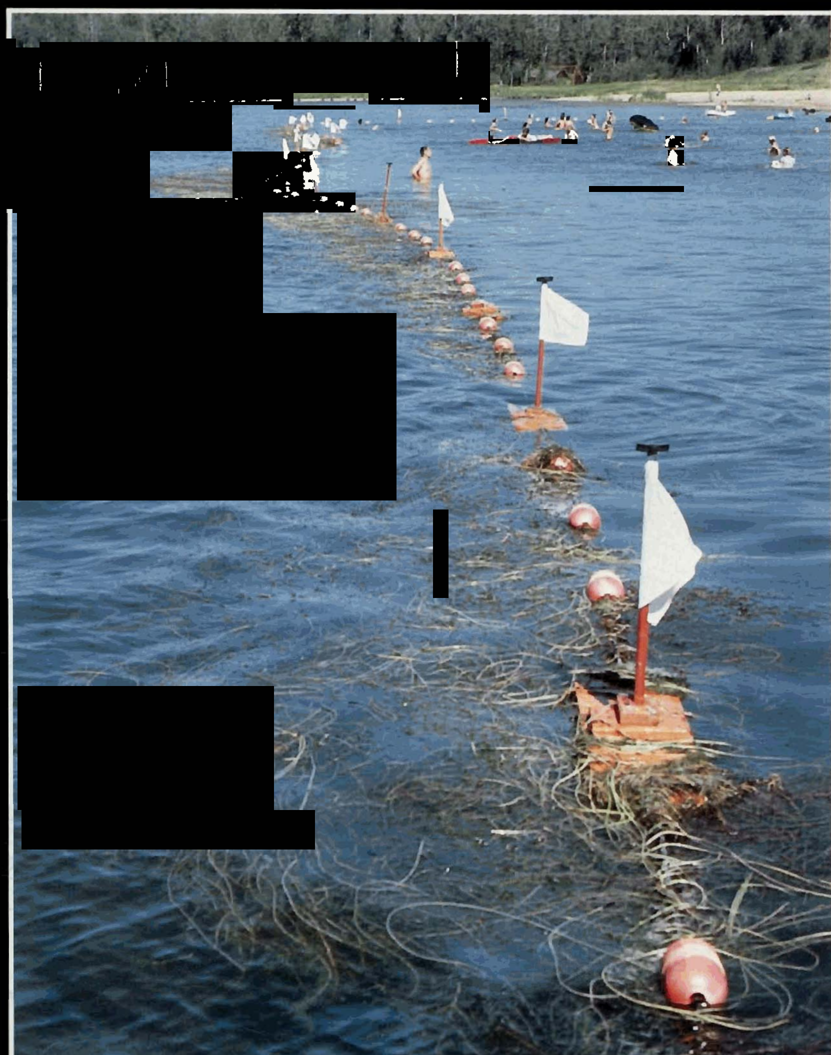
Preservation Of Water Quality In Lake Wabamun

Volume 1



Lake Wabamun Eutrophication Study

Alberta
ENVIRONMENT
Pollution Control Division
Water Quality Control Branch

PRESERVATION OF WATER QUALITY IN LAKE WABAMUN

Lake Wabamun Eutrophication Study

by: Patricia Mitchell
Water Quality Control Branch
Pollution Control Division
Environmental Protection Services
Alberta Environment

April 1985

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Lake Wabamun Eutrophication Study was initiated to address public concerns that water quality in this important recreational lake was deteriorating. The Water Quality Control Branch began the three year study in late 1979; its purpose was to determine sources and quantities of plant nutrients entering the lake, and to assess the lake's present fertility level. This report deals with the first of these two purposes; an additional report will be issued on the lake's present condition.

Nutrient supplies to the lake were measured intensively throughout 1980 and 1981, with additional sampling in 1982. The most important source of phosphorus and nitrogen to Lake Wabamun is its surrounding watershed. Snowmelt and rain transport these nutrients to the lake in streams. Rain, snow, and dust falling directly onto the lake also contribute large quantities. Sewage was found to be a minor source, but weed growth in localized areas could be enhanced by sewage effluent. The bottom sediments contribute phosphorus to the water in late summer, maintaining the lake's fertility when other supplies are reduced.

Only the portion of the nutrient supply that can be attributed to human activities in the watershed is potentially controllable. This represents only about one third of the total supply. Most of this potentially controllable portion cannot be controlled in a practical sense without moving landowners out of the watershed. For these reaons, major nutrient control projects are not warranted. In addition, the lake is too large to use lake restoration techniques to deal with nutrients already in the lake.

However, to preserve the present status of the lake, i.e., to prevent it from becoming more fertile, with associated weed and algae problems, landowners and lake users should actively begin a nutrient control program based on individual effort.

INTRODUCTION

Over the past 25 years or more, people have been concerned that Lake Wabamun is "dying", like the much publicized Lake Erie, or, closer to home, Cooking Lake. To them, death of Lake Wabamun means more and more weed growth and poorer and poorer water quality, until finally the lake is no longer usable. Many long time residents state that weed growth has become worse in the time they've been on the lake, and they believe that unless something is done quickly, Lake Wabamun could be unusable in their lifetime.

We have no way of knowing scientifically whether the lake is deteriorating because there are no previous studies by which such change can be measured. Most people would say that the power plants on the lake, with their former or present discharge of heated water, are the main cause of the problems they see. But in most lakes, as in a vegetable garden, plant growth is directly related to the amount of nutrients such as phosphorus and nitrogen available to them. If nutrient supplies increase, plants grow better. Although macrophytes ("weeds") probably grow larger in the area of the heated discharge, it is unlikely that the rest of the lake is affected now that the nuisance plant *Elodea* has declined[1].

With all of the human activity in Lake Wabamun's watershed, it is probable that nutrient supplies to the lake have increased over the past century. This gradual enrichment, or EUTROPHICATION, is the key to water quality problems in Lake Wabamun.

THE STUDY

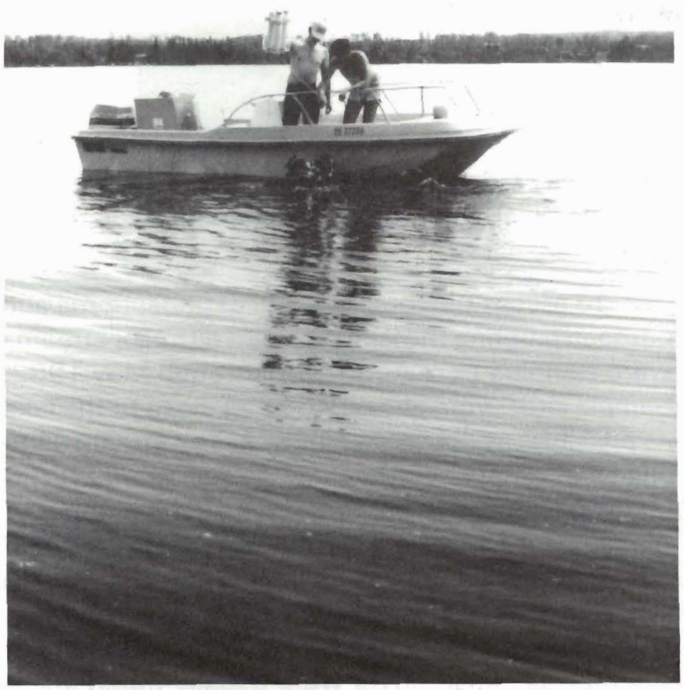
In response to public concern, the Pollution Control Division of Alberta Environment launched the Lake Wabamun Eutrophication Study in November 1979. Its purpose was to gather basic information on nutrient sources and supply, and on the lake's present recreational water quality.

Although weed growth is a primary issue with lake users, the study did not deal with macrophytes directly for several reasons. First, these plants are difficult to quantify. A large amount of time and manpower is needed to get meaningful information about them. Second, they are considered to be less of an indicator of a lake's condition than other components of the water. This is because macrophytes flourish in lakes with low nutrient supplies and clear water as well as in lakes that are green and fertile. Third, nutrient control probably would not reduce weed populations (see below). Therefore, the study was directed toward the cause of the problem, increased nutrient supplies, rather than a symptom, weed growth.

1. Beak Consultants, Ltd. 1980. The effect of thermal discharges on the aquatic plants and other biota of Wabamun Lake, Alberta. 2 vol. Prepared for Calgary Power, Ltd. (TransAlta Utilities Ltd.) 380 pp., maps, figures.

The best indicator of recreational water quality is the amount of algae in the water. Algae are tiny plants that give lakes their green color. Unlike the large plants called "weeds", algae respond quickly to changes in their environment and are easy to measure. Thus, water quality in the lake was addressed by studying several indicators of fertility.

The information obtained in the study is used to assess possibilities of reducing nutrient supplies to maintain the present water quality in Lake Wabamun. In other words, are there sources of excessive nutrients which might be controlled? If so, would controlling them significantly reduce nutrients in the lake, and thereby maintain the present water quality over the long term? This report documents nutrient sources and the quantities measured from each source, and assesses the potential for nutrient control within the watershed. A second report deals with the present condition of Lake Wabamun, including its nutrient status and quantities of algae.



PHOSPHORUS AND NITROGEN

Plant life in Lake Wabamun requires many substances called nutrients. A farm crop will not grow well if it is insufficiently fertilized (provided nutrients). In exactly the same way algae and macrophyte growth can be limited by the quantity of nutrients available to them. The nutrient in smallest supply compared to the growth needs of these plants is called the limiting nutrient.

In Lake Wabamun, phosphorus is the limiting nutrient (see explanation in Appendix 1), as it is in most lakes. This means that algal growth is controlled by the quantity of phosphorus available. If phosphorus is reduced, either naturally or through phosphorus control measures, the quantity of algae in the lake should decline. Improved recreational water quality would be the result.

The situation is more complicated with macrophytes, even though the principle is the same. Macrophytes derive much of their nutrient supply from the mud they are rooted in. Even if the phosphorus in the water is reduced, macrophyte growth may continue undiminished, because phosphorus supplies in the mud are very large.

This report emphasizes phosphorus because it is the limiting nutrient. Additionally, it would be easier to control than nitrogen (since the air is a continual source of nitrogen). Whenever the terms phosphorus and nitrogen are used, *total* phosphorus and *total* nitrogen is meant unless indicated otherwise. Plants can use only a portion of the quantity of nutrient measured as total; the unuseable, or unavailable, portion is mostly tied up in living or formerly living material (organic complexes). The phosphate in commercial fertilizers is an example of a form of phosphorus that plants can use.

SOURCES OF NUTRIENTS

Nutrients are transported mainly by water. A stream that drains through a cattle pasture would contain large quantities of phosphorus and nitrogen: the cattle manure is the source; the stream is the conveyor. The major sources of nutrients to Lake Wabamun are illustrated in Figure 1.

The different types of land surrounding the lake – cottage lots, forest, agriculture, mine areas – yield different quantities of nutrients. Additional sources are precipitation and dust in the air, groundwater and the bottom sediments. These will be discussed in the following sections.

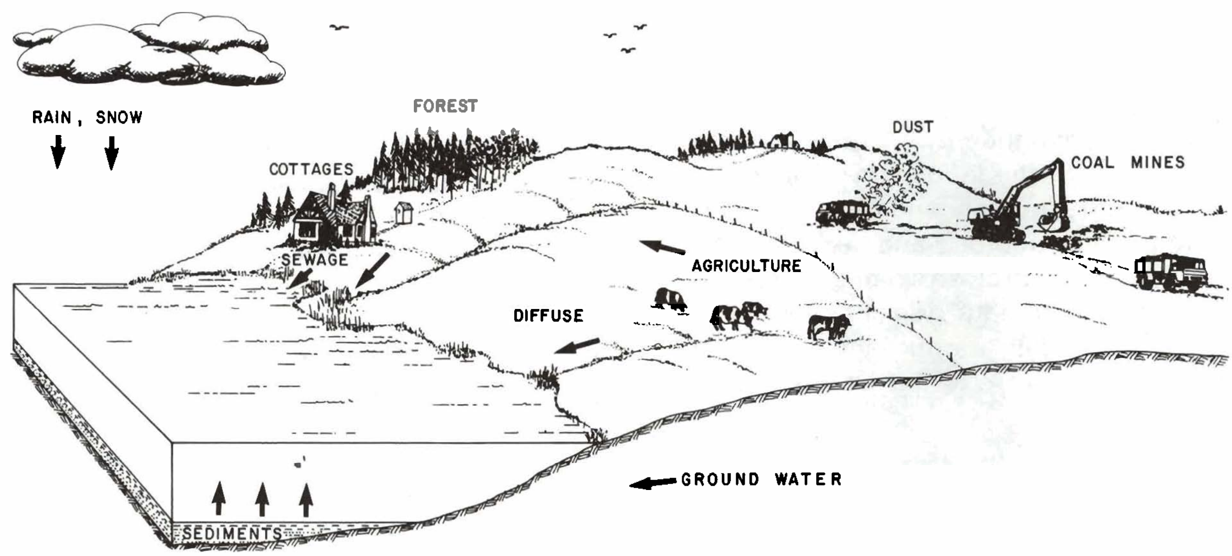


Figure 1. Sources of nutrients to Lake Wabamun.

THE WATERSHED

The watershed is the land surface from which a lake receives its water. The most important source of phosphorus to Lake Wabamun is its surrounding watershed (see Figure 2). Over the winter, leaves and other material slowly decompose, releasing nutrients. These are washed toward the lake as the snow melts in spring. Flowing water and accompanying soil particles, organic material and nutrients form streams which drain into the lake. Heavy rains in summer also transport large quantities of nutrients to Lake Wabamun, but nearly half of the total stream supply enters the lake during snowmelt runoff in spring. The nature and quantity of the materials carried by streams determine in large part the chemical and biological characteristics of the lake.

To assess the total quantity of phosphorus and nitrogen entering the lake in a year, all major streams were sampled from April 1980 through May 1982. Sample sites were chosen to be as close to the lake as possible, as shown in Figure 2. The stream sampling sites shown on the map are designated in this report by a location name as well as the number of the site, for example, Sharon 15. Water flow and nutrients were measured every other day during spring runoff to account for day to day variation. They were sampled somewhat less frequently in summer, because flows were usually much lower than during the spring melt period.

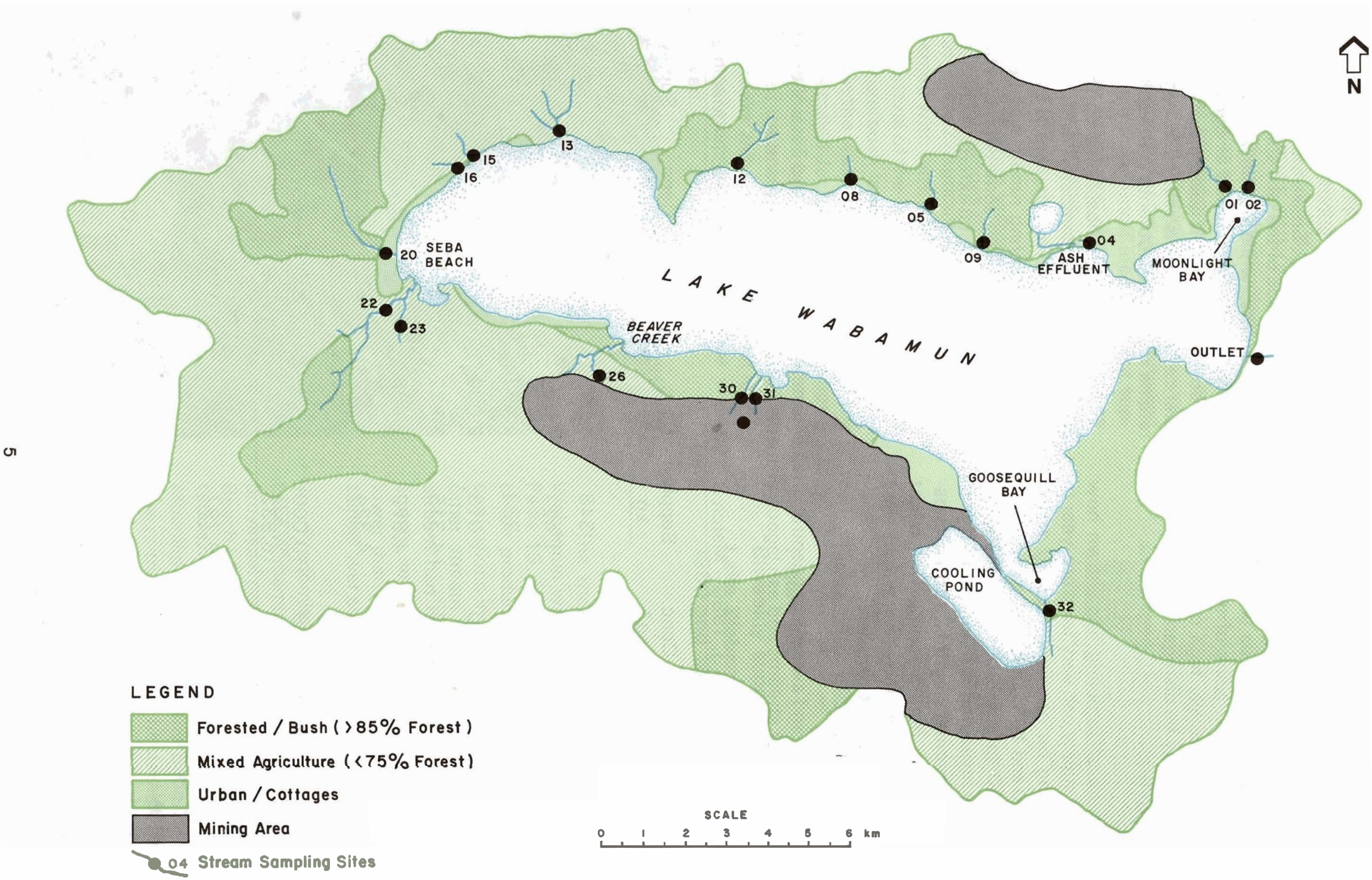


Figure 2. Watershed map - Lake Wabamun.

Alberta
ENVIRONMENT
Pollution Control Division
Water Quality Control Branch

SOURCES OF NUTRIENTS

Nutrients are transported mainly by water. A stream that drains through a cattle pasture would contain large quantities of phosphorus and nitrogen: the cattle manure is the source; the stream is the conveyor. The major sources of nutrients to Lake Wabamun are illustrated in Figure 1.

The different types of land surrounding the lake – cottage lots, forest, agriculture, mine areas – yield different quantities of nutrients. Additional sources are precipitation and dust in the air, groundwater and the bottom sediments. These will be discussed in the following sections.

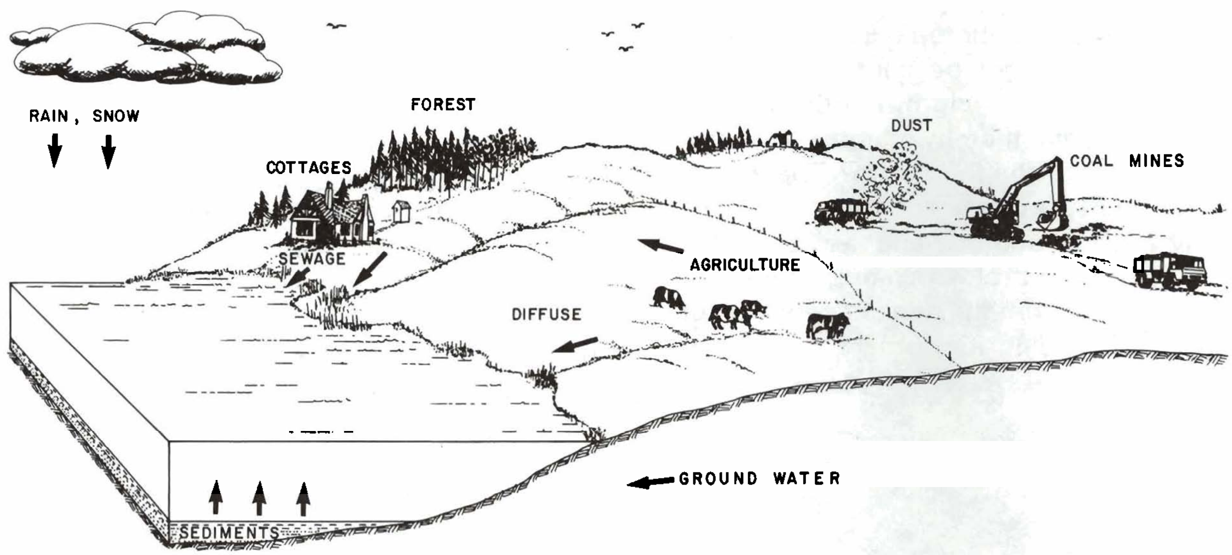


Figure 1. Sources of nutrients to Lake Wabamun.

THE WATERSHED

The watershed is the land surface from which a lake receives its water. The most important source of phosphorus to Lake Wabamun is its surrounding watershed (see Figure 2). Over the winter, leaves and other material slowly decompose, releasing nutrients. These are washed toward the lake as the snow melts in spring. Flowing water and accompanying soil particles, organic material and nutrients form streams which drain into the lake. Heavy rains in summer also transport large quantities of nutrients to Lake Wabamun, but nearly half of the total stream supply enters the lake during snowmelt runoff in spring. The nature and quantity of the materials carried by streams determine in large part the chemical and biological characteristics of the lake.

To assess the total quantity of phosphorus and nitrogen entering the lake in a year, all major streams were sampled from April 1980 through May 1982. Sample sites were chosen to be as close to the lake as possible, as shown in Figure 2. The stream sampling sites shown on the map are designated in this report by a location name as well as the number of the site, for example, Sharon 15. Water flow and nutrients were measured every other day during spring runoff to account for day to day variation. They were sampled somewhat less frequently in summer, because flows were usually much lower than during the spring melt period.

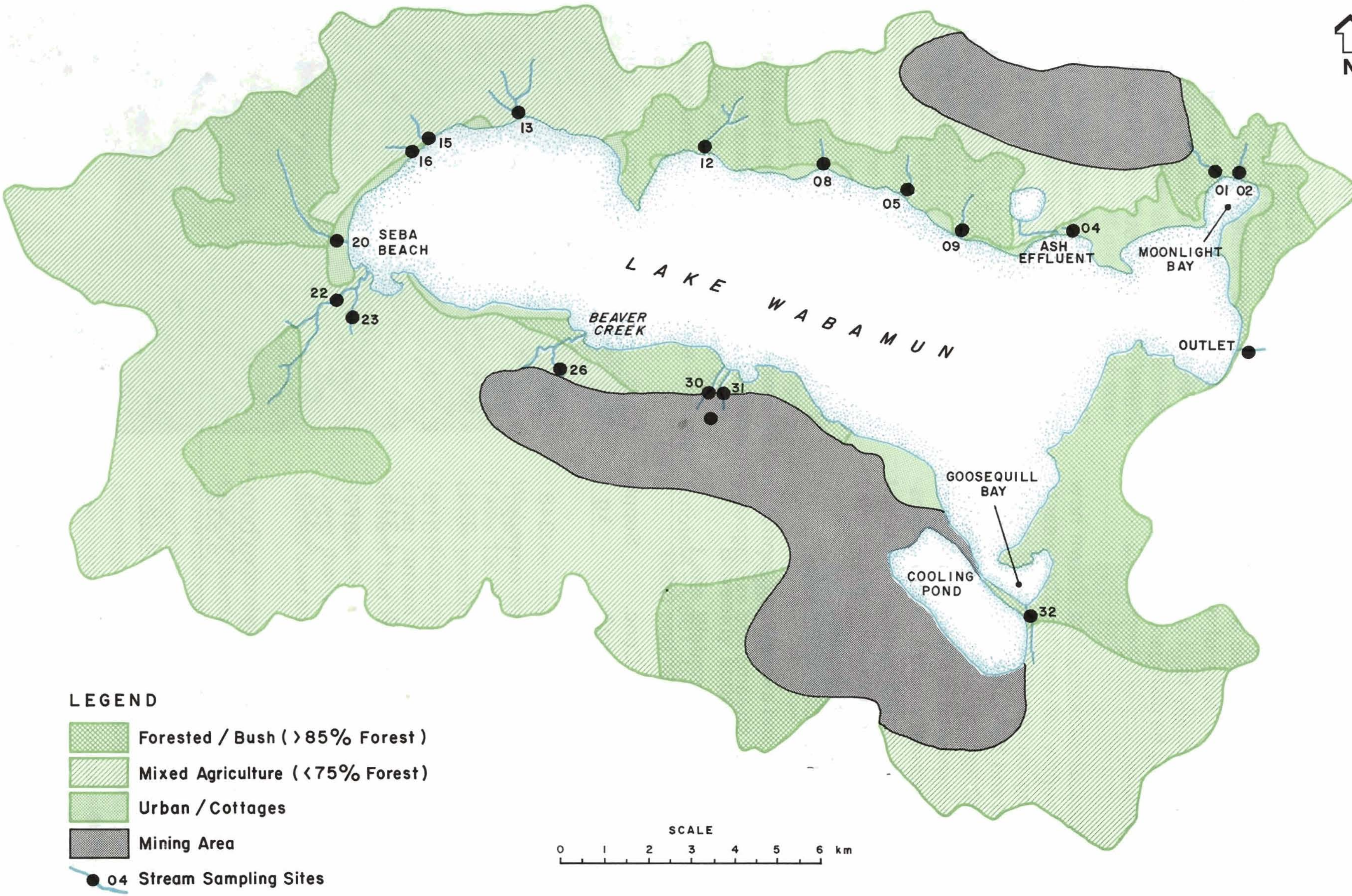


Figure 2. Watershed map - Lake Wabamun.

Alberta
ENVIRONMENT
Pollution Control Division
Water Quality Control Branch

There are at least 35 streams entering Lake Wabamun. Most of these run only during snowmelt runoff. The seven largest streams and the ash lagoon effluent accounted for about 90% of the total stream supply of phosphorus and nitrogen in 1980 and 1981 (Table 1). None of the remaining small streams had especially high concentrations of nutrients. These may be disregarded in contemplating nutrient control.

The two years of sampling has shown how much the nutrient supply can vary from one year to the next, depending on conditions during spring snowmelt. In 1980 and 1981, with normal to below normal runoff, 650 kg and 900 kg phosphorus, respectively, were measured in March and April. In 1982, with above normal runoff, 2856 kg phosphorus was measured during spring. One might expect that conditions in the lake would vary depending on spring nutrient supplies.

Large quantities of phosphorus also entered the lake during heavy summer rains. Each stream behaved differently. Small, mostly forested streams on the north side of the lake showed little response to rain events, while the flow and phosphorus in streams draining disturbed or agricultural land on the south side peaked quickly during rain. The difference in response is related to vegetation which retains water and nutrients in the soil.

The supply of phosphorus contributed to the lake in streams is compared with other external supplies over the two summers of the study in Figure 3. In 1981, spring runoff was below normal, but this was balanced somewhat by summer rainstorms, so that the total external supply for the two years was similar.

TABLE 1. Supply and average concentrations* of Total Phosphorus (TP) and Total Nitrogen (TN) in major streams and ash lagoon effluent, 1980-1982, Lake Wabamun.

	April 3, 1980 – March 3, 1981				March 4, 1981 – March 3, 1982			
	TP		TN		TP		TN	
	Supply kg	Conc. mg/L	Supply kg	Conc. mg/L	Supply kg	Conc. mg/L	Supply kg	Conc. mg/L
COAL 12	59	0.186	348	1.092	57	0.179	273	0.855
FALLIS 13	351	1.437	1,427	5.849	187	0.666	990	3.529
SHARON 15	34	0.216	233	1.462	62	0.363	413	2.436
SEBA 20	80	0.160	1,013	2.030	44	0.133	381	1.142
SEBA 22	537	0.227	4,315	1.822	554	0.288	3,710	1.927
SEBA 23	377	0.192	4,872	2.483	87	0.212	1,023	2.484
SUNDANCE 32	486	0.217	4,324	1.927	572	0.396	3,896	2.696
ASH LAGOON EFFLUENT	1,246	0.129	(10,000)**	–	239	0.070	3,940	0.758
TOTAL	3,170		16,532		1,802		14,626	
TOTAL SUPPLY ALL STREAMS	3,502		19,797		2,043		16,372	
AVERAGE CONCENTRATION ALL STREAMS		0.179		2.122		0.194		1.468

*flow-weighted

**approximate. This was not measured in 1980.

In addition to land areas drained by streams, there were areas, mostly very close to the lakeshore, that contributed runoff directly to the lake. These are called DIFFUSE RUNOFF areas. Since there was no way to measure the supply of nutrients from these areas, it was estimated by first calculating the quantity of phosphorus and nitrogen supplied by a square metre of neighbouring, measured watershed. This supply factor was then multiplied by the size of the diffuse runoff area. Nutrient supplies from areas that were inaccessible, such as within the Paul Band reserve, were also estimated in this way.

The Lake Wabamun watershed is composed of several broad categories of land use. These are illustrated in Figure 2. Agricultural use is the largest but interspersed with farm land are areas of natural vegetation. Several of the major streams drain this mixed agriculture/bush land, including the largest creek system in the watershed, Seba 22 and Seba 23 (sometimes called Jackpine Creek). The supply of phosphorus and nitrogen in this creek system is large because of the amount of land drained. Generally, large creeks will supply large nutrient loads, simply because more land, and therefore water flow, is involved.

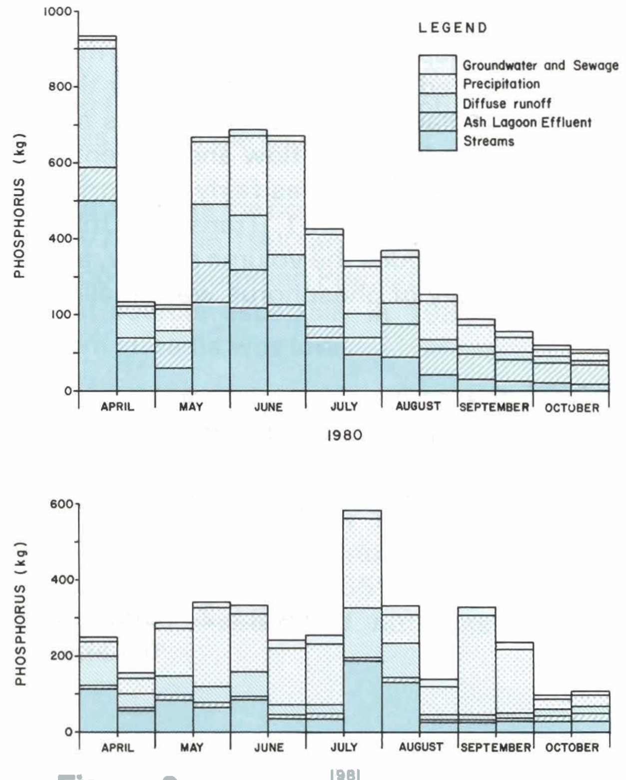


Figure 3.
Biweekly supply of total phosphorus to Lake Wabamun from various sources, 1980 and 1981.

The most intensive agriculture in the Lake Wabamun watershed is located in the drainage of Fallis 13. Much of this area is cleared or used for cattle production. Phosphorus and nitrogen concentrations in this stream were higher than in any other stream measured (Table 1). However, this stream had high flows for only a brief period in spring, so that the yearly supply of nutrients was lower than it would have been if flows were maintained over summer.

Predominantly forested areas still remain in Lake Wabamun's watershed. The areas north of the provincial park and highway, and northwest of Seba Beach have the highest proportion of natural vegetation. These are drained by streams designated as Moonlight 01 and 02, and Seba 20, respectively. The nutrient supply per hectare of land was lower from these areas than from the other land use types.

Areas used for coal extraction are shown in grey on the map. On the north side, this mine drainage is collected in the ash lagoon near the Wabamun power plant, and is discharged as a licensed effluent to the lake. The flow and nutrient concentration in this effluent was fairly uniform throughout the summer. In 1981, TransAlta Utilities Ltd. took steps to reduce the volume of flow, and therefore the supply of phosphorus was smaller than in 1980.

On the south side, mine drainage was collected in ditches, passed through a sedimentation pond, and discharged to Goosequill Bay via sampling station Sundance 32. In 1981, of all streams measured, this station had the largest supply of total phosphorus (10% of total supply). Although much of the silt load carried by this canal falls out in Goosequill Bay, the water leaving the bay (sampled at the railway trestle) was 10 times higher in phosphorus than the lake in spring, and 3 to 5 times higher in summer.

The contribution of phosphorus and nitrogen to Lake Wabamun from watershed sources is compared with other sources in Table 2. The watershed phosphorus supply represents 70% of the total external supply for 1980, and 57% for 1981. However, for nitrogen, the supply from the watershed represents only 47% and 39% of the total external supply.

TABLE 2. Summary of Total Phosphorus and Nitrogen Supply to Lake Wabamun, kg per year.

	3 April 1980 - 3 March 1981		4 March 1981 - 3 March 1982	
	TP	TN	TP	TN
EXTERNAL SUPPLY				
Watershed				
Streams	2,256	19,797	1,804	12,432
Diffuse Runoff	1,159	8,154	1,262	7,020
Ash Lagoon*	1,246	(10,000)**	239	3,940
Precipitation	1,729	40,596	2,034	33,519
Sewage	75	355	75	355
Groundwater	156	1,169	364	2,623
TOTAL	6,621	80,071	5,778	59,889
INTERNAL SUPPLY				
Sediment Recycling	5,000		12,000	
TOTAL INTERNAL AND EXTERNAL SUPPLY	11,621	kg	17,778	kg
Areal Loading g/m³/year	0.160		0.229	

*Excludes phosphorus in lake water used to slurry flyash.
**Approximate. This was not measured in 1980.

PRECIPITATION

Rain and snow falling directly onto the lake surface contains phosphorus, nitrogen and other nutrients. This was measured at Lake Wabamun with eight collectors placed around the lake at the water's edge. Precipitation was allowed to accumulate in these collectors until there was sufficient volume for a sample. This time period averaged two weeks during the period April through November. Snowfall was collected once or twice during the winter. In addition, a survey of phosphorus in snow over the surface of Lake Wabamun was conducted.

To estimate the total amount of phosphorus and nitrogen entering the lake via precipitation in a year, the quantities measured in each collector were averaged for each collection period and extrapolated to the whole surface of the lake. Thus a total annual supply of phosphorus and nitrogen could be estimated.

It was found that about half of the nutrient supply in precipitation was from particulate material — mostly dust, plant pollen, and miscellaneous organic material.

Half of the annual supply entered the lake in June, July, and August. The portion falling on the lake during the winter was small, probably because there is less dust in the air in winter.

Figure 3 shows the portion of phosphorus contributed by rainfall in 1980 and 1981 for each two-week period in the summer. Precipitation was often the largest source, especially in 1981 when the supply from streams was low.

Table 2 summarizes the annual contribution of phosphorus from all sources. For 1980, the portion of the total external phosphorus supply contributed by precipitation was 26%; for 1981 it was 35%. For nitrogen, the portion contributed by precipitation was 51% in 1980; it was 55% in 1981. Precipitation is a major source of nutrients to Lake Wabamun.

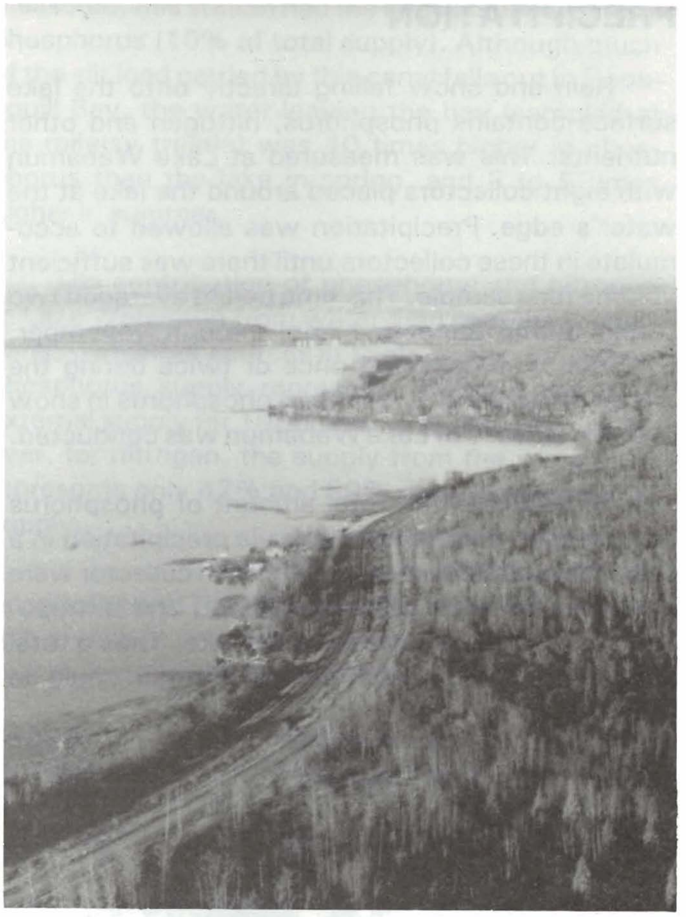
SEWAGE

Sewage leaking from cottage septic fields, pit privies or holding tanks is a potential source of nutrients to the lake. Two methods were used to assess the importance of this source relative to other sources.

Shallow wells (piezometers) were installed at six cottages representing three soil types, in the subdivisions of Whitewood Sands, Point Alison and Kapasiwin Beach. At each cottage, three wells were placed between the septic field and the lake to observe nutrient migration, and three wells were placed up-gradient of the septic field to determine background nutrient levels. These were sampled quarterly beginning in fall 1980.

Only one set of wells, from a cottage at Whitewood Sands, showed evidence of increased phosphorus, chlorides and nitrogen down gradient from the septic field. This cottage is likely a worst-case situation, since the occupants lived in the residence year-round, and the septic field is in sand[1].

To further investigate the potential for sewage contamination in the lake, a septic leachate detector was used in August 1982. Although this instrument is not designed to measure exact quantities of sewage or nutrients entering the lake, it can detect areas where septic leakage may be suspected. As lake water is pumped through the detector, increases in conductivity (salts) and fluorescence register on its meters. Samples for bacteriological analysis were collected in areas where these readings were strongly positive. The shoreline in front of about 250 cottages in the subdivisions of Seba Beach, Sunshine Bay, South Seba, Kapasiwin Beach, Lakeview, and Ascot Beach were surveyed. Although not conclusive, results from samples and the instrument suggested that sewage was entering the lake from nine cottages, or 4 per cent of the total surveyed. If this is extrapolated to the total number of cottages on the lake, and multiplied by a per person sewage input factor (0.93 kg/person/year)[2], approximately 75 kg of phosphorus may be derived from sewage each year. Even if the number of cottages leaking sewage were double, the relative contribution from this source would be small (Table 2). This is not to suggest that sewage inputs to the lake should be ignored, because there may be localized effects in terms of weed growth and potential human health problems from bacterial contamination.



GROUNDWATER

An estimation of nutrient loading from groundwater requires a knowledge of the volume of groundwater entering the lake and the concentration of nutrients in that water. Because groundwater inflow cannot be measured directly or precisely, it was estimated using a computer model to balance the inflow and outflow of water and chemical constituents[3]. The model produced an average groundwater inflow figure of only about 5% of the total water inflow (which includes surface runoff, precipitation and groundwater). This estimation is much smaller than previous studies had suggested, but is likely more accurate because of the low salinity of the lake water. It appears that the water level in the lake is controlled mainly by precipitation and evaporation.

1. Rippon, R. 1981. Migration of cottage sewage effluent at Wabamun Lake. Interim report. Soils Branch, Alberta Environment. 10 p. & appendices.

2. Trew, D.O., D.J. Beliveau, E.I. Yonge, 1978. The Baptiste Lake Study Summary Report. Water Quality Control Branch, Alberta Environment. 105 p.

3. Crowe, A. and F.W. Schwartz. 1982. The groundwater component of the Wabamun Lake Eutrophication Study. Water Quality Control Branch, Alberta Environment.

Nutrient concentrations were measured by sampling 32 domestic wells in the area and a set of wells drilled for this study in 1980 in the Fallis area[4]. It is likely that most of the groundwater entering the lake comes from upper layers of bedrock, that is, within and above the prevalent coal seam. There are two very different types of water in these strata, with high phosphorus concentrations in one type ($\bar{x}$ 0.194 mg/L) and low concentrations in the other ($\bar{x}$ 0.005 mg/L). It is not possible to determine which type enters the lake, so a supply based on an average concentration was calculated. As Table 2 shows, the contribution from this source is small.

SEDIMENTS

Phosphorus tends to fall to the bottom mud (sediment) of lakes and therefore the concentration in the sediment is much higher than that in the water. Under certain conditions, especially when oxygen near the sediments is depleted, a chemical change results in phosphorus moving into the water. This is called phosphorus release or recycling. Other studies have shown that the sediments can play a major role in maintaining eutrophy in a lake. But, since this process is unique to each lake, there was no way to predict whether it occurred in Lake Wabamun, nor could it be measured.

One way to estimate the net supply from within the lake is to balance the supply from outside sources — precipitation, streams, etc. — with the total quantity of phosphorus in the lake for each two week period through the summer. Any amount in the lake water in excess of the balanced inputs and outputs is assumed to have come from the sediments (or in some cases, from decomposing macrophytes). Any shortfall after the balance is assumed to have gone into the sediments. Figure 4 shows the balance for each two-week period in 1980 and 1981. The bars above the zero line indicate sediment release; the bars below the zero line indicate sediment uptake. The figure also shows the external supply for each two-week period. A total summer supply from the sediments can be calculated by adding the net gains (the quantities above the zero line). The total is compared with external supplies in Table 2. The estimated quantity of phosphorus from this source is large compared to the total from outside the lake.

Further evidence that sediment release actually occurs in Lake Wabamun came from analyses of phosphorus in the sediment itself. There was a decline in phosphorus levels in the sediment at the same time that the mass balance showed an increase of phosphorus in the water.

These results suggest that if a portion of the external supply were reduced through watershed control, there would be sufficient phosphorus in the sediments to maintain the lake's fertility. However, an eventual overall reduction in fertility would probably occur, though it could take years or decades.

4. Baldwin, R. 1981. A statistical analysis of groundwater samples in the Wabamun area. Internal report to Earth Sciences Division, Alberta Environment.

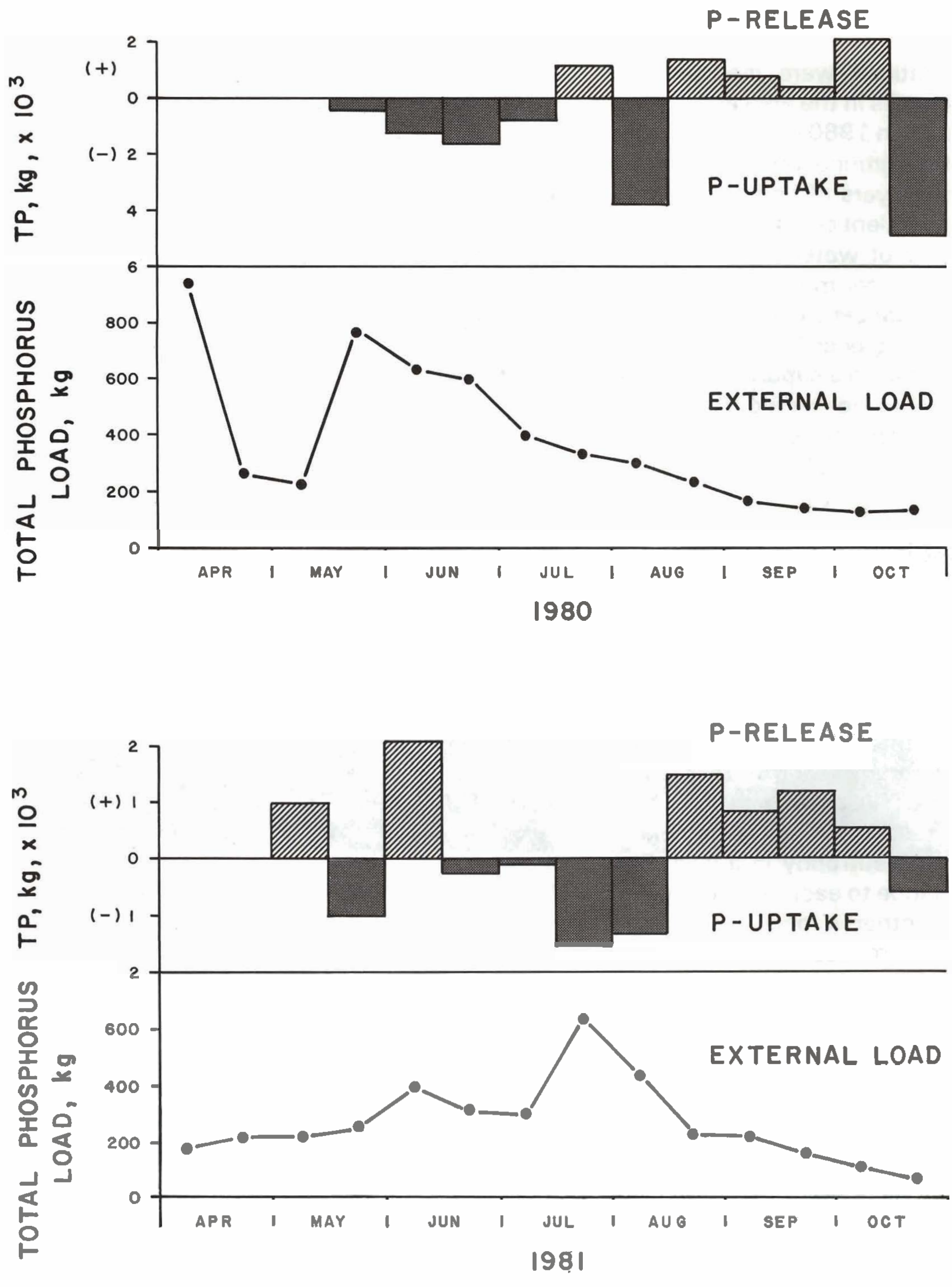


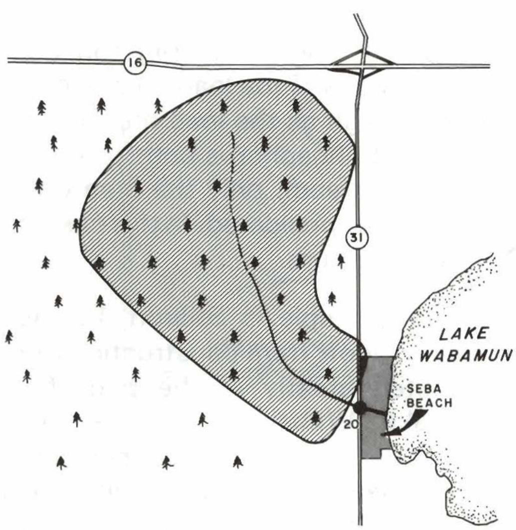
Figure 4. Sediment uptake and release of total phosphorus from mass balance calculations, and measured external load, Lake Wabamun 1980 and 1981.

Alberta
ENVIRONMENT
Pollution Control Division
Water Quality Control Branch

POSSIBILITIES FOR NUTRIENT CONTROL

There is a portion of the total supply of nutrients entering Lake Wabamun — or any lake — that is essentially uncontrollable. An example would be the supply in groundwater. Even from the watershed, there is a background or ''natural'' supply that is uncontrollable. This background supply would be the quantity that entered the lake a hundred or more years ago, before vegetation was cleared for development. Although we have no information for that time, a background phosphorus supply can be estimated by assuming that the whole watershed produces a quantity per square kilometer similar to that measured in 1980 and 1981 from forested areas. Figure 5 shows how this is calculated. The extra portion of phosphorus contributed by the development of coal mines, roads, agriculture, and cottages was calculated to be about 41% in 1980 and 33% in 1981 of the total external supply (Table 3). This is the portion of the annual phosphorus supply that is potentially controllable (although it may not be controllable in a practical sense).

In general, nutrient control should concentrate on phosphorus, not only because it is the limiting nutrient in the lake, but because it has greater potential for control — it is not a component of the atmosphere as nitrogen is. However, the presence of the two nutrients are correlated; when phosphorus levels are high, nitrogen levels tend to be high also. It is probable that if phosphorus levels were reduced, nitrogen levels would also decline.



AREA OF SEBA 20 WATERSHED : 575 ha.

SUPPLY OF PHOSPHORUS : 62 kg / yr.

1. $\frac{62 \text{ kg/yr.}}{575 \text{ ha.}}$ = 0.11 kg./ha./yr.
(phosphorus supply factor)

2. 0.11 kg./ha./yr. x Area of Lake Wabamun watershed - 262.8 km^2
= 2891 kg.

Figure 5. Calculation of background or 'natural' phosphorus supply from forested watershed Seba 20.

TABLE 3. A comparison of the phosphorus supply in kg before development and at present in the Lake Wabamun watershed.

	Before Development	Measured 1980	1981
WATERSHED	2234*	4661	3305
PRECIPITATION	1388**	1729	2034
SEWAGE		75	75
GROUNDWATER	260	156	364
Total	3882 kg	6621 kg	5778 kg

* calculated by applying phosphorus supply factors (export coefficients) for forested land to entire watershed area.
1980 coefficient = 0.10 kg/ha/yr;
1981 coefficient = 0.07 kg/ha/yr;
$\bar{x} = 0.085 \times 26{,}280$ ha.

** calculated by using 1983 precipitation data from forested areas (three locations).

STREAMS

Only seven streams entering Lake Wabamun are large enough to warrant consideration for phosphorus control. The remainder contribute negligible quantities of nutrients.

Phosphorus control should be directed toward those areas within the watershed which contribute the greatest supply. To determine actual sources would require very intensive sampling along the entire length of each creek. Although this was not possible within the resources and capabilities of the study, the major streams were surveyed and sampled once during peak runoff in 1982. Figure 6 shows results for the agricultural stream Fallis 13. The phosphorus load at each site for that day was calculated by multiplying the measured flow by the phosphorus concentration in the sample. Since this represents the situation at one point in time, these quantities can only be used for a qualitative assessment.

As can be seen in Figure 6, most of the tributaries contributed little to the phosphorus load that reached the lake. Only the eastern fork contributed a significant load, and the load measured at site 10 was nearly as high as the load measured at site 1 near the lake. If phosphorus control were contemplated for this stream, only the area upstream of site 10 should be considered. In this case, the creek drains a cattle pasture.

Another example is Sharon 15, near Seba Beach. Silt in runoff from construction of Highway 16 contributed greatly to the phosphorus load entering Lake Wabamun in this creek (see watershed map, Fig. 2). The concentration of total phosphorus measured in a culvert draining the highway was 1.65 mg/L, or 55 times higher than that in the lake water. Even the fraction of phosphorus that plants can use for their growth (orthophosphorus) was 1.00 mg/L, or nearly 100 times that in the lake. In spite of the distance from the highway, the water at the regular sampling site near the lakeshore remained silty, with high concentrations of dissolved and total phosphorus. Such sources of phosphorus from construction projects are potentially controllable, especially if erosion/nutrient control is part of the construction plan and is in place before work begins.

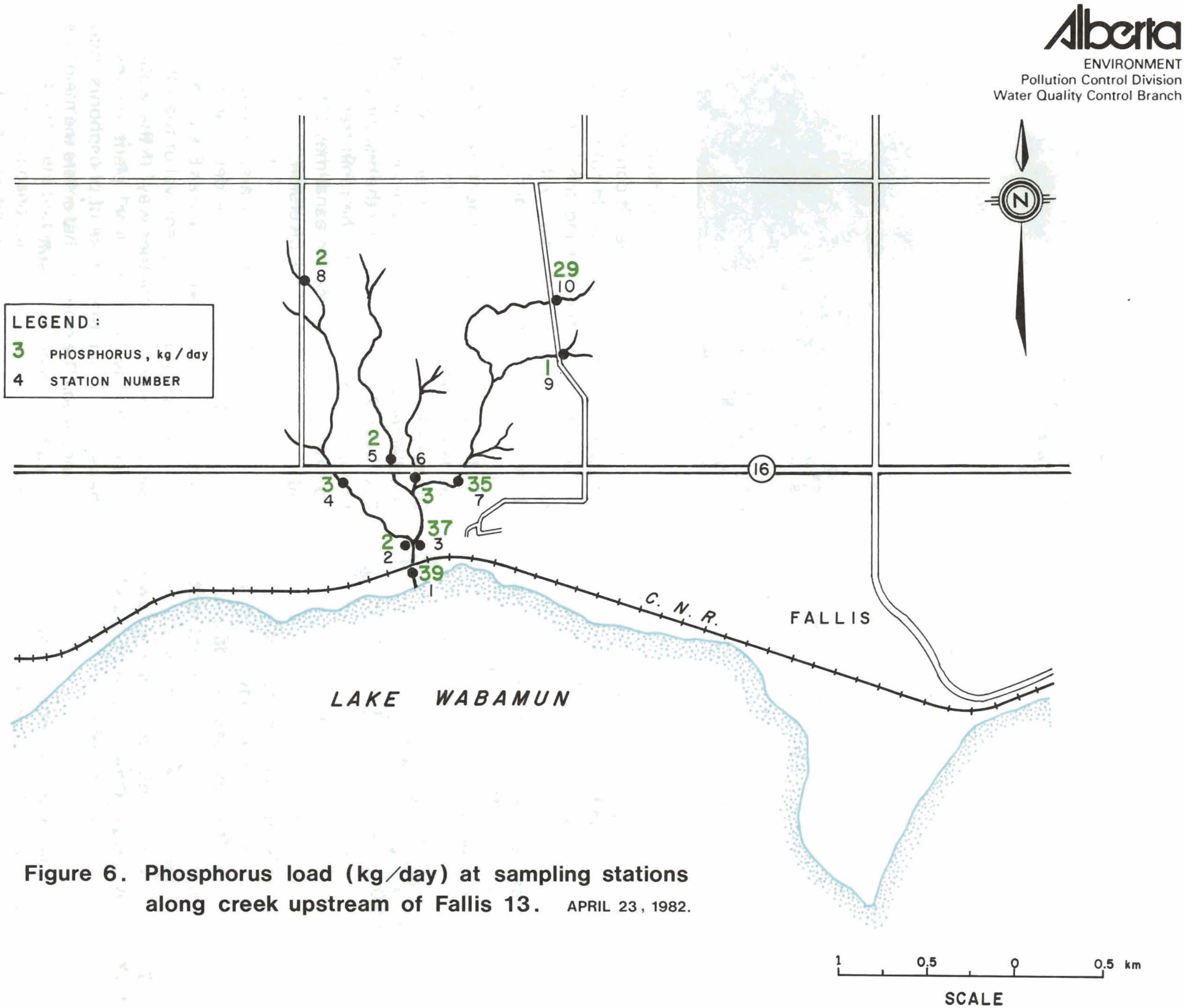


Figure 6. Phosphorus load (kg/day) at sampling stations along creek upstream of Fallis 13. APRIL 23, 1982.

The other creeks sampled in this way exhibited an increase in phosphorus load as the flow volume increased, but there was no obvious source, or sources were diffuse. Further investigation would be required to identify sources in these cases (data for all streams sampled in this way are in the appendix).

Additional studies of nutrient export from various land use types and potential localized or concentrated point sources within the Lake Wabamun watershed are necessary before a plan to control nutrients could be formulated. The watershed sampling during 1982 could be used as basis to exclude non-priority areas, such as the small tributaries in the watershed of Fallis 13. Efforts could concentrate on areas draining larger streams or those in which sources were not obvious, as in the watershed of streams Seba 22 and Seba 23 (Jackpine Creek).

Once high priority areas are identified, a plan to control nutrient loading by improving land management practices could be developed. This could take the form of voluntary compliance by landowners after education and instruction on methods. Since the sources are small and diffuse, major construction projects to control runoff in these areas appear to be unwarranted.

MINE DRAINAGE

Because the land surface is highly disturbed, coal mining activity is a major source of nutrients to Lake Wabamun. It is probably not technically possible to reduce nutrient export from these areas to background levels. The next best approach is to strike a balance between costs of nutrient reduction technology and the lowest possible nutrient supply. This balance is continually being reviewed and revised by Alberta Environment and TransAlta Utilities via their permits and licences.

The very large supply of total phosphorus measured at Sundance 32 (located at southern tip of Goosequill Bay – see watershed map) is derived from mine and agricultural drainage to the south. Mine drainage enters a sedimentation pond which should eliminate much of the silt load. However, in

the Lake Wabamun area, the silt contains very fine clay particles which do not settle out readily. Consequently, the water entering the lake from the sedimentation pond is very silty, with high total and dissolved phosphorus concentrations.

In 1984, most of the effluent from this sedimentation pond was diverted to the cooling pond. Drainage from the agricultural land south of the mine is collected in a canal and directed into Goosequill Bay. It is not possible to predict the resulting reduction in phosphorus, if any. The rapid transport of agricultural drainage via the canal may offset any reduction as a result of the diversion.

If all of the drainage from the area were diverted to the cooling pond, the resulting decrease in phosphorus could have been as much as 8% of the total external supply. However, removal of the silt load may be a benefit in another way. If the water in Goosequill Bay remains clear, plant photosynthesis, and hence the uptake of phosphorus, may be enhanced. The quantity that enters the main lake would be reduced as a result.

There are also problems with slow-settling fine particles in the new sedimentation ponds in the Beaver Creek area. Techniques for flocculating this material to aid in settling are being investigated.

On the north side of the lake, new licence standards for TransAlta's ash lagoon effluent near the Wabamun power plant are in effect. The standard for phosphorus is a maximum daily load of 3.2 kg. This would represent an annual supply of 1168 kg to Lake Wabamun. However, a monthly average daily discharge of phosphorus must not exceed 1.6 kg, or 565 kg/year. Thus, in 1980, this licence standard would have been exceeded, but in 1981, the supply from the lagoon was well below the standard (Table 2).

In general, nutrient export from the mine areas is being reduced to the lowest practical levels.

DIFFUSE RUNOFF

The diffuse runoff areas of concern are those nearest the lakeshore. During rain or snowmelt, water runs directly into the lake from these areas, rather than gathering in streams. Because the nutrient supply from this source was estimated rather than measured, it is not possible to define areas of high phosphorus export.

However, it may be expected that excessive nutrients would come from fertilized lawns near the lake; from exposed soil, such as for cottage or road construction; and from sand or soil brought in to build up beaches or eroded land.

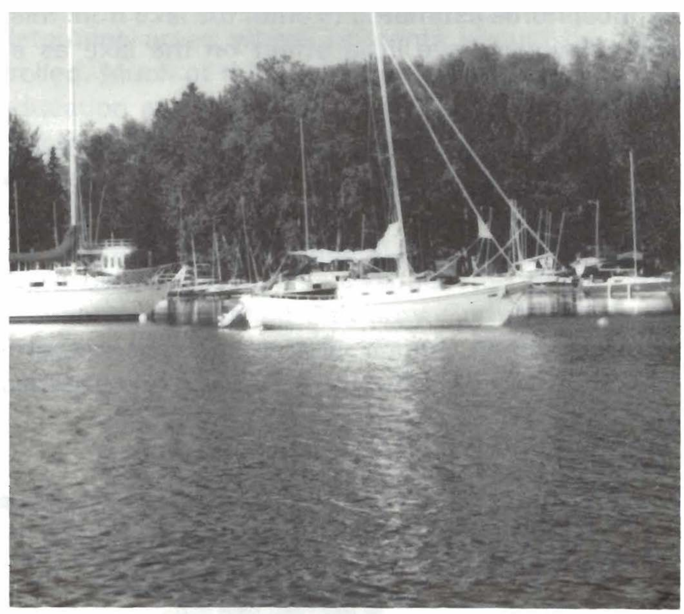
The nutrient supply from all of these sources can be minimized or eliminated with some knowledge and effort by the property owner. For example, if each property owner on the shore of Lake Wabamun were to reduce phosphorus loading by ½ kg/year, this would amount to an overall reduction of 600 - 700 kg/year, or over 10% of the present measured phosphorus supply.

Of all ways to reduce nutrient loading to Lake Wabamun, effort by individual property owners seems to have the greatest potential. Some ways of reducing phosphorus export are obvious, such as using fertilizers that do not contain phosphorus, revegetating exposed soil, and diverting runoff from land exposed during construction onto bush or forest land. However, it is outside the scope of this report to provide detailed methods, since each individual situation would be different.

PRECIPITATION

Forested areas are not extensive enough in the Lake Wabamun area to obtain a background or "natural" supply estimate of phosphorus in precipitation. However, in 1983, collectors were set up at Nakamun Lake, at Dickson Reservoir, and near Fox Creek. The average phosphorus load for the summer from these more forested areas was 13 mg/m² (May – Nov). The load estimated from precipitation collectors at Lake Wabamun averaged 28 mg/m² in 1983.

If it is assumed that 13 mg/m² represents the background summer supply, the excess falling on Lake Wabamun because of activities in the watershed amounts to 15 mg/m², or over 1000 kg. When this figure is compared with the total phosphorus supply measured in 1980 and 1981 (Table 2), it can be seen that this excess represents a significant contribution to the lake.



However, much of this excess is associated with dust particles most likely generated largely by mining activities. Most precipitation samples collected in 1983 contained visible quantities of dust, especially from the collector across the lake from the new pit at Highvale mine.

Test algae were grown in precipitation samples to determine the proportion of phosphorus that plants can take up and use for growth. Results were variable, but an average of only 25% of the total phosphorus was available. In contrast, approximately 50% of stream water was bio-available. This means that the large phosphorus supply measured in precipitation is of less significance to eutrophication of the lake than the figures for total phosphorus would suggest.

In spite of this, a phosphorus control program should include reduction of dust. Although it is unreasonable to expect that all dust within the watershed could be eliminated, especially from an active coal mine, it could be controlled on mine haul roads and exposed berms, or any disturbed area subject to wind erosion.

SEWAGE

Sewage contamination of Lake Wabamun appears to be minimal, according to results of the septic survey and the six sets of piezometer wells installed during the study. The very small quantity of phosphorus estimated to enter the lake from this source would have little effect on the lake as a whole.

However, there are several concerns related to sewage entering the lake. A small but continuous seepage from a septic installation could enhance macrophyte (weed) growth in the area. It could be a source of public health problems if the area is used for swimming or obtaining drinking water. In addition, the proportion of nitrogen and phosphorus that is readily available (immediately useable) by aquatic plants is higher in sewage than in stream water or precipitation. This means that plant growth is enhanced by smaller quantities of sewage effluent than, for example, creek water.

It appears that there are a few leaking systems on Lake Wabamun, and at least one example (at Kapasiwin) of deliberate dumping of sewage into the lake. The responsibility for phosphorus control in these cases rests with the cottage owner. A sewage system inspection survey organized by each summer village or subdivision could be the most efficient way to pinpoint faulty systems.

OTHER SOURCES

Nutrient inputs from groundwater, the sediments and minor sources such as waterfowl feces and leaf-fall are uncontrollable in a practical sense. The process of sediment release of phosphorus is being investigated by many researchers around the world. It seems reasonable that if phosphorus supplies entering the lake from external sources were reduced, the supply from the sediments would also be reduced eventually. This has not been documented in other lakes because of the length of time involved in such studies.

DISCUSSION AND CONCLUSIONS

Water quality in Lake Wabamun can be preserved only by preventing an increase in phosphorus supplies to the lake. But the expenditure of large sums of money to do this cannot be justified because: a) The lake is in relatively good condition; b) the benefits would be unknown; c) restoration techniques used elsewhere in North America are impractical for a lake as large as Wabamun (see appendix 5); d) results would be temporary without active effort by property owners.

Thus, the responsibility for Lake Wabamun's continued viability as a recreational resource rests with those who use it. An organized effort by property owners and local governments would be required. Table 4 lists possibilities for nutrient control in the watershed.

The percentage reduction listed under "comments" are based on either elimination of an input such as the diversion of runoff to the cooling pond at Sundance, or the difference in load between forested and non-forested areas. The reduction predicted from agricultural areas (stream subwatersheds) is based on a 30% reduction in phosphorus load after initiation of best management practices and sediment control[1]. These percentages are rough estimates only since there are no precedents for watershed phosphorus control in Alberta.

Before embarking on a nutrient control program, land owners should understand that the lake would not visibly improve as a result of their efforts, because the reduction in nutrient supply would be small.

However, if nutrients are not controlled, and the watershed continues to be cleared, there could be up to a 50% increase in the average amount of algae in the lake. The water would appear greener than at present, and there could be blooms of blue-green algae during July and August. Summer or winter fish kills could occur.

Prevention of this condition is much easier and less expensive than attempting to correct fertility problems after the lake has become more eutrophic. But it will require effort and understanding by all who own land around the lake. Since cottage owners have the greatest financial and emotional stake in Wabamun's preservation, they will probably assume the greatest role in organizing surveys to determine areas where nutrients should be controlled. Much of the actual control will be through education and individual effort. There is no other practical way to preserve water quality in Lake Wabamun.

Control of weed populations can be done practically only by harvesting, as suggested by the Lake Wabamun Watershed Advisory Committee. It is effective, environmentally sound, relatively inexpensive, and provides a potential resource.

1. Madigan, J., D. Haith, S.O. Quinn, J. Bloomfield. 1984. A simulation model for assessing the success of agricultural best management practices on surface water quality. In "Lake and Reservoir Management", proc. 3rd conference of the North Amer. Lake Man. Society. U.S.E.P.A. 440/5/84-001. p. 77-81.

TABLE 4. Summary of possibilities for nutrient control in the Lake Wabamun watershed

Source	Method of Control	Comments
Stream subwatersheds -12, 13, 15, 22, 23	1. Survey and voluntary compliance by landowners: a) Diversion of pasture runoff through vegetation. b) Restriction of cattle from stream courses c) Replanting bare stream courses. d) Proper use of fertilizer. e) Limitation of soil exposure during construction. f) Investigation of methods for each situation.	1. All relatively inexpensive, but require cooperation of landowners. High degree of compliance could reduce phosphorus supply by 5%.
Mine Areas	1. Continued compliance of licence standards for ash lagoon effluent. 2. Diversion of Pit 02 sedimentation pond effluent into cooling pond. 3. Diversion of southern agricultural runoff into cooling pond. 4. Enhancement of sedimentation in new ponds. 5. Control of dust on mine haul roads and exposed berms.	1. Essential. 2. Should enhance phosphorus uptake in Goosequill Bay. 3. Could reduce total P supply by 8% (but water load would also be reduced. 4. Being investigated. 5. Would reduce direct nutrient supply to lake by approx. 5%.
Cottage lots	1. Survey and voluntary compliance by property owners a) No phosphorus fertilizer on lawns. b) Maintain/plant trees and shrubs near water's edge c) No importation of soil for erosion replacement. d) Bylaws governing erosion control during construction. e) Removal of cut aquatic or terrestrial vegetation. f) Proper disposal of wash water (not in pit privy). g) Inspection and maintenance of sewage systems.	1. Requires organization and commitment of cottage owners. Concerted effort could markedly reduce P supply from these areas. Clean up of all sewage input could reduce phosphorus load by 1%.

APPENDIX 1
Explanation of Terms and Concepts

ALGAE: Tiny one-celled plants that float freely in the water and give the lake its green color. Other types of algae attach to plants or piers and form long threds which may accumulate into mats.

BIOLOGICALLY AVAILABLE: A form or fraction of a nutrient that can be used for plant growth. Only a portion of the quantity analyzed as "Total" is usable by plants. For example, an analysis of water collected from a Wabamun stream might show 100 ug/L of total phosphorus. This would include phosphorus on particles of soil, bacteria, and large organic molecules, none of which algae can use for growth. The dissolved portion that algae can use might amount to only 10 ug/L (10% bioavailability). In comparison, phosphorus in effluent from a septic field might be 90% bioavailable.

DIFFUSE RUNOFF AREA: Areas of land that drain water directly into the lake without gathering in streams. For this study, also included are areas which were inaccessible to sampling.

EUTROPHICATION: A gradual increase in the amount of nutrients in a lake (an increase in fertility), which leads to increased growth of macrophytes and algae.

EXTERNAL NUTRIENT SUPPLY: A quantity of nutrients that is derived from outside the lake itself. Sources include watershed soils, rainfall, and sewage.

HECTARE: 10,000 m^2. 1 ha = 2.5 acres.

LIMITING NUTRIENT: The quantity of algae produced in a lake will be determined by the quantity of the growth substance in lowest supply relative to the needs of the algae. In most lakes, the growth substance in shortest supply is phosphorus. Phosphorus was determined to be the limiting nutrient in Lake Wabamun by calculating the ratio of nitrogen to phosphorus in mid summer. In all cases, the quantity of phosphorus was small compared to the quantity of nitrogen. In another test, radioactive phosphorus (P32) was added to a sample of lake water. The P32 was quickly taken up by algal cells in the water, indicating a demand for phosphorus.

MACROPHYTE: Large, visible aquatic plants. They may be submersed (pondweed) or emergent (growing up into the air – bulrush).

NUTRIENT: Chemical substances required by plants for their growth. Major nutrients are phosphorus (phosphate) and nitrogen (nitrate).

NUTRIENT EXPORT: The movement of nutrients from an area of land to the lake.

ORGANIC MATERIAL: Derived from living things.

SEDIMENT RELEASE: Under certain conditions, phosphorus that is concentrated in the bottom mud will enter the lake water, resulting in increased algal growth.

WATER QUALITY: The condition or state of water relative to its use. For Lake Wabamun, the use is recreation, and water quality relates to the amount of algae, nutrients, and bacteria.

WATERSHED: The land surrounding a lake or stream which drains water toward the water body. Also called drainage area.

APPENDIX 2a. LAKE WABAMUN PHOSPHORUS EXPORT, kg/ha/year

STREAM	AREA ha	FOREST %	1980 EXPORT kg/ha/yr	1980 LOAD kg	1980 CONCENTR. mg/L	1981 EXPORT kg/ha/yr	1981 LOAD kg	1981 CONCENTR. mg/L
FORESTED								
01	334	92	0.13	42.3	0.139	0.09	29.0	0.143
02	67	92	0.10	6.91	0.407	0.22	14.8	0.191
09	210	84	0.19	39.2	0.144	0.12	24.5	0.192
12	1171	88	0.05	59.3	0.186	0.05	57.0	0.179
20	575	91	0.14	79.7	0.053	0.08	44.4	0.133
AVERAGE			0.10		0.094	0.07		0.160
MIXED AGRICULTURE								
05	246	66	0.32	78.0	0.275	0.08	19.8	0.174
13	557	28	0.63	350.	1.437	0.34	187.	0.666
15	227	62	0.15	34.4	0.216	0.27	61.6	0.363
22	4688	40	0.12	537	0.227	0.12	554.	0.288
23	1049	37	0.36	377	0.192	0.08	87.2	0.212
24	174	72	0.24	41.6	0.330	0.11	18.9	0.370
26	399	40	0.06	22.1	0.140	0.09	36.4	0.324
30	206	42	0.06	12.9	0.684	0.12	23.8	0.670
31	180	44	0.06	10.7	0.472	0.09	16.9	0.615
AVERAGE			0.19		0.274	0.13		0.321
TOTAL	10,083			1692			1175	
AVERAGE			0.17		0.218	0.12		0.281

APPENDIX 2b. TOTAL NITROGEN EXPORT, LAKE WABAMUN WATERSHED

STREAM	AREA ha	FOREST %	1980 EXPORT kg/ha/yr	1980 LOAD kg	1980 CONCENTR. mg/L	1981 EXPORT kg/ha/yr	1981 LOAD kg	1981 CONCENTR. mg/L
FORESTED								
01	334	92	1.26	421.8	1.39	0.52	174.1	0.86
02	67.3	92	0.64	43.3	2.55	2.35	158.4	2.04
09	210	84	1.54	325.4	1.19	0.66	139.6	1.10
12	1171	88	0.29	348.1	1.09	0.23	272.6	0.86
20	575	91	1.76	1013.2	0.68	0.66	381.0	1.14
AVERAGE			0.91		0.89	0.48		1.06
MIXED AGRICULTURE								
05	246	66	2.82	695.3	2.45	0.66	163.9	1.44
13	557	28	2.56	1426.8	5.85	1.77	989.9	3.53
15	227	62	1.02	232.8	1.46	1.82	413.2	2.44
22	4688	40	0.92	4315.4	1.82	0.79	3709.9	1.93
23	1049	37	4.64	4872	2.48	0.97	1022.9	2.48
24	174	72	2.57	448.3	3.56	1.04	181.1	3.54
26	399	40	1.21	485.2	3.06	0.85	339.6	3.03
30	206	42	0.26	54.1	2.88	0.54	111.9	3.15
31	180	44	0.43	77.9	3.45	0.46	84.5	3.06
AVERAGE			1.63		2.36	0.91		2.24
TOTAL	10,083			14,760			8,143	
AVERAGE			1.46		1.90	0.808		1.94

APPENDIX 3. Precipitation Loading of Phosphorus and Nitrogen to Lake Wabamun 1980-82, mg/m² lake surface

		TP	TN
1980	summer	17.61	333
	annual	(21.00)	(439)
1981	summer	24.56	546
	annual	26.84	606
1982	summer	13.09	228
	annual	17.71	341
×	annual	21.85	462

APPENDIX 4. WATERSHED SAMPLING, SPRING 1982

	SITE	DESCRIPTION	TP LOAD, kg/day	TP CONC., mg/L	TN LOAD, kg/day	TN CONC., mg/L
SEBA 23						
Tp 52, Rg 5	1	Routine sampling site, sec 31	17	0.28	134	2.26
April 20/82	2	E. fork 50 m S. of site 1, sec 31	15	0.29	148	2.94
	4	Hwy 31, 1 km S. of Seba-Sundance Road, sec 31	9.3	0.27	61	1.78
	7	Hwy 31, 1.5 km S. of Seba-Sundance Road, sec 31	27	0.33	158	1.96
	8	Hwy 31, 3 km S. of Seba-Sundance Road, sec 30	4.0	0.71	13	2.26
	10	0.8 km E. of Hwy 31, sec 30	4.9	0.26	35	1.83
	11	1.2 km E. of Hwy 31, sec 30	4.1	0.94	26	5.82
SEBA 22	1	Routine sampling site, tp 53, sec 1	42	0.69	214	3.50
Tp 52, 53	2	0.6 km W. of site 1, N. fork, sec 1	1.2	0.23	8.6	1.70
Rg 6	3	0.6 km W. of site 1, S. fork, sec 1	15	0.58	75	2.91
April 17/82	4	0.5 km W. of Hwy 31, road culvert, W. fork, Tp 52, sec 36	26	0.58	136	3.01
	5	0.5 km W. of Hwy 31, road culvert, E. fork, Tp 52, sec 36	6.2	0.44	31	2.19
	6	SW ¼ Sec 36, Tp 52, road culvert	11	0.83	30	2.13
	7A	NW ¼ Sec 2, Tp 53, road culvert, N. fork	8.8	0.78	23	2.00
	7B	NW ¼ Sec 2, Tp 53, road culvert, S. fork	3.7	0.75	9.4	1.92
	8	1.2 km W. of Hwy 31, road culvert, W. fork, Tp 52, Sec 36	8.0	0.44	55	3.02
	10	SW ¼ Sec 25, Tp 52	3.0	0.41	9.8	1.35
SEBA 20	1	Routine sampling site Rg 5, sec 7, Seba Bch.	4.0	0.18	42	1.91
Tp 53, Rg 6	2	At lake, pavillion	4.0	0.17	40	1.67
Tp 53, Rg 5	3	Rg 6, sec 12, SE ¼ road culvert	3.2	0.13	37	1.51
April 24/82	5	Rg 6, sec 12, NW ¼ road culvert	0.4	0.15	4.4	1.51
SHARON 15	1	Routine sampling site, sec 17	6	1.07	27	4.48
Tp 53, Rg 5	5	0.6 km South Hwy 16 on Seba Road, Sec 17	16	1.10	68	4.70
April 21/82	6	Culvert east at junction Seba Rd and Hwy 16, sec 20	1.3	0.55	3.2	1.32
April 21/82	7	Culvert west at junction Seba Rd and Hwy 16, sec 20	10	1.65	46	7.33

	SITE	DESCRIPTION	TP LOAD, kg/day	TP CONC., mg/L	TN LOAD, kg/day	TN CONC., mg/L
FALLIS 13	1	Routine sampling site, sec 16	39	0.71	142	2.62
Tp 53, Rg 5	2	First fork north, west tributary, sec 16	2.2	0.46	7.7	1.65
April 23/82	3	First fork north, east tributary, sec 16	37	0.75	148	2.98
	4	On private road S of Hwy 16, sec 16	2.7	0.46	9.0	1.51
	5	Hwy culvert, sec 16	2.0	0.61	5.8	1.81
	6	Hwy culvert, N of Hwy 16, sec 21	2.5	0.73	6.9	1.99
	7	Hwy culvert, S of Hwy 16, sec 16	35	0.88	137	3.48
	8	Along road west side sec 21, 1 km N of Hwy 16	1.5	0.63	3.3	1.41
	9	Along road east side sec 21, 0.6 km N of Hwy 16	0.4	0.39	1.6	1.57
	10	Along road east side sec 21, 0.9 km N of Hwy 16	29	0.78	142	3.79
COAL 12	1	Routine sampling site, sec 14	212	1.38	584	3.78
Tp 53, Rg 5	2	Upstream from site 1, 30 m, west fork, sec 14	1.4	0.64	2.8	1.27
April 23/82	3	Upstream from site 1, 20 m, east fork, sec 14	(21)*	0.83	(50)*	1.97
	5	Highway 16 culvert, sec 13, west fork of main trib.	7.1	0.85	14	1.66
	6	Main tributary upstream Hwy 16, Sec 24	65	0.75	194	2.23
ASCOT 09	1	Routine sampling site, sec 9	1.7	0.15	11	0.97
Tp 53, Rg 4	2	Small fork above footbridge, sec 9	0.1	0.16	1.0	1.33
April 21/82	3	West fork, along road S of railway, sec 9	0.3	0.13	3.9	1.51
	4	East fork, along road S of railway, sec 9	1.2	0.15	8.0	0.97

*Portion of flow only.

APPENDIX 5
RESTORATION TECHNIQUES CONSIDERED FOR LAKE WABAMUN

There are several ways that recreational lakes can be improved or restored after they have become eutrophic through man's activities in the watershed. Restoration techniques that have been proven effective include:

1) Nutrient Diversion

This would include prevention of high nutrient water from entering the lake. In the case of Lake Wabamun, none of the stream inputs have concentrations high enough to warrant costs for such nutrient control works. However, the diversion of the effluent from the Pit 02 sediment pond to the cooling pond is an example of nutrient diversion that has been put in place on the Lake.

2) Dilution or Flushing

These techniques would require very large quantities of low nutrient water. The possibility of flushing with water from the Pembina River and the North Saskatchewan River was investigated, including preliminary costing. The very high costs and the uncertainty of the effect on the lake virtually eliminated this possibility.

3) Phosphorus Inactivation

This involves treating the whole lake with aluminum salts to precipitate phosphorus out of the water and to form a barrier to phosphorus recycling from the sediments. This has worked in small lakes, but the high costs of chemicals would make this technique prohibitive. Additionally, its effectiveness might be short lived because Wabamun is so well stirred by wind.

4) Dredging

Deepening of the lake and removal of phosphorus rich sediments would undoubtedly have a beneficial effect on the lake. However, even if it were practical for Lake Wabamun, at \$14/m^3, the cost would exceed \$1 billion.