Annual Water Balances and Total Phosphorus Loads to Lake Simcoe (2010–2011)

Lake Simcoe Region
conservation authority

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INTRODUCTION

The Lake Simcoe Region Conservation Authority (LSRCA) and the Ontario Ministry of the Environment and Climate Change (MOECC) have been collecting data, calculating water balances and phosphorus loads to Lake Simcoe and reporting the results since the 1990s. Estimates of total phosphorus (TP) loads to the lake are used to evaluate the progress towards achieving water quality-related objectives of the Lake Simcoe Protection Plan (LSPP; MOECC, 2009). This report is intended to complement the public report "Phosphorus Load Fact Sheet: Lake Simcoe 2010–2011" released by the LSRCA in October of 2015 by providing the technical methods and detailed results of the most recent loads. The report includes the methods used for the calculations of all components of the lake water balance, the TP loads, and the loss of TP from the lake through the outlet, and quantitative hydrological and water quality results for the 2010 and 2011 hydrologic years.

Description of the Study Area

Lake Simcoe and its watershed were described briefly by O'Connor et al. (2012) and in more detail by Palmer et al. (2011). For the purpose of this report, the watershed is divided into 17 subwatersheds of the major river systems and/or groups of smaller streams that drain to the lake (Figure 1). One of the larger subwatersheds, West Holland River, was divided further. There are several islands in Lake Simcoe, of which four are used in the water balance and load calculations. Figure 2 illustrates the major land uses [Ecological Land Classification and Land Use (ELC; LSRCA, March 21, 2014)].

METHODS

The water balance and loads calculated in this report are for the 2010 and 2011 hydrologic years, which run from June of the first year to May of the following year. The period for this report covers June 1, 2010 to May 31, 2012.

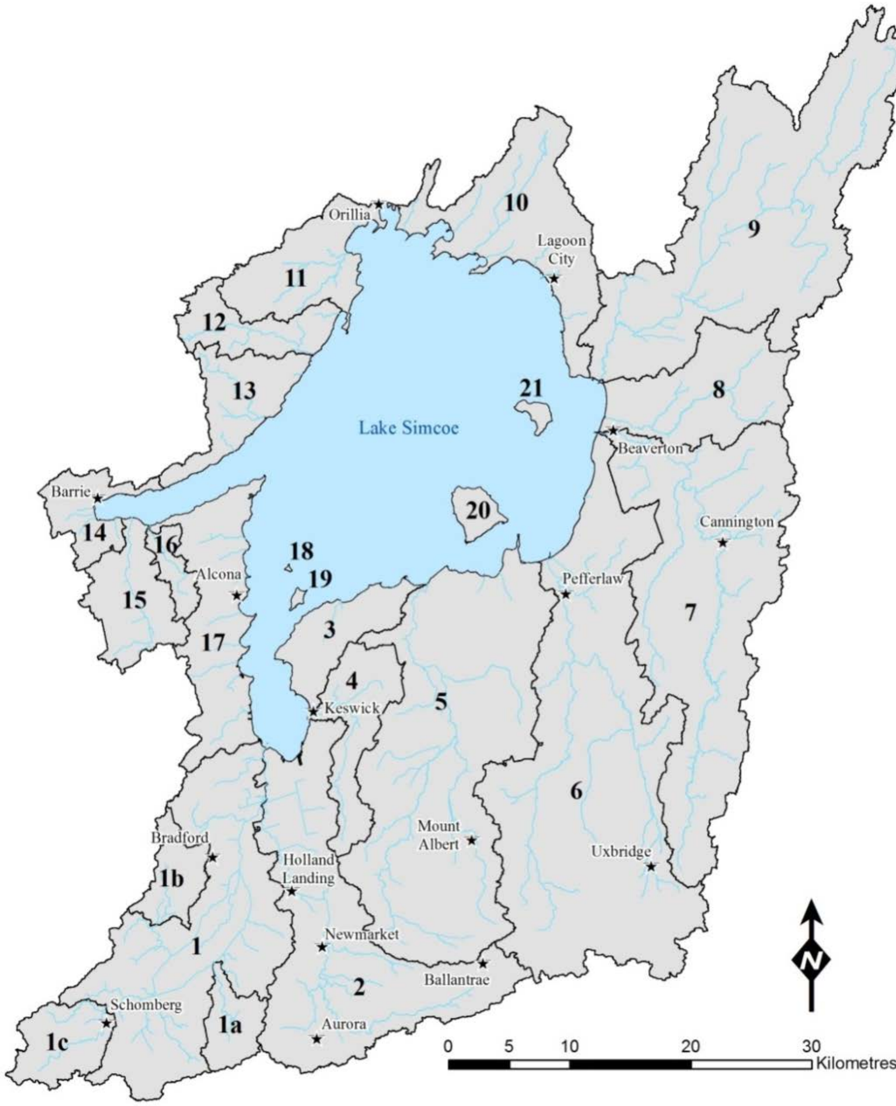
The methods used to calculate 2010–2011 loads generally followed those described by O'Connor et al. (2012) with some updates described by O'Connor et al. (2013). The current technical report will outline changes/improvements to methods and will make reference to the previous technical reports when methods have not changed. For the current report, annual water volumes for the water balance are reported in the units of km^3 ($1\ km^3 = 1 \times 10^9\ m^3$). Annual loads are reported in tonnes (t; 1 t = 1,000 kg).

Watershed and Subwatershed Delineation

The methods for delineating the subwatershed boundaries (Figure 1) were outlined in O'Connor et al. (2012). Delineation was performed within subwatersheds to determine the boundary of areas that were gauged and/or monitored for surface water quality (Figure 3; Table 1). The delineation of the Kettleby Creek subwatershed was revised to relocate the mouth of the creek at the Holland Marsh canal, rather than at the location of the gauge. This revision resulted in shrinking the ungauged portion of the West Holland River subwatershed.

Data Management

Water balance and phosphorus load calculations and data management for this reporting period were performed using a combination of Microsoft Office Excel 2010 and Kisters WISKI 7 software.



1 West Holland River - Unmonitored
1a West Holland River - Kettleby Creek
1b West Holland River - North Schomberg River
1c West Holland River - Upper Schomberg River
2 East Holland River (includes Keswick Creeks)
3 Georgina Creeks
4 Maskinonge River
5 Black River (includes Jacksons Point Creeks)
6 Pefferlaw Brook (includes Uxbridge Brook and Beaverton Creeks)
7 Beaver River
8 Whites Creek (includes Talbot Creeks)
9 Talbot River (includes Upper Talbot River)
10 Ramara Creeks
11 Oro Creeks North
12 Hawkestone Creek (includes Carthew Bay Creeks)
13 Oro Creeks South
14 Barrie Creeks
15 Lovers Creek
16 Hewitt's Creek
17 Innisfil Creeks
18 Fox Island
19 Snake Island
20 Georgina Island
21 Thorah Island

Figure 1. Subwatersheds and islands in the Lake Simcoe watershed. Star symbols are used to display some of the cities and towns in the watershed.

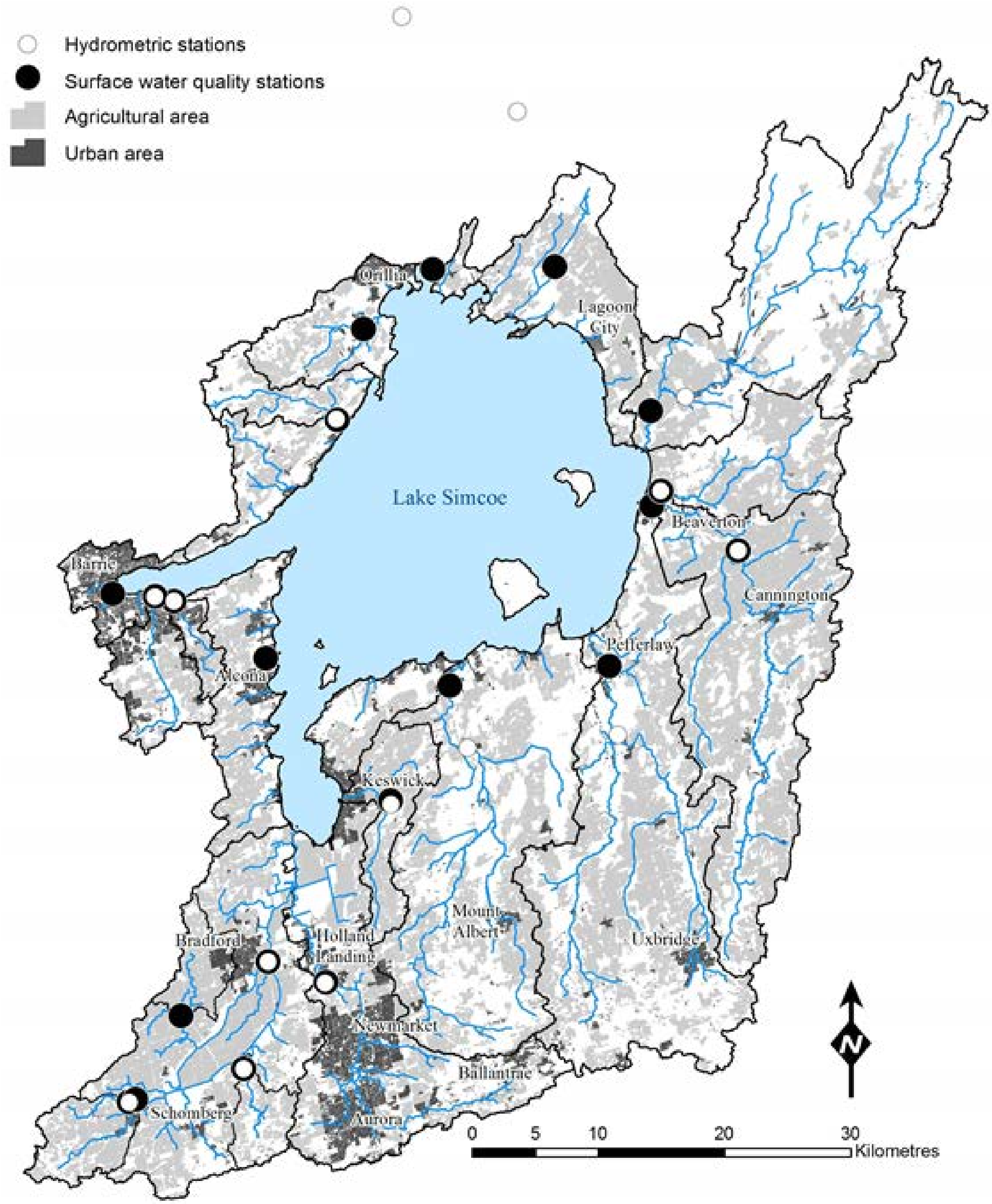


Figure 2. Agricultural and urban land use in the Lake Simcoe subwatersheds [Ecological Land Classification and Land Use (ELC; LSRCA, March 21, 2014)].

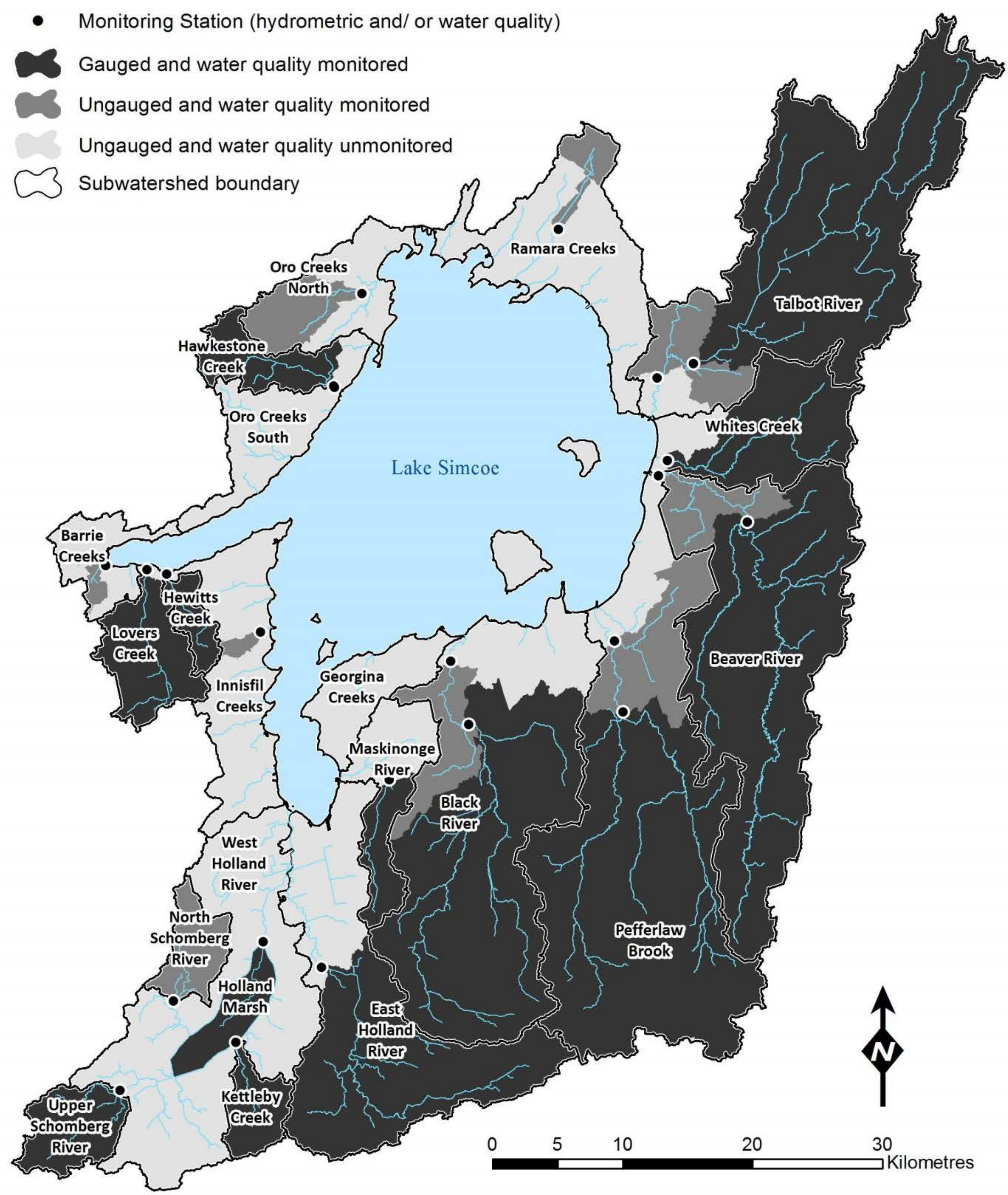


Figure 3. Depiction of gauged and surface water quality monitored areas in the Lake Simcoe watershed (2010–2011).

Table 1. Total subwatershed areas for the tributaries of Lake Simcoe with and without polder and urban areas (below monitoring stations), and gauged, ungauged, monitored and unmonitored areas by subwatershed.

Subwatershed	Total Subwatershed Area (m^2)	Subwatershed Area (not including urban area*) (m^2)	Subwatershed Area (not including urban and polder area)* (m^2)	Gauged Area ** (m^2)	Ungauged Area (m^2)	Monitored Area (m^2)	Unmonitored Area (m^2)
Barrie Creeks	37,534,219	15,522,946			37,534,219	4,400,150	33,134,069
Beaver River	327,254,244			291,197,800	36,056,444	327,031,225	223,019
Black River	375,360,377	373,180,649		277,317,800	98,042,577	316,539,225	58,821,152
East Holland River	247,148,081	240,487,267	233,071,832	173,707,900	73,440,181	173,707,900	73,440,181
Georgina Creeks	49,333,036	45,317,116			49,333,036		49,333,036
Hawkestone Creek	47,838,502			39,539,350	8,299,152	39,585,350	8,299,152
Hewitt's Creek	17,515,026			17,499,775	15,251	17,499,775	15,251
Innisfil Creeks	107,151,891	90,941,315			107,151,891	3,694,800	103,457,091
Lovers Creek	59,947,642	59,226,818		58,417,950	1,529,692	58,417,950	1,529,692
Maskinonge River	63,464,958	61,155,109		28,641,200	34,823,758	28,641,200	34,823,758
Oro Creeks North	75,263,531	60,709,550			75,263,531	31,634,900	43,628,631
Oro Creeks South	57,387,069				57,387,069		57,387,069
Pefferlaw River	446,238,216	445,280,726		347,741,300	98,496,916	409,833,325	36,404,891
Ramara Creeks	143,507,331				143,507,331	16,919,975	126,587,356
Talbot River	367,807,989			311,973,550	55,834,439	353,183,000	14,624,989
West Holland - Ungauged ***	217,838,397	207,402,135	202,667,423		217,838,397		217,838,397
West Holland - Holland Marsh	28,587,955			28,587,955		28,587,955	
West Holland - Kettleby Creek	29,300,800			28,526,875	773,925	28,526,875	773,925
West Holland - North Schomberg	32,133,197				32,133,197	32,133,197	
West Holland - Upper Schomberg	44,073,289			44,073,289		44,073,289	
Whites Creek	105,047,588	104,473,219		88,628,300	16,419,288	88,628,300	16,419,288
Fox Island	203,768				203,768		203,768
Georgina Island	12,912,101				12,912,101		12,912,101
Snake Island	1,355,200				1,355,200		1,355,200
Thorah Island	4,395,143				4,395,143		4,395,143
Lake Simcoe	722,778,556						
Total area of watershed	2,898,599,551						
Total area of watershed (incl. lake)	3,621,378,107						
Total gauged area				1,735,853,044			
Total ungauged area					1,162,746,506		
Total water quality monitored area						2,003,038,392	
Total water quality unmonitored area							895,607,159

* Only urban and polder areas below the gauge/monitoring stations were subtracted for monitored subwatersheds.
All urban or polder area was subtracted for ungauged/unmonitored subwatersheds.

** All gauged areas were used in the proration of flows for ungauged subwatersheds, except for Talbot River and Holland Marsh.

*** Does not include Holland Marsh.

Water Balance Supply and Loss Terms

The annual water balance expression is described by O'Connor et al. (2012).

The Hydrometeorological Monitoring Network

For this report, hydrometric station refers to stations or gauges that are designed for the purpose of measuring hydraulic variables of water, i.e., stage and/or discharge. Meteorological refers to stations designed for the purpose of measuring climatic variables, i.e., air temperature, relative humidity, precipitation depth, etc. Hydrometeorological refers to stations that are designed to measure both hydrometric and climatic variables.

In addition to the 14 hydrometric gauges used in the 2007–2009 report (O'Connor et al., 2013), two additional hydrometric gauges (Kettleby Creek at Highway 9 and Severn River at Swift Rapids) were used to calculate the 2010–2011 annual Lake Simcoe water balances (Figure 4; Table 2). Of these 16 gauges (11 hydrometric and five hydrometeorological), 12 were used to estimate tributary discharge from the various Lake Simcoe subwatersheds, three (Black River near Washago, Severn River at Hamlet Swing Bridge and Severn River at Swift Rapids) were used to estimate the discharge from the Lake Simcoe outlet and one (Bradford Pumping Station #2) was used to estimate discharge from the Holland Marsh. The naming conventions of some stations changed since the previous report (i.e., O'Connor et al., 2013) (Table 3).

Climatic variables used to calculate the 2010–2011 annual Lake Simcoe water balances were obtained from 12 meteorological stations and five hydrometeorological stations in or near the Lake Simcoe watershed (Table 2; Figure 4; Table 4). Stations were selected based on geographic distribution and data integrity.

Discharge from Gauged Tributaries

The method used to estimate discharge (water volume per unit time) was the same as described in O'Connor et al. (2012) for the 15 hydrometric gauges within or downstream of the Lake Simcoe watershed [Table 2; excluding Bradford Pumping Station No. 2, see *Discharge from Holland Marsh (Bradford Pumping Station No. 2)*]. Additionally, the Kettleby Creek at Highway 9 gauge became operational on July 14, 2010, so there was a short period (from June 1, 2010 to July 13, 2010) that was calculated using the same method described by O'Connor et al. (2012) for discharge from ungauged tributaries.

Discharge from Ungauged Tributaries

The method for estimating discharge from ungauged areas was described by O'Connor et al. (2012).

Discharge from Holland Marsh (Bradford Pumping Station No. 2)

The volume of water pumped from the Holland Marsh via the Bradford Pumping Station No. 2 (formerly the Art Janse Pumping Station; Table 3) was calculated for the 2007–2009 monitoring period using a linear regression between known pump volume (m^3) and known hydro consumption (kWh) (O'Connor et al., 2013). Known pump volumes were calculated as the product of the period of time that each pump was in operation and the capacity of each pump. For the 2010–2011 reporting period, the regression was updated to include six additional months of reliable pump volume data and corresponding monthly hydro consumption. The updated regression between hydro consumption and pump volume exhibits a strong positive relationship (r^2 =0.994, n =16). Using the updated regression, discharge for the full period (2010–2011) was modelled for each hydro billing period, which was approximately monthly. Daily discharge was estimated by dividing the discharge from the billing period by the number of days. Calendar month discharges were calculated as the sum of daily pump rates.

Discharge from Urban Point Sources

The method for estimating discharge from Urban Point Sources (i.e., WPCPs) was described by O'Connor et al. (2013), and stations are shown in Figure 5.

Precipitation (Direct to Lake)

The method for estimating precipitation volume direct to Lake Simcoe was described by O'Connor et al. (2013). A minimum of four gauges were used to calculate each daily value, with six or more precipitation gauges being used to calculate 98% of the average daily totals (Table 4).

Groundwater

Ground water contribution to Lake Simcoe was described by O'Connor et al. (2012).

Discharge from the Lake Simcoe Outlet (Atherley Narrows)

The method for estimating discharge from the Lake Simcoe outlet was described by O'Connor et al. (2013). However, for this reporting period the areas for both Lake Simcoe and Lake Couchiching were included in the proration of flows at Atherley Narrows (Figure 6). This increased the proration coefficient from 0.9027 (used for the 2007–2009 report) to 0.9100. Also, numerous small data gaps in the Severn River at Hamlet discharge time series had to be filled using a regression relationship between total daily discharge for Severn River at Hamlet and a downstream gauge, Severn River at Swift Rapids. Regression between the two gauges exhibited a strong positive relationship with a second order polynomial function providing the best fit for the two data sets (r^2 = 0.961, n = 924).

Evaporation (Direct from Lake)

The Complementary Relationship Wet-Surface Evaporation model (CWRE; Morton, 1983) was used to estimate evaporative loss from Lake Simcoe; the method is described in greater detail by O'Connor et al. (2013).

The average of daily minimum and maximum air temperatures was calculated using data from 14 stations (Table 4); nine or more stations were used for more than 90% of the days and no less than seven stations were used for any one day. Average dew point temperature was calculated using six stations; three or more stations were used 94% of the time. Atmospheric pressure from four meteorological stations was used, with 94% of the values calculated using data from three or more stations. Average relative humidity was calculated using six stations, with data from three or more stations used for the entire reporting period. Global radiation data were measured at three stations, HY063, Scanlon2 and Whites Creek at Regional Rd 23, during the 2010–2011 reporting period. However, the Scanlon2 and Whites Creek at Regional Rd 23 stations were not established until June 2011 and April 2012, respectively. Two small gaps (5 days in 2010 and 6 days in the 2011 hydrologic year) existed in the HY063 dataset. The data gaps in global radiation were filled using the Campbell-Donatelli (CD) model previously described by O'Connor et al. (2012). The modelled global radiation data compared reasonably well to the monitored global radiation (n = 47, RMSE = 54.4 W/m^2 or 23.8% of average value for the corresponding period).

Lake Level (Storage)

The method used to calculate annual storage was described in O'Connor et al. (2012). For the 2007–2009 and 2010–2011 reporting periods, the Lake Simcoe water level was monitored by the Trent-Seven Waterway (TSW) Authority at two locations: Atherley Narrows and Jackson's Point (Table 2; Figure 4).

The lake level gauges operated by Parks Canada Trent Severn Waterway were geodetically referenced using the Canadian Geodetic Vertical Datum of 1928 projection. Level data is reported in metres above sea level (masl).

Flushing Time

The method for estimating flushing time was described by O'Connor et al. (2012).

Improvements to the Lake Simcoe Hydrometeorological Network

Improvements were made to the Lake Simcoe hydrometeorological monitoring network for the estimation of the annual water balances:

1) One new hydrometric gauge was established (Kettleby Creek at highway 9) increasing the gauged subwatershed area to 70%.

2) Two new Secondary Standard pyranometers were added to the Lake Simcoe monitoring network, one at the Whites Creek at Regional Rd. 23 station and the other at Scanlon2 MOECC station. These new pyranometers improved the spatial distribution of measured incoming global radiation to Lake Simcoe and in turn improved the estimation of evaporation from the lake.

Uncertainties Associated with Estimation of Evaporative Loss

The current method used to estimate evaporative loss from Lake Simcoe assumes complete ice cover for the period of January through March and, therefore, lake evaporation for this period is estimated as zero. However, as the climate in south-central Ontario continues to change, a shorter period of ice cover on Lake Simcoe has been observed with ice forming later in the winter and ice coming off the lake earlier in the spring (MOECC, 2015). As a result, evaporation may be occurring in the period from January to March. Lenters et al. (2013) report that under ice free winter conditions the highest measured evaporation rates on the Great Lakes occur in late fall and early winter and are driven primarily by: 1) a large difference between air and water temperature, 2) low relative humidity, and, 3) high wind speeds. The CRWE model does not perform well during this time period because it does not take the first and last driver into account. A new method for estimating and/or measuring evaporation from Lake Simcoe that could be calculated at a finer temporal resolution (daily) and that would consider the gradient between air and water temperature as well as wind speed will be investigated for future reports.

Table 2. Station locations and data source collaborators for the water balance supply and loss terms (2010–2011).

	Subwatershed	Station Name	Easting	Northing	Station ID	Data Source	Location Description
Hydrometric Stations	North Black River	Black River near Washago	636126	4952574	02EC002	1	HWY 169, N of Concession 5
	West Holland River - Holland Marsh	Bradford Pumping Station #2	616393	4885174	LS0100	2	Pumphouse Rd
	Hewitt's Creek	Hewitts Creek near Camelot	608925	4913763	LS0202	3	N of Camelot Square, Painswick
	East Holland River	Holland River at Holland Landing	620915	4883503	02EC009	1	Yonge St. and Mount Albert Rd.
	Kettleby Creek	[NEW]Kettleby Creek at Highway 9	614461	4876699	LS0103	3	Highway 9 btw Keele and Jane St
	Maskinonge River	Maskinonge River at Glenwoods	626115	4897630	LS0105	3	Glenwoods btw Woodbine & Warden Ave
	Pefferlaw Brook	Pefferlaw Brook near Udora	644107	4903169	02EC018	1	Old Shiloh Rd, N of Udora
	West Holland River	Schomberg River	605363	4874039	02EC010	1	20th Side Rd, N of Schomberg
	Severn River	Severn River at Hamlet	626975	4960094		4	Hamlet upstream of Sparrow Lake
	Severn River	[NEW]Severn River at Swift Rapids	615225	4968093	02EC003	1	Swift Rapids Power Plant
	Talbot River	Talbot River below Canal Lake Lower	649462	4929977		3/4	Canal Rd and Side Rd 5, Gamebridge
Hydrometeorological Stations	Beaver River	Beaver River near Beaverton	653635	4917772	02EC011	1/3	Brock Concession 2, W of Thorah Side Road
	Black River	Black River at Baldwin	632195	4902146	02EC008	1/3	Hwy 48 in the town of Baldwin
	Hawkestone Creek	Hawkestone Creek at Hawkestone	621815	4928212	02EC020	1/3	11 Line S and Lake Country Oro-Medonte Rail Trail
	Lovers Creek	Lovers Creek at Tollendal	607431	4914109	LS0101	3	Tollendal Mill Rd, Barrie
	Whites Creek	Whites Creek at Regional Rd 23	647491	4922510	LS0402	3	Regional Rd 23, N of Beaverton
Meteorological Stations		Egbert CS	597162	4898508	611E001	5	Egbert
		HY063	648308	4869985	HY063	6	Whitchurch-Stouffville
	Oro Creeks North	Orillia Brain	623886	4940010	6115811	5	Orillia
	Black River	Baldwin	634175	4902897	6110480	5	Baldwin
	Georgian Creeks	Keswick WTP	620848	4901364	LS0107	3	Keswick WTP
		[NEW]Coldwater Warminster	615893	4943012	6111769	5	Coldwater Warminster
	Oro Creeks South	Barrie-Oro	615304	4926580	6117700	5	Guthrie
	Oro Creeks South	Shanty Bay	608876	4917150	6117684	5	N of intersection of Ridge Rd W and Line 1 S
	Pefferlaw Brook	[NEW]Uxbridge West	646987	4884434	6159123	5	Uxbridge
	Pefferlaw Brook	Udora	646875	4902397	6119055	5	Ravenshoe Rd, Uxbridge
	Ramara Creeks	Lagoon City	641656	4934201	6114295	5	End of Poplar Cres, Lagoon City
	West Holland River	[NEW]Scanlon2 MOECC	615691	4890326	SCP-106-2	3/7	Scanlon Creek CA, Bradford
Water Pollution Control Plants Above Gauge Station*	Beaver River	Beaver River - Lagoon 1 (Sunderland)	655254	4904108	120003496	8	Sunderland
		Beaver River - Lagoon 2 (Cannington)	656774	4913373	110001248	8	Cannington
	Black River	Mount Albert WPCP	633919	4889704	120001853	8	Mount Albert
	Pefferlaw Brook	Uxbridge Brook WPCP	650378	4886250	120000756	8	Uxbridge
Water Pollution Control Plants Below Gauge Station *	Barrie Creeks	Barrie WPCP	604731	4914623	120000578	8	Barrie
	Black River	Sutton WPCP	631850	4908144	110001168	8	Sutton
	East Holland River	Holland Landing Lagoon	620461	4885959	120001620	8	Holland Landing
	Innisfil Creeks	Innisfil (Alcona) WPCP	617161	4908615	110002586	8	Innisfil - Alcona
	Maskinonge River	Keswick WPCP	621484	4898562	120001755	8	Keswick
	Oro Creeks North	Orillia WPCP	625875	4938684	120000569	8	Orillia
	Pefferlaw Brook	Lake Simcoe Lagoon - Beaverton	645969	4920030	120002558	8	Beaverton
	Ramara Creeks	**Lagoon City WPCP	641951	4934725	120002255	8	Lagoon City
	West Holland River	Bradford WPCP	615657	4886578	110000944	8	Bradford
		Schomberg WWTP	608410	4874719	120002095	8	Schomberg
		Silani Sweet Cheese	607997	4876068		8	Bradford
Lake Level		Lake Simcoe at Jackson Point	630199	4909673	LS0998	4	Jacksons Point
		***Lake Simcoe at Atherley Narrows	629271	4939891	LS0999	4	Orchard Point

[NEW]New station for the 2010-2011 monitoring period.

Note Whites Creek at Regional Rd. 23 was previously a Hydrometric Gauge (2007-2009) but has been updated to include the measurement of climatic variables.

*WPCP outfall coordinates are not exact but are estimated based on descriptions from the Environmental Compliance Approvals.

The WPCP coordinates have not been verified for accuracy.

**Lagoon City coordinates are for the WPCP as the outfall coordinates were unavailable.

***Formerly refered to as Lake Simcoe at Orchard Point.

1 Environment Canada, Water Survey Canada
2 Holland Marsh Drainage System Joint Municipal Services Board
3 LSRCA
4 Parks Canada, Trent Severn Waterway
5 Environment Canada, Weather Office
6 Toronto Region Conservation Authority
7 MOECC Sport Fish and Biomonitoring Unit
8 MOECC Central Region

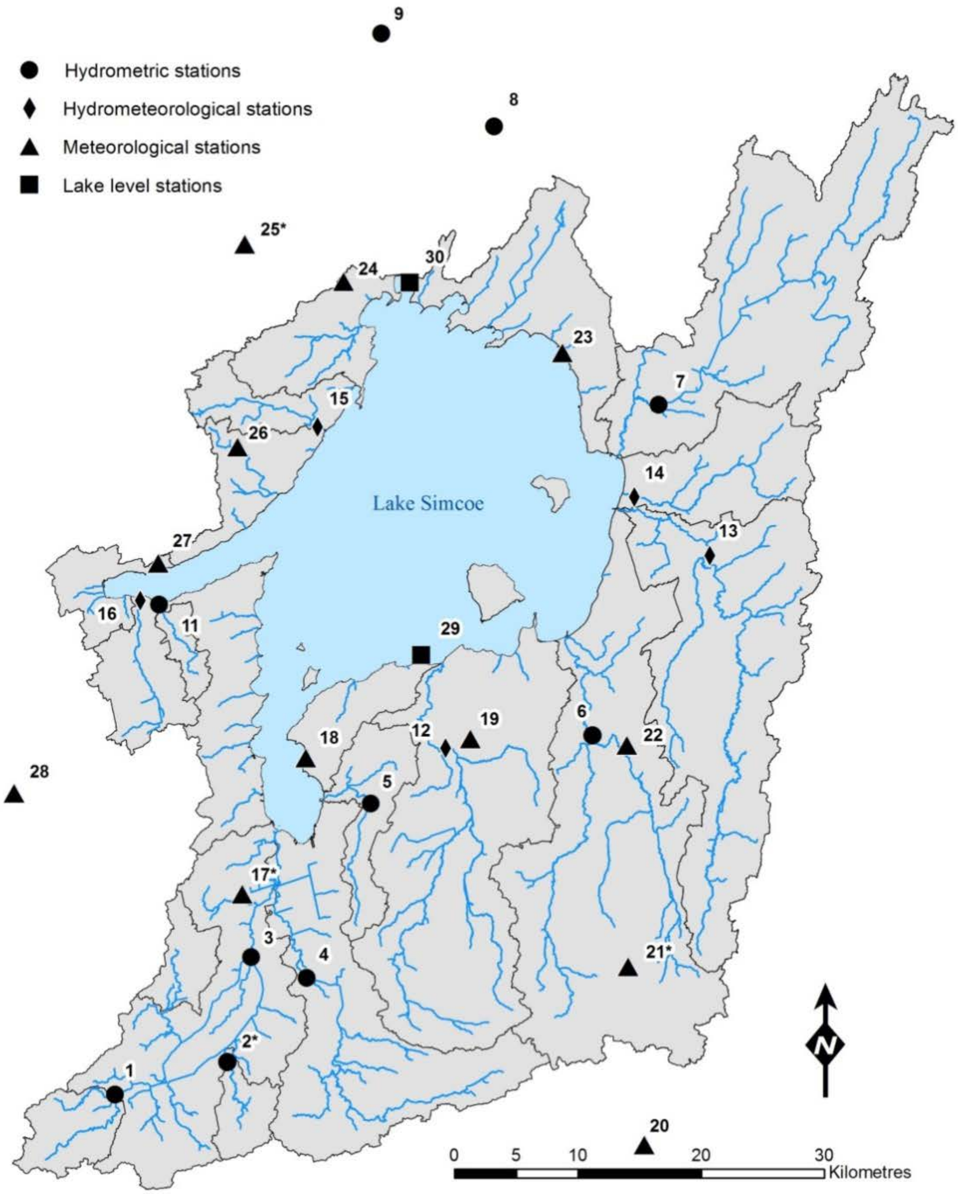
Table 3. Changes to the naming convention of hydrometeorological network stations between the 2007–2009 (O'Connor et al., 2013) and 2010–2011 (this report) reporting periods.

Previous Naming Convention		Current Naming Convention	
Station Name	Station ID	Station Name	Station ID
Art Janse Pumping Station	LS0100	Bradford Pumping Station #2	LS0100
Beaverton River near Beaverton	02EC011	Beaver River near Beaverton	02EC011
Keswick	LS0107	Keswick WTP	LS0107
Pefferlaw River near Udora	02EC018	Pefferlaw Brook near Udora	02EC018
Severn River at Hamlet		Severn River at the Hamlet Swing Bridge	
Talbot River at Gamebridge	LS0109	Talbot River below Canal Lake Lower	

Table 4. List of meteorological/climatic variables used at each station for the calculation of the 2010–2011 Lake Simcoe water balances.

	Meteorological Variable					
Station Name	Precipitation	Air Temperature	Relative Humidity	Dew Point	Global Radiation	Barometric Pressure
Baldwin		X				
Barrie-Oro	X	X	X	X		X
Beaver River near Beaverton	X	X				
Black River at Baldwin	X	X	X	X		
*Coldwater Warminster	X	X				
Egbert CS			X	X		X
Hawkestone Creek at Hawkestone		X				
HY063					X	
Keswick WTP	X	X	X	X		
Lagoon City		X				X
Lovers Creek at Tollendal		X				
Orillia Brain		X				
*Scanlon 2 MOECC	X	X	X	X	X	
Shanty Bay	X	X				
Udora	X	X				
*Uxbridge West			X	X		X
*Whites Creek at Regional Rd 23	X	X			X	

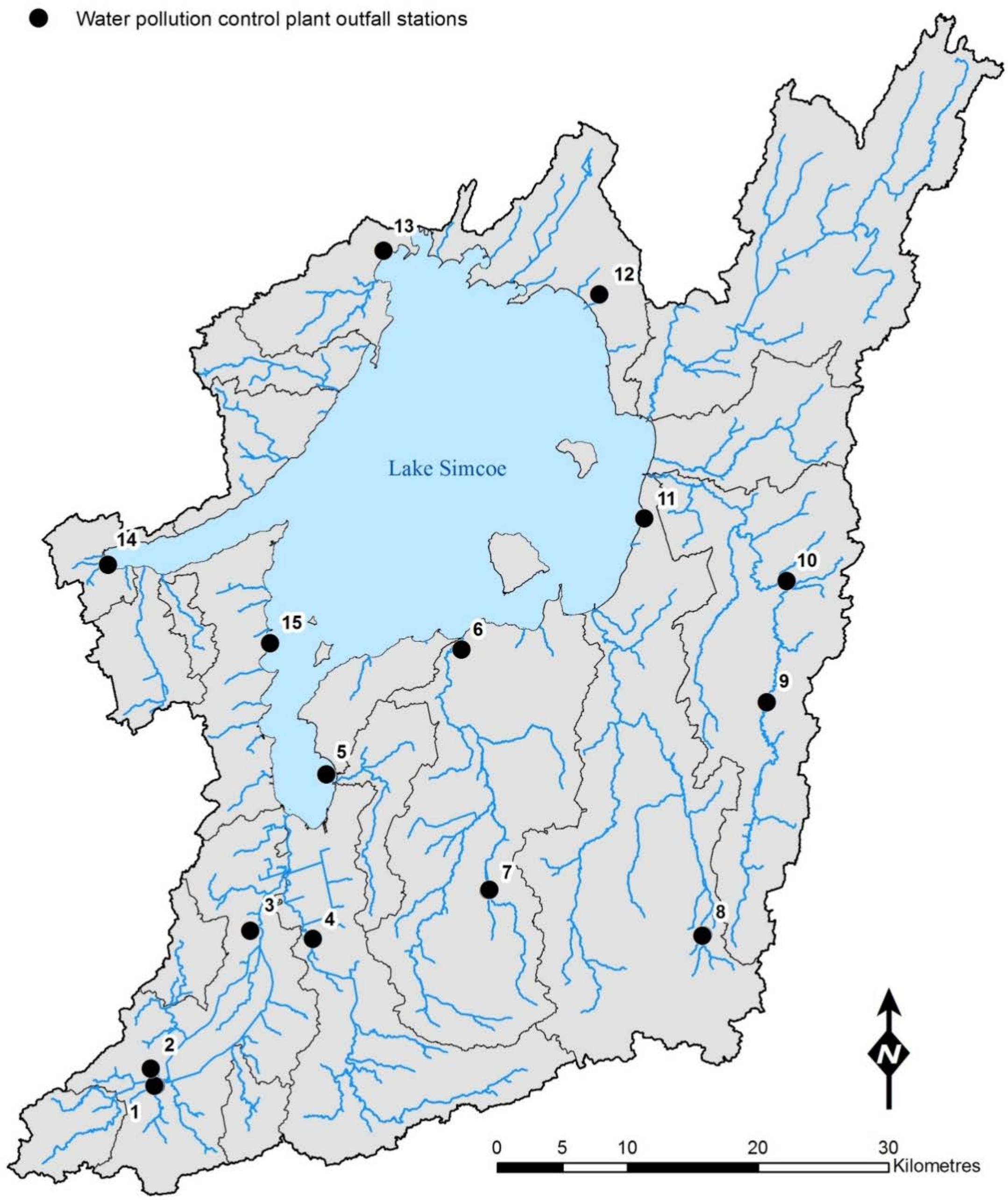
*New station for the 2010-2011 monitoring period.



1	Schomberg River near Schomberg	11	Hewitts Creek near Camelot	21*	Uxbridge West
2*	Kettleby Creek at Highway 9	12	Black River at Baldwin	22	Udora
3	Bradford Pumping Station No. 2	13	Beaver River near Beaverton	23	Lagoon City
4	Holland River at Holland Landing	14	Whites Creek at Regional Rd. 23	24	Orillia Brain
5	Maskinonge River at Glenwoods	15	Hawkestone Creek at Hawkestone	25*	Coldwater Warminster
6	Pefferlaw Brook near Udora	16	Lovers Creek at Tollendal	26	Barrie-Oro
7	Talbot River below Canal Lake Lower	17*	Scanlon2 MOECC	27	Shanty Bay
8	Black River near Washago	18	Keswick WTP	28	Egbert CS
9	Severn River at Hamlet	19	Baldwin	29	Lake Simcoe at Jackson's Point
10*	Severn River at Swift Rapids	20	HY063	30	Lake Simcoe at Atherley Narrows

Note that Severn River at Swift Rapids (10*) gauge is located beyond the northern extent of this map.

Figure 4. Hydrometric (circles), meteorological (triangles), hydrometeorological (diamonds) and lake level stations (squares) used for the 2010–2011 reporting period. Asterisks (*) indicate stations that were new for this reporting period.



1	Schomberg WWTP	9	Beaverton River 1 Lagoon (Sunderland)*
2	Silani Sweet Cheese	10	Beaverton River 2 Lagoon (Canninton)*
3	Bradford WPCP	11	Lake Simcoe Lagoon - Beaverton
4	Holland Landing Lagoon	12	Lagoon City WPCP
5	Keswick WPCP	13	Orillia WPCP
6	Sutton WPCP	14	Barrie WPCP
7	Mount Albert WPCP*	15	Innisfil (Alcona) WPCP
8	Ubridge Brook WPCP*		

*WPCP is located above gauge station.

Figure 5. Water pollution control plant outfall stations used for the 2010–2011 reporting period.

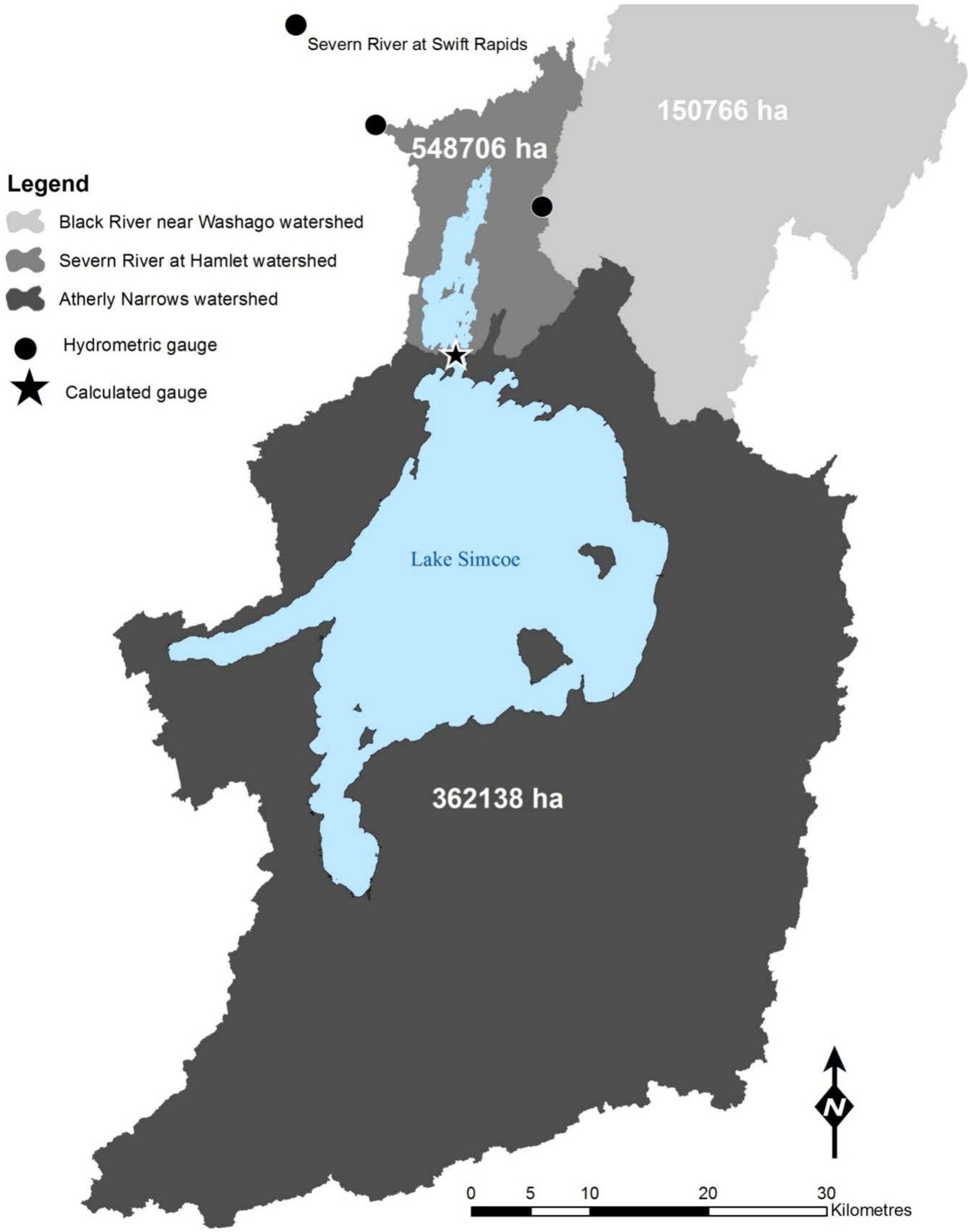


Figure 6. Areas and gauges used to prorate discharge from the Lake Simcoe Outlet (Atherley Narrows).

Phosphorus Loads

Sampling – Surface Water

The surface water sampling methods were described by O'Connor et al. (2012). In total, there were 21 surface water quality stations where TP samples were collected and used for the calculation of loads (Table 5; Figure 7). A new water quality station in the Ramara Creeks subwatershed (Ramara Drain #1 station) was added to the sampling program for the 2011 hydrologic year. As outlined in Table 6, the naming conventions of some stations changed since the previous report.

Note that, while the Talbot River Lock 41 and Talbot at the Park stations have been used in previous years (2004–2009; O'Connor et al. 2012 and 2013), these stations will no longer be used for Talbot River subwatershed load calculations. Data from Talbot River at Gamebridge, which was also used in previous years, will be used solely in this and future estimations as it is most suitable to represent the main Talbot River channel. While Talbot River Lock 41 and the Park station are only seasonally accessible (the lock is in operation late May to early October and the Park station is closed in the winter), Talbot River at Gamebridge is accessible year round. Additionally, surface water at Talbot River Lock 41 and the Park station likely mix with Lake Simcoe at times, while water at the Gamebridge station does not. The water quality sampling sites are part of two monitoring programs: LSPP (Lake Simcoe Protection Plan) program, which was previously called the Lake Simcoe Environmental Management Strategy (LSEMS) program, and PWQMN (Provincial Water Quality Monitoring Network) program. For the LSPP program during the period June 1, 2010 to August 5, 2011, TP was analyzed from water samples filtered through 80-µm nylon mesh or unfiltered samples depending on the random selection of two submitted sample bottles. Sample filtering ended August 5, 2011 for the LSPP program. Samples were not filtered under the PWQMN program.

There were also two temporary sampling projects that were incorporated into the load project. An autosampler collected daily and sub-daily event samples at the East Holland River station from March 1, 2011 to May 31, 2012. From August 5, 2011 to August 4, 2012, another autosampler was located at the Beaver River near Beaverton station collecting daily and sub-daily event samples (Figure 7).

Sampling – Atmosphere

The atmospheric deposition sampling procedures were described by O'Connor et al. (2012) with samples collected at the same six bulk collectors (Table 5; Figure 8). Samples were collected weekly throughout the ice-free period (approximately April to November). During the winter months, sampling was carried-out every three weeks at only three of the stations (Ramara, Scanlon and Hawkestone). Scanlon was moved to a new location (Station ID: Scanlon2; Table 5) on April 2, 2012 where sampling started thereafter. The new station is 1.7 km north-east from the old station and is the same location as the new meteorological station (Scanlon2 MOECC; Table 2, Figure 4).

Laboratory Analysis

Methods for TP analysis were the same as described in the previous technical reports (O'Connor et al., 2012 and 2013); duplicate atmospheric samples were analyzed for TP at the MOECC's Dorset Environmental Science Centre, and single surface water samples of tributaries were analyzed at the MOECC Laboratory Services Branch lab in Toronto. The lab analysis of duplicate samples carried-out routinely at Dorset provides supportive information for outlier evaluation of atmospheric samples (see section below, *Outlier Detection and Data Preprocessing – Atmosphere*). For the autosampler programs, the majority of the surface water samples were analyzed singly for TP at Maxxam Analytics (Mississauga, Ontario) using Method CAM SOP-00407. Some of the samples at the beginning of the autosampler program at the East Holland River station and towards the end for Beaver River near Beaverton station were analyzed at the Rexdale lab.

Outlier Detection and Data Preprocessing – Tributaries

Aggregation and outlier detection of the tributary TP concentration datasets were carried out as described by O'Connor et al. (2012) and using average and standard deviation of concentrations from June 1, 2010–May 31, 2012. Elevated flows were the most common reason for elevated TP concentrations; therefore, no outliers were removed. If two samples were collected in one day but not at the same time, the average of the two samples was used.

Outlier Detection and Data Preprocessing – Holland Marsh

The method of outlier detection and gap-filling for the Holland Marsh TP data was described by O'Connor et al. (2013); samples from June 2005 through May 2012 were used for flagging data outliers and gap-filling. No outliers were removed for the 2010–2011 load period. Concentration data for 13 months in 2010 and 2011 (July 2010 thru February 2011; June, July and September 2011; and January and April 2012) were estimated. See section below, *Comments on Improvements and Uncertainties Associated with Loads,* for an explanation of why these months were estimated.

Outlier Detection and Data Preprocessing – Atherley Narrows

Outlier detection for TP concentrations from Atherley Narrows was performed as tributary outlier analysis described in O'Connor et al. (2012). Only one TP concentration value was flagged as an outlier

(October 12, 2010; TP = 0.028 mg/L); it was removed on the basis that field notes indicated that the sample was clear (as Atherley samples typically are) and water levels were not especially elevated that day. The median concentration in Atherley for the time period was 0.007 mg/L, with the maximum (aside from the value of 0.028 mg/L) was 0.015 mg/L (September 21, 2010).

Outlier Detection and Data Preprocessing – Atmosphere

The TP concentrations from the six bulk collection stations from January 1, 2010 to December 31, 2012 underwent data outlier detection analysis as outlined by O'Connor et al. (2012), with changes as outlined in O'Connor et al. (2013) and using Excel 2010. To flag outliers for the first two steps (identifying outliers within each station), the averages and standard deviations were calculated using all duplicates for each station. This is a different method than outlined in previous reports. In the previous reports (O'Connor et al., 2012 and 2013), calculations were performed individually on each set of duplicates, for each station. The reason for the change is that, for the purpose of flagging outliers, all concentrations of a station can be compared to a single value (i.e., three standard deviations from the long-term average of that station) that incorporates all variation of the dataset of interest.

After these analyses within each station, duplicate pairs were flagged if the difference between the two duplicates of a sample was greater than 100% and both duplicates were greater than or equal to 0.0100 mg/L. Note that percent difference was calculated as the absolute difference divided by the average of duplicate samples. At this stage, the average of duplicate difference from all stations was 39% (using only duplicate pairs with TP concentrations greater than 0.0100 mg/L). An evaluation of samples found that duplicate samples with the greatest difference were 79% for Scanlon (August 7, 2012, 0.0196 and 0.0450 mg/L) and 87% for Ramara (November 13, 2012, 0.0148 and 0.0378 mg/L). The differences observed within all duplicate pairs was determined to be satisfactory and duplicates were averaged to represent a single sample for each sample day in the analysis going forward (unlike the previous report where duplicates were retained for all analysis). In the previous reports, differences within duplicate pairs were not specifically analyzed, but rather were only investigated in instances where one duplicate would be flagged in the outlier process and not the other. One sample at Scanlon (August 16, 2010; TP = 0.0004 mg/L) was removed in the final step of the outlier process because it was much lower than other stations on that day.

Once outlier detection was completed, approximately 77% of the collected samples were retained in the final datasets for Hawkestone, Ramara and Scanlon stations; approximately 60% of the collected samples were retained for Alcona, Oro and Willow Beach to represent the atmospheric nutrient load to the surface of Lake Simcoe.

Table 5. Monitoring station locations and data source collaborators used for phosphorus loads (2010–2011).

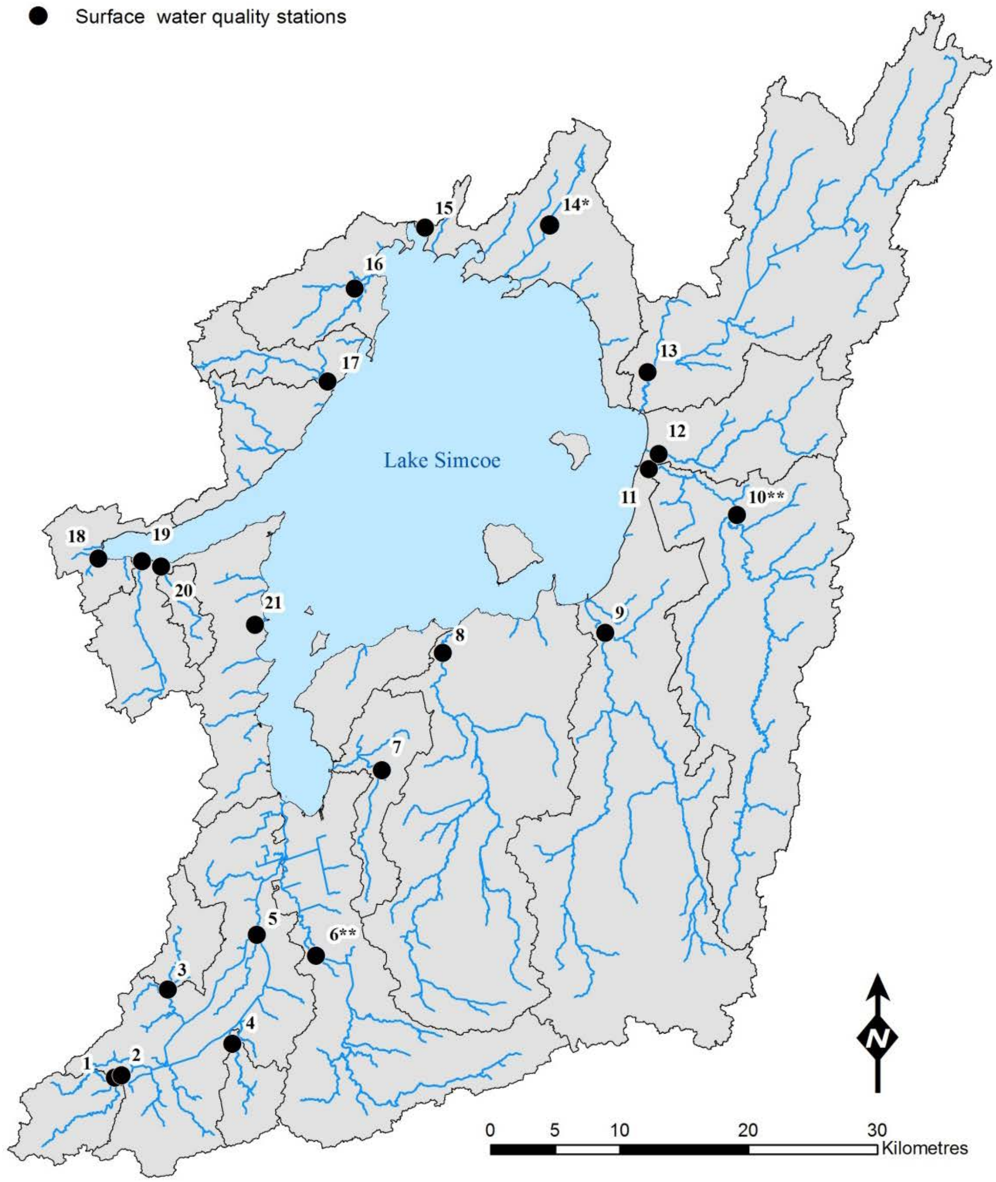
		Subwatershed	Station Name	Abbrev.	Easting	Northing	Station ID (LSPP/ PWQMN)	Program	Data Source	Location Description
Surface Water Quality	**Monitored/ Gauged**	Beaver River	Beaver River	BV	646813	4921324	99994786602/ 03007704102	LSPP/ PWQMN	1-6	Simcoe St, Downstream Mara Rd Bridge, Beaverton
		Beaver River	Beaver River near Beaverton	BV2	653635	4917772	99994786603	Autosampler	1, 3, 5, 6, 7	Brock Concession 2, W of Thorah Side Road
		Black River	Black River	BL	630804	4907067	03007731302/ 03007703802	LSPP/ PWQMN	1-6	High St, Sutton
		East Holland River	East Holland River	HL	620968	4883554	03007731002/ 03007703902/ 03007731002B	LSPP/ PWQMN/ Autosampler	1-7	Yonge St & Mount Albert Rd, Holland Landing
		Hawkestone Creek	Hawkestone Creek	HS	621876	4928139	99994784102/ 03007703602	LSPP/ PWQMN	1-6	Line 11 S, Hawkestone
		Hewitts Creek	Hewitts Creek	HEW	608949	4913770	03007704202	LSPP	1-3, 5, 6	N of Camelot Sqr, Painswick
		Lovers Creek	Lovers Creek	LV	607457	4914162	03007702802	LSPP/ PWQMN	1-6	Tollendal Mill Rd, Barrie
		Maskinonge River	Maskinonge River	MSK	626088	4897958	03007703402	LSPP/ PWQMN	1-6	Glenwoods Ave btwn Woodbine & Warden Ave
		Pefferlaw Brook	Pefferlaw Brook	PFR	643431	4908628	99994783602/ 03007704002	LSPP/ PWQMN	1-6	Pineview Crt, Pefferlaw
		Talbot River	Talbot River at Gamebridge	TAG	646710	4928861	99994783802	LSPP	1-3, 5, 6	Ramara Rd 51, Gamebridge
		West Holland River - Kettleby Creek	Kettleby Creek	KB	614465	4876700	03007730602	LSPP	1-3, 5, 6	Hwy 9 btwn Keele and Jane St
		West Holland River - Upper Schomberg River	Upper Schomberg River	US	605375	4874075	03007731502	LSPP	1-3, 5, 6	20th Sdrd, N of Schmbrg
				SCH	605896	4874266	03007702902	PWQMN	1-6	Cnty Rd 27, N of Schmbrg
		Whites Creek	Whites Creek	WC	647550	4922490	99994784402	LSPP	1-3, 5, 6	Regional Rd 23, N of Beaverton
	Monitored/ Ungauged	Barrie Creeks	Hotchkiss Creek	HTK	604078	4914367	03007704302	LSPP	1-3, 5, 6	Sandford St, Barrie
		Innisfil Creeks	Leonards Creek	LEN	616223	4909232	03007705102	LSPP	1-3, 5, 6	25th Sdrd, Alcona
		Oro Creeks North ⍰	Bluffs Creek	BLU	623970	4935336	99994797602	LSPP	1-3, 5, 6	15th Sdrd, Orillia
		Ramara Creeks (2011)	[NEW]Ramara Drain #1	RDRN1	639115	4940288	03007706102	LSPP	1-3, 5, 6	Hwy 12, W of SideRd 15
		West Holland River - North Schomberg River	North Schomberg River	NS	609486	4880914	03007730702	LSPP	1-3, 5, 6	5th Conc at 5th Line
	Unmonitored/ Ungauged	Georgina Creeks								
		The Islands								
		Oro Creeks South								
		Ramara Creeks (2010)								
		West Holland River - Ungauged/Unmon								
	Polder	West Holland River - Holland Marsh	Bradford Pumping Station #2	PP	616393	4885174	03007730302	LSPP	1-3, 5, 6, 8	Pumphouse Rd, in canal under pumps
	Outflow	Lake Simcoe	Atherley Narrows	ATH	629442	4940066	020133125	LSPP	1-3, 5, 6	Blue Beacon Marina, Hwy 12
WPCP Outfalls *	**Above Gauge Station**	Beaver River	Beaver River - Lagoon 1 (Sunderland)		655254	4904108	120003496		9	Sunderland
			Beaver River - Lagoon 2 (Cannington)		656774	4913373	110001248		9	Cannington
		Black River	Mount Albert WPCP		633919	4889704	120001853		9	Mount Albert
		Pefferlaw Brook	Uxbridge Brook WPCP		650378	4886250	120000756		9	Uxbridge
	Below Gauge Station	Barrie Creeks	Barrie WPCP		604731	4914623	120000578		9	Barrie
		Black River	Sutton WPCP		631850	4908144	110001168		9	Sutton
		East Holland River	Holland Landing Lagoon		620461	4885959	120001620		9	Holland Landing
		Innisfil Creeks	Innisfil (Alcona) WPCP		617161	4908615	110002586		9	Innisfil - Alcona
		Maskinonge River	Keswick WPCP		621484	4898562	120001755		9	Keswick
		Oro Creeks North	Orillia WPCP		625875	4938684	120000569		9	Orillia
		Pefferlaw Brook	Lake Simcoe Lagoon - Beaverton		645855	4918188	120002558		9	Beaverton
		Ramara Creeks	**Lagoon City WPCP		641951	4934725	120002255		9	Lagoon City
		West Holland River - Ungauged/Unmon	Bradford WPCP		615657	4886578	110000944		9	Bradford
			Schomberg WWTP		608410	4874719	120002095		9	Schomberg
			Silani Sweet Cheese		607993	4876064			9	Schomberg
Atmospheric Deposition	**Bulk Collectors**	Georgina Creeks	Willow Beach	WBP	626389	4907949	99994797623	LSPP	1, 3, 5	Kennedy Rd, Georgina
		Hawkestone Creek	Hawkestone	HKP	621854	4928314	99994794523	LSPP	1, 3, 5	Line 11 S, Hawkestone
		Innisfil Creeks	Alcona	ALCP	612965	4907076	99994797723	LSPP	1, 3, 5	Innisfil Beach Rd, Innisfil
		Oro Creeks South	Oro	OROP	617799	4922286	99994797823	LSPP	1, 3, 5	Shelswell Blvd, Oro-Medonte
		Ramara Creeks	Ramara	RM1P	644498	4930111	99994794923	LSPP	1, 3, 5	Concession Rd 1, Ramara
		West Holland River	Scanlon	SCP	614285	4889223	99994794423	LSPP	1, 3, 5	Scanlon Creek CA, Bradford
		West Holland River	[NEW]Scanlon2	SCP	615691	4890326	99994794423	LSPP	1, 3, 5	Scanlon Creek CA, Bradford

Table 5 cont'd.

Footnotes for Table 5:
[NEW] New station for the 2010–2011 reporting period.
*WPCP outfall coordinates are not exact but are estimated based on descriptions from the Environmental Compliance Approvals. The WPCP coordinates have not been verified for accuracy.
**Lagoon City coordinates are for the WPCP as the outfall coordinates were unavailable.
1 LSRCA
2 JDE Ventures Environmental Monitoring Services
3 MOECC Sport Fish and Biomonitoring Unit
4 MOECC Water Monitoring Section
5 MOECC Dorset Environmental Science Centre
6 MOECC Laboratory Services Branch
7 Maxxam Analytics
8 Holland Marsh Drainage System Joint Municipal Services Board
9 MOECC Central Region

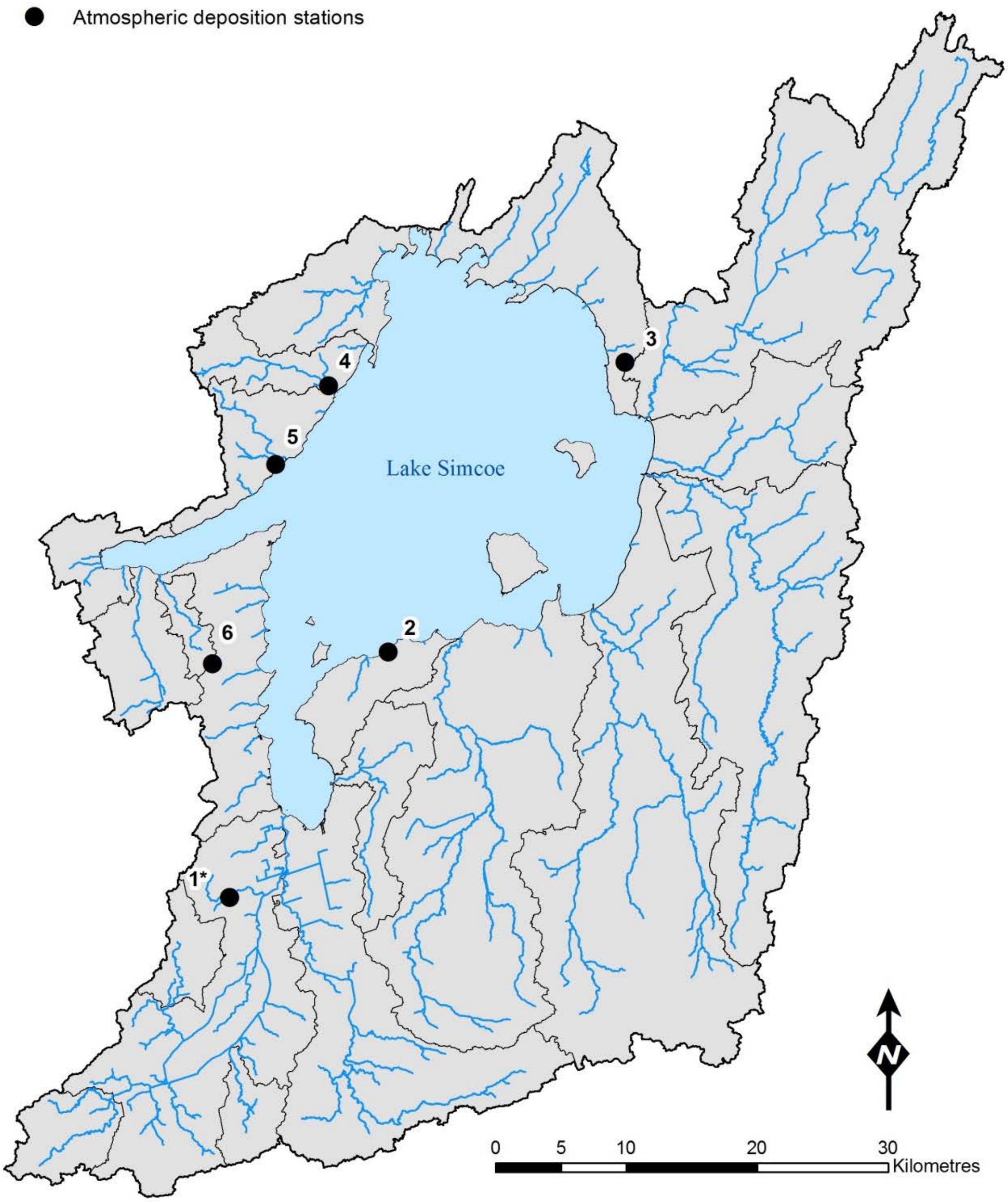
Table 6. Station naming convention changes between the 2007–2009 (O'Connor et al., 2013) and 2010–2011 (this report) reporting periods, for surface water quality stations.

Previous Naming Convention		Current Naming Convention	
Staton Name	Station ID	Staton Name	Station ID
Beaver River - Beaverton	99994786602/ 03007704102	Beaver River	99994786602/ 03007704102
Black River - Sutton	03007731302/ 03007703802	Black River	03007731302/ 03007703802
East Holland River - Holland Landing	03007731002/ 03007703902	East Holland River	03007731002/ 03007703902
Holland Marsh Pumphouse	03007730302	Bradford Pumping Station #2	03007730302
Talbot at Gamebridge	99994783802	Talbot River at Gamebridge	99994783802



1	Upper Schomberg River (LSPP)	8	Black River	15	Atherley Narrows
2	Upper Schomberg River (PWQMN)	9	Pefferlaw Brook	16	Bluffs Creek
3	North Schomberg River	10**	Beaver River near Beaverton	17	Hawkestone Creek
4	Kettleby Creek	11	Beaver River	18	Hotchkiss Creek
5	Bradford Pumping Station #2	12	Whites Creek	19	Lovers Creek
6**	East Holland River	13	Talbot River at Gamebridge	20	Hewitts Creek
7	Maskinonge River	14*	Ramara Drain #1	21	Leonards Creek

Figure 7. Surface water quality stations used for the 2010–2011 reporting period. Single asterisks (*) indicate stations that were new for this reporting period and double asterisks (**) indicate stations where autosamplers were deployed.



1*	Scanlon	4	Hawkestone
2	Willow Beach	5	Oro
3	Ramara	6	Alcona

Figure 8. Atmospheric deposition stations used for the 2010–2011 reporting period. An asterisk indicates that the station (Scanlon) was moved to a new station location (Scanlon2) partway through the reporting period. The location of Scanlon2 can be observed in Figure 4 (Scanlon2 MOECC Meteorological Station).

Loads from Monitored and Gauged Subwatersheds

Both water quality and stream flow were monitored for twelve subwatersheds of Lake Simcoe: Beaver River, Black River, East Holland River, Hawkestone Creek, Hewitts Creek, Kettleby Creek, Lovers Creek, Maskinonge River, Pefferlaw Brook, Talbot River, Upper Schomberg River and Whites Creek (Figure 3; Table 5). Together these monitored areas comprise 65% of the Lake Simcoe watershed (73% when prorated to the mouth excluding polder and downstream urban areas). Methods used for calculating TP loads for this classification of subwatersheds are described in O'Connor et al. (2012). Loads from WPCPs located upstream of monitoring stations (see Table 5) were subtracted from loads calculated at the respective gauges at Beaver River, Black River and Pefferlaw Brook before these loads were prorated to the mouth. Note that a minor error was detected in the calculations of the previously published 2004–2006 loads. While O'Connor et al. (2012) specified that upstream WPCP loads for monitored/gauged subwatersheds were subtracted before proration, which is the correct order of calculations, they instead were erroneously subtracted after proration. This caused a minor overestimate of total load each year of 0.111 t for 2004, 0.075 t for 2005 and 0.057 t for 2006. These calculations were performed in the correct order in O'Connor et al. (2013) and the current report. Kettleby Creek became gauged on July 14, 2010, as stated in the section Water Balance: Supply and Loss Terms, Discharge from Gauged Tributaries. From June 1, 2010 to July 13, 2010, loads from Kettleby Creek subwatershed were calculated using monitored and ungauged methods (described in following section). For simplicity, the status of Kettleby Creek subwatershed is noted as monitored and gauged throughout the TP load portion of this report.

The TP concentration autosampler datasets from East Holland River station and Beaver River near Beaverton station were merged with the routine datasets to calculate the load for the East Holland and Beaver Rivers, respectively. Sub-daily loads were calculated and summed where available to provide daily loads. For the East Holland River, there were daily loads calculated for 97% of the days that the autosampler was in operation. For the Beaver River, daily loads were calculated for 94% of the operating days. The 'midpoint method' (Scheider et al., 1978) was used to fill in daily concentrations where there were gaps and a daily load was calculated. All daily loads were summed for each period (see *Methods, Phosphorus Load to Lake Simcoe, Sampling – Surface Water* for periods of operation for each autosampler).

Loads from Monitored and Ungauged Subwatersheds

Subwatersheds that were monitored but not gauged included Barrie Creeks, Innisfil Creeks, North Schomberg River, Oro Creeks North and Ramara Creeks (2011; Figure 3; Table 5). Together these monitored areas comprise 3% of the Lake Simcoe watershed (12% when prorated to the mouth excluding downstream urban areas). Ramara Creeks was calculated as an unmonitored and ungauged subwatershed until March 31, 2011, because TP concentration data was sparse until that time. Therefore, Ramara Creeks subwatershed was grouped as unmonitored and ungauged in 2010, but for

2011 it was grouped as monitored and ungauged. Methods used for calculating TP loads for this classification of subwatersheds are described in O'Connor et al. (2012).

Loads from Unmonitored and Ungauged Subwatersheds

Subwatersheds that were not monitored for water quality and were ungauged included Georgina Creeks, the Islands, Oro Creeks South, Ramara Creeks (2010) and the ungauged/unmonitored portions of the West Holland River subwatershed (Figure 3; Table 5). These are the same subwatersheds used in the final year (2009) of the previous report (noting that Ramara Creeks became monitored for 2011). For 2011, these subwatersheds (excluding polders and urban areas) comprised 11% of the Lake Simcoe watershed. Methods used for calculating TP loads for this classification of subwatersheds are described in O'Connor et al. (2012), and include matching unmonitored subwatersheds with monitored subwatershed that have the most similar land use based on analysis carried-out by Scott et al. (2006). Table 7 depicts the pairs of matched subwatersheds.

Table 7. Each unmonitored/ungauged subwatershed and the monitored subwatershed that was most similar to it in terms of land use.

Unmonitored/ungauged	Monitored
Georgina Creeks	East Holland River
Islands	Hawkestone Creek
Oro Creeks South	Pefferlaw River
Ramara Creeks	Hawkestone Creek
West Holland River (unmonitored)	Upper Schomberg River

Loads from Urban Runoff not Captured by Monitoring Stations

The methods for calculating TP loads from urban areas below monitoring stations are described in O'Connor et al. (2012), and include updated areas described in O'Connor et al. (2013). These areas make up 3% of the watershed.

Loads from Vegetable Polders

Loads from Holland Marsh were calculated as described in O'Connor et al. (2013), except that loads were calculated on a monthly basis (i.e., calendar month) for the current report and on a hydro billing basis in the 2013 report. Monthly discharge volumes mentioned in the 2013 report actually refers to the billing period rather than calendar months. The average concentration for each billing period was multiplied by the discharge for that period. In the current report, loads for each calendar month were the product of the discharge volume for each month [see section *Methods, Water Balance Supply and Loss Terms, Discharge from Holland Marsh (Bradford Pumping Station No. 2)*] and average monthly concentration.

Loads for other polders in the Lake Simcoe watershed were calculated as described by O'Connor et al. (2012). Polder areas make up 1% of the watershed.

Loads from Urban Point Sources

The same WPCPs (Figure 5; Table 5) and methods from O'Connor et al. (2013) were used to calculate the annual load from urban point sources to Lake Simcoe.

Loads from Septic Systems

The method used to calculate loads from septic systems is described in O'Connor et al. (2012). Not stated in that report was that there were 2197 permanent and 1540 seasonal residential properties assumed to have septic systems (a total of 3737) in the 100 m band around the lake.

Loads from the Atmosphere

The method used to calculate loads from atmospheric deposition is described in O'Connor et al. (2013). For clarification, these loads include only TP deposited directly to the lake surface (not to the surrounding watershed area).

Loads from the Lake Simcoe Outlet (Atherley Narrows)

The method used to calculate loads from the lake outlet is described in O'Connor et al. (2013).

Comments on Improvements and Uncertainties Associated with Loads

As noted by O'Connor et al. (2013), every source of phosphorus load inherently presents some degree of uncertainty associated with how the variable was measured or estimated. There were some improvements made to reduce uncertainty:

- The addition of a water quality station in the Ramara Creeks subwatershed in March, 2011 improved the monitoring network. With the addition of the station, 69% of the Lake Simcoe watershed area was monitored for water quality by 2011. The percentage of watershed monitored for water quality is calculated using the total watershed area upstream of monitoring stations.

- The improved estimate of discharge of Kettleby Creek, as outlined in the water balance section above, improved the reliability of the calculated phosphorus load from this tributary.

- Autosamplers collected daily and sub-daily event samples at the East Holland River station from March 1, 2011 to May 31, 2012 and at the Beaver River near Beaverton station from August 5, 2011 to August 4, 2012. East Holland River subwatershed is one of the highest contributors in the watershed conveying approximately 15% of the TP load; Beaver River subwatershed contributes 4% of the load. The use of autosamplers improved the accuracy of the TP load estimation from these tributaries because continuous datasets (with sub-daily to daily resolution) were compiled that better characterize TP concentrations than would be estimated using the midpoint method. This is especially significant during high discharge events that collectively carry a significant portion of the loads. The calculated TP loads for the East Holland River were higher using the autosampler dataset than compared to analysis using the dataset from the routine monitoring program described in *Methods, Phosphorus Loads to Lake Simcoe, Sampling – Surface Water*, for the same period: TP load was increased by 3,852 kg for 2011, and by 3,125 kg for 2012. For the Beaver River, the load for the 2011 hydrologic year decreased by 2,316 kg using the autosampler dataset as compared to the routine monitoring program.

- Concentrations from unfiltered samples are likely more representative of phosphorus levels in the tributaries for the purpose of load calculations because it is anticipated that the larger material (suspended debris and large particulates) retained by the filter is exported to the lake. Removing filtering from the sampling protocol starting August 6, 2011 is an improvement to the program because concentrations in the stream are better represented and loads at the time of sampling are more accurate.

- Efforts to reduce uncertainty by characterizing discharge events continued during this reporting period with samples taken during the rising limb, peak and falling limb of a storm event (data, results and analysis not shown). However, it is not possible to characterize all discharge events; therefore, alternate approaches to estimating TP loads between samples is being explored to reduce uncertainty associated with storm events. An investigation into the relationship between TP concentration and turbidity is underway with continuous in-situ turbidity measurements at four locations in the watershed.

- Uncertainty associated with the TP load from the Holland Marsh increased during the reporting period due to extended intervals between samples (*Methods*, *Phosphorus Loads to Lake Simcoe, Outlier Detection and Data Preprocessing – Holland Marsh*). Samples are taken at this station (Bradford Pumping Station #2) when the pumps are on, which require staff visits to be coordinated with pumping. This is more difficult during periods when the pumps are on infrequently such as the summer and fall of 2010. To improve the sampling program for future reporting periods, LSRCA staff receive automated notifications via the SMS system of the Holland Marsh Drainage System Joint Municipal Services Board when the pumps are on, and an autosampler was also incorporated for a period of time (starting 2013).

RESULTS

Definition of the Seasons used to describe the Results

For this report, the grouping of months into each season is as follows:

- Summer includes June, July and August
- Fall includes September, October and November
- Winter includes December, January and February
- Spring includes March, April and May

Annual Water Balance: Supply Terms

Discharge from Tributaries

The annual runoff from gauged tributaries (including four upstream WPCPs) to Lake Simcoe for the 2010–2011 reporting period were 0.706 km^3 and 0.655 km^3, respectively. The average annual gauged runoff was 0.681 km^3, equal to 43.2% of the two-year average annual input to Lake Simcoe from all sources. The annual runoff from the ungauged tributaries from 2010–2011 were 0.219 km^3 and 0.199 km^3, respectively, with a two-year average volume of 0.209 km^3 or 13.3% of the annual total input to Lake Simcoe.

In 2010, the greatest flow volume occurred during the spring (0.453 km^3) (Figure 9), which was consistent with the hydrologic regime described in previous technical reports (Scott et al., 2006; O'Connor et al., 2012; O'Connor et al., 2013). However, in 2011, the greatest flow volume was observed during the winter (0.302 km^3). Winter precipitation depths for 2010 and 2011 were similar at 182.1 and 159.8 mm, respectively (Table 8) but winter 2011 observed much greater discharge volume than winter 2010. The discrepancy is partially the result of a very large rain event that occurred at the end of the fall 2011 (63.0 mm between November 27, 2011 and November 30, 2011) but also the air temperature was considerably higher during the winter of 2011 than 2010 (Figure 10). Warmer temperatures likely resulted in more melt and/or rain events during the 2011 winter months and consequentially a higher discharge volume for the 2011 winter period. These winter events also likely depleted the watersheds snow storage which in turn decreased the magnitude of the following spring freshet. The next greatest average discharge volume was in the fall, with a two-year average volume of 0.159 km^3. Summer had the lowest discharge volume despite having the greatest precipitation of any season. Discharge volumes are typically low in summer due to higher infiltration and evapotranspiration rates.

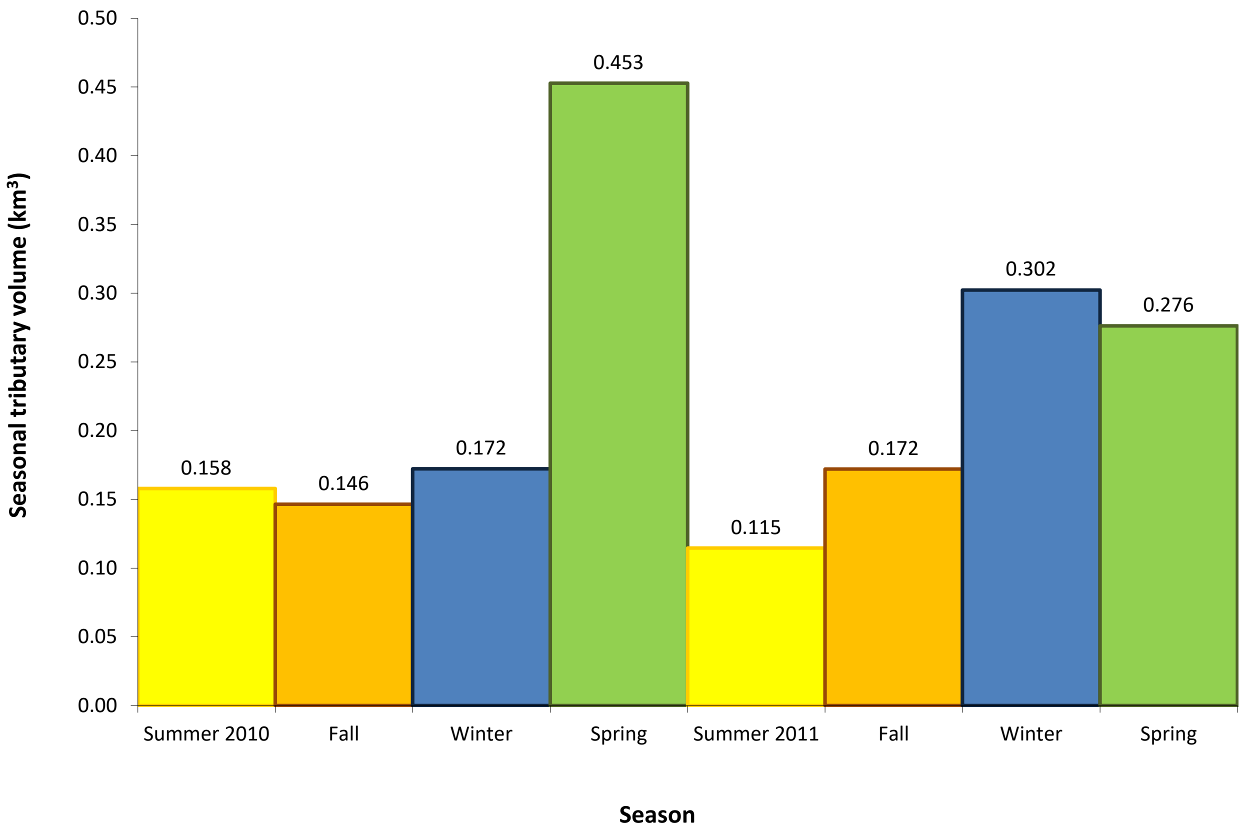


Figure 9. Seasonal tributary discharge volumes to Lake Simcoe (2010–2011).

Note that these results include both gauged and ungauged volumes.

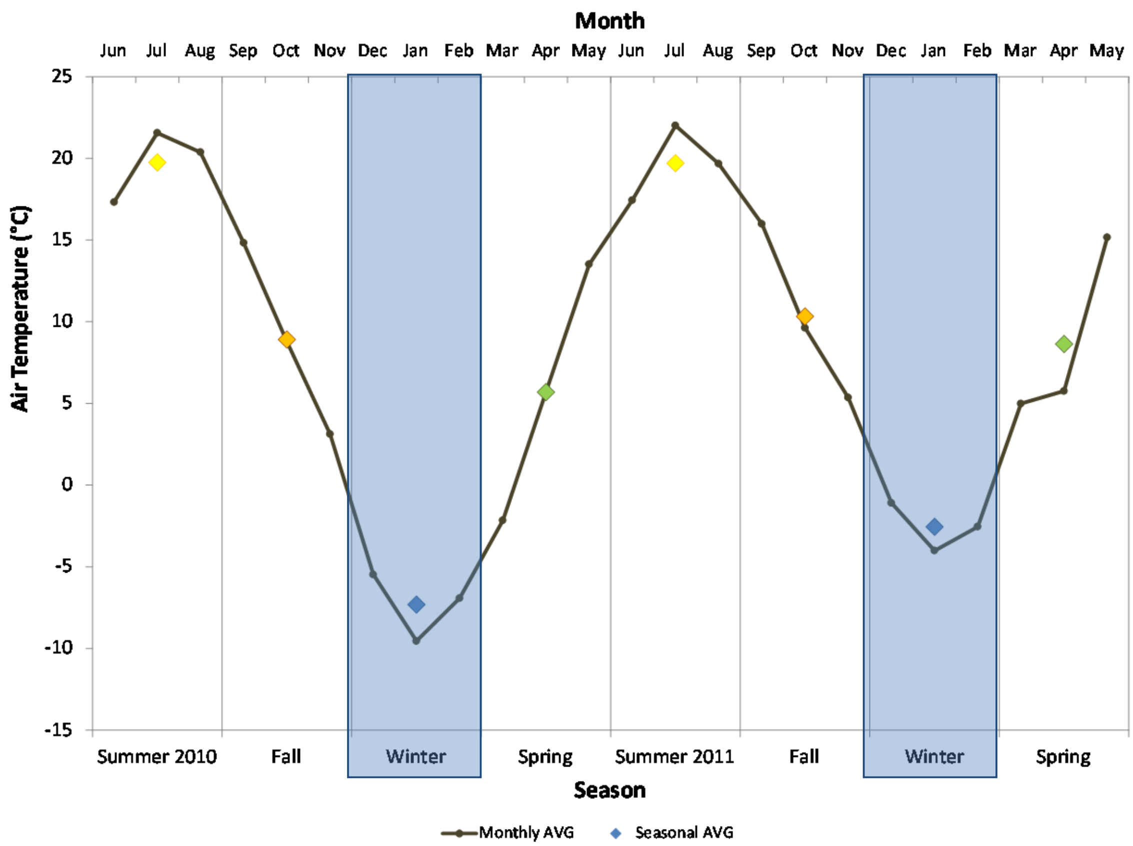


Figure 10. Monthly and seasonal air temperature (2010–2011). Note winter 2010 is approximately 5°C colder than winter 2011.

Discharge from Holland Marsh (Bradford Pumping Station No. 2)

Annual discharges from the Bradford Pumping Station No.2 for the 2010–2011 reporting period were 0.008 km^3 and 0.006 km^3 with a two-year average of 0.007 km^3 or 0.4% of the annual average input to Lake Simcoe from all sources.

The Bradford Pumping Station No. 2 exhibited a similar seasonal discharge regime as the tributaries during the 2010–2011 reporting period. In 2010, the greatest volume was observed during spring (0.004 km^3), followed by winter (0.002 km^3) then fall (0.001 km^3), and summer (0.000 km^3) had the lowest discharge volume (Figure 11). However, in 2011, winter observed the greatest discharge volume (0.003 km^3), followed by spring (0.002 km^3). This is likely due to the unusually warm winter temperature that caused more rain events and/or snowmelt events during the winter months, as described in the *Discharge from Tributaries* section above.

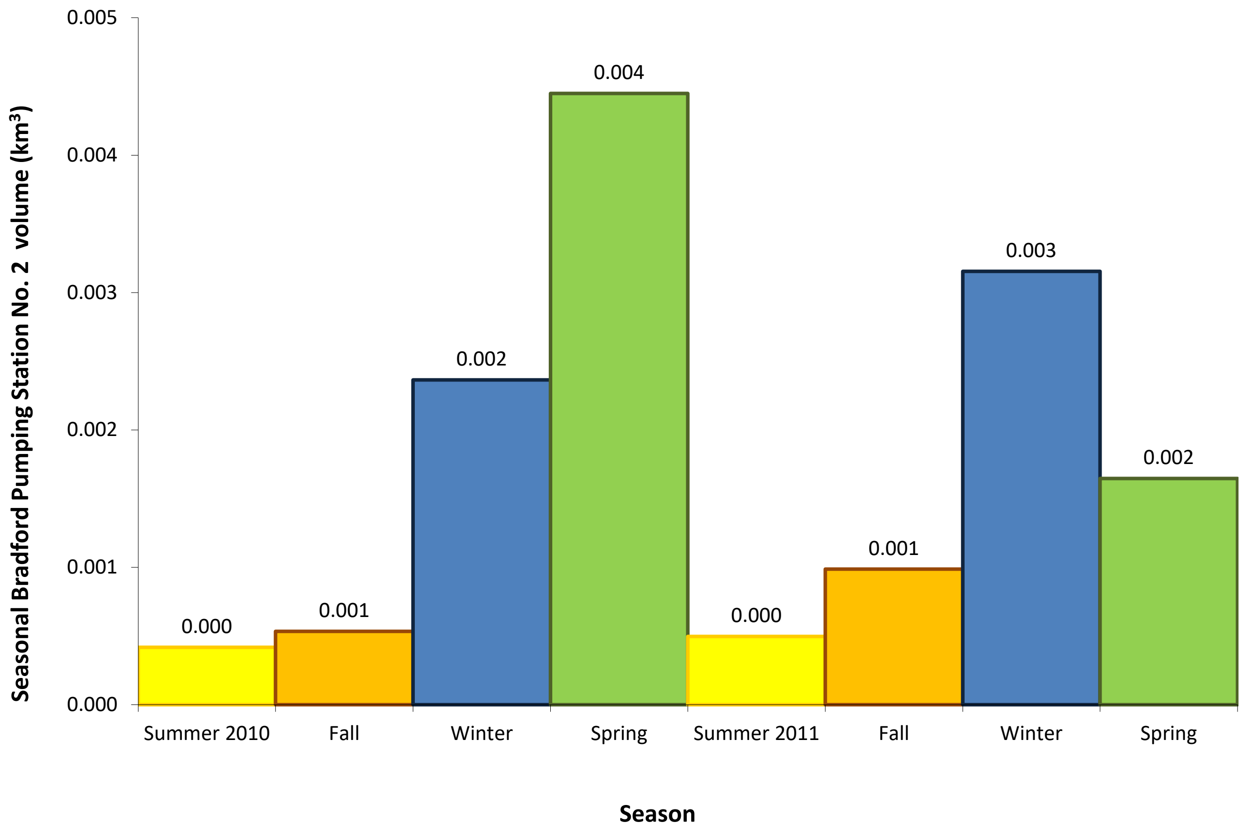


Figure 11. Seasonal Bradford Pumping Station No. 2 discharge volumes to Lake Simcoe (2010–2011).

Discharge from Urban Point Sources

The annual discharge volumes for the 11 WPCPs situated downstream of hydrometric or hydrometeorological gauges in the Lake Simcoe watershed for the 2010–2011 reporting period were 0.037 km^3 and 0.035 km^3. The two-year annual average WPCP volume (0.036 km^3) comprised 2.3% of the annual average input to Lake Simcoe from all sources.

The seasonal discharge volume for the 11 downstream WPCPs was quite consistent during the 2010–2011 reporting period; discharge volumes ranged from 0.008 to 0.010 km^3(Figure 12).

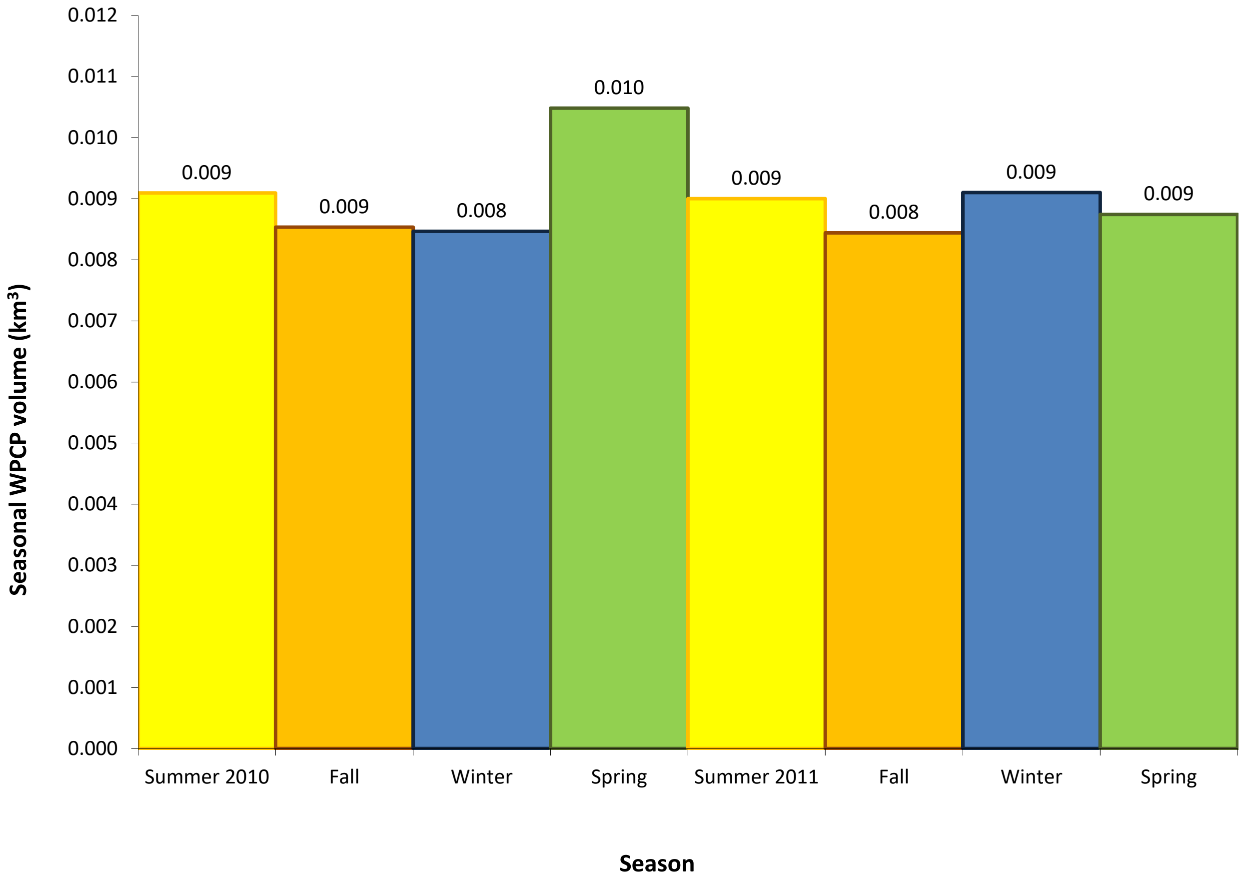


Figure 12. Seasonal Water Pollution Control Plant discharge volumes to Lake Simcoe (2010–2011).

Precipitation (Direct to Lake)

Monthly precipitation depths ranged between 31.6 mm (March 2012) and 167.3 mm (June 2010) with a monthly mean depth of 74.4 mm. The estimated annual precipitation volumes direct to Lake Simcoe for the 2010–2011 reporting period were 0.716 km^3 and 0.574 km^3, with an annual average precipitation volume of 0.645 km^3 or 40.8% of the two-year average annual input to Lake Simcoe from all sources.

Seasonally, summer precipitation volumes were the greatest with a two-year average input of 0.220 km^3, followed by fall with a two-year average input of 0.176 km^3. Spring contributed 0.126 km^3 and winter precipitation input was the lowest with an annual average volume of 0.124 km^3 over the 2010–2011 monitoring period (Figure 13). Summer 2010 was the wettest season in either hydrologic year with a seasonal precipitation depth of 338.7 mm, equaling a volume of 0.245 km^3 directly to Lake Simcoe. The 2010 summer precipitation depth was ~33% greater than the Environment Canada 1981–2010 "Climate Normals" for south-central Ontario (Table 8). The spring of the 2011 monitoring year had abnormally low precipitation (108.8 mm), contributing 0.079 km^3 of water to Lake Simcoe, which was approximately 50% of the 1981–2010 Climate Normal precipitation and less than half of the 2010 spring volume.

Table 8. Seasonal precipitation depths for 2010–2011 monitoring period and Environment Canada Weather Office 1981–2010 "Normals" for Lake Simcoe Weather stations; Barrie WPCC, Shanty Bay and Udora.

	2010	2011	Barrie WPCC 1981-2010	Shanty Bay 1981-2010	Udora 1981-2010
	mm	mm	mm	mm	mm
Summer	338.7	269.0	251.9	248.0	266.9
Fall	231.0	256.7	260.4	268.4	245.4
Winter	182.1	159.8	217.9	242.9	170.8
Spring	238.8	108.8	202.7	208.7	203.1
Total	990.6	794.3	932.9	968.0	886.2

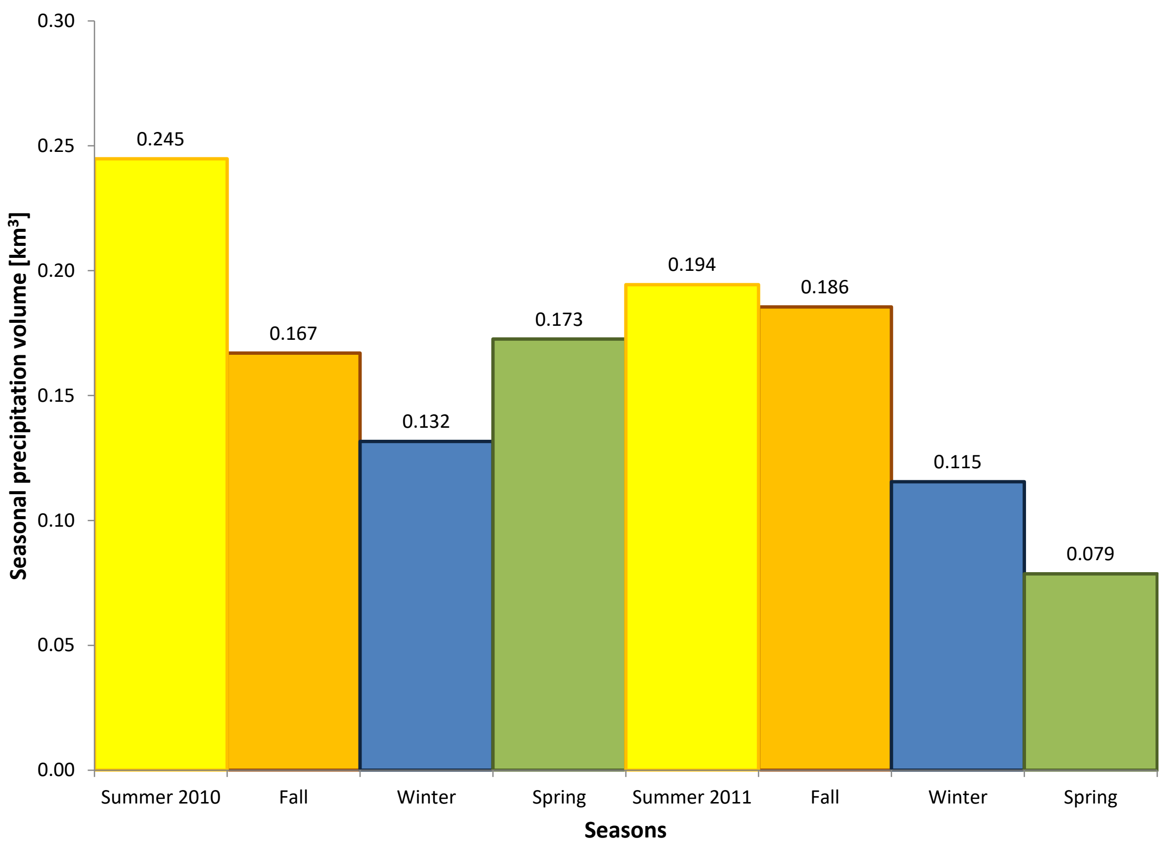


Figure 13. Seasonal precipitation volumes to Lake Simcoe (2010–2011).

Annual Water Balance: Loss Terms

Discharge from the Lake Simcoe Outlet (Atherley Narrows)

The annual discharge volumes for Atherley Narrows for the 2010–2011 reporting period were 1.004 km^3 and 0.823 km^3, representing 60.8% of the annual average loss from Lake Simcoe.

Unlike the 2007–2009 reporting period when spring typically experienced the greatest seasonal discharge volume from Atherley Narrows, 2010–2011 reporting period had the greatest average discharge volumes occurring in the summer (Figure 14) driven by the higher than normal precipitation that occurred in 2010 (Figure 13). The second greatest average discharge volume from Atherley was during the winter, with a two-year average of 0.225 km^3. Notably, winter 2011 was also the first winter on record that Lake Simcoe did not completely freeze over (Figure 15). Spring had the third greatest Atherley discharge volume (0.217 km^3) with relatively high flow during the 2010 hydrologic year but very low flow recorded during the 2011 hydrologic year. The low spring flow observed during the 2011 hydrologic year was likely the consequence of very little snow accumulation in the watershed combined with the lack of ice cover and consequentially little to no snow storage on Lake Simcoe itself. The lowest seasonal discharge volumes in the 2010–2011 reporting period were observed in the fall with an annual average volume of 0.172 km^3.

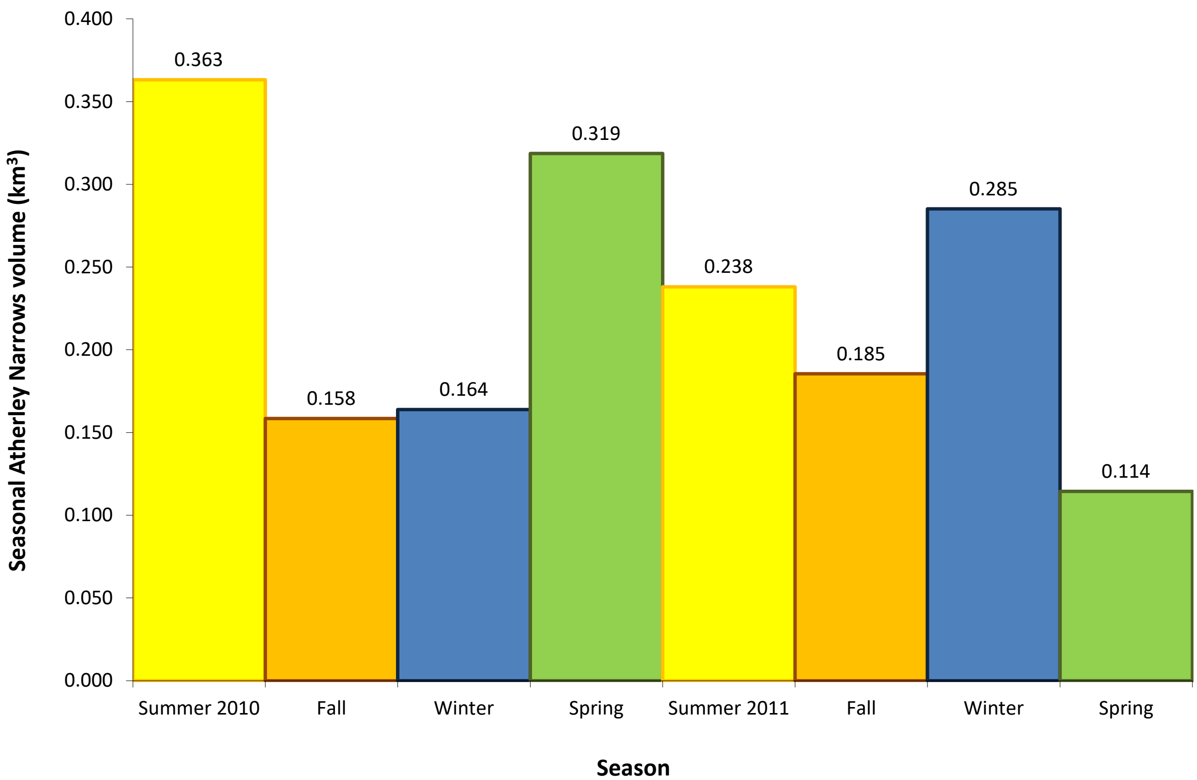


Figure 14. Seasonal discharge volumes for the Lake Simcoe outlet at Atherley Narrows (2010–2011).

Evaporation (Direct from Lake)

The annual average evaporation depth for the 2010–2011 reporting period was 815.7 mm and 858.6 mm in the 2010 and 2011 hydrologic years, respectively. These evaporation depths are equal to an average annual volume loss of 0.605 km^3. Evaporation represents 40.7% of the annual loss from Lake Simcoe, with the majority (~56%) of evaporation occurring during the summer season as illustrated by Figure 16. The 2010 and 2011 evaporative losses from Lake Simcoe are greater than the long-term (1990-2011) average evaporation loss of 0.542 km^3 but agree well with the 2007–2009 reporting period.

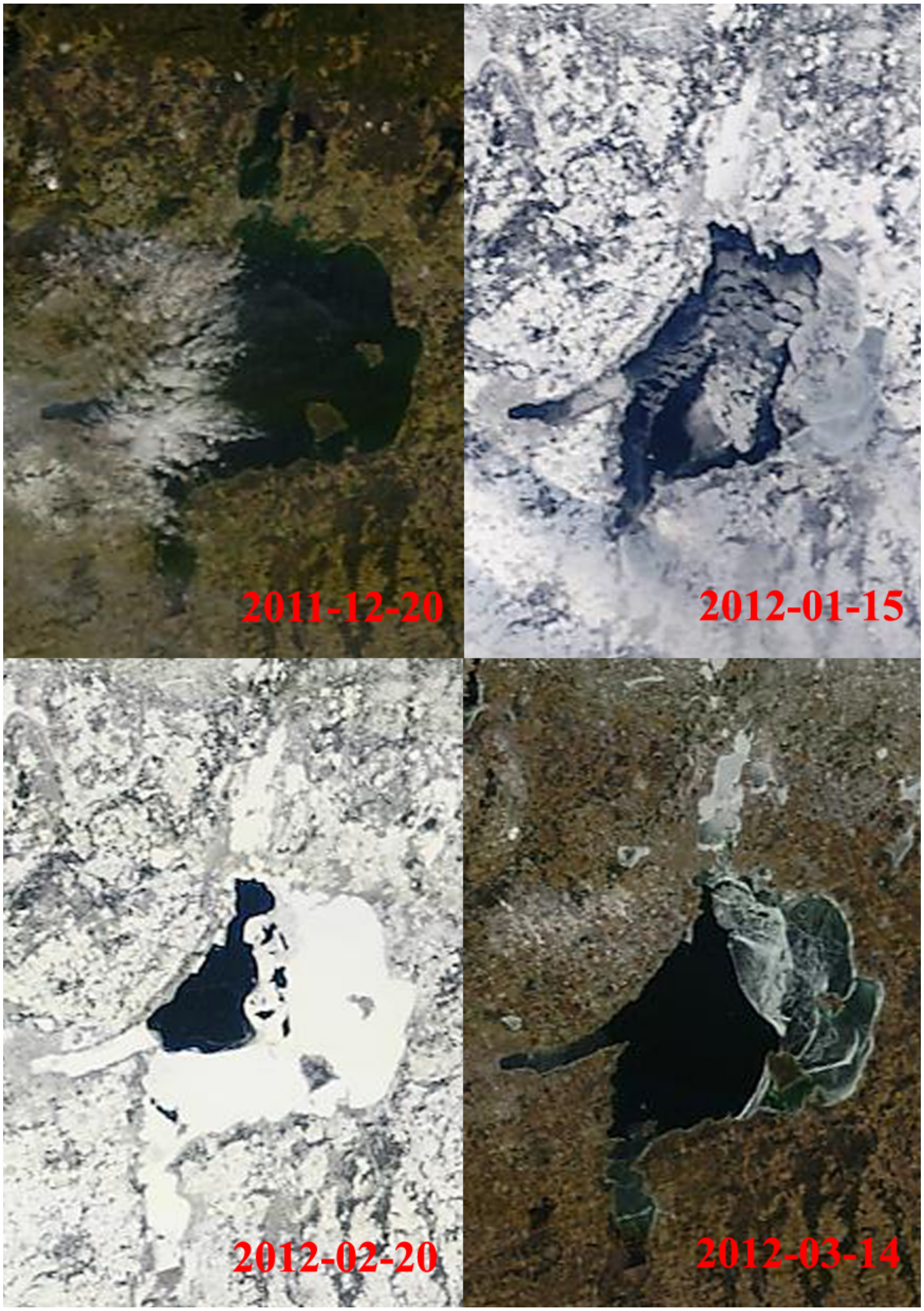


Figure 15. MODIS images of Lake Simcoe illustrating incomplete ice cover during winter of 2011 hydrologic year.

Adapted from Space Science and Engineering Center (SSEC), University of Wisconsin-Madison, http://ge.ssec.wisc.edu/modis-today/.

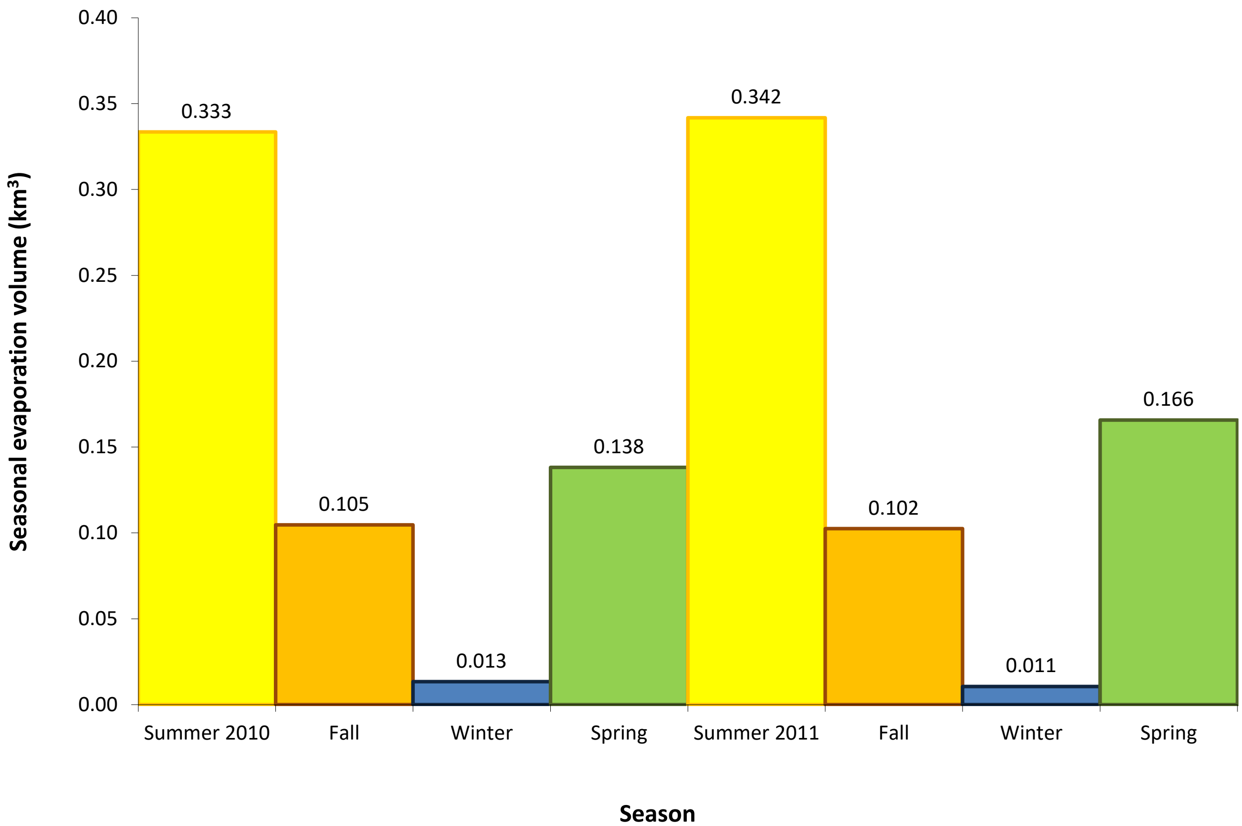


Figure 16. Seasonal evaporation volumes from Lake Simcoe (2010–2011).

Note that evaporation for January, February (included in Winter) and March (included in Spring) is considered to be zero due to ice cover.

Lake Level (Storage)

In 2010, the lake level for Lake Simcoe increased from 219.111 masl on June 1st, 2010 to 219.125 masl on May 31st, 2011, an increase of 0.014 m which is equal to a volume increase of 0.010 km^3. Conversely, the lake level dropped in 2011 from 219.129 masl to 219.059 masl between June 1st, 2011 and May 31st, 2012 for a volume decrease of 0.051 km^3.

Water Balances

The average annual water balance for the 2010–2011 reporting period was -5.3% (Figure 17; Table 9), which is consistent with the average water balance reported by O'Connor et al. (2013) of -3.1%.

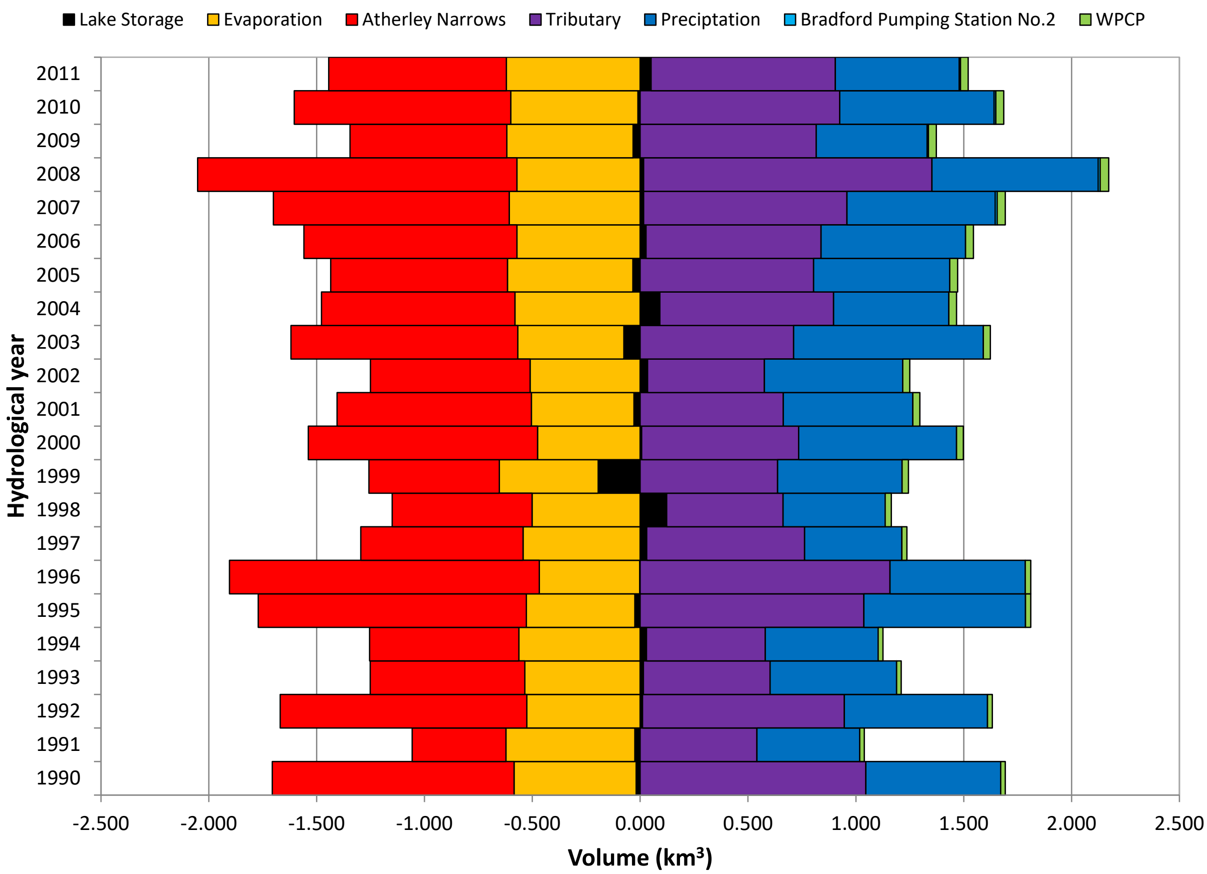


Figure 17. Water balance totals for Lake Simcoe (1990–2011).

Table 9. Water balance totals for Lake Simcoe (2010–2011).

Note WPCP results listed here are for outfalls downstream of gauges only.

	2010		2011	
	km^3/yr	%	km^3/yr	%
Gauged Tributaries	0.706	41.9%	0.655	44.6%
Ungauged Tributaries	0.219	13.0%	0.199	13.6%
Bradford Pumping Station 2	0.008	0.5%	0.006	0.4%
WPCP	0.037	2.2%	0.035	2.4%
Precipitation	0.716	42.5%	0.574	39.0%
TOTAL SUPPLY	**1.686**	**100.0**	**1.470**	**100.0**
Outlet (Atherley Narrows)	1.004	62.6%	0.823	59.1%
Evaporation	0.590	36.8%	0.621	44.5%
Lake Storage	0.010	0.6%	-0.051	-3.6%
TOTAL LOSS	**1.604**	**100.0**	**1.393**	**100.0**
BALANCE	**-0.082**	**-5.1%**	**-0.077**	**-5.5%**

Flushing Time

The 2010 hydrologic year observed a flushing time of 11.4 yr while the 2011 hydrologic year had a flushing time of 13.9 yr.

Phosphorus Loads

Total Loads

The annual loads of TP from all sources (atmospheric deposition to the lake surface, septic systems, WPCPs, polders and tributaries) to Lake Simcoe for the 2010 and 2011 hydrologic years were 91.1 and 77.7 metric tonnes (t), respectively (Figure 18; Table 10). The tributaries contributed the largest portion of phosphorus with a two-year average of 67.0% of the total inputs, followed by the atmosphere at 19.3%. The average annual load for the two-year period was 84.4 t. The five-year average was 90.7 t (2007–2011) and the long-term average was 91.0 t (1990–2011). The East Holland River (12.4 t), West Holland River (including polders and Kettleby, North Schomberg and Upper Schomberg subwatersheds; 11.7 t) and Pefferlaw Brook (5.9 t) subwatersheds contributed the highest annual TP loads to the lake from all subwatershed sources on average (Table 11a and b). Note that subwatershed sources do not include atmospheric deposition loaded directly to the lake surface.

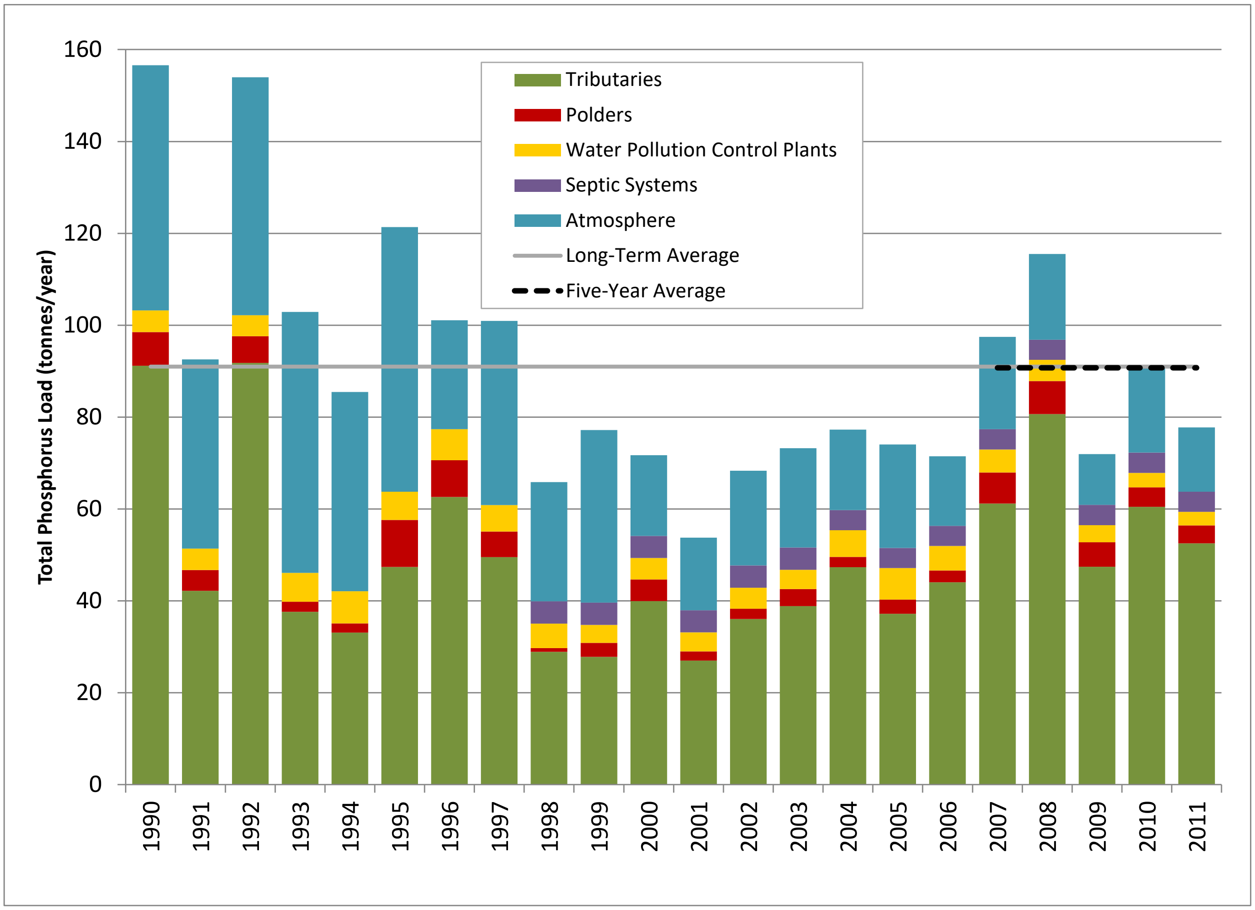


Figure 18. Annual TP loads to Lake Simcoe (1990–2011), including averages from the most recent five years (dashed lines) and long-term (solid line).

Note that methods have changed over time, including improvements to the program for estimating phosphorous from its various sources, but this graph depicts the best data available for each year. For example, there were no estimates for septic system loads prior to 1998.

Table 10. Summary of annual TP loads to Lake Simcoe and through Atherley Narrows (2010–2011).

Note that Ramara Creeks was part of the Unmonitored/Ungauged tributary load group in 2010 and the Monitored/Ungauged group in 2011.

		2010		2011		2-Year Average	
		Annual TP Load (tonnes)	Fraction of Total Load (%)	Annual TP Load (tonnes)	Fraction of Total Load (%)	Annual TP Load (tonnes)	Fraction of Total Load (%)
Polders		4.2	4.7	3.9	5.0	4.1	4.8
WPCPs (above and below gauge stations)		3.2	3.5	2.9	3.8	3.0	3.6
Septic Systems (within 100m of Lake Simcoe)		4.4	4.8	4.4	5.7	4.4	5.3
Atmosphere		18.8	20.6	14.0	18.0	16.4	19.3
Tributaries	Monitored/Gauged	36.7	40.3	29.9	38.4	33.3	39.4
	Monitored/Ungauged	3.0	3.3	5.7	7.3	4.3	5.3
	Unmonitored/Ungauged	10.1	11.0	6.3	8.1	8.2	9.6
	Urban Stormwater (below gauge)	10.7	11.7	10.7	13.7	10.7	12.7
	Total Tributary Loads	60.5	66.4	52.5	67.6	56.5	67.0
Total Load		**91.1**		**77.7**		**84.4**	
Loss via Outflow (at Atherley Narrows)		**7.3**	**8.1**	**5.9**	**7.5**	**6.6**	**7.8**

Table 11. Summary of annual TP loads from all sources of each subwatershed for: a) 2010, and, b) 2011.

Note that urban loads are from below monitoring stations for monitored subwatersheds but are from anywhere in the subwatershed in unmonitored subwatersheds. Also note that the atmospheric load listed in Table 10 includes deposition to the surface of the lake only, and is therefore not listed in Table 11a and b.

a) 2010

Subwatershed	**Monitored/ Gauged**	**Monitored/ Ungauged**	**Unmonitored/ Ungauged**	**Downstream Urban**	**Polders**	**WPCP**	**Septic Systems**	**Annual Subwatershed TP Load (tonnes)**
	Annual TP Load (tonnes)							
Barrie Creeks		0.445		3.560		1.308	0.088	**5.401**
Beaver River	3.044					0.055		**3.099**
Black River	3.590			0.257		0.069	0.665	**4.582**
East Holland River	12.890			0.894	0.772	0.061		**14.616**
Georgina Creeks			2.506	0.490			0.107	**3.103**
Hawkestone Creek	0.505						0.187	**0.692**
Hewitt's Creek	0.572							**0.572**
Innisfil Creeks		1.573		1.779		0.215	0.813	**4.380**
The Islands			0.199				0.016	**0.215**
Lovers Creek	1.274			0.051			0.008	**1.334**
Maskinonge River	0.883			0.274		0.557		**1.714**
Oro Creeks North		0.315		2.064		0.571	0.606	**3.556**
Oro Creeks South			0.824				0.665	**1.489**
Pefferlaw Brook	6.395			0.129		0.117	0.219	**6.859**
Ramara Creeks			1.553			0.035	0.932	**2.520**
Talbot River	3.712						0.083	**3.795**
West Holland - Unmonitored			*4.979*	*1.081*	*3.468*	*0.175*		***9.704***
West Holland - Kettleby Creek	*1.233*							***1.233***
West Holland - North Schomberg River		*0.684*						***0.684***
West Holland - Upper Schomberg River	*1.083*							***1.083***
West Holland - TOTAL	2.315	0.684	4.979	1.081	3.468	0.175		**12.704**
Whites Creek	1.541			0.081			0.022	**1.644**
Annual TP Load (from each type of subwatershed source; tonnes)	**36.721**	**3.017**	**10.061**	**10.660**	**4.240**	**3.162**	**4.413**	**72.276**

Table 11 cont'd

b) 2011

Subwatershed	Monitored/ Gauged	Monitored/ Ungauged	Unmonitored/ Ungauged	Downstream Urban	Polders	WPCP	Septic Systems	Annual Subwatershed TP Load (tonnes)
	Annual TP Load (tonnes)							
Barrie Creeks		0.236		3.560		1.189	0.088	**5.073**
Beaver River	3.705					0.053		**3.758**
Black River	3.474			0.257		0.067	0.665	**4.463**
East Holland River	8.476			0.894	0.704	0.024		**10.098**
Georgina Creeks			1.648	0.490			0.107	**2.245**
Hawkestone Creek	0.549						0.187	**0.737**
Hewitt's Creek	0.360							**0.360**
Innisfil Creeks		0.804		1.779		0.135	0.813	**3.531**
The Islands			0.217				0.016	**0.233**
Lovers Creek	1.054			0.051			0.008	**1.114**
Maskinonge River	1.141			0.274		0.691		**2.107**
Oro Creeks North		0.626		2.064		0.475	0.606	**3.772**
Oro Creeks South			0.575				0.665	**1.239**
Pefferlaw Brook	4.460			0.129		0.103	0.219	**4.911**
Ramara Creeks		3.351				0.027	0.932	**4.310**
Talbot River	3.068						0.083	**3.151**
West Holland - Unmonitored			*3.885*	*1.081*	*3.164*	*0.166*		***8.297***
West Holland - Kettleby Creek	*0.809*							***0.809***
West Holland - North Schomberg River		*0.663*						***0.663***
West Holland - Upper Schomberg River	*0.845*							***0.845***
West Holland - TOTAL	1.654	0.663	3.885	1.081	3.164	0.166		**10.614**
Whites Creek	1.923			0.081			0.022	**2.027**
Annual TP Load (from each type of subwatershed source; tonnes)	**29.864**	**5.680**	**6.325**	**10.660**	**3.868**	**2.932**	**4.413**	**63.743**

Loads from the Tributaries

The total annual tributary loads of TP to Lake Simcoe from all subwatersheds (both monitored and unmonitored tributaries), including all urban areas but not including polder areas, were 60.5 t and 52.5 t for 2010 and 2011, respectively; these represent an average of 67.0% of total TP loads to the lake (Table 10). The two-year (2010–2011), five-year (2007–2011) and long-term (1990–2011) averages were 56.5 t, 60.4 t, and 49.3 t, respectively. Monitored and gauged areas contributed 39.4% of the total load on average, monitored and ungauged areas contributed 5.3% while unmonitored and ungauged contributed 9.6% (averages of 2010 and 2011); urban areas below monitoring stations and in unmonitored subwatersheds contributed the rest of the tributary load, as described later in the section *Loads of TP from Urban Runoff not Captured by Monitoring Stations.* Note that Ramara Creeks was grouped with the unmonitored/ungauged loads in 2010 and with the monitored and ungauged loads in 2011 (Table 11a and b).

The highest tributary loads occurred in the spring, with a two-year average spring load of 22.458 t (Figure 19). The spring 2011 load was lower likely due to low winter snow storage in the watershed resulting in less spring flow (as described in the *Results/Annual Water Balance: Supply Terms/Discharge from Tributaries* section). The other seasons were similar to each other with fall having the second highest average (8.367 t), winter the third (7.612 t) and summer the least (7.396 t). Although winter tributary volume was greater than other seasons in 2011 (Figure 9), this did not translate to greater loads because winter TP concentrations were the lowest of any season.

Assessing the seasonal TP export of the monitored and gauged subwatersheds, and considering all areas except polders and urban areas downstream of stations, the highest seasonal TP export was from the East Holland River most frequently although Kettleby Creek (summer 2010 and fall 2011), Lovers Creek and Upper Schomberg River had the highest TP export for some seasons (Figure 20). Most subwatersheds had the highest TP export in spring 2010, excluding Hawkestone Creek, Talbot River and Whites Creek. For each subwatershed the TP export in the fall and winter of 2010 and summer of 2011 were often lowest.

The annual TP export (two-year average; including all urban and polder areas) for the subwatersheds ranged from 0.009 t/km^2 (Talbot River) to 0.104 t/km^2 (Barrie Creeks; Figure 21). The highest export rates were from subwatersheds with high percentages of urban and/or agricultural land use (i.e., Barrie Creeks, Georgina Creeks, East Holland River, Oro Creeks North and West Holland River subwatersheds).

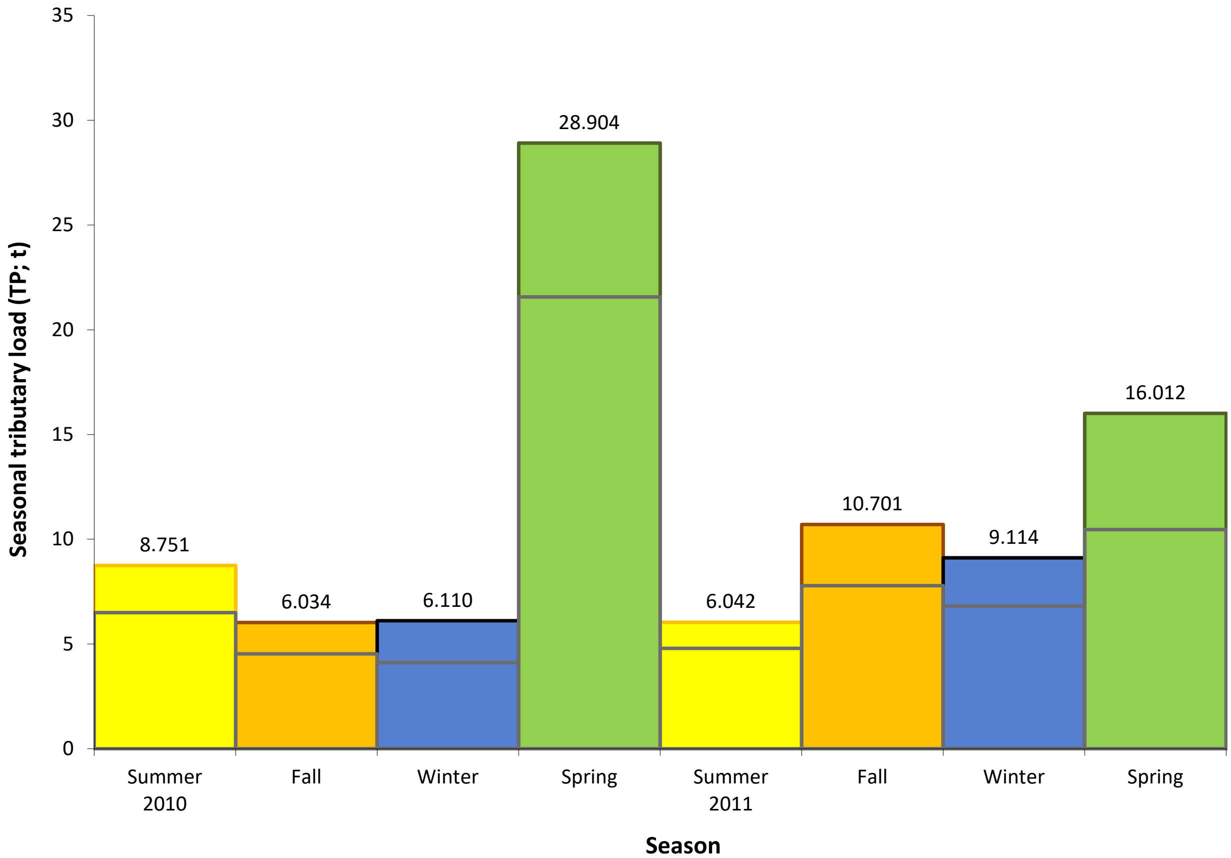


Figure 19. Seasonal TP loads to Lake Simcoe from the tributaries (2010–2011) with the grey border representing the loads from only the monitored/gauged subwatersheds.

Note that loads shown here were prorated to the tributary mouth but do not include loads from urban and polder areas downstream of stations or in unmonitored subwatersheds. Loads from upstream WPCPs are not included.

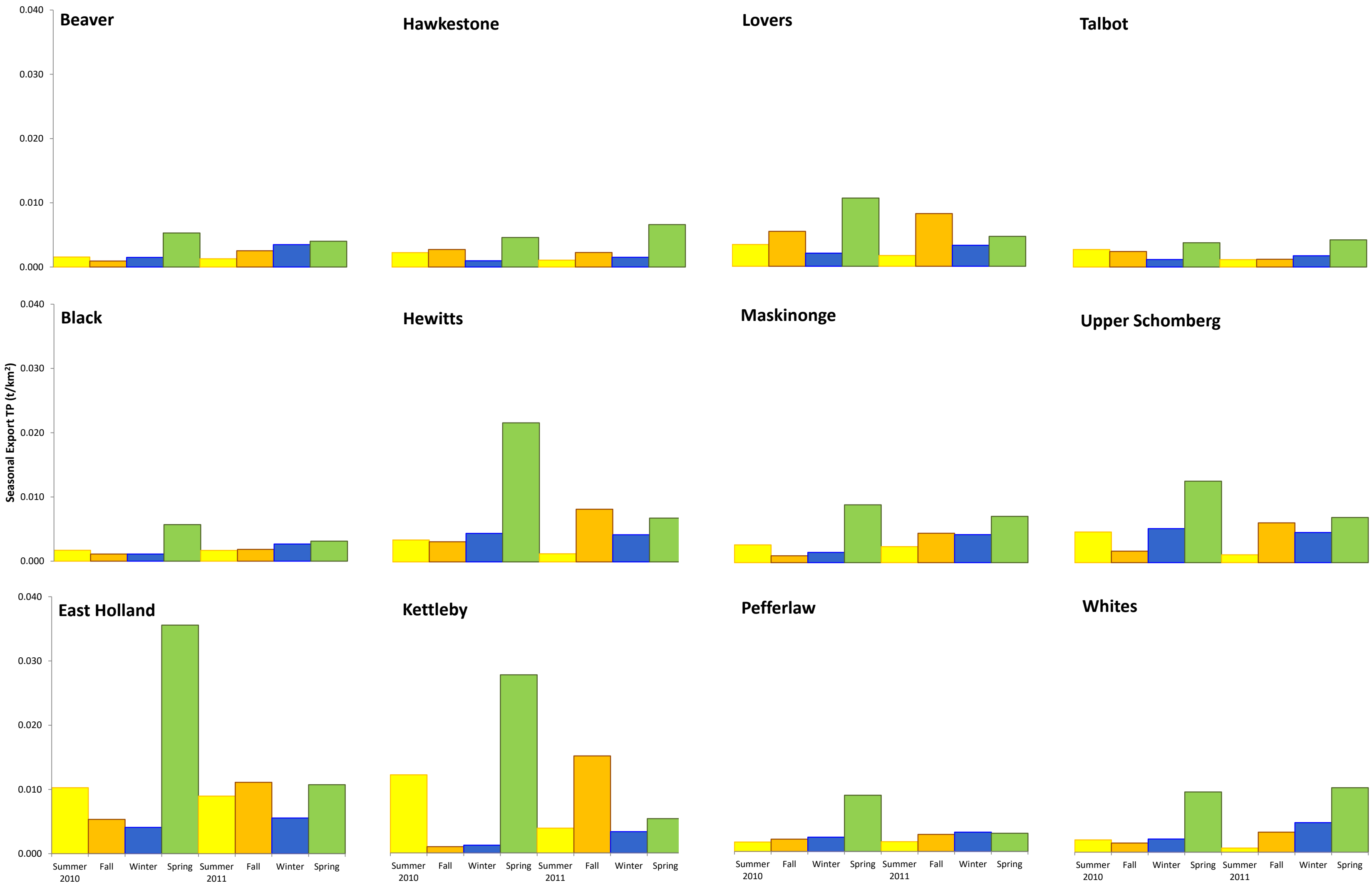


Figure 20. Seasonal TP export (t/km^2 subwatershed area) from monitored and gauged subwatersheds (2010–2011).

Note that calculations do not include urban and polder areas downstream of stations, WPCPs or septic systems.

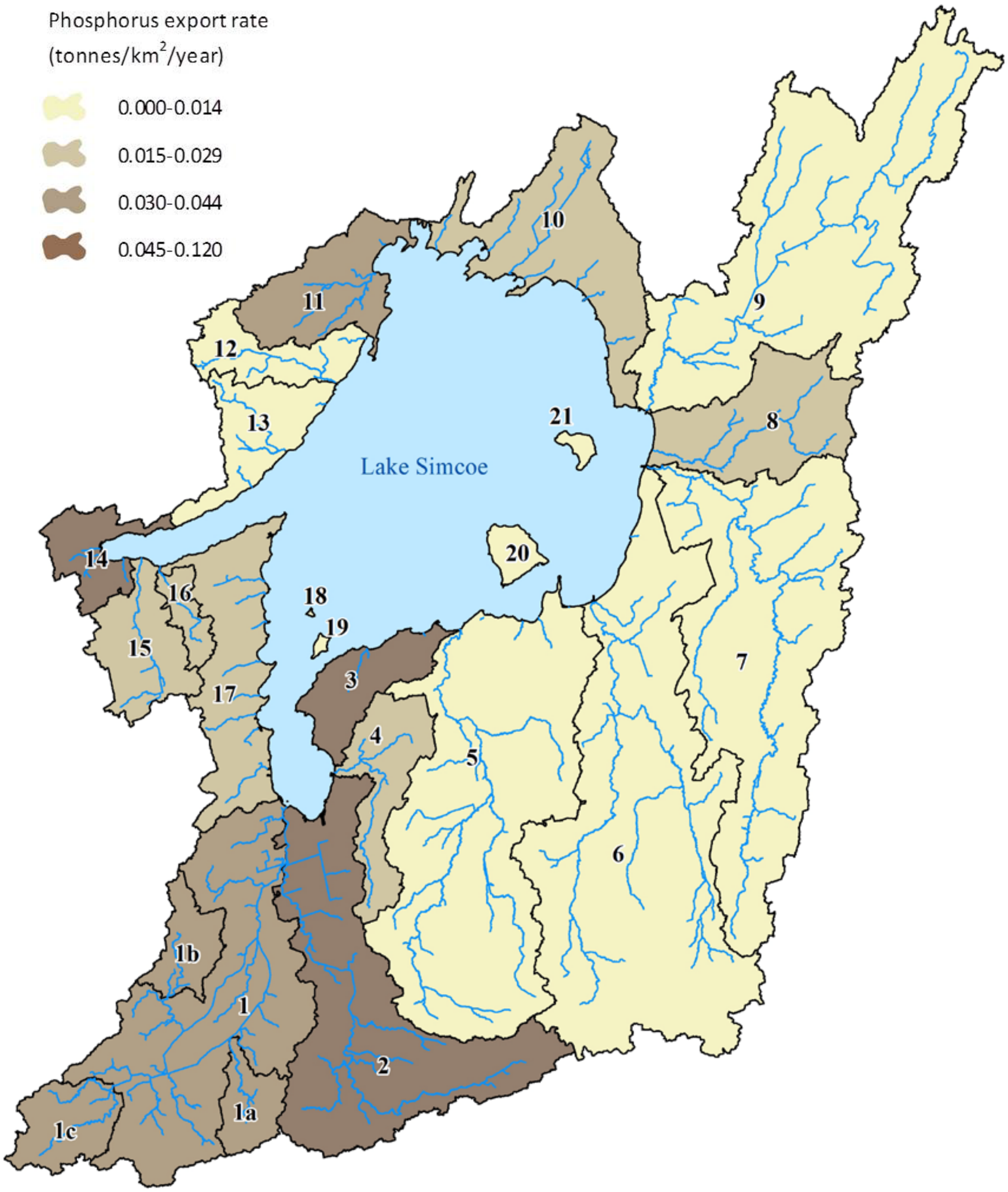


Figure 21. Map of TP export (t/km^2 subwatershed area/year; average of 2010 and 2011) for the Lake Simcoe subwatersheds. Refer to Figure 1 for subwatershed names corresponding with the numeric labels in the map.

Note that export was calculated using loads from all surface areas of the subwatersheds including all urban and polder areas; calculations do not include WPCPs or septic systems. For the West Holland River subwatershed, the loads from Kettleby Creek, North Schomberg River and Upper Schomberg River subwatersheds, and all urban and polder areas as mentioned, were summed and divided by the whole West Holland River subwatershed area. The resultant export rate was applied to the whole subwatershed.

Loads from Urban Runoff not Captured by Monitoring Stations

The estimated annual stormwater load of TP from urban areas below monitoring stations (and in unmonitored subwatersheds) was 10.7 t for each of 2010 and 2011, which is 12.7% of the annual average TP input to the lake (Table 10). This load was included in the tributary load shown in Figure 18. Note that this load is consistent with the urban runoff not captured by monitoring stations load reported for 2008 and 2009 hydrologic years [see areas and loads of each municipality in Table 8 of O'Connor et al. (2013)].

Loads from Vegetable Polders

The annual TP loads to Lake Simcoe from all vegetable polders for the 2010 and 2011 reporting period were 4.2 t and 3.9 t, respectively, with a two-year average of 4.1 t or 5.0% of the total annual TP input to the lake (Tables 9 and 12). The five-year average was 5.5 t (2007–2011) and the long-term average was 4.4 t (1990–2011). For the reporting period, the two-year average annual TP loads were 2.9 t from the Holland Marsh and 1.2 t in the other polders. All of the polders drain into the West Holland River subwatershed, with the exception of the Keswick Marsh, which drains into the East Holland River subwatershed. Colbar Marsh crosses the boundaries of both subwatersheds, but drains into the West Holland (see Figure 4 in O'Connor et al. (2012) for a map of the polders).

Seasonally, spring load from the polders was the highest with an annual average of 1.040 t over the 2010–2011 monitoring period, but the spring of 2010 was almost twice as high as 2011 (1.364 t compared to 0.716 t; Figure 22). Winter had the next highest loads with an average of 0.987 t; summer contributed 0.453 t and fall load was the lowest with an average of 0.347 t. The pattern of loads is similar to the water volumes discharged from Bradford Pumping Station No. 2 (Figure 11).

Table 12. Loads of TP to Lake Simcoe from vegetable polders (2010–2011).

	HM	BM	NBM	CM	CM2	KM	DP	Total
	Annual TP Load (tonnes)							(all)
2010	2.976	0.073	0.067	0.274	0.017	0.745	0.088	4.240
2011	2.733	0.067	0.062	0.252	0.016	0.684	0.081	3.895
Area (m^2)	28587955	704468	644858	2633903*	162626	7155830	848462	38104199

*90% of the area of CM is in the West Holland subwatershed and 10% is in the East Holland subwatershed.
HM = Holland Marsh, BM = Bradford Marsh, NBM = North Bradford Marsh, CM = Colbar Marsh, CM2 = Colbar2 Marsh, KM = Keswick Marsh, DM = Deerhurst Marsh

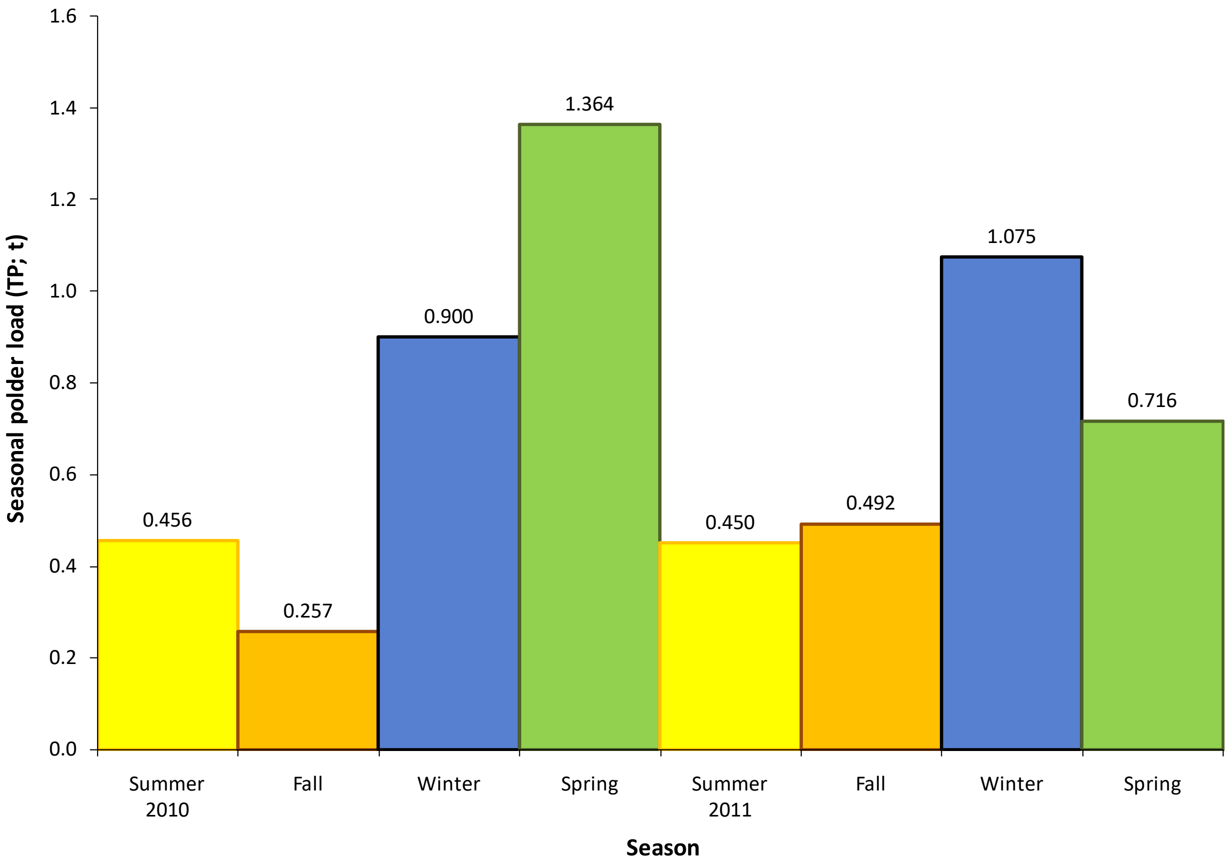


Figure 22. Seasonal TP loads to Lake Simcoe from the vegetable polders (2010–2011).

Note that some of the load results were calculated using estimated TP concentrations (see *Methods/Phosphorus Loads to Lake Simcoe* section*, Outlier Detection and Data Preprocessing – Holland Marsh* and *Loads from Vegetable Polders*).

Loads from Urban Point Sources

Loads of TP from the WPCPs, located both below and above the monitoring stations, were 3.2 t and 2.9 t for the 2010 and 2011, respectively, with a two-year average of 3.0 t or 3.6% of the total TP input to the lake (Tables 9 and 13). The five-year average was 3.9 t (2007–2011) and the long-term average was 5.0 t (1990–2011).

Seasonal loads for the WPCPs were fairly consistent during the 2010–2011 reporting period. Spring load was the highest with an annual average of 0.837 t over the 2010–2011 monitoring period (Figure 23). Winter had the next highest loads with an average of 0.804 t; summer contributed 0.738 t and fall load was the lowest with an average of 0.672 t.

Note that the percent contribution of TP load from WPCPs is similar to the percent contribution from Holland Marsh. Contributions from WPCPs make up 3.4% of the TP load (excluding WPCPs upstream of monitoring stations) while contributions from the Holland Marsh make up 3.1% of the TP load. However, discharge is greater from these WPCPs (2.3% of total water inputs to the lake) as compared to the Holland Marsh (0.4%). TP concentrations from the Holland Marsh are typically much higher than WPCPs: the average for all Holland Marsh samples was 0.512 mg/L while the average TP concentration for all WPCP samples for the 2010–2011 period was 0.090 mg/L.

Table 13. Loads of TP to Lake Simcoe from WPCPs (2010–2011).

	Annual TP load (tonnes)		
	2010	**2011**	**2-year average**
(a) WPCPs below monitoring stations:			
Barrie WPCP	1.308	1.189	1.248
Sutton WPCP	0.060	0.059	0.059
Holland Landing Lagoon	0.061	0.024	0.043
Innisfil (Alcona) WPCP	0.215	0.135	0.175
Keswick WPCP	0.557	0.691	0.624
Orillia WPCP	0.571	0.475	0.523
Lake Simcoe Lagoon - Beaverton	0.026	0.019	0.022
Lagoon City WPCP	0.035	0.027	0.031
Bradford WPCP	0.149	0.133	0.141
Schomberg WWTP	0.012	0.010	0.011
Siliani Sweet Cheese	0.014	0.023	0.019
Total	**3.007**	**2.786**	**2.897**
(b) WPCPs above monitoring stations:			
Beaverton River - Lagoon 1 (Sunderland)	0.008	0.001	0.005
Beaverton River - Lagoon 2 (Cannington)	0.047	0.052	0.049
Mount Albert WPCP	0.009	0.008	0.009
Uxbridge Brook WPCP	0.091	0.084	0.088
Total	**0.155**	**0.146**	**0.151**
Minimum (all WPCPs)	**0.008**	**0.001**	**0.005**
Maximum (all WPCPs)	**1.308**	**1.189**	**1.248**
Annual Total (all WPCPs)	**3.162**	**2.932**	**3.047**

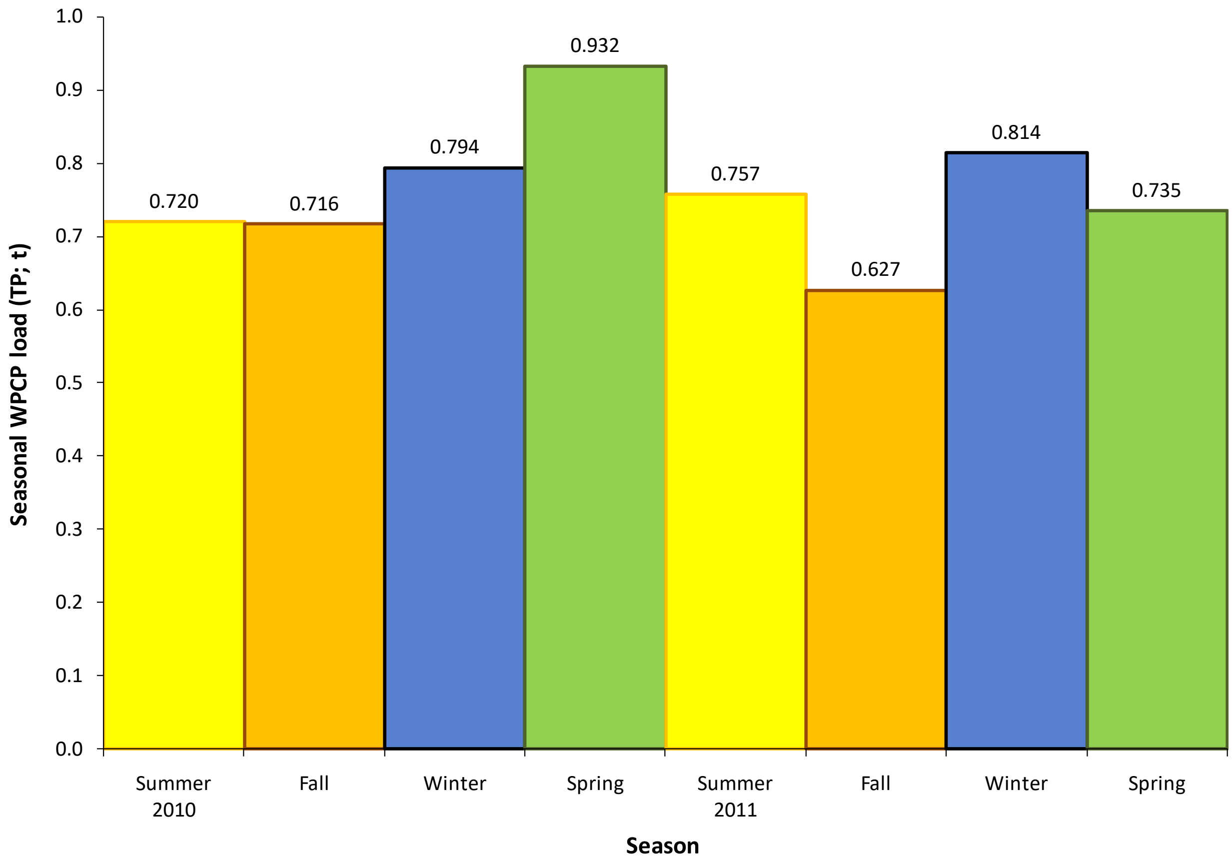


Figure 23. Seasonal TP loads to Lake Simcoe from the WPCPs (2010–2011).

Loads from Septic Systems

Septic systems within a 100 metre band around the lake were estimated to discharge 4.4 t of TP for each year in the reporting period, which averaged 5.3% of the total TP input to the lake (Table 10). The two- and five-year averages were the same (4.4 t; 2007-2011) and the long-term average was 4.6 t (1998–2011). The septic load reported has not changed since 2004 because the same geographic dataset and coefficients were used for the calculation.

Loads from the Atmosphere

The estimated atmospheric deposition of TP onto the lake for 2010 and 2011 was 18.8 t and 14.0 t, respectively, with a two-year average of 16.4 t or 19.3% of the annual TP input to the lake for the two years (Table 10). The five-year average was 16.5 t (2007–2011) and the long-term average was 29.3 t (1990–2011).

Seasonally, summer atmospheric loads were the highest with an average input of 7.234 t, followed by spring with an average input of 4.102 t. Fall contributed 3.748 t and winter was the lowest with an annual average of 1.300 t over the 2010–2011 monitoring period (Figure 24).

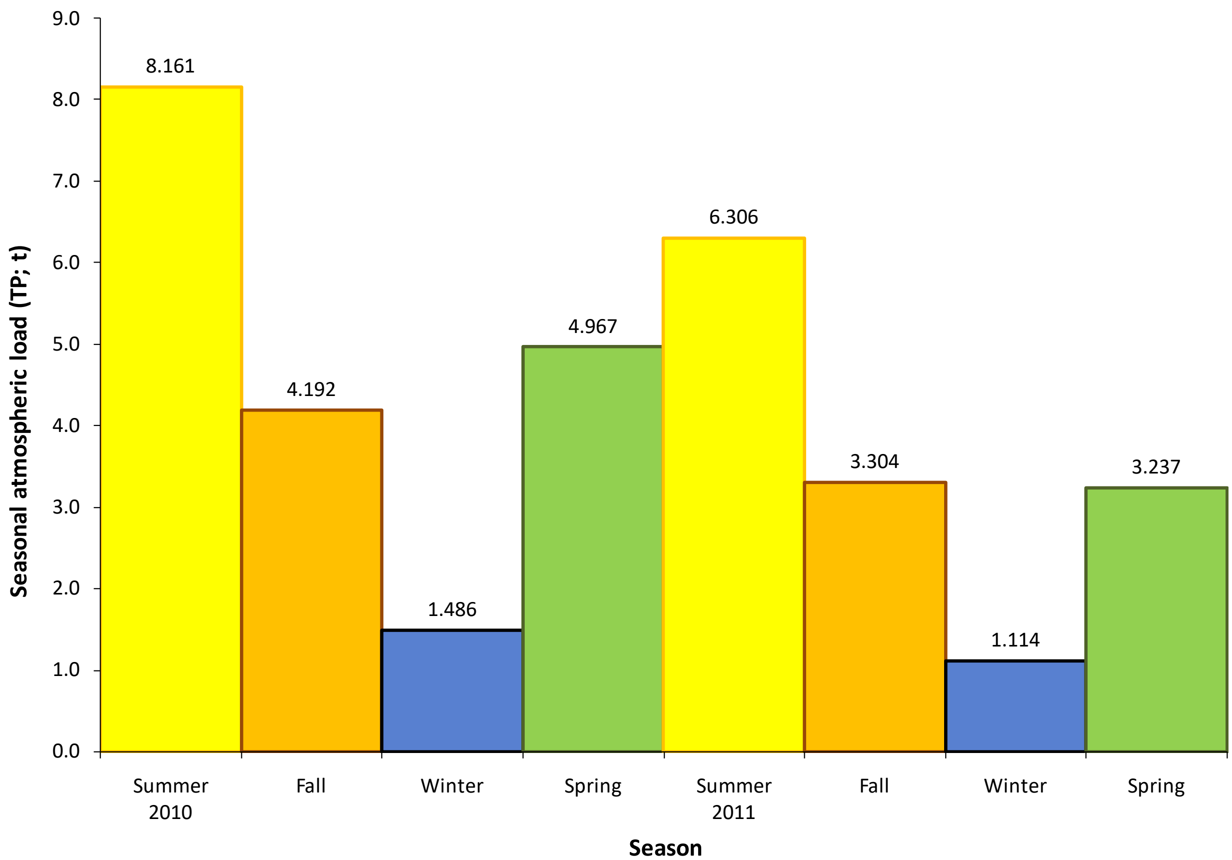


Figure 24. Seasonal TP loads to Lake Simcoe from the atmosphere (2010–2011).

Loads from the Lake Simcoe Outlet (Atherley Narrows)

The total annual TP outputs through the lake's outlet at Atherley Narrows for 2010 and 2011 were 7.3 t and 5.9 t, respectively (Table 10). The average loss for the two-year period was 6.6 t or 7.8% of the annual TP input to the lake. The five-year average was 9.0 t (2007–2011) and the long-term average was 8.4 t (1998–2011).

On average, summer output load was the highest with an annual average of 2.077 t, although it is important to note that summer of 2010 was almost twice as high as 2011 (Figure 25). The high summer output in 2010 was driven by higher than normal precipitation for that period, as described in the Water Balance Results. Seasonally the second highest output load was observed in winter with a two-year average of 1.561 t with winter 2011 higher than winter 2010 likely due to warmer air temperatures in the 2011 winter as described in the Water Balance Results sections. Fall had the third highest two-year average output (1.510 t). Spring had the lowest seasonal output with a two-year average of 1.459 t due to the unusually low output in the spring of 2011. This, in turn, was a factor of the low discharge through the outlet that spring [as described in *Results/Annual Water Balance: Loss terms/ Discharge from the Lake Simcoe Outlet (Atherley Narrows)*].

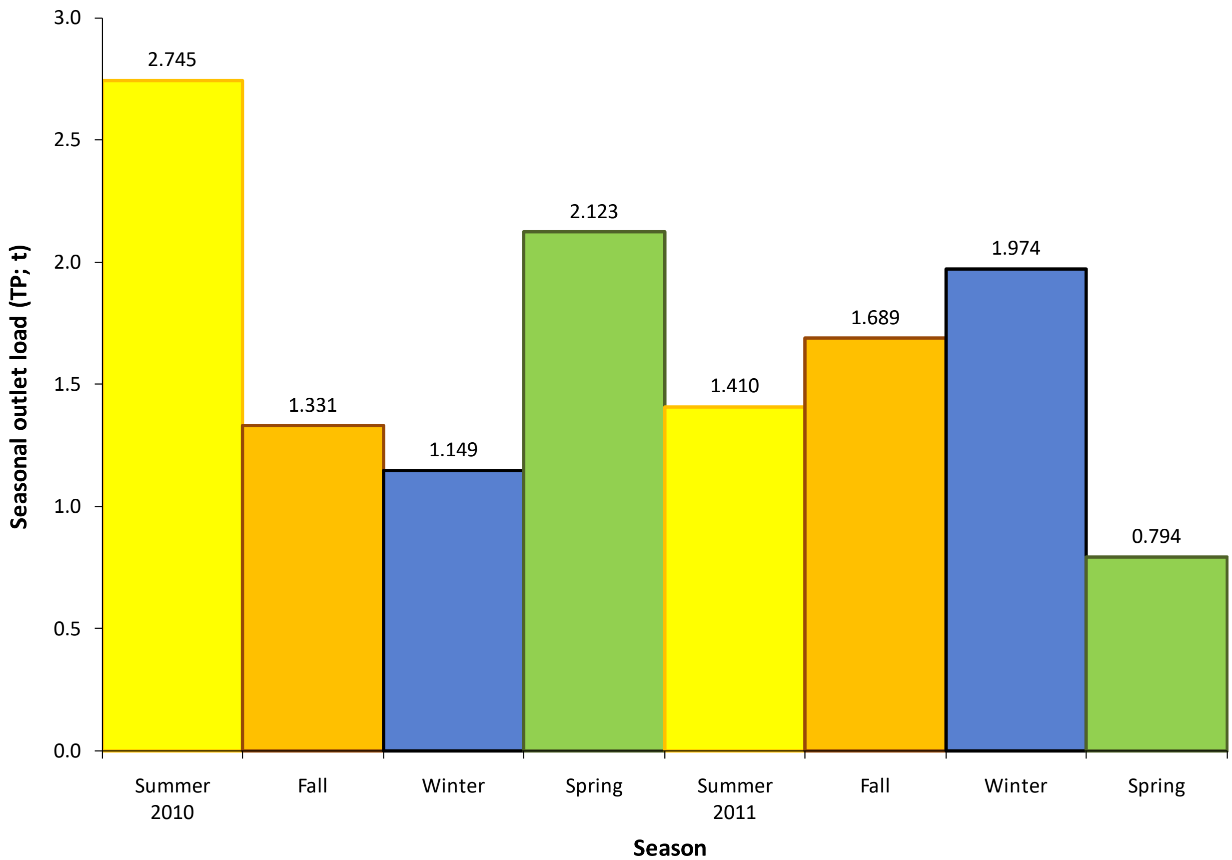


Figure 25. Seasonal TP loads through the outlet at Atherley Narrows (2010–2011).

REPORT SUMMARY

This report outlined the methods and results of annual water balances and annual total phosphorus loads to Lake Simcoe for the 2010–2011 hydrologic years (June 1, 2010 to May 31, 2012). The average water balance for the 2010–2011 period was -5.3%. On average, tributary, precipitation, WPCPs (excluding four WPCPs upstream of hydrometric gauges) and the Holland Marsh volumes contributed

56.5%, 40.8%, 2.3% and 0.4% of the annual hydrologic inputs, respectively. Outflow through Atherley Narrows and evaporation contributed 60.8% and 40.7% to the outputs on average, respectively.

The average annual total load of TP to Lake Simcoe for this reporting period was 84.4 t/yr (2010–2011). The five-year average load was 90.7 t (2007–2011) which is just below the long-term average of 91.0 t/yr (1990–2011). The loads were above the current phosphorus load target 44 t/yr (MOECC, 2009). On average, loads from tributaries, the atmosphere, septic systems, polders and WPCPs contributed 67.0%, 19.3%, 5.3%, 4.8% and 3.6% of the annual TP inputs, respectively. The average loss of TP from the lake through the outlet for the two-year period was 6.6 t/yr, or 7.8% of inputs.

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