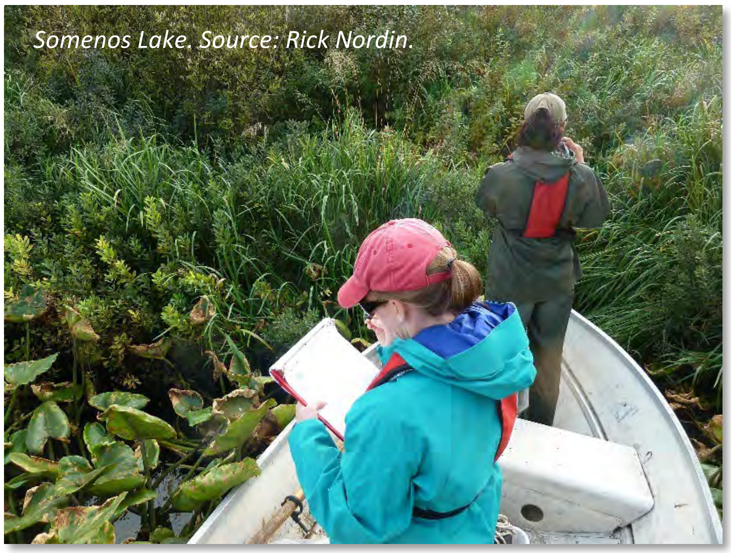
To contribute to good QC, one of the most important precautions is to avoid sample contamination. The following are some recommendations to achieve this:

1. Ensure that all sample bottles have been cleaned using the recommended procedures (usually by the laboratory) before going to the field. Clean sample bottles are generally received from the lab with lids on ready for sampling. In the field, some bottles should be rinsed three times with lake water before taking the sample. Refer to *Rinsing Technique* on the page 8**.**
2. Store sample equipment and bottles in a clean environment (e.g., not in a fuel shed or with the bottle lids removed).
3. Use only the recommended bottles for each analysis.
4. Check labels and expiry dates of reagents and preservatives.
5. Label samples clearly, with site name, date/time, depth, and sampler initials.
6. Never touch the inside of the sample bottles or caps with anything, including your fingers.
7. Do not sample in water that is not representative of the body being assessed (e.g., oil slicks or excess detritus).
8. Always uncap bottles just before sampling and recap immediately after sampling. The insides of the caps must be kept clean while off the bottle.
9. Store samples in clean coolers at 4°C (with ice packs) for transport.

10. Keep samples away from dust, dirt, (exhaust) fumes or any other potential contaminants. Do not smoke when sampling.
11. Do all field measurements at the site unless instructions allow otherwise.
12. Send samples to the laboratory as soon as possible (48 hours is generally the maximum transport time).
13. Conduct routine cleaning procedures on equipment and filters using approved cleaning agents (e.g., phosphorus free laboratory grade cleaning solutions).

Field notes & observations

As part of good quality control, it is important to keep comprehensive field notes. These notes may be used each sample trip to locate monitoring sites and to repeat techniques and measurements. Accordingly, details are very important. All of them should be written in a logbook (ideally on waterproof paper) and then later rewritten or entered into a database. Some of the information that should be included are the names of the people doing the sampling, the date and time of the measurements, current weather conditions, and the purpose of the sampling. A detailed description of the sample location (including a visual picture or map) is also important. Samples should be taken at the same location in the lake at all times. Details on the types of samples being collected and the measurements being made should be included. Finally, any unusual sightings such as fish kills, odours, debris, pollen, surface slicks, and excessive algal growth, etc., should be noted. Waterproof paper and a pencil or mechanical pencil can be used to avoid the loss of information due to water damage.


Somenos Lake. Source: Rick Nordin.

An alternative to the field logbook, particularly for new volunteer samplers, is a standard field form that prompts the volunteer for specific sampling information. Standard forms will usually increase data consistency from trip to trip. Additional observations (e.g., unusual sightings) should be an essential part of these forms. Recommended example field forms, with their related sampling instructions, are provided on the **BCLSS website** under *Data Collection Forms*. Photographs are key pieces of anecdotal information and should be routinely taken. Include anything relevant such as weather and water conditions, presence of algae blooms or aquatic plants observed.

Rinsing technique

Before obtaining water samples from a lake, review the collection techniques for each sample parameter and obtain the appropriate bottles. If your samples are going to be sent to a laboratory for analysis, check to see if pre-cleaned (i.e., acid washed or sterilized) bottles are needed. Laboratories provide these bottles which should not be further cleaned or rinsed prior to sampling. If, for example, the sample is to be analyzed for suspended sediments, contaminants associated with suspended solids, bacteria, or specialized analyses such as trace metals or chlorinated organics, the bottle should not be field rinsed. Bottles that are not pre-cleaned must be rinsed three times with either deionized water or lake water. Your government or BCLSS contact will provide details.

The following procedure is a guideline for proper rinsing technique.

1. Use plastic bottles of 250 mL to 1 L volume, depending on how many tests are needed. Label the bottles using waterproof ink with, at minimum, site name, site number, date, time, depth, and sampler initials.

2. Remove the lid and hold it without touching the inner surface.

3. With your other hand, grasp the bottle well below the neck. Lean out towards the safe side of the boat and in one continuous motion plunge the bottle, opening first, beneath the surface and slowly force it through the water until it is partly full. This motion creates a current over the mouth of the bottle (so that water entering the bottle has not come in contact with your hand).

4. For samples collected at depth using Van Dorn or similar samplers, partially fill the bottle from the sampler drain tube, taking care not to touch the inside of the bottle with the sampler tube or spout (to reduce contamination).

5. Replace the lid and shake the bottle vigorously.

6. Remove the lid and reach across to the opposite side of the boat to pour the water out. Repeat steps 2 through 6 twice more before collecting the sample.

2.2.2 QUALITY ASSURANCE

In order to measure the success of both field and laboratory quality control efforts, all sampling programs must include a field quality assurance (QA) component. QA involves the collection and analysis of specific samples that measure sample accuracy, sample precision and the ability to measure concentrations near the minimum detection level, in this case, using field samples collected by volunteers. **Accuracy** is a measure of how close to the "true concentration" a reported result is. **Precision** is a measure of how often that "true concentration" can be met. Figure 2.2 provides a visual perspective of both these terms.

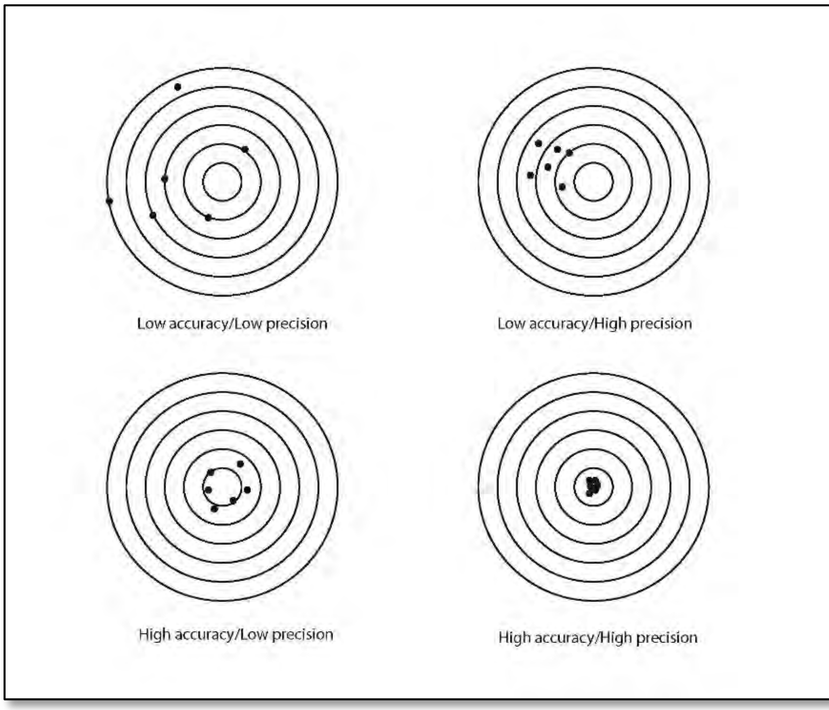


Figure 2.2. Precision vs. accuracy

If necessary, the field QA results can be compared to regularly produced laboratory QA data. By this method we can determine whether a poor precision result was caused by field (i.e., sampler) or laboratory (i.e., analytical) error. Of course, two duplicate samples may provide two different chemical results simply because the samples really were different! This possibility is unavoidable but does not usually take away from the value of the method. We hope for the overall difference between the two samples, or the "total assay error" to be within acceptable limits. With the effort that volunteers expend on collecting samples over many months and perhaps years, recognition of good quality control by the use of an effective quality assurance program is essential. Refer to the following discussion for more detail on QA.

Blank samples for false positives

Blank sample collection is a necessary part of most water sampling programs. Analyses of blanks should find "nothing". That is, sample blanks should return results less than the laboratory's method detection level because they contain only de-ionized "pure" water. Blank analysis tests for systematic and random errors, including bottle contamination and the purity of the chemical preservatives. There are four different types of blank samples potentially involved in water quality testing: field, trip, equipment, and filter blanks, as outlined in table 2.0: Sample Blanks (Cavanagh et al., 1998).

Table 2.0 Sample Blanks		
Type of Sample	**Procedure**	**Purpose**
Field Blank	Mimics the sampling process but does not come into contact with ambient water. These samples are filled at the sampling site using de-ionized water.	Used to indicate contamination that could have occurred from field handling through to laboratory analysis.
Trip Blank	De-ionized water is placed in sample bottles at the lab, sealed and carried throughout the field trip.	Used to assess contamination that could result from transport and storage.
Equipment Blank	Samples of the de-ionized water used in rinsing the sampling equipment prior to the field work.	Used to document contamination that may occur from the sampling equipment.
Filter Blank	De-ionized water passed through the same filters that the samples will be passed through.	Used to indicate contamination that may be associated with the filtration process.

In most lake sampling programs, you will want to include at least a field blank. This could be considered an all-inclusive test for false positives as it can include error caused by dirty bottles, contaminated reagents, poor field technique, transport, storage, and many of the potential laboratory errors. Its advantage is simplicity; its limitation is a failure to identify what specific activity caused a false positive. Repeated blank failures must lead to additional testing to determine exactly where the contamination problem lies. For example, in the case of volunteer lake monitoring, a logical follow up blank would test for contamination in the Van Dorn sampler (i.e., an equipment blank) (Cavanagh et al., 1998).

Replicate samples for precision

Samples are usually subject to influences that affect result precision. These may be environmental variables outside the control of the sampler or may be caused by human error, either in the field and/or at the laboratory. The result can be a loss of data value. Replicate field samples (usually duplicates) are used to test the standardization of the monitoring technique and overall precision of the sample results (Cavanagh et al., 1998). Two different types of replicate samples, co-located and split samples, may be taken to measure precision quality control, as outlined in Table 2.1: Sample Replicates.


Source: BCLSS Files.

Table 2.1. Sample Replicates		
Type of Replicate	**Procedure**	**Purpose**
Co-located	Independent side by side samples collected as close as possible to the same point in space and time.	Used to document 1) the precision of the entire sampling and laboratory process and 2) instantaneous environmental variability.
Split	Aliquots taken from the same container and analyzed by one or more, independent, laboratories.	Used to indicate random or systematic errors that may be introduced during sampling and/or analysis.

All lake sampling programs should include the collection of co-located field duplicates. As with field blanks, these are all-inclusive tests. Field duplicates test for combined field and lab error and also the real environmental variability that could exist between two side by side samples. Field duplicates are easy to collect, but if the resulting data show low precision, the exact problem will require an examination of batch specific laboratory duplicates and perhaps additional testing.

Reference samples for accuracy

The quality assurance (QA) component of a lake sampling program will include the use of high quality, certified reference materials. These reference materials are most often diluted to produce spiked samples that are analyzed to compare the "measured" concentration to the dilution-calculated "true" concentration (Cavanagh et al., 1998). For simplicity, tests for accuracy are usually performed at the laboratory only. Lake volunteers will not normally be asked to collect reference samples. Reference samples are outlined in Table 2.2: Sample References.

Table 2.2 Sample References		
Type of Reference	**Procedure**	**Purpose**
Spiked, check for bias	Spiking aliquots of a water sample (or deionized water) with a known amount of the variable of interest to measure % recovery.	Used to reveal any systematic errors or biases in the analytical method and procedure.
Reference, check for bias	Spiking aliquots of a water sample (or deionized water) with a known amount of the variable of interest to measure % recovery, with wide scale distribution by an independent laboratory or a recognized scientific body such as the National Research Council.	Used to document any bias associated with the laboratory process.

The following table provides an example of a summary of QA/QC data.

Table 2.3 Example of QA/QC Summary

Sample Date	Sample Depth (m)	Ortho P REG (µg/L)	Total Diss. P REG (µg/L)	Total P REG (µg/L)	Ortho P REP (µg/L)	Total Diss. P REP (µg/L)	Total P REP (µg/L)	Ortho P BLK (µg/L)	Total Diss. P BLK (µg/L)	Total P. BLK (µg/L)	Quality Assurance Comments
25-05-20	0.5	4	12	26	4	12	23	<1	2	<2	Good replicate and blank QA. Replicate is similar to regular sample and blanks are less than detection level. Samples are reliable.
	30	16	24	29							
	60	4	9	22							
08-06-20	0.5	<1	8	18				<1	3	<2	Acceptable QA. Note questionable TDP of 14 vs 9 (µg/L). Blank TDP of 3 (µg/L) is notable.
	30	2	11	21							
	60	<1	14	27	<1	9	20				
22-06-20	0.5	<1	11	37				7	5	10	Poor blank QA. Poor replicate TDP. Do not use any of this date's phosphorus data.
	30	<1	25	24	1	10	27				
	60	3	10	27							
06-07-20	0.5	12	8	28				<1	<2	<2	Good blank QA. Poor replicate OP. Do not use OP data.
	30	14	17	25	2	11	25				
	60	18	25	89							
20-07-20	0.5	9	7	18				<1	<2	<2	Good duplicate and blank QA. Regular samples assumed reliable.
	30	1	12	23	2	10	22				
	60	2	16	30							

2.3 LAKE SAMPLING

2.3.1 GETTING STARTED

Lake concerns of citizens are shared by government agencies responsible for environmental management. LakeKeepers recommends that lake monitoring programs are developed in conjunction with the BC Ministry of Environment & Climate Change Strategy (ENV), your local regional government, the BCLSS, or other similar agencies. Doing this will often result in your group being assisted in study planning and provided with the sampling equipment, instructions, and analytical resources necessary to complete the study. Governments are unable to provide the staff necessary to undertake monitoring programs on all lakes (BC has approximately 20,000 lakes over 7 hectares or 18.5 acres in size). Partnerships are viewed favourably, where volunteer lake groups provide the human resource and government and the BCLSS contribute equipment, training, and analytical resources. The BCLSS and ENV work in partnership on volunteer lake monitoring programs throughout the province. More information on this partnership can be found on the **ENV Volunteer Lake Monitoring Program website** and the **BCLSS website**.

This section explains the basics of sampling lakes. Operation of the associated field instruments such as Dissolved Oxygen meters will be found in Chapter 3. Further information on water quality inventory standards can be found on the **ENV website**.

2.3.2 PREPARING FOR FIELD WORK

When preparing to go to the field, there are a number of considerations which are listed below.

1. Sample bottles
   - Ensure that you have extra bottles of each type needed for collecting samples in case bottles are lost, broken or contaminated.
2. Proper field equipment
   - Ensure that you have the proper equipment (such as meters, filtration apparatus, and samplers) and that all are in good working order.
   - Decide what types of batteries are needed for the equipment and be sure to bring extras.
3. Preservatives
   - Check preservative identities and expiry dates before going out in the field. Be sure to take extra vials (in case of spills).
   - Ensure that you include AND WEAR safety glasses when using corrosive preservatives. Gloves should also be worn.
   - Ensure that preservatives are compatible or store them in separate containers.

- o Ensure the preservatives are stored safely so children and others cannot gain access to them.
- o Ice packs (ensure they are fully frozen) and coolers.
- o These items are essential to ensure that the samples are kept at proper temperatures. Thermometers may be useful here.

4. Logbooks
   - o These can be used for recording all information while out in the field. Fill out what you can before you go. Standard field forms are a good way to ensure that all relevant information is noted, by prompting field volunteers for specific observations.
5. Personal Gear
   - o Waders, gloves, extra clothes, raingear are important when working around water.
   - o Ensure life jackets and approved floater jackets/suits are worn by everyone in the boat.
6. First aid kit (preferably in the boat, but at least available on shore)
   - o A proper, complete, and updated first aid kit is mandatory.
7. Camera and video equipment
   - o This equipment is not essential, but pictures and video can help by bringing attention to specific algal or weed accumulations, by assessing visual changes between sites over time and by determining previous sampling locations.
8. Laboratory forms
   - o If samples are being sent away to laboratories, requisitions will often be required. Check with your government contact. Properly fill in all requisitions.

One of the easiest ways to ensure that nothing is forgotten is to use a checklist. A checklist is a simple way to organize and record the items that are needed for a successful trip. The items on the checklist will depend on the types of samples you will be collecting. A field checklist should be developed that is directly applicable to each individual program. An example is shown on the following page.

Field Sampling Checklist

Name:

Date:

Location:

PLANNING

- ☐ Schedule (arrival, departure)
- ☐ Inform someone of your trip plan
- ☐ Emergency contacts
- ☐ Map to nearest hospital
- ☐ Arrangement with lab to receive samples (if applicable)
- ☐ Sampling plan (objectives, number of samples, sample IDs)

HEALTH & SAFETY

- ☐ First aid kit
- ☐ Cellphone
- ☐ Watch
- ☐ Sunscreen
- ☐ Bug spray
- ☐ Bear spray
- ☐ Food (snacks) and bottled water
- ☐ Weather appropriate footwear
- ☐ Weather appropriate clothing
- ☐ Spare set of dry clothing
- ☐ Safety glasses
- ☐ Hi-visibility vest
- ☐ Box of new nitrile/latex gloves

ITEMS FOR RECORDKEEPING

- ☐ Field notebook
- ☐ Logbook and/or field forms
- ☐ 2+ weatherproof pens
- ☐ Ruler
- ☐ Camera

SAMPLE BOTTLES

- ☐ Sample bottles, vials
- ☐ 1+ spare sample bottle
- ☐ Bottle labels

FIELD EQUIPMENT

- ☐ Secchi disc
- ☐ Thermometer
- ☐ Meters (charged and/or with extra batteries)
- ☐ Samplers (Van Dorn, pole sampler)
- ☐ Filtration equipment
- ☐ GPS or compass

SAMPLING EQUIPMENT

- ☐ Distilled water/jug of clean water
- ☐ Lab-provided, non-expired preservatives (check expiry dates)
- ☐ 1+ spare of each preservative
- ☐ Clean cooler
- ☐ Frozen ice packs OR ice cubes in sealed Ziploc bags
- ☐ Ziploc bags (for filled sample bottles to be stored in during transport)

BOATING PREPARATION

- ☐ Boating license (if motorized)
- ☐ Extra boat fuel (if motorized)
- ☐ Oars
- ☐ Personal flotation device
- ☐ Whistle
- ☐ Emergency kit (flare, beacons, etc.)
- ☐ Depth finder or GPS

NEARSHORE PREP

- ☐ Waders

Appendix 2.5 provides an extensive list of field equipment that could be used for a variety of lake sampling programs. The equipment is coded as to which of monitoring levels 1 to 3 it would be used for.

2.3.3 WHEN TO SAMPLE

There are many different times during which sampling can be conducted. The most critical times for a lake are during spring overturn and during the growing season. Most BCLSMP water quality sampling is conducted from early spring (April or May) to late fall (October or November), depending on lake elevation and location within the province. Samples may be collected monthly, but for a better understanding of seasonal change, every two weeks is preferred. If possible, these samples should be collected at the same time of day so that the effects of daylight on lake processes are standardized.

Secchi readings are ideally done weekly as there can be considerable fluctuation with algal blooms[3], especially in eutrophic and mesotrophic lakes. However, as a minimum, Secchi should be done biweekly with sample dates spread evenly through the growing season to get good representation of conditions. Also, to standardize the Secchi readings, it is recommended to make observations between 10:00 AM and 2:00 PM when the angle of the sun is highest and light intensity is greatest.

2.3.4 SELECTING SAMPLING SITES

Knowing the purpose of your sampling program will help you decide where to collect samples. For example, near-shore sites are heavily influenced by groundwater and surface runoff, so may be good locations for bacterial and chemical contaminant sampling of land-based discharges. Deep water sites provide information on conditions associated with stratification and lake trophic state, and overall condition of the lake. If interested in studying a lake's level of algal production or in comparing conditions to other lakes in your region, the lake's deep station (limnological station) will be the preferred place to sample. Monitoring one or both of these types of sites may be appropriate to your program depending on program objectives (Section 2.1.1) and budget (Cavanagh et al., 1998).

Be aware that sampling sites located near shore, and particularly in windward bays, will be influenced by increased densities of algae and debris. Samples collected at these sites may not be representative of the overall state of the lake.

One very important tool to obtain is a bathymetric (bottom contour) map of the lake. In addition to shallows, reefs, and the lake deep station(s), the map should include features such as inflows and outflows and areas of shoreline development. The map will be used to identify your water sampling sites. The BCLSMP typically requests samples to be collected at the deep station(s) of the lake. BC lake bathymetric maps can be obtained at **Fish Inventories Data Query (FIDQ)**. High quality bathymetric maps, with additional information for anglers, can be accessed at **www.anglersatlas.com**. Appendix 2.6 provides examples of both map styles.

[3] In some lakes, sediment input from streams can affect the water clarity and it is important that this distinction is made in the field notes.

2.3.5 SAMPLING FROM SHORE (SUMMER OR OPEN WATER SEASON)

Sampling the water quality of a lake near shore is not recommended for the collection of general limnological information and should only be done if you are specifically interested in shallow, near-shore water quality (e.g., related to human sewage bacteria). The shallow sediments of many interior lakes are dominated by fine organic silts that are easily disturbed and raised from the lakebed. These are very capable of contaminating shallow water samples. If possible, near-shore samples should be collected from a boat to reduce the potential of disturbing bottom sediments. If a boat cannot be used, pick an easily accessible site that will pose no threat to personal safety. If at any time the site cannot be reached, try to find another one nearby or wait until the original site is again accessible. Any changes in site location should be recorded in the logbook.

When sampling from shore, and to minimize sample contamination by suspended sediments, the collector should try to wade out past the point where the wave action disturbs the lake bottom. Care must be taken here as the simple act of walking to the site will cloud the water. If safe to do so, walk slowly "up-current" to sample in undisturbed water.

Shoreline Sampling Protocol (summer)*

*Protocol adapted from the Resource Inventory Protocol Standards (ENV, 2003)

a) Use plastic bottles of 250 mL to 1 L volume, depending on how many tests are needed. Label the bottles using waterproof ink with, at minimum, site name, site number, date, time, depth, and sampler initials.

b) With the labelled bottles, wade into the lake at the most accessible point.

c) Once you reach a sufficient depth (where bottom material will not interfere with the sample) stop and orient yourself towards the center of the lake.

d) Check to see if the bottle is pre-cleaned or needs rinsing. If the bottle and cap need rinsing, follow the Rinsing Technique protocol described in Section 2.2.

e) Remove the lid (without touching the inner surface) and grasp the bottle well below the neck. Lean out towards the center of the lake and in one continuous motion plunge the bottle beneath the surface and slowly force it through the water until it is full. This motion creates a current over the mouth of the bottle (so the water entering the bottle has not come in contact with your hand).

f) Keep the cap clean while off the bottle and replace the cap immediately.

g) Return to shore and pack the sample(s) in a cooler with several ice packs until conditions allow for other necessary procedures to be completed (filtration and/or preservation), which should be done as soon as possible after the samples are collected.

2.3.6 SAMPLING FROM A BOAT (SUMMER)

The preferred method of lake water quality sampling during open water is from a boat. Before going out in a boat, check the local weather conditions. If the weather is poor, sampling should be postponed. Rain is not a safety hazard as long as the weather is calm, and appropriate clothing is worn; however, windy, rough water represents a clear safety hazard and is to be avoided. If the weather deteriorates while sampling, stop and return to shore as quickly as possible and complete the sampling later when safe to do so. If necessary, collect the sample another day. Refer to Section 4.1.2.

Sample sites should be determined and located before going out on the lake. Most sampling is done at the deepest location of the lake or basin (the limnological station). Each site could be referenced by using two or more identifiable shore landmarks and/or by GPS. A depth sounder or fish finder will greatly aid in locating the sampling location. To make locating the site easier for yourself and any future collectors, record and photograph the reference points. Once at the site, try to maintain your position by anchoring the boat or by having another person keep the boat steady. Anchoring is much preferred as it allows both occupants to work on the sampling objective. When sampling from an anchored boat, it is important to ensure that the boat has drifted at least a few metres away from a position directly over the anchor and the muddy water it would have produced. For surface samples, sample from the front of the boat, while moving slowly forward. This will eliminate contamination from the boat and motor.

Source: Marge Sidney.

Surface water sampling

Collect grab samples at arm's length (0.5 m) or at 1 meter depth either from the lake's deep station(s) or from other sites, depending on study design. Refer to the Surface Water Sampling Protocol.

Surface Water Sampling Protocol (summer)*

*Adapted from the Resource Inventory Protocol Standards (ENV, 2003)

a) The person at the bow should always collect the samples. This is because the bow is the anchor point and even with minor wave action, will be "upstream" of the boat engine and its related contamination. In calm water, the samples should be collected prior to anchoring, while the boat is moving slowly forward. These precautions reduce the potential of contamination from the boat or motor. The person in the stern can be responsible for holding the boat's position (when not anchored), taking the field measurements, and recording field notes. Potential contamination from the motor is not as much of a concern for field measurements.

b) Use plastic bottles of 250 mL to 1 L volume, depending on how many tests are needed. Label the bottles using waterproof ink with, at minimum, site name, site number, date, time, depth, and sampler initials.

c) Obtain a labelled sample bottle and remove the lid without touching the inside of the lid (or bottle). Keep the cap clean while off the bottle.

d) Check to see if the bottle is pre-cleaned or needs rinsing. If the bottle and cap need rinsing, follow the Rinsing Technique protocol described in Section 2.2.

e) Reach out an arm's length from the boat to take the sample. Ensure that the person in the stern is providing counterbalance (working over the opposite side of the boat).

f) Plunge the bottle under the surface open end first and move it slowly towards the current (the direction the boat is facing). This should be done at a depth of between 0.5 and 1.0 m.

g) Recap the bottle immediately and pack it in a cooler with ice packs until time and conditions allow for other necessary procedures to be completed (filtration and/or preservation), which should be done as soon as possible after the samples are collected. In inclement weather conditions, this might be done on shore.

Deep water sampling

For samples collected below 0.5 to 1 metre depth, Van Dorn, Kemmerer, or Student Point sample bottles can be used (for BCLSMP studies, a sampler would usually be provided by ENV or BCLSS). These samplers have two different designs and are both lowered to depth on ropes marked in 0.5 m increments. The first uses a horizontal configuration, which is advantageous because it ensures that a very narrow depth range is sampled. This type of sampler should be used for samples taken very near the bottom or from narrow bands of water. The vertical configuration has the advantage of easily flushing water through the open bottle during its downward

Charlie Lake. Source: Edward Stanford.

travel through the water column. This guarantees that the collected water is from the desired depth. Some “back and forth” movement of the rope at surface once final depth is reached is useful for flushing the sampler with water from the desired depth. Both models include drain valves for water sample removal. The vertical design is easier to use for winter sampling through ice holes. Although operation of the vertical and horizontal samplers varies slightly depending on size and style, the basic procedure is the same. Refer to the deep-water sampling protocol.

Deep Water Sampling Protocol (summer)*

*Adapted from the Resource Inventory Protocol Standards (ENV, 2003)

a) Ensure the Van Dorn, Student Point Sampler, etc. is clean (it should be stored in a dust proof box or bag).

b) Open the sampler by raising the end seals and set the trip mechanism to lock the ends. Do not touch any inner surface of the sampler.

c) Rinse the sampler at the lake surface by raising it up and down several times on the rope.

d) Lower the sampler to the desired depth by tracking the rope markings. It is a good idea to tie the rope’s loose end to the boat.

e) Send the messenger down to “trip” the mechanism that closes the end seals. For sticky mechanisms it may help to give the rope a tug just as the messenger hits the trigger.

f) Raise the sampler to the surface, using a steady pull to prevent water loss.

g) Transfer the water sample from the sampler to individual sample containers via the drain valve. Take care to avoid contact between the drain spout or tube and the water sample bottle as contamination at this stage is possible.

h) Rinse bottles and caps three times with the water sample (if they have not been prewashed).

i) Collect samples, recap bottle tightly and store in coolers with ice packs until time and conditions permit other necessary procedures (filtration and/or preservation). This should be done as soon after sample collection as possible.

j) Keep samples cool (4°C) and have analyzed within 48 hours for nutrients and general ions or 24 hours for bacteria. Appropriate hold times for samples are provided by the analyzing lab.

2.3.7 WINTER SAMPLING

Not all BC lakes freeze during winter. For those that do not (such as monomictic lakes of coastal BC), samples can be taken by following the same steps used throughout the regular monitoring season (April to November). It is important to remember that the winter water is near 4°C. and represents a serious hazard to personal safety. Regardless of whether or not the lake is frozen, extra caution must be used during the winter season. Refer to Section 2.1.2, Field Safety**.** The winter sampling protocol for frozen lakes is provided below.

Winter Sampling Protocol for Frozen Lakes*

*Adapted from the Resource Inventory Protocol Standards (ENV, 2003)

Special note: With recent warming trends, many BC lakes do not freeze as solidly as they have in the past and this must be considered for both lake sampling and recreation

a) With safety considerations in mind (refer to 2.1.2), winter sampling locations should be as close as possible to the summer locations. Shallow water sites should be deep enough to avoid stirring up bottom sediments with the auger point and to ensure water movement under the ice.

b) Clear loose ice and snow from the sampling location and drill through the ice with a hand or motorized auger. Keep the area around the hole clear of potential contamination (dirt, fuel, oil, etc.). At least one member of the sampling team should be familiar with the operation and safety of motorized or hand operated augers, whichever is being used.

c) Remove all ice chips and slush from the hole using a plastic sieve.

d) Use a Van Dorn sampler (or similar apparatus) to collect the sample, as arm's length sampling may be too short to reach beneath the ice layer and may actually collect water from the ice itself.

e) In most cases, do not allow samples to freeze. Store in coolers with a minimal number of ice packs or with bottles of room temperature water if there is a possibility of the samples freezing before being returned to shore.

Record the depth of snow and ice in the field notes. The depth of the water at the site should be determined using a depth sounder over the hole so that the sampler does not touch the bottom as stirring of the lake sediments can contaminate the water sample and the sampling device.

2.3.8 GRAB VERSUS COMPOSITE SAMPLES

Norman Lake. Source: Marge Sidney.

Lake samples for water chemistry are typically either grab or composite samples. A grab sample is a sample collected at a selected location, depth, and time. This discrete sample may be hand collected at 0.5 metre depth or collected from a greater depth by using a water sampler such as the Van Dorn. A composite sample is a sample obtained by mixing several discrete samples of equal volumes together. This type of sample provides an estimate of average water quality over space or time. It may be either depth (taken over a predetermined part or the entire depth of the water column) or time integrated. Specially made tubing, hung vertically in the water column, is another way to collect depth integrated samples. Both types of samples are useful depending on the objective of the monitoring program. Most volunteer lake sample programs make use of simple grab samples.

2.3.9 DETERMINING WHAT TO MEASURE

The type of measurements made, or samples collected in a lake monitoring program will depend on the project objectives and the budget available. Measurements such as temperature, pH, dissolved oxygen, and Secchi disk clarity are relatively easy and inexpensive. More complex parameters, including nutrients, chlorophyll *a*, and fecal bacteria, can be analyzed by a laboratory if the need exists and the resources are available. The provincial government or the BCLSS will work with you to determine appropriate sampling parameters for the lake you are interested in monitoring. Chapter 3 will present and discuss a list of potential limnological parameters and how they are measured.

Charlie Lake. Source: Sam Pritchard.

2.4 REPORTING THE RESULTS

Education is the most effective approach for encouraging lake protection and minimizing typical non-point source lake pollution. All users of a watershed have the potential to impair the water or habitat quality of lakes and streams within that watershed. Educational efforts should reach as many of the watershed residents and users as possible. Part A of this manual, *A Guide to Lake Stewardship in BC,* contains information on educational initiatives and resources. The BCLSS web site also has a list of educational materials.

Lake reports are a key educational component of lake protection efforts, and it is important for monitoring results to be reported in a reader-friendly format. Examples of lake reports written by the BCLSS for Level 1 to 3 volunteer water quality assessments can be found in the **BCLSS Document Library**. These lake-specific documents describe observed trends in the lake according to parameters monitored. These reports also provide lake users with an assessment of potential changes in water quality and identify any problems associated with these changes. Where possible, they also make recommendations as to whether further lake monitoring and assessment is needed as a result of the review of the data.

BC Lake Stewardship and Monitoring Program

Heffley Lake 2005-2020

BCLSS

A partnership between the BC Lake Stewardship Society and the BC Ministry of Environment and Climate Change Strategy

British Columbia Ministry of Environment and Climate Change Strategy

The Importance of Heffley Lake & its Watershed

British Columbians want lakes to provide good water quality, aesthetics, and recreational opportunities. When these features are not apparent in our local lakes, people begin to wonder why. Concerns often include whether the water quality is getting worse, if the lake has been impacted by land development or other human activities, and what conditions will result from more development within the watershed.

The BC Lake Stewardship Society (BCLSS), in collaboration with the Ministry of Environment and Climate Change Strategy (ENV), has designed a program, entitled *The BC Lake Stewardship and Monitoring Program*, to address these concerns. Through regular water sample collections, we can come to understand a lake's current water quality, identify the preferred uses for a given lake, and monitor water quality changes resulting from land development within the lake's watershed. There are different levels of lake monitoring and assessment. The level appropriate for a particular lake depends on the funding and human resources available. In some cases, data collected as part of a Level I or II program can point to the need for a more in-depth Level III program. This report gives the 2005-2020 results of a Level I volunteer program for Heffley Lake. A previous report was written on Level II data collected from 2005-2008 and can be found in the BCLSS website Library. Level I Secchi and temperature data were collected by volunteers with the Heffley Lake Community Association, who have provided a very thorough and consistent data set.

The BCLSS can provide communities with both lake-specific monitoring results and educational materials on general lake protection issues. This useful information can help communities play a more active role in the protection of the lake resource. Finally, this program allows government to use its limited resources efficiently with the help of local volunteers and the BCLSS.

A **watershed** is defined as the entire area of land that moves the water it receives into a common waterbody. The term watershed is misused when describing only the land immediately around a waterbody or the waterbody itself. The true definition represents a much larger area than most people normally consider. The watershed area of Heffley Lake is 52 km^2.

Watersheds are where much of the hydrologic cycle occurs and play a crucial role in the purification of water. Although no "new" water is ever made, it is continuously recycled as it moves through watersheds and other hydrologic compartments. The quality of the water resource is largely determined by a watershed's capacity to buffer impacts and absorb pollution.

Every component of a watershed (vegetation, soil, wildlife, etc.) has an important function in maintaining good water quality and a healthy aquatic environment. It is a common misconception that detrimental land use practices will not impact water quality if they are kept away from the area immediately surrounding a waterbody. Poor land use practices in a watershed can eventually impact the water quality of the downstream environment.

Human activities that impact water bodies range from small but widespread and numerous *non-point* sources throughout the watershed to large *point* sources of concentrated pollution (e.g. waste discharge outfalls, spills, etc.). Undisturbed watersheds have the ability to purify water and repair small amounts of damage from pollution and alterations. However, modifications to the landscape and increased levels of pollution impair this ability.

1

CHAPTER THREE: WATER QUALITY PARAMETERS

"We tend to take water for granted, but we do so at our peril. We are utterly dependent on water for our lives. We all use it, and increasingly, we pollute it. So water is not just their responsibility, whoever they are, it is our responsibility. We are all water managers.

- Malcolm Hollick

Swan Lake. Source: BCLSS Files.

Chapter Contents

So far, LakeKeepers has outlined how to form a stewardship group, several important aspects of lake ecology, and components for conducting a lake sampling program. LakeKeepers Chapter 3 will detail some of those specific water quality parameters that should be part of typical lake water quality programs. One design for a trophic characterization study may be based on spring nutrient sampling and regular Secchi disk clarity measured through the open water period, complemented by a late summer sampling after the lake has been stratified for an extended period (Level 2 Program). Another fairly cost-effective design may simply add regular temperature, dissolved oxygen, phosphorus, and algal chlorophyll a measurement (Level 3 Program) The design is limited only by need and resources.[4]

Lake water quality sampling may involve the measuring of a wide variety of physical, chemical and/or biological variables or parameters contained within lake water or bottom sediments. While this chapter could go on at length discussing many of those parameters, we believe that it is better to focus on the parameters that are specifically related to the lake steward's common concern: eutrophication, or nutrient enrichment. The following sections aim to clarify the rationale behind selecting parameters related to lake management. Table 3.1: Examples of Water Quality Parameters lists different physical, chemical, and biological parameters which may be of interest in a lake water quality monitoring program.

Table 3.1 Examples of Water Quality Parameters

Physical	General Chemistry	Metals	Organics	Biological
Air temperature	Alkalinity: total	Aluminum	Hydrocarbons	Chlorophyll a
Cloud cover (%)	Dissolved Oxygen	Antimony	PAHs	Phytoplankton
Windspeed	Organic Carbon	Arsenic	PCBs	Zooplankton
Wave height	DOC[5]	Barium	Herbicides	Benthos
Water temperature	Chloride	Boron	Pesticides	Aquatic plants
Water clarity	Colour (true)	Cadmium	Dioxins	Coliform bacteria
Water colour	Fluoride	Calcium	Glyphosate	
Water odour	Nitrate/Nitrite	Chromium	Oil/grease	
	Nitrogen ammonia	Cobalt	Phenols	
	Nitrogen total	Copper	Microplastics	
	pH	Iron		
	Phosphorus dissolved	Lead		
	Phosphorus total	Magnesium		
	Phosphorus ortho	Manganese		
	Total Suspended Solids (TSS)	Molybdenum		
	Total Dissolved Solids (TDS)	Nickel		
	Silica	Selenium		
	Specific conductance	Silver		
	Turbidity			
NOTES:	PAHs Polycyclic aromatic hydrocarbons; DOC Dissolved organic carbon	PCBs Polychlorinated biphenyls		

[4] The different levels of lake study were described in Chapter 2

[5] DOC is especially important if metals are being analyzed

3.1 WATER CLARITY

3.1.1 DETERMINING WHAT TO MEASURE

Lake water clarity is a measure of visibility from the lake surface to depth. It is determined by the ability of light to penetrate water. Clarity will vary from lake to lake and seasonally, to some degree, in all lakes. For our purposes, lake clarity is most easily considered in terms of Secchi disk clarity.

3.1.2 WHAT AFFECTS IT?

Water clarity will differ between lakes and seasonally on any given lake due to varying concentrations of suspended sediment and algal cells and/or because of dissolved organic matter that produces colour in the water column. Lake water is often most clear during the winter when daylight hours are limited and when ice and snow cover severely restrict light transmission. Algal production is substantially reduced under these conditions. For this reason, and as an ice safety consideration, Secchi readings are not commonly done in winter on interior lakes. Concentrations of suspended solids are also reduced at this time due to a lack of wind, water currents and turbid inflows. Water clarity will often decrease through the open water period, depending on the following variables:

Figure 3.1 Secchi disk attached to a tape

- Nutrient inputs, mainly phosphorus, which promote algal growth
- The density and annual succession of free-floating algae (Chlorophyll a, Section 3.6)
- The grazing on these algae by zooplankton
- Organic colouration of the water due to bog runoff or plant decomposition
- Erosion of the lake shoreline or of stream banks within the watershed which create silty inflows
- Recirculation of lake sediments by heavy winds or motorboat activities

3.1.3 WHY SHOULD IT BE MEASURED?

A decrease in water clarity can profoundly affect the amount of sunlight that reaches deeper water. A loss of sunlight can lead to reduced rooted plant photosynthesis, and to the stressing and possible demise of these populations. Given that many aquatic animals depend on these plants for habitat, dissolved oxygen, and food, a loss of rooted plant life may threaten animal populations as well. Equally important, the dense bloom of algae may itself have a very high demand for oxygen when it decomposes.

We measure Secchi depth to determine how much algae is present, however Secchi depth can be affected by suspended sediment, either as glacial flour or erosional silt. Figure 3.2 illustrates this as well as showing Secchi disk readings in relation to lake trophic classification. It is generally preferable to see greater Secchi depths, inferring a less productive lake that may have greater recreational appeal and less chance of forming blooms that cause fish kills.

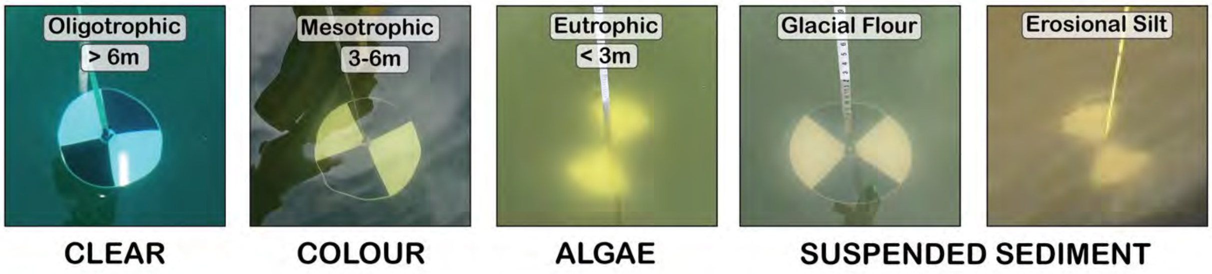


Figure 3.2: Secchi disks in relation to lake trophic classification and sediment

3.1.4 HOW IS IT MEASURED?

Water clarity is most often measured with a Secchi disk (see Figure 3.3), which provides a standard method for measuring light penetration below the water surface. The Secchi disk is a 20 cm diameter circular plate divided into alternate black and white quarters (see Figure 3.1). (Bigger disks are recommended for ultra-oligotrophic lakes where it can become hard to make a reading simply because of the great vertical distance between the reader and the disk). This weighted horizontal disk hangs from a rope marked in 10 cm increments and is lowered into the water column until it can no longer be seen. This depth is recorded, along with the depth at which the disk reappears once pulled back up to the surface. The average of the two recorded depths (say 2.10 m down and 1.80 m up) provides the Secchi depth (1.90 m). A low Secchi depth reading (short distance) indicates that the water is turbid, has large populations of algae or has a high degree of colouration. A high Secchi reading (greater distance) indicates that the water has a low turbidity, low phytoplankton population and little colour. Oligotrophic, low production lakes have greater Secchi depths than do eutrophic, high production lakes. Typically, the lake depth at which sufficient light exists to support algal photosynthesis is roughly two to three times the Secchi disk depth.

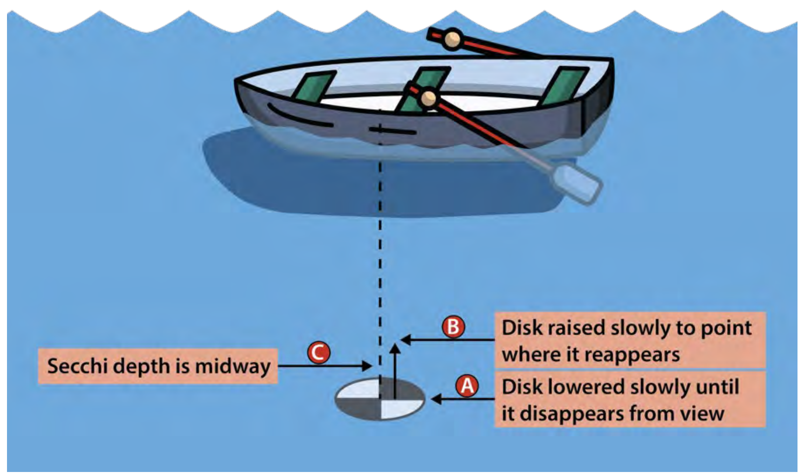


Figure 3.3: How to measure water clarity

Water Clarity Protocol

*Protocol adapted from the BC Inventory Standards, Aquatic Ecosystems (BC ENV, 2008); and the BC Field Sampling Manual (Province of BC, 2013).

a) Secchi disk readings should only be taken during the period from two hours after dawn to two hours before dusk, and preferably between 10:00 AM and 2:00 PM. Sunglasses should not be worn while taking this measurement.

b) Lower the Secchi disk over the shaded side of the boat. Because it must drop vertically, the boat must be stationary, either in calm water or anchored.

c) Record to the nearest 0.10 m the depth at which the disk is lost from sight (say 6.42 m). The disk should be lowered below this depth and then retrieved back to where it is again visible (say 6.82 m). Record this depth. Average the two readings to calculate the Secchi disk depth (6.62 m).

d) Record this value in the field logbook along with the controlling variables (e.g., percent overcast (0/10 for clear to 10/10 for overcast), relative wind speed, surface condition, etc.)

3.2 TEMPERATURE

3.2.1 WHAT IS TEMPERATURE?

Most people are familiar with the concept of temperature. It is the degree of heat a substance contains, usually measured on the Celsius scale, where water freezes at 0°C and boils at 100°C. Water temperatures in most BC lakes typically range from 0°C to 25°C.

3.2.2 WHAT AFFECTS TEMPERATURE?

Lake temperature is principally governed by the amount of solar radiation absorbed at the lake surface and the distribution of that radiation to depth. These are dependent on a lake's latitude, morphometry (mainly volume), elevation and water clarity. Wind action can also have a major impact on a lake's surface temperature when strong winds mix deeper colder water up into the surface layer. Seiches were discussed in Chapter 1 (see Appendix 1.2). Learn more about seiches on our **website**.

3.2.3 WHY SHOULD TEMPERATURE BE MEASURED?

When collected seasonally from a vertical profile, water temperature along with dissolved oxygen are two very important limnological study parameters. Measuring temperature through the water column and over time allows us to understand a lake's specific thermal structure. It allows us to predict the patterns of other variables (e.g., dissolved oxygen and phosphorus) that play a key role in lake productivity and recreational water quality (see Figure 3.4. Bridge Lake Temperature Profiles).

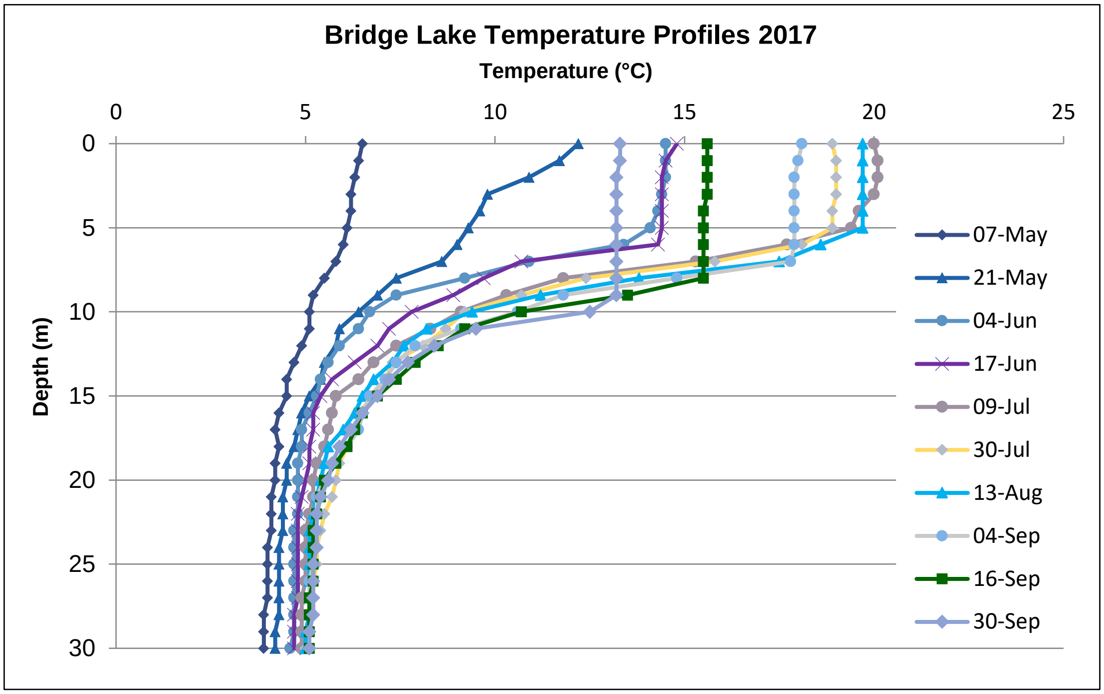


Figure 3.4: Bridge Lake 2017 temperature profiles

Temperature measurement also provides important information on the health of the biological community by indicating when and where the temperature tolerances of fish and other animals or plants may be exceeded, and thermal stress or death might occur. Because each organism has a preferred thermal range, temperature measurement can give us an idea of which are most likely to exist in particular water bodies. On a personal level, we can learn whether the lake on which we hope to build our retirement cottage is a cold-water trout fishery or a warm water lake that may be dominated by coarse fish. Also, measurement of this parameter can tell us when the ideal swimming temperature of nearly 20^{o}C is reached.

The BC ENV's BC Approved Water Quality Guidelines state that to protect freshwater aquatic life in lakes and impoundments, water temperature should not change by more than +/- 1^{o}C from the natural ambient background (ENV, 2019; 2020; 2021) Monitoring is required to determine background conditions and therefore identify trends that may be present.

3.2.4 HOW SHOULD TEMPERATURE BE MEASURED?

Measurement should establish a vertical temperature profile through the water column over time. Temperature can be measured with an alcohol filled thermometer, either mounted inside a water collection bottle (Van Dorn) or from lake water decanted into a 1 litre bucket, or with a long-cabled electronic meter. Meters have the clear advantage of easily establishing vertical temperature profiles that are based on measurement at each metre of depth, and this is the preferred method to ensure the most valuable data set for climate change assessment or other scientific purposes. Alcohol thermometers have the advantage of very low cost but using one to establish a full vertical profile would be laborious. For lake monitoring in BC, glass thermometers are suitable for temperatures at varying depths (see Figure 3.5).

Figure 3.5 Glass field thermometer

Source: The Arborist Store
https://bit.ly/3LSeZbs

The following protocols have been adapted from the BC Inventory Standards, Aquatic Ecosystems, and the BC Field Sampling Manual (BC ENV, 2008; Province of BC, 2013).

Protocol for Measuring Water Temperature
(Alcohol-Filled Thermometers)

*Protocol adapted from the BC Inventory Standards, Aquatic Ecosystems (BC ENV, 2008); and the BC Field Sampling Manual (Province of BC, 2013).

Measure surface water temperatures directly in the water, allowing the thermometer to come to equilibrium before recording the value. For deep waters, never measure the temperature in a sample bottle that is being submitted to the laboratory for analysis, as doing so may contaminate the sample. Collect a grab sample (e.g., with a Van Dorn) and decant some of that sample into a 1 litre "field bottle." Measure the temperature immediately, allowing the thermometer to come to equilibrium before recording the value. Or, if the Van Dorn has been fitted with an internal thermometer, measure temperature once equilibrium has been reached. Ensure that the corresponding depth is recorded for each temperature entered in the field logbook.

Protocol for Measuring Water Temperature
(Electronic Temperature Meters)

*Protocol adapted from the BC Inventory Standards, Aquatic Ecosystems (BC ENV, 2008); and the BC Field Sampling Manual (Province of BC, 2013).

a) Calibrate the meter as per the operating instructions issued for each model.

b) Check meter temperature readings, both in air and in water, against a thermometer of known accuracy as a quality control measure. If the measurements do not agree, the meter can be adjusted to the thermometer reading. This check should be repeated throughout the day to determine if the meter is wandering. All adjustments must be recorded in the field logbook. Temperature data are typically recorded to the nearest 0.5 degree.

c) For depth profiles, read and record temperature in increments of 1 - 2 metres. Provide more time for equilibration when the temperature changes rapidly (at the thermocline). As a quality control measure, record some readings twice, once as the probe descends, and again as it ascends.

3.3 DISSOLVED OXYGEN

3.3.1 WHAT IS DISSOLVED OXYGEN?

Dissolved oxygen (DO) is a measure of the concentration of gaseous oxygen (O_2) present in water. Like many other chemical measures, it is reported as the number of milligrams (of oxygen) in one litre of water, or mg/L. An equivalent measure is parts per million (ppm). Concentrations of dissolved oxygen in water normally range from 0 to 14 mg/L. The saturation concentration in water decreases with increasing altitude and temperature.

3.3.2 WHAT AFFECTS DISSOLVED OXYGEN?

Dissolved oxygen is both regularly produced and consumed in lake water. Its two main sources in a typical lake are natural diffusion of atmospheric oxygen across the water surface and plant photosynthesis that produces oxygen as a by-product. Oxygen is consumed, and carbon dioxide produced, mainly through the respiration of living organisms.

All organisms respire and most require some amount of oxygen. Bacterial decomposers use a great amount of oxygen, sometimes to the detriment of other animals, in breaking down large masses of organic material that settle on the lake bottom. Sport fish and other aquatic animals require at least moderate concentrations of oxygen for basic survival.

Surface oxygen mixes with deeper water at overturn and during windy periods. Extended periods of overturn can occur and will bring DO content up to full saturation throughout the lake. Oxygen will be more readily absorbed into cold water, so lakes in colder climates generally contain higher oxygen concentrations. Tributary inflows can also be a significant source of oxygen, particularly if they are large relative to the lake volume. Daily oxygen fluctuations are also important to consider. Given that algal and plant communities photosynthesize only during daylight hours, productive lakes can vary from oxygen super-saturation during the day to anoxia at night, particularly in the littoral zones. The dissolved oxygen concentration of eutrophic lake water is lowest just before dawn and slowly increases through the day as photosynthesis progresses. Eutrophic lakes, once stratified, can have very low oxygen concentrations in deeper water and DO can actually be eliminated from the hypolimnion. This could restrict the useable habitat for fish and other aquatic life, perhaps to a narrow horizontal band determined by maximum DO and minimum temperature.

3.3.3 WHY SHOULD DISSOLVED OXYGEN BE MEASURED?

Oxygen is essential for the survival of most aquatic life, especially salmonid species (trout, char, and salmon). BC Water Quality Criteria Water column dissolved oxygen should not drop below an instantaneous minimum of 5 mg/L nor a 30-day average of 8 mg/L. In order to effectively protect the aquatic environment, an understanding of its oxygen cycling is necessary (see Figure 3.6. Bridge Lake Dissolved Oxygen).

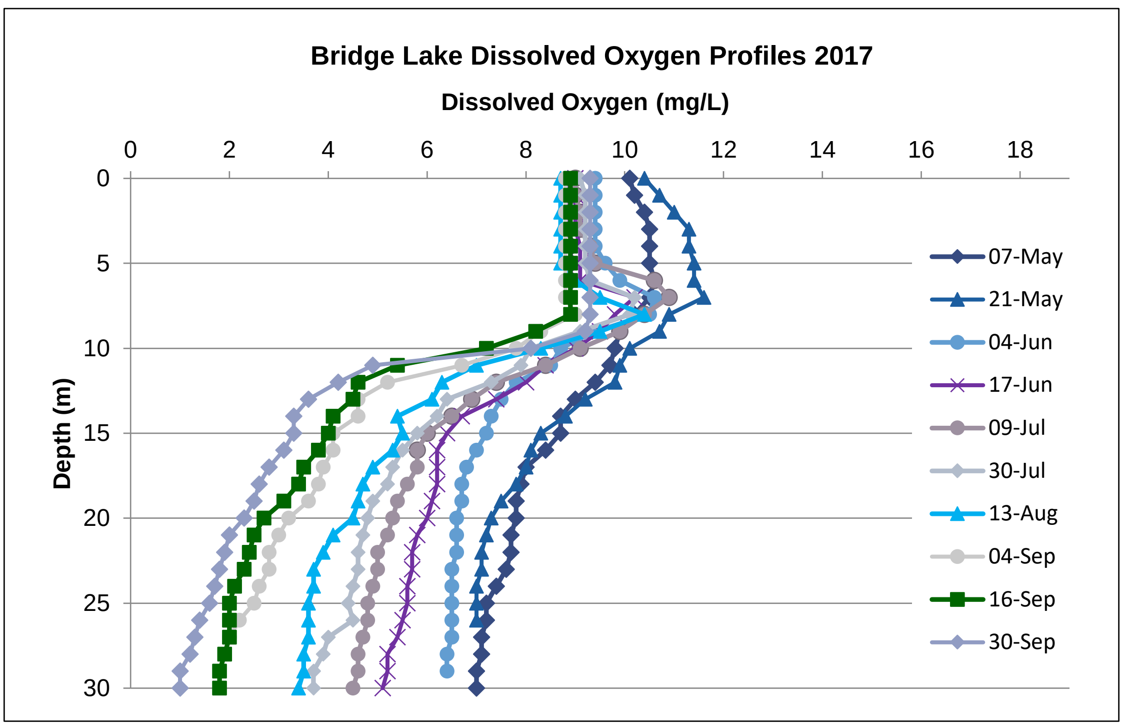


Figure 3.6. Bridge Lake 2017 dissolved oxygen profiles

Additionally, dissolved oxygen has a large effect on water chemistry and nutrient cycling. Under aerobic conditions, much of the phosphorus in a lake is bound to iron, manganese and/or calcium contained in lake bottom sediments. However, when bottom oxygen levels become reduced to near 0 mg/L, the chemical nature of the sediment changes and phosphorus is released into the overlying water. When this phosphorus is mixed into the photic (sunlit) zone, either at overturn or during strong windstorms, plants and algae can utilize it. The phenomenon, known as internal loading, can lead to drastic increases in algae and plant densities. Iron, manganese, and hydrogen sulphide (H_2S) can also be released into the water during these anoxic periods, causing problems in drinking water.

3.3.4 HOW IS DISSOLVED OXYGEN MEASURED?

Like temperature, dissolved oxygen is best measured at each metre of depth in order to produce a vertical profile. At the very least, it should be measured near surface, at mid-depth and near-bottom. Oxygen can be measured using either one of a variety of electronic meters or by using a manual titration kit. Both methods can produce reliable data but require properly trained operators and either fresh chemical reagents (for manual methods) or calibrated meters. DO protocols for electronic meters are outlined below. For chemical-based titration methods, follow the instructions included with the kit. Figure 3.7 shows a YSI ProSolo which is an electronic dissolved oxygen meter.

Figure 3.7 YSI ProSolo

Source: YSI Inc. 2021
https://www.ysi.com/prosolo

Protocol for Measuring Dissolved Oxygen Concentration
(Electronic Dissolved Oxygen Meters)

*Protocol adapted from the BC Inventory Standards, Aquatic Ecosystems (BC ENV, 2008); and the BC Field Sampling Manual (Province of BC, 2013).

Dissolved oxygen measurement by meter is preferred over the use of a manual titration, provided the meter has been properly calibrated before use. Follow the manufacturer's directions for storage, transportation, calibration, and use. When using a DO meter, it is recommended that calibrations be done on a regular basis (daily). Obtain DO readings for increments of 1 metre during the descent and for part of the ascent of the probe. Allow the probe to equilibrate (a steady reading on the meter) at each depth before recording the value. Gentle jigging of the cable may be necessary for equilibration. When passing through a zone of rapid temperature or DO change (a lake thermocline for instance), a longer period may be required for equilibration.

Notes:
When probe function deteriorates the probe membrane, if equipped, should be changed to avoid contamination of the sensing element. Air bubbles should not be trapped under the membrane. Check the meter instructions for a membrane servicing schedule and methods. The probe may become damaged if it remains in waters of low DO (<0.5 mg/L) for long extended periods. Many instruments use optical DO sensing with no membrane. These are easier to maintain than the membrane equipped instruments, but the maintenance requirements should be closely followed none-the- less.

3.4 PHOSPHORUS

P

3.4.1 WHAT IS PHOSPHORUS?

Phosphorus is a naturally occurring element that in most BC lakes is the nutrient in shortest supply and thus will act to limit the production of aquatic plants and algae. It is also, unfortunately, a common component of human and animal sewage, a very effective ingredient of clothes and dish washing detergents and, for obvious reasons, a major constituent of agricultural and garden fertilizers. Total phosphorus (TP) in a lake can be greatly influenced by human activities and when in excess, can accelerate plant growth and artificially age a lake.

3.4.2 WHAT AFFECTS PHOSPHORUS?

Phosphorus has many sources and forms that affect its concentration in water and its availability to the biological community. Phosphorus may exist as particulate inorganic phosphorus (PIP), usually clay particles, that typically enter a lake through erosion of the watershed. This clay is essentially inert. It is neither readily bio-available nor easily converted to more available phosphorus forms. Particulate inorganic phosphorus usually falls to the lake bottom where it is permanently stored. By convention, materials larger than 0.45 µm (0.00045 mm) are referred to as particulate.

At the other end of the scale is dissolved inorganic phosphorus (DIP). This is a less than (<) 0.45 µm, soluble, reactive phosphorus, common in fertilizer and detergent, that is entirely and immediately available to the biological community. Its addition to a lake will result in the rapid development of algal blooms, usually within days.

Two other common phosphorus forms are dissolved and particulate organic phosphorus (DOP and POP). Sewage and manure are two notable sources of this organic form. Both of these phosphorus forms must be converted to DIP before they can be used biologically. Unlike clay, however, both are very degradable. It is only a matter of time before manure will provide DIP phosphorus for the growth of algae and aquatic plants.

3.4.3 WHY SHOULD PHOSPHORUS BE MEASURED?

The production of organic matter in lakes, whether simple phytoplankton cells or valued sport fish, is reliant on a supply of nutrients. All require several basic elements in order to sustain growth and reproduction. The amounts of these nutrients supplied over the long term, help determine the productive status of lakes, which range from ultra-oligotrophic to hyper-eutrophic (see Figure 3.8 Charlie Lake Total Phosphorus).

If it is a management intent to effectively control algal production within a lake, the nutrient most limiting that production must be identified and quantified. In almost all lakes phosphorus, or sometimes nitrogen, limits production and when in excess may accelerate aquatic plant and algae growth to artificially age a lake.

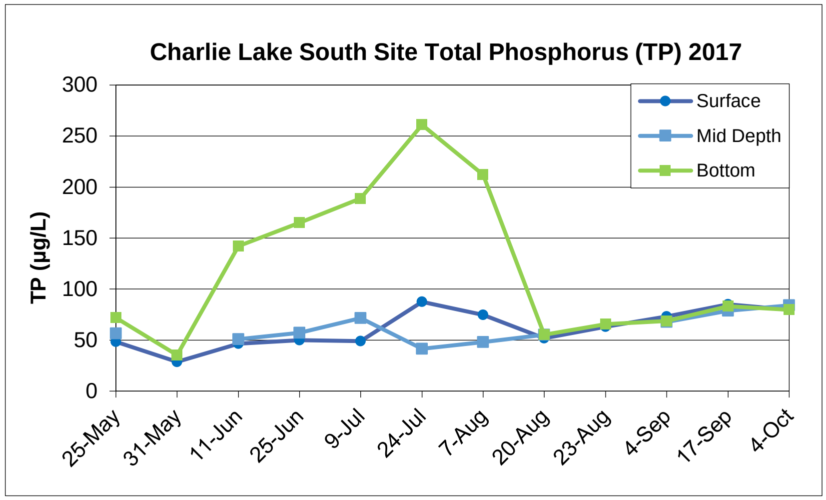


Figure 3.8 Charlie Lake 2017 total phosphorus

This concept of limiting nutrients can be explained in terms of plant composition and the quantities of nitrogen and phosphorus that typically exist in the water column. The composition of plant biota approximates the ratio of those chemicals required for life functions. While the nitrogen to phosphorus ratio of plants is roughly 7:1 (weight ratio), the ratio of available nitrogen to phosphorus in lake water may be many times higher (e.g., 35:1). Phosphorus is usually lacking and will most commonly be the nutrient that limits production in lakes. Generally, N:P ratios of < 5:1 suggest nitrogen limitation and those > 15:1 suggest phosphorus limitation. Intermediate ratios imply a co-limitation if both nutrients exist at very low concentration or no limitation if both are abundant. Because phosphorus can be insufficient and thus limiting it should always be monitored in lake water quality programs.

3.4.4 HOW SHOULD PHOSPHORUS BE MEASURED?

As with most water quality parameters, phosphorus must be chemically analyzed by a certified laboratory. This manual will not discuss analytical methods however it is critical that the data are quality assured.

Regarding phosphorus analysis, we typically have three laboratory forms available to us: total phosphorus (TP), total dissolved phosphorus (TDP, that DOP and DIP material which passes through a 0.45 µm (0.00045 mm) filter) and orthophosphorus or DIP (reactive and < 0.45 µm). Because the water residence time of most lakes is sufficiently long, TP is usually considered a reasonable indicator of bio-available phosphorus and is most often used in productivity modelling. However, in cases of very rapid flushing rates or where much of the TP is inert clay, TDP and OP may be more appropriate indicators. TP may overestimate bio-available phosphorus in lakes: TDP and OP will usually underestimate this factor.

3.5 NITROGEN

N

3.5.1 WHAT IS NITROGEN?

Nitrogen is an important nutrient in the biological production of aquatic environments. However, in most BC lakes, nitrogen is second to phosphorus as the most limiting nutrient.

3.5.2 WHAT AFFECTS NITROGEN?

Molecular nitrogen (N_2) makes up the majority of the volume of dry air. The primary means by which nitrogen enters lake water is by natural diffusion across the water surface. N_2 is then converted by various bacterial means to nitrate (NO_3) and ammonia (ammonium ion, NH_{4+}) which are bio-available to algae and plants. Nitrogen as ammonia and nitrate may also enter lakes via fertilizer, leaching of agricultural wastes via runoff, or sewage discharge.

One response within lakes to a temporary nitrogen limitation is a notable species shift from green algae to scum forming blue-green algae (cyanobacteria) that are capable of utilizing molecular nitrogen. These blooms can be widespread and troublesome to the recreating public. Although their growth is prompted by a lack of available nitrogen, they too are ultimately phosphorus limited.

3.5.3 WHY SHOULD NITROGEN BE MEASURED?

Nitrogen should be measured with phosphorus in lake water until confirmed not to be limiting primary productivity. Nitrogen monitoring should continue if, in fact, it is limiting. Ammonia nitrogen can be toxic to aquatic life so may also require regular monitoring.

3.5.4 HOW SHOULD NITROGEN BE MEASURED?

Nitrogen is another parameter that must be analyzed by a laboratory. Nitrogen samples should be collected using methods similar to phosphorus

Nitrogen can be measured as total nitrogen (TN), Kjeldahl nitrogen (TKN)[6], nitrate-nitrogen (NO_3), nitrite-nitrogen (NO_2), or ammonia-nitrogen (NH_4). Nitrate- and nitrite-nitrogen are usually measured together as combined nitrate-nitrite (NO_3-NO_2). The forms of nitrogen that are available to organisms for growth are NO_3 and NH_4+.

[6] TKN is the sum of ammonia N plus organic N

3.6 CHLOROPHYLL *A*

3.6.1 WHAT IS CHLOROPHYLL *A*?

Chlorophyll *a* is the common green pigment found in almost all plants. In lakes, it occurs in plants ranging from algae (phytoplankton) to rooted aquatic plants (macrophytes). Chlorophyll is a key component of photosynthesis, where sunlight energy is captured by chlorophyll and converted to chemical energy necessary for biological production. While several chlorophyll pigments exist, chlorophyll *a* is the most common. Concentrations of chlorophyll *a* in lake water are indicators of algal density present.

3.6.2 WHAT AFFECTS CHLOROPHYLL *A*?

Algal density and chlorophyll a concentration are both dependent on the availability of sunlight and nutrients, and to a lesser degree on temperature and wind. In direct relation to algal density, chlorophyll *a* concentration can be expected to follow predictable seasonal fluctuations. Chlorophyll typically shows an initial peak in spring when spring overturn brings phosphorus and nitrogen into the upper photic zone. Depending on the trophic nature of the lake, chlorophyll may be sustained at moderate concentrations through the summer with a second peak following fall overturn (in oligotrophic lakes) or may reach very high peaks during late summer and fall (in eutrophic lakes). In coastal lakes, it is not unusual to have early winter algal blooms as the input of nutrients to a lake accompanies fall rainfall and the major inflow of water to coastal lakes.

See Figure 3.9A and Figure 3.9B for examples of typical Secchi depth and chlorophyll *a* levels expected in an oligotrophic and eutrophic lake, respectively.

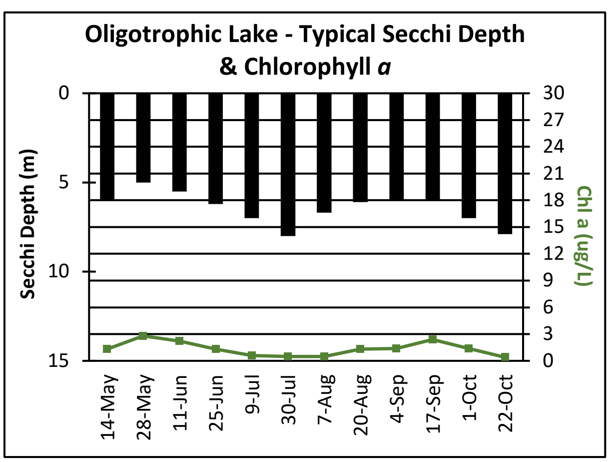


Figure 3.9A. Chlorophyll *a* in an oligotrophic lake

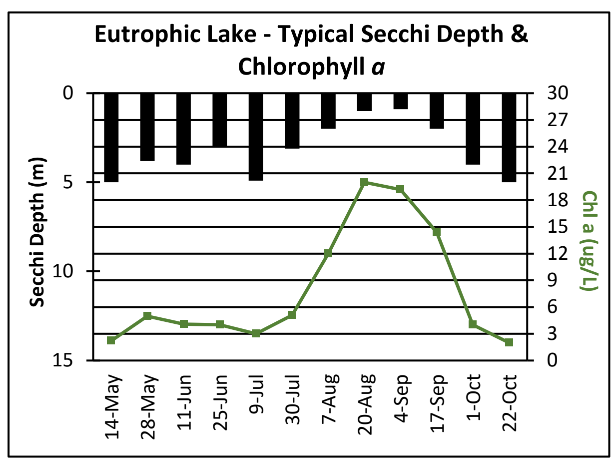


Figure 3.9B. Chlorophyll *a* in a eutrophic lake

Chlorophyll concentration is usually suppressed under winter ice, due largely to reduced light. In cases where the ice is clear and lacks a snow cover, light can continue to provide energy for the growth of plankton. Interesting algal communities can result along the bottom surface of the ice layer.

Wind can also affect chlorophyll. During periods of overturn, wind drives water circulation and with it the delivery of phosphorus into surface waters where light is sufficient to encourage algal growth. In the case of cyanobacteria (blue-green algae), wind can also drive these floating bacteria (with their chlorophyll) across the water surface, causing unsightly blooms on windward bays and beaches. On eutrophic lakes, toxic blue-green algal blooms are associated with this condition and can be responsible for the fatal poisoning of livestock, pets, and wildlife.

Source: rgerber from Pixabay.

3.6.3 WHY SHOULD CHLOROPHYLL *A* BE MEASURED?

Along with the previously mentioned limnological parameters, chlorophyll is a very useful indicator of a lake's biological and chemical make-up. It occurs in direct response to phosphorus concentrations and so, when measured along with that nutrient, will provide a strong picture of water quality conditions. The analysis of chlorophyll *a* is an indirect but accurate method of determining live algal biomass. The BC ENV's Approved Water Quality Guidelines have chosen to develop lake guidelines for phosphorus, rather than chlorophyll, as an indicator of biological production (ENV, 2019; 2020; 2021).

A good reason to sample for chlorophyll *a* is that it measures the density of algae present, whereas Secchi (water clarity) measurements only estimate algal density by correlation. Secchi can be influenced by factors other than algal density such as erosional sediment present, or colouration due to staining from humic compounds associated with runoff from wetlands.

3.6.4 HOW SHOULD CHLOROPHYLL *A* BE MEASURED?

Chlorophyll *a* samples are collected in a manner similar to phosphorus. A one litre volume of water is collected from a depth of 0.5 to 1 m in an opaque poly bottle and stored at 4°C. The sample can be either filtered in the field or shipped overnight to a laboratory.

If filtered in the field, the sample is then typically drawn through a 0.45 µm filter as soon as possible after collection in order to remove water. Chlorophyll is contained within algal cells that are usually large enough to be retained on 0.45 µm filter paper. The liquid chlorophyll sample must not be frozen prior to filtration. Doing so will rupture the algal cells and allow the much smaller chlorophyll pigment to be lost through the filter.

If samples are to be shipped to a laboratory prior to filtering, they must be stored in cool, dark conditions and analyzed at a laboratory within 24 hours.

Protocols are included here for both sample collection and processing. Sample filters may be stored frozen on desiccant crystal for a period of 30 days prior to analysis by a laboratory.

Protocol for Measuring Chlorophyll *a*

*Protocol adapted from the Freshwater Biological Sampling Manual (Cavanagh et al., 1997); and the BC Field Sampling Manual (Province of BC, 2013).

a) Collect sample in a clean, pre-labelled bottle. Secure lid tightly and place in a chilled cooler.

b) Filter an appropriate portion of the chlorophyll a sample through a 0.45-micron (µm) membrane filter, either immediately in the field or in a lab within 24 hours of collection if samples are kept dark and cool[1].

c) As the water sample is filtered, observe the filtration pressure or vacuum (<5psi) and the water level. When all but the last few millilitres of water are drawn through the filter, rinse the top holding cup with de-ionized water and continue to filter. Before the rinse water is fully filtered, add 2-3 drops of Magnesium carbonate ($MgCO_3$) suspension (1g $MgC0_3$/100 mL deionized water) and gently swirl the apparatus to distribute the $MgCO_3$ throughout[2].

d) With clean tweezers, carefully remove the filter and place it in the center of a larger (9 cm) *Whatman* filter paper. Without touching the membrane filter, fold the two papers in half and then in half again (with the smaller membrane filter inside the larger filter paper). Secure the filter papers shut with a plastic paper clip. With a pencil, label the *Whatman* filter paper as a chlorophyll sample. Also, for each sample, identify the site name, site number, date/time and the volume of water filtered directly onto the *Whatman* filter paper[3].

e) Chlorophyll is very sensitive to degradation by light. Place the filter paper in a pre-cooled thermos or dark bottle (amber glass, wrapped with aluminum foil and black tape). The container is also to contain a desiccating agent (i.e., silica gel)[4].

f) Pack the thermos or bottle containing all chlorophyll-a samples in a cooler with ice packs so that they remain frozen until they reach the analyzing laboratory.

g) Filters stored in a thermos or dark bottle with desiccant can be held in a deep freeze for 30 days, but it is far preferable to ship them to the lab immediately.

1Note b: The filtration should not be done under bright light. The amount of sample filtered depends on the density of the algae present; productive lakes may require only 50 mL; unproductive lakes may require 1 L to be filtered. One-litre water samples can be split and filtered as two 500 mL samples for individual analysis. The average concentration is then reported. Conversely, single samples of 500 mL are often filtered and submitted. Always record the volume of sample that was filtered (both in the field logbook and on the Laboratory Requisition Form).

2Note c: $MgC0^{3}$ is a buffer used to stabilize the pH of the algal cells to above 7. The cells are very sensitive to acid pH and the chlorophyll will be degraded to other pigments. Alkaline samples do not require this addition.
3Note d: Some brands of filter papers have disposable plastic separators between the actual filter papers. On occasion, it has happened that people have confused these plastic separators with the actual filters.
4Note e: Silica gel will take up water until it is saturated, at which point it must be rejuvenated by heating it in an oven for several hours. Ordinary silica gel is white, whether fresh or saturated. However, dye is often added to warn you when the gel has been saturated (e.g., pink if saturated, purple if partially saturated). Wet a gel crystal to determine the saturation colour. Never use saturated silica gel.

3.7 FECAL COLIFORM BACTERIA

3.7.1 WHAT ARE FECAL COLIFORM BACTERIA?

Fecal coliform bacteria are a large group of microscopic organisms associated with the intestines of warm-blooded animals. They are excreted in feces and may be found in high numbers in waters that receive animal waste

3.7.2 WHAT AFFECTS COLIFORM BACTERIA?

Fecal coliform bacteria can enter the aquatic environment in a variety of ways. Poorly maintained or located septic systems can lead to contamination of nearby watercourses. When a septic system becomes overloaded, untreated human wastes can flow from saturated soils into ditches and nearby waterways. Old tile fields may fail to provide the contact with coarse soils necessary to remove fecal bacteria. Also, the runoff from roads, parking lots, and lawns can carry animal wastes into streams and storm sewers. In the same way, runoff from livestock operations may contain fecal coliform bacteria that are picked up by water flowing through the pens or fields. Fecal coliforms can also originate from sewage treatment plants or from wildlife that inhabit riparian areas.

Fecal bacteria are sensitive to a number of environmental factors (e.g., temperature and light) and may rapidly respond to changing conditions by die-off or, conversely, by re-growth and numerical increases within the sample bottle. Accordingly, the acceptable transit time for bacterial samples (24 hours between collection and analysis) is much shorter than for general water chemistry samples.

3.7.3 WHY SHOULD COLIFORM BACTERIA BE MEASURED?

The presence of fecal coliforms in the aquatic environment indicates that the water may also be contaminated with pathogens, such as disease producing bacteria, viruses and protozoans that can exist in fecal matter. The presence of fecal contamination in water is an indicator that a potential health risk exists for individuals exposed to this water. High levels of fecal pathogens can be deadly to animals and to humans who consume contaminated water.

3.7.4 HOW SHOULD COLIFORM BACTERIA BE MEASURED?

Fecal coliform testing has been found to have limitations in that their presence does not always correlate well with the incidence of disease and current BC Water Quality Criteria (Province of BC, 2021) have more specific indicators: *Escherichia coli, Enterococci*, and *Pseudomonas aeruginosa.* For bathing beaches and recreational contact with water, BC Ministry of Health Guidelines use *E. coli*.

Samples collected for bacterial analysis are simply grab water samples collected at designated sites. Unlike with nutrients, experience has shown that sampling in deep water for bacteria is generally not informative, as fecal bacteria will more likely be located along the shore, near residential developments and within inflowing streams. Accordingly, bacterial sampling should be conducted near shore.

As with nutrients, bacterial samples are analyzed by a laboratory. This manual will not detail those analytical methods. Again, however, adherence to good quality control and the use of quality assurance methods are critical. All bacteriological samples must be stored in the dark and cooled (to 4°C) as soon as they are collected and must be shipped to the lab as soon as possible. Analysis must be done within 24 hours following sample collection, in order to obtain valid data.

The protocol (following page) for assessing bacterial densities in surface waters was adapted from the 1994 BC Resource Inventory Committee Fresh Water Biological Sampling Manual. To avoid contamination from suspended sediments that are raised either by wave action or in the process of walking to the sample site, the sample collector must wade out past the point where wave action affects the lake bottom and must be aware of sediments that he/ she has raised. The sampler should not exceed a depth where there exists a reasonable chance that water will over top boots or hip-waders or where footing would be difficult; getting wet under cold conditions a risk of hypothermia.

To avoid these pitfalls, it is strongly recommended that nearshore samples be collected from a boat. This reduces the potential for bottom sediments to contaminate samples, assuming care is taken to prevent prop wash from raising bottom sediments.

Protocol for Measuring Coliform Bacteria

*Protocol adapted from the Freshwater Biological Sampling Manual (Cavanagh et al., 1997)

a) Obtain labelled, sterilized, 250 mL bottles and wade into the lake at the most accessible point. Preferably, boat to the sample site, ensuring that the prop wash does not raise bottom sediments. Consider using oars or paddles in the shallows. Do not sample in rough water conditions.

b) Once you walk to a sufficient depth (where bottom material will not interfere with the sample), stop and orient yourself towards the center of the lake. Walk slowly up current to stay ahead of the disturbed sediment. If sampling from a boat, orient yourself toward shore.

c) Grasp the bottle well below the neck. With the other hand, remove the lid and hold it aside without allowing the inner surface to touch anything.

d) Lean out towards the center of the lake (or toward shore if in a boat) and in one continuous motion plunge the bottle beneath the surface to a standardized depth (two frequently used depths for surface samples are 0.5 m or 1.0 m) and slowly force it through the water until it is entirely full. This motion creates a current over the mouth of the bottle such that water entering the bottle has not come in contact with your hand.

e) Pour out enough liquid to provide a 2.5 to 5 cm air space (for lab mixing). Replace cap immediately. Add the appropriate preservative as specified by the analyzing laboratory.

f) Return to shore and/or pack the sample in a cooler containing a sufficient quantity of ice packs (twice the volume of ice to samples in summer months or equal volume when sampling in winter months) to cool the samples to 4^{o}C. Do not allow sample to freeze. Submit samples for analysis within 24 hours.

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Rice Lake. Source: Dawn Roumieu.

LAKEKEEPERS GLOSSARY OF TERMS

Abiotic Components
Non-living components of our natural environment, such as sunlight, water, oxygen, minerals, and temperature.

Acid

Corrosive substances with a pH of less than 7.0; acidity is caused by high concentrations of hydrogen ions.

Aerobic
In the presence of, or requiring, oxygen.

Algae
A plant or plantlike organism of any of several classes of chiefly aquatic, usually chlorophyll-containing, nonvascular organisms that usually include the green, yellow-green, brown, and red algae and the blue-green algae (also known as cyanobacteria).

Algal Bloom
Population explosion of algae in surface waters due to an increase in plant nutrients such as nitrates and phosphates. Usually due to excessive blue green algae growth.

Alkalinity
(aka Basic) The ability of water, or other substances, to absorb high concentrations of hydrogen ions. Substances with a pH greater than 7.0 are considered alkaline. A measure of the amount of carbonates, bicarbonates, and hydroxide present in water. Low alkalinity is the main indicator of susceptibility to acid rain. Increasing alkalinity is often related to increased algae productivity. Expressed as milligrams per litre (mg/L) of calcium carbonate (CaCO3), or as micro equivalents per litre (μeq/L). 20 μeq/L = 1 mg/L of CaCO3.

Amictic Lake
Lake with the absence of circulation periods, as in permanently ice- covered lakes.3

Ammonia
A form of nitrogen found in organic materials and many fertilizers. It is the first form of nitrogen released when organic matter decays. It can be used by most aquatic plants and is therefore an important nutrient. It converts rapidly to nitrate (NO_3) if oxygen is present. The conversion rate is related to water temperature. Ammonia is toxic to fish at relatively low concentrations in pH-neutral or alkaline water.
Under acid conditions, non-toxic ammonium ions (NH_{4+}) form, but at high pH values the toxic ammonium hydroxide (NH_4OH) occurs. The water quality standard for fish and aquatic life is 0.02 mg/L of NH_4OH.

Ammonification
Production of ammonia (NH_3) from organic nitrogenous compounds by decay of dead material and metabolism in living organisms.

Anaerobic
Relating to a process that occurs with little or no oxygen present.

Anoxia
Water conditions where dissolved oxygen is depleted (insufficient available oxygen is present).

Bacteria
Tiny, unicellular organisms that reproduce by cell division and usually have cell walls; can be shaped like spheres, rods or spirals and can be found in virtually any environment.

Benthic
Referring to bottom zones or bottom-dwelling forms.

Benthos
Animals and plants living on or within the substrate of a water body (freshwater, estuarine or marine).

Biodiversity
The existence of a wide range of different types of organisms in a given place at a given time.

Biological Productivity
The total amount of organic matter or equivalent in energy accumulated in an ecosystem.

Biotic Components
Living components of our natural environment, such as people, plants, animals, fungi, and microorganisms.

Blue Listed
Includes any indigenous species or subspecies (taxa) considered to be vulnerable in British Columbia. Vulnerable taxa are of special concern because of characteristics that make them particularly sensitive to human activities or natural events. Blue-listed taxa are at risk, but are not extirpated, endangered, or threatened.

Board of Directors
Individuals within a stewardship group who are key decision-makers and coordinate the activities and operations of a group.

Carnivore
An animal that obtains its energy from consuming other animals.

Charitable Status
A status obtained by legally registering a stewardship or volunteer group as a charity with Canada Revenue Agency (Government of Canada, 2021).

Chlorophyll
A green, light-absorbing pigment found in plants and other photosynthetic organisms. A magnesium-porphyrin complex, it is an essential electron donor in photosynthesis. The amount of chlorophyll present in lake water depends on the amount of algae and is therefore used as a common indicator of water quality.

Clarity
A Secchi disk is a 20 cm (8 inch) diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration). The disk is lowered into water until it disappears from view. It is then raised until just visible. An average of the two depths, taken from the shaded side of the boat, is recorded as the Secchi disk reading. For best results, the readings should be taken on sunny, calm days, without wearing sunglasses.

Cold Monomictic Lake
Cold monomictic lakes have a water temperature that never exceeds 4°C and a period of circulation in the summer. These lakes are mainly found in the Arctic mountains and usually have some contact with glaciers or permafrost.

Condensation
The change in state of water from a vapour to a liquid.

Conductivity
Measures a water's ability to conduct an electric current.
Conductivity is reported in micromhos per centimeter (µmhos/cm) and is directly related to the total dissolved inorganic chemicals in the water. Values are commonly two times the water hardness unless the water is receiving high concentrations of contaminants introduced by humans.

Consumers
A nutritional grouping in the food chain of an ecosystem, composed of heterotrophic organisms, chiefly animals, which ingest other organisms or particulate organic matter.

Cyanobacteria
Known as blue-green algae that are bacteria with a simple cell structure. They are distinguished from other bacteria by the presence of chlorophyll-a and their ability to photosynthesize like plants in the aquatic system.

Decomposers
Heterotrophic organisms (including bacteria and fungi) which break down the complex compounds of dead organisms, absorbs some decomposition products, and releases substances usable by consumers.

Decomposition
The breakdown of dead organic materials.

Detritus
Material that consists of decaying, decomposing organic matter (often dead plants or animals).

Dimictic Lakes
Lakes that experience two mixing events per year, one typically following the summer stratification period and the other following the inversely stratified winter period.

Dissolved Oxygen
The amount of free oxygen absorbed by the water and available to aquatic organisms for respiration; amount of oxygen dissolved in a certain amount of water at a particular temperature and pressure, often expressed as a concentration in parts of oxygen per million parts of water (ppm).

Environmental Stewardship

Stewardship concerned with the biotic and abiotic components of our natural environment in pursuit of enhancing, restoring, and conserving natural resources, ecosystems, and the species associated with them.

Epilimnion

The upper, well-mixed, well-illuminated, nearly isothermal region of a typical stratified lake.

Erosion

Movement of soil by water or wind.

Eutrophic

Lakes that have high levels of biological productivity. An abundance of plants is supported by having high levels phosphorus and nitrogen.

Eutrophication

The process by which lakes and streams are enriched by nutrients, and the resulting increase in plant and algae growth. This process includes physical, chemical, and biological changes that take place after a lake receives inputs for plant nutrients--mostly nitrates and phosphates--from natural erosion and runoff from the surrounding land basin. The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Evapotranspiration

The change in state of water from a liquid to a vapour back to the atmosphere.

Exotic Species

Plant or animal species introduced into an area where they do not occur naturally; non-native species. Examples area Eurasian Milfoil and Purple Loosestrife.

Extirpated

Taxa that no longer exist in the wild in British Columbia, but do occur elsewhere.

Fetch

The maximum distance across a lake where wind can travel without stopping.

Water Exchange Rate

Water exchange rate is the rate of water replacement in a lake. It's unit of measure is times/year. Conversely, retention time is the average length of time water resides in a lake, ranging from several days in small impoundments to many years in large seepage lakes. Retention time is important in determining the impact of nutrient inputs. Long retention times result in recycling and greater nutrient retention in most lakes. Calculate retention time by dividing the lake volume by the volume of water passing through the lake in on year.

Food Chain

The transfer of food energy from plants through herbivores to carnivores. An example: insect-fish-bear or the sequence of algae being eaten by small aquatic animals (zooplankton) which in turn are eaten by small fish which are eaten by larger fish and eventually by people or predators.

Herbivore
An animal that obtains its energy from consuming plants.

Herbaceous
Refers to a plant that has a non-woody stem and which dies back at the end of the growing season.

Hydrological Cycle
The natural movement of water on earth between condensation, precipitation, infiltration, runoff, and evapotranspiration.

Hypolimnion
Lowermost, noncirculating layer of cold water in a typical, thermally stratified lake, usually deficient in oxygen.

Infiltration
The movement of water below the earth's surface.

Isothermic
Lake conditions that present consistent or similar water temperatures at varying depths.

Kjeldahl Nitrogen
The most common analysis run to determine the amount of organic nitrogen in water. The test includes ammonium and organic nitrogen.

Liability Insurance
Covers the legal costs that an organization is responsible for if liabilities have occurred.

Limnetic
Of, pertaining to, or inhabiting the pelagic region of a body of fresh water.

Limnology
The scientific study of inland freshwater systems including lakes & reservoirs, rivers, creeks & streams, groundwater, and wetlands.

Littoral Zone
The lake zone between the shoreline and maximum depth aquatic plants can grow.

Macrophytes
Rooted aquatic plants found in the littoral zone of a lake.

Marginal Lakes
Lakes that historically transition between two mixing classes and often experience unusual mixing behaviour relative to their dominant mixing classification.

Meromictic Lakes
Lakes that are persistently stratified, often owing to their great depths or to the presence of a chemical gradient.

Mesomictic Lakes
Lakes with partial circulation, the lower denser layers never mixing with the upper.

Metalimnion
The central stratum between the epilimnion and hypolimnion in a stratified lake; the region occupied by the thermocline.

Mission Statement
A clear and concise description of your organization's reason for being.

Monomictic Lakes
One vertical mixing event per year.

Morphometry
Referring to the size and shape of a lake. Lake morphometry includes maximum and average depth, surface area, volume, shoreline length, etc.

Nekton
Animals capable of swimming independently of turbulence.

Neuston
Microscopic organisms adapted to living on the upper surface and underside of the surface film on the air-water interface.

Nitrate
An inorganic form of nitrogen important for plant growth. Nitrogen is in this stable form when oxygen is present. Nitrate often contaminates groundwater when water originates from manure pits, fertilized fields, lawns, or septic systems. High levels of nitrate- nitrogen (over 10 mg/L) are dangerous to infants and expectant mothers. A concentration of nitrate-nitrogen (NO_3-N) plus ammonium-nitrogen (NH_4-N) of 0.3 mg/L in spring will support summer algae blooms if enough phosphorus is present.

Nitrification
The conversion of ammonia (NH_3) to nitrate (NO_3^-).

Nitrite
A form of nitrogen that rapidly converts to nitrate (NO_3^-) and is usually included in the NO_3^- analysis.

Nitrogen Fixation
The conversion of atmospheric nitrogen (N_2) into an organic form usable by plants and other organisms; nitrogen is typically fixed by bacteria that live in nodules on the roots of legumes and similar plants.

Nutrients
Elements or substances such as nitrogen and phosphorus that are necessary for plant growth. Large amounts of these substances can become a nuisance by promoting excessive aquatic plant growth.

Nutrient Cycling
The movement of inorganic compounds from nutrient reservoirs through trophic levels and abiotic components.

Nutrient Pollution
The negative effects in lakes brought on by an excess of nitrogen and/or phosphorus, resulting in exponential algae growth.

Oligomictic Lake
Lakes that are persistently stratified in most years yet mix fully in others.

Oligotrophic
Relatively low productivity lakes due to low nitrogen and phosphorus levels. Waters of these lakes are usually quite clear due to limited algae and plant growth.

Orthophosphorus
Dissolved inorganic phosphorus.3 The dissolved inorganic form of phosphorus that is immediately bio-available for absorption by algae. Also, can be referred to as soluble reactive phosphorus (SRP).

Pathogen
A disease-producing agent; usually applied to a living organism. Generally, any viruses, bacteria, protozoans, or fungi that cause disease.

Pelagic
The main open water portion of a lake, beyond the extent of rooted vegetation and above the lake's profundal zone.

Periphyton
Algae and associated microorganisms growing attached to any submerged surface, such as rocks or plants.

Phosphorus
Key nutrient influencing plant growth. Soluble reactive phosphorus (orthophosphorus) is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Photosynthesis
The chemical process by which plants convert sunlight, carbon dioxide, and water to energy (sugars) to live and grow.

Phytoplankton
Microscopic plants found in the water. Algae or one-celled (phytoplankton) or multicellular plants either suspended in water (plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll *a* (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake. Numerous species occur. Algae are an essential part of the lake ecosystem and provides the food base for most lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Plankton
Small plant organisms (phytoplankton and nanoplankton) and animal organisms (zooplankton) that float or swim weakly though the water.

Polymictic Lakes
Permanently or frequently mixed lakes

ppm
parts per million; units per equivalent million units; equal to milligrams per litre (mg/L).

Precipitate
A solid material which forms and settles out of water as a result of certain negative ions (anions) combining with positive ions (cations).8 Metals tend to precipitate in the presence of oxygen.

Precipitation
The movement of water from the atmosphere to the earth's surface.

Producer
An organism that uses light to synthesize new organic material from carbon dioxide.

Profundal (Benthic) Zone
The region occurring below the limnetic (pelagic) zone. The main sediment zone of a lake, the non-vegetated lake bottom sediment.

Quality Assurance
A variety of strategic, careful actions taken to ensure to the highest reasonable degree that methods are sound and followed correctly.

Quality Control
A specific system of maintaining conditions such that results are reliable.

Red Listed
Includes any indigenous species or subspecies (taxa) considered to be extirpated, endangered, or threatened in British Columbia. Extirpated taxa no longer exist in the wild in British Columbia, but do occur elsewhere. Endangered taxa are facing imminent extirpation or extinction. Threatened taxa are likely to become endangered if limiting factors are not reversed. Red-listed taxa include those that have been, or are being, evaluated for these designations.

Respiration
Complex process that occurs in the cells of plants and animals in which nutrient organic molecules such as glucose combine with oxygen and produce carbon dioxide, water, and energy. It is the reverse reaction of photosynthesis. Respiration consumes oxygen (O_2) and releases carbon dioxide (CO_2). It also takes place as organic matter decays.

Restoration
Measures undertaken to return a degraded ecosystem's functions and values, including its hydrology, plant, and animal communities, and/or portions thereof, to a less degraded ecological condition.

Retention Time
The number of years that a lake-volume equivalent of water remains in a lake.

Riparian Zone
The area of land bordering streams, lakes, and rivers containing moist soils and moisture-loving plants that is seasonally inundated with water.

Runoff
The movement of water across the earth's surface.

Secchi Disk
A 20 cm (8 inch) diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration). The disc is lowered into water until it disappears from view. It is then raised until just visible. An average of the two depths, taken from the shaded side of the boat, is recorded as the Secchi disk reading.

Sedimentation
The removal, transport, and deposition of detached soil particles by flowing water or wind. Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and weeds, marl, and soil and organic matter eroded from the lake's watershed.

Seiche
Standing or oscillating wave in an enclosed or partially enclosed body of water.

Shoreline Development Ratio (or Index)
A number that relates the measured shoreline length of a given lake to the shoreline length of a perfectly circular lake of equal area.

SMART Goal
A specific, measurable, achievable, relevant, and time-delineated goal.

Society
An independent, democratic organization that is governed by the Societies Act and the society's own constitution and bylaws.

Spring Overturn
Seasonal springtime mixing of lake layers separated by density due to temperature.

Steward
A person entrusted with the care of something that requires support and attention in order to thrive.

Stewardship
The act of caring for something through dutiful planning and conscientious management.

Thermocline/Metalimnion
The zone in which the largest relative temperature change occurs with depth during lake thermal stratification.

Stratification
The layering of water due to differences in density. Water's greatest density occurs at 4°C (39°F). As water warms during the summer, it remains near the surface while colder water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which usually extends to a depth of about 6.5 m (20 feet). The narrow transition zone between the epilimnion and cold bottom water (hypolimnion) is called the metalimnion or thermocline.

Summer Stratification
Seasonal summertime separation of lake water into layers based on density due to temperature.

Suspended Solids
A measure of the particulate matter in a water sample, expressed in milligrams per liter. When measured on inflowing streams, it can be used to estimate the sedimentation rate of lakes or impoundments.

SWOT Analysis
An exploration undertaken by an organization to identify its strengths, weaknesses, opportunities, and threats.

Thermocline/Metalimnion
The zone in which the largest relative temperature change occurs with depth during lake thermal stratification

Transpiration
The passage of water in plants from the roots through the vascular system to the stoma of the leaves and into the atmosphere.

Trophic Levels
Positions in a food web occupied by a group of organisms with similar feeding modes.

Trophic Status
the relative biological (algal) productivity of a water body usually assessed by measurement of specific quality parameters including chlorophyll a concentration, water clarity and rate of loss of oxygen from profundal waters.

Trophogenic Zone
The zone of a lake where sunlight reaches so photosynthesis/algae growth can occur. In this zone, the rate of photosynthesis is greater than the rate of respiration by phytoplankton. Also referred to as the photic zone.

Turbidity
Degree to which light is blocked because water is muddy or cloudy.

Turnover
(Or Overturn) Fall cooling and spring warming of surface water changes its density, and gradually makes temperature and density uniform from top to bottom. This allows wind and wave action to mix the entire lake. Mixing allows bottom waters to contact the atmosphere, raising the water's oxygen content. However, warming may occur too rapidly in the spring for mixing to be effective, especially in small, sheltered kettle lakes.

Vision
A simple inspirational statement that outlines and ideal that your organization aspires to.

Volunteer Burnout
A situation that arises when a volunteer group has too few members, resulting in the overworking of a small pool of volunteers who may become fatigued or disinterested in the group over time.

Volunteer Saturation
A situation that arises when a volunteer group has too many members, resulting in stress for group managers to coordinate, and insufficient opportunities for a large group of volunteers such that they may become disinterested in the group over time.

Warm Monomictic Lake
Ice-free lake with one period of complete circulation during the cold time of year; temperature stratification occurs in summer.

Water Quality
A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Watershed
The total area above a given point on a watercourse that contributes water to its flow; the entire region drained by a waterway or watercourse that drains into a lake or reservoir.

Zooplankton
Microscopic animals that live in the water column and feed on phytoplankton.

APPENDICES – PART A

APPENDIX 1.1: ANNUAL LAKE SOCIETY BUDGET

YOUR LAKE STEWARDSHIP SOCIETY

ANNUAL LAKE SOCIETY BUDGET

OPERATIONS BUDGET and COMPARISON TO ACTUAL
FOR THE FISCAL YEAR ENDED MONTH, DAY, YEAR

	Budget	Actual	Difference
REVENUE			
Membership	$ 265.00	$ 275.00	$ 10.00
Grants			
Government	750.00	750.00	0.00
Eco-Society	500.00	500.00	0.00
Fundraising			
Raffle	300.00	275.00	-25.00
Donations/Sponsorships			
Individual	185.00	80.00	-105.00
Business/Corp	500.00	750.00	250.00
Donations in kind			
Individual	25.00	70.00	45.00
Business/Corp	150.00	120.00	-30.00
Miscellaneous	34.00	37.00	3.00
TOTAL REVENUE	2709.00	2857.00	148.00
EXPENSES			
Dues and memberships	75.00	95.00	-20.00
Office expense/telephone	265.00	275.00	-10.00
Insurance	100.00	110.00	-10.00
Bookkeeping	100.00	150.00	-50.00
Newsletter	90.00	95.00	-5.00
Office Supplies	50.00	37.00	13.00
Annual Society Filing Fee	25.00	25.00	0.00
Miscellaneous	50.00	24.00	26.00
Project Expenses			
Travel	100.00	85.00	15.00
Equipment	750.00	725.00	25.00
Supplies	500.00	520.00	-20.00
TOTAL EXPENSES	2105.00	2141.00	-36.00
REVENUE OVER EXPENSES	$ 604.00	$ 716.00	$ 112.00

APPENDIX 1.2: EXAMPLE PROPOSAL – HARDY LAKE SYSTEM PROJECT

Hardy Lake System Project

Contact: Jane Smithe
Happy Stewardship Society
5555 Brighton Lane
Large City, British Columbia
V1V 1V1
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Fax: (604) 555-4321
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Business Number: 98765 4321 RR0001

Executive Summary

The Hardy Lake System Project (HLSP) is a community and watershed enhancement project coordinated by Happy Stewardship Society (HSS). The HLSP was initiated to address the pressures affecting the natural resources of the Blue River Watershed. The goal of the project is to inventory, monitor, enhance and protect terrestrial and aquatic habitat in the watershed.

The HLSP currently needs to conduct a fish sampling and water quality monitoring program in Imaginary Creek, the largest of many tributaries flowing into Hardy Lake. The creek is known to be home for coho salmon, cutthroat trout, and rainbow trout but these species, along with other organisms inhabiting the stream, are at risk due to damage resulting from pollution and urban development.

The fisheries inventory program would be the beginning of a stewardship project for Imaginary Creek. After the collection of data over a one-year period, the program will continue with restoration, enhancement and monitoring activities that will be implemented with the help of our community partners. These activities include riparian planting, releasing native fish species, stabilizing banks, monitoring fish and wildlife, and educating the public.

The Hardy Lake System Project requests an amount of $14 500 from the Wilkinson Foundation to implement the fisheries inventory program in Imaginary Creek.

The Need: Inventory of Imaginary Creek

Salmon are one of our most precious resources here in British Columbia. Unfortunately, salmon habitat is under constant threat from logging, urban sprawl, and pollution from environmental contaminants. This is a serious concern.

Efforts are being made along the west coast, from Alaska to California, to protect this precious resource. The Happy Stewardship Society has long recognized the need to maintain the health of this resource and has been at the forefront of this effort. The HSS is committed to the conservation of the Blue River Watershed, located in Large City, British Columbia. The Blue River runs from Hardy Lake into the Fraser River, the largest salmon-producing river in the world. Approximately 800 million juvenile salmon migrate along the Fraser River every year. The health of this river and the streams that flow into it is extremely important in maintaining salmon stocks.

The HLSP was developed to address the pressures affecting the natural resources of the Blue River Watershed. The goal of the project is:

to inventory, monitor, restore, and protect the Blue River Watershed.

The first step in reaching this goal is to map the watershed and conduct stream inventories. The HLSP has been at the forefront of stream inventory work in the Blue Basin. Over 90% of streams within the watershed have been inventoried through the HLSP, who has been at the forefront of inventory work in the Blue Basin.

The second step in reaching this goal is to enhance and protect areas that have been mapped. This will be done through activities such as riparian planting, releasing native fish species, stabilizing the stream bank, monitoring fish and wildlife, and educating the public.

One of the Current areas that the HLSP is focusing on is Imaginary Creek, the largest of many tributaries flowing into Hardy Lake. The HLSP currently needs to conduct a fish sampling and water quality monitoring program in this area to prescribe rehabilitation strategies. Imaginary Creek is known to be home for coho salmon, cutthroat trout, and rainbow trout but these species, along with other organisms inhabiting the stream, are at risk due to damage resulting from pollution and urban development. Conducting the inventory is only the first step in the long-term stewardship of this important tributary.

Imaginary Creek Project Description

The Imaginary Creek project inventory component will take place over a one-year period, beginning in September. Throughout the first and following years, stewardship activities, including enhancing and monitoring the creek will take place.

Objectives

- Survey fish populations in Imaginary Creek.
- Conduct water quality surveys in Imaginary Creek.
- Collect and interpret GPS data for Imaginary Creek.
- Determine areas in need of remediation and prescribe methods to restore these areas.
- Provide learning opportunities for students, volunteers, and the general public.

Methods

Two co-op students will conduct weekly fish population and water quality surveys (for dissolved oxygen, total suspended solids, and sewage related contaminants) in various locations of Imaginary Creek starting in September. They will work under the guidance of a field technician hired on contract. During the initial weeks, the technician will provide the students with survey method training and the technician will provide 160 hours of assistance to the students throughout the project. The students and technician will identify areas in need of restoration while conducting the fish sampling and water quality monitoring program and will prescribe rehabilitation strategies in coordination with project partners. Activities may include enhancing stream characteristics, stabilizing banks, upgrading residential sewage systems, planting riparian areas, deactivating trails leading to sensitive areas, and releasing juvenile salmon species. These restoration methods will be implemented with the help of our community partners.

A GPS Technician will be hired on a contract basis to collect and interpret GPS data for Imaginary Creek. Four weeks are allocated for data collection and the remaining two weeks are allocated for the technician to enter the data into the databases.

This project provides students, the public, and volunteers with many opportunities to gain hands on experience. Every year, two co-op students will conduct stream surveys along Imaginary Creek. At the end of the year they are required to submit a report with their findings. Volunteers will gain experience while assisting with the many restoration and enhancement projects that will improve terrestrial and aquatic habitat of Imaginary Creek. The public will also be provided with learning opportunities through outreach programs.

Evaluation Plan

The HLSP would like to incorporate a weekly monitoring program consisting of water quality measuring and minnow trapping on Imaginary Creek as an annual student project. Collecting data on a yearly basis will allow Imaginary Creek to be monitored over the long-term and we will be able to measure our progress in achieving our goal. Success will be measured based on:

- Qualitative improvements to terrestrial and aquatic habitat (i.e. percent cover of native plant and tree species in riparian areas)
- Results of ongoing water quality monitoring, with comparison to water quality guidelines for the protection of freshwater aquatic life
- Fish population characteristics (i.e. health and size of population)
- Other stream inhabitants' population characteristics (i.e. increase in diversity of invertebrate species)
- Other wildlife population characteristics (i.e. bird and small mammal sightings)

A yearly report that incorporates new data with historical data to measure our progress will be submitted to program partners.

Sustainability

The HLSP has coordinated several programs and events to increase public awareness and engage residents to become more proactive in maintaining the health of their watershed. The dedication of local stewardship groups, government bodies, and local businesses, along with co-op students, will ensure that the effort to improve Imaginary Creek, and the entire Blue Watershed, will continue for years to come.

Organization Information

The Hardy Lake System Project (HLSP) is a widely recognized community and watershed enhancement project. Initiated in 1997 and coordinated by Happy Stewardship Society, the HLSP works through community partnerships to steward the natural resources of the Blue River Watershed. Partners include, Large City, the Regional District, the Ministry of Water, Land, and Air Protection, the Department of Fisheries and Oceans, community organizations, stewardship groups, and local businesses. The extensive support of our partners has enabled us to undertake and complete a wide variety of projects including riparian planting and habitat improvements. The HLSP is very fortunate to have such dedicated and enthusiastic staff and volunteers. Over tens of thousands of volunteer hours have been contributed to the local community since 1997 and the project has been acknowledged by the provincial government as “one of the best examples of stewardship in British Columbia”.

Budget

Estimated Expenditures

Item	*Description*	*Cost*
Survey Equipment	D.O. Meter	$1300
	GPS Rental	$500
	Other	$200
Field Technician	Stream research 160 hrs at $25/hr	$4000
GPS Technician	GPS data collection & interpretation (6 weeks) $25/hr	$6000
Summer Student Workers*	Inventory, restoration work (16 weeks) 2 students at $15/hr	$19 200
Administration	Supplies, communication services	$500
Educational Support	Training	$500

* Funding for this item requested from other sources

Total estimated expenditures = $ 32 200

Estimated In-Kind Contributions

Item	*Description*	*Value*
Student workers (Sept. – May)	Conduct field surveys as part of co-op curriculum 450 hrs at $13/hr	$5 830
Volunteers	Stewardship Activities 1000 hrs at $13/hr	$13 000
Laboratory funds	Analysis of water quality parameters	$2000

Total estimated contributions = $20 830

Benefits for the Donor

As a donor to this exciting program, you will reach a target market and will demonstrate your commitment to watershed stewardship and the natural health of the community. Other benefits include:

- Donor logo on all advertising material, including brochures, posters, and ads in local newspapers. Over 300 000 pieces of advertising material are distributed annually.
- Donor logo on our website, including a link to donor's website
- Donor logo on Hardy Lake System Project t-shirts
- Exhibition space at Hardy Lake System Project conference
- Banner (provided by donor) at Hardy Lake System Project special events and conferences

APPENDICES – PART B

APPENDIX 1.1: USEFUL CONVERSIONS FOR UNDERSTANDING LAKES

Temperature
Water freezes at 0°C or 32°F
Water boils at 100°C or 212°F
1°C = 33.8°F ([1°C x 9/5] + 32 = 33.8°F)
4°C = 39.2°F
10°C = 50°F
20°C = 68°F

Linear
1 metre (m) = 100 centimetres (cm) = 1,000 millimetres (mm) = 1,000,000 micrometres (µm)
1 kilometre (km) = 1,000 metres (m)
1 foot (ft) = 12 inches (in)
1 m contains 39.4 in or 3.28 ft
1 cm contains 0.394 in
1 mm contains 0.0394 in
1 in contains 2.54 cm
1 ft contains 0.3048 m or 30.48 cm

Area
1 square kilometer (km^2) = 1,000,000 metres squared (m^2)
1 hectare (ha) = 10,000 m^2
So, 1 km^2 = 100 ha
1 ha = 2.47 acres

Volume
1 cubic metre (m^3) = 1000 litres
1 litre = 1000 millilitres

Symbols
< = less than
≤ = less than or equal to
> = greater than
≥ = greater than or equal to

Mass
1 gram (g) = 1,000 milligrams (mg) = 1,000,000 micrograms (µg)

Given the density of pure water, 1 gram = 1 mL (1 cubic centimetre). The metric system is partially based on the mass and volume of pure water.

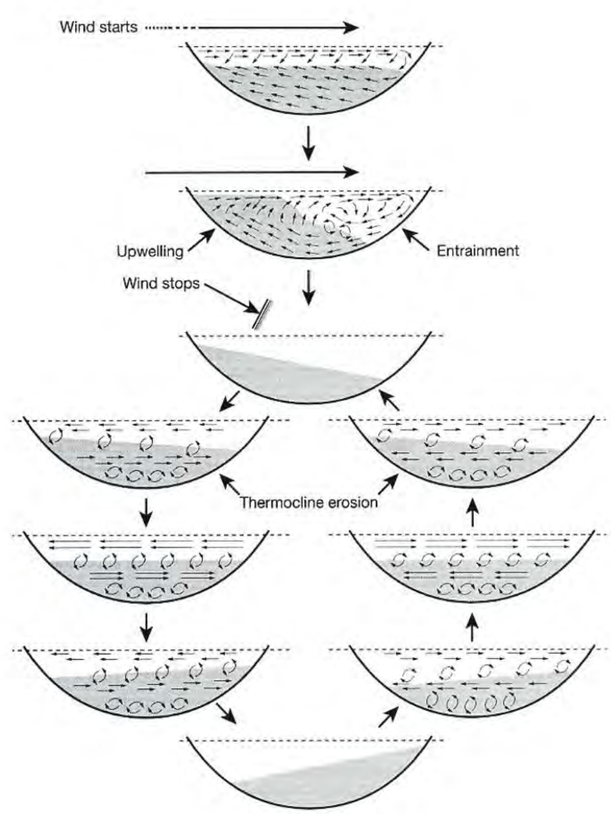
1 gram of a substance (say phosphorus) in 1 litre of water is equivalent to 1 part per thousand (1 ppt). 1 milligram in 1 litre is equivalent to 1 part per million (1 ppm).
So, 1 mg/L = 1 ppm. Also, 1 µg/L = 1 part per billion (1 ppb)

We often discuss phosphorus in terms of 0.001 mg/L, but we could also say 1 µg/L (1000 times smaller, and a bit easier to say). So, a particular lake may have an average water column total phosphorus of 0.025 mg/L during spring overturn, which is the same as 25 µg/L.

APPENDIX 1.2: SEICHE

A seiche is a standing wave oscillating in a body of water, like the water that sloshes back and forth in a bathtub or cup of water when disturbed. They typically occur in enclosed waterbodies such as lakes, reservoirs, or even swimming pools. These waves can be surface waves or internal waves.

What causes a seiche?
They are typically caused by strong winds and rapid changes in atmospheric pressure that push water from one end of a water body to the other. After the wind event, the water rebounds to the other side of the enclosed area and continues to oscillate back and forth for hours or even days, depending on the size of the lake.



Seiches may be noticed under ordinary water conditions as a result of periodic changes in water level or underwater currents associated with the oscillating movement. At some locations and times, these sea-level oscillations and currents may produce hazardous or even destructive conditions. Internal waves form that can be up to 10 to 30 meters high, all unseen from the lake surface.

Seiche waves generate currents and turbulence that rhythmically flow back and forth. These currents can cause bottom water to come to the surface and can also mobilize lake sediments and carry them into the water.

To learn more about seiches, [watch the video]() from Larratt Aquatic Consulting Ltd.

References

National Ocean Service, NOAA, *What is a seiche?* 3 March 2021
https://oceanservice.noaa.gov/facts/seiche.html

Stevens, C. L., & Lawrence, G. A. (1997). Estimation of wind-forced internal seiche amplitudes in lakes and reservoirs, with data from British Columbia, Canada. *Aquatic Sciences*, *59*(2), 115-134.
https://bit.ly/3dbjUV1

APPENDIX 2.1: L1, L2, L3 DATA SUMMARIES

BC Lake Stewardship & Monitoring Program: Levels of Lake Monitoring

Level 1

- Weekly surface temperature and clarity (Secchi) readings.

Level 2

- Level 1 + spring overturn and late summer water chemistry and DO/T profile (BC Lake Monitoring Network lakes).

Level 3

- Level 2 + bi-weekly water chemistry and biological sampling.

Level 4

- Level 3 + watershed study.

Level 5

- Level 4 + full Watershed Assessment, stream monitoring for water chemistry, assessment of riparian areas.

Level 1 Study Langford Lake Centre Site. EMS site 1100953						
Date	**Time**	**Secchi Depth (m)**	**Surface Temperature (⁰C)**	**Weather Conditions**	**Water Conditions**	**Notes**
03-05-2020	10:10	5.7	13.1	partly cloudy, windy	choppy	
10-05-2020	11:00	5.4	17.2	partly cloudy, breezy	rippled	
17-05-2020	10:00	5	16.8	partly cloudy, calm	glassy	
24-05-2020	10:55	4	16.9	overcast, light rain	glassy	
31-05-2020	13:15	4.7	18.2	partly cloudy, windy	choppy	
07-06-2020	10:30	3.9	17.2	overcast, calm	glassy	
14-06-2020	13:50	3.6	17.8	partly cloudy, windy	choppy	
21-06-2020	13:40	4.3	20.2	sunny, breezy	choppy	
28-06-2020	13:40	4.2	21.1	sunny, breezy	choppy	
05-07-2020	11:30	3.2	19.9	sunny, breezy	choppy	
12-07-2020	12:25	3.8	20.4	sunny, breezy	choppy	
19-07-2020	10:00	4.3	21.6	sunny, light wind	rippled	
26-07-2020	10:55	5.6	23.3	sunny, light wind	rippled	
02-08-2020	10:35	5.2	23.1	sunny, light wind	rippled	
09-08-2020	11:05	4.8	22.8	partly cloudy, windy	choppy	
16-08-2020	12:40	4.5	22.8	sunny, light wind	rippled	
23-08-2020	11:15	2.7	21.5	sunny, light wind	rippled	Lake has turned a milky colour
30-08-2020	10:10	2.4	20.2	sunny, breezy	choppy	
06-09-2020	10:10	1.5	20.8	sunny, light wind	rippled	Surface blue-green algae very thick
13-09-2020	10:35	3	19.2	overcast, calm	glassy	Smoky
20-09-2020	10:30	4.4	19	sunny, light wind	rippled	
27-09-2020	10:45	3	17.2	cloudy, light breeze	rippled	
04-10-2020	11:15	3.2	17.2	overcast, calm	glassy	Surface algae is back
11-10-2020	11:00	3.2	15.8	overcast, rain	glassy	
18-10-2020	13:35	3.7	14	partly cloudy, windy	choppy	
25-10-2020	13:05	3.6	12.2	partly cloudy, breezy	rippled	

Level 2 Study																						
Brohm Lake Central Deep Station. EMS ID 1132490.																						
Date	Time	% Overcast	Wind Speed & Direction	Water Conditions	Air Temperature (°C)	Secchi Depth (m)	Sample Depth (m)	Water Temperature (°C)	Ortho-phos (mg/L)	TD-phos (mg/L)	T-phos (mg/L)	T-nitrogen (mg/L)	Ortho-phos replicate (mg/L)	TD-phos replicate (mg/L)	T-phos replicate (mg/L)	Ortho-phos blank (mg/L)	TD-phos blank (mg/L)	T-phos blank (mg/L)	Algal chl *a* (µg/L)	Volunteer hours
27-03-2019	9:50					7.1	1-6		<0.001	<0.002	0.0026	0.076	-	-	-	-	-	-	0.00218	
27-03-2019	9:50						10-25		<0.001	<0.002	0.0036	0.088	-	-	-	-	-	-		
05-05-2019	14:30	0/10	-	Calm	16.3	7.6		15.8												0.5
12-05-2019	15:00	0/10	-	Calm	17.4	7.4		17.2												0.5
19-05-2019	10:45	0/10	-	Calm	19.5	7.2		16.8												1
26-05-2019	10:40	0/10	-	Calm	21.8	8.05		17												1
2-06-2019	10:20	10/10	-	ripples	21.5	7.4		19.8												1.5
15-06-2019	10:20	5/10	-	light ripples	19.1	7.6		19.8												1.5
01-07-2019	10:50	5/10	-	calm to light ripples	23.3	6.8		20												2
07-07-2019	10:40	7/10	-	light ripples	22.8	6.3		19.5												2
21-07-2019	10:45	0/10	-	calm	22.1	7.3		20.3												4
28-07-2019	10:05	0/10	-	calm	20.1	8.25		20.8												2
4-08-2019	10:25	1/10	-	calm	22.2	8.25		21												2
17-08-2019	10:15	10/10	-	light ripples	19.8	7.7		20.8												2
01-09-2019	9:45	8/10	-	light ripples	20.2	9.1		20.5												1.5
08-09-2019	12:40	8/10	-	light ripples	18.5	8.9		20.2												1.5
16-09-2019	10:15	7/10	-	calm	16.3	8.4		17.8												1.5
23-09-2019	14:00	10/10	-	windy, small waves	12.2	8		16.5												1.5
29-09-2019	10:45	7/10	-	windy, ripples	12.2	7.6		14.3												1.5
23-08-2019	8:20					8.2	1-6		<0.001	<0.002	0.0026	0.085	-	-	-	-	-	-	0.00107	
23-08-2019	8:25						9-20		<0.001	<0.002	0.0044	0.082	-	-	-	-	-	-		

Fraser Lake Central Basin Deep Station 0400411 for 2000 Level 3 Assessment

Sample Date/time	% Overcast	Wind Speed Direction	Surface Cond.	Seechi Disk (m)	Air Temp °C	Water Temp °C	Dissolved Oxygen mg/L	Odour	Colour	Sample Depth (m)	O-phos regular data (mg/L)	TD-phos regular data (mg/L)	T-phos regular data (mg/L)	O-phos replicate data (mg/L)	TD-phos replicate data (mg/L)	T-phos replicate data (mg/L)	O-phos blank data (mg/L)	TD-phos blank data (mg/L)	T-phos blank data (mg/L)	Algal Chloro a 0.5m (ug/L)
May 14 1430	1/10	low/W	ripple	4.6	16.5	9.5	13.0	none	clear	0.5	0.002	0.011	0.026				<0.001	<0.002	<0.002	**1.6**
						7.5	13.0	none	clear	13	0.002	0.009	0.023							1.6/1.6
						5.0	10.0	none	clear	26	0.005	0.012	0.030	0.005	0.011	0.030				
May 28 1200	7/10	calm	ripple	4.3	17.0	12.5	13.0	none	clear	0.5	0.004	0.010	0.018				<0.001	<0.002	<0.002	**<0.4**
						8.5	13.0	none	clear	15	0.003	0.011	0.021	0.003	0.010	0.022				<0.4/<0.4
						7.5	12.0	none	clear	29	0.005	0.012	0.024							
June11 1100	2/10	low/W	ripple	4.2	12.0	12.0	13.0	none	clear	0.5	0.002	0.008	0.014				<0.001	<0.002	<0.002	**0.8**
						9.5	13.0	none	clear	14.5	0.005	0.010	0.017							0.5/1.1
						8.0	11.0	none	clear	29	0.009	0.012	0.023							
June 25 1100	0/10	med/W	chop	5.4	19.0	14.0	11.0	none	clear	0.5	0.002	0.007	0.008	0.003	0.007	0.011	<0.001	<0.002	<0.002	**1.2**
						12.0	11.5	none	clear	15	0.004	0.008	0.013							<0.4/2.1
						9.5	9.5	none	clear	29	0.013	0.017	0.034							
July 9 1100	7/10	calm/W	ripple	6.0	18.0	15.0	10.0	none	clear	0.5	0.001	0.008	0.013				<0.001	<0.002	<0.002	**<0.4**
						13.5	9.0	none	clear	15.3	0.006	0.012	0.017							<0.4/<0.4
						11.0	8.0	none	clear	29.5	0.020	0.027	0.038							
July 30 1100	1/10	low/E	chop	6.5	20.5	17.5	10.0	none	clear	0.5	<0.001	0.011	0.011	<0.001	0.007	0.010	<0.001	<0.002	<0.002	**1.9**
						15.0	8.0	none	clear	15	0.008	0.014	0.020							2.1/1.6
						12.0	7.0	none	clear	28	0.028	0.036	0.045							
Aug 7 1830	1/10	high/W	rough	5.8	18.5	17.5	9.0	none	clear	0.5	<0.001	0.005	0.014				<0.001	<0.002	<0.002	**2.2**
						15.5	7.5	none	clear	14	0.012	0.019	0.025							1.6/2.7
						13.5	6.0	none	clear	27	0.033	0.042	0.048							
Aug 20 1100	10/10	med/W	chop	5.0	13.5	16.5	9.0	none	clear	0.5	<0.001	0.008	0.013				<0.001	<0.002	<0.002	**5.1**
						14.5	6.5	none	clear	15	0.015	0.022	0.030	0.016	0.022	0.029				4.8/5.3
						13.0	4.0	none	clear	28.5	0.046	0.053	0.062							
Sept 4 1100	10/10	low/E	ripple	4.	13.	15.	9.	none	clear	0.	0.001	0.006	0.020				<0. 01	<0. 02	<0. 02	**8.**
						14.5	9.0	none	clear	15	0.002	0.007	0.014							8.0/8.0
						12.5	3.0	none	clear	28.8	0.048	0.058	0.065							
Sept 17 1100	10/10	low/E	ripple	4.5	15.5	14.5	10.5	none	clear	0.5	0.004	0.012	0.021							**7.3**
						14.0	8.5	none	clear	14.5	0.006	0.013	0.018	0.009	0.016	0.014	<0.001	<0.002	<0.002	8.7/5.9
						13.0	1.4	algae	clear	28.5	0.053	0.066	0.076							
Oct 1 1100	10/10	med-high/W	rough	3.3	11.0	12.5	9.5	none	clear	0.5	0.010	0.013	0.018							**1.9**
						12.5	8.0	none	clear	14	0.009	0.011	0.019							2.7/1.1
						12.5	9.0	none	clear	27.3	0.010	0.017	0.018	0.010	0.013	0.019	<0.001	<0.002	<0.002	
Oct 22 1100	10/10	med-high/E	wave	4.3	8.5	9.5	10.0	none	clear	0.5	0.010	0.017	0.025	0.009	0.016	0.025	<0.001	<0.002	<0.002	**4.0**
						9.0	10.0	none	clear	14.5	0.009	0.016	0.026							5.3/2.7
						9.5	10.0	none	clear	28.8	0.010	0.018	0.028							

APPENDIX 2.2: COLDWATER EXPOSURE

2.2.1 SURVIVAL IN COLD WATER

Coldwater shock

- Responsible for more deaths than hypothermia
- Sudden shock of cold water can instantly paralyze your muscles, leave you breathless, cause you to swallow water and suffocate you within moments of immersion
- Should you survive cold water shock, hypothermia is the next immediate danger

Hypothermia

- Hypothermia is a drop in body temperature below normal (37°C) that results from a prolonged exposure to frigid waters
- Signs and symptoms:
  1. Stage one: shivering, reduced circulation
  2. Stage two: slow, weak pulse, slowed breathing, lack of coordination, irritability, confusion, and sleepy behaviour
  3. Stage three: slow, weak, or absent respiration and pulse. Potential loss of consciousness.

If you find yourself in cold water, it is essential to do everything possible to conserve energy and body heat. To lengthen survival time:

- Wear your PFD. This will help you stay afloat and keep you head out of the water without wasting energy
- Swim only if you can join others or reach a safe shelter. Do not swim to keep yourself warm, this will only increase your loss of body heat
- If possible, climb on top of a floating object (such as your boat) to keep as much of your body as possible out of the water. Frigid water will lower your body temperature faster than air (25 times faster)
- Assume the fetal position, or if you are not alone, huddle together
- Remove wet clothing of anyone who has fallen into cold water and warm them with dry clothes

How to prepare for cold weather sampling

- Wear multiple layers of dry clothing and a PFD. Wool retains more heat even when wet. Do not wear cotton! Once it is wet, it stays wet.
- Cold water protection gear can also be worn
  - Wet suit
  - Dry suit
  - Immersion suit
  - Survival suit
  - Exposure coveralls
- Wear a hat. As much as 60% of body heat is lost through the head.
- Carry matches in a waterproof container
- Bring high energy food containing sugar
- Check local weather before you head out
- Be prepared. Don't go out alone. Notify a responsible person of where you will be going and when you will be back

Sources

Red Cross, Hypothermia. https://bit.ly/3c6hc2I

Transport Canada, Hypothermia and Survival in Cold Water, 2010. https://bit.ly/3csjppB

2.2.1 RESCUE IN FREEZING WATER

Self-rescue

If you fall through the ice, you have time to save yourself

1 minute to control your breathing:

- You will gasp for air for about 1 minute in reaction to the extreme cold. After 1 minute, the gasping subsides, skin numbs and feeling of intense cold lessens

10 minutes to get out

- **Tread water**: don't panic, resist the urge to gasp. Slowly tread water or grasp the edge of the ice to keep your head above water
- **Kick and pull**: keep your hands and arms on the ice and kick your feet. This brings your body to a horizontal position parallel to the ice.
- **Horizontal kick and pull**: Once you are horizontal, continue to kick and pull. Draw yourself up onto the ice.
- **Roll onto the ice**: keep your weight spread out as you roll. Crawl and slide to reach ice that can support your weight

1 hour before losing consciousness

- After 10 minutes, your muscles will not have the strength to get you out of the water. Eventually, you will lose consciousness. If your arms are not frozen to the ice, you will slip below the surface and drown

2 hours to be found and rescued

- If you stay above the surface of the water, rescue is still possible within two hours. At about 2 hours, your heart will stop when your core temperature drops below 28°C.

Rescue with others

- Safest way to perform a rescue is from shore
- Call for help. Consider whether you can quickly get help from trained professionals or bystanders
- Check if you can reach the person using a long pole or branch from shore – if so, lie down and extend the pole to the person
- If you go onto the ice, wear a pdf, and carry a long pole or branch to test the ice in front of you. Bring something to reach of throw to the person (pole, weighted rope, line, tree branch)
- When near the break, lie down to distribute your weight and crawl/slide towards the hole
- Remaining low, extend your emergency rescue device to the person
- Have the person kick while you pull them out
- Move the person to a safe position on thicker ice or shore, call for help, and administer first aid.

Sources

Work Safe Alberta, Field Guide to Working Safely on Ice Covers, Government of Alberta, 2009. https://bit.ly/2RUgnmY

2.2.3 OTHER RISKS WHEN WORKING IN COLD ENVIRONMENTS

Being in a cold environment comes with inherent risk. Working on ice means working in cold weather.

Risks in cold weather environment:

- Frostnip
- Frostbite
- Hypothermia
- Wet clothing
- Windchill

Table 2.2a. Risk of exposure to cold air temperatures.

Hazard	**Risk**	**What to do**
Air temperature 0° to -20°C	At -20°C and 15km/hr wind, exposed skin is at risk of frostbite in 10-30 minutes	Avoid hypothermia with warm clothing Take regular breaks to warm up Make sure equipment is in good working order at the start of the day
Air temperature -20°C to -45°C	Increased risk of frostbite and hypothermia Outdoor travel can be dangerous Equipment failure has serious consequences	Take breaks in warm heated place such as cab of truck or shelter Check self and others for frostbite and hypothermia
Air temperature colder than -45°C	Serious threat to health and safety Serious risk of equipment failure Gasoline freezes at -56°C	Stop all non-emergency work Check equipment hourly Avoid skin contact with gasoline and metal objects

T air = air temp in ˚C

V_{10} = wind speed at 10 m above the ground in km/h

T air / V_{10}	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
5	4	-2	-7	-13	-19	-24	-30	-36	-41	-47	-53	-58
10	3	-3	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63
15	2	-4	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66
20	1	-5	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68
25	1	-6	-12	-19	-25	-32	-38	-44	-51	-57	-64	-70
30	0	-6	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72
35	0	-7	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73
40	-1	-7	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74
45	-1	-8	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75
50	-1	-8	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76
55	-2	-8	-15	-22	-29	-36	-43	-50	-57	-63	-70	-77
60	-2	-9	-16	-23	-30	-36	-43	-50	-57	-64	-71	-78
65	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79
70	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-80
75	-3	-10	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80
80	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81

Source: Environment Canada

Frostbite guide

- Low risk of frostbite for most people
- Increasing risk of frostbite for most people in 10 to 30 minutes of exposure
- High risk for most people in 5 to 10 minutes of exposure
- High risk for most people in 2 to 5 minutes of exposure
- High risk for most people in 2 minutes of exposure or less

Figure 2.2a. Wind chill chart. https://bit.ly/2RUgnmY

Sources

Work Safe Alberta, Field Guide to Working Safely on Ice Covers, Government of Alberta, 2009. https://bit.ly/2RUgnmY

APPENDIX 2.3: ICE THICKNESS AND SAFETY

2.3.1 ICE THICKNESS

Many factors affect ice thickness including the type of water, location, time of year and environmental factors such as:

- Water depth and size of water body
- Currents tides and other moving water (stream inlet)
- Fluctuations in water level
- Logs, rocks, and docks absorb heat from the sun
- Changing air temperature

Ice thickness is only one consideration and minimum thicknesses should be used as guidelines only. Local conditions will affect ice strength. Check with local authorities about ice conditions before heading out on the ice.

2.3.2 TYPES OF ICE

Activity	Minimum ice thickness
Walking (120 kg)	10 cm
Standing in one place for >2 hours (120 kg)	15 cm
One snowmobile (< 500 kg)	18 cm
Snowmobile and rider (500 kg) in place for > 2 hours	25 cm
Small truck (< 5000 kg)	38 cm
¾ ton 4x4 vehicle (5000 kg) in place for >2 hours	55 cm

- Ice can be thinner around islands, shoals, and shorelines
- Water currents, heavy snowfall, high winds, and sudden changes in temperature can all affect the strength of the ice

Ice Type	Variation	Ice quality and strength
Blue ice on lakes and rivers	Thickness varies little over an area	Higher strength due to uniform thickness and quality
White ice	Ice thickness varies greatly, higher potential for water and air pockets that reduce ice thickness	Ice strength varies with variation in thickness Variation and quality due to higher air content
Grey ice	High variation	May indicate the presence of water. Unsafe.

2.3.3 EMERGENCY PROCEDURE FOR FALL THROUGH ICE

- Stop all work
- Rescue victim if it is safe to do so
- Provide first aid and CPR as needed
- Take steps to prevent hypothermia (dry clothing, sleeping bag/blanket, sweetened hot liquids)
- Call for help (air or road ambulance

- Take those in need of care to nearest medical facility
- Clear the area/road to allow rescue vehicles to reach the victim
- Mark and close the incident site and surrounding area with reflective pylons or flags to warn others of potential danger

The Minnesota National Resources Department provides an **instructional video** about travelling on thin ice, and how to use ice safety picks to pull yourself out of the water should you break through the ice.

Ice safety picks

Ice anchoring screws

Rescue Canada, Ice Safety Training Courses

Sources

Red Cross, Ice Safety. https://bit.ly/3c9NXfu

Work Safe Alberta, Field Guide to Working Safely on Ice Covers, Government of Alberta, 2009. https://bit.ly/2RUgnmY

British Columbia Lake Stewardship Society
1257 Erskine Street, Coquitlam, BC, V3B 6R3
604-474-2441 info@bclss.org

BC Lake Stewardship and Monitoring Program (BCLSMP)
Safety Program for Volunteer Lake Samplers

The BC Lake Stewardship Society (BCLSS) *Safety Program* applies to volunteers performing services in association with the BCLSS. **All volunteer samplers involved with the BC Lake Stewardship & Monitoring Program (BCLSMP) are required to read this material and sign this form.**

The BCLSS recognizes its responsibility to:

- Ensure each volunteer is aware of their safety roles and responsibilities.
- Promote a safe and healthy working environment as well as safe procedures with regard to BCLSS activities.

Under the *Safety Program*, it is the BCLSMP coordinator's (the BC Lake Stewardship Society) responsibility to:

- Conduct meetings and/or phone calls as required with volunteers in order to outline program/project objectives and deliverables.
- Ensure volunteers receive training appropriate for specific sampling tasks and safety issues.
- Identify any risks and hazards of associated tasks and conduct a job/project safety analysis which includes protective clothing, first aid requirements and well-being of volunteers as required.
- Regularly consult with volunteers to assess the task and safety-related knowledge and skills required to ensure safe performance while conducting the BCLSMP.

Volunteers are requested to co-operate with and contribute to the BCLSS *Safety Program*. Volunteers shall:

- Attend meetings, calls, or training sessions as requested by the BCLSS.
- Have a check in procedure in place that will ensure a timely search is initiated upon failure to check in. It is strongly recommended that two people conduct the sampling.
- Adhere to safety programs in day-to-day volunteer activities.
- Adhere to all Federal Boating Regulations and Safe Boating Guide (including operators licensing as applicable).
- Inspect their boats and equipment for unsafe conditions and hazards.
- Use personal protective clothing, devices or safety equipment for boat operation and occupancy as required by regulatory authorities, safety standards, and procedures.
- Correct hazardous or unsafe conditions or work practices.
- Report all accidents, incidents and "near misses" to the BCLSS program coordinator.

Specific Safety Notifications

Volunteers are not expected to sample during adverse or questionable weather conditions.

Volunteers are expected to:

- Have a specific knowledge of safe operation practices for the watercraft used to access your specific monitoring site (Safe Boating Guide).
- Have a reasonable knowledge of safety issues specific to your lake (e.g., shoals, dead heads, local weather anomalies, etc.) and to take these into account during the BCLSMP.
- Be knowledgeable about hypothermia and the risks associated with cold water, particularly in Spring.

In order to maximize safety while conducting a lake stewardship and monitoring program, the *Safety Program* requires that:

- Boats must be of a stable design and in good operating condition. [Canoes are only appropriate during warm water and calm conditions, for Level I programs (Secchi/temperature)].
- Boat specifications regarding carrying capacity and motor restrictions are adhered to.
- Each volunteer wears an approved personal floatation device. If sampling large, cold lakes, a survival suit is strongly recommended.
- Volunteers must be particularly careful to dress appropriately during sampling early and late in the open water season. Cold water temperatures will very easily cause hypothermia and possible fatality of exposed persons. Hypothermia is a drop in body temperature to below normal and is very dangerous.
- Departure and intended return times are logged with a responsible individual on shore.
- Travel and sampling are not to be conducted in rough waters.
- Volunteers follow the orders, notices, and guidance of the Provincial Health Officer (i.e., COVID-19 guidelines).

Waiver and Release of Liability

In consideration of being allowed to participate in any way in the **BC Lake Stewardship and Monitoring Program** the undersigned acknowledges, appreciates, and agrees that:

1. The risk of injury from the activities involved in this program is significant, including the potential for permanent paralysis and death, and while particular rules, equipment, and personal discipline may reduce this risk, the risk of serious injury does exist; and,
2. I KNOWINGLY AND FREELY ASSUME ALL SUCH RISKS, both known and unknown, EVEN IF ARISING FROM THE NEGLIGENCE OF THE RELEASEES or others, and assume full responsibility for my participation; and,
3. I ACKNOWLEDGE, agree, and represent that I understand the nature of boating activities, both on water and land based, and that I am qualified, in good health, and in proper physical condition to participate in such activity; and,
4. I willingly agree to comply with the stated and customary terms and conditions for participation. If, however, I observe any unusual significant hazard during my presence or participation, I will remove myself from participation and bring such to the attention of the nearest official immediately; and,

5. I, for myself and on behalf of my heirs, assigns, personal representatives and next of kin, HEREBY RELEASE AND HOLD HARMLESS the **BC Lake Stewardship Society,** their Directors, officials, agents and/or employees, partners, other participants, sponsoring agencies, sponsors, advertisers, and, if applicable, owners and lessors of premises used to conduct the event ("Releasees"), WITH RESPECT TO ANY AND ALL INJURY, DISABILITY, DEATH, or loss or damage to person or property, WHETHER CAUSED BY THE NEGLIGENCE OF THE RELEASEES OR OTHERWISE.

I HAVE READ AND UNDERSTAND THE ABOVE SAFETY PROGRAM MATERIAL AND UNDERSTAND THE HAZARDS INVOLVED WITH PERFORMING LAKE SAMPLING AND WILL MAKE EVERY EFFORT TO PERFORM THIS SERVICE IN A SAFE MANNER. I UNDERSTAND THAT I CANNOT SAMPLE ON DAYS WHERE THE WEATHER OR LAKE CONDITIONS MAKE SAMPLING HAZARDOUS AND THAT, IF NECESSARY, THE SCHEDULED SAMPLING SHOULD NOT BE CONDUCTED. I HAVE READ AND UNDERSTAND THE RELEASE OF LIABILITY AND ASSUMPTION OF RISK AGREEMENT, FULLY UNDERSTAND ITS TERMS, UNDERSTAND THAT I HAVE GIVEN UP SUBSTANTIAL RIGHTS BY SIGNING IT, AND SIGN IT FREELY AND VOLUNTARILY WITHOUT ANY INDUCEMENT.

______________________________ ______________________________
PARTICIPANT'S SIGNATURE PARTICIPANT'S NAME (PRINTED CLEARLY)

DATE OF BIRTH WITNESS

EMAIL PHONE NUMBER

FOR PARTICIPANTS OF MINORITY AGE
(UNDER AGE 18 AT TIME OF REGISTRATION)

This is to certify that I, as parent/guardian with legal responsibility for this participant, do consent and agree to his/her release as provided above of all the Releasees, and, for myself, my heirs, assigns, and next of kin, I release and agree to indemnify the Releasees from any and all liabilities incident to my minor child's involvement or participation in these programs as provided above.

PARENT/GUARDIAN'S SIGNATURE EMERGENCY PHONE NUMBER

WITNESS

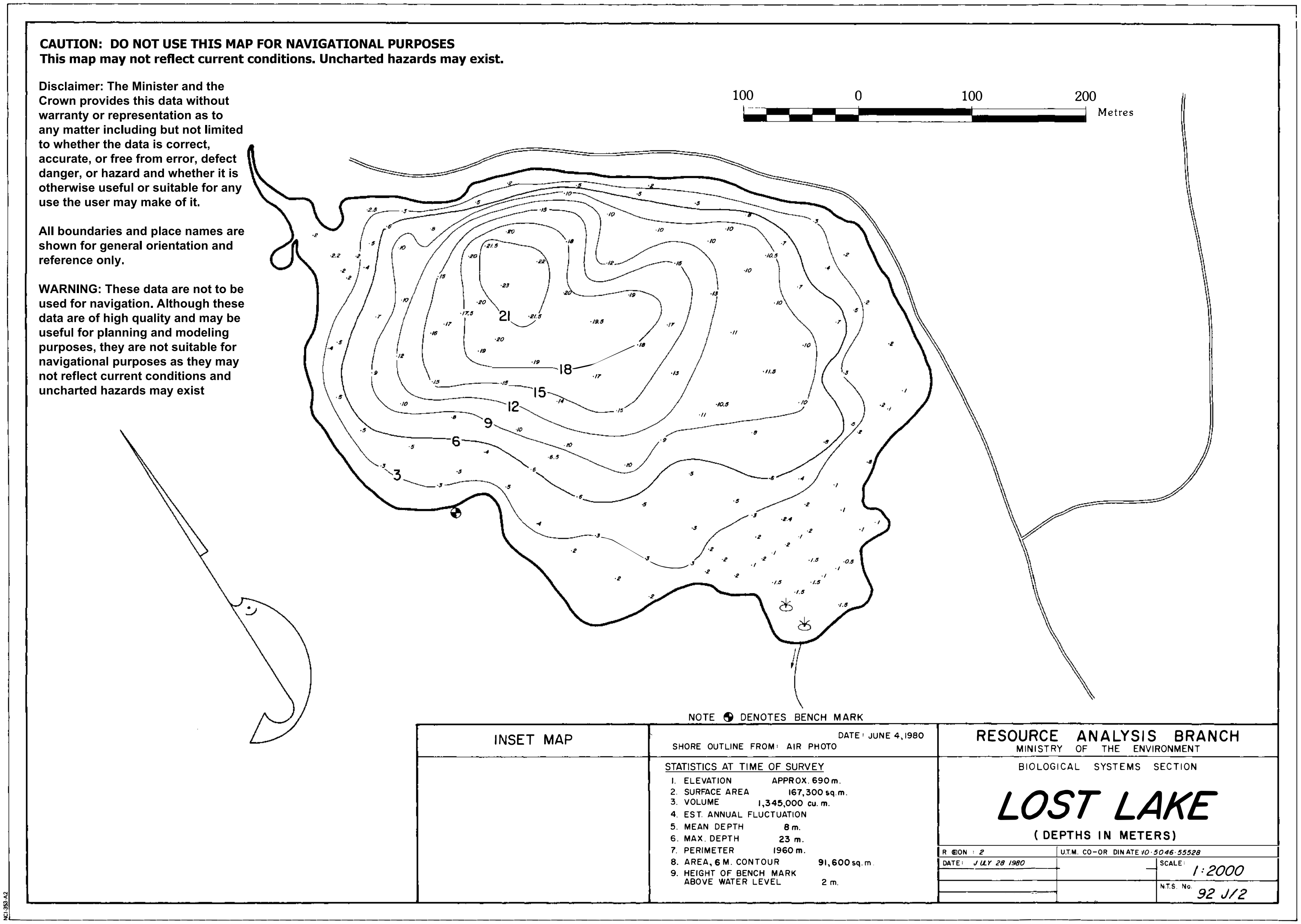
APPENDIX 2.5: LIST OF FIELD EQUIPMENT FOR SAMPLING

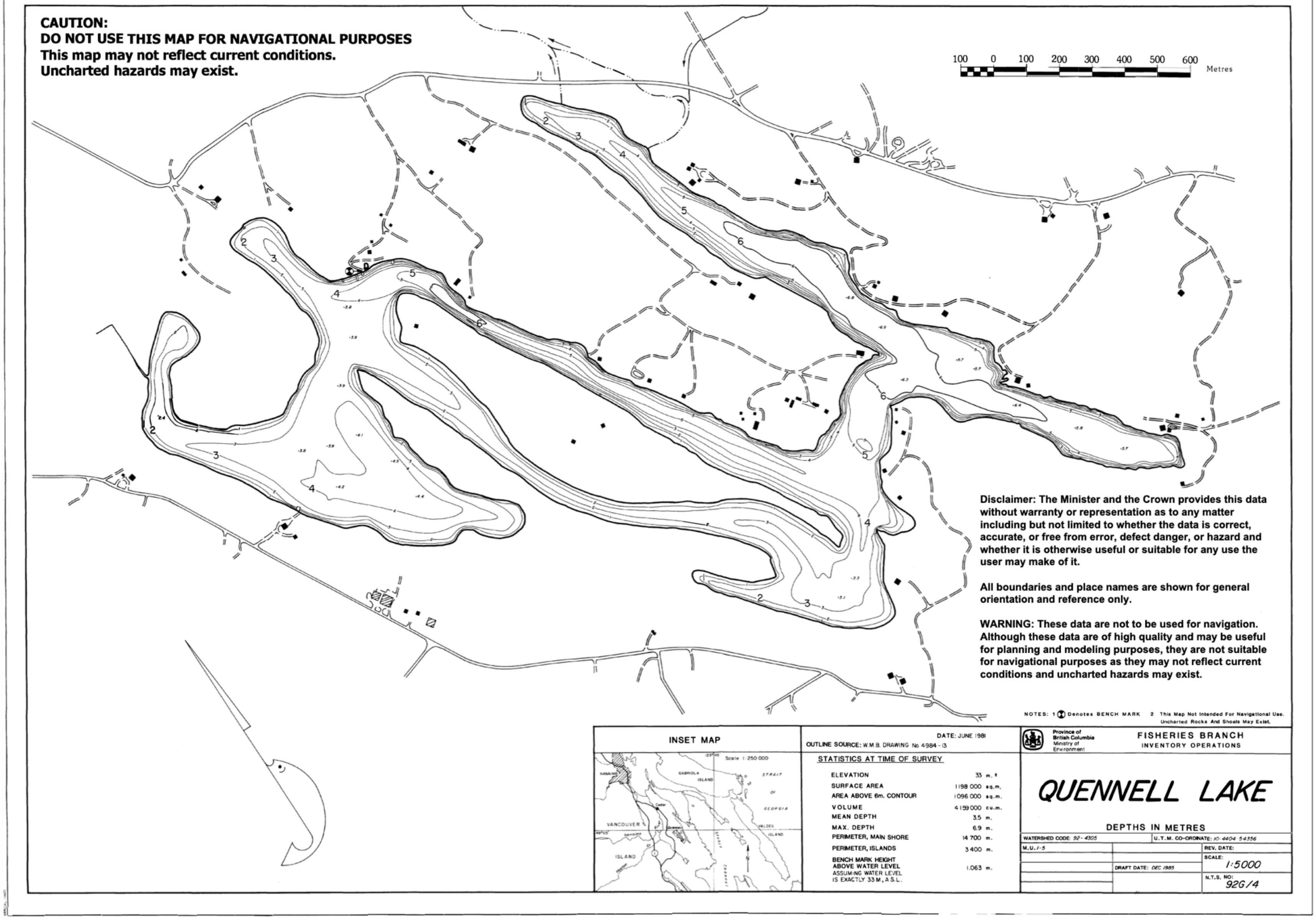
BCLSMP Equipment List for Program Levels 1 to 3			
M: Mandatory for safety or basic project design			
R: Recommended			
Blank: Optional, or project or condition specific			
		BCLSMP Levels	
Safety	**1**	**2**	**3**
Life jacket	M	M	M
Floater thermal jacket	R	R	R
Survival suit (PARTICULARLY FOR LARGE LAKES)	R	R	R
First Aid Kit	R	M	M
Safety glasses (if using preservatives)		M	M
Disposable gloves (if using preservatives)		M	M
Boat Equipment	**1**	**2**	**3**
Canoe		N/A	N/A
Boat (safety equipment and experienced operator)	M	M	M
Paddles or oars	M	M	M
Motor (comply with motor restrictions for lake)		R	M
Fuel tank (full) and fuel line		R	M
Throw Rope	M	M	M
Anchor and rope	M	M	M
Bailer	M	M	M
Whistle	M	M	M
Tool kit	R	R	R
Ice Trips	**1**	**2**	**3**
Survival suits	N/A	M	M
Safety harnesses (one per person)	N/A	M	M
Safety ropes	N/A	M	M
Ice chisel	N/A	M	M
Ice picks (two per person	N/A	R	R
Ice auger (hand or power	N/A	R	R
Spare auger blades	N/A	R	R
Ice skimmer	N/A	R	R
Ice strainer	N/A	R	R

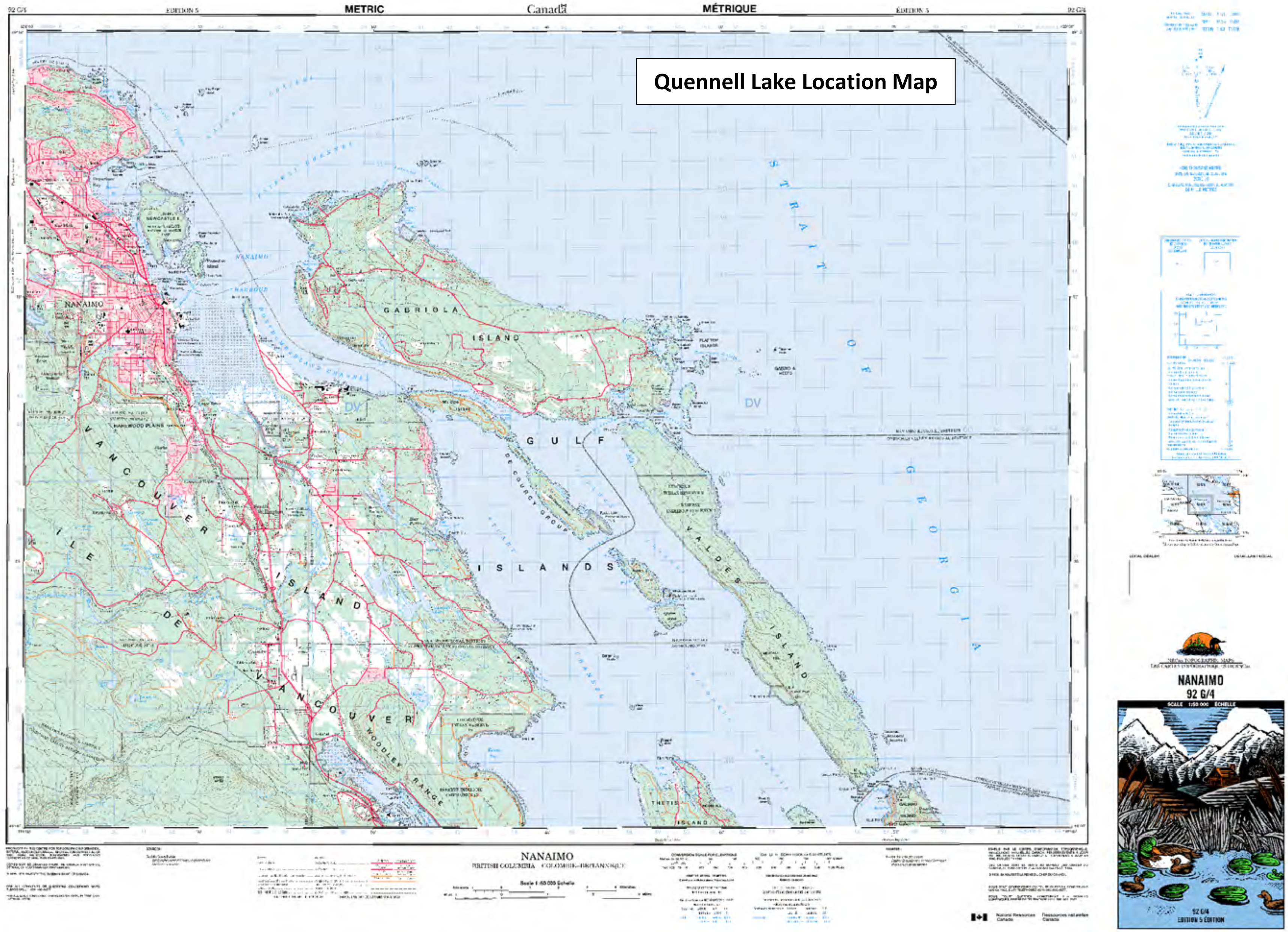
Fuel			
Hearing protection			
Stationary/shipping	**1**	**2**	**3**
Field book (Rite in the Rain)	R	R	R
BCLMSP Field forms (Level 1, 2, or 3)	M	M	M
Sampling instructions protocols			
Level 1, 2, or 3 sampling instructions	M	M	M
Shoreline sampling			
Surface water sampling	N/A	R	R
Deep water sampling			R
Winter sampling for frozen lakes			
Water clarity	R	R	R
Measuring water temperature (thermometers)	M	R	R
Measuring water temperature (electronic meters)			
Dissolved oxygen (electronic meter)			
Dissolved oxygen (Chemical Field Kit)			
Chlorophyll a			M
Sampling bacterIa from shore			
Ball point pen	M	M	M
Pencils	M	M	M
Felt markers (black, waterproof)			M
Site map	R	R	R
Chemistry requisitions			M
Biological requisitions			
Shipping waybills			
Shipping address labels			M
Coolers			M
Ice packs (frozen. 1 in winter, 2-3 in summer)			M
Packing material (bubble wrap, newsprint, cardboard)			R
DO/Temperature meter (charged)			
pH meter (charged)			
Conductivity meter (charged)			
Dip net (aquarium)			
Extra batteries for meters		R	R
Phytoplankton Chlorophyll a:	**1**	**2**	**3**
Syringe			
Tweezers			
0.45/1.0 µ membrane filters			

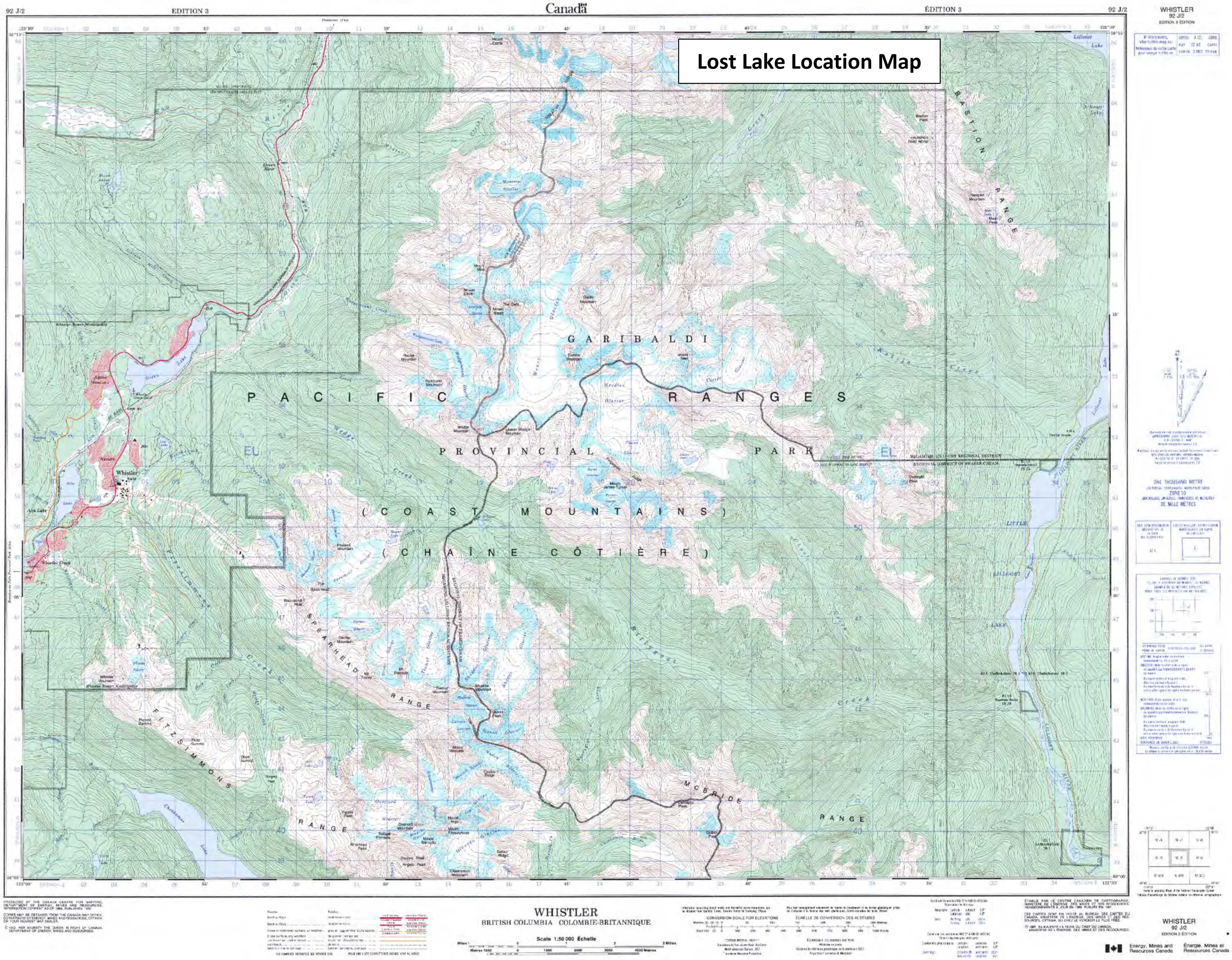
Magnesium carbonate			
Thermos with desiccant crystals			
Wrapping filters (9 cm Whatman #2)			
Paper clips			
Phytoplankton taxonomy	**1**	**2**	**3**
Phytoplankton (500 mL poly)			
Lugols solution			
Zooplankton	**1**	**2**	**3**
Wisconsin Net			
Calibrated rope			
Vaseline			
Squirt bottle			
Tissue cups			
Ethyl Alcohol			
Personal Gear	**1**	**2**	**3**
Rain gear			
Gum boots			
Waders (hip, chest)			
Rubber gloves (wrist or shoulder)			
Sunglasses			
Hat			
Mitts			
Sunscreen			
Packing or fibre tape			M
Pocket knife			M
Camera (film)			
Binoculars			
Observe, Record, Report forms			
Pad of paper			
Sample Bottles	**1**	**2**	**3**
General chemistry (250 mL poly)			M
Nutrients (125 mL poly)			M
De-ionized water (4L poly)			M
Chlorophyll a (1 L poly)			M
Coliforms			

Resealable bags			
Extras - two of each (losses, duplicates, blanks)			M
Tissue cups or twist lock bags			
Sampling Equipment (clean, in good working order)	**1**	**2**	**3**
Water Sampler			
Van Dorn, Student Point, etc.			M
Rope calibrated in meters			M
Decant hose			M
Brass messenger			M
Water sampler (vertical for through-ice sampling)			
Secchi Disk (with tape calibrated in 0.10 meters)	M	M	M
HACH Winkler DO Kit			
60 ml glass BOD bottle with stopper			
DO #1, #2, #3 powder pillows			
Nail clippers, scissors, or knife			
Plastic vial			
Glass jar			
Sodium thiosulphate solution & eye dropper			
Starch solution			
Thermometer (if not included in Student Sampler)	M	M	M
Thermometer (spare, handheld)	R	R	R


CAUTION: DO NOT USE THIS MAP FOR NAVIGATIONAL PURPOSES
This map may not reflect current conditions. Uncharted hazards may exist.
Disclaimer: The Minister and the Crown provides this data without warranty or representation as to any matter including but not limited to whether the data is correct, accurate, or free from error, defect danger, or hazard and whether it is otherwise useful or suitable for any use the user may make of it.
All boundaries and place names are shown for general orientation and reference only.
WARNING: These data are not to be used for navigation. Although these data are of high quality and may be useful for planning and modeling purposes, they are not suitable for navigational purposes as they may not reflect current conditions and uncharted hazards may exist
100 0 100 200
Metres
NOTE DENOTES BENCH MARK
INSET MAP
DATE: JUNE 4, 1980
SHORE OUTLINE FROM: AIR PHOTO
STATISTICS AT TIME OF SURVEY
1. ELEVATION APPROX. 690 m.
2. SURFACE AREA 167,300 sq. m.
3. VOLUME 1,345,000 cu. m.
4. EST. ANNUAL FLUCTUATION
5. MEAN DEPTH 8 m.
6. MAX. DEPTH 23 m.
7. PERIMETER 1960 m.
8. AREA, 6 M. CONTOUR 91,600 sq. m.
9. HEIGHT OF BENCH MARK ABOVE WATER LEVEL 2 m.
RESOURCE ANALYSIS BRANCH
MINISTRY OF THE ENVIRONMENT
BIOLOGICAL SYSTEMS SECTION
LOST LAKE
(DEPTHS IN METERS)
DATE: JULY 28 1980
SCALE: 1:2000
N.T.S. No. 92 J/2


CAUTION:
DO NOT USE THIS MAP FOR NAVIGATIONAL PURPOSES
This map may not reflect current conditions.
Uncharted hazards may exist.
100 0 100 200 300 400 500 600 Metres
Disclaimer: The Minister and the Crown provides this data without warranty or representation as to any matter including but not limited to whether the data is correct, accurate, or free from error, defect danger, or hazard and whether it is otherwise useful or suitable for any use the user may make of it.
All boundaries and place names are shown for general orientation and reference only.
WARNING: These data are not to be used for navigation. Although these data are of high quality and may be useful for planning and modeling purposes, they are not suitable for navigational purposes as they may not reflect current conditions and uncharted hazards may exist.
NOTES: 1 Denotes BENCH MARK 2 This Map Not Intended For Navigational Use. Uncharted Rocks And Shoals May Exist.
INSET MAP
Scale 1:250 000
DATE: JUNE 1981
OUTLINE SOURCE: W.M.B. DRAWING No 4984 - 13
STATISTICS AT TIME OF SURVEY
ELEVATION 33 m. ±
SURFACE AREA 1198 000 sq.m.
AREA ABOVE 6m. CONTOUR 1096 000 sq.m.
VOLUME 4 159 000 cu.m.
MEAN DEPTH 3.5 m.
MAX. DEPTH 6.9 m.
PERIMETER, MAIN SHORE 14 700 m.
PERIMETER, ISLANDS 3 400 m.
BENCH MARK HEIGHT ABOVE WATER LEVEL 1.063 m.
ASSUMING WATER LEVEL IS EXACTLY 33 M, A.S.L.
Province of British Columbia Ministry of Environment
FISHERIES BRANCH
INVENTORY OPERATIONS
QUENNELL LAKE
DEPTHS IN METRES
WATERSHED CODE: 92 - 4305
U.T.M. CO-ORDINATE: 10 · 4404 · 54356
M.U. 1-5
REV. DATE:
SCALE: 1:5000
DRAFT DATE: DEC 1985
N.T.S. NO: 92G/4


Quennell Lake Location Map
METRIC
Canada
MÉTRIQUE
EDITION 5
NANAIMO
GABRIOLA ISLAND
STRAIT OF GEORGIA
GULF ISLANDS
VALDES ISLAND
VANCOUVER ISLAND
ÎLE DE VANCOUVER
WOODLEY RANGE
DE COURCY GROUP
THETIS ISLAND
DV
NANAIMO
BRITISH COLUMBIA COLOMBIE-BRITANNIQUE
NANAIMO
92 G/4
92 G/4
EDITION 5 ÉDITION



Lost Lake Location Map
Canada
92 J/2
EDITION 3
ÉDITION 3
WHISTLER
92 J/2
P A C I F I C
R A N G E S
G A R I B A L D I
P R O V I N C I A L
P A R K
(C O A S T   M O U N T A I N S)
(C H A Î N E   C Ô T I È R E)
S P E A R H E A D
R A N G E
F I T Z S I M M O N S
R A N G E
M C B R I D E
R A N G E
B A S T I O N
R A N G E
Whistler
WHISTLER
BRITISH COLUMBIA   COLOMBIE-BRITANNIQUE
Scale 1:50 000 Échelle
Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada