Lake Wabamun:

A Review of Scientific Studies and Environmental Impacts

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Executive Summary

The following recommendations are in roughly descending order of importance:
The parties who would implement these recommendations are not identified in this report since the Panel assumes that responsibility for implementation would be allocated according to a combination of current government agency mandates and activities, industry permit requirements, and input from citizen or scientific advisory groups (see final recommendation).

Fisheries

Despite heavy recreational activity and industrial use, Lake Wabamun is in moderately good condition. The most serious problem is with the fish community. As a result of commercial fishing, sport overfishing, and destruction of fish habitat, walleye have disappeared from the lake. Few pike survive long enough to reach reproductive age. Lake whitefish have not successfully reproduced for several years.

- *We recommend that commercial fishing be eliminated altogether, and that sport fishing be restricted to catch and release until populations recover to more normal age structures.*

Past efforts to re-introduce walleye have been unsuccessful. High hooking mortality from catch and release angling is probably responsible.

- *We recommend that any future attempts to reintroduce walleye be accompanied by total closure to angling of areas of the lake where walleye congregate, until several age classes are established.*

While great efforts have been made to reduce industry-related fish mortalities, they are still significant and in some cases unpredictable in occurrence. They are, however less important than mortalities caused by angling or commercial fishing.

- *We recommend continued vigilance to prevent and correct fish mortalities. These mortalities should also be taken into account in management and allocation of the fisheries resource.*

Weed harvesting is a relatively insignificant source of direct fish mortality, but it causes a significant loss of fish habitat. Modifications of shoreline properties by cottagers have also resulted in significant loss of fish habitat.

- *We recommend that weed harvesting be discontinued, and that other prohibited destruction of fish habitat, including weedbeds, be monitored and enforced according to the Canada Fisheries Act.*

Lake level, outlet, and water balance
The outlet of Lake Wabamun has been repeatedly and illegally modified and vandalized since 1912 by different groups wishing to regulate lake levels at either very high or very low levels. As a result, 1.5 km of stream channel has been rendered useless as fish habitat. Stabilization of the lake's water level has had an adverse effect on fish spawning and nursery habitats.

- W*e recommend that the weir at the outlet be modified to act as a fish passage to ensure that the upper section of Wabamun Creek can be utilized. This could be done by installation of an appropriate culvert under the roadway that presently acts as a weir, sealing the illegal outlet, and restoring the original channel of the outlet stream, following a qualitative and quantitative assessment of fish habitat. We also recommend that the level of the lake be allowed to fluctuate seasonally and naturally, with the only human intervention being the use of the Wabamun Lake Water Treatment Plant (WLWTP) to replace water that is used or diverted from the lake for industrial activity. The amount used by industry can be accurately predicted from a water balance model, although precipitation measurements need to be improved by making measurements within the watershed of the lake.*

- *Precipitation collections should be made at two or more locations in the lake Wabamun watershed to improve the performance of the water budget model, which is critical to predicting the water needed from the WLWTP.*

- *Reclamation of mined land in the catchment of Lake Wabamun should approximate original land cover as closely as possible.*

Eutrophication
Although there is some evidence of eutrophication during the 20th century, monitoring records since 1980 indicate that the lake is currently stable. While phosphorus originates from external nutrient input, its recycling between water and sediment can greatly intensify eutrophication. If this "internal loading" from sediments increases, it can be very difficult and take decades to reverse.

- *We therefore recommend the implementation of a program designed to prevent further increases in external loading to Lake Wabamun, that would rely on enforcing more stringent guidelines for land-use changes, cottage development, waste disposal and use of fertilizer, as well as public education. We recommend that the lake monitoring program for chemistry and plankton that has been carried out for the last 20 years be reviewed and continued in a consistent manner. Consideration should also be given to monitoring of benthos and fish.*

Changes to Lake Chemistry
Lake Wabamun has increased slowly in salinity, as a result of evaporation in the absence of outflow since 1992, and the chemical inputs from the WLWTP. The increase is not rapid enough

to expect major changes to the lake's biota. The actions recommended above for lake outflow and water level should suffice to protect the lake for the foreseeable future.

Fecal Coliforms

The relatively high frequency with which fecal coliform counts on public beaches exceed guidelines for bathing is of some concern.

- *We recommend that further investigations be made to reveal the source of the coliforms. If the source cannot be eliminated, it may be necessary to move some of the beaches, or restrict human use.*

Trace Metals and PAHs

Power plants in the vicinity of Lake Wabamun have increased the inputs of several trace metals into the lake. Metal levels in the lake's water meet CCME Guidelines (CCME 2001a), but some metals in sediments are above guidelines for the protection of aquatic life. Despite this, metals do not appear to have caused detectable changes in the aquatic community. They are not a human health concern for recreational uses of the lake.

Mercury deposition to the lake's sediments has increased several-fold over background. Comparison with other central Alberta lakes and with earlier sediments indicates that increases are largely the result of regional emissions, in addition to long-range transport of industrial emissions from other areas. Almost all fish in Wabamun Lake are within mercury consumption guidelines for occasional users. Occasional large pike exceed the guidelines, but similar conditions are observed in other Alberta lakes. There is some concern for subsistence consumers, such as the Paul Band, because a moderate number of northern pike exceed consumption guidelines for subsistence use. If the pike population is allowed to recover as recommended, some precautionary measures might be needed if large pike are eaten frequently.

- *We recommend that trace metal studies now conducted by several agencies be coordinated to ensure that consistent sampling and analytical protocols are used, and that metals be included in a revised monitoring program. Mercury concentrations in northern pike should be monitored closely. We recommend the adoption of the recommendations of the CASA November 2003 report for reducing mercury emissions from the power plants as a long-term precautionary measure.*

In addition to natural sources, power plants and other fossil fuel burning activities have caused significant increases in polycyclic aromatic hydrocarbons, some of them known carcinogens, at present these contaminants are well below toxicity thresholds in lake water.

- *Trace metals and PAHs should be periodically assessed by paleoecological sampling, as described in the report.*

Dredging, Disinfection By-products and Thermal Effluents
We found that these three topics required no action, for a variety of reasons.

Dredging does not appear to be likely to provide significant benefits to the lake. It would require lengthy and thorough investigations to ensure that fish habitat was not destroyed.

- *We do not recommend dredging at this time.*

Disinfection by-product concentrations for the Wabamun Lake Water Treatment Plant are low, and below thresholds where effects on human or animal health would be expected. Although little is know about effects on aquatic life, concentrations in the discharge are low and vastly diluted by the volume of the lake.

- *Disinfection by-products are not of concern.*

The thermal effluent from the Wabamun Power Plant will cease as the Plant is decommissioned. Appropriate measures have been taken to mitigate the effects of the thermal effluents. However, the loss of the open water region of the lake in winter after the thermal effluent ceases may result in possible oxygen depletion under ice.

- *We recommend that follow-up studies should investigate the possibility that oxygen depletion under winter ice might occur after heated effluents cease.*

Additional Recommendations
Many of the past studies of Wabamun Lake have been undertaken by Alberta Environment staff or by consultants hired by TransAlta in response to public perception. Some of the perceptions did not justify scientific study, and some other issues were simply not amenable to scientific investigation. Examples include disinfection by-products and dredging.

At present, there are several stakeholder groups that independently pressure Alberta Environment or TransAlta with their own interests.

- *We recommend that a permanent citizens panel, whose objective it is to protect the health of Wabamun Lake, needs to be established and maintained. This panel must have members who are selected by, and representative of, the community of Wabamun Lake users. Representatives of various interest groups, as well as TransAlta and government agencies should also be included in the membership. A parallel scientific panel, consisting largely of independent scientists but including representation from Alberta Environment and TransAlta should be formed to advise the citizens' panel on the scientific value of any proposed studies.*

Introduction

Lake Wabamun is one of the most heavily used lakes in Alberta. Many of the modifications to the lake occurred before records were kept, or before scientific study of the lake began. In many cases, this makes it difficult to deduce the original condition of the lake. Since the 1970s, there are reasonably clear monitoring records and a large number of studies to investigate particular aspects of the lake and its response to various human stresses. In what follows, we use a combination of historical records, paleoecological investigations and contemporary scientific studies to deduce the current condition of the lake and how it has changed in the 20th Century. We make recommendations for managing future human activity in the lake and its watershed, in order to protect the ecological integrity of the lake.

A Brief History of Development around Lake Wabamun

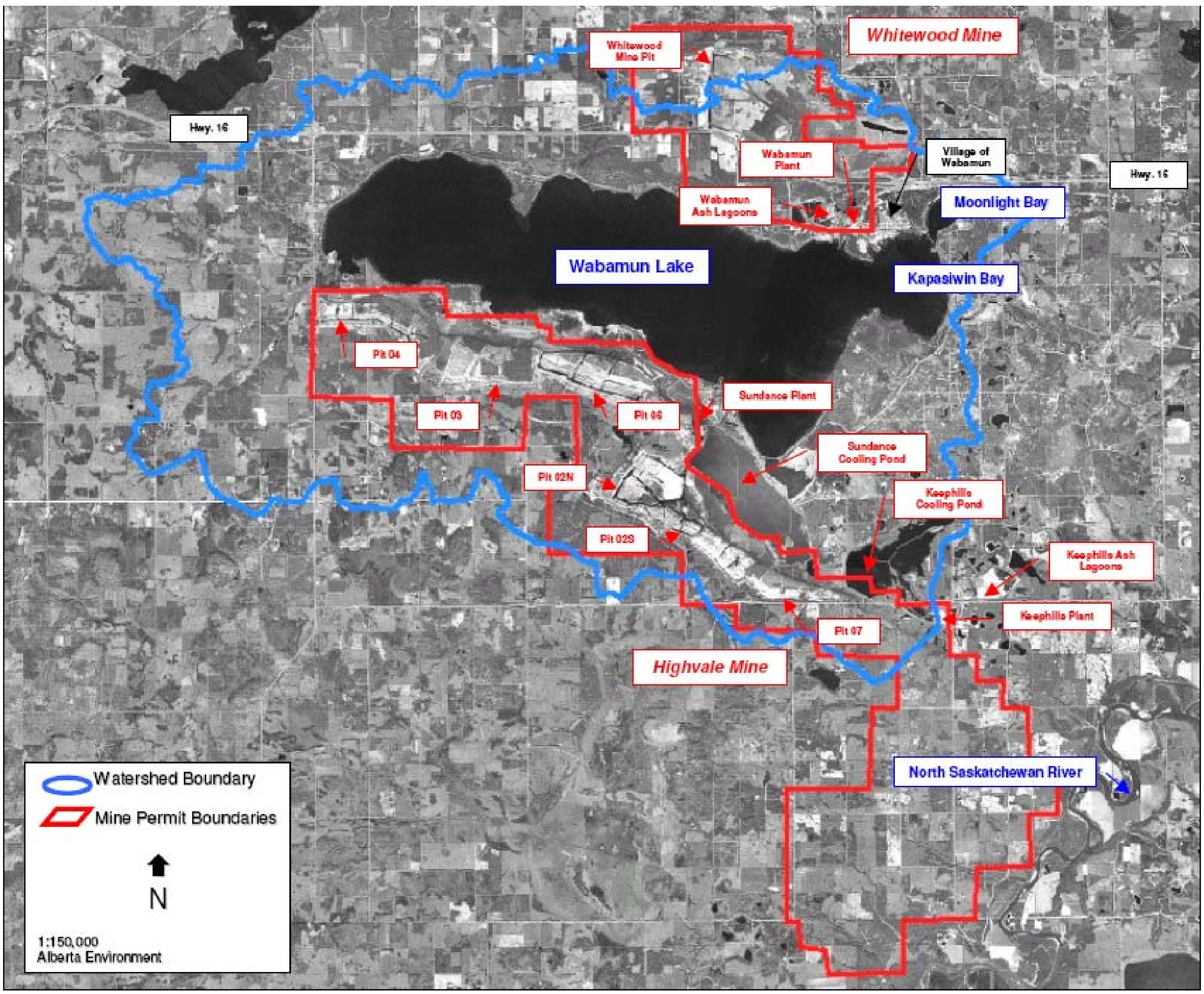

Figure 1. Lake Wabamun and its catchment, showing major features referred to in the text

Lake Wabamun, situated about 60 km west of Edmonton along the Yellowhead Highway (Figure 1), is one of the most popular recreational lakes in Alberta. The lake is large and shallow, 19.2 km long and 6.6 km wide with a surface area of 82 km^2, a mean depth of only 6.3 m and a maximum depth of 11m (Mitchell and Prepas 1990). The watershed of the lake is small, only about 3 times the surface area of the lake. The drainage basin has at least 35 small drainage courses that convey water from spring runoff and summer storms to the lake. Several streams flow continuously. Groundwater is also an important source of water to the lake. The water level of the lake has fluctuated up to 1.1 m over a long-term cycle of 7 to 10 years during the 20th century (Figure 2).

The main features of human development surrounding the lake (Figure 1) are the village of Wabamun, a number of summer villages and subdivisions on the lake shore, the Yellowhead Highway and CNR railroad tracks paralleling the north shore, coal mines north and south of the lake, TransAlta's Wabamun and Sundance power plants, cooling ponds for the Sundance and Keephills power plants, Wabamun Lake Provincial Park at Moonlight Bay, a golf course, and the Paul Band First Nation Reserve at the east end of the lake. The surrounding countryside is rolling aspen parkland, forest and agricultural land.

Non-aboriginal exploitation of the fisheries began in the mid-19th century. It intensified once the railroad reached the lake in the early years of the 20th century, facilitating access for commercial and sport fishermen. Settlers from Edmonton and area began visiting the lake around 1910, taking advantage of organized weekend railway excursions (Mitchell and Prepas 1990). Cottages began to spring up around the lakeshore during this period. Summer villages were built at Lakeview on Moonlight Bay and at Kapasiwin.

The cottage development at Lake Wabamun has grown to be quite dense compared to other Alberta lakes. In 1996, there were 1361 developed lots around the lakeshore, 1173 of which were occupied (Golder Associates 1997). About 151 of these are listed as permanent residences, although the majority of cottages throughout the Wabamun area are capable of providing extended year round or "permanent" use. Half of these cottages are within the summer villages of Seba Beach, Kapasiwin, Point Alison, Lakeview and Betula Beach; the remaining cottages are in the county of Parkland. The village of Wabamun had a population of 601 permanent residents in 2001 (Statistics Canada website). Many of the people living in the village work at TransAlta's power plants or coalmines.

The number of cottages, and easy access to the lake have resulted in heavy fishing pressure since the mid 20th century. For much of its history, the lake has supported a commercial lake whitefish fishery. Fish are also taken by area residents for domestic use. Winter recreational angling targets lake whitefish, while northern pike are primarily sought during the summer months. Decades of heavy harvests by angling and netting have severely impacted the fishery. Large northern pike have become rare, and walleye have been extirpated from the lake. Lake whitefish have had poor reproduction for the past seven years. Fish habitat has been destroyed at numerous locations around the lake and industry-caused fish kills are a periodic problem.

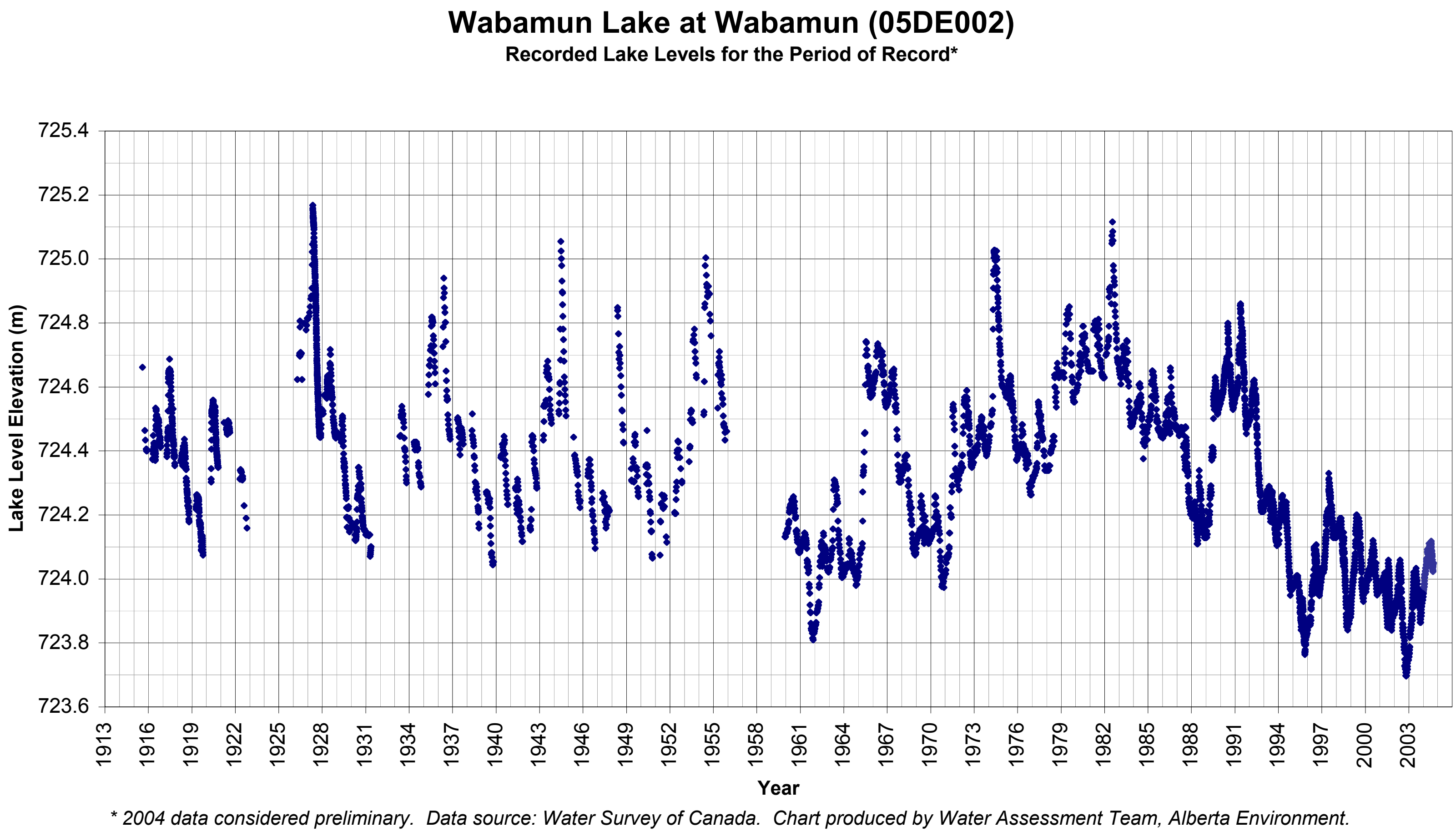

Figure 2. Historical surface levels in Lake Wabamun.

The Lake Wabamun area also serves a number of commercial and industrial users. The first coalmines in the area began as underground operations in 1910 and as strip mines in 1948. In 1956, a power plant was constructed along the north shore at the village of Wabamun. The first two units were commissioned in 1956 (66 MW) and 1961 (66 MW), respectively. Originally, both were gas-fired, but the first was converted to coal-fired in 1963 and the second in 1983. The third unit (150 MW) was commissioned as a coal-fired unit in 1961, and unit four (300 MW, also coal fired) was commissioned in 1966. The Wabamun Plant is now undergoing phased decommissioning. Unit 3 was shut down permanently in November 2002, units one and two will be shut down in late 2004 and unit four will be shut down in 2010. The Wabamun Plant uses lake water for cooling, and cooling water discharge is returned to the lake via a canal. As a result, a large portion of Kapasiwin Bay remains ice-free in winter Golder Associates (1997).

A second, much larger power plant (Sundance) was constructed in 1970, followed by Keephills in 1983. The Sundance Plant used lake water for cooling when it first began operations, but has since used a large cooling pond created in 1975 with the berming of Goosequill Bay, a large wetland complex in the southeast corner of the lake. The Keephills plant relies on a different cooling pond (Table 1). The Genesee plant, added in 1989, is not in the watershed of Lake Wabamun, although the lake receives airborne emissions from the plant.

At present, the four power plants generate 4000 MW. As of 2003, 48% of the province's installed generating capacity was coal-fired (CASA 2003). Together, the coal-fired plants emit 65% of airborne mercury from industrial sources in the province, as well as several other trace metals, sulfate, particulates, water vapour, nitrogen oxides and polycyclic aromatic hydrocarbons. About 74% of Alberta's CO_2 emissions from coal-fired power plants are emitted from the power plants near Lake Wabamun (CASA 2003).

To compensate the lake for water losses resulting from power plant operations, reductions in effective drainage basin size and mine interceptions of ground water, treated water from the Sundance cooling pond has been discharged to the lake since 1997. The Wabamun Lake Water Treatment Plant (WLWTP) treats the cooling water to assure water quality and to eliminate alien species that could enter the pond with make-up water from the North Saskatchewan River. The plant uses a combination of ozone and chlorine for disinfection plus filtration and clarifying in order to treat the water to meet Alberta Environment requirements before discharge into Lake Wabamun. A second treatment plant at the same site began operation in 2001. At present, the plants are capable of treating 23 million cubic meters of water per year. The water is within three degrees of lake temperature when discharged (Golder Associates 1997).

Table 1. Key features pertaining to the power plants in the Lake Wabamun area

Power Plant	Date of Commission	Capacity (Mega-watts)	Condenser Cooling	Ash Handling	Mine Drainage
Wabamun Power Plant	1956	398	Intake of cooling water and return of warm water to Wabamun Lake	Ash lagoon; Fly ash disposal area and off site sales	Whitewood Mine to Wabamun Lake via ash lagoon
Sundance Power Plant	1970	2020	Intake of cooling water and return of warm water to Sundance Cooling Pond; water source North Saskatchewan River	Ash disposal area	Highvale Mine currently to Sundance Cooling Pond, history of discharge to Wabamun
Keephills Power Plant	1983	766	Intake of cooling water and return of warm water to Keephills Cooling Pond; water source NSR	Ash lagoon	Highvale Mine currently to Sundance Cooling Pond
Genesee Power Plant	1989	820 (+ additional 1455 by winter 2004-05)	Intake of cooling water and return of warm water to Genesee Cooling Pond; water source North Saskatchewan River	Ash disposal area	Cooling pond

The first coalmines in the area began as underground operations in 1910, and as strip mines in 1948 (Mitchell and Prepas, 1990). As power generation developed, two coal strip mines were developed in the basin, the Highvale Mine to the south and the Whitewood Mine to the north. By the end of 2003, coal mining in the basin had disturbed 5593 ha, or 22% of the lake's catchment, and 45% of the mined area has been reclaimed. To date, 16% of the historically mined area has received reclamation certificates from Alberta Environment. Most of the reclamation on the south shore of the lake associated with the Highvale Mine has been to agricultural land, rather than the mosaic of forests and wetlands originally found in the landscape. Reclamation to the north of the lake associated with the Whitewood Mine has been largely agricultural, but has included wetlands and forested areas. Most of the unmined part of the catchment has been cleared for agriculture. The effect of the power plants and coalmines on the lake and on other users continues to be a concern. Mine drainage from the Highvale Mine was routed to the lake via Beaver Creek until the mid-80s when it was diverted to the Sundance cooling pond. This diversion resulted in a substantial reduction in the lake's active drainage basin size and supply of water. Over the years of operation, mine drainage from the Whitewood Mine has been directed to the watershed within which mining activity takes place. Currently, the majority of Whitewood mine drainage is directed towards the Lac Ste. Anne watershed, although a portion is routed to Wabamun Lake through the Wabamun Power Plant ash lagoon.

Since 1912, a number of water control structures have been built at the lake outlet; however, agreement on a suitable lake water level has been the subject of controversy for many years. Periods of high water result in complaints of flooding from residents in low-lying areas. Conversely, periods of low water result in complaints of being "left high-and-dry" by residents on higher ground. Little attention has been paid to needs of the fishery in these manipulations of the lake's water level and outflow.

There is abundant natural aquatic vegetation along shorelines and in the bays, but the water in Lake Wabamun is usually fairly clear, and Cyanobacteria (blue-green algae) blooms are rare. The lake has natural beaches along much of the shoreline, but emergent vegetation (e.g., cattails and sedges) restricts recreational use. Since the 1920s, boaters and lakeshore property owners have complained about Lake Wabamun's prolific aquatic weed growth that chokes the bays and washes up on shore (P. Mitchell, pers. comm.). Nuisance growth of the Canada waterweed (*Elodea longivaginata*) in the early 1970s produced floating mats of vegetation that affected recreation and raised concerns about deteriorating water quality. The population of *Elodea* declined rapidly in 1977 and is now much less common (Golder Associates 1997).

The Paul Band signed a treaty in 1876 and settled on the eastern edge of Lake Wabamun. In 1996, the total population of the band was 1397, although only 856 individuals were living on the Paul Band Reserve in 1996 (Department of Indian and Northern Affairs, pers. comm.).

The lake provides a wide variety of recreational opportunities, including camping, angling, ice fishing, power boating, sailing, swimming, birding, golf, and others. The provincial park has a total of 287 campsites, extensive day-use areas, boat launch, and a sandy artificially made beach. Whitewood Sands campground, located on the north end of Lake Wabamun, has a total of 38 campsites (Alberta Tourism, pers. comm.). A scout camp and commercially operated campgrounds are also located on Lake Wabamun. There are boat launches, piers and day use areas at Seba Beach and the village of Wabamun, as well as three day-use areas in the county of Parkland. The lake is an important regional centre for sailing with three sailing clubs.

Additional land uses in the drainage basin of Lake Wabamun include a golf course, agricultural cropland, and cattle grazing (often with unrestricted access to streams flowing into the lake).

In addition to being one of the most popular recreational lakes, Lake Wabamun also holds the distinction of being one of the most studied lakes in Alberta. Since at least 1942, scientists have been conducting studies on the lake, although the majority of studies relevant to management of the lake have been conducted over the past 25 years. As of 1996, there were well over 300 reports and publications (Golder Associates 1997), and there have been a large number of studies since that time. Together, these reports provide a great deal of detailed information about the lake ecosystem in the past quarter century.

The majority of the studies on Lake Wabamun were conducted from the mid 1970s to early 1980s. Another burst of activity in the late 1990's and into 2000-2003, was primarily due to public concern about TransAlta's activities on the lake. Little information is available on the lake prior to 1970, nor are there many data, other than Alberta Environment monitoring data, for a period of approximately 6 years in the mid to late 1980s.

As a result of the small watershed of the lake (Figure 1), the water residence time of the lake is extremely long, estimated by Mitchell and Prepas (1990) to be approximately 100 years. Outflow has occurred intermittently in the 20th century, but not since1992, causing the lake to increase in salinity.

In the remainder of this report, we summarize scientific and historical evidence for changes in the physical, chemical and biological properties of Lake Wabamun as the result of the developments outlined above. Where information is sufficient, we make recommendations for future management of the lake. Where evidence is insufficient, we recommend future study to allow better-informed choices to be made on current or future potential problems. The lack of relevant scientific studies before 1970 and the rapid development of the lake and its catchment for several different purposes before studies commenced make it difficult in some cases to discern the major causes of changes to the lake.

Lake Level and Outflow Regulation

There are no records for lake levels or outflow volumes before 1915. Paleoecological analyses using stable isotopes in sediments (Fritz and Krouse 1972) and salinity-sensitive diatom fossils (Hickman et al. 1984) suggest that the lake passed long periods in the Holocene as a closed or near closed basin (i.e., little or no outflow). Other studies indicate that the climate of the western prairies averaged about a degree warmer than in the mid 20th century (de Menocal et al. 2000).

Lake Wabamun is a headwater lake and the few inflow streams are small. Its catchment is small, and most of the precipitation falling on it is lost to evaporation and transpiration by vegetation. Precipitation on the surface of the lake is by far the largest input of water to the lake. Similarly, the largest loss of water is to evaporation from the surface (Seneka 2002). Groundwater comprises approximately 4% of inflows and 10% of outflows for Lake Wabamun and modelling indicates that there is a natural net loss of groundwater from the lake (Seneka 2002).

A water budget for the lake appears to predict observed lake levels for the past 20 years reasonably well (Seneka 2002), although precipitation, a critical input term, is estimated from two sites well outside the catchment of the lake. Several factors complicate the construction of a natural (pre-industrial development) water budget.

The greatest hindrance to constructing a detailed pre-industrial or 'natural' water budget is lack of hydro-climatic data prior to 1982. As we move back in time, data must be transposed from farther and farther away, thus reducing the ability to model recorded levels accurately. In addition, many of the wetlands in the catchment have been destroyed, and forested land in the southern part of the watershed has largely been reclaimed as agricultural land. Both of these activities affect water retention in the catchment. Finally, coalmines are known to intercept groundwater flow into the lake, and this interception has increased slowly during the decades of mining activity around Wabamun Lake. All of these factors contribute to the lack of an accurate pre-industrial water budget, making it difficult to prescribe a lake level and range of fluctuation that approximate the historical condition of the lake. However, there were water level records prior to 1950, the period before more significant industrial activity began (Figure 2). If the period of these records is a reasonable representation of longer-term climate, the records can imply a natural regime and range of fluctuation, even though outlet tampering and other anthropogenic change have occurred since the turn of the century. Also, we can model the present hydrology of the basin under natural conditions by removing the impacts of TransAlta Corporation that have been accounted for by the water balance model.

Beginning in 1912, the outlet of Lake Wabamun was altered many times to reflect the conflicting interests of lake users. The lake's elevation history is contorted by public perceptions and measurement uncertainties. There is no evidence that the importance of the outlet as fish habitat, or for fish passage, was ever considered in these disputes. If they had been done after 1985, they would be in violation of the fish habitat protection sections of the Canada Fisheries Act.

The following account is abbreviated from Glover (1967):

In 1912, an illegal outlet was dug by unknown persons, bypassing 1.5 km of Wabamun Creek, to drain the lake directly. Although the lake level at the time was not recorded, the illegal outlet caused a serious drop in lake level. The original outlet and the position of the illegal channel are shown in Figure 3.

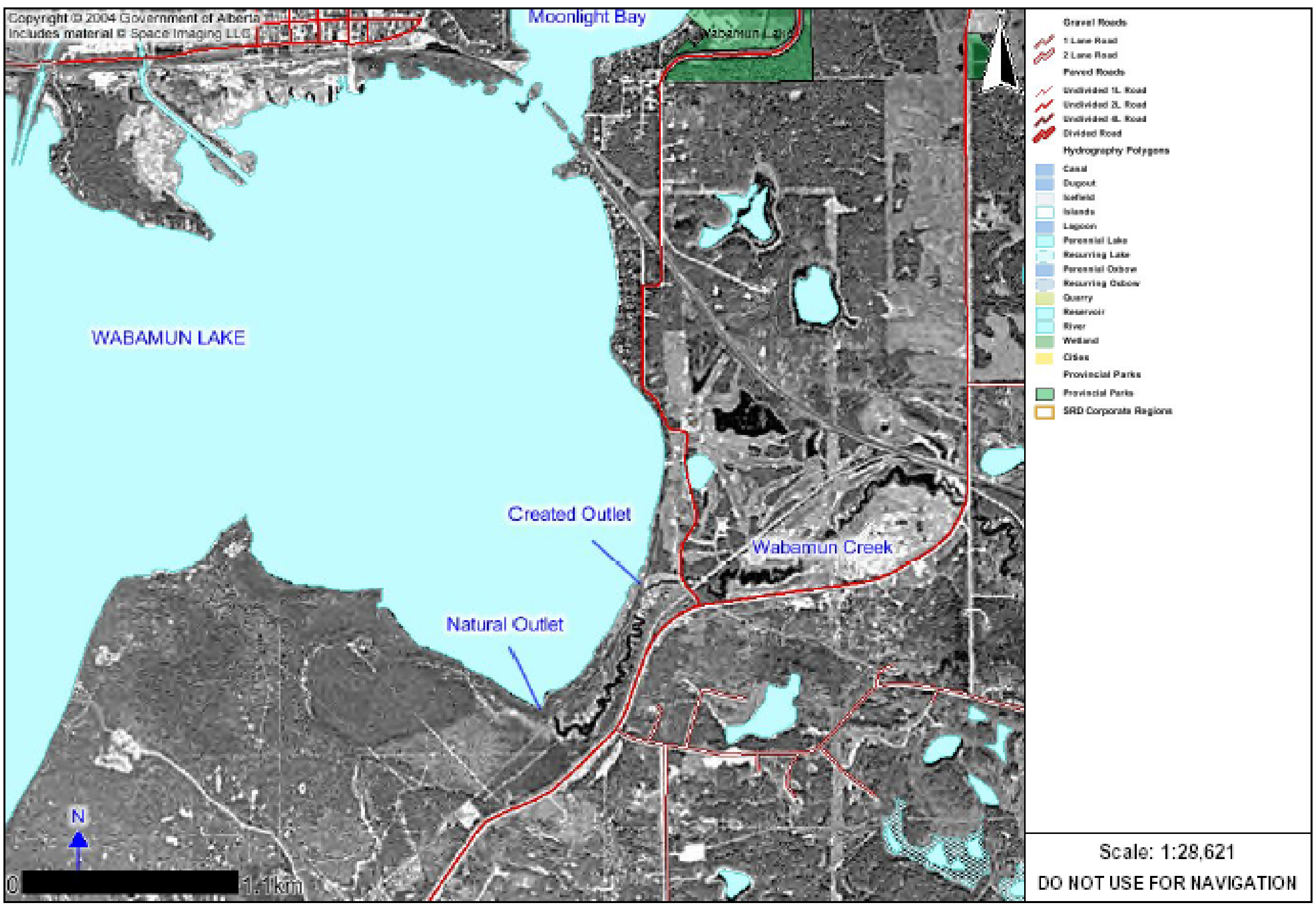

Figure 3. Kapasiwin Bay at the east end of Lake Wabamun, showing the location of the natural outlet, and the artificial outlet created in 1912. The current weir is where the road (red line) crosses Wabamun Creek.

In 1927, following a consensus agreement between communities on the lake and in response to residents' complaints about high water levels, the illegal outlet was dammed with sheet piling to control the lake level at 2372.1 feet (CNR datum; = 723.49 m). Canadian National Railway (CNR) data are not compatible with geodetic elevation and cannot simply be converted to current elevations. Water Survey of Canada has validated the historical lake level database including what they consider to be appropriate conversion factors for CNR data. The highest lake levels on record (725.168 m) occurred on May 9, 1927. The weir was rebuilt in the 1940s. In the 1960s, the original wooden weir was burned and replaced by one of steel sheet piling. This weir, at approximately 724.95 m, controlled the lake level for the next two decades.

In the 1980s, vandals dug a ditch to bypass the steel weir. Lake levels decreased by about 36 inches (0.9 m). In 1988, then Minister of Environment Ken Kowalski met with Lake Wabamun residents. There was unanimous agreement to restore historic lake levels. Considerable controversy has existed concerning the proper level at which to control the lake. Much of this stems from the conversion from the original benchmark in Imperial units used as a reference by the CNR to Geodetic Survey Data and metric units in the early 1980s. It is generally agreed that there is a difference of 4.94 feet between the two benchmarks (Alberta Environment 1993). It has been claimed that an error in calculation reduced the level of the reconstructed weir by 18 inches.

The outlet was again controlled in 1988, by a roadbed at 725 m. It was lowered to 724.55 m in 1990. The roadbed was capped with a concrete apron in 1998 at the same elevation. The reasons for this reduction in controlled water level are not clear, but complaints of flooding and bank erosion are currently lodged when lake levels exceed the present sill by 20-30 cm, i.e. below 724.95 m. The height of the weir remains a subject of controversy, and a lawsuit is reportedly in progress.

The last outflow from the lake occurred in 1992 (Figure 2). As described later, the lower lake levels observed in 2002-2003 have reduced the volume of the lake by 17% relative to the volume coincident with the level of the outflow, caused considerable loss of fish habitat, contributed to the increasing salinity of the lake basin, and exposed large tracts of beach in some parts of the lake. In part, this low level was caused by several years of drought, but past water losses attributed to TransAlta are also partly responsible. TransAlta's deficit is now being repaid with water from the Lake Wabamun Water Treatment Plant.

It was obvious from the committee's helicopter over flight on 28 July 2004 that the current lake level has been lower than historic levels for some time, as evidenced by the incursion of shrubs and small trees into older beds of emergent aquatic vegetation. New emergent weed beds are forming near the recent water level, but are still not fully developed.

Effects of water level and regulation on lake chemistry

As described in detail later, Lake Wabamun has increased in salinity in the past 10 years, from an average of 248 mg/L to 302 mg/L as total dissolved solids (TDS). As a result of dry conditions, there has been little runoff entering the lake and the near lack of outflow from the lake causes chemicals that are not biologically or chemically very reactive such as sodium and sulfate to become more concentrated as water evaporates. Also, sodium, sulfate and chloride are added to treat the water discharged to the lake by the WLWTP, further increasing lake concentrations.

The lack of water renewal also ensures that phosphorus, the nutrient most likely to cause eutrophication, that enters the lake will be trapped with 100% efficiency. In short, some water renewal is desirable to ensure that the lake chemistry remains within levels that do not pose a risk to the ecology of the lake.

Effect of water level regulation on fish passage and fish habitat
Because Lake Wabamun is a headwater lake, there are no upstream sources of fish. The outflow stream (Wabamun Creek) historically provided the only route for fish to enter the lake from the North Saskatchewan River. Only 8 of the 26 species of fish in the North Saskatchewan are found in the lake. This may be evidence that the outflow was a difficult, and probably sporadic route for fish passage, or that the lake did not contain suitable habitat for some fish species from the North Saskatchewan River.

For the past half century, the outlet has not been effective as a fish passage. The first 1.5 km of outlet channel has also been inaccessible as fish habitat since the illegal outlet was dug in 1912. Because of the few small inflows to the lake, the natural outlet was probably used as spawning and rearing habitat, as is commonly observed in central Alberta lakes. Various activities (i.e., weir construction and alteration) designed to control lake levels may result in the loss of a naturally fluctuating water level in Lake Wabamun. These fluctuations have occurred for thousands of years and local fish populations likely are adapted to require periodic low and high water levels. For example, high water creates flooded meadows and marshes that are ideal pike spawning and nursery habitat. Lake whitefish require submerged rocky or gravel bars as spawning substrates. These can be exposed at low water levels, reducing spawning habitat. Natural water level fluctuations are also necessary for maintaining a variety of vegetation in fish habitats needed by several species of small fishes. Construction in 1990 of the current shallow, broad weir control structure has therefore had several important effects, including limiting of sufficient passage for fish, and dampening of lake level fluctuations. As lake level declined, exposure and loss of shoreline weedbeds has undoubtedly contributed to additional loss of fish habitat. Finally, conversion of once-flooded weedbeds to lawns and beaches by cottagers not only limits the possibility of immediate fish habitat use in the event of a wet year, but also contributes to local opposition to management of lake recovery to higher, historical levels.

Recommendations:
Precipitation, a critical factor for the lake’s water budget, should be measured in the basin, preferably at several locations. This would improve the ability to model precise water budgets for the lake and its watershed.

When TransAlta has repaid its debt to the lake, the lake level should be allowed to fluctuate naturally (similar to conditions at nearby lakes such as Lac Ste. Anne, Lake Isle, and Pigeon Lake), with water controls at Lake Wabamun only used to mitigate the losses caused by local industry. Contributions from industry that are needed to allow natural fluctuations in lake level can be predicted accurately from the water budget model, once precipitation monitoring in the basin is improved. A natural regime is needed to maximize the available fish habitat for various species, and to maintain the ecological integrity of the lake. It should take precedence over other factors if the ecological integrity of the lake is to be maintained. Attempts to control the water level at a single elevation should be abandoned. The resulting damage to fish passage to and from Wabamun Creek is in contravention of the Fisheries Act. No single level will satisfy all area residents in any case.

Wabamun Creek should be restored to provide fish passage and effective fish habitat in years when water levels are high enough to create outflow. This would also allow the stream to serve as periodic spawning and rearing habitat for fish.

Thermal Effluents

The heated discharge water from the Wabamun Power Plant has been a source of controversy since the plant was built in 1956. The plant effluent enters the lake directly, at temperatures that are about 10 ^{o}C above lake temperatures in summer, peaking at about 30 ^{o}C in August. In winter the average effluent temperature is about 15 ^{o}C above lake temperature, and occasionally as high as 24 ^{o}C (Golder Associates 1997). About 5% of the total lake area does not meet the Alberta Surface Water Quality Guidelines (Alberta Environment 1999) which recommends a temperature difference no greater than 3 ^{o}C from background to protect aquatic life. In winter, an area of 1.2 to 5.4 km^2 has been kept open by the warm water discharge, representing 1.5 % to 7% of the lake's area. Although the abundance of *Elodea* initially increased as a result of thermal discharge, the species has since declined. The total amount of aquatic plant growth has not increased because of the thermal discharge, however, the distribution and degree of dominance of certain plant species (chiefly *Chara* and *Myriophyllum)* is affected in portions of Kapasiwin Bay (Golder Associates 1999). More detailed information on the impacts of the heated effluent can be found in Beak Consultants Limited (1980) and Golder Associates (1999). The heated effluent will disappear with the decommissioning of the Wabamun Power Plant, so we do not discuss it in detail here, although various effects are mentioned later in discussion of effects on the fisheries of the lake. It should, however, be noted that with the disappearance of the thermal plume, Kapasiwin Bay will freeze completely for the first time in almost half a century. The heated effluent from the Sundance Power Plant is cooled in a cooling pond and does not influence the lake temperature. The temperature of treated water discharged to the lake by the WLWTP is within 3^{o} C of the lake temperature.

Recommendation
With the decommissioning of the Wabamun Power Plant, the heated effluent will disappear. We recommend that a study of Kapasiwin Bay be done to assess the possibility that oxygen depletion under winter ice might occur after the heated effluent disappears. This oxygen depletion may lead to increased release of phosphorus from sediments. Conditions in the lake have changed substantially since the power plant was installed

The Ash Lagoon

The Wabamun Power Plant also has an ash lagoon system, that collects stormwater from the site, wastewater from the facility, ash slurry resulting from coal burning, and drainage from the Whitewood Mine. Effluent is discharged to Lake Wabamun. The discharge sometimes has had a murky appearance, which has elicited public complaints. In a mass-balance study of lagoon inputs and outputs, Golder Associates (2003) found that the lagoon system removed 100% of incoming suspended solids, and over 90% of incoming aluminum, lead, beryllium, cobalt, iron, lead, manganese, silver and titanium. It also removed over 50% of several other trace metals. Its efficiency was lower for arsenic, boron, mercury, molybdenum, selenium and thallium. The discharge has caused levels of some metals to be slightly elevated in Lake Wabamun, particularly in sediments near the outfall from the ash lagoon. Implications are discussed later in the section on metals. Recommendations are made in that section.

Dredging

Recently, dredging has been proposed as an alternative to raising lake levels. It was proposed that dredging certain areas of Lake Wabamun could result in improved navigation, lake circulation and recreational opportunities. An area near the eastern shore of Moonlight Bay was selected as a trial site. It was proposed that removal of 6250 m^3 of sediments would increase an area near shore from 0.6 to 1.1 m in depth, improving navigation. Most effects were estimated to be short-term and local. However, potential damage to fish rearing and spawning habitat could be long-term (Ecomark 2004). It was estimated that several additional studies would be needed in order to consider approval of a pilot dredging permit, including ecological surveys of fish, benthic invertebrates and macrophytes, fish habitat, sediment dewatering, disposal siting and design, fish habitat mitigation plans, and active water quality monitoring during construction.

Recommendation
Given the high costs of dredging, the minimal advantages, and the probability of further damaging a fishery that has already been severely compromised (see below), we recommend not dredging.

Eutrophication

There are no consistent monitoring records for nutrients in Lake Wabamun before the 1980s. However, Hickman et al. (1984) studied the paleoecological record of algal pigments and diatom fossils in lake sediments, establishing that Cyanobacteria (bluegreen algae) have been present throughout the Holocene, and that the lake has varied considerably in productivity and algal composition in the distant past. More recent paleoecological records indicate that for the past century the lake has slowly become more eutrophic, as shown by increasing phosphorus fluxes and changes in diatom species from those indicative of mesotrophic conditions to those indicative of eutrophy.

In the 20th century, sediment records suggest a slow increase in annual phosphorus flux to sediments, generally regarded as an indication that the lake is becoming more eutrophic. The increase is similar to that in other central Alberta lakes that have been subjected to changes in land-use and cottage development (Figure 4). The profiles show accelerated phosphorus deposition in very recent times, but these are not reflected in the contemporary water monitoring record, and it is probable that higher sedimentation rates may be the result of higher concentrations of calcium carbonate caused by evaporation, as discussed below.

After 1980, Wabamun has the most comprehensive monitoring record of any Alberta lake. This record has been recently summarized by Casey (2003a) and Agbeti (2002). There is no evidence in the monitoring record for increasing eutrophication in the past 20 years, either in the form of increased nutrient concentrations or in changes in algal species. In fact, there is a slight suggestion that phosphorus concentrations have decreased since 1998, when the WLWTP began operating. The lake would currently be considered to be highly mesotrophic or slightly eutrophic.

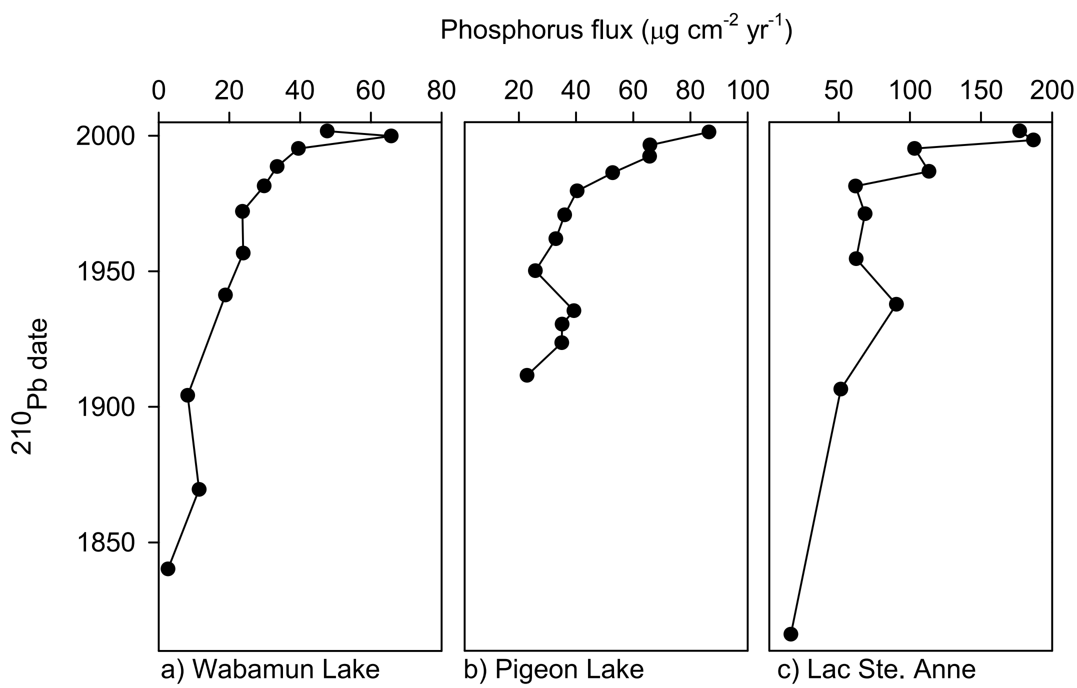

Figure 4. Annual phosphorus flux to the sediments of Lake Wabamun and two other central Alberta lakes that have had land-use changes and cottage development. D. W. Schindler and J. Brzustowski (unpublished data).

Table 2. The present trophic state of Lake Wabamun as compared to "textbook" values.

	Mesotrophic (From Wetzel, 1983)	Eutrophic range (From Wetzel, 1983)	Wabamun in late 90s
TP (µg/L)	11 – 96	16 – 386	30 – 38
Chl a (µg/L)	3 – 11	3 – 78	< 12
Secchi (m)	1.5 – 8.1	0.8 – 7.0	~ 2

TP is total phosphorus concentration. Chl a is the concentration of chlorophyll-*a*, the primary photosynthetic pigment in algae, commonly used as a measure of algal abundance. Secchi is the depth at which a white plate (called a Secchi disk for its inventor) can be seen when lowered into the water on a rope. It is a rough measure of water clarity.

Water from the WLWTP is very low in phosphorus, probably because of efficient flocculation when alum is added during the treatment process. Concentrations in treated water discharged to Lake Wabamun are less than 5 µg/L, similar to values for pristine alpine ecosystems. However, the volume of water replaced each year by the WLWTP is too low for the declining phosphorus in the lake to result entirely from dilution by the WLWTP effluent. It is also unlikely that the phosphorus concentration in runoff from the basin has decreased, because of increased agricultural activity, or that a decline in lake phosphorus is linked to reduced loading due to recent drought conditions, because similar declines are not observed in nearby lakes. More likely, co-precipitation of phosphorus with calcite, which is formed in the water during periods of high productivity as photosynthesizing plants remove carbon dioxide may be partially responsible. Such "whitings" are common in productive lakes in calcareous geological settings. The waters of Wabamun are supersaturated for calcium and carbonate in midsummer, and calcium concentrations have decreased in recent years (Casey 2003a).

There are several likely sources of the increased nutrients observed in cores during the earlier part of the 20th century. Firstly, land use changes, from forests to agricultural land, residential areas, industrial sites and golf courses are well known to increase the runoff of nutrients from watersheds (Dillon and Kirchner 1975, Wetzel 1983). Secondly, a large number of cottages were constructed on the lake, many with septic tanks. Studies in other lakes indicate that septic tanks are often poorly placed, poorly installed, or inadequately maintained, frequently leaking nutrients into lakes. Other common nutrient sources from cottage development are lawn fertilizers, pet excrement, and silt from construction. Four sewage-handling facilities are regulated by Alberta Environment. The town of Wabamun discharges once a year to a creek in the Lac Ste Anne watershed. The summer village of Seba Beach has no discharge. The Sundance power plant discharges to its cooling pond, and the Wabamun Provincial Park discharges to a slough in the Lake Wabamun watershed.

In addition, slowing of water renewal generally causes an increase in lake eutrophication (Vollenweider 1976, Dillon and Rigler 1974, Schindler et al. 1978). The lack of outflow since 1992 indicates that no phosphorus would have been flushed from the lake. The build-up of phosphorus in lake sediments often causes increased release to the water column, generally known as “internal loading.” A budget constructed from 1980 and 1981 data indicated that internal loading (sediment release) accounted for 56% of the total phosphorus input to the lake in those years (Figure 5).

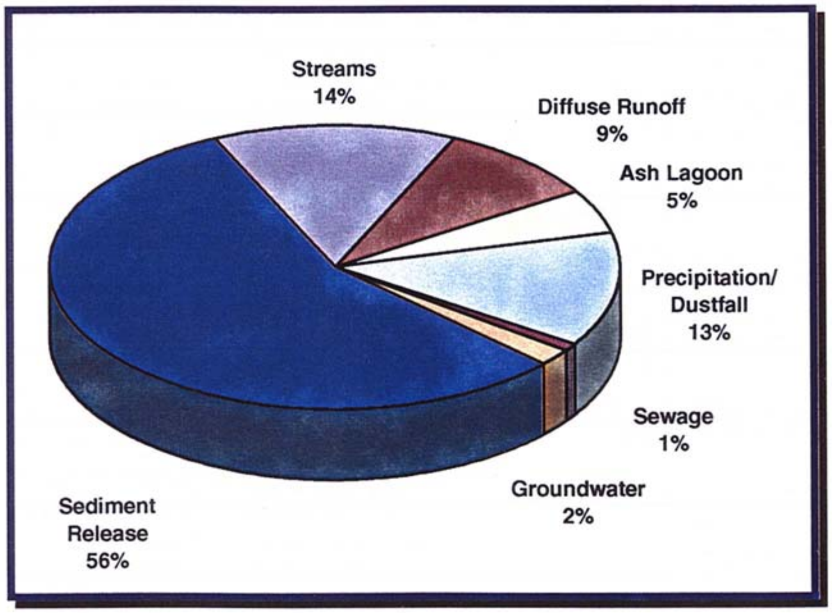

Figure 5. Total phosphorus loading to Wabamun Lake (1980 and 1981). From Golder (1997)- Data are from Mitchell (1985).

Lake Wabamun has ideal conditions for internal loading. It is shallow and windswept, and thermal stratification in summer is weak and transient. Monitoring records indicate that thermoclines form only during still periods on warm summer days. When thermoclines are present, oxygen becomes depleted (anoxia) in near-bottom waters. Phosphorus release from lake sediments is typically high under anoxic conditions. The repeated formation and destruction of stratified conditions (polymixis) promotes algal blooms, because mixing replenishes nutrients to the upper, euphotic zone where algal growth occurs.

A nutrient budget for the lake (Mitchell 1985) indicates that by the early 1980s, Lake Wabamun already has moderate internal loading in midsummer, and to a lesser extent, under winter ice. Internal loading of this magnitude is common in mid-Alberta lakes. It is exacerbated by cottage development and land-use change.

When internal loading becomes large enough to promote large blooms of bluegreen algae (Cyanobacteria), the recovery of a lake becomes difficult. Many European lakes have been studied following reduction in nutrient sources after years of loading. The mean recovery time is about 15 years, but is quite variable (Sondergaard et al. 2000). Because removing internal nutrient sources is an extremely costly and difficult proposition, it would be best to strictly manage the external loading into Lake Wabamun to prevent the lake from becoming more eutrophic than it is at present.

Recommendations:
Because recovery of lakes with high internal loading from eutrophication is difficult, costly and time consuming (decades), all efforts should be made to keep the future inputs of plant nutrients to Lake Wabamun from increasing. Measures should include diversion of all sewage effluents away from the lake, whether they are treated or not. Similarly, storm runoff from urban areas should be prevented from entering the lake. Septic tanks should be replaced with pump-out systems or composting toilets. Fertilizer use on lawns, gardens, and golf courses in the basin should be discouraged. Reclamation of mined land should be to forests, rather than farmland, and fertilizer applied to existing farmland should be strictly regulated. Wetlands and riparian areas in the catchment of the lake should be restored, with emphasis placed on intercepting runoff from agricultural and urban areas.

A study of the potential effects of renewed ice cover in Kapasiwin Bay upon decommissioning of the Wabamun Power Plant should be conducted to evaluate the likelihood for increased phosphorus release from sediments, which might trigger noxious blue-green algal blooms

Other Chemical Considerations

In the period 1982 to 2001, chloride increased by 163%, sulfate by 76% and sodium by 51% (Casey 2003a). Much of the increase occurred after 1992. In contrast, calcium declined, possibly as the result of calcite precipitation, as described later. This precipitation is common in productive prairie lakes, and is why Lake Wabamun is dominated by sodium carbonate rather than calcium carbonate, which is less soluble. If lack of outflow and continuation of chemically treated water from the WLWTP continue, eventually, the lake will be transformed from a sodium bicarbonate lake to one dominated by sodium sulfate, more typical of closed basin lakes in central Saskatchewan. This process will occur very slowly, and while sensitive species of plankton may begin to change, there are no short-term effects expected for fishes.

The rapid increases in sulfate, sodium and chloride of the lake are in part the result of massive amounts of alum and chlorine added as part of the water treatment process, to keep alien species from entering the lake. Furthermore, the Sundance cooling pond, which supplies the treatment plant with source water, has a higher total dissolved solids concentration than the lake. Evaporation, in a system with little outflow, would also contribute to the increases, as discussed above. Chemical additions in water treatment should be kept as low as possible to minimize the increase in conservative ions in the lake, while ensuring that the plant is effective at biological removal. At present, the cost of added chemicals is $2.5 million per year.

Recommendation
If long-term use of the WLWTP is contemplated, the treatment process should be periodically reviewed to determine if chemical additions can be reduced without compromising the plant's effectiveness as a biological "filter." In the long-term, the combination of reduced chemical use at the WLWTP and the measures suggested in the Lake Level and Outflow Regulation section should help to slow the rate of chemical change.

Fisheries

Fishing pressure

Lake Wabamun appears to have been heavily fished since the mid-19th century, when the mission at Lac Ste. Anne is thought to have exploited the fisheries of nearby lakes for food, and to supply customers in Edmonton. Through the latter half of the 20th century, the fishery at Lake Wabamun has attracted huge numbers of sport fishermen. During the 1980s, annual angler effort was 150,000 to 200,000 angler-days. With declining fishing quality, angling effort has also decreased, with approximately 65,000 angler-days on Lake Wabamun during 2001. The commercial fishery has been one of Alberta's largest, in both number of fishermen and amount of fish harvested. In peak years, up to 200 km of gill-nets have been set in Lake Wabamun, with annual harvests often exceeding 100 tonnes of lake whitefish. This commercial fishery has also declined with declining fish stocks, and has been closed for conservation reasons since 2003. The First Nations food fishery (primarily gill-netting by members of the Paul Band) has declined since the early 1990s, likely because of declines in the abundance of whitefish and reductions in the perceived quality of the fish for consumption (Stephen Spencer, personal communication).

The population of walleye in the lake was never large in the 20th century, and the native stock of walleye has now been extirpated, likely as a result of overexploitation by commercial and sport fishing. Extensive efforts to restock the species by Alberta Fish and Wildlife have failed. Continued heavy angling pressure (i.e., a popular walleye sport fishery quickly developed and hooking injuries were commonly observed on sampled walleye), as well as habitat changes because of power plant effluent (i.e. spawning walleye were captured during March in the warm Wabamun Power Plant effluent, approximately 6 weeks earlier than in other area lakes. This may have contributed to the failure of re-establishing walleye in Lake Wabamun.

The northern pike population shows clear signs of over-exploitation. Pike mortality is estimated at 78% per year, far beyond what is sustainable by recruitment and growth. Few fish reach an age of 6 years or a length of over 50 cm. As a result, few fish are large enough to reproduce. In contrast, lightly fished lakes have northern pike of many age classes up to 15 years or more, with large individuals reaching lengths of a meter or more. Although the sport harvest of this species has recently been severely restricted with the imposition of large size limits, the illegal harvest of undersize pike continues to be a significant problem (Patterson 2002). Prior to the closure of the commercial fishery, a large number of northern pike were incidentally taken during the targeted lake whitefish harvest. This incidental commercial harvest typically impacts large, older pike that make up the breeding population and are critical to recovering the population.

Lake whitefish, once supporting the largest commercial and sport whitefish fishery in Alberta, have not adequately reproduced in the past seven years, as evidenced by the lack of young fish caught in test nets. The commercial fishery for whitefish has been temporarily closed to allow the few surviving whitefish to spawn as many times as possible and thereby increase the chances of successful reproduction and recovery of this population.

Yellow perch in the lake do not reach a large enough size to support either a sport or commercial fishery. This size structure is typical of other yellow perch populations in large, eutrophic lakes in central Alberta, such as Lac Ste. Anne and Pigeon Lake.

Changes to fish habitat
Fish habitat has been compromised. As noted earlier, the modifications to the outlet stream and the lowering of lake level have reduced fish habitat, and conversion of shorelines to lawns and beaches has caused an undocumented and therefore unknown loss of shoreline habitat. The transformation of about 300 acres of Goosequill Bay into the Sundance cooling pond also destroyed critical fish habitat. Power plant intakes have affected fish habitat by creating the possibility of fish being "impinged" on intake screens as they attempt to use the habitat near and inside the intake canals. Power plant outflows have affected fish habitat by altering lake temperature and dissolved gas concentrations (see below for further discussion of these issues).

Widespread but undocumented habitat loss along much of the Lake Wabamun shoreline has been caused by cottagers illegally removing fallen trees and weedbeds that are known to be critical habitat for fish. Studies elsewhere indicate that such removals lower fish populations in proportion to habitat availability (Schindler and Scheuerell 2002). Overall, the fish habitat of Lake Wabamun requires drastic protective and restorative action.

Industry-related fish mortalities
While there have been a number of industrially-related causes of fish mortalities, these have not been reflected in the allocation or management of the fisheries of Lake Wabamun.

Throughout the period of TransAlta's operations in the Lake Wabamun area, there have been fish kills that have occurred as result of either normal operating conditions, or plant upsets. TransAlta has been diligent in their attempts to reduce or eliminate these occurrences, however, periodic fish kills still occur. More details are given in Appendix 1.

In February 1973, an unplanned outage at the Sundance power plant (which at that time used the lake as a source of cooling water) caused a rapid temperature decline that resulted in a fish kill due to "cold shock" in the outlet canal of the Sundance power plant. It was estimated that 250 northern pike and 250,000 spottail shiners were killed (Ash et al. 1974). Subsequent to this event, the Sundance cooling pond was constructed and the Sundance plant ceased discharge of cooling water to the lake in 1975.

Fish kills due to thermal stress and gas bubble trauma have also been a periodic occurrence (Golder Associates 1999). These kills have been relatively small in size (limited to less than 100 fish at a time), and have been mostly limited to fish in or near the cooling water outlet canal at the Wabamun power plant. These mortalities have been reduced in recent years by the installation of aerators to reduce gas tension and screens to prevent entry of larger fish into the Wabamun power plant cooling water outlet canal.

Over the fall of 2001 and spring of 2002, the largest documented industrial-related fish kill occurred at Wabamun Lake, involving a combined number of about 3000 lake whitefish, northern pike, and other species. In October 2001, large numbers of dead fish were first noted on the inlet screens of the Wabamun power plant, and a major study was undertaken examine this phenomenon. The primary fish species caught on the screen in the October 2001-Feb 2002 period were lake whitefish with other species such as northern pike and burbot also present, but in far fewer numbers. By March 2002, only a few fish were found on the inlet screens. However, in April of 2002, coincident with their spawning run, northern pike began appearing on the inlet screens in large numbers. This resulted in a large scale fish kill of northern pike in April-May 2002. This pattern was repeated in autumn 2002, but to a lesser extent. After a number of studies were completed, it was deduced that the fish were entering the inlet canal and becoming trapped on the inlet screens of the power plant. There was no indication of toxicity in the fish prior to impingement on the screens. No definitive cause for the behaviour could be determined. However, the behaviour in both northern pike and lake whitefish was coincident with spawning times, leading to the current theory that both species were looking for suitable habitat for reproduction.

TransAlta was proactive in trying to resolve the fish kill problems including 24 hour monitoring of the inlet screens during periods when fish were being trapped on the screens, modifying the inlet screens to reduce fish mortalities, implementing behavioural modification devices such as acoustic and visual deterrents on the inlet screens to keep the fish away and constructing a fish release runway for those fish that did become impinged on the inlet screen. These improvements have reduced the mortalities of fish on the inlet screens to relatively low levels, but have not totally eliminated the problem of industry-related fish kills.

Weed harvesting in Kapasiwin Bay results in the loss of approximately 16,500 fish/year, largely small-bodied fish such as spottail shiner, brook stickleback and Iowa darter (Golder Associates 2000). It is unlikely that weed harvesting is a significant direct source of mortality for these species, although it would remove fish habitat. More details of industry-related fish mortalities are included in Appendix 1.

Recommendations
Industry-related fish mortalities must be taken into account within the management plan for the fishery resource in Wabamun Lake.

The commercial fishing of Lake Wabamun should be ended permanently. Sport fishing should continue to be severely restricted until a natural range of age classes can develop for each target species. Efforts to reduce industry-caused habitat loss and mortality must be continued and industry-related fish mortalities should be included in fisheries management decisions. Existing federal and provincial laws protecting fish habitat should be enforced and illegally destroyed habitat should be restored, including riparian and shoreline areas with cottages. Once the fishery has recovered, it should be cautiously managed to ensure that harvest is no more than annual recruitment, and that a natural age structure is maintained in fish populations.

Any future attempts to reintroduce walleye should be accompanied by total closure to angling of any areas of the lake where walleye congregate until several year classes are established.

Invasive alien species will become more important in the years ahead, for a number of reasons. Voucher specimens of fishes and other organisms that are not easily identified should be kept, and identified by a competent taxonomist to ensure that invasion by alien species is detected early. Regular monitoring for alien species should occur.

Other Organisms

Bottom dwelling animals
Rasmussen (1979) studied the benthic (bottom living) fauna of Lake Wabamun in 1972-1975. He identified nearly 200 taxa of benthic invertebrates, dominated by midges (Chironomini). The number of taxa in the vicinity of heated effluents was similar to in the main body of the lake, although there was a slight switch in taxonomic composition to species associated with aquatic plants.

A November 2002 (Stantec 2003) survey revealed 128 benthic taxa from Lake Wabamun. This result cannot be compared with Rasmussen's because of the lack of seasonal data. Rasmussen also performed more detailed taxonomic analysis, particularly of the Chironomini. Both studies revealed a wide variety of aquatic taxa, including various insect groups (mayflies, caddisflies, true flies, damselflies, midges, beetles, water boatmen, aquatic moths, dragon flies, damselflies), but mites, crustacean, aquatic earthworms, leeches, roundworms, snails, clams, planarians and flatworms, hydras and water bears were also found. The effect of effluent from the ash lagoon was assessed in the 2002 study. A slight difference in invertebrate community composition was shown in the lake between and area near the ash lagoon outfall and a reference location to the west. The difference appears to be a response to mild enrichment, rather than toxicity from the outfall. A slight difference was also noted when comparing invertebrate community composition near the WLWTP outfall with that at a reference location, likely due to the nature of the lake bottom or the influence of treated water.

Zooplankton
Agbeti (2002) analyzed trends in monthly zooplankton data for the open water period in the years 1980, 1988, 1990, 1992 and 1994-2001. There was no evidence of either changes in seasonal patterns, except for a sharp decrease in the abundance of large-bodied crustaceans in 1992. This corresponded with an increase in lake whitefish populations. The populations of large crustaceans have since returned to more typical levels.

Fecal coliform bacteria
In the past there have been periodic beach closures because of concentrations of fecal coliform bacteria in excess of CCME contact recreation guidelines of 200 colonies/100mL of lake water (CCME 2001a). In response to this situation, the Edmonton Capital Health Authority undertook a study in summer of 2004. It involved seasonal surveys of a number of beaches (i.e., Camp YoWoChAs, Fallis, Moonlight Bay Church Camp, Seba, Wabamun Provincial Park, and Village of Wabamun). In general, most water samples had satisfactory fecal coliform counts. However, increases in bacterial counts were noted following rainfall and storm water runoff from land adjacent to the beaches, or following windy periods when lake sediment was re-suspended and lake water became turbid. Beaches that had high numbers of birds in the water, along the shore and on adjacent land often had high fecal coliform counts.

The Capital Health study concluded that the fecal coliform problem at Lake Wabamun is probably caused at least in part by large numbers of birds that use the lake. Some beaches in protected areas away from the main circulation of the lake also tend to have higher fecal coliform counts. There have also been reports of cattle grazing near some of the inlet streams to Lake Wabamun.

Recommendation
Several biomonitoring programs are ongoing (e.g., zooplankton, phytoplankton, fish). These provide an invaluable tool for assessing changes to the aquatic communities as the result of several types of impacts. Their design and suitability for long-term trend assessments need to be reviewed. These programs need to be carried out on an ongoing basis. The need and practicality to incorporate other ecosystem components (benthic invertebrates, macrophytes) needs to be evaluated and, if deemed necessary, a monitoring program designed and implemented. A data analysis and reporting schedule needs to be established.

Monitoring for fecal coliforms needs to be continued. If the current situation persists, a more detailed investigation of sources should be undertaken. Moving some beaches, limiting their use by humans, or further restrictions to human or animal wastes may be needed to correct the situation.

Trace Metals

Metals occur naturally in geological formations. They would be expected to occur in lakes as the result of natural weathering processes in the watershed. Several activities in the Lake Wabamun basin are expected to liberate metals in excess of natural background, including mining, agriculture, transportation and construction. Diversions from mines and ash lagoons, the burning of coal and transportation of coal ash, and emissions from transportation are other potential sources to the lake. Several metals are toxic to humans and aquatic life at low concentrations. The metals do not appear to have caused detectable changes in the aquatic community. Similarly, metals deposited in Wabamun Lake are not a health concern for recreational uses of the lake.

Several studies have been carried out to describe trace metal concentrations in water and sediments from Lake Wabamun. Other lakes in the region were used as reference lakes.

In Lake Wabamun water, metal concentrations in the lake are typically meeting water quality guidelines for the protection of freshwater aquatic life, although some selenium and cadmium measurements are in excess of provincial and Canadian guidelines for the protection of aquatic life (Alberta Environment 1999, CCME 2001a, Casey 2003a). Boron, beryllium, bismuth and molybdenum are also higher than in other lakes of the area (Golder Associates 2002, Anderson 2003).

In sediments of Lake Wabamun and several of the reference lakes, arsenic, cadmium, chromium, copper and zinc exceed Interim Sediment Quality Guidelines for the Protection of Aquatic Life (CCME 2001b). About 25% of arsenic measurements in Lake Wabamun exceed CCME Probable Effects Levels (CCME 2001b), compared to only 4 % of reference lake samples. All samples from Lake Wabamun and reference lakes met the CCME interim Sediment Quality Guideline for mercury (CCME 2001b). Arsenic, cadmium, copper, zinc, mercury, selenium and antimony are higher in Lake Wabamun sediments than in sediments of other lakes of the area.

Metal levels in the vicinity of the ash lagoon outfall tend to be higher than metal levels in similar sediments and at similar depth elsewhere in the lake. This suggests that the ash lagoon has contributed to the metal loading to the lake.

A study of drinking water wells carried out by Alberta Environment in 2002 showed that metal concentrations in all of the wells tested complied with Canadian Drinking Water Guidelines.

At present, none of the metals in Lake Wabamun water and drinking water wells near the lake are at concentrations high enough to be of concern for human drinking water. Metal concentrations in the lake's water are not of concern for aquatic life, but because some metals in sediments were well above interim guidelines for the protection of aquatic live, additional studies were undertaken. These studies showed that the sediments of Lake Wabamun were no more toxic to a range of test species than sediments from reference lakes (HydroQual 2003), and that benthic invertebrates near the ash lagoon outfall, where some metal concentrations are elevated, were as diverse and abundant as in an area away from the ash lagoon (Stantec 2003). Altogether, it seems unlikely that metals in lake sediments have had an acute impact on benthic and planktonic organisms. Further studies would be necessary to determine likelihood of secondary ecological or food-chain effects of trace metals in Lake Wabamun.

Paleoecological studies indicate that some metals have increased since coal mining and burning began in the basin. Metals that have increased include mercury, arsenic, copper, molybdenum, lead, selenium, tungsten and zinc (Donahue et al. unpublished manuscript). All are known to be trace contaminants of coal.

Mercury

Recently, mercury has been a cause for considerable concern in North America, because it is vaporized in combustion and released to the atmosphere in gaseous elemental form that can be carried long distances. There are also some emissions as divalent mercury, probably bound to aerosols and small particulates. Once entering aquatic ecosystems, mercury can be methylated by sulfate-reducing bacteria to methyl mercury. Methyl mercury is biomagnified in aquatic food chains, often to levels that can cause health problems in humans or fish-eating mammals. Such problems have recently been discovered to be particularly acute in developing fetuses and newborn infants (NRC 2000). High mercury concentrations are currently the most common reason for fish consumption advisories in the U.S.A.

The four power plants in the Wabamun vicinity are known to release roughly 600 kg of mercury per year, or about 2/3 of the annual emissions of mercury from electrical production facilities in Alberta (CASA 2003). According to Environment Canada's National Pollutant Release Inventory, in 2002, the Sundance power plant was the second largest industrial aerial emission source of mercury in Canada, with emissions of 275 kg of mercury per year. Other on-site and off-site releases add another 98 kg annually. There are also other sources of mercury to the Wabamun region, including geological formations, forest fires, and long-range transport of the element from sources around the world.

Several studies in North America show that deposition of mercury in lake sediments before the industrial revolution was generally on the order of 4-6 $\mu g/m^2/yr$. In Pigeon Lake, well away from the power plants, current mercury deposition is 6-9 µg/m^2/yr, or 3 to 6 µg/m^2/yr greater than in the early years of the 20th century (Donahue et al. unpublished manuscript). These are similar to current values for mercury deposition for lakes in northern Minnesota and Wisconsin. Current mercury deposition in most pristine areas is about 2-3 times greater than in the mid 19th century. It is believed that this is largely the result of long-range transport of anthropogenically-released mercury in the atmosphere. About half of the atmospheric mercury is believed to be of human origin (Schroeder and Munthe 1998, Mason and Sheu 2002).

A detailed paleocontaminant study of Lake Athabasca, one of the few studies of this kind in western Canada, demonstrated no long-term increase in mercury deposition in northeastern Alberta (Bourbonierre et al. 1996). This, and the small increase in deposition rates in Pigeon Lake, suggests that importance of increases in long-range transport of globally-sourced mercury to Lake Wabamun has likely been minimal when compared to increases in local fluxes to the lake.

Current mercury deposition at Lake Wabamun is somewhat higher, 21-32 µg/m^2/yr. Comparisons with historical values indicate that about 85% of current mercury flux is of anthropogenic origin. Goodarzi (1996) measured mercury deposition at 36 sites in the basin, by analyzing mercury concentrations in cleaned moss pillows taken from the catchment. These indicated an average deposition rate of 7 µg/m^2/yr. While these are lower than lake values, they are more susceptible to re-emission to the atmosphere. Nearby Lac Ste Anne receives 10-15 µg/m^2/yr of Hg. These data clearly indicate that nearby sources as well as long-range transport are affecting the mercury input to the lake. A dated sediment core from Lake Wabamun indicates that the timing of mercury increases above the long-range transport background in Lake Wabamun corresponds well with the installation of power plants (Figure 6). It should be noted that the Lake Wabamun data are from a single dated core, and other sites in the lake may be more variable. However, similar observations were made in Minnesota lakes near to coal-fired power plants (Engstrom and Swain 1997).

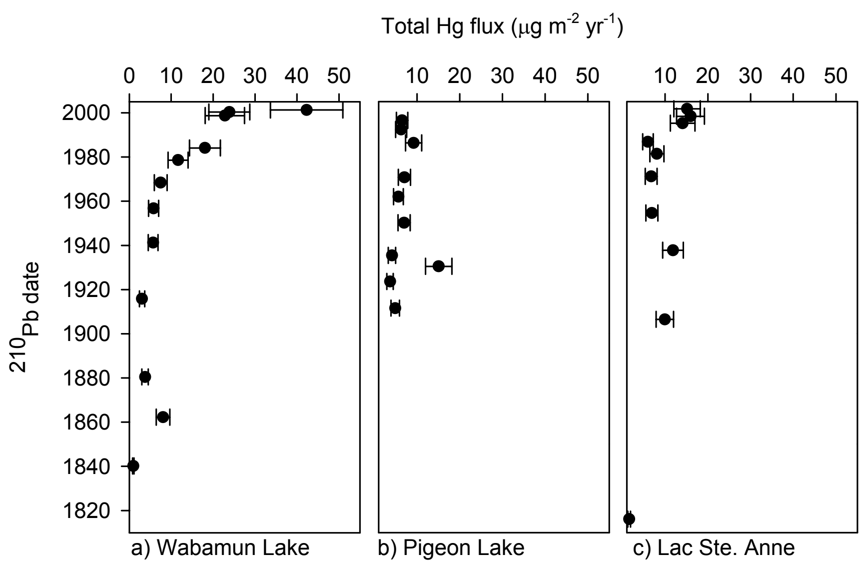

Figure 6. Annual total flux of mercury to the sediments of Lake Wabamun, Pigeon Lake and Lac Ste. Anne. From W. Donahue et al. (unpublished Ms).

Until recently, some claimed that the increase in mercury near the sediment surface could be explained by redox phenomena, as the result of mobilization of iron under anoxic conditions in sediments (Rasmussen 1994). In a recent review of the evidence, Fitzgerald and Lamborg (2003) discounted this theory, pointing out that when atmospheric mercury sources were decreased, concentrations of mercury at surface sediments also decreased. This is not consistent with redox-controlled movement.

Although the current mercury deposition in Lake Wabamun is higher than in other lakes of the area, it does not seem to have contaminated fisheries to a large degree. Northern pike in Lake Wabamun collected in 1996 and 2001 had mercury concentrations that were generally similar to levels recorded in pike from other lakes in the region and fell within the mid-range of Alberta waterbodies, including those in pristine areas (Figure 7). Mercury concentrations in Wabamun pike were below the Health Canada guideline for occasional consumption (0.5 mg/kg). Many northern pike exceeded the subsistence guideline (0.2 mg/kg), and there is some concern for those who eat northern pike regularly. This may be of particular concern for members of the Paul Lake Band. Lake whitefish in Lake Wabamun collected in 1996 and 2001 had mercury concentrations that met both occasional and subsistence consumption guidelines (Golder Associates 2002).

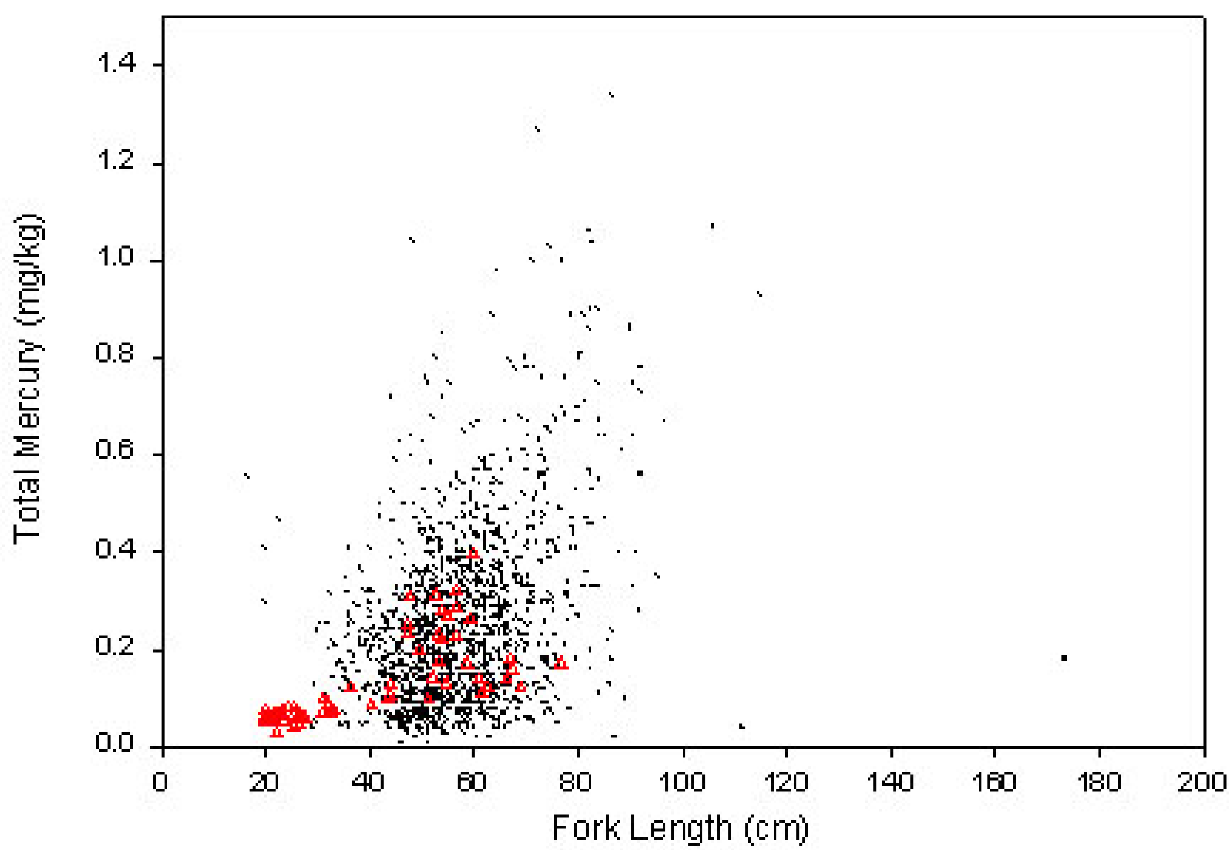

Figure 7. Mercury in northern pike from Alberta waterbodies. Data for Wabamun Lake shown as open triangles, all other locations shown as dots. Data from references provided in the text.

Several factors could change the mercury concentrations of northern pike in the future. Firstly, most of the fish in the lake are very young, as the result of the over-exploitation of fisheries reported above. In general, larger, older piscivorous fish contain the highest mercury concentrations. If the fishery is allowed to recover as recommended, large northern pike could contain concentrations of concern, although data from 1996 and 2001 show that the older, larger fish in the sample were still within regional and Alberta-wide ranges and did not exceed occasional consumption guidelines.

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Secondly, methylation of mercury is generally done by sulfate reducing bacteria. In studies of eastern lakes where sulphate concentrations are low, methylation is limited by the availability of sulfate. It is not known if mercury methylation is limited at the 10-fold higher sulfate concentrations found in Lake Wabamun. Sulfate concentrations in the lake are increasing, as the result of the use of alum and thiosulphate in the WLWTP and the lack of flushing.

Recently, CASA has developed a framework for significant reduction of emissions of mercury from thermal generating facilities in Alberta by end of 2009 (CASA 2003). CASA recommends that the requirement for such reductions be part of the operating approvals for all coal-fired plants. For existing facilities, operators will be required to implement mercury emissions controls that are equivalent in performance and cost to fabric filters and activated carbon, at an injection rate to be determined as part of the CASA BATEA review for mercury. New facilities that already have fabric filters would be required to install the equivalent of activated carbon injection. Older facilities that are reaching the end of operation are exempt.

Recommendations:
Implementation of the November 2003 CASA recommendations for reduced emissions. These will be in place by 2009 for all power plants, and involve about 50% reduction in mercury emissions (CASA 2003). This should adequately protect the lake from any future increases in mercury loading, including those that may result from further industrial development in central Alberta.

Our above recommendations for limiting nutrient inputs should be sufficient to protect the fisheries from further increases in mercury as the result of increased biomagnification.
The situation deserves some continued monitoring, especially as older fish age classes recover after the recommendations for fisheries are implemented, although as noted above even larger, older fish are generally within guidelines.

A review of current programs for monitoring trace metals (AENV, TAU/EPCOR, CASA, others) is in order to ensure that objectives are clearly defined and tractable, methods used are comparable and attainable, and redundancy is avoided. In order to assess changes in the relative contribution of industrial activity in the watershed and airshed of the lake, periodic studies of deposition in lake sediments from deeper parts of the lake would be useful, using methods that are well-described in the scientific literature and consistent from study to study.

Organic Contaminants

Disinfection by-products

In the process of treating water to remove organisms, the WLWTP produces halogenated and non-halogenated disinfection by-products, including trihalomethanes, haloacetic acids, aldehydes and several related compounds (Casey 2003b). Concentrations are generally within the limits expected from modern drinking water treatment plants. The plant effluent would be further diluted by the volume of the lake and by the volatilization of compounds. The discharge of treated water to stabilize a lake's level is an unusual situation. Although there should be no concerns for human health, little is known about the toxicity of disinfection by-products to aquatic life.

PAHs

Twenty-one PAHs were identified in near-surface lake sediments from Wabamun. Total fluxes are 73-114 $ug.m^{-2}\ yr^{-1}$, 2 to 6-fold higher than in lakes farther from the coal-fired power plants. Comparisons with deeper sediments and other lakes also indicate that the power plants, coal mining, fossil fuel burning to power engines, and exposed coal seams in or near the lake are the most likely sources. Of the compounds detected, 12 have guidelines. Concentrations of six compounds exceed guidelines. However, the concentrations in sediments are an order of magnitude lower than probable- effects levels. PAHs do not bioaccumulate or biomagnify in food chains, and those in Lake Wabamun currently represent no significant threat to humans. (next to nothing is known about secondary and interactive effects of PAHs on aquatic life).

Recently, concerns have developed over the effects of trace amounts of pharmaceuticals, antibiotics, and personal care products in freshwater (ref). Early studies show that such compounds are numerous, and some are poorly degraded in sewage treatment or septic systems. So far, investigation of toxicity has barely begun. The possible implications for Lake Wabamun should be reviewed in a few years when scientific studies are more numerous. Nonetheless, diversion of all sewage away from the lake, as recommended for reducing nutrient delivery to the lake, should coincidentally limit delivery of these organic compounds.

Recommendations

No current action is recommended for potentially toxic organic compounds. The need for further investigation should be reviewed periodically in view of rapidly increasing scientific understanding of these compounds and their toxicity.

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Leanne Zrum constructed Figures 1 and 3. She and Elan Gluckie arranged the July workshop, and facilitated the acquisition of information on reclamation of mined areas and bacterial quality of beaches.
Margaret Foxcroft helped assemble the report.

Appendix 1. Lake Wabamun Fisheries

Historical Records

Journals from travelers in Alberta during the 19th century comment on the importance of the fishery at Father Lacombe's mission at Lac Ste. Anne (Kane 1859, Milton and Cheadle 1865, Cheadle 1931). Supplying fish to Fort Edmonton and area must have resulted in extensive local fishing pressure because of the heavy consumer demands of people and, in particular, because of the large population of sled dogs (Southesk 1875). Although not specifically mentioned in these early writings, it is likely that Lake Wabamun was also heavily fished to supply this large demand.

The first published accounting of fish harvests at Lake Wabamun refer to commercial catches from 1915 to 1945 (Miller 1947). Annual commercial fishing records from 1942 to 1976 are presented in Scott (1978).

Fishing Pressure

Angler surveys conducted during the 1980s resulted in estimates of angling pressure of 161,000 angler-days (Berry 1986). Of this effort, approximately 86% occurred during the winter season and 14% during the summer. In 2001, a summer-season creel survey was conducted and angling effort was estimated at 9,464 angler-days (95% CI, 6428 – 12499, Patterson 2002). Based on the winter/summer effort ratio from the 1980s, the total effort during 2001 may have been approximately 65,000 angler-days. Even with this reduction in popularity from the 1980s to 2001, Lake Wabamun receives some of the heaviest angling pressure of any Alberta lake (Sullivan 2003).

Commercial fishing records for Lake Wabamun have been kept since 1915 and repeatedly show periodic high levels of harvest followed by collapse (Figure 1). During the past 20 years, approximately 250 commercial fishermen have been licensed to fish at Lake Wabamun, setting up to 200 km of gill-nets during each fishery.

First Nations fishermen are licensed to fish for food in Lake Wabamun, in accordance to their Treaty rights. Typically, this fishery involves gill-netting for lake whitefish. Records of the numbers of licenses issued since 1980 (Figure 2) show a strong increase during the late 1980s, when whitefish were unusually abundant in Lake Wabamun. Recently, the number of licenses issued has declined. First Nations fishers have complained about the poor quality of fish in Lake Wabamun, although the specific cause of these complaints is unknown (Stephen Spencer, personal communication)

Walleye

A lack of commercial fishery records and only anecdotal reports suggest that walleye were an incidental species in Lake Wabamun. Fishery monitoring (both commercial and sport) failed to record the catch of any walleye during the 1970s and 1980s (Glen Clements, personal communication). During 1983 to 1986 (inclusive), approximately 12 million walleye fry were stocked in Lake Wabamun (Berry 1992). Although the stocked walleye did create a minor, localized fishery (concentrated in the Wabamun Power Plant effluent) for a few years, the fish failed to reproduce and the fishery collapsed (Watters 1991).

Northern Pike
The Lake Wabamun pike population structure was measured during 2001 (Patterson 2002). The age-class density showed evidence of severe growth-overfishing compared to pike from a lightly exploited Alberta lake (Figure 3). Based on the 2001 catch curve, pike total annual mortality at Lake Wabamun was 78%. This high level of mortality will prevent large pike from becoming abundant and will allow reproduction from only 2 or 3 year-classes (compared to more than 15 reproducing year-classes at lightly exploited fisheries). Long-term sustainability of the pike population is reduced with such a truncated age structure.

Following provincial guidelines (Berry 1999), the sport harvest of pike at Lake Wabamun was restricted to fish larger than 63 cm. During the 2001 creel survey, however, 46% of the pike harvested by anglers were illegal (Patterson 2002). This level of illegal harvest is of concern to both fish population management (Sullivan 2002, Post et al. 2003) and from an enforcement and social perspective (Walker 2003).

The commercial fishery harvests large numbers of pike incidental to the lake whitefish fishery. During the past 60 years, the commercial pike harvest has averaged 3000 kgs per year (Figure 4). This harvest is concentrated on large pike that are particularly vulnerable to the large-mesh gill-nets used in this fishery (Figure 5). With the recent restrictions on the sport harvest of smaller pike, the abundance of large pike will likely increase and result in even heavier incidental harvests of pike by the commercial fishery.

Lake Whitefish
Sport angling for lake whitefish in Alberta was initially developed at Lake Wabamun during the 1960s (Paetz and Nelson 1970, Nelson and Paetz 1992) and attracted hundreds of thousands of anglers in the 1980s (Berry 1986). It has been one of Alberta's largest and most important commercial fisheries, both in terms of magnitude of harvest and by participation (Scott 1978).

Although the whitefish fishery at Lake Wabamun has fluctuated greatly over the past century (Figure 1), recent low catches appear to be the result of repeated recruitment failures (Figure 6). A strong year-class of whitefish has not been produced since 1986, and recruitment during the past 7 years (1997 to 2004) has been unusually low. In response to the low catches and poor recruitment, the commercial fishery was temporarily closed in 2003 for conservation reasons (Spencer 2003).

Fish Habitat
Shoreline areas along Lake Wabamun are important for fish habitat. Flooded marshes and emergent weed beds provide spawning and rearing habitat for northern pike (Scott and Crossman 1973). Gravel beaches exposed to naturally-occurring wave action are necessary for lake whitefish spawning (Ash 1974). The importance of these habitats is reflected in the Canadian Federal Fisheries Act, Section 35(1), which states, "No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat." Provincial and municipal acts also recognize the value of these habitats and prohibit unauthorized alterations to shorelines of lakes. In spite of these legal protections, portions of the

shoreline of Lake Wabamun, particularly along cottage subdivisions, has been altered and destroyed. Cottagers have removed weedbeds, dumped sand, dredged channels, and cleared shoreline shrubs. Studies in boreal Canada have shown that removing 50% of the shoreline vegetation can result in a similar 50% decline in pike populations (Mills et al. 1999).

Industrial activities have also resulted in the loss of fish habitat. A large portion of Goosequills Bay, noted for pike spawning, was cut off from Lake Wabamun to create the cooling pond for the Sundance Power Plant (Ash 1974). Strip-mining along the south shore of Lake Wabamun has destroyed much of the Beaver Creek watershed, once used by spawning pike. The near-lake section of Wabamun Creek was destroyed by channel alterations during the construction of the outlet weir, again likely an area that was once important to spawning pike.

Industry-caused Fish Kills

Fish kills attributed to industrial activities have been a recurring problem at Lake Wabamun. Three types of kills have been documented, all associated with the electrical power generating stations. In February 1973, thermal shock associated with an emergency shutdown of the Sundance power plant resulted in an estimated kill of 258,000 spottail shiners and 250 northern pike (Ash et al. 1974).

Gas bubble trauma was documented as a cause of fish kills during the late 1990s near the Wabamun power plant (Golder Associates 1999). Water containing supersaturated gases (formed when cold lake water was heated and discharged during the normal course of plant operations) was concentrated within the effluent stream. Fish caught in this stream were injured and killed as gas bubbles developed in their gills, eyes, skin, and internal organs. TransAlta attempted to reduce this problem by building fish barriers to prevent fish from entering the discharge stream and by mechanically de-gassing the water before it enters Lake Wabamun. Periodic, recurring problems have included fish moving past the barriers and mechanical malfunctions with the de-gassing process.

A third major type of fish kill has been entrainment and destruction of fish in the water intake stream to the Wabamun power plant. Large numbers of dead pike and lake whitefish have been collected from the intake filter screens during each winter since 2001. The direct cause of these deaths appears to be mechanical trauma caused by the rotating filter screen, but the reason for the recent appearance of large numbers of dead and injured fish is not has not clearly ascertained (Greg Goss, personal communication). It is possible that a change in the debris removal procedure on the filter screen has simply resulted in the observations of these fish and similar, but unobserved mortality has been occurring since the plant was built (Stephen Spencer, personal communication).

In each of these instances of large-scale fish kills, the safety of consuming fish from Lake Wabamun been of wide-spread public concern. No evidence of human health risks, however, has been confirmed.

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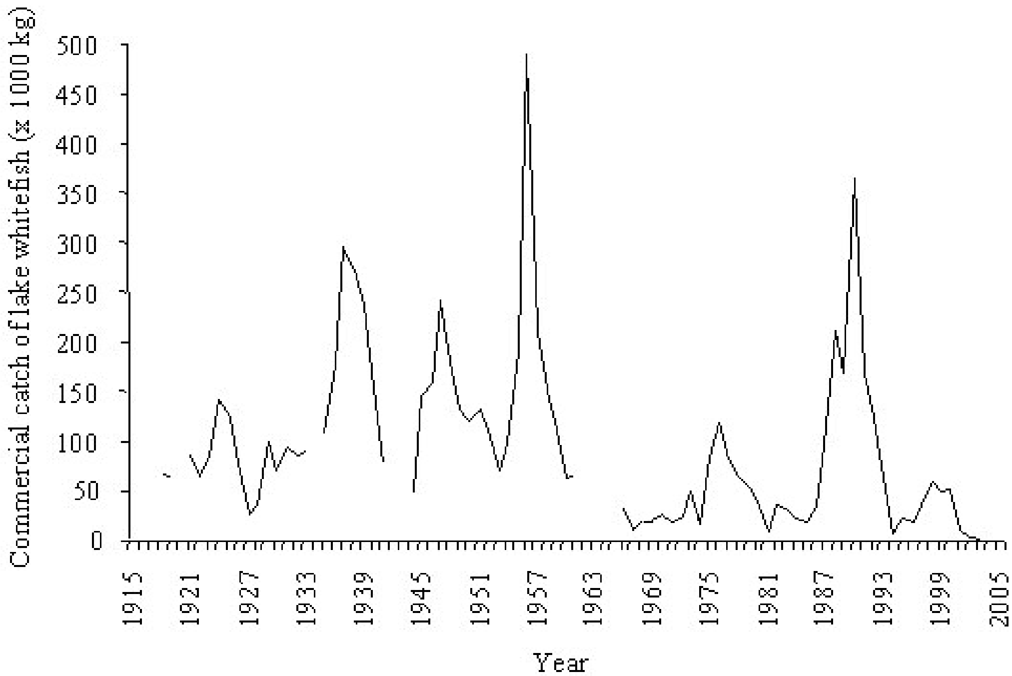

Figure 1. Commercial catches of lake whitefish at Wabamun Lake, 1918 to 2004.

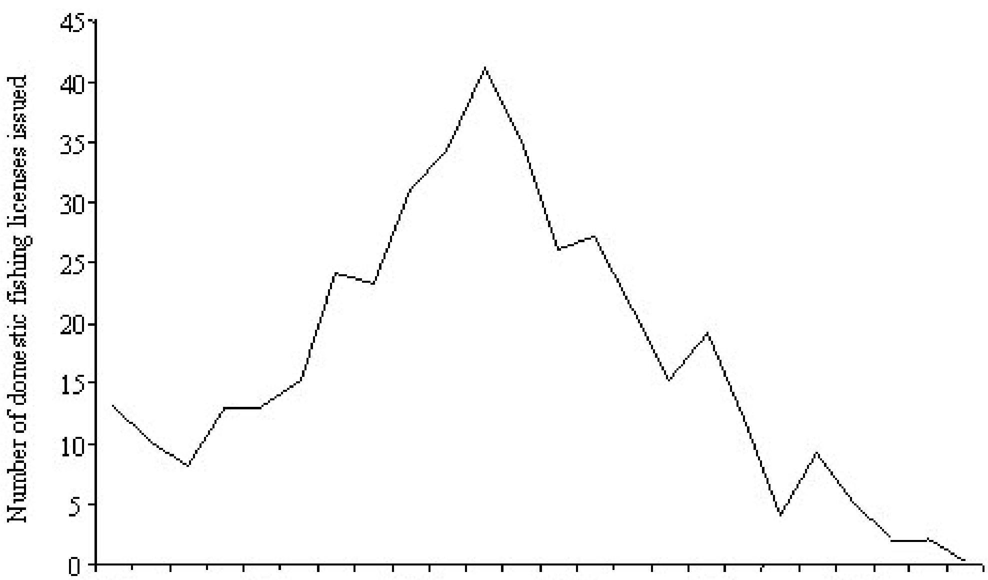

Figure 2. Number of First Nation fishery licenses issued at Lake Wabamun, 1980 to 2004.

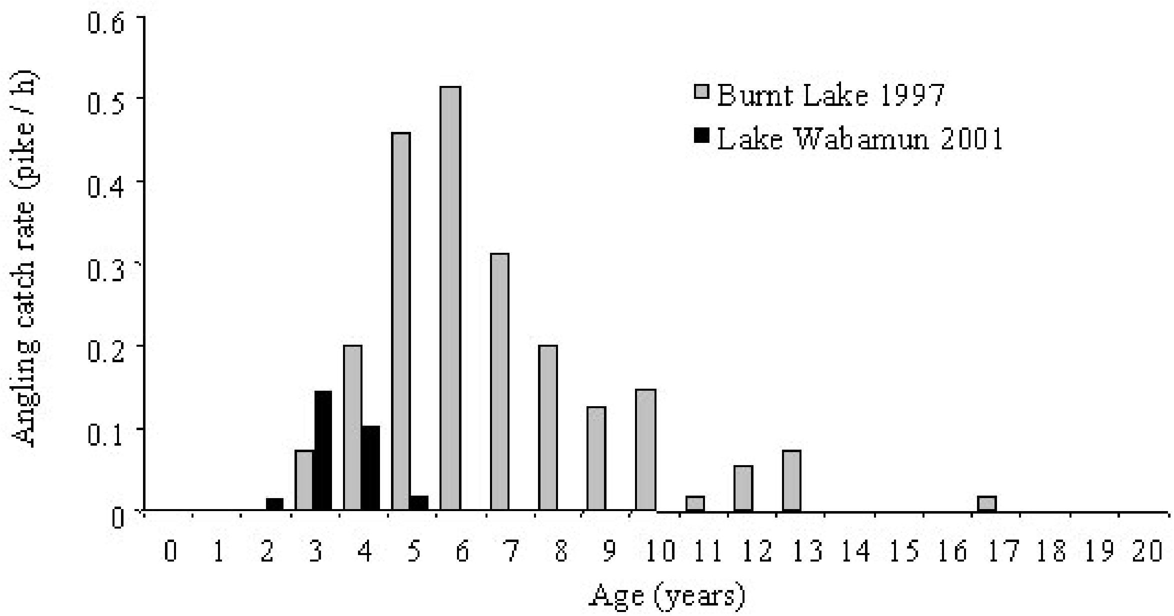

Figure 3. Age-class distributions and densities of angler-caught pike at Wabamun Lake (2001) and Burnt Lake (1997).

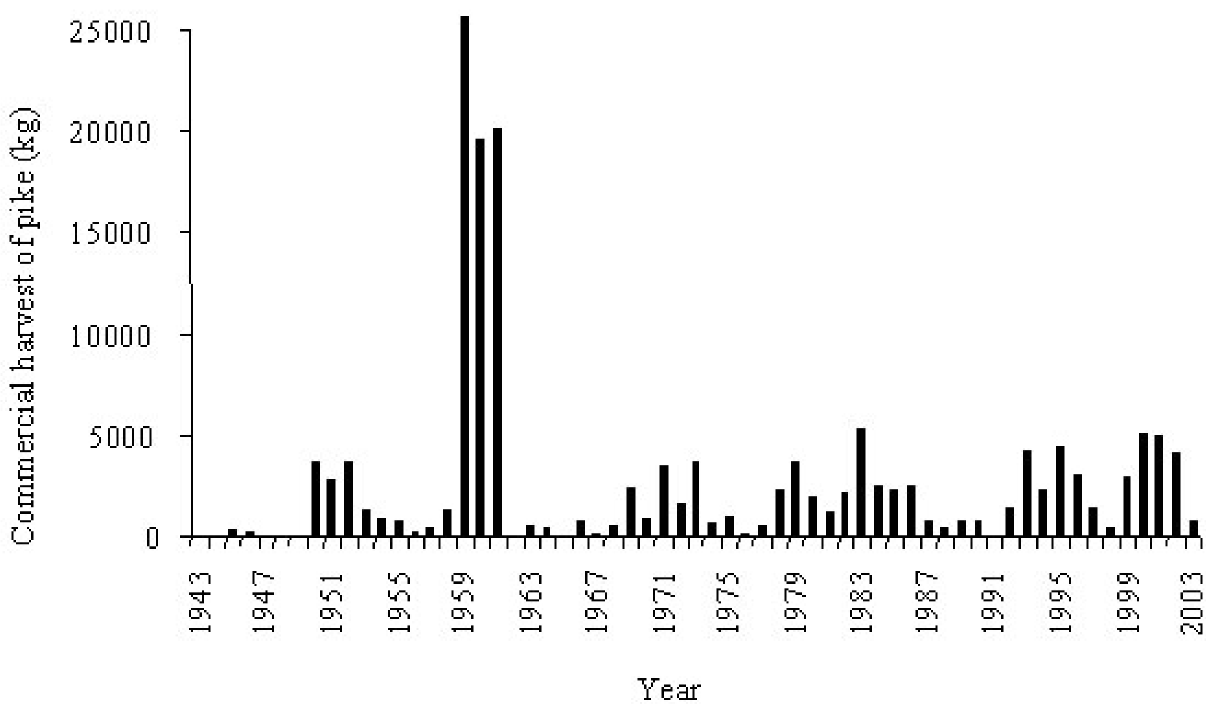

Figure 4. Commercial harvest of northern pike at Lake Wabamun from 1943 to 2003.

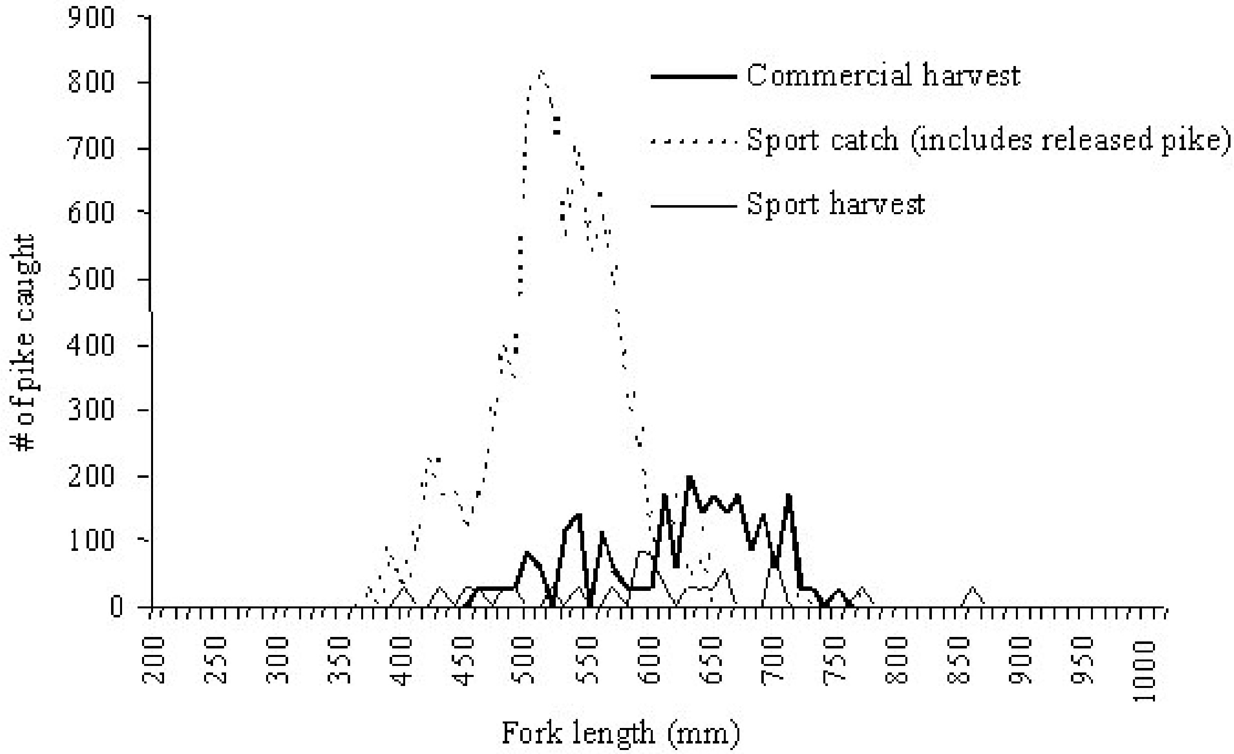

Figure 5. Commercial and sport catches of northern pike at Lake Wabamun, 2001.

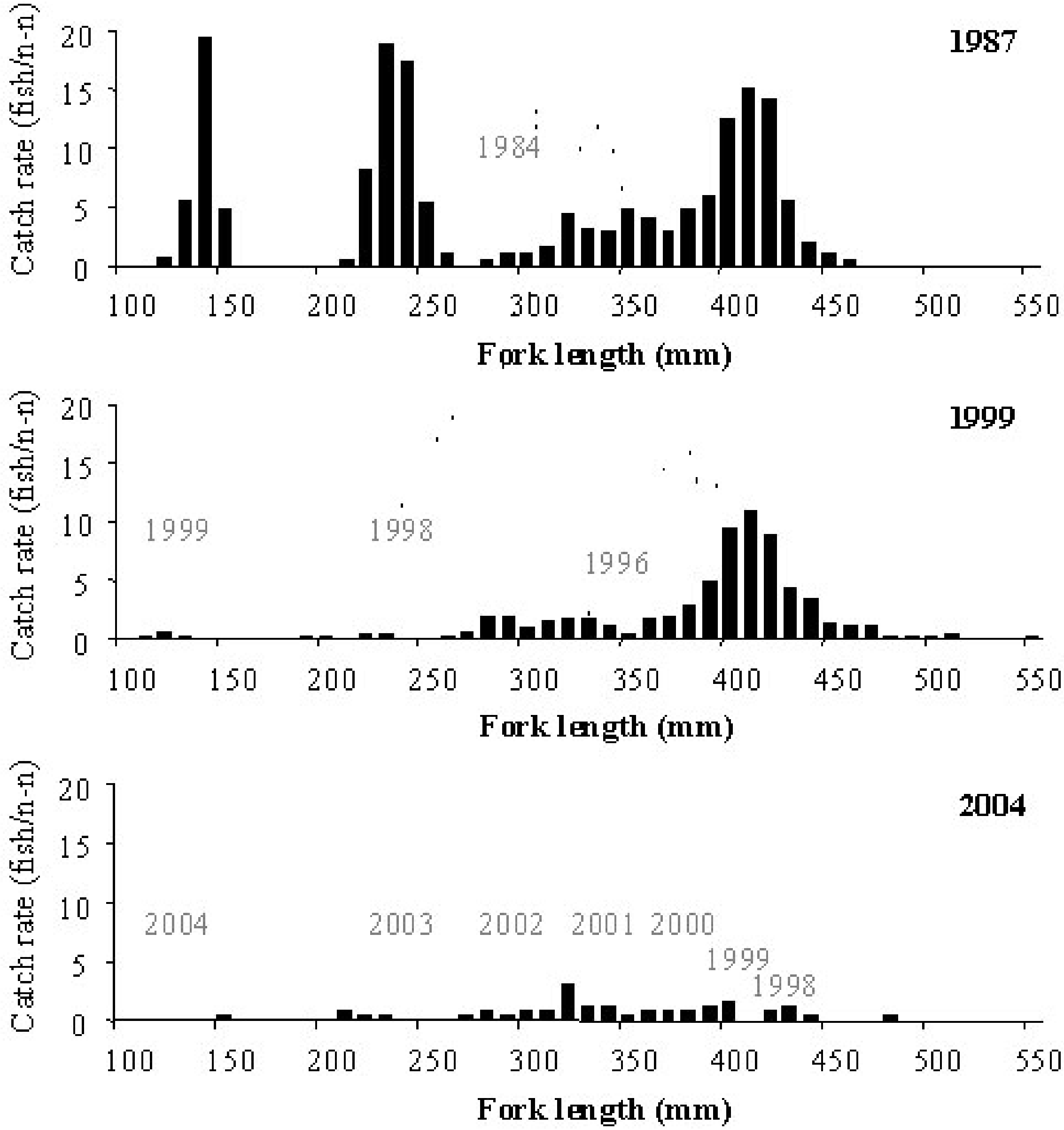

Figure 6. Length frequency distributions of lake whitefish caught in test-nets at Lake Wabamun 1997 to 2004. Density is scaled to commercial catch rate from each year on whitefish recruited to commercial nets (fish larger than 350 mm fork length). Year-classes with unusually low recruitment are marked with the year of birth above the missing size –classes.