MINISTRY OF ENVIRONMENT

Water Quality Assessment and Objectives for Osoyoos Lake: A First Update

Technical Report
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SUMMARY

This document updates the water quality objectives for Osoyoos Lake in order to help protect aquatic life, drinking water and recreation, now and into the future. These water quality objectives are proposed on the basis of an assessment of Osoyoos Lake water quality data collected over the past 40 years, and an evaluation of land use changes in the watershed. Nutrients, particularly phosphorus, have decreased in all three basins of the lake, and dissolved oxygen concentrations in the bottom waters of the north basin have increased in the fall. These changes are primarily attributed to decreases in point source nutrient loading to the Okanagan River upstream of Osoyoos Lake. A quantitative assessment of the non-point source nutrient load is not possible with the available data, however decreases in phosphorus load to Osoyoos Lake from septic tanks and other land uses are also likely. Over a multi-decadal time frame, Osoyoos Lake water quality has improved in trophic status from eutrophic to mesotrophic. Importantly, bottom waters of the north basin contain more dissolved oxygen in the fall now than in years past. The Okanagan River discharge, however, strongly affects nutrient concentrations in Osoyoos Lake on a seasonal and interannual basis, and significant internal phosphorus loading continues, particularly in the central and southern basins. As a result, water clarity has shown no change over time. The water quality objectives recommended here, take into account these background conditions and changes in land use. Continued population growth and development within the watershed, in addition to increasing recreational use, will present challenges to water quality protection in the future.

The water quality objectives proposed for Osoyoos Lake reflect the more comprehensive data set available for the Monashee site at the center of the north basin. Over time, it is expected that attainment of the water quality objectives for dissolved oxygen, phosphorus, chlorophyll-*a*, phytoplankton composition, and Secchi depth, at the Monashee site, will promote water quality improvements in the central and south basins. The proposed objectives are summarized in Table 1. It is recommended that these objectives be reviewed every five years to determine whether they continue to be protective of water uses, and revised as required to reflect any future improvements or technological advancements in water quality assessment and analysis.

Table 1. Summary of proposed water quality objectives for Osoyoos Lake at the Monashee site.

Variable	Objective Value	Timing
Dissolved oxygen	$\geq$ 5.8 mg/L @ 15m depth	on August 15th
Total phosphorus	$\leq$ 15 µg/L	Spring (February - March)
Phytoplankton chlorophyll-*a*	$\leq$ 4.0 µg/L	Seasonal mean (May to September)
Secchi depth	$\geq$ 3.5 m	Seasonal mean (May to September)
Cyanobacteria	$\leq$ 700 mm^3/m^3 mean; $\leq$ 2000 mm^3/m^3 max.	Seasonal mean (May to September)

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ACKNOWLEDGEMENTS

The list of individuals and organizations that have contributed to the water quality information available for Osoyoos Lake for the past 40 years, would fill many pages. Three individuals, however, who have made significant contributions to the water quality data collection, and stewardship of Osoyoos Lake are Dr. Jim Bryan, Dr. Kim Hyatt, and Lionel Dallas. Although the provincial agency titles varied over many years, Jim's determination to provide an unbroken legacy of water quality data for Okanagan basin lakes, never faltered. Kim has strongly influenced the integration of climate, hydrology, and water quality information to address fisheries ambitions of the Okanagan Nation Alliance (ONA); without the ONA's data collection, much of this assessment would have been impossible. Lionel was an early champion of Osoyoos Lake stewardship sampling, and one of the founding members of the Osoyoos Lake Stewardship Society. Lionel saw the importance of Osoyoos Lake to the health of the local ecosystem and economy, and inspired many to take action.

1.0 INTRODUCTION

1.1 BACKGROUND

Osoyoos Lake is a transboundary waterbody straddling the Canada - United States border in south-central British Columbia (BC). Osoyoos Lake, the 7th lake in a series of valley bottom lakes within the BC Okanagan Basin, receives inflow from the Okanagan River which drains 54 km south from Okanagan Lake at Penticton, through Skaha and Vaseux lakes before entering Osoyoos Lake. The Okanogan (American spelling) River then drains Osoyoos Lake in Washington State, and joins the Columbia River 127 km to the south (Figure 1). Rapid population growth within the arid Okanagan Basin, local economic reliance on water for tourism and agriculture, and the presence of many resident and anadromous fish species within the system pose challenges to water resource management.

The water quality of Osoyoos Lake has been a concern to locals and water resource managers for a number of decades. From the time of one of the first water quality studies in the Okanagan Basin (Rawson, 1939) to the present, the human population of the Okanagan Basin has tripled every 30-40 years and now is approximately 355,000. As the valley population increased, so too 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 upstream Skaha Lake due to the discharge of secondary treated effluent from Penticton (Fleming and Stockner, 1975). Algal blooms on Osoyoos Lake were also a concern at that time (Booth, 1969). Public concern for water resources in the Okanagan Basin led to comprehensive monitoring of water and wastewater quality under the Federal-Provincial Okanagan Basin Study (OBS) (Stockner and Northcote, 1974). The study identified that reducing phosphorus (P) inputs from sewage, septic, agriculture, and other diffuse sources was essential to preventing nuisance algal blooms and eutrophication of the Okanagan lakes (Haughton et al., 1974). Conversion to tertiary treatment, or the use of effluent irrigation, commenced in many Okanagan communities before the mid 1980s. In 1985, to further guide nutrient reduction actions, protect water quality, and guide liquid waste management planning by communities, the Ministry of Environment (MOE) developed a spring total phosphorus (TP) water quality objective for each of the Okanagan lakes, including Osoyoos (Nordin, 1985). Since that time, annual sampling has been conducted to determine lake status and trends relative to the objective. Recent partnerships with First Nations, stewardship groups, and local and senior levels of government, on both sides of the BC-Washington border, have increased the amount of data and other information available to guide water resource management of Osoyoos Lake (McQueen et al., 2010; Tran et al., 2011).

The goals of this document are to briefly summarize the status and trends of key water quality indicators for Osoyoos Lake, re-assess the existing spring TP water quality objective in light of any new information, and propose objectives for other water quality parameters appropriate to water resource management of this lake and its catchment. Together these objectives will serve as reference points for determining the lake's status and its response over time to natural and anthropogenic influences. These objectives may in the future also enable the calculation of a water quality index specific to Osoyoos Lake.

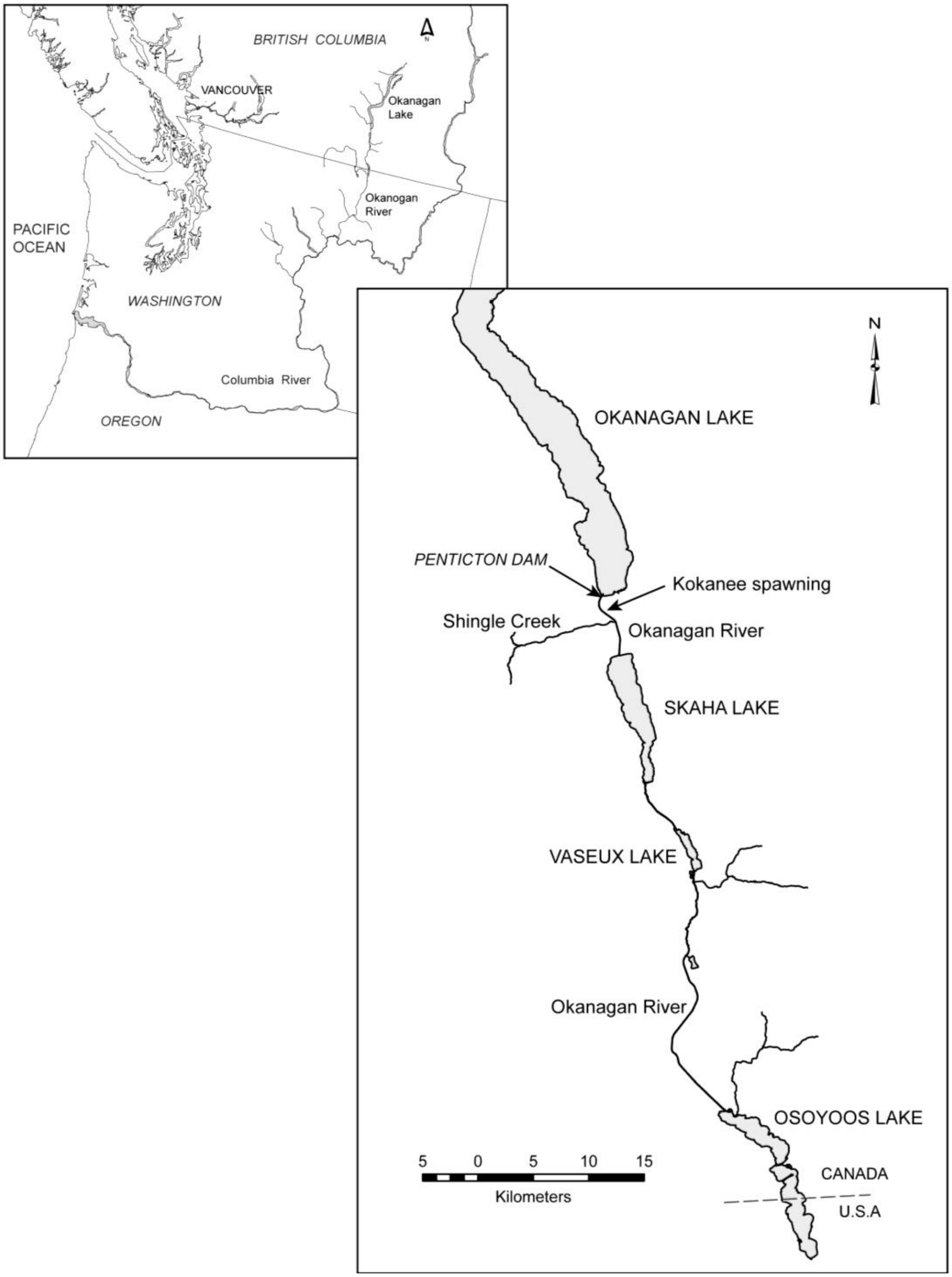

Figure 1. Location of Osoyoos Lake in relation to Columbia and Okanagan drainages (map source: D. McQueen et. al. 2010).

1.2 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 Environment'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 future.

Water quality objectives are based on scientific guidelines that are safe limits of the physical, chemical, or biological characteristics of water, (including the water column), biota (plant and animal life), and sediments which protect water uses. In BC, objectives are established for waterbodies on a site-specific basis. They are often derived from the BC Water Quality Guidelines by considering local water quality, water uses, water movement, and waste discharges. Objectives are based on the best available science, however, professional judgment may also influence how the objectives are expressed.

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;
- recreation and aesthetics;
- agriculture (livestock watering and irrigation); and
- industrial water supplies.

By protecting the most sensitive water use, all designated uses for a given waterbody are also protected. Water quality objectives have no legal standing at this time and are not directly enforced. However, they do 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, licenses 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 water body can be checked, and help determine whether basin-wide water quality studies should be initiated. Water quality objectives are also a standard for assessing the Ministry's performance in protecting water uses.

2.0 BASIN PROFILE, CLIMATE, AND HYDROLOGY

2.1 PROFILE AND CLIMATE

Osoyoos Lake is the 3rd largest of the Okanagan lakes in surface area, and the 4th largest in volume. Overall, it measures 16 km in length, has a surface area of 23 km^2, a volume of 397 Mm^3, a maximum depth of 63 m, and a mean depth of 14 m. Osoyoos Lake is relatively shallow, having the greatest littoral area (23%) of the main lakes in the Okanagan basin (Pinsent and Stockner, 1974). Osoyoos Lake is comprised of three basins, the larger and deeper north basin, a smaller central basin, and an intermediate sized shallower southern basin, of which more than half is within Washington State (Figure 2). Estimated volumes for each of the basins are shown in Table 2.

Table 2. Osoyoos Lake morphometry. Estimates based on Stockner and Northcote (1974), Rensel (1998) and on the Osoyoos Lake bathymetric map published by the Province of B.C. Fisheries Branch, Inventory Operations, in October 1971.

Basin	Surface area (ha)	Mean depth (m)	Maximum depth (m)	Volume (m^3)
North	995	21	63	255,870,000
Central	213	7	30	23,110,000
South	1092	10	29	118,020,000
Total	2300			397,000,000

Formed by tectonics and glaciation, the Okanagan Valley or Basin, is situated in the rain shadow of the Coast and Cascade Mountains, affording an idyllic setting for a series of large lakes within a fertile valley. The Basin climate is arid and gets hotter and drier as elevation and latitude decrease.

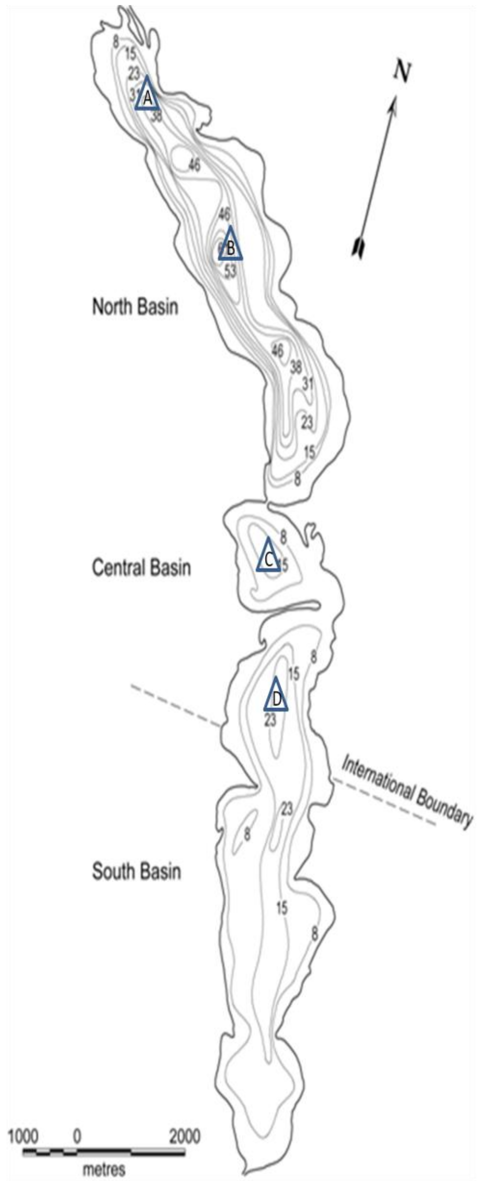

Figure 2. Bathymetric map of Osoyoos Lake (contours in m) showing Ministry of Environment sampling stations; A= North, B= Monashee, C= Central, D= South (modified from: http://www.fishwizard.com).

Annual precipitation at Osoyoos is about 32 cm. Half of the annual precipitation, which occurs from June through October, is evaporated and does not contribute significantly to run-off. Precipitation from October through April is stored as snow at higher elevations and contributes to peak flows during spring run-off and as much as 90% of annual stream flows (Dobson, 2004). The Osoyoos area is within the northern extremity of the Great Basin Desert. This unique biogeoclimatic setting supports many plants and animals, some found nowhere else in Canada. Climatic norms for Osoyoos can be found at: www.climate.weatheroffice.ec.gc.ca/.

2.2 HYDROLOGY

The annual hydrographic profile for the Okanagan River, the largest inflow to Osoyoos Lake, is dominated by snow melt (Figure 3). Seasonal discharge is regulated by operation of a dam at the outlet of Okanagan Lake and various secondary control structures for the purposes of flood prevention, drought management, and optimizing instream flow for fisheries interests (Glenfir Resources, 2006; Hyatt et al., 2003). In recent history, the Okanagan River total annual discharge near Oliver has varied from a low of 194 Mm^3 in 1988 to a high of 1,608 Mm^3 in 1997 (Figure 4). Inkaneep Creek, the next largest direct surface water inflow to Osoyoos Lake, was 1.5% of Okanagan River flow in 2009.

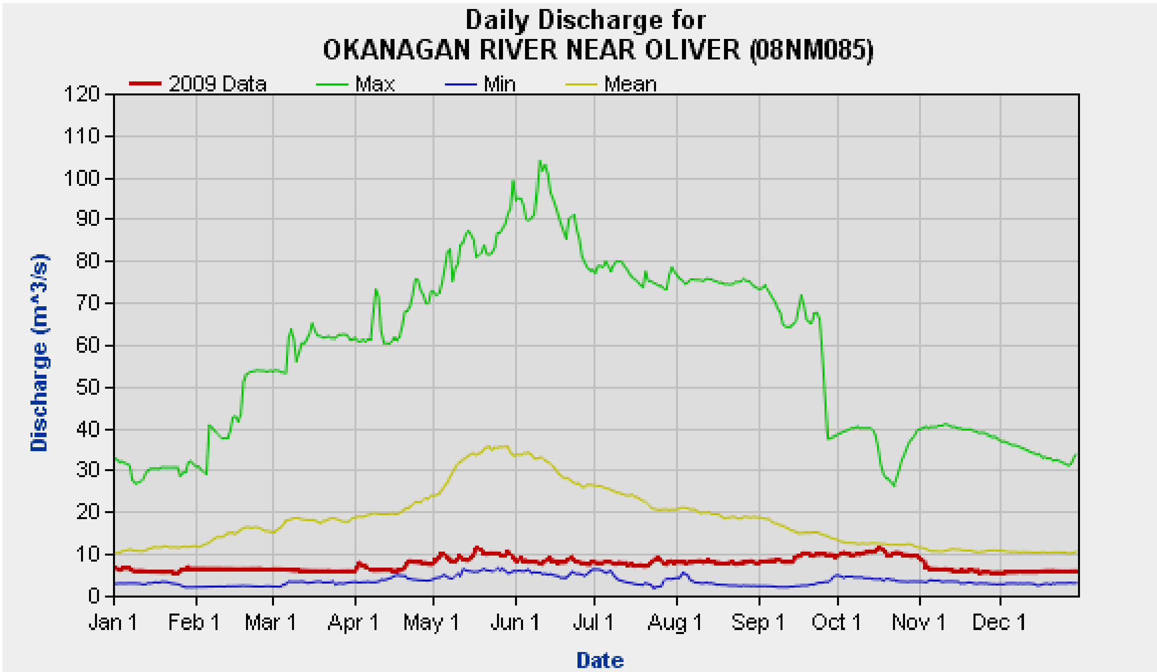

Figure 3. Minimum, maximum, and average daily discharge for Okanagan River near Oliver (Water Survey Canada station 08NM085).

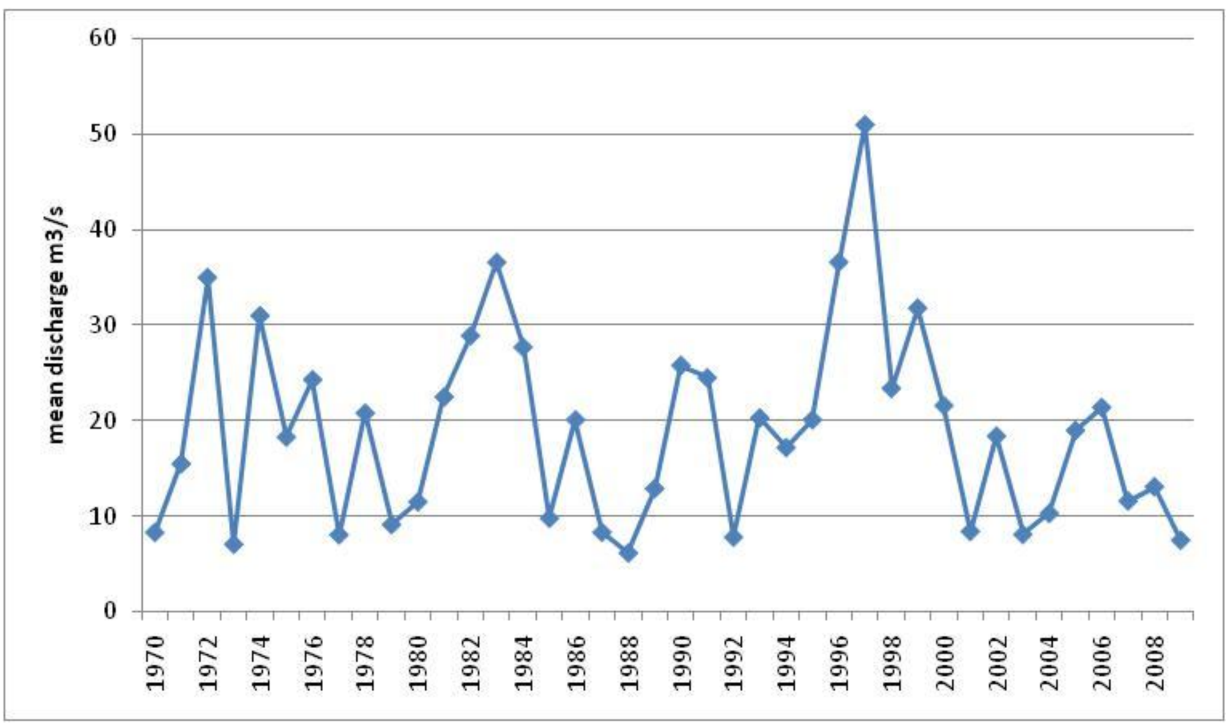

Figure 4. Annual mean discharge (m^3/s) for Okanagan River near Oliver for the period 1970 to 2009 (Water Survey Canada station 08NM085).

The Okanagan River inflow to Osoyoos Lake governs the hydraulic residence time of the lake, or the length of time that a unit of water theoretically spends in the lake before being flushed downstream. Hydraulic residence time of lakes strongly influences the opportunity for time dependent processes to occur within the lake. For example, lakes with very short residence times (i.e., days to weeks) are strongly linked to their catchments and lake water variation resembles that of input waters. In these lakes, planktonic algae would likely be flushed from the lake before accumulating. Similarly, any release of nutrients from lake-bottom sediments would be exported downstream before significant year over year accumulation could occur in the water column. Conversely, lakes with a long residence time (i.e., years to decades) are strongly influenced by in-lake processes. For example, phosphorus losses to, or releases from sediments, can overshadow inputs from the watershed. Assuming a lake volume of 397 Mm^3, the flows noted above would yield a theoretical flushing period of 2.05 years for 1988 and 0.25 years for 1997. Flushing rates of the epilimnetic or warm surface layer of water would be considerably faster. Using an estimate of 130.5 Mm^3 for the top 15 m of the water column (P. Rankin, pers. comm. 2011) and an average incoming flow of approximately 370 Mm^3 during the 6 month stratified period (May through October), yields an average flushing rate of 0.35 years for the epilimnion. The central and southern basins have smaller volumes, and would thus have greater flushing rates and shorter residence times. The average water residence time for the entire volume of Osoyoos Lake has been estimated at approximately 0.7 years (Pinsent and Stockner, 1974). Thus, Osoyoos Lake water could be influenced by both external and internal processes, and year to year changes in the Okanagan River discharge might strongly influence water quality. The influence of hydrology on the water quality of Osoyoos Lake will be further explored in Sections 4 and 6.

3.0 WATER USES

3.1 WATER LICENSES

Six water purveyors of various sizes utilize water from all three basins of Osoyoos Lake for drinking water. All report to the Interior Health Authority, and all are on boil water advisory (R. Birtles, pers. comm. 2011). The annual licensed water withdrawals, taken either directly or indirectly (upstream) from Osoyoos Lake, total 85.4 M m^3 for irrigation and 0.07 M m^3 for domestic purposes (S. Thompson, pers. comm. 2011) (see Appendix 1). Surface water license records for Osoyoos Lake are also available at: http://www.env.gov.bc.ca/wsd/water_rights/water_rights.html

3.2 FISHERIES

The Osoyoos Lake fish community consisted of about 20 species at the time of the 1974 Okanagan Basin Study (Stockner and Northcote, 1974). Common resident and non-anadromous species included: chiselmouth, kokanee, lake chub, largescale sucker, longnose sucker, lake whitefish, mountain whitefish, northern pikeminnow, peamouth chub, pigmy whitefish, prickly sculpin, rainbow trout, and slimy sculpin. By 2004, the total had increased to approximately 28 with the addition of bass, bullheads, suckers, chub, perch, dace, sculpin and carp to the species list (Rae, 2005). The most common introduced (non-native) species into Osoyoos Lake are: black bullhead, black crappie, bluegill, carp, lake trout, largemouth bass, pumpkinseed, smallmouth bass, and yellow perch. Osoyoos Lake provides a good recreational fishery for rainbow trout, pumpkinseed, yellow perch, smallmouth bass and largemouth bass.

Osoyoos Lake also provides important rearing and migratory habitat for anadromous species including chinook and sockeye salmon, and steelhead trout. Adult sockeye bound for the Okanagan begin their upstream migration during May through June, negotiate 10 fishways placed at dams in the Columbia and Okanogan rivers, and arrive at Osoyoos Lake from July through to September. During 2010 and 2011, the returning sockeye population was large enough to support a limited sports fishery. The sockeye hold in the lake until late September and then migrate north into the Okanagan River where they spawn during October through November. The eggs over-winter in the river gravels, hatch in April-May, and newly hatched age-0 juveniles move downstream to Osoyoos Lake where they over-winter and finally leave as age-1+ smolts in April and May of the next year. The importance of water quality to rearing conditions for the survival of resident and anadromous fishes is described in Section 6.

3.3 RECREATION

Water based recreation is important to the local economy. Although there are no readily available statistics, residents and tourists are drawn to Osoyoos Lake and the surrounding area because of the warm waters and extensive public access to the lake foreshore for recreation and boating (Osoyoos Lake Water Quality Society, 2011).

3.4 DESIGNATED WATER USES

Designated water uses, are those water uses that are designated for protection in a watershed or waterbody. Water quality objectives are set for the substances or conditions of concern in a waterbody so that their attainment will protect the designated uses. Water quality objectives are developed to protect the most sensitive water use relative to the parameter of interest. Based on the preceding discussions, the water uses to be protected on Osoyoos Lake include aquatic life, primary-contact recreation, drinking water, and irrigation water. It is expected however, that setting objectives to protect aquatic life, will also protect recreational use, and enable more effective treatment of potable water.

4.0 POTENTIAL INFLUENCES ON WATER QUALITY

Changes in settlement and associated non-point and point source inputs of nutrients, coupled with varying hydrology, are strong determinants of lake water quality. In the case of Osoyoos Lake, upstream changes in point source nutrient inputs from sewage treatment works have made important contributions to water quality protection. Changes in land use and non-point source nutrient loading from septic tanks, agriculture and forest harvest, are common drivers of surface water quality, and likely have a cumulative effect on Osoyoos Lake. While it is beyond the scope of this report to develop detailed nutrient loading estimates for Osoyoos Lake, changes in settlement and land use, and point source nutrient load are described below in order to suggest what changes in phosphorus loadings (the key nutrient controlling eutrophication) may have occurred since estimates were last prepared (Anon., 1985).

The effects of other site-specific or dispersed activities in the immediate catchment will not be considered in this assessment. Mining, for example, which consists of limited exploration, is unlikely to influence water quality of Osoyoos Lake or its tributaries at the present time. Recreation, both land and water-based, however, may affect water quality of Osoyoos Lake through increased catchment and shoreline erosion, or re-suspension of lake sediments, and thus increase nutrient availability (Asplund, 2000). However, as there is no specific information available for Osoyoos Lake, no further assessment of these influences on water quality are possible at this time.

4.1 SETTLEMENT AND NON-POINT SOURCE NUTRIENT LOAD

Settlement of the Osoyoos Lake catchment area downstream of Skaha Lake continues to be largely rural and focused on tourism and agriculture. The majority of the watershed south of Skaha Lake is forested crown land (Table 3). In 1985, the anthropogenic non-point source P load to Osoyoos Lake was estimated at 23% of the 20,000 kg total load, with the balance coming from natural processes such as precipitation and erosion. At that time, septic tanks were estimated to contribute approximately 12% of the total P load to Osoyoos Lake.

Table 3. Summary of land use within the Osoyoos watershed (1,279 km^2) from outlet of Skaha Lake to the US border (BC Forest Lands Natural Resource Operations Geospatial Services, 2011).

Land Use	% of total watershed area
Crown Land or unsurveyed land (2011)	81.0
Private land	19.2
Agriculture (1990-1997 data)	7.8
Urban (1990-1997 data)	1.0
Mountain Pine Beetle (since 2001)	0.2
Forest Fire (since 1985)	4.2
Forest Harvest (since 1985)	5.0

From 1996 to 2001, rural population growth in the Osoyoos area was less than 1% (E. Riechert, pers. comm., 2011). Since 1985, sewage collection has been extended along shoreline areas within the Town of Osoyoos and Regional District of Okanagan Similkameen (RDOS) areas. By 2000, approximately 400 existing homes in the Osoyoos area were taken off septic tanks and connected to the community system (T. Underwood, pers. comm. 2011). Recent efforts to extend the northwest sewer connector to Willow Beach, at the north end of Osoyoos Lake, are expected to connect another 106 properties before 2013. Modest growth coupled with expansion of sewage collection into environmentally sensitive areas, suggest that phosphorus loading from septic tanks should be lower now than in 1985.

Agricultural land use, which occupies 7.8% of the watershed between Skaha and Osoyoos lakes (Table 3), can also influence surface and groundwater quality. Phosphorus loading estimates in 1985 apportioned 13% to livestock and 13% to fertilizer usage (Anon., 1985). Although changes in livestock numbers are not readily available, it is likely that agricultural waste run-off may have declined with improvements to farm practices since the 1980s (Jensen and Epp, 2001). Limited numbers of livestock with direct access to Osoyoos Lake, and the limited movement of phosphorus in groundwater, suggests that this input is already largely accounted for in the phosphorus load estimates on Okanagan River. Nitrate nitrogen, however, is mobile in soils. Nitrate (NO_3) is elevated in shallow groundwater discharging to Osoyoos Lake, as a result of nitrogen (N) fertilizer applied to orchards in the Osoyoos area. Fortunately, nitrate concentrations in 50% of the groundwater wells sampled between 1997 and 2008, exhibit a decreasing trend over time (Athanasopoulos, 2009). This is attributed to changes in fertilizer use in the area, as well as the shift from tree fruits to vineyards managed at lower N fertilizer application rates. Phosphorus is also elevated in groundwater west of Osoyoos Lake (M. Suchy. pers. comm. 2011). Phosphorus, however, is a minor component in orchard and vineyard fertilizers, and generally less mobile in soils than nitrate nitrogen. From this, it might also be inferred that agricultural phosphorus loading to Osoyoos Lake via groundwater might also be decreasing.

Phosphorus loading to Osoyoos Lake from logging was estimated at 22% of the controllable load in 1985. Forest cover changes since 1985, due to mountain pine beetle infestation, harvest or fire, are relatively small (Table 3). These changes have generally occurred in the Shuttleworth drainage upstream of Vaseux Lake, or immediately downstream in the Vaseux drainage, thus buffering direct inputs of sediment and nutrients to Osoyoos Lake. Vegetation changes resulting from mountain pine beetle infestations and recovery from fire will occur over time. Overall this suggests little or no change in nutrient loading from this sector.

Overall it seems reasonable to conclude that phosphorus loading from non-point sources may have decreased since 1985. However, improved estimates of both nitrogen and phosphorus loading from non-point sources would greatly aid in making informed land management decisions aimed at protecting the water quality of Osoyoos Lake. It should be noted that prior to the channelization of the Okanagan River system in 1950s, the river had wide meanders, active flood plains and extensive wetlands (Glenfir Resources, 2006). In this unconfined state, spring floods, and associated sediment loads, would have dissipated more effectively within the flood plain. At lower flows the significantly longer travel path would have enabled greater nutrient uptake and transformation within biota and sediments.

4.2 POINT SOURCE NUTRIENT LOAD

Only 1% of the area south of Skaha Lake is urban (Table 3). The population of the Osoyoos area is approximately 10,000 (Glenfir Resources, 2006), with roughly half residing within the Town of Osoyoos (E. Riechert, pers. comm., 2011). Municipal sewage collection began in 1965 within the Osoyoos town core area and a small portion of the East Osoyoos area. Sewage treatment consisted of a facultative lagoon system and ground infiltration on the west Osoyoos bench area. The system was upgraded between 1975 and 1980 to incorporate aerated lagoons, winter effluent storage, and lands for spray irrigation disposal (Underwood, 1987). A Liquid Waste Management Plan (LWMP), dated April 1987 and approved by the Minister of Environment on February 25, 1988, authorized the Town of Osoyoos, under the *Environmental Management Act* (ME 12214), to continue storage of secondary treated effluent (aerated lagoons) in lined storage reservoirs, and implement effluent irrigation after chlorination, or rapid infiltration. A total sewage inflow of 752,706 m^3, was reported in 2010 for a serviced population of 5,571. Water conservation and conversion of campgrounds to lower density seasonal occupation, have held the 2010 inflow to that of 2001 levels, despite a 24% increase in the population of Osoyoos over the same time period (TRUE Consulting, 2011). Estimates of phosphorus or nitrogen loading to surface waters from effluent irrigation return flow are not available, however the assumption has been that the phosphorus loading from effluent irrigation is equivalent to, or better than, tertiary-treated effluent provided it is applied at agronomic rates (Anon., 1985).

Discharge of treated effluent to the Okanagan River, immediately upstream of Osoyoos Lake, ceased in 1984 when the Town of Oliver discontinued discharge of secondary effluent and began effluent storage and spray irrigation. This eliminated the only proximate point source load, roughly 900 kg of phosphorus, to Osoyoos Lake. More recently, a Liquid Waste Management Plan was approved for the RDOS Okanagan Falls area in 2011. Construction of a new tertiary treatment plant for Okanagan Falls, with an outfall to the Okanagan River 3 km upstream of Vaseux Lake and 30 km upstream of Osoyoos Lake, is expected to be commissioned in the near future. Effluent irrigation and wetland enhancement with effluent water are potentially future disposal options. Using population growth estimates of 2.5%, the flows are expected to increase to approximately 2,743 m^3/d by 2035 (Ford, 2011). The phosphorus load from this source in 2035 is expected to be approximately 200 kg/yr or 1.4% of the present long term annual average load in the Okanagan River near Oliver (see below). Effluent irrigation or discharge to wetlands could significantly reduce this point source phosphorus load.

4.3 VARIATION IN OKANAGAN RIVER HYDROLOGY AND NUTRIENT LOAD

A Federal-Provincial water quality monitoring station on Okanagan River downstream of Oliver at #18 Road provides useful long term trend information. Recent analysis of this data for 1990 to 2007 shows a statistically significant decreasing trend in flow and phosphorus concentration (Dessouki, 2009). A strong relationship exists between mean annual discharge and estimated phosphorus load in the Okanagan River downstream of Oliver (Figure 5; Appendix 2). The decreasing trend in Osoyoos Lake phosphorus could therefore, in part, be related to changes in annual or peak discharge over that period. Between 1984 and 2009, the annual load of total phosphorus varied from a low of about 3,400 kg in 2003 to a high of 48,000 kg in 1997, and averaged approximately 14,000 kg. These estimates use monthly mean flow and average nutrient concentration data (generally 1-4 values per month). Figure 5 shows that discharge and annual phosphorus load become less tightly coupled in the latter half of the monitoring period, and over time the load appears to have decreased relative to discharge, presumably due to decreasing phosphorus concentrations. Assuming that the Okanagan River supplies the majority of the water and solute load to the lake, then it follows that the phosphorus load in recent history is roughly 30% lower than the 1985 total phosphorus load estimate of 20,000 kg. Better estimates of direct inputs of phosphorus from Inkaneep Creek, groundwater and stormwater to Osoyoos Lake would clarify the relative importance of the various phosphorus sources to the lake. It is interesting to note that the Okanagan Basin Study estimated a 30% reduction in phosphorus from 1970 levels (approximately 23,000 kg) was necessary to maintain or improve Osoyoos Lake water quality (Pincent and Stockner, 1974). The response of Osoyoos Lake to Okanagan River discharge and phosphorus load will be examined in Section 6.

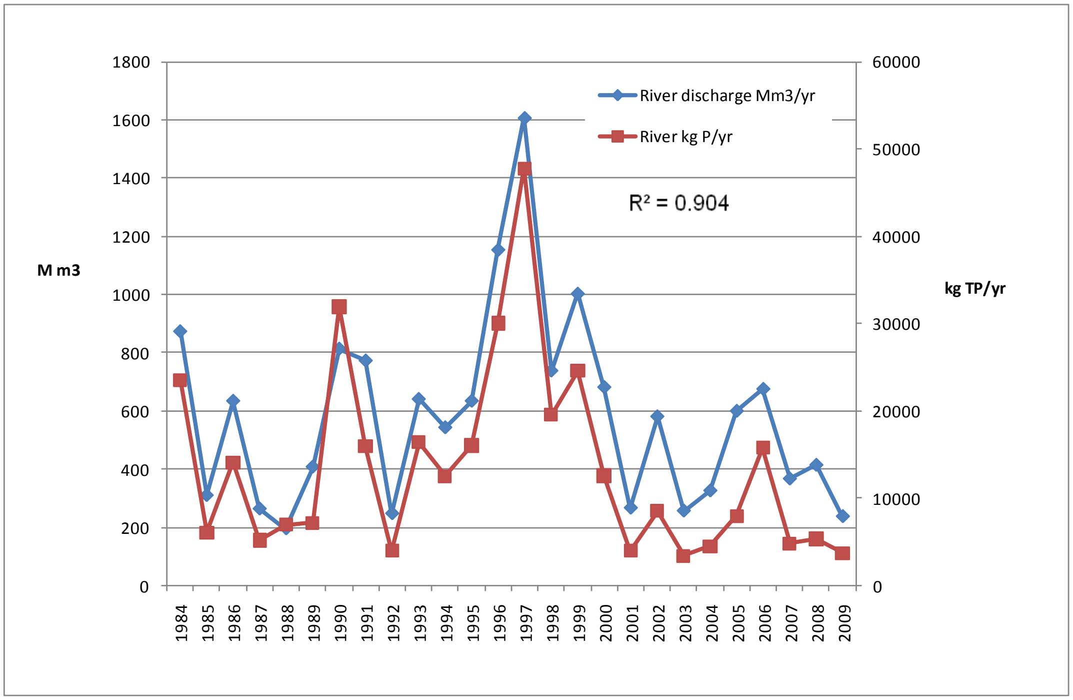

Figure 5. Okanagan River total annual discharge (Mm^3) and estimated annual total phosphorus load (kg TP) for the period 1984 to 2009.

4.4 WILDLIFE

The influence of an increasing Canada goose population on foreshore and water quality in the Osoyoos area has been a recent concern to local citizens. Indeed, feces from water fowl are linked to water quality concerns (Manny et al., 1994). An Interior Health Authority assessment of three Osoyoos bathing beaches between late-June and late-August, 2010 found *E. coli* values occasionally elevated, but on average were well below BC MOE primary contact guideline (R. Birtles, pers. comm., 2011). An egg addling program and other management efforts are underway in the south Okanagan to control geese numbers.

5.0 WATER QUALITY DATA SOURCES

Comprehensive water quality data collection for Osoyoos Lake began in the late 1960s with a series of studies (Booth, 1969; Coulthard and Stein, 1969; Stein and Coulthard

1971) which culminated in the Okanagan Basin Study reports summarized in Pinsent and Stockner (1974). During the Okanagan Basin Implementation Study, Osoyoos Lake was re-evaluated by Truscott and Kelso (1979) and Jensen (1981) to see whether Okanagan lakes were responding to nutrient control efforts.

BC Ministry of Environment sampling of the lake, as part of a regular spring and fall program (March and September) on all mainstem Okanagan lakes, dates from approximately 1977, and continues to the present time. Initially only the 2 sites (Monashee and North) in the north basin (Table 4; Figure 2) were consistently sampled. Sites on the central and south basins were added to the program in 1988.

Table 4. Description of main water quality data collection sites on Osoyoos Lake (see Figure 2 for map).

Figure 2 symbol	Site Name	EMS Id	Location (Lat/Long)
A	Osoyoos Lake North End	0500249	49.0693 N / 119.514 W
B	Osoyoos Lake opposite Monashee Coop	0500728	49.0544 N / 119.485 W
C	Osoyoos Lake Central Basin	E220540	49.0204 N / 119.456 W
D	Osoyoos Lake South Basin	0500248	49.0033 N / 119.442 W

In addition to the spring and fall data collection by the MOE, the Osoyoos Lake Water Quality Society (OLWQS) has recorded water clarity, temperature, and oxygen at these same 4 sites since 2000, as well as one additional site near the White Sands Condo development. The Okanagan Nation Alliance (ONA) fisheries program, in conjunction with Fisheries and Oceans Canada, has made significant contributions to Osoyoos Lake water quality data acquisition, and has sampled the two sites in the north basin twice monthly since 2001. The ONA has also recorded Secchi depth and temperature and oxygen profiles at the South and Central sites since 2001. The primary data sources considered in this assessment are those developed by the MOE, ONA, and the OLWQS. Table 5 provides an overview of these sampling efforts and illustrates some of the differences in programs between groups. A number of other water quality data sources are cited by Glenfir Resources (2006). These have not been considered in this review due to the difficulties of integrating multiple data sets.

Table 5. Summary of Osoyoos Lake sampling period and locations employed by various agencies and groups considered within this assessment.

Sampling Agency	Project	Sampling Period	Sample Timing	Sampling Sites
MOE	Large Lakes Monitoring	~1970 to present	Spring and fall	2 sites north basin (0500249, 0500728) 1 site central basin (E220540) 1 site south basin (0500248)
	Sediment Core	2008	June	1 site north basin (0500728) 1 site south basin (0500248)
	Periphyton	2009	July	11 Sites (7 north, 2 central, 2 south)
ONA	Osoyoos Limnology	2001 to present	Monthly May to Oct	2 sites north basin (0500249, 0500728)
OLWQS	Seasonal monitoring	2000 to present	Spring through summer	3 sites north basin (0500249, 0500728, White Sands) 1 site central basin (E220540) 1 site south basin (0500248)

Routine parameters and differences in sample composite methods used by the MOE, ONA, and OLWQS, are shown in Table 6. Water chemistry samples have generally been collected as integrated depth composites of near surface waters (epilimnion), and composites or discrete samples of deeper water (hypolimnion) below the thermocline. The thermocline is the zone of rapidly decreasing water temperature with depth, and is generally between 10 and 20 m in Osoyoos Lake. Therefore, these sampling depths (> 10 m and >20 m) are fixed as the lower and upper depths of the surface and bottom water composites respectively. Chlorophyll-*a* samples were also collected as composites from the epilimnetic water (<10 m). Water clarity was measured using a 20 cm diameter Secchi disk, deployed on the shaded side of the boat. Chemistry and chlorophyll-*a* samples collected by MOE and ONA were analyzed at the same analytical laboratory using standard methods. Quality assurance (QA) samples were periodically submitted by both the MOE and ONA to assess data quality.

Table 6. Summary of protocols and parameters employed by agencies sampling Osoyoos Lake.

Sampling Agency	Epilimnetic Samples	Hypolimnetic Samples	Parameters Analyzed
MOE	Composite of 1, 5 and 10 m samples	Composite of 20, 32 and 45 m. If shallower than 45m then composite of 20 m, ~2 m from the bottom, and half way in between	Chlorophyll-*a*: (epilimnion only) Nitrogen: (total N, total Kjeldahl N, NO_3+NO_2) Phosphorus: (total P, total dissolved P, ortho-P) Reactive silica Secchi depth (viewing box) Other parameters periodically.
	Discrete 15 m samples (spring only)		Total Phosphorus Anions (chloride, sulphate) Total hardness
ONA	Samples from 1, 5 and10 m depths were integrated then sub-sampled	Averaged from discrete samples collected at 20, and 32 or 45 m (depending on site depth)	Chlorophyll-*a*: (epilimnion only) Nitrogen: (total N) Phosphorus: (total P) Secchi depth (viewing box) Phytoplankton taxonomy Zooplankton taxonomy
OLWQS	n/a	n/a	Secchi depth (no viewing box), temperature and dissolved oxygen profiles

Water chemistry, phytoplankton chlorophyll-*a*, Secchi depth, temperature, and dissolved oxygen data, are stored in the BC MOE database, and is available upon request.

Samples for phytoplankton and zooplankton taxonomic composition and measures of abundance have been infrequently collected by MOE, but have recently been a focus of the ONA (McQueen et al., 2010). Other focused studies, such as periphyton composition and abundance in 2009 (Thomas et al., 2010) and paleolimnolgical analysis (Cumming et al., 2009) have contributed to a more integrated picture of the present condition of Osoyoos Lake and how it may have changed over time. As well, information describing trace contaminants (PCB, DDT etc.) in fish tissues (Kozlova, 2009; Rae and Jensen, 2007) is available. These assessments are complete entities, and are beyond the scope of this report.

6.0 WATER QUALITY ASSESSMENT AND OBJECTIVES

Water quality will be first assessed, and objectives proposed, for the physical properties of water temperature and lake stratification, and its effects on dissolved oxygen of Osoyoos Lake. Next, the nutrients nitrogen and phosphorus will be considered. Finally, the biological measures of phytoplankton chlorophyll-*a* and community composition, will be considered along with water clarity. These commonly measured parameters contribute to an overall understanding of the health of Osoyoos Lake, and it is expected that efforts to maintain or improve water quality for aquatic life and recreation will also benefit the protection of drinking and irrigation water uses.

Not all sites have been sampled with the same intensity (Table 5). The Monashee site (Site B, Figure 2) has the only seasonal data set of significant duration, and as a result, seasonal patterns in water quality and all water quality objectives expressed as seasonal values, are based on Monashee site data.

For all sites, water quality data were tabulated and graphically inspected for outliers. Relationships between variables were explored using Pearson's product moment correlation (r). To identify trends over time in parameters of interest, the non-parametric seasonal Kendall trend test (Hirsch et al., 1982), which accounts for seasonal trends, non-normal distributions, and missing data (Gilbert, 1987), was used. The null hypothesis is that there is no monotonic trend while the alternative hypothesis is that there is a monotonic trend, either upward or downward. A strong advantage of this test is that one does not have to make assumptions, apart from monotonicity, about the functional form of any trend that may be present (e.g., linear or exponential); the test only considers whether within-season/between-year differences tend to be monotonic (Smith et al., 1996). These tests were performed using programs available from the US Geological Survey (Helsel et al., 2006) specifying 12 seasons (i.e., equal time periods) per year.

In summary, trends help identify meaningful change in a parameter over time. Correlations (r) test the linear association between 2 variables. Regression (r^2) provides a measure of dependence of variation in one variable on another variable, for example, water clarity and phosphorus. Recent average or mean values, typically over the past decade, indicate the norm for parameters of interest. Water quality objectives will be based on these "normative" values providing certain assumptions can be made. First, it must be assumed that these values typify some steady state condition (i.e., no on-going trend). Second, it must be expected that these values do not impair water use. Third, it should be expected that significant improvement in the parameter would be unlikely. Finally, consistent non-attainment would indicate water quality degradation and an impact on water use.

6.1 WATER TEMPERATURE AND DISSOLVED OXYGEN

6.1.1 Temperature and Dissolved Oxygen

Water quality guidelines for temperature have been developed in BC for several water uses (Oliver and Fidler, 2001). For drinking water supplies, it is recommended that water temperature be less than 15°C to protect the aesthetic quality of the water. For the protection of aquatic life in streams, the optimum temperature ranges for salmonids are based on specific life history stages such as incubation, rearing, migration and spawning. In lakes, the allowable change in temperature is ±1°C from naturally occurring levels. Levy (1990) showed that nocturnal depth distributions for juvenile sockeye in 12 British Columbia nursery lakes were determined by water temperature. In all cases, sockeye moved vertically in the water column at night to depths where temperatures ranged from 6 to 16 °C (mean 10.9°C). An upper temperature limit of 17°C has been recommended for optimal conditions for rearing of the juvenile sockeye salmon in Osoyoos Lake (Hyatt et al., 2003).

Adequate dissolved oxygen (DO) is critical for the survival of aquatic organisms, especially species sensitive to low oxygen levels such as salmonids. Oxygen becomes dissolved in water on the surface of lakes as a result of diffusion from the atmosphere, as well as from photosynthetic activity from plants and algae. When deeper waters of a lake no longer mix with surface waters due to thermal stratification, DO concentrations can decrease. This occurs as a result of decomposition of organic materials, especially in eutrophic lakes (i.e., lakes with high levels of nutrients and therefore high biological productivity). If the euphotic zone (the zone where light penetration is sufficient to allow photosynthesis) lies above the thermocline, no photosynthesis occurs in deeper waters, and therefore oxygen depletion from decomposition occurs.

The BC guideline for the minimum instantaneous DO concentration for aquatic life is 5 mg/L For many years, DO depth profiles for the north basin only extended from the surface to approximately 44 m. These consistent measurements of DO in mid-September at the 44 m depth at the Monashee site by Ministry of Environment suggest some improvement in DO in bottom waters from the 1980s to the 1990s but considerable year to year variation (Figure 6). Never-the-less, the data shows that continued oxygen depletion in hypolimnetic waters reduce DO concentrations to levels below the aquatic life guideline (5 mg/L) by late-summer.

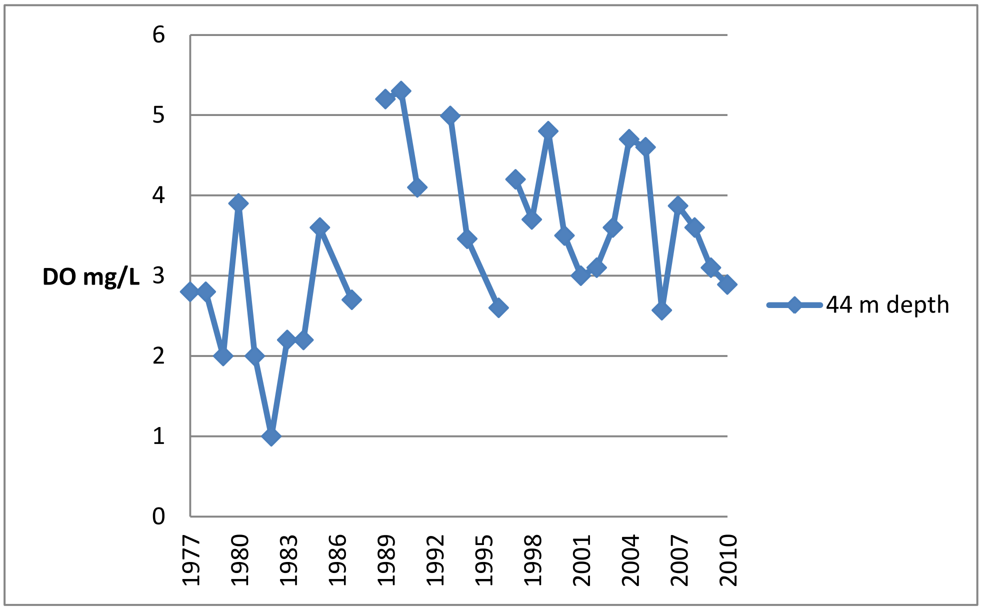

Figure 6. Dissolved oxygen in Osoyoos Lake opposite Monashee Coop at the 44 m depth in mid-September.

Seasonal data collected by the ONA and Fisheries and Oceans Canada has recently been used to investigate the relationship between salmonid survival and temperature and DO conditions in Osoyoos Lake. Hyatt and Stockwell (2010) have proposed that Osoyoos Lake waters with water temperatures <17°C and DO concentrations >4 ppm represent a volume of optimum water (VOW) for the rearing of juvenile sockeye salmon and returning adults. When these isopleths overlap, leaving no VOW, the growth and survival of sockeye salmon is compromised.

The surface waters of Osoyoos Lake typically warm in May pushing the 17°C temperature isopleth down to about 15 m where it stabilizes through the summer before rising in late September-October. In the deeper waters of the north basin, the 4 ppm DO concentration isopleth typically remains near the bottom until late July, but then moves upwards stabilizing between 15 and 35 m during September or October, and then descends with fall turnover in mid to late October. The 4 ppm DO and 17°C isopleths tend to converge at about 15 m water depth. However, the timing of the shallowest DO isopleth typically lags behind the timing of the deepest 17°C isopleths. One result of this lag is a persistent layer of water having optimal conditions for growth and survival of juvenile sockeye salmon (i.e., DO > 4 ppm and temperature < 17°C) in the north basin. In some years, this layer of optimal water is not present at all in the north basin. Hypolimnetic oxygen concentrations regularly exclude juvenile sockeye salmon from the south and central basins of Osoyoos Lake in the summer and fall (K. Hyatt, pers. comm. 2007). Figure 7 illustrates the progression of temperature and DO isopleths in the three basins in 2001.

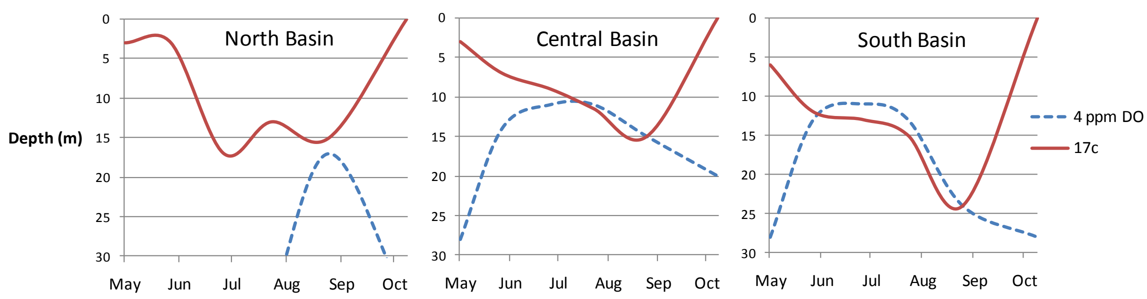

Figure 7. Seasonal changes in the isopleths of 17°C water temperature and 4 mg/L dissolved oxygen in the north, central and south basins of Osoyoos Lake in 2001 (ONA data).

Controlling water temperature is generally not tenable for lakes, but improving DO concentrations is possible. Depletion of DO in bottom waters is a function of lake productivity, and efforts to control nutrient loading from upstream and in-lake sources can reduce oxygen demand in bottom waters, in turn improving available habitat for Okanagan sockeye (K. Hyatt, pers. comm. 2007). The hydrology of the Okanagan River is also known to affect Osoyoos Lake VOW. Higher Okanagan River inflow to Osoyoos Lake in August has been shown to improve VOW (Hyatt and Stockwell, 2010). Based on this relationship, it is possible to adjust water releases from Okanagan Lake to reduce the severity and duration of temperature-oxygen "squeeze" events downstream in Osoyoos Lake. Observations of DO at 15 m on Aug 15th is presently used to classify whether the VOW remaining for occupation by juvenile sockeye will result in a severe, moderate or minor squeeze event. Dissolved oxygen concentrations at 15 m of ≥5.8 mg/L on August 15th are associated with either no squeeze or a minor squeeze event lasting 0-3 days, and starting after September 21st. This value has been met 75% of the time in recent years (K. Hyatt, pers. comm. 2011). Utilization of upstream storage on Okanagan Lake to increase late-summer flows through the north basin is considered as interim remediation during low-flow years, while reductions in upstream nutrient load to the lake may offer the best long-term solution (K. Hyatt, pers. comm. 2011).

Therefore, to ensure that Osoyoos Lake waters provide a refuge for the rearing and migration of juvenile and adult sockeye salmon, a ***water quality objective is proposed for DO. The objective is that DO at the 15 m depth in the north basin should be 5.8 mg/L or greater on August 15th. This objective applies to the waters of the north basin of Osoyoos Lake, and may serve as a long-term objective for the central and south basins of the lake.***

6.2 NUTRIENTS

Nitrogen (N) and phosphorus (P) are important nutrients to freshwater ecosystems. Nitrogen and P occur naturally but can increase in lakes through inputs of sewage, septic tank seepage, from agricultural inputs via manure or fertilizers, or from erosion of soils to downstream waters. The environmental consequences of increased N and P concentrations in aquatic ecosystems is eutrophication, and the associated increased incidence of nuisance or toxic algal blooms, fish mortality due to anoxia, increased costs of water treatment, reduced water clarity, loss of recreational appeal and reduced tourism.

There are several analytical measures of the various forms of N and P in the aquatic environment. However, total N, total P, and the N:P ratio, are the most widely measured variables for predicting eutrophication in freshwaters. Phosphorus limitation in freshwaters is considered to be more likely to occur at N:P ratios greater than 10:1 (Nordin, 1985). While these total measures tend to overestimate the actual amount of bioavailable N and P, they are considered the most reliable indicators because of the dynamic nature of nutrients in the aquatic environments in terms of biological uptake (Nordin, 1985).

6.2.1 Phosphorus

Of the two nutrients, P is most often the least abundant in freshwaters, and usually limits primary productivity in lakes, however co-limitation by both P and N can also occur. Lakes with abundant P inputs allow N deficiencies to enable N-fixing cyanobacteria, or blue-green algae, to dominate plankton communities. Thus, P control is the preferred strategy for controlling eutrophication of freshwaters (Schindler et al., 2008), and has been successfully applied to Okanagan basin lakes (Jensen and Epp, 2002).

Phosphorus is non-volatile and atmospheric transport of P is limited to movement as a dust or aerosol. The Okanagan Basin Study estimated that dustfall and precipitation contributed approximately 500 kg P to Osoyoos Lake each year (Haughton et al., 1974). This equates to roughly 20 mg/m^2/year, which is similar to rates reported for several Alberta lakes (Shaw et al., 1989). Lakes usually receive the majority of their P through surface flows. Phosphorus inputs via groundwater are usually limited because soils tend to bind P unless the soil is saturated and anoxic. In soils, phosphate in solution reacts quickly with ions to become unavailable to plants and decreases the potential for leaching of P to lakes. Thus, groundwater is not usually a significant source of P to lakes. Transport of P to lakes is more likely to occur with soils as a result of erosion. Once delivered to a lake, P is usually retained fairly efficiently by a combination of biological assimilation by biota, and deposition to the lake bottom. A smaller portion is exported downstream. Phosphorus binding in lake bottom sediments with aluminum and ferric hydroxides is particularly strong. However, in anoxic conditions the ferric ions are reduced and the binding is weakened allowing the phosphate to diffuse more freely to the water column (Wetzel, 2001).

Phosphorus has been measured in Osoyoos Lake as total P (TP), dissolved inorganic orthophosphate (PO_4^{-3}) and total dissolved P (TDP). Total P consists of PO_4^{-3}, TDP and particulate P (>0.45 µm in diameter), which can be both organic and mineral in origin. The TDP fraction consists of PO_4^{-3} and a fraction of dissolved organic P from the breakdown of biotic material and polyphosphates (Nordin,1985). Total P is the best overall measure because PO_4^{-3} in eutrophic waters is often rapidly assimilated by algae and bacteria. Lakes with spring TP below 10 µg/L are nutrient poor, or oligotrophic. Those above 30 µg/L are eutrophic, or nutrient rich and over-productive. Those in between are mesotrophic, or of moderate productivity. Total P and TDP data for Osoyoos Lake are summarized in Appendices 3 and 4. The BC water quality guideline for protection of drinking water and recreation use of lakes is 10 µg/L TP, and a range of 5 to 15 µg/L is considered protective of aquatic life (Nordin, 1985).

Spring turnover values for TP in near surface waters (1-10 m) are similar for the three basins of Osoyoos Lake (Figure 8). A statistically significant decreasing trend (p <0.001) is apparent for all north and south basins and is attributed to reduced P loading from point and non-point sources to the lake, and incremental reduction in internal loading of P from sediments in the north basin. A decreasing trend is also evident for spring TP in the central basin, but is not statistically significant, due to the shorter monitoring period. Prior to 1994, spring TP was consistently greater than the spring TP objective of 15 µg/L for Osoyoos Lake. Since the early 1990s, spring TP has often been below the water quality objective.

The Osoyoos Lake spring TP water quality objective was set in 1985 for the North site in the north basin, on the assumption that nutrient inputs from upstream sources would initially affect water quality in the north end of the lake. The WQO was set at 15 µg/L based on the BC aquatic life guideline upper limit, with an expectation of lake recovery following reductions in upstream loading. Spring surface TP values are highly correlated between the North and Monashee sites, with TP somewhat higher at the Monashee site over the past 2 decades (r = 0.862, p <0.0001). Given this, it would be conservative to apply the objective in the future at the Monashee site (see Figure 2 and Table 4). For the Monashee site, the average spring surface water TP concentration for the periods 1990-2010 and 2001-2010 are 16.1 µg/L and 12.8 µg/L, respectively. The spring TP average concentration for all epilimnetic and hypolimnetic samples for this site from 2001 to 2010 is 13.7 µg/L.

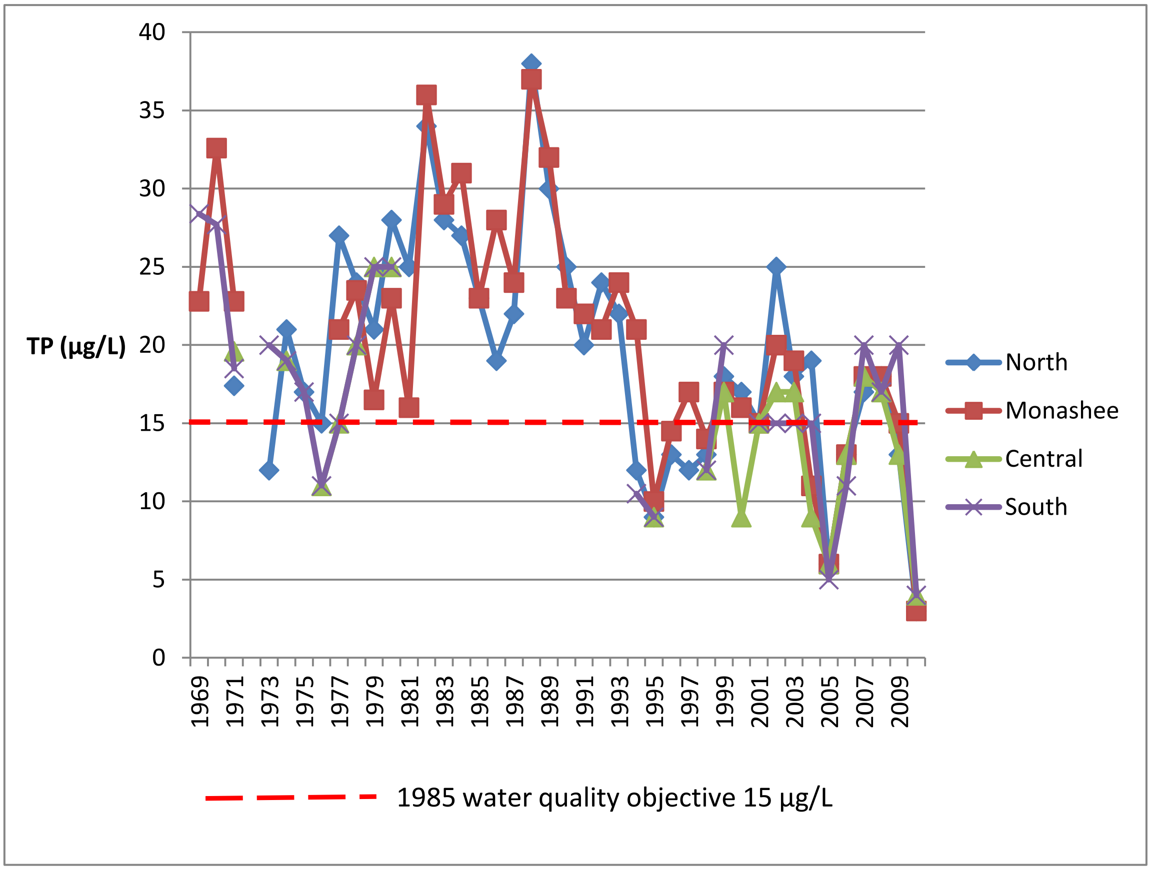

Figure 8. Spring total phosphorus (TP) concentrations in surface waters (1-10 m depths) of all four sampling sites in Osoyoos Lake, relative to the spring TP water quality objective of 15 µg/L set in 1985.

Phosphorus accumulates in the bottom waters of all three basins over the growing season. This is most pronounced in the central and south basins where significant releases of sediment-bound P occurs during periods of anoxia (Appendix 5). The improving (decreasing) P trend in hypolimnetic waters (>20 m depth) of the north basin suggests a combined response to reduced upstream and internal TP loads. A decreasing trend in hypolimnetic TP is readily apparent up to 2001. However, between 2001 and 2010, no trend is apparent. This suggests that for the north basin, internal loading has been substantially reduced over time, but has been relatively static for the past decade. Internal P loading within the central and south basins is a continuing concern and shows no obvious trend over the period of record (Appendix 5).

The seasonal pattern for TP in surface waters of the north basin, is for values to be greatest in the spring and diminish through the growing season from the processes of phytoplankton uptake, sedimentation, and outflow. Fall surface water TP is generally less than spring TP in all three basins. Thus, spring values reflect the effects of combined river inputs and any internal loading from the previous year. Furthermore, they provide a conservative measurement of the potential plankton response in the upcoming growing season.

Given that Osoyoos Lake phosphorus has declined significantly over the past 20 years, and that the north basin spring TP values have been, on average, near the existing objective of 15 µg/L, it is proposed that 15 µg/L continue to serve as the long term water quality objective for all three basins of Osoyoos Lake.

It is proposed that the objective be assessed in the spring before stratification and significant biological uptake has occurred. A depth integrated value of surface, mid, and bottom waters should be used to check attainment of this objective at the Monashee site. Sampling at the North site on the north basin could be discontinued provided other parameters show a strong correlation with that of the Monashee site. Consistent attainment of this objective should be the long term goal. It is important to note, however, that the spring TP objective of 15 µg/L falls at the lower end of the range predicted by paleolimnological analysis of Osoyoos Lake sediments (Cummings et al., 2009). Diatom and pigment data for Osoyoos Lake sediments generally indicate mesotrophic conditions (seasonal mean TP ~17-20+ µg/L) existed prior to European settlement of the area some 200 years ago. Sediment records suggest that the highest TP levels in the north basin occurred between 1950 and 1990, and from approximately 1960 to 1990 in the south basin.

6.2.2 Okanagan River hydrology and Osoyoos Lake phosphorus

Tran et al. (2011) found weak but positive correlations between Okanagan River spring discharge (March-May) and summer (June-September) TP in all three basins of Osoyoos Lake for the period 1994-2008. Because the lake might not have achieved steady state condition following nutrient reduction early in this time period, we examined a more recent time series (2001-2008) when consistent seasonal records (Monashee site) for nutrients were gathered by the ONA. Our analyses of the seasonal data also show higher spring river flows contribute to high spring TP in the north basin of Osoyoos Lake (Figure 9). Note that spring sampling occurs in February and March, while the river discharge averaging period used here is March through June, when higher turbid flows occur. Despite an average flushing rate of 0.7 years, spring TP is strongly influenced by the previous year's freshet. Cold spring river water during freshet may descend to the lake bottom and not become fully mixed into the water column until winter turnover. Interestingly, higher spring flows appear to have the opposite effect of flushing the epilimnion of the lake with clear river flows and diminishing the effects of internal loading (Figure 10). Osoyoos Lake P response to varying hydrology and external TP load, can be complex, potentially exhibiting various patterns depending on the time scale and measurement period of interest. Therefore, attainment of the spring TP water quality objective should be assessed in relation to inter-annual variation in Okanagan River discharge and inter-annual variation in P load. Spring TP concentrations above 15 µg/L is more likely to occur following wet springs with greater run-off. Conversely, concentrations of spring TP above 15 µg/L following years of low flow should be uncommon. An increasing frequency of non-attainment without a corresponding increase in above normal run-off should be unexpected. However, efforts to improve on this preliminary understanding of Osoyoos Lake TP response to changes in Okanagan River discharge are warranted.

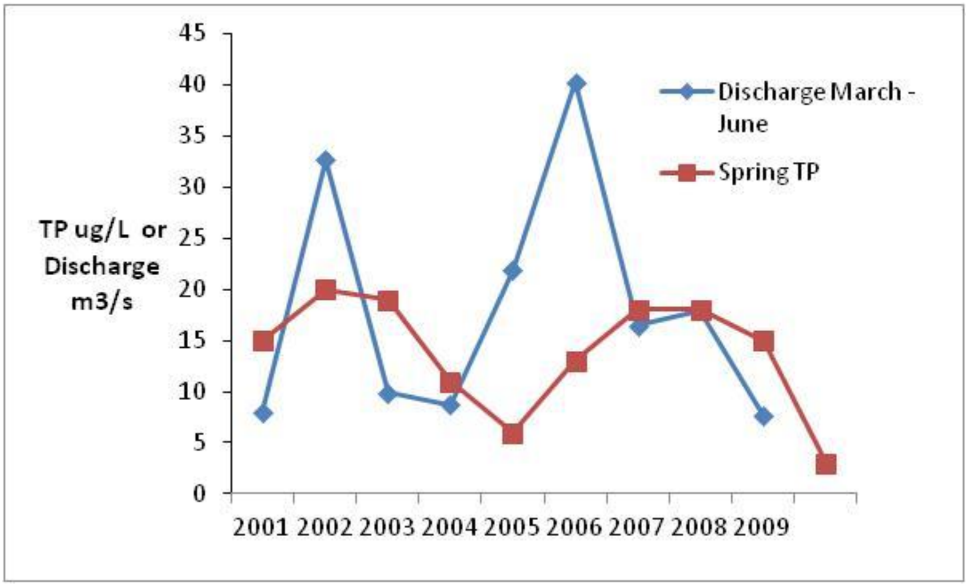

Figure 9. Okanagan River average spring (March – June) discharge (m^3/s) and Osoyoos Lake surface water (1-10 m) total phosphorus (µg/L) in the spring (February –March).

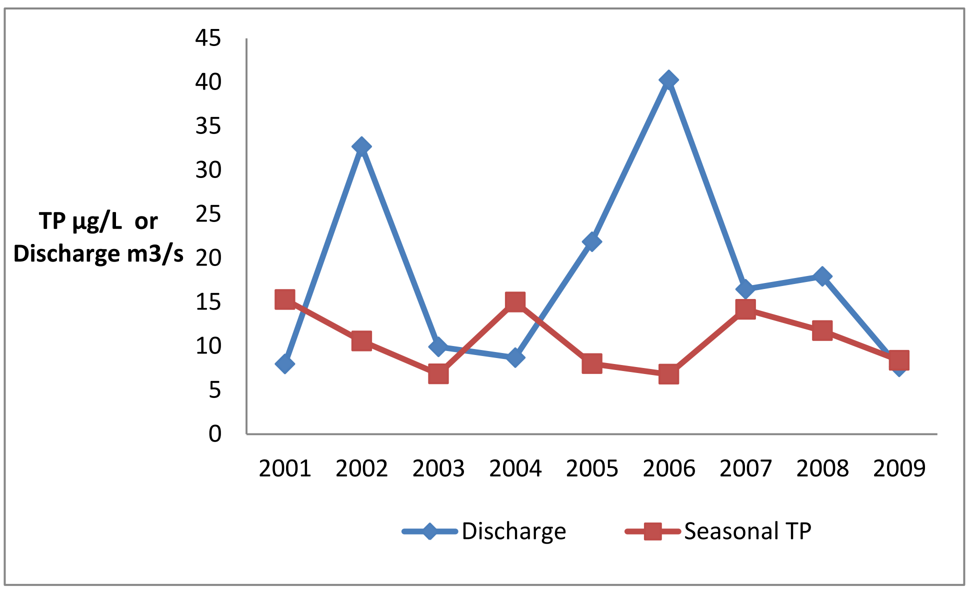

Figure 10. Okanagan River average spring (March – June) discharge and Osoyoos Lake surface water (1-10 m) seasonal (May-September) phosphorus (µg/L).

6.2.3 Nitrogen

Nitrogen, along with P, carbon and hydrogen, is one of the major constituents of the cellular protoplasm of organisms and plays a key role in the productivity of freshwaters (Wetzel, 2001). Nitrogen occurs mainly in the amino acids and proteins of organisms (Brönmark and Hansson, 1998) and is also involved in the functions of nucleotides, nucleic acids, chlorophyll and coenzymes. Nitrogen limitation in lakes is less common than P limitation because of the potential for fixation of atmospheric N by cyanobacteria (Nordin, 1985).

The aquatic N cycle is a balance of N inputs and N losses from an aquatic environment. Nitrogen inputs to aquatic systems include atmospheric (particulate fallout and precipitation), N-fixation in both the water and the sediments, and inputs from both groundwater and surface water. Nitrogen losses occur through outflows from the basin, N gas (N_2) losses to the atmosphere, and sedimentation of inorganic and organic N-containing compounds (Wetzel, 2001).

Nitrogen occurs in the environment in a number of forms; the most important to primary production are the inorganic forms ammonia and nitrate (Nordin, 1985). Ammonia is the most reduced inorganic form found in water and exists in two states in equilibrium, depending on environmental conditions: ammonia (NH_3) and ammonium (NH_4^+) (Nordin & Pommen, 1986). Ammonia is the most favourable form of N for cell uptake (Brönmark and Hansson, 1998), however, the preference for either ammonia or nitrate (NO_3^-) will depend on the algal species (Nordin, 1985). Ammonia is usually low in aerobic waters because of the utilization by plants in the photic zone (Wallace, 2002) and nitrification to nitrate. Inorganic N can also be absorbed to sediments and released when conditions in the water change. Other forms of N include nitrite (NO_2^-), which can be very toxic to aquatic life and humans, but is an unstable intermediate form of N and generally not present in large quantities in undisturbed lakes; dissolved organic N usually in the form of polypeptides and complex organics; and, particulate organic N present as phytoplankton, zooplankton and detritus. Dissolved organic N may be biologically available as amino acids and is quickly utilized by bacteria.

The water quality guideline for nitrate in source drinking waters is 10 mg/L (Nordin and Pommen, 1986). For the protection of freshwater aquatic life, the 30-day average concentration should not exceed 3.0 mg/L, and the maximum concentration at any time is 31.3 mg/L (Meays, 2009). The nitrite guideline to protect aquatic life is based on chloride concentrations (Nordin and Pommen, 1986); for the protection of drinking water sources, the guideline is 1.0 mg/L. Ammonia guidelines to protect aquatic life are pH and temperature dependent (Nordin and Pommen, 1986). There are no water quality guidelines for total nitrogen.

Total nitrogen (TN), and nitrate (NO_3) or nitrate+nitrite (NO_3+NO_2), have been measured at all sites in Osoyoos Lake since 1971. As with other parameters, a longer spring/fall and seasonal data set is available for the Monashee site. Spring values measured at Monashee in 1977, 1978, and 1979 did not agree with results measured at the North and Central sites, and were removed from this analysis. Total N results from 2010 also conflicted between sites (a range of 20 – 500 µg/L between the 4 sites) and were judged anomalous and removed from the data set.

The N data are summarized in Appendices 6 and 7. Spring TN concentrations (<10 m) are illustrated in Figure 11. Spring surface TN concentrations ranged between 200 and 300 µg/L in the early 1970s, and peaked at approximately 500 µg/L in 1980. Since that time, spring TN concentrations have fluctuated between 200 and 400 µg/L at all sites. These results suggest Osoyoos Lake can be classified as mesotrophic (Nordin, 1985). Overall, significant decreasing trends in TN were found at the north basin (p = 0.0045), Monashee (p = 0.0303), and the central basin (p = 0.0731). TN concentrations at the south basin decreased over time, however the trend was not statistically significant (p = 0.1058).

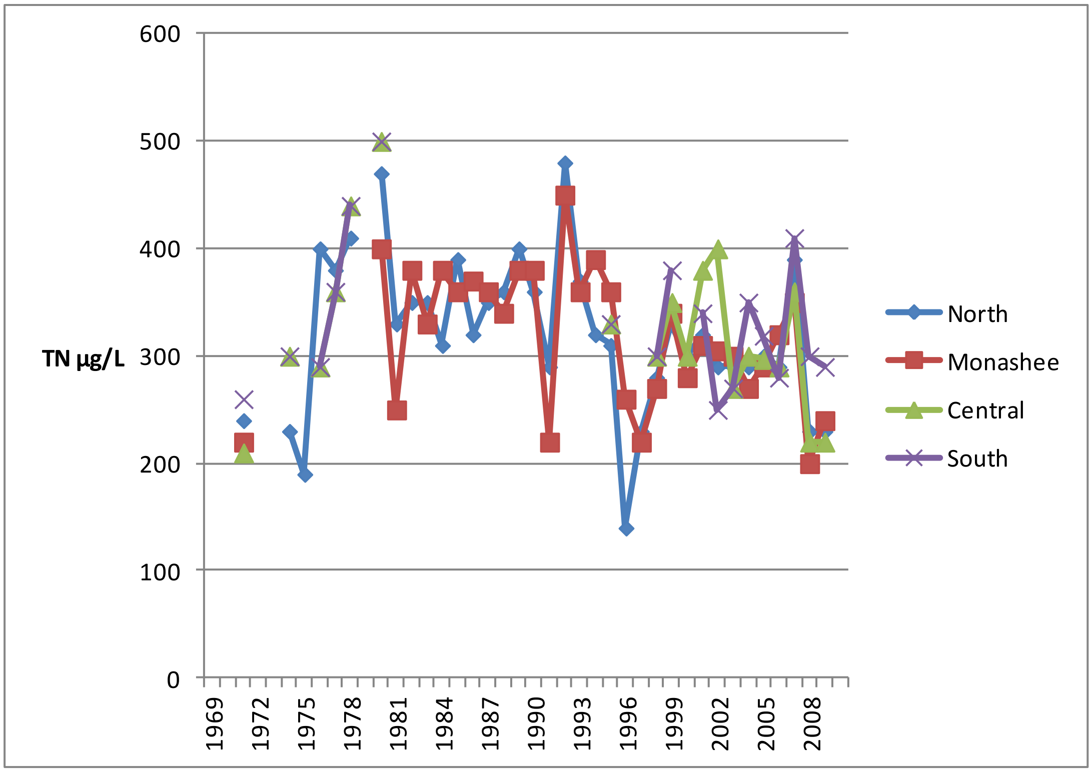

Figure 11. Osoyoos Lake spring surface water (1 – 10 m depths) total nitrogen concentrations.

Okanagan River discharge influences nitrate in Osoyoos Lake. As with P, higher spring flows result in higher spring nitrate (Figure 12). Consequently, over time, NO_3+NO_2 concentrations are highly variable from one year to the next (Figure 13). In general however, nitrate concentrations are low (i.e., <200 µg/L), and well below all water quality guidelines. Significant decreasing trends in epilimnetic (<10 m) NO_3+NO_2 were found at the North (p = 0.0001), Monashee (p = 0.0051), and South sites (p = 0.0805). Nitrate+nitrite concentrations were lower in recent years at the Central site, although the decreasing trend was not significant (p = 0.1156).

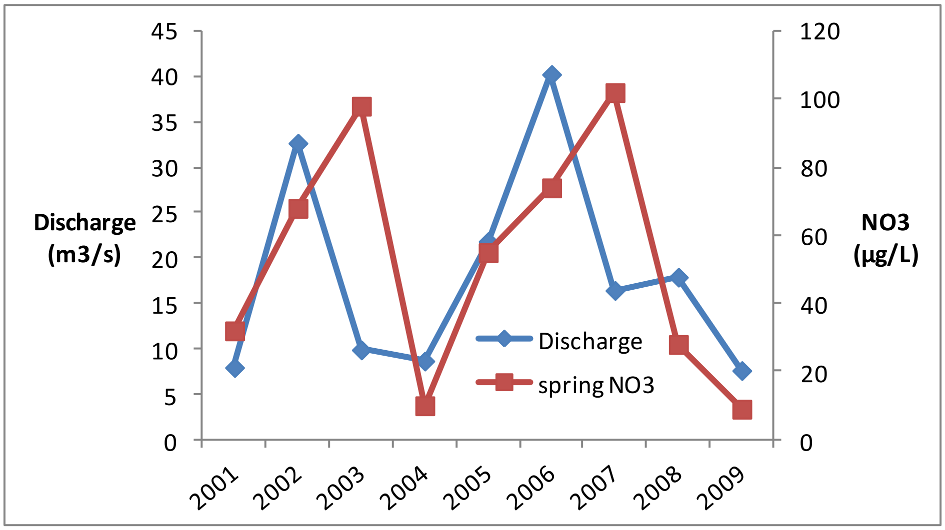

Figure 12. Osoyoos Lake spring surface water (< 10 m depths) nitrate concentrations and Okanagan River spring (March to June) average discharge.

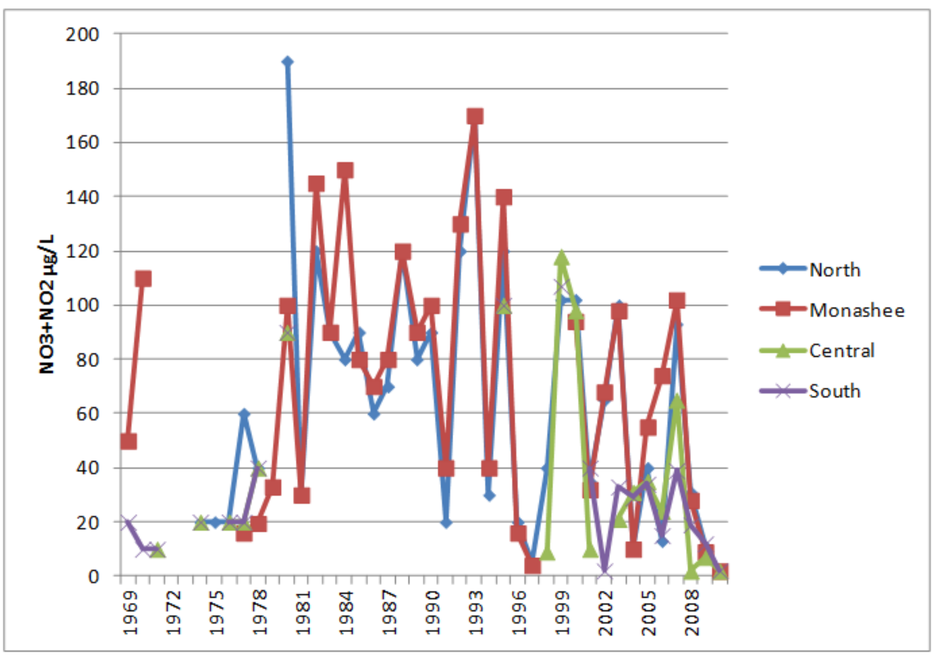

Figure 13. Osoyoos Lake spring surface water (1 – 10 m depths) nitrate concentrations.

The North and Monashee sites are located relatively close to one another and similar results between the two sites are expected. Spring TN and NO_3+NO_2 were significantly correlated between the two sites (r = 0.793, $p < 0.0001$; r = 0.848, $p < 0.0001$, respectively). In light of this, future monitoring costs could be reduced by sampling only one site in the north basin.

Total N and NO_3+NO_2 were within an acceptable range throughout the period of record, and in fact have shown decreasing concentrations over time. While elevated levels (>500 µg/L) of TN can be associated with eutrophication, the inorganic forms (e.g., nitrate) are more likely to be taken up directly by algae and should, therefore, be of more concern. The low and diminishing levels of NO_3+NO_2 found in Osoyoos Lake suggest that nitrate N is not a concern in Osoyoos Lake, providing P sources continue to be controlled so that nitrogen limitation does not occur. Spring and fall TN:TP ratios in surface waters of all three basins are typically greater than 10:1. Given the diminishing N levels in Osoyoos Lake and the fact that eutrophication is more effectively addressed through P input control, ***no water quality objectives for TN or NO_3+NO_2 are recommended at this time.***

6.3 PLANKTON AND WATER CLARITY

Plankton and water clarity are important indicators of water quality. Nutrient enrichment of lakes, particularly by P, affects phytoplankton density and diversity, and can produce phytoplankton surface blooms or “scums”, reduced water clarity, and diminished hypolimnetic oxygen (Nordin, 1985). Phytoplankton chlorophyll-*a* provides an estimate of algal biomass, while Secchi depth is a simple but common estimate of water clarity. Long-term spring and fall records of chlorophyll-*a* and Secchi depth are available for Osoyoos Lake, particularly the north basin. Over the past decade the ONA has also measured growing season (May to September) chlorophyll-*a* concentrations and Secchi depths, which are often used to estimate trophic status of a lake. The ONA has also developed considerable phytoplankton and zooplankton community composition information over the past decade (McQueen et al., 2010). Of interest to this assessment is the presence and abundance of cyanobacteria or “blue-green algae” which are common species in nuisance algal blooms. Zooplankton and fish populations are also influenced by changes in the abundance or palatability of the phytoplankton community. For

Osoyoos Lake, a significant portion of the phytoplankton is considered too large or too gelatinous to be consumed by zooplankton (McQueen et al., 2010). The seasonal and year to year variation in Osoyoos Lake zooplankton community continues to be assessed by the ONA to support salmonid recovery efforts.

Water quality objectives for phytoplankton chlorophyll-*a*, water clarity (Secchi depth), and phytoplankton taxonomic composition are included in this assessment. A comprehensive assessment of other biological communities (e.g., zooplankton, periphyton, macrophytes, fish) with the intent of proposing other biological water quality objectives would be an ambitious and worthwhile challenge in the future.

6.3.1 Phytoplankton Chlorophyll-*a*

Chlorophyll-*a* is the primary photosynthetic pigment of all algae, cyanobacteria, and photosynthetic organisms other than photosynthetic sulphur bacteria (Wetzel, 2001). Seasonal mean chlorophyll-*a* values in lakes below 3 μg/L are considered an indication of low productivity (oligotrophic), while values above 15 μg/L are generally considered to indicate high productivity (eutrophic). There are no provincial guidelines for chlorophyll-*a* in lake waters. However, setting lake specific objectives for phytoplankton chlorophyll-*a* is not uncommon in BC (e.g., Nordin, 2005; Rieberger, 2007).

Spring and fall sampling of Osoyoos Lake has included epilimnetic chlorophyll-*a* at the two north basin sites for almost 40 years, and at the central and south basins since the mid-1990s. All spring, fall and seasonal average chlorophyll-*a* values are provided in Appendix 8. Spring chlorophyll-*a* is similar in all three basins but highest at the Central and Monashee sites (Table 7). Fall values are lowest in the north basin and highest in the south basin (Table 7). Over the past four decades, spring and fall chlorophyll-*a* concentrations have been quite variable with only a slight downward trend apparent in fall values (Appendix 9). Given that P has declined in Osoyoos Lake, one might expect a more definitive response in chlorophyll-*a*. Strong relationships between P and chlorophyll-*a*, however, are best illustrated by logarithmic relationships using seasonal data from many lakes with diverse P concentrations (Mazumder, 1994). The impact of relatively modest changes in Osoyoos Lake P on spring and fall phytoplankton chlorophyll-*a* could be obscured by interannual variation in grazing rates by herbivores, or variability of river inflow and bioavailability of P entering from the Okanagan River.

As with phosphorus, there was a positive correlation ($r = 0.816$, $p<0.0001$) between chlorophyll-*a* in the North End and Monashee sites in the spring when the lake is well mixed (1977-2010). When the north basin is stratified in the fall, the correlation is weaker ($r = 0.615$, $p<0.0001$) but still significant. In both cases chlorophyll-*a* is often higher at the Monashee site than the North End site. This again supports objectives attainment monitoring at the Monashee site.

Table 4. Average spring and fall chlorophyll-*a* concentrations for Osoyoos Lake 2001-2010.

Chl-*a* (μg/L)	North End	Monashee	Central	South
Spring	8.0	8.7	9.6	8.4
Fall	4.2	4.4	4.9	5.7

Over the past decade, the ONA has collected monthly chlorophyll-*a* samples, from May through September, in the north basin at the Monashee site (Appendix 10). The largest phytoplankton blooms in Osoyoos Lake, as with many north temperate lakes, occur early after ice-off in the spring and are commonly followed by a smaller bloom in the late-summer or early-fall. March often yields the highest chlorophyll-*a* values for the season and have been almost twice the fall value over the past decade (Figure 14). Between 2001 and 2010, growing season (May to September) chlorophyll-*a* concentrations for the Monashee site ranged from 2.7 to 5.3 μg/L and averaged 4 μg/L (Figure 15). However, as with other measures of biological productivity, there is some year-to-year variation. No trend is apparent, nor expected, given the short time span for seasonal data, and relatively constant P over that time period. These values are indicative of a mesotrophic system, which is generally considered to have a growing season range of 3-11 µg/L and a mean value of 4.7 µg/L or a mean peak value of 16.1 µg/L (Wetzel, 2001).

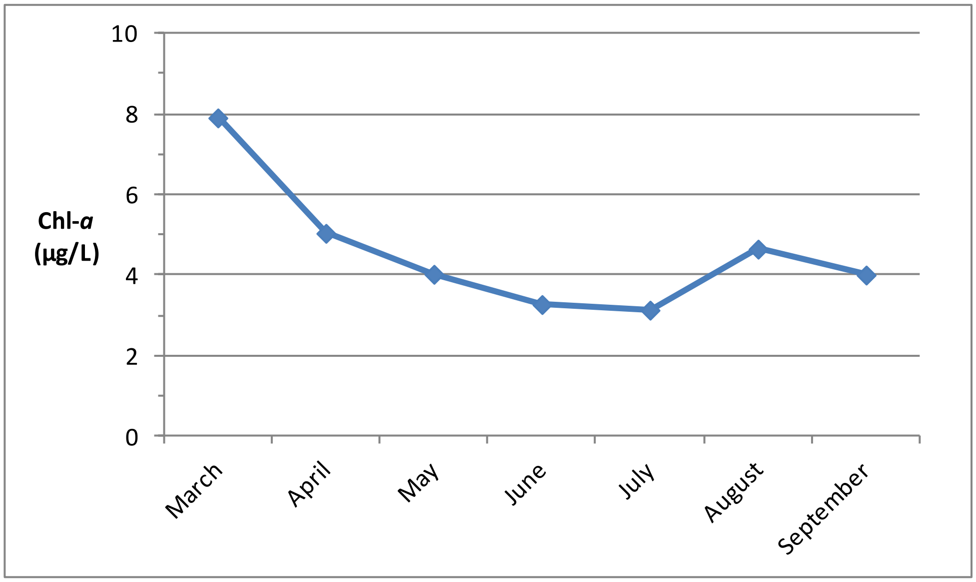

Figure 14. Phytoplankton chlorophyll-*a* seasonal pattern for the Osoyoos Lake Monashee site, averaged over the period 2001 to 2010.

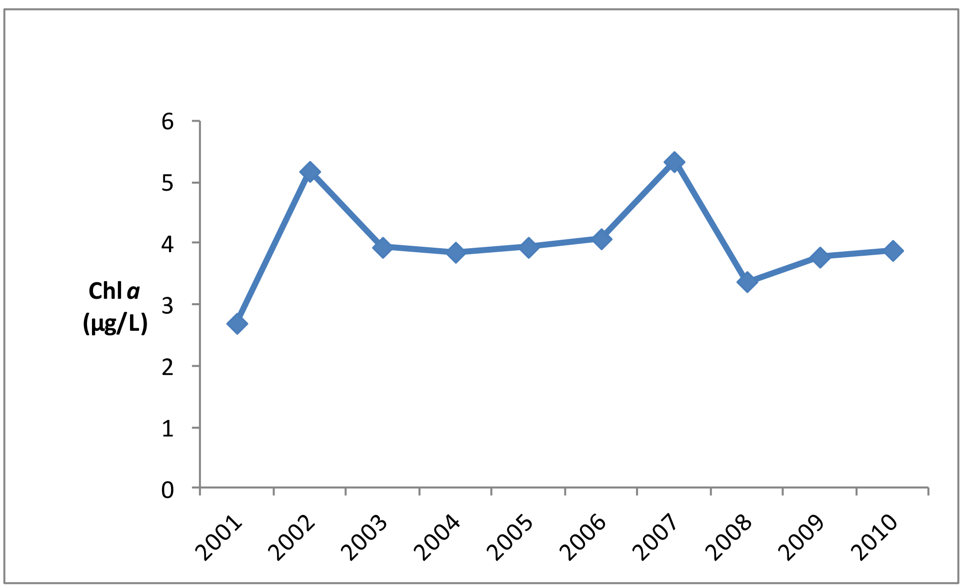

Figure 15. Growing season averages (May to September) for chlorophyll-*a* over the period 2001 to 2010, for the Monashee site.

Given the role of seasonal chlorophyll-*a* in establishing trophic status, ***the proposed objective for chlorophyll-a is a growing seasonal average of ≤4 µg/L in the epilimnetic***

waters of the north basin of Osoyoos Lake. The average should be calculated from 5 monthly values collected between May and September. This objective would have been met 70% of the time over the past decade, and consistent attainment of this objective should be the long term goal. It is important to note that reliable long-term seasonal data are only available for the Monashee site in the north basin. The central and south basins have consistently higher spring and fall chlorophyll-*a* values over that past few decades, and it is reasonable to expect that growing season means would also be higher. Seasonal data for these two basins will be needed to check attainment and adequacy of the chlorophyll-*a* objective.

6.3.2 Water Clarity

Osoyoos Lake water clarity has routinely been measured using a Secchi disk. This is a standard and simple measure of water clarity or transparency, and can be used to indicate changes in water quality, as transparency decreases with increasing colour, suspended sediments, calcite crystals in alkaline lakes, or algae. Because of its simplicity, the Secchi disk can provide 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 other uses (Nordin, 2005).

Spring and fall sampling of Osoyoos Lake by the MOE has included Secchi depth measurements for several decades. The two north basin sites have long-term Secchi measurements starting from the mid-1970s, while the central and south basins have measurements from the mid- to late-1970s, and then from the mid-1990s to the present (Appendix 11). Average spring and fall Secchi values over the past decade are often greatest in the north basin and lowest in the south basin (Table 8).

Table 5. Average spring and fall Secchi depths for Osoyoos Lake, 2001-2010.

Secchi (m)	North End	Monashee	Central	South
Spring	4.3	4.5	3.9	3.3

Fall	3.9	4.1	3.8	3.2

Over the past four decades, spring and fall Secchi depth have been highly variable, but data from the north basin suggest a slight increasing trend. However, no trends are apparent for the shorter and intermittent time series for the Central and South sites (Appendix 12).

Secchi depth has also been measured seasonally (May to September) at all four sampling sites in Osoyoos Lake since the late-1990s by the ONA (Appendix 11). Similar seasonal patterns in Secchi depth occur in the north and central basins, with water clarity increasing slightly over the growing season. The opposite pattern is apparent for the south basin (Figure 16). Between 2001 and 2010, growing season mean Secchi depths, mirror spring and fall data, with the highest water clarity in the north basin (Monashee site = 3.6 m) and the lowest in the south basin (3.2 m).

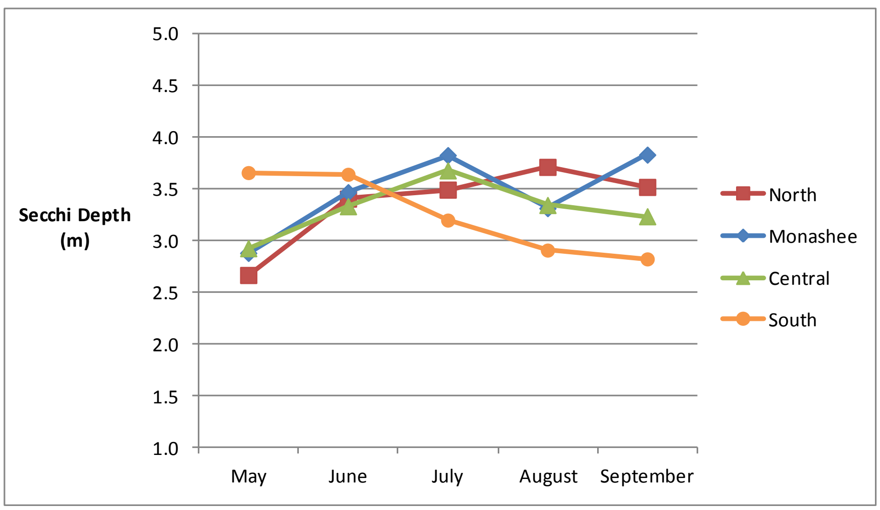

Figure 16. Seasonal pattern of Secchi depths averaged over the period 2001 to 2010, for Osoyoos Lake North, Monashee, Central, and South sites.

Seasonal changes in water clarity in Osoyoos Lake correspond, in part, to changes in algal abundance. Over the growing season at the Monashee site, as phytoplankton chlorophyll-*a* increases, Secchi depth decreases (Figure 17). Water clarity in Osoyoos Lake also has an inverse relationship with annual discharge of the Okanagan River.

Generally, in years of higher flow, mean seasonal Secchi depth is lower, and in low-flow years, mean seasonal Secchi depth is often higher (Figure 18). High discharge years have higher nutrient and sediment loads, which contribute to decreased lake water clarity. For example, an unusually low Secchi depth of 1.4 m at the North end site in the fall of 2010 is attributed to sediment released from Testalinden Creek after heavy fall rains.

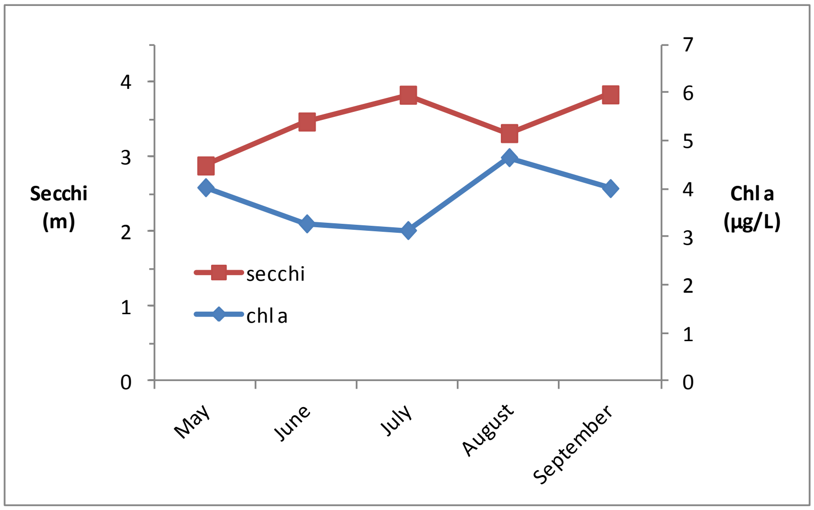

Figure 17. Average seasonal (May – September) pattern in Secchi depth and chlorophyll-*a* for the Monashee site (2001- 2010).

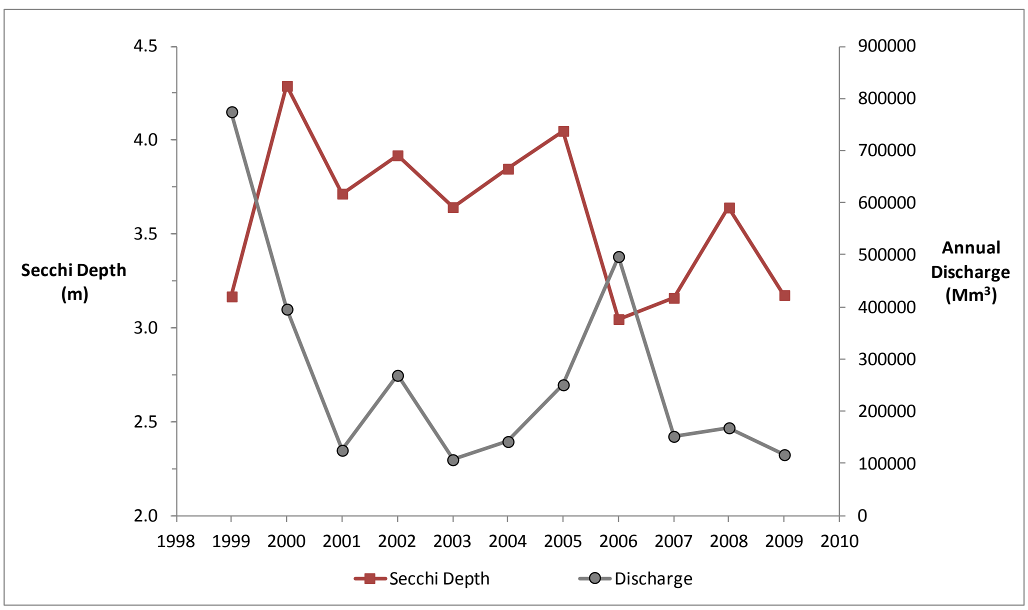

Figure 18. Growing season mean Secchi depth at the Monashee site and annual Okanagan River discharge into Osoyoos Lake over the period 1999 to 2009.

The Health Canada water clarity guideline for Canadian recreational waters is 1.2 m to ensure there is negligible risk to the health and safety of recreational users (Caux et al., 1997). All long-term spring, fall and seasonal records for Osoyoos Lake are greater than this Guideline. ***Given that Secchi depth has averaged 3.6 m at the Monashee over the past decade*, *the proposed objective for Secchi depth is a minimum depth of 3.5 m in the north basin of Osoyoos Lake at the Monashee site. This value represents the average of 5 monthly measurements over the growing season (May-September).***

Over the past decade (2001-2010) this objective would have been met 60% of the time at the Monashee site, 40% of the time at the Central site, but only 10% of the time at the South site. Box plots of spring, fall and seasonal Secchi depth statistics are presented relative to this objective in Appendix 13. The goal should be for this objective to be consistently met at the Monashee site, and serve as a long-term objective for the Central and South sites. This objective should be adequate to protect recreational water use, however, greater water clarity would benefit all water uses. Considering the relationship between water clarity and hydrology/nutrient loads, it is important to note that Secchi depths will tend to be lower in wetter years due to biotic and abiotic factors noted above. Although nutrient loads have decreased over time, water clarity has not largely improved. Osoyoos Lake internal phosphorus load continues to affect primary productivity and therefore water clarity. Water clarity is also influenced by inorganic sediments entering the lake, and re-suspension of organic and inorganic material from the large littoral areas of the lake. Osoyoos Lake water clarity therefore is the combined effect of biotic and abiotic processes.

6.3.3 Phytoplankton taxonomy

Phytoplankton is typically comprised of a diverse community of taxonomic algal groups (Wetzel, 2001). The phytoplankton community is constantly changing in response to changes in nutrients, available light, mixing conditions and other growing conditions. This primary production is important to the aquatic ecosystem. Elevated nutrients, however, can cause algal blooms and surfacing scums which impart taste and odours to drinking water, requiring more expensive treatment to remove algal particles. This in turn, can contribute to the generation of disinfection by-products which are potentially carcinogenic (Nordin, 1985). Some types of cyanobacteria (blue-green algae) can produce neuro- and hepatotoxins which are occasionally associated with animal and livestock deaths. This situation is rare, and fortunately has not been reported for Osoyoos Lake. More commonly, algal blooms are an aesthetic issue, as they reduce water clarity and give the water a strong odour. Additionally, increased algal concentrations can reduce dissolved oxygen at depth as the plankton settle, and decompose in bottom waters (see Section 6.1.1).

Phytoplankton community measures use metrics such as cell number or cell volume per unit of lake water, or percent composition; all have been used to express water quality objectives for lakes in BC (Cavanagh et al., 1994; Nordin, 2005; Rieberger, 2007). As methods of sample collection, cell count, and volume estimation differ somewhat among the various Osoyoos Lake studies, an exhaustive analysis of the phytoplankton community change over time is beyond the scope of this document. It is useful to note, however, that nuisance blooms of cyanobacteria may be less pronounced now than several decades ago. For example, significant blooms of *Anabaena* and *Oscillatoria* species occurred from June through July in 1968 (Booth, 1969). The following summer, *Lyngbya* and *Aphanizomenon* species were dominate algal species (Stein and Coulthard, 1971). Okanagan Basin Study work in the early 1970s, noted that the cyanobacteria *Oscillatoria* were often the dominant algae on Osoyoos Lake (Pinsent and Stockner, 1974). Later in that decade, however, the numbers of cyanobacteria were reduced from the counts in 1969 (Jensen, 1981;Truscott and Kelso, 1979). Peak summer phytoplankton biomass estimates in the late 1970s ranged from 2520 to 17,200 mm^3/m^3 (Jensen, 1981).

More recently, the ONA has developed an extensive algal database for Osoyoos Lake to assist with fisheries studies (McQueen et al. 2010). Between 2005 and 2010 algal biomass maxima ranged from approximately 1,700 to 2,500 mm^3/m^3 and annual average values range from 852 to 1,505 mm^3/m^3 (Figure 19; Appendix 14). Although cyanobacteria continue to dominate the phytoplankton community, bloom conditions with floating “scums” have been infrequent in recent years. Between 2005 and 2010, the cyanobacteria growing season average biomass was approximately 620 mm^3/m^3, and monthly values peaked near 1900 mm^3/m^3 on a few occasions. This reduction in phytoplankton total biomass over late-1970s estimates could be the result of reduced P and N inputs to Osoyoos Lake, however, the confounding influence of variations in biomass estimation methods cannot be ruled out.

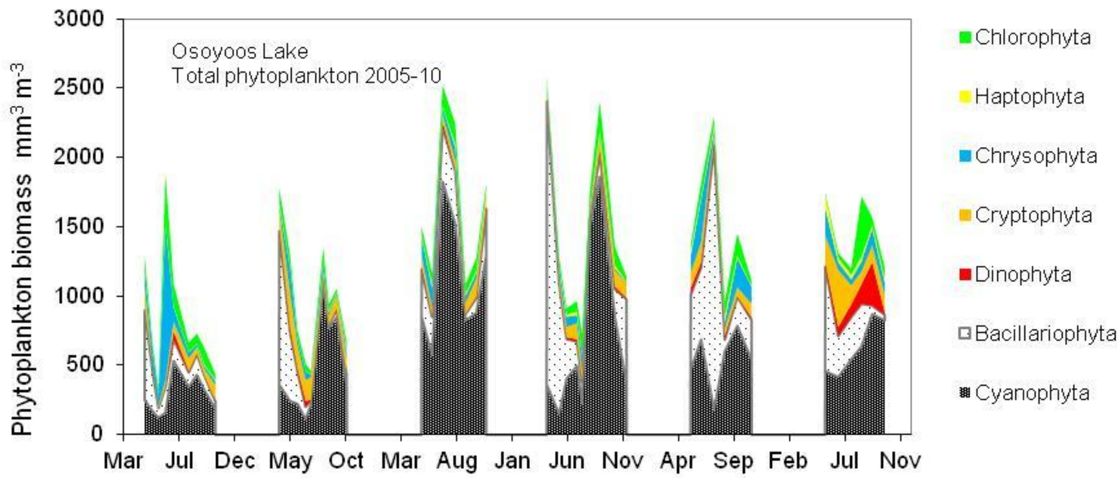

Figure 19. Osoyoos Lake total algal biomass (mm^3/m^3) at the Monashee site (2005-2010) (McQueen et al., 2010).

Nevertheless, since algal biomass and taxonomic composition are useful indicators of lake tropic status, a water quality objective for phytoplankton biomass, based on the recent data collected by the ONA at the Monashee site, is proposed for Osoyoos Lake***. It is proposed that the seasonal mean (monthly values from May through September) cyanobacteria standing crop should not exceed 700 mm³/m³, and no single sample should be greater than 2,000 mm³/m³.*** The mean objective would have been met 60% of the time between 2005 and 2010. It is important that the methods of cell count and organism biovolume used by the ONA remain consistent for this water quality objective to have on-going utility. Details regarding the phytoplankton sampling and biomass estimates are provided in McQueen et al. (2010).

7.0 SUMMARY OF PROPOSED WATER QUALITY OBJECTIVES

In British Columbia, water quality objectives are mainly based on approved or working water quality guidelines. These guidelines are established to protect designated water use; for Osoyoos Lake, the water uses that are sensitive and should be protected are aquatic life, drinking water, and recreation. The water quality objectives recommended in this report take into account background conditions, impacts from current land use and any potential future impacts that may arise within the watershed. Since Osoyoos Lake water quality is strongly influenced by variations in Okanagan River hydrology, the water quality objectives have been set to reflect the average conditions over the past decade. Additional efforts to understand and manage phosphorous inputs to the basin are likely required for continued improvement in Osoyoos Lake water quality. Non-attainment of the objectives is more likely to occur in higher run-off years. It is expected that consistent attainment of the objectives for dissolved oxygen, phosphorus, chlorophyll-*a*, and Secchi depth at the Monashee site on the north basin will, over time, promote the long term goal of water quality improvements in the central and south basins.

All proposed objectives for Osoyoos Lake are summarized in Table 9. The dissolved oxygen objective is depth and date specific. Total phosphorus should be assessed using the average of at least three values representing surface (1-10 m), mid (15 m), and deep (20-45 m) water composites. Attainment of chlorophyll-*a* and cyanobacteria biomass objectives should be determined on surface water composite samples (1-10 m) collected monthly from May through September. Similarly, attainment of the Secchi depth objective should be determined as the average of monthly measurements taken from May through September. It is recommended that these objectives be reviewed every five years to determine whether they continue to be protective of water uses, and revised to reflect any future improvements or technological advancements in water quality assessment and analysis.

Table 6. Summary of proposed water quality objectives for Osoyoos Lake at Monashee site.

Variable	Objective Value	Timing
Dissolved oxygen	≥5.8 mg/L @ 15 m depth	on August 15th
Total phosphorus	≤15 µg/L	Spring (February – March, depending on ice-off)
Phytoplankton chlorophyll-*a*	≤4.0 µg/L	Seasonal mean (May to September)
Secchi depth	≥3.5 m	Seasonal mean (May to September)
Cyanobacteria	≤700 mm^3/m^3 mean; ≤2000 mm^3/m^3 max.	Seasonal mean (May to September)

8.0 MONITORING RECOMMENDATIONS

The water quality objectives for Osoyoos Lake include both spring and seasonal values. As a result, it is recommended that sampling of the north basin be carried out in March and then monthly from May through September. Sampling in other months, such as April and October (typically transition periods of stratification or destratification) are useful but historical data for these months is either lacking or was not used for establishing the proposed water quality objectives. Given the strong correlation between measurements from the North and Monashee sites, it is recommended that monitoring at the Monashee site be used for objectives attainment and sampling of the North site could be discontinued.

In addition to the water quality objectives parameters, the monthly sampling program at Monashee should include a suite of water chemistry parameters (pH, specific conductivity, turbidity, true colour, ammonia nitrogen, nitrate + nitrite nitrogen, total nitrogen, orthophosphate, total dissolved phosphorus, dissolved silica) to provide a more comprehensive record of water quality change over time. The March sampling event should also include chloride and sulphate at one depth, to provide trend information for these conservative ions.

Spring and fall sampling of the central and south basins is recommended to determine long-term trends in these basins, and further develop these data sets to better determine how water quality changes in the north basin affect the basins downstream. Continued collection of seasonal records for Secchi depth, and temperature and oxygen profiles at all three sites, provides valuable seasonal and trend information at low cost.

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10.0 APPENDICES

Appendix 1. Summary of water licenses for Osoyoos Lake

Licence No	Purpose	M3	Units	Qty/Flag	Licensee	Priority Date	Licence No	Purpose	M3	Units	Qty/Flag	Licensee	Priority Date
C019087	Irrigation	542731	MY	T	OSOYOOS IRRIGATION	19490802	C118233	Irrigation	88811	MY	T	BORGES ROGER FRANCIS &	20030319
C019949	Irrigation	928810	MY	T	OSOYOOS IRRIGATION	19500728	C120182	Irrigation	98678	MY	T	OSOYOOS LAROSE ESTATE	20041116
C019988	Irrigation	453921	MY	T	BOUNDARY LINE	19440129	C121236	Irrigation	75859	MY	T	PEMBOROUGH	19310502
C030131	Irrigation	789427	MY	T	OSOYOOS VINEYARDS	19650122	C121265	Irrigation	89551	MY	T	NOBLE-HEARLE GLENN A ET	19310502
C030425	Irrigation	16035	MY	T	0772056 BC LTD	19430108	C121335	Irrigation	54273	MY	T	FERNANDES THOMAS &	19430920
C035568	Waterworks	33186	MY	T	OSOYOOS IRRIGATION	19690312	C121336	Irrigation	4934	MY	T	FERNANDES HOLDINGS LTD	19430920
C035794	Waterworks	49780	MY	T	OSOYOOS IRRIGATION	19700306	C121337	Irrigation	39471	MY	T	NOBLE-HEARLE GLENN A ET	19430920
C038683	Irrigation	148018	MY	T	OSOYOOS INDIAN	19710211	C121909	Irrigation	44405	MY	T	OSOYOOS INDIAN BAND	19310502
C042698	Irrigation	1480	MY	T	GRIGG CINDY & TRACY	19310422	C122200	Irrigation	59207	MY	T	OSOYOOS INDIAN BAND	19570620
C042699	Irrigation	1480	MY	T	NAGY NICHOLAS	19310422	C122414	Irrigation	99295	MY	T	DAWSON FARMS LTD	19310425
C042700	Irrigation	9251	MY	T	BROOKVALE HOLIDAY	19310422	C122415	Irrigation	99295	MY	T	HOLLER BARBARA R	19310425
C043221	Irrigation	72351990	MY	M	TO BE DETERMINED	19080130	C122557	Irrigation	84185	MY	T	DEOL NIRMAL S	19280410
"	Waterworks	829661	MY	M	TO BE DETERMINED	19080130	C122797	Enterprise	191	MD	T	OSOYOOS INDIAN BAND	20011029
C045322	Land Improve	16366	MD	M	OLIVER TOWN OF	19741003	"	Irrigation	86344	MY	T	OSOYOOS INDIAN BAND	20011029
C052948	Irrigation	35746	MY	T	OASIS R V	19310425	"	Watering	181322	MY	T	OSOYOOS INDIAN BAND	20011029
C052950	Irrigation	2479	MY	T	OASIS R V	19310425	C123294	Irrigation	123348	MY	T	OSOYOOS LAROSE ESTATE	19950619
C052951	Irrigation	38115	MY	T	RUSCH WILLIAM C &	19310425	C123592	Domestic	2	MD	T	GARSIDE DEBORAH	20080122
C060358	Irrigation	3084	MY	T	FERNANDES HOLDINGS	19821029	C124789	Irrigation	78943	MY	T	DRIVER ROSS F & MARNIE C	19430108
C060359	Irrigation	4626	MY	T	FERNANDES HOLDINGS	19821222	C124861	Irrigation	8634	MY	T	HARTMANN EWALD D &	19470915
C061559	Irrigation	1998	MY	T	SZUCS ZOLTAN F &	19310422	C124862	Domestic	2	MD	T	HARTMANN DAVID W	19470915
C062099	Domestic	2	MD	T	HULTON ROBERT J	19821013	"	Irrigation	43172	MY	T	HARTMANN DAVID W	19470915
C066560	Irrigation	95274	MY	T	BORGES ROGER	19650311	C125040	Irrigation	2467	MY	T	ZELKO GORDON E & KELLY T	19310422
C070211	Domestic	5	MD	T	REINHOLD GORDON &	19890519	F010371	Domestic	2	MD	T	MITCHELL RODNEY &	19310502
C070420	Res. Lawn/Garden	9868	MY	T	632402 BC LTD	19900402	"	Irrigation	51683	MY	T	MITCHELL RODNEY &	19310502
C070949	Irrigation	1332	MY	T	FRIESEN DWAYNE M ET	19590520	F012993	Irrigation	59207	MY	T	SHAW LORA	19430108
C070950	Irrigation	43813	MY	T	FARINHA ALFRED &	19340517	F013114	Irrigation	53286	MY	T	BRAR NACHHATTAR S	19430920
C070951	Irrigation	41840	MY	T	FERREIRA JOSUE L &	19340517	F013115	Irrigation	69075	MY	T	OSOYOOS IRRIGATION	19430920
C070952	Domestic	2	MD	T	COSTA LAURIE &	19340517	F013116	Irrigation	73022	MY	T	OSOYOOS IRRIGATION	19430920
"	Irrigation	3059	MY	T	COSTA LAURIE &	19340517	F013157	Irrigation	16775	MY	T	NICHOL JOHN C & NORMA R	19440601
C103784	Irrigation	3700	MY	T	DOUGLAS HELEN	19310422	F014187	Irrigation	31577	MY	T	TO BE DETERMINED	19460222
C103852	Domestic	2	MD	T	GRAHAM JAMIE &	19911115	F014188	Irrigation	9374	MY	T	AMANAT ARDESHIR &	19460222
C103868	Watering	51806	MY	T	4203763 CANADA INC	19910610	F014189	Domestic	2	MD	T	AMANAT ARDESHIR &	19460222
C106361	Irrigation	18502	MY	T	DUST ROMAN &	19930325	"	Irrigation	68581	MY	T	AMANAT ARDESHIR &	19460222
C106889	Res. Lawn/Garden	1542	MY	T	WILDMAN CHARLES E &	19930723	F014190	Domestic	2	MD	T	BRAR J S ET AL	19460222
C108101	Construct.Works	0	TF	T	OSOYOOS TOWN OF	19940505	"	Irrigation	51313	MY	T	BRAR J S ET AL	19460222
C109601	Irrigation	11101	MY	T	O'DONNELL LEONA &	19950502	F014560	Irrigation	53730	MY	T	DE SOUSA LEONEL &	19340517
C109815	Irrigation	35549	MY	T	0703885 BC LTD	19310422	F014563	Domestic	2	MD	T	DE SOUSA LEONEL &	19340517
C109816	Irrigation	17737	MY	T	SATPAL KALKAT	19310422	"	Irrigation	53730	MY	T	DE SOUSA LEONEL &	19340517
C111339	Irrigation	246696	MY	T	PENDERGRAFT	19960726	F014564	Irrigation	29406	MY	T	MARCAL MANUEL & MARIA	19340517
C111340	Irrigation	83877	MY	T	MARK ANTHONY	19960726	F014754	Irrigation	29110	MY	T	ENOTECCA WINERY AND	19470915
C111341	Irrigation	84863	MY	T	MARK ANTHONY	19960726	F014798	Irrigation	48352	MY	T	TOPAZ PROPERTIES LTD	19470922
C111668	Irrigation	370044	MY	T	PENDERGRAFT JAMES F	19961024	F015712	Processing	91	MD	T	TO BE DETERMINED	19470331
C111764	Domestic	2	MD	T	HOCHSTEINER GAIL	19961113	F016487	Irrigation	12335	MY	T	SCALES FRED & KATHERINE	19530327
C111765	Domestic	2	MD	T	MARK ANTHONY	19961113	F016608	Irrigation	34537	MY	T	HILARIO JOSE F & VERICA	19530615
C112832	Irrigation	98678	MY	T	HOCHSTEINER GAIL	19780712	F016613	Irrigation	14802	MY	T	MOREIRA CLAUDE ET AL	19511124
C112833	Irrigation	453921	MY	T	MARK ANTHONY	19780712	F018227	Irrigation	1233	MY	T	SEVY ALBERTA U	19630612
C113116	Irrigation	42925	MY	T	JACKLE GARY MELVIN &	19770307	F018353	Domestic	2	MD	T	STEBER JENNIFER A &	19630715
C113313	Domestic	2	MD	T	DUST ROMAN &	19471021	F019224	Irrigation	31577	MY	T	R 459 ENTERPRISES LTD	19480113
"	Irrigation	40458	MY	T	DUST ROMAN &	19471021	F047734	Irrigation	19736	MY	T	HUNGLE DANIEL J & LEONA J	19760831
"	Irrigation	4933920	MY	M	1318052 ONTARIO INC.	19920923	F048391	Irrigation	308	MY	T	MARTIN MICHAEL B &	19761119
C114385	Irrigation	34537	MY	T	FORSYTH DONALD A &	19990511	F052214	Irrigation	34537	MY	T	KELLIHER STANLEY L &	19650311
C114438	Irrigation	8634	MY	T	LIEBEL CYNTHIA A &	19990511	F052215	Irrigation	48106	MY	T	OSOYOOS INDIAN BAND	19430108
C114486	Res. Lawn/Garden	3700	MY	T	QUINTAL EDWARD M &	19990602	F052216	Irrigation	64141	MY	T	OSOYOOS INDIAN BAND	19570524
C114653	Amusement Park	77	MD	T	OSOYOOS TOWN OF	19990902	F052339	Irrigation	6167	MY	T	OSOYOOS INDIAN BAND	19650311
F068285	Irrigation	43172	MY	T	4203763 CANADA INC	19821029	**MY=m3/year; MD=m3/day**		**T=single point of diversion; M=multiple points of diversion**				

Appendix 2. Summary of Okanagan River flow and total phosphorus load calculations.

Water Survey Canada Data — Flow monthly mean in m3/s WSC Station **08NM085**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	annual total
1984	13.3	31.5	24.6	31.2	53.4	58.1	43.5	28	17.4	11.7	11.6	8.95	27.7	874
1985	9.16	9.5	9.34	10.3	13.4	9.13	8.2	8.66	10.7	10.9	10.9	7.35	9.79	309
1986	6.07	16.4	19.4	13.9	49.3	31.7	25.6	33.3	13.1	11.3	12.7	8.12	20.1	634
1987	6.66	7.87	9.21	10.4	10.9	6.73	8.33	7.96	10.4	10.6	5.64	5.29	8.32	262
1988	4.62	4.21	6.69	7.02	9.67	8.09	6.25	5.76	5.81	5.5	5.23	4.96	6.16	194
1989	4.54	5.28	4.55	9.95	12.4	26.8	26.5	14.8	18	15.2	8.09	7.73	12.9	407
1990	8.71	9.85	8.07	9.54	18.8	87.8	68.2	54.1	21.3	9.74	6.05	5.97	25.8	814
1991	5.64	34.1	40.6	10.9	56.1	50.9	32.5	29.5	11.3	10.1	6.09	6.17	24.5	773
1992	5.48	5.16	12	6.98	7.56	8.3	10.2	7.81	8.8	10.4	5.82	5.05	7.81	246
1993	5.57	5.1	4.6	7.01	37.7	25.9	45.7	59.2	27.6	10.5	7.13	5.89	20.3	640
1994	24.1	8.19	26.3	36.7	26	14.9	15.8	11.7	18.4	11.5	6.43	6.12	17.2	542
1995	8.06	18.8	27.9	30	58.4	16.8	11.7	19.8	20.2	11	6.66	11.3	20.1	634
1996	26.4	27	43.6	57.8	63.4	83.6	49	38.6	17.5	10.7	6.87	14.5	36.6	1154
1997	25.9	34.6	49.8	59.1	80.2	84.4	76.8	75.4	63.2	19.5	25	16.8	51	1608
1998	20.3	28.1	29.3	37.4	47.5	40.2	29	11.1	11.7	11.7	8.19	7.06	23.4	738
1999	18	26.2	31.2	53.7	69.3	36.1	50.6	44	15.1	10.6	7.42	18.3	31.8	1003
2000	15.6	19.4	8.92	25.2	48.3	41.6	34.7	15.7	23.4	12.2	7.81	6.12	21.6	681
2001	5.69	5.67	5.8	6.24	10.4	9.4	10.2	10.7	11.3	10.5	7.58	7.44	8.42	266
2002	7.88	8.6	15.8	22.2	41.5	51.2	16.9	16.2	17.1	11.1	6.8	5.96	18.4	580
2003	6.2	6.15	6.09	9.62	12.7	11.2	9.58	9.32	9.52	6.23	5.29	5.19	8.1	255
2004	5.7	5.25	5.17	7.75	11.8	9.98	9.95	11.2	17.4	11.5	7.67	20	10.3	325
2005	22.5	28.9	19.4	25.9	23.5	18.6	40.4	16.4	10.6	10.7	6.26	5.79	19	599
2006	5.98	20.3	22.7	19.6	51	67.7	22.1	11.4	15.3	10.5	5.75	5.65	21.4	675
2007	5.65	7.99	17.2	21.4	18.7	8.5	8.93	10.9	17.1	11	5.86	5.97	11.6	366
2008	5.79	6.24	6.66	12	22.9	30.1	14.3	15	21.8	10.5	6.96	5.45	13.1	413
2009	6.01	6.36	5.99	6.81	9.47	8.24	7.8	7.97	8.99	10.1	6.32	5.71	7.49	236

TP monthly mean in mg/L for Okanagan River d/s Oliver (Fed Prov data) Site 0500720

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1984	0.025	**0.027**	0.029	0.028	0.032	0.039	0.020	0.016	0.014	0.022	0.021	0.019
1985	0.013	0.012	0.019	0.031	0.027	0.020	0.021	0.017	0.017	0.020	0.019	0.019
1986	0.015	0.023	0.021	0.032	0.039	0.020	0.016	0.014	0.012	0.015	0.015	0.017
1987	0.019	0.017	0.018	0.015	0.033	0.017	0.018	0.019	0.017	0.018	0.024	0.022
1988	0.024	0.020	0.023	0.025	0.027	0.017	0.021	**0.200**	**0.020**	**0.020**	0.019	**0.018**
1989	0.017	0.017	0.019	**0.019**	**0.019**	**0.019**	0.020	0.017	0.015	0.017	0.016	0.018
1990	0.015	0.017	0.016	0.021	0.028	0.088	0.028	0.016	0.014	0.013	0.013	0.014
1991	0.015	0.030	0.022	0.017	0.033	0.016	0.014	0.012	0.013	0.013	0.016	0.015
1992	0.018	0.018	**0.016**	**0.016**	**0.016**	0.015	0.019	0.015	0.013	0.017	0.019	0.013
1993	0.017	0.015	0.016	0.028	0.075	0.020	0.015	0.019	0.012	0.010	0.015	0.014
1994	0.017	0.010	0.013	0.058	0.027	0.016	0.015	0.014	0.012	0.010	0.011	0.010
1995	0.012	0.009	0.012	0.018	0.055	0.037	0.014	0.013	0.013	0.017	0.014	0.016
1996	0.027	0.012	0.018	0.037	0.016	0.043	0.025	0.022	0.025	0.010	0.017	0.017
1997	0.029	0.018	0.018	0.024	0.021	0.064	0.046	0.026	0.016	0.017	0.012	0.017
1998	0.019	0.015	0.015	0.022	0.055	0.035	0.021	0.016	0.017	0.014	0.017	0.016
1999	0.015	0.020	0.020	0.022	0.057	0.020	0.013	0.012	0.016	0.016	0.015	0.020
2000	0.016	0.013	0.011	0.024	0.019	0.018	0.019	0.016	0.020	0.020	0.022	0.026
2001	0.014	0.013	0.016	0.016	0.024	0.013	0.014	0.013	0.011	0.017	0.016	0.013
2002	0.011	0.013	0.015	0.013	0.023	0.013	0.008	0.009	0.016	0.017	0.014	0.013
2003	0.008	0.013	**0.016**	**0.016**	0.019	0.014	0.014	0.010	0.011	0.009	0.013	0.014
2004	0.011	0.014	0.009	0.021	0.016	0.012	0.014	0.011	0.011	0.011	0.014	0.018
2005	0.016	0.013	0.013	0.014	0.018	0.016	0.012	0.009	0.009	0.009	0.017	0.010
2006	0.012	0.014	0.009	**0.015**	0.061	0.020	0.011	0.009	0.009	0.008	0.013	0.011
2007	0.012	0.016	0.016	0.015	0.015	0.009	0.011	0.012	0.012	0.011	0.013	0.012
2008	0.012	0.012	0.013	0.014	**0.014**	0.015	0.011	0.012	0.012	0.012	**0.011**	**0.010**
2009	0.009	0.010	0.014	0.014	0.018	0.014	0.010	0.048	0.014	0.008	0.014	0.013

Okanagan R TP load during month in kg/d

days in month	**31**	**28**	**31**	**30**	**31**	**30**	**31**	**31**	**30**	**31**	**30**	**31**	Annual River kg P/yr
1984	891	2058	1911	2281	4634	5848	2330	1175	613	676	616	455	23488
1985	329	271	463	814	969	461	450	394	458	584	523	374	6090
1986	236	893	1091	1135	5084	1602	1097	1249	407	439	494	370	14096
1987	339	324	452	404	963	288	402	394	445	497	351	305	5164
1988	297	204	403	446	699	356	352	3086	301	295	258	239	6935
1989	207	217	232	490	631	1320	1384	654	677	672	329	373	7184
1990	350	393	346	519	1410	19913	5115	2318	773	348	204	224	31913
1991	227	2475	2338	480	4959	2045	1219	948	366	352	253	248	15908
1992	257	218	514	289	324	312	505	314	285	474	282	176	3950
1993	254	185	197	500	7573	1343	1775	2960	858	281	268	221	16415
1994	1094	202	937	5517	1880	618	614	439	572	308	183	156	12520
1995	248	409	897	1400	8525	1611	423	689	654	486	233	469	16045
1996	1874	751	2044	5468	2717	9318	3281	2223	1134	272	294	660	30036
1997	1977	1507	2401	3676	4511	14001	9531	5251	2539	862	778	765	47798
1998	1033	1020	1177	2133	6934	3595	1592	476	500	439	361	293	19552
1999	723	1268	1650	2993	10580	1871	1762	1414	607	440	279	980	24567
2000	682	587	269	1568	2393	1941	1719	659	1213	654	445	426	12556
2001	210	175	249	251	669	317	392	358	322	464	305	259	3969
2002	232	260	635	719	2557	1725	362	369	709	505	247	208	8528
2003	133	195	258	394	629	404	353	241	281	145	174	188	3395
2004	169	171	122	426	520	310	369	321	512	351	286	943	4500
2005	946	895	675	957	1114	778	1277	373	234	269	279	157	7954
2006	187	668	541	762	8333	3422	624	274	375	219	193	161	15759
2007	174	305	723	814	735	198	273	344	552	313	193	191	4815
2008	191	179	234	426	859	1204	406	476	672	346	198	146	5337
2009	142	154	222	239	449	306	200	1033	315	207	229	205	3702

Appendix 3. Summary of spring (Feb – Mar) and seasonal (May – Sept) phosphorus values for Osoyoos Lake.

	North End (0500249)						Monashee (0500728)					Central (E220540)				South (0500248)			
	TDP < 10m	TDP > 10m	TP < 10m	TP > 20m	TDP 15m	TP 15m	TDP < 10m	TDP > 10m	TP < 10m	TP Seasonal mean < 10m	TP > 20m	TDP < 10m	TDP > 10m	TP < 10m	TP > 20m	TDP < 10m	TDP > 10m	TP < 10m	TP > 20m
1969	–	–	–	–	–	–	–	–	23	–	23	–	–	–	–	–	–	28.4	29.3
1970	–	–	–	–	–	–	–	–	33	–	36	–	–	–	–	–	–	27.7	22.8
1971	–	–	17	19	–	–	–	–	23	–	55	–	–	19.6	–	–	–	18.5	16.3
1972	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1973	–	–	12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	20	–
1974	–	–	21	–	–	–	–	–	–	–	–	–	–	19	21	–	–	19	21
1975	5	5	17	17	–	–	–	–	–	–	–	–	–			5	5	17	22
1976	5	5	15	21	–	–	–	–	–	–	–	4	5	11	19	4	5	11	19
1977	11	11	27	25	–	–	8	11	21	14	29	6	6	15	20	6	6	15	20
1978	7	8	24	25	–	–	5	5	24	13	20	9	17	20	31	9	17	20	31
1979	–	–	21	20	–	–	5	6	17	–	18	–	–	25	25	–	–	25	25
1980	17	17	28	28	–	–	8	11	23	–	21	10	9	25	22	10	9	25	22
1981	7	6	25	24	–	–	8	9	16	–	18	–	–	–	–	–	–	–	–
1982	26	17	34	36	–	–	18	25	36	–	42	–	–	–	–	–	–	–	–
1983	10	9	28	27	–	–	14	10	29	–	23	–	–	–	–	–	–	–	–
1984	7	8	27	30	–	–	15	15	31	–	34	–	–	–	–	–	–	–	–
1985	8	8	23	22	–	–	8	8	23	–	28	–	–	–	–	–	–	–	–
1986	5	5	19	18	–	–	5	5	28	–	21	–	–	–	–	–	–	–	–
1987	7	7	22	23	–	–	8	8	24	–	24	–	–	–	–	–	–	–	–
1988	18	20	38	35	–	–	19	19	37	–	39	–	–	–	–	–	–	–	–
1989	5	5	30	28	–	–	5	5	32	–	30	–	–	–	–	–	–	–	–
1990	3	3	25	24	–	–	3	3	23	–	24	–	–	–	–	–	–	–	–
1991	3	3	20	21	–	–	4	7	22	–	25	–	–	–	–	–	–	–	–
1992	18	17	24	24	–	–	21	19	21	–	27	–	–	–	–	–	–	–	–
1993	14	9	22	20	–	–	10	14	24	–	22	–	–	–	–	–	–	–	–
1994	3	3	12	13	–	–	4	5	21	10	15	–	–	–	–	7	7	11	14
1995	7	–	9	–	–	–	13	9	10	–	10	***3***	6	9	8	***3***	6	9	8
1996	6	6	13	11	–	–	6	6	15	–	14	–	–	–	–	–	–	–	–
1997	5	5	12	15	–	–	5	6	17	–	15	–	–	–	–	–	–	–	–
1998	4	5	13	13	–	–	5	4	14	–	12	4	5	12	13	4	5	12	13
1999	5	5	18	17	–	18	5	5	17	–	17	6	6	17	18	9	6	20	35
2000	9	16	17	12	–	17	7	9	16	–	16	17	8	9	71	–	–	–	–
2001	6	5	15	15	–	13	6	6	15	15	17	5	5	15	15	6	6	15	16
2002	12	8	25	21	16	22	6	14	20	12	26	7	6	17	21	6	4	15	14
2003	7	7	18	20	8	19	8	9	19	6	19	4	3	17	17	4	4	15	11
2004	2	***2***	19	19	–	–	3	2	11	16	10	***2***	***2***	9	12	2	3	15	17
2005	3	2	6	6	–	–	2	3	6	9	5	4	***2***	6	5	2	3	5	7
2006	5	4	13	9	–	–	6	5	13	5	8	4	***2***	13	15	4	4	11	13
2007	15	13	17	14	–	–	16	15	18	13	16	14	19	18	18	13	15	20	15
2008	16	12	18	18	–	13	15	14	18	10	17	14	14	17	17	15	14	17	15
2009	13	12	13	14	–	13	13	13	15	7	14	12	15	13	17	17	16	20	16
2010	2	3	3	3	–	9	2	3	3	8	3	2	3	4	3	3	3	4	3
mean	8.5	8.0	19.5	19.6	12.0	15.5	8.4	9.0	20.4	10.6	21.4	7.1	7.4	14.8	19.4	6.8	7.3	16.6	17.7
median	7.0	6.5	19.0	20.0	12.0	15.0	6.5	8.0	21.0	10.0	20.0	5.5	6.0	15.0	17.5	6.0	6.0	17.0	16.2
min	2.0	2.0	3.0	3.0	8.0	9.0	2.0	2.0	3.0	5.0	3.0	2.0	2.0	4.0	3.0	2.0	3.0	4.0	3.0
max	26.0	20.0	38.0	36.0	16.0	22.0	21.0	24.5	37.0	16.0	55.4	17.0	19.0	25.0	71.0	17.0	17.0	28.4	35.0
mean 2001-2010	8.1	6.8	14.7	13.9	12.0	14.8	7.7	8.4	13.8	10.1	13.5	6.8	7.1	12.9	14.0	7.2	7.2	13.7	12.7

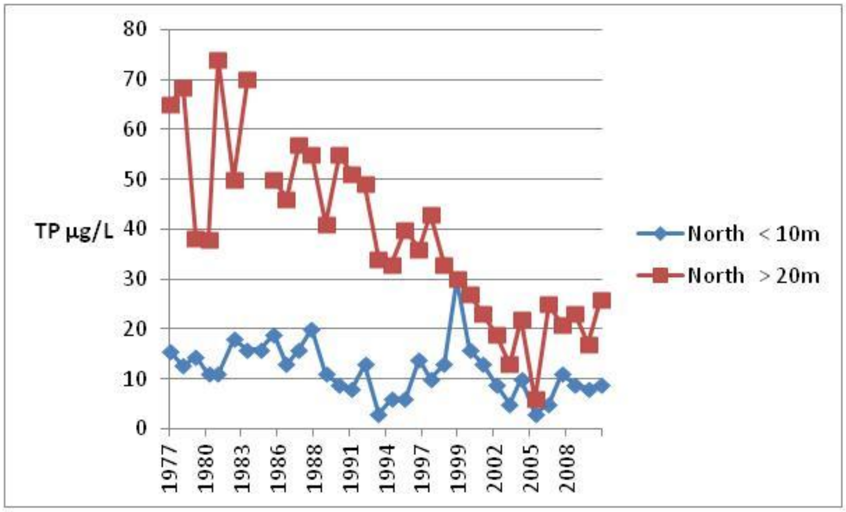
TDP = total dissolved phosphorus
TP= total phosphorus
< 10m = surface water composite of 1, 5 and 10m depths
>20m = bottom water composite of 20, 32, 45m or 20m, mid depth and 2 m off bottom if shallower.
Seasonal mean June to September for 1-10m composite only; 20 -45m seasonal data not shown
Other data also available, including orthophosphorus
bold and italicized data less than detection limit

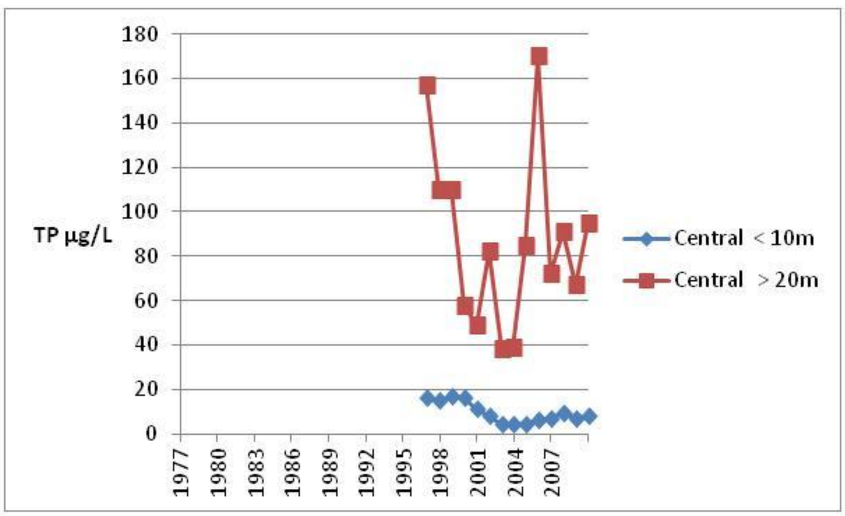
Appendix 4. Summary of fall (September) phosphorus values for Osoyoos Lake.

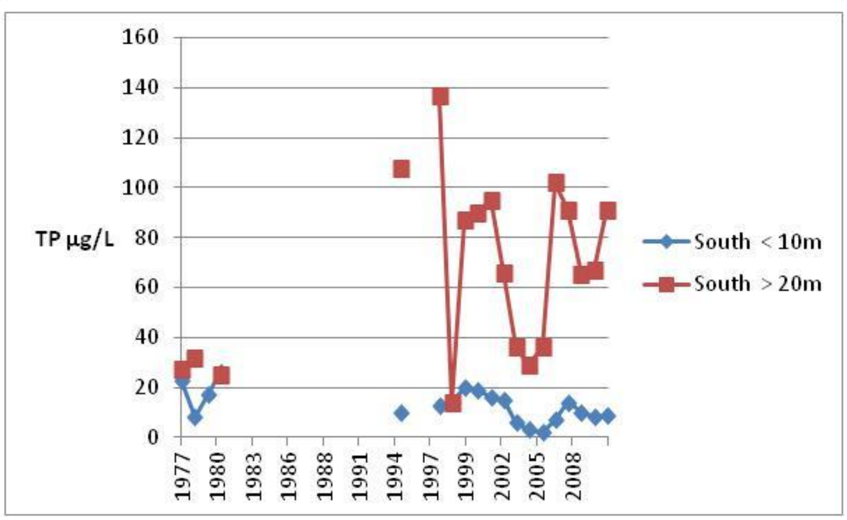
	North End (0500249)				Monashee (0500728)				Central (E220540)				South (0500248)			
	TDP < 10m	TDP > 10m	TP < 10m	TP > 20m	TDP < 10m	TDP > 10m	TP < 10m	TP > 20m	TDP < 10m	TDP > 10m	TP < 10m	TP > 20m	TDP < 10m	TDP > 10m	TP < 10m	TP > 20m
1968	–	–	–	–	–	–	26	45	–	–	–	–	–	–	31	46
1969	–	–	–	–	–	–	19	23	–	–	–	–	–	–	13	26
1970	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1971	–	–	16	62	–	–	13	34	–	–	–	–	–	–	17	29
1972	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1973	3	46	–	–	–	–	–	–	–	–	–	–	–	3	–	–
1974	–	–	15	13	–	–	–	–	–	–	–	–	–	–	13	–
1975	6	21	17	27	–	–	–	–	–	–	–	–	5	62	13	106
1976	6	73	13	83	5	47	11	18	–	–	–	–	20	36	31	52
1977	4	50	19	59	6	57	16	65	–	–	–	–	5	8	23	27
1978	5	53	14	59	5	60	13	68	–	–	–	–	6	23	8	32
1979	6	35	16	48	8	32	15	38	–	–	–	–	7	–	17	–
1980	7	27	20	33	8	29	11	38	–	–	–	–	8	7	26	25
1981	7	49	18	64	8	66	11	74	–	–	–	–	–	–	–	–
1982	7	44	18	49	9	43	18	50	–	–	–	–	–	–	–	–
1983	6	24	18	35	5	62	16	70	–	–	–	–	–	–	–	–
1984	11	–	22	–	7	–	16	–	–	–	–	–	–	–	–	–
1985	7	39	16	50	7	43	19	50	–	–	–	–	–	–	–	–
1986	5	32	13	39	5	41	13	46	–	–	–	–	–	–	–	–
1987	–	16	–	38	–	–	16	57	–	–	–	–	–	–	–	–
1988	–	–	20	41	–	–	20	55	–	–	–	–	–	–	–	–
1989	4	37	12	45	6	36	11	41	–	–	–	–	–	–	–	–
1990	3	41	13	56	3	48	9	55	–	–	–	–	–	–	–	–
1991	4	35	10	47	4	46	8	51	–	–	–	–	–	–	–	–
1992	3	35	14	41	4	41	13	49	–	–	–	–	–	–	–	–
1993	3	9	4	12	3	24	3	34	–	–	–	–	–	–	–	–
1994	4	17	12	20	3	29	6	33	–	–	–	–	7	89	10	108
1995	17	16	10	38	7	35	6	40	–	–	–	–	–	–	–	–
1996	5	29	6	25	6	29	14	36	–	–	–	–	–	–	–	–
1997	2	39	12	74	5	36	10	43	3	116	16	157	2	102	13	137
1998	5	23	14	31	4	24	13	33	6	79	15	110	4	13	14	14
1999	8	20	12	30	9	12	30	30	8	94	17	110	8	53	20	87
2000	9	15	17	23	9	22	16	27	9	44	16	58	9	58	19	90
2001	3	11	13	19	2	18	13	23	3	23	11	49	3	48	16	95
2002	6	13	7	21	10	8	9	19	8	53	8	82	5	44	15	66
2003	2	2	10	12	2	2	5	13	2	20	4	38	2	22	6	36
2004	15	5	21	7	2	16	10	22	2	30	4	39	2	23	3	29
2005	2	18	5	18	2	3	3	6	2	81	4	85	2	30	2	36
2006	2	18	4	25	3	20	5	25	2	130	6	170	2	56	7	102
2007	–	17		20	9	21	11	21	8	59	7	72	11	77	14	91
2008	8	18	10	20	9	22	9	23	9	87	9	91	9	64	10	65
2009	3	15	7	17	4	15	8	17	5	45	7	67	4	44	8	67
2010	3	9	3	9	3	24	9	26	4	78	8	95	6	60	9	91
mean	5.6	27.2	13.1	35.4	5.5	31.5	12.4	37.8	5.1	67.1	9.4	87.4	6.0	43.9	14.3	63.4
min	2.0	2.0	3.0	7.0	2.0	2.0	3.0	6.0	2.0	20.0	4.0	38.0	2.0	3.0	2.0	14.0
max	17.0	73.0	22.0	83.0	10.0	65.5	30.0	74.0	9.0	130.0	17.0	170.0	20.0	102.0	31.0	137.0
mean 2001-2010	4.9	12.6	8.9	16.8	4.6	14.9	8.2	19.5	4.5	60.6	6.8	78.8	4.6	46.8	9.0	67.8

TDP = total dissolved phosphorus
TP= total phosphorus
< 10m = surface water composite of 1, 5 and 10m depths
>20m = bottom water composite of 20, 32, 45m or 20m, mid depth and 2 m off bottom if shallower.
Seasonal mean June to September for 1-10m composite only; 20 -45m seasonal data not shown
Other data also available, including orthophosphorus
bold and italicized data less than detection limit

Appendix 5. Trends in total phosphorus in surface and bottom water composites of Osoyoos Lake in September.







Appendix 6. Nitrogen in surface and bottom water composites for Osoyoos Lake in spring (Feb-Mar).

	North End (0500249)				Monashee (0500728)				Central (E220540)				South (0500248)			
	NO3 <10m	NO3 >10m	TN <10m	TN >20m	NO3 <10m	NO3 >10m	TN <10m	TN >20m	NO3 <10m	NO3 >10m	TN <10m	TN >20m	NO3 <10m	NO3 >10m	TN <10m	TN >20m
1969					50	30							***20***	***20***		
1970					110	110			***10***		210		***10***	***30***		
1971			**240**	**320**			220	190					***10***	***10***	260	360
1972																
1973									***20***	***20***	300	270				
1974	20	20	230	230									***20***	***20***	300	270
1975	20	20	190	280					***20***	***20***	290	440				
1976	20	20	400	320					***20***	***20***	360	380	***20***	***20***	290	440
1977	60	60	380	390	16	9	129	126	40	90	440	580	***20***	***20***	360	380
1978	40	70	410	440	20	48	121	91					40	90	440	580
1979					33	40	120	111	90	90	500	470				
1980	190	200	470	490	100	165	400	465					90	90	500	470
1981	30	20	330	330	30	20	250	285								
1982	120	110	350	320	145	130	380	335								
1983	90	90	350	370	90	90	330	380								
1984	80	80	310	370	150	150	380	420								
1985	90	90	390	360	80	100	360	370								
1986	60	70	320	330	70	90	370	360								
1987	70	80	350	360	80	80	360	350								
1988	120	120	360	360	120	120	340	340								
1989	80	80	400	360	90	100	380	360								
1990	90	100	360	350	100	110	380	350								
1991	20	30	290	320	40	60	220	420								
1992	120	130	480	470	130	130	450	470								
1993	170	170	370	410	170	170	360	410								
1994	30	30	320	320	40	40	390	330	100	100	330	290				
1995	120	110	310	280	140	140	360	350					***100***	100	330	290
1996	20	20	140	210	16	16	260	197								
1997	5	9	230	230	4	7	220	240	9	13	300	300				
1998	40	40	280	270			270	260	118	118	350	360			300	300
1999	102	104	330	330		115	340	310	98	100	300	300	107	109	380	470
2000	102	104	300	290	94	94	280	300	10	14	380	310				
2001	35	48	320	310	32	33	310	300			400	610	40	51	340	380
2002	65	80	290	300	68	69	305	305	21	31	270	280	***2***	***2***	250	270
2003	100	102	290	300	98	102	300	310	31	6	300	290	33	40	270	280
2004	11	***40***	290	300	10	23	270	250	35	31	297	287	29	47	350	350
2005	40	42	300	300	55	47	290	300	24	48	290	290	34	116	319	541
2006	13	9	290	260	74	79	320	300	65	67	360	340	15	19	280	270
2007	93	92	390	360	102	100	350	350	2	18	220	290	39	39	410	420
2008	31	25	230	260	28	31	200	260	7	6	220	220	19	22	300	240
2009	11	7	230	200	9	10	240	240	***2***	***2***	20	20	12	17	290	270
2010	2	2	40	20	***2***	***2***	500	***20***					***2***	***2***	100	***20***
mean	64	67	312	317	70	76	307	299	38	44	307	333	33	43	319	347
min	2	2	40	20	2	2	120	20	2	2	20	20	2	2	100	20
max	190	200	480	490	170	170	500	470	118	118	500	610	107	116	500	580

NO3 = nitrate nitrogen or nitrate + nitrite nitrogen

TN = total nitrogen

< 10m = surface water composite of 1, 5 and 10m depths

> 20m = bottom water composite of 20, 32, 45m or 20m, mid depth and 2 m off bottom if shallower.

Seasonal mean June to September for 1-10m composite only; 20 -45m seasonal data not shown

bold and italics = value below detection limit

Appendix 7. Nitrogen in surface and bottom water composites of Osoyoos Lake in the Fall (September).

	North End (0500249)				Monashee (0500728)				Central (E220540)				South (0500248)			
	NO3 <10m	NO3 >10m	TN <10m	TN >20m	NO3 <10m	NO3 >10m	TN <10m	TN >20m	NO3 <10m	NO3 >10m	TN <10m	TN >20m	NO3 <10m	NO3 >10m	TN <10m	TN >20m
1969					***20***	190							***10***	***10***		
1970																
1971	***20***	215	350	365	***20***	120	70	340					***10***	***10***	190	260
1972																
1973	25	185	280	350									0	20		430
1974																
1975	30	170	280	320									***20***	***20***	300	390
1976	***20***	270	360	600	2.5	162.5										
1977	30	290	310	480	17	325	149	338								
1978	***20***	280	290	480	9	323	131	523								
1979	***20***	280	430	560	***20***	290	280	485								
1980	30	300	470	750	***20***	335	390	560								
1981					***20***	290	290	510								
1982	***20***	250	260	500	***20***	265	285	555								
1983	***20***	150	320	360	***20***	260	330	610								
1984	***20***	270	290	480	***20***	290	290	490								
1985	***20***	270	290	470	***20***	280	330	460								
1986	***20***	210	270	490	***20***	230	270	400								
1987	***20***	190	300	370	***20***	220	410	440								
1988	***20***	190	370	360	***20***	210	400	390								
1989	***20***	220	220	370	***20***	210	230	350								
1990	***20***	240	220	400	***20***	250	310	400								
1991	***20***	230	260	410	***20***	240	300	410								
1992	***20***	230	430	470	***20***	240	350	430								
1993	***20***	280	260	520	***20***	290	260	520								
1994	***20***	160	340	370	***20***	170	260	370								
1995	***20***	120	170	880	***20***	120	200	250								
1996	112	207	230	420	4	190	260	360								
1997	7	210	240	410	11	197	200	370	16	84	260	870	***2***	3	200	700
1998	18	203		280	23	200	300	360	21	55	280	550	***2***	3	270	820
1999		***2***	270	400	***2***	191	250	390	***2***	10	290	600	***2***	***2***	290	590
2000	11	134	300	370	3	160	310	360	***2***	6	340	490	***2***	***2***	310	960
2001	6	147	360	320	4	144	240	320	17	4	290	670	***2***	***4***	310	760
2002	***2***	67			***2***	54	220	250	***2***	4	240	460	***2***	***5***	260	450
2003	***2***	44	250	270	***2***	53	260	270	***2***	***2***	290	420	***2***	***2***	340	650
2004	8	87	290	280	8	155	290	350	12	10	280	530	11	8	280	280
2005	11	165	270	330	16	111	250	290	14	12	350	490	14	12	320	590
2006	5	170	230	370	14	166	280	350	19	82	260	790	5	30	270	550
2007		158		350	***2***	158	270	343	3	54	300	630	25	8	360	1010
2008	***2***	107	120	210	***2***	107	200	200	***2***	***2***	190	530	***2***	***2***	230	480
2009	7	126	170	290	***2***	134	150	280	***2***	***2***	180	280	4	***2***	200	290
2010	8	101	320	290	***5***	123	280	450	***2***	***2***	280	700	***2***	***2***	280	600
mean	19	187	289	415	14	201	266	394	8	24	274	572	7	8	276	577
min	2	2	120	210	2	53	70	200	2	2	180	280	0	2	190	260
max	112	300	470	880	23	335	410	610	21	84	350	870	25	30	360	1010

NO3 = nitrate nitrogen or nitrate + nitrite nitrogen

TN = total nitrogen

< 10m = surface water composite of 1, 5 and 10m depths

> 20m = bottom water composite of 20, 32, 45m or 20m, mid depth and 2 m off bottom if shallower.

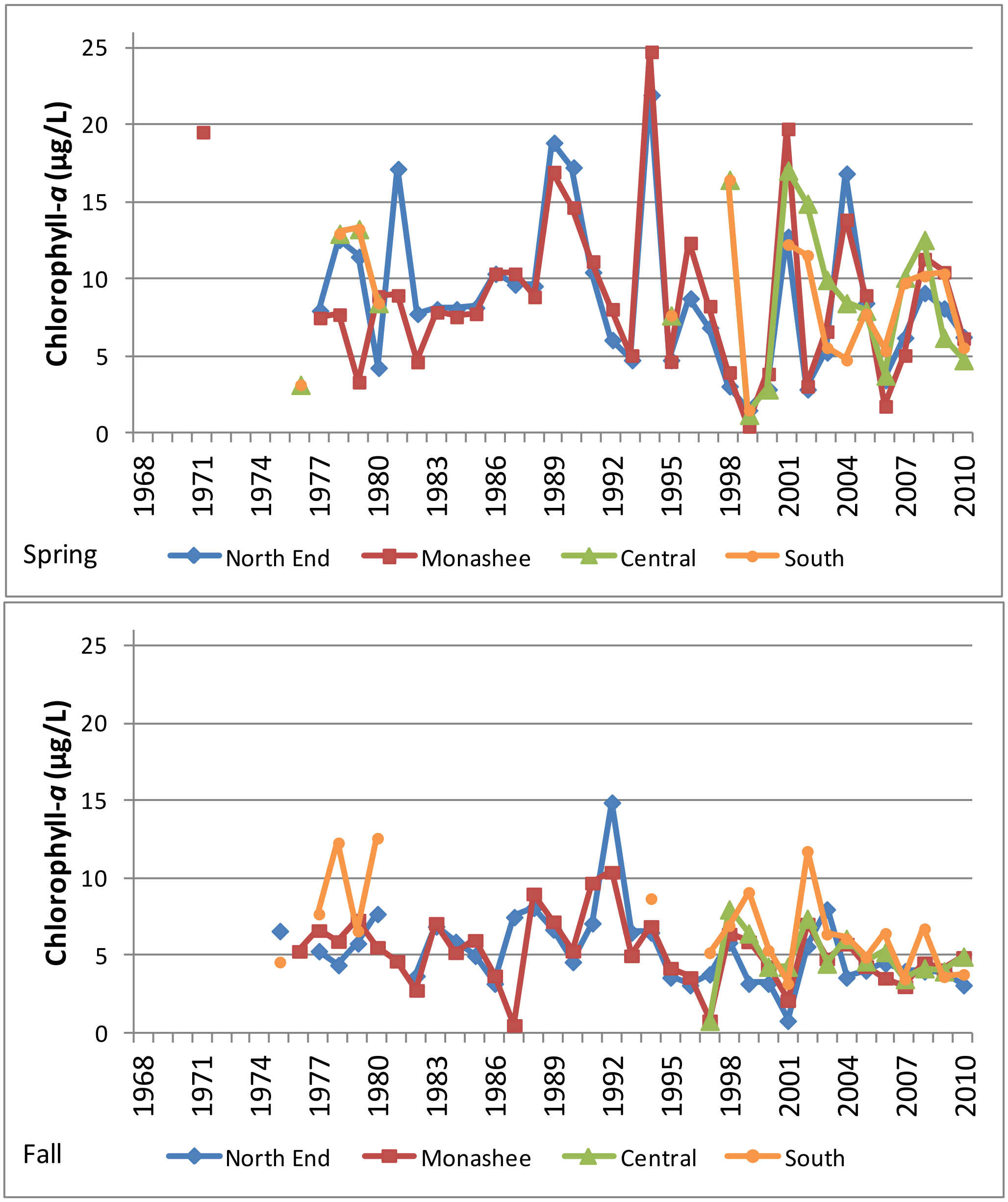
Seasonal mean June to September for 1-10m composite only; 20 -45m seasonal data not shown

bold and italics = value below detection limit

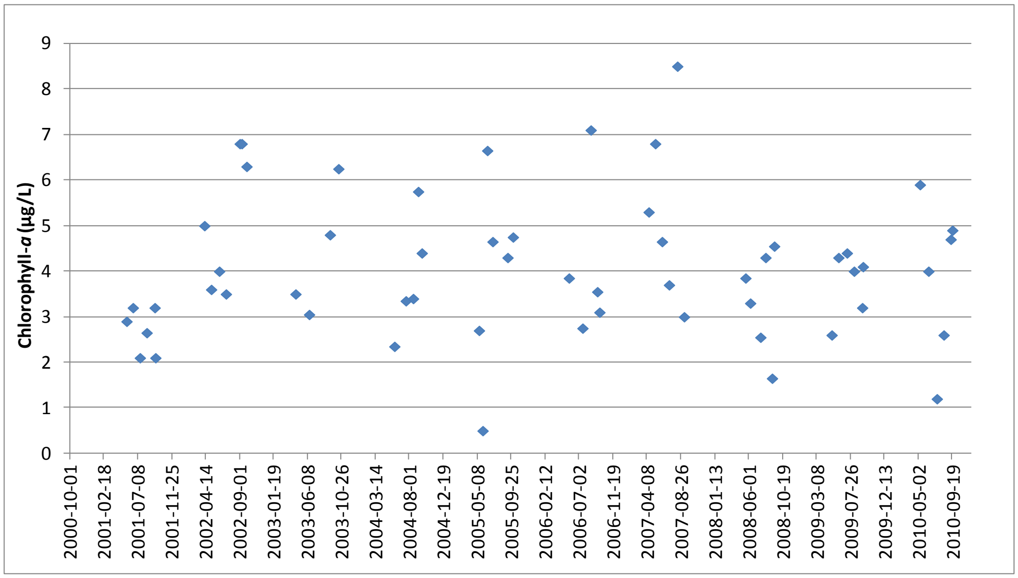
Appendix 8. Summary of spring (Feb – Mar), seasonal, and fall (Sept) phytoplankton chlorophyll-*a* values for Osoyoos Lake

	North End (0500249)			Monashee (0500728)			Central (E220540)			South (0500248)		
Year	Spring	Seasonal Mean (May-Sept)	Fall	Spring	Seasonal Mean (May-Sept)	Fall	Spring	Seasonal Mean (May-Sept)	Fall	Spring	Seasonal Mean (May-Sept)	Fall
1971				19.6								
1972												
1973												
1974												
1975			6.6									4.6
1976						5.3	3.2			3.2		
1977	8.0		5.3	7.5		6.6						7.7
1978	12.6		4.4	7.8		5.9	13.0			13.0		12.3
1979	11.5		5.8	3.4		7.3	13.3			13.3		6.6
1980	4.3		7.7	8.9		5.6	8.5			8.5		12.6
1981	17.2			9.0		4.7						
1982	7.8		3.7	4.7		2.8						
1983	8.1		6.9	7.9		7.1						
1984	8.1		5.9	7.6		5.2						
1985	8.2		5.0	7.8		6.0						
1986	10.4		3.2	10.4		3.7						
1987	9.7		7.5	10.4		0.5						
1988	9.6		8.1	8.9		9.0						
1989	18.9		6.7	17.0		7.2						
1990	17.3		4.6	14.7		5.3						
1991	10.5		7.1	11.2		9.7						
1992	6.1		14.9	8.1		10.4						
1993	4.8		6.5	5.1		5.0						
1994	22.0		6.5	24.8		6.9						8.7
1995	4.8		3.6	4.7		4.2	7.7			7.7		
1996	8.8		3.1	12.4		3.6						
1997	6.9		3.8	8.3		0.8			0.8			5.2
1998	3.1		5.9	4.0		6.4	16.5		8.0	16.5		7.0
1999	1.6		3.2	0.5		5.9	1.3		6.5	1.6		9.1
2000	2.9		3.2	3.9		4.3	2.9		4.3			5.4
2001	12.8		0.8	19.8	2.7	2.1	17.1	3.1	4.3	12.3	3.1	3.2
2002	2.9	4.0	5.6	3.1	5.2	7.1	15.0		7.4	11.6		11.8
2003	5.3		8.0	6.7	3.9	4.8	10.0		4.5	5.6		6.4
2004	16.9		3.6	13.9	3.9	5.8	8.5		6.1	4.8		6.1
2005	8.5	4.4	4.1	9.0	3.9	4.3	8.0		4.7	7.8		4.9
2006	3.5	4.1	4.5	1.8	4.1	3.6	3.8		5.3	5.4		6.5
2007	6.3	4.7	4.0	5.1	5.3	3.0	10.2		3.5	9.8		3.5
2008	9.2	3.1	4.0	11.4	3.4	4.6	12.6		4.2	10.3		6.8
2009	8.2	4.4	4.0	10.5	3.8	4.1	6.3		4.0	10.4		3.7
2010	6.3	3.4	3.1	6.2	3.9	4.9	4.8		5.0	5.6		3.8
Mean	8.9	4.0	5.3	9.0	4.0	5.2	9.0	3.1	4.9	8.7	3.1	6.8
Min	1.6	3.1	0.8	0.5	2.7	0.5	1.3	3.1	0.8	1.6	3.1	3.2
Max	22.0	4.7	14.9	24.8	5.3	10.4	17.1	3.1	8.0	16.5	3.1	12.6

Appendix 9. Long-term trends in spring and fall epilimnetic chlorophyll-*a* concentrations for Osoyoos Lake.



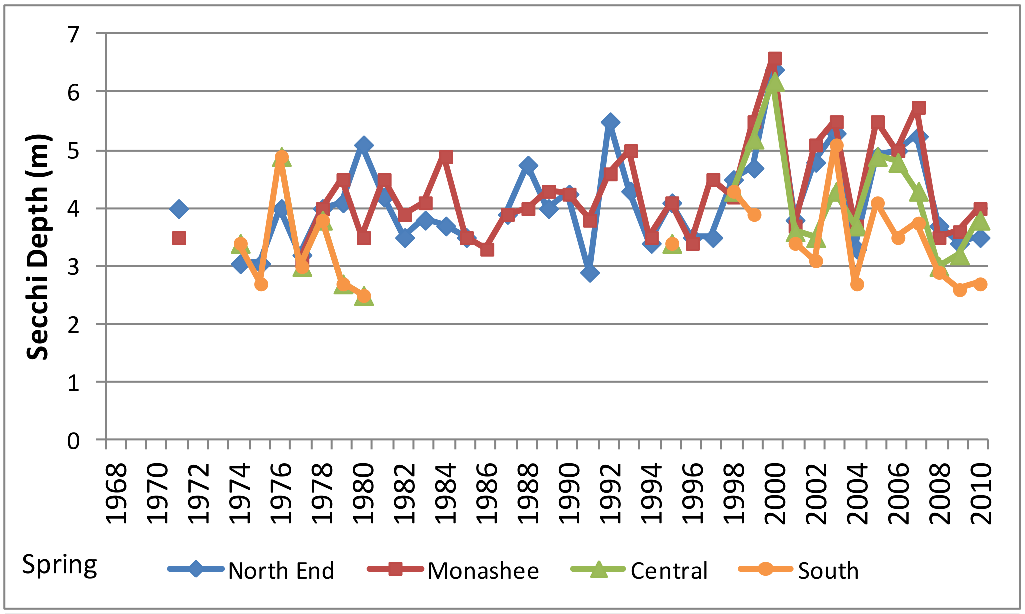
Appendix 10. Seasonal (May–Sept) chlorophyll-*a* concentrations from the north basin (Monashee site).

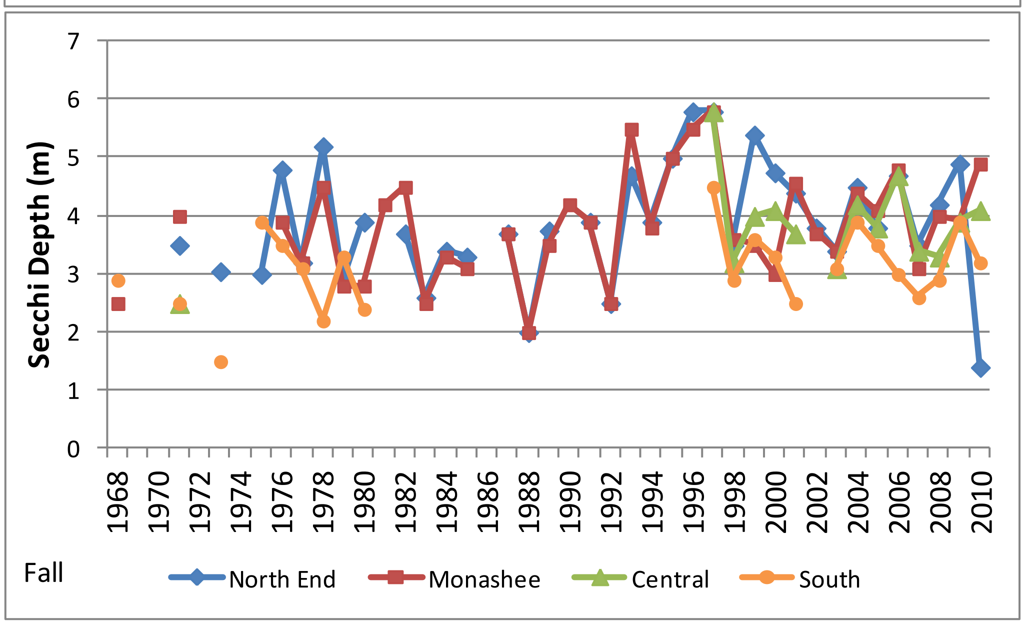


Appendix 11. Summary of spring (February to March), seasonal (May to September), and fall (September) Secchi depths in metres, for Osoyoos Lake.

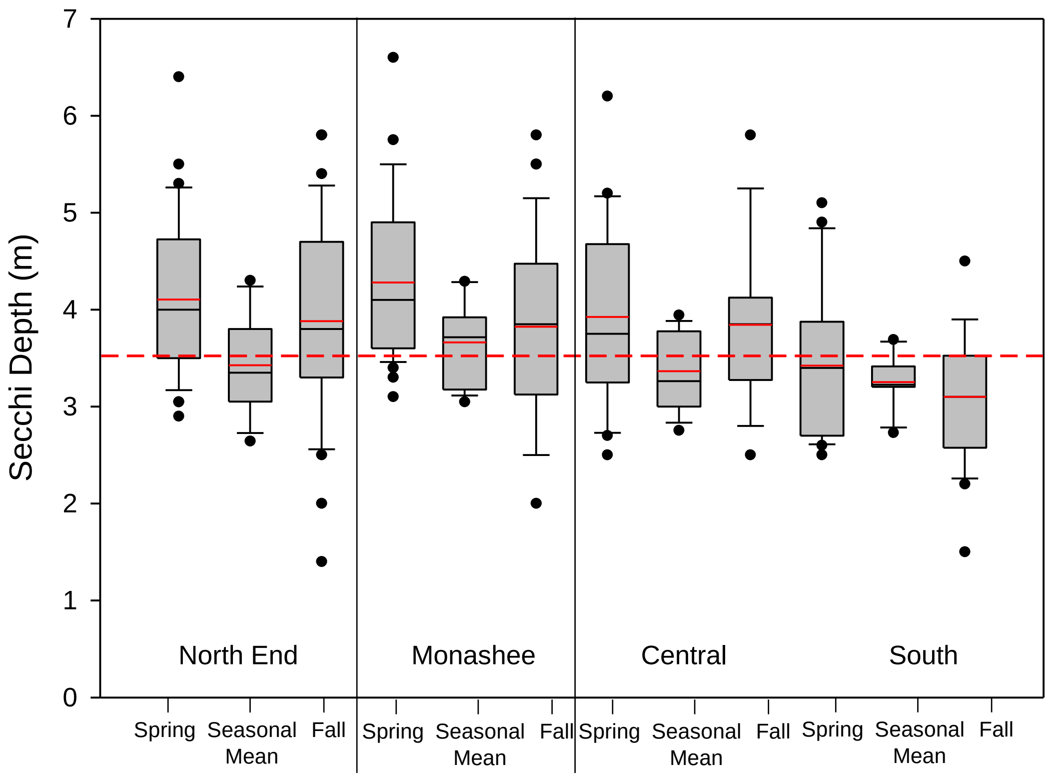
	North End (0500249)			Monashee (0500728)			Central (E220540)			South (0500248)		
Year	Spring	Seasonal Mean (May-Sept)	Fall	Spring	Seasonal Mean (May-Sept)	Fall	Spring	Seasonal Mean (May-Sept)	Fall	Spring	Seasonal Mean (May-Sept)	Fall
1968	-	-	-	-	-	2.50	-	-	-	-	-	2.90
1969	-	-	-	-	-	-	-	-	-	-	-	-
1970	-	-	-	-	-	-	-	-	-	-	-	-
1971	4.00	-	3.50	3.50	-	4.00	-	-	2.50	-	-	2.50
1972	-	-	-	-	-	-	-	-	-	-	-	-
1973	-	-	3.05	-	-	-	-	-	-	-	-	1.50
1974	3.05	-	-	-	-	-	3.40	-	-	3.40	-	-
1975	3.05	-	3.00	-	-	-	-	-	-	2.70	-	3.90
1976	4.00	-	4.80	-	-	3.90	4.90	-	-	4.90	-	3.50
1977	3.20	-	3.20	3.10	-	3.20	3.00	-	-	3.00	-	3.10
1978	4.00	-	5.20	4.00	-	4.50	3.80	-	-	3.80	-	2.20
1979	4.10	-	2.90	4.50	-	2.80	2.70	-	-	2.70	-	3.30
1980	5.10	-	3.90	3.50	-	2.80	2.50	-	-	2.50	-	2.40
1981	4.20	-	-	4.50	-	4.20	-	-	-	-	-	-
1982	3.50	-	3.70	3.90	-	4.50	-	-	-	-	-	-
1983	3.80	-	2.60	4.10	-	2.50	-	-	-	-	-	-
1984	3.70	-	3.40	4.90	-	3.30	-	-	-	-	-	-
1985	3.50	-	3.30	3.50	-	3.10	-	-	-	-	-	-
1986	-	-	-	3.30	-	-	-	-	-	-	-	-
1987	3.90	-	3.70	3.90	-	3.70	-	-	-	-	-	-
1988	4.75	-	2.00	4.00	-	2.00	-	-	-	-	-	-
1989	4.00	-	3.75	4.30	-	3.50	-	-	-	-	-	-
1990	4.25	-	-	4.25	-	4.20	-	-	-	-	-	-
1991	2.90	-	3.90	3.80	-	3.90	-	-	-	-	-	-
1992	5.50	-	2.50	4.60	-	2.50	-	-	-	-	-	-
1993	4.30	-	4.70	5.00	-	5.50	-	-	-	-	-	-
1994	3.40	-	3.90	3.50	3.79	3.80	-	3.26	-		3.23	-
1995	4.10	3.67	5.00	4.10	3.78	5.00	3.40	3.13	-	3.40	3.20	-
1996	3.50	3.75	5.80	3.40	4.28	5.50	-	3.78	-	-	3.66	-
1997	3.50	-	5.80	4.50	-	5.80	-	-	5.80	-	-	4.50
1998	4.50	-	3.50	4.20	-	3.60	4.30	-	3.20	4.30	-	2.90
1999	4.70	2.81	5.40	5.50	3.17	3.50	5.20	3.26	4.00	3.90	3.45	3.60
2000	6.40	4.30	4.75	6.60	4.29	3.00	6.20	3.84	4.10	-	3.23	3.30
2001	3.80	3.40	4.40	3.70	3.72	4.57	3.60	3.94	3.70	3.40	3.38	2.50
2002	4.80	3.49	3.80	5.10	3.92	3.70	3.50	3.78	-	3.10	3.21	-
2003	5.30	3.95	3.40	5.50	3.64	3.40	4.30	3.68	3.10	5.10	3.69	3.10
2004	3.30	3.06	4.50	3.70	3.85	4.40	3.70	3.46	4.20	2.70	3.03	3.90
2005	4.90	4.18	3.80	5.50	4.05	4.10	4.90	2.94	3.80	4.10	3.21	3.50
2006	5.00	3.02	4.70	5.00	3.05	4.80	4.80	2.75	4.70	3.50	2.82	3.00
2007	5.25	3.30	3.50	5.75	3.16	3.10	4.30	2.89	3.40	3.75	3.21	2.60
2008	3.70	3.23	4.20	3.50	3.64	4.00	3.00	3.25	3.30	2.90	3.32	2.90
2009	3.40	3.18	4.90	3.60	3.18	3.90	3.20	3.54	3.90	2.60	3.42	3.90
2010	3.50	2.64	1.40	4.00	3.43	4.90	3.80	3.00	4.10	2.70	2.73	3.20
Mean	**4.10**	**3.43**	**3.88**	**4.28**	**3.66**	**3.82**	**3.93**	**3.37**	**3.84**	**3.42**	**3.25**	**3.10**
Min	**2.90**	**2.64**	**1.40**	**3.10**	**3.05**	**2.00**	**2.50**	**2.75**	**2.50**	**2.50**	**2.73**	**1.50**
Max	**6.40**	**4.30**	**5.80**	**6.60**	**4.29**	**5.80**	**6.20**	**3.94**	**5.80**	**5.10**	**3.69**	**4.50**

Appendix 12. Long-term trends in spring and fall Secchi depth for Osoyoos Lake.





Appendix 13. Box plots of Secchi depth data from 4 sampling stations in Osoyoos Lake. Outliers (solid dots) are samples outside the 5th and 95th percentiles. The red dashed line indicates the proposed growing season mean Water Quality Objective of 3.5 m for all basins.



Appendix 14. Osoyoos Lake phytoplankton biomass, 2005 to 2010 (ONA data, McQueen pers. comm. 2011).

Date	Lake	Cyanophyta	Dinophyta	Cryptophyta	Euglenophyta	Chysophyta	Haptophyta	Tribophyta	Chlorophyta	Raphidophyta	Bacillariophyta	**TOTAL**
25-Apr-05	Osoyoos	251	19	150	0	107	8	0	91	0	649	**1275**
17-May-05	Osoyoos	167	18	22	0	120	1	0	44	0	271	**644**
01-Jun-05	Osoyoos	124	0	20	0	77	3	0	44	0	68	**336**
20-Jun-05	Osoyoos	161	6	50	0	1111	11	0	351	0	185	**1874**
12-Jul-05	Osoyoos	533	56	71	0	104	5	0	160	0	158	**1086**
22-Aug-05	Osoyoos	345	10	94	0	42	1	0	69	0	104	**665**
13-Sep-05	Osoyoos	433	6	47	2	21	3	0	73	0	149	**733**
04-Oct-05	Osoyoos	321	2	49	0	24	8	0	115	0	102	**620**
02-Nov-05	Osoyoos	186	9	112	0	28	7	0	42	0	55	**439**
24-Apr-06	Osoyoos	360	29	130	0	26	16	0	106	0	1111	**1777**
23-May-06	Osoyoos	244	30	252	0	182	2	0	86	0	499	**1296**
12-Jun-06	Osoyoos	225	19	171	0	45	2	0	58	0	233	**753**
04-Jul-06	Osoyoos	113	46	148	0	64	2	0	54	0	88	**515**
18-Jul-06	Osoyoos	216	2	163	0	20	1	0	23	0	34	**460**
21-Aug-06	Osoyoos	1075	0	47	0	65	5	0	99	0	56	**1346**
05-Sep-06	Osoyoos	769	0	64	0	22	8	0	50	0	29	**941**
26-Sep-06	Osoyoos	847	8	106	0	16	2	0	23	0	53	**1055**
23-Oct-06	Osoyoos	343	5	107	0	56	14	0	55	0	93	**673**
14-May-07	Osoyoos	852	26	76	0	131	8	0	66	0	338	**1498**
11-Jun-07	Osoyoos	576	8	62	0	139	23	0	80	0	274	**1162**
10-Jul-07	Osoyoos	1827	35	58	0	50	2	0	153	0	394	**2518**
13-Aug-07	Osoyoos	1518	8	74	0	90	23	0	145	0	382	**2240**
10-Sep-07	Osoyoos	823	1	82	0	49	14	0	68	0	49	**1086**
09-Oct-07	Osoyoos	881	7	137	0	39	12	0	93	0	107	**1277**
05-Nov-07	Osoyoos	1295	35	81	0	11	17	0	40	0	334	**1812**
17-Apr-08	Osoyoos	358	23	47	0	52	23	1	27	0	2049	**2580**
20-May-08	Osoyoos	151	8	53	0	57	14	1	58	0	937	**1278**
09-Jun-08	Osoyoos	404	13	77	0	72	16	11	44	0	287	**923**
07-Jul-08	Osoyoos	499	17	118	0	57	24	1	76	0	174	**965**
21-Jul-08	Osoyoos	226	12	81	0	105	2	0	148	0	153	**727**
11-Aug-08	Osoyoos	1498	13	36	0	23	9	0	121	0	50	**1751**
07-Sep-08	Osoyoos	1862	28	95	0	23	21	1	206	0	163	**2399**
18-Oct-08	Osoyoos	843	18	119	0	16	19	1	132	0	208	**1356**
18-Nov-08	Osoyoos	369	10	105	0	9	3	1	36	0	608	**1142**
11-May-09	Osoyoos	471	50	114	0	123	36	1	40	0	540	**1374**
08-Jun-09	Osoyoos	688	37	150	0	304	7	17	110	0	518	**1830**
13-Jul-09	Osoyoos	179	39	43	0	33	22	0	65	0	1909	**2291**
11-Aug-09	Osoyoos	603	28	54	1	45	45	0	105	0	83	**964**
14-Sep-09	Osoyoos	787	4	67	0	210	16	2	158	0	209	**1454**
22-Oct-09	Osoyoos	542	19	98	0	125	2	3	45	0	288	**1121**
10-May-10	Osoyoos	460	30	194	0	198	92	4	17	0	753	**1749**
14-Jun-10	Osoyoos	417	67	413	0	55	31	5	36	0	295	**1319**
19-Jul-10	Osoyoos	543	91	141	0	42	32	1	43	0	306	**1199**
16-Aug-10	Osoyoos	639	142	94	7	72	33	0	433	0	306	**1725**
14-Sep-10	Osoyoos	871	313	123	0	121	22	1	54	0	61	**1567**
18-Oct-10	Osoyoos	826	20	125	0	86	28	3	81	0	39	**1206**

Cyanophyta	mean	603
	min	113
	max	1862

11.0 GLOSSARY

Ambient
Refers to conditions in the surrounding environment.

Ammonia
A measure of the most reduced inorganic form of nitrogen in water and includes dissolved ammonia (NH_3) and the ammonium ion (NH_4^+).

Anadromous
Fishes which spend most of their lives in the sea and migrate to fresh water to breed.

Bathymetric map
A map showing the depth (bottom contours) of water in lakes, streams, or oceans.

Chlorphyll-*a*
The primary green-coloured pigment found in plants and algae which traps and converts light energy to chemically stored energy.

Colour, true
A measure of the dissolved colouring compounds in water. The colour of water is attributed to the presence of organic and inorganic materials which absorb different light frequencies.

Cyanobacteria
Cyanobacteria are also known as blue-green algae, that obtain their energy through photosynthesis. Some species are able to fix nitrogen gas into ammonia. The name "cyanobacteria" comes from the color of the bacteria.

Designated water use
A water use that is to be protected at a specific location.

Disinfection
The process of killing or rendering harmless microbiological organisms in water which cause disease by the application of a disinfectant (e.g., chlorine, chloramines, ozone, ultraviolet radiation).

Disinfection by-products
Chemicals (e.g., trihalomethanes) formed when a disinfectant (e.g., chlorine) is added to water containing organic matter. Such by-products are suspected to be human carcinogens.

Dissolved oxygen (DO)
Oxygen dissolved in water and essential for respiration by most aquatic organisms.

Environment Management System (EMS)
BC Environment environmental data storage system.

Epilimnion
The surface layer of a thermally stratified lake.

***Escherichia coli* (*E. coli*)**
A coliform bacteria inhabiting the gut of humans and other warm blooded animals which are used as an indicator of water contamination. Some forms are pathenogenic (e.g., O157:H7).

Eutrophic

A body of water, commonly a lake or pond, of high primary productivity due to excessive nutrients and is subject to algal blooms resulting in poor water quality. The bottom waters of such bodies are commonly deficient in oxygen.

Eutrophication
Increasing nutrient content in a body of water over time. This natural process may be accelerated by nutrient-rich discharges from agriculture or sewage, resulting in algal blooms, excessive growth of macrophytes or undesirable changes in water quality.

Geometric mean
The N_{th} root of the product of N observations.

Grab sample
A single sample taken at a given place and time.

Hardness
The hardness of water is generally due to the presence of calcium and magnesium in the water. Hardness is reported in terms of calcium carbonate as mg/L. Waters with values exceeding 120 mg/L are considered hard while values below 60 mg/L are considered soft.

Hepatotoxin
A chemical compound, such as microcystin, produced by certain cyanobacteria, which is toxic to the liver.

Hypolimnion
The cooler, deeper waters of a thermally stratified lake.

Isotherm
A line drawn on a map or chart linking all points of equal or constant temperature.

Kjeldahl nitrogen
A measure of both the ammonia and the organic forms of nitrogen.

Limnology
The study of fresh water bodies including biological, geological, physical and chemical aspects.

Littoral
The region along the shore of a non-flowing body of water.

Mesotrophic
A body of water, commonly a lake or pond, of moderate primary productivity

mg/L
Milligrams per liter

MOE
BC Ministry of Environment

Morphometry
The physical characteristics of a lake such as size and shape of a lake basin, mean depth, maximum depth, volume, drainage area, and flushing rate.

90th percentile
The value in a data set at which 90% of the results fall below. For example, a data set consisting of 10 samples are ranked from lowest to highest with the 9_{th} highest value representing the 90_{th} percentile.

Nitrate + nitrite ($NO_3 + NO_2$)
A measure of the most oxidized and stable form of N in a water body (NO_3) and an intermediate form (NO_2) that occurs in the biological conversion of NH_4 to NO_3.

Non-point source contamination (NPS)
Contaminants enter air or water from many different (often individually small) sources with no specific solution to rectify the problem, making it difficult to regulate. Agriculture, urban run-off, septic tank seepage are often categorized as NPS. NPS is the leading cause of water pollution.

Okanagan Nation Alliance (ONA)
First Nations Tribal Council in the Canadian province of British Columbia, spanning the Nicola, Okanagan and Similkameen Districts of the Canadian province of British Columbia and also the Colville Indian Reservation in Washington State

Okanagan Basin Study (OBS)
A federal – provincial water resource study of water resources in the Okanagan basin from 1971-1974. Follow-up studies were conducted under the Okanagan Basin Implimintation Agreement from 1976-79.

Oligotrophic
A water body with limited nutrient input or cycling, resulting in low levels of primary production.

Ortho-phosphorus
A measure of the inorganic oxidized and biologically available form of soluble phosphorus.

Osoyoos Lake Water Quality Society (OLWQS)
The Osoyoos Lake Water Quality Society was founded in 1991 by community members to help promote public awareness of the lake, covering issues such as conservation, pollution, and lake management. It is a non-political, non-profit charitable organisation run entirely by volunteers.

Paleolimnology
The study of lake sediment cores using chemical, biological and physical analyses to determine changes in lake condition occurring over long time periods as a consequence of climate change, eutrophication or acidification.

pH
A measure of the hydrogen ion concentration of a solution which provides a quantitative expression of its acidity or alkalinity ranging, from 0 to 14. pH 7 is neutral, less than 7 is acidic and more than 7 is alkaline or basic.

Phytoplankton
An assemblage of small plants suspended in the water column with little or no powers of locomotion.

Point source contamination
Contaminants that enter air or water from direct site specific sources such as a sewer or effluent discharge pipe. More easily quantified and regulated than NPS.

ppm
Parts per million or mg/L.

ppb
Parts per billion or µg/L.

Primary productivity
A measure of algal productivity or rate of growth in a body of water; the primary productivity measures the mass of carbon used annually by algae per unit area of lake surface.

Recreational primary contact
Activities like swimming and water sports where a person has or risks direct contact with water through immersion or ingestion.

Secchi disc
A black and white disk used to measure the transparency or clarity of water in a lake by measuring the depth at which it can be seen.

Specific conductance
A quantitative measure of the ability of water to conduct an electrical current, related to the type and concentration of ions in solution. Specific conductance can be used for approximating the total dissolved solids concentration in water.

Thermal stratification
The vertical temperature stratification of a lake which consists of: (a) the upper layer (**epilimnion**), (b) the middle layer (**thermocline**) and (c) the bottom layer (**hypolimnion**).

Thermocline
A well defined vertical temperature change or boundary; often associated with **thermal stratification** in lakes.

Total nitrogen (TN)
A measure of all forms of nitrogen (organic and inorganic).

Total Phosphorus (TP)
A measure of all forms of phosphorus (organic and inorganic).

Water column
The portion of an aquatic or marine environment extending from the water surface to the bottom or the surface of the sediment.

Water Quality Guideline
Numerical value(s) for a physical, chemical or biological characteristic of water, biota or sediment which must not be exceeded to prevent specified detrimental effects from occurring to water use.

Water Quality Objective
A water quality guideline adapted to protect the most sensitive designated water use at a specified location with an adequate degree of safety, taking local circumstances into account.

Water residence time
A measure of measure of how often, usually in years, water is replaced in a lake based on flows into and out of the system.

VOW
A volume of optimum water suitable for rearing of the juvenile and returning adult sockeye salmon; for Osoyoos Lake this is water less than 17°C and having more than 4 ppm dissolved oxygen (DO).

Watershed
All lands enclosed by a continuous hydrologic drainage divide and lying upslope from a specified point on a stream.

Zooplankton
Microscopic animals which swim freely in the water column or are carried about by water currents. Many feed on phytoplankton and are in turn a staple diet of small fish