State of the Baptiste Lake Watershed

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Prepared for the Baptiste Lake Watershed Stewardship Group

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Executive Summary

In response to concerns regarding the health of lakes in the region, summer villages at Baptiste, Island and Skeleton Lakes have formed the Baptiste, Island, and Skeleton Lakes Watershed Management and Lake Stewardship Council (BISL). BISL's vision for Baptiste Lake is to "maintain a healthy lake and watershed, recognizing the importance of living within the capacity of the natural environment and providing sustainable recreational, residential, agricultural, and industrial benefits". The State of the Watershed report contributes to achieving the vision by describing the current condition of the Baptiste Lake and its watershed, and assessing potential strategies to improve the health of the lake and watershed. Baptiste Lake is located approximately 16 km west of the town of Athabasca and 165 km northwest of Edmonton. The lake is well used for recreational activities such as fishing and boating, and is surrounded by numerous residences. Although naturally eutrophic, concerns regarding the health of the lake emerged in the 1970's in response to frequent algal blooms. Also of concern are the status of fish populations and the condition of the shoreline. To inform management actions to address these concerns, this report evaluated four indicators of the health of Baptiste Lake: water quality, fisheries, shoreline condition, and water level.

Water Quality

Total phosphorus (TP) and chlorophyll-a data collected since 1984 indicate that the lake is in a eutrophic to hypereutrophic state and presents a moderate health risk due to blue-green algae. Directional change in TP and chlorophyll-a over the past 20 years is not apparent, however, indicating that water quality is stable and the lake has been highly productive (i.e. eutrophic) for thousands of years. A variety of stressors contribute to the high productivity of Baptiste Lake. The relative importance of stressors and the potential to reduce their impact were assessed using available data. Although regional data were used when possible, such information was not always available and the assessment of stressors should be interpreted with caution.

By altering the rate at which phosphorus enters the lake from the watershed, land use can profoundly affect lake primary productivity. Of the land uses assessed, agriculture was the largest potential source of phosphorus due to the potential runoff of manure from livestock wintering sites. Phosphorus input from wintering sites can likely be eliminated by locating the sites away from streams and containing runoff. These strategies may already be implemented across much of the watershed which would substantially reduce the relative importance of this stressor. However, if agriculture were to expand and nutrient containment was insufficient, phosphorus runoff to the lake could increase. As such, protection of the large, forested subwatersheds west of the lake was identified as an effective management strategy.

Other land uses in the watershed that likely contribute phosphorus are industrial footprint and residences. Approximately four percent of the watershed is covered by industrial footprint including 296 km of roads, 921 km of seismic lines, and 77 km of pipelines. These disturbances may increase phosphorus runoff due to increased exposure of soil to water and wind and perhaps increased mineralization of soil phosphorus. This

phosphorus source may be substantial due to the extent of these footprints, but the actual magnitude is uncertain. Residences surrounding the lake are also a source of phosphorus due to the high phosphorus concentration of residential wastewater. The size of this phosphorus source is likely small relative to other sources, and a recent questionnaire suggests that many residents are employing responsible wastewater management. However, sound wastewater practices remain important especially given that development around the lake has approximately doubled over the past 30 years.

Internal sources are also contributing to the eutrophication of Baptiste Lake. Stratified lakes in northern Alberta typically exhibit depleted water oxygen levels in the lower strata (hypolimnion) during the summer. This process causes the release of phosphorus from bottom sediments and, during spring and fall turnover, the phosphorus-rich water from the hypolimnium is transported to the surface of the lake where it becomes available for phytoplankton production. Internal loading was estimated to be a large source of phosphorus to the lake. The feasibility of options to manage the process, however, are limited. Although treatments such as liming can substantially reduce internal phosphorus loading, the cost of applying such treatments to a lake as large as Baptiste may be prohibitively high.

In addition to nutrient availability, productivity of Baptiste Lake is likely controlled by the trophic structure of the lake's food web. Northern lakes, including Baptiste, typically display a simple trophic structure with four levels: piscivorous fish (walleye and pike), which feed on planktivorous fish (perch, cisco, etc.), which feed on zooplankton, which feed on phytoplankton (e.g., algae). A decline in the abundance of piscivorous fish can ultimately increase algae through trophic cascade. Due to reduced predation pressure from piscivorous fish, planktivorous fish increase in abundance and decrease the abundance of zooplankton that feed on phytoplankton, with the end result that phytoplankton increase in abundance. Evidence from Baptiste Lake suggests that a trophic cascade has occurred. The primary piscivorous fish in Baptiste Lake (walleye and pike) have dramatically declined in both abundance and size since the mid-twentieth century. The limited data that are available indicate that the zooplankton community has changed in a way that is consistent with trophic cascade. Finally, the abundance of algae is higher than would be suggested based solely on phosphorus concentration, suggesting that trophic cascade is contributing to abundant algae populations. Fishing regulations to recover these fish populations to what they were prior to heavy angling pressure are needed to reduce the impact of trophic cascade.

Fisheries

Northern pike and walleye were used as indicators of the status of the Baptiste Lake fisheries due to the value of these species to the recreational fishery, their position atop the aquatic food web as predators, and their sensitivity to angling. Creel survey data collected between 1984 and 2005 indicate that catch rates (a good measure of fish abundance) for walleye and pike declined in recent years and are as much as 300-times lower than catch rates reported from historical surveys. Average weights of walleye and pike also declined relative to reported historical levels. The substantial decline in catch rates and weights suggest that the walleye and pike fisheries have collapsed.

Baptiste Lake's fish populations are susceptible to angling because of their low productivity and the high angling pressure in the region. Sustainable management of angling is therefore needed to recover Baptiste Lake's fish populations. The current regulations of minimum size limits were initially successful but have since proven to be insufficient to sustain the fish populations. The partial recovery of the fishery that was initially achieved by the minimum size limits attracted additional anglers to the lake, with the result that fish harvest and hooking mortality exceeded sustainable levels. Other management options such as protected zones, slot size limits, and short seasons are likewise ill-equipped to mitigate the angling pressure that the lake's fish populations can be exposed to. Restrictive fishery regulations may be needed to improve the status of fisheries at Baptiste Lake given that catch-and-release mortality alone (through accidental hooking and handling injuries) may now nearly account for the entire annual yield from this depressed walleye population.

Habitat degradation may also contribute to fish population declines at the lake, especially migration barriers that can occur at stream crossings and impede access of fish to spawning sites. The majority of culverts (80%) located along fish bearing streams in the watershed potentially impede fish movement, primarily as a result of poor installation or insufficient maintenance. Blockage of fish movement upstream can best be mitigated by minimizing the use of culverts. If culvert construction is deemed necessary, sound culvert construction and diligent monitoring and maintenance are essential.

Shoreline Condition

The shoreline zone sustains the greatest diversity of plants and animals in the lake and provides essential ecosystem services including filtering runoff entering the lake and protecting the shoreline from erosion. Degradation of shoreline vegetation can inhibit these valuable services. Clearing of lakefront vegetation along lakefront properties can increase shoreline erosion, cover fish-spawning beds with silt, contribute to algal blooms by increasing nutrient input, reduce fish and wildlife habitat, and degrade natural scenery. The status of the shoreline zone could not be assessed due to lack of data. It is likely, however, that the condition of the shoreline has declined because development of waterfront property at Baptiste Lake has increased. A survey of shoreline vegetation being conducted by the Baptiste Lake Watershed Stewardship Group is underway to provide more accurate assessment of shoreline status. Most of the lake's shoreline is established as an environmental reserve up to 30 m inland from the lake to protect shoreline vegetation. Many residents may not be aware of the environmental reserve, however, and disturbance of vegetation within the reserve appears to have occurred.

Water Level

Changes to Baptiste Lake's water level can influence water quality, fish and wildlife habitat, and recreational opportunities. However, Baptiste Lake's water volume has been relatively stable over the long-term despite short-term fluctuations.

Prioritizing Management Options

Several management options exist to improve the health of the lake. Prioritizing management opportunities can be aided by considering both the relative financial cost and effectiveness of the options. Low cost options with high potential to improve lake health are top in priority and include implementing a restrictive fishery, preventing conversion of existing forest, and protecting shoreline habitat. Social acceptance of these strategies may be low, however, suggesting that regulation will be necessary combined with education to improve awareness of why the actions are needed. Although residential wastewater management, conservation-tillage agricultural, and repairing problem culverts have low potential to improve lake health relative to other strategies, the potential is not negligible and the strategies should still be promoted due to their low cost. Second in priority are moderate cost strategies, especially controlling runoff from cattle wintering sites if existing sites are not hydrologically separated from tributaries. Implementation of these strategies will require coordination with the provincial government to restrict forest conversion or offset costs incurred by farmers to separate cattle from streams. Last in priority in terms of Baptiste Lake management options is chemical treatment (liming) of sediments. Due to high cost relative to other options, liming or other treatments should only be pursued if algal growth is unacceptably high after other management strategies have been implemented.

Cost		
High		Liming
Moderate	Replacement of problem culverts	Control runoff from cattle wintering sites
Low	Conservation-tillage Residential waste water management Repair problem culverts	Highly restrictive fishery Protect/reclaim shoreline Forest protection
	Impact	
	Low	High

Cost-impact matrix demonstrating cost and potential impact of Baptiste Lake management options. Cost refers to the financial cost of implementing the management strategy. Impact refers to the potential to improve water quality, fisheries, and/or shoreline condition at the lake.

Acknowledgements

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Contents

1 Introduction

In response to concerns regarding the health of lakes in the region, summer villages at Baptiste, Island and Skeleton Lakes have formed the Baptiste, Island, and Skeleton Lakes Watershed Management and Lake Stewardship Council (BISL). BISL's vision for Baptiste Lake is to "maintain a healthy lake and watershed, recognizing the importance of living within the capacity of the natural environment and providing sustainable recreational, residential, agricultural, and industrial benefits". BISL is working to achieve this vision by increasing awareness of the factors affecting the health of the lake, identifying threats to the health of the lake, and developing an action plan to maintain, restore, and protect the health of the lake. This State of the Watershed report contributes to achieving the vision by describing the current condition of Baptiste Lake and its watershed, and assessing strategies to improve the health of the lake and watershed. As such, the report seeks to increase awareness of the health of the lake and, ultimately, to inform the development of a management plan for the lake and its watershed.

Baptiste Lake is located approximately 16 km west of the town of Athabasca and 165 km northwest of Edmonton. The moderate sized lake covers almost 10 km^2, has an average depth of almost 9 m (Prepas 2004), and has two distinct basins (South and North Baptiste). The lake is located within the Boreal Plains ecozone which is characterized by boreal mixedwood forest and sedimentary soils. Twelve tributary streams that drain the 288 km^2 watershed feed into the lake mainly along the western and southern shores (Prepas 2004). The single outlet stream, Baptiste Creek, is located on the northeast shore and feeds into the Athabasca River. Due to the large watershed area and the nutrient rich sedimentary soils (Prepas et al. 2001a), water flowing into the lake is high in nutrients and the lake has been highly productive (i.e. eutrophic) for thousands of years (Hickman et al. 1990, Trew et al. 1987). The lake is well used for recreational activities such as fishing and boating, and numerous residences surround the lake. Concerns regarding the health of the lake emerged in the 1970's due to frequent algal blooms. Also of concern are the status of fish populations and the condition of the shoreline.

This state of the lake report evaluates the following four indicators of the health of Baptiste Lake: water quality, fisheries, shoreline condition, and water level. Of these, water quality receives the most attention because it is the primary environmental issue at the lake. In addition, land cover is evaluated due to the watershed's influence on the lake's health. Each indicator's status, trend (declining, stable, or increasing), and management options are assessed using a variety of datasets, results from previous studies, and the land use simulation tool ALCES. The information used to assess indicators and stressors was at times of poor quality due to limited information availability. Of greatest concern is that relationships derived from other regions were sometimes used to evaluate the importance of stressors and management options. As a result, the assessment must be interpreted as approximate. Despite the uncertainty, the assessment is sufficient to differentiate those stressors with high and low impact. The report concludes by recommending management priorities for improving the health of

Baptiste Lake. The prioritization must be followed up with more in-depth evaluations of high priority management options.

2 Land cover

Baptiste Lake is fed by a 288 km^2 watershed that is dominated by deciduous (44%), coniferous (18%), and mixedwood (7%) forest. The type of forests found in the region support a diversity of species including 76 bird species, and 33 mammal species, and numerous insect and anthropod species (Stelfox 1995). The capacity of the watershed to support the full spectrum of native wildlife is affected by the degree to which the watershed is altered by land uses such as agriculture and roads. The health of Baptiste Lake is also likely impacted by land cover changes in the watershed. As discussed in the water quality section of this report, clearing of forest for agriculture and other land uses can increase the rate at which nutrients are carried from the land to the lake. As a result, disturbance of forests in the region may increase the susceptibility of the lake to algal blooms.

2.1 Status

Status: 20% conversion to agriculture and anthropogenic footprint
Trend: stable/increasing

Major land uses in the watershed include agriculture, forestry, oil and gas exploration, and settlements (Figure 1). Of these, agriculture is the predominant land use type. Settlement of the region for agriculture began in 1904, and aerial photographs show that conversion of the watershed to agriculture increased steadily in the second half of the 20^{th} century (Figure 2). More recently, farm area appears to have stabilized in the broader region based on a comparison of farm area statistics for Athabasca County No. 12 from the 2001 and 2006 Agriculture Censuses (Statistics Canada 2008a, 2008b). Within the watershed, however, there have been several examples of land clearing for agriculture noted within the past year. The watershed is located on the agriculture development frontier, which suggests the potential exists for future land clearing for agriculture. The actual long-term trend in farm area in the watershed is uncertain and is rated as stable/increasing because, although growth in farm area is low in the Athabasca County No. 12, there are recent examples of land clearing for agriculture in the Baptist Lake watershed.

Based on the 2004 Alberta Vegetation Inventory, 11.4 % of the watershed has been converted to pasture and 4.9% has been converted to cropland. The actual long-term trend in farm area is uncertain, however, because the comparability of Trew et al.'s (1987) estimate, which was based on planimetry from maps, and the Alberta Vegetation Inventory is not known. In addition to farmland, approximately 11.7 km^2 of anthropogenic footprint covers 4.1% of the watershed. The footprint includes 296 km of roads, 921 km of seismic lines, 77 km of pipelines, 0.18 km^2 of well sites, and an estimated 2 km^2 of human settlements. A more detailed presentation of the composition of the watershed is provided in Appendix 1.

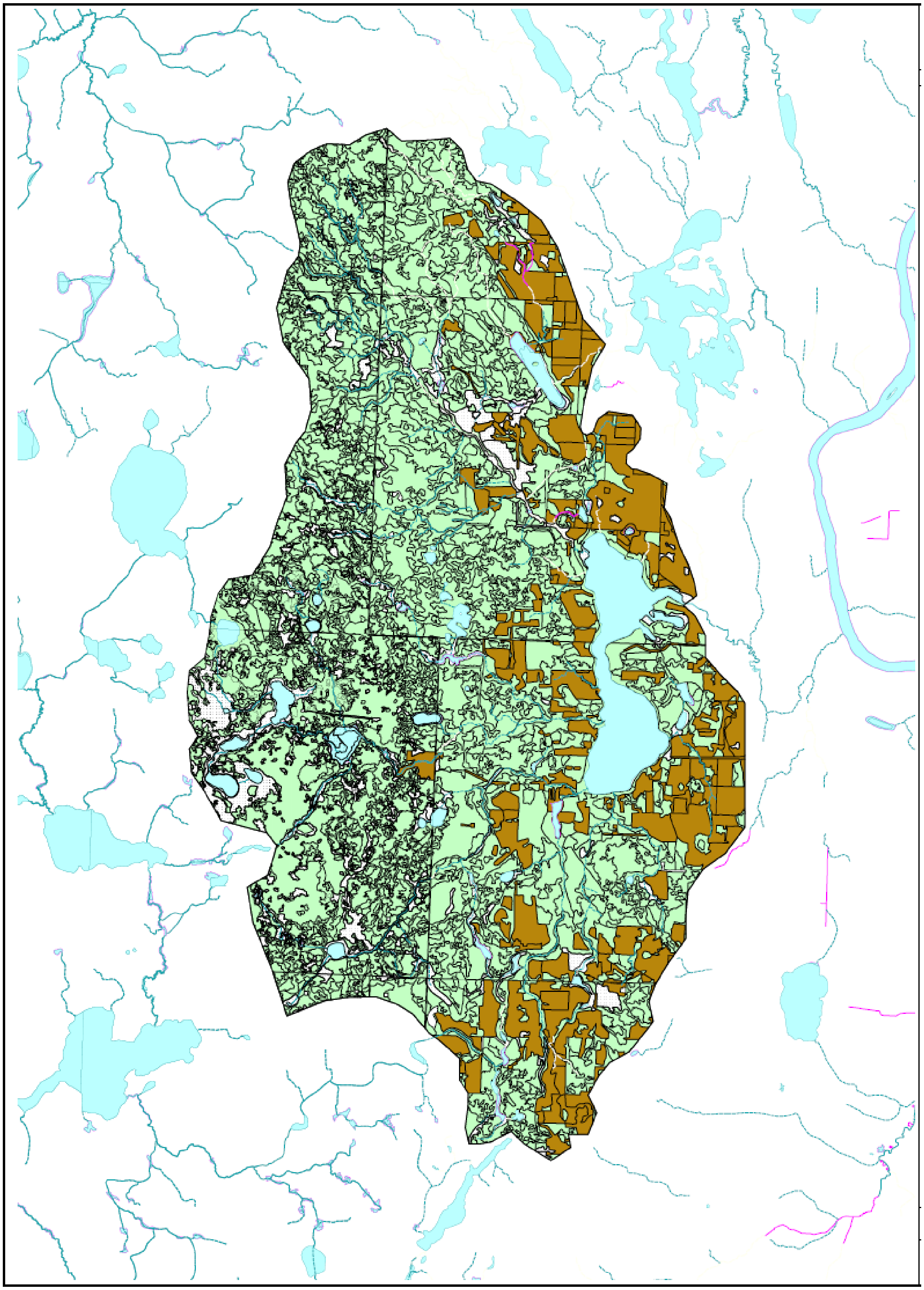


Figure 1. Approximate current location of cropland and pasture within the Baptiste Lake watershed is indicated by the brown polygons. Based on the Alberta Vegetation Inventory and ortho photos.

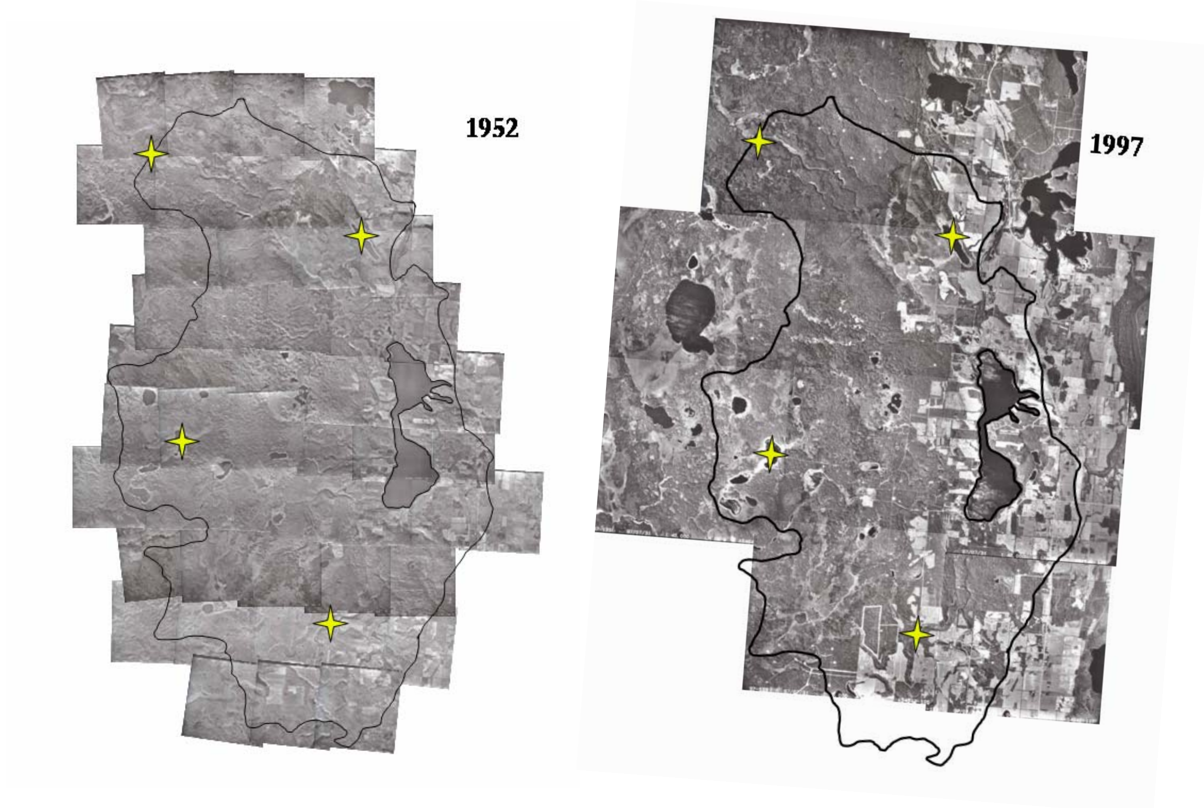


Figure 2: Aerial photograph mosaics from 1952 and 1997 demonstrating the expansion of agriculture in the eastern portion of the watershed. The watershed is outlined in black and the yellow stars are reference points to aid comparison of the mosaics. The mosaics were compiled by Bill Donahue.

3 Water Quality

The primary water quality issue at Baptiste Lake is high productivity leading to an extreme propensity for the lake to develop algal blooms (Baptiste Lake Watershed Stewardship Group 2006). Algal blooms cause a variety of problems including decreased recreational value (e.g. unpleasant odor and unsightly conditions), and exposure of humans and wildlife to toxins released by blue-green algae. Rapid die-off of an algal bloom also depletes dissolved oxygen when the algae decompose, which can cause fish kills if depletion of dissolved oxygen is sufficiently severe. Although Baptiste Lake is naturally eutrophic, research conducted in the late 1970's concluded that land use in the watershed has increased the productivity of Baptiste Lake (Trew et al. 1987).

Flow of human sewage or livestock manure into Baptiste Lake could introduce bacteria that present a human health risk. This aspect of water quality was not assessed due to a lack of data. Fecal bacteria such as fecal coliforms and Escherichia coli are not measured by Alberta Environment's lake water quality monitoring program. It may be worthwhile monitoring fecal bacteria at Baptiste Lake in the future to assess potential health hazards to water users.

3.1 Status

Status: Eutrophic to hypereutrophic. Moderate health risk due to blue-green algae
Trend: Stable

The water quality of Baptiste Lake was assessed using total phosphorus (TP) and chlorophyll-a data collected from Baptiste Lake since 1983 (Alberta Environment 2005). While data for additional water quality indicators are available, these 2 indicators provide a succinct representation of water quality given the biophysical characteristics of the lake and the primary stressors. These indicators demonstrate that the lake is in a eutrophic to hypereutrophic state and presents a moderate health risk due to blue-green algae. Water quality is assessed to be stable because although TP and chlorophyll-a concentration data collected since 1983 display variation within and between years, they do not display a noticeable trend.

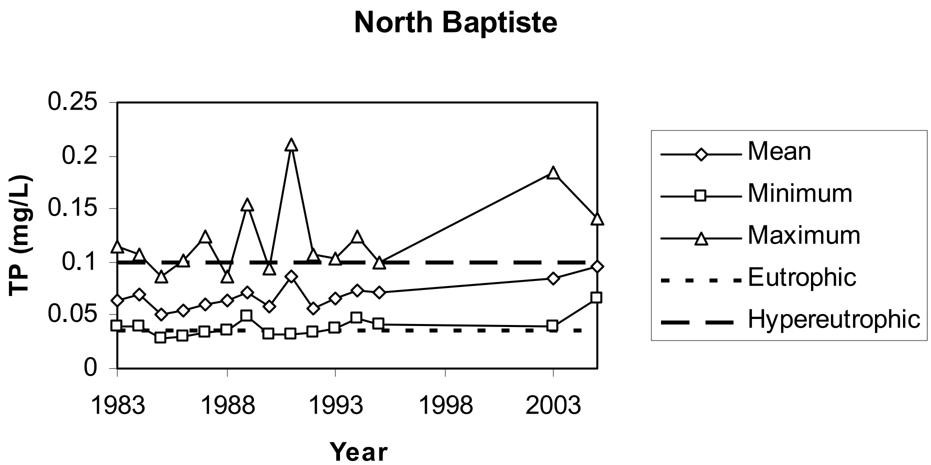
3.1.1 Total phosphorus

Algae in Lake Baptiste are phosphorus limited[1]. Mean total phosphorus (TP) was relatively consistent between 1983 and 2005 with no trend apparent (Figure 3). Within a given year, TP was highly variable likely due to lake mixing. As described by Trew et al. (1987), phosphorus in Baptiste Lake is high during spring turnover due to both spring runoff and mixing of accumulated nutrients in bottom sediments. During the summer when the lake stratifies, phosphorus concentration declines because phosphorus rich sediments are isolated from the epilimnion. During fall turnover, phosphorus concentration again increases when phosphorus rich water from the lake bottom mixes throughout the lake.

In contrast to mean TP, maximum TP was highly variable across years. However, no trend in maximum TP is apparent and the variability may be an artifact of whether timing of data collection in a given year happened to coincide with the timing of high phosphorus concentration for that year. Each year, sampling occurred six to eight times between May and October and may have missed short-term influxes of phosphorus associated with, for example, heavy rainfall or lake turnover. As such, high intra-annual variation in TP could potentially obscure long-term trends if sampling frequency is insufficient.

Using TP concentration as an indicator of trophic status (Kelker 2000), mean concentrations consistently indicate that Baptiste Lake is eutrophic on average. Maximum concentrations, however, indicate that especially the northern basin of the lake is often hypereutrophic at some point during the year.

[1] Algae require a nitrogen to phosphorus ratio of 7.2 to 1 (Trew et al. 1987). All water quality data collected form Lake Baptiste (1983-2005) show a total nitrogen to total phosphorus ration that is greater than 7.2, indicating that nitrogen is available in excess relative to phosphorous. Further evidence that Baptiste lake algae growth is limited by phosphorus is provided by the similarity between chlorophyll-a and phosphorus fluctuations in Baptiste Lake (Trew et al. 1987).



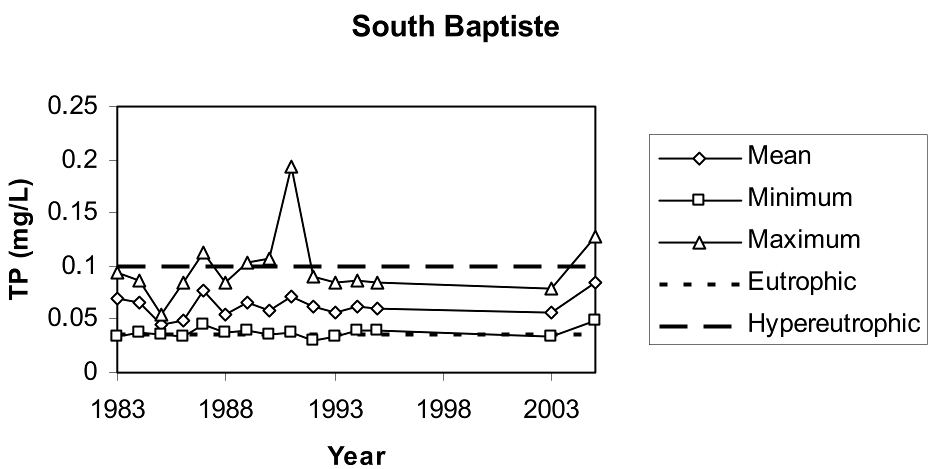


Figure 3. Mean, minimum and maximum yearly total phosphorus (TP) concentrations at the northern and southern Baptiste Lake basins between 1983 and 2005. TP concentrations exceeding the "Eutrophic" line indicate that the lake is eutrophic and concentrations exceeding the "Hypereutrophic" line indicate that the lake is hypereutrophic. Thresholds between trophic conditions are from Kelker (2000).

3.1.2 Chlorophyll-a

Chlorophyll-a, a pigment produced by plants, increases in concentration during periods of high algal growth. High algal growth can present health risks if cyanobacteria (blue-green algae) are present because of the toxins that they produce. The World Health Organization provides chlorophyll-a guidelines for water bodies exhibiting cyanobacterial dominance to help determine whether algal growth is sufficient to pose a health risk (WHO 2003). Although chlorophyll-a itself is not toxic, high levels of chlorophyll-a are indicative of high cyanobacterial growth and therefore cyanotoxins. According to the guideline, there is a relatively low probability of adverse health effects at 10 μg/L chlorophyll-a and a moderate probability of adverse health effects at 50 μg/L chlorophyll-a. At 10 µg/L chlorophyll-a, health risks are short-term symptoms such as skin irritation and gastrointestinal illness, and providing information for visitors to swimming areas is advised. At 50 µg/L chlorophyll-a, there is potential for long-term illness and swimming should be discouraged and risk advisory signs posted.

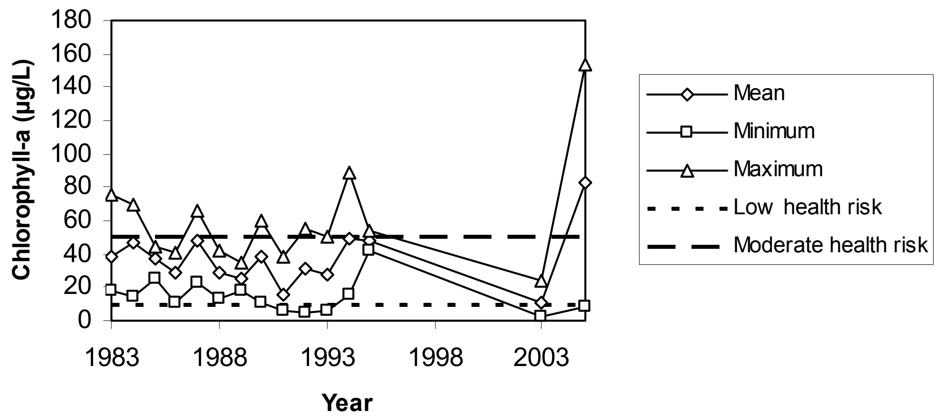
Trew et al. (1987) report that cyanobacteria generally dominates algae biomass at Baptiste Lake from early June to mid-September. To assess the risk of adverse health effects at Baptiste Lake, the WHO guideline was compared to chlorophyll-a levels collected at the lake from June 8 to September 14. Mean chlorophyll-a level consistently exceeded the low heath risk guideline and at times exceeded the moderate risk guideline, especially in the northern basin (Figure 4). In both basins, maximum chlorophyll-a levels frequently exceeded the moderate health risk guideline. Baptiste Lake therefore appears to frequently pose a moderate health risk due to toxins from abundant cyanobacteria between June and September.

Chlorophyll-a concentration is also an indicator of lake productivity. Average chlorophyll-a concentration in both basins exceeds 25 µg/L in most years, indicating that the lake is hypereutrophic (Alberta Environment 2006).

As with TP, no trend in mean chlorophyll-a is apparent from the data collected between 1983 and 2005, but high intra-annual variability is evident likely in response to fluctuation in TP caused by lake mixing and high runoff events. The variability is such that only large trends in chlorophyll-a could be detected as demonstrated by the wide confidence intervals[2] for mean annual chlorophyll-a, especially for the north basin (Figure 5).

[2] Confidence intervals were calculated assuming normally distributed residuals.

South Baptiste



North Baptiste

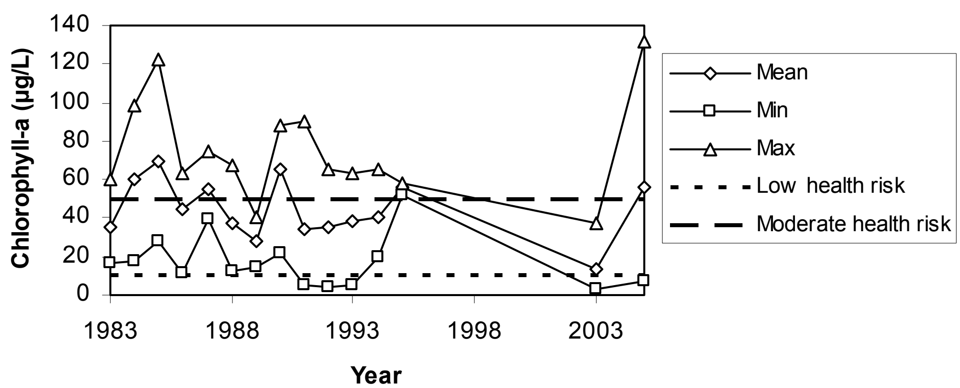
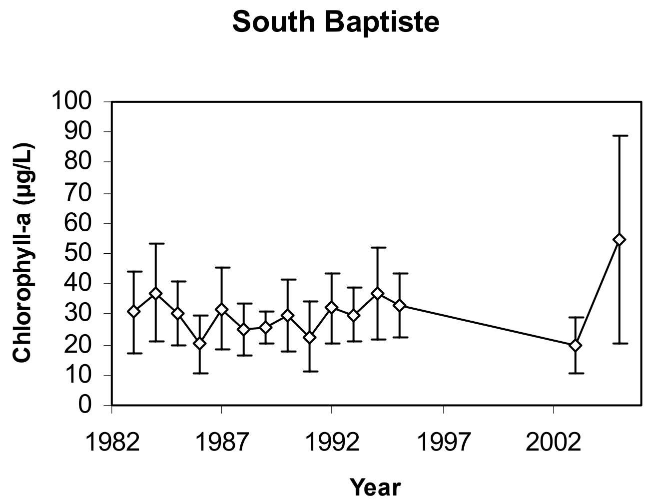


Figure 4. Mean, minimum and maximum chlorophyll-a concentrations from samples collected between June 8 and September 14 at the northern and southern Baptiste Lake basins between 1983 and 2005. As explained in the text, chlorophyll-a concentrations exceeding the "moderate health risk" line indicate that toxins from cyanobacteria pose a health risk and that swimming such be discouraged.



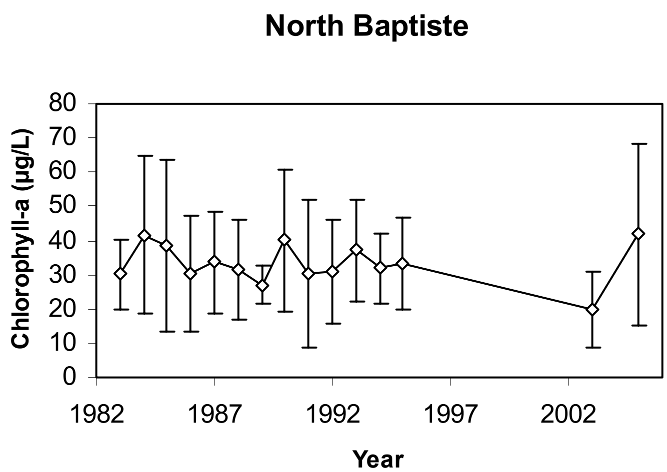


Figure 5. Mean yearly chlorophyll-a concentrations at the northern and southern Baptiste Lake basins between 1983 and 2005 with 90% confidence intervals.

3.2 Management

A variety of stressors can contribute to increased lake productivity (Schindler 2006). External loading of phosphorus to the lake can be elevated by wastewater from residences and from phosphorus-rich runoff from farmland, anthropogenic footprint, and cut-blocks. Internal loading of phosphorus can occur from lake-bottom sediments. Climate can increase lake phosphorus levels through changes in stream inflow and residence time. Productivity can also be increased by declines in fish populations that, through trophic cascade, decrease grazing pressure by zooplankton on algae.

The importance of each stressor to Baptiste Lake has been assessed by estimating the relative magnitude of their impacts and the potential to manage the impact. Relationships derived from other regions were sometimes used to evaluate the importance of stressors because of data limitations. As a result, the assessment should be interpreted as approximate.

3.2.1 Residential wastewater effects on phosphorus transport

Impact Magnitude

Residences in the watershed are not connected to a central wastewater collection system but rather use holding tanks, septic tanks, pit toilets and gray water pits to dispose of domestic wastewater. TP concentrations in typical wastewater is 210 mg/L, 31 mg/L, and 3,730 mg/L for septic tanks, holding tanks, and pit toilets, respectively (Alberta Environment 2004). Due to these high concentrations, any flow of wastewater into the lake is a source of phosphorus.

Septic systems and holding tanks, if managed properly, should not result in the flow of substantial nutrients into Baptiste Lake. A holding tank is an underground, usually cement, tank that holds wastewater until it is pumped out and transported offsite. In the Baptiste Lake watershed, pumped-out wastewater is disposed of at a sewage lagoon located a considerable distance from the lake.

A septic system treats wastewater onsite by first separating liquid from solids in a septic tank and then treating the waste water in a leaching bed where bacteria consume wastes during the growing season and soil filters wastes prior to the water entering the groundwater system. Phosphorus in wastewater is absorbed by soil, and the capacity of soil to retain phosphorus is greater than the typical phosphorus load from residential wastewater unless the soils are sandy or coarse. Given that the clay soils in the Baptiste Lake watershed have a high phosphorus retention capacity (Trew et al. 1987), septic systems in good working condition are likely effective at removing phosphorus from wastewater.

Pit toilets are also unlikely to be a substantial source of nutrients into Baptiste Lake provided that human sewage, and not also grey water, is deposited into the pit. In the absence of grey water, there is insufficient water in the sewage to allow significant flow of the sewage and accompanying nutrients beyond the pit. The clay soils in the watershed should also contribute to the capacity of pit toilets to retain sewage. In addition, some pit toilets are lined to further prevent flow. The relative permanence of pit toilets is demonstrated by the fact that phosphorus levels in pit toilets in Alberta are approximately 100 times higher than phosphorus levels in holding tanks (3,730 mg/L vs 31 mg/L). However, pit toilets may be sources of nutrients under certain conditions such as high runoff events, the presence of permeable soils, and proximity to the lake. These conditions could create rare but large inputs of phosphorus as a result of the high nutrient concentration typical of the sewage contained in pit toilets.

In contrast to pit toilets, grey water pits are likely to result in phosphorus flow into lake water. Grey water is high in phosphorus and, due to the high volume of water usually sent to the pit in surges, can flow through soil or overflow and move into the lake (Richard Zwicker, Executive Director, Rtd., Alberta Onsite Wastewater Contractors' Association, pers. com.).

Based on questionnaires completed by 70 property owners in West and South Baptiste Villages, holding tanks are used at 77% of the residences and are the dominant wastewater management system. Pit toilets are used at 34% of the residences and half of pit toilets are lined. Septic systems, used at 17% of the residences, are relatively rare. Grey water pits are virtually non-existent (3%). Although the questionnaires do not provide wastewater management information for all dwellings around the lake, the 70 surveys are likely to represent a substantial portion of the dwellings in West and South Baptiste Villages given that the municipal profiles for these villages report a combined population of 171 people inhabiting 40 dwellings (http://www.municipalaffairs.gov.ab.ca/cfml/profiles/index.cfm). It is apparent that wastewater management has substantially improved since 1977 when 84% of lakeshore dwellings used pits to dispose of grey water and 87% used pit toilets for sewage (Trew et al. 1987). It is possible that the questionnaires under-represent poor wastewater disposal practices such as grey water pits. However, the 70 questionnaires likely represent a high proportion of the dwellings in the villages that have a combined population of 173 residents (http://www.municipalaffairs.gov.ab.ca/cfml/profiles/index.cfm). Given the dominance of holding tanks and the rarity of grey water pits reported in the questionnaires, it seems unlikely that a substantial portion of phosphorus and other pollutants in sewage are reaching Baptiste Lake. This conclusion is supported by a 1982 study at Wabumun Lake that estimated that only 3-4% of the cottages on the lake were contributing sewage contamination (Mitchell 1982). The wastewater management strategies used by the cottages at Wabumun Lake during the 1982 study is not known, however, so the applicability of the study to the Baptiste Lake situation is limited.

Due to the impracticality of assessing the potential seepage of wastewater from dwellings, Trew et al. (1987) assumed that the entire phosphorus load from lakeshore dwellings seeped into the lake. In 1977, 15 permanent and 310 vacation residences around lakeshore were estimated to produce 208.4 kg P/year. Since then, ownership of Baptiste lake waterfront has doubled. It is therefore assumed that the number of residences around the lake has approximately doubled since 1977. In addition, the proportion of dwellings that are permanent residences may have increased. Using the growth in residences to update Trew et al.'s (1987) estimate, the current phosphorus load from lakeshore dwellings is estimated to be 416.8 kg P/year. As discussed previously, it is unlikely that a substantial portion of the phosphorus load from lakeshore dwellings seeps into the lake. Estimates of the portion range from 4%, based on the Wabumun Lake sewage contamination study (Mitchell 1982), to 100% based on Trew et al.'s (1987) approach of assuming all phosphorus is released to the lake. Phosphorus input from lakeshore dwelling wastewater is therefore estimated to be in the range of 16.7 to 416.8 kg P/year.

Management Potential

Although wastewater is likely a small contributor of phosphorus to Baptiste Lake relative to other sources, controlling this source is important and easily achieved. The most important practice is to eliminate the use of grey water pits at all lakeshore dwellings. Additional practices focus on maintaining waste water disposal systems in proper working order. Overflowing of holding and septic tanks must be avoided, and owners should be diligent in locating and fixing leaks. Pit toilets should be lined to prevent seepage of sewage during high runoff events.

3.2.2 Agriculture effects on phosphorus transport

Impact Magnitude

Manure, fertilizers and soil erosion can cause runoff from farmland to contain high levels of phosphorus. Research in the Baptiste Lake watershed determined that export of phosphorus from farmland, especially cow-calf operations, is higher than forest. Cooke and Prepas (1998) used water samples to estimate TP export coefficients for forest watersheds, a watershed that was dominated by cropland (80%), and a mixed-agriculture watershed. Averages of the TP export coefficients reported by Cooke and Prepas (1998) for the forest, cropland, and mixed-agriculture watersheds are 12.25 kg/km^2/year, 13 kg/km^2/year, and 69.5 kg/km^2/year, respectively. The mixed-agriculture watershed was made up of cow-calf operations (25%), cropland (34%), woodlots and a homestead. To estimate a TP export coefficient for just the cow-calf operation portion of the watershed, I assumed that the TP export coefficient for the remaining 75% of the watershed was 13 kg/km^2/year (i.e., the export coefficient for the cropland dominated watershed). This resulted in an export coefficient of 239 kg/km^2/year for cow-calf operations. The TP export coefficients in Table 1 may underestimate the contribution of agriculture to eutrophication of Baptiste Lake because phosphorus runoff from agricultural land tends to be high in dissolved phosphorus which is readily available to algae. A study in Baptiste Lake watershed found that dissolved phosphorus accounted for 82% of the total phosphorus in streams in agricultural subwatersheds compared to 43% in forested subwatersheds (Cooke and Prepas 1998). Alternatively, runoff coefficients may overestimate the contribution of agriculture to eutrophication of Baptiste Lake because the coefficients are based on in-stream measurements and do not account for potential uptake of phosphorus by fluvial sediments prior to reaching the lake (e.g., McDowell and Sharpley 2003).

Forest	Cropland	Cow-calf operations
12.25 kg/km^2/year	13 kg/km^2/year	239 kg/km^2/year

Table 1. TP export coefficients used to estimate the TP contribution of agriculture. The export coefficients are derived from Cooke and Prepas (1998).

The export coefficients derived from Cooke and Prepas (1998) for cropland, cow-calf operations and forest (Table 1) were used in this study to estimate the contribution of phosphorus to Baptiste Lake by cropland, pasture, and natural (i.e. non-agricultural) areas in the in the watershed, respectively. These cropland coefficient is similar to estimates from a study conducted at Haynes Creek in central Alberta. In the Haynes Creek study, TP export coefficients for conventionally tilled cropland ranged from 1.5 to 26.2 kg/km^2/year (Anderson et al. 1998) compared to 13 kg/km^2/year reported by Cooke and Prepas (1998). The Haynes Creek study also assessed export coefficients from cattle wintering grounds. A 26 ha cattle wintering ground with access to Haynes Creek had TP export coefficients of 12.7 kg/km^2/year and 925.8 kg/km^2/year in 1995 and 1996, respectively (Anderson et al. 1998). The large export coefficient at the Haynes Creek site in 1996 was due to high spring runoff which resulted in flooding of the wintering grounds. In comparison, a cattle wintering ground where runoff was low and cattle were fenced away from the stream had TP export coefficients of 2 kg/km^2/year and -44 kg/km^2/year in 1995 and 1996, respectively (Anderson et al. 1998). The 239 kg/km^2/year TP export coefficient for pasture calculated from Cooke and Prepas (1998) likely represents a worse-case scenario whereby a high proportion of the nutrients in manure ends up in a stream. Indeed, the cattle operations studied by Cooke and Prepas (1998) had unrestricted access to a stream and were fed and wintered next to the stream. It also should be noted that the stream along which the cattle operation is located does not flow into the lake but rather into Baptiste Creek. As such, the cattle operation in question does not directly impact the lake's water quality but rather is assumed to be representative of other cattle operations that could impact the lake's water quality.

Cropland covers 14.71 km^2 (5 %) and pasture covers 34.41 km^2 (11.7 %) of the watershed, not including 14.37 km^2 of grazing leases on forested land. Applying the TP export coefficients calculated from Cooke and Prepas (1998) (Table 1), TP load from cropland and pasture in excess of natural (i.e. forest) levels is 11 kg and 7,802 kg, respectively, for a total load of 7,813 kg TP. In comparison, Trew et al. (1987) estimated that TP loadings to Baptiste Lake from agricultural land through streams and diffuse runoff areas in 1977 equaled 2,411.4 kg/year. The estimate made here based on Cooke and Prepas (1998) is a worst-case estimate, as it assumes that cattle have unrestricted access to streams and are fed and wintered next to streams at all pastures within the watershed. The actual position of livestock operations, especially wintering sites, relative to Baptiste Lake's tributaries needs to be investigated to confirm whether this worst-case estimate is realistic.

Management Potential

The transport of phosphorus from agricultural land to water bodies is a well-recognized problem and a variety of best management practices are promoted as strategies to mitigate the issue. For pasture, rotational grazing, alternate water sources, and fencing can be used to separate livestock from riparian areas (Alberta Agriculture, Food and Rural Development 2000). In wintering areas, where high accumulation of manure occurs, strategies focus on safe storage and disposal of manure. Corrals and manure storage can be located away from waterbodies and berms, ditches and lagoons can be built to prevent the transport of manure in surface runoff (Alberta Agriculture, Food and Rural Development 2000). For cropland, best management practices focus on appropriate application of manure and fertilizer and maintaining soil cover (Alberta Agriculture, Food and Rural Development 2000). Limiting manure application to rates recommended for crop nutrient requirements can prevent phosphorus accumulation in soils. Not applying manure or fertilizer on frozen or snow-covered soils or when heavy rains are expected can limit the transport of nutrients to surface water. Reducing summer fallow and using conservation-tillage practices helps to maintain soil cover, thereby limiting runoff and erosion. For both pasture and cropland, conserving riparian areas is beneficial due to the capacity of these areas to buffer water bodies from contaminated runoff.

Research conducted in central Alberta (Wuite and Chanasyk 2003) makes it possible to estimate the capacity for cropland and livestock best management practices to reduce phosphorus input to Baptiste Lake. Wuite and Chanasyk (2003) found that conservation-tillage achieved a TP load reduction of 5.10 kg/year in their 40 ha study area. Applying this load reduction rate (0.1275 kg/ha/year) across the 1471 ha of cropland in the Baptiste Lake watershed, conservation-tillage has the potential to reduce TP load by 188 kg. This potential is likely exaggerated because conservation-tillage may already be used at some farms in the watershed. Across Alberta, non-conventional tillage (reduced or zero-till) was practiced on 62% of all seeded acreage in 2001 (Wuite and Chanasyk 2003). Based on Trew et al.'s (1987) estimated annual phosphorus loading of Baptiste Lake of 3,407-12,208 kg, a 188 kg reduction is concluded to be small. The phosphorus management potential of no-tillage is therefore rated as low.

Phosphorus load associated with cattle generally occurs during spring runoff when accumulated manure from wintering sites can be washed away during high spring runoff events. At a Baptiste Lake subwatershed containing cattle operations, 75% of the phosphorus load was delivered during spring runoff. This is in contrast to forested subwatersheds where 74% of the TP load was delivered during the summer (Cooke and Prepas 1998). As a livestock best management practice, Wuite and Chanasyk (2003) studied the diversion of manured runoff to a lagoon at a wintering site in central Alberta that was fenced and located 40 m from the stream. The practice achieved a TP load reduction of 9.0 kg/year, which was sufficient to eliminate all detectable phosphorus export from the wintering site. Approximately 180 cattle were housed at the wintering site, resulting in a TP load reduction per head of cattle of 0.05 kg/head/year. This case study implies that it may be possible to eliminate phosphorus export from wintering sites in the Baptiste Lake watershed by locating the sites away from streams, preventing cattle access to streams, and diverting manured runoff. As a result, these practices are assessed here to have a high potential to reduce phosphorus input to Baptiste Lake. As with conservation-tillage, however, this potential is likely exaggerated because livestock best management practices may already be used at some farms in the watershed.

Wuite and Chanasyk (2003) provide estimates of the annual cost of TP load reduction achieved by conservation-tillage and livestock best management practices or relocation. Conservation-tillage results in a savings due to reduced fuel consumption. Changes in yield associated with conservation-tillage were not considered. Wuite and Chanasyk (2003) present costs of TP load reduction for livestock wintering sites along Haynes Creek in Alberta and nine sites in Saskatchewan that were originally reported by Knopf et al. (2003). Both the Haynes Creek and Saskatchewan estimates were calculated using the net present value method whereby installation costs and annual maintenance costs are compared against the annual benefits realized through increased forage yield crops and, in the case of the Saskatchewan sites, increased calf production. Net present value was averaged over a 20-year period using a 9% discount rate for costs and benefits. The estimated cost of installing a ditch and berm and realigning the corral fence to divert runoff from a wintering site along Haynes creek was $49 per kg TP. If the site had to be relocated to prevent runoff, the cost was higher at $75-108 per kg TP. The cost of relocating or modifying wintering sites in Saskatchewan ranged from a cost of $155 per kg TP to a net benefit of $41 per kg TP. These costs, while substantial, are low compared to the costliest management practice considering in this report (liming at $238 per kg TP). As such, prevention of phosphorus export from wintering sites is concluded to be associated with a moderate cost. The Canada Alberta Farm Stewardship Program and the Canada Alberta Farm Water Program both provided funding to producers in the past to off-set some of the costs associated with developing watering systems and fencing off riparian areas. The programs were part of the Agriculture Policy Framework, a federal-provincial-territorial agreement on agriculture that recently ended. Whether similar programs will be available in the future is uncertain.

3.2.3 Forestry effects on phosphorus transport

Impact Magnitude

Prepas et al. (2001b) compared the chemistry of 12 Boreal Plain lakes 2 years before harvest and 2 years after harvest. Total phosphorus at stratified lakes was 43.2 +/- 4.9 mg/L preharvest. In the first year postharvest, TP increased to 63.3 +/- 17.7 mg/L and in the second year declined to 27.5 +/- 3.4 mg/L. The first year postharvest experienced higher than average rain and the second year postharvest experienced lower than average rainfall. It therefore appears that phosphorus runoff may increase during the first year after harvest if heavy precipitation occurs, although the increase is not significant and may be negated by below average TP export when rainfall declines. A study of 19 lakes with upland dominated catchments in the Boreal Plain found that percent of the drainage basin harvested explained a nondetectable ($p>0.05$) 12% of the variation in total phosphorus concentration (Prepas et al. 2001b, Prepas et al. 2001c), providing further evidence that timber harvest does not strongly influence phosphorus export to lakes with upland dominated catchments in the Boreal Plain such as Baptiste Lake. Devito et al. (2000) concluded that the presence of large wetland areas connected to a lake increases the susceptibility of lakes in the Boreal Plain to nutrient loading from logging. Wetlands cover just 0.5 % of Baptiste Lake's catchment, less than any of the lakes studied by Devito et al. (2000), suggesting that Baptiste Lake may be relatively resilient to the impacts of logging.

Phosphorus export can potentially increase after timber harvest if soils become warmer due to increased sunlight and wetter due to decreased evapotranspiration. Warmer and wetter soils promote increased decomposition of organic matter which increases the rate of phosphorus mineralization. Evans et al. (2000) found no difference in shallow subsurface water phosphorus concentration or phosphorus export coefficients in harvested and unharvested subcatchments of a Boreal Plain lake (Moose Lake). Research at the same lake found no differences in extractable soil phosphorus between harvest and forested areas one-year after harvest (Macrae et al. 2005). Rapid aspen regeneration and the dry climate led to soil moisture deficits and limited surface runoff, suggesting that timber harvest effects on phosphorus mineralization are low on the Boreal Plain (Macrae et al. 2005). Forest floor and organic surface soils had a large potential to release P in both harvested and forested areas. Subsurface soils, on the other hand, had low potential to release P due to the large absorption affinity of mineral subsoils that are typical in the region (Macrae et al. 2005).

The studies summarized above are short-term (2-4 years) and investigated catchments where percent harvested did not exceed 30%. Longer term studies are needed to better understand the impact of logging on phosphorus export to lakes (Devito et al. 2000). However, based on available evidence, logging is assumed here to not influence phosphorus runoff. This conclusion is in contrast to findings from eastern boreal lakes where logging has been found to be associated with high phosphorus concentrations in lakes (e.g. Carignan et al. 2000). Western boreal lakes appear to be less sensitive than eastern boreal lakes to potential phosphorus loading from logging, perhaps due to the drier climate, low relief, and poorly drained soils relative to Boreal Shield catchments.

Management Potential
Given the apparent lack of a substantial impact from forestry on phosphorus runoff in the region, the feasibility of managing the impact is not assessed.

3.2.4 Forest conversion effects on phosphorus transport

Impact Magnitude
As discussed previously, the rate of phosphorus export from cropland and pasture is greater than that from forest. Phosphorus export from anthropogenic footprint such as roads, seismic lines, wellsites, pipelines, and residential lots should also increase relative to forest due to increased exposure of soil to water and wind and perhaps increased mineralization of soil phosphorus. Information on phosphorus export from anthropogenic footprint is limited, however. The Maine Department of Environmental Protection (2000) estimates that phosphorus export from all road types is 3.5 kg TP/ha/year and phosphorus export from residential lots, not including septic systems, is estimated to be 0.25-0.35 kg TP/ha/year. Oil and gas infrastructure is assumed to have the same export coefficient as roads (3.5 kg TP/ha/year). Applying the coefficients to the current area of footprints in the watershed, phosphorus export from footprints is estimated to be 3,400 kg TP per year. This estimate should be regarded as highly uncertain due to the paucity of information on phosphorus runoff rates from anthropogenic footprints. The applicability of the runoff coefficients derived from Maine to the Baptiste Lake watershed is unknown. The applicability of runoff coefficients for roads to other types of industrial footprint such as seismic lines is also unknown. For example, if seismic lines are assumed to instead cause no increase in phosphorus runoff, the total estimated phosphorus export from footprints is reduced from 3,400 to 1,343 kg TP per year in excess of natural levels.

To explore how the watershed may change in response to future development, the land use simulation model ALCES (www.alces.ca) was applied. ALCES is a tool designed to contribute to strategic land use planning by evaluating the regional effects of anthropogenic and natural disturbances to a variety of ecological and socioeconomic indicators. ALCES was applied to simulate the expansion of disturbances associated with land use in the region and to estimate the effects to forest cover and phosphorus export. Land use projections (Appendix 2) predict agricultural land could remain stable over the next 50 years, roads could increase by 2.1 km^2, settlements could increase by 3.2 km^2, and gas infrastructure could decrease[3] by 3.3 km^2. Applying phosphorus export coefficients for cropland, pasture, and footprints, this transformation of the watershed would decrease phosphorus export by an average[4] of 168 kg per year relative to today (Figure 6). The decrease in phosphorus export is the result of a predicted decrease in footprint associated with gas exploration[6].

The low impact of forest conversion is dependent on the assumption that agriculture will not expand in the region. If farming was to increase in the watershed, phosphorus export from the watershed would also increase. To demonstrate the potential impact if agriculture were to increase in the watershed, an alternative scenario was simulated in ALCES whereby agriculture expanded at the rate of growth that occurred in Alberta between 1991 and 2001[5]. Cropland grew from 9,184,457 ha in 1991 (http://www.statcan.ca/english/censusag/ab.htm) to 9,728,181 ha in 2001 (http://www.statcan.ca/english/freepub/95F0301XIE/tables/html/Table5Can.htm#48) for an annual growth of 0.59% relative to 1991. The cattle and calf population grew from 4,756,365 in 1991 (http://www.statcan.ca/english/censusag/ab.htm) to 6,616,201 in 2001 (http://www.statcan.ca/english/freepub/95F0301XIE/tables/html/Table19Can.htm) for an annual growth of 3.91% relative to 1991. If agricultural activity in the Baptiste Lake watershed were to grow at these rates over the next 50 years, phosphorus export would increase by an average of 11,618 kg per year relative to today. It is emphasized that this scenario is for exploratory purposes only and is not meant as a prediction of what will happen in the Baptiste Lake watershed. It does, however, demonstrate the potential impact if agricultural activity, and especially livestock operations, were to grow in the region.

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[3] The decrease in gas infrastructure is due to the high density of seismic lines that currently occur in the Baptiste Lake watershed relative to the Alpac FMA. The high density of seismic lines gradually reclaims to forest during the simulation, resulting in an overall decrease in the area of energy infrastructure.

[4] -168 kg is the difference between future (i.e. simulated) phosphorus export and current phosphorus export from the watershed, averaged across all years.

[5] The period of 1991 to 2001 was selected to provide an example of a period of growth in agricultural activity in Alberta. Between 2001 and 2006, in contrast, agricultural activity decreased in Alberta.

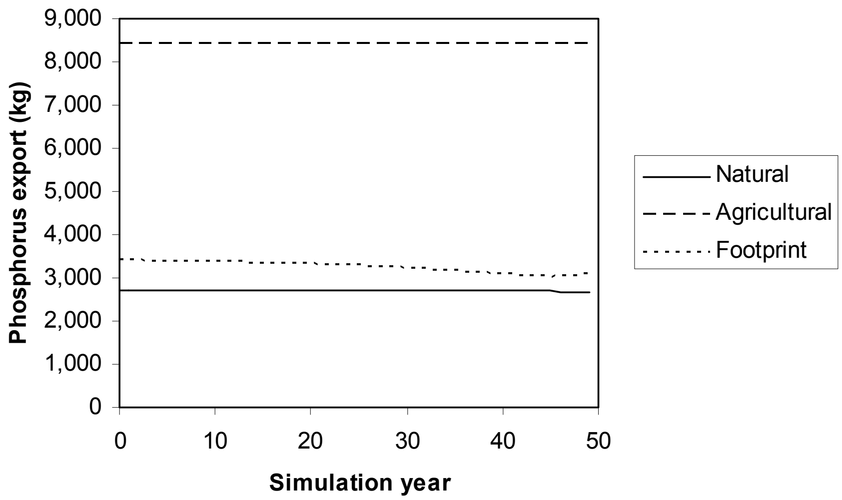

Figure 6. Predicted future phosphorus export from natural and agricultural land and footprint in the Baptiste Lake watershed. Based on an ALCES simulation using assumptions described in Appendix 2.

Management Potential

Conversion of forest to agriculture appears to have been low in recent years. However, future trends in agricultural expansion are uncertain. Given the potential susceptibility of water quality to agricultural expansion (especially livestock operations), a proactive management strategy could be to plan land use such that future conversion of land to agriculture in the watershed is restricted. For example, three large subwatersheds covering 233 km^2 located to the west of the lake and remain largely forested and land use could be planned to maintain these subwatersheds in a forested condition. The cost of restricting agricultural expansion is likely low given that most areas in the watershed that are not yet converted to agriculture have soils with very severe limitations that restrict their capability in producing perennial forage crops (Figure 7). Existing farms in Athasbasca County, which are likely located on the best available soils, generated on average $20.26 per ha per year in 2001 which is low relative to the Alberta average of $60.54 per ha[6]. Due to the low anticipated economic benefit of agricultural expansion and the high potential phosphorus runoff associated with livestock operations, the cost of reducing TP through prevention of farm expansion is assessed as low.

[6] Based on Statistics Canada's 2001 Census of Agriculture, Alberta Agriculture reports average net farm operating incomes per farm of $5,912 and $23,764 for Athabasca County No.12 and Alberta, respectively. Average farm sizes are reported to be 721 acres and 970 acres for Athabasca County No. 12 and Alberta, respectively. These net income and farm size figures were combined to estimate that average farm net income per ha of $20.26 and $60.54 for Athabasca County No. 12 and Alberta, respectively.

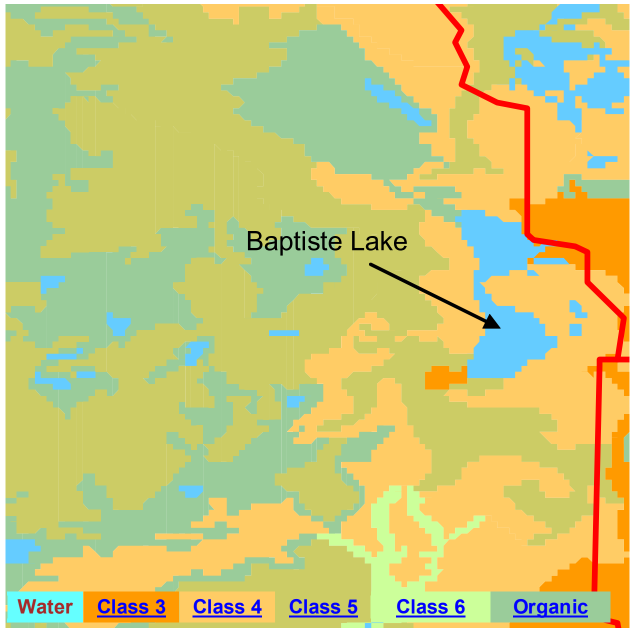

Figure 7: Soil capability for agriculture in the region surrounding Baptiste Lake. The majority of areas not yet converted to agriculture are class 5 soils, which have very severe limitations that restrict their capability in producing perennial forage crops. Based on the Soil Capability Classification of Agriculture and downloaded from http://geogratis.cgdi.gc.ca/cgi-bin/geogratis/cli/agriculture.pl.

3.2.5 Internal phosphorus loading

Impact Magnitude

Stratified lakes in northern Alberta typically exhibit depleted water oxygen levels in the lower strata (hypolimnion) during the summer. This process causes the release of phosphorus from bottom sediments and, during spring and fall turnover, the phosphorus-rich water from the hypolimnium is transported to the surface of the lake where it becomes available for phytoplankton production. The importance of this process is demonstrated by seasonal fluctuations in surface concentration of TP in South Baptiste Lake (Trew et al. 1987). In 1977, surface concentration of TP was 0.080 mg L^{-1} during spring turnover. Surface concentration subsequently declined to 0.050 mg L^{-1} during the summer months when the lake became stratified. During fall turnover, surface concentration of phosphorus again increased to 0.100 mg L^{-1} and remained high until freeze up.

Applying total phosphorus release rates for the southern and northern basins of Baptiste Lake (Reedyk et al. 2001), annual phosphorus release from sediments is estimated to be 4741 kg[7]. This estimate suggests that sediment phosphorus release makes up a large

[7] Average total phosphorus release rates (TPRR) between 1991 and 1993 were 5.8 mg m^{-2} d^{-1} and 5.4 mg m^{-2} d^{-1} in the summer and 0.5 mg m^{-2} d^{-1} and 1.0 mg m^{-2} d^{-1} in the winter for the north and south basins, respectively. Assuming that lake surface area is a reasonable approximation of sediment area, the sediment areas are 5.07 km^2 and 4.74 km^2 for the northern and southern basins, respectively (Prepas et al. 2001c). Based on these sediment areas and TPRR's, daily TP release from northern basin sediments is 29.57 kg d^{-1} in the summer and 2.54 kg d^{-1} during the winter, while daily TP release from southern basin sediments is 25.44 kg d^{-1} in the summer and 4.50 kg d^{-1} during the winter. To calculate total annual phosphorus release from sediments, I assumed that summer phosphorus release occurs during periods of thermal stratification and that winter phosphorus release occurs from one-month following freeze-up until mid-February (Reedyk et al. 2001). Based on 1977 data (Trew et al. 1987), thermal stratification occurred between early July and

component of phosphorus input to Baptiste Lake waters, but not as large as Prepas's (2004) estimate that phosphorus release from sediment at the lake is 7 times greater than from external inputs.

Management Potential

A variety of treatments exist to reduce phosphorus release from lake sediments. Chemical treatments focus on increasing the capacity of sediments to retain phosphorus. These include oxygenation and/or iron application to increase binding surfaces for sediment phosphorus and lime and/or alum treatments to form phosphorus precipitates (Burley et al. 2001). Laboratory experiments using sediments from Baptiste and two other nearby lakes indicate that alum treatment should be the most effective treatment, reducing TP to 14% of reference concentrations (Burley et al. 2001). However, alum is unlikely to be feasible in practice due to aluminum toxicity concerns. Lime treatments, in comparison, reduced TP to 35% of reference conditions (Burley et al. 2001). Iron and oxygenation treatments were concluded to be ineffective at controlling phosphorus. In summary, based on the laboratory experiments, lime is likely to be the most successful chemical treatment for reducing sediment phosphorus release.

Lime application to whole lakes indicates that substantial reductions in lake TP concentration can be achieved, but only if lime application is ongoing. A single summertime lime treatment to two hardwater eutrophic lakes with similar chemistry to Baptiste reduced sediment phosphorus release to 21.5% of pre-treatment values by the first winter following treatment. However, TP and chlorophyll-a concentrations were not reduced and sediment phosphorus release returned to pre-treatment levels the following year (Reedyk et al. 2001). In contrast, repeated lime applications over a 7 year period to Halfmoon Lake in northern Alberta reduced summer sediment phosphorus release by 41% (Prepas et al. 2001d). Based on TPRR at Baptiste Lake provided by Reedyk et al. (2001), this reduction equates to 1,770 kg TP per year. Although liming has the potential to damage ecosystems if lake water becomes too basic, careful management of lime application was able to keep pH within the natural range and therefore avoid detrimental side-effects (Prepas et al. 2001d). Based on Trew et al.'s (1987) estimated annual phosphorus loading of Baptiste Lake of 3,407-12,208 kg, an 1,800 kg reduction is concluded to be substantial. The management potential of liming is therefore rated as high.

Prepas et al. (2001c) conclude that lime is an economical treatment but do not provide cost estimates. During their experimental liming of Halfmoon Lake in Alberta, Prepas et al. (2001d) applied an average annual dosage of 47 mg/L of lime, adjusted to account for the fact that liming did not occur every year. Applying a per tonne cost estimate for lake liming provided by White (2000), the annual estimated cost of liming Baptiste lake is

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the end of August (approximately 60 days) in the northern basin and between mid June and early October (approximately 100 days) in the southern basin. It was thus assumed that summer phosphorus release lasted 60 days in the northern basin and 100 days in the southern basin. Freeze-up occurred mid-November in both basins (Trew et al. 1977), suggesting the wintertime phosphorus release occurred for approximately 60 days. Therefore, annual total phosphorus release from sediments in Baptiste Lake is estimated to equal 4741.1 kg.

$422,000[8]. This estimate likely substantially underestimates the cost of liming because it assumes a lime cost of $30/tonne (White 2000) which is one-third of the current lime cost of approximately $90/tonne (S. Wasel, pers. comm.). When combined with the estimated 1,770 kg TP internal loading reduction that could be achieved at Baptiste Lake through liming, the estimated cost per kg of TP load reduction is at least $238.42 which is assessed as high. This estimate is approximate and for discussion purposes only.

Application of hypolimnetic oxygenation at Amisk Lake (within 75 km of Baptiste Lake) demonstrates that this treatment can also achieve reductions in TP concentrations, albeit less so than lime application. During the 4 summers of treatment, hypolimnetic TP concentrations dropped to <50% of pretreatment concentrations, which caused a 13 and 55% reduction in epilimnetic TP and chlorophyll-a concentrations. Summer phytoplankton biomass decreased by 33% and composition shifted from cyanobacterial dominance to mixed assemblage of diatoms and cyanobacteria. However, oxygenation was found to be expensive which resulted in the cancellation of the treatment half way though the experiment and the conclusion that oxygenation of lakes much larger than Amisk Lake, such as Baptiste Lake, is not economically feasible (Prepas et al. 1997).

An alternative to chemical treatments are in-lake physical controls such as withdrawal of phosphorus rich water from the hypolimnium. Hypolimnetic water withdrawal was successfully used at Pine Lake, a 3.89 km^2 eutrophic lake near Red Deer for which internal sources accounted for an estimated 61% of the total TP loading (Sosiak 2002). A pipe 1400 m in length and 530 mm in diameter was used to extract hypoliminetic water to a wetland that was constructed along an outlet stream of the lake. Cost of the system was $348,200 plus $145,164 of volunteer labour and materials (Sosiak no date). Restoration of the lake achieved a 44-47% reduction in TP concentration, of which 29% was attributable to hypolimnetic water withdrawal and the remainder to reductions in external phosphorus input. While successful at Pine Lake, a detailed review would be needed to determine whether the treatment is feasible at a larger and more phosphorus rich lake such as Baptiste Lake. The pipeline at Pine Lake removed approximately 230 kg TP per year, which is only a small fraction of Baptiste Lake's phosphorus budget. Substantially more hypolimnetic water would need to be removed at Baptiste Lake. In addition, the Pine Lake project experienced problems in pipeline water flow due to impoundment of the pipe outlet by beaver dams. This problem could also occur at Baptiste Lake because numerous beaver dams exist along the sole outlet stream.

Another in-lake physical control is artificial circulation whereby water pumps, surface aerators or bottom diffusers are used to maintain water movement in order to achieve destratification (Wagner 2004). An example is the SolarBee, a solar-powered pump designed to circulate water. If destratification can be achieved through artificial circulation, increased oxygen levels in the hypolimnion can reduce the release of phosphorus from sediments. Another potential benefit is a shift from blue-green algae to

[8] The volume of Baptiste Lake is 85,526 dam^3 (Trew et al. 1987). A dosage of 47 mg/L/year of lime would therefore require application of 4,020 tonnes of lime. White (2000) estimates that the cost of lake liming is $105/tonne, assuming easy access and that boats and vehicles do not need to be purchased. Based on these dosage and cost estimates, the annual estimated cost of liming Baptiste Lake is $422,000.

less noxious algae. This can occur by way of two mechanisms. First, physical disruption can reduce the buoyancy of blue-green algae. Second, carbon dioxide levels can increase due to increased contact of water with the atmosphere and cycling of carbon dioxide rich water from the hypolimnion, which in turn causes reduced pH to the detriment of blue-green algae. However, the effectiveness of artificial circulation in northern temperate lakes is unproven and field trials are needed before the technique can be recommended (Al Sosiak, Alberta Environment, pers. com.). Another potential drawback is cost. Wagner (2004) estimates that artificial circulation of a 100-acre lake would cost between $70,000 and $400,000 over 20 years. Extrapolating this to Baptiste Lake's surface area of 2424 acres results in a cost estimate of $1.7 million to $9.7 million over 20 years, or $85,000 to $485,000 per year (US funds). A SolarBee has been purchased by the Summer Village of Whispering Hills, providing an opportunity to test the effectiveness of the approach at a local scale.

Despite the apparent success of treatments such as liming to reduce internal phosphorus loading, it is important to realize that the treatments require a long-term commitment and are potentially expensive. In addition, the treatments are unlikely to succeed unless external phosphorus inputs are successful controlled (Schindler 2006, Reedyk et al. 2001).

3.2.6 Climate effects on phosphorus transport

Impact Magnitude

Precipitation in the region is predicted to increase by approximately 11% over the next 100 years in response to climate change (Donahue 2004). Higher precipitation will cause increased stream flow and potentially increased external input of phosphorus to the lake (Schindler 2006). At the same time, evaporation is expected to increase by approximately 40% over the next 100 years due to higher temperatures in the region (Donahue 2004). Loss of lake water due to evaporation is expected to outweigh the addition of water from increased precipitation, resulting in a moderate (approximately 0.1 m) reduction in lake level. The negative water balance will increase residence time, which refers to the time needed to replace the volume of the lake with inflowing water. Increased residence time causes the concentration of chemicals to increase, resulting in increased phosphorus concentration and eutrophication (Schindler 1998). To summarize, two predicted changes in climate (increased precipitation and increased temperature) would both act to increase phosphorus levels and therefore the productivity of Baptiste Lake.

Modeling of expected changes in Baptiste stream flow is needed to predict the magnitude of climate change effects to phosphorus concentration. Changes in residence time have the potential to have a large impact; a doubling of residence time has roughly the same impact on lake phosphorus concentration as does doubling phosphorus input (Schindler 1978).

Management Potential

The impact of climate change on lake phosphorus concentration is difficult to manage because of the phenomenon's global scale. Residence time, and therefore phosphorus concentration, could conceivably be reduced by increasing outflow from the lake although the benefit might be at least partially offset by the associated decline in lake level. The lake's sole outflow is Baptiste Creek which drains water from the lake to the Athabasca River. If beaver dams along the creek reduce flow rate, removal of the dams could decrease residence time and lake phosphorus concentration. This effect is hypothetical, however, and requires detailed investigation to assess potential effectiveness prior to implementation.

3.2.7 Trophic cascade effects to the plankton community

Impact Magnitude

Phytoplankton productivity is likely controlled in part by interactions with other trophic levels in the lake's food web. Northern lakes, including Baptiste, typically display a simple trophic structure with four levels: piscivorous fish (walleye and pike), which feed on planktivorous fish (perch, cisco, etc.), which feed on zooplankton, which feed on phytoplankton. Studies have demonstrated that a decline in piscivore abundance can cause planktivore abundance to rise due to reduced predation pressure (Schindler 2006). A rise in planktivore abundance causes predation pressure on zooplankton to increase, with the result that larger zooplankton species in particular decrease in abundance. The decreased abundance of large-bodied zooplankton ultimately causes phytoplankton to increase. This process, called trophic cascade, can cause large changes to the phytoplankton community.

The influence of trophic cascade on primary productivity may be similar in magnitude to that of nutrient input (Carpenter and Kitchell 1987). Experimental modifications of fish communities in Wisconsin lakes dramatically demonstrate the potential impact of trophic cascade on primary productivity. For example, a lake from which piscivorous fish were removed displayed 6 times higher primary productivity compared to a lake with an intact fish community (Carpenter et al. 2001). Research has also demonstrated that lakes with healthy piscivorous fish communities may not experience high algal production even when nutrient levels are high due to the ability of abundant zooplankton to control algal biomass (Carpenter et al. 1995).

Several factors suggest that the primary productivity of Baptiste Lake may be enhanced due to trophic cascade. The lake's low biodiversity creates a simple food chain that is more susceptible to a trophic cascade effect than more biodiverse systems (Polis 1994). Also contributing to the lake's susceptibility is the abundance of Daphnia, a type of zooplankton that enhances the trophic cascading effect (Schindler 2006). As discussed elsewhere in this report, populations of piscivorous fish in the lake have collapsed due to over-fishing over the past 3 decades. Over the same time period, the zooplankton community has also undergone substantial changes. Between 1976 and 1995, the average length of Daphnia decreased by approximately one-third (0.3 mm) (Figure 8). These changes in the zooplankton community are consistent with changes documented at lakes where trophic cascade has occurred (decline in large bodied grazers such as Daphnia (Hodgson 2005)). A more thorough assessment of changes in zooplankton length at Baptiste Lake is in progress and will be added to this report once available.

An experiment conducted by Carpenter et al. (1996) is useful for comparing the potential impact of trophic cascade and nutrient inputs to primary production. In the experiment, lakes with and without healthy piscivorous fish populations were enriched with phosphorous and nitrogen to assess the impacts of nutrification and trophic cascade on primary production. The scientists concluded that a 1-mm change in mean zooplankton length has roughly the same effect on primary production as a change in the summer mean enrichment rate per unit of epilimnion volume of 1 mg m^{-3} d^{-1}. The experiment was conducted at Wisconsin lakes with very different geochemistry than Baptiste Lake. Regardless, a decrease is zooplankton body size is likely to increase primary production and Baptiste Lake is likely to be sensitive to changes in the zooplankton community due to the lakes low diversity and the presence of Daphnia (as discussed above). Applying the trophic cascade/phosphorus input conversion to the 0.3 mm decrease in average Daphnia length[9], trophic cascade is estimated to have caused an increase in Baptiste Lake productivity that is equal to the effect of increasing phosphorus input by 1,450 kg per year[10]. However, because the Daphnia length data are unpublished and were provided without metadata, the estimate of the magnitude of the trophic cascade impact is highly uncertain. A more extensive zooplankton dataset is being acquired and will be used to obtain a more complete understanding of how the zooplankton community has changed over time at Baptiste Lake.

The importance of trophic cascade to Baptiste Lake's productivity is supported by differences in trophic status as assessed by phosphorus vs chlorophyll-a concentration. Phosphorus concentration is an indirect measure of trophic status and in effect assumes that phosphorus is the primary mechanism responsible for lake productivity. Chlorophyll-a concentration, on the other hand, provides a direct measure of trophic status. The average phosphorus concentration between 1980 and 2003 indicated a eutrophic lake, whereas the average chlorophyll-a concentration over the same time period indicated a hypereutrophic lake (Alberta Environment 2006). The tendency for phosphorus concentration to underestimate the algae concentration as indicated by chlorophyll-a suggests that another mechanism is also contributing to the lake's productivity. This mechanism may be trophic cascade caused by over-fishing.

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[9] The length of cladoceran herbivores such as Daphnia is among the best indicators of grazing intensity (Carpenter et al. 1995).

[10] Daphnia length decreased by approximately 0.4 mm between 1976 and 1995 (Hornung nd). Applying the conversion factor from Carpenter et al. (1996), the trophic cascade at Baptiste Lake could equate to a change in the summer mean P enrichment rate per unit of epilimnion volume of 0.3 mg $m^{-3}d^{-1}$. This enrichment rate was converted to an annual P load for comparison with phosphorus sources. The depth of the epilimnion was estimated to be 8 m, which was the maximum height recorded for the anoxic zone during summertime stratification (Trew et al. 1987). Using an area/capacity curve for Baptiste Lake (Prepas 2004), the 8 m deep epilimnion was estimated to contain 54 x 10^6 m^3 of water. Therefore, the 0.3 mg $m^{-3}d^{-1}$ P enrichment rate per unit of epilimnion volume is estimated to account for a total P enrichment rate of 16.2 kg per day. Applying this enrichment rate over the roughly 3-month (i.e. 90 days) summer period, the impact of decreased grazing pressure from a trophic cascade may be roughly equivalent to an annual phosphorus load of 1,450 kg.

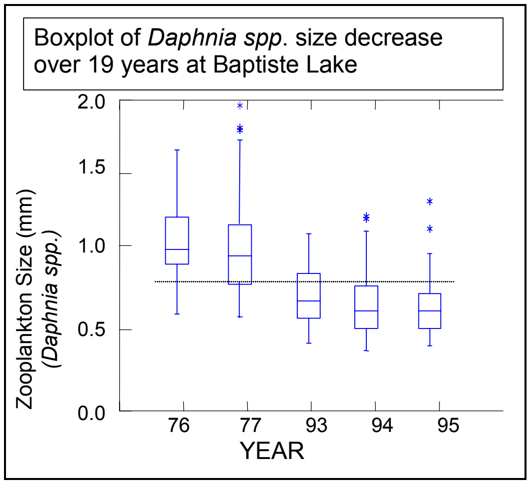

Figure 8. Change in Daphnia spp. size over 19 years at Baptiste Lake. The graph is from the poster "Cascading Trophic Interactions Altering Alberta's Freshwater Ecosystems" by Jon Hornung. Used with permission of the author.

The above discussion has focused on trophic cascades caused by angling. A natural event such as a winterkill may also precipitate a trophic cascade. A winterkill occurs when oxygen depletion in an ice-covered lake is sufficient to cause high fish mortality (Tonn et al. 2004). Winterkills occur during severe winters and climatic variability is such that winterkills are intermittent and changes to trophic structure are temporary. In contrast, changes in trophic structure caused by angling will remain until angling pressure is sufficiently reduced to allow fish populations to recover. Another difference between winterkill and angling is that, unlike angling, a winterkill does not selectively kill piscivorous fish but instead kills both piscivores and planktivores (Tonn et al. 2004). As such, a winterkill may not cause the increase in phytoplankton that can occur in response to angling. Indeed, two lakes in northern Alberta did not display increased chlorophyll levels in summers after winterkills (Tonn et al. 2004).

Management Potential

Given the high natural nutrient levels of Baptiste Lake, high algae growth is likely to continue even if anthropogenic nutrient inputs are curtailed unless zooplankton grazing pressure can be enhanced by increasing piscivorous fish populations. If the aquatic community could be restored to what it was in 1975, increased grazing pressure by zooplankton could presumably achieve the equivalent of approximately 1,450 kg per year reduction in phosphorus input. Based on Trew et al.'s (1987) estimated annual phosphorus loading of Baptiste Lake of 3,407-12,208 kg, a 1,450 kg reduction is concluded to be substantial. The management potential of restoring fish populations is therefore rated as high. An important exception is that grazers (i.e. zooplankton) appear to have little influence on blue-green algae (Carpenter et al. 1995, Carpenter et al. 2001). Therefore, while overall algae growth may be reduced by restoration of the walleye and northern pike fisheries, control of blue-green algae must rely on controlling nutrient levels.

As discussed previously, the estimate of the magnitude of the trophic cascade impact is highly uncertain. A more extensive zooplankton dataset is being acquired and will be used to obtain a more complete understanding of how the zooplankton community has changed over time at Baptiste Lake and the implications for eutrophication.

4 Fisheries

A variety of fish species inhabit Baptiste Lake including walleye, northern pike, yellow perch, and cisco. These populations, especially northern pike and walleye, support a recreational fishery which drew between an estimated 1,389 and 5,699 anglers per year between 1984 and 2005[11]. Fish are also an essential component of the lake ecosystem, and changes in fish populations can have large implications for the health of the lake. Fish form the top of the lake food web and, as discussed previously, changes to fish populations can cascade throughout the food web to affect a wide variety of aquatic species and lake water quality.

Northern pike and walleye are used here as indicators of the status of the Baptiste Lake fisheries due to the value of these species to the recreational fishery, their position atop the aquatic food web as predators, and their sensitivity to stressors such as angling (Post et al. 2002). Creel survey data collected between 1984 and 2005 was used to assess recent catch rates and average weights (Walker and Lovely 2006). High angling pressure has occurred at Baptiste Lake since only the 1970's and, as such, the creel survey data likely does not provide an accurate representation of the natural condition of the fishery (i.e. in the absence of angling). Instead, historical surveys of anglers who fished at the lake between 1920 and 1975 were used to assess the expected condition of the lake prior to heavy angling pressure (Valastin and Sullivan 1996).

4.1 Status

Status: collapsed walleye and pike fisheries
Trend: declining

4.1.1 Walleye

The total catch rate for walleye based on a 2005 summer creel survey is 0.03 fish/hour. This extremely low catch rate suggests that the walleye population may be near extirpation. Several walleye fisheries in Alberta were lost and only a few have recovered after catch rates fell this low (Sullivan 2003). This catch rate also represents a drastic decline from the most recent previous creel survey in 1999 that estimated a total catch rate of 0.78 fish/hour. Even more dramatic is the comparison between the 2005 total catch rate and the estimated historical catch rate. An angler who fished in Baptiste Lake from 1955 recalls that it would take as little as half an hour and usually no more than one hour to harvest the 10 walleye limit. A catch rate of 10 fish/hour is over 300 times higher than the 2005 total catch rate.

[11] Number of anglers per year as estimated by creel surveys were: 5,232, 5,318, 5,699, 4,089, and 1,389 for the years 1984, 1995, 1997, 1999, and 2005, respectively (Walker and Lovely 2006).

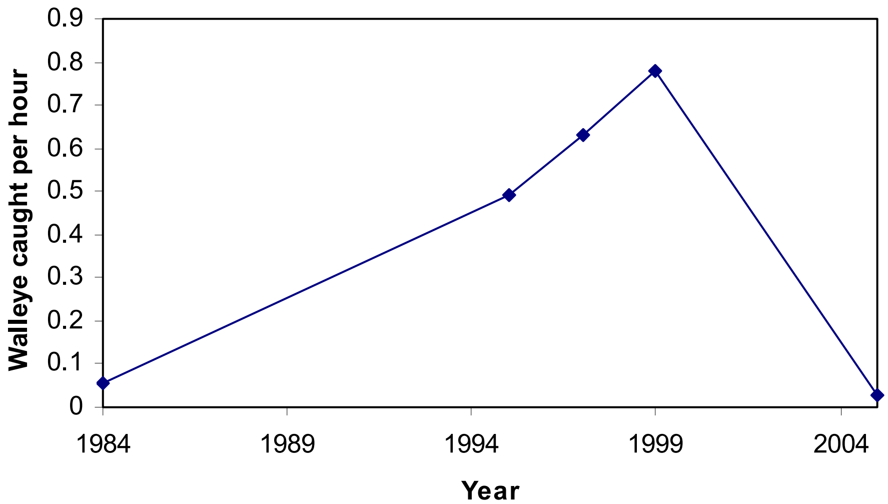

Figure 9. Walleye catch per unit effort as measured from creel surveys at Baptiste Lake. Historical catch per unit effort may have been as high as 10 fish per hour.

The mean weight of walleye also indicates a decline in the status of the fishery. Mean weight from the 2005 creel survey was 1.12 kg, a reduction from mean weights estimated in 1999 (1.425 kg) and 1997 (1.785 kg) surveys. The mean weight in 2005 is also low compared to mean weights reported by anglers who fished Baptiste Lake between 1920 and 1970. Averaged across anglers reporting weights, the reported historical mean weight was 1.7 kg.

The dramatic reduction in total catch rate from recent and historical levels, combined with a reduction in the mean walleye weight, indicates a severely collapsed walleye fishery at Baptiste Lake. This assessment is confirmed by a recent assessment of the fishery by Alberta Sustainable Resource Development (Walker and Lovely 2006).

4.1.2 Northern Pike

The northern pike fishery displays similar characteristics to the walleye fishery. The total catch rate for northern pike based on a 2005 summer creel survey is 0.05 fish/hour, a substantial decline from 1999 when the total catch rate was 0.38 fish/hour. An angler who fished the lake in 1975 reported catching 22 fish in 1.5 hours (14.7 fish/hour). If this catch rate is representative of the historical total catch rate, the catch rate has declined almost 300-fold compared to historical levels.

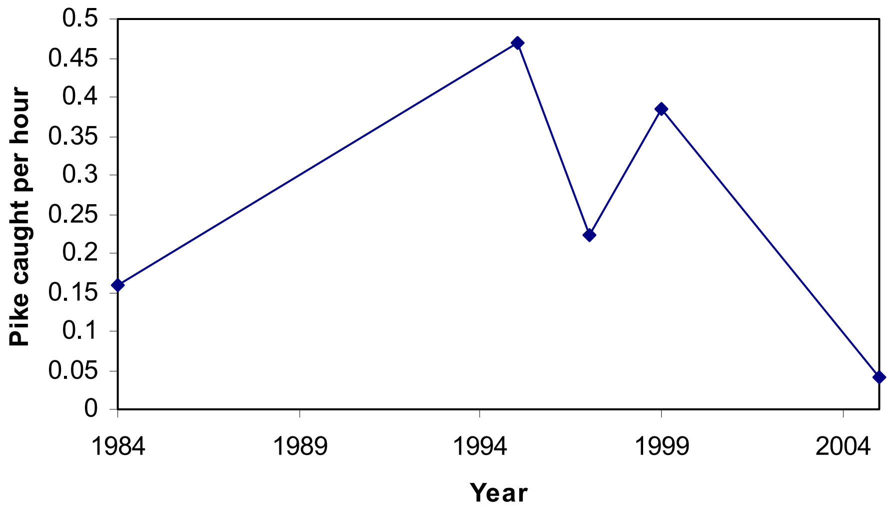

Figure 10. Northern pike catch per unit effort as measured from creel surveys at Baptiste Lake. Historical catch per unit effort may have been as high as 15 fish per hour.

The mean weight of northern pike in 2005 was 1.32 kg, an increase from 1999 when mean weight was 1.26 kg. However, interviews with anglers who fished Baptiste Lake earlier in the 20th century indicate that catching large northern pike (i.e. 10 kg) was common and that the average weight was likely over 4 kg. This suggests that size of northern pike in Baptiste Lake has declined compared to historical levels.

The large reduction in total catch rate and mean weight indicates that the northern pike fishery in Baptiste Lake is collapsed. This assessment is confirmed by a recent assessment of the fishery by Alberta Sustainable Resource Development (Walker and Lovely 2006).

4.2 Management

Unsustainable rates of angling have caused wide-spread declines in Albertan recreational fisheries (Post et al. 2002). Sustainable management of angling is critically important to the recovery of Baptiste Lake's fish populations, and options are discussed below. Habitat degradation may also contribute to fish population declines at the lake. To assess habitat degradation, the results of an assessment of stream crossings (i.e., intersections of roads and streams) in the watershed are discussed. Inadequate stream crossings can impede access of fish to spawning sites. Crossings can also contribute sediment to streams. High sediment loads can negatively impact fish populations by impeding foraging, reducing refugia, diminishing fish production, and causing physiological stress.

4.2.1 Angling

The current regulations in place at Baptiste Lake impose minimum size limits of 50 cm for walleye and 63 cm for northern pike (Walker and Lovely 2006). The minimum size limits were implemented in the mid 1990's in response to the collapsed status of the lake's fisheries. The minimum size limit was initially successful. Walleye total catch rate increased fourteen-fold from 0.054 fish/hour (1984) to 0.778 fish/hour (1999), and northern pike total catch rate more than doubled from 0.159 fish/hour (1984) to 0.468 fish/hour (1995). The walleye and northern pike fisheries have subsequently collapsed, however, despite the minimum size limit remaining in effect.

The reason for the most recent collapse appears to be that partial recovery of the fishery in the 1990's attracted more anglers to Baptiste Lake and, on average, each angler caught more fish. As a result, both directed fish harvest and incidental mortality on released fish (through accidental hooking and handling mortality) increased. Estimated walleye hooking mortality, for example, increased 38-fold between 1984 and 1997. Adding to the demise of the fishery is a high rate of illegal harvest. Based on the 2005 creel survey, an estimated 45% of sub-legal sized fish caught by anglers are kept (Walker and Lovely 2006). As evidenced by the collapse of the walleye and northern pike fisheries between 1990's and 2005, harvest, hooking mortality and illegal harvest has exceeded the sustainable harvest level of the lake.

Due to the collapsed state of Baptiste Lake walleye and northern pike fisheries, a review of the current strategy for managing the fisheries is needed (Walker and Lovely 2006). Regulations that have been implemented elsewhere in Alberta include protected zones, slot size limits, short angling seasons, and catch-and-release only fishery. The effectiveness of these regulations is now discussed based on walleye fishery management experience from other Alberta lakes (Sullivan 2003, and pers. com.).

Protected zones are unlikely to be successful because fish can move between protected and unprotected zones. At Calling Lake, for example, the allowable harvest was exceeded four-fold despite the implementation of protected zones implemented in 2002 (Sullivan, no date).

Slot size limits are intended to provide protection of mid-sized fish to increase the number of fish that survive to larger sizes. A slot size limit protecting 43-52 cm length walleye was implemented at Touchwood, Siebert, and Spencer lakes in the 1990's. The regulation failed to recover the fisheries, with no fish surviving to 52 cm due to heavy harvest of small fish and high illegal harvest of 43-52 cm fish. Also detrimental to the walleye populations was high harvest of fish below the size limit (Sullivan 2002).

A short season was implemented at Vincent (3 weeks) and Long (4 weeks) lakes in 2003. Despite the shortened season, angling pressure was sufficient to heavily over harvest the walleye populations in these lakes. The annual allowable harvest at Vincent Lake was reached in just 2.1 days and at Long Lake in just 3.4 days. By the end of the shortened season, the annual allowable harvest at both lakes had been exceeded approximately seven-fold (Daryl Watters, Sustainable Resource Development, pers. com.).

In summary, experience from Baptiste and other lakes in northern Alberta suggests that conventional fishing regulations will fail to sustain viable Baptiste Lake fisheries. Two factors contribute to the failure of conventional approaches. First, the cold climate means that the productivity of Alberta's fisheries is far lower than at southern regions where conventional fishing regulations have been applied to greater success. For example, memorable-size (630 mm total length) walleye caught from Baptiste lake is likely older than 15 years of age (Sullivan 2003). Second, angling pressure in Alberta is high due to the rapidly growing population and the small number of lakes relative to other jurisdictions. The number of licensed anglers per lake in Alberta in the mid-1990's was 312, whereas anglers per lake in Saskatchewan, Manitoba and Ontario was only 2 (Sullivan 2003).

Given the failure of conventional fishing regulations, implementation of a catch-and release-fishery is likely needed to improve the status of walleye and northern pike fisheries at Baptiste Lake. Using walleye as an example, it is apparent that a considerable portion of the annual production of Baptiste Lake's fishery can be lost to hooking mortality alone. In 1997, angler effort for walleye at Baptiste Lake was 19,699 hours and the catch rate was 0.63 walleye per hour (Walker and Lovely 2006). Assuming 5% hooking mortality (Chris Davis, Sustainable Resource Development, pers. com.) and an average fish weight of 0.85 kg (Walker and Lovely 2006), hooking mortality for walleye in 1997 is estimated to have been 527 kg. Baptiste Lake's walleye population was assessed to be in stable condition in 1997, implying a theoretical production of 0.86 kg/ha or 955 kg/year (Heather Lovely, Sustainable Resource Development, pers. com.). Hooking mortality therefore could account for 55% of the annual theoretical production of a stable walleye population at the lake. Additional production would be lost to illegal harvest. Given the collapsed status of the fishery, the current sensitivity to hooking mortality and illegal harvest is presumably even higher.

4.2.2 Stream Crossings

Populations of fish such as walleye and northern pike utilize both Baptiste Lake and its tributaries to spawn. Long-time anglers report that walleye spawning has historically occurred in tributaries draining from west of the lake, and white sucker spawning runs were observed in tributaries in 1989 (O'Neil et al. 1990). The use of tributaries for spawning is likely variable, and the abundance of spawning sites in tributaries during wet years can create strong recruitment events that help to sustain populations. At Baptiste Lake, O'Neil et al. (1990) hypothesized that the relatively strong year-classes for 1977, 1978, and 1979 may have resulted from favourable climatic conditions during spawning and/or rearing.

Where roads intersect tributaries (i.e. stream crossings), upstream fish passage is potentially impeded. Due to the cost of bridges, culverts are used for many stream crossings. If undersized, improperly installed, or poorly maintained, culverts can prevent fish passage due to high water velocity within the culvert, blockage within the culvert, or hanging. A hanging culvert develops when water exiting a culvert scours the stream bed and, over time, causes the downstream end of a culvert to hang above the stream water level, thereby impeding upstream movement of fish into the culvert. If fish passage is blocked, decreased access to spawning areas and diminished recruitment can occur.

A stream crossing survey was conducted in the Baptiste Lake watershed during August 2007 to assess the status of all known crossings that could be accessed by truck or by walking a short distance from a road (Stanislawski 2007). 45 watercourse crossings were assessed[12], of which 7 were bridges, 32 were culverts, and an additional 6 were in need of bridges or culverts (Figure 11). The vast majority (83%) of watercourse crossing and road cross-drain culverts were crushed, compressed, or bent and 45% were of insufficient size for flow of the watercourse. This is reflected in 80% of all culverts not draining properly and led to at least 50% of the culverts having their inlet and/or outlet not embedded or hanging.

Of the stream crossings assessed during the survey, 24 were determined to be fish bearing or potentially fish bearing. This included 15 culverts, 7 bridges, and 2 crossings without culverts or bridges. Of the 15 culverts, 10 were determined to potentially obstruct fish movement due to culvert overhang and/or high water velocity resulting from an undersized culvert. An additional two of the culverts were partially blocked by beaver dams which also could impede fish movement. Overall, 80% of culverts assessed along fish bearing streams in the watershed potentially impede fish movement. All bridges were determined to not obstruct fish passage.

Stanislawski (2007) also assessed sedimentation problems at stream crossings. Introduction of sediment into streams from roads was found at just two crossings, both of which were culverts and one of which was fish bearing. Sediment transport downstream of these crossings was not detected, suggesting that the introduction of sediment was a localized impact. Erosion at culverts was detected at an additional eight crossings, of which only one displayed downstream sediment transport. In summary, the introduction of sediments at crossings did not appear to be a major impact and is not considered further in this report.

Blockage of fish movement upstream can best be mitigated by minimizing the use of culverts. If culvert construction is deemed necessary, sound culvert construction and diligent monitoring and maintenance are essential (Stanislawski 2007). Culverts should be as wide as the annual high water mark to avoid high water velocity, which often requires installation of larger culverts than was required by construction methods and regulations in the past. To avoid development of hang, culverts should be embedded a minimum of 25% below the stream bed. Markings should be installed and maintained at both culvert ends to prevent impacts by graders, mowers, and brush removers which can damage culverts and constrict flow. Monitoring of crossings should occur frequently (i.e. every year and scheduled to occur during above average water flows) and problems fixed promptly. The crossing survey determined that most crossings in the watershed are problematic. Straightening of crushed culverts and cleaning out of blockages can be accomplished with relatively low effort. However, culverts with overhang or of insufficient size require replacement and will likely need to be prioritized due to associated cost. Fish bearing watercourses should be given the highest priority. More detailed guidance on culvert construction and maintenance is available from the Alberta Pacific Forest Industries document “Watercourse Crossings: Best Management Practices”.

[12] An additional 17 sites were road cross-drain sites, referring to areas of water flow across a road that are not part of a natural watercourse.

Although most stream crossings are problematic, angling pressure is far more serious. Most larger fish bearing tributaries have bridges within the immediate vicinity of the lake (Figure 11). In addition, spawning runs during wet years would likely be insufficient to recover the fishery if angling pressure is not also reduced. However, combined with the implementation of a catch-and-release fishery or fishing moratorium, repair or replacement of substandard culverts would increase the likelihood of the fishery recovering by increasing recruitment during wet years.

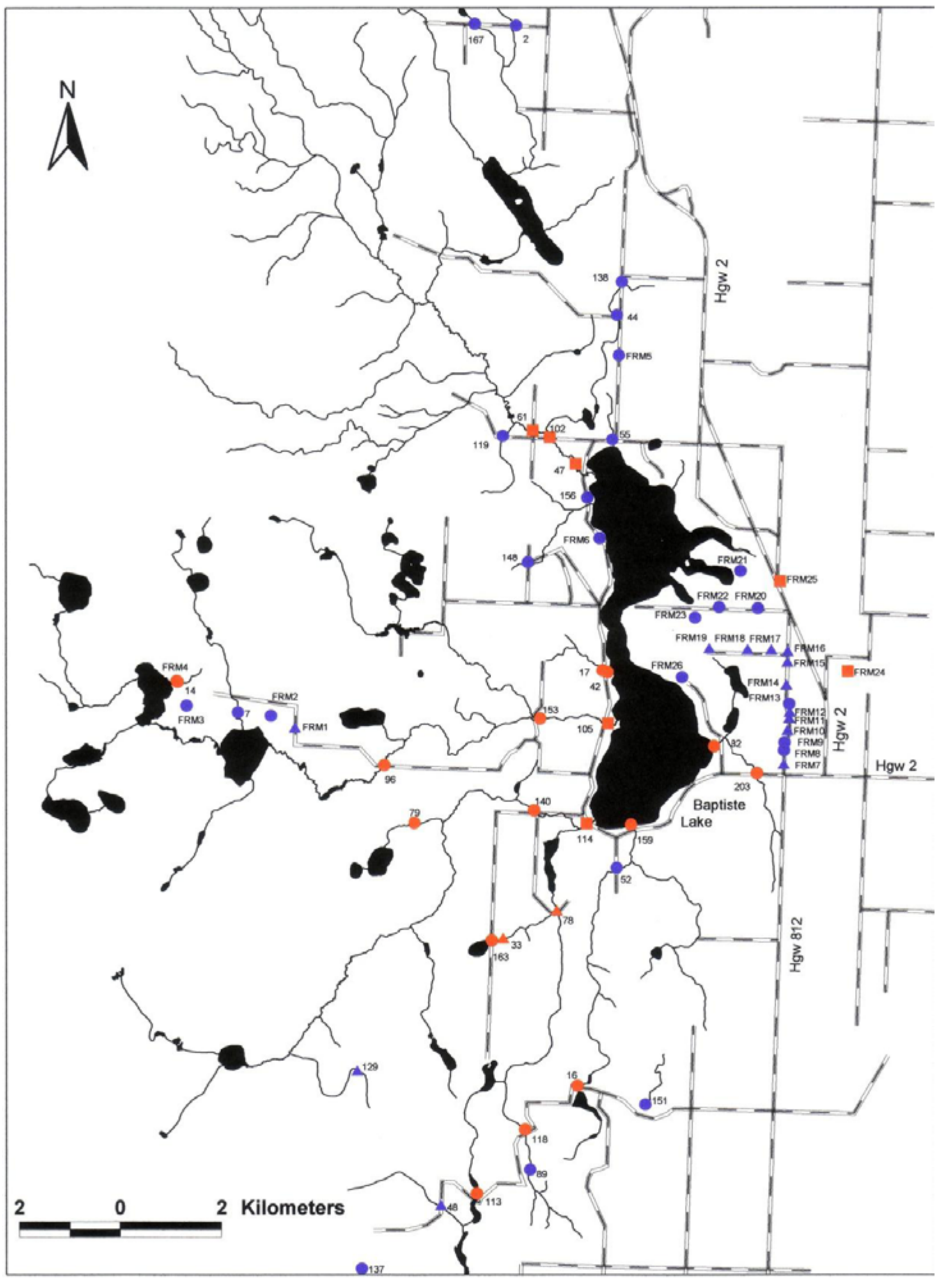

Figure 11. Map of 62 crossings in the Baptiste Lake watershed surveyed in August 2007. Culverts are represented by circles, bridges by squares, and no culvert sites by triangles. Fish-bearing sites are identified by red symbols. Copied from Stanislawski (2007).

5 Shoreline Condition

The shoreline zone sustains the greatest diversity of plants and animals in a lake (Valastin 1999). Aquatic plants, referred to as aquatic macrophytes, produce oxygen for fish and provide spawning and rearing habitat for many species including northern pike which attach their eggs to the stalks of plants. Other types of animals supported by aquatic macrophytes include birds, amphibians, reptiles, and some mammals such as muskrat (Chambers 2004). Shoreline vegetation also protects water quality by removing nutrients from diffuse runoff which accounted for approximately 10% of external phosphorus input to Baptiste Lake between 1976 and 1978 (Trew et al. 1987). The shoreline is also protected from erosion by shoreline vegetation which binds soil particles and absorbs energy from waves.

Degradation of shoreline vegetation can inhibit these valuable services. Clearing of lakefront vegetation along lakefront properties can increase shoreline erosion, cover fish-spawning beds with silt, contribute to algal blooms by increasing nutrient input, reduce fish and wildlife habitat, and degrade natural scenery (Valastin 1999).

5.1 Status

Status: unknown
Trend: declining

Data on Baptiste Lake shoreline vegetation is limited to an aquatic macrophyte survey conducted in 1984 (Stockerl and Kent 1984). The survey found aquatic macrophytes to grow in areas up to a maximum depth of 3.5 m, reaching a maximum horizontal distance from shore of 155 m. Emergent macrophytes, referring to plants that grow above the water's surface but are rooted beneath the water or in water saturated soil, were more abundant than submergent macrophytes. Of the 11 emergent macrophyte species, the most common were common great bulrush, common cattail, and yellow waterlily. Of the 11 submergent macrophyte species, the most common were Richardson pondweed, large-sheath pondweed, and northern watermilfoil.

Stockerl and Kent (1984) reported that bulrush beds were often broken along developed portions of the shoreline to provide boat and swimming access for residents. The extent of this disturbance was not quantified, nor is the current condition of the shoreline known. It is likely, however, that the condition of the shoreline has declined because development of waterfront property at Baptiste Lake has doubled over the past 30 years (Wasel 2007). A survey of shoreline vegetation is underway to provide more accurate assessment of shoreline status.

5.2 Management

Shoreline condition can best be managed by minimizing disturbance to shoreline vegetation and substrate. For example, rather than clearing all plants along the shore and/or depositing sand or rocks to create a swimming area, a narrow path to an offshore swimming dock can be used. If shoreline vegetation has already been cleared, aquatic plants will regenerate if the area is not disturbed (Valastin 1999).

Alberta's Municipal Government Act states that subdivisions must dedicate the shoreline as an environmental reserve in order to prevent pollution and provide public access (Association of Summer Villages of Alberta 2006). The depth of the environmental reserve varies around the lake from 0 to 30 m inland from the shoreline (Wasel, pers. comm.). Land within a shoreline environmental reserve can not be altered without permission from the municipal authority. Most property owners are likely not aware of the environmental reserve. Action by the municipal authority to communicate and regulate the environmental reserve at Baptiste Lake could improve the health of the shoreline.

6 Lake Water Level

Changes to Baptiste Lake's water level can influence water quality, fish and wildlife habitat, and recreational opportunities.

6.1 Status

Status: Normal to below normal
Trend: Stable

Baptiste Lake's water volume has been relatively stable over the long-term despite short-term fluctuations (Prepas 2004). Between 2002 and 2006, the lake's water level was assessed as normal for 3 years and below normal for 2 years (Alberta Environment 2006). Baptiste Lake's water level is predicted to decrease only moderately (approximately 0.1 m) over the next 100 years in response to increased evaporation caused by climate warming (Donahue 2004). Due to the stability of Baptiste Lake's water level, the lake water volume indicator is assessed as good and stable.

6.2 Management

Due to the absence of large-scale diversions from the lake or its tributaries, human activities are unlikely to affect lake volume.

7 Conclusions and Recommendations

The status of Baptiste Lake presents several challenges. The lake is eutrophic to hypereutrophic and a moderate health risk is posed by blue-green algae. The popular recreational fishery is collapsed. While little information is available on shoreline condition, private ownership of shoreline has steadily increased and potentially degraded shoreline habitat. On a positive note, lake water level is relatively stable and appears to be of little concern.

No single stressor is responsible for the condition of the lake. Rather, a suite of stressors are impacting the ecosystem. As a result, several management options exist to improve the health of the lake (Table 2). A promising management opportunity is implementation of a catch-and-release fishery or fishing moratorium. Eliminating fish harvest could likely restore fish populations over the long-term and, in turn, improve water quality by increasing grazing pressure on algae. The magnitude of the role of trophic cascade on Baptiste Lake primary productivity is uncertain, however, and will be investigated in greater depth. Also important for improving water quality is prevention of phosphorus runoff from farmland and conservation of forest in the relatively intact western portion of the watershed. Other strategies to reduce lake phosphorus levels include chemical treatments to reduce the release of phosphorus from sediment and careful management of waste water from residences around the lake. Protection or restoration of shoreline vegetation at lakefront properties would also be beneficial.

Indicator	Status	Management strategies	Impact	Cost
Water quality	Eutrophic to hypereutrophic	Catch and release fishery	High	Low
		Liming	High	High
		Forest protection	High	Low
		Conservation-tillage	Low	Low
		Separation of cattle from streams	High	Moderate
		Residential waste water management	Low	Low
Fishery	Collapsed	Highly restrictive fishery	High	Low
		Repair problem culverts	Low	Low
		Replace problem culverts	Low	Moderate
Water level	Normal to below normal	None required	Na	Na
Shoreline condition	Unknown	Protect/restore environmental reserve	High	Low

Table 2: Summary of the status of Baptiste Lake and the impact and financial cost of management options.

To be viable, management options must be cost-effective. Several of the management options for Baptiste Lake are associated with little or no financial cost but instead rely on responsible actions by residents and visitors. These include restrictive fishery regulations, responsible management of residential waste water, and protection or restoration of shoreline habitat. It should be noted, however, that while the financial cost of strategies such as restrictive fishery regulations and restoring shoreline habitat are low, they may be undesirable to some residents because they require changes in lifestyle. The cost of protecting forest is hard to estimate because the incurred cost is due to lost opportunities for future agricultural expansion. However, given the low availability of soils that are suitable for agriculture, forest protection is assessed to be associated with low cost. Other management options require moderate to high financial investment. The cost of liming is high, likely over $200 per kg TP load reduction. Agricultural best management practices range from moderate cost to actually providing a small savings (conservation-tillage by reducing operating costs).

Prioritizing management opportunities can be aided by considering both the relative cost and effectiveness of the options (Figure 12). Implementing restrictive fishery regulations, protecting forest from agricultural expansion, and protecting shoreline habitat are highest in priority because of their low cost and high potential effectiveness. Social acceptance of these strategies may be low, however, suggesting that regulation will be necessary, combined with education to improve awareness of why the actions are needed. Although residential wastewater management, conservation-tillage agricultural, and repairing problem culverts have low potential to improve water quality and fisheries relative to other strategies, the potential is not negligible and the strategies must be promoted due to their low cost. Second in priority are moderate cost strategies, especially controlling runoff from cattle wintering sites given the high potential to improve water quality if existing wintering sites are not hydrologically separated from tributaries. Controlling runoff from cattle wintering sites may require coordination with the provincial government to offset costs incurred by farmers. Last in priority in terms of Baptiste Lake management options is chemical treatment (liming) of sediments. Although liming has the potential to substantially reduce phosphorus levels, the strategy would likely cost hundreds of thousands of dollars annually. Due to the high cost relative to other options, liming or other treatments to reduce the internal release of phosphorus such as hypolimnion water withdrawal or artificial circulation should only be pursued if water quality remains poor after the other recommended management strategies have been implemented.

Cost	Impact: Low	Impact: High
High		Liming
Moderate	Replace problem culverts	Control runoff from cattle wintering sites
Low	No-tillage Residential waste water management Repair problem culverts	Highly restrictive fishery Protect shoreline Forest protection

Figure 12: cost-impact matrix demonstrating cost and potential impact of Baptiste Lake management options. Cost refers to the financial cost of implementing the management strategy. Impact refers to the potential to improve water quality, fisheries, and/or shoreline condition at the lake.

The accuracy of cost and effectiveness estimates is limited by knowledge gaps. Whenever possible, data from the region were applied to evaluate management strategies.

When regional data was not available, however, information from outside of the region had to be relied on. In such cases, estimates have reduced accuracy and should be interpreted with caution. Despite the uncertainty, the assessment should be sufficient to differentiate high and low priority management options. The prioritization should be followed up by more in-depth evaluations of the effectiveness of management options assessed to be of high priority.

Recreational lakes such as Baptiste Lake are common destinations for Albertan's to live and play. Development of native forest and wetlands on lakeshores and adjacent lands for residential or agricultural use has the potential to affect water quality and health of lakes. Careful analysis of long-term and cumulative effects of these developments must be considered over meaningful time to ensure the watershed and lake ecosystem are conserved for our future enjoyment. Regional land use planning, identifying which activities can occur where, will be an essential tool for future watershed planning and conservation of the health of Baptiste Lake.

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Appendix 1: Composition of Baptiste Lake Watershed

Table 2 presents the estimated area in natural, agricultural, and footprint cover types within the Baptiste Lake watershed. GIS analysis of Alberta Vegetation Inventory (AVI) was used to estimate the area in natural and agricultural cover types and to estimate the area of well sites. AVI data for the western portion of the watershed that is located within the Alberta-Pacific Forest Management Agreement Area is current to 2004. The eastern portion of the watershed is only current to 1989 and 1990. Based on an inspection of more recent ortho photos, as estimated 100 ha of the eastern portion has been converted since 1989 and the landscape composition estimates were adjusted accordingly.

The AVI does not include estimates of linear features such as roads, seismic lines, and pipelines. A separate linear feature dataset was used to estimate the length of these disturbances, and linear feature width estimates for the region[13] were used to convert the length estimates to area estimates.

The only information available on settlement area was Trew et al.'s (1987) estimate of 1.023 km^2 of developed lakeshore lots around Baptiste Lake as of 1977. Between 1975 and 2005, the area of privately owned lots around the lake doubled (Wasel 2007). Therefore, to estimate current area lots around the lake, the 1977 estimate was doubled.

Cover Type	Area (ha)
Coniferous forest	5,113
Deciduous forest	12,339
Mixedwood forest	2,046
Shrub	2,045
Wetland	155
Grassland	373
Non-vegetated	22
Lake	1,300
Cropland	1,471
Pasture	3,441
Well site	18
Paved road	21
Unpaved road	232
Pipeline	154
Seismic line	540
Settlement	205
Total	29,475

Table 3: Composition of the Baptiste Lake watershed as estimated from Alberta Vegetation Inventory, ortho photos, and a geospatial linear footprint dataset.

[13] Based on assumptions made in the Alberta-Pacific Forest Management Agreement Area 2004 Forest Management Plan (Alberta Pacific Forest Industries 2004), it is assumed that major roads (i.e. paved) are 40 m wide, other roads are 8 m wide, pipelines are 20 m wide, seismic lines are 5 m wide, and well sites are 0.81 ha.

Appendix 2: Land use growth rates used in ALCES simulations

Agricultural area was assumed to remain constant in the ALCES simulation due the relative stability of farm area in recent years. Between the 2001 and 2006 agriculture censuses, farm area in Athabasca County No. 12 grew only slightly from 2,802.59 km^2 (Statistics Canada 2008a) to 2,804.68 km^2 (Statistics Canada 2008b), which is equivalent to an annual growth in farm area of 0.015% relative to 2001. Applied to Baptiste Lake watershed's 4,912 ha of cropland and pasture, this equals a projected annual farm area growth of only 0.37 ha.

To estimate the future rate of gas exploration, information compiled for the Alberta-Pacific FMA area (Alpac FMA) was used. The Alpac FMA is a 67,000 km^2 area in northeastern Alberta that is under lease to Alberta Pacific Forest Industries for timber harvesting. The western portion of the Baptiste watershed is located within the Alpac FMA. To evaluate how the Alpac FMA may change in the future, substantial effort has been spent gathering information on future development patterns for a variety of land use types including gas exploration. Baptiste Lake watershed is 0.4387% as large as the Alpac FMA. Therefore, the predicted growth in gas wells in the Alpac FMA was multiplied by 0.4387% to estimate that an average of just under 2 productive wells will be drilled per year in the watershed. Growth in associated footprints (seismic lines and pipelines) was based on the current density of these footprints per well in the Alpac FMA[14]. The simulation assumed that the footprints reclaim to native vegetation after a period of 50 years for well sites, 50 years for pipelines, and 45 years for seismic lines.

As gas and forestry development expands in the watershed, an expanded road network will be required to access and transport resources. Growth in the primary (paved) and secondary (unpaved) road network was 0.33 km and 2.19 km each year, respectively, based on assumptions made for the Alpac FMA (Schneider 2003). Roads were assumed to be permanent.

The area of human settlements in the region is also likely to grow to accommodate a growing population. Between 1991 and 2001, 660 private dwellings were constructed in Athabasca County No. 12 (http://www.albertafirst.com/profiles/statspack/20649.html) accounting for a 32.5% increase relative to 1991 (3.25% per year). This growth rate is assumed to be a reasonable approximation of the future growth in human settlement area in the Baptiste Lake watershed. Given that the current settlement area is approximately 2.05 km^2, the simulation assumed that settlement area will grow by 0.067 km^2 each year.

Agricultural, gas, road, and settlement development were assumed to be additive, i.e. non-overlapping.

[14] According the Alpac FMA Area Detailed Forest Management Plan (Alberta Pacific Forest Industries 2004), each well site in the region is 0.81 ha and is associated with 0.46 km of pipeline and 3.75 km of seismic line.