Phosphorous Budget for the Salmon River

FINAL REPORT

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Executive Summary

This report summarizes analyses and inferences from the hydrometric and water chemistry analyses conducted on the Salmon River watershed from Westwold to Salmon Arm 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 Shuswap Lake. The parts of the watershed were, Upper Reaches (UR), tributary watersheds (TW), and incremental flow sub-watershed (IFSW). The anthropogenic contributions to phosphorus loading are through land use changes occurring primarily in the IFSW.

A water balance was calculated for the Salmon River using measurements of discharge in the main-stem river at Highway 1 (Water Survey of Canada) and in tributaries (Ludwig 2018). Three estimates of flows from UR and 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). Contributions are dominated by UR (deriving mainly from discharge of the Westwold and contributions from IFSW, with relatively small contributions from TW.

A phosphorus balance was calculated for the Salmon River by multiplying the flow measurements and estimates by measured concentrations of phosphorus. Thus, measured discharges (TW) have one calculated flux, and estimated discharges (UR and IFSW) 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 at Hwy 1 from that for UR and TW. By all methods, contributions of phosphorus are generally dominated by UR followed closely by IFSW with small contributions from TW. In the Salmon River Watershed, the upper reaches and IFSW are about equal in size and have similar land use distributions.

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 Salmon River this is above Falkland and includes the Westwold Aquifer (UR).

Tributary Watershed Sub-Watershed: Watershed areas that contribute to creeks that ultimately contribute discharge to the mainstem of the river. They typically run year-round and are defined as 2nd 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) to the Salmon River, because it is an important contributor of P to Shuswap Lake (Tristar Environmental Consultants 2014). Despite its large size (310 km2) and rapid flushing rates ~ 2 years) Shuswap Lake experienced largescale 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 Consultants 2014). Using export coefficient models (ECM), the Salmon River was identified to be a significant contributor of P into Shuswap Lake. 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 Shuswap Lake a priority. Identifying the sources and transport mechanisms of P into Shuswap Lakes from the Salmon 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 Consultants 2014). Contributions of TP are from non-point sources and 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 lake (98%) was coming in from the watersheds through drainage, with small contributions from salmon carcasses and discharges directly to Shuswap Lake from a wastewater treatment plant on Shuswap Lake (Tristar Environmental Consultants 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 from human activities (anthropogenic P) 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 Salmon River (Falkland to Salmon Arm) to inform decisions on nutrient management. In order to quantify the TP and TDP from UR, TW and IFSW, 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 are in low elevation areas of the watershed, and contain the majority of the anthropogenic activities within the watershed, IFSW is the portion of the watershed identified in the ECM as contributing the majority of the anthropogenic phosphorus (Tristar Environmental Consultants 2014). Anthropogenic activities, particularly agriculture and urbanization, are well known to enhance phosphorus loading to surface waters. For agricultural 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

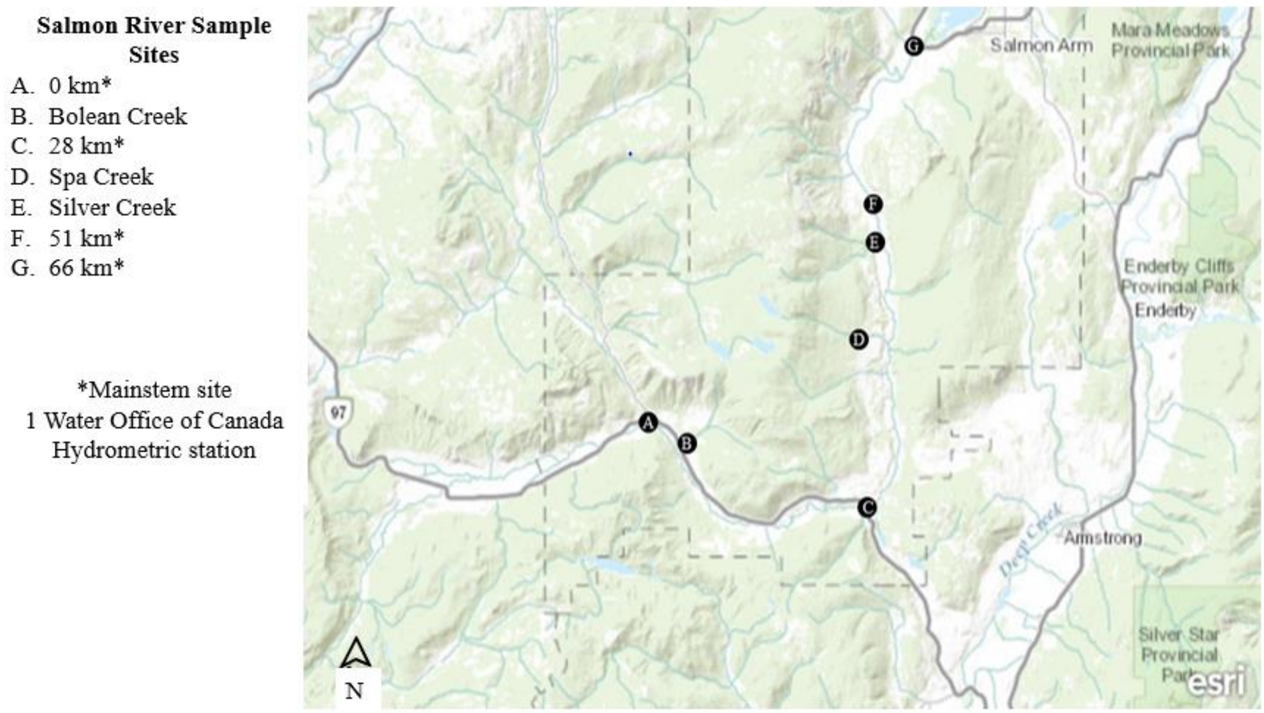
Discharge was measured at kilometer 66 (Fig. 1) by the Water Survey of Canada. We measured discharge in tributaries including Bolean, Spa and Silver Creeks (Figure 1; and described in detail in Ludwig 2018).

Discharge from IFSW was determined using 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 and complex flow path, three approaches were used to create a robust range of estimates. These were the same as employed in the companion study of the Shuswap River, and are described elsewhere in detail (Ludwig 2018).

Sampling for Chemical Analysis

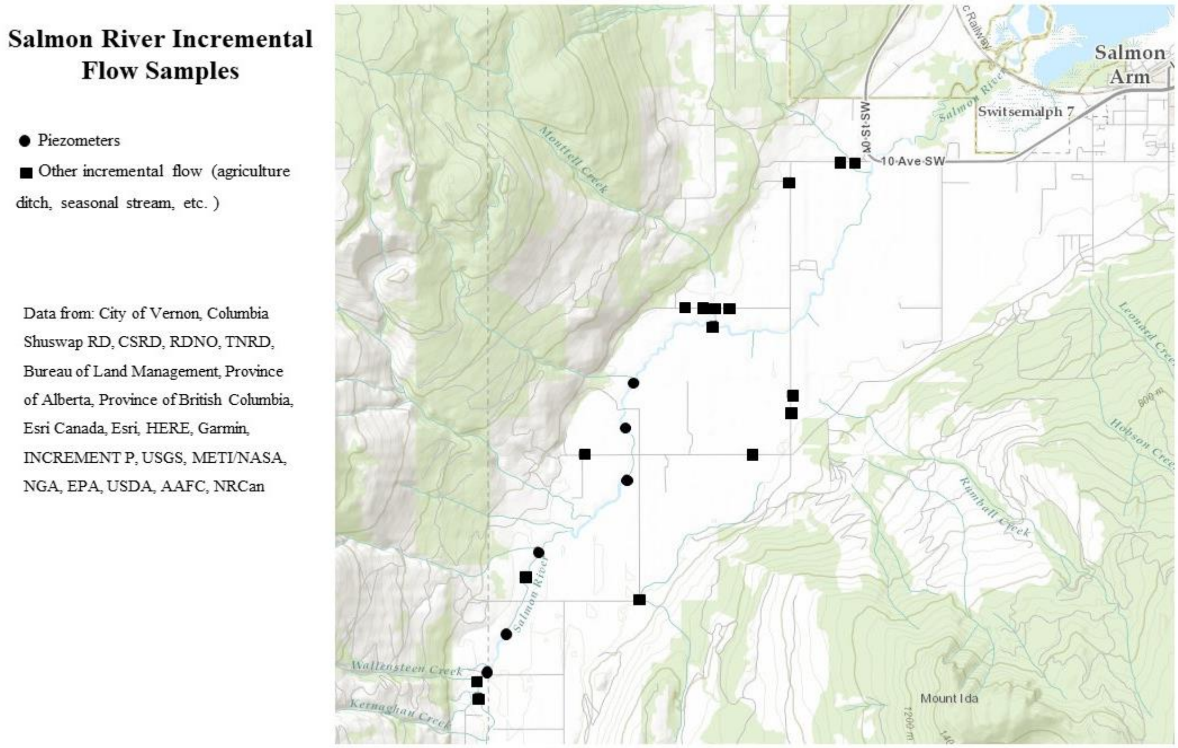
Samples for chemical analysis were collected at intervals from the Salmon River at Falkland (km 0, Upper Reaches, UR), Bolean, Spa and Silver Creeks (TW), Incremental Flow Sub Watersheds (IFSW), and the Salmon River at river kilometers 28, 51 and 61 km, (Figure 1). Sample intervals varied from a minimum of three times weekly to monthly, with sample frequency increasing with discharge.

Figure 1: Map of Sample sites on Salmon River



Chemical sampling of water draining the IFSW included the sampling of groundwater, seasonal streams and ditch water (Figure 2). 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 once 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 Salmon 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 Salmon River at Falkland (UR) tributaries (aggregate), IFSW (aggregate), and the Salmon River at Highway 1 at about km 66 are shown in Appendix 1. There are three discharge scenarios for the Salmon River at Falkland (UR), and IFSW 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 2.06×10^8 (CV 20%), 3.0×10^7, 9.1×10^7 (CV 62%), and 2.4×10^8 m^3 y^{-1} for UR, TW, IFSW and SR km 66, respectively. There is no coefficient of variation (CV) for TW and for SR at km 66 because they are based on measurement rather than estimates. Coefficients of variation for IFSW are largest because they are all estimated indirectly, whereas estimates for UR are constrained by measurements at SR km 66 and in tributaries.

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 2.

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 2.1 X 10^4 (CV 26%), 2.7 X 10^3, 1.3 X10^4 (CV 98%), and 2.47 X10^4 kg y^{-1} for UR, TW, IFSW and SRkm66, respectively. Average total dissolved phosphorus (TDP) loadings for the three methods were 1.35 X 10^4 (CV 20%), 1.51 X 10^3, 7.67 X10^3 (CV 99%), and 1.1 X10^4 kg y^{-1} for UR, TW, IFSW and SRkm66, respectively. There is no coefficient of variation (CV) for TW and for SR km 66 because they are based on measurement rather than estimates. Coefficients of variation for IFSW are largest because they are all estimated indirectly, whereas estimates for UR are constrained by measurements at SR km 66 and in tributaries.

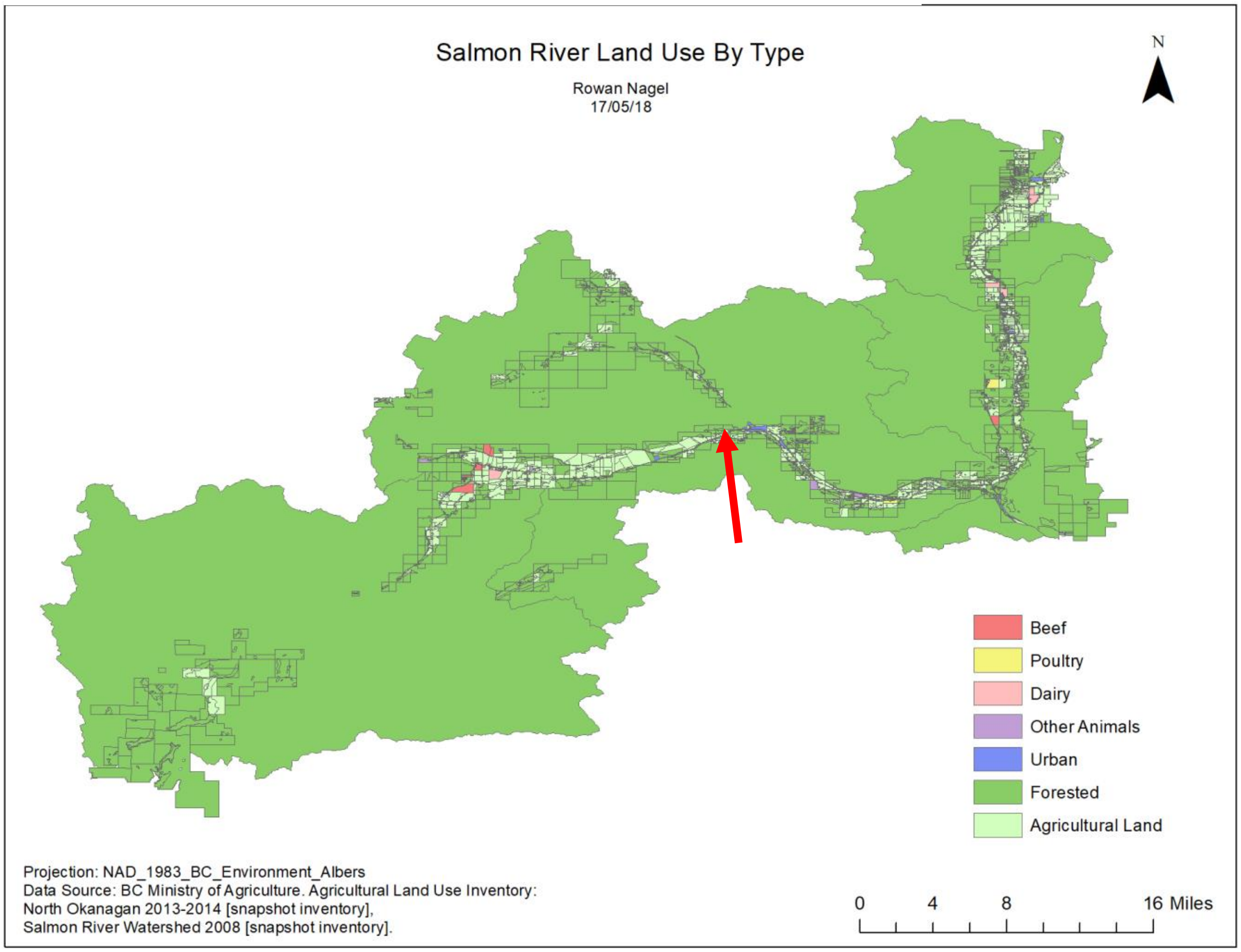
Yields of phosphorus were calculated to express the quantity of phosphorus per unit of area from the different components of the watershed. Annual total phosphorus (TP) yields averaged for the three methods were 0.425, 0.16, 0.17, and 0.16 kg ha^{-1} y^{-1} for UR, TW, IFSW and SRkm66, respectively. Average total dissolved phosphorus (TDP) yields for the three methods were 0.10, 0.09, 0.1, and 0.08 kg ha^{-1} y^{-1} for UR, TW, IFSW and SRkm66, respectively. Coefficients of variation are the same as for phosphorus loadings because the loadings have only been divided by watershed area. Annualized phosphorus flux and yield data are summarized in Appendix 3.

A final calculation of loadings from IFSW can be made by subtracting the loadings from UR and TW from the flux calculated for SRkm66. 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 both negative -2.1 X 10^3 and -4.0 X 10^3 kg y^{-1}, respectively. This suggest the likelihood that the river retains (stores) phosphorus or loses it from surface water to groundwater. A high degree of communication between surface water and groundwater combined with significant abstraction has been indicated by others (Burt and Wallis, 1997), and consequently considerable water and phosphorus are probably lost from the Salmon River in its lower reaches.

TP and TDP yields are relatively higher for UR and TW than expectation for undisturbed watersheds in BC (Ludwig, 2018). Yields for IFSW were only slightly higher than for UR. This is probably because the land use in IFSW is similar in the UR and somewhat similar in Bolean Creek the most dominant tributary (Figure 3). The lowest yield for any of the tributary watersheds was for Silver Creek (0.05 kg ha^{-1} y^{-1}). If we extrapolate relatively undisturbed watershed phosphorus yields from Silver Creek to IFSW, anthropogenic sources of excess phosphorus can be estimated. Relatively undisturbed IFSW might have only contributed 3850 kg of phosphorus per year. This would reduce the flux at SRkm66 by as much as 37%. A reduction of this magnitude would change loading normalized concentration of 110 mg $m^{-}3$ TP to about 70 mg m^{-3}, and improve the present trophic state predicted from the Vollenweider-OECD model (Janus and Vollenweider, 1981) from hyper-eutrophic to eutrophic.

Figure 3*: Land uses in the Lower Salmon River, created by Rowan Nagel. The arrow indicates approximately km 0.*



References

Burt, DW and M Wallis (1997). Assessment of salmonid habitat in the Salmon River, Salmon Arm. Department of Fisheries and Oceans, Fraser River Action Plan

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

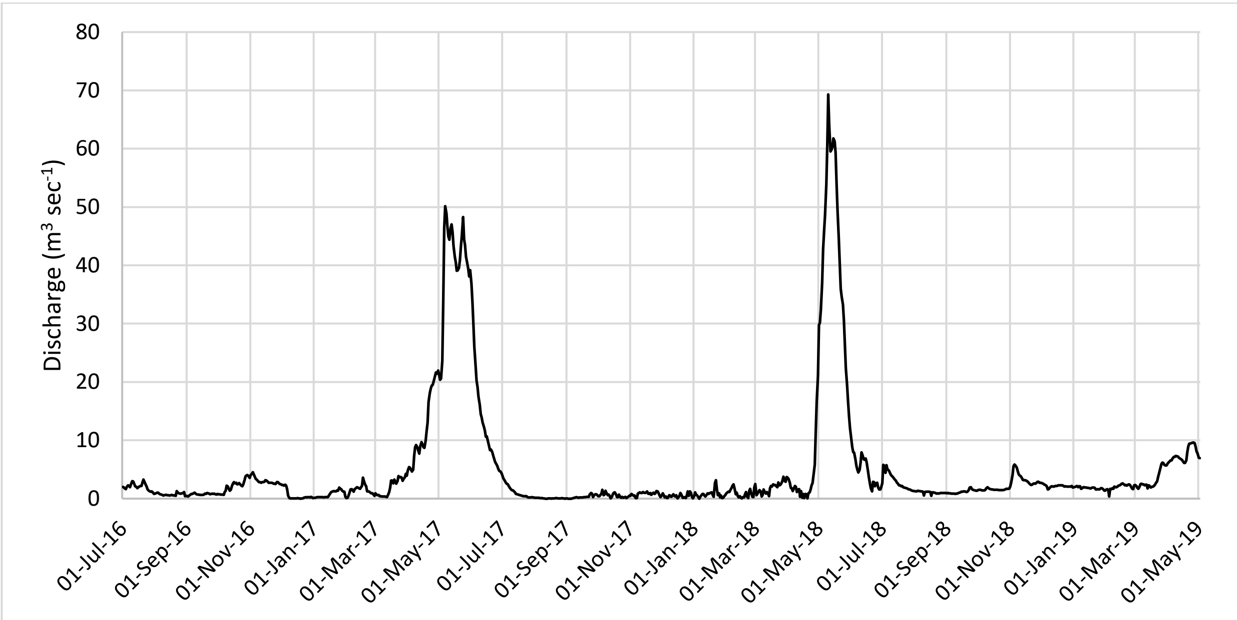
Ludwig ME (2018) A Multi-Method Approach for Determining a Phosphorus Budget for the Shuswap and Salmon Rivers in Southern Interior British Columbia. MSc. Thesis, The University of British Columbia.

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

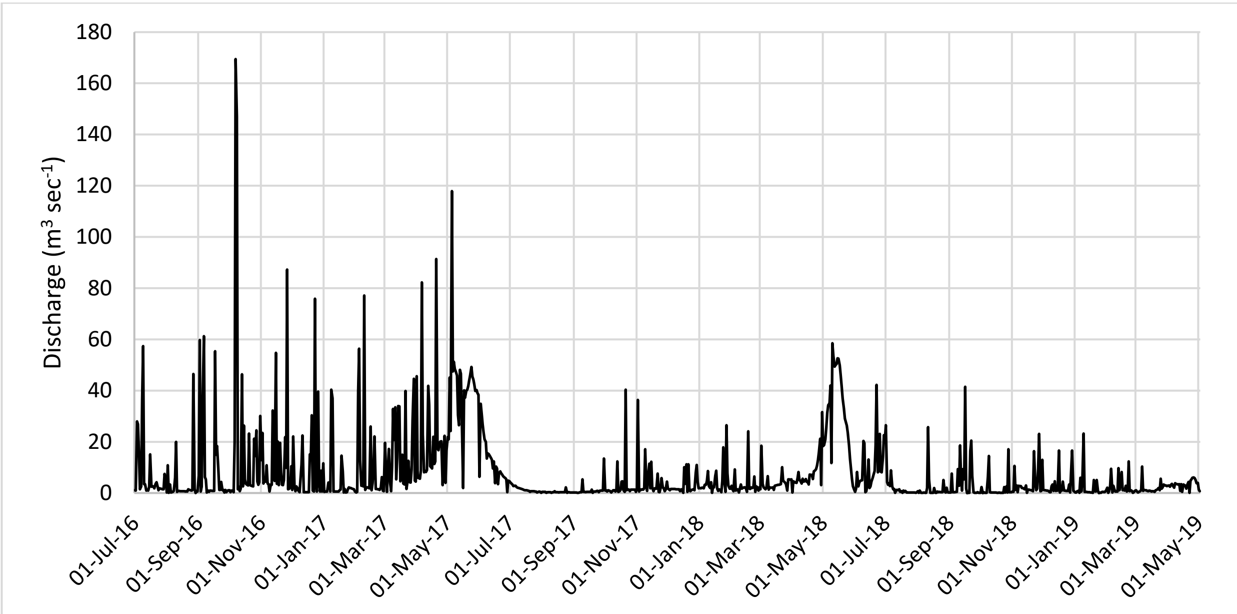
Wolf, D and HA Klaiber (2017) "Bloom and Bust: Toxic Algae's Impact on Nearby Property Values."Ecological Economics, vol. 135, 5, pp. 209-221.

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

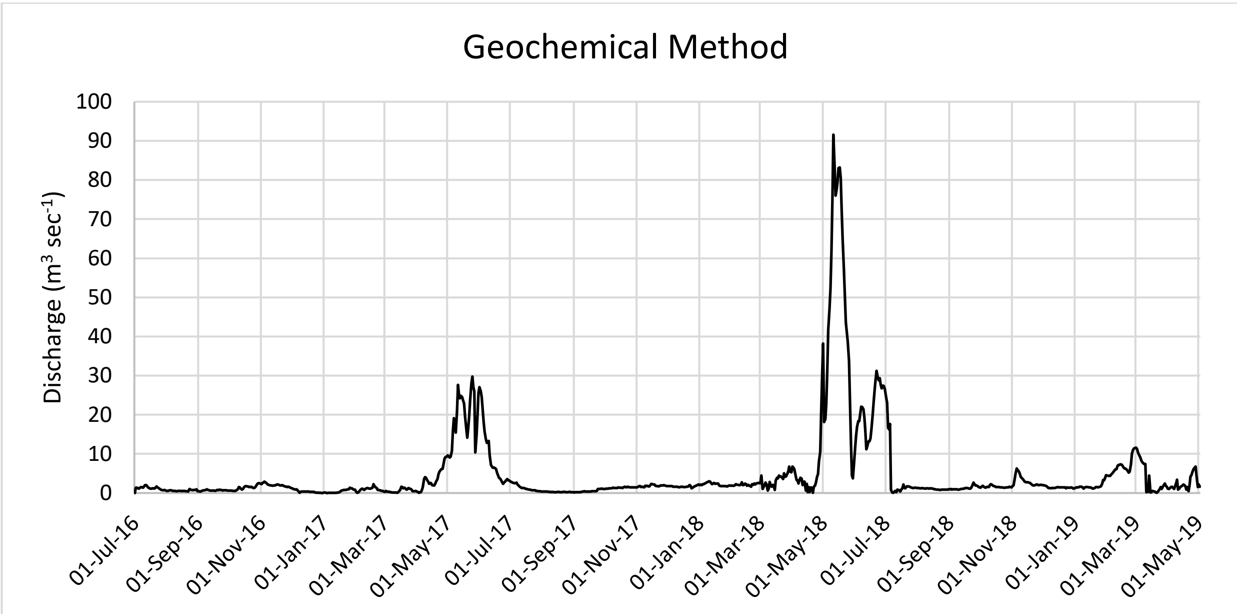
Appendix 1a. Discharge at Falkland (UR), Extrapolation Method



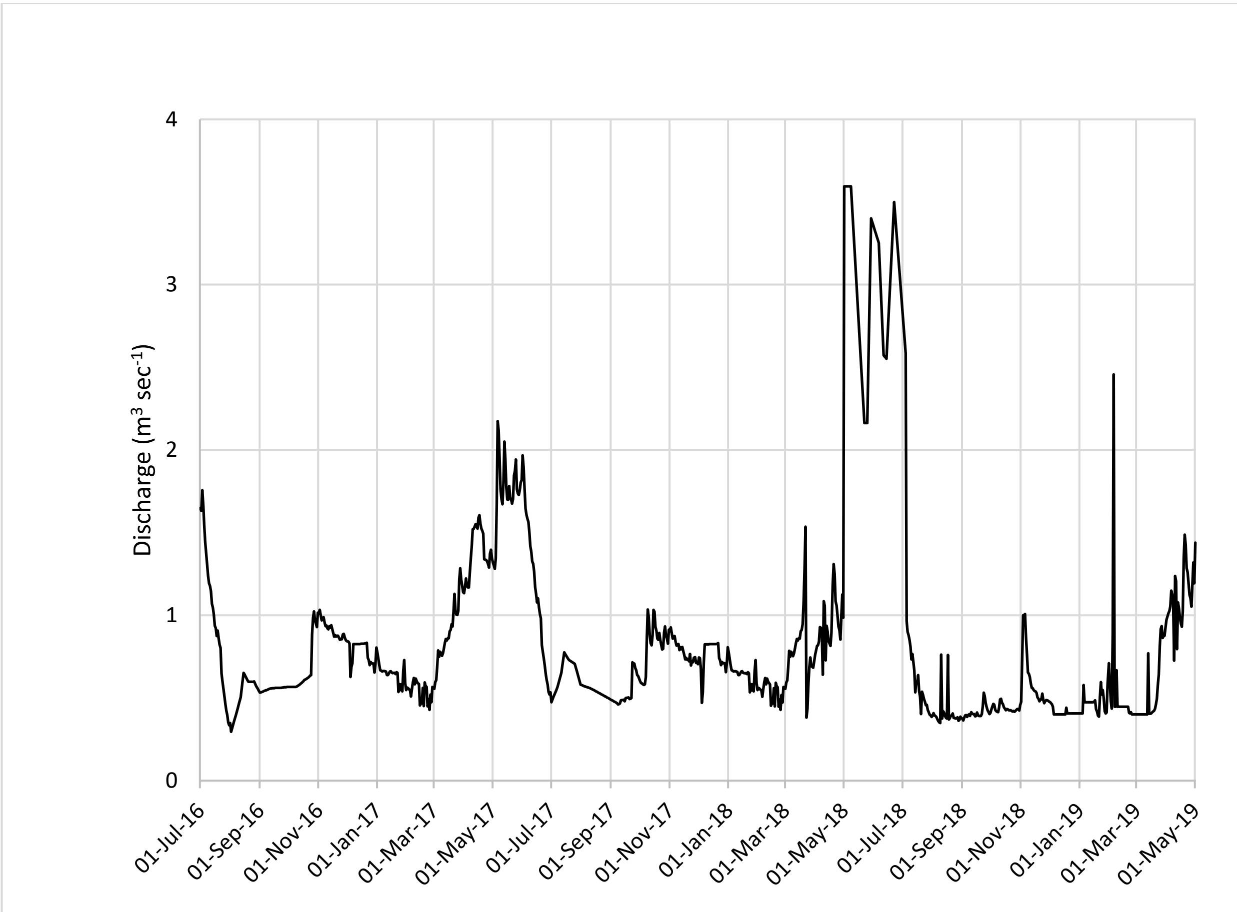
Appendix 1b. Discharge at Falkland (UR), Runoff Coefficient Method



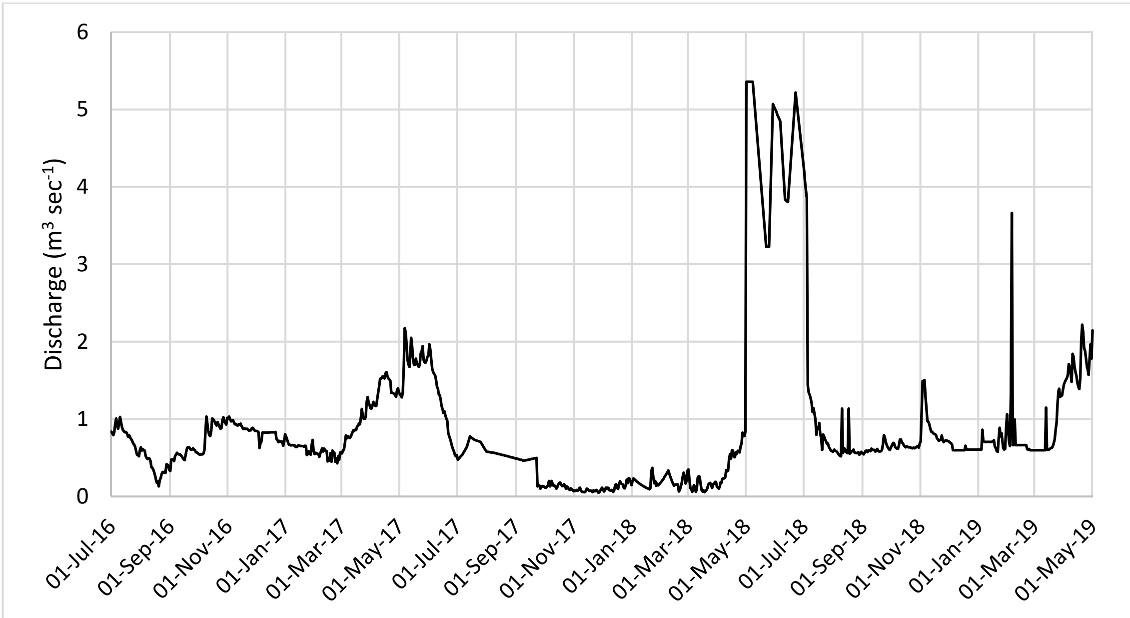
Appendix 1c. Discharge at Falkland (UR), Geochemical Method



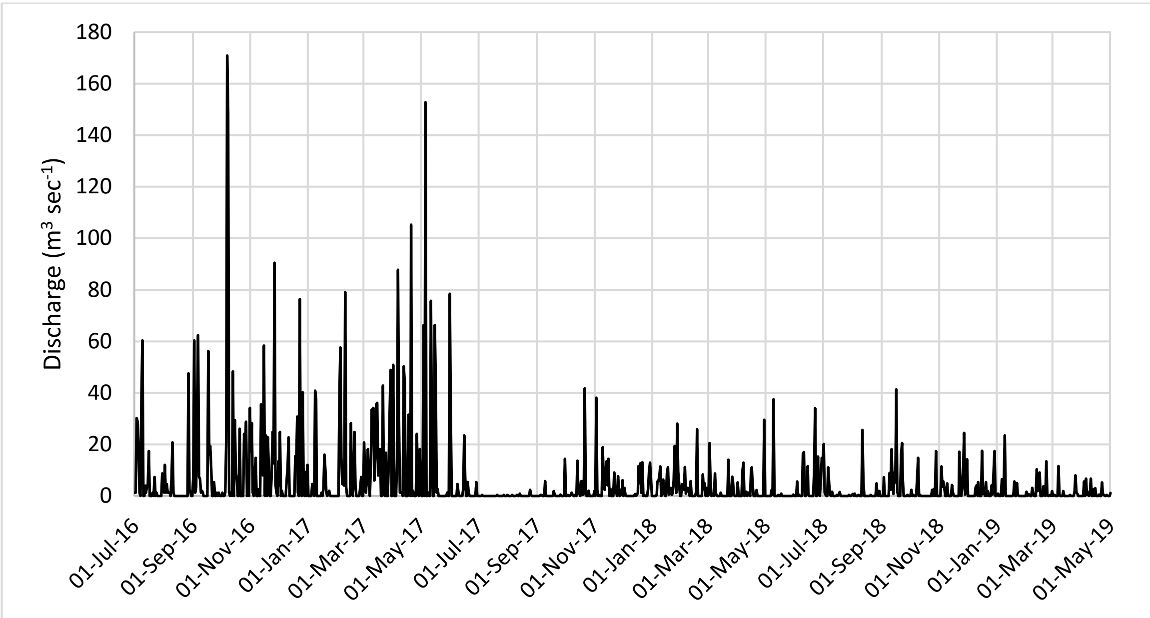
Appendix 1d. Discharge, sum of Tributaries



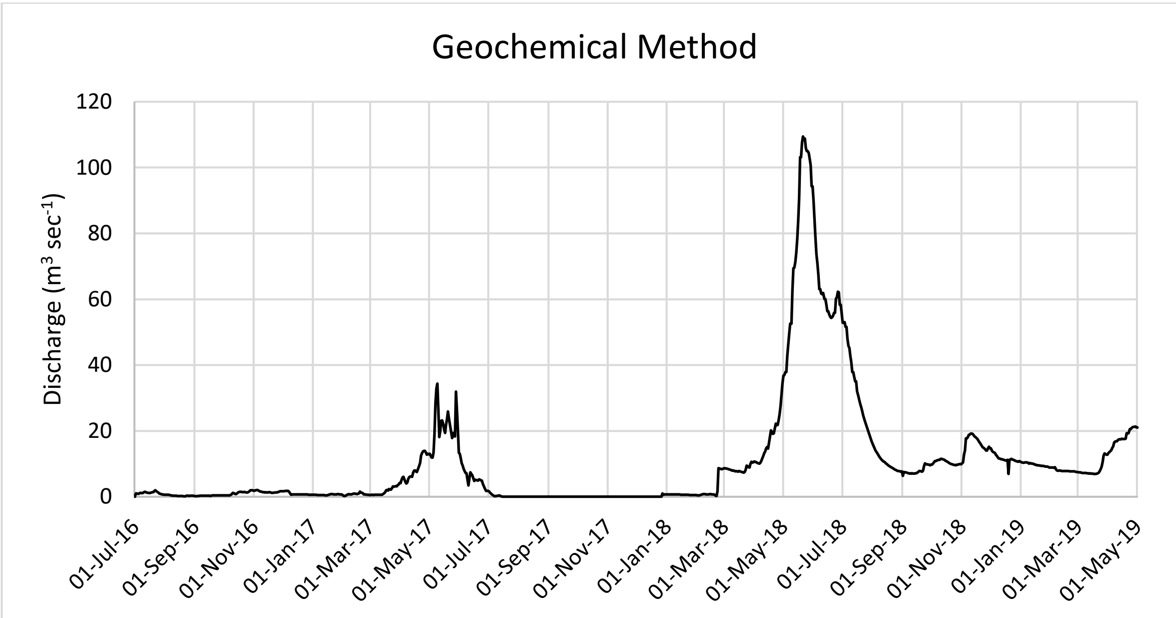
Appendix 1e. Discharge from IFSW, Extrapolation Method



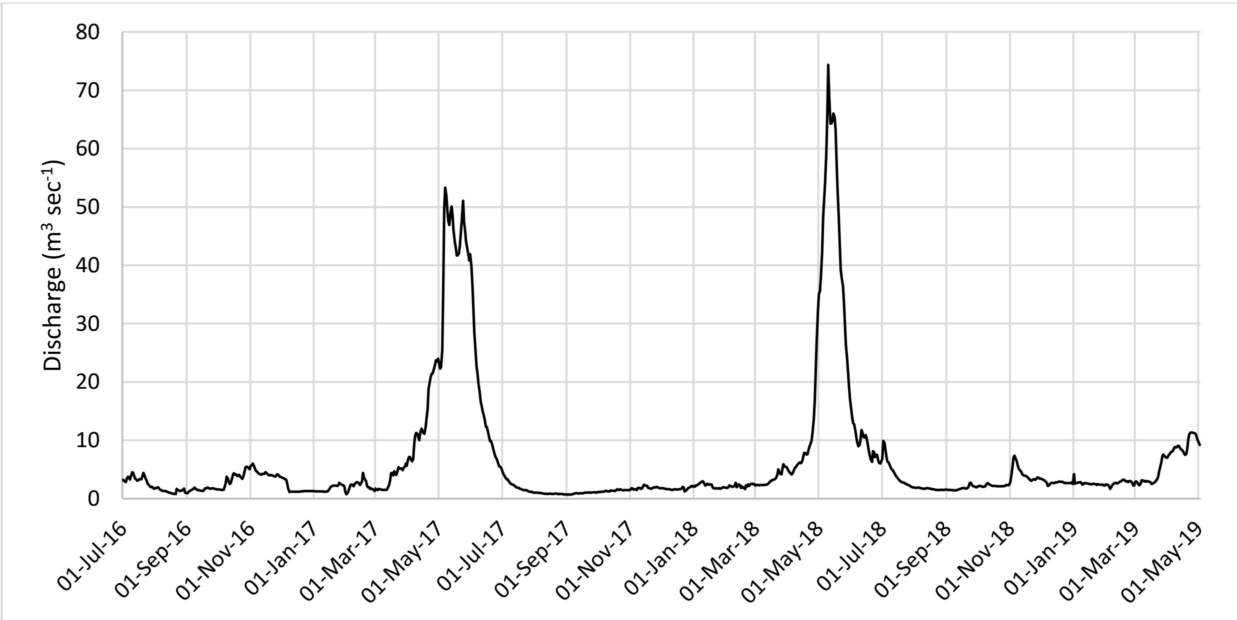
Appendix 1f. Discharge from IFSW, Runoff Coefficient Method



Appendix 1g. Discharge from IFSW, Geochemical Method

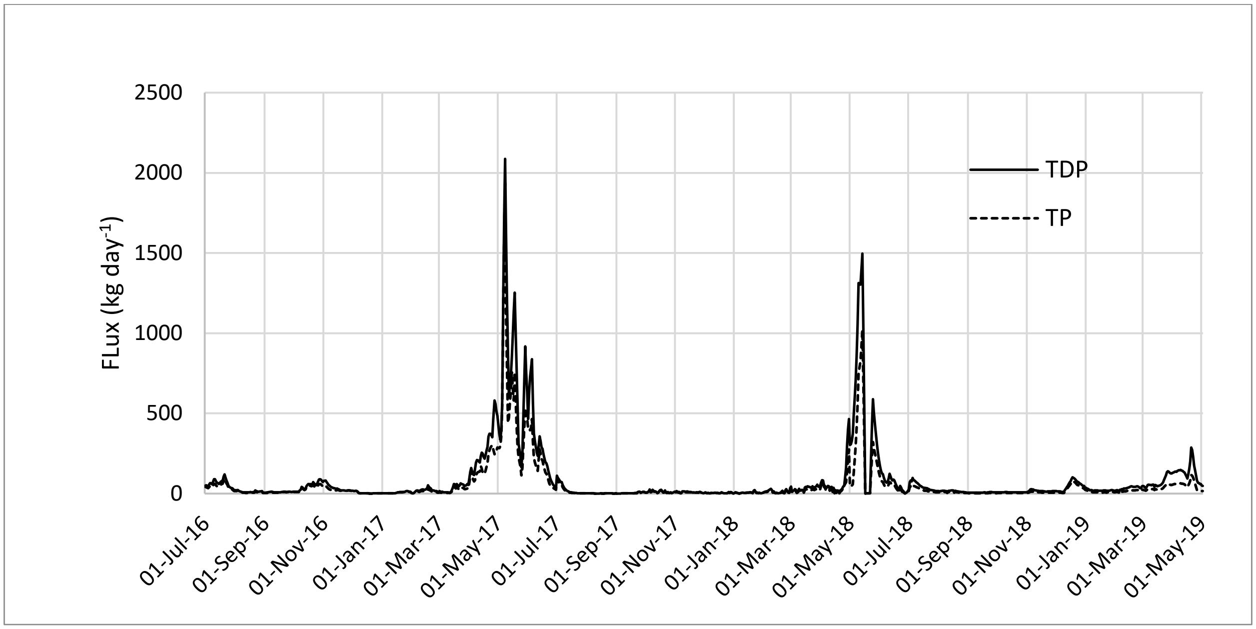


Appendix 1h. Discharge at Highway 1

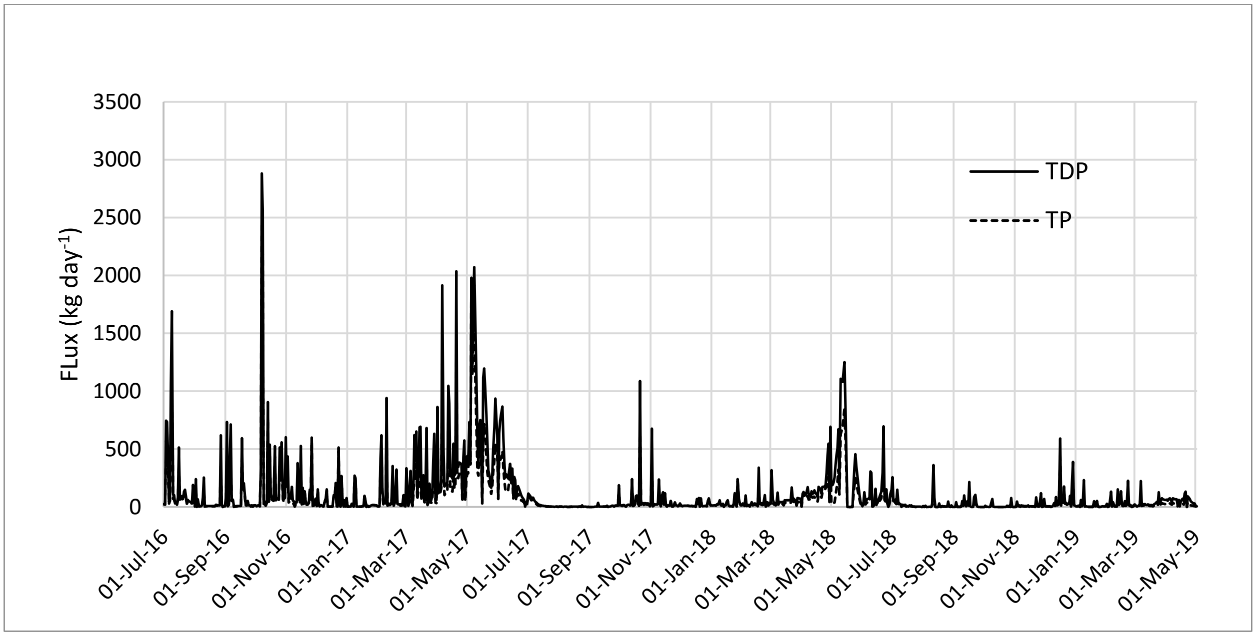


Appendix 2: Measured and calculated Phosphorus flux for the Salmon River Watershed.

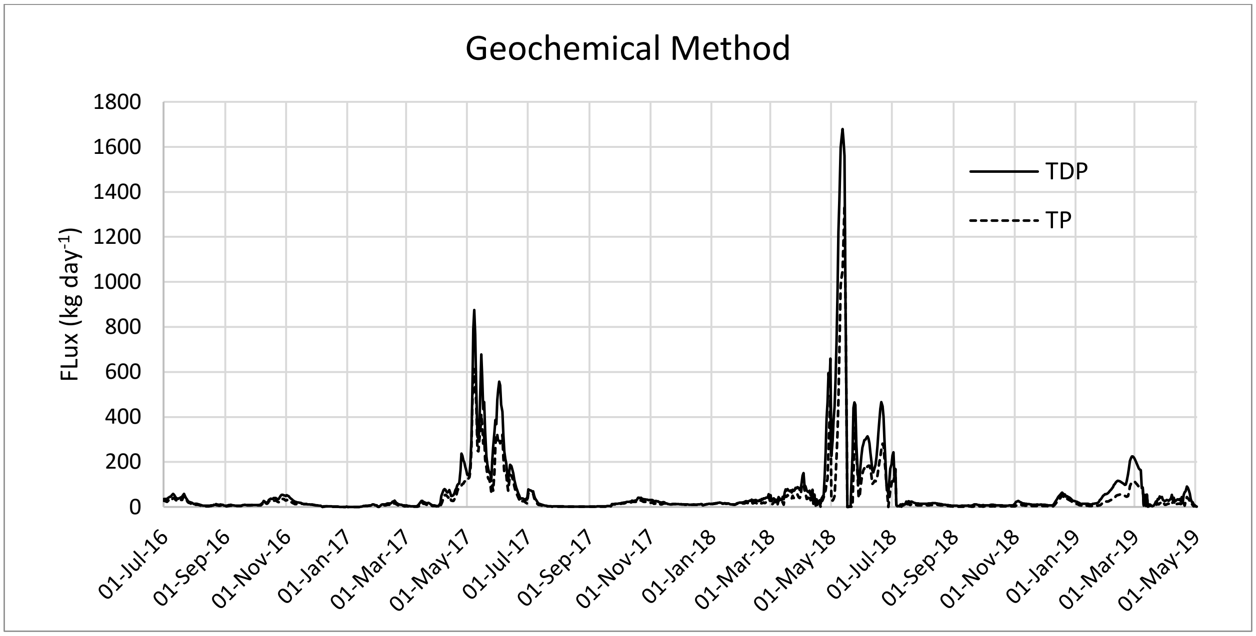
Appendix 2a. Phosphorus Flux at Falkland, Extrapolation Method



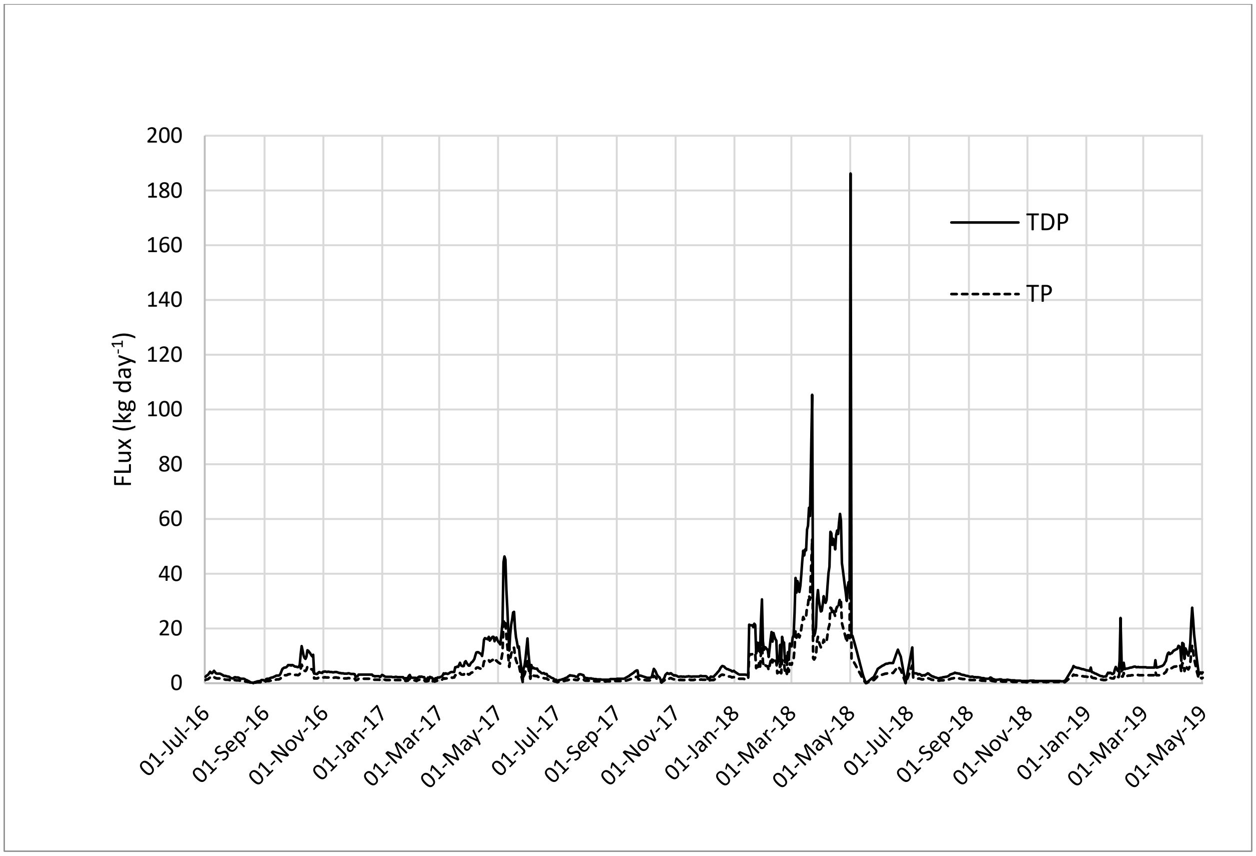
Appendix 2b. Phosphorus Flux at Falkland, Runoff Coefficient Method



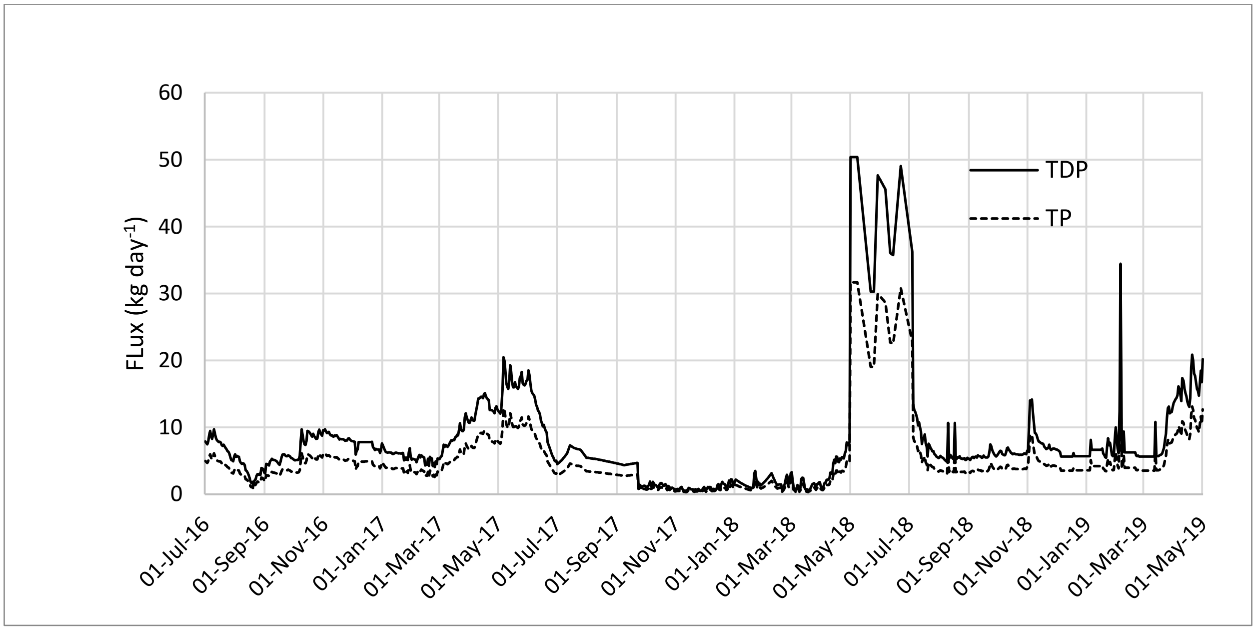
Appendix 2c. Phosphorus Flux at Falkland, Geochemical Method



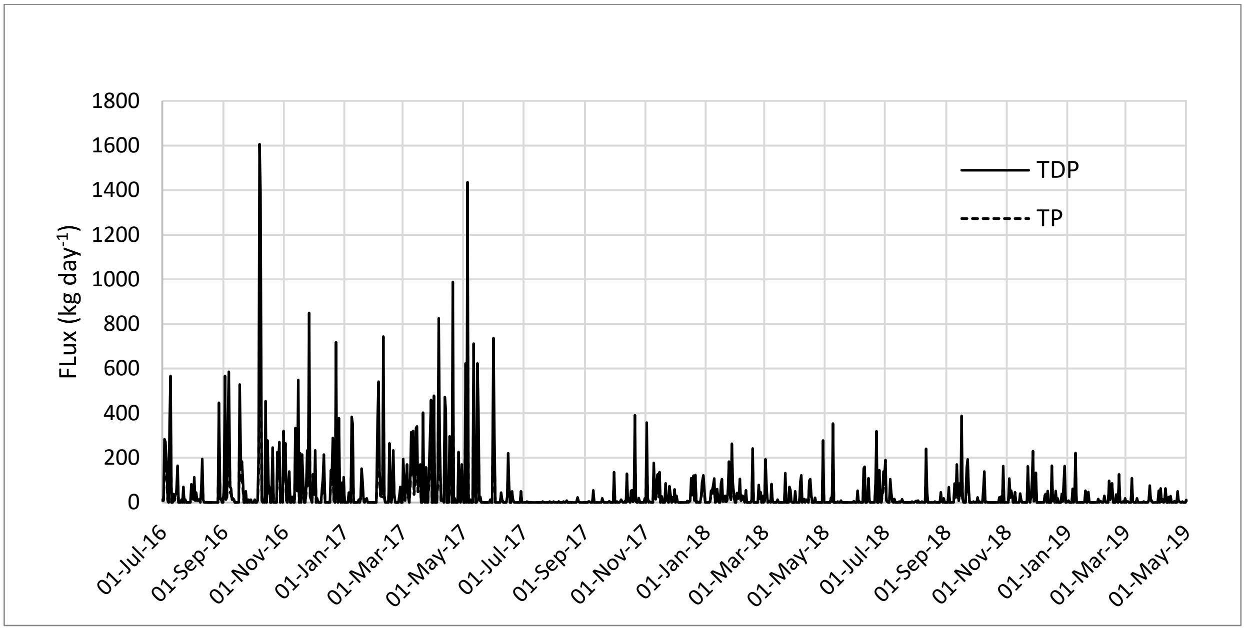
Appendix 2d. Phosphorus Flux, sum of Silver, Spa and Bolean Creeks



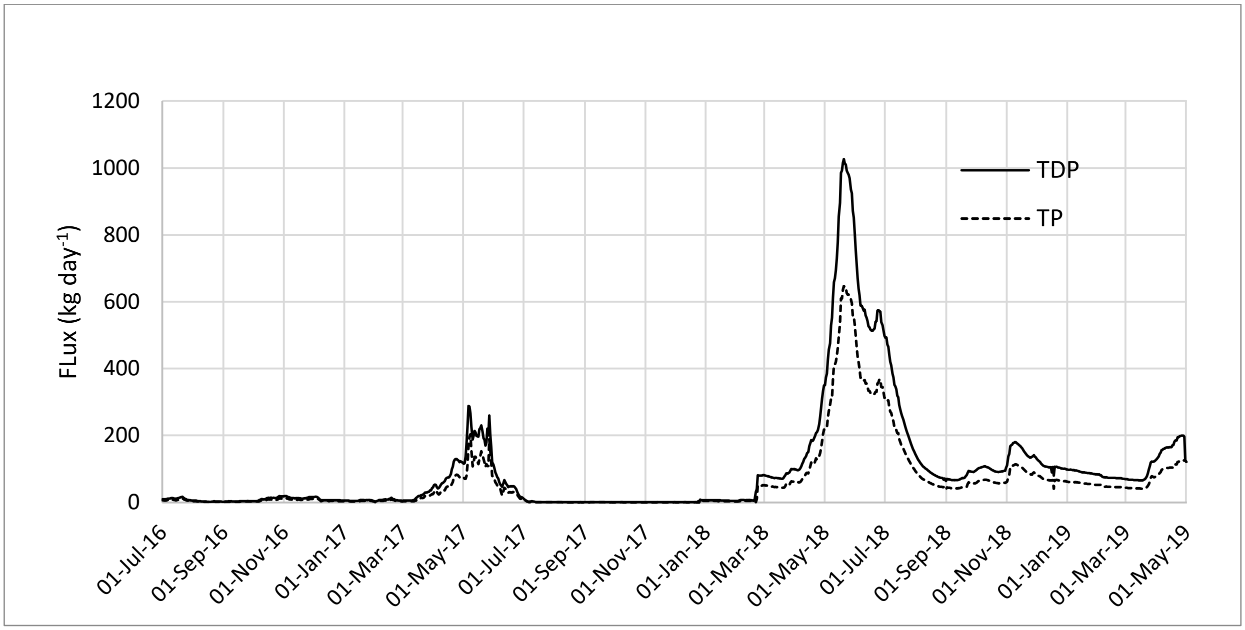
Appendix 2e. Phosphorus Flux from IFSW, Extrapolation Method



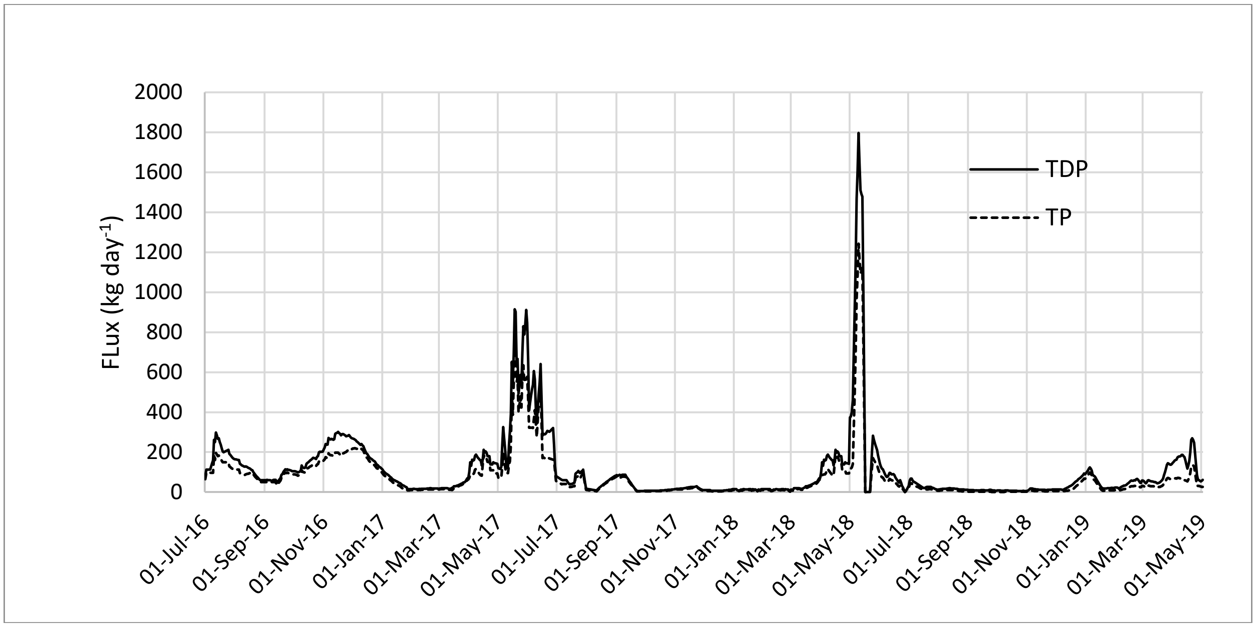
Appendix 2f. Phosphorus Flux from IFSW, Runoff Coefficient Method



Appendix 2g. Phosphorus Flux from IFSW, Geochemical Method



Appendix 2h. Phosphorus Flux at Highway 1



Appendix 3: Phosphorus yield for the Salmon River Watershed.

	Tributaries	CV, %	IFSW	CV, %	Falkland	CV, %	HWY1	CV, %
Area, ha	1.72E+04		7.82E+04		5.46E+04		1.13E+05	
Q, m3/y	2.97E+07		9.11E+07	63	2.06E+08	20	2.36E+08	
Y, m/y	1.73E-01		1.16E-01		3.77E-01		2.09E-01	
TP Flux (kg/y)	2.70E+03		1.30E+04	99	2.41E+04	26	2.47E+04	
TP Yield (kg/ha/y)	1.57E-01		1.66E-01		4.42E-01			
TDP Flux (kg/y)	1.51E+03		7.67E+03	99	1.35E+04	19	1.10E+04	
TDP Yield (kg/ha/y)	8.78E-02		9.81E-02		2.47E-01			