Hutchinson
Environmental Sciences Ltd.

Callander Bay Subwatershed Phosphorus Budget

Prepared By: Hutchinson Environmental Sciences Ltd.
Prepared For: North Bay – Mattawa Conservation Authority

Project Number: J100024
Date: November, 2010

DRAFT FOR DISCUSSION

3-1 Taylor Road, Bracebridge, ON P1L 1S6 ph: 705 645 0021

HESL

Hutchinson Environmental Sciences Ltd., 3-1 Taylor Road, Bracebridge, ON P1L 1S6 ph:705 645 0021

November 2, 2010 Project #: J100024

Ms. Sue Miller
North Bay – Mattawa Conservation Authority
15 Janey Avenue
North Bay, Ontario
P1C 1N1

Dear Ms. Miller:

Re: Callander Bay Subwatershed Phosphorus Budget – Draft Report

It is with pleasure that I submit this draft report of the Callander Bay Subwatershed Phosphorus Budget.

I look forward to presenting the results of the phosphorus budget with you and the Technical Advisory Committee at our meeting next week, and to addressing comments and questions that may arise for the final reporting stage and public presentation.

Sincerely,
HESL

T. KRR

Tammy Karst-Riddoch, Ph.D.
tammy@environmentalsciences.ca

Signatures

Dörte Köster, Ph.D.
Senior Aquatic Scientist

Neil Hutchinson, Ph.D.
Principal Scientist

Tammy Karst-Riddoch, Ph.D.
Senior Aquatic Scientist

Table of Contents

List of Figures

List of Tables

Appendices

1. Introduction

In recent years, there has been growing concern over the occurrence of algal blooms dominated by *Cyanobacteria* species (commonly known as bluegreen algae) in Callander Bay as well as Wasi Lake, a shallow productive lake in the Callander Bay watershed. Both Callander Bay and Wasi Lake have elevated concentrations of the algal nutrient phosphorus (> 20 μg/L), which is known to increase algal biomass and the risk of cyanobacterial blooms.

Cyanobacterial blooms not only affect the aesthetic and recreational water quality of water bodies (e.g., by decreasing water clarity, causing taste and odour problems), but many species of cyanobacteria produce toxins that can pose a risk to human health. The human health risk is particularly important as Callander Bay is the municipal drinking water source for the Town of Callander. As a result of cyanobacteria blooms dominated by taxa that are known to produce toxins, the toxin, 'microcystin', is listed as a drinking water issue for the Callander intake under Ontario's Drinking Water Source Protection (DWSP) program as mandated by the *Clean Water Act* (2002) (NMBCA, 2010).

Callander Bay and Wasi Lake have been subjected to a variety of human disturbances since settlement of the area in the mid 1800s that increased their supply of phosphorus such as logging and sawmill operations, agricultural activities, rural and urban development. Notably, operation of the Portage Dam at the outlet of Lake Nipissing following its construction in 1950 resulted in significant lowering of lake water levels particularly in spring, which in turn is thought to have altered flushing rates and mixing regimes in Callander Bay. In a study of historical changes of total phosphorus concentrations using paleolimnological techniques, these hydrological changes were suspected to have altered internal nutrient dynamics of Callander Bay, which ultimately increased total phosphorus concentrations (AECOM, 2010). Since ~1950, the combination of human activities that supply phosphorus to Callander Bay and hydrological changes were inferred to have increased total phosphorus concentrations from moderate levels (~15 to 20 μg/L) indicative of 'mesotrophic' conditions to greater than 20 μg/L indicative of 'eutrophic' conditions.

Despite large-scale human influences over the past century, there is no evidence from the paleolimnological study or monitoring data of recent increases in total phosphorus concentrations in Callander Bay over the past few decades (AECOM, 2009; HESL, 2010) that would cause the recent observed increase in cyanobacterial bloom activity. For many already productive water bodies with elevated phosphorus concentrations like Callander Bay and Wasi Lake (including those with minimal watershed disturbance and human nutrient loading), however, effects of recent warming with climate change can exacerbate cyanobacterial blooms (e.g., AECOM, 2009; Wagner and Adrian, 2009; Rühland et al., 2010). It is therefore conceivable that Callander Bay and Wasi Lake, given their already high total phosphorus concentrations that increase the risk of nuisance algal growth, have enhanced susceptibility to climate-mediated cyanobacterial blooms.

Development of effective watershed management plans that aim to control human sources of phosphorus and ultimately reduce the risk of cyanobacterial blooms in Callander Bay and Wasi Lake requires knowledge of the relative contribution of all sources of phosphorus in the watershed – that is, a phosphorus budget. A phosphorus budget is also required to evaluate and further inform aspects of DWSP for the Callander drinking water intake, specifically: 1) the delineation of areas within the defined Vulnerable Area of the intake that contribute phosphorus to the bay, the 'issue contributing area', 2) the identification and designation of activities in the issue contributing area that are prescribed to be drinking water threats and that may result in the release of phosphorus as 'significant drinking water threats', and 3) the development of policies to mitigate these significant drinking water threats related to phosphorus.

The following study provides a subwatershed scale phosphorus budget for Callander Bay and Wasi Lake that quantifies human and natural sources of phosphorus using a combination of export coefficient modelling and measured phosphorus loadings. Recommendations for future monitoring requirements and potential mitigation strategies for the most relevant sources of human phosphorus are provided to guide future management plans. Finally, results of the phosphorus budget are assessed as they relate to DWSP for the Callander drinking water intake.

2. System Characterization

Phosphorus is plentiful in the natural environment as it occurs in inorganic phosphate-bearing rocks (e.g., apatite) and soils, and as organic phosphates in all living cells. The supply of phosphorus to surface water is dependent upon hydrological conditions, land cover, geology, soil type and depth, human activities, and climate. The following sections provide an overview of primary factors influencing phosphorus loading to Callander Bay and Wasi Lake and resultant observed phosphorus concentrations in these water bodies as they relate to the development and validation the phosphorus budget.

2.1 Hydrology

Phosphorus is most readily transported by water. It enters surface water from precipitation, tributary flow, overland runoff and groundwater. In surface water bodies, the concentration of phosphorus is then moderated by the quantity of water in the surface water body, mixing regimes that influence loss to the sediments and outflow which transports water carrying phosphorus downstream. Hydrological characteristics of a water body and its watershed are therefore important in the determination of phosphorus loads and concentrations in surface water.

Callander Bay is a large bay with a surface area of 12.06 km^2 located at the east end of Lake Nipissing. It has a comparatively large catchment area (296.12 km^2) that receives overland runoff and discharge from tributaries draining the Wastiwising River (Wasi River) subwatershed, and portions of the Bear-Boleau Creeks and La Vase River subwatersheds (Figure 1). Dominant flows in Callander Bay are towards the main body of Lake Nipissing and the bay likely receives only limited water from the lake during periods of flow reversals that occur due to wind mixing (HESL, 2010).

Figure 1. Callander Bay and watershed area.

Insert map – full page

The Wasi River is the largest tributary to Callander Bay draining an area of 234.61 km^2, which represents 83% of the Callander Bay catchment. Flows in the Wasi River have been monitored by the Water Survey of Canada since 2008 (http://www.wsc.ec.gc.ca/hydat/H2O), providing only two full years of data (Table 1). Tributary flows, however, can vary considerably from year to year depending on precipitation patterns; the total annual discharge of the Wasi River differs by than 20% in 2008 and 2009 (Figure 2). Flows in these two years may therefore not be representative of the long-term average conditions. The available flow data from 2010 are still preliminary and should be viewed with caution until they have been verified by the WSC, but 2010 monthly flows to date are much lower than those observed in 2008 and 2009 (Figure 2).

Table 1. Water Survey of Canada Hydrometric Station Summary

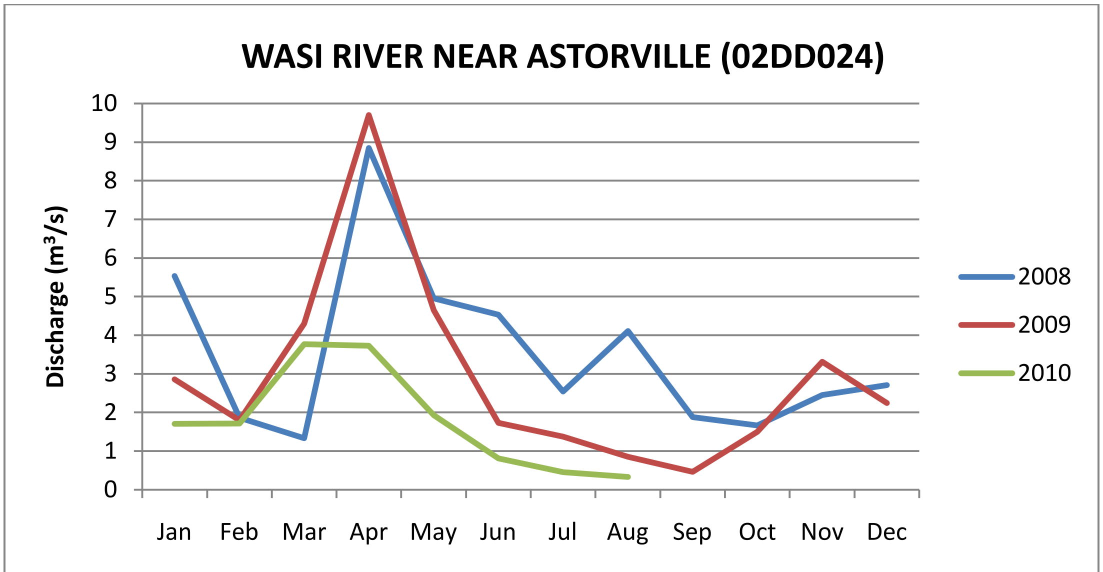
Station Name	Wasi River near Astorville	La Vase River at North Bay
Station ID	02DD024	02DD013
Data Years	2007-2009	1974-2009
Measurement Type	Flow and Level	Flow and Level
Gross Drainage Area (km^2)	301.00	70.40
Geographic Coordinates	46°10'41" N 79°18'36" W	46°15'48" N 79°23'42" W

The nearby La Vase River flows have been monitored continuously since 1974 (Table 1) and can be used to assess the representativeness of the Wasi River flow data. While the La Vase River subwatershed is considerably smaller than the Wasi River subwatershed, flows in both rivers displayed similar seasonal patterns in 2008 and 2009 (Figure 2) and depth of runoff (flow per unit drainage area) in the two subwatersheds is similar (Table 2), suggesting similar hydrological characteristics.

Like most areas of north eastern Ontario, flows in the La Vase Rivers were elevated throughout the summer months in 2008 (Figure 2) resulting in a total annual discharge of 6,403 dam^3 in comparison to the long-term 34-year mean of 4,614 dam^3. In 2009, early spring flows following snow melt were exceptionally high due primarily to the large amount of snow that fell in the preceding winter. These elevated flows occurred over the course of a few days in early April resulting in flood conditions in the watershed, but overall mean monthly flows in the La Vase River in 2009 were similar to the long-term means (Figure 2). It is therefore likely that the 2008 Wasi River flows represent high flow conditions and that the 2009 flows more closely resemble the long-term mean conditions for this river. This is supported by the fact that runoff in 2009 (0.43 m) calculated from the Wasi River discharge data is equivalent to the average annual runoff calculated by Gartner Lee (2007) using a hydrological modelling approach (Table 2). The 2008 runoff of 0.53 m represents a 23% increase in over mean annual runoff.

Additional flow data were collected by the NBMCA from 4 tributaries draining to Callander Bay from May to August in 2009 (Table 3). Depth of runoff for the catchment areas of these tributaries ranged from 0.07 for Windsor Creek to 0.14 m for Cranberry Creek, which drains Cranberry Marsh and contains flows from discharge of the Callander sewage treatment plant lagoons in spring and fall. Runoff for the catchments of tributary NB-323 (0.10 m) and Burford Creek (0.09 m), both located within the greater La Vase River subwatershed, were similar to the runoff calculated for the entire La Vase River subwatershed (0.11 m) over the same period suggesting that localized differences in runoff within these areas of the watershed are minimal during the summer months.

Figure 2. Wasi River and La Vase River monthly stream discharge (2008-2010).



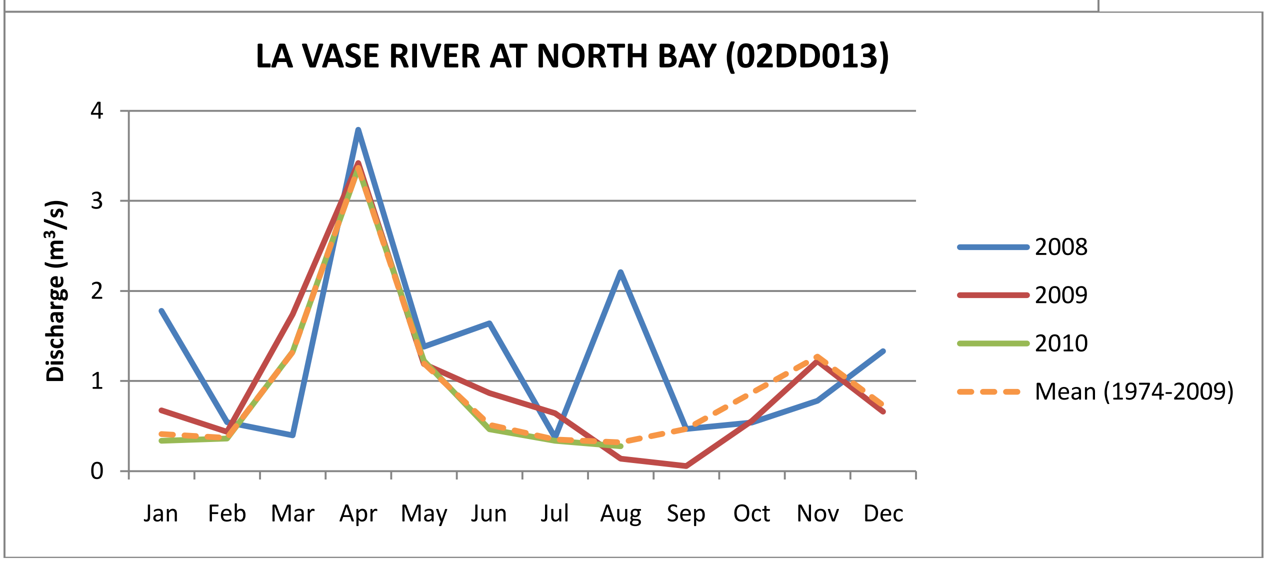


Table 2. Wasi River and La Vase River Discharge and Depth of Runoff Summary

Year	Discharge at Monitoring Gauge *(dam³)*	Depth of Runoff in Subwatershed *(m)*	Area of Subwatershed Draining to Callander Bay *(km²)*	Total Discharge to Callander Bay *(dam³)*
WASI RIVER				
2008	111,770	0.53	234.614	123,943
2009	91,320	0.43		101,266
LA VASE RIVER				
2008	40,773	0.58	11.056	6,403
2009	31,048	0.44		4,876
Mean (1974-2009)	29,383	0.42		4,614

Table 3. Discharge and Depth of Runoff Summaries for Tributaries of Callander Bay, May to August 2009

Tributary	Mean Discharge (m^3/s)	Discharge Volume (dam^3)	Drainage Area (km^2)	Depth of Runoff (m)
Burford Creek	0.11	1,164	12.7	0.09
Cranberry Creek	0.04	402	2.8	0.14
NB-323	0.03	338	3.4	0.10
Windsor Creek	0.16	1,692	25.8	0.07
La Vase River	0.71	7,527	70.4	0.11
Wasi River	2.15	22,848	234.6	0.11

Based on an estimated mean annual runoff of 0.43 m calculated from measured flows in the Wasi River, an average of 127,993 dam^3 of water is discharged from Callander Bay to Lake Nipissing each year assuming no inflow of water from Lake Nipissing to Callander Bay. As previously described, inflow from Lake Nipissing can occur periodically as a result of wind events that cause flow reversals back into the bay. Flow reversals are likely of short duration and have a minimal affect on the total discharge from Callander Bay to Lake Nipissing. The volume of Callander Bay is approximately 66,316 dam^3 (assuming a mean depth of 5.5 m) and so at this discharge rate, the total volume of water in Callander Bay is replaced approximately 1.9 times per year under average conditions.

2.2 Land Cover and Land Use

The amount of phosphorus supplied to a water body by runoff from land areas is dependent upon the type of land cover and land use. Phosphorus is exported from natural undeveloped areas (e.g., forest, wetland, grassland) from the decomposition of plant material, animal waste and from soil erosion. Human activities and disturbance of natural areas in the watershed typically increase the supply of phosphorus in runoff, for example by increasing erosion, fertilizer and detergent use, and human waste disposal.

Land cover in the Callander Bay watershed has been classified into 12 classes using QuickBird satellite imagery and verification by ground-truthing (Master of Science project, Lake Nipissing University, 2010; Figure 3). The imagery was captured between May and June 2007 with a spectral resolution of 0.6 m but reduced to 2.8 m for data processing. For the purposes of the phosphorus budget, QuickBird land classes were grouped into 5 classes (i.e., agriculture, forest, wetland, grassland, bare rock, urban (as infrastructure) and open water) and areas of each class were determined on a subwatershed scale and for Intake Protection Zones (IPZs) of the Callander drinking water intake (Figure 4). It should be noted that there was a relatively large area (~12% of the subwatershed) that was classified as cloud cover/shadow in the QuickBird classification. The area of shadow/cloud within each subwatershed was added proportionally to the known land cover classes (e.g., if forest accounted for 30% of the land area, 30% of the cloud cover/shadow area was added to the forest class). Due to limitations in the spectral resolution of the QuickBird imagery, the agriculture class does not differentiate between types of agricultural lands (e.g., pasture and row crops) and manicured grassy areas (e.g., lawns and golf courses) that have markedly different phosphorus export.

Figure 3. QuickBird-derived land classes in the Callander Bay watershed.

Figure 4. Intake Protection Zones (IPZs) of the Callander drinking water intake (from HESL 2010).

Major land cover classes are summarized by area (Table 4) and by percent cover (Figure 5) for the Callander Bay watershed. Land cover is predominantly natural with forest, wetland and grassland comprising 86% of the total land area in the watershed. Of note is the large percentage of wetland area (24%) in the watershed. Agricultural areas (including manicured lawns and golf courses) represent the greatest proportion of disturbed areas (91%) that contribute human sources of phosphorus to Callander Bay. It is noted, however, that areas classified as agriculture, particularly those subwatershed areas in the vicinity of the Town of Callander, are mostly manicured lawn areas and golf courses. Less than 1% of the land area in the Callander Bay watershed is classified as urban.

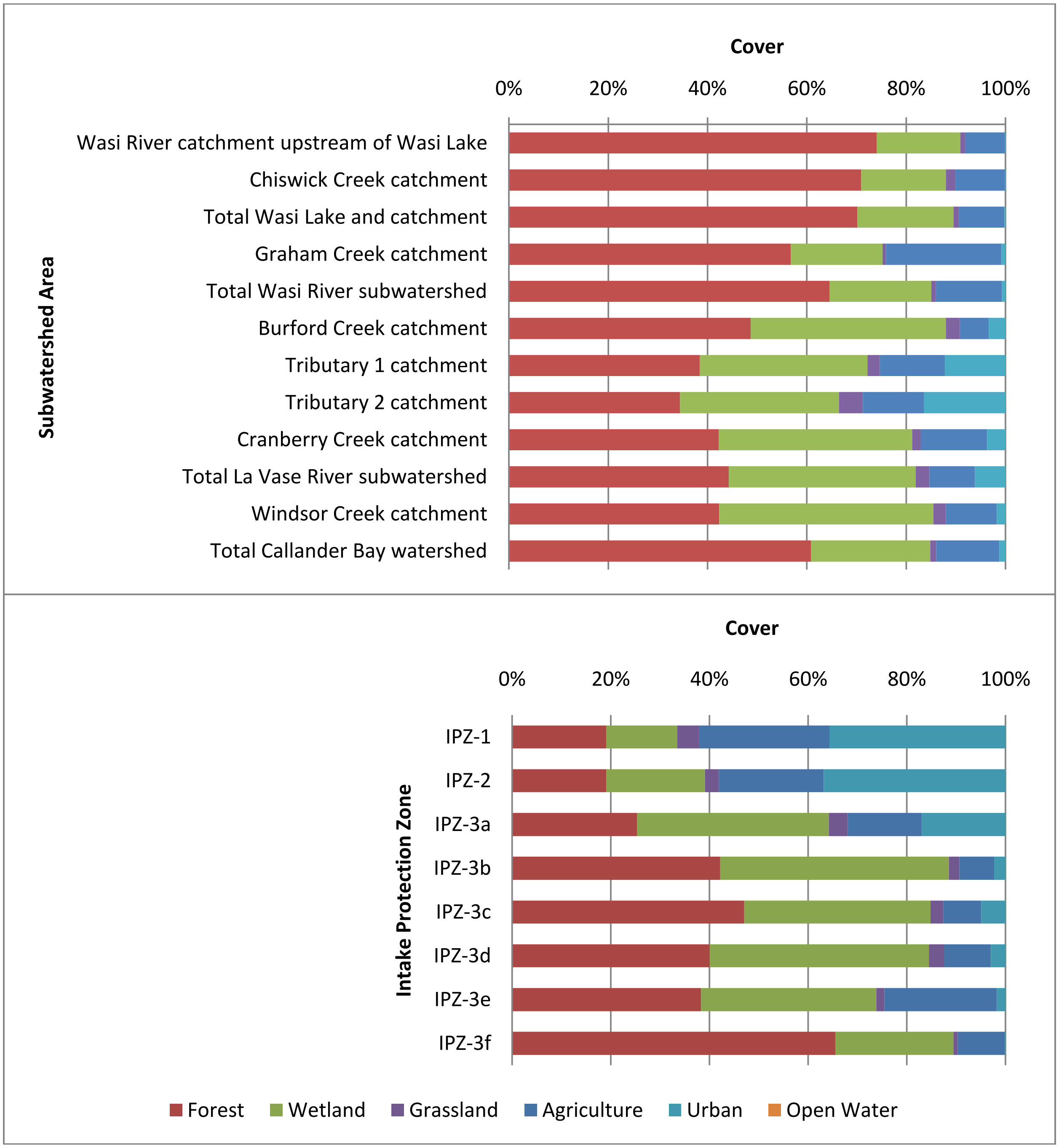
The Intake Protection Zones of the Callander drinking water intake encompass 41% of the land area in the Callander Bay watershed and include 49% of the disturbed lands, that is 47% of the agricultural area and 71% of the urban area in the Callander Bay watershed is located within 120-m of a water course or water body. The proximity of disturbed areas to surface water has implications for the supply of phosphorus to Callander Bay as phosphorus contained in overland runoff from these areas is more likely to reach surface waters and be transported to Callander Bay.

Table 4. Land Cover Summary by Callander Bay Subwatershed and Intake Protection Zone

Area		Land Cover (ha)						
		Forest[1]	Wetland[2]	Grassland	Agriculture[3]	Urban	Open Water	Total
By Suwatershed								
Wasi River Subwatershed	Wasi River catchment upstream of Wasi Lake	6,723	1,529	88	727	11	517	9,596
	Chiswick Creek catchment	1,281	307	34	180	2	114	1,918
	Total Wasi Lake and catchment	8,639	2,382	136	1,130	26	1,228	13,542
	Graham Creek catchment	3,429	1,114	41	1,404	50	678	6,716
	Total Wasi River subwatershed	13,134	4,180	190	2,707	144	3,106	23,461
La Vase River Subwatershed	Burford Creek catchment	560	452	32	67	39	120	1,271
	Tributary 1 catchment	119	104	8	41	38	34	343
	Tributary 2 catchment	83	77	12	29	39	12	252
	Cranberry Creek catchment	197	181	8	62	17	45	511
	Total La Vase River subwatershed	959	815	60	199	133	211	2,376
Bear-Boleau Creeks Subwatershed	Windsor Creek catchment	904	921	53	218	38	445	2,580
Total Callander Bay watershed (includes surface area of bay)		**14,997**	**5,916**	**303**	**3,125**	**315**	**4,968**	**29,623**
By Intake Protection Zone								
IPZ-1		5	4	1	7	10	nd	27
IPZ-2		4	4	1	4	7	nd	20
IPZ-3a		41	63	6	24	28	nd	162
IPZ-3b		123	135	6	21	7	nd	292
IPZ-3c		724	582	41	117	76	nd	1,540
IPZ-3d		585	650	44	139	44	nd	1,461
IPZ-3e		922	855	38	549	42	nd	2,407
IPZ-3f		4,077	1,487	54	593	11	nd	6,222
Total Intake Protection Zones		**6,481**	**3,779**	**192**	**1,455**	**224**		**12,131**
% of Callander Bay Watershed		**43**	**64**	**63**	**47**	**71**		**41**[4]

Notes:
nd – data not available at time of report production
[1]includes coniferous, deciduous and forest regeneration QuickBird classes
[2]includes marsh, swam and treed fen QuickBird classes
[3]includes agriculture 1 and agriculture 2 QuickBird classes (which includes golf courses and some manicured lawn areas)
[4]calculated as percent of Callander Bay land area only

Figure 5. Percent land cover in the Callander Bay watershed by subwatershed area and Intake Protection Zone excluding open water areas.



2.3 Phosphorus Concentrations

The concentration of phosphorus in surface water is a function of the supply of phosphorus and water from external sources and is moderated by aspects of basin morphometry (e.g., depth, surface area) that influence internal phosphorus dynamics (e.g., mixing regimes, sedimentation and resuspension of phosphorus). Phosphorus concentration monitoring by the NBMCA and the Province's Provincial Water Quality Monitoring Network (PWQMN) provide recent, quality phosphorus concentration data for Callander Bay, Wasi Lake and Wasi River that is representative of existing conditions and can be used with confidence to develop and validate the phosphorus budget as described in Section 3.

The NBMCA has been monitoring total phosphorus concentrations in Callander Bay and Wasi Lake on a nearly biweekly basis over the open water season since 2007. This monitoring program was expanded to include several locations along the Wasi River (11 sites), Graham River (6 sites) and Chiswick Creek (3 sites) from June to October in 2009 (Figure 6). In 2010, monitoring included an additional 2 sites, one on Burford Creek and one on Windsor Creek.

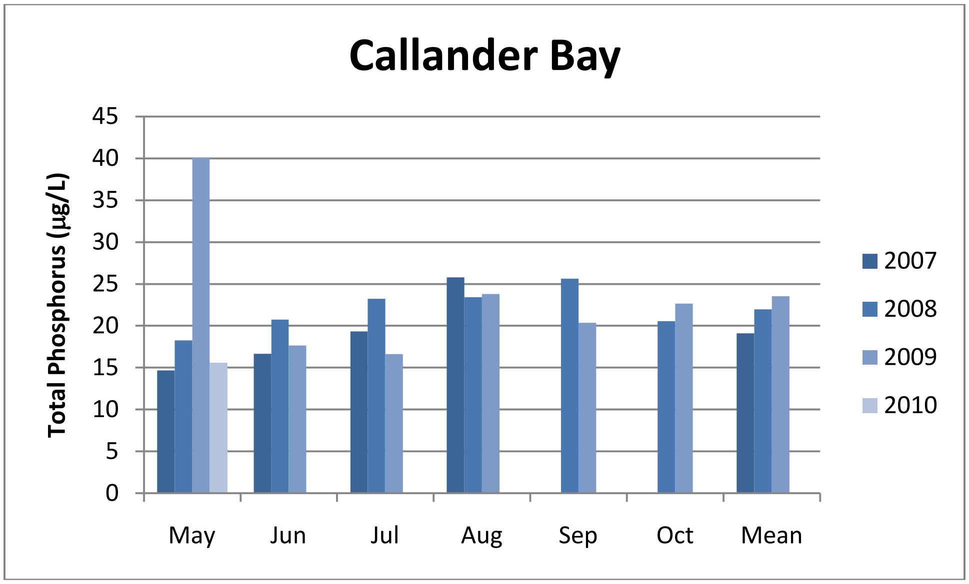
For the Wasi River, longer term total phosphorus concentration data are available from the Province's Provincial Water Quality Monitoring Network (PWQMN) station, which is the same location as the NBMCA's station W11. The Wasi River PWQMN station has been monitored sporadically since 1984, with a total of 14 years of total phosphorus concentration data collected monthly over the ice free period, typically from April to November.

Raw total phosphorus concentration data from all sources are presented in Appendix A (digital format) along with details of data evaluation (i.e., identification of outliers).

The mean ice free total phosphorus concentration in Callander Bay from 2007 to 2009 is 21.5 μg/L, which exceeds the Provincial Water Quality Objective of 20 μg/L for the protection against nuisance growth of algae. Concentrations are typically lowest in the spring (mean spring TP = 16.2 μg/L) and increase over the growing season reaching highest concentrations in mid to late summer (mean August TP = 24.3 μg/L) (Figure 7).

Figure 6. NBMCA phosphorus monitoring sites in Wasi River, Chiswick Creek and Graham Creek.

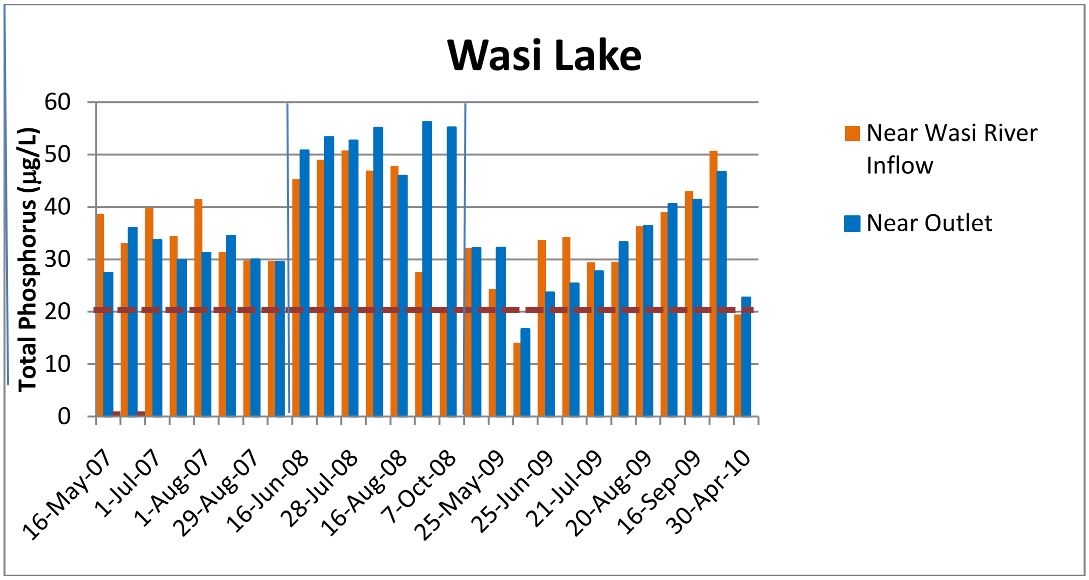
Figure 7. Mean monthly total phosphorus concentrations in Callander Bay (2007-2010) monitored by the NBMCA.



Note: Observed total phosphorus concentrations in May of 2009 are suspect of contamination or field/laboratory error.

For Wasi Lake, ice free total phosphorus concentrations from 2007 to 2009 were very high with a mean concentration of 36.2 µg/L, which greatly increase the risk of cyanobacterial blooms. Unlike Callander Bay, patterns in phosphorus concentration between years and over the ice free period are highly variable (Figure 8). Mean ice free concentration ranged from 39.7 µg/L in 2008 to 33.3 µg/L in 2009, representing a 20% difference in concentration between years. In 2007 and 2008, phosphorus concentrations did not display any apparent trend over the growing season, but in 2009, a strong increasing trend occurred with concentrations increasing from 30.2 mg/L in May to 48.7 ug/L in October. Variability is also noted between phosphorus concentrations measured near the inlet of the Wasi River and the outlet of Wasi Lake. Variability in phosphorus concentrations in Wasi Lake indicate that this lake is highly sensitive to hydrological differences (e.g., river discharge and precipitation patterns) and variability in phosphorus loading over the course of the growing season. Heightened sensitivity to changes in phosphorus and water loads may be due to the large surface area of the lake relative to the lake depth (mean depth ~2 m) in combination with the large watershed area of this lake relative to its surface area.

Figure 8. Mean monthly total phosphorus concentrations in Wasi Lake (2007-2010) monitored by the NBMCA.



Total phosphorus concentrations in Wasi River and tributaries in the Callander Bay watershed in 2009 and 2010 are summarized in Table 4 and Figures 9 to 11. Longer term monitoring data for the Wasi River from the PWQMN station are presented in Figures 12 and 13.

The Wasi River and smaller tributaries (Burford, Chiswick and Graham and Windsor creeks) monitored by the NBMCA all have mean total phosphorus concentrations above the PWQO of 30 µg/L for the protection against nuisance plant growth. For Chiswick and Graham creeks, phosphorus concentrations increase with distance downstream suggesting increased phosphorus loading to these tributaries as they become subject to human sources of phosphorus in the watershed (Figures 9 and 10). This trend is not consistently apparent along the length of the Wasi River (Figure 11); although concentrations typically increase downstream of station W2 with the occurrence of human disturbance in the watershed.

Mean annual phosphorus concentrations measured since 1984 in the Wasi River are variable ranging from 27 µg/L to 52 µg/L with a mean concentration of 43 µg/L (Figure 12). This interannual variability likely reflects annual differences in precipitation patterns, but may also be due to differences in the timing of sample collection as concentrations can vary considerably over the ice free season (Figure 13). With the exception of 2004, mean monthly phosphorus concentrations in the Wasi River increase following snowmelt and the spring freshet reaching maximum concentrations in August, then decrease to near spring concentrations by fall.

Table 5. Total Phosphorus Concentrations in Tributaries to Callander Bay, 2009-2010

Tributary (Code) Station	Total Phosphorus Concentration (µg/L)					n
	2009[1]	2010[2]	Mean	Minimum	Maximum	
BURFORD CREEK (BC)		**37**	**37**	**22**	**47**	**5**
BC1	nd	37	37	22	47	5
CHISWICK CREEK (C)	**46**	**34**	**40**	**10**	**93**	**39**
C1	47	22	35	10	71	15
C2	42	nd	42	21	93	9
C3	49	46	48	23	73	15
GRAHAM CREEK (G)	**39**	**43**	**41**	**10**	**81**	**77**
G1	18	20	19	10	30	14
G2	28	34	31	18	52	15
G3	43	nd	43	16	73	9
G4	46	59	53	20	79	15
G5	48	nd	48	21	75	9
G6	52	57	55	25	81	15
WASI RIVER (W)	**46**	**48**	**47**	**14**	**100**	**130**
W1	38	nd	38	28	49	8
W2	44	29	37	14	72	13
W3	42	nd	42	23	61	8
W4	47	55	51	18	100	13
W5	51	nd	51	36	98	8
W6	50	56	53	35	84	13
W7	44	44	44	31	57	13
W8	44	nd	44	32	76	8
W9	49	nd	49	28	87	8
W10	51	53	52	32	81	14
W11	46	47	47	28	62	24
WINDSOR CREEK (WC)	**nd**	**64**	**64**	**49**	**108**	**5**
WC1	nd	64	64	49	108	5

Notes: [1]average of biweekly samples collected June to October, [2]average of biweekly samples collected June to August, nd – no data

Figure 9. Mean monthly total phosphorus concentrations in Graham Creek (2009-2010). Sites numbers correspond to those provided in Figure 6 and increase with distance downstream in the river (G1 is the furthest upstream site and G6 is the furthest downstream site).

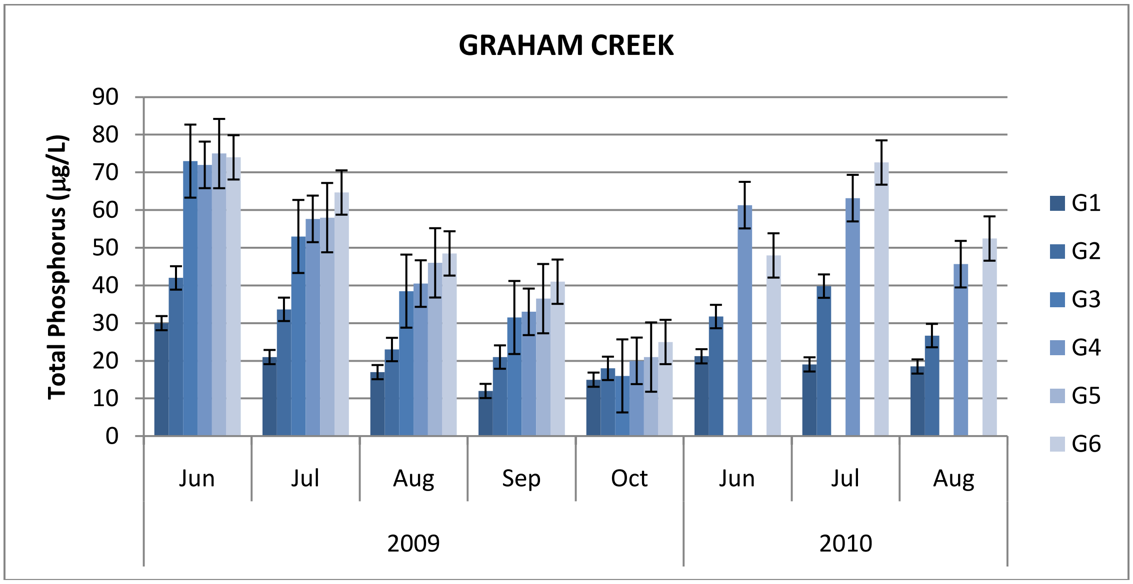


Figure 10. Mean monthly total phosphorus concentrations in Chiswick Creek (2009-2010). Sites numbers correspond to those provided in Figure 6 and increase with distance downstream in the river (C1 is the furthest upstream site and C3 is the furthest downstream site).

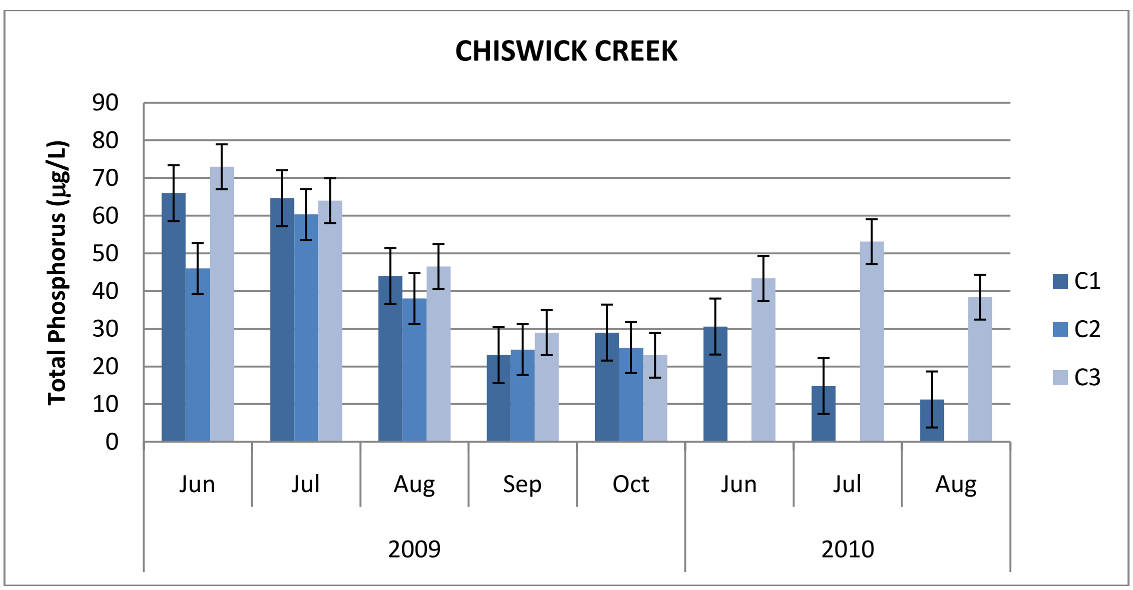


Figure 11. **Mean monthly total phosphorus concentrations in Wasi River (2009-2010). Sites numbers correspond to those provided in Figure 6 and increase with distance downstream in the river. Sites 1-6 (blue) are located upstream of Wasi Lake and sites 7-11 (red) are located downstream of Wasi Lake.**

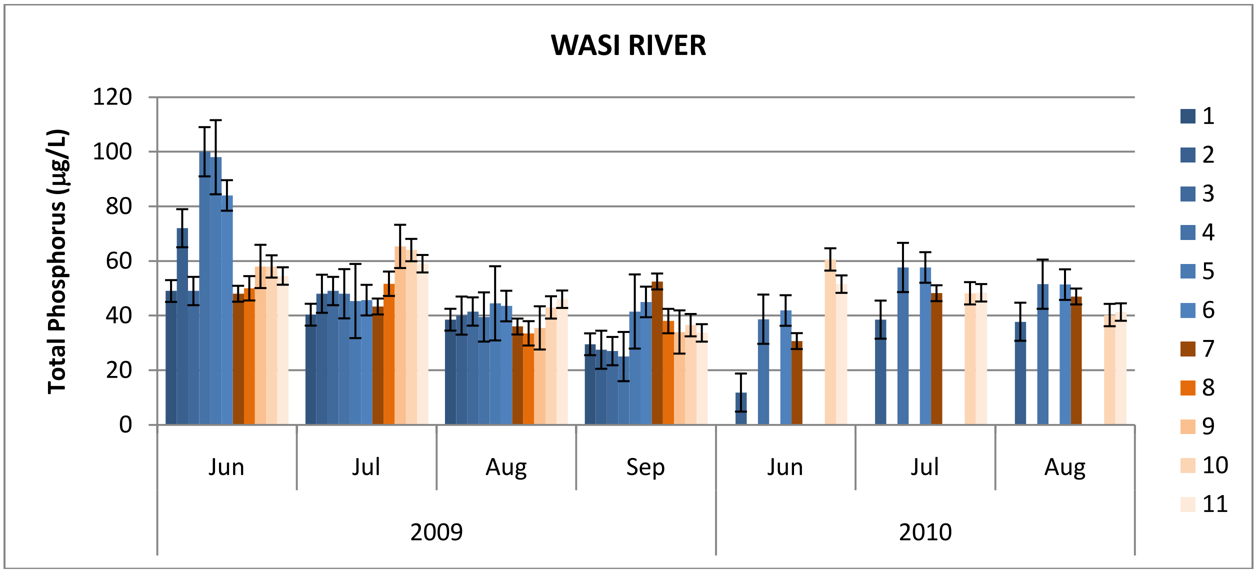
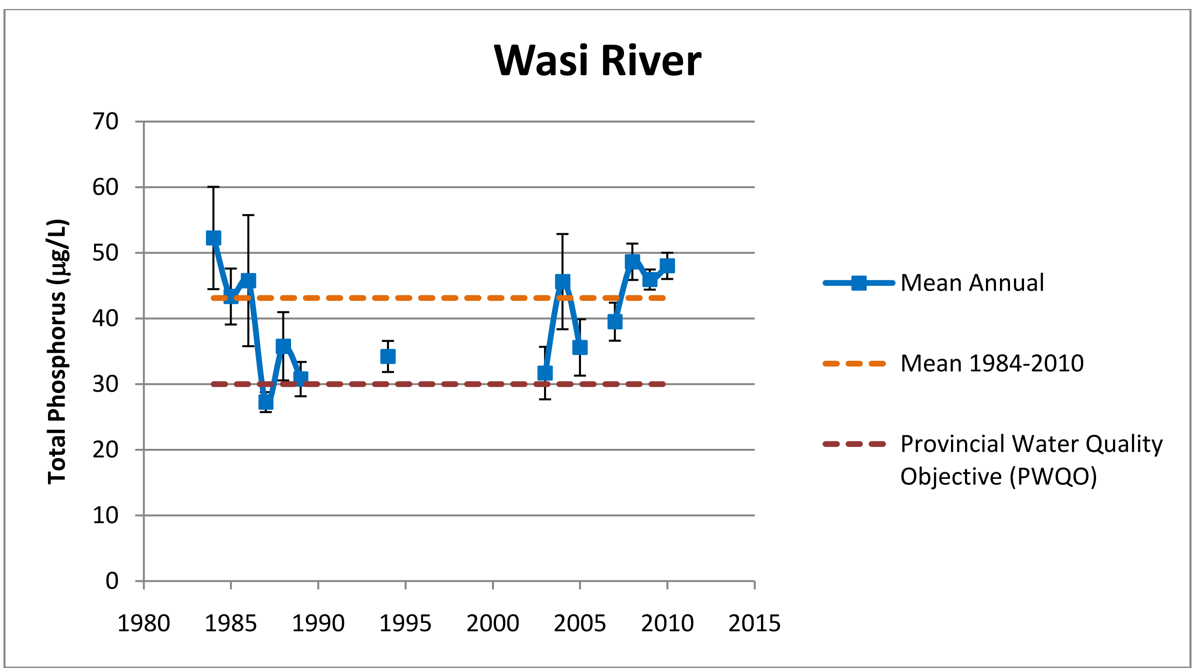
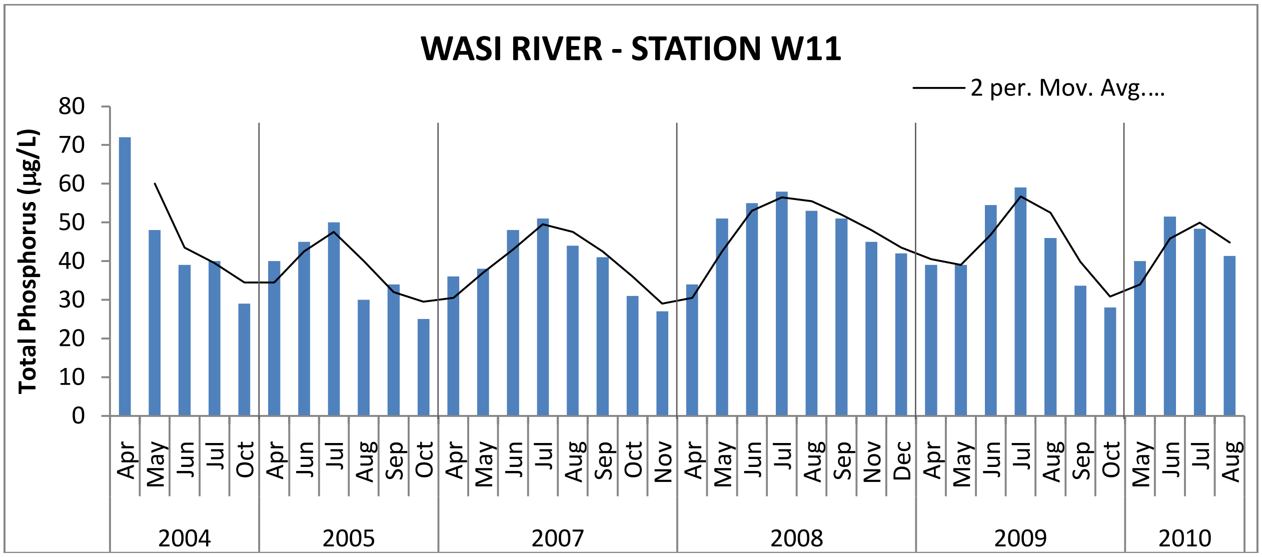


Figure 12. **Mean annual ice-free total phosphorus concentrations in Wasi River (PWQMN station data, 1984-2010).**



Note: Includes years with at least 4 measured values in the ice-free season (April to October).

Figure 13. **Mean monthly total phosphorus concentrations over the ice-free period in Wasi River at the PWQMN station (2004-2010).**



3. Phosphorus Budget Approach

We used two approaches to estimate the loading of phosphorus to Callander Bay. Export coefficient modelling was used to estimate the loading from specific source areas in the watershed, to identify the most important source terms and, for the future, to allow assessment of how source-specific terms might change with specific management practices. Total annual loadings were calculated from measured data on flow and concentration in the Wasi River to compare with estimates made by export coefficient modelling. To further validate the loading calculations, observed phosphorus concentrations in Wasi Lake and Callander Bay were concentrations predicted from a steady-state, mass balance water quality model.

3.1 Export Coefficient Modelling

An export coefficient modelling approach was used to calculate phosphorus loading to Callander Bay from non-point sources. The approach was developed in North America to predict nutrient inputs to lakes and streams (Dillon and Kirchner, 1975; Beaulac and Reckhow, 1982; Rast and Lee, 1983) and is now a well-established method of estimating phosphorus export when measured tributary flows and total phosphorus concentration data are lacking (e.g., Dillon *et al.* 1986, Johnes 1996, Winter and Duthie 2000, Paterson et al., 2006). The export coefficient approach is also used where it is desirable to forecast nutrient export from a land area prior to a change in land use or prior to implementing Best Management Practices, in which case it is used as a predictive tool.

The use of phosphorus export coefficients for estimating phosphorus loading is based on the knowledge that specific land use types yield or export quantities of phosphorus to a downstream waterbody over an annual cycle. The export coefficients are developed from intensive, long-term monitoring programs that are typically carried out by academic institutions or government agencies. Knowing the area of land in a watershed devoted to specific uses and the quantities of nutrients exported per unit area of these uses (nutrient export coefficients), it is possible to estimate total annual loads of phosphorus to Callander Bay from non-point sources using the equation:

$$L = \Sigma EiAi + P + S,$$

where L is the phosphorus load delivered to Callander Bay, Ei is the export coefficient selected for the specific land use/cover, Ai is the area of the land use/cover, P is the input from precipitation to the bay and S is the estimated input from septic systems within 300 m of the shoreline of Callander Bay and its tributaries. Export coefficients are expressed as rates (kg/ha/yr) and were derived from a survey of the literature.

Details of export coefficient selection and load calculations specific to each land use/cover type, precipitation and septic systems are provided in Section 4.

3.2 Measured Phosphorus Load Calculations

Phosphorus loads can be calculated for any water source carrying phosphorus to a water body (e.g., tributary, sewage effluent) if the total volume of water discharged to the water body and its phosphorus concentration are known, where:

$$P\ Load = Discharge \times TP\ Concentration$$

For the Callander Bay phosphorus budget, phosphorus loads were calculated using measured data for the Wasi River and for the Callander Sewage Treatment Plant.

3.2.1 Wasi River

Phosphorus loading from Wasi River to Callander Bay was calculated using measured discharge data in 2009 from the WSC monitoring site near Astorville and total phosphorus concentration data collected by the NBMCA and from the PWQMN Wasi River station (2004 to 2010).

Ideally, phosphorus loads should be calculated using long-term data to capture variability in discharge and phosphorus concentrations from year to year. For the Wasi River, however, only two full years of discharge data (2008 and 2009) are available from the WSC monitoring site near Astorville. As described above, the 2009 discharge data are likely representative of the long-term average while the 2008 flows were higher than average. Calculations are therefore based on 2009 discharge data only to better reflect average flow conditions.

Monthly runoff was calculated by dividing the monthly discharge of the river by the watershed area upstream of the monitoring station. Discharge from the total Wasi River watershed was then calculated for each month on a *pro rata* basis and summed to provide the total annual discharge.

Mean monthly total phosphorus concentrations were determined for the months of April to October using all available data from 2004 to 2010. Concentrations for the months of November to May were estimated by taking the average concentration observed for the months of October and April.

3.2.2 Callander Sewage Treatment Plant (STP)

Treated sewage discharge flows and phosphorus concentrations from the Callander Sewage Treatment Plant (STP) were obtained from Annual Reports prepared by the Ontario Clean Water Agency (OCWA) for the Municipality of Callander (2002-2009). Phosphorus loads during the lagoon release times (spring and fall) were calculated by multiplying the total volume of effluent discharged by the mean total phosphorus concentration of the treated effluent. The annual total phosphorus load from the STP is then the sum of the spring and fall loads.

3.3 Phosphorus Concentration Modelling

A variant of MOE's Lakeshore Capacity Model (LCM) was used to predict phosphorus concentrations in Wasi Lake and Callander Bay. This model is a steady-state, phosphorus mass balance model initially developed by Dillon et al. (1986) and revised in recent years by Hutchinson (2002) and Paterson et al. (2006), and is the recommended tool for setting development guidelines for Precambrian Shield lakes in Ontario (MOE, 2010). The model predicts total phosphorus concentration [TP] in lakes by estimating hydrologic and phosphorus loads from natural (watershed runoff and atmospheric deposition) and human (septic systems and land disturbance) sources and linking them together with an understanding of lake dynamics, using the equation:

$$[TP]_{ice\ free} = L_T * (1\text{-}R) * (0.965 * q_s)^{-1}$$

where L_T is the areal phosphorus loading rate (i.e., the total phosphorus loading divided by the lake surface area), R is the retention coefficient and q_s is the areal water load (i.e., outflow discharge divided by lake surface area).

For Callander Bay and Wasi Lake, total phosphorus loading was estimated as the sum of all loadings from natural and human sources as calculated using the export coefficient approach described above. Hydrological data from the Wasi River were on a *pro rata* basis to estimate water loads. It should be noted that the model is a 'closed basin' model and therefore cannot account for mixing of water between Callander Bay and Lake Nipissing and total phosphorus concentrations predicted by the model should be viewed with caution.

Predicted phosphorus concentrations from the model were compared to measured concentration to validate the phosphorus load calculations. If predicted and measured concentrations differ by 20% or less, this provides confidence in the choice of export coefficients and the calculation of the phosphorus budget.

Finally, the phosphorus concentration model was used to predict the responses of Callander Bay and Wasi Lake to reduced phosphorus loads that may be achieved by mitigation.

4. Phosphorus Budget Components

4.1 Natural/Undeveloped Phosphorus Loading

4.1.1 Atmospheric Loading

In nature, phosphorus has almost no gaseous forms and so the major transport mechanism is by water flow. Nevertheless, significant amounts phosphorus are transported via the atmosphere as dust and dissolved in precipitation and deposited directly to the lake surface. For many lakes, atmospheric deposition constitutes a significant portion of the total phosphorus load, particularly for those lakes with a large surface area relative to their catchment area.

Atmospheric loads are difficult to measure due to complexities with the collection and interpretation of precipitation chemistry data. It is preferable, therefore, to use estimates derived from regional, long-term study locations where reliable estimates of phosphorus in rainfall have been derived for multiple station datasets. In this case, a phosphorus deposition rate of 0.167 kg/ha/yr derived from 17-year records (1984-2001) at three meteorological stations in central Ontario at the Ontario Ministry of the Environment's Dorset Environmental Science Centre represents the nearest relevant atmospheric phosphorus deposition estimate. This loading rate was multiplied by the surface areas of water bodies to calculate phosphorus loading to the surface of Callander Bay, Wasi Lake and open water areas in the watershed (Table 6). Atmospheric loads to land surfaces are captured by the export coefficients used to calculate watershed loads from land areas.

Atmospheric deposition contributes a phosphorus loading of 201 kg/yr directly to the surface of Callander Bay and 629 kg/yr to the surface of open water bodies in its watershed for a total loading of 830 kg/yr.

Table 6. Phosphorus Loading from Atmospheric Deposition to Open Water Areas

Area		Open Water Area *(ha)*	Phosphorus Loading *(kg/yr)*
Wasi River Subwatershed	Wasi River catchment upstream of Wasi Lake	517	86
	Chiswick Creek catchment	114	19
	Total Wasi Lake and catchment (including Chiswick Creek and Wasi River catchments)	1,228	205
	Graham Creek catchment	678	113
	Total Wasi River subwatershed	3,106	519
La Vase River Subwatershed	Burford Creek catchment	120	20
	Tributary 1 catchment	34	6
	Tributary 2 catchment	12	2
	Cranberry Creek catchment	45	8
	Total La Vase River subwatershed	211	35
Bear-Boleau Creeks Subwatershed	Windsor Creek catchment	445	74
Callander Bay		**1,206**	**201**
Total Callander Bay and Open Water Areas in the Watershed		**4,968**	**830**

4.1.2 Runoff Loading

Natural phosphorus loads from the overland runoff in the watershed originate from phosphorus-bearing soils and decomposed organic matter. Groundwater may also contribute to natural phosphorus loads, but in Shield environments these contributions are most often negligible (Paterson et al., 2006).

For Canadian Shield lakes, wetlands can significantly control phosphorus loads from the watershed (Dillon and Molot, 1997). Based on 20 years of monitoring data at 20 lake watersheds in central Ontario by the Dorset Environmental Science Centre (DESC), natural phosphorus loads were observed to increase with wetland area following the equation:

$$P\ export\ (kg/yr) = catchment\ area\ (km^2) * (0.47 * \%\ wetland\ area + 3.82)$$

Given the large proportion of wetland area in the Callander Bay watershed, the Dillon and Molot (1997) equation was used to calculate the phosphorus loading from natural forested areas, which are summarized in Table 7 by individual subcatchment areas and by Intake Protection Zone (IPZ) of the Callander vulnerable area for drinking water source protection. Catchment area in the equation above includes all natural undeveloped vegetated areas (all forest, wetland and grassland areas described in Section 2.2).

It should be noted that not all phosphorus loads to Wasi Lake are transported downstream via the lake's outlet due to in-lake retention processes (uptake of dissolved phosphorus by plant life (algae) and settling of particulate phosphorus to lake sediments). Phosphorus loading rates in Table 7 do not account for phosphorus retention in Wasi Lake. The potential retention of phosphorus in Wasi Lake is discussed in Section 4.4.

The total phosphorus loading from natural runoff to Callander Bay is 3,403 kg/yr, 64% of which (2,162 kg/yr) originates from the vulnerable area of the Callander drinking water intake. Natural runoff contributes a total of 1,546 kg P/yr to Wasi Lake.

Table 7. Phosphorus Loading from Natural Runoff

Area		Natural Runoff Area (ha)	Wetland Area (%)	Phosphorus Loading (kg/yr)	Phosphorus Export (kg/ha/yr)
By Subcatchments					
Wasi River Subwatershed	Wasi River catchment upstream of Wasi Lake	8,341	18	1,024	0.123
	Chiswick Creek catchment	1,622	19	207	0.128
	Total Wasi Lake and catchment (including Chiswick Creek and Wasi River catchments)	11,158	21	1,546	0.137
	Graham Creek catchment	4,584	24	692	0.151
	Total Wasi River subwatershed	17,505	24	2,633	0.150
La Vase River Subwatershed	Burford Creek catchment	1,045	43	251	0.240
	Tributary 1 catchment	231	45	58	0.250
	Tributary 2 catchment	171	45	43	0.250
	Cranberry Creek catchment	387	47	100	0.259
	Total La Vase River subwatershed	1,834	43	441	0.240
Bear-Boleau Creeks Subwatershed	Windsor Creek catchment	1,879	49	505	0.269
Total Callander Bay watershed		**21,218**	**24**	**3,579**	**0.169**
By Intake Protection Zone					
IPZ-1		10	38	2	0.217
IPZ-2		8	48	2	0.264
IPZ-3a		110	57	34	0.306
IPZ-3b		264	51	73	0.278
IPZ-3c		1,346	43	323	0.240
IPZ-3d		1,279	51	355	0.278
IPZ-3e		1,815	47	470	0.259
IPZ-3f		5,618	26	901	0.160
Total Intake Protection Zones		**10,452**		**2,162**	**0.207**

4.1.3 Internal Loading

Internal loading of phosphorus to a lake can occur by either release from anoxic lake sediments or through the slower mineralization of organic matter from sediments in shallower areas of warmer water bodies. Callander Bay is sufficiently shallow to allow complete mixing of the water column and sediment resuspension is likely. Data collected by the NBMCA, however, indicate that periods of weak stratification do occur during the summer and anoxia develops in bottom waters. Both internal load mechanisms are therefore possible in Callander Bay. Internal loading is also likely in Wasi Lake. This lake is shallower than Callander Bay and periods of stratification-induced anoxia are unlikely to occur. Internal phosphorus load would most likely occur due to slow mineralization processes.

One way to assess whether internal phosphorus loading is an important contributor to phosphorus concentrations is through the use of lake modelling. In Section 4.4.2, we use a mass balance modelling technique to estimate total phosphorus concentrations in Callander Bay and Wasi Lake. The resulting modelled phosphorus concentrations compare very well with actual measured concentrations for Wasi Lake suggesting that internal load contributions are not likely significant. For Callander Bay, the model overestimated phosphorus concentrations. If internal phosphorus loading was significant, then the modelled values would be expected to underestimate concentrations because a loading source is not being accounted for.

Based on comparison of modelled and measured phosphorus concentrations, internal phosphorus loading is not likely a significant component of the phosphorus budget for Callander Bay or Wasi Lake.

4.2 Anthropogenic Phosphorus Loading

Human sources of phosphorus include point and non-point sources. Point source loads are direct inputs from a specific pollution source such as a sewage treatment plant or an industrial effluent discharger, and can be determined directly from measurements of concentration and volume of the discharge. Non-point sources are diffuse sources, which include septic systems, urban runoff (storm water) or agricultural runoff. Point and non-point sources may discharge directly to the water body or may enter from the watershed upstream of the water body.

4.2.1 Septic Systems

Calculation of phosphorus loads from septic systems follows the approach recommended by MOE's Ontario's Lakeshore Capacity Model (Paterson et al., 2006) where:

*Load per septic system (kg) = per capita phosphorus load (kg/capita/yr) * occupancy rate (capita yrs/yr)*

Based on a review of measured data and the literature pertaining to phosphorus concentrations in septic systems and average water usage, the per capita phosphorus load from septic systems is estimated to be 0.66 kg/capita/yr, 0.44 kg/capita/yr and 0.22 kg/capita/yr for septic systems within 100 m, between 100 and 200 m, and between 200 and 300 m of the shoreline, respectively. The majority of shoreline residences in the Callander Bay watershed are likely occupied year-round, therefore the permanent occupancy rate of 2.56 capita yrs/yr was chosen for all septic systems. The total number of septic systems was estimated by the number of un-serviced lots that lie (wholly or in part) within 100 m, 100 to 200 m and 200 to 300 m of the shoreline of Callander Bay or water courses and water bodies draining to Callander Bay. It should be noted that this is a gross approximation of the actual number of septic systems and actual counts would be required to refine estimates of the phosphorus loads.

While shoreline septic systems can be a significant source of phosphorus to lakes, recent scientific studies have shown that much of the septic phosphorus load is attenuated by acidic and mineral-rich soils found in the Precambrian Shield. Mechanistic evidence (Stumm and

Morgan, 1970; Jenkins *et al.*, 1971; Isenbeck-Schroter *et al.*, 1993) and direct observations made in septic systems (Willman *et al.*, 1981; Zanini *et al.*, 1997; Robertson *et al.*, 1998; Robertson, 2003) all show strong adsorption of phosphate on charged soil surfaces and mineralization of phosphate with iron (Fe) and aluminum (Al) in soil. The mineralization reactions, in particular, appear to be favoured in acidic and mineral rich groundwater in Precambrian Shield settings (Robertson *et al.*, 1998; Robertson, 2003), such that over 90% of septic phosphorus may be immobilized. The mineralization reactions appear to be permanent (Isenbeck-Schroter *et al.*, 1993). Recent studies conclude that most septic phosphorus may be stable within 0.5 m of the tile drains in a septic field (Robertson *et al.*, 1998, Robertson, 2003).

Trophic status modelling also supports the mechanistic and geochemical evidence of phosphorus attenuation by soils. Dillon *et al.* (1994), for example, reported that only 26% of the potential loading of phosphorus from septic systems around Harp Lake, Muskoka, could be accounted for in the measured phosphorus budget of the lake. The authors attributed the variance between measured and modelled estimates of phosphorus to retention of septic phosphorus in thick tills in the catchment of Harp Lake.

Given strong scientific evidence supporting attenuation of septic phosphorus by soils, combined with the large areas of deep till deposits in the watershed of Callander Bay, it is likely that not all phosphorus from shoreline septic systems is delivered to Callander Bay. Much of the phosphorus load from septic systems in areas of deep soils that are rich in iron and aluminum is likely attenuated with only a fraction of the potential load reaching the lake. Potential septic system phosphorus loads to Callander Bay were therefore estimated assuming 1) that all phosphorus reaches the bay (0% attenuation by soils), and 2) that only 26% of the septic phosphorus moves to the bay (74% attenuation by soils), in line with the findings of Dillon *et al.* (1994) (Table 8). Additional site specific information regarding soil conditions of septic systems is required to better estimate the actual phosphorus loads to Callander Bay from this source.

By definition, the vulnerable area (area of all IPZs) of the Callander drinking water intake for Drinking Water Source Protection includes all water bodies contributing water to Callander Bay and land area draining to those water bodies to a maximum setback of 120 m from the high water mark. As such, nearly all shoreline septic system phosphorus loads to Callander Bay originate from the vulnerable area of the Callander drinking water intake.

Septic systems contribute as much as 1,373 kg of phosphorus per year to Callander Bay and 381 kg per year to Wasi Lake assuming that 100% of the phosphorus is transported from the septic system to the adjacent water course or lake. Phosphorus loading from septic systems may be as little as 329 kg/yr and 91 kg/yr for Callander Bay and Wasi Lake, respectively if soils are assumed to attenuate 76% of the phosphorus. Additional site specific information regarding septic systems, their locations (distance from the shoreline) and soil conditions is required to more accurately estimate septic system loading.

Table 8. Phosphorus Loading from Shoreline Septic Systems

Area	Distance from Shoreline			Phosphorus Load (kg/yr)	
	<= 100 m	>100 - 200 m	>200 - 300 m	0% Attenuation	76% Attenuation
Wasi Lake shoreline	79	21	17	166	40
Wasi River and Chiswick Creek upstream of Wasi Lake	127	nd	nd	215	51
Wasi River downstream of Wasi Lake and Graham Creek	161	nd	nd	272	65
Total Wasi River Subwatershed	367	21	17	653	157
La Vase River subwatershed tributaries	192	nd	nd	324	78
Windsor Creek (Bear-Boleau Creeks subwatershed)	125	nd	nd	211	51
Callander Bay shoreline	66	47	36	184	44
Total Callander Bay	**750**	**68**	**53**	**1,373**	**329**
By Intake Protection Zone (IPZ)[1]					
IPZ-1	67			113	27
IPZ-2	43			73	17
IPZ-3a	67			113	27
IPZ-3b	5			8	2
IPZ-3c	192			324	78
IPZ-3d	125			211	51
IPZ-3e	161			272	65
IPZ-3f	206			348	84
Total IPZ	**866**			**1,463**	**351**

Notes: 'nd' – no data. [1]By definition, the IPZs include land area of up to 120 m from the high water mark of a water body or water course. Some septic systems in the IPZs may lie beyond 100 m and therefore contribute a lower phosphorus load than reported.

4.2.2 Agriculture

Specific agricultural practices in the Callander watershed are largely unknown but do include livestock operations (horse, sheep, cattle, pigs) with pasture and some cropland. In the absence of specific data, a general export coefficient of 0.30 kg/ha/year for cropland was chosen for agricultural areas, as the mean export from 198 watersheds draining cropland in North America calculated by Chambers and Dale (1997; range = 0.12-0.39 kg/ha/yr) and recommended for use in MOE's Lakeshore Capacity Model (Paterson et al., 2006). This coefficient is higher that the accepted export from cleared land/pasture (0.098 kg/ha/yr; Paterson et al., 2006), but recognizing that there are several livestock operations (with manure piles, feedlots) and some cropland with higher phosphorus exports, phosphorus supply from agricultural lands in the Callander Bay watershed is likely higher than from pasture alone. It should also be noted that manicured lawns and golf courses are included in the agriculture land class that would also have different phosphorus exports depending on fertilizer use, etc. More detailed agricultural land use data (e.g., area and type of cropland, number and type of livestock) and differentiation of lawns and golf courses are required to refine the calculation of phosphorus loading from agricultural lands to Callander Bay.

Phosphorus loading from agricultural lands are provided in Table 9 by subcatchment area and by Intake Protection Zone (IPZ) of the Callander vulnerable area for drinking water source protection.

The total phosphorus loading from agricultural runoff to Callander Bay is 937 kg/yr, 47% of which (436 kg/yr) originates from the vulnerable area of the Callander drinking water intake. Agricultural runoff contributes a total of 339 kg P/yr to Wasi Lake.

4.2.3 Urban Runoff

Urban runoff includes runoff from paved areas, disturbed surfaces, parking lots, lawns (fertilized and non-fertilized) and rooftops. This runoff can contain phosphorus from direct additions (i.e., fertilizers, animal droppings) and indirect sources such as erosion induced by increased runoff. The characteristics of urban runoff will therefore vary with the contributing areas and sources.

For the Callander Bay watershed, an export coefficient of 1.32 kg/ha/yr for developed urban areas was chosen from the nutrient model of Winter *et al.* (2003) for Lake Simcoe and recommended by the MOE for mid to high density urban areas. The resultant phosphorus loading from urban runoff are summarized in Table 9 by subcatchment area and Intake Protection Zones (IPZ) of the Callander vulnerable area for drinking water source protection.

The total phosphorus loading from urban runoff to Callander Bay is 315 kg/yr, 71% of which (296 kg/yr) originates from the vulnerable area of the Callander drinking water intake. Urban runoff contributes a total of 34 kg P/yr to Wasi Lake.

Table 9. Phosphorus Loading from Agricultural and Urban Lands

Area		Agricultural Land Area (ha)	Agricultural Phosphorus Loading (kg/yr)	Urban Land Area (ha)	Urban Phosphorus Loading (kg/yr)
By Subcatchments					
Wasi River Subwatershed	Wasi River catchment upstream of Wasi Lake	727	218	11	15
	Chiswick Creek catchment	180	54	2	3
	Total Wasi Lake and watershed	1,130	339	26	34
	Graham Creek	1,404	421	50	66
	Total Wasi River subwatershed	2,707	812	144	190
La Vase River Subwatershed	Burford Creek catchment	67	20	39	51
	Tributary 1 catchment	41	12	38	50
	Tributary 2 catchment	29	9	39	52
	Cranberry Creek catchment	62	19	17	23
	Total La Vase River subwatershed	199	60	133	176
Bear-Boleau Creeks Subwatershed	Windsor Creek catchment	218	65	38	50
Total Callander Bay watershed		**3,125**	**937**	**315**	**415**
By Intake Protection Zone					
IPZ-1		7	2	10	13
IPZ-2		4	1	7	10
IPZ-3a		24	7	28	36
IPZ-3b		21	6	7	9
IPZ-3c		117	35	76	101
IPZ-3d		139	42	44	58
IPZ-3e		549	165	42	56
IPZ-3f		593	178	11	14
Total Intake Protection Zones		**1,455**	**436**	**224**	**296**

4.2.4 Urban Waterfowl

Callander Bay has a large littoral area and abundant wetlands that provide exceptional natural habitat for waterfowl. There is concern, however, about large numbers of nuisance waterfowl (Canada geese) near waterfront areas of the Town, for example, at Centennial Park. In urban areas, habitat for waterfowl is increased due to human alteration of the landscape, often resulting in large numbers of waterfowl. Nuisance waterfowl sites in urban settings are typically associated with areas where forage materials are abundant (e.g., short grass) and where foraging birds can easily seek refuge on water if disturbed. Golf courses, parks, beaches and large expanses of lawns with unimpeded access to water often attract foraging waterfowl in large numbers, which can contribute significantly to the phosphorus load in urban settings.

The following provides an estimate of potential phosphorus loading from geese at Centennial Park based on casual observations of goose numbers in the summer and fall of 2010 and published estimates of phosphorus contributions from goose feces.

Following the methods of Moore et al. (1998), the average adult Canada goose (*Branta canadensis maxima*) exports approximately 1.22 g of phosphorus per day in feces. Given that geese do not reside at the park for the full day, not all of this phosphorus is input directly to the bay adjacent to the park, some is likely to be exported to other areas removed from the water or even other watersheds not draining to the bay. For this exercise, therefore, we assume that 50% of the potential phosphorus from the goose droppings (0.66 g) is delivered to the bay in the vicinity of Centennial Park. The occurrence of geese at Centennial Park is variable, with numbers ranging from approximately 25 to 70 geese per day beginning at the end of July to the end of September and with migratory flocks of over 100 birds in October (based on observations by J. Celentano, 2010). Assuming an average of 50 birds per day in August and September and 75 birds per day in October, approximately 3.0 kg of phosphorus is exported to the Bay from geese residing at Centennial Park. This is a gross estimate based on casual counts of birds at Centennial Park. There have been other reported cases of large numbers of foraging geese at Osprey Links golf course and at the ball field west of Callander Bay Drive. More detailed observational data would be required to more accurately determine the number of geese residing and foraging in urban areas near Callander Bay and to calculate the potential phosphorus load from this source.

While the export of phosphorus from urban waterfowl at Centennial Park is small in comparison to other sources, the export occurs over a short time period in a concentrated area. This source of phosphorus could therefore be a significant contributor to the phosphorus load during late summer and result in localized algal bloom activity in the beach area of the park. Moreover, the phosphorus-rich goose feces may be directly deposited to the lake and or washed into the lake from nearshore areas contributing to phosphorus enrichment of the sediments, which can lead to enhanced growth of nuisance aquatic macrophytes.

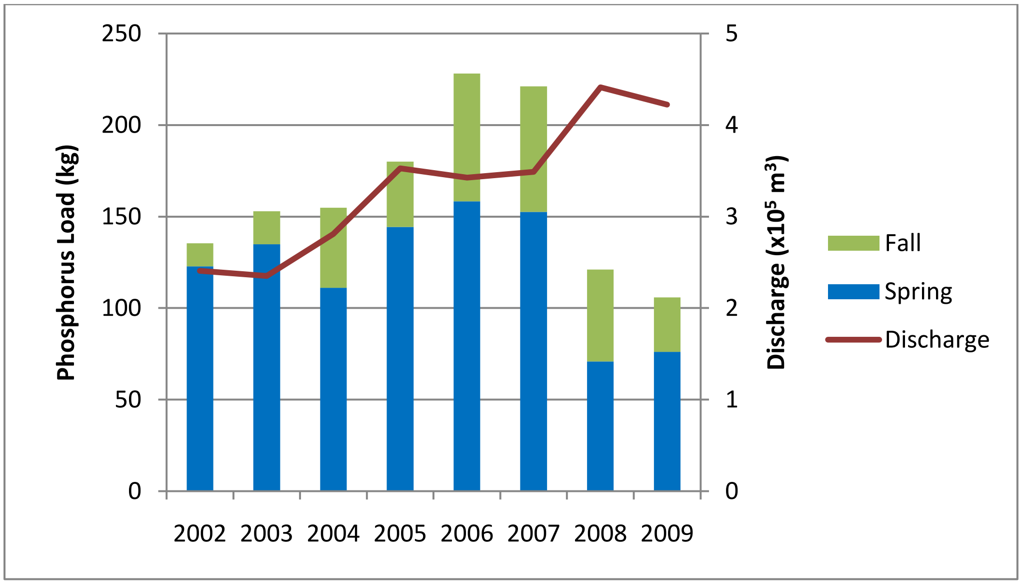
Canada geese residing at Centennial Park contribute approximately 3.0 kg of phosphorus per year to Callander Bay based on gross estimates of bird numbers and resident days.

4.2.5 Point Sources

The Callander Sewage Treatment Plant (STP), servicing approximately 1,400 people, is the only known point source of phosphorus to Callander Bay. The treatment system is a Class 1 Treatment system that consists of two seasonal release waste stabilization lagoons with a total volume of 264,000 m^3, and a 4,600 m^3 sludge disposal lagoon. The lagoons are treated with ferric sulphate to remove phosphorus and are released in spring and fall to Cranberry Creek, which then discharges to Callander Bay.

The total discharge of treated effluent to Callander Bay from the STP has increased steadily since 2002 from 240,714 m^3 to 422,354 m^3 in 2009 (Figure 14). Phosphorus loads increased proportionally with discharge until 2008, when improvements were implemented at the STP that effectively lowered the concentration of phosphorus in the treated effluent resulting in significantly lower phosphorus loads. The mean total phosphorus loading in 2008 and 2009 was 113.48 kg/yr in comparison to the 2002-2007 average loading of 178.72 kg/yr.

Figure 14. Phosphorus loads and effluent discharge volumes to Callander Bay from the Callander Sewage Treatment Plant (2002-2009).



The Callander STP contributes a loading of 113 kg P/yr to Callander Bay, which reflects current phosphorus removal abilities at the plant.

4.3 Total Loading

The total phosphorus loading to Callander Bay from all sources described above ranges from 7,065 kg/yr assuming all septic phosphorus migrates to the bay, to 6,022 kg/yr assuming that soils attenuate 76% of the septic load. These loading estimates, however, do not take into account the potential for phosphorus retention in Wasi Lake. Not all phosphorus contained in a lake is passed on to downstream lakes because a portion of the phosphorus is lost from the water column to the sediments.

The amount of phosphorus retained in a lake (R) is a function of the relationship between its areal water load (q) and the settling velocity (*v*) of phosphorus, where:

$$R = v/(v+q)$$

The settling velocity (*v*) of phosphorus is estimated to be 12.4 m/yr for stratified oligotrophic lakes on the Precambrian Shield and 7.2 m/yr for those stratified lakes with anoxic hypolimnia (Dillon *et al.* 2006). These settling velocities, however, are not applicable to Wasi Lake. Wasi Lake is very productive (eutrophic) and because it is shallow (mean depth = ~2 m), its water column is easily mixed by wind which prevents thermal stratification and maintains oxic conditions near the sediments. In shallow lakes, wind mixing results in slower settling of phosphorus (and reduced in-lake retention) in comparison to stratified lakes with similar areal water loads. There are no known published estimates of settling velocities for shallow, productive lakes like Wasi Lake. Based on comparisons between measured and modelled phosphorus concentrations in shallow lakes in the City of Elliot Lake (HESL, 2010) and in Seguin Township (AECOM, 2009), a settling velocity of 3.6 m/yr was found to best approximate phosphorus retention in shallow lakes. Using this settling velocity, the phosphorus retention (R) in Wasi Lake is 0.29; that is 29% of the phosphorus in Wasi Lake is lost to the sediments and not passed downstream to Callander Bay. This retention is consistent with the results of detailed phosphorus mass balances constructed by measuring all inputs and losses of phosphorus to Rice Lake and Sturgeon Lake by the Ontario Ministry of the Environment (Hutchinson et al, 1994). The average phosphorus retention for three years was 21% for Rice Lake (average depth = 2.4 m) and 24% for Sturgeon Lake (average depth = 3.5 m).

A summary of phosphorus loading to Callander Bay is presented in Table 10 by subcatchment area and by Intake Protection Zones (IPZs) of the Callander drinking water vulnerable area for drinking water source protection considering a 29% retention of phosphorus in Wasi Lake. The relative contribution of the individual sources to the total loading to Callander Bay and Wasi Lake is summarized in Figure 15 assuming no attenuation of septic phosphorus by soils.

The total phosphorus loading to Callander Bay from all sources is 6,523 kg/yr assuming that all septic phosphorus reaches the bay and 5,564 kg/yr assuming 74% retention of septic phosphorus by soils. Between 58% and 65% of the total load to Callander Bay is supplied from land area encompassed by the Callander drinking water IPZs. For Wasi Lake, the total phosphorus loading from all sources is 2,505 kg/yr or 2,215 kg/yr assuming 0% and 74% attenuation of septic phosphorus by soils, respectively.

While there is likely some attenuation of septic phosphorus by deep minerogenic soils in the Callander watershed, results of the phosphorus budget validation suggest that septic phosphorus is for the most part, mobile (see Section 4.4). The 0% attenuation scenario is therefore likely to provide a closer estimate of the total phosphorus load from septic systems in the Callander watershed. As previously noted, more details septic system information is required to improve estimates of phosphorus loading from this source.

Assuming that all septic phosphorus reaches the lake, 60% of the total loading to Callander Bay is from natural sources. Septic systems are the largest human sources of phosphorus, supplying ~19% of the total loading to Callander Bay, followed by agriculture (13%) and urban runoff (6%). Only 2 % of the phosphorus loading is supplied by the Callander sewage treatment plant. A large portion (up to 84%) of the loading from human sources to Callander Bay originates from the IPZs.

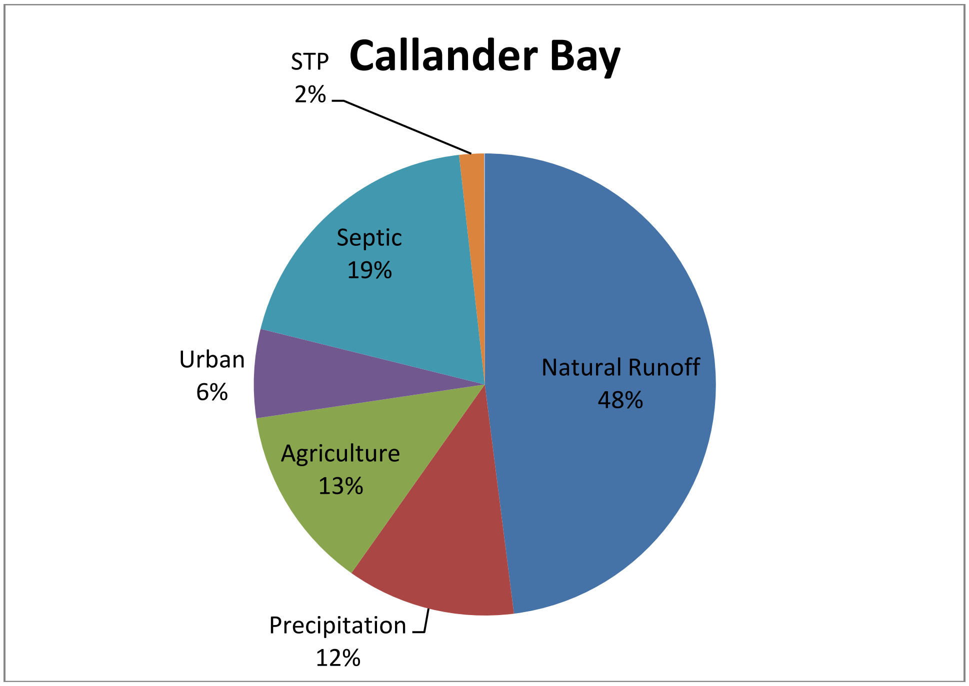
Assuming that all septic phosphorus reaches the lake, 70% of the total loading to Wasi Lake is from natural sources. Septic systems and agriculture contribute nearly equal loading (~15%) and urban runoff contributes only 1% of the total loading to Callander Bay, followed by agriculture (13%) and urban runoff (6%). Only 2 % of the phosphorus loading is supplied by the Callander sewage treatment plant.

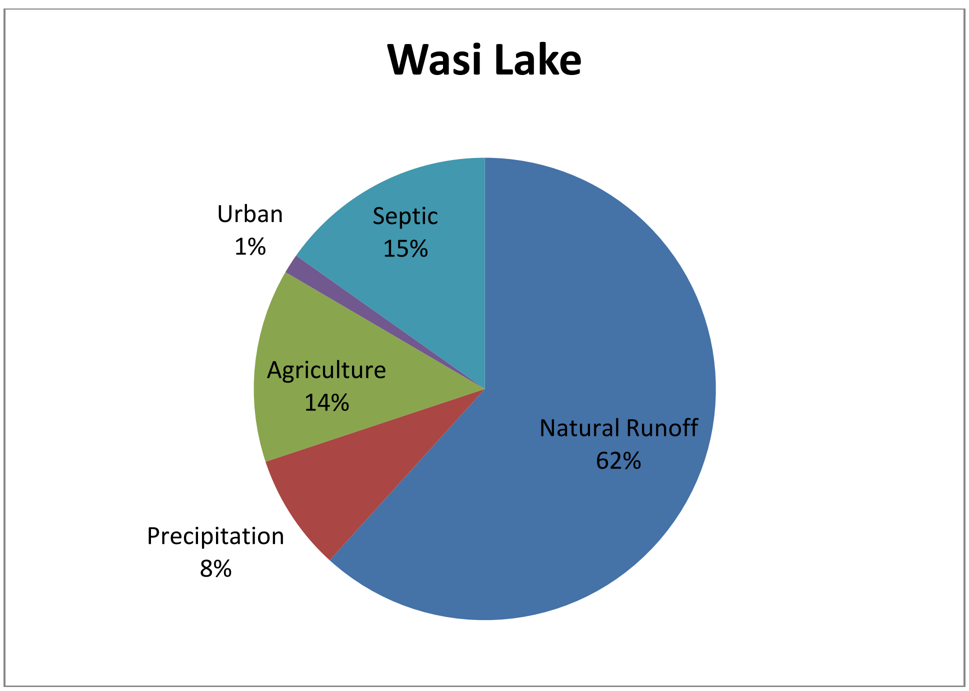
Table 10. Total Phosphorus Loading Summary

Area	Loading (kg/yr)								0% Attenuation of Septic Phosphorus		76% Attenuation of Septic Phosphorus	
	Natural Runoff	Precipi-tation	Agricultural Runoff	Urban Runoff	Septic[2] 0% Attenu-ation	Septic[2] 76% Attenu-ation	STP	Urban Water-fowl	Total Loading (kg/yr)	% of Loading to Callander Bay	Total Loading (kg/yr)	% of Loading to Callander Bay
By Subcatchments												
Wasi River catchment upstream of Wasi Lake	1,024	86	218	15					1,343	21	1,343	25
Chiswick Creek catchment	207	19	54	3					283	4	283	5
Total Wasi Lake and catchment	1,546	205	339	34	381	91			2,505	40	2,215	41
Graham Creek catchment	692	113	421	66					1,293	20	1,293	24
Total Wasi River subwatershed[1]	2,185	459	714	180	543	130			4,081	64	3,668	68
Burford Creek catchment	251	20	20	51					342	5	342	6
Tributary 1 catchment	58	6	12	50					125	2	125	2
Tributary 2 catchment	43	2	9	52					106	2	106	2
Cranberry Creek catchment	100	8	19	23					149	2	149	3
Total from La Vase River subwatershed	441	35	60	176	324	78			1,036	16	789	15
Windsor Creek catchment	505	74	65	50	211	51			905	14	745	14
Total Callander Bay[1]	**3,130**	**770**	**839**	405	**1,262**	**303**	**113**	**3**	**6,523**	**100**	**5,564**	**100**
By Intake Protection Zone (IPZ)												
IPZ-1	2		2	13	113	27		3	133	2	47	1
IPZ-2	2		1	10	72	17			85	1	30	1
IPZ-3a	34		7	36	113	27			190	3	104	2
IPZ-3b	73		6	9	8	2			96	2	90	2
IPZ-3c	323		35	101	323	78			782	12	537	10
IPZ-3d	355		42	58	210	51			665	10	506	9
IPZ-3e	470		165	56	271	65			962	15	756	14
IPZ-3f [1]	640		0	0	640	0			1,280	20	640	12
Total IPZs	**2,162**		**436**	**296**	**1,371**	**329**			**4,265**	**65**	**3,223**	**58**

Notes: [1]values adjusted to account for a 29% retention of phosphorus in Wasi Lake; 2septic systems around the shoreline of Callander Bay are included in the totals for Total Callander Bay and Watershed area only (not in individual subwatershed areas)

Figure 15. Relative contribution of phosphorus sources to the total phosphorus loading to Callander Bay and Wasi Lake assuming no attenuation of septic phosphorus by soils.





4.4 Phosphorus Budget Validation

4.4.1 Measured Versus Modelled Loading from the Wasi River

On average, the Wasi River supplies a loading of 4,105 kg/yr from all sources in its watershed to Callander Bay based on measured long-term total phosphorus concentration data (2004-2010) and limited hydrological data (2009) (Table 11), which represents an export of 0.184 kg/ha/yr from the Wasi River watershed to Callander Bay. More than 55% of the loading occurs during the spring (March to May) when runoff from the watershed is greatest.

The measured loading from Wasi River differs by 18% from the loading of 4,834 kg/yr that was calculated using an export coefficient approach (modelled loading) and is greatly improved to a difference of only 1 to 11% when phosphorus retention in Wasi Lake is accounted for in the budget (modelled loading = 4,081 kg/yr) (Table 12). The close agreement between measured and modelled phosphorus loading from the Wasi River provides confidence in the chosen export coefficients to estimate phosphorus load from different land use types in the Callander Bay watershed as well as the estimation of phosphorus retention in Wasi Lake. Furthermore, the closer agreement between measured and modelled loading when no septic system phosphorus is assumed to be attenuated by soils suggests that septic system phosphorus is mobile in the watershed.

Table 11. Measured Phosphorus Loading from the Wasi River to Callander Bay

Month	Mean Total Phosphorus Concentration (µg/L)	2009 Depth of Runoff (m)	Total Phosphorus Load (kg)	% of Annual Phosphorus Load
Jan	35.9	0.036	307	7.47
Feb	35.9	0.021	174	4.24
Mar	35.9	0.054	460	11.20
Apr	44.2	0.119	1,235	30.10
May	42.7	0.059	594	14.47
Jun	50.2	0.021	252	6.13
Jul	53.2	0.017	217	5.28
Aug	43.8	0.011	111	2.71
Sep	37.8	0.006	51	1.23
Oct	27.6	0.019	123	3.00
Nov	35.9	0.041	343	8.35
Dec	35.9	0.028	239	5.83
Annual	***39.9***	***0.432***	***4,105***	***100.00***

Table 12. Comparison of Measured and Modelled Loading from the Wasi River to Callander Bay Assuming 29% Retention of Phosphorus in Wasi Lake

Scenario	Loading *(kg/yr)*
Measured	4,105
Modelled with no septic attenuation *% difference from measured*	4,081 *1*
Modelled with 74% septic attenuation *% difference from measured*	3,668 *11*

4.4.2 Phosphorus Concentration Modelling

Wasi Lake

The modelled total phosphorus concentration in Wasi Lake ranges from 31.8 μg/L assuming that all of the phosphorus from shoreline septic systems reach the lake, to 28.2 μg/L assuming that 74% of the septic phosphorus is attenuated by soils.

The modelled phosphorus concentrations reflect long-term steady state conditions in Wasi Lake and compare well with measured phosphorus concentrations observed in 2007 and 2009 (Table 13). In 2008, mean total phosphorus concentration was elevated by more 35% over the 2007/2009 average, which exceeds the inter-annual variability of ~20% that is typically seen in Shield lakes monitored by MOE's Lake Partner Program (Bev Clark, p. comm.). This suggests that phosphorus concentrations were anomalously high in 2008, likely due to the high precipitation that occurred that summer, and are not likely representative of long-term mean conditions in the lake.

Both modelled phosphorus concentrations (with and without septic phosphorus attenuation by soils) are within 20% of the mean measured concentration in 2007 and 2009) (Table 13), which is an acceptable degree of error (Paterson et al., 2006) and provides confidence the estimated phosphorus loads to Wasi Lake. There is a better agreement between measured and modelled total phosphorus concentrations in Wasi Lake when no attenuation of septic phosphorus is considered in the model. This suggests that phosphorus from shoreline septic systems is mobile and reaches the lake.

Table 13. Comparison between Measured and Modelled Phosphorus Concentration in Wasi Lake

		Total Phosphorus Concentration (μg/L)	n
Measured	**2007**	33.7	14
	2008	44.8	16
	2009	32.9	22
	Mean	37.1	
	Mean 2007 and 2009	33.3	
Modelled	**No attenuation of septic P**	31.8	
	% difference from Mean (2007/2009)	4.5	
	74% attenuation of septic P	28.2	
	% difference from Mean (2007/2009)	15.3	

Callander Bay

The modelled total phosphorus concentration in Callander Bay ranges from 31.7 μg/L assuming that all of the phosphorus from shoreline septic systems reach the lake, to 27.0 μg/L assuming that 74% of the septic phosphorus is attenuated by soils. These estimates differ by 45% and 25%, respectively from the observed mean ice free phosphorus concentration in the bay (2007-2009) of 21.7 μg/L. Reasons for the discrepancy between modelled and measured phosphorus concentrations may be due to:

1. Inability of the model to account for mixing with Lake Nipissing. As the phosphorus concentrations in Lake Nipissing are lower than those in Callander Bay, inflow of water from Lake Nipissing would result in a reduction of the potential phosphorus concentration in Callander Bay given the same loading estimates,
2. Inability to accurately determine settling velocity and the loss of phosphorus to the sediments. A settling velocity of 7.2 m/yr was assumed for the above model predictions. This settling velocity is greater than that used for Wasi Lake (3.6 m/yr) as Callander Bay is deeper and does undergo periodic stratification.
3. Over-estimation of total phosphorus loading to Callander Bay. While an over estimation of the phosphorus loading to the bay is possible, we note that there was excellent agreement between measured and calculated loads in the Wasi River, which encompasses a large portion of the total watershed area of the bay. It is possible that septic phosphorus loads are over-estimated for Callander Bay due to attenuation by soils, or an over estimation of the number of septic systems in the Callander Bay watershed. We note, however, that evidence from measured and modelled phosphorus loads in Wasi River and predicted and measured phosphorus concentrations in Wasi Lake suggest that septic phosphorus is most likely mobile.

In summary, the large discrepancy between measured and predicted phosphorus concentrations in Callander Bay precludes the use of the model to estimate phosphorus concentration changes with loading reductions by mitigation.

4.4.3 Validation Summary

Overall, there is a high degree of confidence in the total estimated phosphorus loading to Callander Bay from the Wasi River. This is supported by the agreement between measured and modelled loadings for the Wasi River (Section 5.4.2) and measured and modelled phosphorus concentrations in Wasi Lake (Section 5.4.3).

Results of the validation also suggest that phosphorus from shoreline septic systems is mostly mobile. While there are deep, mineral-rich soils in much of the Wasi River subwatershed that would potentially prevent or slow the movement of phosphorus to Callander Bay, hydrological conditions such as an elevated water table that reaches the septic beds may be preventing the soil attenuation processes. Site specific observations of shoreline septic systems that document soil type and depth, distance from the shoreline and depth of the water table are required to more confidently confirm the degree of septic phosphorus mobility.

For Callander Bay, there is discrepancy between measured and modelled total phosphorus concentrations likely due to a combination of inaccuracies in model inputs (i.e., settling velocity) and the inability of the model to account for mixing with Lake Nipissing, but also from an overestimation of the total phosphorus loading to the bay. Based on the excellent validation results from the Wasi River and Wasi Lake modelling, however, we suspect that the loading estimates for Callander Bay are likely a good approximation of the actual loads and that inaccuracies in the model result from the inability to accurately address phosphorus retention and mixing with Lake Nipissing.

5. Information Gaps and Future Monitoring Requirements

It should be noted that while total loadings from the Wasi River subwatershed to Callander Bay appear to be accurate, there remain information gaps that lead to uncertainty in the relative contribution of different sources of phosphorus to Callander Bay, particularly for agricultural activities and septic systems.

The agricultural land cover class does not differentiate between agricultural activities or identify livestock operations that would supply significantly different amounts of phosphorus. We therefore recommend that agricultural land use class be refined to include areas of pasture, field crops and row crops. In addition, information regarding the number and type of animals, location and sizes of feed lots and manure piles, etc. should be collected to aid in the determination of phosphorus loading from livestock operations.

The number of septic systems that lie within 300 m of a water body or water course in the Callander Bay watershed is still uncertain. Confirmation of septic systems, their distance from the water and the soil conditions around and under the tile bed is recommended to better estimate the phosphorus loadings from this source.

In summary, to refine phosphorus loading estimates the following information is required:

a) the areal coverage of existing agricultural practices, e.g., the area of pasture versus hayfields versus cropland,
b) the identification and area coverage of manicured lawns and golf courses,
c) the number of livestock present in the watershed,
d) the level of access of livestock to surface water bodies,
e) the number of septic systems in the watershed,
f) the condition of septic systems and soil characteristics in the watershed, and
g) the distance of septic systems to the next surface water body.

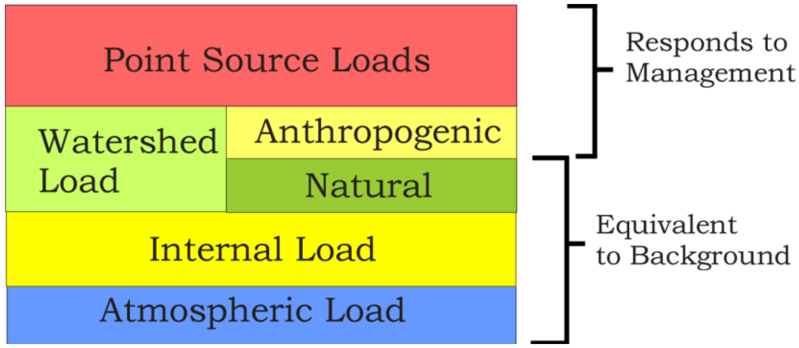
To assist with the validation of phosphorus loading using export coefficients, it is recommended that the tributary monitoring conducted by the NBMCA continue in future years. At the time of report production, phosphorus concentration data were only available for June to September, 2009. Additional data are required to estimate concentrations for the remainder of the year particularly in spring (April, May), and to establish mean concentrations. These data could then be used to validate the export coefficient loading estimates at discrete points along the tributaries as was done for Wasi River.

Finally, it is recommended that additional monitoring sites be established in agricultural streams to collect phosphorus concentration and flow data. This information would allow the calculation of landuse–specific phosphorus export from agricultural lands and be used to inform management opportunities. The number of additional sites and types of agricultural streams should be determined based on the relative amounts of different agricultural practices determined in the watershed.

6. Recommendations for Mitigation

Phosphorus loads from diffuse human sources represent a high proportion of the total load to Wasi Lake (30%) and Callander Bay (38%), which can be controlled by management practices (Figure 16).

Figure 16. Schematic illustrating phosphorus loads that can be controlled by management techniques.



The first step in developing a nutrient reduction strategy for a watershed is to identify the main nutrient sources in the watershed. This information is instrumental to developing watershed management measures that target the largest contributors and therefore will have the highest likelihood of improving downstream water quality. Based on this information, a priority list of issues to address can be developed that will guide the subsequent steps in the process, such as stakeholder consultation, financial considerations and decision making regarding the implementation of best management practices.

While the phosphorus budget for Callander Bay and Wasi Lake identifies agricultural practices and septic systems as the two primary human sources of phosphorus, additional information is required for both of these sources (see Section 5) to make definite management recommendations or to predict the potential loading reductions that could occur with implementation of management practices. At this stage, we provide a list of common Best Management Practices that focuses on agriculture and septic system sources (Table 14).

All of the BMPs listed in Table 14 have the potential to reduce nutrient loads to surface and ground water in the Callander Bay watershed, but to a different degree based on the importance of the practice in the watershed and the percentage of nutrient removal by the specific BMP. In order to quantify the potential nutrient load reduction by a specific BMP, the size of the operations to be managed and the effectiveness of the BMP in terms of nutrient load reduction need to be determined. The effectiveness of BMPs in terms of percent reduction in nutrient loads has been estimated in a number of studies, particularly for agricultural BMPs, with results differing from study to study. Reviews of these studies have been completed, however, such that an approximate effectiveness for some BMPs can be provided (e.g., Table 15).

Table 14. List of Best Management Practices to Reduce Diffuse Phosphorus Sources in the Callander Bay Watershed

Category	Best Management Practices	Regulated (R)/ Voluntary (V)
Urban		
Stormwater Management	Source controls (pet waste collection, street cleaning, reduced fertilizer)	V
	Lot level controls (e.g. grading, infiltration, green roofs)	V
	Conveyance (transport) controls (permeable pavement, pervious pipe, grass swales)	V
	Stromwater treatment (e.g. constructed wetlands, sand filters, OGS[1])	V
	Stormwater Ponds	V
	manufactured BMP systems (alumn additions, etc)	V
Riparian	Buffer strips, riparian maintenance in urban areas	V
Agriculture		
Runoff from Crops	Match fertilizer application to crop nutrient requirements and soil properties	V
	Crop rotations	V
	Proper fertilizer application timing	V
	Cover crops during non-grow season	V
	Improved fertilizer storage	V
	Reduced or no tillage	V
	Buffer strips (Vegetated areas along waterways), riparian maintenance	R
	Irrigation management (e.g. low water-loss technologies, reduced system leakage, optimal irrigation timing)	V
Livestock Operation	Restrict livestock access to surface water	R
	Rotation of grazing pastures	
	Minimizing runoff from livestock yards	V
	Milkhouse wash water treatment	V
Runoff from Farm Yards	Stormwater retention ponds, constructed wetlands, berms (soil barrier), planted waterways etc.	V
Manure	Manure storage controls	V
	Manure treatment (dewatering & nutrient removal systems)	V
	Manure land application practices (e.g. crop requirements)	V
	Distance from waterways, buffer strips between piles and waterways	R
Airborne Nutrients	Wind breaks (trees, hedges etc. to reduce soil erosion)	V
Biosolids	Restrictions on timing of applications	R
	Setbacks, application factors (soil type, slope, compaction)	R
Shoreline Development		
Septic Systems	Design/installation and initial inspection	R
	Use of best available technology	V
	Maintenance - pump regularly etc.	V
	Follow-up inspections	V
	Use of phosphate free products (into septics)	V
Overland Flow	By-laws regulating new lot sizes in Official Plans	R
	Limit use of lawns and fertilizers	R/V
	Buffer strips, riparian maintenance	V
Recreation	Grey water (non-sewage wastewater) disposal from boats	V

Table 15. Examples of Effectiveness of Best Management Practices for Phosphorus Load Reduction from Agriculture and Septic Systems

BMP Category	Specific BMP	Phosphorus Load without BMP	Phosphorus Export Reduction (%)
Milkhouse wastewater treatment	Flocculator	0.69 kg TP/cow/yr (excluding manure); 2.76 kg TP/cow/yr (including manure)	95-99
	Vegetated Filter Strip		7.2 – 100
	Settling Basins		5 – 67
	Constructed Wetland		45% - 99
	Anaerobic Lagoon		54-91
	Facultative Pond		5.5 – 91 (most > 80)
	Aerobic Lagoon		30-47
Manure storage	Daily Spreading	15.2 kg TP/cow/yr	90
	Dry & Roof		90
	Earthen		60-80
	Lagoon/flush		40-80
	Open Lot		70 +/- 20
	Pits & slats		95
	Scrape/storage tank		85-90
	Dairy pile manure	15.6 kg TP/cow/yr	80
Clean water diversion	Roof Diversion for Feedlot manure	Same as for Manure Storage	70
	Roof Diversion for Stockpiled Dairy Manure		80
	Berm Diversion for Feedlot Manure		70 for portion of runoff that is being retained by berm (often ~half)
Restrict livestock access to streams	Fencing Off (providing alternative water source)*	0.46 kg/cow/yr (Beef) 0.23 kg/cow/yr (Dairy) (from manure only)	100 (effect on manure only)
	Fencing Off	Erosion loss to be calculated for access area	75 – 98 reduced TP loss from erosion
Conservation tillage	Disk	1 kg/ha/yr	93
	Ridge Till		59
	Reduced Till		85%
	No Till		61%
Buffer strips for streams through crop land	Width ≤ 5 m		56%
	Width 6-10 m		67%
	Width 11 + m		74%
Cover crops			60%
Fragile land retirement			30%
Septic systems	Improve failing septic systems (only if within 50 m of a surface water body)	0.6 kg TP /capita/yr	70%

Notes: *Source: South Nation Conservation 2003. "Phosphorus Loading Algorithms for the South Nation River". Updated Source Accounting Methodology for the Rural Water Quality Program (prepared by Chris Allaway, University of Ottawa). *Providing alternative water source does not guarantee 100% reduction, but can still be effective (77% of reduction in stream bank loss and 98% in TP loading)*

The phosphorus reduction rates presented in Table 15 demonstrate that BMPs provide large opportunities for reducing the phosphorus contribution of diffuse sources from agricultural lands and septic systems to Callander Bay.

Once data gaps have been filled for agricultural areas and septic systems, appropriate BMPs can be selected to best address phosphorus loadings from these sources.

7. Implications for Source Protection Planning

The Technical Rules for Drinking Water Source Protection under the Clean Water Act (2002) require the delineation of an 'Issue Contributing Area (ICA)', that is, the area within which activities contribute to the concentration of a contaminant at a drinking water intake that is listed as a drinking water issue. For the Callander intake technical studies completed by HESL (2010), phosphorus was listed as a drinking water issue based on the documented occurrence of toxin-producing cyanobacteria blooms in Callander Bay and the known relationship between phosphorus concentrations and algal bloom activity. Recognizing that there are natural sources of phosphorus in the watershed and without knowledge of the contribution of phosphorus from human activities, the ICA was defined as the entire vulnerable area of the Callander intake (i.e., all IPZ areas), which is the maximum area allowed by the Technical Rules. Uncertainty remained, however, in the representativeness of the defined ICA to capture the primary sources of phosphorus to Callander Bay from human activities.

Results of the phosphorus budget for Callander Bay indicate that a large portion of the land area in the Callander Bay watershed is encompassed by the Intake Protection Zones, or the Issue Contributing Area (ICA). Furthermore, human sources of phosphorus in the ICA contribute a large portion (up to 84%) of the loading from human sources to Callander Bay. Based on these findings, it is concluded that the ICA defined by HESL (2010) does capture the primary sources of phosphorus to Callander Bay from human activities in the watershed and recommend that the ICA remain as defined.

In addition to the delineation of the ICA for the Callander intake, the phosphorus budget can be used to better inform the classification of threats (i.e., as significant, moderate or low) for drinking water source protection. Threats are defined by the Technical Rules as activities that contribute or potentially contribute to a contaminant at the intake. For threats related to phosphorus, this could be achieved by ranking human phosphorus sources according to their potential phosphorus loading contribution. This would, however, require refinements of the phosphorus budget to specifically account for loadings from different agricultural activities and from septic systems.

8. Conclusions

The phosphorus budget for Callander Bay derived from export coefficient modelling and measured phosphorus loads provides a reasonable estimate of phosphorus loadings from all major sources in the watershed, including natural sources (i.e., atmospheric deposition and runoff from undisturbed land areas) and human sources (i.e., agriculture, urban runoff, septic systems and STP effluent). Validation of the phosphorus budget with measured phosphorus loads in the Wasi River and by comparison of measured and modelled phosphorus concentrations in Wasi Lake provides a high degree of confidence in the total load estimates. Uncertainty in the relative contribution of phosphorus loadings from septic systems and different agricultural practices remains, however, but can be address with the collection of additional site-specific information.

Human sources account for approximately 38% of the total phosphorus loading to Callander Bay and 30% of the loading to Wasi Lake, a large portion of which can be controlled by Best Management Practices. Identification of the most appropriate BMPs for Callander Bay and Wasi Lake requires refinement of the phosphorus budget to better account for loadings from different types of agricultural practises and from septic systems.

While considerable load reductions can be achieved by BMPs, the natural phosphorus loading to Callander Bay and Wasi Lake is large such that these water bodies would remain relatively productive with potential for algal bloom activity even if all human sources of phosphorus were eliminated. Phosphorus load reductions, however, can reduce phosphorus concentrations in Callander Bay and Wasi Lake over current levels and hence reduce the risk of cyanobacteria blooms.

9. References

AECOM, 2009:
Callander Drinking Water Source Protection Technical Studies Update. Report prepared for the North Bay-Mattawa Conservation Authority, October 6th, 2009.

AECOM, 2010:
Big Bay Point Resort Development. Golf Course & Nutrient Management Plan – Environmental Management Plan. Prepared for Kimvar Enterprises Inc.

Downing, John A., S.B. Watson and E. McCauley, 2001:
Predicting *Cyanobacteria* dominance in lakes. Can. J. Fish. Aquat. Sci. 58:1905-1908.

Dillon, P.J., K.H. Nicholls. W.A. Scheider, N.D. Yan and D.S. Jeffries. 1986:
Lakeshore Capacity Study, Trophic Status. Research and Special Projects Branch, Ontario Ministry of Municipla affairs and Housing. Queens Printer for Ontario. 89p.

Dillon, P.J., W.A. Scheider, R.A. Reid and D.S. Jeffries, 1994:
Lakeshore Capacity Study: Part 1 – Test of effects of shoreline development on the trophic status of lakes. Lake and Reserv. Manage. 8:121-129.

Hutchinson, N.J., B.P. Neary and P.J. Dillon, 1991:
Validation and use of Ontario's trophic Status Model for establishing lake development guidelines. Lake and Resv. Manage. 7:13-23.

Hutchinson, N.J., 2002:
Limnology, plumbing and planning: Evaluation of nutrient-based limits to shoreline development in Precambrian Shield watersheds. In: R.L. France (ed). Handbook of Water Sensitive Planning and Design, CRC Press, London. Pp. 647-680.

Hutchinson Environmental Sciences Ltd. (HESL) 2010:
Callander Drinking Water Source Protection Technical Studies Update. Report prepared for the North Bay-Mattawa Conservation Authority, May 5th, 2010

Isenbeck-Schröter, M., U. Doring, A. Moller, J. Schroter and G. Matthes, 1993:
Experimental approach and simulation of the retention processes limiting orthophosphate transport in groundwater. J. Contam. Hydrol. 14:143-161.

Jenkins, D., J.F. Ferguson and A.B. Menar, 1971:
Chemical processes for phosphate removal. Water Res. 5:369-389.

Molot, L.A., P.J. Dillon, B. Clark and B.P. Neary. 1992:
Predicting end-of-summer oxygen profiles in stratified lakes. Can. J. Fish. Aquat. Sci. 49:2363-2372.

Ontario Ministry of the Environment, Lake Partner Program,
http://www.ene.gov.on.ca/envision/water/lake_partner/index.htm

Ontario Ministry of Environment, Lakeshore Capacity Handbook, EBR registry number 010-0690,
http://www.ene.gov.on.ca/envision/env_reg/er/documents/2008/Lakeshore%20Handbook.pdf

Ontario Ministry of Environment and Energy. 1996:
1995 Performance Report: Water Quality Analyses Section (ISSN 1198-3043).

Paterson, A. M., P. J. Dillon, N. J. Hutchinson, M. N. Futter, B.J. Clark, R. B. Mills R. A. Reid and W. A. Scheider 2006:
A review of the components, coefficients, and technical assumptions of Ontario's Lakeshore Capacity Model. Lake and Reserv. Manage. 22: 7-18.

Robertson, W.D., 2003:
Enhanced attenuation of septic system phosphate in noncalcareous sediments. Ground Water, 41:48-56.

Robertson, W.D., S.L. Schiff and C.J. Ptacek, 1998:
Review of phosphate mobility and persistence in 10 septic system plumes. Ground Water 36:1000-1010.

Rühland, K.M., A.M. Paterson, K. Hargan, A. Jenkin, B.J. Clark, and J.P. Smol, 2010:
Reorganization of algal communities in the Lake of the Woods (Ontario, Canada) in response to turn-of-the-century damming and recent warming. Limnol. Oceanogr., 55, 2433–2451.

Stumm, W. and J.J. Morgan, 1970:
Aquatic Chemistry. An Introduction Emphasizing Chemical Equilibria in Natural Waters. Wiley Interscience. New York. 583 pp.

Willman, B.P., G.W. Petersen and D.D. Fritton, 1981:
Renovation of septic tank effluent in sand-clay mixtures. J. Environ. Qual. 10:439-444.

Zanini, L., W.D. Roberson, C.J. Ptacek, S.L. Schiff and T. Mayer, 1998:
Phosphorus characterization in sediments impacted by septic effluent at four sites in central Canada. J. Contam. Hydrol. 33:405-429.

Tippett , J.P., and R.C. Dodd 1995:
Cost-Effectiveness of Agricultural BMPs for Nutrient Reduction in the Tar-Pamlico River Basin (NC). North Carolina State University College of Agricultural and Life Sciences. The NCSU Water Quality Group Newsletter Number 72 July 1995 ISSN 1062-9149.

10. Appendices

Phosphorus and hydrologic data files (digital)