Phosphorous Budget for the Shuswap River

FINAL REPORT

Megan Ludwig | Jeff Curtis, Ph.D. | June 2020

Executive Summary

This report summarizes analyses and inferences from the hydrometric and water chemistry analyses conducted on the Shuswap River watershed from Mabel Lake to Mara Lake from July 2016– May 2019. The purpose of this study was to evaluate the relative contributions of different parts of the watershed to total phosphorus loading to Mara and Shuswap Lakes. The parts of the watershed were, Mabel Lake (ML), tributary watersheds (TW), and incremental flow sub-watershed (IFSW). The anthropogenic contributions to phosphorus loading are through land use changes and direct waste discharges occurring in the IFSW.

A water balance was calculated for the Shuswap River using measurements of discharge in the main-stem river at Ashton Creek (Water Survey of Canada) and in tributaries (Ludwig, 2018). Three estimates of flows from IFSW were estimated by extrapolation from measurements in tributaries, by application of runoff coefficients derived from the literature combined with precipitation data, and by un-mixing the geochemistry river water as IFWS contributions increase downstream (Ludwig, 2018). From these three estimates of IFSW flows, and the measured contributions of tributaries, the flows from ML (by subtraction relative to Shuswap River flows at Ashton Creek) and flows to Mara Lake (by addition relative to Shuswap River flows at Ashton Creek). Contributions are dominated by ML, followed by TW, with relatively small contributions from IFSW.

A phosphorus balance was calculated for the Shuswap River by multiplying the flow measurements and estimates by measured concentrations of phosphorus. Thus, measured discharges have one calculated flux, and estimated discharges have three estimated fluxes derived from the three different methods for estimating discharge. We also calculated phosphorus contribution from IFSW by the difference of estimated phosphorus flux to Mara Lake from that for ML and TW. By all methods, contributions of phosphorus are also dominated by ML even though the concentration of phosphorus is very low. This is because the contributions to flow are so large. Contributions of phosphorus from TW and IFSW are similar even though the contributions of water are

much higher for TW than IFSW. This is because the concentration of P in water from IFSW is much higher. Expressed as a contribution per unit of contributing area, the IFSW contributes about ten times the quantity of phosphorus relative to the TW.   This is consistent with contributions of phosphorus expected when land is converted to agricultural/urban land use.

Key Terms

Upper Reaches: The portion of the watershed that contributes discharge to the river that flows through the defined 0 km mark in the study. It is essentially the discharge present at the most upstream site in the study. For the Shuswap River this is Mabel Lake (ML).

Tributary Watershed Sub-Watershed: Watershed areas that contribute to large creeks and streams that ultimately contribute discharge to the mainstem of the river. They typically run year-round and are defined as 2^{nd} order stream or higher. Collectively, these sub-watersheds constitute Tributary Watersheds (TW)

Incremental Flow Sub-Watershed (IFSW): These sub-watersheds can be considered ungauged portions of the watershed that directly contribute discharge to the river in the form of runoff, as well as groundwater inflows, seasonal streams, and agricultural ditches that directly run into the river. They do not contribute to tributary sub-watershed or upper reaches. These areas are typically smaller, low lying and contain the majority of the anthropogenic activity.

End Member Mixing Analysis (EMMA): EMMA is the discharge modelling technique in the geochemical method. It uses changes in the concentration of conservative tracers to determine the proportional contribution of water from different sources, or end members, in water samples composed of a mixture of the sources (Kendall and McDonnell 1998).

Project Overview

Motivation

The aim of the project was to determine the sources of total phosphorus (TP) and total dissolved phosphorus (TDP) into the Shuswap River, because it is an important contributor of P to the Mara and Shuswap Lake system (Tristar Environmental Consulting 2014). Despite their large size (19.5 and 310 km2, respectively) and rapid flushing rates (~1 month and ~ 2 years, respectively) Mara and Shuswap Lake experienced large-scale algae blooms in 2008 and 2010. There is no official threshold level to determine what an algae bloom is, but it can be considered a concentration of hundreds to thousands of algae cells per milliliter, depending on the algae species present which results in lowering of oxygen levels (Wolf and Klaiber 2017). No algae blooms have been reported since, but elevated algae growth was reported in 2011 and 2012.

The algae blooms were determined to be associated with phosphorous (P) entering the lakes from the Shuswap and Salmon Rivers (Tristar Environmental Consulting 2014). Using export coefficient models (ECM), the Shuswap River was identified to be a significant contributor of P into Mara and Shuswap Lakes. Algae blooms are not only harmful to human and livestock health, but they also reduce tourism, thus hurting the economy, consequently making prevention of future algae blooms within the Mara and Shuswap Lakes system a priority. Identifying the sources and transport mechanisms of P into Mara and Shuswap Lakes from the Shuswap River, is essential to remediate P loadings and prevent future algae blooms.

Past Studies

The potential sources of P entering the Shuswap and Mara Lakes system were examined in a study undertaken by Shuswap Lake Integrated Planning Process (SLIPP) in 2014 (Tristar Environmental Consulting, 2014). Contributions of TP from permitted discharges, direct loadings (e.g. Enderby waste water treatment plant), and non-point source loadings, including tributaries, to the overall P budget into Mara and Shuswap Lakes were estimated using an Export Coefficient Model. The exercise estimated TP loadings for individual land uses using a combination of runoff coefficients and TP concentrations taken from literature (ibid.).

Results indicated that nearly all the phosphorus flux to the lakes (98%) was coming in from the watersheds through drainage, with small contributions from salmon carcasses and discharges directly to Shuswap Lake a wastewater treatment plant on Shuswap Lake (Tristar Environmental Consulting 2014). The TP load from atmospheric deposition and other natural sources were not estimated. The majority of the phosphorus flux to Mara and Shuswap Lake was calculated to be from the Shuswap and Salmon Rivers (78.1%) (ibid.). The study also inferred that the majority of the P entering the lake system was from agriculture storm water runoff (ibid.).

Objectives

The objective of this study were to measure and estimate the fluxes of total phosphorus (TP) and total dissolved phosphorus (TDP) in the lower Shuswap River to inform decisions on nutrient management In order to quantify the TP and TDP from tributaries sub-watersheds, IFSW, and contribution from upper reaches, we chose a robust approach using a combination of field measurements of P concentrations and three estimation methods for hydrologic inputs; extrapolation, runoff coefficients (RC), and geochemical methods.

We focussed our analyses of phosphorus flux on the portion of the watershed dominated by anthropogenic land uses (agriculture/urbanization). This portion is overwhelmingly within the IFSW. IFSW are ungauged sub basins, but also include direct contributions to the rivers through groundwater, seasonal streams, agriculture ditches, etc. Because IFSW exist in low elevation areas of the watershed that contain the majority of the anthropogenic activities within the watershed corresponding to the portion of the watershed identified in the ECM as contributing the majority of the anthropogenic phosphorus (Tristar Environmental Consulting 2014). Anthropogenic activities, particularly agriculture and urban areas, are well known to enhance phosphorus loading to surface waters. For agriculture areas, the increased P export is due the removal of natural vegetation, and application of P rich fertilizer and manure on the lands. In urban areas, much of the increased P export is due the impermeable surfaces which drastically increase runoff and transport particulate and dissolved forms of P into the river systems.

Measurements

Discharge

Discharge was measured at kilometer 29 (Fig. 1) by the Water Survey of Canada. We measured discharge in tributaries including Kingfisher, Cooke, Fall, Trinity, Ashton, Brash, and Fortune Creeks (Figure 1; and described in detail in Ludwig (2018).

Discharge from IFSW was determined using one of three estimation methods; extrapolation, runoff coefficients or geochemical methods outlined in Table 1. Because IFSW are difficult to estimate due to their small size and somewhat sporadic nature, three approaches were used to create a robust range of estimates. These approaches are described elsewhere in detail (Ludwig 2018). A stepwise summary is provided in Table 1.

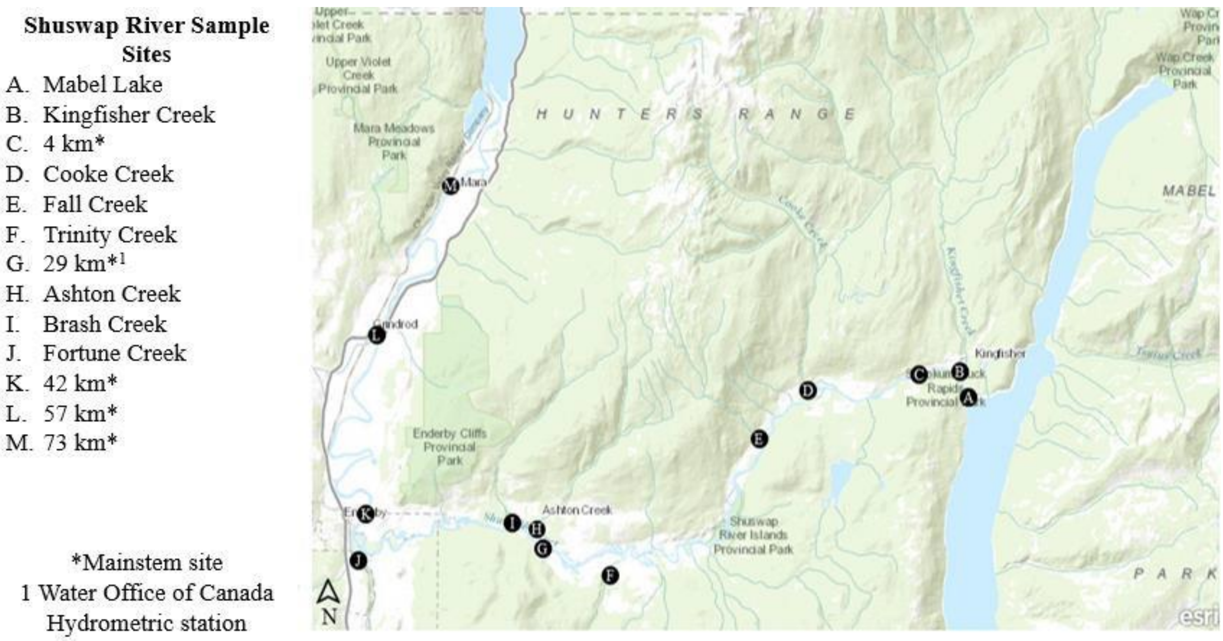
Method	Summary of Steps
Extrapolation	1. Determine the average daily discharge yield from tributary sub-watersheds (mm day^{-1}) 2. Extrapolate the discharge yield to IFSW by multiplying the area of land occupied by IFSW by the average yield of the tributary sub-watersheds (found in step 1) 3. Use mass balance techniques to determine the discharge of the ungauged reaches by adding or subtracting measured tributary discharge and estimated IFSW discharge from the discharge measured at the Water Office of Canada hydrometric station

Runoff Coefficients (RC)	1. Determine the runoff coefficient- proportion of precipitation that will reach the surrounding water body- from literature for urban, agriculture and forested land uses based on watershed characteristics that best match the study watershed. 2. Determine the area of urban, agriculture, and forested land use within IFSW 3. Retrieve daily precipitation data for the area 4. Determine discharge from IFSW by multiplying precipitation (m) by area of each land (m^2) and the runoff coefficient pertaining to that land use (unitless) to get the discharge (m^3) 5. Use mass balance techniques to determine the discharge of the ungauged reaches by adding or subtracting measured tributary discharge and estimated IFSW discharge from the discharge measured at the Water Office of Canada hydrometric station
Geochemical	1. Determine a conservative tracer for the area – for this study tracers included elements, CDOM and nitrate. 2. Retrieve water samples and determine the concentration of tracers from a mixed sample, and two end-members in question (e.g. groundwater and river water). 3. Use EMMA to determine the proportion of water from the end-members

Sampling for Chemical Analysis

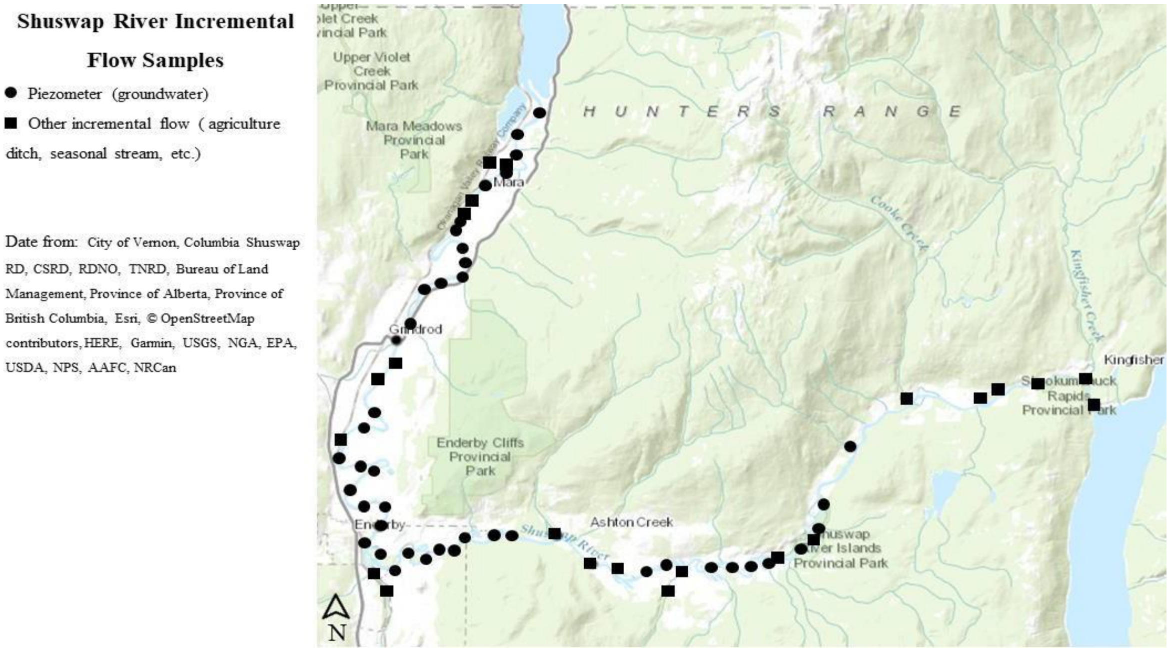
Samples for chemical analysis were collected at intervals from all tributaries, the Mable Lake outflow, and at river kilometers 4, 29, 42, 57, and 73 (Figure 1). Sample intervals varied from a minimum of three times weekly to monthly, with sample frequency increasing with discharge.

Figure 1: Map of Sample sites on Shuswap River



Chemical sampling of water draining the IFSW included the sampling of groundwater, seasonal streams and ditch water. Sampling of IFSW was done less frequently than sampling of tributaries, upper reaches, and other mainstem sites along the river, because groundwater composition changes slowly, and because seasonal streams and ditch water only flow during times of high runoff. Groundwater sampling was done twice per year, while ditch and stream water sampling was done in the spring when runoff was sufficient enough to cause them to flow.

Figure 2: Map of IFSW Sample sites on Shuswap River



Results

Data Availability

All data and calculations presented in this report are available through the Shuswap Watershed Council.

Discharge

Discharge for the intervals July 2016 – May 2019 for the tributaries (aggregate), Mable Lake outflow (ML; Shuswap River), IFSW (aggregate), and Mara Lake inflow of the Shuswap River km at about km 73 (SRkm73) are shown in Appendix 1. There are three discharge scenarios for ML, IFSW, and SRkm73 for the different methods.

Discharge by most methods is seasonal because hydrology is dominated by snowmelt in interior British Columbia. The Runoff Coefficient method differs somewhat because runoff from precipitation is not attenuated by flow through the ground or storage in snowpack. We attempted to smooth the data by a running average approach to attenuate the event flows. No running average produced a characteristic snowmelt hydrograph. Thus, the RC method is probably best used only for estimation of long-term (e.g. annual) discharge.

When expressed annually, discharge should be summed over a hydrologic year, typically starting and ending in a low flow period to minimize the variability introduced by an arbitrary choice. Here, the hydrologic year can correspond to the calendar year because low flows occur reliably in January. Average annual flows were calculated for period 1 January 2017 – 31 Dec 2018. Average flows for the three methods were 3.1 X 10^9 (CV 14%), 3.1 X 10^8, 4.0 X10^8 (CV 128%), and 3.4 X10^9 m^3 y^{-1} (CV 12%) for ML, TW, IFSW and SRkm73, respectively. There is no coefficient of variation (CV) for TW because it is based on measurement rather than estimates. Coefficients of variation for ML and SRkm 73 are small because they are dominated by measurements of TW and the Water Survey of Canada discharge measurement at km 23. Coefficients of variation for

IFSW are largest because they are all estimated indirectly. Discharge data is summarized in Appendix 2.

Phosphorus Loading

Phosphorus loading from different portions of the watershed was calculated by multiplying the concentration of phosphorus (mass volume^{-1}) by the discharge (volume time^{-1}) to give phosphorus loading (mass time^{-1}). Discharge was expressed daily, and consequently phosphorus concentration required interpolation between samplings. We interpolated phosphorus concentration temporally because concentration did not depend on discharge (Ludwig 2018). Phosphorus loadings for the entire sample period are shown in Appendix 3.

Average annual phosphorus loadings were calculated for the same two hydrologic years 1 January 2017 – 31 Dec 2018. Average total phosphorus (TP) loadings for the three methods were 4.1 X 10^4 (CV 13%), 5.9 X 10^3, 2.5 X10^4 (CV 144%), and 6.9 X10^4 (CV 5%) kg y^{-1} for ML, TW, IFSW and SRkm73, respectively. Average total dissolved phosphorus (TDP) loadings for the three methods were 2.8 X 10^4 (CV 24%), 3.2 X 10^3, 1.5 X10^4 (CV 143%), and 2.7 X10^4 (CV 6%) kg y^{-1} for ML, TW, IFSW and SRkm73, respectively. There is no coefficient of variation (CV) for TW because the discharge is based on measurement. Coefficients of variation for ML and SRkm 73 are small because they are dominated by discharge measurements of TW, and measurements of Shuswap River discharge (Water Survey of Canada) at km 23. Coefficients of variation for IFSW are largest because they are all estimated indirectly.

Yields of phosphorus were calculated to express the quantity of phosphorus per unit of area from the different components of the watershed. Average total phosphorus (TP) yields for the three methods were 0.1, 0.1, 5.1, and 0.14 kg ha^{-1} y^{-1} for ML, TW, IFSW and SRkm73, respectively. Average total dissolved phosphorus (TDP) yields for the three methods were 0.07, 0.06, 3.0, and 0.06 kg ha^{-1} y^{-1} for ML, TW, IFSW and SRkm73, respectively. Coefficients of variation are the same as for phosphorus loadings because the loadings have only been divided by watershed area. Phosphorus loading and yield data are summarized in Appendix 3.

A final calculation of loadings from IFSW can be made by subtracting the loadings from ML and TW from the flux calculated for SRkm73 (inlet to Mara Lake). Even though our sampling of IFSW source waters was spatially intensive, this calculation integrates IFSW contributions in both time and space. IFSW TP and TDP loadings were 2.2 X 10^4 and -4.3 X10^3 kg y^{-1}, respectively. Yields of TP and TDP for IFSW were 4.4 and -0.9 kg ha^{-1} y^{-1}. Values for TDP are negative, probably because all of the net conversion of phosphorus from all sources into particulate form (biomass of organisms) is assigned to IFSW. TP fluxes and yields were not significantly different from those estimated by the three hydrologic methods indicating that the concentrations used in calculating fluxes and yields from IFSW were representative.

TP and TDP yields are very low for ML and TW and within expectation for undisturbed watersheds in BC (Ludwig 2018). Yields for IFSW are on average 50 times higher than for undisturbed watershed, but are also within the range of values reported for agricultural and urban land use. If we extrapolate relatively undisturbed watershed phosphorus yields from TW to IFSW, anthropogenic sources of excess phosphorus can be estimated. Relatively undisturbed IFSW might have only contributed 500 and 280 kg or phosphorus per year. This would reduce the flux at SRkm73 (Mara Lake) by as much as 56%. A reduction of this magnitude would change loading normalized concentration of 20 mg m^{-}3 TP to about 9 mg m^{-3}, and improve the present trophic state predicted from the Vollenweider-OECD model (Janus and Vollenweider 1981) from oligo-mesotrophic to oligotrophic.

References

Janus, L and R Vollenwelder (1981). The OECD Cooperative Program on Eutrophication.

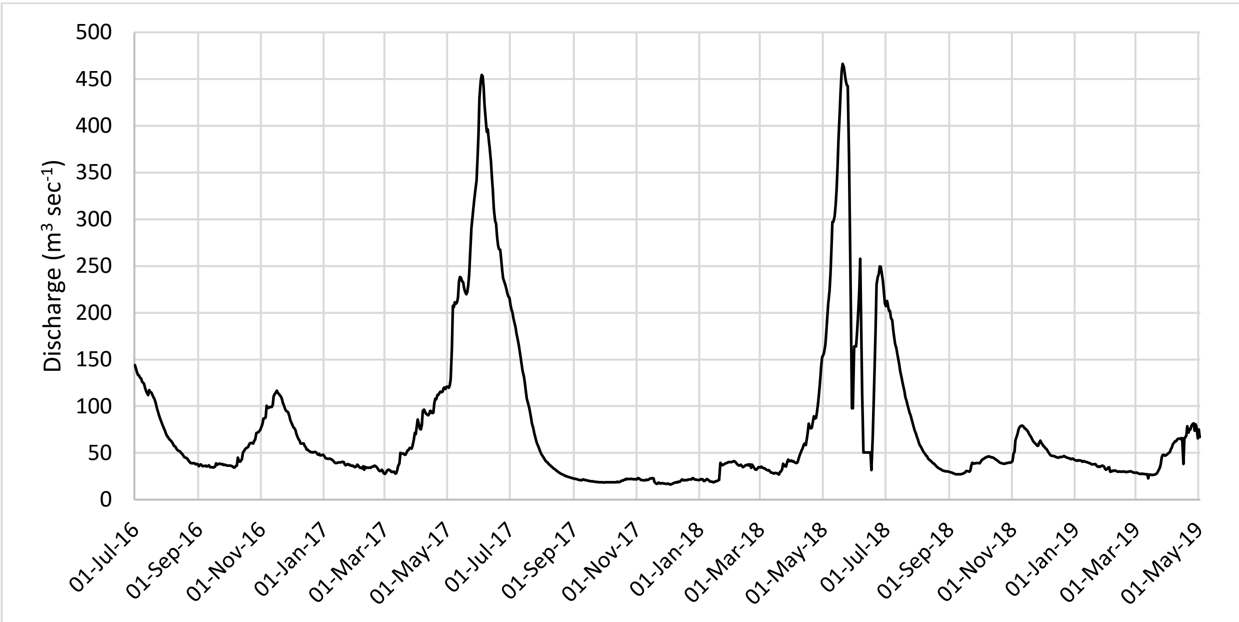
Ludwig ME (2018) A Multi-Method Approach for Determining a Phosphorus Budget for the Shuswap and Salmon Rivers in Southern Interior British Columbia. MSc. Thesis, The University of British Columbia.

Tristar Environmental Consulting (2014) SLIPP Water Quality Report: Sources of Nutrients 2014. Prepared for the Shuswap Lake Integrated Planning Process and Fraser Basin Council.

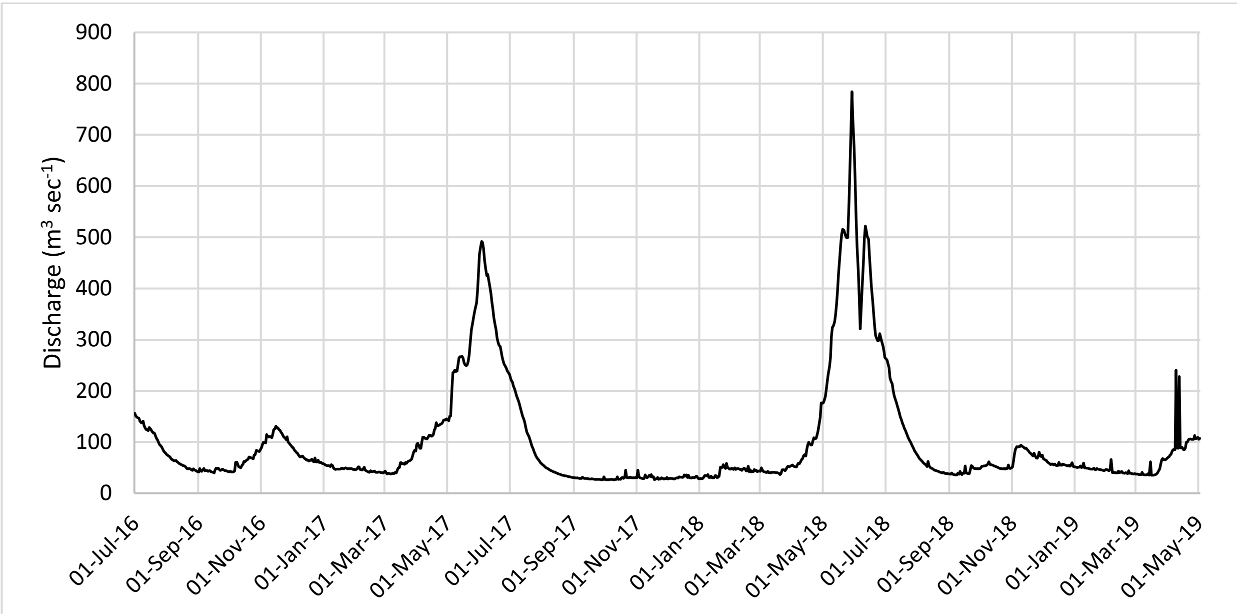
Wolf, D and HA Klaiber (2017) "Bloom and Bust: Toxic Algae's Impact on Nearby Property Values."Ecological Economics, vol. 135, 5, pp. 209-221.

Appendix 1: Measured and calculated discharge for the Shuswap River Watershed.

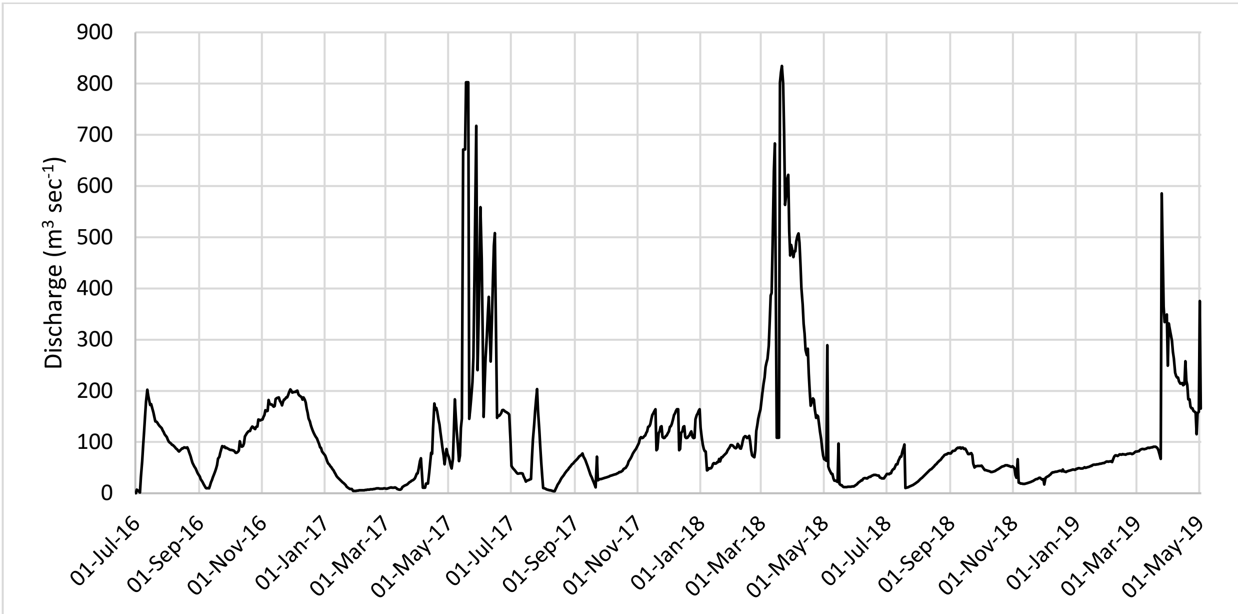
Appendix 1a. Discharge at Mabel Lake, Extrapolation Method



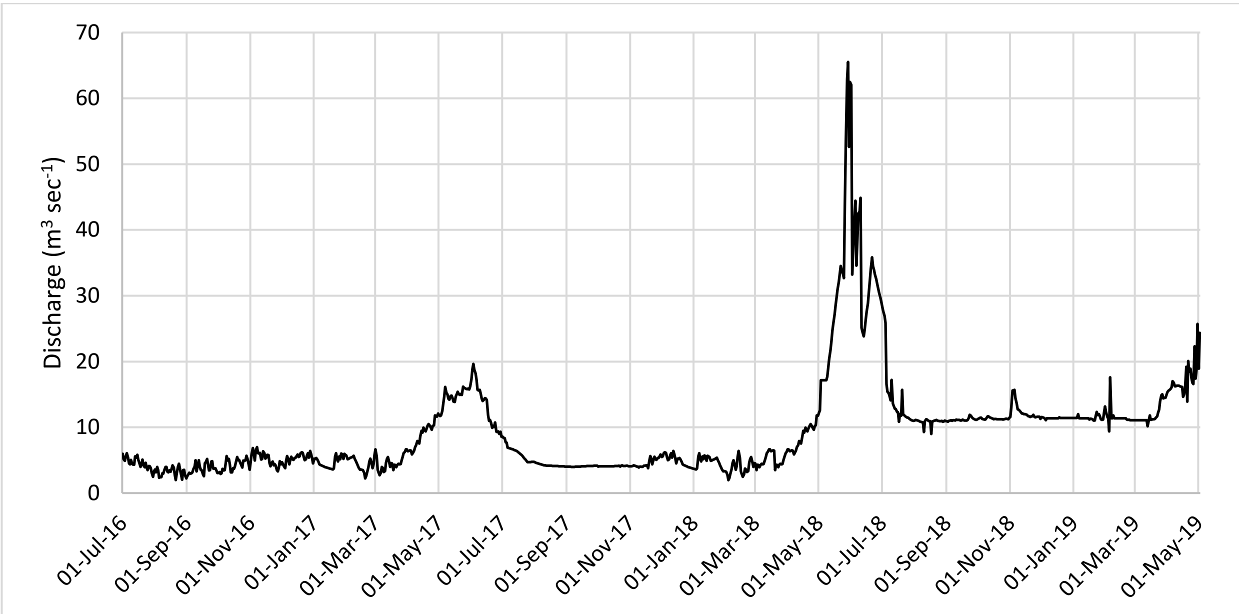
Appendix 1b. Discharge at Mabel Lake, Runoff Coefficient Method



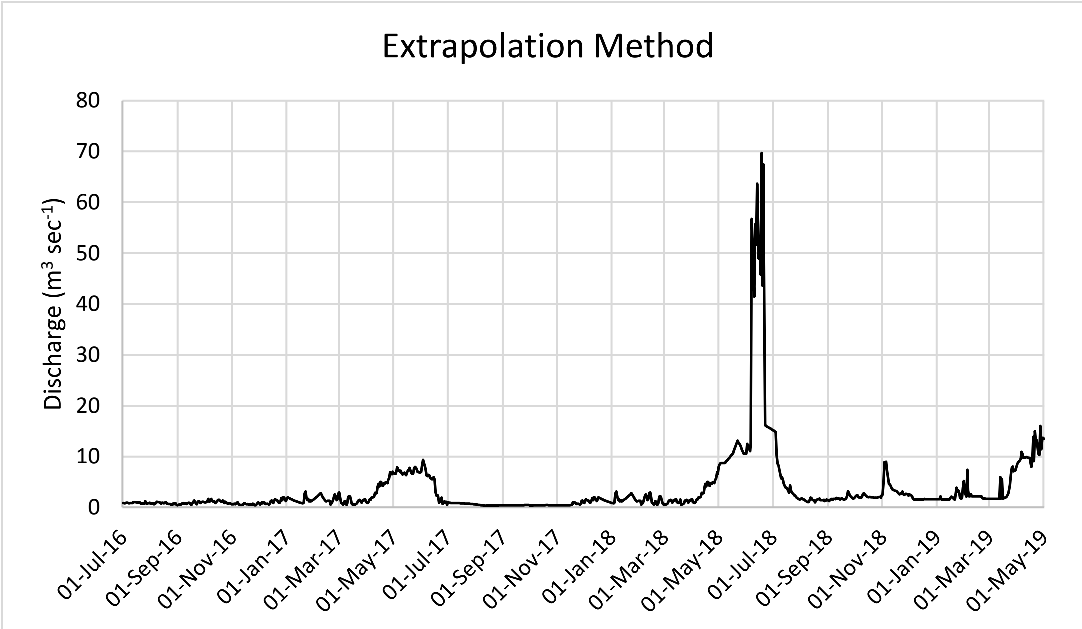
Appendix 1c. Discharge at Mabel Lake, Geochemical Method



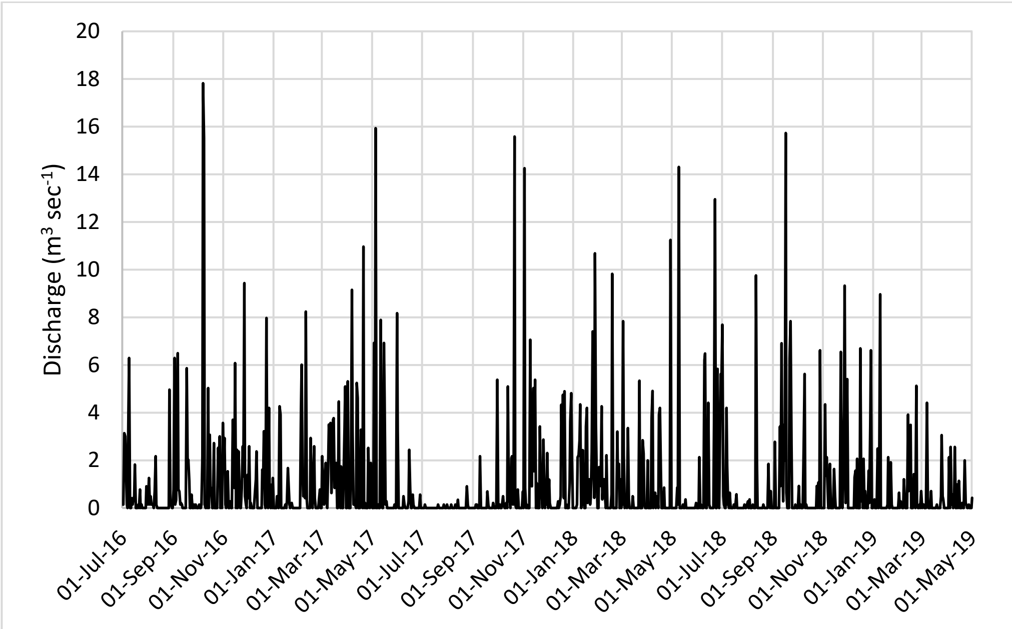
Appendix 1d. Discharge, sum of Tributaries



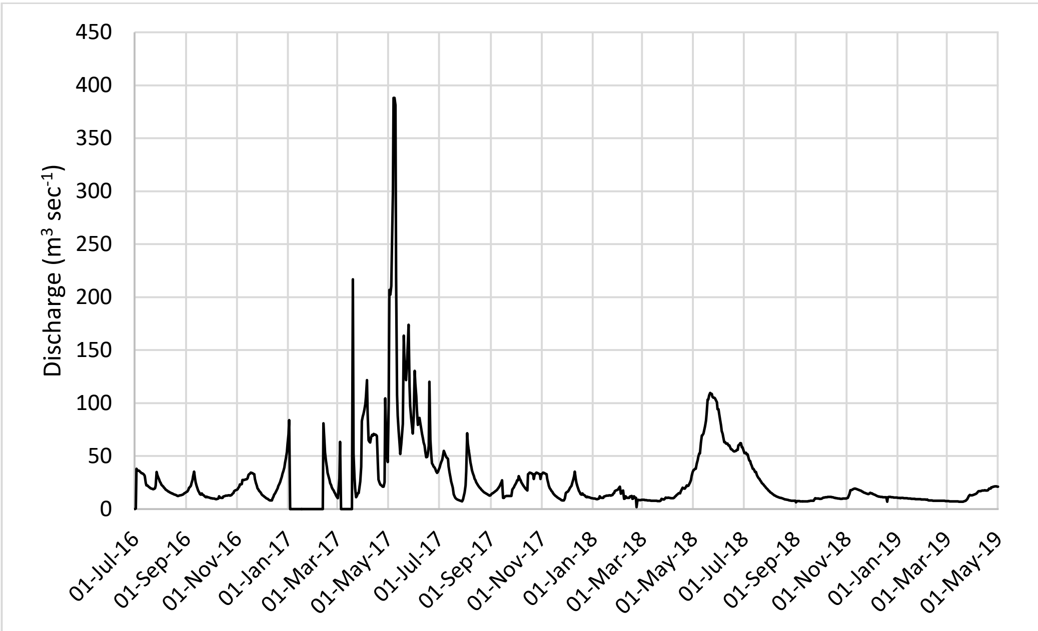
Appendix 1e. Discharge from IFSW, Extrapolation Method



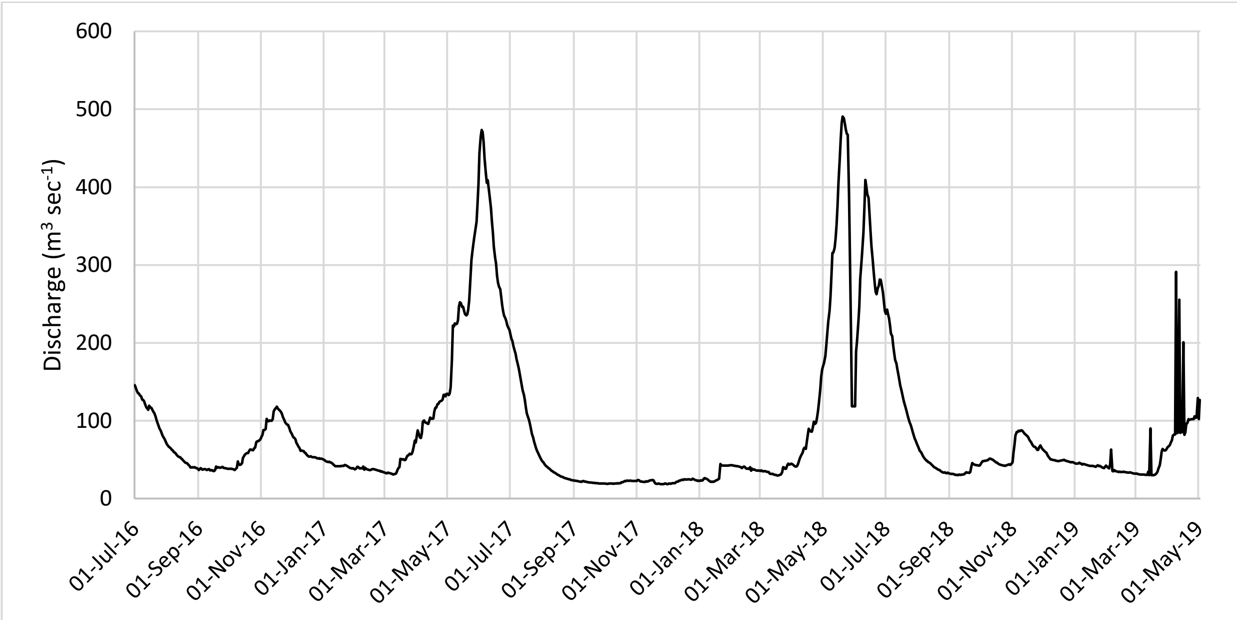
Appendix 1f. Discharge from IFSW, Runoff Coefficient Method



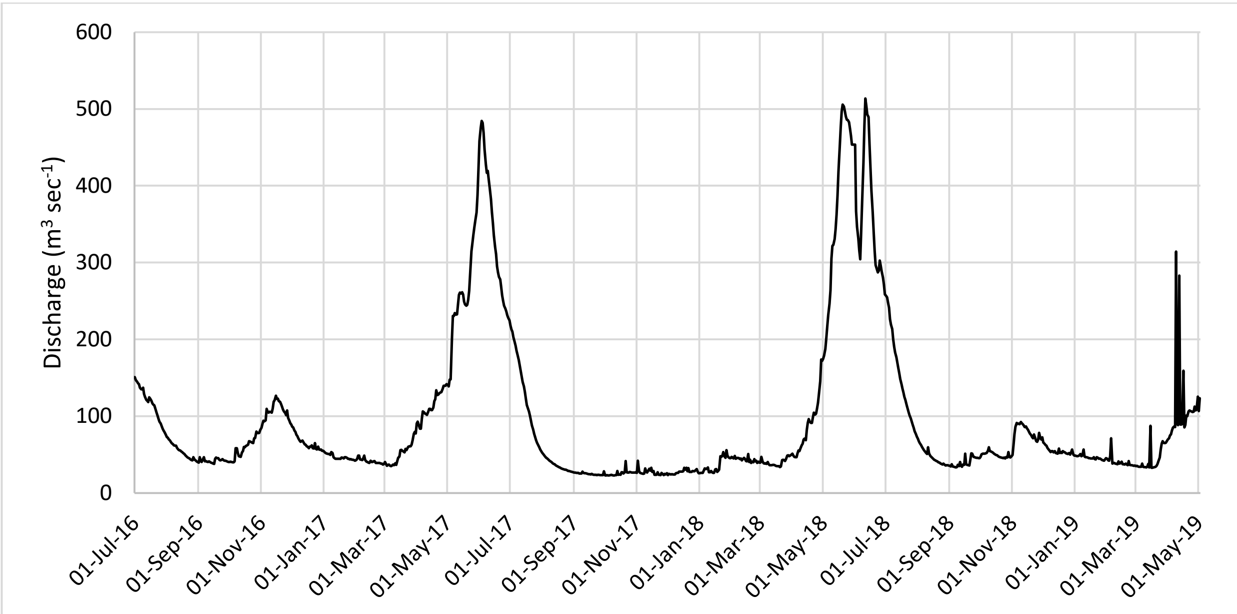
Appendix 1g. Discharge from IFSW, Geochemical Method



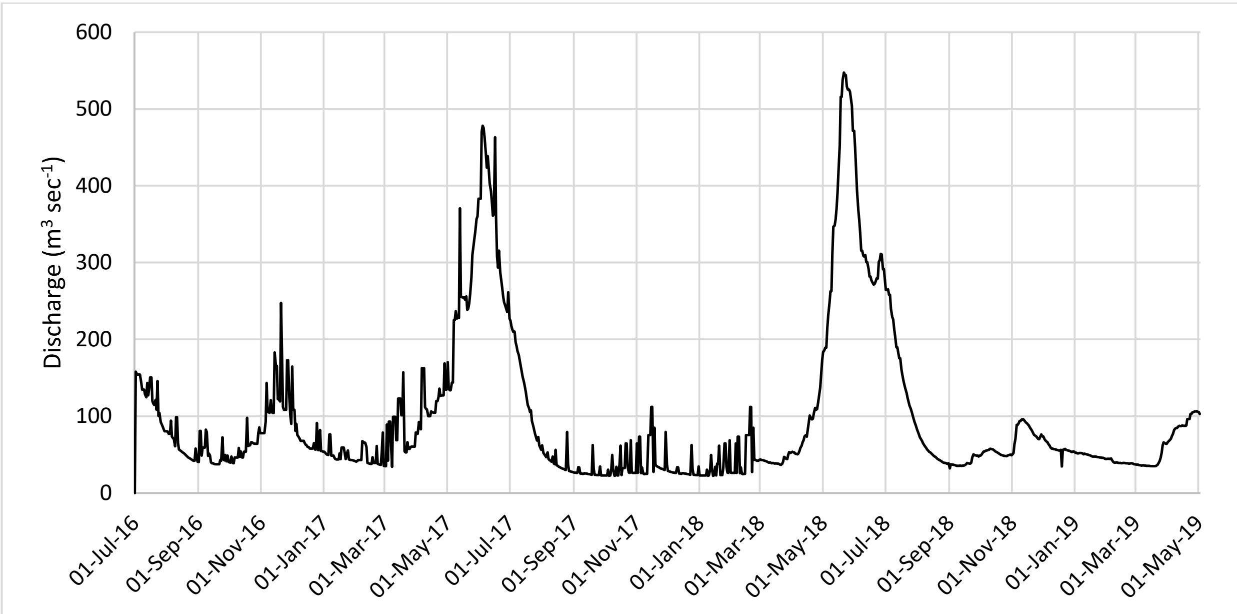
Appendix 1h. Discharge at Mara Lake, Extrapolation Method



Appendix 1i. Discharge at Mara Lake, Runoff Coefficient Method

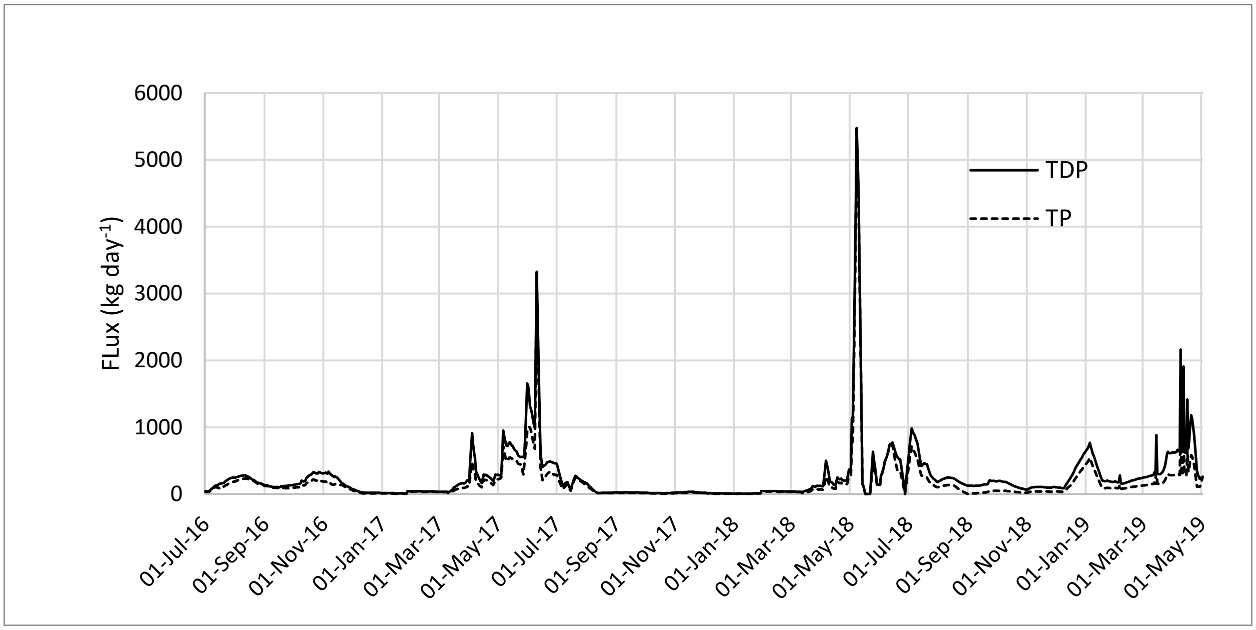


Appendix 1j. Discharge at Mara Lake, Geochemical Method

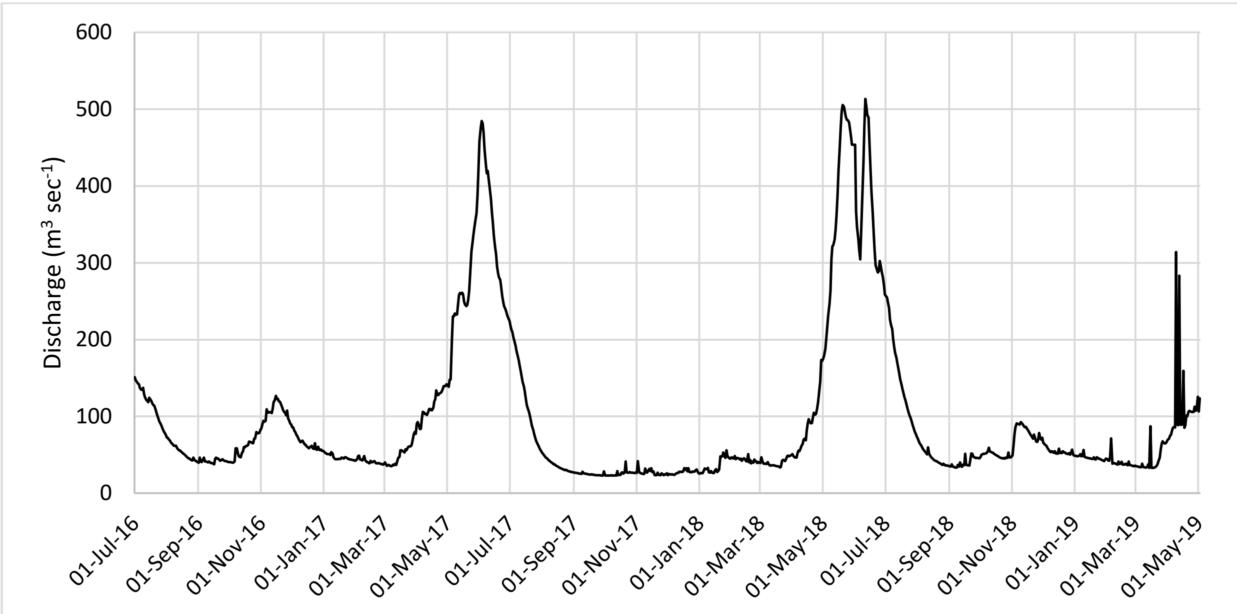


Appendix 2: Phosphorus Flux for the Shuswap River Watershed.

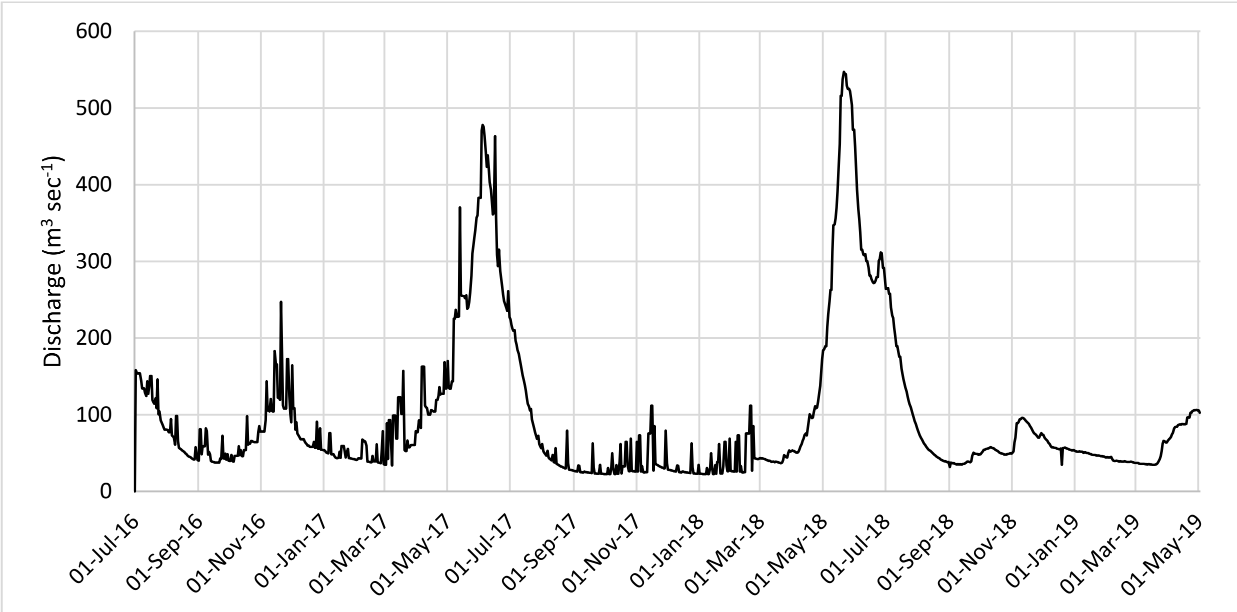
Appendix 2a. Phosphorus Flux at Mabel Lake, Extrapolation Method



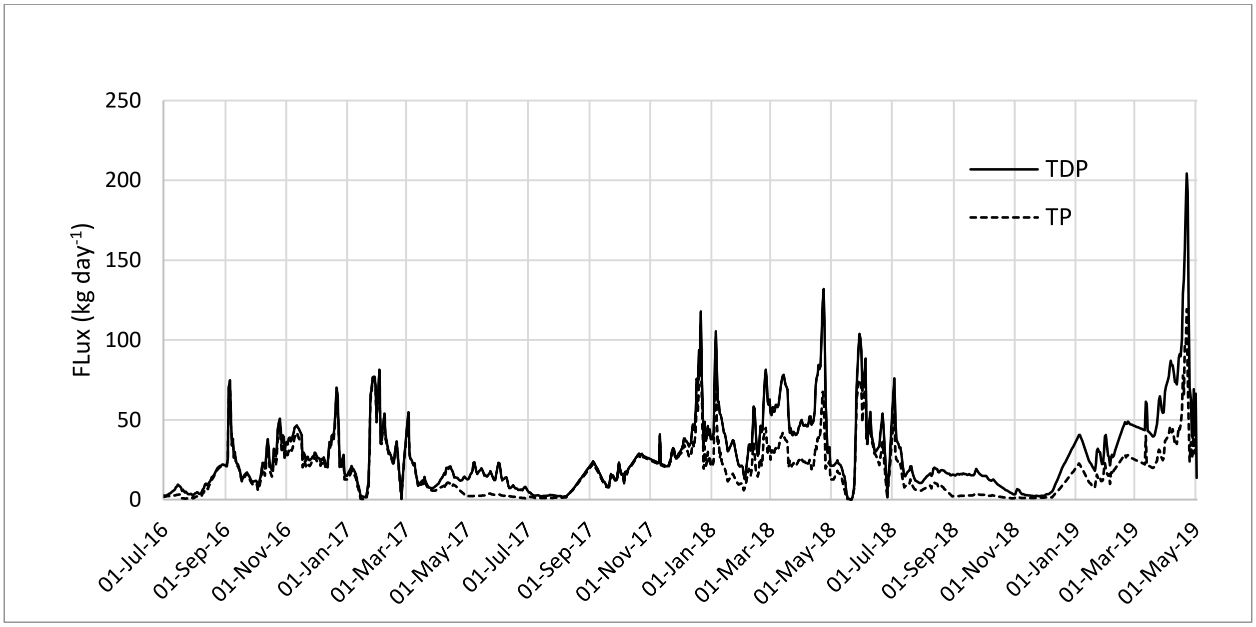
Appendix 2b. Phosphorus Flux at Mabel Lake, Runoff Coefficient Method



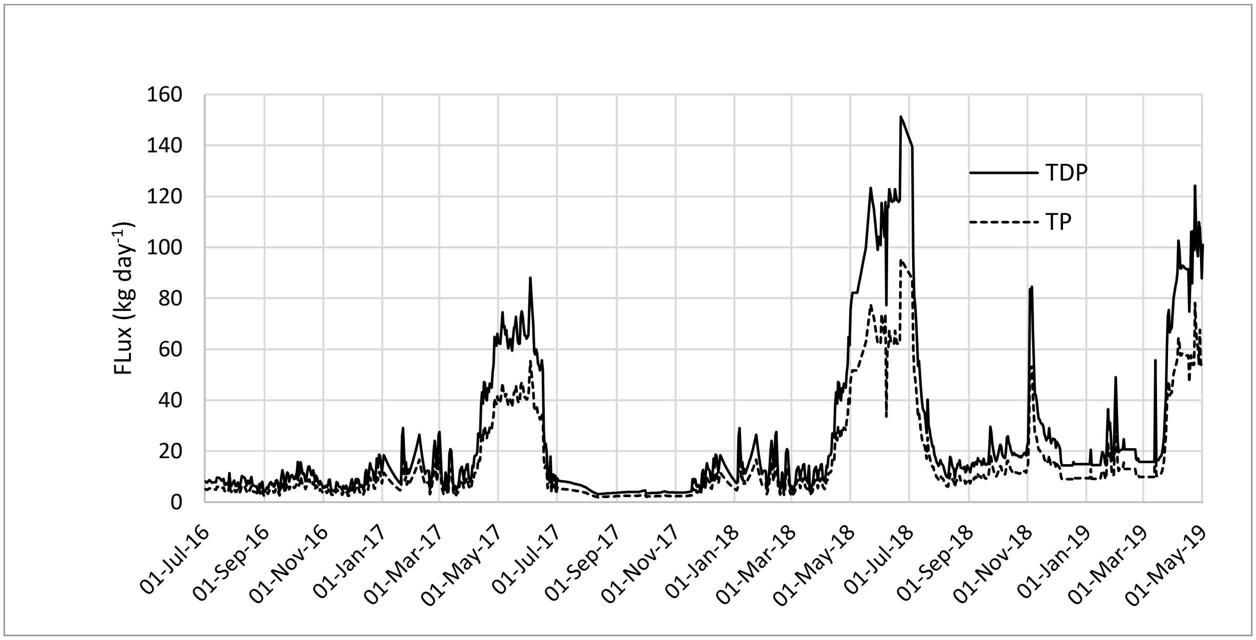
Appendix 2c. Phosphorus Flux at Mabel Lake, Geochemical Method



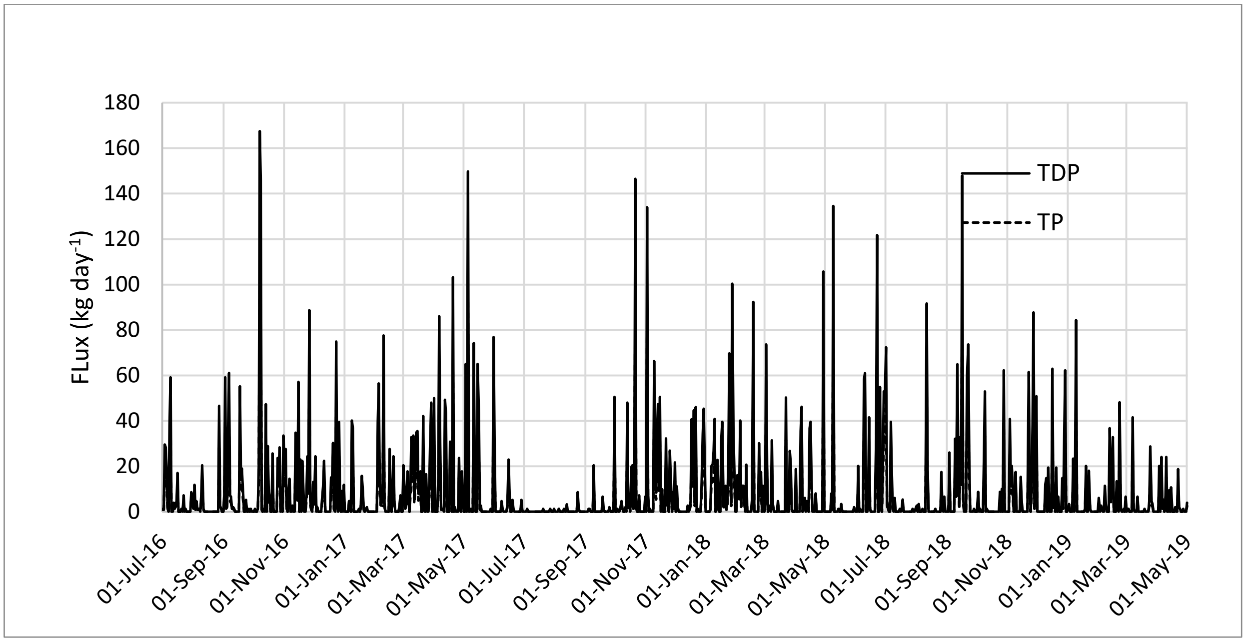
Appendix 2d. Phosphorus Flux, sum of Tributaries



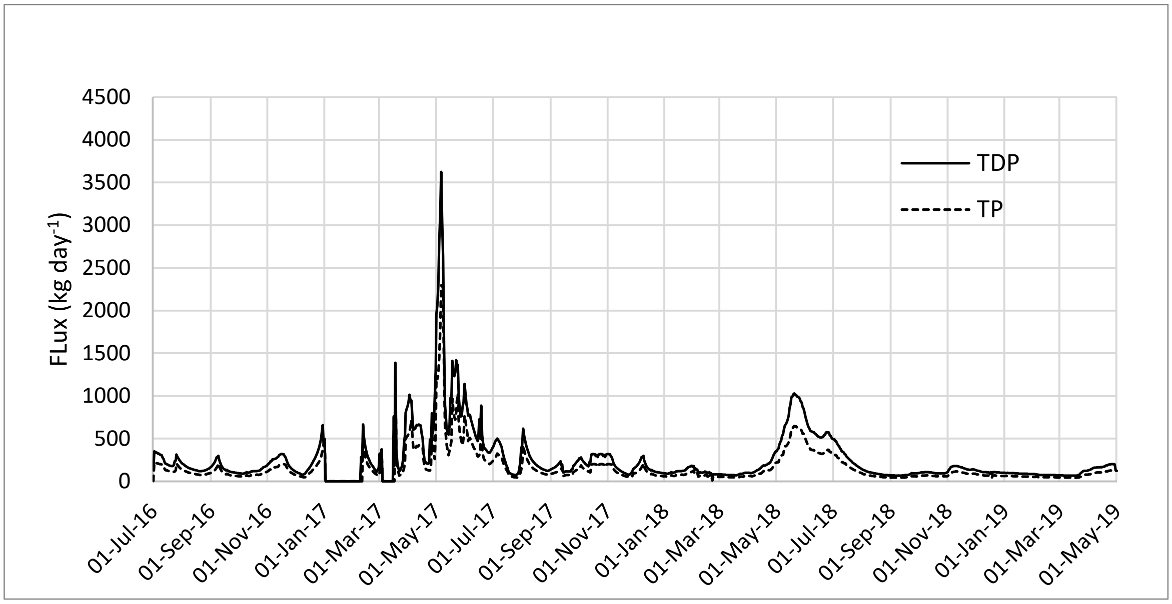
Appendix 2e. Phosphorus Flux from IFSW, Extrapolation Method



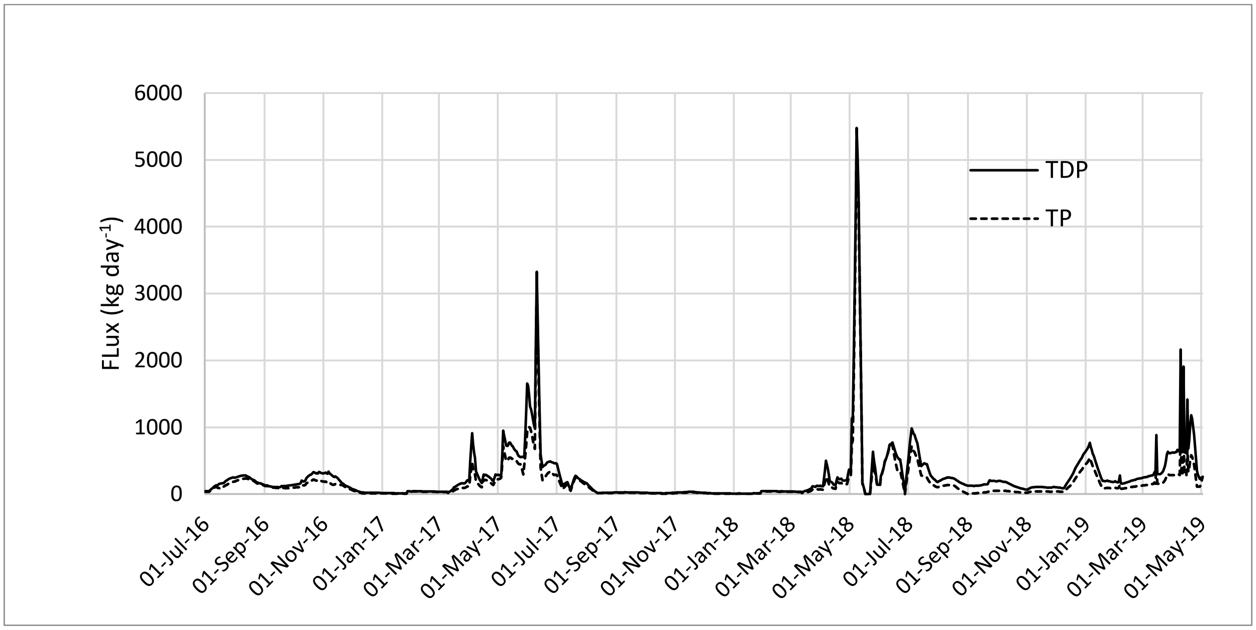
Appendix 2f. Phosphorus Flux from IFSW, Runoff Coefficient Method



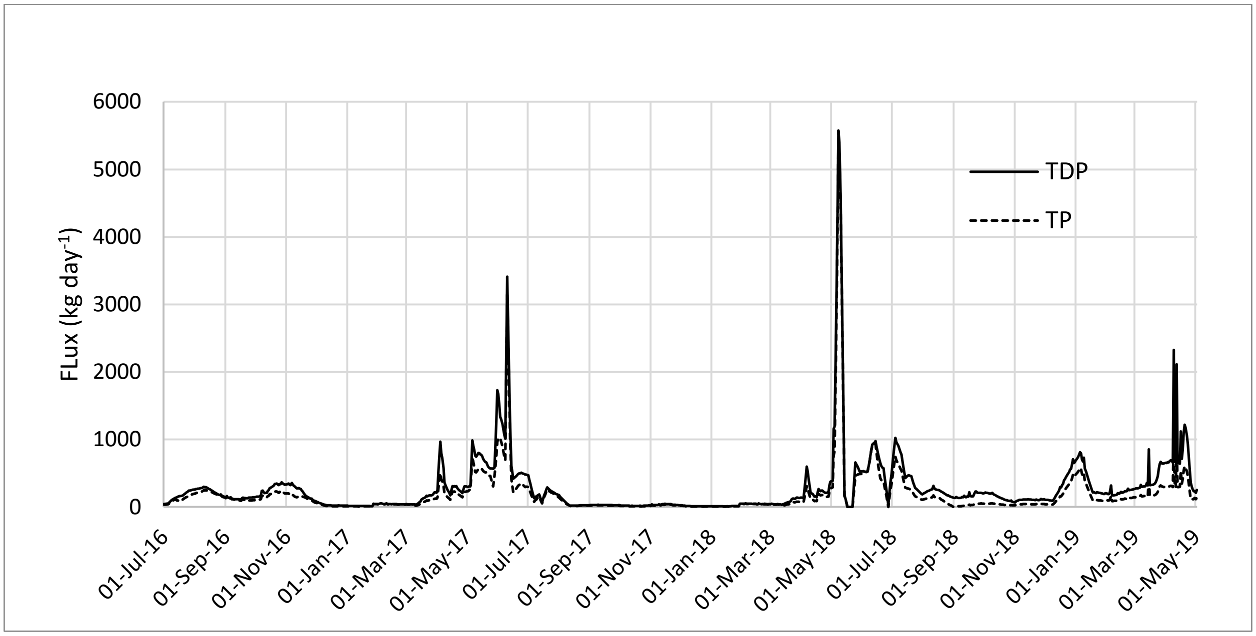
Appendix 2g. Phosphorus Flux from IFSW, Geochemical Method



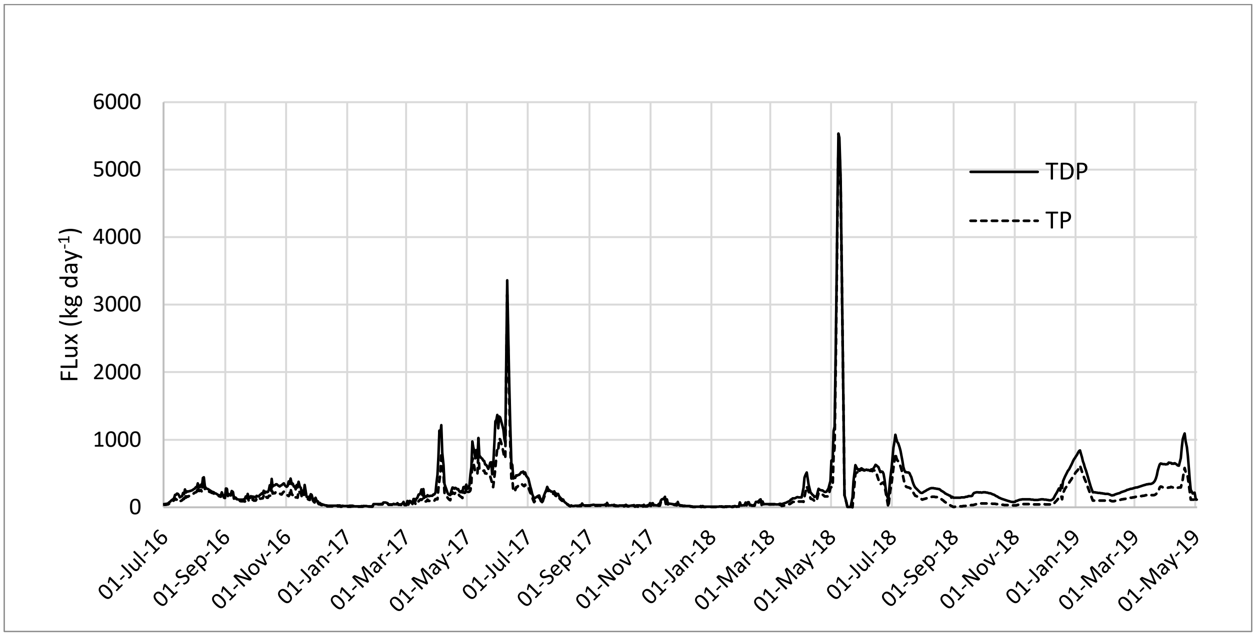
Appendix 2h. Phosphorus Flux at Mara Lake, Extrapolation Method



Appendix 2i. Phosphorus Flux at Mara Lake, Runoff Coefficient Method



Appendix 2j. Phosphorus Flux at Mara Lake, Geochemical Method



Appendix 3: Phosphorus flux and yield for the Shuswap River Watershed.

	Mabel Lake	CV, %	Tributaries	CV, %	IFSW	CV, %	Mara	CV, %
Area, ha	4.42E+05		5.74E+04		4.80E+04		5.47E+05	
Q, m3/y	3.08E+09	1.39E+01	3.12E+08		3.99E+08	128	3.35E+09	1.24E+01
Y, m/y	6.98E-01		5.44E-01		8.32E-01		6.12E-01	
TP Flux (kg/y)	4.14E+04	1.32E+01	5.89E+03		2.52E+04	144	6.89E+04	5.16E+00
TP Yield (kg/ha/y)	9.36E-02		1.03E-01		5.26E-01			
TDP Flux (kg/y)	2.83E+04	2.39E+01	3.23E+03		1.50E+04	144	2.72E+04	5.80E+00
TDP Yield (kg/ha/y)	6.40E-02		5.63E-02		3.12E-01			