Phosphorus Loading Study for Quamichan Lake in Duncan, B.C.

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EXECUTIVE SUMMARY

Quamichan Lake, located on Vancouver Island 3km north east of Duncan, has for decades been experiencing deteriorating water quality in the form of algal blooms and periodic fish kills. These occurrences are related to excessively high nutrient levels in the lake, as a result of both internal and external loading. The primary nutrient of concern in this eutrophic lake is phosphorus. Therefore, this study was completed in order to identify and quantify sources of phosphorus, thereby estimating a phosphorus loading budget for Quamichan Lake. Results of this study show that roughly 30% of the phosphorus loading is generated internally from lake sediments, around 55% of phosphorus loading comes from external stream flow (roughly 40% from streams draining agricultural and rural lands; 15% draining residential areas), and the remaining 15% of the load comes from aerial deposition (rainfall). The estimate for the total mass of phosphorus annually input to the lake is 338.2-359.6kg. The annual outflow of phosphorus from the lake is estimated to be 132.6kg, and the remainder, 205.6-227kg, is deposited to lake sediments. Although there is a difference in the absolute phosphorus mass estimates depending on the modelling method applied, the important point to make is that both methods estimate similar relative contributions of phosphorus sources and sinks in the phosphorus budget. Roughly 27% of the total phosphorus input to the lake also flows out of the lake annually. The remaining 73% stays in the lake and is deposited in the sediments. The results of this study provide a good basis from which to move forward with lake restoration and watershed management plans and actions. Both internal sediment loadings, as well as external loadings from streams draining agricultural/rural and residential lands will need to be addressed in future watershed management planning.

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STUDY BACKGROUND

This study seeks to identify and quantify the sources of phosphorus inputs into Quamichan Lake. Phosphorus is typically a limiting nutrient for aquatic photosynthetic growth. Therefore, enhanced inputs of this nutrient can promote lake eutrophication and its associated symptoms such as aesthetically displeasing murky green waters, and fish kills. External inputs of phosphorus include surface runoff from agricultural lands, urban residential areas and cleared or disturbed areas. Other sources of phosphorus include the removal of riparian vegetation, and seepage from aging or failing septic fields. There can also be internal phosphorus input from the lake bottom sediments. By measuring the phosphorus concentrations and flow measurements of the several small streams feeding into the lake, and Quamichan Creek, the main outflow of the lake, phosphorus sources can be mapped and quantified. This information will be useful when developing a management plan for long-term solutions to improving the lake quality.

LAKE HISTORY

Quamichan Lake is a large, but shallow lake located on Southern Vancouver Island, in Duncan, B.C. It is a recreational lake, used for activities such as boating and swimming, and is an important habitat for fish and other aquatic life. Quamichan Lake has experienced deteriorating water quality over the last 50 years (McPherson, 2006), and is currently classified as a mesotrophic-eutrophic lake. This classification means that there is an abundance of nutrients in the lake enabling excess plant growth in the lake. This plant growth is primarily in the form of phytoplankton; unicellular photosynthetic life that grows within the surface layer of water column. When plant growth is enhanced by nutrient inputs into the lake, there are several ensuing adverse effects on the quality of the lake. First of all, photosynthetic growth appears at the surface of the lake as thick suspended green particles, resembling murky pea soup, making the lake aesthetically undesirable for recreational activities such as swimming and boating. A second adverse affect of enhanced photosynthetic growth in the lake, is the subsequent depletion of oxygen. When the algae at the surface die, they sink to depths, and consume oxygen as part of the decomposition process. Oxygen can be sufficiently depleted through this process to create an anoxic, or near anoxic environment at depth, inhospitable to fish seeking refuge from warmer surface temperatures. Therefore, lake eutrophication, such as in Quamichan Lake, can result in massive fish kills.

Rainfall flushes excess phosphorus and other elements from the surrounding lands of the Quamichan Lake watershed, feeding surface flow in the form of several small streams and ditches, into Quamichan Lake. Different types of land use, such as agriculture, hobby farms, or compact residential areas, are associated with different amounts of phosphorus contributions to surface water run-off. For example, fertilized agricultural fields typically have higher nutrient concentration run-off, than a fallow, un-utilized pasture area. Subsurface water flow through unsaturated ground will also draw nutrients into the lake. Of concern in this case, would be areas of aging or failing septic fields. Both surface and subsurface flow present external sources of phosphorus to the lake.

There are also internal sources of phosphorus from within the lake which can also be a significant nutrient source. In oxic conditions, phosphorus is bound to metals (iron, aluminium, manganese, calcium, etc.) in lake bottom sediments. But when conditions become anoxic and reducing (dissolved oxygen less than 1mg/L), the phosphorus is released from the metal complex into the water column. Therefore, phosphorus and metal concentrations are highest at an anoxic sediment-water interface. Mixing of the shallow lake brings phosphorus released from sediments to the surface where it can be utilized by photosynthetic organisms. Over time, phosphorus will build up in the sediments from continuous deposition, sinking of dead surface biomass, and pro-longed eutrophication of the lake, as is the case with Quamichan Lake

PHOSPHORUS HISTORY AT QUAMICHAN LAKE

Between 1985 and 2005, the average total phosphorus in Quamichan Lake was 60ug/L, ranging between 5-255ug/L. The Criteria for Drinking Water and Recreation is 10 ug/L maximum. During this period, 60/66 (90%) of samples during this period exceeded the criteria, 83% (55/66) exceeded the upper limit of the Aquatic Life Maximum criteria and 98% (65/66) exceeded the lower limit of Aquatic Life Maximum criteria (McPherson, 2006). Total phosphorus concentrations peak from mid September to mid October at which point fall turnover and increased run-off mix the lake and hopefully some of the nutrients are flushed from the lake.

SUMMARY OF INPUT STREAMS

The Quamichan Lake drainage basin is estimated to be 1707.98 hectares (pers. comm., Brent Nielsen, North Cowichan Regional District). The surface area of Quamichan Lake constitutes 313 ha (www.fishwizard.com). The Quamichan Lake watershed (Figure 1) intersects 1727 parcels of land in the North Cowichan Municipal District, 1525 of which are designated Residential, and 181 of which are designated Agricultural. Of all the parcels, there are 127 land parcels with a waterfront boundary. The East side of the lake is predominantly urban, with more recent residential developments. It is also much steeper than the north and west sides, which are typically more rural, with many agricultural properties, and smaller hobby farm-type lands.

Numerous small ditches and creeks, running through culverts and various properties constitute the main surface water inputs to Quamichan Lake. Jim Cosh and Per Dahlstrom, volunteers from the Quamichan Watershed Stewardship Committee familiar with the area, identified a total of 15 stream sites in 2006 and 2007 to be sampled. These stream inputs into Quamichan Lake are seasonal, characterized by low flow, with peak flow in winter months, and very little or no flow between late spring and October/November. Stream inputs were sampled during the rainy season, and after the lake's fall turnover, which typically occurs by mid-October (McPherson, 2006). The advantage to sampling intake streams at the beginning of the rainy season is that nutrient loading signals from the surrounding land use areas will be amplified by increased runoff, but not yet diluted, as they will be further into the rainy season.

Twelve stream sites, which feed Quamichan Lake, were sampled after heavy rainfall events in fall 2006. Thirteen stream sites, and Quamichan Creek, the lake's outflow, were sampled after heavy rainfall events in fall 2007. All samples were measured for total phosphorus concentration. In 2007, stream velocity and depth were also measured using a SWOFFER current meter. Inflow stream sites ranged between 1.5- 24.4cm deep and 0.3-1.5m wide (wetted), averaging 6.6cm deep and 74cm wide (wetted) in 2007. Quamichan Creek, the lake's outflow stream was much wider, and measured 2 meters, then 4 meters wide (wetted width), 3 weeks later. On both occasions, the outflow was too fast flowing to safely measure a full depth-velocity stream profile. Instead, two depth/flow measurements were taken safely from the bank of the creek.

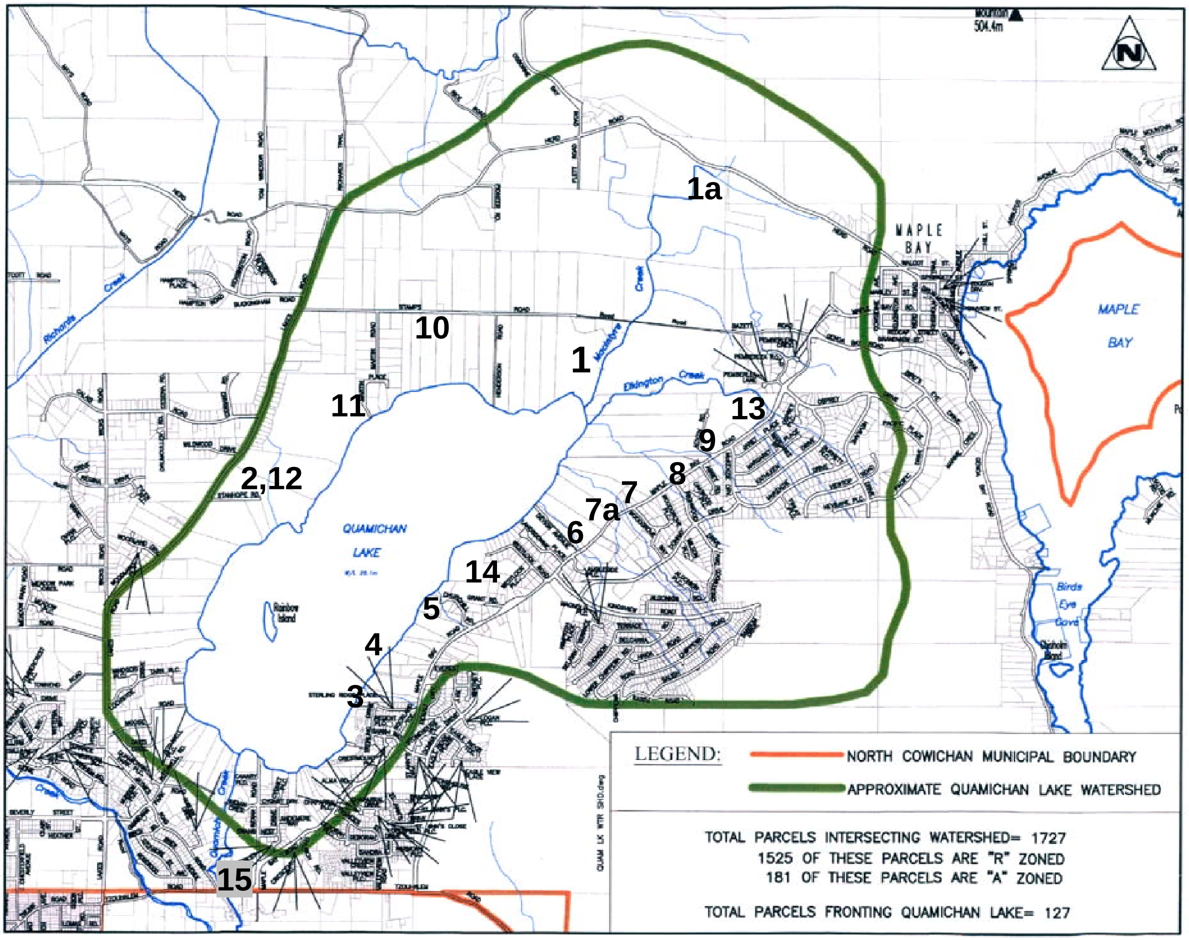

Figure 1. Quamichan Lake Watershed Boundary (provided by Bent Nielsen of the Municipality of North Cowichan), and sampled stream locations: **1**=MacIntyre Creek; 1a=MacIntyre Creek at Herd Rd; **2**=1950 Stanhope Rd; **3**=Garth Creek Pumphouse; **4**=Sterling Creek; **5**=Churchill Creek; **6**=Deykin Creek; **7**=Woodgrove Creek; **7a**=South Woodgrove Creek; **8**=Highwood Creek; **9**=Aitken Creek; **10**=1840 Stamps Rd; **11**=Martin Place; **12**=Stanhope Creek; **13**=Osprey Creek; **14**=Trumpeter Point; **15**=Quamichan Creek (outflow).

Runoff proportion, the amount of precipitation reaching the land that will run off the land into creeks and lakes, was estimated using a standard value of 48.4% (Sprague, 2007). Given the similarity in geology and surficial bedrock type between Quamichan Lake and

Cusheon Lake of Saltspring Island (Geological Survey of Canada, 1965 & 1980), this is a reasonable approximation. Most of the Quamichan Lake drainage basin is underlain by Quaternary period formations, consisting of sand, gravel, silt and clay (the Capilano Sediment formation). Smaller portions of the drainage basin, on the east side of the lake, are underlain by older upper Cretaceous period shale, siltstone, sandstone, conglomerate formations. The Cusheon Lake drainage basin on Saltspring Island is also underlain by these same shale, siltstone, sandstone, conglomerate formations. Quamichan Lake basin surficial bedrock consists of predominantly silt, clay, stony clay and till-like mixtures, thicknesses up to 75 feet, as does the Cusheon Lake drainage basin.

Evaporation is estimated at 0.713 meters per year, again based on values used in models of nearby Cusheon Lake (Sprague, 2007).

From these estimates for annual evaporation and surface runoff proportions in the watershed, and a value of 1.36m precipitation falling in the watershed (Environment Canada, 2007), a theoretical water balance budget for the lake can be calculated. Inputs to the lake include surface runoff from the watershed (48.4% x 1395ha (area of watershed not including lake surface) x 1.36m precipitation), and precipitation directly on the surface of the lake (1.36m x 313ha). Therefore, these two water sources contribute 9,182,000m^3 and 4,257,000m^3 of water, respectively, into Quamichan lake, for a total of 13,439,000m^3 annually. Evaporation from the lake surface removes 2,231,690m^3 (0.713x313ha) of the water from the lake (17%). Therefore, assuming a steady state over a year's period, the remaining percentage (83%) is outflow from the lake, and is estimated at 11,207,558m^3 per year. From this simple water budget calculation, the water residence time (flushing rate) for Quamichan Lake is estimated to be 1.02 years, meaning that the entire volume of the lake is effectively replaced by inflowing water every 1.02 years. The slower residence time means that water is retained in the lake over the course of a year, allowing nutrients to accumulate in the lake.

SURFACE WATER PHOSPHORUS LOADING DATA

Table 1 below summarizes the total phosphorus concentrations from the 2006 and 2007 Quamichan Lake inflow/outflow stream sampling. Figure 2 illustrates that in both sampling years, total phosphorus concentration has been consistently higher in the creeks draining agricultural and rural areas. Calculations of total phosphorus loading, based on phosphorus concentrations and flow volumes (Figure 3), also show a higher loading from creeks draining agricultural/rural land, as well as peaks at two stream sites draining residential areas (#7a South Woodgrove Creek, and #9 Aitken Creek). Other residential sites have relatively low total phosphorus loadings.

Table 1. Phosphorus concentration (mg/L) of Quamichan Lake inflow and outflow streams, as sampled in fall of 2006 and 2007.

	Site #	**Site Description**	**Total Phosphorus (mg/L) (RDL = 0.002)**			
			2006-11-05	**2006-11-16**	**2007-11-13&14**	**2007-12-05**
Quamichan Lake Inflows	1	Macintyre Creek	1.56	0.002	not sampled	not sampled
	2	1950 Stanhope Rd.	0.087	0.061	not sampled	not sampled
	3	Garth Creek Pumphouse	0.012	0.004	0.039	0.03
	4	Sterling Creek	0.01	<0.002	0.017	0.02
	5	Churchill Creek	0.011	0.003	0.04	0.022
	6	Deykin Creek	0.05	0.003	0.017	0.02
	7	Woodgrove Creek	0.009	<0.002	0.007	0.007
	7a	South Woodgrove Creek			not sampled	0.018
	8	Highwood Creek	0.029	<0.002	0.009	0.008
	9	Aitken Creek	0.015	<0.002	0.014	0.02
	10	1840 Stamps Rd	0.205	0.201	0.78	1.26
	11	Martin Place	0.097	0.004	0.096	0.125
	12	Stanhope Creek	<0.002	0.004	0.049	0.071
	13	Osprey Creek	0.015	0.003	0.018	0.011
	14	Trumpeter			0.016	0.023
Sum of Inflows			2.101	0.293	1.102	1.635
Quamichan Lake Outflow	15	Quamichan Creek			0.145	0.059

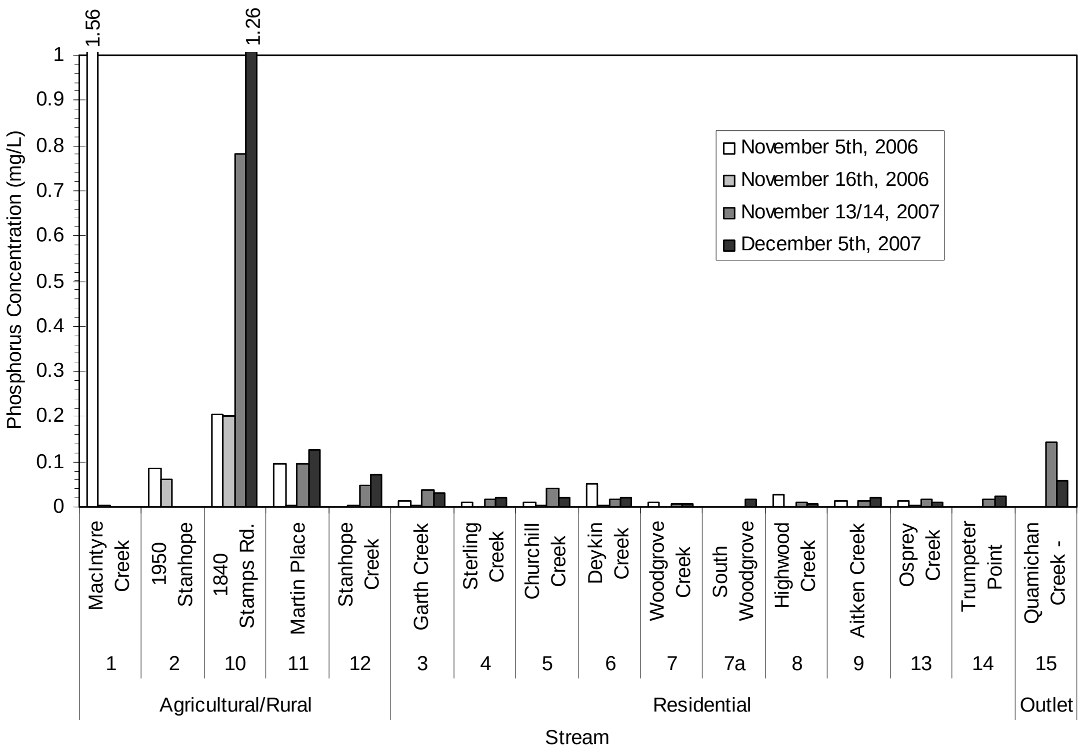

Figure 2: Phosphorus concentration (mg/L) of surface flow streams feeding Quamichan Lake.

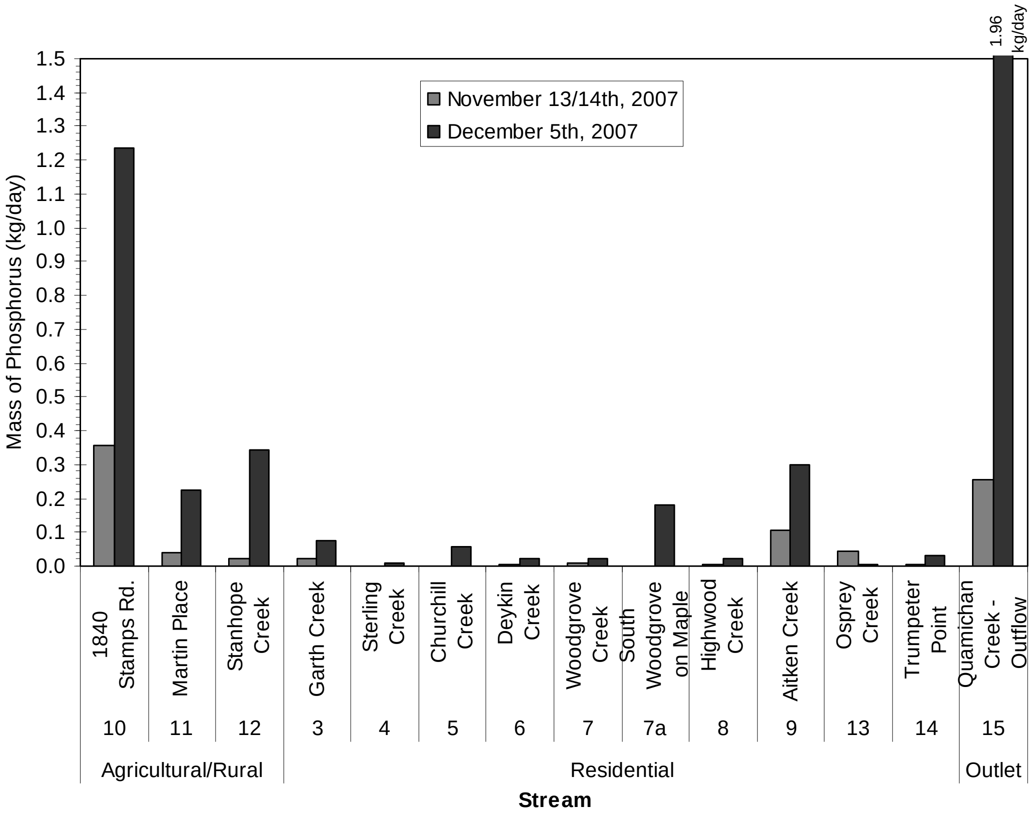

Figure 3: Total phosphorus loadings (kg/day) from surface flow streams feeding Quamichan Lake. See Appendix A for data.

The two creeks with higher phosphorus loadings that are draining residential areas are located on the more northern end of the lake's east-side. Portions of this north-western developed area of the watershed are currently still on septic, but have plans to be switched over to sewer in the near future (pers. comm., Glen Andison, engineering technician at the District of North Cowichan, 2007). Therefore, it is suspected this may be a contributing factor behind the high phosphorus loadings at these two sites. Switching the area to sewer could potentially reduce this phosphorus source, and should be monitored after sewage connection for confirmation.

MacIntyre Creek, the creek identified on most maps as the main inflow to Quamichan Lake, was not sampled in 2007 because there was no identifiable, single distinguished main stream channel. Close to the lake (access via a property at the end of Stamps Rd.), the creek had many braided channels through a flooded, grassy field. It was observed that there would be too much influence from lake levels here at the time of sampling. Higher up on the creek, off Herd Rd, there was also no visible, flowing channel to sample.

The 2007 data shows that the major surface source of phosphorus to the lake is from the agricultural/rural area land area along the northern side of the lake. Loadings were higher in the second sampling December 5th (2007) than the first sampling on November 13/14, 2007, for all stream sites except one, Osprey Creek (#13). Increasing phosphorus concentrations of inflow streams as precipitation continues through the winter season is characteristic of a developed watershed (Nordin et al., 1983). To calculate an annual phosphorus loading from streams, this report tried different estimates for the number of days the stream had flowing water, and different values for stream concentration, to give a range of probable loadings from surface inflow streams, as reported in Table 2.

Table 2: Phosphorus loading of Quamichan Lake from surface inflow streams. See Appendix B for detailed breakdown of loadings per individual creek. Only 2007 data was used in these calculations, as no quantitative flow data was collected in 2006.

		LOWER ESTIMATE	UPPER ESTIMATE	MID ESTIMATE
# of stream flow days		105	166	120
Loading concentration (kg/day)*****	Agricultural/Rural	0.4185	1.8040	1.1115
	Residential	0.1983	0.7231	0.4607
	Output	0.2540	1.9565	1.1052
Annual loading (kg/year)	Agricultural/Rural	43.9	299.5	133.4
	Residential	20.8	120.0	55.3
	TOTAL Inflow	**64.8**	**419.6**	**188.7**
	Output	**26.7**	**324.8**	**132.6**

*Nov 13/14, 2007 loading data used for lower estimate; Dec 5, 2007 loading data used for upper estimate; An average of November and December sampling days' data used for the mid estimate.

OTHER PHOSPHORUS INPUTS

Groundwater

There could be seasonal variation in interactions between the aquifer and surface water bodies. Analytical methods that evaluate river hydrographs following rainfall events can be used to determine the component of groundwater base flow that infiltrates stream baseflow and the lake. To do this, data from surface water gauging stations on the inflow creeks would be required (Sylvia Kenny, pers. comm. Ministry of Environment, Nanaimo).

No groundwater data was available at the time of this study, so it is not included in the phosphorus budget analysis. However, it has been reported that groundwater potential in the area is low to nil (McPherson, 2005), therefore it is likely that its contribution to Quamichan Lake loading is also low to nil, and it is reasonable to exclude it from the model.

Aerial Loading

Rain, snowfall and dust deposit an estimated 0.1592 kg of phosphorus per hectare per year in the Quamichan Lake watershed. This value was derived from an estimate of aerial source phosphorus concentrations used in a similar study on nearby Cusheon Lake (Sprague, 2007), and adjusted for a slightly higher precipitation (1.36m in 2007, Environment Canada) in Quamichan Lake area, than at Cusheon Lake (0.98m per year average). Therefore, over the surface area of Quamichan Lake (313 ha), an estimated **49.83kg** of phosphorus enters the lake system over one year.

INTERNAL PHOSPHORUS LOADING FROM SEDIMENTS

There is significant increase in the lake’s phosphorus concentration at depth towards the end of the summer months, as illustrated in Figure 4. The deep phosphorus concentration then decreases and approaches surface concentration during the fall months, because of fall turnover mixing. This summer increase, and subsequent fall decrease, is strong evidence that phosphorus is being generated internally, and the lake bottom sediments are acting as a source of phosphorus to the water column (Nordin et al., 1983).

To better quantify the amount of phosphorus regenerated from lake sediments, several methods were applied.

Method I: One method of estimating the amount of phosphorus regenerated from lake-bottom sediments is to measure total phosphorus concentration at the surface just before, and just after autumnal mixing (Sprague, 2007). The difference between these two measurements will give an estimate for the amount of phosphorus brought to the surface by wind mixing and fall de-stratification of the lake (Table 3). The assumption here is that autumnal mixing occurs before major precipitation events that bring new phosphorus from external sources.

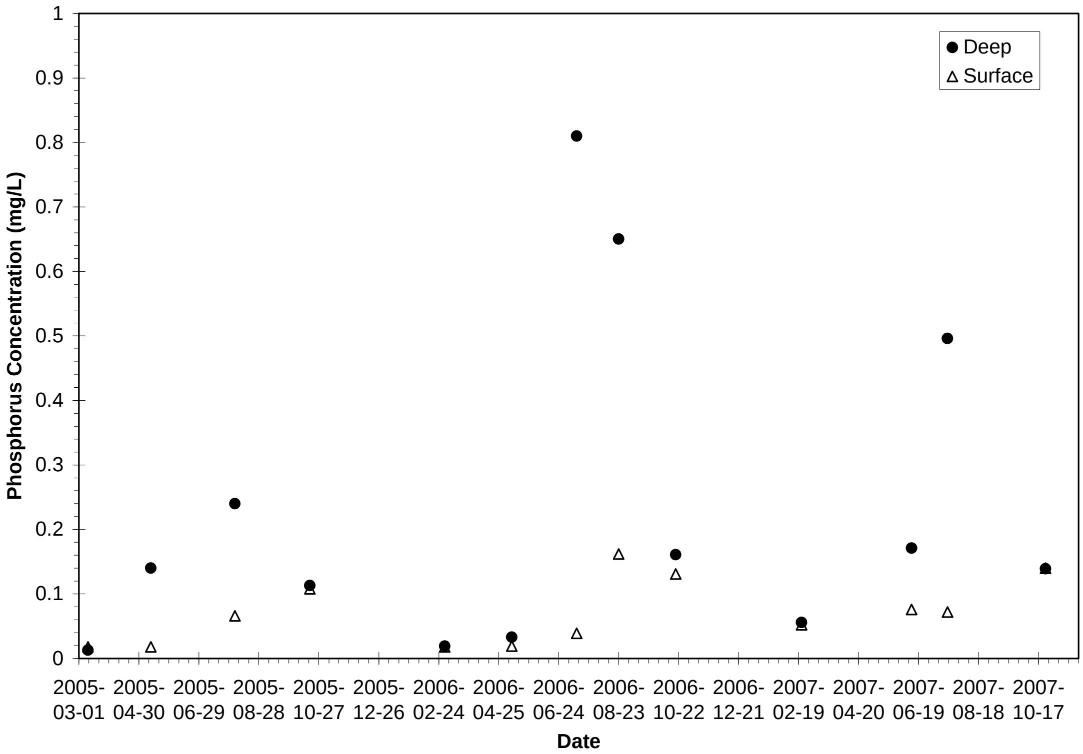

Figure 4. Phosphorus concentration in Quamichan Lake at the Deep Station Site (EMS E207465), at the surface, and at depth (7-8 meters), 2005-2007.

Table 3: Estimate of regenerated phosphorus load from sediments in Quamichan Lake, calculated with Method I: Surface total phosphorus concentrations before fall turn-over is subtracted from surface total phosphorus concentrations just after fall turn-over. Mass of phosphorus from sediment source is calculated by multiplying the regenerated phosphorus concentration and lake volume (1,480,000,000 L).

Year	[P] Before Mixing (mg/L)	[P] After Mixing (mg/L)	Regenerated Phosphorus Concentration (mg/L)	Mass of P from sediment source (kg)	"Before" sampling date	"After" sampling date
2005	0.066	0.108	0.042	62.16	Aug 4th	Oct 18th
2006	0.039	0.131	0.092	136.16	July 12th	Oct 19th
2007	0.072	0.140	0.068	100.64	July 18th	Oct 24th
		Average	**0.0673**	**99.65**		

A Modification on Method I:
The following equation, based on the equation for conservation of mass, was used to provide another estimate for phosphorus loadings from sediments:

$$[P]_{\text{deep premix}} \text{ x } V_{\text{hypolimnion}} \; + \; [P]_{\text{surface premix}} \text{ x } V_{\text{epilimnion}} \; = \; [P]_{\text{average postmix}} \text{ x } V_{\text{lake}}$$

Where $[P]_{\text{deep premix}}$ = Total phosphorus concentration, before fall turnover
$V_{\text{hypolimnion}}$ = Volume of hypolimnion (220,500,000L)
$[P]_{\text{surface premix}}$ = Total phosphorus concentration, before fall turnover
$V_{\text{epilimnion}}$ = Volume of epilimnion (1,259,500,000L)
$[P]_{\text{average postmix}}$ = Average surface and deep total phosphorus concentration
V_{lake} = Volume of lake (1,480,000,000L)

The equation was solved for $[P]_{\text{deep premix}}$, and as shown in Table 4 below, the calculated value for phosphorus concentration in the hypolimnion quite reasonably approximates the actual measured value. The estimates of the modified method I are slightly higher than those of method I, likely because this modified method considers fall turnover as a distinct event in time, with a distinct static boundary at 5 meters depth between the hypo and epilimnion leading up to this event. In reality, the depth, and therefore volume, of this boundary wavers above and below 5 meters, as the temperature profile shifts over time. Additionally, the entire volume of the hypolimnion likely does not get fully mixed with the surface waters in a single mixing event, but rather, over several mixing events in the fall. However, both of these methods still give similar estimates for the amount of phosphorus regenerated from the sediments.

Table 4: Estimate of regenerated phosphorus load from sediments in Quamichan Lake, calculated with a modified method I. Mass of phosphorus regenerated from sediment source is calculated by multiplying the $[P]_{\text{deep premix}}$ and the hypolimnion volume (220,500,000 L).

Sample year	$[P]_{\text{surface premix}}$ (mg/L)	$[P]_{\text{average postmix}}$ (mg/L)	Calculated $[P]_{\text{deep premix}}$ (mg/L)	Measured $[P]_{\text{deep premix}}$ (mg/L)	Mass of regenerated P (kg)
2005	0.066	0.1105	0.3647	0.24	80.41
2006	0.039	0.1460	0.7572	0.65	166.96
2007	0.072	0.1395	0.5251	0.496	115.78
				Average	**121.05**

Method II: This second method of estimating the amount of phosphorus released from sediments involves a more detailed breakdown of the hypolimnion. Depth of the hypolimnion upper surface is estimated to be at 5 meters, based on representative annual temperature profiles for 2004/2005 at the Quamichan Lake deep site (McPherson, 2006). The hypolimnion was then broken down into twenty-five 10cm deep horizontal slices. The total mass of phosphorus contained in each slice was calculated from its volume and concentration. Concentration was adjusted by subtracting the existing concentration in the surface mixed layer. The total mass of regenerated phosphorus in the whole hypolimnion was arrived at from the summation of the calculated mass in each slice. Appendix D lays out in more details these calculations. A total of **25.635kg** (based on extrapolated 0.6853 mg/L bottom phosphorus concentration), or **15.855kg** (based on measured 0.462 mg/L bottom phosphorus concentration) of phosphorus are regenerated annually from the sediments, based on this method.

These estimates are much lower than the 99.65kg, and 121.05kg estimates using the first method. A likely reason for this is the assumption that phosphorus concentration of the hypothetical 10cm slices decreases at a steady, consistent rate with depth. It is more likely that phosphorus concentration will only slightly decrease in the 50 to 100cm above the lake bottom. Concentration may also not increase as rapidly with depth near the hypolimnion surface, as was approximated in these calculations. When these adjustments are approximated in the calculations detailed in Appendix D, the sum of slices, total phosphorus loading, approaches much closer to the estimates of method I. In order to use this second method, more data should be collected. A more empirical picture of the change in phosphorus concentration with depth prior to fall turnover, as well as a more detailed bathymetric assessment of the volumes of the slices, and observations over time of pre-turnover partial mixing of the hypolimnion surface will all contribute to a more accurate phosphorus loading estimate from method II. As such, the estimates from method I (and modified), more likely approximate the true sediment loadings in Quamichan Lake, and therefore, will be used in the budget calculations below.

LAKE PHOSPHORUS BUDGET

A phosphorus budget for Quamichan Lake was calculated, to identify relative contributions of each phosphorus source to the loading of the lake. Table 5 below summarizes the budget. Keep in mind that the values used in this budget analysis incorporate several judgemental interpretations and approximations (for example, number of stream flow days per year). However, these approximations were carefully considered, and made in light of current limnological knowledge. The assumptions used in this analysis allow an approximation that is very useful in this evaluation of Quamichan Lake phosphorus loading sources.

Table 5. Quamichan Lake phosphorus budget estimate, based on 120 days per year of flowing water in the inflow creeks, and a 99.65 – 121.05kg internal load (calculated with different methods).

Source	Load (kg/yr)	% of Total Input
Internal Loading	99.7 - 121.1	29.5 - 33.7
Streams	188.7	52.5 - 55.8
Agricultural/Rural Streams	*133.4*	*37.1 - 39.3*
Residential Streams	*55.3*	*15.4 - 16.3*
Aerial Load	49.8	13.9 - 14.7
TOTAL INPUT	**338.2 - 359.6**	
Outflow	132.6	
Phosphorus deposited to sediments (kg/year) (input minus output)	205.6 - 227	

The estimates presented in Table 5 are the most acceptable, because they use the mid-estimate for the stream loading concentrations, thereby averaging seasonal trends in stream flow concentration. In this estimate, stream input contributes almost twice as much phosphorus as internal phosphorus recycling does. Streams draining agricultural and rural lands account for **37.1 to 39.3%** of the total loadings. Streams draining residential areas on the lake's east and south sides contribute **15.4 to 16.3%** of the total loadings. Therefore, total stream inputs account for 52.5-55.8% of lake phosphorus loading. Loadings from recycling of lake bottom's sediments contribute **29.5 to 33.7%** of the total loadings. The sum of phosphorus loadings (approximately 350kg) to the lake, exceed the outflow (132.6kg), meaning that phosphorus continues to build up in the bottom sediments. Appendix E details the budget calculations using the upper and lower estimates of stream flow concentrations, and the different sediment loading estimates.

In addition to the models illustrated above which use actual field data in the calculations, there are other theoretical methods to estimate lake phosphorus budgets. Wetzel (2001) uses the relationship between the lake's volume, flushing rate, and phosphorus concentration, to evaluate a phosphorus budget for the lake. When this method is applied to Quamichan Lake, it estimates a much larger phosphorus load in the lake of 826kg. This is based on an average lake phosphorus concentration of 60 ug/L (McPherson 2006), and a lake volume of 13,770,000,000L (www.fishwizard.com). This secondary method suggests that the absolute quantity of phosphorus inputs calculated from the field data may in fact be underestimated. Dr. Rick Nordin, a lake limnology expert from the University of Victoria, suggests several factors to which these differences can be attributed (pers. comm.). One factor is the behaviour of the lake, and its dynamic water column temperature and oxygen profile. It is a shallow lake, and therefore, the stratification, which allows development of the anoxic bottom conditions necessary for phosphorus release from sediments, occurs episodically throughout the warm, calmer summer months. This episodic stratification creates periodic bursts of large amounts of phosphorus released from sediments, rather than a continuous and constant release over time. These quite large pulses are very difficult to catch with out a more time and resource-intensive monitoring regime, and would lead to an underestimate of the phosphorus loading based on the limited field data used in this report. .

Although the estimates for the absolute mass of phosphorus coming into and leaving the lake vary depending on the model applied, the field data-derived estimate presented in this report, the secondary, more straightforward estimate based on Wetzel (2001) and Dr. Nordin's expert opinion, all result in comparable estimates for the relative proportions of phosphorus sources and sinks in the model. Field data based estimates show around 38% of total phosphorus input leaves the lake through the outflow, and around 62% of inputs remain in the lake and are deposited to sediments. These values are in good agreement with the 28% of input leaving the lake, and 72% remaining in lake, as estimated using Wetzel and Nordin's method. The important message here is that the relative contributions from internal and external phosphorus sources are consistent. Therefore, the results presented in this report provide a good starting point from which to move forward with watershed restoration and management plans. These results still clearly show that it will require a combination of efforts to improve the water quality of Quamichan Lake, with respect to nutrient loading. Both the issue of recycled sediment loadings from the lake bottom, as well as loading from surface flow stream inputs, will need to be addressed in the water management planning process.

FUTURE STEPS

The information presented in this report will serve as a basis for pursuing watershed planning objectives and strategies to improve the water quality by reducing phosphorus loading to Quamichan Lake. The budget will help guide and prioritize lake improvement initiatives that will have the most likelihood of success in reducing phosphorus input to the lake. Both the external and internal sources of phosphorus loading will need to be addressed in the water management planning process.

The budget indicates that about 54% of the loadings come from surface runoff. This source can be alleviated with a combination of several strategies, including but not limited to the following: re-vegetation and maintenance of vegetation in both riparian and non-riparian areas; corroboration with farmers and agricultural management plans with respect to seasonal timing and quantity of fertilization; inspections, and potential upgrades of septic systems or replacement with sewage systems; development of and compliance with storm water management programs. The budget indicates that about 30% of the loadings are re-generated internally from the lake's sediments. There are various options for addressing this source, which include aeration, lake destratification, and addition of phosphorus-complexing chemicals. Education of landowners in the watershed, as to their responsibilities and actions they can take, will also play an important role in reducing the phosphorus load, and improving the health of the lake.

Suitability of each of the above mentioned tactics for reducing phosphorus input to Quamichan lake vary based on four considerations: ease of implementation, speed of the strategy's effectiveness, economics, and side-effects. These four considerations will come to play as the watershed management plan develops. The emphasis is on incorporating a combination of tactics into the watershed management planning process, ensuring that both external and internal phosphorus sources to Quamichan Lake are addressed.

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