Water Quality Trends in Okanagan, Skaha and Osoyoos Lakes in Response to Nutrient Reductions and Hydrologic Variation.

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Abstract
The population of the Canadian Okanagan basin is approximately 300,000, tripling every 30-40 years since 1940, and presently exhibits one of the fastest growth rates in the province of British Columbia. To guard Okanagan, Skaha, and Osyooos lakes from excessive eutrophication, phosphorus (P) reduction from municipal sewage treatment plants was implemented in various stages since 1971. Oligotrophication is now evident in Skaha Lake. Spring phosphorus, and autumnal phytoplankton chlorophyll *a* values are decreasing and hypolimnetic dissolved oxygen readings have increased in Skaha. Similar trends but to a lesser extent have occurred in Osoyoos Lake but with considerable year to year variability. Reductions in municipal point source phosphorus loading to Okanagan Lake improved water quality near two points of discharge. Two recent multi-year periods of increased water discharge from Okanagan Lake (1981-84 and 1996,1997 1999) are closely associated with increased spring and fall P, reduced water clarity and elevated phytoplankton chlorophyll *a* in Okanagan Lake. Despite a long residence time, changes in hydrology clearly affect nutrient loading, and aquatic ecosystem processes in Okanagan Lake. Hydrologic variation and non-point source nutrient pollution account for the majority of the nutrient variation observed in these lakes. Management efforts to reduce NPS nutrient loading are described and multiple benefits to non-point source pollution control noted. Further study is needed to more accurately apportion and effectively manage non-point source nutrient loading from agriculture, urban run-off, and forestry. Setting more comprehensive water quality objectives for the Okanagan lakes is recommended as a key component of ecosystem based management of the Okanagan basin.

The Okanagan River basin drains through a chain of lakes (Ellison, Wood, Kalamalka, Okanagan, Skaha, Vaseux, Osoyoos) in the southern interior of BC before crossing the US Canada boarder and flowing on to the Columbia River. Water resources, both quantity and quality, have frequently presented management challenges in this semi-arid and rapidly urbanizing landscape. From the time of one of the first water quality studies in the Okanagan (Rawson, 1939) to the present time, the human population of the Okanagan Basin has tripled every thirty to forty years and now is approximately 300,000. As population in the valley increased, so did wastewater collection and discharge to surface waters. By 1970 the valley population had reached 100,000 and algal blooms occurred twice a year on Skaha Lake (Fleming et.al. 1975) due to the discharge of secondary treated effluent from Penticton. Deteriorating water quality was also a concern at Wood Lake, and where Vernon effluent entered Vernon Arm of Okanagan Lake. Public concern for water resources of Okanagan, Skaha and Osoyoos lakes led to comprehensive monitoring of water and waste water quality under the Okanagan Basin Study (Stockner et. al. 1974) and the Kalamalka Wood Study (Anon. 1974).

An Overview of Waste Management Efforts in the Okanagan Basin

Similar to the history of many lake management efforts elsewhere, the 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. 1974). The point sources of phosphorus 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), dustfall & precipitation, and watershed sources. Agriculture and septic tanks were considered as controllable sources while dustfall, precipitation and watershed sources were thought of as uncontrollable**.** Point source nutrient loads can be quantified relatively accurately through regular measurements of volumes and concentrations in the discharges.

Municipal Point Source Phosphorus Control

Being more amenable to control strategies, point source control of P has been implemented progressively over the past three decades in many communities (Table 1) 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 STP to the Bardenpho tertiary process in 1983 (Bryan, 1990; Nordin, 1990).

However, a decade after implementation of these point source P reductions, the monitoring of Skaha Lake immediately downstream of Penticton, and Osoyoos Lake further downstream, did not show reduced phosphorus levels. A lack of response was rationalized to be confounded by inaccuracies in nutrient loading estimates, changes in NPS loading over the study period, and hydrologic fluctuations (Nordin,1990; Fleming, 1975). At the same time P levels in Okanagan Lake were also found to be increasing. For these and other reasons, in 1985 the provincial government declared the Okanagan an environmentally sensitive area and renewed waste management planning efforts under the Okanagan Water Quality Control Program (OKWATER) to reduce phosphorus by 95% from sewage discharges. For the sake of brevity the reductions in municipal P loading to the present time are documented in Table 1.

Non-Point Source Phosphorus Control Efforts

Diffuse source controls began to be implemented by OKWATER (1985-94) because it was recognized that further gains from point source reductions were limited and that eventually population growth increases would exceed technological advances allowing further P reduction. Point source reductions appear now to have run their course for these three lakes, going from 47,000 kg P in 1970 to 2600 kg in 2001.

The very nature of diffuse source nutrients release, makes direct measurement of diffuse source loading very difficult if not impossible and forces reliance on estimates (Figure 1). 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 in the early 70's, the Okanagan Basin Implementation Agreement studies around 1980 and the OKWATER work of the late 1980's. 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

Agriculture

Agricultural phosphorus loadings were first estimated in 1970 (Kennedy and Oldham, 1972) for two separate components: a) movement of phosphorus through soil from irritated / fertilized cropland and b) direct runoff of animal wastes. Nutrient movement through soil from cropland was modelled 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). 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 new farms with very different waste management practices than their predecessors. Agricultural loading estimates for 1980 are therefore shown as being at least 2 to 3 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 seen as being 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 later 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.

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 8 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 bioavailable phosphorus. This estimation technique is very coarse and subject to a variety of estimation 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.

In summary Figure 1, the results have been carried backwards to 1970 and forwards 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 focussed 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 which was implemented in 1995. Current logging disturbance levels do appear to be significantly lower then 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.

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 also 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 (1985-94) septic control efforts focussed on identification of problem septic areas and formulation of sewering 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 and 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 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).

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 analysis of samples from dustfall collection canisters placed in representative locations around the basin. Unit area loadings range from a low of approximately 0.1 kg of P /year / Ha of lake area for Wood Lake to a high of 0.4 kg of P /year / 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 changes unit loading changes were recommended and so the dustfall and precipitation loading estimate has not been revised for either 1980 or 1990.

Watershed Sources

Watershed sources in Figure 1, includes everything else which is not included in the point source measurements and diffuse source estimates described above. A large component of the watershed source load is associated with 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 P loadings / year / ha of watershed area. The values used appear to range from a low 0.08 kg P / ha / yr in the Okanagan basin to a high of 0.25 kg P / ha / yr 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 (Grey 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 loading of contaminants was monitored during the Okanagan Basin Study but was 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 loading from this sector 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 also vary considerably 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 between the lows and highs. As such, annual watershed source loadings could be significantly lower in dry, low peak flow years and could be much higher in wet years with high peak flows. Finally, consideration of variable bio-availability based on limited sampling could further compound the variation from the expected result as per the estimates.

Water Quality Objectives

In 1985 maximum desirable concentrations, or water quality objectives for spring time lake total phosphorus concentrations were set as realistic management tools for protection of Okanagan lake, as opposed to further refinement of nutrient loading studies directed at determining critical loading values. Water quality objectives for spring P in Okanagan (0.01 mg/L), Skaha (0.015 mg/L) and Osoyoos (0.015 mg/L) lakes were set to further guide nutrient control efforts (Anon. 1985). The spring P objectives were based on an assessment of existing P levels and eutrophication issues in the Okanagan and elsewhere, and were set to protect the most sensitive water use; for Okanagan Lake the uses were recreation and aesthetics; drinking water and fisheries uses were also acknowledged.

Given this backdrop of three decades of point source and non-point source nutrient control it is useful to examine the changes in water quality of the Okanagan lakes. This overview will primarily report the year to year variations observed in the water quality of Okanagan, Skaha, and Osoyoos lakes from the mid 1970's through to 2001 The influence of hydrology and changes in nutrient loading are identified where cause and effect are apparent.

Lake Study Methods and Data Sources

Water quality data has been collected on Okanagan, Skaha and Osoyoos lakes in the spring and fall, by the Ministry of Water, Land and Air Protection (WLAP), Environmental Protection Division staff since approximately 1975. Sampling methods and site locations have been previously reported (Bryan, 1990, Jensen, 1999) and to the extent possible the sites match those used during the OBS (Stockner and Pinsent, 1974) and OBIA (Truscott and Kelso, 1979) studies. Not all sites and data gathered by this sampling program for the three lakes are presented here. Representative sites were chosen to demonstrate trends observed to be common for each lake as a whole. For Okanagan Lake a site central in the southern basin, near Summerland was chosen, however multi-site averages have also been included to illustrate certain trends. For Skaha Lake the main site opposite Gillies Creek in the centre of the north basin was used. The central site on the north basin of Osoyoos Lake was selected for this overview, as it has the longest sampling record. Water quality variables pertinent to eutrophication assessment such as total and dissolved forms of phosphorus, nitrate and total nitrogen, phytoplankton chlorophyll *a*, hypolimnetic dissolved oxygen minima, and water clarity or Secchi disk depth were recorded in February or March, depending on ice cover, and again in the fall, usually in September. Recent interest in declining kokanee stocks in Okanagan Lake (Ashley et al. 1999) and sockeye rearing capacity of Skaha and Osoyoos lakes (Rensel, 1998;ONFC unpublished data.) have prompted seasonal studies under the Okanagan Lake Action Plan and Okanagan Nation Fisheries Commission respectively. These seasonal studies have adopted sites and methodologies similar to that of the WLAP program. All data is stored on the provincial data archive presently called the Environmental Monitoring System (EMS).

Water Quality Trends in Okanagan, Skaha and Osoyoos Lakes

Phosphorus Trends

Of the three lakes, Skaha Lake spring total phosphorus (TP) has declined most noticeably, from approximately 25 ug/L in 1978 to 12 ug/L in 2001 (Figure 2), and has met the water quality objective over the past decade. Higher spring TP average values (31.7 ug/L to 41.3 ug/L) were noted in 1969 and 1970 (Coulthard and Stein, 1969; Stein and Coulthard, 1970). This change is largely due to the reduction in phosphorus load from the Penticton sewage treatment plant from approximately 13,530 kg in 1970 to 508 kg in 2001. Osoyoos Lake which has benefited from the Penticton load reduction as well as removal of the Oliver discharge (1400 kg in 1983), also has reduced spring phosphorus, from approximately 25 ug/L in 1978 to 15 ug/L in 2001(Figure 2) and has met the water quality objective in 4 of the past 7 years. Spring phosphorus in Osoyoos Lake was somewhat higher historically, ranging from 23-37 ug/L in the spring of 1969 and 1970 (Coulthard and Stein, 1969; Stein and Coulthard, 1970). As noted previously, phosphorus removal or reduction by Vernon and Kelowna respectively has improved water quality local to the discharge point. Despite a phosphorus reduction of approximately 42, 000 kg/yr from municipal sources to Okanagan Lake, spring phosphorus in Okanagan Lake, as demonstrated by data for the southern basin, near Summerland, shows little or no decrease, with some recent spring TP values (yr. 2000: 13 ug/L) higher than those recorded for the past 25 years (Figure 2). For the past 5 year Okanagan Lake spring TP has been within a microgram or two of the water quality objective. Averages of yearly data for seven deep sites shows that in 2001 the spring lake average exceed 0.01 mg/L. However, on many spring dates between 1996 and 2001, one or more individual sites exceeded the objective. Total dissolved phosphorus (TDP) shows trends similar to those for TP in Osoyoos and Okanagan, but Skaha TDP appears since 1975 to have been a smaller portion of the total phosphorus so the downward trend in TDP is less significant than for TP (Figure 3). Total phosphorus, in the fall after much of the growing season also shows declining trends in Skaha and Osoyoos lakes, but not in Okanagan Lake (unreported). Further indication of oligotrophication of Skaha and Osoyoos lakes, is shown in declining hypolimnetic phosphorus levels over the past 25 years (Figures 4 and 5).

Nitrogen Trends

Spring total nitrogen (TN) has decreased in Skaha Lake from 0.35 mg/L in 1980 to 0.25 mg/L in 2000. Over the past five years spring TN in Skaha Lake has been similar in concentration to those in the southern basin of Okanagan Lake (Figure 6) where TN has not change significantly over the 25 year period. Osoyoos Lake north basin spring TN appears relatively unchanged for the period of record. Fall TN in Okanagan Lake southern basin, and Osoyoos Lake north basin show no long term trend while Skaha Lake shows a steady decline from 0.37 mg/L in 1980 to 0.21 mg/L in 2000 (Figure 7).

Spring nitrate nitrogen trends in Skaha and Osoyoos lakes show no long term trends, with relatively low values in the mid 1970's (0.02 mg/L), peaking in 1988 for Skaha Lake (0.12 mg/L), and then trending downward to lower values by the mid to late 1990's (Figure 8). This pattern perhaps reflects nitrate loading trends from the Penticton STP. Spring nitrate nitrogen has been steadily increasing in Okanagan

Lake. In the southern basin, spring values increased from 0.03 mg/L in 1980 to 0.083 mg/L in 2000. Fall nitrate concentrations in all three lakes are generally at or below the varying detection limits used over the years (Figure 9).

Phytoplanton Chlorophyll a and Secchi Disk Depth Trends

Of the three lakes only Skaha Lake spring phytoplankton chlorophyll *a* data shows a decreasing trend from 19.7 ug/L in 1980 to 3.2 ug/L in 2000, and then rising to 9.7 ug/L in 2001 (Figure 10). Fall phytoplankton chlorophyll *a* shows no clear trend in Skaha or Osoyoos lakes, with considerable year to year variation, likely dependent on timing and species incorporated in the fall phytoplankton populations (Figure 11). Okanagan Lake however, shows higher fall chlorophyll *a* over the past decade than previous records. In recent years increased public complaints have been recorded regarding water quality. In the spring of 1998 an extensive but transient cyanophyte bloom of (*Anacyctis areuginosa* or *Microcystis areuginosa)* occurred in the southern basin of Okanagan Lake. In the fall of the same year, accumulation of surface foams on Okanagan Lake and Skaha Lake were extensive and a great concern to the public. In summer 2001 the cyanophyte *Aphanothece sp.* produced prolonged surface scums along the west shoreline of the Casa Loma area of Okanagan Lake. In fall 2001 *Botyrococcus Braunii* produced shoreline scums in Vernon Arm of Okanagan Lake.

Spring Secchi disk depth, a record of water clarity, is gradually increasing in both Okanagan and Skaha lakes (Figure 12). Fall water clarity of Skaha has improved markedly from Secchi depths of 3.0m in 1980 (3.9m av. 1976-1978; Truscott and Kelso, 1979) to a high of 10.0m in 1999 with subsequent retreat to 7.7m in 2001 (Figure 13). Osoyoos Lake shows no long term trend in spring or fall water clarity. Okanagan Lake fall Secchi depths were greatest in the period 1986 to 1994 with decreased clarity prior and subsequent to that period.

Hypolimnetic Dissolved Oxygen Trends in Skaha and Osoyoos Lakes

Variable timing of fall sampling, and inconsistent selection of a bottom sampling depth compromises long term trend assessment of bottom dissolved oxygen levels in these two lakes. To reduce the influence of some of these variables, only the DO records for the 44 metre depth (a commonly used depth over the years) measured in September was used to determine hypolimnetic oxygen trends. A hypolimnetic oxygen depletion problem was noted for both Skaha and Osoyoos Lakes in 1977 and 1978 (Truscott and Kelso, 1979) particularly in October with bottom samples approaching anoxia. Although a greater depletion rate was noted in Skaha Lake at that time, since then bottom waters have progressively contained more dissolved oxygen (DO) during the September sampling (1977: 4mg/L; 2000: 8 mg/L), thus corroborating the reduced phosphorus and primary productivity and increased water clarity shown in Skaha Lake over the same time period (Figure 14). Minimum hypolimnetic DO values in recent years (3.5 mg/L @ 50m, 1999) are greater than some values noted in the past (0.7 mg/L @ 50m, 1978). Osoyoos Lake bottom waters in September show a slightly increasing trend in dissolved oxygen from 1979 (2.6 mg/L) to 1989 (5.3 mg/L) with no trend since then.

Hydrologic Influences on Water Quality Trends and Productivity

Nutrient availability, limitation, and characteristics of primary and secondary productivity may be expected to vary considerably from year to year depending on run-off. Wetter years will load more phosphorus both dissolved and particulate; repeat wet years may accentuate the extent and timing of nitrogen limitation of phytoplankton growth (Figure 15). Phosphorus limitation or co-limitation may be accentuated during dry years (Figure 16) . Much of the phosphorous delivered by Okanagan tributaries during wet years occurs during the few weeks of snowmelt, and is associated with suspended sediments. Previous estimates have suggested biologically available phosphorous portion is generally low, ranging from 19 to 98% (Gray and Kirkland, 1986). Biologically available nitrogen varied less at 58 to 98% in Okanagan streams. Unfortunately, no historical trend monitoring of Okanagan Lake tributaries has been conducted to determine changes in loading related to hydrology or changes in land use.

Two recent wet year periods of increase water discharge from Okanagan L (1981-84 and 1996,1997 1999) are closely associated with increased spring and fall TP in Okanagan Lake (Figure 17 and 18). These wet year periods approximately double the spring and fall TP in Okanagan Lake from 0.005 mg/L to 0.010 mg/L. Previous studies also noted increased P loading with increased discharge (Haughton and Feddes, 1974). These same wet year periods (1981-84 and 1996,1997 1999) appear to be synchronous with periods of increased shore spawning and stream spawning kokanee counts on Okanagan Lake (Figure 17 and 18). Shore spawner response appears delayed approximately 2-4 years, while stream spawner counts peak 1-2 years following periods of higher run-off. Assuming an average Okanagan Lake P value of 5 ug/L during dry years and twice that during dry, the total in-lake phosphorus mass changes from roughly 131,000kg to 262,000 kg; a portion of which would be biologically available. Factors other than increased phosphorus, such as elevated stream flows, alteration of in-lake nutrient ratios, or other variable might well be responsible for part of all of the apparent increased kokanee counts during periods of increased stream discharge. This apparent enhancement of kokanee stocks following wet year periods and the staggered timing of the two stocks should be investigated further to determine the basis of this linkage.

The intervening lower run-off period (1984-1995), and period of reduced Okanagan Lake phosphorus concentrations is also of interest. Leith and Whitfield (1998) used the hydrological period 1984-1995 as a surrogate to describe possible climate-change effects on hydrologic processes in the southern interior. Implications of climate change on nutrient loading and aquatic ecosystem processes should be examined further.

Discussion

In 1970, roughly half the phosphorus load to Okanagan Lake was estimated to be from municipal point sources on an average flow year. For Skaha the estimated load was slightly larger due to the smaller watershed and proximity to the Penticton STP discharge. For Osoyoos Lake the point source load was considerably smaller but the main-stem loading which incorporated the Penticton STP discharge resulted in a net point source contribution of roughly 50%. Application of best available tertiary treatment technology to this sector has reduced the P load by an order of magnitude (47,000 to 2,600 kg) for the three lakes combined. Skaha Lake has undergone oligotrophication and algal blooms have not occurred since the early 1970's. To a lesser extent Osoyoos Lake has also undergone oligotrophication. Reduced response of Osoyoos Lake was anticipated due to lower direct point source contribution, and morphometrics of the basin. Modelling the response times of these two lakes to point source P reductions could be instructive and clarify the component related to changing residence times with wet and dry year cycles. In 1970 wet years cycles would have improved water quality of Skaha and Osoyoos lakes. By 1980 this may no longer have been the case as non-point source and main-stem loading would have been proportionally larger in wet years. Modelling lake response would assist determining whether Skaha and Osoyoos lakes will continue to decrease in phosphorus or how climate change might affect water quality. Paleolimnological evaluations of Skaha Lake are recommended to better determine historic productivity levels and direct future management efforts.

Non-point source management efforts in the Okanagan Basin are thought to have collectively reduced P loading from agriculture, forest harvest and septic tanks by 5,000 to 10,000 kg. It has been shown that watershed sources and the remaining NPS component constitutes the majority of the phosphorus loading to the Okanagan Lakes. Limitations of the NPS estimates have been identified, and the range of loading between wet and dry year cycles illustrated by fluctuations in Okanagan Lake phosphorus concentrations. Diffuse source P from forestry, agriculture & septic tanks will tend to be variable from year to year in response to hydrologic variation because this loading relates to erosion, runoff and soil flow through which all will increase in wet years with high runoff. As such, they will be high when watershed sources are high and low when watershed sources are low. Diffuse source controls may have little noticeable effect in dry years because the load is less in those years and so the actual reduction is minimal. Further work on diffuse source P reductions is needed if wet year P concentration peaks are to be lowered, particularly because those are the years where the diffuse P loads are the highest, and as discussed previously these wet years elevate spring phosphorus levels to the water quality objective for Okanagan Lake.

Given the uncertainty of NPS estimates, any management action to further control P from these sectors should be adopt a conservative management approach based on a better understanding of nutrient sources. There is a lot of uncertainty in the current status of diffuse source loading, and re-evaluation of the diffuse source estimates is warranted. For example, some diffuse sources (like septic tank loading) require a simple but comprehensive update of the changes in sewered areas and locations of new houses to see what has been accomplished. Recent FRBC water quality data from the Community Watershed water quality objectives development process could be used to better quantify the current status of sediment loading from forest harvesting as well as natural watershed sources. Dustfall/precipitation was a very significant component (8,900 kg/yr for Okanagan Lake; Anon. 1982) of earlier estimates, which was assumed to be totally non-controllable. Better understanding of the dustfall component could lead to control strategies. Watershed sources include cultural impacts which could be quantified and potentially controlled. For example, in 1979, storm water runoff from Vernon, Kelowna and Penticton was calculated to contribute about 1200 kg P / year. This had increased proportionally from 1972 in response to larger urban centres with larger storm drainage systems. It is conceivable that the current storm water loading could be several times greater again which might warrant specific control strategies

Waste management efforts to date in the Okanagan Basin have focused primarily on phosphorus control. Continued application of best available waste water treatment technology is recommended to offset population increases. Diffuse source strategies should be approached from a basin wide best management practices view with multiple resource benefits as an objective. For example, restoration of riparian buffer zones along disturbed urban or agricultural streams could lead to reduced phosphorus loading through reduced stream bank erosion and interception of surface erosion and nutrients in groundwater, reduce flooding damage and improve fish habitat. Anthropogenic (agricultural and urban) stream bank erosion could be a significant P load which may be controlled through riparian habitat retention. Similarly, soil erosion from agricultural (cropped fields) and a variety of urban situations (e.g. road side ditches and construction activities) may be a significant controllable P load. Changes to urban stormwater quantity and quality, which will ensue from increased population density in larger urban cores, needs to be better understood and managed. As urban stormwater also contains may other contaminants (bacteria, hydrocarbons, pesticides and metals) and is exacerbated by riparian habitat loss, the multiple benefits of control efforts in this NPS component will have a number of positive outcomes for stream and lake ecosystems. Under an ecosystem based management framework all environmental outcomes of a management action need to be considered. Non-point source nutrient control must be re-examined to determine where multiple benefits are available to protect habitat and reduce overall contaminant loading to surface and groundwaters of the Okanagan Basin.

The positive influence of wet year cycles on kokanee populations in Okanagan Lake is strongly suggested in the data presented here. The apparent changes in P loading and in-lake P variation between wet and dry year periods are considerable. That the kokanee don't respond more dramatically to these large changes in P loading is perhaps surprising. Further examination of this relationship is warranted to better understand the vulnerability of this species to other limiting factors, hydrologic and nutrient loading cycles, and climate change. Factors other than increased phosphorus, such as elevated stream flows, alteration of in-lake nutrient ratios, or other variables might well be responsible for part or all of the apparent increased kokanee counts following periods of increased stream discharge.

The Okanagan lakes are resources of incalculable worth to a variety of human uses and natural processes. Increasingly apparent is the potential for future management challenges in satisfying the needs of all user groups; the primary ones being recreation, drinking water and aquatic life. Given the multiple uses of Okanagan main-stem lake waters and given the increasing management efforts to satisfy these at time conflicting uses, it is recommended that comprehensive multi-parameter water quality objectives be established to guide lake management decisions in the future. These objectives would set lake specific biological, chemical, and physical measures, which would be based on the best available science, adaptive management experience, and consultation with a broad range of interested groups.

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Geri Huggins and Jodi Unger summarized much of the data, and prepared many of the figures used in this paper. Ron Townson provided Table 1 and Figure 1 showing changes in P loading from municipal point sources. Seasonal data for Okanagan Lake were collected by Rob Kirk and Dave Cassidy for the Okanagan Lake Action Plan. Kokanee count data was supplied by Steve Matthews. Ron Townson, Dr. R. Nordin and Dr. T. Northcote reviewed the manuscript and provided valuable comments. Many people over

the years contributed to the various monitoring and waste management efforts pertaining to the Okanagan lakes. Key individuals in these endeavours were Dr. J. Bryan, T. Forty, D. Nickel and Dr. R. Nordin.

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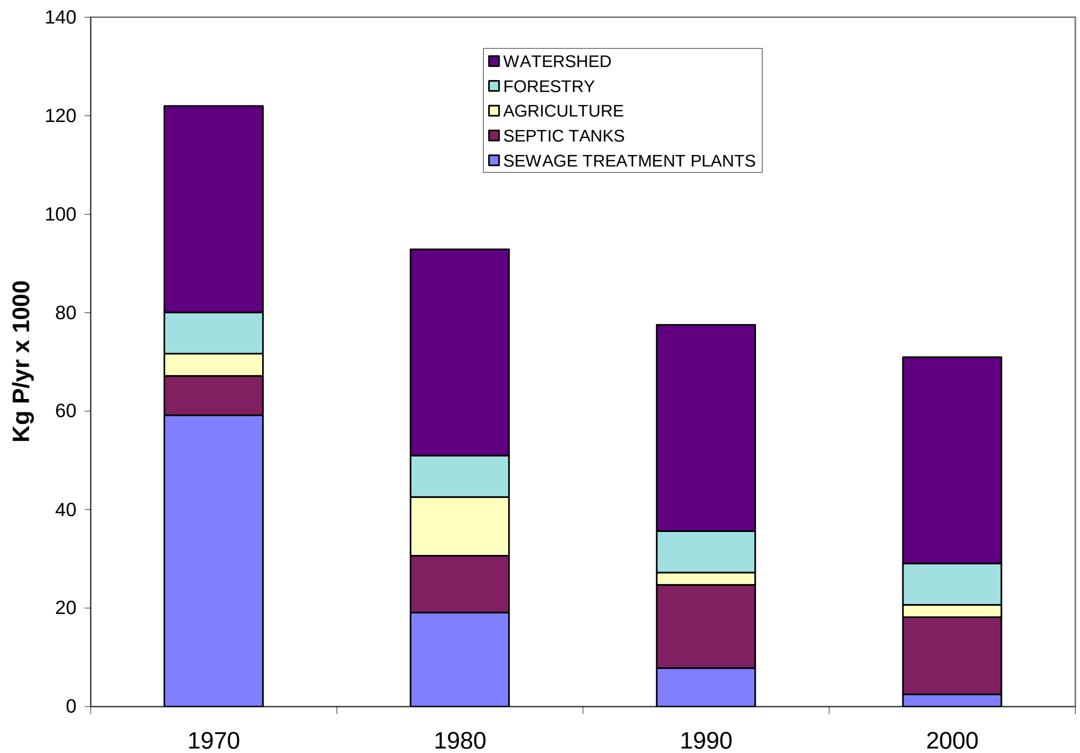
TABLE 1 . Municipal Phosphorus Loading* (Kg/yr) from Sewage Treatment Facilities in the Okanagan Valley, 1970 to 2001.

Year	Kelowna	Penticton	Armstrong	Westbank	OK Falls	Brandt's	Summerland	Osoyoos	Oliver	Vernon	Total Kg
1970	20,300	13530	1,023	516					1,900	21879	59,148
1980	11,030	2725	2,411	1,312		111			1,525		19,114
1981	9,750	3135	3,228	1,040		1,120			1,050		19,323
1982	10,500	5581	3,255	913		1,030			980		22,259
1983	4,020	3375	2,630	438		491			1,420		12,374
1984	6,739	2536	2,431	831		1,416				348	14,301
1985	5,014	2215	1,982	741		865				217	11,034
1986	6,993	2354	2,963	742		289					13,341
1987	5,360	2082	2,681	1,397		133		NOTE: loadings from			11,653
1988	3,111	2619	2,980	959		167		irrigation tailwater			9,836
1989	1,384	2823	3,620	1,077		98		not included			9,002
1990	1,034	2794	3,740	70		175			3		7,817
1991	1,055	2736	5,455	333		23					9,602
1992	1,175	2395	6,484	144		45					10,243
1993	1,241	2219	0	145		23					3,628
1994	2,047	862	417	113		9					3,448
1995	1,871	0	256	174		19					2,320
1996	1,616	658	332	184		24					2,814
1997	1,822	617	446	218		50					3,154
1998	1,462	443	315	222		42	85			651	3,220
1999	1,920	523	99	359		106	93				3,100
2000	1,426	597	0	330		38	112				2,503
2001	1,513	508	0	374		72	175				2,642

Ron Townson: Personal communication.

Figure 1. Phosphorus loading estimates* from various source sectors to Okanagan surface waters



* Ron Townson: personal communication

Figure 2 Spring total phosphorus (ug/L) in north basins of Skaha and Osoyoos lakes, and the south end of Okanagan Lake, 1975 to 2000.

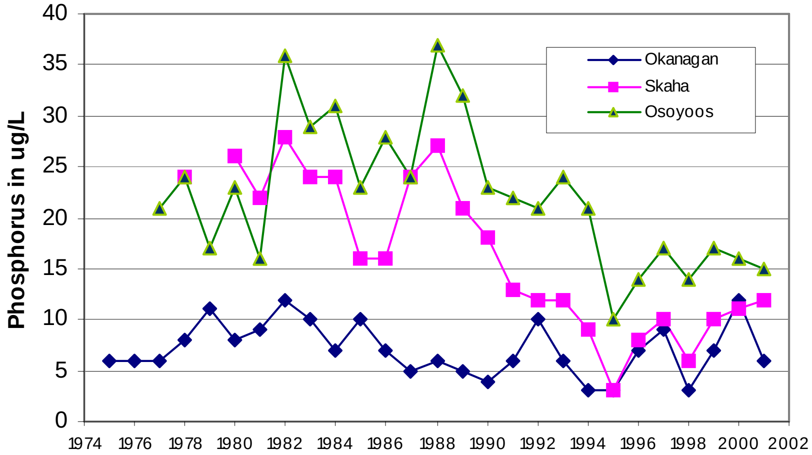


Figure 3 Spring Total Dissolved Phosphorus in north basins of Skaha and Osoyoos lakes, and South Basin of Okanagan Lake, 1975 to 2001

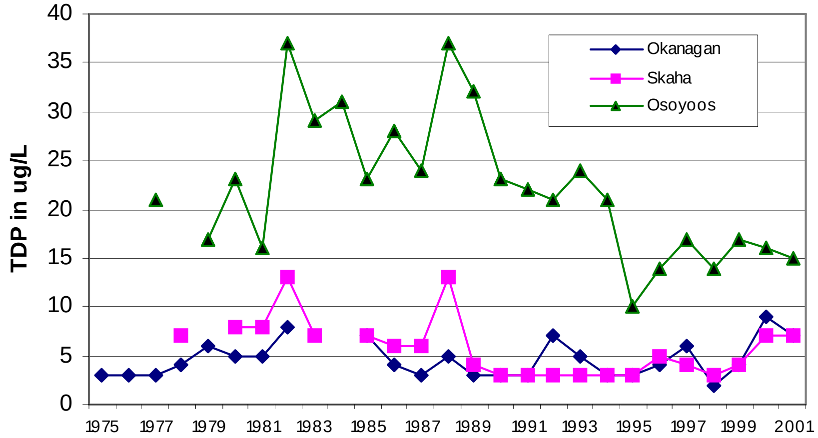


Figure 4 Fall Total Phosphorus in Skaha Lake (sites:453,615,846), 1975 to 2001

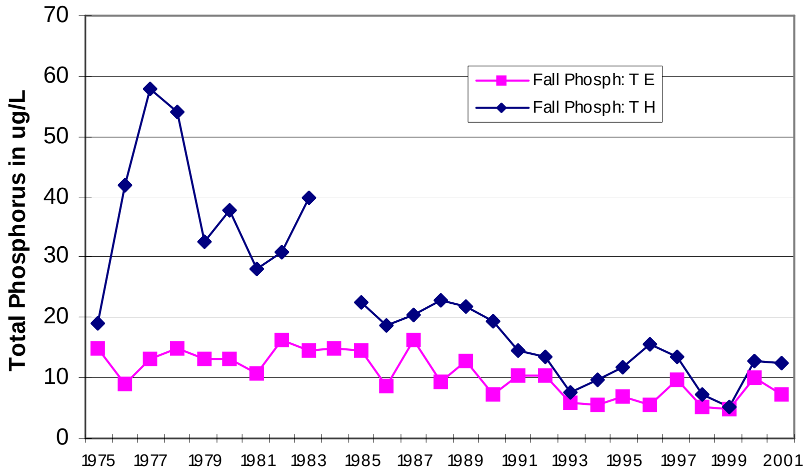


Figure 5 Fall Total Phosphorus in Osoyoos Lake North Basin (site 728), 1971 to 2000

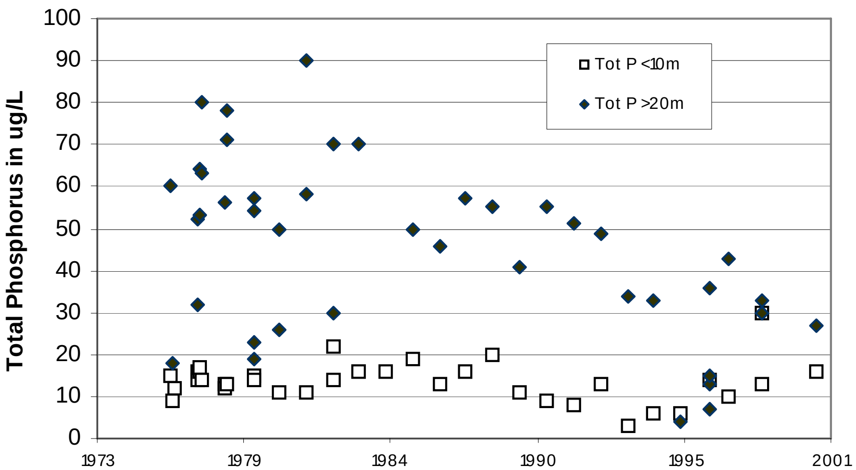


Figure 6 Spring total nitrogen (mg/L) in north basins of Skaha and Osoyoos lakes and the southern basin of Okanagan Lake, 1975 to 2000

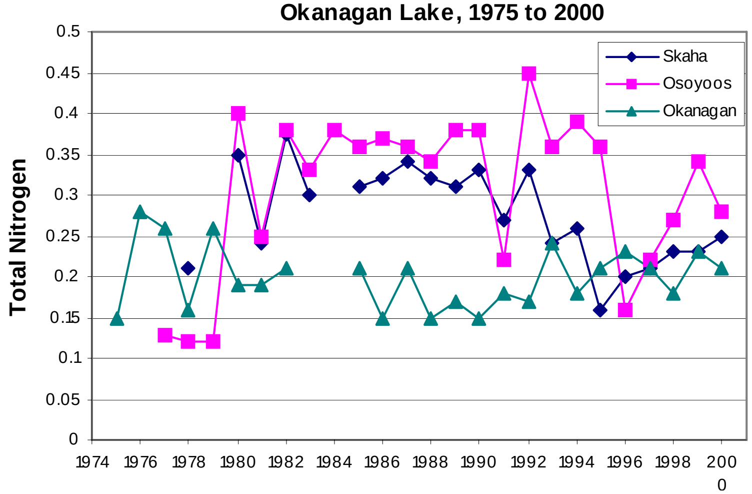


Figure 7 Fall total nitrogen (mg/L) in north basins of Skaha Osoyoos lakes, and southern basin of Okanagan Lake, 1977 to 2000

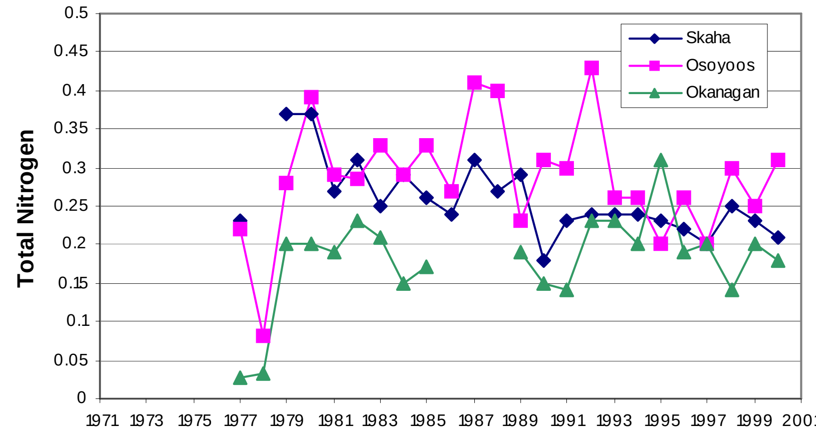


Figure 8 Spring total nitrate nitrogen (mg/L) in north basins of Skaha and Osoyoos lakes and the southern basin of Okanagan Lake, 1975 to 2000.

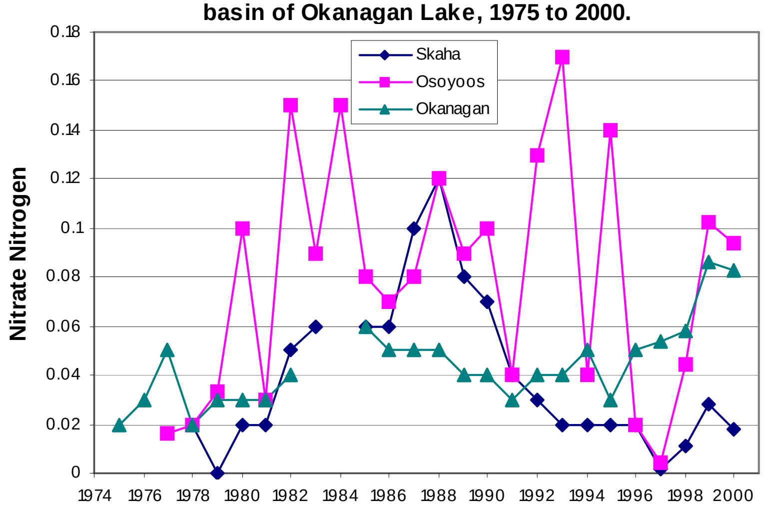


Figure 9 Fall nitrate nitrogen (mg/L) in north basins of Skaha, Osoyoos lakes, and southern basin of Okanagan Lake, 1976 to

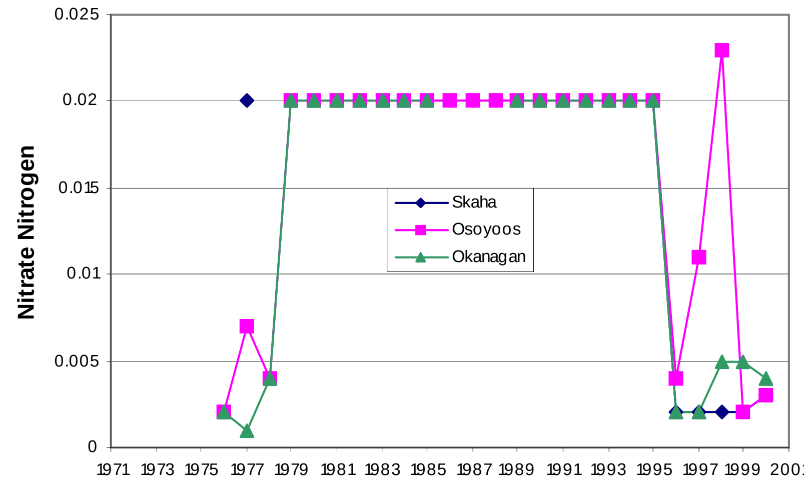


Figure 10 Spring Phytoplankton Chlorophyll *a* (ug/L) in north basins of Skaha and Osoyoos lakes and the southern basin of Okanagan Lake, 1977 to 2001.

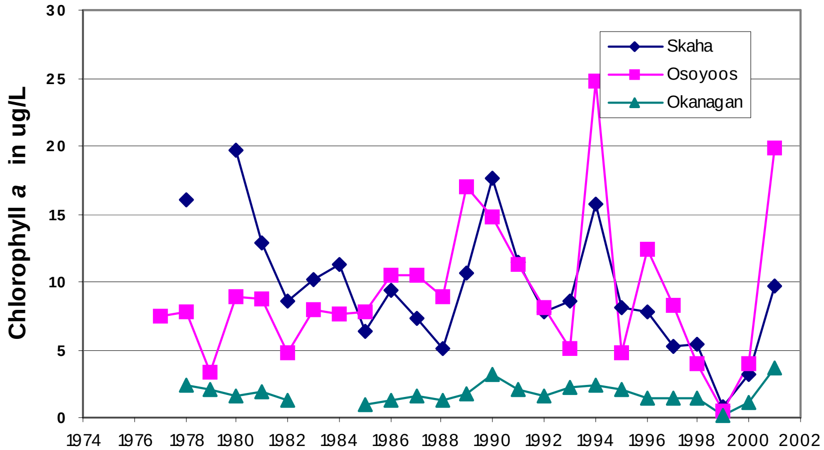


Figure 11 Phytoplankton Chlorophyll *a* in north basins of Skaha, Osoyoos lakes and southern basin of Okanagan Lake, during the fall, 1976 to 2001

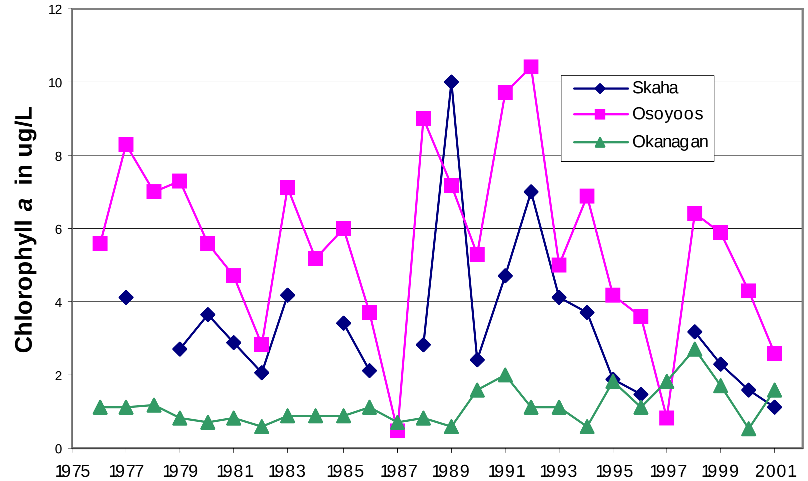


Figure 12 Spring Secchi disk depth in noryth basins of Skaha and Osoyoos lakes, and the southern basin of Okanagan Lake, 1975 to 2001

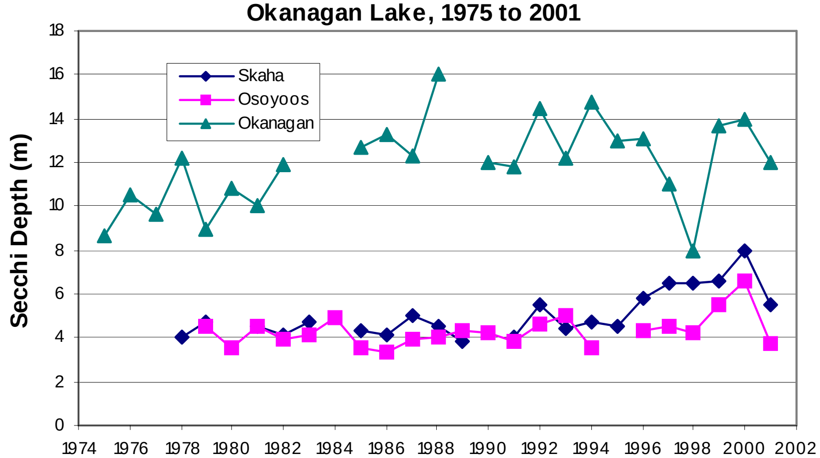


Figure 13 Fall Secchi disk depth in Skaha and Osoyoos lakes, and the southern basin of Okanagan Lake, in September, 1976 to 2001

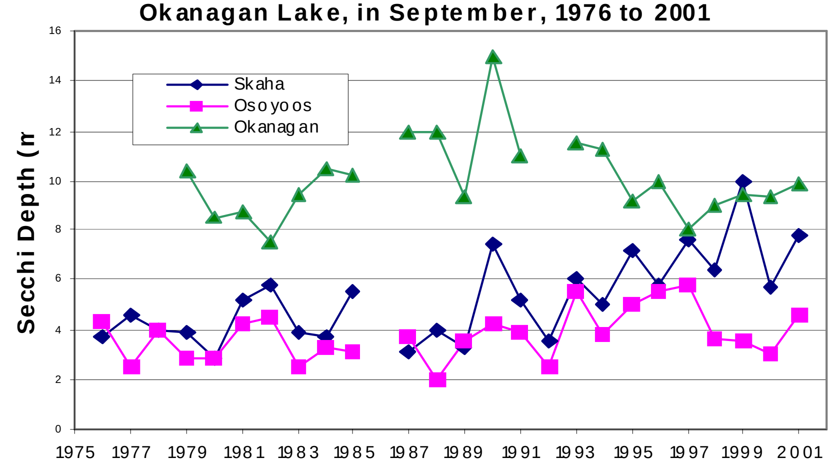


Figure 14 Dissolved Oxygen in the hypolimnion (44m depth) of Skaha and Osoyoos lake north basins, during the month of September, 1977 to 2001

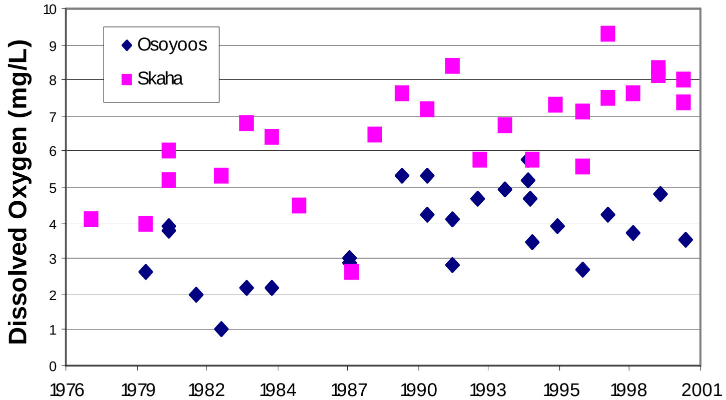


Figure 15 Nitrate Nitrogen and Dissolved Phosphorus and Phytoplankton Chlorophyll A in Okanagan Lake (454/730), 2000

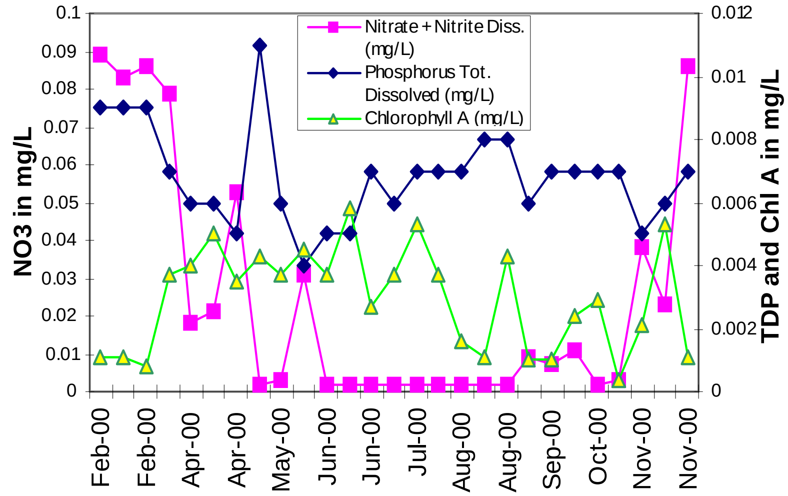


Figure 16 Total Dissolved Phosphorus, Nitrate Nitrogen and Phytoplankton Chlorophyll A in Okanagan Lake, 2001

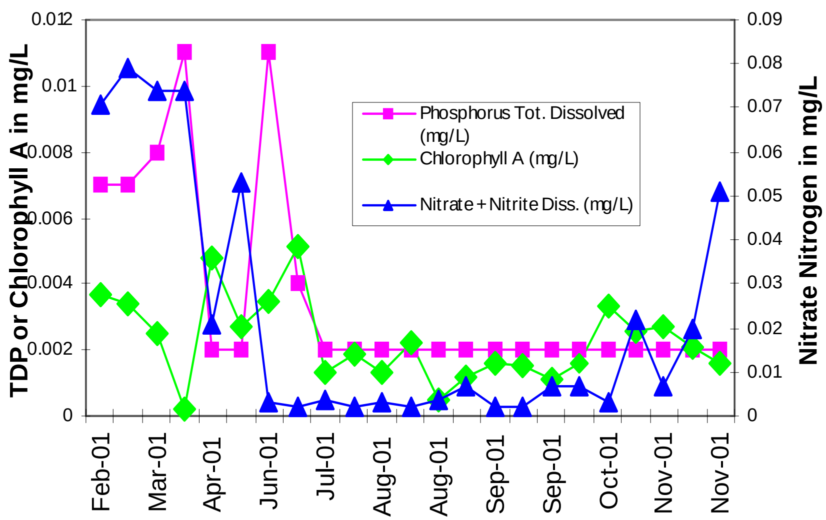
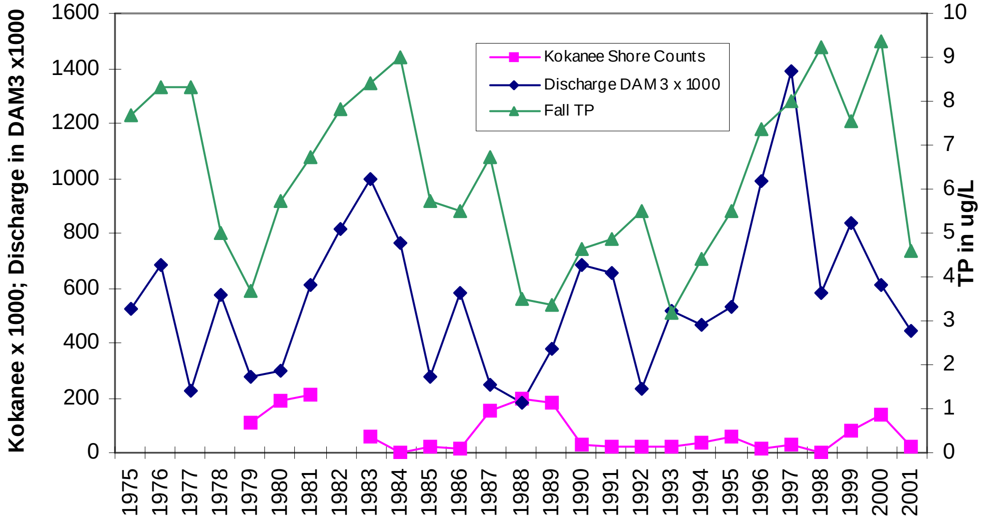


Figure 17 Okanagan Lake Fall TP*, Shore Spawning Kokanee Counts, and Total Annual Discharge from Okanagan River at Penticton



*Fall TP is an average of up to 7 deep water sites from Vernon to Summerland sampled in September; years prior to 1980 includes August data

Figure 18 Okanagan Lake Fall TP, Stream Spawning Kokanee Counts, and Okanagan River Total Annual Discharge at Penticton