TYHEE LAKE MANAGEMENT PLAN

Prepared for:

The Tyhee Lake Protection Society

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June 1999

Acknowledgments

The first edition of the Tyhee Lake Management Plan was prepared by Shauna Rysavy, under the guidance of Ian Sharpe, Impact Assessment Biologist, B.C Ministry of Environment, Lands and Parks (MELP). This edition of the Plan was prepared by Katimavik Volunteers Eloise Gaudreau and Catherine Gagne, under the guidance of Lisa Westenhofer, Consulting Biologist. Elosie Gaudreau also authored the section on The Common Loon of Tyhee Lake, under the guidance of Len Vanderstar, BC MELP Regional Forest Ecosystems Specialist. We extend a special thank you to Rick Nordin, BC MELP Water Quality Branch Limnologist and Lakes Stewardship Society (BCLSS) Vice President, and Ken Ashley, BC MELP Fisheries Management Branch for their advice and review. We thank the many individuals, citizens and agency staff of the Bulkley Valley who provided the information contained in the plan. The co-operation, support and input of the Tyhee Lake Protection Society members was greatly appreciated.

This project was originally funded through a BC Ministry of Environment Lands and Parks Environmental Youth Team grant, awarded to the Tyhee Lake Protection Society, in partnership with the Bulkley, Nechako Regional District. Additional financial support since 1998 has been provided by MELP Skeena Region Pollution Prevention Program.

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1. Management Plan Goal Statements

The objective of the Tyhee Lake management plan is to benefit users by improving the quality of the natural environment of the lake (i.e. to slow down or eliminate eutrophication) and thereby improving the usefulness of the lake for human use. The requirements of the plan must include maintenance of human land and water use as well as aquatic and terrestrial wildlife use (plants and animals).

1.1 Strategic Planning/ Systems Design

There are two standard ways of approaching a problem. One way is to use tactical thinking and the other involves strategic thinking (Spitzer, 1991). Tactical thinking is short-term and treats only the symptoms of a problem as opposed to strategic thinking which is long-term and treats the causes of the problem. Cultural eutrophication is a complex problem and a strategic approach is the most appropriate one. In general, a tactical approach may be the simplest and appear to be the least expensive. However, a tactical approach to a problem is usually an expensive one because the problem is never solved and the symptoms will keep reappearing (Rast and Holland, 1988). A strategic approach requires long term commitment and may be expensive but it is the most practical and efficient approach to solving a complex problem.

In order to address the problem of designing a strategic lake management plan for Tyhee Lake, a systems approach was taken. This approach is warranted due to the complexity of the problem(s) and the variety of the stakeholders. This is a problem solving model which is designed to initiate creative thinking about exceedingly complex physical and social phenomena which interact and evolve over time (Spitzer, 1991).

The systems design approach is used to set up a framework for decision making which is flexible to allow integration and consideration of new information and data as it is made available.

There are five phases to the systems design approach; analysis, design, development, implementation, and evaluation/revision. The design model is interactive and the process is non-sequential as illustrated in Figure 1.

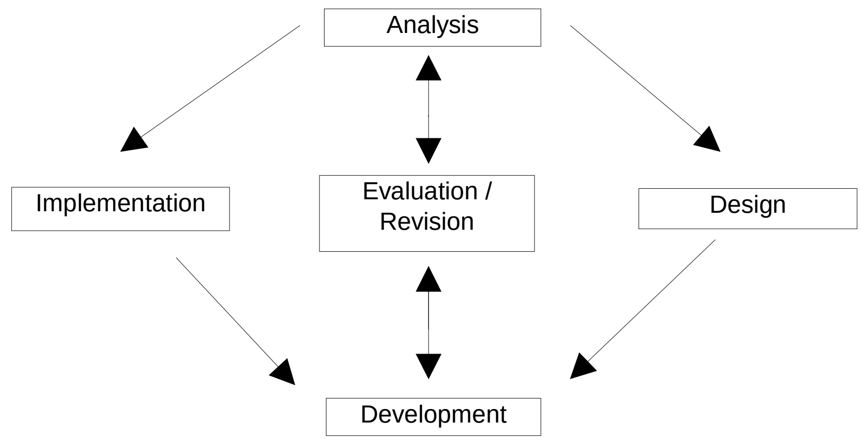


Figure 1: Interactive Model of the Systems Design Approach (Spitzer, figure 2.4, 1991)

- **Analysis** is the process of identifying and refining the goals and requirements of the lake management plan. The water quality characteristics of a specific water-body can affect the selection of specific eutrophication management goals.
- Phase two is **design**. Specifications for meeting the lake management goal and requirements are identified by this process. In the case of the Tyhee Lake management plan, three systems were identified; biological, socio-economic, and chemical-physical.
- **Development** is phase three. This is the process of improving and revising the plan according to feedback from the stakeholders.
- The **Implementation** process involves trying out the plan to see if it works.
- **Evaluation and Revision** are implemented throughout the process. Phase five is used to evaluate the system, identify improvements and make changes to the system accordingly. It is acknowledged that evaluation/revision drives the systems design process and therefore the plan is never completely finished, and will always be subject to improvements through testing and evaluation.

Systems design goes from the general, exhaustive inventory and analysis of the inter-related systems and system components, through a process of analysis and refinement, to a decision making process which utilizes a refined set of systems and system components. The process is iterative in nature and uses an interactive approach which allows stakeholders to participate throughout. For more information on the interrelatedness analysis see Section 3.0 and Appendix A.

A more thorough discussion on the systems design approach and a breakdown of the system components can be found in Appendix 2 and in the accompanying Generic Lake Management Plan (Lightowlers, 1995).

1.2 Consensus Building

A successful lake management program begins with a lake management plan which has widespread support from stakeholders. It is essential to involve all interested groups and regulatory agencies in the planning process to discuss the issues and work toward achieving a consensus (Gibbons *et al*., 1994). Persons that are invited to participate at an early stage of the planning process are more likely to become advocates of the program. This is essential for implementation and perpetuation of the plan (Rast and Holland, 1988). Stakeholders include government agencies, lake residents, lake user groups, environmental groups and others. For a full list of the stakeholders involved in the Tyhee Lake Management Plan, see Appendix C.

Due to the complexity of the problem and the variety of the stakeholders, consensus building is a very important part of the lake management planning process. The plan design must acknowledge that lake management planning is a group endeavor and that each person's opinion is important and should be recognized (Gibbons *et al*., 1994). There is no substitute for local knowledge of the lake's problems and/or a lifetime of observations of a lake (Rast and Holland, 1988). This knowledge can be documented for use in developing the management program.

All interested parties should be involved from the formative stages and throughout the planning process to constructively discuss the issues and work towards achieving widespread support. During the planning process it is critical to conduct public meetings and keep the community informed. Key times for conducting stakeholder meetings have been identified and include; during identification of the plan goals and requirements, when possible alternatives have been identified, after a plan has been selected but before it is carried out, during implementation of the selected lake management program, and once a year after a plan has been implemented to conduct post-treatment evaluation and revision of the long term plan (Gibbons *et al* , 1994).

Due to the technical nature of the cultural eutrophication problem, in some cases it is necessary to use the knowledge of experts to clarify misconceptions (Gibbons *et al* ,1994). The goal of consensus building is to inform and assist decision making by identifying advantages and disadvantages of different lake management options. The relative merits of different lake management options should be compared and assessed by individual stakeholders who then must collaborate and come to an agreement on the most effective and feasible plan (Shaffer, 1991).

The key role of the lake management planner is to ensure at an early stage that the goals and objectives of the lake management plan are acceptable to all stakeholders.

2. The Nature of the Eutrophication Process

Over thousands of years, through the natural aging process of shallow lakes, a lake may eventually become a marsh and then, finally, a terrestrial system (Rast and Holland , 1988). Following excessive additions of silt, nutrients and organic matter, gradual deterioration of a lake will occur. Rooted plant biomass will increase, water clarity will become reduced, the lake volume will decrease and algal blooms will be more frequent (Cooke *et al*., 1993). This is the process of eutrophication.

The observed water quality in the lake, reflects in part the cumulative effects of the materials carried in all waters flowing into the waterbody (Rast and Holland, 1988). The process of eutrophication can be accelerated through increased materials carried into the lake due to human settlement, clearing of forests and development of farms within the lake's watershed (Rast and Holland, 1988). This is generally termed cultural eutrophication (Cooke *et al*., 1993). An increased growth rate of the flora and fauna in a lake is associated with a loss in recreational value, and a potentially unsafe water supply (Cooke *et al*., 1993).

A lake undergoing cultural eutrophication can be restored so that it will again have water quality more characteristic of the natural situation (Rast and Holland, 1988). If cultural eutrophication is left unmanaged, the result will be significant ecological changes (such as changes in fish) and significant reduction in appeal of the lake for residents and recreational user groups who use it.

Table 1 illustrates the general chemical, physical and biological trophic criteria responses to increased eutrophication in a lake (Rast and Holland, 1988). Lake eutrophication is considered to be synonymous with an increased growth rate of the biota (Wetzel, 1983). As eutrophication progresses, the transparency of the water decreases and total suspended solids increase. The algal bloom frequency increases and are all inter-related as they are all part of the complex biota of the lake.

Table 1: **Water Quality, trophic indicator parameters and their responses to eutrophication** (Rast and Holland, 1988)

	Physical	Chemical	Biological
↑	Suspended Soli	Nutrient Concentrations	Algal Bloom Frequency and Duration
↑	Odours	Chlorophyll a	Phytoplankton Biomass
↑		Electrical Conductance	Littoral Vegetation
↑		Dissolved Solids	Zooplankton
↑		Hypolimnetic Oxygen Deficit	Fish
↑		Epilimnetic Oxygen Supersatur	Primary Production
↓	Transparency		Bottom Fauna Diversity
↓			Algal Species Diversity

↑ indicates that the value of the parameter generally increases with the degree of eutrophication

↓ indicates that the value of the parameter generally decreases with the degree of eutrophication

Under the biological heading in Table 1, it is apparent that there are qualitative and quantitative changes associated with an increasing degree of eutrophication (Rast and Holland, 1988). Increased eutrophication may lead to increased biomass of organisms (quantitative change) but a decreased number of species (qualitative). It should also be noted that beyond a certain degree of eutrophication, there may be a decrease in numbers and species of fish in hypolimnetic waters as a result of hypolimnetic oxygen depletion (Rast and Holland, 1988). There may also be a decrease in bottom fauna diversity due to high concentrations of H_2S (hydrogen sulfide), CH_4 (methane), or CO_2 (carbon dioxide) or again due to oxygen depletion (Rast and Holland, 1988). One of the most prominent trophic indicators of increasing eutrophication is an increase in primary production. The most easily measured criterion of accelerated productivity is increasing rates of annual photosynthesis by algae and larger plants over a given area (Wetzel, 1983).

2.1 Nutrients: Limiting vs. Non-limiting

There are a number of things that are required for aquatic life. For algae and aquatic plants, sunlight, oxygen, hydrogen, carbon, nitrogen, phosphorus and a number of micronutrients are essential. Oxygen and hydrogen exist in chemical abundance far in excess of requirements (Wetzel, 1983). The ratio of carbon(C):nitrogen(N):phosphorus(P) by weight in plants is 40C:7N:1P and this is the ratio which is needed in their environment for growth (Wetzel, 1983). Assuming that sunlight and other micronutrients are available, phosphorus will become the first of these three nutrients to become limiting. However, if phosphorus is in excess within the aquatic environment, then increased levels of photosynthesis can occur until the nitrogen becomes scarce and therefore becomes the next limiting nutrient (Wetzel, 1983). Therefore, lakes are most commonly phosphorus limited but can also be nitrogen limited or co-limited by phosphorus and nitrogen (Rast and Holland, 1988).

From this information, it is apparent that phosphorus and nitrogen are the main nutrients of concern. Increased nutrient concentrations entering the aquatic environment are almost always an impact of pollution (Wetzel, 1983). When assessing the available nutrient levels in the aquatic system, it should be noted that only the dissolved reactive fraction and some portion of the particulate fraction of phosphorus are available to organisms for growth (Cooke *et al*., 1993). In lakes (with clear water - no suspended sediments) generally total P is considered to equal available phosphorus (It is all cycling through the system)

2.2 Phosphorus Limited Lakes

Excessive growth of algae and aquatic plants can cause decreased dissolved oxygen levels, decreased recreational value due to odors and aesthetics, and poor habitat conditions for other aquatic organisms such as fish (Wetzel, 1983). A reduction of phosphorus inputs is generally the most effective method to reduce the excessive growth of algae and aquatic plants in a lake that is receiving a continuous loading of nutrients (Wetzel, 1983).

Atmospheric levels of phosphorus are very low, as it does not have a gaseous phase and the nutrient is chemically reactive. These two characteristics make phosphorus technologically easier to control and remove from water than nitrogen (Wetzel, 1983). Once external loading to a lake is decreased the lake will require from 2 to 10 years, depending on the water exchange rate of the lake, for recovery from eutrophication symptoms such as increased algal growth (Wetzel, 1983)..

2.3 Nutrient Sources - Internal versus External Nutrient Loading

Sources of nutrients to a waterbody include external and internal sources such as groundwater seepage and sediments, in various states of chemical equilibria (oxidative and reducing conditions). External nutrient loading consists of point sources and nonpoint sources. Any direct nutrient sources to the lake such as discharges through culverts and storm drains are considered to be point sources whereas, overland flow and groundwater seepage are considered to be nonpoint sources. Internal loading from groundwater seepages, decomposing organisms and sediment contributions can add nutrients to the water column at rates equal to or greater than external loading at some times of the year (Cooke *et al*, 1993). If a reduction of total phosphorus in the water column is the objective of the lake management program, the major sources of the nutrient inputs to the lake must be identified and quantified.

2.4 Nutrient Models

Once the limiting nutrient for the lake has been identified, possible sources of influx and outflux of the nutrient should be quantified to construct a nutrient model.

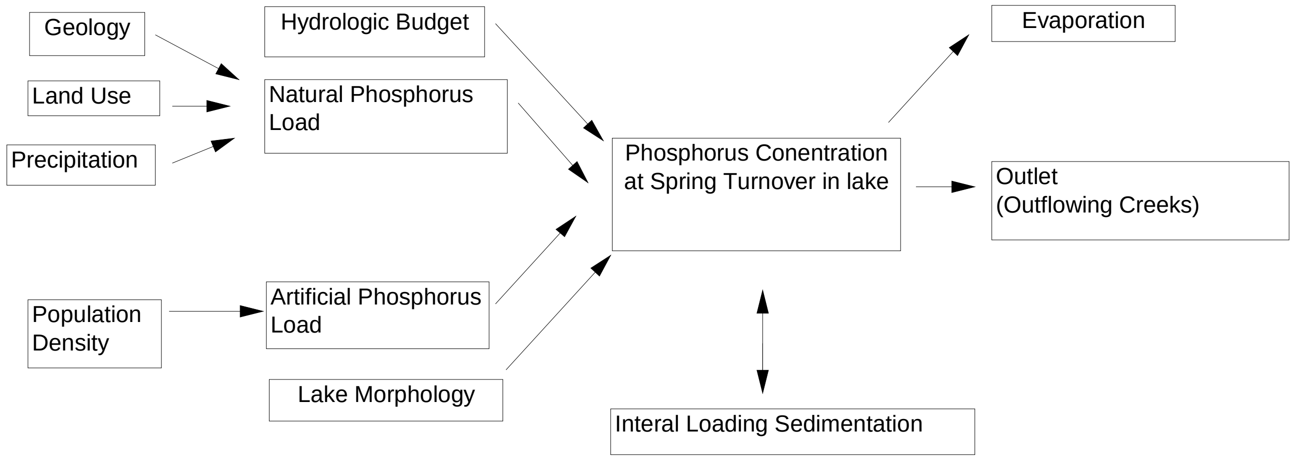


Figure 2: Diagram of a Typical Nutrient Budget (adapted from Dillon and Rigler,1975).

Total Nutrients into the lake minus the total nutrients out of the lake should equal the total phosphorus concentration in the lake at Spring turnover plus or minus the internal nutrient loading (if sediments are a source of the nutrient) or sedimentation

There are several approaches to construction of a nutrient budget. The Mass Balance model assumes that the mass of water is neither created nor destroyed, therefore, all inputs of water to the system must equal all outputs of water from the system (Larsen and Mercier, 1976). Further to this, it is assumed that the mass of particulate and dissolved materials (including nutrients) entering the lake is neither created nor destroyed. The model describes the relationship between nutrient concentrations in a lake and the internal and external supply of nutrients to the lake by assuming that the total nutrients into the lake minus the total nutrients out of the lake should equal the total phosphorus concentration in the lake as measured at spring turnover. In fact, this will almost never be true because the model at this point does not account for internal loading from the sediments or sediments which may act as a "sink" by absorbing nutrients from the water column. In addition, decaying macrophyte biomass may serve as a nutrient sink for a period of time. If a significant increase in the growth of a species such as *Elodea canadensis* occurs over a number of years, then the nutrients locked up in the plant biomass may be sequestered for a period of time. These nutrients will then be liberated back to the nutrient cycle once the infestation has subsided. To determine whether the sediments are contributing or absorbing nutrients, the calculation is as follows, the total nutrients in minus the total nutrients out minus the total concentration of nutrients in the lake. If the difference remaining is positive, then the gross rate of sedimentation exceeds the gross rate of sediment release of nutrients and if the remaining difference is negative, then the gross rate of sediment release of nutrients exceeds the gross rate of sedimentation and this is termed internal loading (Cooke *et al*., 1993).

There are many variations on this approach. Some models are constructed by multiplying each term in the water budget by a representative nutrient concentration (determined from water quality analysis) and some models, such as the Dillon-Rigler model, use pre-determined coefficients to estimate the total nutrient input (Dillon and Rigler, 1975). In 1980, Reckhow and Simpson developed a procedure for estimating the prediction uncertainty associated with the indirect estimation of inputs with coefficients and came up with a new model which incorporates some lake quality data (Cooke *et al*., 1993).

3. Diagnosis of Tyhee Lake

3.1 Interrelatedness Analysis

In the analysis stage of the plan, three systems (socio-economic, biological, and physical) were identified. The systems are artificial and most likely incomplete but were a systematic attempt at identifying and classifying all the important and controllable aspects of the lake system and it's watershed.

A complete inventory of all components of the lake and watershed was developed. The interrelatedness analysis created an overview of the entire lake ecosystem and it's components and how these relate to social, economic and political factors.

For further information on the method of the interrelatedness analysis, see Appendix 1 which also contains the systems inventory and the interrelatedness analysis. This exercise facilitated the commencement of the plan by allowing the determination of key components relevant to Tyhee Lake. Every lake will have different key components. In the event that a professional limnologist or expert in the field of lake management is developing the plan, some of this exercise may be unnecessary, as the expert may be able to identify key components based on prior experience.

3.1.1 Key Components of the Physical System

3.1.1.1 __Flushing Rate__ - What affects it?

There is often a direct correlation between flushing rate and productivity of a lake. Algal growth is correlated to flushing rate and nutrient availability for growth. If the flushing rate is high, algal growth becomes more dependant on this factor and less dependant on nutrient supply (Cooke *et al*., 1993). Frequency and duration of algal blooms are increased if the flushing rate is slow. In addition, a slow flushing rate is correlated with increased sedimentation rates and therefore increased submergent and emergent macrophyte growth. Generally, a slower flushing rate can be translated to mean increased chance of poor water quality whereas, a higher flushing rate can be associated with an increased chance of maintaining good water quality when nutrients are added.

An increase in the frequency and duration of algal blooms and the growth of macrophytes leads to a decrease in recreational quality and use of the lake. Potability of lake water may also deteriorate as a result of chemical and physical changes associated with nutrient enrichments under low flushing rate conditions.

3.1.1.2 __Water level__ - What role does it play?

Through manipulation of the outlet (raising or lowering it), the water level in the lake can be altered. Beavers can manipulate the level of the outlet by building dams. Once a beaver sets up house in the outlet of a lake, the water level can increase significantly which can alter shoreline vegetation and wetland areas. A water level which changes frequently will cause increased shoreline erosion.

Many aquatic organisms require an area of overhanging shoreline vegetation to provide temperature moderating influences. The prevalence of overhanging shoreline vegetation can be altered by a rise in water level. The presence/absence of beavers may determine the mix of species of waterfowl that will inhabit the lake by altering the species composition of aquatic and terrestrial plants. An increase in the water level will lead to drowning of riparian vegetation which means loss of habitat for a variety of species from loons to benthic invertebrates.

Many residential users are opposed to beaver inhabiting the lake outlet since water level increases cause inundation of shoreline property. The consequences of this are loss of property and destruction of established beaches.

The lake outlet may be lowered through manipulation which can have significant effects. If the water level in the lake is decreased, spawning areas associated with inflowing creeks may dry up more quickly, which would effect fish populations, species, stocking plans and fish harvest management. This would also cause habitat disruption for invertebrates which are an important part of the food web.

Annual precipitation is the major influence on water level, flushing rate and stream inflow rates.

3.1.1.3 Shoreline and Watershed Erosion as it relates to Sediment Deposition Rates

A slow flushing rate allows sediments a longer time to settle and cause infilling. When the flushing rate is slow, nutrients may concentrate in the lake and not be “flushed” out. This may cause a decrease in water quality and an increase in growth of algae and aquatic plants, if the ratio of suspended sediment to nutrient rich organic matter is low.

Activities including agriculture practices, horticulture and gardening, and forest harvesting may have a destabilizing effect on the soils making them more susceptible to erosion during overland runoff of precipitation. Overland runoff which passes over areas of new development and recent cultivation, may be high in suspended solids and therefore contribute to an increased rate of sedimentation in the lake.

Healthy growth of riparian vegetation can help to prevent shoreline erosion due to mechanical wave action (e.g. boat wakes) and slows down overland runoff by absorbing some of the runoff and the nutrients that the runoff carries.

Backfilling and erosion of the shoreline can cause increases in suspended solids and sedimentation rates. Increased total suspended solids in the water leads to decreased water quality and therefore decreased fish habitat quality. Excretion of wastes by waterfowl (loons, geese, ducks) can cause a significant decrease in water quality and potability through an increase in nutrients and fecal pathogens.

Inflowing streams often carry a high level of nutrients and suspended solids when the rate of flow is high (e.g. during the spring melt) due to mechanical erosion of stream beds and initial flushing of animal waste deposited throughout the winter.

3.1.1.4 Pristine Water Source

An increased inflow of pristine water low in nutrients may mean an increased flushing rate which may improve the aesthetic and chemical qualities of the lake.

Algal blooms cause a decrease in water potability and fewer people use the lake as a recreational area for camping, swimming and water-skiing. Algal blooms usually cause a decrease in water clarity and an increase in smell, causing decreased aesthetic quality. An increased flow of water low in nutrients can lead to a decrease in algal bloom frequency and duration.

Groundwater or overland runoff which runs into the lake may pick up contaminants from leaking septic systems or gardens (e.g. insecticides, fertilizers) which may cause decreased quality of the water for contact, recreation and consumption. Septic system inputs may carry poisonous or dangerous household products which could alter water quality with respect to human contact and consumption, rendering it unacceptable.

3.1.2 Biological - Chemical System

3.1.2.1 Resources at Risk

Sport fishing and recreational uses of the lake are extremely important to user groups. The lake is stocked annually with Rainbow trout since 1990, by BC Environment Fish and Wildlife Branch. Other fish species which exist in the lake include ling cod, peamouth chubb, northern squawfish, longnose sucker, and burbot (S. Hatlevik, pers. comm., 1995). The lake is also home to a species of fish that was identified in 1965 by McCart, the Giant Pygmy Whitefish. This species is found only in one other lake in British Columbia, McLeese Lake, and is therefore on the rare and endangered species list. However, there is the possibility that the species in Tyhee Lake is a large size race of Pygmy Whitefish and confirmation of the rare and endangered status of the species requires genetic analysis.

Wildlife at Tyhee Lake includes moose, deer, black bear, otter, muskrat and beaver (T. Smith, pers. comm., 1995). A variety of eagles, hawks and owls are also a part of the lake ecosystem. Loons, Canada geese, mallards, golden eye, mergansers, grebes and teal nest and live at Tyhee Lake (G. Schultz, pers. comm., 1995). Many other species of waterfowl, especially Sandhill Cranes, use Tyhee Lake for staging in the fall as they are flying South .

Each of these species is a part of the intricate food web that exists at Tyhee Lake. If eutrophication of Tyhee Lake continues at its present rate, disruption of the natural balancing forces which maintains the aquatic ecosystem in its present form will occur and it is possible that some species will not be able to meet their life cycle requirements in the lake.

In addition to aquatic and terrestrial wildlife resources present, Tyhee Lake is a source of drinking water for residents and park users. It is also a popular recreation area with high swimming and boating activity levels. These uses are also dependant on water quality being maintained within limits as defined by water quality or objectives (water quality objectives). These are outlined in chapter 8.

3.1.2.2 Food Web Approach

Each species that lives in or around the lake is a part of the ecosystem. The species depend on one another for food and habitat requirements. As a lake eutrophies, some species are no longer able to survive and will become extinct from the lake ecosystem. When this occurs, it triggers a chain reaction and other species will become extinct which relied on the original species for food and habitat requirements. The lake biota is represented in Figure 3 as a food web. Like any web, when too many threads are cut, it will collapse.

3.1.2.3 Physical Habitat

The lake has three distinct and interacting biotic communities. These include the wetland-littoral zone and its sediments, the open water pelagic zone and the benthic (deep water) zone and sediments (Cooke *et al*., 1993). The three communities are interacting and any symptoms of eutrophication in one zone will affect the other two zones as well. All three zones provide reproductive, feeding, resting and escape habitat for different species of aquatic and terrestrial wildlife. Through eutrophication, the ecosystem is altered and as a result the populations and species of wildlife will change.

New development may destroy shoreline vegetation and wetland areas, thereby destroying habitat for waterfowl. Riparian vegetation is an essential part of waterfowl habitat which is often altered or destroyed by gardening, landscaping and creating views of the lake. Removal of riparian vegetation can also lead to increased shoreline erosion thereby altering feeding, escape and reproductive habitat for fish, waterfowl, and invertebrates.

Wetland areas with emergent macrophytes are vital to fish life cycle requirements as they provide food and refuge areas.

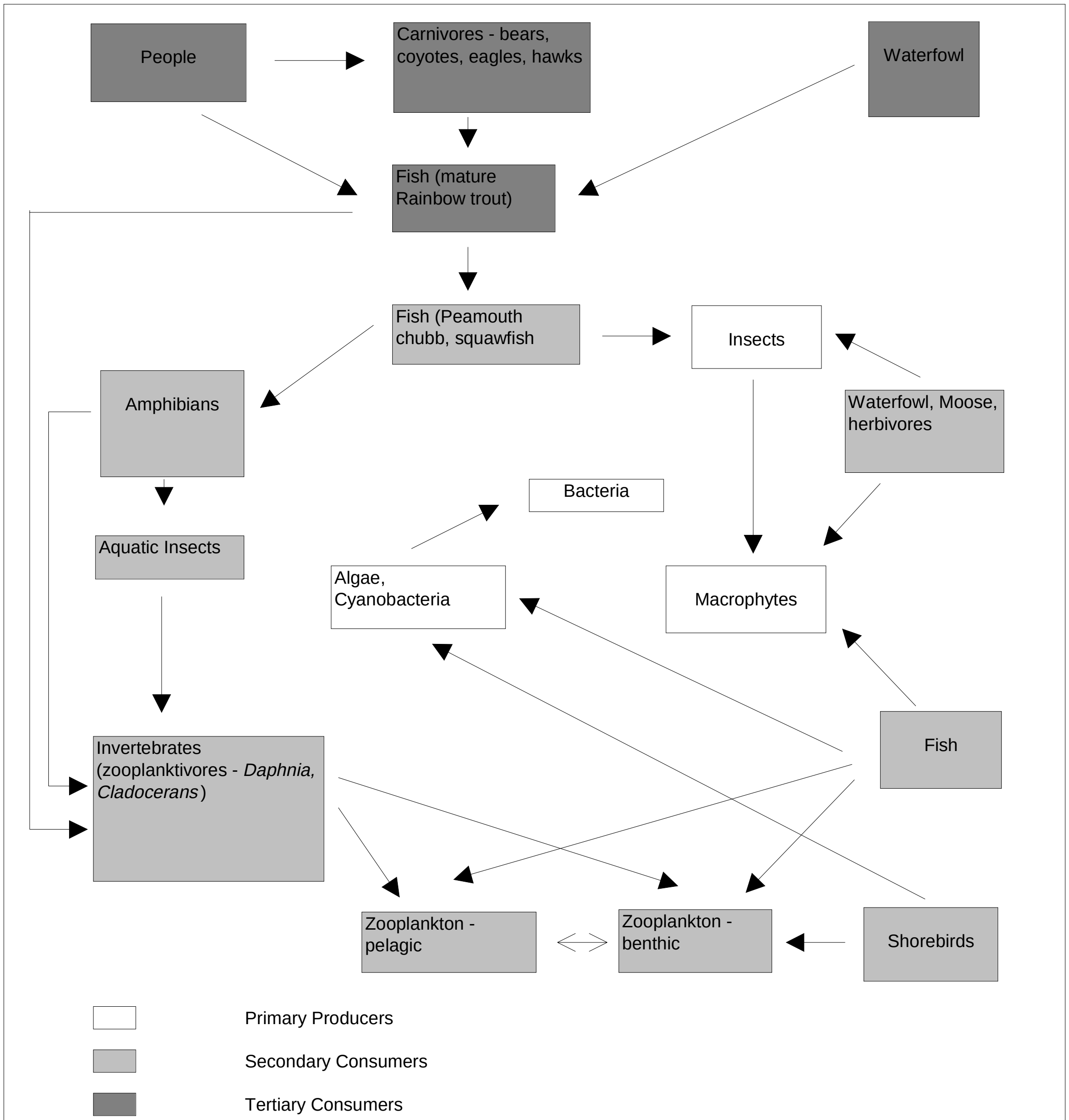


Figure 3: Diagram of the Food Web Approach to the Organization of the Lake Biota

3.1.2.4 Sources of Phosphorus - What makes it available or not?

Poor quality stream inflow, slow flushing rate and incomplete turnover can all lead to increased available phosphorus within the lake system which in turn leads to an increase in productivity. Improper sewage disposal, overland runoff from agriculture, dairy and horse farms, and cultivation are land uses likely to result in high phosphorus loading to the lake. An increase in the concentration of phosphorus in the lake may lead to increased algal bloom frequency and duration and excessive growth of aquatic plants.

Shoreline vegetation plays an important role in absorbing nutrients such as phosphorus from the water table which may carry septic field seepage.

3.1.2.5 Phosphorus Concentrating Factors

Phosphorus is concentrated in sediments, hypolimnetic water, plant organic matter and other organisms. Removal or reduction of one of the phosphorus concentrating factors could lead to a significant decrease in phosphorus concentration in the lake.

A low flushing rate causes nutrients to concentrate in the lake rather than being diluted and flushed out. Boat wakes, wind, and other mixing can cause disturbance of the bottom sediments which allows phosphorus to be liberated into the water column.

3.1.2.6 Ecological Consequences of High Phosphorus - Nutrient Cycles

Resuspension of sediments can increase the concentrations of bioavailable nutrients, leading to algal blooms. When the algae die and decompose, the biochemical reactions require oxygen which leads to a decrease in dissolved oxygen levels. If the decrease in dissolved oxygen levels in the lake is significant, it could lead to a decrease in fish populations. There is also a significant increase in available phosphorus when algae die off and decompose. Decaying organic matter resulting from algal blooms contributes to sediment buildup which becomes a phosphorus reservoir for later release.

As part of the food web, macrophytes, algae, and fish play a role in nutrient cycling of phosphorus. Lake aesthetic values decrease as nutrients increase, additional nutrients promote increased biomass of algae and macrophytes. As eutrophication of the lake progresses, species diversity decreases, while populations of some eutrophication tolerant species increase.

3.1.2.7 Dissolved Oxygen and the Biochemical Oxygen Demand

Decomposing organic matter has a high biochemical demand for oxygen. Therefore, once a pelagic algae bloom begins to decay, a risk to fish populations occurs as there is an immediate decline in the available dissolved oxygen. This risk is heightened under ice cover.

Flushing rate and mixing (by wind or turnover) are also key factors in determining the levels of dissolved oxygen available. An increase in either mixing or flushing rate should lead to an increase in dissolved oxygen levels.

3.1.2.8 Other Chemicals - Nitrogen, Hydrogen Sulfide, algal toxins etc.

An algal bloom leads to a decrease in water quality with respect to criteria for recreation and contact. Blooms of cyanobacteria can lead to a decrease in drinking water quality. Cyanobacterial toxins can cause mortality of aquatic and terrestrial life and other animals that consuming contaminated lake water (e.g. livestock).

As mentioned in chapter 2.0, nitrogen is often the second limiting nutrient in lakes. If it occurs in excess through introduction into the aquatic ecosystem through land use (e.g. fertilization) then aquatic plant infestations may result if other nutrients are available.

A leaking septic tank or nonfunctional septic field may drain into the groundwater and carry nutrient rich water to the lake. This drainage may also be high in fecal pathogens. Fecal pathogens can be hazardous to the health of many species and decrease the water quality for human consumption and contact recreation.

Sewage disposal directly into the lake may contribute significantly to poor clarity and smell of the lake water.

3.1.3 Socioeconomic System

3.1.3.1 Range of Desired Outcomes of Varied User Groups

Each group of lake users has their own interests to protect. It is likely that residential users have the most at stake in terms of the lake. The value of their land, their quality of life and the water which they drink are all dependant on the state of the water in the lake. Excessive macrophyte and algae growth will lead to deterioration of the water quality for drinking and recreational purposes. Residential users maintain an interest in the viability of waterfowl populations and wish to see their population survival perpetuated in order to fulfill their vision of the lake.

Recreational users include water-skiers, swimmers, tourists, campers, beach users, anglers, and wildlife observers.   Anglers are interested in the maintenance of the fish habitat and sport fish populations such as Rainbow trout and Giant Pygmy Whitefish.

There are many factors involved in maintaining fish habitat including dissolved oxygen levels, macrophyte and algae growth, temperature of the water, and maintenance of thermal stratification of the lake. For all recreational users, high water quality and lake aesthetic quality are a top priority.

3.1.3.2 Potential Changes to Land Use

The effects of overland runoff on eutrophication of the lake depend on land use in the area. Agricultural land use with no runoff treatment will lead to increased nutrient loading to the lake and therefore an increased rate of eutrophication. Horse and dairy farming without management practices to regulate nutrient loading to the lake may contribute to decreased potability of the water and reduction in aesthetic qualities.

In the case of Tyhee Lake, there is a large dairy farm at the northeast end of the lake and a horse farm at the north and south ends. The dairy farmer has taken measures to control runoff by installing settling ponds, although an evaluation of their effectiveness has not been completed. High nutrient loading prior to installation of control works may have already caused increased eutrophication by increasing the nutrient reservoir in the sediments available for internal loading under anoxic conditions. It is important that before implementation of any in-lake restoration measures, external nutrient loading from land use is addressed and a plan for reduction implemented.

Through proper care taken by forest managers, upper reaches of the creeks should remain intact and unaltered to reduce erosion caused by overland runoff.

Roads and highways which cross over creeks require proper fish passage structures to minimize disruption of the habitat. New development of roads could affect fish populations if there is a negative impact on nearby creeks through restriction of access and sedimentation.

Residential land uses include horticulture, gardening and creation of beaches. This development can reduce the area of riparian vegetation which reduces the amount of absorption of nutrients in overland runoff.

3.1.3.3 Financial & Institutional Resources Available

Skeena Region of BC Environment is currently developing a volunteer program for monitoring loon populations at Tyhee Lake.

Two applications for project funding were submitted to the Habitat Conservation Fund in October, 1994. One project involves rehabilitation of Hidber Creek for Rainbow trout spawning. The second project requires funding to support a graduate student through the University of Northern British Columbia to study the Giant Pygmy Whitefish, including genetic studies to determine whether it is a rare and endangered species or if it is a well-fed Pygmy whitefish. If the funding for the Giant Pygmy Whitefish project is not granted by the Habitat Conservation Fund, it is possible that a research institution may be interested in funding and carrying out the study.

A grant was obtained by the Tyhee Lake Protection Society in partnership with the Telkwa Elementary School to establish a lake management science and awareness program in the school. The goal of the program is to increase community awareness about lake management science.

The Volunteer Lake Stewardship Program is a new government initiative which will provide some funding, technical support through the Ministry, monitoring assistance and establish a user group support network which will produce educational materials and provide guidance. The Protection Society has qualified for an initial grant of seventy-five hundred dollars ($7,500) and will have an opportunity to apply for ongoing funding.

Other private initiatives for raising funds include protection society membership dues, fundraising events, and donor campaigns.

3.1.3.4 Regulatory Requirements

As illustrated in Table 2, many of the lake components are protected by federal, provincial, regional district or municipal legislation.

3.1.3.5 Major Risks Associated with Lake Management

There is a possibility that the beaver dam at the outlet may one day collapse and the outlet will then be lowered, allowing a huge outpour of water which would likely wash out Highway 16 and downstream private property.

<u>Table 2</u>: Regulatory Requirements for Specific Lake Components

Component	Legislation	Regulatory Agency
agriculture land use		Agriculture Canada
beavers	Water Act	BC Environment, Water Management
boat launch		BC Parks
fish	Fish and Wildlife Act	BC Environment, Fish and Wildlife
wildlife	Fish and Wildlife Act	BC Environment, Fish and Wildlife
park use		BC Parks
power boats	Navigable Waters Act	Canada Coast Guard
residential subdivision development and land use (forestry, agriculture)	Official Community Plan, Zoning Bylaws	BC Transportation and Highways Regional District of Bulkley Nechako
riparian vegetation	Fisheries Act	Department of Fisheries and Oceans
septic systems	Health Act	Ministry of Health BC Environment, Environmental Protection Program
waterfowl	Migratory Game Bird Act	CWS

4. Watershed & Limnological Background Information

This section of the lake management plan includes a description of the area, including maps and morphometric-hydrologic data, and an accurate summary of all measurement methods and sampling locations.

4.1 Watershed

Tyhee Lake is located south-east of Smithers in Northern British Columbia (map sheet 93L) as illustrated in Figure 4 . The lake is within the Smithers-Telkwa Official Community Plan area.

Figure 4: Location of Kathlyn, Seymour, Round and Tyhee Lakes

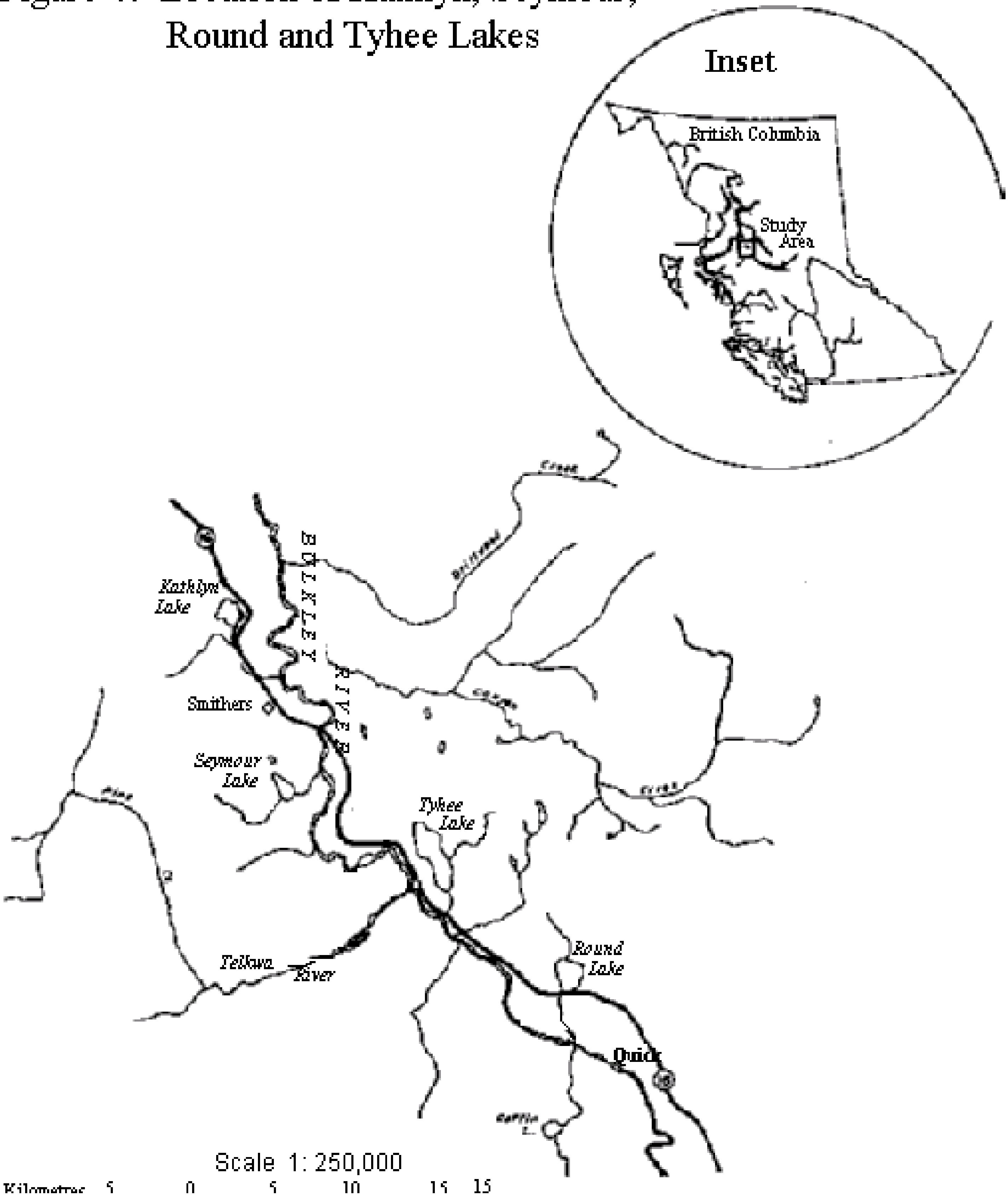


Figure 5: Tyhee Lake Catchment Basin Map

Scale: 1:58000

1 0 1 Kilometers

Tyhee Lake Basin

Basin Area = 3500 Ha
Lake Area = 367 Ha

Countor Interval 20 m

X Deep station sampling site

BC Min. Env. Lands, Parks
Skeena Region
April 30, 1999

British Columbia

Tyhee Lake is in the Skeena watershed and the catchment basin is outlined in Figure 5 (Skeena GIS, 1995). The approximate size of the catchment basin is 35 km^2 (3500 ha). The catchment basin is determined by the physical height of the land and the boundary outlines the area within which all water flows towards the lake.

4.1.1 Land Use Activities

Land use activities in the Tyhee Lake Catchment Basin include:

- agriculture -livestock (dairy and horse farming)
  -cultivation/harvesting
- residential
- provincial park
- forested areas
- institutional camps (e.g. Camp Caledonia)

The percentage of land used for each of these activities can be roughly estimated using aerial photographs.

4.1.2 Zoning

Zoning of the land is determined by the Bulkley Nechako Regional District as a part of the Official Community Plan. The types of land use activities which are taking place in the watershed are restricted by the zoning by-laws. As determined by the Official Community Plan, the catchment basin includes land zoned as follows:

- Rural Resource ~22% (8/36)
- Rural Agricultural ~74% (26.5/36)
- Parks & Recreation ~2% (.5/36)
- Indian Reserve ~3% (1/36)

4.1.3 Water Sources (tributaries, groundwater)

Sources of water inflow into the lake include groundwater, creeks, precipitation, and overland runoff (water flowing over the ground following a precipitation event or spring melt). During spring melt, the creeks are at high flow and by the time the summer season arrives, most of the creeks have dried up. Table 3 lists the sampling sites, their description and their site number and Figure 6 shows the sites on the map.

<u>Table 3</u>: Sampling Sites within the Tyhee Lake Watershed

Station Type	Description	Site Number	Other Information
Deep Station Sampling Site	South East Basin	E216924	
Deep Station Sampling Site	North West Basin	Nosite NW Basin	
Creek/culvert	Seaplane Base Creek	E219760	weir/staff gauge
Creek/culvert	Fox Creek	E219761	
Culvert	Below Horse Camp	Nosite Below Horse Camp	
Creek/culvert	Horse Camp	E219762	
Creek/culvert	Yakisda Bik'a Camp	E219763	
Creek/culvert	Howard's Creek	E219764	
Culvert	Fisher Rd. Creek	E219765	
Culvert	Hoek's Creek	E219766	
Culvert	Vanhorn's Creek	Nosite Vanhorn's ck	
Culvert	Hidber Subdivision Creek	Nosite Hidber Subdiv.	
Creek/culvert	Hidber Road Creek	E219767	weir/staff gauge
Culvert	Koopman's #1	E219768	
Culvert	Koopman's #2	E219769	
Culvert	Pole 55 Creek	Nosite Pole 55	
Culvert	Pole 52 Creek	Nosite Pole 52	
Culvert	Pole 51 Creek	Nosite Pole 51	
Culvert	Pole 50 Creek	Nosite Pole 50	
Culvert	Penner Rd. Creek - Pole 47	Nosite Pole 47	
Culvert	Pole 45 Creek	Nosite Pole 45	
Culvert	Pole 44 Creek	Nosite Pole 44	
Creek/Culvert	Victor Creek	E219770	weir/staff gauge
Culvert	Pole 39 Creek	Nosite Pole 39	
Culvert	Burger Creek	Nosite Burger's Ck	
Culvert	Koopman's #3	Nosite Koopman's #3	
Culvert	Pole 36 Creek	Nosite Pole 36	
Culvert	Pole 34 Creek	Nosite Pole 34	
Creek/culvert	Hislop Rd. Creek	E219771	
Culvert	Pole 29 Creek	Nosite Pole 29	
Culvert	Pole 26 Creek	Nosite Pole 26	
Culvert	Pole 22 Creek	Nosite Pole 22	
Culvert	Pole 20 Creek	Nosite Pole 20	
Culvert	Pole 19 Creek	Nosite Pole 19	
Culvert	Pole 15 Creek	Nosite Pole 15	
Culvert	Pole 14 Creek	Nosite Pole 14	
Culvert	Pole 13 Creek	Nosite Pole 13	
Outlet	Tyhee Creek	Nosite Tyhee Lake Outlet	staff gauge

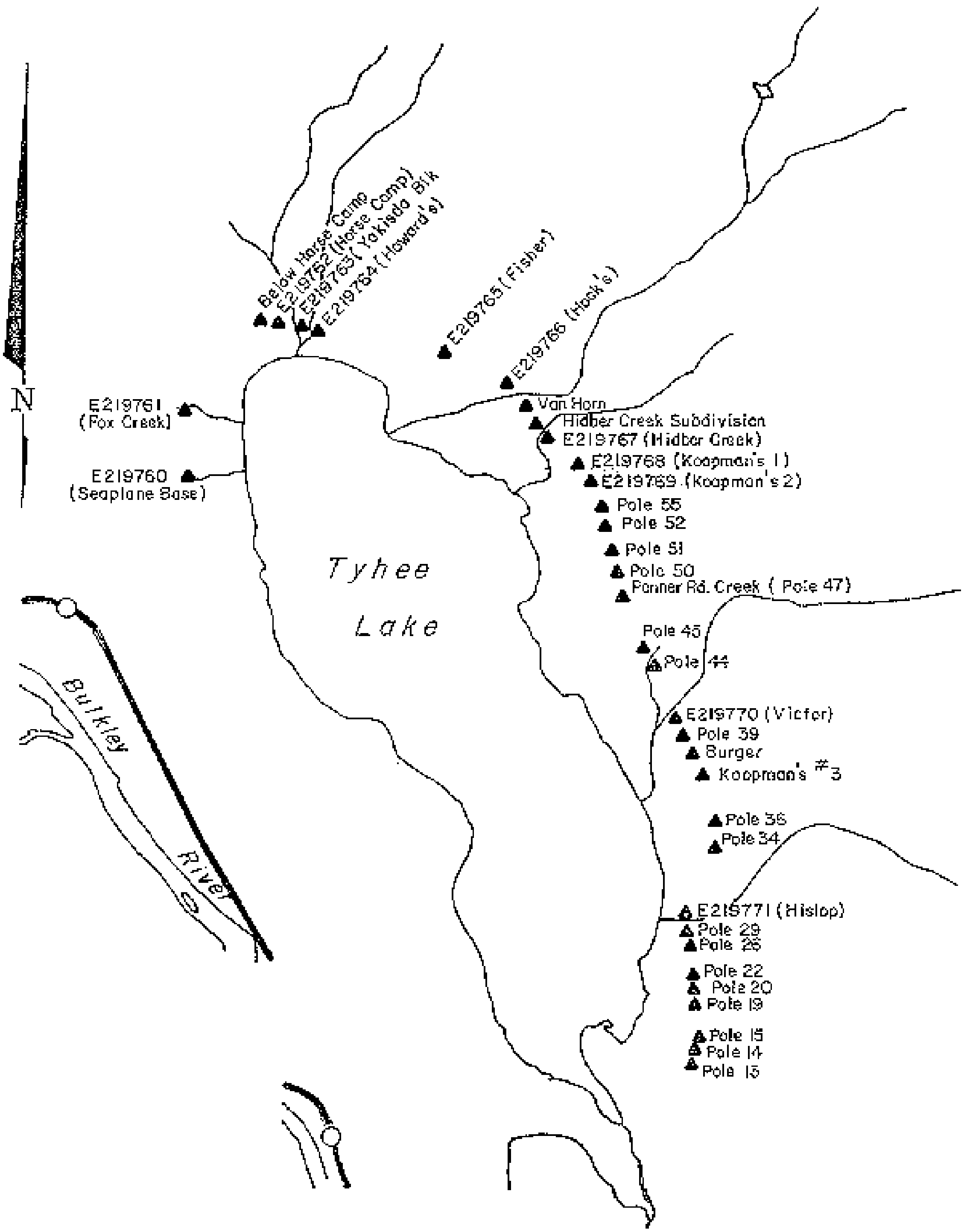


FIGURE 6 Tyhee Lake Water Quality Monitoring Site Map

4.2 Limnological Characteristics

4.2.1 Morphometric Data

Tyhee lake is the largest of five lakes in the Smithers/Telkwa area with a surface area of 318 hectares (ha) and a volume of approximately 36,000 cubic decametres (dam^3). Table 4 summarizes the morphometric data for Tyhee Lake as described by Ian Boyd *et al*.,(1984).

The littoral area of the lake can be calculated on a contour map. Assuming that any area which has a depth of less than 5 metres is littoral zone, the area is roughly 20 - 30% of the total surface area.

Figure 7 illustrates the bathymetry of Tyhee lake (Boyd*et al*., 1984).

Table 4: Summary of Morphometric Data (Boyd, 1984)

Attribute		**Value**	**Units**
Elevation		549	metres (m)
Surface area		318	hectares (ha)
Volume		35,278	cubic decametres (dam^3)
Mean Depth		11.1	m
Littoral Area (<5m)		20-30	percentage of lake surface area (%)
Maximum Depth		22.2	m
Perimeter		9,754	m
Water Retention time	Max.	16.6	years (yr)
	Min.	2.94	yr
	Mean	5	yr
Flushing Rate	Max.	0.3	1/years (yr^{-1})
	Min.	0.06	yr^{-1}
	Mean	0.2	yr^{-1}

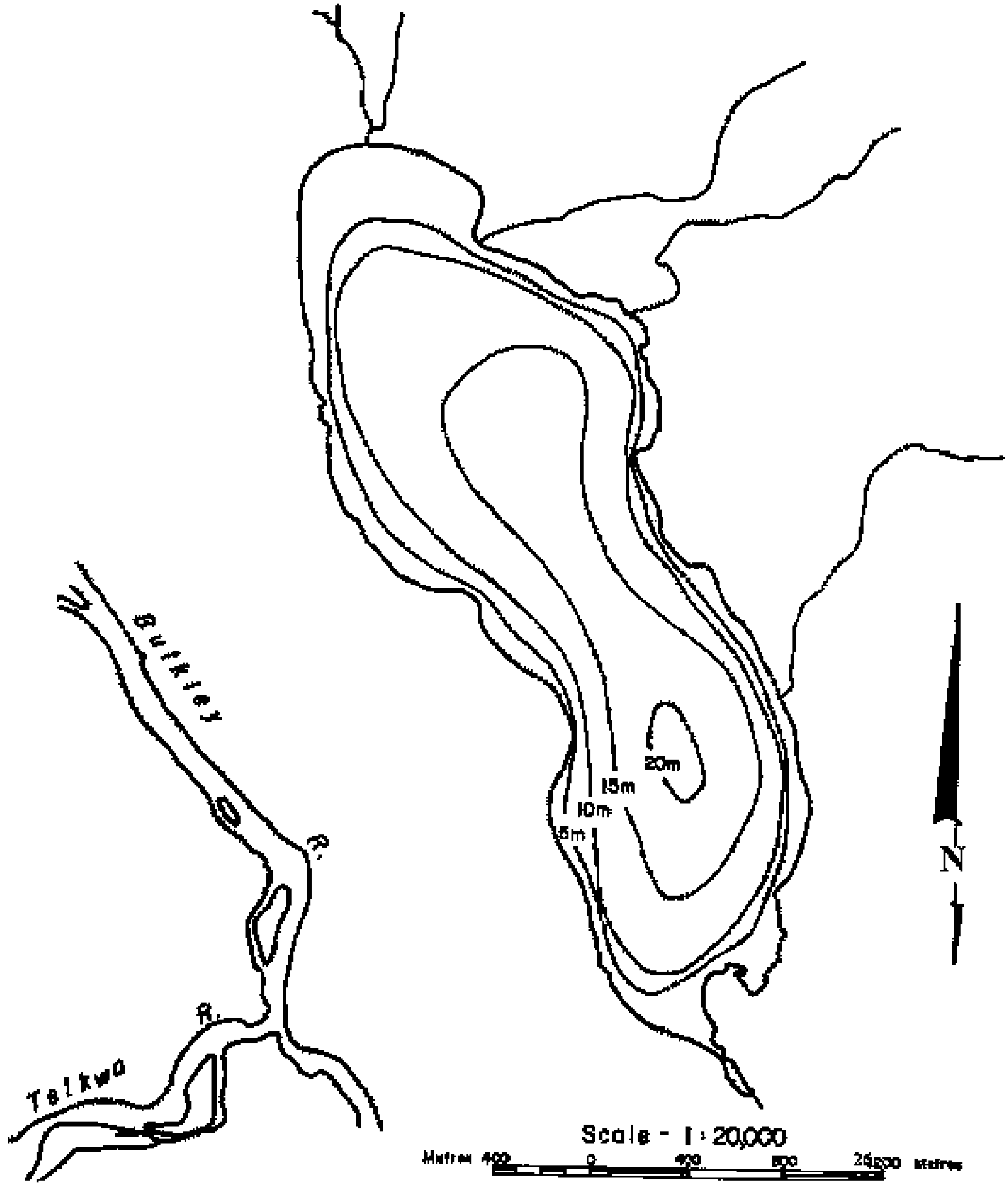
4.2.2 Physical/Chemical Water Quality Characteristics

4.2.2.1 Transparency

The transparency of the lake is related to the density of algal and total suspended solids. The more transparent the lake, the more light will penetrate to deeper depths and as a result there will be potentially higher growth rates of aquatic plants, if nutrients are available (Cooke *et al*., 1993). Transparency can be an indicator of the trophic status of a lake (Michaud, 1991) but it is a difficult parameter to set objectives for. The black and white Secchi disk is lowered into the water with a rope until it is no longer visible, at which point the depth is recorded.

Through the Water Quality Objectives Monitoring Program for Smithers lakes, the colour of Tyhee Lake has been monitored and has met the objective 98% of the time from 1987 to 1993.

Figure 7: Bathymetry of Tyhee Lake



4.2.2.2 Temperature Profile

Tyhee Lake is dimictic. Turnover occurs twice a year, once in the spring and once in the fall, however, the turnover is not always complete (Portman, 1992).

The lake turnover is complete if the water column is isothermal (uniform temperature and density at all depths). At the deepest point in the lake (shown in Figure 5 - catchment basin), temperature measurements are taken at different depths. If the temperatures at each depth are different, then the lake is said to be thermally stratified.

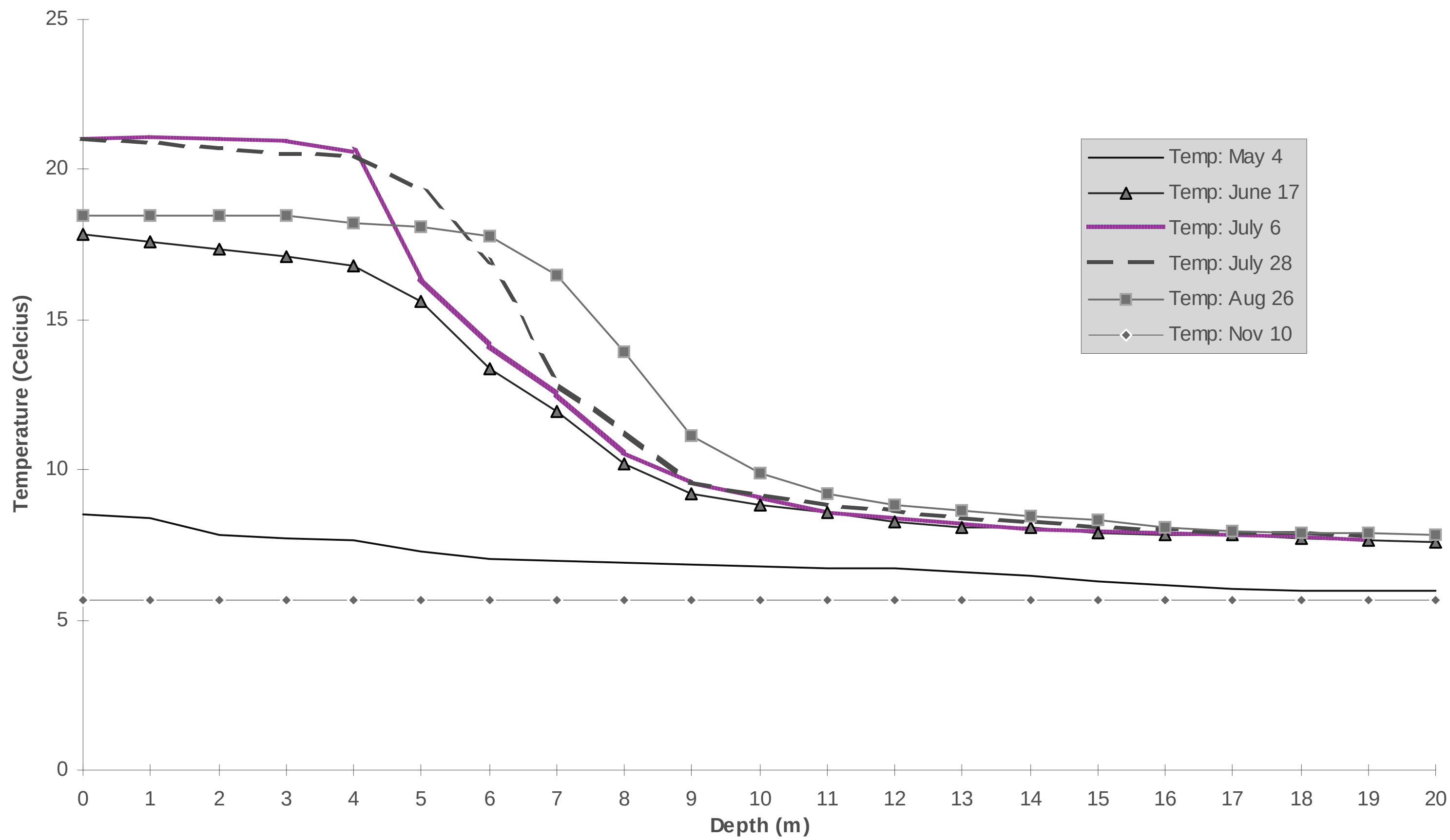
From sampling done in 1992, the temperature profile shows that the lake was isothermal on May 4. Prior to May 4, the lake was stratified. Following May 4, the sun warmed the upper layers of the lake water, causing the lake to slowly regain thermal stratification. With the onset of cooler temperatures in the fall season, by November 10, the lake was once again isothermal. The temperature profile is illustrated in Figure 8 (Portman, 1992).

4.2.2.3 Dissolved Oxygen Profile

Oxygen is essential for life in the lake. Cold water holds more oxygen than warm water, so as the temperature of water increases, oxygen is released (Cooke *et al*., 1993). Renewal of dissolved oxygen levels occurs through exchange at the surface waters, wind mixing the epilimnion, photosynthesis and inflow of high oxygen water into the lake. Dissolved oxygen levels in the lake are strongly correlated to the thermal profile. During spring and fall turnover of the lake, the water becomes isothermal and the lake destratifies. Loss of the thermal layering in the lake, allows oxygenated surface waters to mix with depleted deeper layers. In this way, the water in the lake becomes replenished with dissolved oxygen. Figure 9 illustrates the relationship between temperature and dissolved oxygen.

If the water at the sediment-water interface is anoxic, phosphorus may be released from the sediments and into the water column. If the water at the interface is oxygenated, phosphorus is trapped in the sediments. Another cyclic relationship exists between algal growth, dissolved oxygen levels and phosphorus concentrations in the water. After turnover, the dissolved oxygen levels in the lake are high. Algal blooms occur leading to two effects; one is that the photosynthesis gives off oxygen, the second is that the algae will die, and the decomposition of the organic matter increases the chemical oxygen demand. In addition, at night, plants and algae respire which depletes the dissolved oxygen levels (Cooke *et al*., 1993). Overall, biochemical and chemical oxygen demand is greater than the oxygen replenishment. Depletion of dissolved oxygen allows phosphorus release from the sediments into the water column. An increase in phosphorus concentrations leads to increased algal growth and the cycle continues until the anoxic water is replenished with oxygen.

Figure 8: Temperature Profile for Tyhee Lake, May to November 1992 (Portman, 1992)



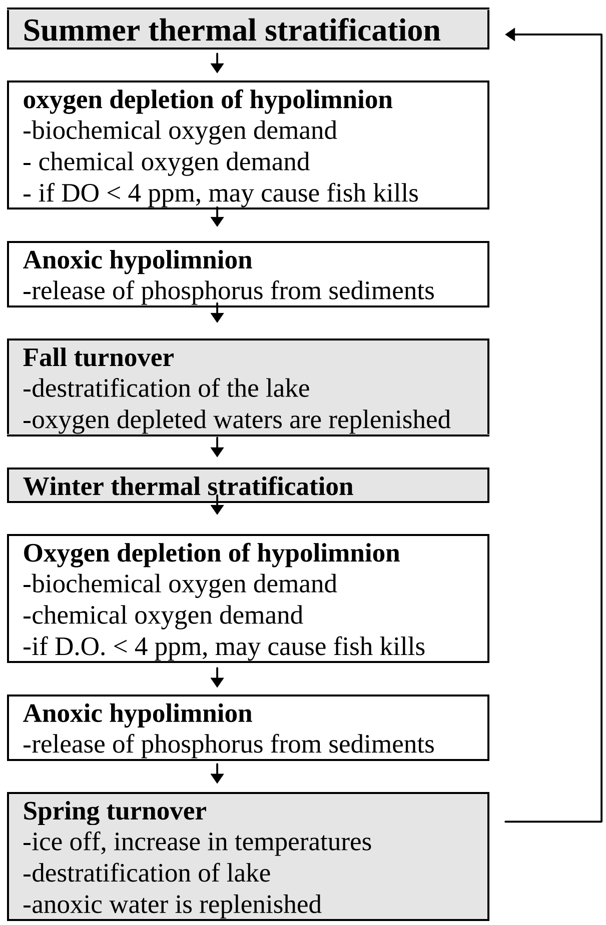
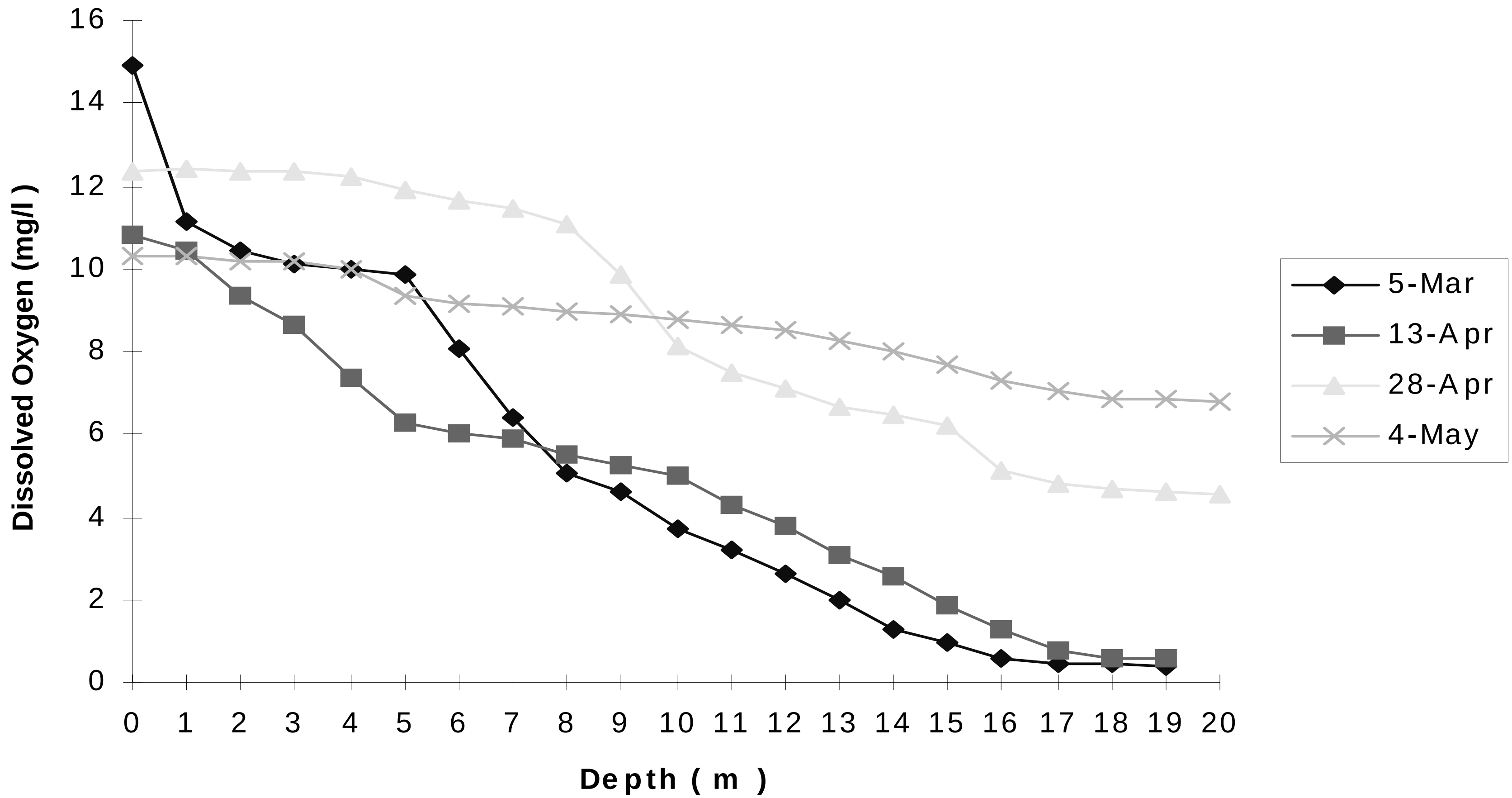


Figure 9: Diagram of the Relationship between Dissolved Oxygen Levels and Temperature Profile of a Dimictic Lake.

In Tyhee Lake, the depth and size are important factors in turnover. Wind plays an important role in assisting the mixing of the lake at turnover. Figure 10 illustrates the dissolved oxygen profile of the lake in the spring (Portman, 1992). From Figure 10, it was determined that the turnover date for 1992 was May 4. Prior to turnover, the deepest 2 meters of water are completely anoxic (Portman, 1992). It is apparent that as the lake approached turnover, dissolved oxygen levels increased in the deep waters, however, the increase was minor suggesting that turnover may not be complete (Portman, 1992). If anoxic conditions at depth are not completely replenished at turnover, during the summer stratification, the hypolimnion dissolved oxygen depletion occurs much more rapidly, allowing a longer time period for anoxic conditions to persist. Anoxic conditions at the sediment-water interface allows for phosphorus transport from the sediments into the water column, which may lead to more severe algal problems.

<u>Figure 10</u> Dissolved Oxygen for Tyhee Lake, 1992 (Portman, 1992)



4.2.2.4 Alkalinity

In 1982, Boyd *et al*. determined the alkalinity of Tyhee Lake to be 140 mg/L (Boyd *et al*., 1984). The lakes buffering capacity is a measure of it's ability to neutralize acid and thereby, resist changes in pH. Tyhee Lake has a fairly low sensitivity to acid precipitation due to a relatively high alkalinity (Boyd *et al*., 1984).

When considering alkalinity as a long term monitoring tool, the water quality standard should be "no measurable change from its natural conditions" (Michaud, 1991).

4.2.2.5 Nutrients - Phosphorus and Nitrogen

Nitrogen and phosphorus are usually the two limiting nutrients in freshwater systems. Before a lake management action plan can be identified, it is important to determine which is the limiting nutrient in the lake or if the nutrients are co-limiting (as discussed in Section 2.1). In Tyhee Lake, the weight ratios of nitrogen to phosphorus were reviewed in 1982 as illustrated in Table 5. If the weight ratio of total nitrogen to total phosphorus in the lake is greater than or equal to 15:1, the plankton growth is limited by the availability of phosphorus and if the weight ratio is less than or equal to 5:1, the plankton growth is limited by nitrogen (Boyd *et al*.,1984). The data illustrates that the ratio of total nitrogen to total phosphorus is consistently greater than 15:1, indicating that plankton growth in Tyhee Lake is limited by phosphorus (Boyd *et al*., 1984).

Table 5: Summary of Total Nitrogen : Total Phosphorus Weight Ratios for Lake Water in 1982 (Boyd et al, 1982).

Date	Nitrogen : Phosphorus Ratio
1982/01/25	23:1
1982/05/14	29:1
1982/06/09	21:1
1982/07/21	33:1
1982/09/08	52:1
1982/10/20	35:1

The water quality of Tyhee Lake was reviewed by Boyd *et al*. in 1984. It was suggested to maintain good lake water quality that the total phosphorus concentration at spring overturn should not exceed 0.015mg/L. This objective applies to the average of three samples taken 1 metre below the surface, at mid depth and 1 metre above the bottom at the deep station sampling site.

Diagnosis of a lake's specific eutrophication problems begins with construction of an accurate water budget. Water quality of the lake reflects cumulative effects of nutrients which originally entered from inflowing water (Cooke *et al*., 1993). Before a lake management action plan can be identified, a nutrient budget and at least one year of lake data is necessary. Following identification of the limiting nutrient or nutrients in the lake, it must be determined whether the majority of the nutrient loading to the lake is coming from internal or external sources (Cooke *et al*., 1993). Internal sources include nutrient recycling, groundwater and sediments whereas external sources can be grouped into point sources such as septic systems and creeks and non-point (diffuse) sources such as overland runoff. A decrease in the rate of eutrophication of a lake may be observed following a reduction in amount of the limiting nutrient entering the lake. If the major load is coming from point sources, then external lake management measures, such as public education, control and treatment of agricultural and urban stormwater runoff may be the best options to consider. However, if the major load of the limiting nutrient is coming from internal nutrient recycling, then in-lake restoration measures must be seriously considered in addition to external nutrient source control.

Mathematical models provide an easy and relatively accurate approach to the construction of a nutrient budget. The Reckhow and Simpson input/output (black box) empirical model is the most practical model considering limited sampling funds (Reckhow and Simpson, 1980). The model accounts for phosphorus loading to the lake as a result of climate, watershed characteristics and human activities. The input is modified by environmental factors and yields an output: the lake's average phosphorus concentration. Prediction from a model is inherently uncertain. However, with quantification of the prediction uncertainty, the model can be used with the quantified prediction uncertainty used as a weight indicating the value of the information contained in the prediction (Reckhow and Simpson, 1980). There are two ways to approach the model; with quantitative data or with qualitative data. A quantitative set of data would be comprised of monitoring data over an entire season (freshet) from a select percentage of input sources. The total input to the lake would then be estimated and the average phosphorus load would be calculated. A qualitative set of data would be comprised of a few sampling "blitzes". In other words, a couple of days within the freshet period were chosen and only on those days sampling occurred. However, every available source was sampled (creeks, ditches, outlet etc.) during that sampling exercise.

The Reckhow and Simpson model does not require any sampling for the estimation of external phosphorus loading. The general idea is to divide the watershed catchment basin into smaller areas based on land use, including residential (urban), forest harvesting and agricultural. The percentage of the total area of the catchment basin is multiplied by a predetermined phosphorus export coefficient to determine the phosphorus loading to the lake (Reckhow and Simpson, 1980) for that particular land use. When selecting a phosphorus export coefficient, the lake management planner or hydrologist must select the most appropriate coefficient from the high, mid, and low choices. The coefficient represents the expected annual amount of phosphorus transported into the lake per unit source (for example, per square meter). The external loading is subtracted from the phosphorus concentration in the lake and the difference is concluded to be due to internal loading. This method has a very high error associated with it and only provides a very rough estimate of the nutrient budget.

Although this method is thought to be sufficient for estimating total phosphorus loading, it is advantageous to work into the equation some "real" sampling data from the creeks and external sources to reduce the error associated with the model.

Phosphorus is the growth limiting nutrient in Tyhee Lake (Boyd *et al*., 1984). In 1994, a sampling program was put in place to determine whether the majority of the phosphorus load was coming from external sources or from internal nutrient recycling. Paul Marquis, the water management hydrologist, calculated the phosphorus budget using a modified Reckhow and Simpson model supplemented with real sampling data. The results are shown in Table 6.

<u>Table 6</u>: Phosphorus Balance using the Reckhow Equation (P. Marquis, pers. comm., 1995)

Variable	Quantity	Units	Definition
Q (inflow water volume)	6,000,000	m^3/yr	
A (lake surface area)	3,180,000	m^2	
M (total mass loading)	250	kg	
qs (areal water loading)	1.887	m/yr	Q/A
L (phosphorus loading)	0.079	g/m^2 yr	
P (phosphorus concentration)	0.006	mg/L	

Using the data that was obtained from 1994 freshet sampling, the lake's average phosphorus concentration (P) was calculated to be 0.006 mg/L. This translates into 210 kg of phosphorus loading to the lake annually. The total mass loading of phosphorus (M) to the lake in a year was calculated to be 250kg. Internal loading divided by total mass loading shows that external loading is responsible for only 16% of the total phosphorus to the lake each year. This suggests that internal loading of phosphorus is responsible for 84% of the phosphorus concentration in the lake.

In order to justify the use of in lake restoration measures in the lake management plan, it is suggested that the internal recycling must comprise more than 55% of the total loading (K. Ashley, pers. comm., 1994). Therefore, if the internal loading is calculated to comprise 84% of total loading, the error associated with the prediction model for Tyhee Lake must be less than 29%. Using the data available to us from 1994, the error associated with the model is much higher than 29%. In order to decrease the amount of error associated with the model, it was necessary to do some additional sampling. The most cost efficient way to approach the additional sampling was to increase the quality of the data by carrying out two or three extensive sampling exercises during the 1995 spring freshet. One the sampling exercise at the onset of freshet, one during mid-freshet and one near the end of freshet.

Collection of the additional data was estimated to cost $4,000 lab dollars and sampling was completed by volunteer members of the Tyhee Lake Protection Society and the Telkwa Elementary School.

4.3 Biological Characteristics

4.3.1 Aquatic Plants and Algae

Algal biomass and species diversity are an indicator of trophic status in a lake. An eutrophic lake is usually characterized by high algal biomass and frequent algal blooms, which generally indicates a high level of available forms of nutrients in the water column. There are several types of aquatic plants, submerged plants, emergent plants, rooted plants and mobile (non-rooted) plants. Rooted plants are dependent on available nutrients in the sediments, whereas floating plants are dependent on levels of available nutrients in the water column.

In 1977, Dr. Pat Warrington conducted an aquatic plant survey on Tyhee Lake. Then in 1992, samples were collected from Tyhee Lake and analyzed by Dr. Warrington. It was found that there were extensive shallow water areas with dense beds of *Myriophyllum sibiricum* and *Potamogeton* spp. *Lemna minor*, *Lemna trisulca, Spirodela polyrhiza*, *Wolffia columbiana* and *Ceratophyllum demersum* were abundant. None of the previously listed plants are rooted plants and therefore must obtain nutrients from the water column. The presence of these species indicates that there are high levels of available nutrients in the water column.

It is interesting to note that *Elodea canadensis,* one of the most abundant aquatic plants in the lake in 1992, was not present in the lake in 1977 (Warrington, pers. comm., 1992). *Elodea canadensis* is characterized by maximum growth one year followed by a population crash the next and then a slow increase in the growth again (Warrington, pers. comm., 1992). *Elodea canadensis* is a nuisance plant in many lakes in British Columbia because it can rapidly cover the entire surface area of a lake and may block or clog the outlet causing an increase in the water level of the lake.

Table 7 summarized the dominant species of phytoplankton at different depths in Tyhee Lake and their corresponding concentrations.

4.3.2 Zooplankton

The dominant species of zooplankton present in Tyhee lake are summarized in Table 8. Zooplankton are an important part of the food web in a lake system because they feed on algae. The technique of reversing or controlling eutrophication in lakes through biomanipulation depends on zooplankton species to control algal biomass (Cooke *et al*., 1993). Zooplankton also serve as a food source for fish (Gibbons *et al*., 1994).

4.3.3 Fish

Rainbow trout (Blackwater variety) are stocked in Tyhee Lake each year by the Fish and Wildlife Branch, BC Environment. Other fish which have been identified in Tyhee Lake include peamouth chubb, northern squawfish, longnose sucker, cutthroat trout, burbot, prickly sculpin, ling cod and redside shiner.

Most importantly, the lake contains Giant Pygmy Whitefish which are found in only two British Columbia lakes, Tyhee Lake and McLeese Lake (McCart, 1965). Genetic analysis of the species is required to confirm whether or not the whitefish is in fact the Giant Pygmy Whitefish or a well fed Pygmy Whitefish.

<u>Table 7</u>: Concentrations of Dominant Phytoplankton at Three Depths in Tyhee Lake (Sampling Station E216924) in 1992 (Portman, 1992)

Date	Order	Species	#cells/mL at each depth		
			0 metres	3 metres	6 metres
92/04/13	Centrales	*Stephanodiscus astaea var. menutula*	2142	2820	10674
92/06/17	Chroococcales	*Anacystis delicatissima*	622	1913	5355
	Cryptomonodales	*Chroomonas acuta*	260	non-dominant	non-dominant
		Cryptomonus ovata	130	non-dominant	non-dominant
92/07/06	Chlorococcales	*Crucigenia rectangularis*	61.6	100.8	non-dominant
		Sphaerocystis schroeteri	89.6	non-dominant	136.8
	Cryptomonodales	*Chroomonas acuta*	57.4	243.6	285
	Tetrasprales	*Gloeocystis ampla*	33.6	89.6	non-dominant
92/07/28	Nostacales	*Anabaena flos-aquae*	2578	1012	93.5
	Chlorococcales	*Botryococcus braunii*	non-dominant	204	non-dominant
	Cryptomonodales	*Chroomonas acuta*	non-dominant	296	255
02/08/26	Cryptomonodales	*Chroomonas acuta*	134	285	251
	Nostacales	*Anabaena flos-aquae*	84	non-dominant	non-dominant
	Chroococcales	*Anacystis elachista*	392	non-dominant	1140
		Anacysta limneticus	89.6	non-dominant	274
	Chlorococcales	*Botryococcus braunii*	non-dominant	68.4	non-dominant

Table 8: **1992 Dominant Zooplankton Species in Tyhee Lake at Station E216924 (Portman, 1992)**

Date	Phylum	Order	Species	# organisms/total sample			
				Replicate 1		Replicate 2	
92/04/14		Cyclopoida	*Diacyclops bicuspidatus thomasi*	adult 13965	copepodite 5320	adult 8118	copepodite 4653
92/06/17		Cladocera	*Daphnia pulex*	25323		18550	
		Cyclopoida	*Diacyclops bicuspidatus thomasi*	adult 20687	copepodite 18548	adult 18725	copepodite 12250
	Rotifera	Ploima	*Kellicottia longispina*	10878		7700	
			Asplancha	22827		18725	

Terrestrial Wildlife and Waterfowl

There are two types of waterfowl at Tyhee Lake, those which use the lake as a home and those which use the lake as a rest stop when flying south for the winter or north for the summer. Waterfowl which nest at the lake include loons, ducks (mergansers, grebes, mallards, golden eye, and teal), and Canada geese (G. Schultz, pers. comm., 1995). Sandhill cranes are among those which use the lake for staging in the spring and fall .

Eagles, hawks, owls, moose, black bears, otters, coyote, fox, muskrat, beavers, and deer also depend on the lake as a part of their life cycle habitat requirements and are therefore a part of the lake biota (T. Smith, pers. comm., 1995).

4.4 The Common Loon of Tyhee Lake

4.4.1 Morphology

Loons are large birds inhabiting the lakes of North America. They are similar in size to a small goose, but have a larger wingspan, about four feet, and are generally heavier. They have been graced with strong legs situated at the back of their body to help with swimming. This complicates walking as their large body must balance from front to rear, giving them a characteristic awkward walk.

Loons need a long distance to take flight. It is not uncommon to see a loon taking off from one side of the lake and not get into the air for several hundred meters, leaving behind a large splash. Once in flight we can’t help but notice their grace and strength.

Loons possess an unequaled ability to navigate in the water. The placement of their feet at the back of their body lends itself to their diving and swimming ability. They are able to dive to great depth and can remain submerged for several minutes.
The body, wings, head, neck and beak are black. We can recognize loons by the white ring around their neck and by the fine white checkerboard patterned line over the wings.

4.4.2 Diet

The loon's diet is primarily fish, but they occasionally eat crustaceans, frogs, or vegetation. They generally hunt for food during the day, as they rely primarily on vision to locate and pursue their prey. They usually feed in clear, shallow waters.
They ordinarily consume small fish as they are usually abundant and easier to catch. Loons need a large quantity of fish to survive. It is estimated that more than 30 kilograms of fish are needed to feed a chick to its eleventh week. In addition, another 148 kg are needed to feed the parents. In total about 180 kg of fish are needed to support a family of two parents and one chick to adulthood. A second chick would bring this to 210 kg of fish. During the four weeks prior to the migratory period, the demand for food will be 40-50 % greater. The large amount of fish required to feed a family explains why we rarely find more than ten loon families around a medium sized lake. (Jewels in the Forest; Lakes of the Boreal Shield)

4.4.3 Habitat

Loons need large, clear lakes with an abundance of fish in order to survive. They make their nest in the riparian vegetation around the lake and sometimes right in the water on a floating island of grass anchored to the shore. The fact that the nests are so near the water explains why loons are perceptive to changes in water level, as a fluctuation of a few centimeters could flood the nest or make it inaccessible.

4.4.4 Life Cycle

Immediately after the ice in the lake thaws the loons arrive from the south or from coastal water retreats in pairs. Usually they return to the lake they inhabited in prior years. Once they arrive they start building their nest. Generally the couple will nest in the same location as previous years, provided the location is still suitable. In June, after mating, the eggs are laid, usually two. The parents incubate the eggs for 26 to 31 days after which they will hatch provided no predators have visited the nest. Around the end of June, the chicks will be able to leave the nest on the backs of their parents. This permits them to conserve heat and provides protection from predators such as carnivorous fish, turtles, eagles, crows and gulls. They don't return to the nest.

When fall arrives the adults of the region group together to migrate to the south before the ponds and lakes freeze. The young and the adults travel separately.

Sometimes migration will be compromised due to late renesting. This phenomenon follows the first nesting. It seems as though the nesting instinct is so strong that certain loons don't know when to abandon the idea of building a new nest. A nest built later in the season leads to delayed egg laying and hatching. The chicks born from the late renesting are at a disadvantage to those born at the proper time. They will have less time to build up their fat reserves for migration, and less time to completely develop their wing muscles. Consequently these birds will have a lower survival rate. If this practice persists year after year, and is performed by a lot of loon pairs, the survival rate will diminish considerably.

Animal behavior is instinctive from generation to generation. If the chicks born from late renesting survive to migration the chance that they will repeat this habit is highly likely. In addition to disrupting the life cycle, this will lead to a direct decline in the population as nothing will guarantee the survival of the chicks. Fortunately, this has not been the case for the Tyhee Lake loon population as yet.

4.4.5 Cause and Effects of Population Decline

4.4.5.1 Nest Predation

Predation of nests has been a problem inherent in nature for all time. From a biological standpoint, we can't change anything as foxes, coyotes, ravens and other predators will never stop wanting and searching for eggs. On the other hand we are guilty of attracting many predators to nesting areas. Bears and ravens are more attracted to the lake shores due to the abundance and availability of our trash. We also increase the likelihood that the eggs will be eaten by scaring the loons away from their nests, leaving the incubating eggs vulnerable to predation. On occasion humans even act as predators by taking eggs with the intent of protecting them.

4.4.5.2 Gardening and Lake Access

At first glance lake front gardening seems like a harmless activity, but in reality in can put loon populations at risk when it is not practiced in an ecologically sound manner. Several homeowners living around the lake wish to have vegetation free access to water so they remove shoreline and aquatic vegetation. However, a pair of loons may be may be living in this vegetation. Loons need riparian vegetation as it is their primary habitat. Cutting trees and removing aquatic and emergent vegetation around the lake alters the loons natural habitat and destroys their nesting areas.

Once the riparian vegetation is removed, there is nothing left to bind the soil and it is vulnerable to erosion.

Another problem is that gardening and landscaping are often synonymous with pesticide and herbicide use, which is harmful to the environment as well as the local fauna. These chemicals leach into the soil and seep into the lake. This contaminates the soil, plants, food and water used by the loons.

4.4.5.3 Nest Disturbance

Approaching a nest frightens the loons and has several impacts. Disturbance can lead to abandonment of nests, and if continuous, abandonment of the lake. If the eggs have already been laid prior to disturbance this will lead to late renesting and the birds hatched from this second mating will likely not develop enough to migrate in the fall.

Disturbing a nesting site during incubation poses a serious threat and causes many problems. Once the parents are scared away from the nest the eggs become a prime target to predators. The eggs can also get cold or the chicks can die while the parents are wasting their energy flying around. This extra expenditure of energy also leads to a reduction of fat stores. Usually in a quiet environment a bird will spend about 1.1% of its time in flight, however when continually disturbed this percentage could reach 11.7%. (Korschgen, 1992.) This energy loss leaves less energy for hunting, caring for chicks, and building up fat stores for migration. Loons and other aquatic birds are most often disturbed by bird watchers and hikers, not motor boats, jet skis, photographers and egg collectors that are not aware on considerate of their habitat.

During nesting any disturbance can provoke fleeing of nests during mid construction. Some loons will simply find a new place to nest, whereas others will keep trying to build the nest before finding a site away from the disturbance, which leads to late hatching and the problems associated with late renesting. Some loons will even decide not to rebuild their nest and leave the lake never to return.

4.4.5.4 Motorized Traffic

Usually loons will try to build nests in a quiet place away from sources of disturbance. The primary source of noise at Tyhee Lake is motorized traffic, in the form of jet skis and motor boats. There is also an airport for float plane next to the lake, meaning that the loons are often disturbed by planes. The use of motor boats presents problems for both the flora and fauna of the area.

In the last few years bird watchers have noticed that the presence of motor boats on the lake has led to reduced reproductive success of the loons. The noise from the boats scares the loons from their nests, leaving the eggs vulnerable to predation. Predation can increase by 200-300 % due to disturbance. Sometimes the noise will force the loons to leave the lake permanently. The consequences of boat traffic are similar to those for nest invasion.

Presence of waves is equally harmful to the nests as they can lead to flooding of the banks and carry the eggs out of the nest or by changing the water level make the nest inaccessible by submerging it.

One problem is the chance of a collision of a floating loon chick and a boat. It is extremely difficult to see the chicks to avoid them, and once struck they usually die on impact. It seems that some boaters even attempt to run down families of loons for no reason. The most significant impact that motorized craft have on Tyhee Lake loons is displacement of optimal feeding/rearing habitat at critical time of the day. Motorized craft, notably jet skis are penetrating the bays beside nest sites that serve as optimal feeding and rearing habitat. This disturbance poses one of the most serious threats to the success of parents rearing their young. (L. Vanderstar, pers. comm., 1999)

4.4.6 Solutions

4.4.6.1 Public Awareness

Since population decreases for loons are primarily caused by human interventions, the only way to get rid of the problem is by starting a public awareness campaign. This would educate the public as to the effects of disturbance and explain what they can do to help.

Since 1995 yearly surveys have been completed to track how many loons are returning to the lake, the number of birds hatching & surviving through to September, whether the Tyhee Lake loon population is increasing or decreasing whether the nesting areas remain the same from year to year. A Katimavik volunteer has prepared loon information flyers to be distributed to the residents and users of Tyhee Lake. The Tyhee Lake Protection Society and the Ministry of Environment, Lands and Parks are also considering putting signs around the lake to encourage human avoidance of feeding and nesting areas.

Since humans are the main disturbance to the loons of Tyhee Lake, we must change our habits to ensure that humans and birds will enjoy the lake without any loss of freedom.

5. Water Body Usage Map

The water body usage map provides a visual representation of the specific uses of the lake (Gibbons et al., 1994). This allows the many different uses to be identified and recognized in the lake management plan.

Specific uses of Tyhee Lake include a boat launch area, waterfowl nesting areas, wetland areas, beaches and swimming areas, a Provincial Park area, a seaplane base, water supply intakes and others as illustrated in Figure 11.

6. Discussion of Lake Management Alternatives

The eutrophication process and specific lake problems have been identified along with the lake and watershed physical characteristics. A set of actions must be identified so that the goals and objectives of the plan may be achieved given local constraints (Rast and Holland, 1988). The process of identifying lake management options which are feasible can be a complex process. Decisions must be made with serious regard to cultural, social and political dimensions (Brewer, 1986) as well as ecological and financial dimensions. This is a complex, uncertain process as there is difficulty in assessing cultural, social, political, ecological, and financial dimensions and expressing each in terms of relative value on a common scale.

A technique called decision analysis allows one to describe both a conceptual framework and a set of applied procedures that have been developed as a means of gaining insight into decisions involving conflicting objectives and many uncertainties (McDaniels, 1992). The most helpful aspect of decision analysis is the incorporation of subjective judgments in the assessment of alternatives and establishment of an explicit framework for integrating the multidimensional components of complex values (Gregory *et al*., 1993).

Each of the lake management options will have consequences which must be analyzed in terms of the basic objectives of the lake management plan (McDaniels, 1992). As a result of the decision analysis, it is 9expected that one or more of the lake management alternatives will be determined to be the most effective in terms of achieving the goals of the plan.

6.1 Types of Analysis

6.1.1 Cost Benefit

One approach used to assess the worth of lake management alternatives is the cost-benefit analysis. The cost-benefit analysis is based on a branch of Economic Theory called "welfare economics" (Rast and Holland, 1988). Cost-benefit analysis compares all of the positive and negative elements of each lake management alternative in a general, broad context.

Traditionally, cost-benefit analysis looks only at monetary costs and benefits which can be estimated in dollar figures. However, the problem with this approach is that some dimensions are difficult to quantify, such as cultural values, long-term sustainability of natural resources, political realities, societal and governmental structure and stability, and the national or regional distribution of wealth (Rast and Holland, 1988). Some of these elements cannot be quantified at all or else can only be quantified in an artificial and perhaps inaccurate manner.

The nature of cultural eutrophication involves ecological, social, political and cultural dimensions. An approach which encompasses all of these as well as the financial dimension is needed to determine whether or not the expected benefits are a good investment of funds (Rast and Holland, 1988).

6.1.2 Social Impact Ranking Matrix

Another approach used to evaluate the worth of lake management options is the social-impact ranking matrix (Rast and Holland, 1988). This approach offers an alternative way to assess the different lake management options to rank them.

Instead of considering only costs and benefits, various ranking criteria are identified. The ranking criteria should stem from the requirements of the plan, in this case, human land use, potable water, recreation use, esthetics, wildlife habitat, maintenance of ecosystems, and managed species - fish and furbearers, while at the same time consider financial costs so that the plan has some reasonable chance of implementation. Care should be taken in identifying these ranking criteria as it is recognized that the specific ranking criteria and their relative weights can significantly affect the eutrophication-control program ultimately chosen (Rast and Holland, 1988).

The social-impact ranking matrix relies on consensus building to determine social, cultural, ecological and political costs and benefits. A consensus exercise must be completed where stakeholders are asked to put a value on specific social and ecological values (Gregory *et al*., 1993).

The matrix considers the relative "social impact" of each control option and allows assignment of priority to the various control alternatives being considered. The ranking criteria can either be assigned equal ranking or weighted ranking. Equal ranking assumes that the ranking criteria are of equal social value which may not be the case. Weighted ranking allows assignment of a value to the ranking criteria signifying it's relative social importance and incorporation of this value in the ranking of the lake management alternatives (Rast and Holland, 1988). This is important because in many cases, one or more factors may be more important than the other factors, and this must be accounted for in the decision analysis (Rast and Holland, 1988). The value assigned to the ranking criteria can be on the basis of personal experience of the lake management planner or limnologist, however, it is recommended that either a canvass of opinions from the technical experts or public consensus or some combination of the two, be used to determine the relative social importance of the ranking criteria (Rast and Holland, 1988).

6.2 Approaches for Value Tradeoffs [McDaniels, 1992]

There are three common approaches for assigning a value to intangible goods such as environmental quality, wilderness preservation or safety. The first one is contingent valuation which consists of a series of questions asked of a person to determine what value they would put on a "non-market good" (intangible good). This method has been criticized for it's lack of objectivity. The results can be dramatically affected by changing the questions posed by the planner (McDaniels, 1992).

The second method is Multiattribute Utility Theory (MAUT) where impacts are described and displayed in a matrix and decision makers (stakeholders) are expected to implicitly judge tradeoffs among lake management alternatives (McDaniels, 1992). This approach is relatively new to Canada and was developed specifically for eliciting values for environmental resources (Gregory *et al*., 1993). Using MAUT, the values for non-market goods are constructed in a manner designed to rationalize the process (Gregory *et al*., 1993).

The third method is that of consensus. Individual and public meetings are held for discussion of lake management alternatives and the intent is to get a diverse cross-section of views regarding the options. The problem with consensus is that there is no mechanism for clarifying tradeoffs (McDaniels, 1992). Public involvement often emphasizes positions over underlying values and interests and has limited use to the planner according to McDaniels (1992).

It doesn't matter which of the approaches is used, as long as a system is maintained.

To assess the lake management alternatives in terms of feasibility for Tyhee Lake, a combination of cost-benefit analysis and social-impact ranking matrix was used. The ranking objectives chosen were financial cost, ecological cost, ecological benefit and effectiveness in reducing eutrophication. An equal ranking system was chosen for the first iteration which assumes that the ranking objectives are of equal social importance. However, this is only an estimation and it is suggested that in further iterations of the analysis, weightings of the criteria be established and incorporated.

Initially, an exhaustive list of possible lake management alternatives was developed. Each option was thoroughly researched and the negative and positive aspects of the alternatives were recorded in a chart. To facilitate the review process, each lake management alternative was ranked in the matrix with H (high), M (medium) or L (low) rating under the different ranking objectives, and the accompanying chart listed the trade-offs for each. A simplistic form of the multiattribute utility theory (MAUT) was used by faxing the matrix to a number of experts and asking them to review the ranking and make any changes they felt were necessary with reasons for their views as well as add any points that may have been overlooked for each particular option. The comments and changes were phoned in or faxed back. This process was considered equivalent to a "canvass of the experts" (Rast and Holland, 1988). Once the matrix was in a final draft, it was presented to the executive directors of the Tyhee Lake Protection Society and a consensus exercise was completed. A copy of the final version of the options analysis is included in Appendix D.

When consensus on the rank of the options had been reached, the High, Medium, and Low rankings were directly translated to a numerical scale of -5 to +5 where a high benefit is equivalent to +5 and a high cost is equivalent to -5. The rankings of the criteria for each option were then summed and the total was used to rank the options.

One problem with this approach is that it assumes that a high rank is reason enough to implement a specific option. If resistance to implementation is experienced, it may be necessary to complete further iterations of the matrix. This will allow the determination of the most important plan objectives based on social impact values. It is also possible that different ranking criteria are needed and this should not be overlooked in subsequent iterations of the social-impact matrix

6.3 Lake Management Alternatives

Before discussion of the specific lake management alternatives, two points about costs and benefits need to be made. The first is that it is important that all available resources be considered for each option including technical expertise, financial resources, volunteer labour and equipment among others. It should also be noted that eutrophication control costs can vary substantially in different areas due to the local cost of labour, equipment, supplies and availability of specialized equipment (Rast and Holland, 1988). For example, when considering aquatic plant harvesting as a lake management option, it must be acknowledged that a harvester would have to be transported from southern BC to the northern area at a cost.

6.3.1 The option of doing nothing

It is important to consider the consequences of doing nothing because it offers one basis of comparison with the potential effects of implementing a lake management program (Rast and Holland, 1988). Evaluation of the option of doing nothing can help decide if implementation of a lake management program is even required. However, it is difficult to estimate the rate of cultural eutrophication and therefore, difficult to estimate the state of the lake at any given future year. It is known that a lake exhibiting eutrophication symptoms is likely to become worse over time and if a lake is allowed to deteriorate indefinitely it will decrease the chances for a timely rehabilitation while increasing the cost of restoration (Rast and Holland, 1988). On the other hand, a delay in taking action may be advantageous since new knowledge and techniques are presently being developed which may be better in term of efficiency of resources and chances of success.

6.3.2 Other Lake Management Options

There are three general categories of lake management options; those which treat the symptoms of eutrophication, those which treat the causes of eutrophication, and those in-lake methods which attempt to restore a eutrophied lake. In general, the in-lake methods are usually less effective over the long term than those options which treat the causes of eutrophication, if they are used in isolation (Rast and Holland, 1988). Often a combination of lake management options is required to maximize the effectiveness of restoration and control of eutrophication of the lake.

6.3.2.1 Treating the Symptoms of Eutrophication

Generally, these options treat only the symptoms and not the causes of eutrophication in a lake. Some of these symptoms include nuisance aquatic plant growth, algal blooms, and turbid water. When the symptoms are treated without any effort to identify and correct the problem and it's causes, this treatment will only be temporary. Until the problem is identified and the causes of the problem are addressed, eutrophication will continue to occur and the symptoms will continually reappear. However, if the problem has been identified and corrective measures are taken, many of the following alternatives will work effectively as part of a long term lake management program.

6.3.2.1.1 Lime (calcium carbonate) addition

Addition of lime (calcium carbonate) can improve water quality in hard-water eutrophic lakes by blocking access to growth-limiting nutrients (such as phosphorus) for phytoplankton (Prepas *et al*., 1990). Although this lake management technique has been used with success in Alberta in a number of lakes, it was eliminated from the social impact matrix because it is not feasible for Tyhee Lake. It is necessary to have a hard-water lake to employ this technique and Tyhee Lake does not meet this physical requirement.

6.3.2.1.2 Commercial Dye Application

Commercial dyes can be added to a water body and used to suppress plant growth by limiting light. The blue concentrate is especially effective against *Elodea* which is a concern in Tyhee Lake. However, this option was omitted from analysis because the dye can only be used in closed systems such as small ponds and cannot be used in a potable water source (Cooke *et al*., 1993).

6.3.2.1.3 Copper Sulfate

Excess copper added to the ecosystem through chemical treatment of the lake with copper sulfate, works as an algicide (Cooke *et al*., 1993). Almost immediately after treatment, water clarity increases and algal blooms decrease (Cooke *et al*, 1993). The effects are very short term and the treatment has no affect on macrophyte growth (R. Nordin, pers. comm., 1995). The annual costs are high (approximately two hundred thousand dollars) and a pesticide permit would be required.

Copper sulfate treats only a symptom of eutrophication rather than addressing the problem itself. There is a high possibility of negative impacts on non target organisms, including the possibly rare and endangered Giant Pygmy Whitefish, and benthic invertebrates. Over time, the sediments will become contaminated with copper and reach levels of toxicity which can lead to complete destabilization of the ecosystem (R. Nordin, pers. comm., 1995).

The high ecological costs associated with copper sulfate treatment are considered unacceptable and therefore this option was omitted from further analysis.

6.3.2.1.4 Hypolimnetic Aeration

From rough nutrient budget calculations, it is thought that in Tyhee Lake the majority of phosphorus is from bottom sediments. This internal phosphorus loading is controlled by oxidation-reduction (redox) reactions. This means that under aerobic conditions at the sediment-water interface, the chemical equilibrium of phosphorus is towards sequestering in the sediments which act like a “sink” (Wetzel, 1975). Under anaerobic conditions, phosphorus is released from the sediments and into the water column, causing internal loading. The idea behind hypolimnetic aeration, is to re-oxygenate the oxygen deficient water in the hypolimnion to suppress phosphorus release. It should be mentioned that some lakes have internal phosphorus loading which is controlled by microbial activity or non-oxygen dependent processes and hypolimnetic aeration will not have any positive results on these lakes (P. Newroth, pers. comm., 1995)

Hypolimnetic aeration allows for maintenance of thermal stratification within the lake by providing oxygen to only the hypolimnetic thermal layer. This does not promote mixing of waters across the thermocline.

The aeration system is expensive to install (a few hundred thousand dollars). There would also be some annual maintenance and pumping costs. The hypolimnetic aeration system can be tricky to install and if it is not set up properly, it will be ineffective and possibly damaging to the ecosystem (K. Hamel, pers. comm., 1995), but was proved to be effective in appropriate situations, for example, St mary Lake, Saltspring Island (R.Nordin, pers. comm., 1998)

6.3.2.1.5 Artificial Circulation / Aeration

Another method which is often used to increase dissolved oxygen levels in the water is complete circulation/aeration. This involves pumping air into the water using a diffuser/aerator or by spraying the lake water into the air and letting it fall back into the lake. The artificial circulation/aeration alternative will cause mixing of the thermal layers in the lake (also known as destratification). The system is expensive to install and is most effective in non nutrient-limited lakes.

If phosphorus release from the sediments is not controlled by redox reactions, but instead by calcium, aeration can actually increase the amount of phosphorus released into the water column from the sediments (Cooke *et al*., 1993).

Aeration and circulation increases the dissolved oxygen levels in the entire lake instead of just the hypolimnion as is the case with hypolimnetic aeration. As a result of destratification, the temperature of the lake will increase. An increased temperature of the hypolimnion can destroy habitat for cold water species of fish (Cooke *et al*., 1993). However, habitat for aerobic organisms is increased and this may lead to increased incidence of blue-green algal blooms (K. Hamel, pers. comm.).

This alternative can be implemented in shallow lakes to prevent fish kill due to depleted dissolved oxygen over winter (Cooke *et al*., 1993). Aerators operating throughout the winter can prevent areas of the lake from freezing over, thereby creating a safety hazard due to the presence of open water (S. Hatlevik, pers. comm., 1995).

In Tyhee Lake, the cold water game fish which include Rainbow Trout and the Giant Pygmy Whitefish would most likely not survive an increase in temperature of the lake due to destratification and it is possible that these populations would be diminished (S. Hatlevik, pers. comm., 1995).

6.3.2.1.6 Macrophyte Harvesting

One common symptom of eutrophication is an abundance of aquatic plant growth. The Tyhee Lake Protection Society has determined that control of the aquatic plants is one of the foremost requirements of the lake management plan.

There are many different methods for harvesting aquatic plants. This plan will not discuss the different methods but rather refer interested parties to a guide published by the Washington Dept. of Ecology called *A Citizen's Guide to an Integrated Aquatic Vegetation Management Plan* (Gibbons *et al*., 1994).

Aquatic plants must be removed from the water within 24 hours of harvesting or nutrients may leach back into the lake. The plants should be allowed to dry and then hauled to a compost area where drainage can be percolated through the ground or discharged to an oligotrophic water body. An immediate increase in plant growth may occur when fragments escape during harvesting and this may even cause the spread of plants to other areas of the lake (K. Hamel, pers. comm., 1995). The effects of aquatic plant harvesting on algae are uncertain. Harvesting can cause disruption of the sediments and possibly an increase in internal loading of phosphorus which could lead to immediate algal blooms.

A lake management plan should contain a map indicating areas which are used for spawning and rearing of fish so that these areas may be protected (Gibbons *et al*., 1994). Young fish can be mistakenly harvested with the plants (K. Hamel, pers. comm., 1995) Once the research on the Giant Pygmy Whitefish is completed by a U.N.B.C. graduate student, a map indicating any areas which should not be harvested should be added to the plan.

Harvesting will not eradicate plants since it does not remove root systems. However, an acre or two per day can be harvested with the right equipment to provide quick, predictable results in small localized areas. Harvesting may foster volunteer spirit and is an excellent way to clean up local beaches or swimming areas but it falls in the category of dealing with the symptoms of a problem rather than dealing with the problem itself.

6.3.2.1.7 Grass Carp

Another method of controlling aquatic plant growth which is common in some areas of the United States, is introduction of sterile (triploid) grass carp (Cooke *et al*., 1993). Grass carp feed on aquatic vegetation and prefer *Elodea* (K. Hamel, pers. comm., 1995). Introduction of carp to a lake changes the ecosystem and can eliminate aquatic vegetation which provides valuable hiding places for young fish and important food for waterfowl.

It is difficult to estimate the stocking rate needed for a slow but significant reduction of macrophyte biomass. The carp are expensive (approximately $50 - $200 per acre depending on stocking density - Gibbons *et al*., 1994). Once carp are stocked in the lake, they are impossible to eradicate. A permit for stocking is required from the Ministry of Environment Fish and Wildlife Branch and it is very unlikely that this would be granted especially before the habitat requirements are defined for the possibly rare and endangered Giant Pygmy Whitefish (D. Atagi, pers. comm., 1995). If Tyhee Lake was stocked with grass carp, the outlet would have to be equipped with a fish containment barrier to prevent grass carp from escaping into the Bulkley River (P. Newroth, pers. comm., 1995). The containment barrier would be expensive to install and would require frequent maintenance.

6.3.2.1.8 Sediment Covers

Plants are dependant on light for photosynthesis of sugars which are an energy source. Light blocking screens can be used to cover and kill rooted plants. The covers are also effective in reducing internal loading of phosphorus from the sediments (Wetzel, 1983). The covers impede the loss of oxygen in the waters overlying the sediments and decrease the rate of release of phosphorus, iron and ammonium from the sediment (Wetzel, 1983).

The screens are rolled out onto the sediments and generally are easier to set up if large aquatic plants are harvested prior to installation. Often, slits need to be cut in the material prior to installation because gas evolution from the sediments may cause the barrier to become buoyant.

The screens, which are usually made of polyethylene or a similar material, are approximately twenty thousand dollars per acre (K. Hamel, pers. comm., 1995).The light barriers are very effective in small areas and ideal for regions around docks and sections used for swimming (K. Hamel, pers. comm., 1995).

6.3.2.1.9 Water Level Drawdown

Water level drawdown refers to the removal of approximately two thirds of the lake water for the winter to expose macrophytes to extreme weather conditions. It is expected that the macrophytes will not survive the extreme conditions and the aquatic plant biomass will be reduced. This lake management alternative is considered to treat only the symptoms of eutrophication as it does not actually remove excess phosphorus from the lake. This technique is better suited to small reservoirs. In natural lakes such as Tyhee, the water level drawdown may have a negative impact on fish populations (Cooke *et al*., 1993). Water level drawdown has been used on lakes infested with *Milfoil* without many benefits according to Peter Newroth (pers. comm., 1995).

Water level drawdown is not feasible for Tyhee lake because a large reservoir to hold the removed water is required and not available (K. Hamel, pers. comm., 1995) and freshet is not sufficient to recharge the basin if the water was flushed down to the Bulkley River .

6.3.2.2 Treating the Causes of Eutrophication

Most of the options listed under this category involve reducing point and non-point sources of external nutrient and sediment inputs by implementing specific land use management practices. In a lake which obtains the majority of it’s phosphorus loading from external sources, appropriate watershed management can provide long-term control of aquatic plant growth.   This is not the case for Tyhee lake as it obtains the majority of it’s phosphorus from historic internal sources, specifically, the sediments. It is thought that this condition is present as a result of past agricultural practices which did not limit the amount of animal waste entering the lake. However, Ken Ashley specified that in any lake, external sources of nutrient loading must be addressed before internal management options are considered (pers. comm., 1993) Since the watershed and lake are interconnected, any reduction in contaminant loading to a water body as a result of land use management practices can maintain or extend effectiveness of in-lake controls (Gibbons *et al*., 1994).

6.3.2.2.1 Septic System Failure Definition Remediation/Maintenance

The amount of nutrient loading to the lake through septic systems can be varied and it is very difficult to estimate the total nutrient contribution to the lake from septic systems. However, using a water budget formulation where input is equal to output (black box model) other sources of nutrient loading can be measured and the nutrient contribution from septic systems can be estimated indirectly (Cooke *et* al.,1993). This modeling exercise is likely to show that septic system discharges comprise only a small percentage of total external and internal loading, however, it may be a large percentage relative to external loading only.

Since this is most likely the case, long term maintenance of septic systems is an important part of reducing cultural eutrophication of Tyhee Lake. It is a fact that problems associated with septic system failure are difficult to diagnose, therefore it is up to the individual house owner to maintain the system. Often, people do not realize that there is a problem with their system until it has reached a serious failure stage. One way of diagnosing failing systems is through the use of a septic leachate detector by the Ministry of Health. The Health Inspector adds a dye to the septic system and then assesses whether any of the dye seeps into the lake (detection of plumes). This process is not always effective and can be time-consuming, but is nonetheless worthwhile.

The efficiency of removal of phosphorus is directly related to groundwater flow characteristics and soil type (Kerfoot and Skinner, 1981). Kerfoot and Skinner. (1981) observed a high correlation between location of nutrient rich plumes and attached plant growth. Well-drained, porous soils were observed to be the most efficient for attenuation of nutrients from wastewater. A diverse range of soil types are found in the Tyhee Lake watershed (see Figure x adapted from Boyd *et al*., 1984). There are two areas of the lake, the south end and the upland area on the east side which have poor suitability for septic systems (Boyd, 1984). Boyd recommended that septic systems in these two areas be set back a minimum of 300 metres from the shoreline (1984). This could be addressed through Zoning Bylaws for presently undeveloped land in this area.

6.3.2.2.2 Sewage Systems Installation

To reduce nutrient contributions from septic system leachate, another option is to install a community sewage treatment plant. The cost of this would be millions of dollars, part of which would be borne by the lake residents. An immediate result would be a reduction in nutrient input to the lake. However, the percent contribution of phosphorus in the lake from septic is not known but expected to be small.

6.3.2.2.3 Control of Forest Management

Land use management practices within the watershed catchment basin of Tyhee Lake, all have some effect on external nutrient loading. Forest management programs such as logging, and forest renewal may involve uprooting vegetation, decreasing stability of soils, and application of nutrient rich fertilizers. Erosion reduction and runoff control are key management practices which could significantly reduce the sediment and nutrient loads to the lake. The cost of these programs would be borne by forest managers and the practices would have to be evaluated as to their effect on forest productivity .

6.3.2.2.4 Control of Inputs from New Development

New development within the watershed catchment basin of Tyhee Lake can contribute significant amounts of nutrients and sediments to the lake which would further increase the rate of eutrophication. Ditches used to catch and store nutrient rich runoff may be effective. Management practices which increase retention of overland runoff may be expensive and the associated cost would be borne by developers. Subdivision zoning bylaws specifying acceptable land use management practices could be set in place by the Bulkley Nechako Regional District, through the Official Community Planning Process.

6.3.2.2.5 Runoff from Agricultural Lands

Runoff from agricultural land accounts for a significant amount of nutrient loading to Tyhee Lake. There are farming practices which can be implemented that would have an immediate effect on reducing nutrients and pathogens to the lake. These practices are expensive and the cost would be borne by individual farmers, unless special funding mechanisms are put in place. Farmers must be convinced of the benefits to the lake of new runoff control treatment practices, especially if the suggested changes may be more expensive than the status quo (Rast and Holland, 1988). The education program must include those farms located at a seemingly great distance from the lake but within the catchment basin.

One very effective practice involves the use of manure storage, bunkers which trap and hold runoff that was mixed with animal waste. This can be highly effective provided that animal waste is adequately collected and stored in the contaminant area(s) and byproducts (rotted manure and collected runoff) are properly used as soil amendment on lands of some distance from the lake or it's tributaries. In addition, ditches and impoundments used to catch and hold nutrient rich runoff from pastures from entering the lake can provide additional benefits. The runoff is diverted into settling ponds where suspended solids and nutrients are allowed to settle out. The water which then seeps out of the treatment pond to the lake is much reduced in nutrient concentration. An advantage of this practice is that the nutrient rich pond water can be used for irrigation of fields which may improve forage production. However, the treatment works are expensive to install, require regular maintenance, and may reduce the area of pasturage available .

Another method to reduce nutrient rich runoff, is to implement specific plowing methods and reduce the amount of fertilizer applied to fields. Also, leaving a fringe of vegetation between pastures and the lake, allows attenuation of nutrients from runoff before it reaches the lake. If the suggested practice can be demonstrated to cause a benefit to the farmer, it will be most easily implemented.

6.3.2.2.6 Public Education

Every lake management plan must include a public education program. It will encourage a larger portion of the population to take responsibility for the part they play within the watershed and the perpetuation of the plan. Through education, public involvement, which is essential to implementation and perpetuation of the plan, will result. Public education can also be effectively used to reduce external loading of nutrients and sediments. The public must be informed about land use/management practices to reduce nutrient loadings. This may include using phosphate free detergents, choosing to promote the growth of riparian vegetation and reducing fertilizer use.

6.3.2.3 Lake Restoration Methods

As with the options which treat the symptoms of eutrophication, these options do not solve the problems causing eutrophication. Instead, they restore the lake to a prior nutrient status for periods of years. Treatment life can be extended if the alternatives are used in conjunction with those which treat the causes of eutrophication.

6.3.2.3.1 Diversion/ Pristine Water Inflow

Diversion of a pristine water source into the lake is a restoration method which relies on increased flushing and replacement of nutrient rich, oxygen depleted waters with oxygen rich water which contains no more than one fifth the nutrient concentrations (Cooke *et al*., 1993). This option was eliminated from the alternatives analysis because there is not an available water source near to Tyhee Lake. In the first round of options analysis, Canyon Creek was considered but it was found to be too far away from the lake for a diversion to be practical. In addition, it would be difficult to obtain a license for the diversion as there are already numerous water licenses on Canyon Creek (R. White, pers. comm., 1995).

6.3.2.3.2 Hypolimnetic Withdrawal

Hypolimnetic withdrawal involves removal of nutrient rich, oxygen deficient water at depth, replacing the natural outflow of surface water (Cooke *et al*., 1993). The ultimate goal of hypolimnetic withdrawal is to increase the output of phosphorus from the lake. This could be accomplished through removal of hypolimnetic water which would be replaced with water higher in dissolved oxygen. The residence time of the hypolimnion would be decreased which would in turn decrease the period of anoxia. Ultimately, the depth of the anoxic boundary would change which would lead to a decrease in phosphorus diffusion from the sediments (Cooke *et al*., 1993).

Hypolimnetic water could be removed by siphon and discharged through the outlet of Tyhee Lake and into the Bulkley River. There is a six week freshet when the water could be siphoned out of Tyhee Lake while maintaining the water level (P. Marquis, pers. comm., 1995). Due to the limited siphoning time period, it may take 5-10 years before signs of restoration are visible.

To be effective, hypolimnetic withdrawal must be done in late summer.

The initial installation of the pipes for withdrawal will be relatively expensive because of the size and topography of the lake. Prolite Plastics are currently working on a cost estimate for the hypolimnetic withdrawal piping system. It is likely that a pump would be needed to assist in removal of the hypolimnetic water since the lake is more than 20 metres deep and the outlet is very flat, and there may not be enough head to run the siphon without a pump (P. Marquis, pers. comm.). It is estimated that the installation would cost approximately twenty thousand dollars. Annual maintenance and pumping costs would be in addition to this.

6.3.2.3.3 Alum (aluminum sulfate) Addition

Aluminum sulfate is added to lakes to lower phosphate content by removal of phosphate from the water column and by retarding phosphate release from lake sediments (Cooke *et al*., 1993). It is most effective under anoxic conditions. Alum only prevents phosphate release from sediments below the alum layer. Therefore, if the external nutrient sources are not reduced and the phosphorus into the lake remains high, nutrient rich sediment will build up on top of the alum layer and begin releasing phosphorus into the water column. The faster the rate of sediment deposition in the lake, the faster the alum treatment will lose it's effectiveness. Generally, alum treatment is effective for 5 to 10 years depending on factors such as amount of alum applied, rate of sedimentation and external phosphorus loading, and the lake topography (P. Garrison, pers. comm., 1995). The sedimentation rate of Tyhee Lake appears to be quite low, so this would not be a major concern. It is apparent from the Reckhow and Simpson Model that external loading is small in relation to internal loading from sediment sources. This would tend to support the use of alum. Lastly, lake topography is such that anoxic conditions promoting phosphorus cycling from the sediments takes place over a broad area of the lake bottom. This would tend to increase the area required to be treated and thus makes it a fairly expensive option if done in isolation from other options.

The effectiveness of alum in binding phosphorus is pH and temperature dependent (Cooke et al., 1993). In most cases, a buffer is added to the lake with the alum to ensure that pH remains steady (K. Hamel, pers. comm., 1995).

The main benefit in adding alum to a lake is reduction of algal biomass and increased water clarity. These results are immediate (Cooke *et al*., 1993). However, an increase in water clarity can increase the depth of light penetration allowing for an increase in growth of rooted macrophytes such as *Elodea* and possibly an increase in temperature (T. Eberhardt, pers. comm., 1995).

Alum has been added to lakes as large and larger than Tyhee Lake with success. It is most economical to add alum only to the portion of the lake that becomes anoxic (P. Garrison, pers. comm., 1995). If alum is added to sediments that are continually overlain with oxygenated water, it will not be effective in binding phosphate.

The exact quantity of alum needed for the treatment to be most effective can be calculated using specific equations (Cooke *et al*., 1993). If too little alum is added, the treatment will not be effective and if too much is added, the treatment could be toxic to the biota.

It is possible that there is a correlation between aluminum and Alzheimer's disease . This may make the option less favourable among lake residents, some of whom obtain their drinking water from the lake. It is important to acknowledge this as the lake residents will be part of a funding formula for any options which are implemented.

6.3.2.3.4 Biomanipulation

Manipulation of the lake biota can have significant effects on algal biomass and phosphorus concentrations in the lake (Carpenter, 1995). A piscivorous fish is one which feeds on other fish. Addition of piscivorous fish to the lake community causes a decrease in the planktivorous fish populations which, in turn, allows an increase in zooplankton populations. Zooplankton are efficient algal grazers. This is known as "top-down" biomanipulation (Cooke *et al*., 1993). Once the piscivorous fish are mature, they are likely to be removed from the lake by anglers. Removal of a fish which weighs several pounds from the lake only removes a few milligrams of phosphorus from the system and is not an effective way of removing phosphorus. Effective biomanipulation requires an extensive knowledge of the lake biota and the specific mechanisms of the pelagic food web (Cooke _et al_., 1993).

This alternative was not included in the cost-benefit analysis because it is neither feasible nor believed to be effective in Tyhee Lake. There are a couple of others reasons why this option could not be implemented. The first reason is that the only piscivorous fish available for stocking in Tyhee Lake, that might be approved by the Fish and Wildlife Department, would be Coho and this species tends to be planktivorous in lake environments (D. Atagi, pers. comm., 1995). The second reason why this option cannot be implemented is for protection of the potentially rare and endangered species, the Giant Pygmy Whitefish. If genetic analysis of the Giant Pygmy Whitefish suggests that the population is not a rare and endangered species, it may be worthwhile to investigate the option of biomanipulation further at that time.

6.3.2.3.5 Sediment Removal

Even if external phosphorus sources are significantly reduced, it is likely that signs of lake recovery will not be evident for a period of years. The reason is that the internal phosphorus cycling will still be high due to internal loading from the sediments. One alternative for restoration of the lake to a state prior to cultural eutrophication, is to remove the phosphorus laden sediments from the lake basin using a hydraulic dredge (Cooke _et al_., 1993). Before employing this restoration method, the sedimentation rate must be determined to ensure that the technique will be effective over the long term. This technique is used to remove sediment buildup from the mouth of the Fraser River, however for entirely different reasons.

A lake in Thurston County which is similar in size to Tyhee Lake is undergoing sediment removal and the estimated cost is three million dollars (K. Hamel, pers. comm., 1995). Once the sediment is pumped out of the basin, it must be transported to a disposal site. The disposal site is ideally near the lake but outside the catchment basin. It is likely that the property chosen as the disposal site would have to be purchased and re-zoned by the Regional District for this use. The sediment pile can have similar characteristics to a mine tailings pile, specifically acid drainage. This may lead to requirements for an effluent or refuse permit under the Waste Management Act (BC Environment, Environmental Protection Program). Studies using techniques similar to acid/base accounting could be employed to predict whether and how much acid may be generated by the sludge, and what may be expected in terms of leachate contaminant concentrations. Resuspension of fine sediments in the water column can occur during dredging which may be harmful to the biota (E. Petticrew, pers. comm., 1995). A decrease in internal loading will only be observed if the deeper sediments contain lower phosphorus concentrations than the sediments removed. This must be confirmed with additional sediment sampling.

Sediment removal is effective in small applications. It appears from sediment core samples that the sediments in Tyhee Lake are approximately 50% water and should theoretically be easy to pump out with a suction dredge. In addition, they are nutrient rich (mean = 796 *u*g/g total phosphorus, 13535 *u*g/g nitrogen total Kjeldahl) as determined from sampling to date.

7. Discussion of the Recommendations

Now that the costs and benefits of each of the lake management alternatives have been identified (Appendix D) and a value has been attached in terms of the four ranking criteria, the values can be summed and the options can be ranked. Table 9 provides a summary of the results of the Lake Management Options Analysis included in Appendix D..

Internal options are only cost effective if the majority of the nutrient loading to the lake is determined to be coming from internal sources such as groundwater and lake sediments. At this time, it has been estimated that 83% of the phosphorus loading to the lake is coming from the sediments (P. Marquis, pers. comm.). This estimate is supported by work done in 1984 where the Reckhow and Simpson Model was used to calculate that 80% of the annual phosphorus loading to the lake was from the anoxic sediments (Boyd *et al*, 1984). In an effort to fine-tune the model by using stream flow and chemistry data, an intensive sampling campaign was carried out during spring freshet of 1995 and 1996. Three rounds of sampling were conducted over the freshet period. This data can now be plugged into the existing Reckhow and Simpson model to better determine what the margin of error might be in th ecalculation of internal loading. The following recommendations are based on the assumption that the majority of the nutrient loading to the lake is derived from internal sources.

Table 9: Summary of the Ranked Tyhee Lake Management Options

Option Type	Option	Overall Rank
internal	hypolimnetic withdrawal	1
internal	hypolimnetic aeration	2
internal	aquatic plant harvesting	3
internal	sediment removal	3
internal	sediment covers	4
internal	circulation/aeration	4
internal	aluminum sulfate addition	4
internal	grass carp	5
internal	water level drawdown	5
external	public education program	1
external	agricultural runoff control	2
external	septic system maintenance	2
external	forest management control	2
external	control of inputs from new development	3
external	sewage systems installation	4

With the exception of the sewage systems installation alternative, all of the lake management alternatives which fall under the external category are feasible. Since all of those options fall under the category of options which address the problem of eutrophication, implementation of these options be a significant step towards achieving the goal of the plan, to slow down or eliminate eutrophication of the lake and thereby benefit residential users by improving the quality of the natural environment of the lake.

7.1 Managing External Nutrient Contributions

7.1.1 Public Education Program

Implementation of a public education program is the top ranking alternative among external options.

It is important to educate the public about how they directly affect the lake eutrophication process through their choices and activities. The long term life of the plan depends on public awareness and volunteer involvement.

A public education program was designed and implemented in 1995. Through a grant awarded by the Ministry of Employment and Investment, Partners in Science and Awareness Program, the Tyhee Lake Protection Society and the Telkwa Elementary School held a science & technology public education and awareness program in the spring of 1995. The program encouraged elementary school students to become involved in the implementation and evaluation of the plan through water quality monitoring. The students prepared an educational display for National Science Week in October of 1995 and some educational brochures were produced and distributed for community use. The Tyhee Lake Protection Society should continue to publicize the plan and it's contents and seek support from the public for funding and regulatory approvals.

A loon awareness educational program and volunteer monitoring program has been being designed and implemented by Len Vanderstar, the MOE Forest Ecosystem Specialist for the Bulkley District. Community members and Tyhee Lake Protection Society volunteers will work in conjunction with Len to monitor the loon population. This program has been underway since 1996.

In addition, the public education and awareness program should encompass reduction and control of external nutrient loading through agricultural runoff treatment, septic system maintenance and control of inputs from new development as discussed in Section 6. Residential owners should be educated about the need to keep septic systems maintained and potential impacts on water quality from gardening, shoreline development and other activities.

Fertilization, cultivation methods, dairy, horse and hobby farming have been addressed to some degree. It would be beneficial to conduct a study of the effectiveness of Koopman's runoff control to see if the settling ponds and runoff control works are decreasing the amount of nutrient loading to the lake from the dairy farm especially now in light of the fact that about $30 dollars of work has been carried out. This could be carried out after obtaining the necessary approvals & permissions of all parties involved.

7.1.2 Septic System Maintenance

Leaking and failing septic systems may contribute a significant amount of nutrient to the lake. Each septic system which is on lakefront property should be assessed and any maintenance needed should be undertaken by the owners. The regional health officer may be able to inspect each septic system on a request basis. Residents should be encouraged by the Tyhee Lake Protection Society to register on a voluntary basis with the Health Officer for a maintenance inspection. Although septic maintenance is of great importance, the potential input from septic system needs to be quantified to determine if there is really a problem.

7.2 Internal (In-Lake) Management Techniques

7.2.1 Hypolimnetic Withdrawal

As discussed in Chapter 6.0, hypolimnetic withdrawal involves the removal of nutrient rich, oxygen deficient water in place of the natural outflow of epilimnetic water (Cooke et al., 1993). The residence time of the water in the hypolimnion would be decreased, allowing for a shorter anoxic period in the turnover cycle.

At this stage of the analysis, hypolimnetic withdrawal is the most feasible option. However, there are many questions which will need to be answered before the option is implemented. A siphon system needs to be designed by an engineer. It is recommended that this be one of the first steps towards implementation of the Tyhee Lake Management Plan. Within the design, the following questions should be addressed:

- What is the volume of the freshet outflow?
- What is the maximum volume of water which can be siphoned out of the hypolimnion in the six week freshet period? How many years of siphoning will be required to reduce the concentration of phosphorus in the lake at spring turnover to below the water quality objective (0.015mg/L)?
- What are the pumping needs for the system? Is there enough head that the system can run using only siphoning or will a pump be required? Will the pump have to run continuously or will it only be required to prime the siphoning system?
- What are the safety considerations?
- Will a discharge license be required? What are the costs and liabilities associated with the license?

- Will the discharge pipe need to be underground to prevent freezing and cracking during the winter?
- Will the water level of the lake change due to siphoning? What is the minimum and maximum levels that are acceptable for the lake?
- How much P could be exported with a siphon under best conditions and under likely conditions?
- Does the high costs justify the amount of P that is exported?

If hypolimnetic siphoning is implemented, a tailored long term water quality monitoring plan needs to be implemented in order to assess the success of the siphoning. Dissolved oxygen, temperature, and phosphorus concentrations should all be measured over the depth profile for both deep basins at spring turnover. After an undetermined number of siphoning seasons, dissolved oxygen should increase, phosphorus concentration should decrease and temperature should remain similar to previous years. The monitoring program should include water quality monitoring at the point where Tyhee Lake Creek crosses the highway on the way to the Bulkley River. In addition, chlorophyll *a* and macrophyte biomass in the lake should be monitored annually. In 1998 the estimated cost for an engineering study is $6,000-7,000.

7.2.2 Hypolimnetic Aeration

The second ranked option to implement in Tyhee Lake is hypolimnetic aeration. Hypolimnetic aeration would lock the phosphorus in the sediments, reducing the phosphorus concentration in the lake and increase the dissolved oxygen levels in the deeper water (hypolimnion) which would increase the quality of the habitat for fish. As a result of decreased phosphorus loading from the sediments, it is expected that there would be a decrease in aquatic plant biomass and frequency and duration of algae blooms.

There are many questions which would need answering before the hypolimnetic aerator could be installed:

- How would the aerator be installed?
- How much air would be enough?
- What is the hypolimnetic oxygen demand?

- How much would the system cost for installation and then for annual maintenance? What are the power requirements and how could it best be generated and delivered?
- What would be the permit requirements for such an aeration system?

A contractor would have to be hired to prepare a plan design for hypolimnetic aeration before this option could be implemented.

7.2.3 Aquatic Plant Harvesting

Aquatic plant harvesting can be implemented on several different levels. Individuals can harvest plants in swimming and dock areas at their own pace or the Tyhee Lake Protection Society (TLPS) could work together as a group to harvest predetermined areas. Harvesting equipment could be donated by society members or purchased by the group. The subject of aquatic plant harvesting should be addressed at a protection society meeting and following a decision, more information on the types of harvesting and the associated costs could be researched.

It is important to remember that if the harvested plants are not removed from the lake, the nutrients in the plants may leach back into the water. Some questions which must be addressed in regard to this option are:

- Which areas of the lake have the highest priority for harvesting?
- What type of equipment will be used for harvesting and who will operate it?
- How will the harvested aquatic plants be removed from the lake and where will they be transported to?

A monitoring program would need to be set up to evaluate the effectiveness of the harvesting program over a number of years. Chlorophyll *a*, aquatic plant biomass and phosphorus concentration at spring turnover could be used to measure the effectiveness of the harvesting program. The amount of plant biomass which is removed from the lake should be estimated in tonnes. Using this number and multiplying it by the amount of phosphorus per tonne of plants can be a tool for estimating the number of kilograms of phosphorus removed from the lake through aquatic plant harvesting. Removing biomass (whether plants or fish) is a very inefficient way of removing phosphorus. For example, there is more phosphorus in a litter of bottom mud than in a ton of plants.

7.2.4 Sediment Removal

Removal of sediment is one of the best ways to restore a eutrophic lake suffering from internal loading to a prior state of acceptable water quality. However, it is also one of the most expensive lake management alternatives. The option also requires a large storage area for the sediments which is adjacent to the lake. Due to the large amount of sediment that would need to be removed from Tyhee Lake, and the high cost associated with this option, it ranked fourth in the ranking matrix.

There are many questions which would require an answer before this option could be implemented. This includes:

- What is the actual amount of sediment that would be removed? This depends on the areal extent and depth of phosphorus laden sediments.
- Could someone with dredging equipment be contracted to do the job and how much would it cost?
- What is the rate of sedimentation in Tyhee Lake?
- Where would the sediment be stored? Could it be composted and used by farmers as fertilizer?

If this option was going to be considered further, a more in depth study of the sediment and removal would need to be completed. To date, sediment core data indicates that surface sediments are enriched with phosphorus. Refer to section 8.4 for more information.

7.2.5 Sediment Covers

Sediment covers could be a useful way to reduce aquatic plant growth in localized areas. For example, sediment covers could be used in private beach and swimming areas. The covers would be purchased by private land owners and are quite expensive. If many local lake residents (perhaps including Lake Kathlyn, Seymour Lake, and other local lakes) are interested in purchasing the sediment covers, it may be possible to purchase the covers in bulk at a reduced price.

7.2.6 Circulation/Aeration

Another technique for increasing dissolved oxygen concentrations in the lake is circulation. This option ranked only fourth overall because although it increases dissolved oxygen levels, it also causes destratification. Complete mixing of the thermal layers in the lake leads to an overall increased temperature which may be detrimental to cold water species of fish (see Chapter 6.0 for more information).

Before this option can be given more consideration, the following questions must be answered:

- Does the Giant Pygmy Whitefish reside in the hypolimnion?
- Will the Rainbow Trout be able to survive if the temperature of the lake is increased?
- What would be the overall increase in temperature?

This option may not lead to a decrease in algal blooms or aquatic macrophyte biomass and is more suitable as a technique for maintaining sport fisheries but it eliminates cool water refuges for fish..

7.2.7 Aluminum Sulfate Addition

When added to a lake, aluminum sulfate binds phosphorus in the water column, forming a flocculate which then sinks to the bottom and aids in retarding phosphorus release from the sediments. The main benefit of this method is immediate reduction of algal biomass and increased water clarity. The treatment may benefit the lake for 5- 10 years or longer. However, before implementation of this option, there are a number of questions which need to be answered:

- Are there any adverse long term effects on lake residents who drink the water in lakes which have been treated with alum?
- What precise concentration of alum would be needed in Tyhee Lake?
- The effectiveness of alum is pH and temperature dependent. Would a buffer be required to ensure that the pH remains steady during alum addition?
- What is the rate of sedimentation in Tyhee Lake?
- What are the costs?

As discussed in Section 6, addition of aluminum sulfate may lead to an increase in aquatic plant biomass due to increased water clarity and decreased algal biomass.

8. Monitoring and Evaluation of Lake Quality

8.1 Water Quality

Monitoring data is essential as it allows us to compare the quality of the lake from year to year. An extensive baseline data set is already established for Tyhee Lake, allowing the development of first approximation of a P budget for the lake and comparison of water quality before and after implementation of lake management techniques A monitoring plan is essential from this point on to ensure aid in decisionmaking. Once a decision to proceed with a management option is made, those parameters which may assist in demonstrating a change (if one occurs) are first summarized and tracked over the implementation period. This allows continuing evaluation of the effectiveness of the actions taken, and provides a basis on which to determine "how much is enough". If it is desired, parameter specific goals such as a 50% reduction in total P concentration at spring turnover can be chosen ahead of time, and used to check original assumptions regarding the costs and benefits of the option.

To establish a nutrient budget for the lake, water chemistry sampling and flow rate data were collected for the inflowing creeks and outlet of Tyhee Lake. The lake was monitored in successive years by measuring temperature and dissolved oxygen at spring turnover (approximately two weeks following ice off). At the precise time of turnover occurrence water samples were taken at 5 meter depth intervals and sampled for concentration of total phosphorus, total nitrogen, nitrates, nitrites, and total Kjeldahl nitrogen. The phosphorus data has been reported and interpreted in the BC Environment Water Quality Objectives Annual Attainment documents for the period of 1987 to 1993. A summary of this data has been provided in an October 1994 Water Quality status Report brochure published by the ministry. Results indicate that throughout this period, the objective related to eutrophication effects caused by phosphorus of .015 mg/l total P has never been met at spring turnover. This spring turnover sampling for nutrients should be continued, and used as the primary indicator of eutrophication effects in the lake on an annual basis.

Sampling of this type requires a dissolved oxygen meter and probe (with a 30 meter cable between meter and probe), Hach DO kit for instrument calibration and Van Dorn water sampler for sampling at 5 m depth intervals. Pre-washed sample bottles and coolers for trans-shipment to the Ministry contract lab are also necessary. It is anticipated that this hardware can be made available to the Protection Society for use at turnover.

8.2 Creek Hydrology and Water Quality

During spring freshet in 1994 and 1995, most of the creeks flowing into the lake (as well as the outlet) were gauged and daily flow measurements taken throughout the freshet period. In addition, water sampling at each of the gauging locations was done on 8 occasions in 1994 and 3 times in 1995. Samples were analyzed for nutrients, including total P. In 1994, little attention was paid to the quality of outflowing water, and not all outflowing creeks were subject to flow measurements. This was identified as a deficiency in the dataset for nutrient modeling purposes, and was rectified in the 1995 round of sampling. This data was used for the nutrient budgeting exercise.

Further refinement of the phosphorus budget using additional inflowing creek data may be required once the P budget has been subject to a thorough review. This requirement would not necessarily have to be acted upon, unless serious deficiencies are identified in the near future. A decision to periodically (say every 5 years) repeat the phosphorus budgeting exercise necessitating additional rounds of creek hydrology and water quality sampling can be made based on the degree of management which the Protection Society is able to bring to bear on the lake. The Protection Society is presently working on carrying out another round sampling in the spring/summer of 1999.

The Water Management Branch of BC MELP has installed a permanent hydrometric station at the outlet of the lake. Flow rates are periodically monitored by ministry staff so that an ongoing indication of lake flushing rate on an annual basis is possible. This information is important in the context of judging the relative contributions of lake management options and the natural effects of annual climatic conditions (wet vs. dry years).

Once decisions regarding external lake management options have been made and implementation is imminent, a schedule of creek monitoring to track the success of nutrient limiting activities may be necessary. This may include a selection of target creeks, based on prior evaluation of anthropogenic nutrient sources. For instance, if those residents keeping livestock within the watershed choose to cooperate in limiting the entry of fecal nutrients into the lake, the success of these measures can be measured through monitoring specific creeks associated with the properties involved.

Tools necessary to continue this type of sampling include pre-washed bottles for grab sampling, plywood, 2x4 and sandbag constructed weirs on the larger creeks and a Parshall flume for periodic measurements of the smaller creeks. Bottles and the flume can be provided at no cost for use by volunteers by the Ministry of Environment. Shipping and lab analytical costs may amount to $3,000 - $5,000 pert year for this sampling. It is anticipated that these costs could be cost shared on an equal basis with the MELP EP Program, provided budgets allow. Materials for weirs may cost $200 - $300, depending on the number of creeks monitored.

8.3 Biological Sampling

Of most importance to the potential for implementation of some of the more invasive lake management options is the need to establish definitively the rare and endangered status (or lack of it) of the giant pygmy whitefish. The work entails the capture and DNA analysis of 20 fish from Tyhee Lake, and another control lake containing a known population of pygmy whitefish. This work will be done by a graduate student at the University of Northern BC, through a grant provided by the Habitat Conservation Fund (BC MELP).

As the lake management plan matures, it will be necessary to conduct inventories of algae, invertebrates and fish to monitor the "health" of the aquatic ecosystem. Inferences regarding the eutrophic status of the lake based on algal and invertebrate species present and their relative abundances can be made, and a warning of any impending changes in fish populations may be possible also.

8.3.1 Aquatic Macrophytes

Aquatic weed harvesting has been recommended as an immediately implementable management option. Once harvesting has commenced, a running tally of the tonnage of biomass removed is necessary, along with the harvesting locations. Once an annual weight has been calculated, then the weight of P removed can be calculated. This will be accomplished by converting wet weight to dry weight through direct measurement and conversion. Then dry weight P concentrations determined from lab analyses of a few samples can be used in a calculation of total weight of P/wet weight tonne. Sampling of biomass harvested will require no specialized equipment. The MOF lab in Smithers can be used to convert wet to dry weight, and biomass samples can be sent to the BC MELP laboratory for P concentration analyses. Costs for this work will be approximately $200 - $300 / year.

8.4 Sediment

Sediment studies including source identification (part of the inflowing creek studies) and documentation of nutrient sinks as sources of internal nutrient loading within the lake are necessary. Over the past 3 years it has been demonstrated that sediment cores taken from deep depositional zone(s) within a eutrophic lake can be used to make some extremely powerful inferences regarding the relative contributions of anthropogenic and natural nutrient sources. A combination of lead isotope (Pb^{210}) dating, diatom assemblage analysis and nutrient concentration analyses of slices of the sediment cores allows a determination of P loadings in 2 to 3 year intervals, (provided the sedimentation rate is sufficient). Then a comparison of “pre-settlement” loading rates with current rates conclusively determines the impact of settlement over the “post settlement” period. This would help in setting best lake watershed management strategies for the future.

In 1996 sediment cores samples were obtained from Tyhee Lake. The sediment cores were separated into 1 cm thin slices and shipped to Dr. John Smol at Quenns University in Kingston, Ontario for analyses. The results are contained in a sonn to be published report entitled “Paleolimnological Analyses of Cultural Eutrophication Patterns in British Columbia Lakes” and will be available through the Pollution Prevention Branch of MELP. The report was written by Euan D. Reavie and John P. Smol.

According to Reavie and Smol (1999), a qualitative assessment of diatom species changes indicates that Tyhee Lake is naturally productive (mesotrophic), but has eutrophied significantly in response to human impacts in the late 20th century.

Organic content in the lake sediment cores was lowest prior to ca. 1850, but increased to a s high as 52% in the 20th century, indicating an increase in organic inputs following settlement of the area (Reavie and al., 1999). A general increase in diatom-inferred total phosphorus concentrations within the last 40 years is a convincing indication of increased nutrient loading, occurred in response to human development (Reavie et al., 1999)

Tyhee Lake has a large watershed area relative to the lake's size, so it is not surprising that cultural activities have affected Tyhee Lake to a large degree.

The estimated costs for these analysis was between 5000$ and 6000$ per core. Now completed, core sampling and analysis would not need to be repeated in the foreseeable future.

8.5 Populations and land use characteristics of the drainage basin

One of the long range goals of the management plan is to ensure that as few new P loading sources as possible occur. These should be documented through the use of a periodically updated land use map and database. It should include the location and type of every potential loading in the watershed, including livestock pasturing and feedlot locations and number of animals present, onsite sewage disposal systems, and their state of functioning (to be documented on a voluntary basis), and any other discharges such as stormwater runoff from new housing subdivisions in the watershed. This map will then serve as a focus for such things as educational initiatives and loading source monitoring.

9. Implementation - Action Plan

9.1 Short Term

9.1.1 Plan Review and Revision - Testing

A systems design approach is subject to ongoing evaluation and revision, and it is accepted that a portion of the resources allocated to its implementation must be focused on refining it. In the first year of implementation, there should be a review of the plan by lake management experts. The review should also include those regulators who may be called upon to write permits and licenses or cooperate in some way to implement the various management options. Ensuring that this occurs should be the first priority, and could be easily accomplished with assistance from the MELP EP Program.

9.1.2 Financial Support

To begin implementation of the lake management plan, an overall budget is required. Costs may include:

- planning - sending the draft plan out for review to experts in the province and elsewhere
- contracts (e.g. hiring a contractor to design a hypolimnetic siphon system and determine final feasibility)
- equipment (e.g. pipe for siphon system)
- monitoring and evaluation programs
- monitoring and evaluation programs - training volunteers and carrying out needed water, sediment and biota monitoring
- permits (water licence fees for siphon system)

Acquiring adequate funding to cover implementation costs will be challenging, therefore a funding strategy must be developed. Once a consensus on the management options has been reached, the level and duration of funding needed must be identified.

Some options for raising funds include:

- voluntary donations, which should be sought in a systematic manner, such as an appeal campaign
- modifying the lake association to allow the ability to collect revenue in the form of membership dues from anyone interested in helping.
- formation of a taxing district regulated by the Regional District. There are two possibilities for forming one, the Local Service Area or the Local Improvement District. More information on the process of establishing one of these areas can be obtained from the Bulkley Nechako Regional District.
- application for grants or loans from public agencies. Grants or loans from public agencies include options such as the Habitat Conservation Fund, the Public Assistance Conservation Fund, the Water Stewardship Grant, and the BC 21 Program. An example of this process at work can be found in the Bulkley Valley. The Lake Kathlyn waterfront property owners voted in a Spring 1995 referendum sponsored by the Regional District of the Bulkley Nechako to form a taxing district. All waterfront

property owners will pay a parcel tax each year for five years. The money is collected by the Regional District and will be used to maintain the Club Creek diversion which was originally implemented through volunteer labour, voluntary donations and assistance from the Water Management Branch of BC Environment. This option is one of several currently being implemented by the Lake Kathlyn Protection Society. In this case, a goal of twenty thousand dollars was set and the sum was divided by the number of waterfront property owners over a five year program.

Committees should be struck immediately to formulate the financial strategy. Fundraising methods should be inventoried, evaluated and decisions made as to their applicability in this instance.

9.1.3 Volunteer Groups

Committed volunteers are essential to the success of the plan. Managing a lake is an ongoing process and a mechanism is needed to keep the plan in motion after the plan is written. therefore an aggressive membership program is needed, that is flexible enough to accommodate more than one level of participation (both financial and volunteer wise).

Volunteer groups who will assist with the implementation of the plan must be identified. In the Bulkley Valley, this may include, but is not limited to:

- Lake Protection Societies
- Friends of the Bulkley
- youth and service clubs (4H, Rotary etc.)
- North American Lake Management Society, BC chapter
- BC Lake Stewardship Society

Volunteers can also assist with monitoring. One method of ensuring that tasks are completed successfully includes placing the volunteers in groups (committees), delegating tasks to each group and making sure adequate training is provided. Each group consists of one leader and their assistants. Each group is responsible for completing a set of well defined tasks. Examples of volunteer subcommittees are:

- funding
- sampling and monitoring

- land use
- education

To ensure that the tasks are carried out indefinitely, no leadership position is to be vacant in any given year. An evaluation of the group's status should be held at regular intervals. Lake and inflowing stream monitoring can be carried out by properly trained volunteers. It is recommended that a training program be set up immediately in conjunction with MELP EPP to enable the volunteers to learn proper procedures for the necessary sampling.

9.1.4 Regulatory Agencies

Most of the affected regulatory agencies have been consulted and involved in the development of the lake management plan. It is essential to identify all affected regulatory agencies and obtain the necessary approvals and permits. When applying for permits and approvals, it is helpful to include a deadline for which the approval is needed as it will allow the agency to priorize incoming applications for approval. Allow sufficient time for the agencies to respond.

The first step towards contacting all the necessary regulatory agencies is to determine the effects of the option (e.g. hypolimetic siphoning will affect Tyhee Lake and the Bulkley River). Using Table 10 below, identify the agency which has the authority to regulate these effects (e.g. Department of Fisheries and Oceans or BC Environment, Fish and Wildlife). Finally, contact the affected agencies and obtain the necessary approvals which may be in the form or a permit, approval, license, or a regulation.

9.1.5 Aquatic Weed Harvesting

It has been accepted by a number of lake management experts that aquatic weed harvesting conducted at a modest scale will at worst do no long term harm, and at best improve esthetics in harvested areas and remove nutrients in the form of biomass from the lake, rendering it unavailable.

It is recommended that aquatic weed harvesting commence as soon as is practical. A multi-year harvesting plan should be developed and executed. This should include harvesting locations and timing as well as a disposal plan that does not impair other waterbodies. This could occur through leaching of nutrients from the rotting aquatic vegetation. It is likely that MELP harvesting equipment can be made available for some or all of the harvesting through Mel Maxnuk, head of Aquatic Plant Management in the Vernon office (see Appendix 5 for more details)

Table 10: Activities and Associated Regulatory Agencies

Activity	**Regulatory Agency**
Land Use Control	• Regional District - Zoning Bylaws • Village of Telkwa - Bylaws • Municipal Affairs - Official Community Plan • Ministry of Transportation and Highways - Highway Planning • Ministry of Forests - Local Resource Management Plans and Cutting Permits • Ministry of Agriculture - ALR
Health	• Ministry of Health - Public Health Inspector • Health and Welfare Canada
Pollutants	• Ministry of Environment, Environmental Protection Program • Ministry of Agriculture - Ag. Waste Regulation
Fish and Wildlife	• Department of Fisheries and Oceans • Ministry of Environment, Fish and Wildlife
Public Land	• Ministry of Environment, Lands and Parks - Crown Lands, Parks • Ministry of Forests - Recreation Branch
Water Management	• Ministry of Environment Lands and Parks Water Management Branch
Land Development	• Ministry of Transportation and Highways - Subdivision Approvals • Ministry of Agriculture - ALR • Ministry of Environment, Lands and Parks - Environment Referral service

9.1.6 External Lake Management Options

All of the external lake management options are implementable immediately.

9.1.6.1 Public Education

The education component has been underway since May of this year, and has included a major initiative by the Telkwa Elementary School to bring the science of lake management into the classroom, and the homes of its students. Part of the school program is a public education campaign aimed at a broader audience including other schools and the general public. Funding was provided under the Partners in Science Program of the provincial government. The grant will be spent throughout the period ending in March 1996, although plans are being made by the school to ensure that resources will be available in succeeding years to carry on with the initiative. Participation and assistance in this initiative should be a high priority for the Protection Society.

In addition to the school program, other means of heightening awareness through educational opportunities should be sought. These might include soliciting help from the BC Parks interpretive program staff, promoting environmentally friendly recreational use through signage on and around the lake (no power boat use zones in sensitive areas for loon nesting and brood rearing), provision of brochures to be distributed at Tyhee Lake Provincial Park, Volunteer run booths at public functions such as the fall fair, promoting public education and membership, making presentations to service clubs, chambers of commerce, town councils, schools, showing the management plan and what progress has been made to date and soliciting media coverage of the implementation of the plan and at milestones within it, such as fundraising targets for installing and maintaining siphoning equipment.

9.1.6.2 Affecting Inflowing Stream Water Quality

<u>Agricultural </u>runoff control has been a priority in the past for the Koopman dairy farm on Tyhee Lake Road. It is apparent from stream water quality results that some fine tuning of livestock operations and pollution control works could further reduce nutrient inputs to the lake (Appendix **??** Inflowing stream Data). It is also apparent from the stream

quality data that a large number of other nutrient sources should be addressed. These will include other livestock inputs, from both large acreages and hobby farms, as well as those from failing septic systems. The stream water quality database should be analyzed by the Protection Society using local knowledge of land use activities to set priorities for action. Since this will involve private property and individual property owners with limited resources, it is suggested that guidelines for land development and use similar to those published for the Regional District of Fraser-Fort George (Lakeshore Guidelines) be written and distributed to land users in the watershed as a first step. This could be done by a small subcommittee with guidance from the Regional district and MELP EPP. This should then be followed with a voluntary program promoting participation in efforts to limit nutrient inputs to the lake. The program could include tile field inspections by the Environmental Health Officer, with recommendations for improvement if required on a voluntary property by property basis. The current EHO has already expressed a willingness to participate in such a program. Similarly, the District Agriculture Representative could be invited to engage in a similar program for agricultural lands within the watershed. Means of acquiring financial assistance for landowners facing the prospect of major works to eliminate nutrient inputs to the lake should be sought and developed. Hopefully this along with the public education initiatives will provide the impetus for action. If these efforts fall short of the desired effect, then enforcement of pollution control statutes by government should be considered and sought if deemed appropriate.

9.1.6.3 Controlling Nutrient inputs From New Developments

New developments slated for the watershed should be carefully monitored at the earliest stage possible, to ensure that nutrient and other contaminant input concerns are addressed "up front". This planning function is best done through the incorporation of bylaws into the Smithers/Telkwa Official Community Plan administered by the Bulkley Nechako Regional District. Once discussions with Regional District staff have been initiated, it may become apparent that the formation of a local improvement district or similar designation will provide additional means of regulating land uses to assist in lake restoration. In addition to this, new environmental protection legislation being evaluated by the government may provide new means to regulate the land use to reduce or eliminate nutrients and other contaminants entering the lake.

If high density residential development in the watershed is contemplated by the village of Telkwa, then planning for placing these lots on the central sewer system should take place. The Protection society should appoint a member to monitor the development of such plans at the local government level, as well as through MOTH.

9.1.6.4 Preventing Nutrient Inputs Through Forest Management Planning

Although there does not appear to be much forest management in the Tyhee Lake watershed, representation of the Society on the Local resource Management Planning (LRMP) committee should be sought. This will provide a link at the appropriate level to alert the Society to any possible changes to the status quo.

9.1.7 Monitoring - Immediate Needs

9.1.7.1 Eutrophic Status Of The Lake

Prior sampling and analyses of water quality and aquatic life (phytoplankton and zooplankton) has established that Tyhee lake is quite eutrophic. All of the qualitative evidence available points to the theory that although the lake is naturally eutrophic, human caused inputs of nutrients in the last 80 years has greatly speeded up the rate of eutrophication. The quatitative evidence to further support this theory comes from the results obtained from sediment cores analyses conducted by Euan Reavie and John Smol as described in section 8.4.

In addition to this work, a number of sediment grab samples representative of the range of depths and area of the lake should be taken and subject to lab analyses for P concentration. This will assist in determining the extent of the lake bottom that must be affected by any internal lake management options implemented. sampling should be carried out by volunteers under the supervision of MELP EPP staff. Analyses may be cost shared with EPP depending on budget availability.

9.1.7.2 Extent of Aquatic Weed Coverage

A mapping exercise to determine the approximate extent and locations of the Elodea canadensis coverage in the lake is needed. This should be done using a sampling method which provides a rough level of quantification of the biomass of the plant by location. This could be done by setting permanent transects between known landmarks, and measuring the approximate depth of the water and volume occupied by plant material. A conversion to biomass could then be made if a cylindrical sample of known volume could be cut through the mass, and the weight (both wet and dry) of plant material determined. Once this baseline has been established, then the effects of the management options employed on weed biomass ca be established in future years.

During harvesting operations an attempt should be made to determine the biomass removed from the lake, so that nutrients sequestered from the lake by this method can be determined. This will assist in ongoing evaluations concerning which lake management options may be causing the greatest effect.

9.1.8 Long Term Needs

9.1.8.1 Spring Turnover Sampling

The most important indicator of the eutrophic status of the lake on a year to year basis is the average P concentration of the depth profile at the deepest part of the lake at spring turnover. This time period (turnover) is brief, and it is difficult to track whether turnover has actually occurred. It is also suspected that Tyhee Lake may be subject to incomplete mixing and destratification in some years, further complicating the problem. Nevertheless, it is important on a yearly basis to sample the depth profile at deepest parts of the two basins in the lake. If turnover is detected, and the profile shows uniform P concentrations, then calculations of the instantaneous P mass in the lake are straightforward. If turnover is incomplete, then the added step of documenting P concentrations in each of the depth slices of the lake (defined by the bathymetric profile) must be completed. This yearly exercise over the period of many years will provide the “yardstick” by which judgments about the success of the lake management plan are made. MELP EPP did turnover sampling and analyses in 1996. In future years however, it may be necessary for volunteers to carry out this sampling. Once again, it is expected that budget permitting the costs associated with these analyses would be shared beyond 1996. It is estimated that this program would require $300 - $500 in analysis costs, depending on how many rounds of depth profile sampling are needed to ensure that spring turnover (well mixed conditions) has been sampled.

9.1.8.2 Nutrient Budget - Success Indicator

One of the most difficult tasks in lake management planning is creating a nutrient budget (phosphorus in this case) that provides a high degree of confidence for decision making at an affordable price. Tyhee Lake has been subject to sporadic water quality sampling for a period of almost 10 years, and yet the P budget still remains subject to a high degree of potential error. In 1994 an attempt was made to refine the budget by inputting measurements of the quantity and quality of inflowing streams. Weirs were put on 4 streams, and water quality sampling was conducted at weekly intervals on these streams as well as most of the others providing water to the lake. This provided a coarse indicator of the relative contributions of internal vs. external loadings to the lake (see appendix 7 for the data and P budget calculations). It was determined from this data that the majority of P loading at turnover was attributable to internal sources, but the potential margin of error was quite large. In an attempt to refine the P budget, another round of inflowing creek sampling was initiated in the spring of 1995. This time all creeks were subject to quantity and quality measurements on 4 occasions during the freshet period, and the outlet stream was sampled as well. When the P budget was refined using this data it confirmed the previous model, but showed that P loadings from both internal and external sources were higher than those from the previous year. Since this was the case it is suspected that there were laboratory analysis problems associated with the 1994 dataset, as opposed to there being large changes in loading rates from one year to the next. This interpretation has been corroborated through discussions with EPP biologists throughout the province.

Since a years worth of inflowing creek and lake data is suspect, it may be necessary to continue with the P budgeting exercise future. A decision on this awaits a thorough review of the existing data by a number of experts in nutrient budgeting..

Regardless of the nutrient budgeting sampling needs, it is apparent from the 1995 inflowing creek dataset that P sources to the lake are both considerable and widespread. It is possible that since the nutrient flush occurs in such a short time period, that some of the larger sources have been missed using a sampling frequency of 4 times in 40 days. It is therefore recommended that the inflowing creek sampling program be repeated at a higher frequency for those creeks that over the 2 year sampling interval have shown P concentrations in excess of the WQO of .015 mg/l. this should include both quality and quantity measurements. As nutrient source control options are implemented, creek quality and quantity sampling should be done to track whether actions are successful in reducing nutrient inputs to the lake. Care will need to be exercised in establishing a database that accounts for the vagaries of weather from one year to the next. Of particular importance in this regard is the timing and frequency of sampling necessary to capture the period of greatest loading. Funding for creek monitoring should be proposed on a cost share basis with MELP EPP, using ministry lab services if possible.

9.2 Long Term

9.2.1 Hypolimnetic Withdrawal

A final feasibility study and an engineering design for a siphon system including specifications for its installation and operation should be developed, along with a cost breakdown and tentative implementation schedule. This will require the expertise of an engineering consultant with relevant recent experience in this application.

Once the system has been designed and funds have been secured for implementation, the system should be installed and operated until the desired effect of reducing internal P loading from bottom sediments is achieved. An appropriate means of objectively measuring progress of the plan through sediment and water chemistry must be defined prior to commencement.

9.2.2 Other Internal Lake Management Options

Although it is recommended that hypolimnetic siphoning be the focus of inlake management efforts, there may be some advantage to localized use of geotextile fabric on the lake bottom in those areas where shoreline eradication of aquatic macrophytes is desirable. If there is enough demand for its installation, there may be some advantage in bulk purchasing. This should be investigated.

Some new studies of the use of predatory (piscivorous) fish which feed on zooplankton consumers are showing promising results. The premise is that predatory fish feeding on zooplanktivorous fish cause increases in zooplankton which graze on algae. As zooplankton populations increase, there is a corresponding decrease in algae. Studies of this nature, and others focusing on new and novel approaches to eutrophic lake management should be kept track of through the North American lakes Management Society (NALMS), and the newly formed BC Chapter. Information regarding gaining membership should be obtained from Dr. Rick Nordin of MELP Water Quality Branch in Victoria.

9.3 Genetic and Population Status of the Giant Pygmy Whitefish

Regardless of which management options are employed, it is essential to move ahead with determining the genetic and population status (rare and endangered) of the giant pygmy whitefish. A graduate student working under the auspices of UNBC and funded by a grant from the MELP Habitat Conservation Fund should be commencing this research in the fall of 1995. This work should be monitored, as the rare and endangered status of the fish may affect the ability of the Protection Society to try aggressive means of reducing eutrophication, such as stocking the lake with piscivorous fish. It is anticipated that this graduate student will make contact with the Protection Society as part of his or her studies.

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LIST OF APPENDICES

SYSTEM 1: Physical

A) Nutrients: External Loading

- Point Source:
  - septic
  - creeks - documented and undocumented (some non point characteristics. Example: forestry)
- Non-Point Source:
  - air
  - rain/snow
  - groundwater
  - watershed - overland runoff
    - sediment
    - agriculture:
      - * organic matter
      - * excrement
      - * fertilizer
    - domestic

B) Nutrients: Internal Loading

- Decaying organic matter
- Sediment
- Bathymetry
- Outlet Characteristics
- Wind
- Turnover: complete or incomplete
- Flushing Rate:
  - inflow
  - diversion
- Water level
- Erosion
- Accretion/infilling
- Backfilling
- Boat wakes:
  - with respect to erosion
  - with respect to resuspension of sediments and matter
- Organic
- Other Chemicals
- Toxins

SYSTEM 2: Socio-Economic

A) Human values

- Fishing
- Vision of the lake (residential)
- Recreation:
  - park facilities
  - viewing
  - beaches
  - trails
  - camping
  - tourism
- Resistance to change
- Land uses:
  - agriculture
  - dairy
  - horse
  - cultivation
  - forest managers
  - residential
    - garden and horticulture
    - sewage disposal
    - existing and new development
  - recreation - dispersed versus intensive users
    - campers
    - day users (beaches)
    - boaters: * ski
      * fish
  - transportation
  - institutional - camps (ex: Camp Caledonia on Tyhee Lake)

B) Taxation/Monetary Assistance

- International: ex. World Health Organization
- Federal: ex. NSERC
- Provincial: ex. Habitat Conservation Fund (BC Environment)
- Regional District ex. Local Improvement District and other taxation instruments
- Town/Village ex. - Social contract (machine funds)
  - Health and social needs for citizens

C) Regulatory Agencies

- Promote or constrain action through statute or policy
- Federal - DFO contact: **Pierre Lemieux**
- Provincial
  - Water Management contact: **Reid White**
  - Fish and Wildlife contact: **Brian Fuhr**
  - BC Health contact: **David Butt**
  - BC Parks contact: **Jim Dehart**
  - Transportation and Highways contact: **Lorne Kelly**
  - BC Agriculture contact: **Dave Riendeau**
- Regional District - Bulkley Nechako contact: **Jay Simons**
- Town/Village (Stormwater Regulation)

D) Institutions

- Examples:
  - North America Lake Management Society (NALMS)
  - Ducks Unlimted
  - Sport Fishing Association ?
  - UBC Fisheries Research
  - EPA-US
  - Lake Protection Societies
  - Guide Outfitters Association

SYSTEM 3: Biological "population and habitat"

- plants and animal species present
- gene pool
- option value

- Water Quality Criteria for:
  - protection of life
  - human consumption
  - human contact
  - irrigation
  - livestock/wildlife

- Aquatic Life (macrophytes)
  - Flodea Canadensis and other submergent growth
  - Algae
  - Benthic (bottom feeders) and Pelagic (floaters)

- Invertebrates
  - Emergent macrophytes (reeds, cattails etc.)
  - Pathogens
  - Decomposers - bacteria
  - Fish:
    - excluded species
    - fish population and habitat
    - fish stocking/stock management

- Terrestrial
  - riparian vegetation
  - wildlife:
    - moose
    - eagles
    - loons and other waterfowls
    - beavers
    - other furbearers

THE SYSTEM DESIGN APPROACH

- this is a problem solving model
- used to set up a framework for decision making which is flexible enough to allow integration and consideration of new information and data as it is made available
- designed to initiate creative thinking about complex physical and social problems

THE FIVE PHASES TO THE SYSTEM DESIGN APPROACH

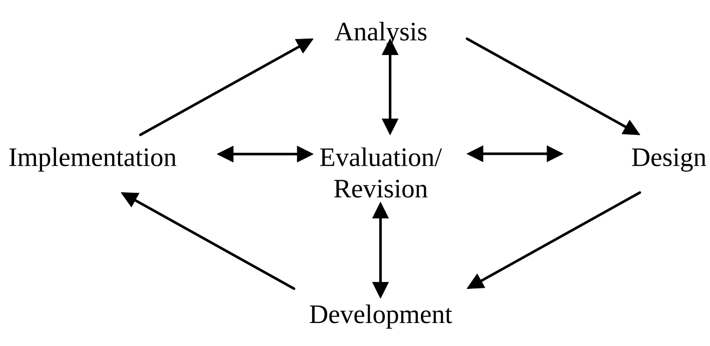
ANALYSIS: the process by which the goal(s) and requirements of the plan are identified and refined (Why do we need a plan?)
For example, the goal may be to reduce the rate of cultural eutrophication (the excessive addition of materials carried into the lake due to human activities).

DESIGN: During this phase, the specifications for meeting the lake management plan goal(s)
are identified. For example, specifications may include nutrient concentrations, algal biomass and the aerial extent of macrophyte growth within the context of chemical and biological systems.

DEVELOPMENT: This is the process of creating or improving a system in accordance with system specifications. The plan is improved and revised according to feedback from you, the stakeholders.

IMPLEMENTATION: This is the process of trying out the system to see how it works.

EVALUATION/REVISION: This phase drives the process and is implemented throughout. It involve determining how well the system is working, identifying
possible improvement. Improving the system makes it work better.



<u>Figure 1</u>: Interactive Model of the Systems Design Approach (Spitzer, figure 2.4, 1991)

APPENDIX C

List of Stakeholders

ORGANIZATION/ASSOCIATION	CONTACT NAME	PHONE	FAX
Bulkley-Nechako Regional District	Jay Simmons	692-3195	692-3305
MELP Parks	Jim Dehart	847-7655	847-7659
MELP Water Quality Branch	Reid White	847-7275	847-7591
Department of Fisheries and Oceans	Pierre Lemieux	847-3916	847-4723
MELP Fisheries Branch	Ken Ashley	222-6751	660-1849
Ministry of Transportation and Hwys	Loren Kelly	847-7403	847-7219
Tyhee Lake Protection Society	Gary Rysavy (pres.)	847-4045	
Lake Kathlyn Protection Society	Allison Candelat (pres.)	847-2211	
Ministry of Agriculture	Dave Riendeau	847-7246	847-7592
Ministry of Health and Safety	Dave Butt	847-7360	847-7557
B.C. Lakes Stewardship Society	Michelle Boshard	868-1027	

Cost Benefit Analysis of Lake Management Options for Tyhee Lake

Option	Explanation	Costs	Benefits
do nothing	allow eutrophication to proceed at unknown rate	• unknown	• none
lime (calcium carbonate)	not applicable (need alkaline lake)		
alum (aluminum sulfate)	bind P to alum to reduce in-lake P cycling	• lasts 5 - 10 years depending on amt. added • reduces pH (unless applied with a buffer) • increases growth of rooted plants (ex. *Elodea*) • effectiveness is temperature/pH dependent • aluminum:alzheimers correlation (? - concern, but still contentious - no strong tie) • alum is cheap, but application is expensive (in the area of $200,000 for Tyhee Lake)	• immediate results • increased water clarity • decreased algal blooms
copper sulfate	addition of excess copper to the ecosystem works as an algacide	• this option treats a symptom of eutrophication rather than addressing the problem itself • effects are very short term • annual costs are high ($200,000) • negative impacts on nontarget organisms (toxic to fish) • negative impacts on benthic invertebrates and possibility of completely destabilized ecosystem • contamination of sediments with copper (reaching levels of high toxicity) • does not affect macrophyte growth • requires pesticide permit	• decreased algal blooms • can be used to control ‘swimmer’s itch’ • immediate and highly effective results • increased water clarity

Option	Explanation	Costs	Benefits
diversion/pristine water inflow	pipeline or ditching from source to lake	• need water source with 1/10th nutrient concentrations of lake water • ditching or pipeline required (approx. $50,000 to install) • improvement in water clarity is directly related to increase in flushing rate • need water license • need $ for yearly maintenance (approx. $10,000/year) • uncertain rate of results	• potential long term results • potential increase in flushing rate • potential to improve water esthetics • potential increase dissolved oxygen levels
hypolimnetic withdrawal	removal of P rich hypolimnetic water by siphon through the outlet and into the Bulkley River	• initial installation relatively expensive because of size and topography of lake *(cost estimate coming from Prolite Plastics should be approx. $20,000)* • will have some impact on outfall creek (used for spawning) • very small time window in spring when water can be siphoned off while maintaining water level (if necessary) • *what is volume of hypolimnion? what is max. amt. of water which can be removed (normal outflow volume)?*	• many examples of this technique proven to be effective • maintains lake stratification while eliminating anoxic layer (but this will not happen if pumping only occurs in spring) • easily regulated • low annual maintenance costs • no environmental impact to lake
hypolimnetic aeration	maintenance of oxidative state on bottom reducing P dissolution on bottom of lake	• expensive to install *(need $$)* • expensive to maintain • tricky to make aerator work effectively • only feasible if the P internal loading process is controlled by redox, not likely to see positive effect if P liberation is due to microbial activity or non-oxygen dependent processes	• maintains lake stratification • provides oxygen to oxygen deficient water

Option	Explanation	Costs	Benefits
circulation/aeration	complete circulation of lake water in order to destratify and aerate the lake	• destratifies lake • most effective in non nutrient-limited lakes • expensive to install ($200,000) • can cause increased P in the water column, if p release from the sediment is controlled by calcium • can increase blue-green algal blooms • increases lake temperature (especially of hypolimnion which is habitat for cold water species of fish) • may increase internal loading (depending on lake processes at sediment/water interface) • open water could create winter safety hazard (if aeration continues throughout winter)	• increases dissolved oxygen content throughout the lake • can prevent fish kill over winter in shallow lakes • increases habitat for aerobic organisms • can decrease P if controlled by iron
sediment removal/pumping	removal of high phosphorus sediments from the lake basin using a hydraulic dredge	• must transport sludge/sediment somewhere • need large disposal area capacity • sediment pile can create a 'tailings' pile with acid drainage • expensive equipment needed • cost in $1,000,000's range • pumping costs very high • very large amount of sediment to be removed from basin • must determine sedimentation rate before dredging • can cause resuspension of fines which may be harmful to organisms	• effective in small applications • sediment/sludge at Tyhee Lake is approx. 50% water (therefore easy removal with hydraulic dredge) • long term/permanent solution • decrease internal P loading (assuming that the deeper sediments are "better" than the surface ones)

Option	**Explanation**	**Costs**	**Benefits**
weed harvesting	removal of macrophytes from lake	• need area to haul weeds to (compost area) • may see increase in weed growth as an immediate result (fragments escape and may spread plants) • uncertain effects on algae • need equipment - barge/boat and cutting tools • may harvest young fish with plants • harvesting will not eradicate plants as it does not remove root systems	• quick results in small areas (an acre or two per day maximum) • may foster volunteer spirit • localized method/controllable
grass carp	introduction of sterile (triploid) grass carp into the lake to reduce vegetation (control aquatic plant growth)	• introduction of carp to a lake changes the ecosystem • need permit from BCE- Fish and Wildlife Branch (very unlikely to get approval) • grass carp eliminate aquatic vegetation which provides valuable hiding places for young fish and important food for waterfowl • carp are very difficult to eradicate • difficult to estimate stocking rates • very expensive	• reduction of macrophyte biomass • selective feeding (prefer Elodea)
sediment covers	using light blocking screens to cover and kill the rooted plants	• very expensive ($20,000 per acre) • need to cut slits in material because gas evolution from the sediments will cause barrier to "float"	• effective in small areas (good idea for around docks and swimming areas)
water level drawdown	removal of approx. two thirds of the lake water for the winter in order to expose the macrophytes to extreme weather conditions	• very expensive (high pumping costs) • may have negative impact on fish populations • tested on *Milfoil*, didn't see a lot of benefits • need reservoir • doesn't actually remove excess P from lake	• may kill rooted macrophyte populations • may compact flocculent sediments

APPENDIX D

Option	Explanation	Costs	Benefits
public education - includes household product use fertilizer/detergent	campaign to increase awareness about product use among people living in the catchment basin	• difficult to be effective and hard to judge success • difficult to target large and diverse populations	• long term changes • increased awareness
agriculture runoff control & treatment	use of ditches to catch and divert nutrient rich runoff from entering the lake	• expensive - cost borne by individual farmers • treatment works require maintenance • reduces area of pasturage	• immediately effective - reduces nutrients/pathogens to the lake • may improve forage production
septic system failure definition remediation/maintenance		• difficult to diagnose problems • cost borne by individual • difficult to measure results • inputs from septic systems only comprise a small portion of the nutrient loading problem	• fairly immediate result
sewage systems installation	installation of a community sewage treatment plant	• very expensive • cost borne by lake residents	• immediate result of input from this source is significant
control of forest management			
control of inputs from new development			

APPENDIX E

Except from a letter on Provincial Weed Harvesters. The letter dated May 25 1995 was sent to Mr. Ian Sharpe, Environmental Impact Assessment Biologist and was written by Mr.Maxnuk, Head of aquatic Plant management at the time.

MACHINE AVAILABILITY

The province owns five aquatic plant harvesters. Three are committed for the use on Eurasian watermilfoil management programs in the Okanagan/Shuswap area. These machines are used extensively during early summer; it is unlikely any would be available at he time of the year when one would be required in the Smithers area.

One of the five machines was damaged in an accident and is not operational at this time.

The fifth machine has been loaned to the Regional District of Fraser Fort George for use in Tabor Lake near Prince George. This machine is not dedicated for exclusive use in Tabor Lake; it could be used in other lakes in the area. Use in your area would have to be coordinated with Tabor Lake operation.

CONDITION FOR USE

The aquatic plant population proposed for management must constitute a significant nuisance. The weedbeds must be extensive and dense and have either a negative impact on human use of the water body or an adverse environmental impact. On many occasions when people report a bad weed problem, upon investigation we observe either sparse growth or very small weedbeds that do not warrant using a machine the size of one of our harvesters. Ideally, I would like to have someone who is knowledgeable in aquatic plant management observe the areas proposed for harvesting and confirm that the degree of weed growth is severe enough to warrant this method of control.

Any aquatic plant management activity would have to be approved by the appropriate environmental agencies in our office and perhaps DFO if there is a salmon concern.

The project would also have to be supported by the local municipal authority that has jurisdiction in the areas proposed for harvesting. We do not loan our machines to groups or private citizens, societies, associations, etc. The local municipal authority would have to assume responsibility for the project and any loan of equipment would be made under the terms of a written agreement between the local authority and the Province.

The project would have to be fully locally funded. We are not in a position to provide financial support. If requested, one of us can visit the area to do the initial assessment. We also can provide assistance in making arrangements with the local authorities.

The machine must be operated only by a person who is fully trained and experienced with the specific machine being used. The operator must demonstrate to us competency in the operation of an aquatic plant harvester.

A work plan must be drawn up and operations conducted according to good aquatic plant harvesting practices.

TRANSPORT COSTS

Due to its relative proximity and availability, the machine most likely to be used in the Smithers area would be the one that is currently on loan to the Regional District of Fraser Fort George. I have no idea what the transport costs would be. I suggest you contact a commercial transport company for an estimate. In the Okanagan/Shuswap, the harvesters are transported on a low trailer that can unload the machine directly into the water in the same way that launches a boat from a boat trailer. If the boat launches around Tyhee Lake and Lake Kathlyn are inadequate or if the transport company is not willing to submerge the rear wheels of their trailer, the machine must launched and retrieved using a crane. Suffice to say that transport costs will not be insignificant. If your harvesting project proceeds into the planning stage we would be glad to provide specific advice regarding transport.

Lake Kathlyn Protection Society
Box 4513,
Smithers B.C.
V0J 2N0

Mr. Ian Sharpe
Environmental Protection
Bag 5000
3726 Alfred Avenue
Smithers B.C.
V0J 2N0

Dear Mr. Sharpe:

Thank you for your support this year. In particular, thank you for arranging the student employment grant for development of a Lake Management Plan, and for applying for and gaining a Lake Stewardship Grant for our society and the Tyhee Lake Protection Society. Your work on behalf of the environment in our local community is very much appreciated by the society.

At our meeting last Thursday, August 3, we discussed what you believed would be the minimal testing requirement for a water quality, sediment quality, and hydrology profile of Lake Kathlyn. You stated that you felt that this was a necessary requirement for the development of a phosphorus budget for Lake Kathlyn, and would give us the data needed to make informed choices within the Lake Management Plan.

Consequently, the executive of the society requests that you approve the following plan for the expenditures of funds granted to us under the Lake Stewardship Programs.

1. The expenditure of a maximum of $5150 for sampling and analysis to be done at freshet in 1996. This would be done on a cost sharing basis with the Environmental Protection Program funds, providing EPP funds are available. This would make $5150 available for a sampling program, and our society would be responsible for a maximum of 2575.00.

The funds would be spent in the following area:

A) **Water Sampling for nitrogen and phosphorus analysis:**
   a) 8 stations on 6 sampling dates through freshet
   b) 1 deep station on three sampling dates at turnover

The costs would be as follows:

*The first two dates at $80 per site:	$1280
*Remaining six dates at $25 per site:	$1200
*Deep station turnover sampling:	$ 240

B) **Sediment Sampling**

Core at deep station: (Lead 210 dating and diatom assemblage)	$2000
Chemistry (12 slices at $15 (TP):)	$180

C) **Hydrology**

Five weirs of plywood v. Notch construction. 4 inflow, 1 outflow:	$250
TOTAL COST	**$5150**

The expenditure of $2575 would leave us with $4925. As I informed you earlier, we would like to spend this money on maintenance of the diversion works at Glacier Gulch, which is bringing glacier water into Lake Kathleen again, and weed harvesting.

Our estimated expenses in this area are:

*Insurance costs for 1995/1996 re: diversion works	$1050
*Maintenance costs for cleaning of the silt trap, cover for the manhole, new screen, plus other costs which may occur before January 1996 when the Regional	

District takes over maintenance costs.	$1375
*Weed clearing costs	$2500

These costs total to the 7500 which was received by our society under the Lake Stewardship grant. We will also commit the Lake Kathlyn Protection Society funds to a maximum of $200 for a sampling training session with a technical person from the ministry who can train our volunteers in sampling procedures for the tests to be done in the spring of 1996.

I hope that this budget plan meets with your approval. I look forward to hearing from you in the near future.

Once again, thank you for the many hours of out-of-office time that you have volunteered to our society. Your professional knowledge makes your contribution as a volunteer, along with that of Mr. McGonigal who works at Water Management, of tremendous value to our society. We would simply be unable to make progress in rehabilitating the lake without your knowledge, support and assistance.

Yours sincerely,

Alison Candela
Director acting for the Kathlyn Protection Society
847-5624 (town) or 847-5697 (lake)

APPENDIX G

Tyhee Lake Inflowing Creek Water Quality

Site	Date	Average of Total P mg/l	Flow l/s	P loading g/day	Total P loading g
Below Horse Camp	24-Apr-95	0.013	2.4	3	42
Burger creek	18-Mar-95	0.109	0.1	1	19
Burger creek	7-Apr-95	0.106	0.1	1	
Burger creek	25-Apr-95	0.01	1.2	1	
Fisher Rd Jcn Creek E219765	17-Mar-95	1.03	48.8	4345	67341
Fisher Rd Jcn creek E219765	7-Apr-95	0.033	0.1	0	
Fisher Rd Jcn creek E219765	25-Apr-95		0	0	
Fox creek E219761	18-Mar-95	0.603	5.6	290	4490
Fox creek E219761	7-Apr-95		0	0	
Fox creek E219761	25-Apr-95		0	0	
H.C. Overland Runoff - Pasture	17-Mar-95	2.28		0	
H.C. Overland Runoff - Paddock	17-Mar-95	4.16		0	
Hidber subdivision Creek	17-Mar-95	0.142	1	12	190
Hidber subdivision Creek	7-Apr-95	0.01	0.8	1	
Hidber subdivision runoff	17-Mar-95	2.75	6	1426	22097
Hidber Rd Creek E219767	17-Mar-95	0.406	7.5	263	4078
Hidber Rd creek E219767	7-Apr-95	0.024	17	35	
Hidber Rd creek E219767	25-Apr-95	0.016	22	30	
Hislop rd. Creek E219771	18-Mar-95	0.385	7.5	249	3867
Hislop rd. Creek E219771	8-Apr-95	0.035	3.9	12	
Hislop rd. Creek E219771	25-Apr-95	0.019		0	
Hoeks Creek E219766	17-Mar-95	0.414	9.7	346	5356
Hoeks Creek E219766	7-Apr-95	0.067	1.2	7	
Hoeks Creek E219766	25-Apr-95	0.047	0.4	2	
Horse Camp E219762	17-Mar-95	1.23	0.3	27	412
Horse Camp E219762	7-Apr-95	0.02		0	
Howards creek E219764	17-Mar-95	0.486	0.5	21	319
Howards creek E219764	7-Apr-95	0.024	0	0	
Howards creek E219764	25-Apr-95	0.016	0	0	
Koopmans S (#2) E219769	17-Mar-95	1.835	27	4281	66351
Koopmans S (#2) E219769	7-Apr-95	0.114		0	
Koopmans S (#2) E219769	25-Apr-95		0	0	

APPENDIX G

Site	Date	Average of Total P mg/l	Flow l/s	P loading g/day	Total P loading g
Koopmans #3 creek	18-Mar-95	0.277	3.5	83	1284
Koopmans #3 Creek	8-Apr-95	0.03	11.4	30	
Koopmans #3 Creek	25-Apr-95	0.008	8	6	
Koopmans N (#1) creek E219768	17-Mar-95	2.535	7	1531	23730
Koopmans N (#1) creek E219768	7-Apr-95		0	0	
Koopmans N (#1) creek E219768	25-Apr-95		0	0	
Penner Road Creek (pole 47)	18-Mar-95	0.424	0.7	26	397
Penner Road Creek (pole 47)	7-Apr-95		0	0	
Penner Road Creek (pole 47)	25-Apr-95		0	0	
Pole 13 creek	18-Mar-95	1.82		0	
pole 13 creek	8-Apr-95	0.189		0	
Pole 14 creek	18-Mar-95	1.59		0	
Pole 14 creek	8-Apr-95	0.041		0	
Pole 14 creek	25-Apr-95	0.034		0	
Pole 15 creek	18-Mar-95	1.12	10.8	1047	16229
Pole 15 Creek	8-Apr-95	0.031	0.3	1	
Pole 19 creek	18-Mar-95	1.97	0.8	134	2084
Pole 19 creek	8-Apr-95		0		
Pole 20 creek	18-Mar-95	1.33	1.8	205	3170
Pole 20 creek	8-Apr-95		0		
Pole 22 creek	18-Mar-95	0.76	3.9	253	3918
Pole 22 creek	8-Apr-95		0		
Pole 26 creek	18-Mar-95	0.618	5.1	273	4229
Pole 26 creek	8-Apr-95		0		
Pole 26 creek	25-Apr-95		0		
Pole 29 creek	18-Mar-95	0.23	4.3	85	1312
Pole 29 creek	8-Apr-95	0.068	1.5	9	
Pole 29 creek	25-Apr-95	0.021	0.4	1	
Pole 34 Creek	8-Apr-95	0.041	1.5	5	82
Pole 34 Creek	18-Mar-95		7	0	
Pole 34 Creek	25-Apr-95	0.017	0.3	0	
Pole 36 Creek	18-Mar-95	0.367	3.5	110	1701
Pole 36 Creek	8-Apr-95	0.079	1.8	12	
Pole 36 creek	25-Apr-95	0.034	0.3	1	
Pole 39 creek	18-Mar-95	0.063	0.8	4	65
Pole 39 creek	25-Apr-95	0.01	0.6	0	

Site	Date	Average of Total P mg/l	Flow l/s	P loading g/day	Total P loading g
Pole 42 creek	18-Mar-95	0.104		0	
Pole 45 creek	18-Mar-95	0.343	0.1	3	46
Pole 45 creek	7-Apr-95		0	0	
Pole 45 creek	25-Apr-95		0	0	
Pole 50 creek	18-Mar-95	0.107	2.4	22	344
Pole 50 creek	7-Apr-95		0	0	
Pole 50 creek	25-Apr-95		0	0	
Pole 51 creek	18-Mar-95	0.101	0.4	3	53
Pole 51 creek	7-Apr-95		0	0	
Pole 51 creek	25-Apr-95		0	0	
Pole 52 creek	17-Mar-95	0.254	8	176	2728
Pole 52 Creek	7-Apr-95	0.031	0.1	0	
Pole 52 Creek	25-Apr-95	0.014	0	0	
Pole 55 Creek	7-Apr-95	0.019	0.4	1	10
Pole 55 Creek	25-Apr-95	0.018		0	
Pole 56 Creek	25-Apr-95	0.064		0	
Seaplane Base Creek E219760	17-Mar-95	1.245	12	1291	20008
Seaplane Base Creek E219760	7-Apr-95	0.087	1	8	
Seaplane Base Creek E219760	25-Apr-95	0.238	0	0	
VanHornes creek	7-Apr-95	0.045	0.8	3	46
VanHornes creek	25-Apr-95	0.018	3.1	5	
VanHornes creek	17-Mar-95	2.2	5.6	1057	
Victor creek E219770	18-Mar-95	0.209	7.7	139	2155
Victor creek E219770	7-Apr-95	0.024	17	35	
Victor creek E219770	25-Apr-95	0.008	25	17	
Yakisda Bik'a E219763	17-Mar-95	0.783	8	543	8412
Yakisda Bik'a E219763	25-Apr-95	0.015		0	
Total				**18468**	**266565**
Tyhee Creek outlet	18-Mar-95	0.297			
Tyhee Creek outlet	7-Apr-95	0.083			
Tyhee Creek outlet	25-Apr-95	0.076			
Tyhee Creek outlet	8-May-95	0.068			
averge for outflow		**0.131**			

APPENDIX H

SEDIMENT SAMPLING RESULTS
Tyhee Lake Deep Station
Sediment Core Sampling Results Nov. 15, 1994
-

Time	Depth - Upper	Depth - Lower	Phosphorus (ug/g)	P-ortho diss. (ug/g)	Nitrogen Kjel. Tot. (ug/g)
9:10	0	0.03	898	40	883
9:12	0.04	0.06	983	57	
9:14	0.07	0.09	865	43	16500
9:16	0.1	0.12	782	33	14500
9:18	0.13	0.15	653	24	15400
9:20	0.16	0.18	827	18	15100
9:22	0.19	0.21	653	13	13900
9:24	0.22	0.24	799	12	13600
9:26	0.25	0.27	701	11	18400
			Average - 796	Average -28	Average - 13535

Tyhee Lake Northwest Basin - Station 2
Nov. 15, 1994

Time	Depth-Upper	Depth-Lower	Phosphorus (ug/g)	P-ortho diss. (ug/g)	Nitrogen Kjel. Tot. (ug/g)
10:00	0	0.03	1020	59	21400

Sample Date Core Depth cm	Sediment Wet Weight g	Core - Volume cm3
+1 - 0	13.89	15.2
0 - 1	15.29	15.2
1 - 2	15.04	15.2
2 - 3	14.6	15.2
3 - 4	14.12	15.2
4 -5	14.28	15.2
5 - 6	14.57	15.2
6 - 7	14.77	15.2
7 - 8	13.47	15.2
8 - 9	13.9	15.2
9 - 10	13.14	15.2
10 - 11	16.36	15.2
11 - 12	16.2	15.2
12 - 13	14.22	15.2
13 - 14	16.03	15.2
14 - 15	13.51	15.2
15 - 16	14.95	15.2
16 - 17	15.73	15.2
17 - 18	16.05	15.2
18 - 19	16.05	15.2
19 - 20	14.2	15.2
20 - 21	14.73	15.2
21 - 22	15.7	15.2
22 - 23	15.22	15.2
23 - 24	15.18	15.2
24 - 25	16.11	15.2
25 - 26	17.28	15.2
26 - 27	15.05	15.2
27 - 28	15.74	15.2
28 - 29	15.99	15.2
29 - 30	15.24	15.2
30 - 31	16.55	15.2
31 - 32	16.86	15.2
32 - 33	16.37	15.2
33 - 34	17.11	15.2
34 - 35	14.81	15.2
35 - 36	16.49	15.2
36 - 37	15.6	15.2
37 - 38	14.76	15.2
38 - 39	15.73	15.2
39 - 40	15.95	15.2
40 - 41	17	15.2
41 - 42	15.5	15.2
42 - 43	15.98	15.2
43 - 44	16.83	15.2
44 - 45	15.52	15.2
45 - 46	16.78	15.2
46 - 47	16.03	15.2

APPENDIX H