WATER QUALITY OBJECTIVES FOR OKANAGAN LAKE
A FIRST UPDATE

January 2005

Prepared for the Ministry of Water, Land and Air Protection
Penticton and Kamloops BC

by
Richard N. Nordin Ph.D.
Limnos Water Associates
1226 Laurel Road
North Saanich BC V8L 5K8

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Summary

Water quality objectives for Okanagan Lake are proposed to protect the water resource from deterioration. This report is designed to be an update and expansion of a report produced by the Ministry of Environment in 1985. That report proposed water quality objectives for all the main stem lakes in the Okanagan valley for one indicator, the spring phosphorus concentration. This report confines itself to Okanagan Lake but recommends an increased number of water quality objectives that might be used to provide guidance for long-term water quality protection.

Okanagan Lake is an extremely important water body for a number of uses. The objectives proposed were designed with consideration of three major uses: recreation and aesthetics, drinking water and aquatic life (fisheries). Inclusion of all these uses is necessary for long-term management and protection of this lake.

A review of extensive background information provides the basis for proposed new objectives. A review of water uses including aquatic life provides the background for setting new objectives. Although there have been a variety of changes in different components of the ecosystem, some components, like phytoplankton and zooplankton, have shown remarkable stability with few changes over the period of record.

A summary of the objectives that are proposed for Okanagan Lake:

	North Basin	Central Basin	South Basin	Armstrong Arm
Secchi disc Transparency (m) (growing season average)	6	6	7	5
Dissolved Oxygen	-	-	-	5 mg/L min in bottom waters
Total Phosphorus (µg/L) (maximum at spring overturn)	8	8	7	10
Chlorophyll-a (µg/L)(maximum seasonal average	4.5	4.5	4	5
Total Nitrogen (µg/L) (maximum)	230	230	230	250
N:P ratio (spring .weight ratio)	>25:1	>25:1	>25:1	>25:1
Phytoplankton Structure (heterocystous cyanobacteria by numbers)	<5%	<5%	<5%	<5%
Phytoplankton growing season average biomass	<0.75 g/m^3	<0.75 g/m^3	<0.75 g/m^3	<0.75 g/m^3
Zooplankton designated species mix minimum biomass	50 ug/m^3	50 ug/m^3	50 ug/m^3	50 ug/m^3
Zooplankton Structure (minimum of cladocerar by numbers)	5%	5%	5%	5%
Contaminants in fish tissue and Mysis tissue	Below human consumption and wildlife protection guidelines	Below human consumption and wildlife protection guidelines	Below human consumption and wildlife protection guidelines	Below human consumption and wildlife protection guidelines

Table of Contents

Tables

Figures

Preface

Purpose of Water Quality Objectives

Water quality objectives are prepared for specific bodies of fresh, estuarine and coastal marine surface waters of British Columbia as part of the Ministry of Water, Land and Air Protection's mandate to manage water quality. Objectives are prepared only for those waterbodies and water quality characteristics that may be affected by human activity now or in the near future.

This document is one in a series that presents ambient water quality objectives for British Columbia. This report provides general and specific information about the water quality of Okanagan Lake. It is intended for both technical and general audiences. Separate tables listing water quality objectives and monitoring data are included for those readers requiring data about the waterbody. The report presents the details of the water quality assessment for Okanagan Lake and forms the basis of the recommendations and objectives presented in the summary.

How Objectives Are Determined

Water quality objectives are based on an evaluation of historical norms for a particular water body as well as the BC approved and working guidelines and national water quality guidelines. Water quality guidelines are safe limits of the physical, chemical, or biological characteristics of water, biota (plant and animal life) or sediment which protect water use. Objectives are established in British Columbia for waterbodies on a site-specific basis. They are derived from the guidelines by considering local water quality, water uses, water movement, waste discharges and socio-economic factors.

Water quality objectives are set to protect the most sensitive designated water use at a specific location. Designated water uses include:

- raw drinking water, public water supply, and food processing
- aquatic life and wildlife
- agriculture (livestock watering and irrigation)
- recreation and aesthetics
- industrial water supplies.

Each objective for a location may be based on the protection of a different water use, depending on the uses that are most sensitive to the physical, chemical or biological characteristics affecting that waterbody.

How Objectives Are Used

Water quality objectives routinely provide policy direction for resource managers for the protection of water uses in specific waterbodies. Objectives guide the evaluation of water quality, the issuing of permits, licences and orders, and the management of fisheries and the province's land base. They also provide a reference against which the state of water quality in a particular waterbody can be checked, and help to determine whether basin-wide water quality studies or enhanced protection measures should be initiated.

Water quality objectives are also a standard for assessing the Ministry's performance in protecting water uses. While water quality objectives have no legal standing and are not directly enforced, these objectives become legally enforceable when included as a requirement of a permit, licence, order, or regulation, such as the Forest Practices Code Act, Water Act regulations or Waste Management Act regulations.

Objectives and Monitoring

Water quality objectives are established to protect all uses which may take place in a waterbody. Monitoring (water or environmental sampling) is undertaken to determine if all the designated water uses are being protected. The monitoring usually takes place at a critical period of time when the water quality objectives are least likely to be met. It is assumed that if all designated water uses are protected at the critical time, then they also will be protected at other times when the threat is less.

For some water bodies, the monitoring period and frequency may vary, depending upon the nature of the problem, severity of threats to designated water uses, and the way the objectives are expressed (*i.e.*, mean value, maximum value).

1.0 INTRODUCTION

Okanagan Lake is the most important and valuable lake in British Columbia. The lake serves as the economic and cultural backbone of the Okanagan Valley. Without the presence of the lake, the communities and the economy would be so different it would be difficult to imagine. The lake is the focus of life in the valley, a source of recreation and drinking water for an ever-growing population as well a habitat for a wide range of organisms. Changes in the lake have the potential of affecting a wide range of economic and aesthetic values and the general social fabric and structure of the communities that border the lake.

Okanagan Lake, because of its importance, is also one of the most studied lakes in the province, at least in the past 35 years. Before 1967 there was little technical data gathered but since then there have been a number of studies which have provided an understanding of the scientific and technical details and a basic understanding of the biology, chemistry, physics, hydrology, geography and geology of the lake and its watershed. The first major study carried out was the Okanagan Basin Study between 1969 and 1973. This was the first of a number of national watershed studies carried out as a co-operative and shared responsibility between the federal and provincial governments.

The second major study was the Okanagan Implementation Study of 1976 to 1982. This study was designed to gauge the effectiveness of the implementation of recommendations of the Okanagan Basin Study.

A third major study is presently underway. This is the Okanagan Lake Action Plan (OLAP) which began in 1995 due to concerns about the rapidly declining numbers of kokanee (*Oncorhynchus nerka*). OLAP is designed to be a 20-year project broken into four phases of five years each.

The other major long-term information on water quality that has been gathered is the lake monitoring data collected on an annual basis by the Penticton regional office of the Ministry of Water, Land and Air Protection. Parallel to the water quality work, the Ministry has also been actively gathering information on the fisheries resources in order to effectively manage them.

There are several other studies which contribute to the understanding of the ecology of the Okanagan valley. Part of the purpose of this report is to review all of the previous reports related to water quality as a basis for proposing these updated water quality objectives for Okanagan Lake. A detailed bibliography and reference list is included at the end of the report.

It would seem useful to provide a summary and chronology of the studies that have been produced and what is known of the science of Okanagan Lake. Many of these studies will be referred to in greater detail in later sections of the report but an introduction provides the background needed to understand what information has been gathered and what data might need be gathered in the future.

The first scientific sampling of the lake was done in 1935 by D.S Rawson, the father of Canadian limnology. He made some basic measurements and published these observations with his colleagues in 1939 (Clemens *et al.* 1939) and in Rawson (1942). These papers contain considerable information and are the only point of reference for the condition of the lake from that era and as such are a valuable point of reference.

The next water quality related sampling program was done in 1949/50 as part of a federal government survey of the water resources of the country (Thomas 1953). These data provide another useful benchmark during a time when little data were gathered.

In response to a number of water quality concerns in the 1960's, a detailed study was conducted from 1965-1967 by the North and South Okanagan Health Units (Health Branch 1973). They were concerned with chronic algal blooms in Skaha Lake – and a particularly notable bloom in August 1967. Other concerns included the use of pesticides and fungicides in agriculture and their effects on drinking water and biota. There was particular concern for the state of drinking water with complaints of taste and odour, and with recreational use of the water with frequent reports of skin, eye, ear, nose and throat infections.

In the late 1960's in response to public concern about deteriorating water quality in the Okanagan valley, a number of significant studies were undertaken, culminating in the Federal-Provincial Okanagan Basin Study (OBS). Publications by Coulthard and Stein (1969, 1970) and Stein and Coulthard (1971) all provide data on which to evaluate the conditions of the time. Another important report (Department of Fish and Forestry of Canada and the International Pacific Salmon Fisheries Commission, 1969) examined a proposal for diverting large volumes of water from the Shuswap drainage into the Okanagan Valley – in response to concerns over lack of available water for irrigation and development at that time. The report seems to have been instrumental in the proposal being dropped after it identified the negative consequences for salmon runs in the upper Shuswap drainage. BC Research (1971) also sampled Okanagan Lake in the spring of 1970 and provided a report on that work.

However it is the Okanagan Basin Study itself which provides us with detailed and comprehensive information on Okanagan Lake (and other lakes and streams of the valley). There were 12 large reports on several topic areas, the most relevant for this evaluation are the volumes on water quantity (Leach *et al*., 1974) water quality and waste loadings (Haughton *et* *al*., 1974a), and especially limnology (Pinsent and Stockner, 1974). In the interest of completeness, all of the publications of the OBS are listed separately in the references. There are a number of task technical reports that are now quite difficult to find that were used in preparation of the Technical Supplements. The information in these task reports was not all compiled into the main supplements.

In 1996, funding was proposed for the Okanagan Lake Action Plan (OLAP), designed to determine the causes of a decrease in kokanee numbers in Okanagan Lake. The OLAP is planned as a 20 year program to provide the technical understanding of the controls on fish populations and suggest management actions to ensure a sustainable fishery for the future. The initial plan (Ashley and Shepard, 1996) was formulated and annual reports provided which documented a variety of studies and reviews that were undertaken (Ashley *et al*. 1998, Ashley *et al*. 1999, Ashley *et al.* 2000, Andrusak *et al.* 2000, Andrusak *et al*. 2001, Andrusak *et al.* 2002). The outline of Phase 2 (the second 5-year portion of OLAP) was presented in Andrusak and McGregor (2001). This set of reports provides the best current review of many of the subject areas related to the factors affecting kokanee biology and populations, which is the focus of OLAP. An examination of nutrient sources and their ecological impacts was included with the Year 5 report (Hall *et al.* 2001). It summarizes some relevant data and also suggests some causes of the kokanee declines.

One of the important features of the lake is the physical limnology. The movement, distribution and availability of water flows are directly related to the stratification and the directions and strengths of currents. Unfortunately, only limited information is available for this critical aspect of the lake. The water movements likely strongly effect the flux of nutrients from epilimnion to hypolimnion, the horizontal movement of plankton and temperature effects on fish. Some of the most recent and comprehensive work on physical limnology was done in the Kelowna area to examine the input of water from creeks and outfalls specifically with regard to the water intakes for the City of Kelowna. The work (Hay and Company, 2000) showed a number of critical but poorly understood features of the lake circulation and physics: that seiche and internal wave magnitudes, the extreme changes in the thermocline position with weather and season, and the interchange of water between basins are all extremely important in the horizontal transport of contaminants from creeks and outfalls. The extrapolation of that work has a number of implications for both lake physics and biology.

Despite this apparently large volume of technical information on the lake, there is far from sufficient knowledge to completely understand many of the complex biological, chemical and physical processes that are necessary to manage the lake with a high level of certainty. While some progress is being made, caution still needs to be used before taking actions which may be difficult to reverse.

This report was designed to update existing water quality objectives for the Okanagan lakes (Ministry of Environment, 1985). Water quality objectives are designed to provide guidance for the public and goals for the government managers of this valuable public resource. The 1985 report proposed water quality objectives for phosphorus only. The goal of this report is to propose a broader suite of aquatic measures to guide the management of Okanagan Lake water quality in the future. It is also intended that the accompanying assessment will provide context and linkages to the OLAP efforts to restore kokanee populations since water quality, limnology and fisheries health are intimately linked. The best example of this is a paper published by Rigler (1982). The paper is an important philosophical discussion about what is still an outstanding problem in freshwater science: the lack of interaction and understanding between fisheries and limnology scientists.

2.0 THE WATERSHED AND LAKE

2.1 Morphometry

Okanagan Lake is situated in south central British Columbia and is part of the Columbia River drainage system. The lake is 113 km long and quite narrow, generally two to four km wide and oriented in a north-south axis in a steep sided valley. The lake has a surface area of 351 km^2 with a catchment area of approximately 6,200 km^2 and is the largest of the five main and interconnected lakes in the main stem of the Okanagan valley. The lake is comprised of three basins and their relative morphometric data are listed in Tables 1, 2 and 3.

Table 1: Okanagan Lake morphometric data

Lake surface area:	351 km^2
Volume :	24,644 Mm^3
Maximum depth:	230 m
Mean depth:	76 m
Shoreline length:	270 km
Water residence time (outflow/volume):	53 years
Water residence time (inflow/volume):	35 years
Catchment area (incl. Kalamalka and Wood catchments):	6,188 km^2
Catchment:lake surface area ratio:	17.6:1
Mean epilimnetic volume (mid July 15 m epilimnion):	3,700 Mm^3 (15% of total lake volume)
Mean hypolimnetic volume (mid July):	18,500 Mm^3 (75% of total lake volume)
Littoral area:	19.4 km^2 (5.5% of total lake surface area)
North basin littoral area:	10.6 km^2 (28.5% of North Basin surface area)
Central basin littoral area:	3.5 km^2 (9.8% of Central Basin surface area)
South basin littoral area:	5.3 km^2 (8.6% of South Basin surface area)

Table 2: Okanagan Lake morphometric data by basin (Ministry of Environment, 1985)

	Volume (Mm^3)	Surface Area (km^2)	Mean depth (m)	Maximum depth (m)
Vernon Arm	171	12	15	30
Armstrong Arm	464	28	17	50
North basin	12,171	126	97	230
Central basin	7,085	96	74	205
South basin	4,753	89	54	150

Table 3: Okanagan Lake key limnological characteristics

Spring total phosphorus (recent years):	8 µg/L (except Armstrong Arm – 20 µg/L)
Spring total nitrogen (recent years):	230 µg/L (except Armstrong Arm – 330 µg/L)
N:P ratio:	28:1
Mean summer chlorophyll (recent years):	3.9 µg/L (except Armstrong Arm – 5.1 µg/L)
Secchi depth (growing season mean):	6.5 m (except Armstrong Arm – 3.5 m)
Total dissolved solids:	165 mg/L
Specific conductance:	280 µS/cm
Calcium:	33 mg/L

The Okanagan Valley is U-shaped as a result of glacial activity 10,000 years ago with mountains rising on both sides to 2,500 m. The geological history is summarized by Nasmith (1962) and St John (1973). Several hundred metres of unconsolidated materials were deposited during earlier glaciation in the Pleistocene epoch which line the valley bottom. These materials probably resulted from glacial outwash, direct glaciation and lacustrine fluvial sedimentation. At the end of the late Pleistocene, prehistoric Lake Penticton was higher in elevation than present Okanagan Lake. It likely covered the Kal-Wood Basin and Okanagan Valley and drained northward to the Shuswap. The surface elevation of the lake was controlled by a plug of outwash materials and stagnant ice in the area presently between Okanagan Falls and McIntyre Bluff. Notable characteristics of the valley, particularly at the south end, are the terraces which were formed with the lowering of postglacial lake levels. St. John (1973) indicates that one bench presently exists 15 m below the present level of Okanagan Lake and represents an earlier lake level. The fertile benches above the lake are used extensively for horticulture, principally fruit trees and grape growing.

Okanagan Lake has an average surface water elevation of 342 m above sea level. The lake level is regulated by a control structure at the outlet of the lake and is normally operated at between 341.2 m and 342.54 m above sea level (Ward and Yassien in Andrusak, 2000).

Okanagan Lake is divided into three basins and is a relatively deep lake with a maximum depth of 230 m in the north basin. The lake has relatively low biological productivity (oligotrophic); however, the two shallower reaches (Vernon Arm and Armstrong Arm) have poorer water circulation resulting in higher nutrient levels and greater plankton abundance. The lake in longitudinal profile (Figure 1) shows the relative size of three basins: a large north basin, and smaller central basin and southern basins.

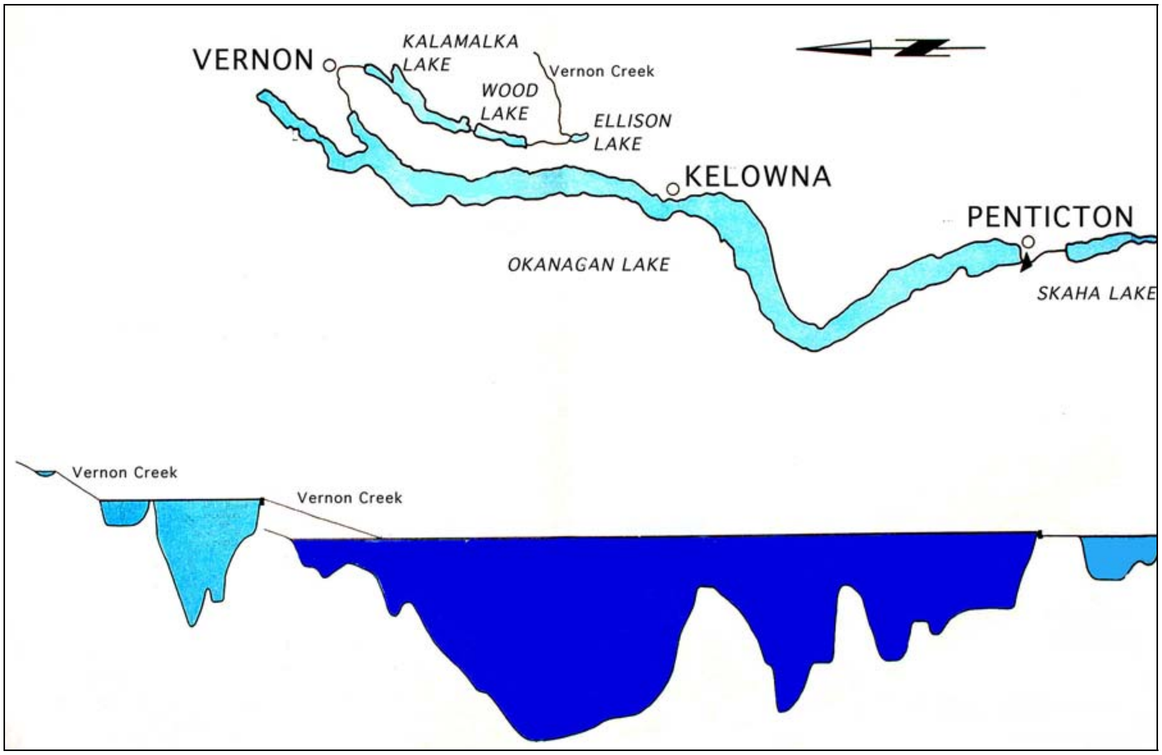


Figure 1: Longitudinal profile of Okanagan Lake

2.2 Hydrology

The low average precipitation of the Okanagan Valley (315 mm) is also a key factor in understanding the lake ecology. The long-term precipitation data have been summarized in the OBS reports and other documents. There are several main points that need to be considered. There is a north to south precipitation gradient with total precipitation at Armstrong of 448 mm, 387 mm at Vernon, 315 mm at Kelowna and 290 mm at Penticton (Hall *et al.* 2001). The mean precipitation for the watershed is 550 mm (because there is higher precipitation at higher elevations). Only 12% of the precipitation reaches the lake with 85% being lost to evaporation and evapotranspiration (Hall *et al.* 2001). About 2% of the water flows out from the lake. The main inflow from the watershed tributary creeks to the lake takes place generally in May and June. The year-to-year variation is high with extremes in runoff covering a range of more than an order of magnitude. In addition, there is some evidence that water availability will decrease with global warming (Leith and Whitfield 1998).

The Kalamalka and Wood Lake basins drain into the north end of Okanagan Lake via Vernon Creek near Vernon. There are many other tributaries which drain from the direct catchment area (Figure 2), the largest of these being Mission Creek on the east side of the central basin and Trout Creek on the west side of the south basin. The outlet from the lake is at the south end to Skaha Lake by the Okanagan River. The Okanagan River flows south through Skaha Lake, Vaseaux Lake and Osoyoos Lake joining the Columbia River near Brewster, Washington.

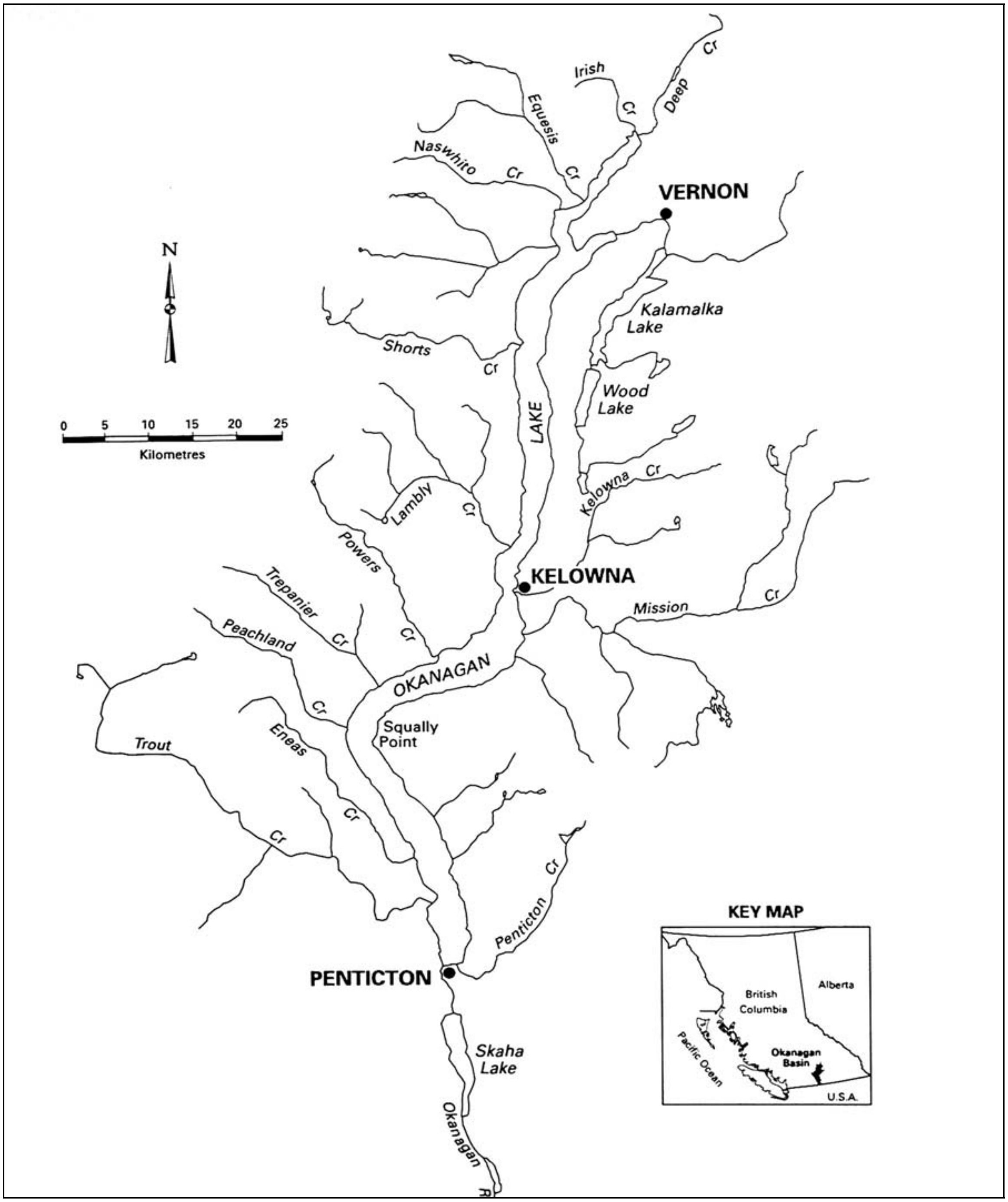


Figure 2: Okanagan Lake tributaries (Andrusak et al., 2001)

The main tributaries and their relative flow contributions are listed in Table 4. The table does not include all of the inflow streams so is an underestimate of the total inflow to the system.

Table 4: Mean annual inflows to Okanagan Lake from major tributary streams (Ministry of Environment, 1985)

Tributary	Volume (Mm^3)	% of total inflow
Vernon Creek	49,500	8.6
Deep Creek	15,500	2.7
Equesis Creek	20,500	3.6
Shorts Creek	33,500	5.8
Lambly Creek	49,000	8.5
Powers Creek	23,100	4.0
Trepanier Creek	33,500	5.8
Peachland Creek	12,500	2.2
Trout Creek	68,000	11.8
Kelowna Creek	18,700	3.2
Mission Creek	199,000	34.5
Bellevue Creek	12,500	2.2
Penticton Creek	20,600	3.6
Total	555,900	96.5

The total inflows to Okanagan Lake since 1950 are illustrated in the Figure 3. What is notable from this information is that the range of flow is very wide – from a low flow of 130 Mm^3 in 1970 (note that this was the period when much of the OBS sampling was being done) to a high flow of 1,401 Mm^3 in 1997. (Data from Brian Symonds, BC Ministry of Water, Land and Air Protection).

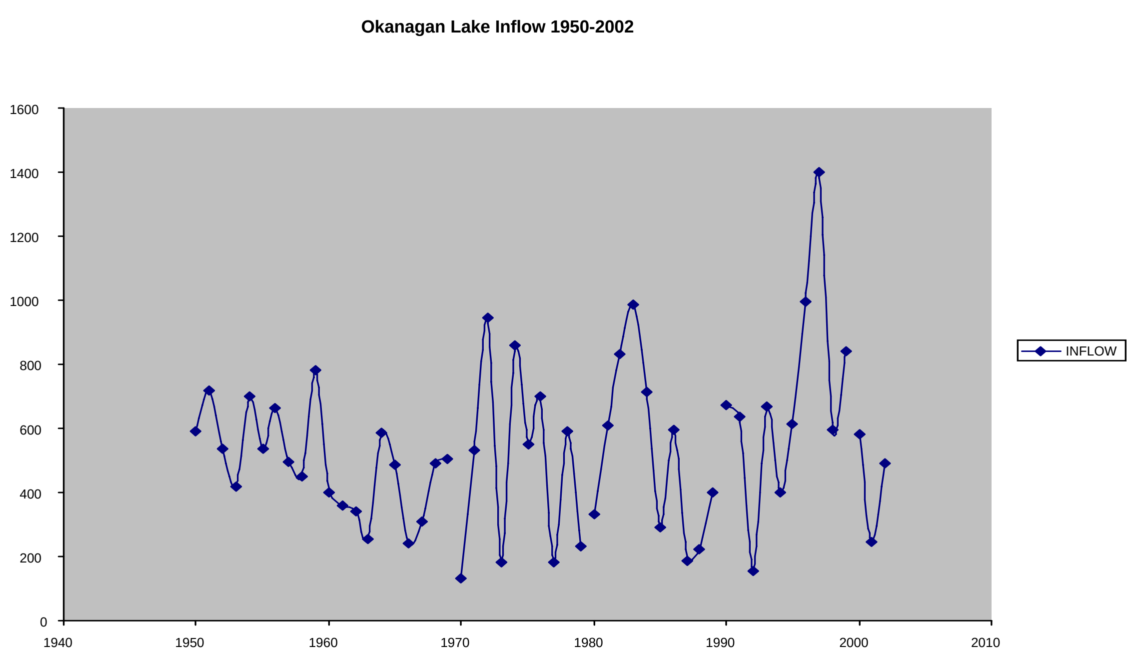


Figure 3: Total inflows (Mm^3) to Okanagan Lake over time

Figure 4 suggests there is some indication (not very significant) that inflows to the lake have been increasing over time; however, this impression may be due to the very high inflow of 1997 and very low flows of the 1920's and 30's.

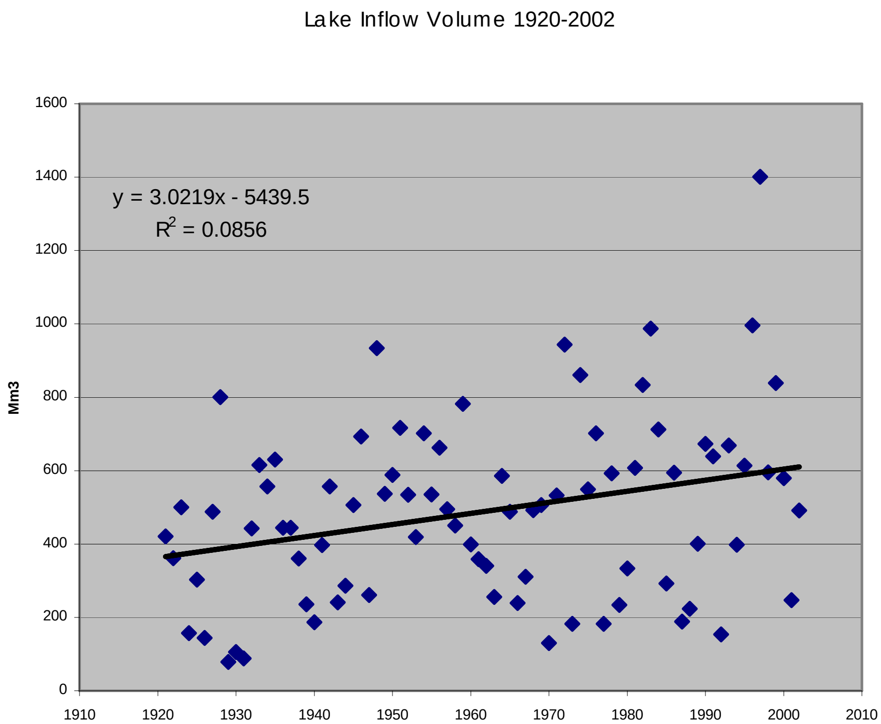


Figure 4: Okanagan Lake total inflows (Mm^3) as a function of time

2.3 Lake Water Balance

The amount of water in Okanagan Lake and subsequent lake level, is a result of the balance between the amount of water that enters the lake and the water that leaves the lake. The water that comes into the lake is primarily from stream inflows and secondarily from the precipitation that falls directly on the lake surface. The losses of water from the lake are from two major components: the outflow of the Okanagan River at Penticton; and evaporation from the lake surface. A third and lesser source of loss are consumptive water withdrawals for irrigation and drinking water.

There are several studies that have estimated the basic water balance components for the Okanagan Lake basin. The OBS estimated an average inflow of 780 Mm^3 and an outflow of 465 Mm^3. The major difference between inflow and outflow is evaporation. The OBS estimated a loss from the lake by pan evaporation techniques of approximately 228 Mm^3 (710 mm/yr lost from the lake surface) (Okanagan Basin Study, 1974). The OBS estimates did not provide an accurate estimate as there was a discrepancy between inputs and losses. The Okanagan Implementation Study felt the OBS evaporation estimate was inaccurate and estimated evaporation using a mass transfer model which resulted in lower evaporation amounts. Their estimates were 321 to 360 mm/yr or 119 Mm^3/yr (Okanagan Basin Implementation Board, 1982).

The weakest components of this water balance estimate are in the output components. These include evaporation, which is difficult to measure, and measuring how much water returns to the lake via groundwater and sewage treatment (of the water that is withdrawn from the lake for irrigation and drinking water). The estimates for this have ranged from 50 to 65% return rate.

The estimates of Ward and Yassien (2000) provide the closest estimate for average annual water balance (within about 5% in balancing inputs and outputs). They calculated net inputs of 880 Mm^3 (stream inflow of 780 Mm^3 plus precipitation on the lake surface of 100 Mm^3). They estimated water losses of 834 Mm^3. The components of the losses were evaporation (330 Mm^3 based on evaporation of 940mm/year); net abstraction (34 Mm^3 based on a licenced water withdrawal of 96 Mm^3 with a return flow of 62Mm^3) and river outflow 470 Mm^3. This information expressed in relative percentages provides the following values:

- Lake water inputs: streamflow 89%, precipitation on the lake surface 11%.
- Lake water losses: outflow 56%, evaporation 40% and net abstraction 4%.

A key understanding is that the amount of water that enters (and leaves) the lake is a very small volume relative to the lake volume. In an average year an input of 880 Mm^3 (and no outflow) would raise the lake level by 2.5 metres but add only 3.3% to the volume of water in Okanagan Lake. Evaporation from the lake surface removes almost a metre of water in an average year.

2.4 Water Movements

The lake, because of the moderate climate, is generally ice-free. The entire lake has only had complete ice cover during three to four years in the past 100 years and not at all in the past 20 years. In cold winters, Vernon Arm and Armstrong Arm generally have ice cover. The lake surface is usually open and the lake volume mixes vertically and horizontally through the winter with no thermal stratification present. The lake becomes thermally stratified in spring and remains strongly stratified from June through October. The thermocline is generally found between 10 m and 25 m with most of the volume of the lake below the thermocline at a temperature of 4-6 degrees. Surface water temperatures in mid summer are slightly more than 20 °C in open water and may exceed 25 °C in shallow areas. As the lake cools in the fall, the thermocline deepens and the lake becomes vertically mixed downward with the energy of the autumn storms. The lake then circulates without any thermal stratification throughout the winter. The limnological term for this type of stratification pattern is warm monomictic.

The lake also needs to be viewed as essentially a closed basin as the outflow is almost a negligible fraction of the lakes volume (2%). There is also a mistaken view that water "flows" from north to south. Because of the long water residence time, there really is no directional flow as might be visualized with a flowing river. Only a very small fraction of the water that either enters the lake or is in the lake, ever leaves the lake. The lake has distinctive water chemistry in each of the three basins and there is water movement among them but not equally in all directions. One of the reasons for the differences in different parts of the lake is that major tributaries flow into the south and central basins of the lake and the water chemistry of the tributaries are distinctive. As a result each of the major basins has a distinct water chemistry character and differ in their biological productivity.

2.5 Population Trends

Three major population centres are located along Okanagan Lake: Vernon at the north end (2001 population: 33,494); Kelowna midway down the lake (2001 population: 96,288); and Penticton at the south end (2001 census: 30,984) (http://www.bcstats.gov.bc.ca/data/cen01/mun_rd.htm) The City of Kelowna, has a very high growth rate (the city was founded in 1905 and the population at that time was 600). By 1975 it was about 50,000 and at present is approximately 100,000.

The three regional districts comprising the Okanagan Valley grew by 81 per cent between 1976 and 2001 - from 174,000 to an estimated 317,000 at present (Summit Environmental Consultants 2000). One estimate is that by the year 2021, an additional 132,000 people will reside in the region, making the total estimated population 447,000 - an increase of 42% over this 20-year period. (BC Ministry of Community Aboriginal and Women's Services website). Another growth projection suggests the population doubling in the next 20 years (CMHC website), while a third projection is that if the present annual growth rate (2.5%) continues, the 2023 population would be one million (Hall *et al.* 2001).

Population growth in the Okanagan-Shuswap Land and Resource Management Plan area is expected to continue at rates exceeding the provincial average. Forecasted rates of growth indicate that the population would reach around 440,000 by 2010. Currently 312,807 persons reside in the LRMP plan area. The population primarily resides in urban areas with approximately 74% living in cities or smaller communities. The region's population is slightly older than the provincial average, and is expected to remain so. Several First Nations Bands reside or have traditional territory within the plan area. The 1995 Status Indian population of Bands within the LRMP region (including all reserves of those Bands within the LRMP) totals 6,211 individuals. (Ministry of Sustainable Resource Management,2001).

2.6 Economy of the Okanagan Catchment

The most comprehensive planning exercise for the area was the process of putting together the Okanagan-Shuswap LRMP. The information below is taken from the LRMP summary.

The area's natural resources provided the foundation for the establishment of the local economy, with its early economy based on primary industries, such as agriculture, forestry and mining. More recently, the local economy has become much more diversified, with significant manufacturing, tourism and service sectors. However, the area's natural resources continue to make an important contribution to the health and growth of the local economy.

In recent years, the Okanagan area has been one of the fastest growing areas in BC. Much of this growth can be attributed to improved highway links to the Lower Mainland with the completion of the Coquihalla Highway, the quality of life offered by the area (pleasant climate, scenic values, recreational amenities) and new opportunities offered by a growing economy. This has enhanced the area's attractiveness to businesses, as well as to retirees.

Contributors to the economy's growth and diversification include: the further processing of primary resources (e.g., wood manufacturing plants, food processing plants); both community-based tourism (such as golfing, automobile touring) and outdoor/adventure tourism (such as houseboating, skiing and fishing); population growth; good rail and highway connections to the Lower Mainland, the rest of Canada, the US and offshore markets; and local governments' pursuit of new industries such as communications, electronics and high-tech products and services. Overall the economy is dominated by the "non-resource" sectors – those sectors not directly dependent on Crown land and resources. The largest share of personal after-tax income in the plan area (46%) is from non-employment, a combination of transfer payments, investment income and pension income, as well as income generated through the spending of this income.

Sectors of the economy considered as the most directly dependent on Crown land and resources are the agriculture, forest, mining and tourism sectors. These "resource-based" sectors account for 19% of total after-tax basic income, and 32% of total employment (including direct employment in those sectors, plus the sectors that provide goods and services to the sector and its employees). The relative importance of various sectors of the economy varies amongst regions within the area.

The North Okanagan Regional District (NORD) supports a diversified economy that has been growing faster than the provincial average. Forestry, agriculture, manufacturing and tourism all are important sectors within NORD's economy, although this varies across the communities.

The economy of the Regional District of Central Okanagan (RDCO) is not significantly dependent on any particular industry sector. The non-resource sectors account for the majority of basic income, including pensions and investments, non-primary resource industries, and the public sector. Kelowna also acts as a service, health and education centre for the area. The strong service infrastructure is a key factor in the region's ability to attract retirees to the area, and rapid growth supports a relatively large construction industry.

The Regional District of Okanagan - Similkameen (RDOS) also has a diversified economy. The communities of Penticton and Summerland act as the service centres for the area and the rural communities of Osoyoos, Oliver and Keremeos, and support the more traditional sector of agriculture, especially tree fruits. The influx of retirees is reflected by the area's high dependence on pension and investment income.

3.0 WATER USE

Multiple water uses are a fundamental conceptual issue for management of Okanagan Lake. The water uses of Okanagan Lake are varied and this is the basis for much of the challenge associated with managing this resource. There are three major uses of the lake: water supply (irrigation and drinking water), aquatic life (including, but not restricted to, fish) and recreation (swimming, boating, water skiing, etc). There are fundamental differences between the expectations for water quality for recreation and drinking water (where low biological productivity and high water clarity is a priority) compared to recreational fisheries (where a higher level of biological productivity may be desirable). The technical basis of this difference is discussed in Section 4 of the report. Defining an optimal range for water quality attributes which strikes a balance between the various public expectations of Okanagan Lake water uses has always been challenging. There is another use which may be difficult to define but might be called aesthetics. The lake and its appearance is a part of many people's lives whether it is living beside the lake, looking out at the lake from a car window or lakeside bench, or simply walking along the beach. It is difficult to set objectives for this use but presumably by specifying objectives for other uses, this aspect will also be protected.

3.1 Human Consumption and Use

There are 919 licences at present that have been issued to allow a variety of local water utilities, government organizations, and individuals to use water from Okanagan Lake. The total licenced withdrawal volume is about 110 Mm^3 and 17 of the largest licences account for about 92 Mm^3 (84%) of this withdrawal volume (Ward and Yassien, 2000). Of the major water licence holders, the largest are the City of Kelowna, Riverside Forest Products (for cooling water), Winfield and Okanagan Centre Irrigation District, the City of Penticton, the District of Summerland, Glenmore-Ellison Irrigation District, and the Ministry of Transportation and Highways. A listing of the major licences is provided in Table 5.

Table 5: Major Water Licenses on Okanagan Lake (modified from Ward and Yassien, 2000)

Licence no.	Purpose	Annual diversion (Mm^3)	Licensee
C032633	cooling	19.9	Riverside Forest Products
C032829	water works local authority	14.9	Kelowna
C022362	water works local authority	9.9	Kelowna
C108281	water works local authority	8.7	Winfield & Ok Centre ID
C032828	water works local authority	8.3	Kelowna
C027158	water works local authority	5.0	Kelowna
C019680	water works local authority	4.1	Penticton
C025236	water works local authority	3.3	Penticton
C040839	water works local authority	3.3	Kelowna
C032615	water works local authority	2.7	District of Summerland
C014633	water works local authority	2.5	Kelowna
C015910	irrigation local authority	2.2	Glenmore-Ellison ID
C066159	waterworks (other)	1.8	Min of Trans &Highways
C019098	waterworks local authority	1.7	Kelowna
C034312	irrigation local authority	1.2	RD of Okanagan-Similk
C016811	irrigation	1.1	Okanagan Indian Band
C020914	irrigation local authority	1.1	West Bench ID
Sum of the above 17 licences contributing to over 83% of the total diversion from the lake		91.9	
Other 902 licensees		18.4	
Total licenced diversion from Okanagan Lake		110.3	

In addition to these major commercial licences, there are hundreds of smaller group and individual licences which also are important. There are also many non-licenced, small volume withdrawals for drinking water supplies.

Historically many of the irrigation districts which also supply drinking water have used storage in higher elevation reservoirs and lakes in the mountains above the valley to provide summer water supplies. With increasing demand, these water supplies are becoming too small to supply the volumes of water which are needed. Concern has also been raised over the security and quality of these systems as they are in multiple use watersheds with a mixture of land tenures where water supply management is becoming increasingly difficult. In general, Okanagan Lake supplies a very high quality of raw water in comparison to the small upland lakes, reservoirs and streams.

Catchment headwater storage presently accounts for approximately 140 Mm^3 and the number of small storage dams in the Okanagan has increased considerably over time. In 1913 there were only 11 dams in the basin: by 1956, 45 dams; by 1972, 81; and by 1998 there were 147 dams (Hall *et al.*, 2001). There are potential consequences to this change in the water storage of the basin. The obvious one is that water input occurs at a later time of the year and that less of the water from the watershed actually reaches Okanagan Lake. There are also potential consequences for the supply of nutrients to the lake as additional storage has the possibility of trapping nutrients that might otherwise reach the lake. This problem in the extreme, but unrelated, case has been manifested by the construction of large hydro reservoirs upstream from Kootenay Lake and Arrow Reservoir (Ashley *et al.* 1999, Pieters *et al.* 1998). In the Okanagan, most of the storage is in higher elevation upland reservoirs and the storage is accomplished by increasing the volume of pre-existing lakes and so are a relatively less severe consequence. In the case of the Okanagan, these storage systems should not substantially alter the amount of nutrients captured on sediments that are transported downstream. The upland reservoirs generally have low inputs of suspended sediments in comparison to the higher gradient streams that drain the upland reservoirs. It would seem that nutrient sedimentation as a consequence of increased headwater storage may play some role but that role is likely a small one.

The type of drinking water supply - upland reservoirs with stream intakes, groundwater or Okanagan Lake itself is one many water purveyors are currently considering if they have a choice. The upland reservoirs and streams have the advantage of gravity flow and no pumping costs, but in many cases have water quality which is poorer than the lake. Upland lakes and streams often have much higher colour and suspended sediments and a higher risk of pathogen contamination than Okanagan Lake because of different land uses in the drinking water supply watersheds. Studies by BWP Consulting (2001, 2002) on watersheds in the Kelowna and Vernon areas, have shown that potential contamination can originate with wildlife, cattle and human sources. The lake provides very high quality source water but requires pumping water and the associated energy costs to provide water into domestic systems. Several water utilities are considering moving from upland sources to Okanagan Lake because of the water quality contamination risks.

Okanagan Lake water as a source of drinking water seems to in large part be undervalued economically. No economic evaluation has been done but considering the decreasing amounts of water from high elevation storage and the potential water quality problems that these systems are vulnerable to, there needs to be a valuation of the water as an economic commodity and resource as the population becomes more reliant on Okanagan Lake water.

3.2 Aquatic Life

There are several important components of aquatic life in Okanagan Lake. Of most interest is the fish community but it is obvious that other parts of the aquatic food chain have a major effect on fish growth and numbers. Economic value can be placed on fish but not on phytoplankton and zooplankton; however, changes in the phytoplankton and zooplankton and benthos can have a direct effect on fisheries so there is a clear and high value on these other components. The non-fish aquatic life resources have a very high value and need to be protected, not just as fish food but as valuable resources in their own right. Sampling of Okanagan Lake, at least in the pelagic zone, has been more or less standardized to stations that were initially established by the Okanagan Basin Study.

3.2.1 Phytoplankton

There have been a number of evaluations of the phytoplankton of Okanagan Lake. The observations of Rawson (1936) when the lake was sampled in July and August 1935 are very notable. The data may not be typical of that period but is all that is available until the lake was sampled again 20 years later. Clemens *et al*. (1939) noted three major groups of phytoplankton: blue-greens (eight species) of which the dominants were *Anabaena* and *Aphanizomenon*; greens (20 species) of which the dominants were *Dictyosphaerium, Oocystis, Staurastrum* and *Botryococcus*; and diatoms (34 species) of which he listed the six most abundant (*Asterionella, Cyclotella, Fragilaria, Melosira, Stepanodiscus and Tabellaria*). All of these genera are reported as components of the modern macro phytoplankton community (Rawson used a net to sample so would have missed seeing smaller forms). The fact that blue-greens formed a major component of the 1935 summer phytoplankton community is significant and indicates that there may not have been a major change in community species composition over time. He noted that “on a few occasions there was a concentration of the blue-green alga *Anabaena* on the surface constituting a slight water bloom”. He also estimated the standing crop of plankton by strata and the nitrogen content of the plankton. He compared the nitrogen content to Paul Lake near Kamloops which he also had surveyed, and concluded that Okanagan Lake plankton had a lower nitrogen content. This is not unexpected since Paul Lake is a smaller more productive lake (with a higher overall nutrient content). No quantitative data are available but the qualitative information is quite useful.

Sampling by Stein and Coulthard (1971) (the first quantitative phytoplankton data), was done from May 1969 to April 1970. They reported that the phytoplankton distribution was more or less consistent throughout Okanagan Lake except for a lag in the blue-green algal dominance in summer in the south and central basin. Their description of the seasonal succession was as follows. In early June the diatoms *Fragilaria* and *Asterionella* were dominant but by mid-June the blue-greens *Anabaena* and *Lyngbya limnetica* were dominant in the Armstrong and Vernon arms area and in the north basin. In the south basin the diatom numbers diminished but only in July did the blue-greens become dominant. From mid-July through September the blue-greens dominated the phytoplankton community. *Aphanothece nidulans* dominated many times but other blue-greens present in significant numbers were *Aphanothece microscopica*, three species of *Anabaena, Lyngbya limnetica, Chrococcus dispersus* and *Coelosphaerium*. The diatom *Melosira italica* was also present in appreciable numbers through the summer. By October the bluegreens (particularly *Aphanothece*) declined and the diatoms increased (*Asterionella* and *Melosira*). The winter phytoplankton numbers were low and dominated by diatoms and phytoflagellates. The April increase was described as dominated by *Asterionella* and phytoflagellates. *Fragilaria* was dominant in the central basin and the green *Ankistrodesmus* in the south basin.

They noted a gradient of numbers, with the highest in the north basin stations and lowest in the south basin. This gradient has since been noted by several investigators.

A summary of numbers by phytoplankton group from Stein and Coulthard (1971) is given in Table 6 for mid-month sampling dates 1969-70.

Table 6: Okanagan Lake Phytoplankton reported by Stein and Coulthard (1971)

Confluence of Armstrong and Vernon Arms (mid month sampling dates) (=OK7)											
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	Apr
Total phyto	2,990	2,912	2,050	1,805	633	409	213	234	351	6,485	
Blue-greens	2,095	2,520	1,638	1,661	355	154	59	2	8	77	
Greens		0	56	55	24	12	11	2	13	23	210
Diatoms	788	258	172	82	234	186	119	163	241	4,880	
Phytoflagellates	107	78	185	38	32	58	33	56	77	1,318	

North basin (north of Kelowna) (mid month sampling dates) (=OK5)											
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	Apr
Total phyto	2,033	2,160	2,128	1,383	638	471	150	28	75	3,837	
Blue-greens	756	1,662	1,693	1,225	400	176	42	4	46	103	
Greens		0	52	24	49	9	15	4	0	0	214
Diatoms	1224	361	317	71	200	218	90	13	17	1,761	
Phytoflagel	53	85	94	38	29	62	14	11	12	1,759	

Central basin (Okanagan Landing) (mid month sampling dates) (=OK3)											
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	Apr
Total phyto	3,254	810	1,314	1,452	631	390	NNN???	101	327	5,515	
Blue-greens	882	551	930	1,301	319	142	NNN	8	9	128	
Greens		0	25	25	31	16	13	NNN	4	8	208
Diatoms	2151	187	293	88	269	185	NNN	69	266	3,105	
Phytoflagellates	221	47	66	32	27	50	NNN	20	44	2,073	
South basin (off Trout Creek) (mid month sampling dates) (=OK1)											
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	Apr
Total phyto	2,202	385	977	1,951	483	105	121	177	351	8,450	
Blue-greens	168	264	747	936	258	9	28	3	15	218	
Greens		0	3	18	12	3	0	0	4	12	5,836
Diatoms	1927	80	179	34	212	95	86	118	266	1,450	
Phytoflagellates	107	38	33	69	10	1	7	52	56	940	

Note: Numbers in the table are reported as cells per mL but colonial and filamentous numbers were counted as units so cell numbers, especially for blue-greens, are underestimated (e.g. a count of "one" *Anabaena* =12-15 cells, a count of 1 *Aphanothece*=10-15 cells. See Stein and Coulthard (1971) page 90.

In summary, the description of the phytoplankton community by Stein and Coulthard (1971) is similar to that of Rawson in that the mid-summer community is dominated by blue-greens and the successional patterns are what might be expected for a large, oligotrophic alkaline, temperate lake like Okanagan Lake (Reynolds, 1984). It also serves as a point of reference for subsequent sampling and potential changes.

No phytoplankton sampling was done during the Okanagan Basin Study.

In the Implementation Study (1976-78) Truscott and Kelso (1979) sampled for phytoplankton species and numbers but additionally collected detailed chlorophyll samples for the first time to provide some evidence of algal biomass estimates. In summarizing the results from their sampling, Truscott and Kelso concluded that "it appeared that no great change had taken place [at the station most comparable to the Stein and Coulthard 1969-70 data], except perhaps for a slight shift to more oligotrophic algal assemblage". The phytoplankton data are described in more detail in Deimert and Kelso (1980). The phytoplankton counts they provided seem quite low when compared to the data of Stein and Coulthard (1971). However in the comparison that they did, they concluded that the numbers were comparable to the 1969-70 data.

The 1976-78 data (Truscott and Kelso, 1979) indicated there was a notable year-to-year variation and that conditions seemed different from the previous seven years. There had been some decrease in nutrient loading, and the change in the phytoplankton community seemed to support that. The numbers and mix of groups in 1976-78 was less dominated in summer by blue-greens and the numbers and chlorophyll seemed to be slightly lower. The mean phytoplankton densities cited for samples from the three basins were 451 cells/mL in 1976, 163 cells/mL in 1977 and 438 cells/mL for 1978.

One advance they attempted to provide was an estimate of biomass as they realized that the small size of cyanophytes provided a bias when numbers of algal cells were presented. Their biomass data also reflected the high variability as the range in phytoplankton biomass differed by a factor of three (1.4 g/m^3, 1976, 0.4 g/m^3 1977 and 0.8g/m^3, 1978).

Phytoplankton has been collected since 1976 as part of routine annual monitoring by the provincial government regional office in Penticton. These data provide species and numbers during spring overturn and in September, thereby providing a long-term indication of change. Unfortunately not all the data have been analyzed because of costs so the set is incomplete. A summary table of the dominant species and numbers for the available data are given as Appendix 2. What this data set seems to indicate (consistent with the other data collected) is that there has been little change in species composition or of phytoplankton numbers over the period of record (also see Nordin, 1998).

During the OLAP period, additional sampling and interpretation of the state of the phytoplankton has been done and this provides perhaps the most detailed understanding of this aspect of the lakes ecology. The sampling done in 1996 was summarized by Nordin (1998) in a comparison between Kalamalka Lake and Okanagan Lake (Year 1 and 2 OLAP report, Ashley *et al.*,1998). The review of the Okanagan Lake phytoplankton community composition compared to previous years indicated some evidence for shift in species. The dominant group by numbers were the cyanophytes, but with some increased numbers in the late summer which might represent some change over earlier work. The total numbers were higher in 1996 than previous years but the small size of the cyanophytes makes the total number of cells per unit volume higher than it might be without the dominance of cyanophytes. This may also reflect the inter-annual variability noted in previous sampling.

In the Year 1 and 2 OLAP report (Ashley *et al*. 1998), Vidmanic and Ashley (1998) looked at long-term (300 year) changes in diatom species composition and numbers in sediments for two sites – one in the north basin and one in the south basin. Their analysis showed no major changes in dominant diatoms or numbers over the length of the core. No dating by depth is given but based on the sedimentation rates estimated in Stockner and Pinsent (1974), the recent (past 100 years) sedimentation rates are about 1 mm per year and so the cores collected in 1996 and 1997 represent a 300 to 350 year record. This indicates, at least for diatoms, little change in community composition.

In the Year 3 OLAP report (Ashley *et al.* 1999), Jensen (1999) reviewed the phytoplankton sampling done for OLAP for 1996-1998. In addition to reporting numbers he also reported the relative dominance of algal groups by biovolume as well as by numbers which makes the comparisons between groups and between years more realistic. Jensen noted that cyanophytes were more dominant in Armstrong Arm than in other parts of the lake, which can be expected as a result of its higher nutrient status. He concluded that phytoplankton density had not changed appreciably since 1969 with a dominance of Cyanophytes, especially in the summer. He indicated that *Lyngbya limnetica* might be increasing in proportion to other cyanophytes. One notable point made in Jensen's summary was a description of a bloom of *Microcystis* in the south arm of Okanagan Lake in June, 1998 for which no obvious cause was identified, although it might have been a localized phenomenon related to nutrient input resulting from construction of a sewer line.

In the Year 4 OLAP report (Andrusak *et al*. 2000), Stockner reviewed the 1999 data and described the higher numbers of phytoplankton in the north basin and the lag effect of the onset of the spring bloom from north to south. He used both numbers and biovolumes to quantify the phytoplankton community. He also documented the importance of the smaller fractions of phytoplankton (picoplankton). It appears, based on the data reported for phytoplankton numbers and species mix, that no significant difference from previous years was apparent. Stockner did identify what he felt was nitrogen limitation in some areas of the lake, and one of the consequences was increasing dominance by cyanobacteria and gradual loss of the autumn diatom bloom.

The most recent work done on Okanagan Lake phytoplankton was reported by Stockner (2001 and 2002) which compared 2000 and 2001 data to previous data as well as data for other BC lakes. Stockner's (2002) overall comments on phytoplankton trends was that although there have been subtle changes in the dynamics of phytoplankton populations (e.g. increases in the abundance of blue-greens and gradual elimination of the autumnal diatom increase), overall they have remained quite stable despite the rapid scale of development within the basin.

As a summary of the available phytoplankton data, the following points can be made:

1. There seems to be little evidence of major change in either phytoplankton numbers or general taxonomic composition over the past 30 years. This seems consistent with a relatively stable lake concentration of nutrients despite major increases in population. This is likely due to phosphorus removal at sewage treatment plants.
2. The successional pattern begins with a spring peak of diatoms and flagellates followed by a summer assemblage dominated by cyanophytes which persist into the fall when diatoms and flagellates typically regain dominance, although in recent years, extended dominance by cyanophytes has been reported. There may be some influence of hydrology in both the species dominance and timing since wet and dry years might result in a differential supply of nitrogen and phosphorus.
3. In examining average numbers of phytoplankton, there seems to have been an increase in numbers; however, this may be a result of differences in counting methods (colonial species being counted as 1 unit by Stein and Coulthard (1971)). The biomass of phytoplankton between the Implementation Study period (1977-79) and present seems to have decreased.
4. The species mix seems to be somewhat unusual in comparison to other large oligotrophic lakes but seems to be similar to what it was at least in 1969-70 and may be similar to the historical natural phytoplankton community if the sampling by Rawson (1936) was representative. It is difficult to find a direct comparison to Okanagan Lake as it has the unusual attributes of being a middle latitude, relatively large, monomictic fjord lake with a very long water residence time (a consequence of being located in an arid geographical region) and moderate biological productivity (oligotrophic near the threshold with mesotrophy).

Table 7: Summary of phytoplankton community characteristics (all stations)

	Dominants algae spring/summer*	Cell counts (#/mL)	Biomass mm^3/L	Productivity $mgC/m^2/d$
Rawson (1935)	C (summer)			
Stein & Coulthard (1971)	D/C	1498		
Truscott and Kelso (1979)	D/C	1578 (1978)	1.04 (1978)	
Ministry 1970's				
Ministry 1980's				
OLAP year 1 (1996)	D/C	3194		
OLAP year 2 (1997)				
OLAP year 3 (1998)				
OLAP year 4 (1999)	D/C	5354	0.77	
OLAP year 5 (2000)	D/C	5010	0.69	165 (Sept only)
OLAP year 6 (2001)	D/C	3978	0.68	

*D=diatoms, C=Cyanobacteria

One of the concerns regarding the phytoplankton community is that it is dominated by cyanophytes. These are undesirable as a food source for zooplankton grazers since they may be nutritionally poorer than other groups of algae (Brett and Muller-Navarra 1997, Muller-Navarra *et al.* 2000). Cyanophytes also present a higher risk of causing taste and odour or treatment problems in drinking water supply. Their dominance in the lake has been attributed to an imbalance in the N:P ratio (a decrease in N or increase in P) (Stockner 2000, 2001); however, there are a variety of other factors which can effect the species mix of phytoplankton. Low turbulence, or water movements, results in heavier taxa like diatoms to settle out, providing a competitive advantage to cyanophytes which have more control over their buoyancy. Other favourable conditions for cyanophytes include high pH (cyanophytes tend to do better in alkaline pH) and higher temperatures (cyanophytes tend to dominate in warmer water and in Okanagan Lake and are most dominant in mid summer).

3.2.2 Chlorophyll

The early data for chlorophyll are worth summarizing here as they are the basis of comparison for later sampling and examination of trends. The OBS Technical Supplement V (Pinsent and Stockner, 1974) gives a single mean chlorophyll value of 5.0 µg/L for Okanagan Lake with little detail as to what exactly it represented. Truscott and Kelso (1979) revisited the original data and extracted annual growing season means for three index stations in each of the main basins (north, central and south) of 5.6 µg/L, 3.8 µg/L and 4.0 µg/L, respectively. They also calculated mean seasonal values from their data chlorophyll *a* only and with chlorophyll plus phaeopigments. These results, plus results from 1980 (Jensen, 1981) are listed in Table 8.

Table 8: Summary of chlorophyll data (growing season means) from Pinsent and Stockner (1974), Truscott and Kelso (1979), and Jensen (1981) (spring values only)

		Chlorophyll-*a* only				Chlorophyll plus phaeophytin			
Station	1971	1976	1977	1978	1980	1976	1977	1978	1980
OK-1	5.6	1.5	1.7	2.1	5.0	2.2	2.1	3.0	5.6
OK-2	3.8	1.0	1.2	2.4	5.0	2.4	1.3	2.2	5.9
OK-3	4.0	1.1	0.7	1.3	1.9	2.4	1.3	2.2	2.4
Mean	4.5	1.2	1.2	1.9	4.0	2.3	1.6	2.5	4.6

Although there is some question about the methodology from the OBS study (chlorophyll-*a* only or chlorophyll plus phaeopigments), in general there seems to be little evidence for any substantial changes in algal biomass as indicated by chlorophyll concentration from 1970 to 1980. There is, as with other measures of biological productivity, considerable year-to-year variation.

A longer set of chlorophyll *a* data collected by the Ministry regional office in Penticton has been published in a number of reports that document different periods of time. It has the limitation of only being collected in early spring (February or March) and in September so can't easily be used in direct comparison to the seasonal data collected during the Implementation Study (or to the seasonal data collected during OLAP). However, it does provide a long continuous record on which to judge trends in phytoplankton biomass (1976 to present) and represents a valuable data set.

The Ministry data is illustrated in Figure 5. The data set includes three sites, one from each basin, and shows considerable year-to-year variation, however the sites track each other reasonably well in their inter-annual cycles. The discontinuity about 1990 may be a result of a change in analytical laboratories.

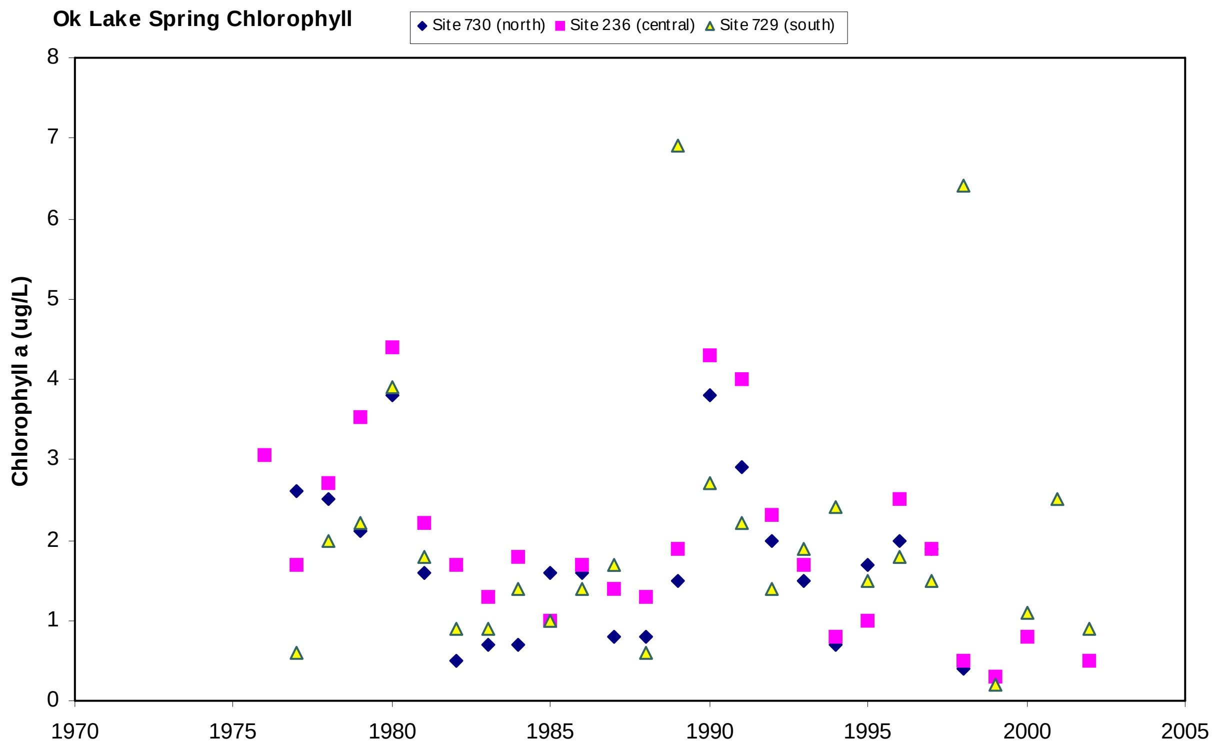
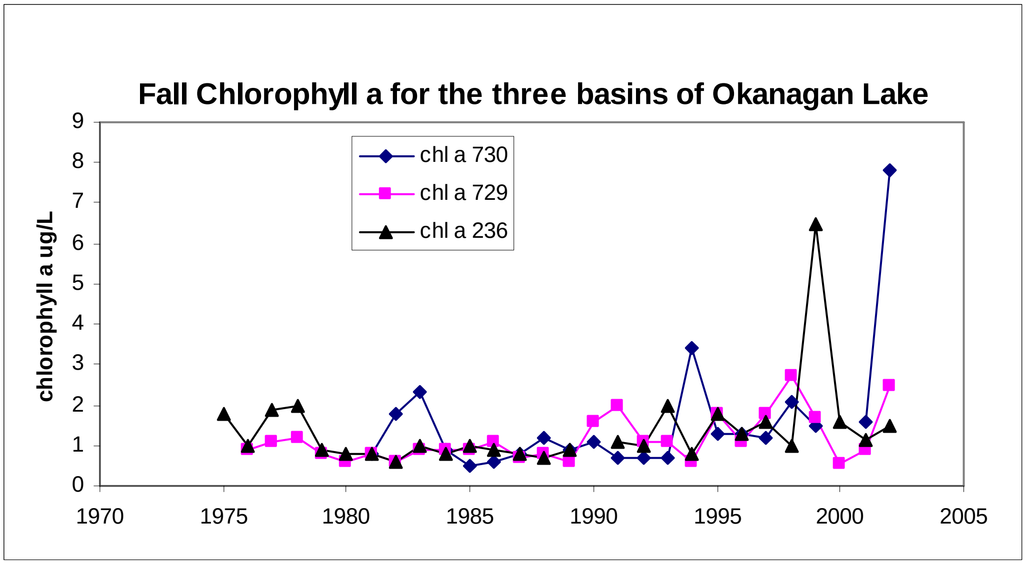


Figure 5: Okanagan Lake spring chlorophyll a data

The fall chlorophyll *a* data collected by the Ministry may present a better representation of long-term trends. The data below (Figure 6) show quite a different pattern than the spring data but there seems to be little difference between the three main basin stations. The data do show a minor increase in chlorophyll *a* in the recent few years.



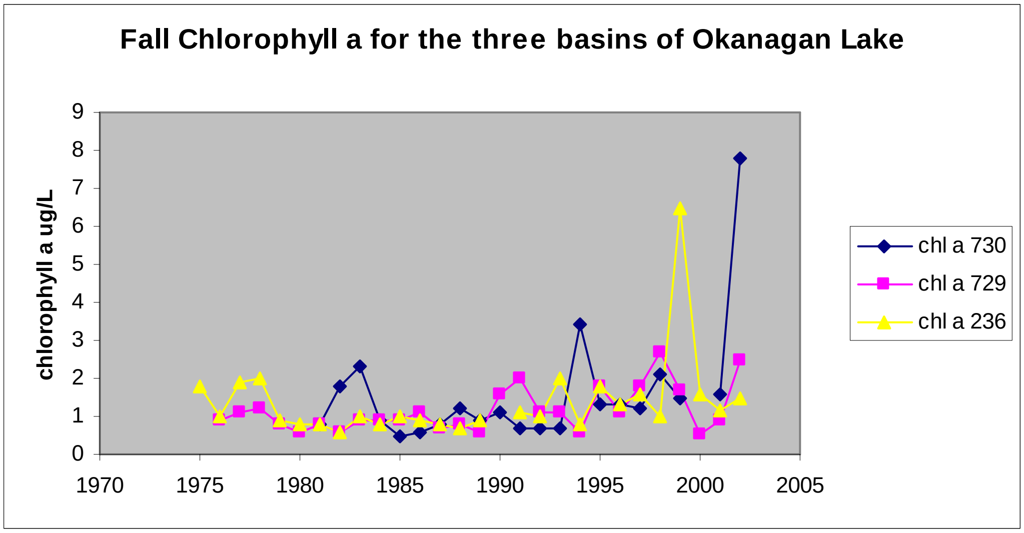


Figure 6: Fall Chlorophyll a for the three basins of Okanagan Lake

The detailed chlorophyll data set collected by OLAP was summarized by Wilson and Cassidy (2002). The data over this period are quite consistent and provide the first seasonal data collected since the Implementation Study of 1977-79.

Table 9: Okanagan Lake chlorophyll a concentrations (µg/L) (Wilson and Cassidy, 2002)

Year		OK1-OK4	OK5-OK-7	Mean main lake	Armstrong Arm (OK8)
1997		2.3	2.9	3.1	5.7
1998		3.4	4.7	4.1	5.7
1999		5.6	5.7	5.7	5.9
2000		4.0	3.4	3.7	4.6
2001		3.3	3.5	3.4	3.7

The summary of these data support the previous phytoplankton data and suggest that although there is inter-annual variation in nutrient input (which in turn seems to be strongly influenced by water inflow into the lake), the scale of change is within a range that would be considered normal for this lake. The OLAP data may indicate slightly higher seasonal mean concentrations than has been noted previously in the 1976-79 OBIA study data.

It should be noted that the mean values for chlorophyll *a* concentration are above the points of reference for oligotrophy used by standard texts and indicative of a mesotrophic system. A growing season mean value of 1.7 µg/L or a mean peak value of 4.2 µg/L (Wetzel 2001) is used as a threshold for transition from oligotrophy to mesotrophy.

3.2.3 Periphyton

Considerable effort was expended during the Okanagan Basin Study to document the periphyton in the lakes of the basin. There are a number of reasons to use periphyton as an indicator of water quality and suitability, especially in the littoral areas. Periphyton can be used as an indicator of water quality for drinking and recreation, but it is also an important indicator of shallow water biological productivity. The shallow littoral areas of the lake are the closest to sources of pollution and therefore most vulnerable. As such, they should show the effects of disturbances and inputs much sooner than the deep water areas which typically receive most of the water quality monitoring attention. The shore and shallow areas are important for human recreation and a variety of aquatic species – especially as spawning and rearing habitat for a number of fish species like shore-spawning kokanee populations.

Stockner *et al.* (1972) and Pinsent and Stockner (1974) present periphyton data for eight stations in Okanagan Lake and provide rates for seasonal average growing rate (0.62 mg/cm^2/14 days), net production (446 mg/m^2/d), and biomass production (225 mg/m^2/d). They also measured the N:P ratios in periphyton tissue and found that the N:P ratio in more productive areas was lower (5:1) as compared to 14:1 at less productive stations. The dominant periphyton genera were *Synedra, Amphora, Spirogyra, Epithemia, Gomphonema* and *Diatoma*. Successional patterns and species were also described. Standing crop (measured as chlorophyll *a*) was generally found to be 1-3 µg /cm^2 (10-30 mg/m^2) but was much higher in Vernon Arm which, at the time, was subject to higher nutrient levels from sewage inputs.

As part of the Implementation Study, Truscott and Kelso (1979) also examined periphyton. They used a different substrate type (plexiglass) than Stockner's (year) glass microscope slides, but did find the two sampler types to be reasonably comparable. Overall, they found the chlorophyll levels lower than what was found in 1971, but felt that this was within the range of variability and not indicative of a change. The only area a change was noted was Vernon Arm where a decrease in periphyton apparently resulted from the diversion of the Vernon sewage discharge to land disposal in 1977. They compared some of the other measures of periphyton abundance in 1977-78 to the OBS data of 1971. All of the data seemed to be fairly consistent considering the differences in collection and analytical methods. Table 10 provides a summary of periphyton data for Okanagan Lake.

Table 10: Summary of periphyton data for Okanagan Lake (adapted from Truscott and Kelso (1979). Values are given as means of all stations

Parameter measured	1971	1977	1978
Periphyton dry weight productivity (mg/m^2/d)	6.0	4.7	2.6
Periphyton dry weight productivity (mg/m^2/d)	596	547	815
Periphyton ash-free dry weight productivity (mg/m^2/d)		139	113

The Ministry of Environment regional office in Penticton sampled periphyton at a variety of sites on Okanagan lakes in 1995 and 1996. A summary of the data for Okanagan Lake is provided in Table 11. These samples were obtained from natural substrates (cobble) so are only marginally comparable to earlier work. It should also be noted that the variability within sites and between dates is relatively high and makes characterization of sites difficult.

Table 11: Summary of 1995 and 1996 Okanagan Lake periphyton data

Site	Dry weight	Ash-free dry weight	Chlorophyll *a*
Ok central	37 g/m^2	2.7g/m^2	56 mg/m^2
Ok north	52 g/m^2	3.3 g/m^2	229 g/m^2
Ok south	247 g/m^2	12.7 g/m^2	294 g/m^2

The reports also identified the dominant periphytic taxa for the North, Central and South basins which were respectively: 48% *Lyngbya* and 22% *Rivularia* (N), 29% *Achnanthes* and 26% *Lyngbya* (C), and 38% *Achnanthes* and 26% *Lyngbya* (S).

These data suggest the periphyton standing crop was substantially higher than the previous reports; however, these samples used natural substrates and might be expected to yield higher results.

From the data presented here, a basic characterization and quantification of the biomass, productivity and species composition can be discerned; however, it is very difficult to identify any trends over time. There may have been some decrease between 1971 and 1978 that corresponds to a similar decrease in phytoplankton chlorophyll-a. This may have been due to sewage treatment plant upgrades or simply a variation in hydrological patterns or nutrient loadings. It is recommended that future sampling of periphyton be done using natural substrates so that it can at least be compared to the 1995 and 1996 data and compared to available guidelines (e.g., Nordin 1986).

3.2.4 Aquatic Macrophytes

One area of lake biology that has changed significantly over the period of record is the aquatic plant community. The change is largely due to the introduction of *Myriophyllum spicatum* in the early 1970's. The efforts to control this species are well documented in a number of reports (Newroth (1981, 1993) and in a large series of reports based primarily on work done in the Okanagan (see the Ministry of Water, Land and Air web site: http://wlapwww.gov.bc.ca/wat/wq/public/tpcapm.html).

The harvesting and management of this species is still a major program of the Okanagan Basin Water Board. Distribution maps and quantification of plant species were prepared as part of the Aquatic Plant Management Program that the provincial government had in place in the 1970's and 1980's. Less documentation of freshwater aquatic plants has been done in recent years and no attempt has been made to evaluate the biomass or coverage of plants over time. This is an important aspect of Okanagan Lake that bears on many other issues.

3.2.5 Zooplankton

Zooplankton is an extremely important component of the aquatic ecosystem of Okanagan Lake and there is a long sampling record for zooplankton similar to phytoplankton. The first data are from 1935 with Rawson's initial sampling in July and August. A second set of samples were taken by Northcote in July 1951 and the data presented as part of the analysis of the Okanagan Basin Study (Patalas and Salki (1973), Pinsent and Stockner (1974)). The OBS data were collected in September 1969 and August 1971. These three studies summarize what was known of the zooplankton community to that stage and are the point of reference for subsequent collections. The main points from the OBS Technical Supplement 5 (Pinsent and Stockner, 1974) are:

1. There were 13 species found – and it appears that there was no shift in species when the 1935, 1951 and 1969-70 species lists were compared.
2. Two species of copepods *Cyclops bicuspidatus thomasi* and *Diaptomus ashlandi* contribute approximately 60% and 30% respectively to the numbers of zooplankton species. *Daphnia*, the major cladoceran species at that time, contributed only 1-2% of numbers.
3. Most zooplankton were concentrated in the upper 25m of the water column. Nauplii of *Cyclops* can be found in the 25-50 m depth and 89% of zooplankton were found in the top 50 m.
4. The horizontal distribution is relatively homogeneous with less numbers in the north basin and higher numbers in the south basin.
5. There was an increase in zooplankton numbers between 1935 and 1969-70 based on settled volume. Zooplankton increased by a factor of 3-5, apparently reflecting an increase in nutrient loading over that 35-year period. Quantitatively the 1969-70 sampling showed a density of 101-188 animals/cm^2.

The next major sampling was done as part of the Okanagan Implementation Study. Truscott and Kelso (1979) found the same dominant species with the exception that the small cladoceran *Bosmina* sometimes was more plentiful than the larger *Daphnia*. The estimates of abundance in 1979 showed slightly higher numbers (185 animals/cm^2). This finding is comparable to the OBS data as were the settled volume data (general range 9-19 mm^3/cm^2 depending on the values used).

An important and continuous data set exists for zooplankton data collected by the Ministry of Environment from 1979 to 1994. A summary of some of these data were presented by Nordin (1996).These data are not by themselves a good indicator of zooplankton standing crop on an annual basis as they were only collected at two times of the year (spring overturn and September). They do however provide the best long-term data set on which to evaluate year-to-year trends in the lake zooplankton community. For settled volume of both spring and September zooplankton samples there seems to be little change in zooplankton biomass over this period. The inter-annual range seems to be relatively small – a factor of two to three. The numbers are lower than the standing crop that was given in Patalas and Salki (1973) but represent a less productive time of year. Figure 7 illustrates settled volume biomass (spring sampling) from the regional office annual monitor up to 1995 and compares biomass to the OBS study data (1969 and 1971).

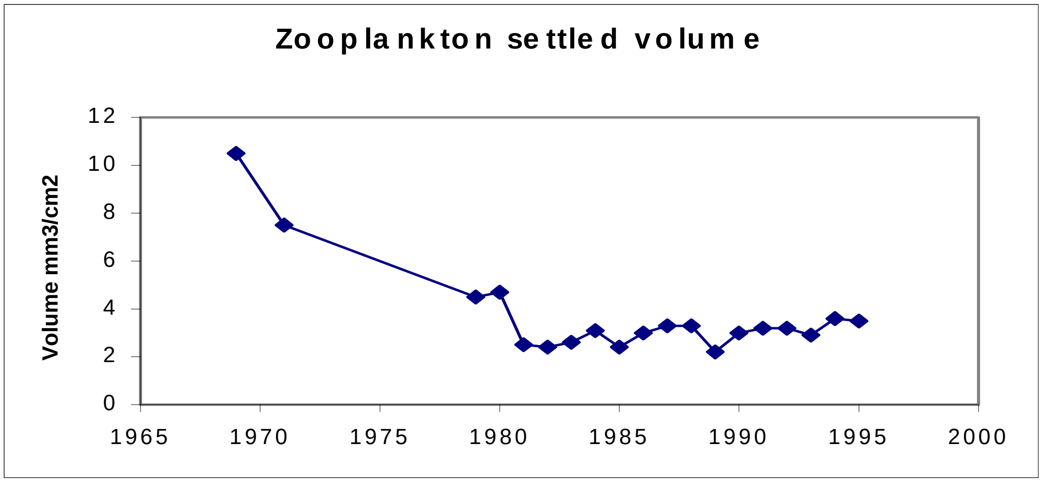


Figure 7: Settled zooplankton biomass for Okanagan Lake

Figure 8 shows the trends for the main basin stations versus Armstrong Arm, again using spring zooplankton standing crop. Armstrong Arm seems to have one to three times the standing crop, but is more variable from year-to-year.

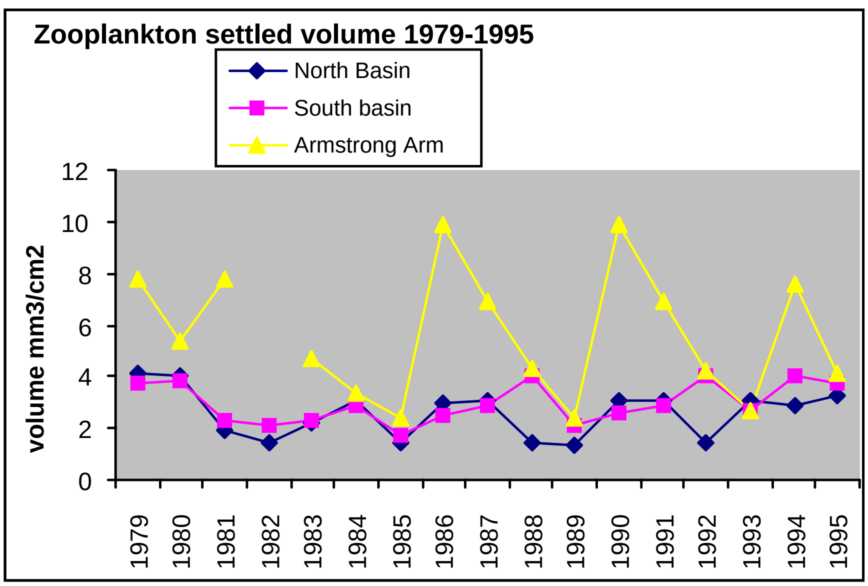


Figure 8: Comparison of north and south basin zooplankton standing crop to Armstrong Arm standing crop

Thompson and Kuzuk (1998a) examined samples collected in Okanagan and Kalamalka lakes in 1996 and concluded that there had been no change in species composition from the samples of 1969 and 1971. Thompson and Kuzuk (1998b) also examined the counting techniques used as part of the Ministry of Environment's regular zooplankton monitoring and those used by the Fisheries Centre at UBC. They found that "the analytical techniques…. used produce similar results for zooplankton densities and proportions of Cladocera".

Despite the difficulty in comparing the data (different measurement units used by different workers e.g. numbers by volume (per litre) or area (per cm^2), settled volume estimates, differing net meshes and sampling at different times of the year), they seem to indicate relatively minor changes over the past 30 years. Wilson and Vidmanic (2002), after examining the long-term trends, noted that "both cladoceran and copepod densities are reasonably consistent over the past 20 years considering the range of analytical methods". Their results, reproduced in Figures 9, 10 and 11 below, show the same ranges that were reported for settled volume estimates of standing crop (typically three to four-fold difference) and the same lack of major change over the period of record.

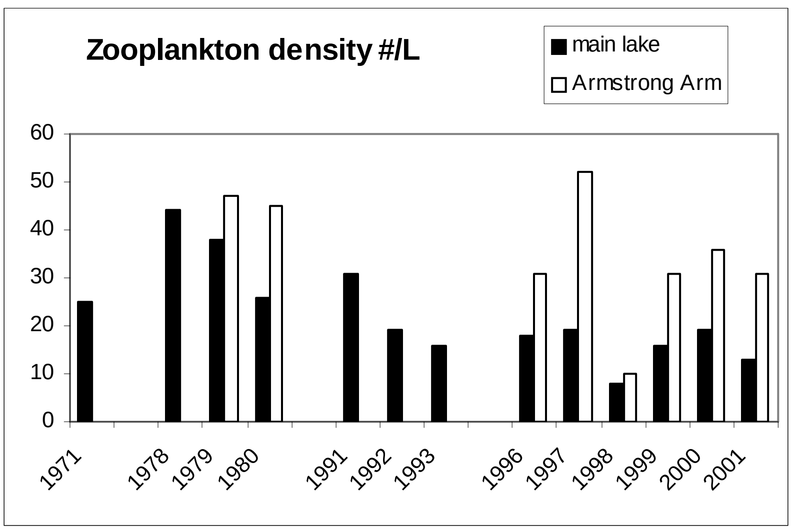


Figure 9: Total Zooplankton density (#/L) in main body and Armstrong Arm of Okanagan Lake, 1971 to 2001

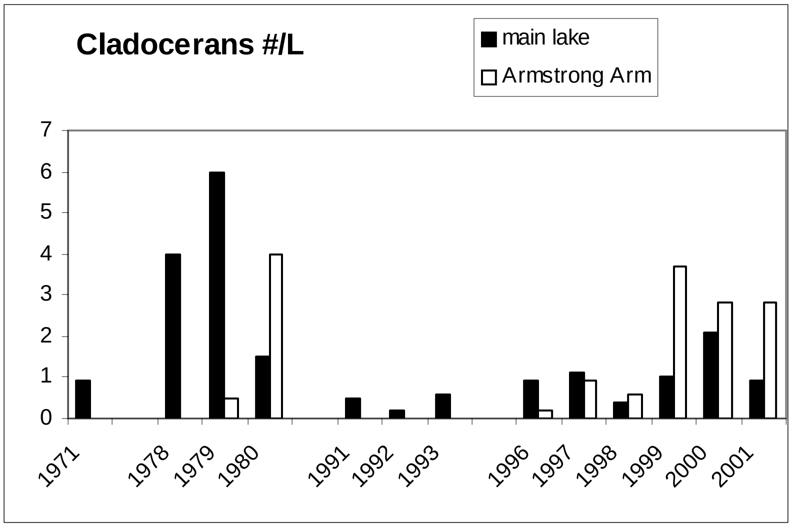


Figure 10: Cladoceran density (#/L) in main body and Armstrong Arm of Okanagan Lake, 1971 to 2001

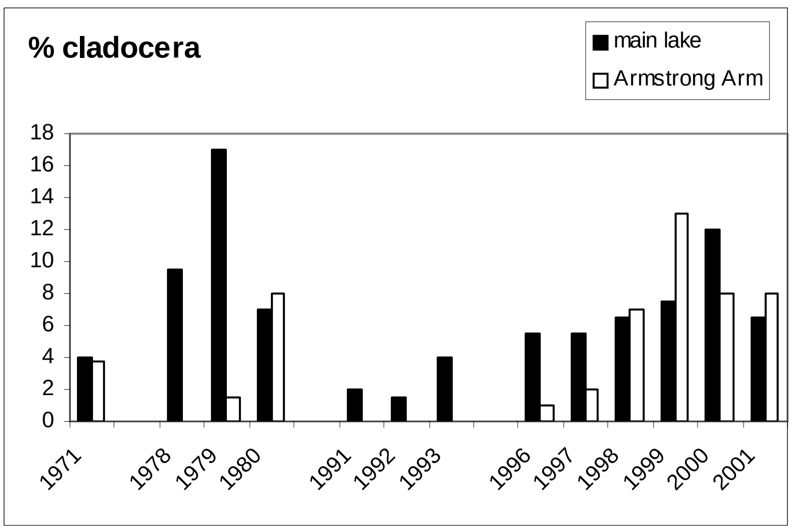


Figure 11: Percent Cladoceran in zooplankton in main body and Armstrong Arm of Okanagan Lake, 1971 to 2001

Much additional insight regarding the details of zooplankton population dynamics has been gained during the OLAP project which began a systematic full summer zooplankton sampling program in 1996. The data for 1996 and 1997 were compiled and interpreted by McEachern (1998). She reported that the numbers and relative proportions of copepods to cladocerans were comparable to previous surveys done for Okanagan and Kalamalka Lakes (Shepherd (1993), Pinsent and Stockner (1974). In the Year 3 OLAP report, McEachern (1999) reviewed the 1996-1998 data. These data also provide additional information and allow comparison to earlier data. One of the specific concerns is the relative contribution of cladocera (a preferred fish food item) to the overall crustacean zooplankton numbers. McEachern reported that the 1996-1998 data seemed to indicate higher percentage of cladocera but lower overall numbers of crustacean zooplankton in the most recent sampling years. Wilson (2000) added the 1999 data and provided some comparisons to previous years and to other BC lakes. He noted that Okanagan Lake has a slightly lower percentage of cladocerans in comparison to Kootenay (fertilized), Arrow and Alouette (but similar to Kalamalka). The 2001 data were reported in the Year 6 OLAP report by Wilson and Vidmanic (2001). The authors provide an excellent summary of the most current interpretation of trends in the historical time scale and the present situation. The key points from Wilson and Vidmanic (2001) are:

1. There is a north to south trophic gradient of zooplankton with higher biomass in the north basin and less in the central and south basins (as is the case with phytoplankton).
2. Vernon and Armstrong Arms show higher biomass because of their shallow morphometry and higher nutrient concentrations.
3. Cladocerans account for 5-7% by numbers but 15-20% of average annual crustacean zooplankon biomass. This is similar to Kootenay Lake.
4. There appears to be reasonably consistent cladocera and copepod densities over the past 20 years but some decrease, although not significant.
5. Cladoceran populations form, peak and decline quite quickly (generally in August) in comparison to copepods, and the timing of sampling is critical for evaluation of this component of the zooplankton population.

Some of these same observations were also contained in the Hall *et al.* (2001) summary. They noted that the zooplankton population had not varied greatly in the period 1970-2000 and there were no major shifts in species composition. They did feel that the zooplankton density of Okanagan Lake was low for the size and production capacity.

3.2.6 Benthos

A very detailed survey of the benthic communities of Okanagan Lake was done as part of the Okanagan Basin Study (in Saether (1970) and Stockner and Pinsent (1974)). However, since the OBS study there have been no efforts to repeat this work or use benthos as a means of evaluating environmental quality. For Okanagan Lake, Saether felt that, based on the shallow water benthic fauna of 1969 compared to the data collected by Rawson in 1935, the lake had become more productive over the preceding years. He estimated the increase to be eight-fold.

Saether (1970) found evidence that some areas of the lake were receiving pollutants because of the presence of pollution-tolerant organisms. He also noted that some areas had a high occurrence of deformed chironomids, suggesting damage from insecticides while

Stockner and Pinsent (1974) noted that the fauna of the deep water sediments "showed no apparent change over the 1935 condition".

3.2.7 *Mysis*

Mysis relicta are now an important component of the biology of Okanagan Lake and have been the subject of considerable attention, especially during OLAP. *Mysis* were introduced into Okanagan Lake in 1966 by fisheries managers as a means of enhancing fish production. The introduction of *Mysis* was first suggested by Rawson to enhance lake whitefish and later implemented after the apparent enhancement of kokanee growth rates in Kootenay Lake after the introduction of *Mysis* (later proven to be an erroneous conclusion). The present view is that the large numbers of *Mysis* in the lake are negatively affecting kokanee stocks since they compete with the juvenile kokanee for food (zooplankton and specifically large cladocerans). This is one of the major issues, the trophic relationship between *Mysis* and cladocera, and whether cladocera were a major food source for *Mysis*. This question was investigated by Whall and Lazenby (2000). They concluded on the basis of stomach contents, bioenergetics and stable isotope analyses that the *Mysis* competition for zooplankton alone would not account for the decline of kokanee in Okanagan Lake.

The situation with *Mysis* has been documented by several studies as part of OLAP (Lazenby, 1996, Whall and Lazenby, 1998, Quirt and Lazenby, 1998, McEachern, 1999, Whall and Lazenby, 2000). The historical background was well summarized in the Year 4 OLAP report by Andrusak (2000) and the sampling results by Wilson and Vidmanic (2001, 2002). *Mysis relicta* abundance and biomass estimates are presented in Table 12.

Table 12: Average seasonal (May to October) abundance and biomass by station of Mysis relicta in pelagic and near shore sample hauls from seven sample sites in Okanagan Lake (1997-2001) (after Wilson and Vidmanic, 2002)

	OK1	OK3	OK4	OK5	OK6	OK7	OK8
Numbers /cm^2	239	356	254	218	282	846	280
Numbers /cm^2	90	168	124	154	131	252	163
Biomass pelagic (g/m^2 dw)	1.9	3.6	1.9	1.5	2.0	9.1	3.6
Biomass near-shore	0.7	1.4	0.7	0.8	0.9	2.7	1.9

Another area of interest is the distribution. It seems clear from the data collected (Table 13) that the density of *Mysis* is at least twice as high in the deep water pelagic areas as the shallow areas. The following table is from Wilson and Vidmanic 2002.

Table 13: The average seasonal (May to October) abundance and aerial biomass by year of Mysis relicta in the pelagic and near-shore sample hauls of Okanagan Lake (1997-2001). Results for all stations are combined except those in Armstrong Arm

		Abundance (#/m^2)				Biomass (g dry wt /m^2)	
Year		Near-shore	Pelagic			Near-shore	Pelagic
1997		130	314				
1998		128	427				
1999		68	225			0.48	2.72
2000		128	429			0.56	3.16
2001		312	436			2.55	4.33
Average		153	366			1.20	3.33

What the sampling results suggest is that *Mysis* have had relatively stable numbers over the past five years with some year-to-year variation (about a factor of two difference in annual means between high and low years).

3.2.8 Fish

The history of the fishery on Okanagan Lake evolved from initial exploitation by settlers and native peoples for food sources in the early part of the century, to a sport fishery in Okanagan Lake which declined in the 1940's due to increasing populations. Commercial fisheries were also present in the 1920's and 1930's, diminishing in the 1940's but continuing through the 1960's.

In 1935, Clemens *et al.* (1939) described the fisheries of the lake in some detail. They were primarily concerned with the low fish productivity and made some suggestions for enhancing fisheries. Kokanee received little attention – there was no mention at that time of large numbers of fish or spawning populations and few data were available. To directly quote from that paper, "Information concerning kokanee is so meager that no policy can be presented. The obvious importance of this species to trout (rainbow) production has been pointed out and it is possible that investigation may reveal that the kokanee production may be so managed as to provide a limited supply for human use as a well as a food supply for the trout".

As part of the Okanagan Basin Study, additional data were gathered for Okanagan Lake. They reported 15 species:

Oncorynchus nerka (kokanee)
Oncorynchus mykiss (rainbow trout)
Prosopium williamsoni, (mountain whitefish)
Lota lota (burbot)
Coregonus clupeaformis (lake whitefish)*
Catostomus macrocheilus (largescale sucker)
Catostomus catostomus (longnose sucker)
Cyprinus carpio (carp)*
Ptychocheilus oregonensis (northern pikeminnow)
Mylocheilus caurinus (peamouth chub)
Acrocheilus alutaceus (chiselmouth)
Richardsonius balteatus (redside shiner)
Rhinichthys falcatus (leopard dace)
Cottus asper (prickly sculpin)
Cottus cognatus (slimy sculpin)

Lake whitefish and carp (marked with an asterix) are not native to the lake. Carp were not reported in the 1935 survey (Clemens *et al*., 1939) but were present in the 1971 OBS survey. The species most important for recreational sport fishing are kokanee and rainbow trout. Lake trout, mountain whitefish and lake whitefish are also caught by recreational anglers (Shepherd, 1994).

Lake trout (*Salvelinus namaycush*) were reported from Kalamalka Lake in the 1971 survey but not from Okanagan Lake. However they were subsequently (1990-91) reported to be in Okanagan Lake, apparently as a result of downstream migration from Kalamalka Lake (Shepherd, 1994). Yellow perch (*Perca fluviatilis flavescens*) were reported as a growing sport fishery in the north part of the lake (Shepherd, 1990). Sebastian and Scholten (2001) reported that pygmy whitefish (*Prosopium coulteri*) were present in trawl catches in 1999 and 2000. Pygmy whitefish were also reported from Skaha Lake in 1971 (Pinsent and Stockner,1974) but not in Okanagan Lake at that time.

Stocking of non-indigenous fish began as early as 1894 when 1.5 million lake whitefish (*Coregonus clupeaformis*) were stocked in Okanagan and Kalamalka lakes. A variety of private and government agency efforts attempted at various times to introduce Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), steelhead (*O. mykiss*), whitefish, brook trout (*Salvelinus fontinalis*), and even mosquitofish, *Gambusia*. (Bull 1983).

The most numerous species, as indicated by standard net sets in the 1971 OBS survey, were kokanee (35%), peamouth chub (24%), northern pikeminnow (11.5%) lake whitefish (10%) and largescale sucker (7%). There are some differences in densities in different parts of the lake but it is difficult to draw any consistent patterns.

The OBS fish study compared the numbers of fish caught in the 1935 survey and the 1971 survey at comparable sites. The numbers were quite comparable (490 fish for 1935, 501 for 1971). Pinsent and Stockner (1974) interpreted that the apparent change in trophic structure had not affected the fish populations in Okanagan Lake. In a comparison of the size of fish species for Skaha Lake, there was a noticeable increase between fish collected in 1948 (Ferguson) and fish in 1971. No change in the size of Okanagan Lake rainbow trout was seen between 1935 and 1971 (apparently it was the only fish species examined).

Larkin and Northcote (1969) used the relative abundance of salmonids-to-coarse fish as an index of trophic status and as a ranking tool for the Okanagan lakes. Okanagan and Kalamalka lakes were the most oligotrophic lakes and had the highest salmonid-to-coarse fish ratios.

3.2.8.1 Kokanee

Kokanee are regarded as the most important species in Okanagan Lake, especially with respect to the sport fishery over the last 20 years. Their decline in the 1980's caused much concern and resulted in the establishment of the Okanagan Lake Action Plan (OLAP).

There are two distinct populations of kokanee in Okanagan Lake: a stream spawning population and a shore spawning population. They differ in the timing and behaviour at spawning, as well as size and possibly age at maturity (Shepherd 1990). The numbers of stream spawners are summarized in the Figure 12.

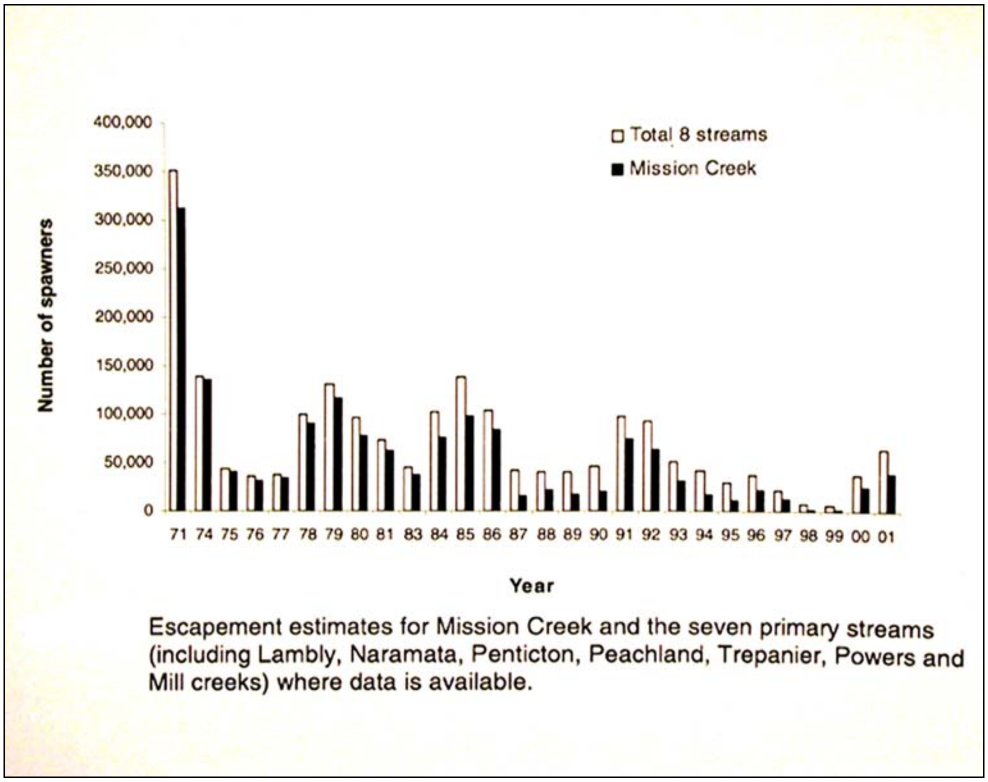


Figure 12: Escapement of stream spawning kokanee in Okanagan Lake (Webster and Andrusak, 2002)

The stream spawning kokanee originate primarily from six streams: Mission (the most important), Lower Vernon, Powers, Peachland, Kelowna and Trepanier creeks, plus a hatchery supported population in Penticton Creek. There are small numbers that use some of the smaller tributaries for spawning as well. The shore spawning populations use areas of the north basin for spawning as well as the area around Squally Point. Escapement of Okanagan Lake shore spawning kokanee is illustrated in Figure 13. There is much more confidence in the present than the earlier estimates and the current belief is that the majority of kokanee in Okanagan Lake are shore spawners (Andrusak and Sebastian, 2000).

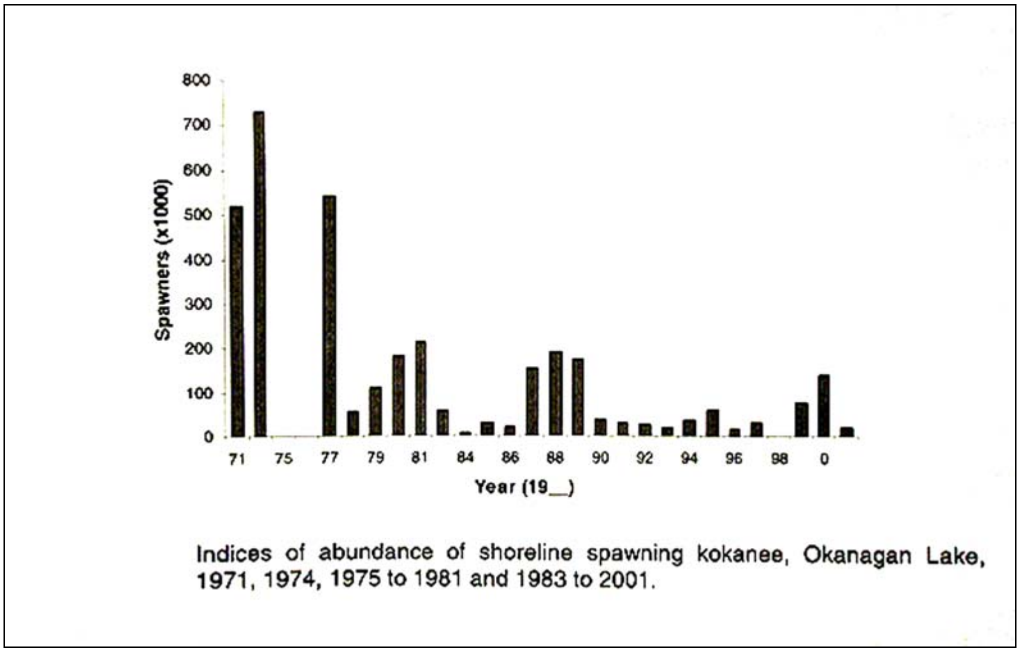


Figure 13: Escapement of shore spawning kokanee in Okanagan Lake (Andrusak et al., 2002)

Much effort has been made in recent years to restore some of the damaged stream habitat but low flows are a major problem in many small streams. Galbraith and Taylor (1969) (cited in Bull, 1983) estimated that by the mid 1900's, 93% of the historical spawning areas in the major tributaries to Okanagan Lake had been lost to irrigation dams, stilling basins and channelization. Northcote *et al.* (1972) also identified the lack of stream spawning habitat. The shore spawning populations have also been impacted through the loss of natural shore habitats (Northcote and Northcote, 1996).

Life history

The stream populations spawn in September and October while the shore spawners tend to spawn in the last two weeks of October. The fry emerge in late December and January. Kokanee spawning habitat potential in creeks is a subject of some interest. Shepherd (1990) estimated 219,100-404,700 potential spawners in seven creeks. Shore spawners also have specific habitat requirements and tend to use very shallow waters (<1 meter) (Andrusak *et al.* 2002).

The feeding habits in the early life stages of kokanee are entirely planktiverous and they may be competing directly with *Mysis* for food. As they grow larger, *Mysis* increasingly becomes a part of their diet. This is illustrated in Figure 14 (Shepherd, 1994). Kokanee stomach contents sampled from 1987-1992 indicated the major food types were copepods (29%), *Mysis* (22%), unknown plankton (12%) and larval insects (11%). Thirty percent of the fish sampled in this work had empty stomachs.

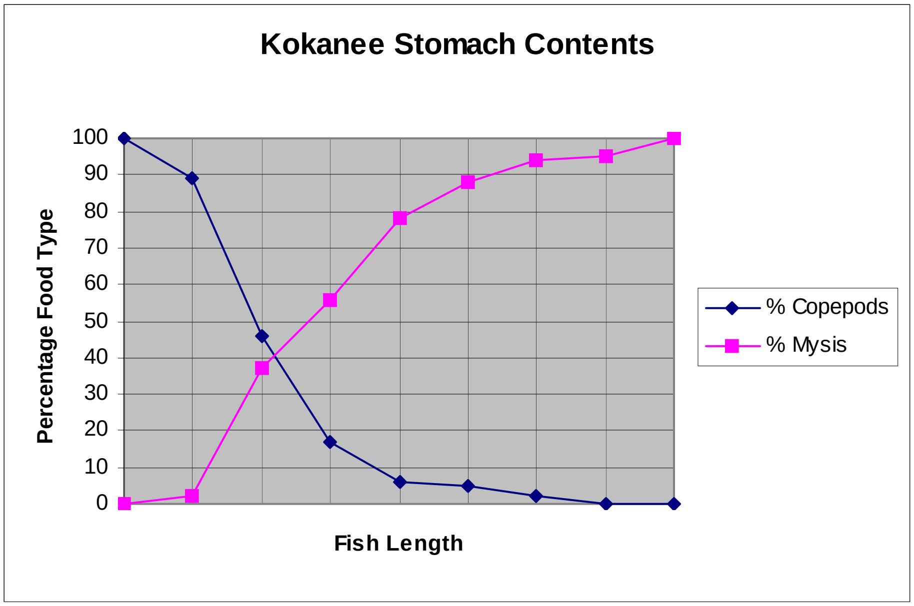


Figure 14: Kokanee stomach contents (percentage food type versus fish length)

There was little information on population estimates of individual fish species until hydroacoustic technology became available. Most of the effort in this regard has been directed toward kokanee. In the most recent review of kokanee abundance, the pelagic estimates the range from 3 to 14 million fish between 1988 and 2000 (Sebastian and Scholten, 2001). Parkinson (1986) stated that the fish density of kokanee in Okanagan Lake was 276 fish/ha with a total population estimate of 9.6 million. The weight for kokanee (September) was estimated at 1.3 g for age 0+, 14 g for 1+, and 103 g for 2+.

Kokanee Harvesting

Bag limits for Kokanee have changed considerably over time. Up to 1967 there was no limit, in 1968 daily catch was limited to 25 fish, in 1981 daily limit was 15, then decreased to 10 fish in 1985, then to five fish in 1989. The sport fishery was finally closed in 1995.

Bull (1987) estimated the annual kokanee catch for 1980 to be 222,867 and 13,109 for rainbow trout.

Shepherd (1990, 1994) gives rates for harvest for rainbow trout and kokanee in Table 14 and 15. The differences between the catch and kill numbers in Table 15 is the use of catch and release techniques by fishers.

Table 14: Catch and release estimates for Okanagan Lake kokanee and rainbow trout (Shephard, 1990)

	Total catch		Total kill		Kokanee exploitation rate	
	KOK	RBT	KOK	RBT	total	stream pop
1971	239K	11K	239K	11K	19%	34%
1988	118K	14K	88K	12K	26%	59%
1989	111K	24K	75K	18K	24%	>100%

Table 15: Estimates of Okanagan Lake kokanee and rainbow trout harvest (Shephard, 1994)

	KOK	RBT
1971	178,000	8,000
1988	63,000	20,000
1989	52,000	25,000
1990	21,000	23,000
1991	23,000	23,000
1992	19,000	14,000

There are several possible causes for the decrease in kokanee numbers in Okanagan Lake. Bull (1987) identified the following reasons :

1. introduction of carp, whitefish, mysid shrimp and Eurasian milfoil;
2. loss of spawning habitat and quality of spawning habitat due to channelization, dam construction and diversion of water for irrigation and domestic use; and,
3. increase in fishing pressure with increasing human population near the lake.

There have been numerous cases where the introduction of *Mysis* into lakes has caused kokanee populations to decline. The most well known of these include Lake Tahoe (Morgan *et al.* 1978, Richards *et al.* 1991) where both kokanee and subsequently *Mysis* were introduced, Flathead Lake where lake trout and whitefish population increases and kokanee declines have been linked to *Mysis* introductions (Rieman and Falter, 1981, Chess and Stanford, 1998, Tohtz, 1993) and Kootenay and Arrow (Ashley *et al.* 1997, Northcote 1973) reservoirs where reduction in nutrients was also a factor. Similar declines in kokanee under a variety of different circumstances have taken place in Priest Lake, Lake Coeur d'Alene and Lake Pend Oreille.

Much of the recent focus of OLAP has been on the limitation of kokanee production by food availability ("bottom up" control) and discussion of a "trophic bottleneck" – a poor energy transfer from phytoplankton to zooplankton. The phytoplankton - animal interface is the most variable and least predictable link in lake food chains (Muller-Navara *et al.*, 2000, Brett and Goldman, 1997, McQueen *et al.*, 1989). There has been considerable evidence provided in the literature that at the top of the food chain, fish provide "top-down" control, and can be a far more important factor (McQueen *et al.*, 1986, 1989), especially in oligotrophic systems.

There has been considerable concern expressed regarding the vulnerability of kokanee where the stocking of rainbow trout has been used as an enhancement strategy. Rainbow trout were stocked in Okanagan Lake from 1978-1983 as a fisheries enhancement technique. At present, with a closed sport fishery on rainbow trout, kokanee may be under considerable pressure from the species that prey on them, rainbow trout, in the absence of any predation on the rainbow trout by a top predator (e.g., through fishing pressure). The kokanee in the late 1970's and early 1980's would have been in a particularly vulnerable position with competition from *Mysis* for their food supply and enhanced populations of their main predator. In the light of this, a collapse of kokanee stocks is not surprising.

This vulnerability of kokanee to increased numbers of rainbow trout was emphasized by Bull (1983) in discussing the effects of a rearing facility at Kelowna which was designed to enhance rainbow stocks. Stocking of 15,000 –20,000 rainbow fingerlings increased harvest rates by 30-40% in the late 1970's and early 1980's (Bull, 1983). He was concerned that these cultured fish would both jeopardize natural stocks of rainbow trout and the kokanee numbers due to increased predation. Shepherd (1990) indicated that an evaluation had begun in 1988 to assess the success of the seven-year supplemental stocking of rainbow trout from 1978-1983.

In other large Pacific Northwest lakes, *Mysis* and kokanee (as well as other fish) introductions have presented major changes, especially in declines of kokanee. At Lake Pend Oreille in Idaho one of the recommendations for recovery of kokanee has been enhanced harvesting of rainbow trout and lake trout.

Figure 15 is from Shepherd (1996) and shows an increase in numbers of rainbow trout (as indicated by catch rates) that are coincident with decrease in numbers of kokanee (also indicated by catch rates).

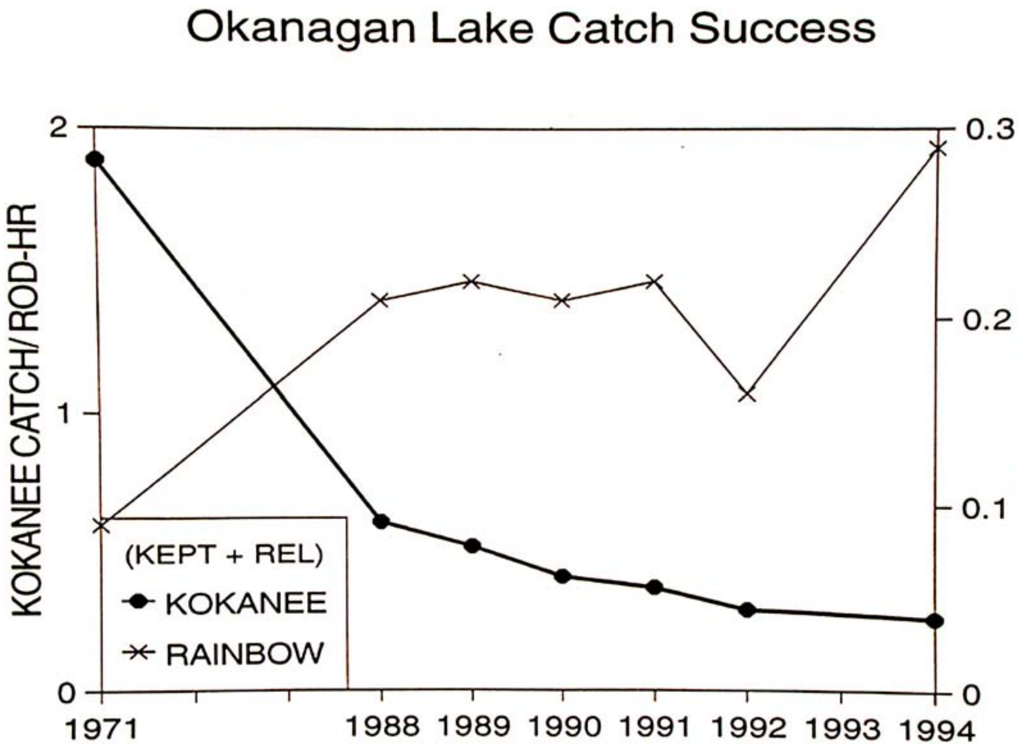


Figure 15: Numbers of rainbow trout (as indicated by catch rates) and kokanee (also indicated by catch rates). from Shepherd (1996)

There have also been large die-offs of kokanee in Okanagan Lake in recent years that could affect population numbers. There is no confirmed explanation, but these die-offs have happened in other large kokanee bearing lakes as well. Between 30,000 and 100,000 fish (age 2+) died in Okanagan Lake in 1986 and 1989.

In 1979 and 1980, the estimated harvest of rainbow trout was 6,000 to 13,000 fish. The estimates for returning adult spawners was about 700 fish. The estimated consumption of kokanee by rainbows (per year) at that time was estimated be between 160,000 and 250,000 fish (Bull, 1983). The annual harvest of kokanee by recreational anglers at the time of the report was 200,000 fish. With escapements declining from 700,000 in 1974 to 200,000 in 1982, there was some concern that the exploitation rate of kokanee was far too high (Bull, 1983).

3.2.8.2 Rainbow Trout

As in several other large lakes with kokanee populations, there is a large picivorous rainbow trout population which uses the kokanee as a major food source. In Kootenay Lake, it is the Gerard rainbow trout and in the Arrow Lakes system there is an ecologically equivalent strain of rainbow trout.

Shepherd (1990) estimated of rainbow trout adult production in Okanagan Lake at 1,100 -1,700 fish per year. Rainbow escapement counts are available from Mission Creek for 1975-1979 and are between 245 and 573 fish (Shepard, 1990).

Attempts at using hatchery stocks to enhance the lake fisheries was curtailed in the 1960's in response to negative experiences with this strategy (Shepherd, 1990). In the late 1970's, attempts were made to enhance the rainbow populations by releasing Gerard strain hybrids from a rearing pond on Mission Creek (Shepherd, 1990).

It seems that rainbow trout populations, which likely fluctuate over a wide range, will have a significant effect on governing the kokanee populations. The rainbow trout and kokanee harvest rates for the years for which there are some data are shown in Figure 16.

No clear goal has been established for a desirable kokanee population in the lake. The first survey in 1970 of one million spawners is sometime used as a point of reference. However, there has been some questioning of the accuracy of earlier data and the laek was receiving a greater point source nutrient load than at present.

3.2.9 Comments on the data describing the aquatic resources of Okanagan Lake

The components of the biological community are very difficult to quantify. It is a very complex and dynamic system. There is considerable variability from year-to-year which is difficult to explain, much less predict. The different components of the biological community are known at different levels of detail. We have a reasonable idea of the present phytoplankton community in terms of dominant species and the relative size of its standing crop. The magnitude of productivity and what governs the growth of the phytoplankton over the course of the year is still the subject of some discussion.

The range of annual phytoplankton biomass seems to vary over a factor of about two for seasonal means (chlorophyll between 3-6 µg/L) and a factor of 10 for variation within a year (highest to lowest monthly measurements is typically 1-10 µg/L). Cell numbers have similar ranges: a factor of two between years (3000-5000 cells/mL for cell numbers) and biomass. Variation between months within a year varies by up to a factor of 10.

Almost nothing is known of the bacterial biomass and physiology (respiration rates, oxygen consumption and substrate preferences).

Little is known of the importance of the micro-zooplankton (protozoans and rotifers). Some very basic data are contained in the annual monitoring data for zooplankton carried out by the Ministry regional office and by Shepherd (1993). These data were collected coincidentally when crustacean zooplankton were collected. The smaller zooplankton may play a very important role in the transfer of energy in the lake.

Nothing is known of the present state of the benthic community of Okanagan Lake. The detailed work of Saether (1970) has not been followed up on. The benthos are an important environmental indicator and likely a major source of food for many fish including juvenile rainbow trout. Benthos are likely a good indicator of environmental conditions especially near outfalls and urbanized areas.

Zooplankton community structure and standing crop are probably as well known as might be expected. The year-to-year variability in zooplankon biomass seems to be about a factor of three (between 1997 and 2001, with ranges from a low of 8/L (1998) to 25/L (1999) (Wilson and Vidmanic 2002). Some measurements of zooplankton production would be useful. This is particularly important if issues like food suitability and trophic transfer and are to be addressed.

The knowledge of fish population numbers is still at a very rudimentary stage. Considerable effort has been placed on kokanee and a reasonable estimate and technology (hydro acoustics) now exists for in-lake populations. Estimates of escapement, especially for shore spawners, is still in need of improvement to provide high confidence in the data. Annual estimates over the past 15 years for kokanee in the lake vary over a considerable range, as do the estimates of spawner numbers.

It has been acknowledged that fish numbers are highly variable from year-to-year and there should not be any expectation for stability in numbers, especially for exploited populations (Rose *et al*., 2001). Defining quantified goals for fish populations and management policies to achieve the goals would be helpful.

Recent, even approximate estimates of population numbers for fish species other than kokanee and rainbow trout are not available. The interaction between species is likely important and numbers of recently introduced species (e.g., perch, lake trout) would be particularly useful.

There are a number of readily available diagnostic measurements which would provide additional understanding of trophic relationships. It would certainly be useful to have stable isotope analyses done on all the major components of all the trophic levels. Measurements to provide an indication of nutrient limitation (alkaline phosphates, N and P uptake rates) are needed. In addition, the analysis of C:N:P ratios of phytoplankton and zooplankton at different times of the year would be very useful in evaluating limitation of production.

3.3 Recreational Use

Phipps and James (1980) conducted a survey of water-based recreation for the Okanagan Implementation Study building on a similar survey done in 1970 (O'Riordan and Collins). The survey indicated the beach days in 1980 was 7.2 million, which was higher than the predictions made in 1970. Projections to the year 2000 were for 9.9 million beach days. The survey indicated tourists spend 80% of their vacation days at the beach and the average length of stay was 9.7 days. The relative importance of activities associated with water were, in order, swimming (73%), sunbathing (53%), water skiing (13%), boating (12%), hiking (8%) and fishing (6%). Water quality was identified as one of the major considerations for tourist beach users (58.5%) along with safety (58.5%) and scenery (63.4%). Proximity, lack of crowds and beach quality were also considerations.

McNeil (1983) found a significant relationship between water quality and beach use in the Okanagan. His evaluation was that a decrease in water quality from oligo-mesotrophic to mesotrophic over a 10 year period would result in an annual beach day loss of 196,000 and $2 million per year for two large and two small beaches. He calculated a "present day value" (in 1982) of the losses for those four beaches to be about $15 million.

Shepherd (1990) estimated the Okanagan Lake recreational sport fishery to be about 72,000 angler days and valued at $2 million per year.

4.0 INFLUENCES ON WATER QUALITY

There are numerous natural processes and human activities which affect the water quality of Okanagan Lake. Describing and quantifying the range of influences is a difficult task. The two major influences which are considered here are nutrients and hydrology.

Nutrients have been the object of most of the pollution control efforts since phosphorus was identified as one of the major influences on an easily perceived attribute of water quality (algal growth and water clarity). Considerable efforts have been made by a variety of individuals and agencies to quantify the nutrient loadings since the Okanagan Basin Study first attempted it in the early 1970's when nutrients were recognized as an important issue in the protection of the lake resource. However there has been less effort to examine other potential pollutants (toxicants for instance).

Prior to the Okanagan Basin Study, there was little experience in doing large multidisciplinary studies involving different levels of government on large watersheds. A comprehensive assessment of water and fisheries resources conducted during the OBS identified point and non-point source control of phosphorus (P) as essential to preventing nuisance algal blooms and controlling the rate of eutrophication of surface waters in the Okanagan Basin (Haughton *et al*., 1974a). These sources were prioritized and recommendations made to improve the discharges. The major point sources of phosphorus identified in 1970 included the municipal effluent discharges from Armstrong, Vernon, Kelowna, Westbank, Penticton and Oliver, as well as industrial discharges from a trade waste treatment plant in Kelowna and the Summerland Fish Hatchery. The diffuse sources of phosphorus identified in 1970 included: agriculture (livestock waste and fertilizer); septic tank systems (on-site sewage disposal); miscellaneous sources (pets and lawn fertilizer); and, dustfall and precipitation; and, watershed sources (natural and upstream lakes). Agriculture and septic tanks were considered as controllable sources while dustfall, precipitation and watershed sources were thought of as uncontrollable**.** The point source nutrient loads were quantified relatively accurately through regular measurements of volumes and concentrations in the discharges during the study and are the basis of the management policies that were followed over the next 20 years (highest priority being the reduction of nutrients from sewage treatment plants).

Because they were more amenable to control strategies, point source control of P has been implemented progressively over the past three decades in many communities with the initial goal of 90% P removal. Subsequent monitoring during the Okanagan Basin Implementation Study documented water quality improvements in Vernon Arm (Truscott and Kelso, 1979; Jensen, 1981) following diversion of City of Vernon's effluent to spray irrigation disposal in 1977 (Bryan, 1987). Improvements were also observed along the City of Kelowna foreshore of Okanagan Lake following conversion of the Kelowna Sewage Treatment Plant to the Bardenpho tertiary process in 1983 (Bryan, 1990; Nordin *et al.*, 1990).

The strategy of tertiary treatment at sewage treatment plants seems to have resulted in major improvements in Skaha and Osoyoos lakes; however, it appears that in Okanagan Lake, the reduction of nutrient loading has resulted in only maintaining the lake nutrient concentrations. Although this might be seen as a limited success, it is a major achievement considering the increase in population. The decrease in point source loading seems to have been offset by an equal increase in non-point source inputs.

There have been a number of studies investigating long-term trends and responses to the changes in loadings or other conditions for both water quality of the lake and tributaries (eg Bryan 1987, Bryan 1990, Jensen 1999, Jensen and Epp 2002, Swain 1982, 1986, 1990a,b, 1994) and for fisheries (Bull 1983, 1986, Shepherd 1990, 1993, 1994, 1996 and the Okanagan Lake Action Plan reports).

4.1 Point Source Inputs

At the conclusion of the Okanagan Basin Study, efforts were made to reduce the major inputs of phosphorus from the sewage treatment plants. The goal at that time was a 90% reduction in phosphorus inputs to the lake from these point sources.

The emphasis on water quality protection has been directed toward the sewage treatment plants at the larger population centers. In 1970, the phosphorus discharged from the sewage treatment plants to Okanagan Lake was estimated to be 44 tonnes; by 1980 it was estimated to be 15 tonnes; by 1990, 5 tonnes; by 1994, 2.6 tonnes; and by 2001, 2.1 tonnes. Between 1970 and 1993, the volume of effluent increased from 8 Mm^3 to 12.6 Mm^3 (Forty, 1995).

It is fortunate that there are few direct discharges to Okanagan Lake remaining at present. This is partially a recognition of the value of the lake held by the public and, through them, of government agencies' policies and activities in water quality protection. The major manifestation of this came in September, 1985 the provincial government declared the Okanagan valley an Environmentally Sensitive Area under the *Environment Management Act*. This is the only time in the province this designation has been invoked.

The City of Vernon was the first city to act on reducing discharges to the lake. The strategy they have employed is spray irrigation of secondary-treated (trickling filter) effluent on agricultural land. The volume of discharge to the lake in 1970 was 2.2 Mm^3. By 1995 Vernon had 920 ha in use for effluent irrigation. The system also provides irrigation water for two golf courses, a city park, two forestry seed orchards, a tree nursery and private farmland (Forty, 1995). The annual volume of effluent produced by the City of Vernon is 5.2 Mm^3. The City of Vernon also has in-place an effluent discharge pipe at a depth of 60 m in Vernon Arm of Okanagan Lake. It was designed to be used if the amount of effluent produced exceeded the capacity of the irrigation system to dispose of the effluent (due to increased population, cool summer temperatures, overfilled reservoir). Discharges were made to the lake in 1984 and 1985 when storage capacity was low (Bryan, 1987). The rates of irrigation have been noted as being artificially high (higher than normal agricultural irrigation rates) in some years in order to preclude lake discharge. This has resulted in overland flow, surfacing of effluent, land sloughing and effluent in ditches. The results of monitoring of groundwater wells indicated that the groundwater P concentrations are not significantly different from any of the advanced wastewater treatment plants in operation at some of the other cities in the valley (120 µg/L) (Forty, 1995). However the concentrations are elevated and some P likely does reach the lake. Figure 16 is taken from Hall *et al.* (2001) and shows P concentrations at monitoring well E207932.

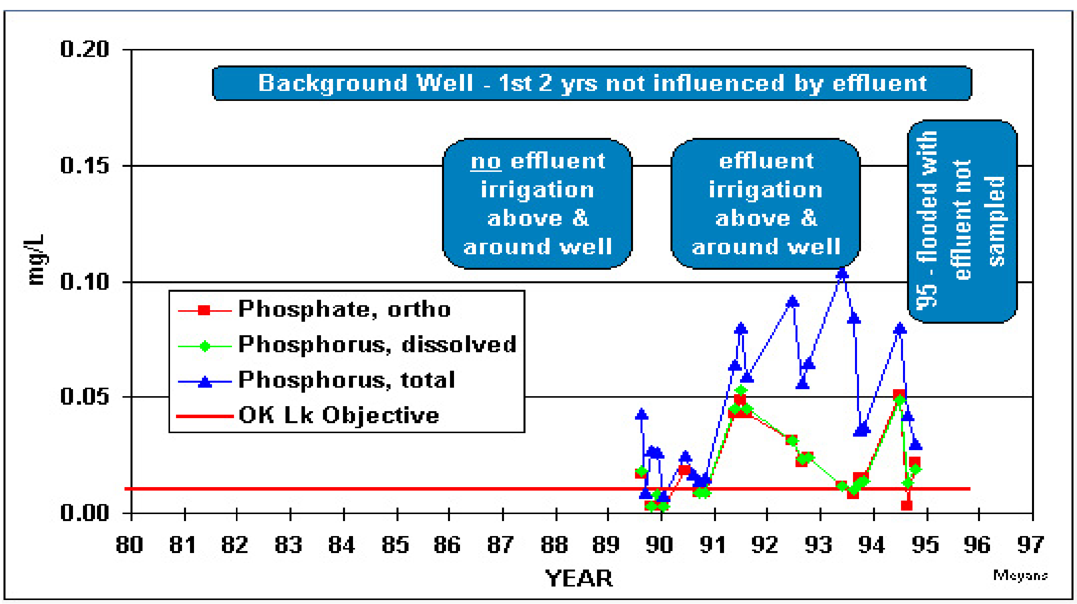


Figure 16: **Phosphorus in groundwater at Vernon effluent spray irrigation monitoring well E207932 (from Hall et al 2001)**

The City of Vernon is presently constructing a new sewage treatment plant. It will be designed for biological nutrient removal using the same process as the Westbank plant. This new plant is expected to maintain the option of discharging to the lake, however the effluent could also continue to be spray irrigated on agricultural land.

One drawback for the wastewater treatment plants employing spray irrigation (or septic tank discharges) is that while the wastewater treatment plants discharge at deep depths in the lake (typically 60 m), the return flow from the irrigation system enters the lake at the lake edge in shallow depths and contributes directly to the biologically active and productive surface and littoral waters. One of the concerns is increased attached periphyton and aquatic plant growth in these shallow water areas. This has consequences for fish spawning and rearing habitat, recreational use, and degradation of water withdrawals.

The City of Kelowna has operated an advanced wastewater treatment plant since 1982 which uses biological nutrient removal. Considerable effort and innovation have resulted in an increased efficiency of removal for both nitrogen and phosphorus over time (Barnard *et al.*, 1995). At present the effluent has a mean annual total phosphorus concentration of 130-150 µg/L and a mean annual total nitrogen concentration of 3.5 mg/L (nitrate 1.8 mg/L, ammonia 0.4 mg/L)(Hall *et al.*, 2001). The volume treated has increased from 2.5 Mm^3 in 1970 to 5 Mm^3 in 1986, 8.2 Mm^3 by 1996, and 10.3 Mm^3 in 2002. The present discharge volume is about 10 Mm^3/yr. The effluent is of very high quality as it is filtered, chlorinated and dechlorinated before being discharged at a 60 m depth in the lake. The wastewater characteristics at the Kelowna Sewage Treatment Plant are listed in Table 16.

Table 16 Wastewater Characteristics at the Kelowna Sewage Treatment Plant. Values in mg/L (from Hall *et al.* 2001)

	Influent	Effluent	Removal (%)
BOD		2.9	
Total N	37.5	3.47	91
Ammonia	21.4	0.38	98
Nitrate	0.27	1.86	adds (7X)
Total P	6.8	0.13	98
Ortho P	3.81	0.04	99

The Kelowna phosphorus load to the lake in 2002 (at 145µg/L and 10.3 Mm^3/yr) is 1.5 tonnes. The nitrogen load is 42 tonnes. The N:P ratio of the effluent is in the range 23:1 to 27:1.

Brandt's Creek Trade Waste Treatment Plant, prior to 1973, discharged untreated waste from a cannery and a winery into Brandt's Creek which flows into Okanagan Lake near Kelowna. Secondary treatment was installed in 1973 and tertiary treatment in 1987. The volume of flow was 50,000 m^3/a in 1970, rising to 400,000 m^3/a by 1986. A portion of effluent is diverted to the Kelowna Sewage Treatment Plant. When the Trade Waste plant effluent quality is within permit limits it is discharged to Brandt's Creek. In 2002, 72,800m^3 were discharged with a phosphorus load of 0.05 tonnes to Okanagan Lake via Brandt's Creek.

At Westbank (Regional District of Central Okanagan), a small (1.4 Mm^3/yr) plant serves a rapidly increasing population area. Sewage is also treated from Peachland which is brought to the plant by an in-lake pipeline. Inflow to the plant in 1986 was 0.2 Mm^3, increasing in 1996 to 0.75 Mm^3, and to 1.7 Mm^3 in 2002. The plant was constructed in 1989 and is of a similar design to the Kelowna plant. The discharge is by deep discharge via an outfall pipe at 60 m. Prior to 1989, the treatment provided was by aerated lagoons with discharge to Okanagan Lake via Westbank Creek. The volume at that time was about 1,000 m^3/d resulting in a loading of 0.5 to 0.8 tonnes per year. As the biological nutrient removal process is improved over time, a similar level of removal to Kelowna plant should be achieved (150 µg/L P, 3.5 mg/L N). With a discharge volume of 1.7 Mm^3 in 2002, at a concentration of 0.48 mg/L P, the annual phosphorus loading would be about 0.82 tonnes per year. The nitrogen loading is 5.1 tonnes/yr. Hall *et al.* (2001) estimated the N load at 5.5 tonnes in 1999. The N:P ratio of the effluent averages 26:1.

At the City of Armstrong, prior to 1992, secondary-treated effluent (aerated ponds) was discharged to Deep Creek which discharges into Armstrong Arm. In 1970 the effluent volume was 100,000 m^3/year but by 1985 the volume had increased to about 2,000m^3/d (800,000 m^3/a) with an input of 2.5 tonnes of phosphorus to Armstrong Arm. After 1992, a system of effluent storage, chlorination and irrigation was put in place and gradually implemented. In 1999, the last year of discharge, 193,600 m^3 were released for an estimated P load of 99 kg. No effluent was discharged to Deep Creek in 2000 to 2002. The water is used in the adjacent municipality of Spallumacheen on approximately 55 ha of agricultural land. At the present, there are no direct discharges to Armstrong Arm.

The District of Summerland operates a plant which serves the Summerland area. The plant provides tertiary treatment and the effluent is discharged to the lake through a deep outfall at 40 m. The discharge in 2001 was 578,300m^3/a (Jensen and Epp, 2002). The estimated loading would be about 175 kg/a. Hall *et al.* (2001) estimated the annual TN loading at 1.6 tonnes.

The Summerland Trout Hatchery has a permitted discharge to Okanagan Lake which contributes a relatively large volume of waste water but relatively low nutrient concentrations, resulting in an input of 200 kg P per year. The hatchery was established in the 1920's and the organic wastes received only primary treatment before 1976. Some improvements have been made since that time. Concern was expressed in the early 1980's for increased nitrate in the groundwater used for the hatchery (Shaunessy Spring). The increased nitrate was due to human activities in the recharge area (Swain, 1986).

The total estimated nutrient load from the three major point sources of Kelowna, Westbank and Summerland in 1998 was 56,600 kg of nitrogen and 1800 kg of phosphorus (Hall et al. 2001).

In addition to the nutrients, there are a variety of other more subtle contaminants that enter the lake through the sewage outfalls. Some are broken down by the treatment but others are not. There have been concerns raised in other areas about groups of chemicals like endocrine disrupters and pharmaceuticals; however, no data on these chemicals are available for Okanagan Lake. Heavy metals, like mercury, which may have been partially contributed through the sewage outfalls, were identified as a concern in the Okanagan Basin Study, as high concentrations were seen in some larger fish at the top of the food chain. Recent data (Figure 18) have shown the concentrations are lower than during the OBS study. Organic chemicals such as pesticide residues, DDT and PCBs were also raised as a concern at one time but there is only limited monitoring data of these persistent organic pollutants and no results that show particular problems (Figure 17/18). These contaminants can also be contributed by non-point source inputs (storm sewers, stream inflows, dustfall) and that may be the major pathway by which these persistent chemicals end up in fish.

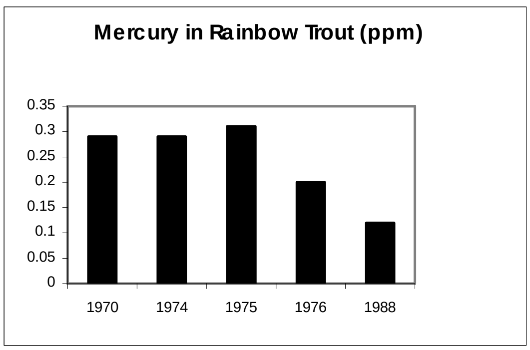


Figure 17: Mercury in Rainbow trout from Okanagan Lake. From Bryan and Jensen 1994, Okanagan Lake in The Book of Canadian Lakes. Can. Assoc. On Water Quality

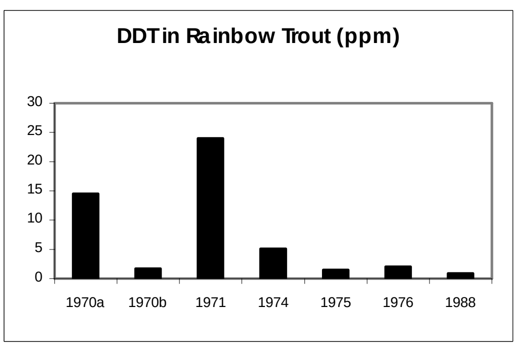


Figure 18: DDT in Rainbow trout from Okanagan Lake. From Bryan and Jensen 1994, Okanagan Lake in The Book of Canadian Lakes. Can. Assoc. On Water Quality

4.2 Non-point Source Inputs

At present, non-point sources of waste are the major inputs of pollutants to the lake. Setting objectives to manage these inputs is, in many cases, much more difficult than for conventional point source discharges. These non-point contaminants are potentially derived from urban storm run-off, agricultural activities, past logging operations, past mining activities and poorly maintained and/or located septic tank or tile field systems.

In contrast to the accurate and well documented inputs from the point sources of nutrients, the data for non-point inputs is far less quantified and certain. In all of the major reports that have been produced, the data have been qualified with caveats as to the accuracy of the data. Particularly difficult to determine the relative accuracy of are the estimates for septic tank nutrients that reach the lakes. The other components, in addition to septic tank inputs, that are used to describe the non-point component of nutrient inputs are agriculture and forestry. There is also significant input from stormwater runoff.

It is particularly relevant to understand the interaction of the flows of the tributary streams and the lake water. Stream water flowing into the lake from creeks during freshet does not flow into the lake at the lake's surface, but sinks into the warmer and less dense lake water, flowing into the lake at a depth which corresponds to the creek's density (primarily determined by temperature). Because the creeks are colder and carry more suspended and dissolved material than the lake, they settle in the lake at depths of the mid to bottom thermocline (15-25m). The streams thus deliver the nutrients and other materials to depths below the photic zone and do not provide direct supply to the phytoplankton at the base of the food chain. As the inflows become mixed in, some water and nutrients do become available to the surface water.

There have been two recent re-evaluations of the estimates for non-point contributions of nutrients to Okanagan Lake. The first has been adapted largely from Jensen and Epp (2002) and provides a good review and estimates on the relative loadings and in changes over time. The second is part of the OLAP program which was provided in the form of a CD by Hall *et al.* (2001).

Management of diffuse inputs began to be implemented by OKWATER (a Ministry of Environment program running from 1985 to 1994). It was recognized that further gains from point source reductions were limited because the very nature of diffuse source nutrients makes direct measurement of diffuse source loading very difficult if not impossible and forces reliance on estimates.

The magnitude of the diffuse source loading was first estimated in 1970 as part of the Okanagan Basin Study. Loading estimates tended to be reported in 10-year increments that reflect the original Okanagan Basin Studies 1969-1971, the Okanagan Basin Implementation Agreement studies finishing around 1980 and the OKWATER work of the late 1980's. The basis of the loading estimates and management actions to control diffuse sources of phosphorus are described below. Comments are also provided to give some context to phosphorus contributions from dustfall and precipitation and from watershed sources which would be comprised of natural sources plus urban stormwater and some portions of the forestry component.

4.2.1 Agriculture

Agricultural phosphorus loadings were first estimated in 1970 (Kennedy and Oldham, 1972) for two separate components: a) movement of phosphorus through soil from irrigated and/or fertilized cropland and b) direct runoff of animal wastes. Nutrient movement through soil from cropland was modeled on soil conditions (texture and depth to groundwater), irrigated acreage, climate (drier climate in south requires more irrigation and therefore is assumed to result in greater nutrient movement), and rate of fertilizer (including manure) application by sub-basin. Calculation of fertilizer application rates included a comprehensive inventory of fertilizer usage within the Okanagan Basin. Direct runoff of animal wastes was calculated by tabulating the potential phosphorus loading from the total number of animals on each individual farm and multiplying this by the proportion that was estimated to be lost on that farm through consideration of the waste handling facilities and management practices on that farm.

Re-evaluation of the agriculture P component during the Okanagan Basin Implementation Study (Kennedy, 1982) incorporated changes in the cropped / irrigated land base and used current soil data for the southern half of the Okanagan. The 1980 fertilizer loading / unit area in each sub-basin was left the same as in 1970. The 1980 estimated P loadings from fertilizer loadings are nominally higher due to more accurate soils information and increases in irrigated area (Figure 1) – where is this?. The 1980 animal waste runoff update included a review of current animal populations in each sub-basin, but unlike 1970, there were no on-site animal counts or management practice assessments, assuming that waste management practices remained constant in each sub-basin between 1970 and 1980. The latter point is a major flaw in the accuracy of the 1980 estimates, as the overall number of animals increased by a factor of about 2.6 times during this decade. However, the increased animal populations were typically associated with modern farms employing very different waste management practices than their predecessors. Agricultural loading estimates for 1980 are therefore shown as being at least two to three times higher than they likely were.

A new on-farm inventory of animal numbers and waste management practices was conducted in 1986 (Anon., 1986) as part of the OKWATER efforts. This study of 158 commercial beef, dairy, swine and poultry farms in the Okanagan Basin showed that while animal populations had increased 15% over the 1980 populations, the overall waste runoff was estimated to be an order of magnitude lower than calculated for 1980, but still a phosphorus source requiring on-going management. Agricultural control efforts during OKWATER dealt with the animal waste runoff portion of the agricultural load as this portion was readily identifiable, unnecessary and controllable when compared with the fertilizer component which is an integral part of cropping systems. Farms with identified waste runoff problems were prioritized and approached on an individual basis to undertake corrective actions. Annual helicopter overview flights were implemented in the spring of 1987 to ensure that all problems had been identified and that corrective actions were succeeding. Corrective actions included expanded as well as new winter manure storage facilities on dairy farms, relocation of feedlot pens and cattle wintering further from water courses, waste runoff control facilities at feedlots and changes to cattle management. Annual helicopter flights and follow up continued until 1996 by which time it was felt that most waste runoff problems had been dealt with. No effort was made to update fertilizer loadings during the latter 1980's as there appeared to be only nominal change between 1970 and 1980 and because fertilizer sources were not being targeted for reduction through the OKWATER efforts. Agricultural loading estimates for 1990 reflect a combination of the 1986 waste runoff inventory combined with a carry forward of the 1980 fertilizer loading estimates. Agricultural waste runoff is likely to have declined further during the last decade as farm-specific improvements continued to be implemented while fertilizer inputs are not anticipated to have changed significantly.

4.2.2 Forest Harvesting

Forest harvesting contributes phosphorus through increased erosion and sediment transport following soil disturbance along haul roads, landings and skid trails as well as channel disturbance resulting from riparian harvest and increased peak flows. Phosphorus loading from forest harvesting practices was estimated for the Okanagan Basin for the first and only time in 1981 (Alexander and Wiens, 1982). Thus, the 1980 nutrient loading values separated a logging (forest harvesting) component out of the watershed sources as another controllable diffuse source. The forestry loading model was based on one year of water quality data collected from eight sub-basins with variable amounts of harvesting in two south Okanagan watersheds. A unit area loading in relation to percentage of basin logged relationship was developed from these results and extrapolated to all other logged watersheds in the Okanagan Basin. The extrapolated loadings were then reduced based on bioavailability measurements and extrapolations, to come up with estimated loading of bioavailability phosphorus. This estimation technique is very coarse and subject to a variety of concerns including the limited duration of the sampling in relation to annual variability and the extrapolation of results from two south Okanagan watersheds, to over 33 other watersheds which differ in a variety of aspects, such as watershed size and terrain features.

The 1980 results have been carried backwards to 1970 and forward to 1990 with no extrapolation, thereby showing the forest loading as constant over time. It is difficult to project how logging-related phosphorus has changed since 1980. Initial efforts focused on reducing soil and riparian disturbance and associated erosion through better harvesting practices. This began with the Okanagan Timber Supply Area Timber Harvesting Guidelines which were instituted in 1991. These were superseded by the province wide *Forest Practices Code Act* which was implemented in 1995. Current logging disturbance levels do appear to be significantly lower than what was observed in the early 1980's. Some reduction of forest harvesting related sediment sources is anticipated from the Forest Renewal BC Watershed Restoration Program which began in the 1994 and ended on March 31, 2002. This program was oriented towards improving drinking water quality and fish habitat, but many of the measures implemented such as slide stabilization, road deactivation and stream bank stabilization will also reduce phosphorus movement. Uncertainty over the contribution from this sector remains however, as the total amount of land that has been harvested is still increasing, and older harvesting could have lingering effects, green-up and road deactivation notwithstanding.

4.2.3 Septic Tank Systems

Septic systems contribute varying quantities of phosphorus to Okanagan lakes depending primarily on the coarseness of the soil material, the depth to water table and the horizontal travel path to surface water. Septic tank phosphorus loading was first estimated in 1970 (Kennedy and Oldham, 1972), utilizing a transmission model similar to that used for agricultural fertilizer. The transmission model considered soil texture, depth to water table and horizontal distance to surface water as the factors that would determine how much phosphorus could move from a septic system to surface water. Individual house locations were determined relative to these boundary conditions to complete the loading model.

The Okanagan Basin Implementation Study (Kennedy, 1982) re-evaluation of septic phosphorus loading estimates used updated soils information to provide more accurate base conditions, but relied on population estimates of increased population on septic tanks in each of the major lake basins. The numbers were derived by taking population projections and subtracting the number of people known to be on sewer in each area. In hind-sight, the flaw in this approach was that it assumed that the new houses were spread throughout each basin in the same proportion, and on the same soil conditions as the older houses. In actual fact, the new growth tended to be concentrated in new subdivisions, thus population growth was not uniform across each sub-basin. The overall magnitude of the septic increase may have been reasonable, but the actual loading shown for any given sub-basin was open to question.

OKWATER (1985-1994) septic control efforts focused on identification of problem septic areas and formulation of sewer options through formal Waste Management Plans with local governments. Collection systems were expanded to collect sewage from problem areas around the existing systems in Vernon, Kelowna, Westbank, Oliver and Osoyoos. As well, new systems were put in-place in Summerland, Peachland, and Lake Country. Since 1990 there have been significant sewer extensions or new sewer systems to priority septic loading areas. There have also been significant sewer extensions for other reasons to areas which had lower identified phosphorus loadings. Enhanced sewage disposal regulations for environmentally sensitive areas were also implemented by the Ministry of Health in 1992 to limit new septic impacts in areas with high phosphorus transmission potential. Septic phosphorus loadings were re-estimated in 1987 (MELP, unpublished data), using an updated, computerized version of the 1970 model with new digital soil maps and with updated house locations from recent air photos. This provided precise loading and location information for waste management planning purposes, but the absolute magnitude of the loading remains an estimate rather than a measurement. It is likely that current septic phosphorus loading is significantly lower than in 1990 due to the sewer extensions and the probability that most new septic systems in rural areas are in less sensitive locations (e.g. non lakeshore).

4.2.4 Dustfall and Precipitation

Dustfall and precipitation loadings to the Okanagan lakes were first calculated as part of the Okanagan Basin Studies (Anon**.,** 1982). The estimation method used lake unit area loadings which were based on the analysis of samples from dustfall collection canisters placed in representative locations around the basin. Unit area loadings ranged from a low of approximately 0.1 kg of P /a / ha of lake area for Wood Lake to a high of 0.4 kg of P /a / ha of lake area for Skaha Lake. The material collected in the canisters is made up of dustfall from both natural and cultural sources as well as other components such as pollen and insects.

Additional measurements were conducted in 1982 and 1987, but no unit loading changes were recommended and so the dustfall and precipitation loading estimate has not been revised for either 1980 or 1990.

4.2.5 *Watershed Sources*

Watershed sources (Table 17) include everything else which is not included in the point source measurements and diffuse source estimates previously described. A large component of the watershed source load is associated with the natural erosion of soils and sediments. A variety of cultural sources, such as stormwater runoff and non-forestry related roads, would also be included in the results. Watershed sources were first calculated in 1970 as part of the Okanagan Basin Studies and then again in 1980 (Alexander, 1982) as part of the OBIA studies. The 1980 estimates were considered more accurate, and with no reason seen for change over time, the 1980 values are shown as a constant value for each time period. Watershed loadings are based on water quality measurements at the mouths of a number of Okanagan tributaries over several years. Any known or estimated point and diffuse source loads within those areas were subtracted from the calculated loads and the result was divided by the drainage areas to arrive at unit area watershed phosphorus loadings/a /ha of watershed area. The values used range from a low 0.08 kg P/a/ha in the Okanagan Basin to a high of 0.25 kg P/a/ha in the Kalamalka/Wood Lake Basin. The resulting values were further reduced to account for bioavailability which ranges from 16% to 95% in individual tributaries (Gray and Kirkland, 1986) and was estimated to range from an overall low of 43% for the Okanagan Basin to a high of 75% in the Wood Lake Basin. Storm sewer discharges were monitored for contaminants during the Okanagan Basin Study but not targeted for control strategies. During the Okanagan Basin Implementation Study, storm sewers were recognized as additional point source discharges in 1980 but again no control strategy was formulated. Waste management planning conducted by some Okanagan communities through the late 1980's and early 1990's considered this contaminant source, but progress on characterizing and reducing contaminant loadings from this source overall has been limited.

There are several factors that need to be considered when utilizing the watershed source estimates. First, the values reported are based on a limited data set, and may not accurately reflect average conditions. Second, tributary suspended sediment loads vary considerably from year-to-year in relation to total runoff and from day-to-day in relation to peak runoff events. It would not be unreasonable to expect that annual suspended sediment yields could vary by an order of magnitude. As such, annual watershed source loadings could be significantly lower in dry years and could be much higher in wet years. Finally, consideration of variable bio-availability, based on limited sampling, could further compound the variation from the expected result as per the estimates.

Table 17: Phosphorus loading in tonnes from different sources for the Okanagan Valley (adapted from Jensen and Epp (2002)

	Watershed	Forestry	Agriculture	Septic tanks	Sewage TP	Total
1970	42	8	5	8	59	122
1980	42	8	13	12	19	95
1990	42	8	2	18	8	78
2000	42	8	2	16	2	68

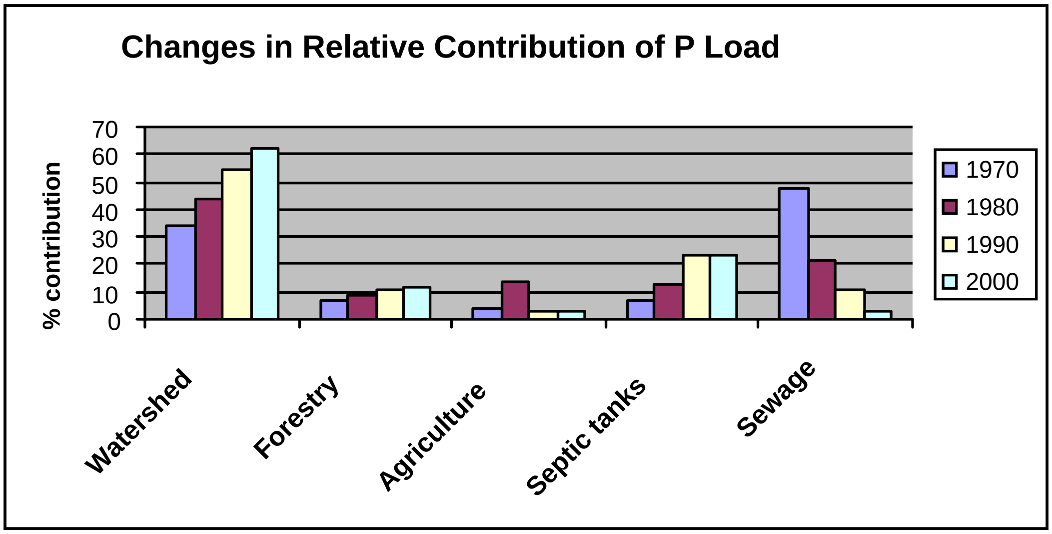


Figure 19: Changes in relative phosphorus loading by percent from different sources for the Okanagan Valley (adapted from Jensen and Epp (2002)

From the review of Jensen and Epp (2002) we can conclude the following:

1. the total phosphorus loadings to Okanagan Lake have decreased by about a third, in absolute terms, since 1970 (Figure 19).
2. the portion of P derived from sewage treatment plants (the point sources of P) have decreased from about half of the total loading to less than 3% .
3. the contribution from septic tanks has doubled in absolute terms and now represents about a quarter of P inputs into the lakes.
4. the contribution by agriculture and forestry are low and are not increasing according to the best available estimates.
5. background loadings (watershed runoff, precipitation and dustfall) represent about 60% of the loading to the lake, while non-point anthropogenic inputs (septic tanks, agriculture and forestry) represent about 40% of the phosphorus inputs.

The work of Hall *et al.* (2001) recalculated a number of the non-point source components and presents a different look at describing and quantifying the effects of these inputs on Okanagan Lake. The estimates from this work are quite different in some cases from Jensen and Epp (2002) as they are based on a number of different assumptions.

Hall *et al.* (2001) feel that agriculture did not represent a major contribution to the lake as most of the nutrients generated would be retained in the soil. The nitrogen loadings were quantified as negative (presumably meaning that there was no contribution to the lake due to agriculture) but some contributions from phosphorus were to be expected, especially in the north and south part of the valley (see Figure 20).

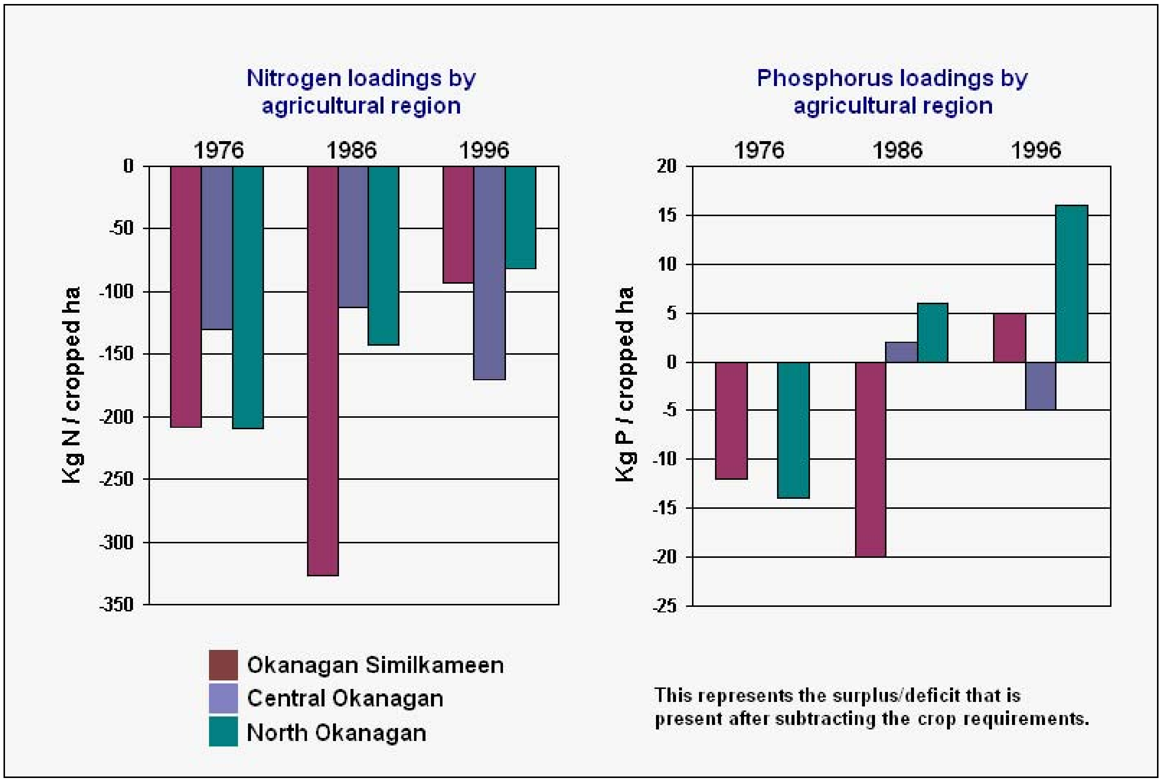


Figure 20: Nitrogen and phosphorus loadings from agriculture in the Okanagan valley (Hall *et al.*, 2001)

This interpretation of no inputs of nitrogen from agriculture seems at odds with previous evaluations and the subject of agricultural loadings needs to be re-examined in more detail.

Forest harvesting as a contributor of nutrients received a very detailed evaluation, focusing on Trout Creek as an example watershed. They made some comparisons between estimates derived from models and actual measured export and found them to be in reasonable agreement (Table 18).

Table 18: Trout Creek watershed export of nitrogen and phosphorus. (Hall *et al.*, 2001)

Trout Creek Watershed: Nutrient Export (kg/yr)

Nutrient	Nutrient form	Monitoring	Calculated
Nitrogen	Total Nitrogen (TN)	32,247	-
	Biological Available N	22,303	-
	Dissolved Kjeldhal N	-	27,826
	Nitrate	-	17,727
Phosphorus	Total Phosphorus (TP)	6665	-
	Biological Available P	1095	-
	Total Dissolved P	-	3,902

From their evaluation, Hall *et al*. (2002) found that the 1970 input estimates for forest harvest (8,400kg/a) did not need to be modified and that it was a reasonable representation. They also calculated the increases in export values that might be expected with increasing harvest within the catchment (Table 19).

Table 19: Trout Creek watershed export of nutrients from logging activities (Hall *et al.*, 2001)

Nutrient export from logging activities

Watershed Logging (%)	Nitrate N (kg/ha/yr)	Dissolved Kjeldhal-N (kg/ha/yr)	Total Dissolved P (kg/ha/yr)
0	0.03	0.28	0.03
22	0.32	0.40	0.06
46	0.67	0.47	0.095

In their evaluation of septic tank inputs, Hall *et al*. (2001) estimated the increases of nitrogen and phosphorus to water categorized by different areas of the valley (Figure 21).

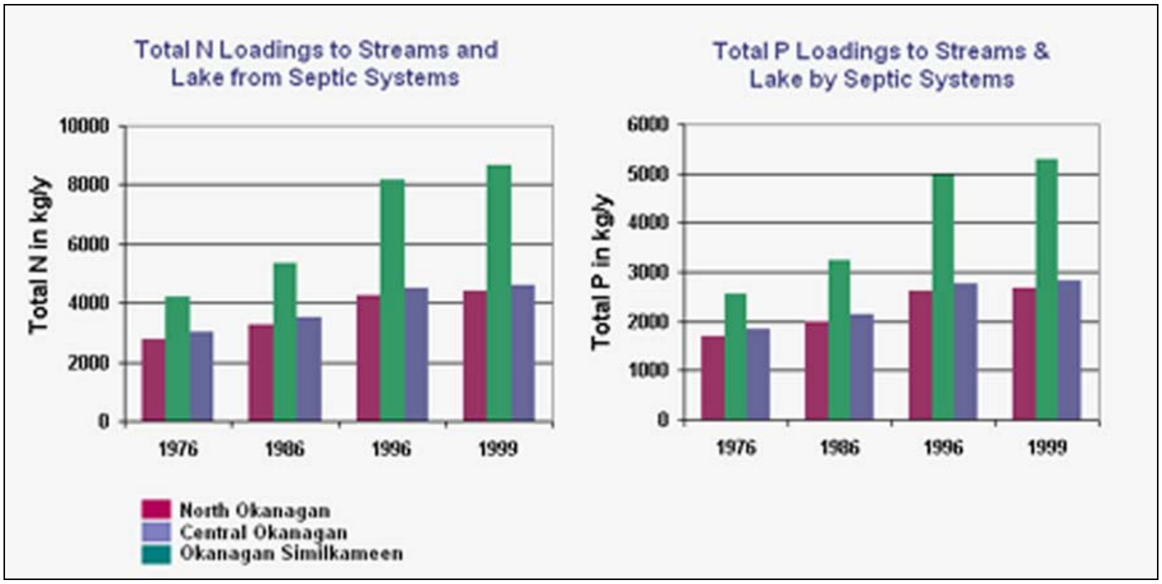


Figure 21: Nitrogen and phosphorus loading to Okanagan Lake from septic systems (Hall *et al.,* 2001)

This interpretation shows that the relative ratio of nitrogen to phosphorus in septic tank effluent is extraordinarily low (1.5:1). Unlike point sources that have decreased over time, the septic system contribution to Okanagan Lake is increasing (doubling over the past 25 years). Most non-point sources of nutrients tend to have a low N:P ratio (Kalff 2002).

Hall *et al.* (2001) also re-evaluated the existing stormwater data by examining nutrient loadings on a per capita basis (Table 21). For the Okanagan, they calculated per capita annual inputs for nitrogen and phosphorus at 626 g and 41 g, respectively. Of this they determined that 27% of the urban nitrogen loading was from non-point sources (largely stormwater) and 73% through sewage treatment plants. For phosphorus, 59% of the urban contribution was from stormwater and 41% through sewage treatment plants. The data is largely from the work of Swain (1982) in looking at Kelowna area stormwater quality (Table 22).

Stormwater contributions for the four major developed areas of the valley are summarized in Table 20.

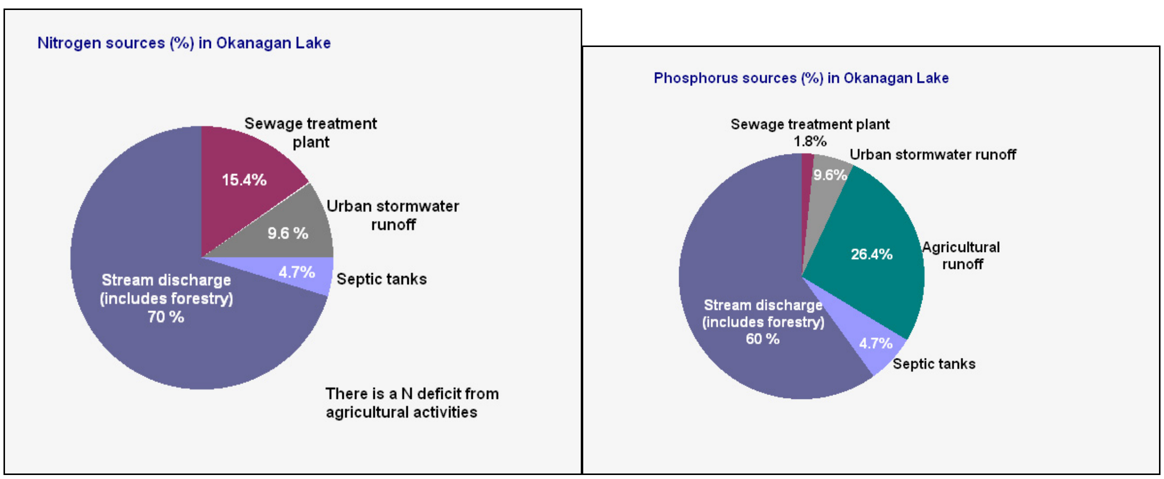
Table 20: Estimated stormwater nutrient contributions (kg/yr) to Okanagan Lake from urban areas .(Hall *et al.*, 2001)

	Total N	Bioavailable N	Total P	Bioavailable P
Kelowna	14,000	8500	2050	675
Vernon	5500	3100	750	275
Summerland	1700	1050	250	80
Armstrong	650	390	95	30

Table 21: Summary of the nutrient loading estimates of Hall et al. (2001), the overall nutrient input to Okanagan Lake in tonnes

	Nitrogen	Phosphorus
Stream inputs (total)	312	57
Stream inputs (biologically available)	219	29
Agriculture	0	25
Septic	17	11
Stormwater	35	5
STP's	57	1.8
Total(biologically available)	328	72

Figure 22: Nitrogen and phosphorus sources to Okanagan Lake as percentages contribution



from Hall *et al.* (2001)

There are some limitations with these data since it was largely based on the earlier work of Swain (1982) and Gray and Kirkland (1986) to estimate bioavailability. One of the assumptions was that stormwater inputs can be separated from stream inputs. This is very difficult to do and there may be either duplication (double counting) or missing of inputs. The use of Kelowna stormwater data and extrapolation of that data to other cities in the catchment may over estimate the contribution from these smaller and less densely populated cities.

4.2.6 Phosphorus Mass Balance

The accuracy of quantifying the total phosphorus inputs (both point and non-point sources) can also be evaluated by looking at the lake concentrations and basic lake processes of input and loss. There have been a number of simple relationships described in the literature which link loading and concentration or mass with some basic hydraulic and morphometric measurements.

Because Okanagan Lake has such a long water residence time, the losses through the outflow are considered negligible (<2% of both the water and phosphorus mass). Therefore, all the losses from the lake water are by sedimentation to the bottom sediments. The important question to be considered is the rate at which phosphorus is lost or more simply, what percentage of the annual load of P that enters the lake is lost to the sediments.

We know the mass of phosphorus in the lake quite accurately using the spring phosphorus concentration (when the lake is well mixed) for each basin and the corresponding basin volume. For Okanagan Lake, the P mass in simple terms use 2000 and 2001 data is shown below in Table 22.

Table 22: Estimation of phosphorus mass in Okanagan Lake in 2000 and 2001

	Volume (Mm^3)	Spring P 2000 (µg/L)	Spring P 2001 (µg/L)	P mass (tonnes)
Vernon Arm	171	8	7	1.3/1.2
Armstrong Arm	464	13	12	6.0/5.6
North Basin	12171	8	7	97/85
Central Basin	7085	7	4	50/28
South Basin	4753	7	4	33/19
Sum for Lake				187/139

Because of year-to-year variations, the mass will change. A simpler estimate would be to assume a P concentration of 8 µg/L (a reasonable long-term mean) and calculate a lake mass of 197 tonnes (rounded to 200 tonnes for the purpose of discussion). An outflow of 466.7 Mm^3 at 8 µg/L is an export of 3.7 tonnes (about 2% of lake mass).

Knowing the mass of P in the lake, the loading can be calculated using equations that have been used for other lakes to relate loading and concentration (Dillon and Rigler, 1974).

However because Okanagan Lake tends to be at the periphery of the set of lakes that were used to derive the relationships, some caution needs to be used. However it serves the purpose of providing an independent check of the total loading to the lake.

The relationship is most easily provided as:

$P=L/z(\sigma+\rho)$, (Dillon and Rigler 1974)

where P is the lake concentration (in mg/L), L is the loading in grams/m^2/a, z is mean depth, σ is the sedimentation rate (i.e., the fraction of P lost to sedimentation on an annual basis) and ρ is the fraction of water lost annually through the outlet. The term that is most difficult to quantify is σ but it can be estimated in other ways (see below). For, ρ there are fairly good estimates that 2% of the water (and phosphorus) is lost through the outlet. This term is often substituted with the more commonly used term R (Larson and Mercier 1976). For Okanagan Lake, Larson and Mercier (1976) use an R of 0.95, but since R is more accurately 0.98, the ρ term becomes 0.02.

If loading estimates are correct (about 70 tonnes/a input at present) then the annual sedimentation should be about the same as input assuming concentrations remain constant (there is essentially no export through the outlet – about 2%). Sedimentation and/or input as a portion of mass is 70/200 or 35%. The s term in the relationship can be estimated at 0.35 and then the equation solved for an assumed mean lake concentration of 7 µg/L. This provides a loading estimate of 0.196 g/m2/a or about 69 tonnes which is in quite reasonable agreement with P load estimates.

4.2.7 Nitrogen Mass Balance

A basic evaluation of nitrogen inputs and mass balance is also necessary since there is considerable concern about the role of nitrogen in controlling biological productivity and food chain transfer efficiencies. Nitrogen mass balance is generally not amenable to this approach because of nitrogen fixation and denitrification taking place in lakes; however, neither of these processes are likely significant in Okanagan Lake (the potential of nitrogen fixation in mid-summer needs to be examined both for mass balance considerations and for evaluation of nutrient limitation). For the purpose of this exercise, no nitrogen fixation (or denitrification) is assumed.

The estimated mass of N in the lake, using an N concentration of 230 µg/L and a volume of 24,644 Mm^3, is 5,670 tonnes). The N loading estimated by Hall *et al.* (2001) to the lake was about 320 tonnes. The loading estimate based on lake mass (using the same method as for P) (assuming the same general process of loss through the outlet and annual sedimentation proportion i.e. ρ=0.02, σ=0.35, mean depth 76m) would result in a loading estimate of 2279 tonnes corresponding to a main lake concentration of 230 µg/L. The existing loading for nitrogen seems low on this basis. Another indication that the N loading estimates were low is the N:P ratio. The TN:TP ratio (by weight) of the lake water is about 28:1. The phosphorus loading estimate is about 70 tonnes; thus, the nitrogen loading should be about 2,000 tonnes. In estimating nitrogen inputs, it seems that at least some of the components have been greatly underestimated. There needs to be continuing work on efforts to more accurately estimate inputs of nutrients from point and non-point sources. Any effort to manage nutrients (especially nitrogen) is dependent on this critical knowledge.

4.3 Hydrology

The basics of hydrology of the Okanagan Lake basin were provided in Section 2. As part of OLAP, Ward and Yassien (1999) provided some excellent work showing that the precipitation patterns in the Okanagan are controlled by global climate patterns and that strong correlations exist between the Southern Oscillation Index (SOI), snowpack and subsequent runoff (SOI in April to September and May and June stream flows in the following year). These changes in runoff from year-to-year have major effects on the productivity of the lake system.

4.3.1 Effects of inter-annual differences in precipitation and runoff

The watershed of Okanagan Lake is an area of low precipitation (mean annual precipitation for Armstrong is 387 mm, for Kelowna is 305 mm, and for Penticton is 288 mm). It follows that the amount of runoff should be a major factor affecting the processes of the lake, including nutrient loading, processing and availability. Historically, the range of runoff has been more than an order of magnitude. Using the volume of outflow, the volume ranged from 88 Mm^3 (1927) to 1,401 Mm^3 (1997) with a mean of about 470 Mm^3. The outflow volume at Penticton proves an easy measure of water supply, but because of the storage provided on the lake and the management of lake levels, outflow is not the best indicator of inflow. The hydrometric data for the inflow streams themselves or the precipitation records would provide a better index.

The effect of a year with high precipitation and runoff would be a proportionally higher nutrient loading. This would be reflected in both point source and non-point source inputs (stormwater inputs, groundwater movement, erosion and soil disturbance). The relationship would not likely be direct as there are many factors that would interfere with direct cause and effect.

The data illustrated in Figure 23 are from Jensen and Epp (2002) and early works by Haughton *et al.* (1974) and Nordin (1982, 1983). What has not been fully appreciated is the major effect of water inputs into this low precipitation catchment. The high flow year of 1997 likely had a far larger effect than is understood. Figure 23 indicates a reasonable relationship between the amount of water that the lake receives and the lake phosphorus concentration. However, there are a number of factors (several noted previously) which would prevent a strong linkage between hydrology and nutrient concentration. Firstly, the analysis uses outflow volume which may not be a good indicator of inflow. Secondly, the input of water in the spring is not mixed into the whole water column until the winter; therefore the September concentrations may not be the best estimate of lake P concentration. And thirdly, the lake's response to nutrient inputs is affected in a significant way by the previous year's inflow.

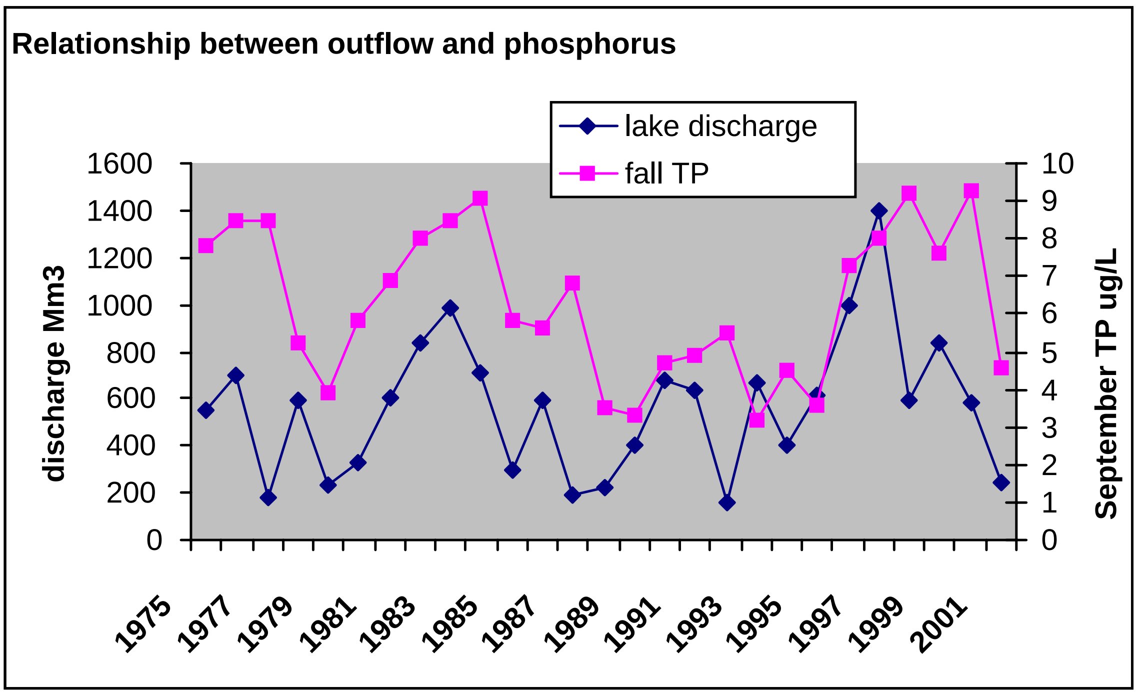


Figure 23: Relationship between flow (discharge from Okanagan Lake) and September total phosphorus concentration (from Jensen and Epp, 2001)

The OBS study began in response to algal blooms in Skaha and Wood lakes which may have been significantly influenced by a period of relatively low flows (1970 was the lowest flow in the past 50 years). These occurred when the Penticton Sewage Treatment Plant discharge was a major contributor of nutrients to Skaha Lake and would have assumed a larger role (i.e., less dilution) than under normal hydrologic conditions. Another local illustration of a lake's response to hydrologic changes is the affect of the input of Hiram Walker cooling water flow on Wood Lake where a reduced water residence time reduced phosphorus concentrations between 1970 and 1995.

The other major factor for reducing the influence of the sewage treatment plants on Okanagan Lake, in addition to nutrient reductions with advanced wastewater treatment (e.g. Biological Nutrient Reduction (BNR) technology, and spray irrigation), has been the placement of outfalls at depths below the thermocline. This practice delivers nutrients to the deep water where they are not immediately available to the food chain and a proportion of the nutrient load is lost to sedimentation while the lake is stratified. The diversion of nutrients to spray irrigation (Vernon and Armstrong) and the deep disposal (at Kelowna, Summerland and Westbank) mean that during the period of highest flows (summer tourist season) the supply of nutrients are reduced to the lake food chain. The deep discharge may have a delayed effect as it will take some time for concentration to come into equilibrium with loading.

There are a number of climatic and physical factors which make predicting changes in nutrient concentration difficult:

1. Timing of freshet – the later in the year, the deeper tributaries flow into the lake.
2. The larger the inflow the farther it disperses within the lake and occurs over a longer duration.
3. The higher the flow, the higher percentage of non-bioavailable P.
4. Weather conditions (particularly temperature) in any particular spring or summer will affect the sedimentation rate of P due differences in stratification depths and horizontal water movement velocities.
5. The influence of wet and dry years is often obscured by years of moderate flow and alternating years of higher or lower flow. It is only when there are a number of wet years together (or dry years together) or extreme years (e.g.1997) that the response of the lake ecosystem to hydrologic variation becomes apparent.

From this discussion we can conclude that, by itself, input flows may not be a good direct indicator of lake nutrient concentration, but it certainly has a major influence. In recent years, all the Okanagan lakes show similar patterns of peaks in nutrients in the 1996-1997 period of high water input. The importance of input flows to a lake in a very dry geographic region seems to be considerable.

4.3.2 Response Time

Another aspect to be addressed is the response time of Okanagan Lake to changes in nutrient loading. The response time has been described for other lake systems and is best expressed as a relationship between water exchange time and sedimentation rate.

The response time for a non-conservative substance (like nitrogen or phosphorus) to reach 90% of equilibrium is:

$t(90\%) = 2.3\tau_w (1\text{-}R)$ (Kalff 2002).

In this relationship, τ_w is the water exchange time in years (lake volume divided by outflow), R is the annual retention coefficient or the portion of the incoming material which does not go out the outlet.

On an average basis, the τ_w term for Okanagan Lake is 53 years and the R term for phosphorus is 0.95 (export of 3.7 tonnes through the outlet – 467 Mm^3 at a concentration of 8µg/L). The time to 90% of the new equilibrium concentration is 6.1 years with "average" hydrology. However the range of water retention times can cause the response time to be as little as 2.8 years (high water input using an outflow of 1,000 Mm^3 / τ_w of 24 years) and as long as 28 years (low water input using an outflow of 100 Mm^3 / τ_w of 246 years). The R value would likely be higher in this scenario, if R=0.99 then response time would be 5.7 years. It can be concluded from this evaluation that the response time to changes in water input is relatively short, much shorter than might be expected by the long water residence time of Okanagan Lake. With a significant change in water input, the lake would respond immediately and be complete within a few years.

The lake is in a constant state of response to changes in water input, but there is an overall rate dictated by trends in inflow. Often there are two-, three- and four-year periods of high or low inflow. During these periods, the response times are compressed or expanded.

The inflow volume is important since the nutrient loading is proportional to inflow. With twice the inflow there should be twice the nutrient load (in approximate terms).

4.3.3 Climate Change

There certainly seems to be a growing appreciation that climate patterns are changing and for a valley that is sensitive to precipitation, any increase in warming could have a significant effect. The graph below is from Hall and Stockner (2001) (Figure 24) and shows the long-term trend in air temperature. Leith and Whitfield (1998) also provide data that indicate significant changes in water supplies may be occurring. It is important to note that their predictions of earlier freshet, lower summer flows and increased fall flows may have important consequences for the input of nutrients and the processing of nutrients in the Okanagan Lake.

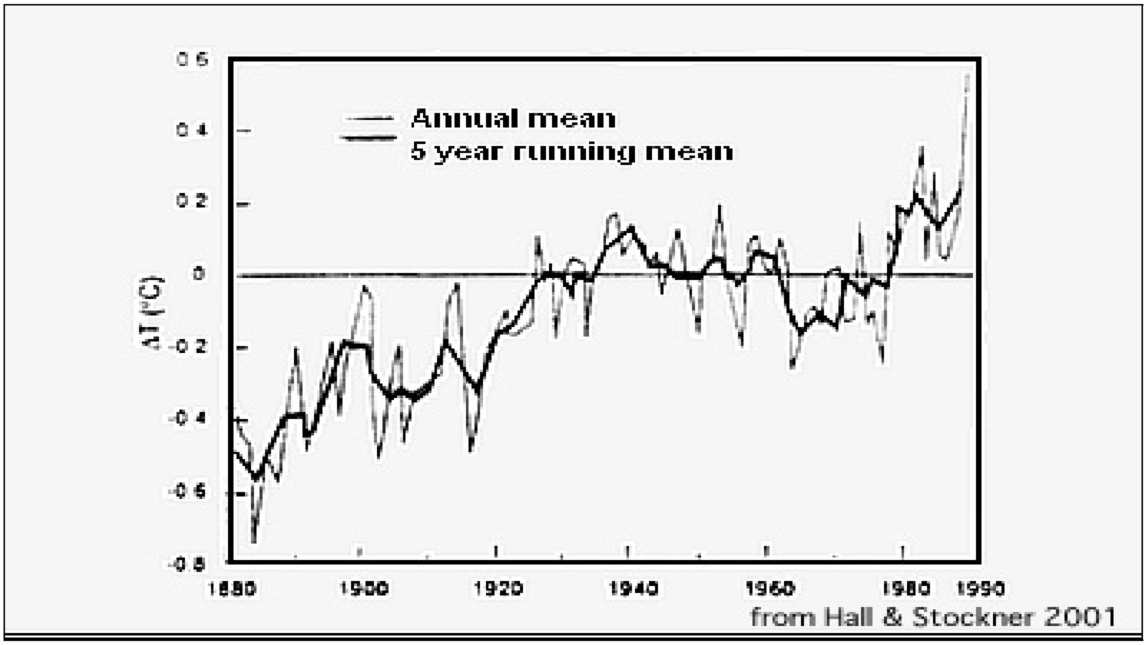


Figure 24: Trend in annual mean temperature (Hall and Stockner, 2001)

5.0 WATER QUALITY ASSESSMENT AND OBJECTIVES

5.1 Introduction

A key water protection goal of the Okanagan Basin Study was the reduction of phosphorus inputs to the lake to protect the quality of this valuable resource. The approach was to primarily reduce the discharges of phosphorus from the sewage treatment plants (and other potential contributors, like agriculture and industry, by 90%. This target was based on extensive estimates quantifying the P loadings to the lake from a number of sources then applying the relationship (innovative at the time) which had been defined by Vollenweider (1968) between loading and concentration. This idea of using loadings as a means of protecting water values is the major tool in use by the American Federal government using the Total Maximum Daily Load (TMDL) approach. The setting of water quality objectives by specifying concentrations in the water is the approach favoured by the Canadian federal government (CCME,1987)) and the British Columbia provincial government (MWLAP 1998a, 1998b). This approach has been applied to several specific water bodies in the Okanagan Valley (Water Management Branch,1985, Swain, 1990a, Swain, 1990b, Swain, 1994)

There are several advantages to using water quality guidelines (as opposed to loadings) as a means of water quality protection. Concentrations are considerably easier to measure than loadings. Loading estimates during the OBS and subsequent studies have considerable uncertainties associated with them, which does not make them an easy or accurate tool for evaluating lake status or defining water protection goals. Also, the linkage between loading and lake response is not always clear and can be influenced by a number of factors including hydrology, climate and food chain response.

There have been few attempts to use guidelines other than the measurable and definable chemical guidelines. There are considerable advantages in using biological objectives since aquatic life are generally the most sensitive resource to be protected. The specificity of biological objectives focuses monitoring on individual biological components of the aquatic ecosystem. The combination of chemical and biological guidelines adds considerably to the utility and strength of the water quality objectives setting process. Reynoldson *et al.* (1989) suggested a biological objective for benthic communities in the Great Lakes using key and important species. For streams, the Index of Biotic Integrity (IBI) approach suggested by Karr has received considerable use for stream evaluation and protection (Fore *et al.* 1994). Other agencies, especially in USA and Australia, are actively developing biocriteria (e.g. USEPA, 1999). The only prior example of setting biological water quality objectives in BC lakes is for Christina Lake (Cavanaugh *et al.*, 1994). There have been biological guidelines established for stream periphyton biomass for British Columbia (Nordin, 1985) which have been used in a variety of locations in BC to set water quality objectives.

Water quality and biology in Okanagan Lake have been sampled with some continuity at a set of common stations established by the Okanagan Basin Study. Some locations have been added over the years and some have been labeled inconsistently between the different studies. Table 23 lists those sites presently in use by the MWLAP regular and OLAP programs. Results are stored on the Ministry of Water, Land and Air Protection's Environmental Management System (EMS) database.

Table 23: Okanagan Lake major sites sampled monthly by OLAP

OLAP	EMS No.	Site Name	Depth (m)
OK1	0500454	Okanagan Lake South Prairie Creek	80
OK2	0500729	Okanagan Lake South Squally Point	110
OK3	E223295	Okanagan Lake Opp. Rattlesnake Island	140
OK4	0500236	Okanagan Lake DSN Kelowna STP	80
OK5	0500456	Okanagan Lake UPS Kelowna ST P	140
OK6	0500730	Okanagan Lake N. Okanagan Centre	220
OK7	E206611	Okanagan Lake at Vernon Outfall	60
OK8	0500239	Okanagan Lake Central Armstrong Arm	50

Other sampling sites monitored by MWLAP spring and fall to September 2003 include

EMS No.	Site Name	Depth (m)
0500238	Vernon Arm	22
0500240	Off Summerland hatchery (shallow)	6
0500242	Near Kelowna outfall (no longer sampled)	13
0500458	Kin Beach Vernon Arm (shallow – no longer sampled)	9
0500460	Armstrong Arm at Deep Creek (shallow)	12
0500911	Off Peachland (shallow)	12
0500912	near Trepanier Creek (shallow)	12
E222119	Kelowna deep outfall	60
E206570	South Powers Creek	50
E227650	Summerland outfall	45

5.2 Secchi Disk (water clarity)

The Secchi disc is a basic tool used by aquatic scientists to measure water clarity and assist in trophic status determination. It has been criticized as being too simple and too subjective to be used as a monitoring tool, however, the continued use and acceptance of the Secchi disc seems to discount this. Because of its simplicity, the Secchi disk provides an easily understandable measure for the general public, who perceive water clarity as a key factor in the acceptance of the water for recreational and domestic uses.

Secchi depth represents the sum of organic (mostly phytoplankton) and inorganic suspended sediment (negligible in the open water of Okanagan Lake). The relationship between Secchi depth and phytoplankton, measured as chlorophyll *a*, has been well established in many areas of the world. Data for Okanagan Lake follows a pattern indicating a reasonable relationship between transparency and algal concentration (Figure 25). There is considerable variation and the relationship may be stronger in some years than others.

The long-term Secchi depth and chlorophyll *a* data for Okanagan Lake (compiled by MWLAP staff) provides trend data for spring and fall time periods. The data however, are not ideal for setting objectives since measurements were only taken twice a year, at spring overturn (typically February - March when chlorophyll is low and Secchi high) and September (when the situation is generally reversed). This sampling pattern misses the peak of phytoplankton productivity and standing crop which seems to occur in May to June.

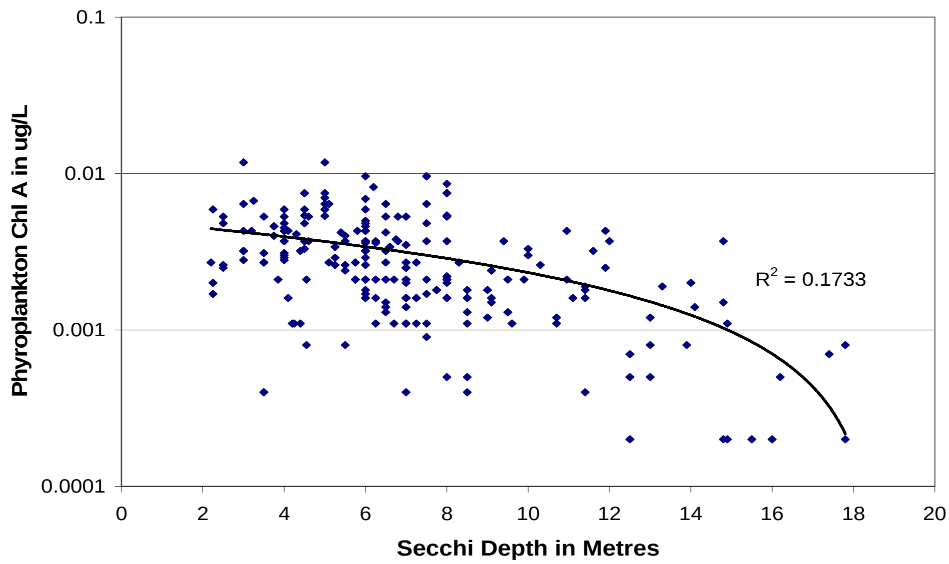


Figure 25: Water clarity (Secchi depth) versus phytoplankton chlorophyll A in Okanagan Lake at deep sites, 1983 to 2003

The first Secchi depth data for Okanagan Lake were reported by Rawson (1936) at which time he noted depths of 8-10 metres in July and August 1935. These are greater than what's been measured in recent years, but within what has been measured in the last 10 years.

Long-term spring and fall Secchi disc monitoring results, collected by MWLAP staff in Penticton, are illustrated in Figures 26 and 27.

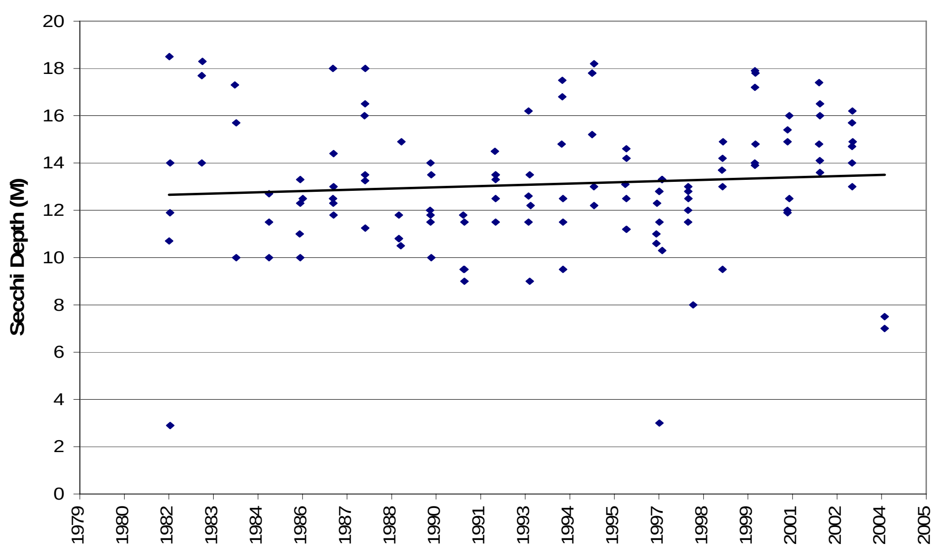


Figure 26: Secchi depth at Okanagan Lake deep sites in February and March

The spring data suggests Okanagan Lake clarity has not changed appreciably over the monitoring period. The fall Secchi data show a decrease during periods of higher run off (82-83, 96,97,99) which also correspond to periods of increase nutrient loading and increased phosphorus concentrations. Separating long-term water quality change related to anthropogenic influence, from that related to climate variability has been used elsewhere (Jassby, 2003) and could be beneficial for understanding long term trends in Okanagan Lake water quality.

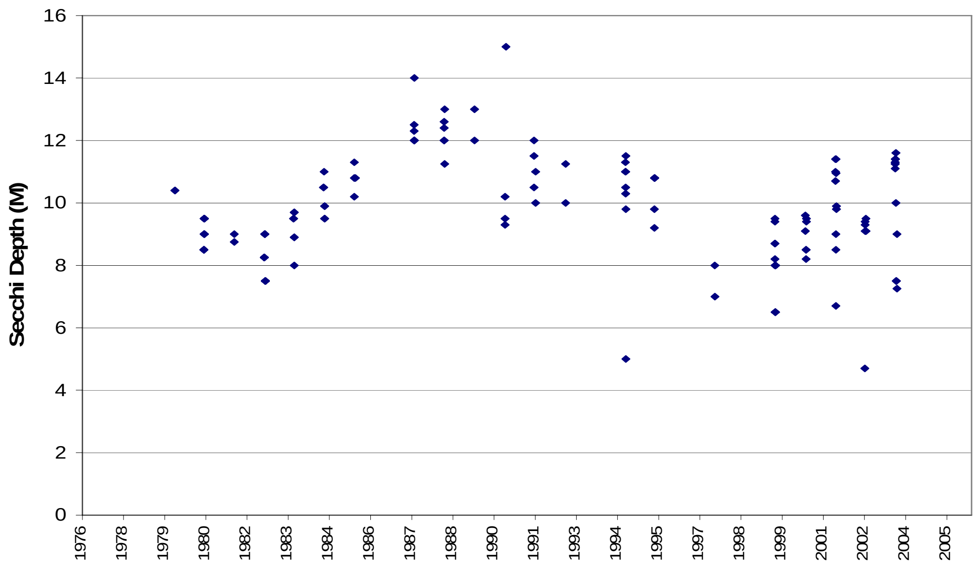


Figure 27: Secchi depth at Okanagan Lake deep sites in September

The monthly Secchi measurements gathered by the OLAP program since 1997 provides seasonal Secchi depth averages which are listed in Table 24 (Wilson and Vidmanic, 2002). These data are a better comparison to OBS and OBIA data which span April to October, although a number of intervening months are missing in each year in both studies. A decrease of roughly one metre in water clarity is apparent over the two decades between the OBIA and OLAP study periods. However, plus or minus one metre is still within the variation possible for the sampling technique and inter-annual variability and may not represent a real trend. The decrease in clarity across the three periods (OBS 1971, OBIA 1976-78 and OLAP 1997 to present) is consistently downward and worthy of note. Differences in hydrology during the study periods likely account for some of the apparent decrease over this 30-year period; 1970 was a dry year and therefore low input of nutrients, 1996, 1997 and 1999 were wet years and therefore a higher nutrient input (see Section 4.3.1).

Table 24: Seasonal (May-October) average Secchi disk (m) recorded in the main basins of Okanagan Lake 1971-78 and 1997-2001

Year	South Basin	North Basin	Main Lake Average	Armstrong Arm
OBS				
1971	9.5(OK2/3)	9.1 (OK1)	9.0	
OBIA				
1976	7.6(OK2/3)	7.9(OK1)		
1977	8.2	7.0		
1978	7.7	7.4		
Mean 76-78	7.8	7.4	7.6	
OLAP	OK 1-4	OK 5-7		OK 8
1997	6.7	6.1	6.4	3.1
1998	8.1	7.1	7.6	3.4
1999	5.8	5.8	5.8	3.1
2000	6.0	6.5	6.2	3.5
2001	6.8	6.7	6.7	4.2
	6.7	6.4	6.5	3.5

Secchi disc objectives are proposed for four locations defined by the generally accepted divisions of the lake (each of the main basins plus Armstrong Arm). The numbers proposed are based on the long-term seasonal averages and take into account the variation caused by inter-annual variation, as discussed above, which is generally a consequence of water inflow. **The objectives are summer means based on monthly samples from April to September**. They are designed to protect the water clarity from deterioration from the present condition except for Armstrong Arm where the goal is for an improvement in present conditions which would be expected with the reduction in nutrient loading that occurred since 2000. The response time for a change to reflect the reduced input would be five to seven years based on Armstrong Arm volume of 464 Mm^3, an inflow of 15.5 Mm^3 and a water residence time of 30 years.

The Secchi disc transparency objectives proposed for Okanagan Lake are:

Armstrong Arm: 5.0m
North Basin: 6.0m
Central Basin: 6.0m
South Basin: 7.0m

The Secchi objective is designed to provide a point of reference to determine the suitability of Okanagan Lake for recreational and drinking water purposes. It applies to all pelagic areas of the lake. Since historical data suggest that similar or better water clarity (if it can be used as an index of lake productivity) existed 30 years ago when higher Kokanee populations existed in Okanagan Lake, these objectives should be adequate to protect fisheries interests as well. When interpreting the data for any particular year in relation to the objectives, it is also important to consider the water input into the lake (hydrology) and the effect on Secchi disk readings. Secchi depths will tend to be lower in wetter years because of the increase in nutrient loadings associated with increased water input.

5.3 Dissolved Oxygen

For all areas of the main lake with a large hypolimnetic volume relative to the epilimnion, there is little concern for problems associated with hypolimnetic oxygen depletion. However in Armstrong Arm, the data indicate that deep water oxygen depletion is a concern. Low dissolved oxygen restricts fish habitat, reduces benthic productivity and may cause internal loading of nutrients (return of phosphorus and nitrogen from sediments back into the water column). There is evidence that *Mysis* move out of Armstrong Arm in response to this oxygen depletion (McEachern, 1999). In recent years, the September dissolved oxygen profile in Armstrong Arm shows values of less than 5 mg/L at depths below the thermocline with minimums of 1.0 mg/L, 1.5 mg/L and 1.7 mg/L in years 2002, 2001 and 2000, respectively, at a depth of 48 m.

For Armstrong Arm, the proposed dissolved oxygen objective is a minimum of 5 mg/L, measured within two metres from the bottom in the deepest part of the basin (50 m). The concentration is based on the provincial guideline to protect fisheries habitat (Truelson, 1997). This objective is likely not currently being met in the fall months, but as with Secchi depth, the oxygen concentration in Armstrong Arm is expected to improve in response to the decreased nutrient loading resulting from the diversion of Armstrong sewage from Deep Creek.

5.4 Phosphorus

Phosphorus was the only water quality objective specified in the 1985 report for the Okanagan lakes (Water Investigations Branch, 1985) and has proven to be a useful measure of nutrient status for the lakes it was specified for. For the Okanagan Lake main basins, Vernon Arm and the Armstrong Arm, the water quality objective specified for phosphorus measured at spring before stratification was 10 µg/L.

Figure 28 illustrates the long-term phosphorus trends in Okanagan Lake, as measured by MWLAP regional staff in February or March. The data from the Ministry 25-year record shows little change other than response to annual inflow of water into the lake (Jensen and Epp, 2002). The 25 yr WLAP data set for TP south of the bridge averages out at 7 ug/L, and north of the bridge 8 ug/L.

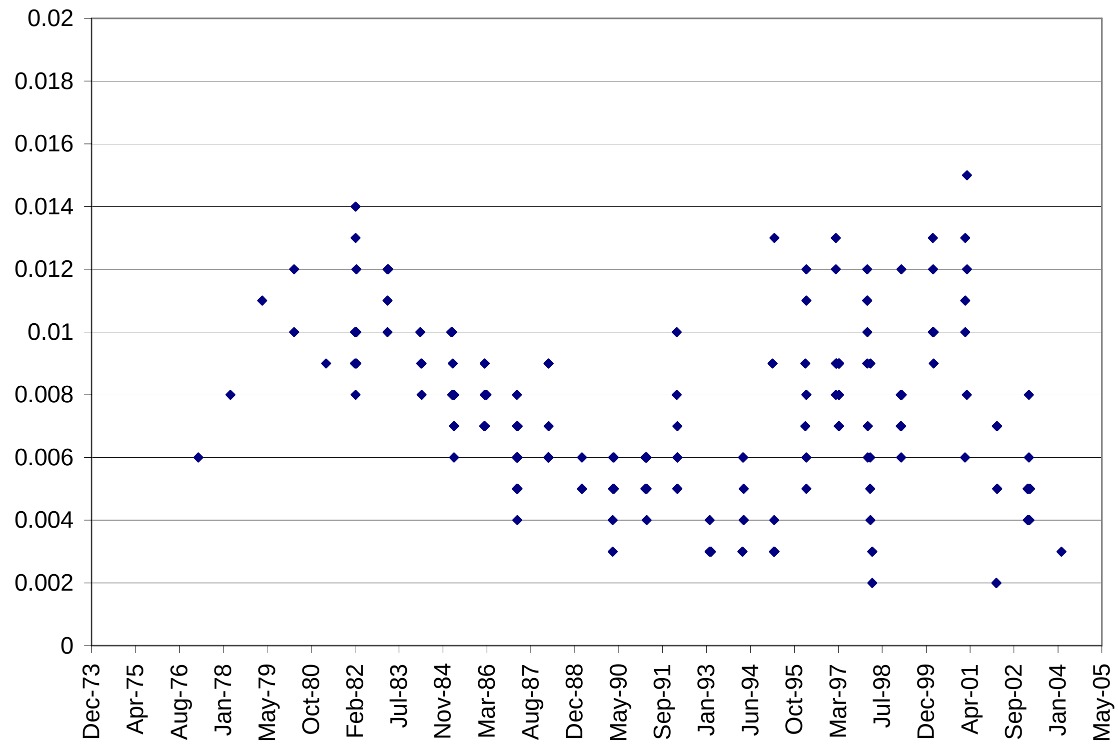


Figure 28: Total Phosphorus (mg/L) in Okanagan Lake (south, central and north basins) in February or March

Table 25 lists the average phosphorus concentrations for Okanagan Lake from 1997 to 2001, as gathered by the OLAP program in the month of April of each year., spring TP values for these years within the OLAP study period are surprisingly close to the 43 year averages given that 1996, 1997 and 1999 were much wetter than the 43 year average.

Table 25: Total phosphorus concentrations recorded during April in the main basins of Okanagan Lake, 1997-2001. Values presented are an average of 0-10 m composite, 20 m and 45 m samples in µg/L

Year	OK1-4	OK5-7	Lake average	Armstrong Arm
1997	10	13	12	45
1998	5	5	5	10
1999	7	11	9	22
2000	7	8	7	13
2001	4	7	6	12
Average	7	9	8	20
25 year mean Feb/March	7	8	8	20

Water quality objectives are based on water quality guidelines and are linked to specific water uses of the water body in question. For phosphorus, the most important water uses are aquatic life, recreation and drinking water and the three uses have quite different target or threshold concentrations.

For drinking water and primary-contact recreation and aesthetics, it would be ideal to have a very low phosphorus concentration (less than 5µg/L). Minimizing algal content of raw water, and maximizing water clarity for recreation would provide a very attractive lake to many tourists and residents. The Okanagan Basin Study proposed that a desirable Okanagan Lake phosphorus concentration would be 5 µg/L.

Stockner *et al.* (2000), in a discussion of lake oligotrophication, provides a graph showing the optimal phosphorus concentration range for maximum fisheries production would be about 20-30 µg/L (Figure 29). This is outside historic norms for the main basins of Okanagan Lake, but it does illustrate the differences in optimal concentrations for different water uses (i.e., recreation and drinking water versus fisheries production). In the past, the lake has had nutrient concentrations similar to, if not somewhat lower than, present concentrations which supported acceptable fish production. In Figure 29, a concentration on 8-10 µg/L is still within the "optimal" range identified for fish production.

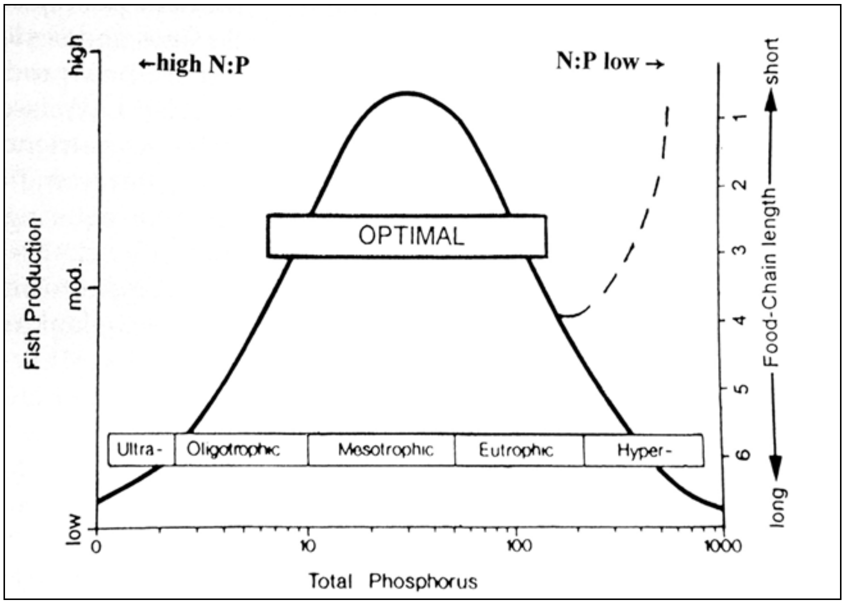


Figure 29: Relationship between total phosphorus and fish production in freshwater lakes (Stockner *et al.*, 2000)

For the north (OK 6) and central (OK 4) basins of Okanagan Lake, an objective of 8 µg/L is proposed. For the south basin (OK 2), an objective of 7 µg/L is proposed. For Armstrong Arm, an objective of 10 µg/L is proposed. The changes in objectives from the 1985 report are recommended based on recent and historical data, and a reasonable expectation that they will be met and provide a higher level of protection for the lake. Should nutrient resource ratios be found of importance to fisheries and water quality interests, further reduction in the phosphorus objectives may be recommended through a broader nutrient management framework for the lake.

Vernon Arm, which was identified separately in the previous objectives, now has essentially the same concentration as the main body of the lake, although at the time of setting the 1985 objective it averaged about 12 µg/L. The influences of the periodic sewage discharge and NPS nutrient inputs in the Vernon area seem to presently have a relatively minor influence on the open water phosphorus concentrations. The influences of the 1998 sewage discharge were found to have a relatively minor influence on the open water phosphorus concentrations near the outfall. With tertiary treated sewage, discharged at a depth of 60 m near the confluence of Vernon Arm and the main body of Okanagan Lake there would not likely be a measurable effect on Vernon Arm. Rather, phosphorus concentrations in Vernon Arm will respond to wet weather and loading from Kalamalka Lake and NPS in the Vernon area. In any case, the Vernon Arm concentration should not exceed the objective for the main body of the north basin. Armstrong Arm still exceeds the 10 µg/L objectives but the present concentration (approximately 12 µg/L in 2003) is reduced from the 1985 concentration of 25 µg/L. It is expected that the concentration should continue to decline and approach the main lake concentration. The significant P inputs from Equesis and Deep creeks from apparently natural and agricultural sources may have some effect on achievement of this objective.

The phosphorus objectives are to be checked at the three main basin stations (OK2-0500454, OK4-0500236, and OK6-0500730) and in Armstrong Arm (OK8-0500239) in the spring before stratification begins (typically February to March). The samples should be taken from at least three different depths to represent the water column (surface, mid-water and deep water).

There may need to be some compensation of these objectives in years of high inflow volume as nutrient levels would be expected to be higher. The objectives are based on a year of average inflow (in the year prior to sampling).

5.5 Nitrogen

In addition to phosphorus, nitrogen is a very important nutrient for the lake. Nitrogen can have an effect on the biological productivity and ecology of water quality since the balance between phosphorus and nitrogen plays an important role. Nitrogen concentrations in the lake need to be kept within a desired range to prevent the growth of undesirable algae. In monitoring the nitrogen concentration of lakes, there are several fractions of nitrogen that can be analyzed. Ammonia is the reduced inorganic fraction, nitrate is the oxidized inorganic fraction and Kjeldahl nitrogen, the sum of both the ammonia fraction and the organic fraction, is often reported. Nitrate nitrogen is the inorganic fraction of nitrogen readily utilized by phytoplankton.

Because of the greater complexity of the nitrogen cycle over the phosphorus cycle, setting objectives for nitrogen in the lake is more complicated. A discussion of the importance of N:P ratios in lakes, and how the ratio can influence aquatic life of the lake and the water quality in general, is provided in Section 5.6.

Nitrate

The long-term spring monitoring of nitrate in Okanagan Lake indicates a significant increase in nitrate (the dominant inorganic bio-available nitrogen fraction) over the past ten years (Figure 30). The trend is most pronounced in the southern basin and may actually have begun in the 1980's. The increase in nitrate concentration in Okanagan Lake at spring overturn also occurs in adjacent Kalamalka Lake but not in nearby Mabel or Sugar lakes which also have long-term monitoring data. The long-term data for all lakes shows a common phosphorus trend related to water inputs. The increase in nitrate results in a concentration in the lake which is much higher than historical concentrations.

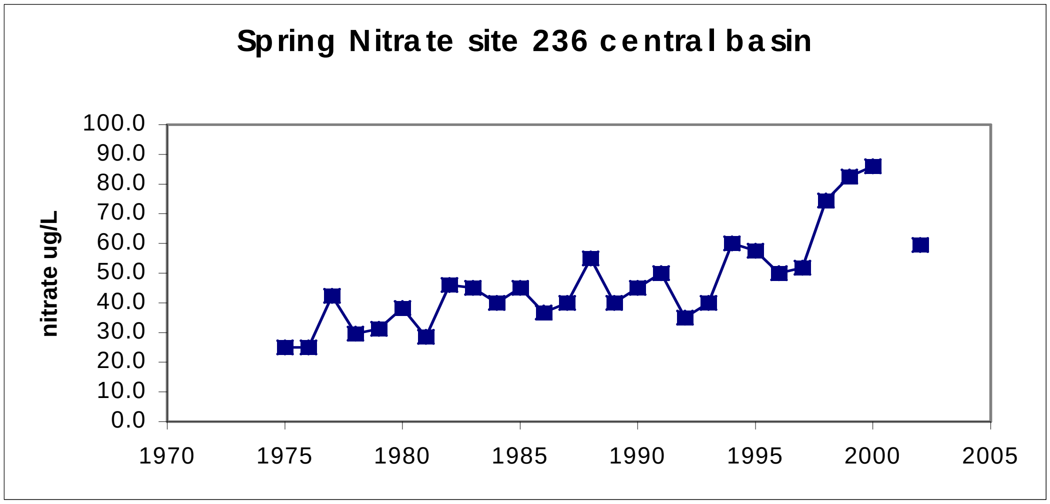


Figure 30: Nitrate nitrogen in spring samples collected from the central basin of Okanagan Lake at site 0500236 downstream of the Kelowna STP outfall

OLAP studies (Stockner 2001, 2002) have identified that there may be low concentrations of available nitrogen in the surface water in summer due to phytoplankton uptake through the spring period when phytoplankton growth is high. The low summer nitrate availability may lead to nitrogen limitation and a competitive advantage for the undesirable cyanobacteria. This in turn might affect carbon transfer to zooplankton since cyanobacteria are regarded as a less desirable food source and there would be less zooplankton or poorer quality zooplankton available as food for kokanee. In the absence of more than three or four years of annual seasonal nitrate patterns, it would seem premature to attempt to describe goals for nitrate itself either as concentration or timing. The issue of nutrient limitation as a separate objective is discussed in Section 5.6.

Total Nitrogen

The long-term trends for total nitrogen at two stations are shown in Figures 31 and 32. There are differences between basins in the lake but generally concentrations do not exceed 250 µg/L. The OK4 (0500236 central basin) data show little change over time. Figure 32 (OK1 south basin/0500454) shows three forms (total, organic and Kjeldahl) and their similar trend, decreasing through the late 1980s and then increasing in recent years.

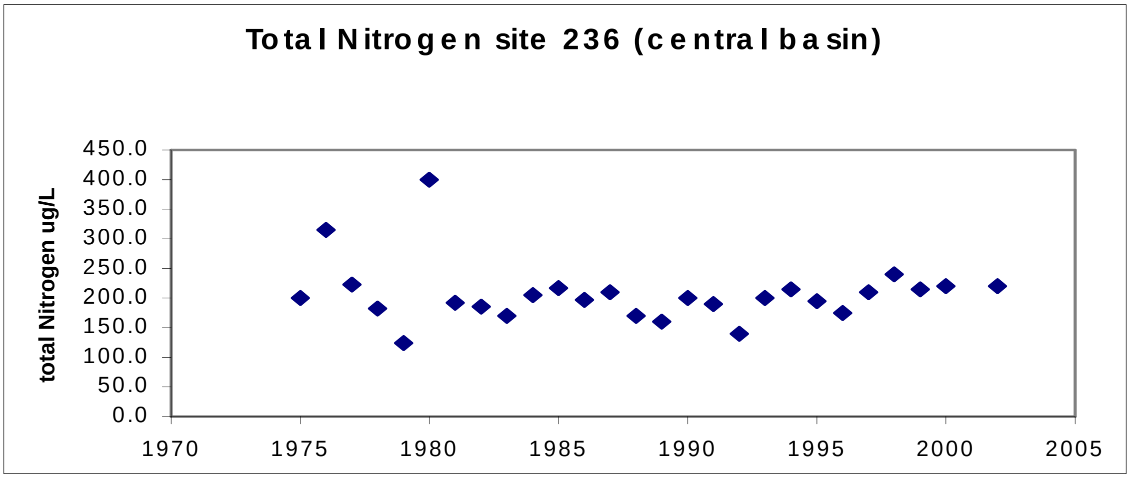


Figure 31: **Total Nitrogen in spring sampling at site 0500236 in the central basin of Okanagan Lake**

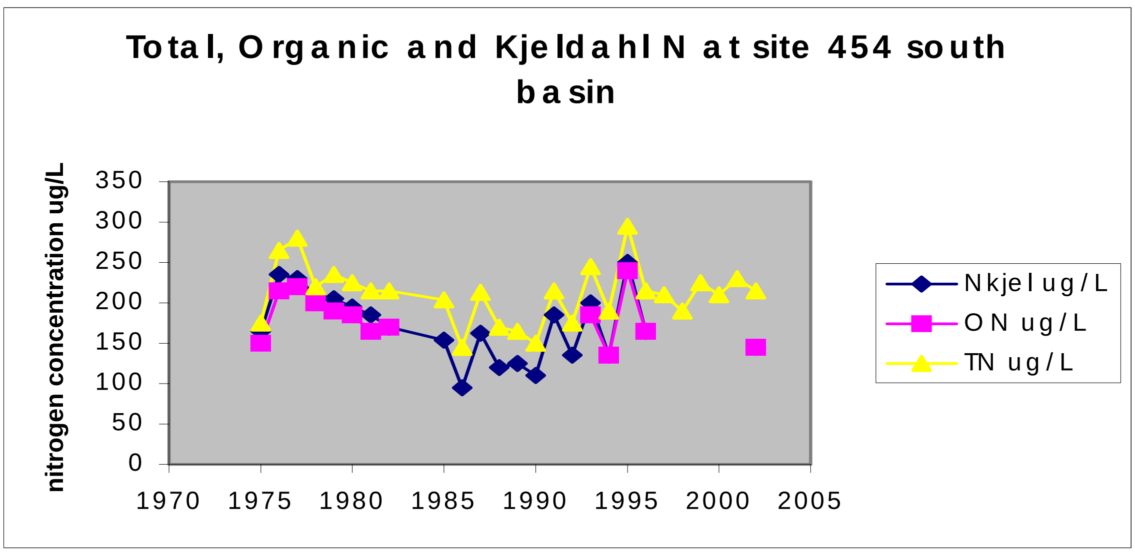


Figure 32: **Total Nitrogen, organic nitrogen and Kjeldahl nitrogen in spring sampling at site OK2-0500454 in the south basin of Okanagan Lake**

Recent OLAP sampling (Table 26) shows fairly consistent concentrations in the main basin, but higher concentrations (as would be expected) in Armstrong Arm.

Table 26: Concentrations of total nitrogen (µg/L) recorded during April in the main basins of Okanagan Lake, 1997-2001 (Wilson and Vidmanic, 2002) and WLAP spring (March or April), 1974-03. Values presented are an average of 0-10 m composite, 20 m and 45 m samples

	OK1-4	OK5-7	main lake average	Armstrong Arm
April 1997	210	220	220	470
April 1998	290	260	270	410
April 1999	240	240	240	250
April 2000	240	250	250	300
April 2001	200	170	180	200
April Average 97-01	236	228	232	326
Feb/March Average 75-03	204	194	199	299

An objective of 230 µg/L total nitrogen (maximum concentration) at spring overturn is proposed for Okanagan Lake north, central and south basins. This is the main lake average TN for the OLAP and historical data sets and will provide spring TN:TP ratios of ≥ 25:1 for the proposed TP objectives. For Armstrong Arm the long term objective is 250 µg/L to achieve a spring TN:TP ratio of ≥ 25:1, however in the near future levels above 250 µg/L will likely prevail until this sub-basin responds to point and non-point nutrient reduction efforts of the past 2 decades. These objectives are recommended based on recent and historical data, with a reasonable expectation that they can be met during average or below average run-off years. The objectives are to be checked at the three main basin stations (OK2, OK4 and OK6) and in Armstrong Arm (OK8) in the spring before stratification begins (typically February - March). The samples should be taken from at least three different depths to represent the water column (surface, mid-water and deep water).

5.6 N:P ratios and Aquatic Food Chain Response

The concept of nutrient limitation in aquatic systems comes from the observation first put forward by Redfield *et al.* (1963) that phytoplankton require the three main nutrients, carbon, nitrogen and phosphorus, in a stochiometric ratio determined by their metabolic machinery. The Redfield ratio of 106:16:1 (C:N:P) (atomic/molar ratio) can then be used to evaluate the relative supply of these major nutrients. This ratio indicates that when the N:P ratio is significantly above this ideal ratio of 16:1, for example 25:1, P is clearly the limiting nutrient, and when it is below the ideal ratio, for example 10:1, nitrogen is the limiting nutrient. In between these two ratios, depending on the algal species, there is a reasonably balanced supply – what is often called co-limitation. The preference for different ratios of N:P by different algae covers a wide range from 3:1 to 30:1 (atomic) (Kilham and Kilham, 1984; Kilham and Hecky, 1988).

The Redfield ratio is given as an atomic (molar) ratio, but when comparing water chemistry concentrations – which are typically reported in µg/L, it is more convenient to express the ratio as one by weight. In this case, the Redfield ratio is 40:7:1 and the ratio for P limitation is generally considered to be when the N:P ratio is greater than 15:1 and N limited when N:P ratios fall below 5:1. Co-limitation or approximate balance is when the N:P is in the 5-15:1 range.

As part of the OLAP studies (Stockner 2000, 2001, 2002) there has been considerable discussion of changes in N:P ratios and the resulting consequences, particularly with respect to trophic transfer. The observation has been made that a decrease of inorganic bio-available nitrogen (nitrate and ammonia) in the photic zone of Okanagan Lake down to detection limits during late spring and early summer is evidence of nitrogen limitation. It has been concluded that this represents a change in the lake nutrient dynamics and represents a change to strong nitrogen limitation during the summer.

In examining some of the premises for this conclusion of summer nitrogen limitation, little evidence was found for some of these assumptions. First there is no evidence that the supply ratio of N:P has changed significantly in the past 30 years. The sewage treatment plant's higher rate of P removal in comparison to N has been cited as the driving force for this: however, this differential removal (lower efficiency of N removal) should assist in driving the system to stronger P limitation by increasing the supply of nitrogen. It must also be noted that the contribution of N and P from sewage treatment plants is at present relatively small in comparison to all the other nitrogen and phosphorus sources to the lake. The dominant nutrient loading is from streams and secondarily from non-point sources.

There have been no detailed data prior to OLAP that show the seasonal patterns of epilimnetic nitrate depletion. Truscott and Kelso (1979) noted (on the basis of only four samplings per year) that depletion of nitrate occurred in July and remained low until at least October. The concentrations they reported for spring overturn were quite low (April concentrations of <10 µg/L), in comparison to present concentrations, and varied widely from station to station (from 1 to 50 µg/L). The ammonia concentrations they reported seem quite high in relation to present concentrations (ranging from 3 µg/L to 40 µg/L in the main basins). As such, it is difficult to know if the pattern of nitrate depletion has changed over time.

What seems obvious from the long-term data is an increase in nitrate supply or availability as indicated by increasing spring concentrations over time (Figure 33). If any conclusion can be drawn it would be that nitrogen limitation is less of a possibility than it has been in the past. This increase in nitrate does not seem to be a specific characteristic of Okanagan Lake as Kalamalka Lake shows a similar increase in spring nitrate concentration over time (Jensen, 1999). The reason for this trend is not apparent at the present time but is likely related to land use practices, sewage disposal, and hydrologic variation.

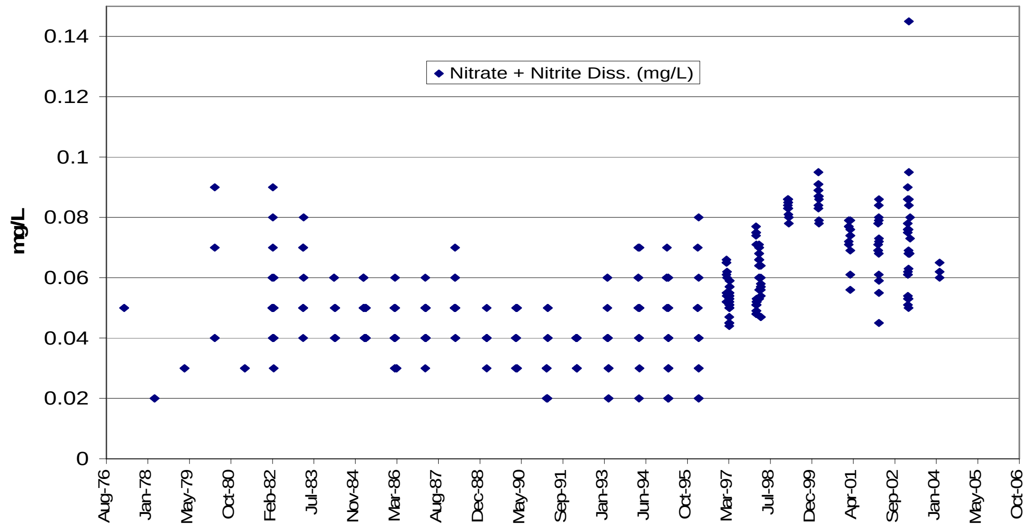


Figure 33: Spring nitrate nitrogen in Okanagan Lake at all deep stations

Another piece of evidence that nitrogen limitation is not a strong force in determining phytoplankton community structure is the species composition data, especially of the cyanobacteria. If strong nitrogen limitation were present in summer, the dominant species would be expected to be those normally associated with nitrogen fixation. Not all cyanobacteria are nitrogen fixers and the dominants in Okanagan Lake are species which do not fix nitrogen (*Synechococcus, Oscillatoria limnetica* (also called *Lyngbya limnetica*) and *Oscillatoria agarhii*) (Stockner, 2000). In lakes, cyanobacteria which fix nitrogen are those species which possess specialized cells called heterocysts which are the sites of nitrogen fixation.

The present N:P ratio of about 28:1 (total N: total P) is in reasonable balance and would not encourage the proliferation of cyanobacteria. There is a clear phosphorus limitation in spring and early summer and likely co-limitation by N and P in summer and fall. This appears to be the pattern over the period of record. Furthermore, there is no evidence that the concentrations of total N and P have changed significantly over the past 30 years. The variation that has occurred is the result of inter-annual changes in hydrology. This variation also alters the TN:TP ratio (Figure 34) with higher ratios during periods of lower run-off.

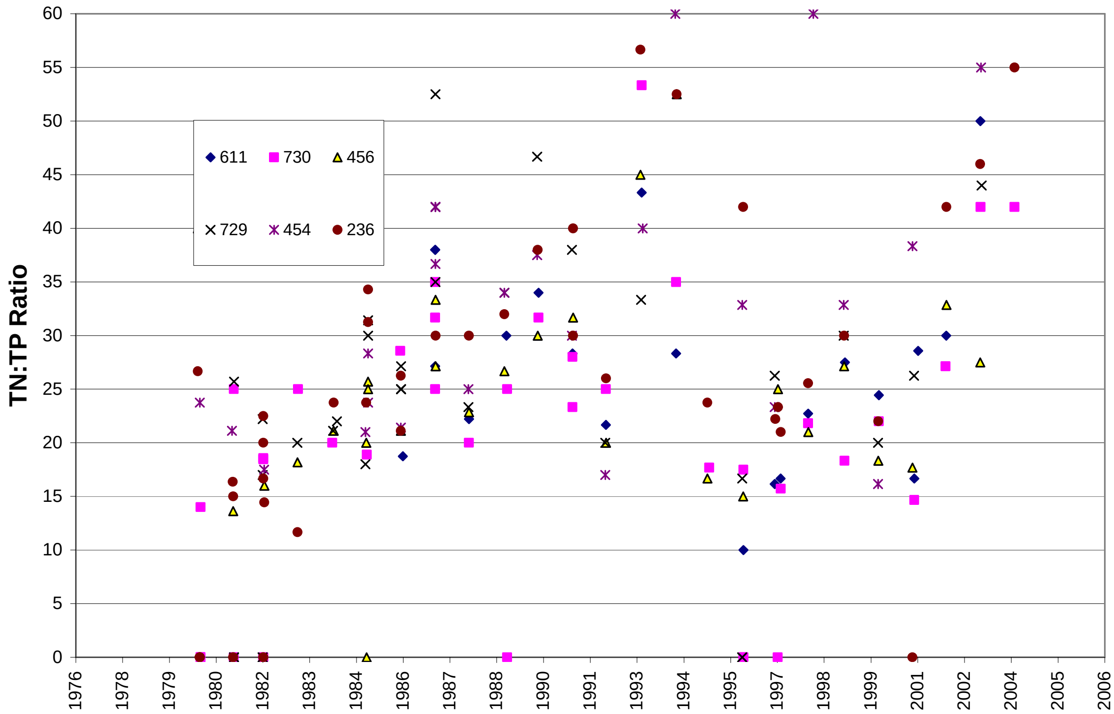


Figure 34: Spring TN:TP ratio for six sites on Okanagan Lake

In the phytoplankton communities of Okanagan Lake, cyanophytes dominate in summer, but they have done so in all the data collected since 1935. Summer dominance by cyanobacteria is not unusual in several large BC lakes (Stockner *et al.*, 2001), especially in the smaller picoplankton size fractions, (Stockner and Shortreed, 1991) and even in conjunction with high N:P ratios. A variety of factors other than nutrients influence the composition of phytoplankton including light, temperature, turbulence, pH, ionic concentration, trace metals and a wide range of other biological, chemical and physical influences (Reynolds 1998, 1999). Okanagan Lake, with high pH, high temperature and high dissolved solids, might be considered to have relatively suitable conditions - even without a low N:P ratio.

There is evidence presented in the OBS nutrient bioassay studies that co-limitation was the most frequent situation present in the phytoplankton of Okanagan Lake (see Tech Supplement V (Pinsent and Stockner, 1974 and Stockner *et al.*, 1972). Nitrogen limitation was indicated only in areas of the lake where there were discharges or nutrient inputs (Vernon Arm, Armstrong Arm, and the near-shore areas near Kelowna and Summerland).

Another point of discussion is the way N:P ratios were calculated during OLAP. For evaluation of N:P ratios during OLAP, the concentrations of nitrate to total dissolved phosphorus were used. This is an unconventional way of calculating N:P ratios and has not been widely used by other researchers. In the open water of most lakes, all forms are bioavailable to some degree and are moving within the different fractions of both N (ammonia, nitrate, organic N) and P (soluble reactive phosphorus, total dissolved phosphorus, total phosphorus) (Lean and Rigler, 1973; Hudson *et al.* 1999). The total pool represented by total phosphorus is the best indicator of phosphorus available to bacteria and phytoplankton. The most common view of the major components of phosphorus within lake water is the one originally proposed by Lean and Rigler (1973) where most of the phosphorus is in the form of total P, essentially as biota. A smaller fraction is composed of cellular material in the process of being broken down by bacteria and in various small size fractions (able to pass through a filter), not necessarily immediately bio-available, but likely to be within the near future. This fraction is best characterized as total dissolved phosphorus. The third fraction is the mineralized, inorganic P that is immediately available for uptake by bacteria and phytoplankton. This is generally measured and reported as ortho-P or soluble reactive phosphorus (SRP). This fraction is generally only present in very small amounts as it is taken up very quickly, especially in phosphorus limited lakes. Low concentrations of ortho-P in water are indicative of P limitation. Okanagan Lake typically has no detectable ortho-P during the growing season.

Similarly for nitrogen, the fractions directly usable by bacteria and phytoplankton are ammonia and nitrate. Organic nitrogen represents the nitrogen tied up in the biota which is constantly being recycled as biota die and are transformed to ammonia and nitrate. The presence of either ammonia or nitrate in the surface is indicative of a surplus of nitrogen for biological up take, i.e., phosphorus limitation.

It might be useful to use dissolved inorganic nitrogen (DIN) (the sum of ammonia plus nitrate) to SRP as a measure of relative nutrient limitation. There would unlikely be immediately available SRP in the surface waters of Okanagan Lake. Soluble reactive P is taken up immediately by the biota and is a clear sign of phosphorus limitation. The fact that nitrate is available into the summer indicates P limitation, and a surplus of immediately bioavailable nitrogen. Total dissolved P is not a readily available form of P as it contains a variety of materials which may pass through a filter but are small organic particulates and not immediately available for bacterial or phytoplankton uptake (Lean and Rigler, 1973). The DIN to TDP ratio used in evaluating Okanagan Lake nutrient limitation employs two non-equivalent fractions and therefore seems to be of questionable utility.

Spring TN:TP seems to the best indicator of relative limitation for phytoplankton (and bacteria) and the proposed water quality objective is a reflection of N:P ratios in the recent past in order to maintain the present lake conditions.

N:P ratios from forested watersheds tends to be higher (38:1) in contrast to agriculture (13:1) or urban runoff (5:1) (Kalff, 2002 – not in references). Thus with time and increasing deforestation and agriculture, it would be expected that N:P ratios would decrease (and perhaps have already done so) with increasing watershed development and population. The substantial increases in spring nitrate over the past 20 years may be an indication of a fundamental change in the lake system.

The OLAP work has suggested that the perceived N:P imbalance represents a bottleneck to production of zooplankton (Stockner, 2002). Stockner hypothesizes that the production of cyanobacteria are not suitable or efficient food source for zooplankton since they are not a preferred food source and do not have the most desirable biochemical constituents (Müller-Navara *et al.*, 2000).

If this were severe, there should be a proportionally small transfer from one trophic level to another, from phytoplankton to zooplankton and an accumulation of phytoplankton due to low zooplankton grazing. The relationships between phytoplankton and zooplankton standing crop and production can be used to evaluate whether Okanagan Lake is atypical in this aspect.

In terms of a general relationship, Hanson and Peters (1984) showed the relationship between total P and zooplankton biomass. For a lake concentration of 10 µg/L, the expected zooplankton biomass would be about 35 mg dry weight/m^3. The best estimate for crustacean zooplankton for Okanagan Lake is from OLAP where they estimated the zooplankton biomass to be 41-61 mg/m^3, above what might be expected. In addition, the primary production of the lake also supports a large *Mysis* population (absent before 1966 and likely of little trophic impact until 1976 or later as it would have taken at least 10 years to reach some kind of population plateau). The present estimate of *Mysis* biomass is approximately 640 tonnes (1.8g/m^2 or 24 mg/m^3 over the water column) which when added to the copepods and cladocera biomass, would indicate a lake with reasonably good secondary production.

Okanagan Lake has been compared to several of the other large BC lakes in order to evaluate the zooplankton productivity. Okanagan Lake is quite different than other large BC lakes in that is has a long water residence time and a significantly higher nutrient concentration. With increases in lake productivity, phytoplankton increases as do zooplankton, but zooplankton biomass increases at a lower rate (Kalff, 2002).

The relatively low proportion of cladocera as a component of the zooplankton community has been identified as a limitation to fish production. Some lakes do have a higher proportion of cladocera, but Okanagan is not outside the range of sampled lakes (OLAP data).

The proposed water quality objective is to maintain an N:P ratio of greater than 25:1 (weight ratio). This would be evaluated at spring overturn using total nitrogen and total phosphorus concentrations at the three index stations in the three main basins plus Armstrong Arm.

It should be anticipated that due to the effects of wet and dry runoff years and the differential effects of hydrologic input between N and P, that the N:P ratio might be expected to decrease in wet years and increase in dry years.

5.7 Chlorophyll a

Chlorophyll *a* is the standard measurement used to quantify the amount of phytoplankton in lake water and is widely used as a surrogate of phytoplankton biomass. There is generally a strong relationship between phosphorus (the major nutrient for phytoplankton) and chlorophyll (the major pigment group in phytoplankton). For Okanagan Lake, the relationship between phosphorus and chlorophyll is typical for lakes to which it is most appropriately compared. Figure 35 (Stockner and Shortreed, 1991) illustrates the correlation between total P and chlorophyll for a number of British Columbia lakes. Okanagan Lake data from 1997 to 2002 (Wilson and Vadmanic,2002) is denoted with the symbol +.

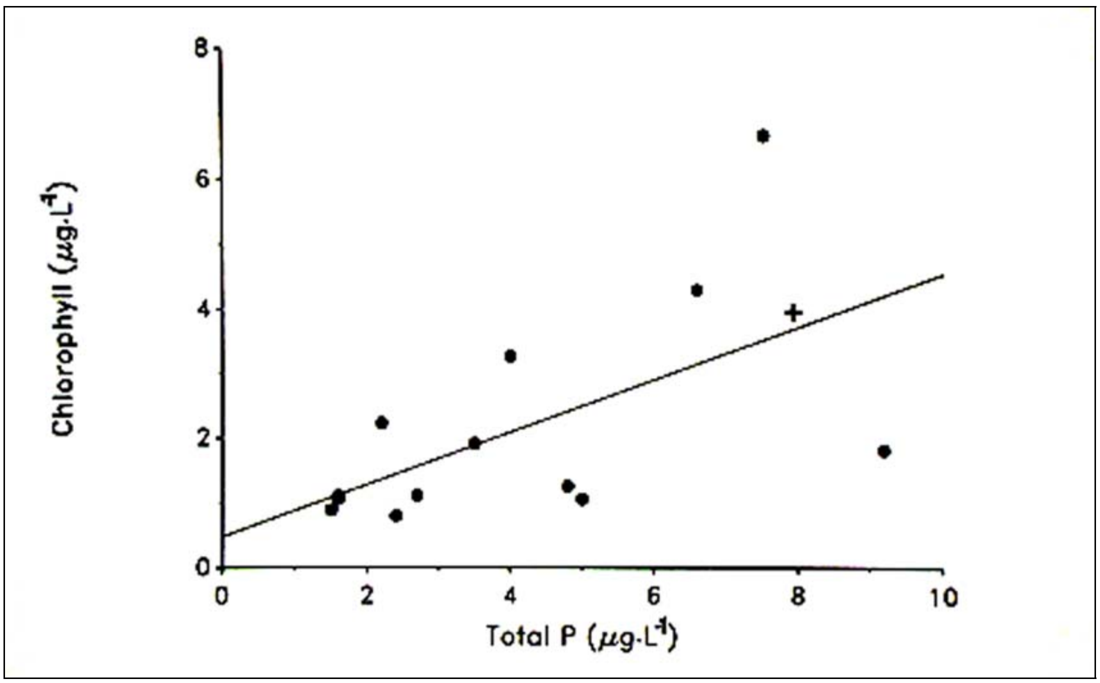


Figure 35: Relationship between phytoplankton chlorophyll *a* and total phosphorus in freshwaters (Stockner and Shortreed, 1991)

Table 27 below is from Wilson and Vidmanic (2002) and lists detailed chlorophyll *a* data from the OLAP program.

Table 27: Average seasonal (May to October) chlorophyll *a* concentrations (µg/L) in the main basins of Okanagan Lake, 1997-2001

	OK1-4	OK5-7	Lake Average	Armstrong Arm OK8
1997	2.3	2.9	2.6	5.7
1998	3.4	4.7	4.1	5.9
1999	5.6	5.7	5.7	5.9
2000	4.0	3.4	3.7	4.6
2001	3.3	3.5	3.4	3.7
Average	3.7	4.4	3.9	5.1

In looking at longer term trends (Figures 36, 37, and 38), the MWLAP spring data show fairly consistent concentrations with some inter-annual variations but no noticeable changes over the period of record.

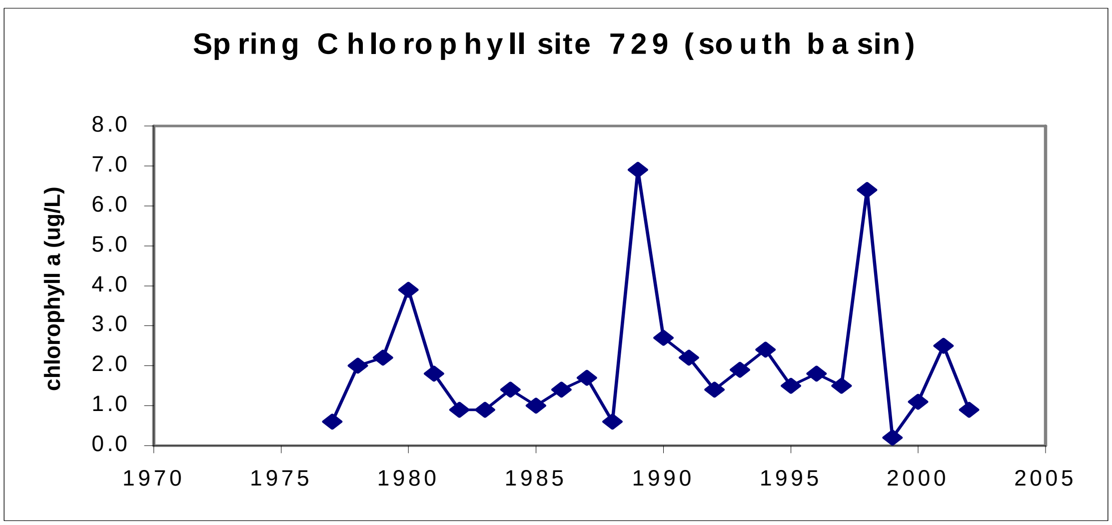


Figure 36: Spring chlorophyll at Okanagan Lake site OK2- 0500729

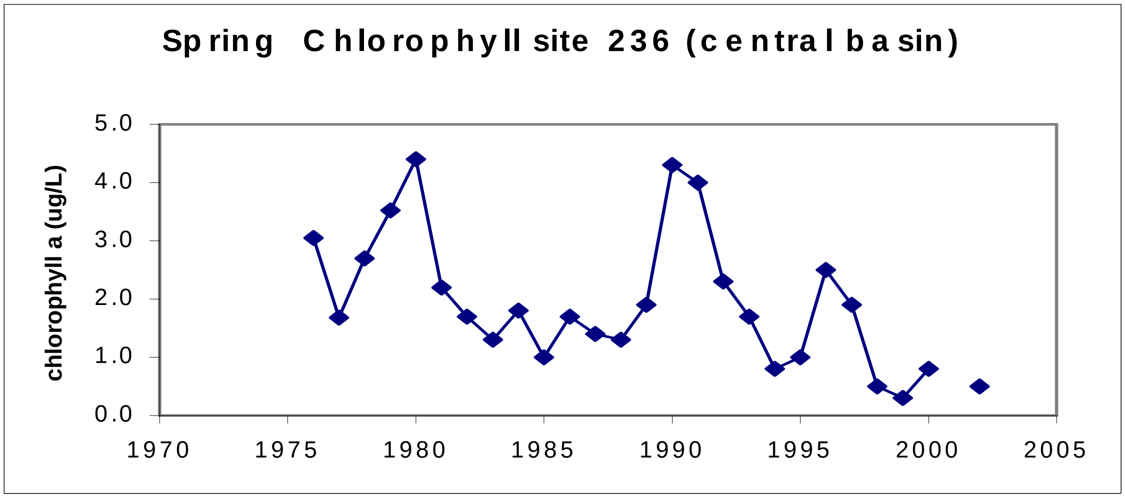


Figure 37: Spring chlorophyll at Okanagan Lake site OK4-0500236

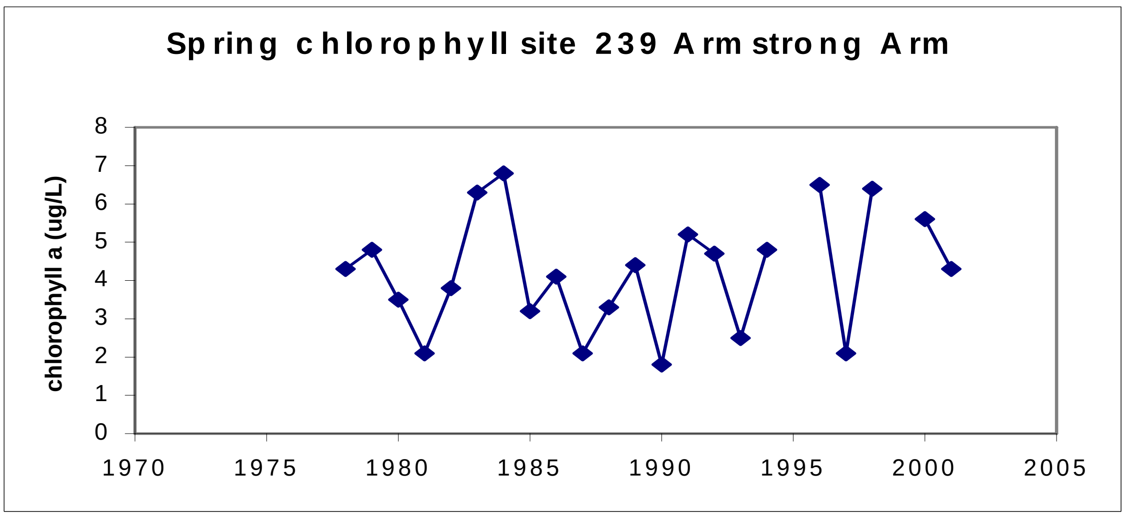


Figure 38: Spring chlorophyll at Okanagan Lake site OK8-0500239

The proposed objectives are for a maximum chlorophyll *a* concentration of 5 µg/L in Armstrong Arm, 4.5 µg/L in the north and central basins and 4 µg/L in the south basin. Values are growing season averages for the epilimnion.

5.8 Phytoplankton

Another commonly used indicator for environmental quality and ecological conditions is the biological communities in a given waterbody. Phytoplankton have been used in many situations as indicators of environmental quality (Wetzel, 2001; Hutchinson, 1967). To characterize the phytoplankton community, two aspects can be used, community composition and quantification. For Okanagan Lake, the relatively consistent community structure (noted in Section 3.2.1) with a minimum of cyanobacteria present is desirable for both drinking water and fisheries (and aquatic life in general) uses. However the presence of cyanobacteria as a major phytoplankton component in large BC lakes is not unusual. For example, Stockner *et al.,* (2001) reported that in Williston Reservoir, the pico-cyanobacteria were numerically dominant. In terms of understanding and managing lake systems, cyanobacteria should not be encouraged through human actions which result in increasing nutrient inputs.

A typical seasonal community pattern in Okanagan Lake is dominated numerically by flagellates and cryophytes in the thermally un-stratified period between November and March. Diatoms dominate in the early stratification period between April and June, followed by cyanobacteria domination during the period of maximum stratification in July through September. The autumn period is dominated by diatoms and flagellates.

Table 28 (Stockner, 2002) serves as a point of reference for a summary of Okanagan Lake in comparison to two BC reservoirs: Williston and Arrow. Arrow Reservoir may not provide the most appropriate comparison as it is fertilized, but it does serve as a point of reference.

Table 28: Comparison of Okanagan Lake phytoplankton abundance and biovolume with Williston and Arrow Reservoirs

		Okanagan	Williston	Arrow
Abundance (cells/mL)	1999	5345	4852	4777
	2000	5100	4571	4993
	2001	3978	-	8479
Biovolume (mm^3/L)	1999	0.77	0.34	0.29
	2000	0.69	0.25	0.46
	2001	0.68	-	0.92

Of the two usual means of expressing phytoplankton abundance, there is considerable advantage to using biovolume rather than numbers. For Okanagan Lake with a high number of very small picoplankton, biovolumes provide a more accurate means of estimating biomass.

The proposed objective for phytoplankton for Okanagan Lake is a biomass maximum of 0.75mm^3/L (0.75 g/m^3). This biomass is to be evaluated as a growing season (April to September) mean for all main basin stations (monthly samples, eplimnetic volume). In addition to this objective, it is also proposed that less than 5% of the phytoplankton biomass to be composed of nitrogen-fixing cyanobacteria species. For

Okanagan Lake, potential nitrogen-fixing species are identified as those species with heterocysts present.

As a check on this biomass objective and reference to inter-annual variation, there should be a reasonable agreement between the chlorophyll*a* concentration and the algal biomass since they represent essentially the same characteristic, that is, phytoplankton abundance.

5.9 Zooplankton

The zooplankton have been discussed in detail in section 5.3. Data listed in Table 29 and illustrated in Figure 39 are from OLAP (Wilson and Vidmanic, 2002) and MWLAP regional long-term monitoring efforts.

Table 29: Average seasonal (May to October) abundance (#/L) and biomass (µg/L) of cladoceran and copepod zooplankton at five Okanagan Lake sample sites, 1997-2001 (biomass 1999-2001)

		OK1	OK3	OK6	OK7	OK8	Whole Lake
Abundance (#/L)	Cladocera	0.79	0.59	0.89	0.98	1.98	1.1
	Copepoda	12.6	14.6	17.5	17.4	28.7	18.1
	Total	13	15	18	18	31	19
Biomass (µg/L)	Cladocera	13	8	14	19	48	20
	Copepoda	31	32	40	42	76	44
	Total	43	41	54	61	124	65

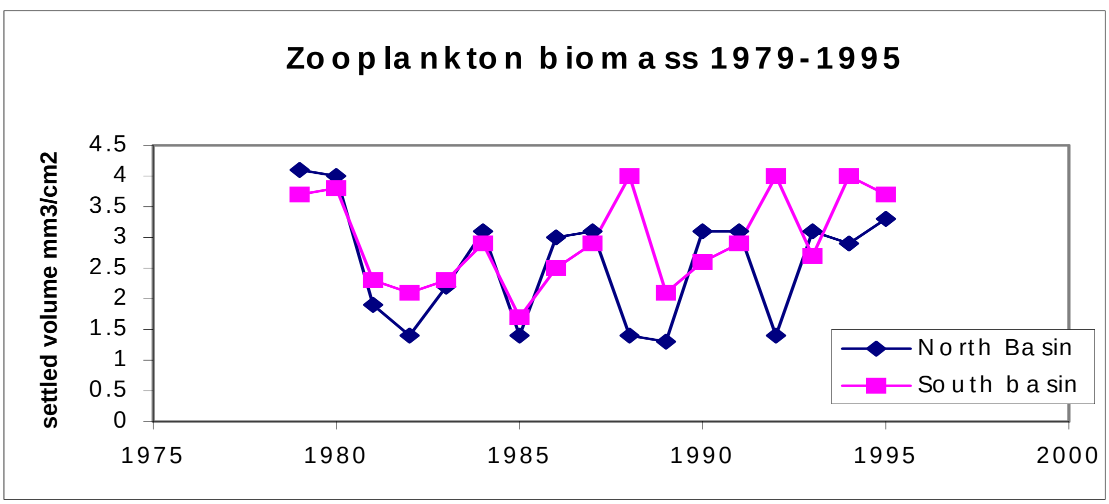


Figure 39: Zooplankton biomass at Okanagan Lake north and south basins

Zooplankton have also been used as environmental indicators and sufficient information is known of the dominant species and numbers in Okanagan Lake that they can also be proposed as water quality objectives.

The zooplankton objective proposed for Okanagan Lake is for a minimum seasonal average biomass of 50 µg/L for the main basin of the lake measured for the top 50 m of the water column. Additionally, there should be no significant change in dominant species. The dominant species that are present in Okanagan Lake (and have been over the past 30 years) should be used as indicators of biological change; these include the calanoid copepod *Leptodiapomus ashlandi*, the cyclpoid *Diacyclops bicuspidatus* and the cladocerans *Daphnia galeata mendotae*, *Diaphanasoma* and *Bosmina*. There should also be a minimum of 5% by numbers of cladocerans (averaged over the growing season) in the zooplankton community.

Zooplankton production might be a better measure of ecological health, a fast turnover of zooplankton and phytoplankton with low standing crop (of both trophic levels) is a measure of ecological efficiency for the movement of nutrients and carbon through the food chain. In the absence of production data, biomass is a reasonable alternative.

5.10 Trace Contaminants in Biota

An area that has received little attention in recent years is the concentration of man-made contaminants in selected biota. Sampling done as part of the Okanagan Basin Study (Northcote *et al.*, 1972) identified mercury and DDT as potential contaminants. More recently, DDT and PCB's were sampled in the lower Okanagan system after concerns were expressed regarding trace contaminants in the Okanagan system (Serdar, 2002).

Because of agricultural activity and increasing urban storm runoff into Okanagan Lake (Swain 1982), there are many potential contaminants, as well as toxicants used in the past, which still may exist stored in lake sediments. A local case study that can be used as an example is Wood Lake (Walker *et al.,* 1994) where a peak in arsenic and lead in lake sediments deposited in the 1940's can be attributed to the use of lead arsenate as a pesticide to control codling moth damage to fruit orchards. The use of these heavy metals, as well as DDT after World War 2 may also explain the virtual disappearance of the benthic community of Wood Lake, which went from being described as abundant (Clemens *et al.*, 1939), to non-existent by 1969 (Saether and McLean, 1972).

Monitoring efforts of MWLAP regional staff indicates that there do not seem to be any serious contamination problems with fish and *Mysis* with respect to human consumption guidelines. Limited monitoring of rainbow trout tissues in the 1990's indicate that the levels of DDT and mercury are generally below safe human consumption guidelines (Bryan and Jensen, 1994). Some recent preliminary scans for pesticide residues on *Mysis* tissues indicated no contaminants of concern, but this should be followed up with more detailed sampling and evaluation relative to wildlife protection levels which are more restrictive. The potential for additional contaminants previously bound in deep lake sediments being moved back into the water column by *Mysis* or dredging activities should be investigated. The work of Bentzen *et al*., (1996) suggested that *Mysis* were particularly important with respect to the food web effects and as a vector for transport of PCBs and DDT residues from the sediments to fish.

The Canadian Food Inspection Agency standards and protocols can be found at (http://www.inspection.gc.ca/english/anima/fispoi/guide/chme.shtml)
http://www.inspection.gc.ca/english/corpaffr/foodfacts/mercurye.shtml

Canadian Guidelines for Chemical contamination and toxins in fish and fish products: contaminants, product type and action level:

Mercury - All fish products (swordfish, shark, fresh & frozen tuna excepted): 0.5 ppm
2,3,7,8 TCDD (Dioxin) - All fish products: 20 ppt
DDT and Metabolites (DDD & DDE) - All fish products: 5.0 ppm
PCB - All fish products: 2.0 ppm
Other agricultural chemicals or their derivatives: - all fish products: 0.1 ppm

Canadian (CCME) tissue residue Guidelines for the protection of wildlife consumers of aquatic biota are (expressed as wet weight):

Methyl mercury – 33 ppb
Polychlorinated dibenzo-p-dioxins/
Polychlorinated dibenzofurans: – mammals 0.71 ppt TEQ diet wet weight
- avian 4.75 ppt TEQ diet wet weight
DDT (total): 14 ppb
Polychlorinated biphenyls (PCBs):
– mammals 0.79 ppt TEQ diet wet weight
- avian 2.4 ppt TEQ diet wet weight
Toxaphene – 6.3 ppb

As a water quality objective for Okanagan Lake, it is proposed that rainbow trout and lake trout (with an emphasis on larger size fish i.e., those at least three years old) be tested for contaminants normally examined by the Canadian Food Inspection Agency and CCME guidelines to protect wildlife consumers of aquatic biota. With regards to fish, which are subject to recreational fishing, it is normally the responsibility of provincial governments to monitor mercury levels and to set and publicize safe consumption information. In this case it is recommended to use the guidelines set by the Canadian Food Inspection Agency.

Sampling will be done at three sites in Okanagan Lake for *Mysis* and large rainbow trout. The tissue will be analyzed for mercury, dioxins and furans, DDT and metabolites, PCB's, and a scan of agricultural chemicals that might be considered to be a risk. Five fish of at least one kg in weight are to be sampled from each location every five years. Concentrations of contaminants should be below the CFIA action levels.

5.11 Bacterial Indicators

There should be a program established for shallow water sampling (littoral areas out to 10 m depth) in areas where drinking water intakes exist and at bathing beaches. The latter is presently being sampled in the summer months by local health authorities and needs to be continued to identify human health risk. Monitoring outside beach areas in the vicinity of water intakes might be best taken on by the water utilities that use the water as part of their monitoring programs if it is not already being done.

The water quality objectives proposed for Okanagan Lake to protect drinking water supplies is fecal coliforms counts less than 10 colony forming units (CFU)/100 mL and *E. coli* counts less than 1/100 mL. The water quality objectives proposed to protect recreational areas is a geometric mean fecal coliform concentrations of less than or equal to 200 CFU/100 mL and mean *E. coli* concentrations of less than or equal to 77/100 mL.

Samples should be collected five times in 30 days in the months of May and July. Sites should be located in areas with water intakes and near potential sources, especially stream inflows. These locations should be determined by Ministry staff in consultation with drinking water utilities and health authorities. Potential sites may include areas like the mouth of Kelowna (Mill) Creek, the mouth of Mission and Trout creeks. Monitoring inflow streams in the vicinity of water intakes may provide an alternative strategy.

6.0 MONITORING RECOMMENDATIONS

The terms of reference for this report included a request to review the existing Ministry monitoring program and comment on the rationale for selection of key variables to be monitored, including spatial and temporal considerations. Annual and cyclical components of an integrated lake monitoring program were to be proposed. The point of reference for a monitoring program would be the proposed objectives. However, the monitoring would be expected to be broader than simply measuring the objectives and would include other important indicators of lake status.

There are many stations which are presently monitored to assess lake water quality in Okanagan Lake. It would be useful, in terms of strategic allocation of resources, to concentrate sampling on four sites: the north, central and south basins plus Armstrong Arm, to provide continuity in the evaluation of the lake. The dataset that has been gathered since 1975 at these sites provides an excellent baseline to assess further changes in the lake. This long-term monitoring must be continued.

Although there has been considerable improvement at the larger sewage treatment plants in terms of nutrient removal, there are still concerns over other contaminants (particularly biological pathogens, viruses, bacteria and protozoans) and biochemically active constituents like pharmaceuticals and hormone mimics that could be discharged from the sewage treatment plant outfalls. Monitoring of these locations should be the responsibility of the discharger to ensure discharges are not having a negative effect. The design and implementation of these programs need to be negotiated between the discharger and the appropriate government agency, with government maintaining authority for approval of the monitoring program.

For further monitoring, it is recommended that a chemistry program be implemented consisting of nutrients (ammonia, nitrate and total nitrogen, SRP, TDP and TP) at depths representing the whole water column (i.e., epilimnion and top and bottom of the hypolimnion). The key sampling time is in the spring prior to stratification with sampling on a monthly frequency until autumn destratification. Other chemistry measurements to be taken at spring overturn would include general anions and cations including silica, metals and dissolved and total inorganic carbon.

The biological limnology program should include a continuation of the current OLAP program. This would include monthly sampling of phytoplankton samples for species composition and chlorophyll *a*. Zooplankton samples require the additional sampling to calculate zooplankton production values.

One component of biological water quality which needs additional work is to characterize the littoral periphyton community. The sampling done previously has used a variety of techniques and sampling locations that make any long-term comparison impossible. A program of shallow water periphyton sampling should be established that will enable future comparisons to be done. The principles of this program should include sampling of natural substrates, establishment of stations in about three key locations and sampling during one or two key periods of the year.

OLAP has set an excellent standard for the timely publication of the studies that it has undertaken. It would also be an advantage for the MWLAP regional office, as a regular part of their ongoing monitoring program, to publish in some regular format (perhaps web-based) the results of the year's sampling in a compiled format within three months of the end of the year with a comparison to either water quality objectives or past data. This report would not necessarily need to include detailed interpretations. This would provide a regular compilation of data, as well as information to the public, many of whom have an ongoing interest in the lake. This also serves the purpose of making the public more aware of the activities of government and the status of the lake.

It is beyond the scope of this report to set objectives for fisheries: however, such goals would be useful in the overall management of the basin's aquatic resources. Bull (1983) provided a goal, which could be considered as an objective: "regional target for rainbow trout is to maintain a catch success of 2 fish per day averaging 25 cm in length". Other goals/objectives might include area of spawning habitat (area or linear distance) that should be present, spawning numbers for kokanee or population numbers for kokanee. Rationalized and quantitative fisheries goals are necessary and appropriate management guidelines but the Fisheries Program should take on this task.

There are a variety of other specialized studies which would be very useful in understanding of the Okanagan Lake ecosystem.

Future studies which should be considered would be an examination of nutrient limitation in Okanagan Lake and the seasonal changes and relative importance of nitrogen and phosphorus (see Healy and Henzel, 1980; Hecky and Kilham, 1988; Elser *et al.* 1990).

One of the major areas of knowledge for Okanagan Lake that needs improvement is the understanding of the trophic structure. There are two techniques that could be very useful in explaining where each species fits in and what each species is dependant on for its food supply. This is obviously very important for managing kokanee. Stable isotope analysis is a powerful tool by which to judge the relative trophic position of different species (nitrogen stable isotopes) and what area of the lake, pelagic or littoral, organisms derive their energy from (carbon isotopes). There have been a number of recent papers that have been shown the value of stable isotope studies (Vander Zanden and Rasmussen, 2001, Vander Zanden and Vadeboncoeur, 2002). This approach would be valuable in describing the trophic pathways that support the kokanee populations, as some preliminary work has already shown (Whall and Lasenby, 1998, 1999, 2000). Studies using stochiometry (the carbon, nitrogen and phosphorus contents of different species or organisms at different trophic levels) is also a technique that can be used to understand food chain complexity (Stemberger and Miller, 1998; Schindler and Eby, 1997; Elser and Foster, 1998).

Another area which needs considerable research is the physical limnology of the lake. A beginning has been made with the work sponsored by the City of Kelowna (Hay and Company, 2001) but so much of the understanding of the biology and chemistry of the lake is based on the stratification and water movements of this lake. The experience with the value of physical limnology that came about after the studies of Kamloops Lake (Carmack *et al.*, 1979) where the interaction of the Thompson River with Kamloops Lake was critical in explaining the downstream proliferation of periphyton. As well, an understanding of the stratification, mixing and internal waves were needed for Kootenay Lake to understand the lake chemistry and biology (Jasper *et al.*, 1983). Both these studies from BC are frequently cited examples in the limnological literature of the essential nature of lake physics to overall ecosystem understanding.

As noted previously, there are several areas of lake biology that need more work. These include examining the bacterial numbers and production, estimates of numbers and production of protozoans and rotifers, and a comparison of the status of the benthic community in comparison to the survey of Saether (1970) done during the Okanagan Basin Study. The other major component of the lake with poor information is the periphyton, which is discussed below.

6.1 Other objectives considered but not proposed

6.1.1 Dissolved ions

Another indicator of long-term trends is changes in conservative ions in Okanagan Lake water. Because measurements like nutrients were generally inaccurate or absent in early sampling (before 1965), other measurements can be used to evaluate long-term changes, especially from non-point source inputs. Conservative ions are those which are not affected by biological processes and include the major cations calcium, sodium, magnesium and potassium and the anions chloride, sulphate, carbonate and bicarbonate. The latter two compounds do play a role in photosynthesis but are still considered conservative.

Total dissolved solids and conductivity are measures of the amount of minerals that are washed into the lake from both watershed processes and human activities. In light of the increases observed over the period of record, which likely reflect human disturbance, objectives for total dissolved solids , conductivity and chloride at spring overturn could be proposed to monitor the overall effects of land use activities in the watershed.

Bryan (1996) discussed changes to sodium concentration, which increased from 8 mg/L in1949 measurements to 10 mg/L in 1985 (Figure 40). Chloride is another parameter that can be used to track watershed disturbance. Okanagan Lake chloride concentrations are increasing, based on an examination of the available data (Figure 41). The increases in sodium and chloride likely result from discharge of municipal wastewater, and stormwater run-off.

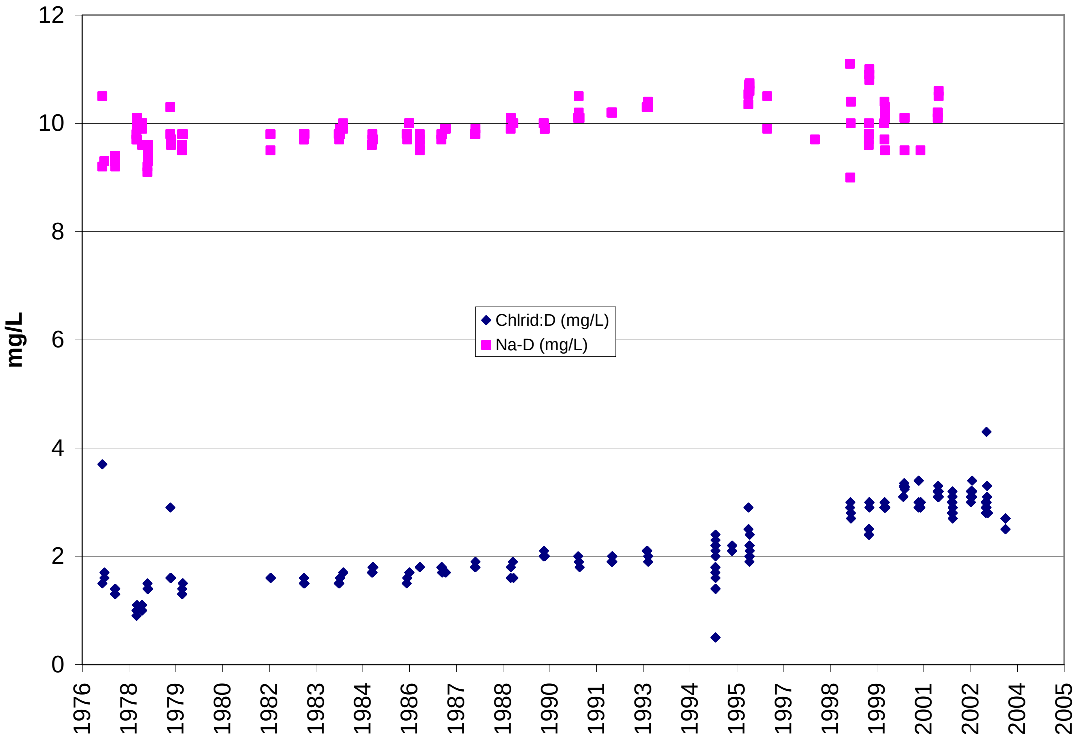


Figure 40: Sodium and chloride concentrations (mg/L) in Okanagan Lake

6.1.2 Periphyton

Periphyton are becoming increasingly recognized as a vital component in lake systems (Vadeboncoeur and Steinman, 2002). The abundance and community structure of periphyton are probably better indicators of the effects of human nutrient inputs to an aquatic system than the measures of pelagic water chemistry and biology because of its proximity in the littoral zone to the sources. As noted earlier in the report, periphyton, as an indicator of lake health, has not received the attention that other indicators have. Periphyton do have the potential for major impacts on recreation (the shallow areas favored for swimming) and on fisheries (shore spawning kokanee may be impacted by the growth and subsequent decay of periphyton biomass in the shallow areas of the lake).

The proposed objective would apply to natural substrates at three rocky shore sites which have been identified as important for kokanee spawning or for recreational use. Measurements would be made from replicate samples at the time of maximum biomass (mid-summer or late summer). At least three years of sampling would be required prior to setting a water quality objective for periphyton.

7.0 ACKNOWLEDGEMENTS

In conclusion and with respect to the feasibility of continuing and future monitoring plans the following comments are offered. There are generally difficulties in obtaining the resources to do the basic monitoring necessary to provide the data for informed decisions on the management of natural resources. This is certainly the case with Okanagan Lake. The lake is an extremely valuable resource and the amount of money that is allocated to manage this multi-million dollar resource is presently inadequate. This needs to change. The OLAP program, if it is continued, will provide much needed information in understanding and managing the kokanee. However a wider view of water resource management is needed and some larger appreciation and leadership is necessary to carry on into the future. One of the main recommendations of the Okanagan Basin Study was to create a Board to do just that. It is important that a local regional authority take on this necessary role.

Acknowledgements

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