TECHNICAL MEMORANDUM

Nutrient loading and concentration dynamics in the Sevenmile Creek system – 2019

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INTRODUCTION

Ecological restoration of the Upper Klamath and Agency Lakes watershed is an essential element of the overall restoration and ecosystem health in the entire Klamath Basin. Nutrient loading to Upper Klamath and Agency Lakes (Kann and Walker 1999; Walker et al. 2012; ODEQ 2002) and reduction of nutrient loading to the lakes (particularly phosphorus, P) has been identified as an important means of improving water quality affecting native fishes[1], as well as reducing export of organic matter and nutrients to the Klamath River downstream of UKL[2]. The dependence of bloom-formers (primarily *Aphanizomenon* and secondarily hepatotoxin producing *Microcystis*) and subsequent poor water quality on nutrients (primarily P) that are both externally derived and internally recycled (Walker et al. 2012) led to development of a TMDL calling for reduction of external anthropogenic P loads[3] (Walker 2001; ODEQ 2002). The TMDL model was expressed in terms of long-term-average P load and it was determined that achieving the loading target (109 metric tons/year of TP) would require a 40% reduction in external P load relative to the historical baseline.

Previous nutrient balances using data collected between 1992 and 1998 (Kann and Walker 1999) formed the basis for the original TMDL (ODEQ 2002) as well as a more recent update to the TMDL model (Wood et al. 2013). Wood et al. (2013) provided additional uncertainty analyses[4] for the 2002 TMDL model and showed that although predicted UKL P and algal biomass (chlorophyll) were somewhat higher than earlier predictions, a 40% reduction in external P load was predicted to decrease in-lake P and chlorophyll by ~40% (the average reduction based on various model runs). Using water and nutrient balances for UKL updated through 2010 (Walker et al. 2012), Wherry et al. (2015) recalibrated the TMDL model and predicted that the TMDL target watershed P reduction of 40% would achieve steady-state concentrations for water column total P and chlorophyll of 74 ppb and 27 ppb, respectively, and would reduce the overall magnitude and frequency of algal (cyanobacterial) blooms[5].

Sources of P in the UKL watershed have been related to erosional inputs occurring during the past century, including timber harvest, drainage of wetlands, agricultural activities associated with livestock grazing and irrigated cropland, and hydrologic modifications such as water

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[1] Upper Klamath and Agency Lakes are hypereutrophic and are seasonally dominated by large blooms of the nitrogen-fixing cyanobacterium *Aphanizomenon flos-aquae* (Kann 1998; Kann and Smith 1999), and secondarily by microcystin toxin producing *Microcystin aeruginosa* (Eldridge et al. 2013). Bloom-driven water quality degradation that includes extended periods of low dissolved oxygen, elevated pH, and toxic levels of un-ionized ammonia has been associated with the decline of native endangered fish populations, including the Federally Listed shortnose (*Chasmistes brevirostris*) and Lost River (*Deltistes luxatus*) suckers (Perkins et al. 2000). More specifically these conditions have been linked to large fish kills and redistribution of the endangered sucker species in UKL (Perkins et al. 2000; Kann and Welch, 2005; Wood et al. 2006; Banish et al. 2009).
[2] Water quality degradation in the Link and Klamath Rivers below UKL is associated with phytoplankton derived organic matter exported from UKL (e.g., Sullivan et al. 2013)
[3] ODEQ determined that reducing P loads linked to watershed development would be the most effective means of improving water quality conditions in the lake.
[4] Model uncertainty was evaluated based upon alternate chlorophyll models, P recycle mechanisms, phosphorus and light limitation coefficients, and updated initial sediment P concentration.
[5] Modelling indicated that the time required to achieve steady state was 19 years. In addition, further steps were recommended to reduce model uncertainty (Wherry et al. 2015).

diversions and channelization (Snyder and Morace 1997; ODEQ 2002; Bradbury et al. 2004; Eilers et al. 2004)[6].

The Wood River and Sevenmile Creek systems represent 41% of the overall annual tributary P load to the lakes despite their relatively small drainage areas (Table 1). The Sevenmile system in particular showed very high watershed export (load per unit area) of both P (153 kg/km^2/yr) and nitrogen (N; 510 kg/km^2/yr) indicating that it is a prime area to target for nutrient reduction activities in line with the 40% anthropogenic P load reduction specified in the TMDL.

Table 1: Summary of TP and TN Loads, concentrations, and export for UKL tributaries, 1992 – 2010

	Flow	**Nutrient Loads**		**Percent of Tributary Inflow to Upper Klamath and Agency Lakes**			**FWM Nutrient Concentration**		**Drainage Area**	**Run-off**	**P Export**	**N Export**
System	**hm^3/yr**	**TP mt/y**	**TN mt/y**	**Flow**	**TP**	**TN**	**TP ppb**	**TN ppb**	**km^2**	**m/yr**	**kg/km^2/yr**	**kg/km^2/yr**
Wood River	317.7	35.6	55.7	25%	29%	14%	112	175	394	0.81	90	141
7-Mile Creek/Canal	103.4	14.8	49.2	8%	12%	12%	143	476	96	1.07	153	510
Sprague River	501.9	38.1	177.3	40%	31%	44%	76	353	4,171	0.12	9	43
Williamson River[1]	344.0	35.3	118.9	27%	29%	30%	103	346	3,641	0.09	10	33
Total Tributary Inflow	1,267.0	123.8	401.1	100%	100%	100%	98	317	8,302	0.15	15	48

[1]not including Sprague River inputs

source: Walker et al. 2012

Sevenmile study site

The Sevenmile Creek system originates in the Cascade Range and flows through a higher gradient forested area before entering the relatively low gradient Wood River Valley, after which it flows approximately twelve miles along the valley floor to where it enters the completely diked channel at the intersection of West Canal before continuing to its confluence with Agency Lake (Figure 1). The twelve miles of Sevenmile Creek upstream of West Canal have been highly altered due to irrigation diversion and return flow as well as impacts to streambanks and riparian vegetation due to cattle grazing (e.g., GMA 2009; ONRCS 2010). Previous studies indicated that disturbed areas, which generally lack healthy riparian zones, are prone to enhanced transport of nutrients during agricultural activities and higher flow events (e.g., GMA 2004). In addition, earlier studies showed that West Canal (Figure 2), which contains comingled irrigation return flow from the Sevenmile, Annie Creek and Wood River systems, contributes highly elevated nutrient loads to lower Sevenmile Canal and to Fourmile Canal (GMA 2004, 2010, 2012; Kann 2017). West Canal is fed by numerous smaller canals that serve as the receiving water for flood-irrigated pasture runoff occurring throughout the Wood River Valley (Ciotti et al. 2010).

[6] Paleolimnological and coring studies in particular showed increases in various indicators (e.g. Ti, Al, tephra, and charcoal) of watershed erosional inputs to UKL in the 20th century (Bradbury et al. 2004; Eilers et al. 2004; Simon and Ingle 2011)

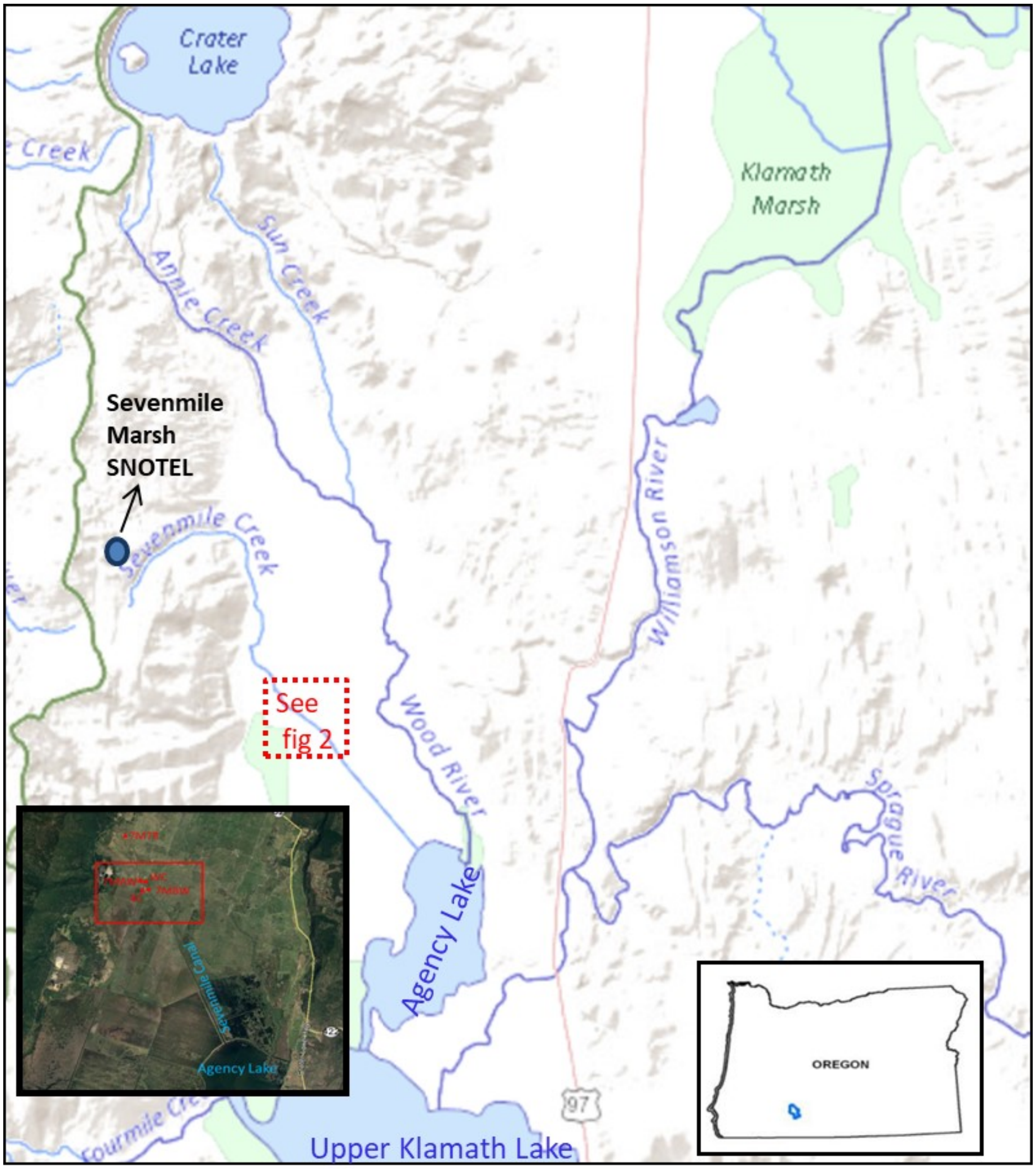

Figure 1. Location of the Sevenmile Creek/Canal system located in the Agency Lake watershed in Oregon. Inset photo shows sample station locations: 7M7R=Sevenmile @ Sevenmile Rd; 7MAW=Sevenmile above West Canal; WC=West Canal; 4C=Fourmile Canal; 7MBW=Sevenmile Below West Canal. Map source: https://txpub.usgs.gov/DSS/streamer/web/

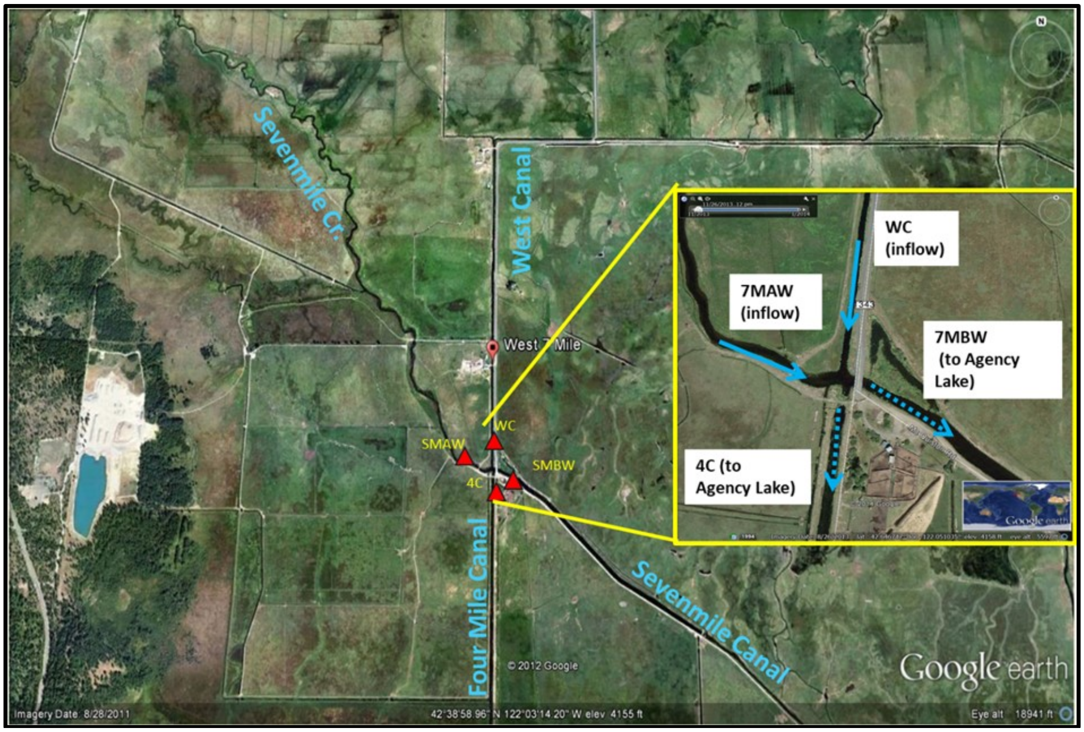

Figure 2. Location of sample stations located at the junction of West Canal at the McQuisten Road Bridge. Blue arrows indicate flow direction with dashed arrows showing flow into Agency Lake. Sample locations: 7MAW=Sevenmile above West Canal; WC=West Canal; 4C=Fourmile Canal; 7MBW=Sevenmile Below West Canal.

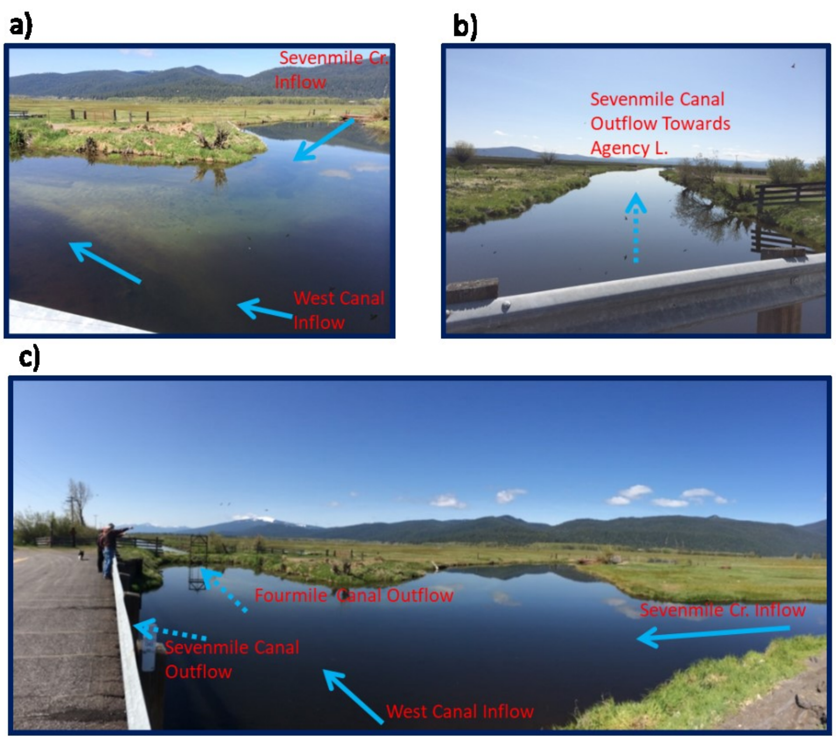

Figure 3. View upstream and downstream of the West Canal confluence with Sevenmile Creek at the McQuisten Road Bridge. West Canal turbid water and Sevenmile clear water (a); Sevenmile Canal flowing towards Agency Lake (b); West Canal and Sevenmile Creek shown with Fourmile and Sevenmile Canal flowing towards Agency lake (c). Blue arrows indicate flow direction; dashed arrows show flow into Agency Lake.

A field-level study in the Sevenmile watershed showed that flood irrigation events induced elevated total dissolved P and N concentrations in tailwater (prior to entering irrigation return-flow canals) relative to the source water applied to the pasture (Ciotti et al. 2010). To determine the net effect of such pasture runoff events, in 2016 the Klamath Tribes initiated a longitudinal study of nutrient concentrations and loads on the Sevenmile system between Sevenmile Creek at Sevenmile Rd. (7M7R) and Agency Lake (Figure 1). That study clearly showed increased concentrations and loads in Sevenmile Creek due to the direct impact of West Canal, with nutrient loads from West Canal entering Agency Lake via both Fourmile Canal and Sevenmile Canal (Kann 2017). The darker colored water entering from West Canal can be visually observed mixing with the clearer Sevenmile Creek water before continuing downstream via West Canal and Fourmile Canal to Agency Lake (Figure 3).

Objective

Given high unit area loading (the Sevenmile drainage represents ~1% of the land area but 12% of the P load), and the observed effect of West Canal on nutrient concentrations and loading (Kann 2017), there has been considerable interest in management and restoration to reduce nutrient loading in the Sevenmile system. For example, diffuse source treatment wetlands have been proposed and pilot projects implemented to treat pasture-level runoff associated with cattle grazing (Stillwater 2013), and larger-scale nutrient treatment wetlands have been proposed for properties adjacent to Sevenmile and Fourmile Canals (GMA 2009, 2010; Stillwater Sciences 2013; Cardno Entrix 2013). Although previously collected data exist to help characterize nutrient dynamics in the Sevenmile system (e.g., GMA 2012), the most recent sampling effort by the Klamath Tribes occurred in 2016 (Kann 2017). Given potential climate changes and implementation of Klamath Tribes specified minimum in-stream flows that can affect nutrient runoff characteristics, additional flow and nutrient data are needed to adequately characterize current conditions in the Sevenmile system. Thus, the specific objective for this study was to further characterize flow, nutrient concentration, and nutrient loading dynamics to inform restoration activities (e.g., treatment wetland design) aimed at reducing nutrient loading to Upper Klamath and Agency Lakes.

METHODS

Beginning in April of 2019 a sampling program was implemented for the Sevenmile Creek system at five stations selected specifically to determine the effect of West Canal (WC) irrigation return flow on overall nutrient dynamics of Sevenmile Creek and Canal (Figure 1; Figure 2; Table 2). Sampling methods followed the Klamath Tribes established procedures for field collection and laboratory analysis of water quality parameters (see Klamath Tribes QAPP and SOP; 2013 for a complete description of these methods). Nutrient parameters (Table 3) were collected at the five stations during the 2019 sampling season at an approximately biweekly frequency, and instantaneous discharge measurements were collected at all stations except Sevenmile at Sevenmile Road (Figure 4). Discharge measurements were missing for the early-May sampling event, and sampling for both nutrients and discharge was discontinued in mid-August due to the lack of measureable flow in WC at that time.

Table 2. Sevenmile system sampling station names and site identification codes.

Location	Site ID Code	Latitude : Longitude
Sevenmile Creek @ Sevenmile Rd.	7M7R	42.670336 122.0568030
Sevenmile Creek Above West Canal	7MAW	42.646525 122.0523110
West Canal	WC	42.646850 122.0514970
Fourmile Canal	4C	42.645956 122.0514360
Sevenmile Creek Below West Canal	7MBW	42.646417 122.0508500

Table 3. Nutrient parameters collected in the Sevenmile Creek system, 2019.

Parameter	Abbreviation/Unit	Grab [a]
Total Phosphorus	TP (µg/L)	X
Soluble Reactive Phosphorus	SRP or PO_4^{3-} (µg/L)	X
Total Nitrogen	TN (µg/L)	X
Ammonia Nitrogen	NH_4^+-N (µg/L)	X
Nitrate-Nitrite Nitrogen	NO_3^-+NO_2^--N(µg/L)	X
Nitrite Nitrogen	NO_2^--N (µg/L)	X
Total Suspended Sediments	TSS (mg/L)	X
Turbidity	NTU	X

[a] Grab = integrated water column sample and x-sectional sample collected with a Van-Dorn sampler.

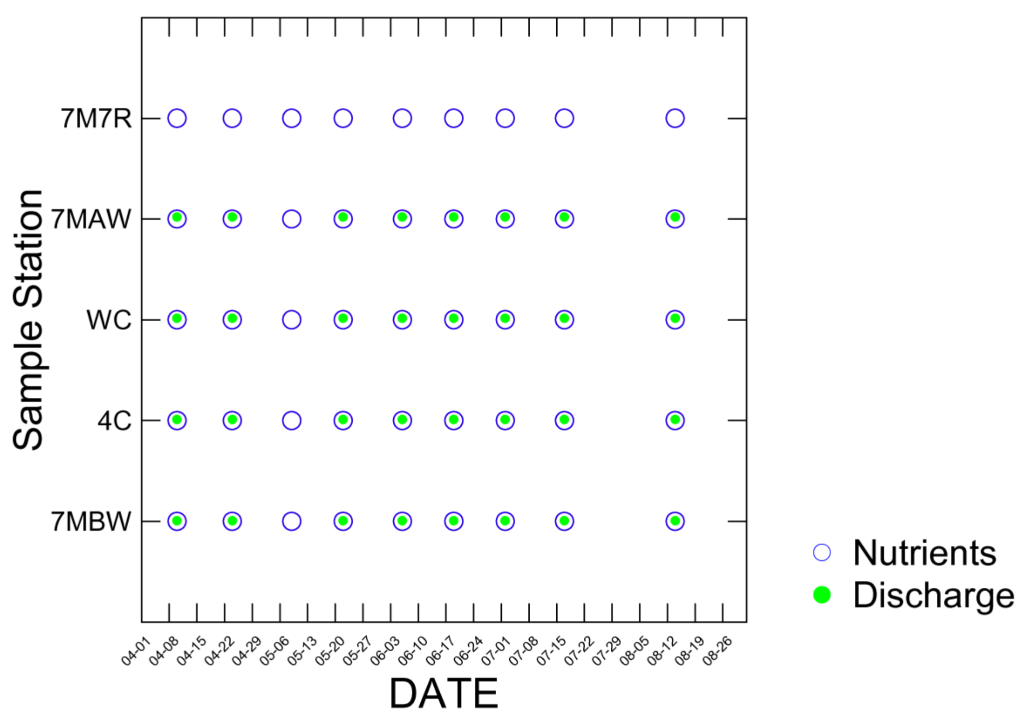

Figure 4. Nutrient and discharge sampling frequency for the Sevenmile system in 2019.

Particulate P (PP) was estimated by subtracting PO_4^{3-} from TP (PP = TP - PO_4^{3-}) and particulate or organic N (PN) was estimated by subtracting inorganic N from TN (PN = TN – ([NO_3^-+NO_2^- N] + [NH_4^+-N]). It is important to note that PP calculated as above, may represent both true particulate and other non-particulate P forms, especially for WC[7]. Total instantaneous loads (reported as kg/day) for the major nutrient parameters were calculated as the as the product of daily water volume and measured nutrient concentration for each 2019 sample station and date[8]. The total load to Agency Lake was computed as the sum of the load at 7MBW and 4C, and was denoted as 4Mile+7MBW for reporting purposes. To compare 7MAW nutrient concentrations with the concentration entering Agency Lake (4Mile+7MBW), the flow-weighted mean nutrient concentration (FWMC) was computed as the total 4Mile+7MBW load divided by the total 4Mile+7MBW flow on a given sample date[9]. Total seasonal (April to mid-August) loads and flows for each parameter were computed as the area under the curve (y) using the trapezoidal rule: $(x_{i+1} - x_i) (y_i + y_{i+1}) / 2$ for each sample day (x_i) and associated nutrient or flow value (y_i). For piecewise linear curves such as the time-series presented here the trapezoidal rule provides the exact area under the curve equating to total load or flow for the sampling 2019 period. The April to mid-August FWMC was then computed from the total load divided by total discharge.

In addition, temperature, dissolved oxygen, pH, and specific conductivity measurements were taken at the same time as nutrient samples using a YSI® multi-parameter probe (see Klamath Tribes 2013 for probe calibration and collection methodology).

To place results from the 2019 study in the context of hydrological and climate conditions relative to the previous 2016 study, snow water equivalent (SWE) data were obtained from the Sevenmile Marsh SNOTEL station located near the Sevenmile Creek headwaters (Figure 1)[10], and air temperature and precipitation data were obtained from the Agency Lake AgriMet station[11]. In addition, daily net-inflow data to Upper Klamath Lake were obtained from the USFWS Klamath Falls Office[12].

RESULTS/DISCUSSION

Discharge

Discharge in the Sevenmile system above the confluence of WC (7MAW) declined seasonally from a high of 171 cfs in early-April to summer flows of ~ 50 cfs (Figure 5; Appendix I showing basic seasonal statistics). The maximum flow for WC also occurred in early-April (117 cfs) before declining during late-April (~25 cfs), increasing to 50 cfs in late-May before

[7] Based on a single West Canal sample event by the Klamath Tribes in August of 2017 that included a measurement of total dissolved P (TDP), it is likely that calculated PP reflects both dissolved organic P (DOP) as well as true particulate P for the West Canal system.
[8] Load in kg/day = (concentration as µg/L x discharge as cfs) x 0.0024469
[9] FWMC in µg/L = (load as kg ÷ discharge as cfs) x 408.7645
[10] https://wcc.sc.egov.usda.gov/nwcc/site?sitenum=745 Sevenmile Marsh SNOTEL station 745
[11] https://www.usbr.gov/pn/agrimet/webarcread.html AGKO - Agency Lake Ranch, Oregon AgriMet Station
[12] Adam Johnson USFWS Klamath Falls Office: 1/23/2020 excel data transmittal "Daily_UKL_net_inflow_Apr2017_FINAL.xlsx"

declining to seasonal lows (~15 cfs) in July and August (Figure 5). The total flow to Agency Lake (4Mile+7MBW) was driven by flow at 7MAW plus the flow from WC, with variable quantity going down either WC or 4C. During the April higher flow period a greater quantity flowed to Sevenmile Canal (7MBW) than it did to Fourmile Canal (4C), whereas during the late-spring and summer lower flow period, water quantity flowing to WC and 4C was similar[13]. Unlike 2016 when measureable WC discharge continued through the fall, flows were not detectable after mid-August during 2019.

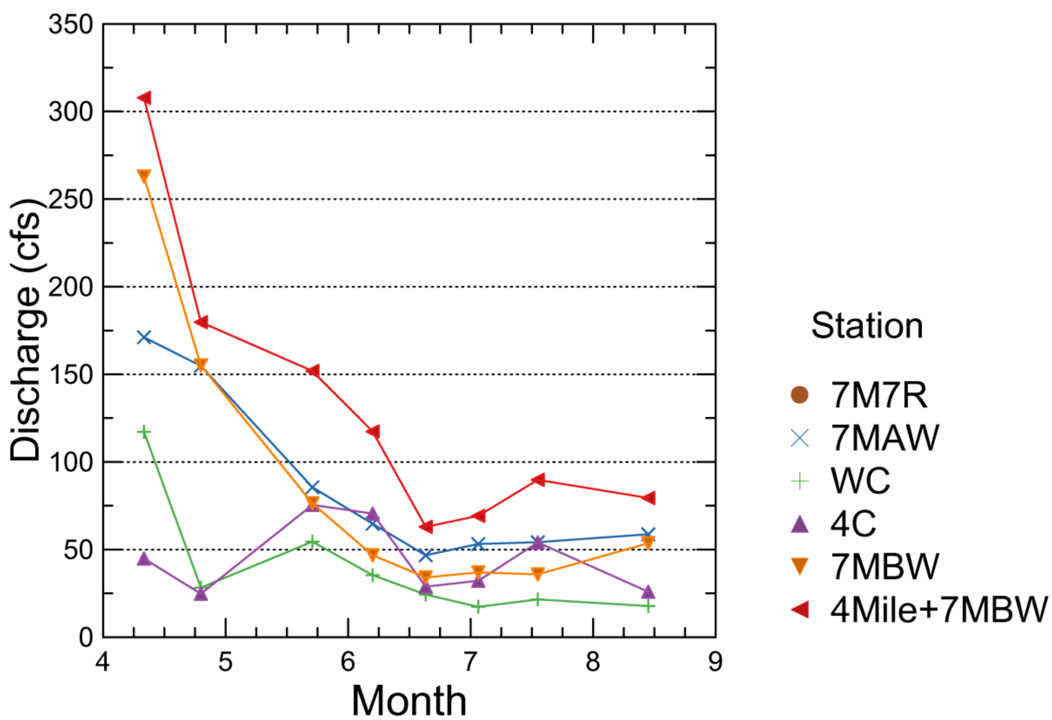

Figure 5. Discharge (cfs) measurements coinciding with nutrient sample collection dates, 2019. No discharge measurements were taken at 7M7R in 2019.

Concentration time-series

<u>Phosphorus and Nitrogen</u>

Unlike the 2016 Sevenmile sampling effort (Kann 2017), when the biweekly time-series indicated pronounced seasonal increases from April-August for TP and PO4 at station WC, concentrations increased initially, but then declined in late-May before again increasing in late-June and peaking during late-July (Figure 6a,c), Seasonal trends in PP were less pronounced than either TP or PO4 (Figure 6a,c,e). Seasonal concentration patterns of the P parameters at 4C and 7MBW generally followed those of WC, and high WC P concentrations (all forms) clearly caused elevated concentrations downstream at 4C and 7MBW. In fact, P FWMC's at the combined 4C and 7MBW site (4Mile+7MBW) averaged 1.5 to 2x higher (up to 4x higher for PP) than both stations (7M7R and 7MAW) located upstream from the WC confluence.

[13] Fourmile Canal flow can be controlled via a headgate and it is not clear whether water control influenced the observed seasonal flow contribution differences.

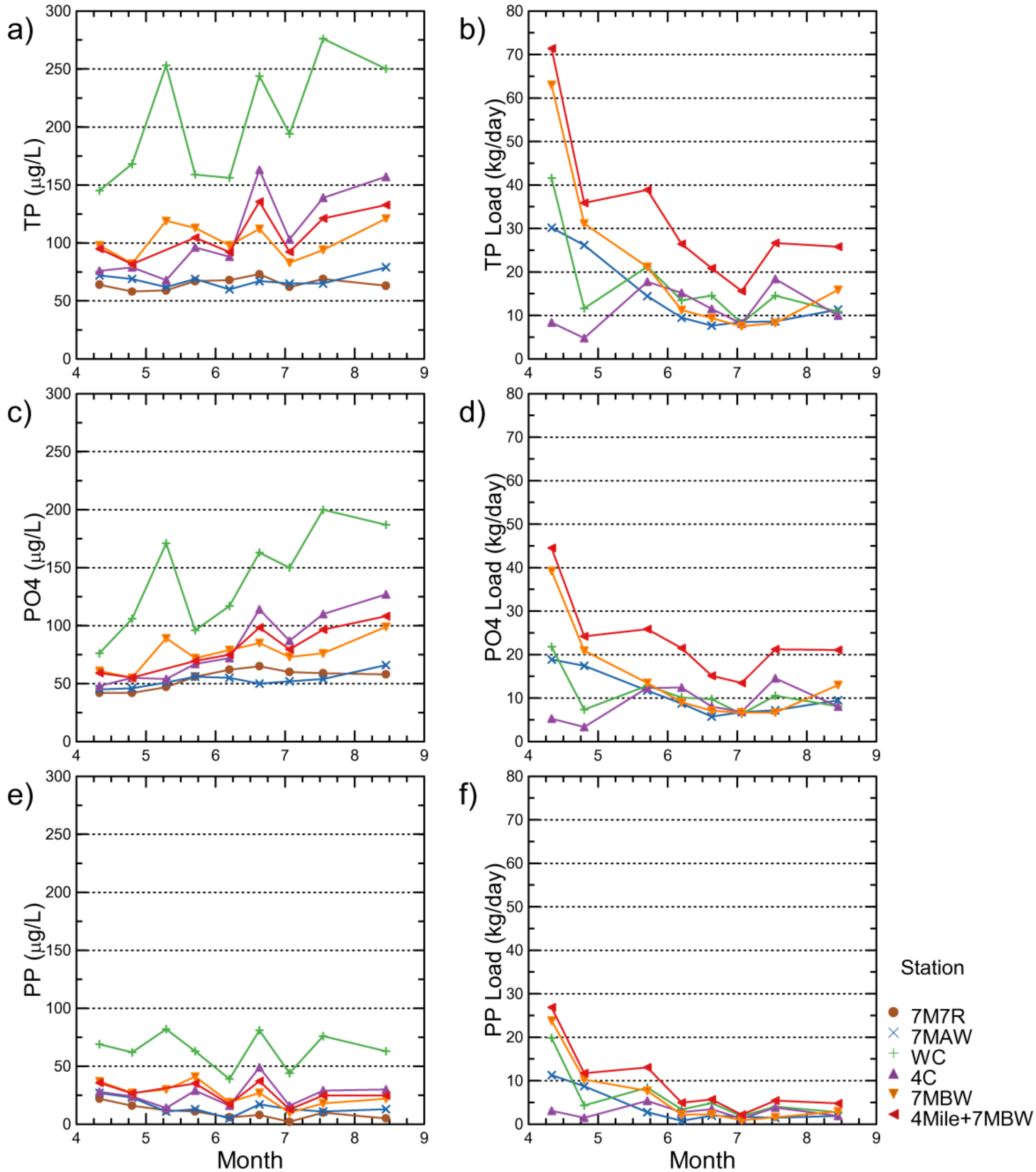

Figure 6. Biweekly time-series of TP concentration (a), TP load (b), PO4 concentration (c), PO4 load (d), PP concentration (e), and PP load (f) for Sevenmile Creek, 2019.

Seasonal concentration increases were less pronounced for the N species (Figure 7). However, similar to the P species, FWMC for TN was ~3x higher (maximum ~8x higher), PN 2-10x higher, and total inorganic N (TIN=NH4+NO3_NO2) 1-2x higher at 4Mile+7MBW compared to 7MAW upstream (Figure 7a,c,e,g). West Canal in general, was substantially elevated for N species relative to other stations. As noted above ,the primary management target for control of UKL algal blooms is P, and the low ratios of TN:TP (<5) and TIN:PO4 (<1) in the Sevenmile system are conducive for the growth of the N-fixing cyanobacteria (e.g., *Aphanizomenon*) occurring in Upper Klamath and Agency Lakes. However, the increased N concentrations (and loads - see below) in water entering Agency Lake due to the influence of WC are of concern since elevated N may foster the growth of toxin-producing *Microcystis*, a non N-fixing species that relies upon ambient N since it cannot fix atmospheric N.

At times there was a slight increase between 7M7R and 7MAW for some parameters (PO4, TN, and PN) but they were smaller relative to the increase occurring downstream of WC. On one occasion in late June concentrations of TN and PN were highly elevated at SM7R (Figure 7a,g)[14]. Due to mixing characteristics and dilution from Sevenmile Creek at the site of the WC confluence, concentrations declined in both 7MBW and 4C relative to WC, but not always at the same rate.

Particulate vs. inorganic P and N forms

The forms of P and N are important to understand relative to the types of nutrient management being considered. For example, wetland restoration that favors emergent vegetation such as tule (i.e., *Scirpus sp.*) is likely more conducive for both the settling of particulate P and PO4 sequestration. For WC, seasonal trends in percent PP load and percent PO4 load show that PO4 comprised ~50 % to 75% of the total P load while the PP fraction comprised 25% to 50% (Figure 8a,b). In addition, the PP contribution was highest at higher flows during the spring and lowest during summer low flows. The inverse was observed for percent PO4 load where the contribution was lowest during the spring and higher during the summer irrigation season. Although both PO4 and PP concentrations were substantially higher in WC relative to 7MAW (Figure 6c,e), the relative loading contribution within WC showed a higher percent contribution from PP, and a lower percent contribution from PO4 compared to other stations (Figure 8a,b). The trends were generally opposite for N, where particulate (or organic) N comprised the majority of the total N load (>80% for most stations), and the inorganic forms were low, particularly for WC (<15%). Seasonal patterns were also less apparent for N (Figure 8c,d).

TSS, Turbidity, Silica, and YSI® Sonde data

Concentrations of both TSS and Turbidity[15] tended to be higher during the spring high flow period than during the summer (Figure 9a; Figure 10), although turbidity fluctuated to a greater degree through the season than TSS. TSS and turbidity showed higher concentrations at both high flow and during the summer irrigation season for WC. Although many of the TSS values

[14] Although QA checks did not reveal data issues, the lack of a comparable spike in TP causes this data point to be flagged as a potential QA issue.
[15] Turbidity measurements indicate the concentration of suspended material as well as color derived from humic acid and other dissolved organic material.

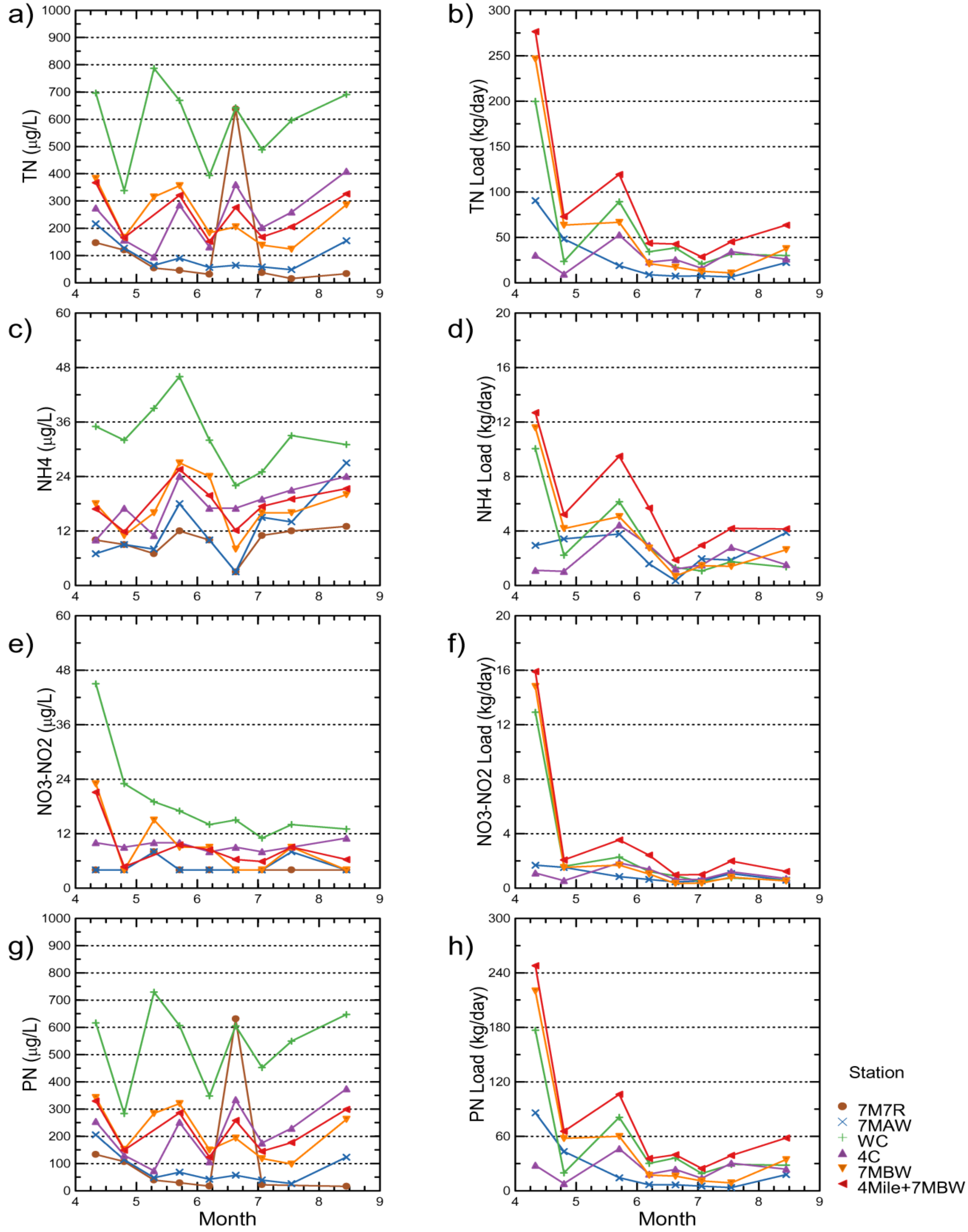

Figure 7. Biweekly time-series of TN concentration (a), TN load (b), NH4 concentration (c), NH4 load (d), NO3+NO concentration 2 (e), NO3+NO2 load (f), PN concentration (g), and PN load (h) for Sevenmile Creek, 2019.

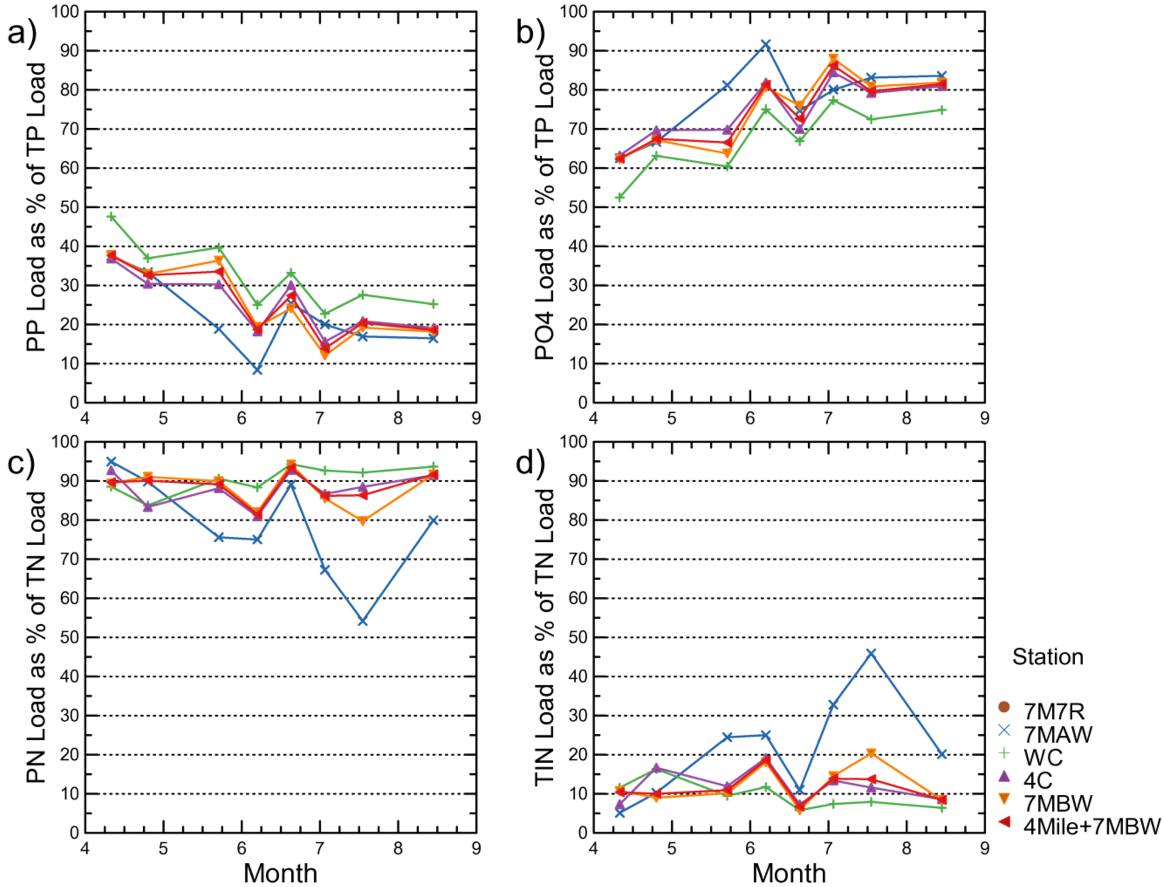

Figure 8. Biweekly time-series of percent PP load (a), percent PO4 load (b), percent PN load (c), and percent TIN load (d). Computed as percent of the total P or total N load within a given station. 2019.

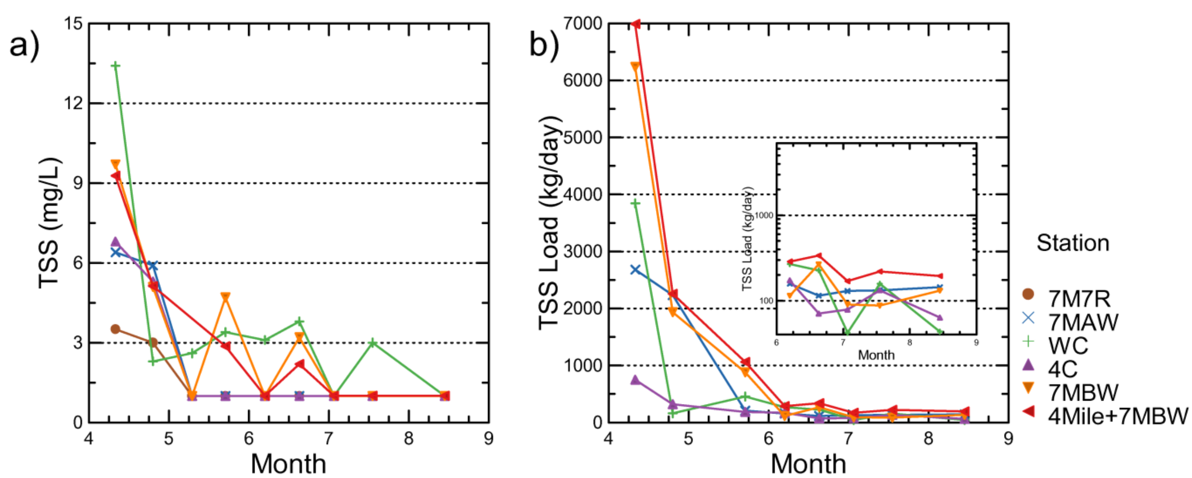

Figure 9. Biweekly time-series of TSS concentration (a), and TSS load (b) for Sevenmile Creek, 2019. Inset graph on 8(b) shows June-Aug TSS load using a log scale to facilitate distinction among sites.

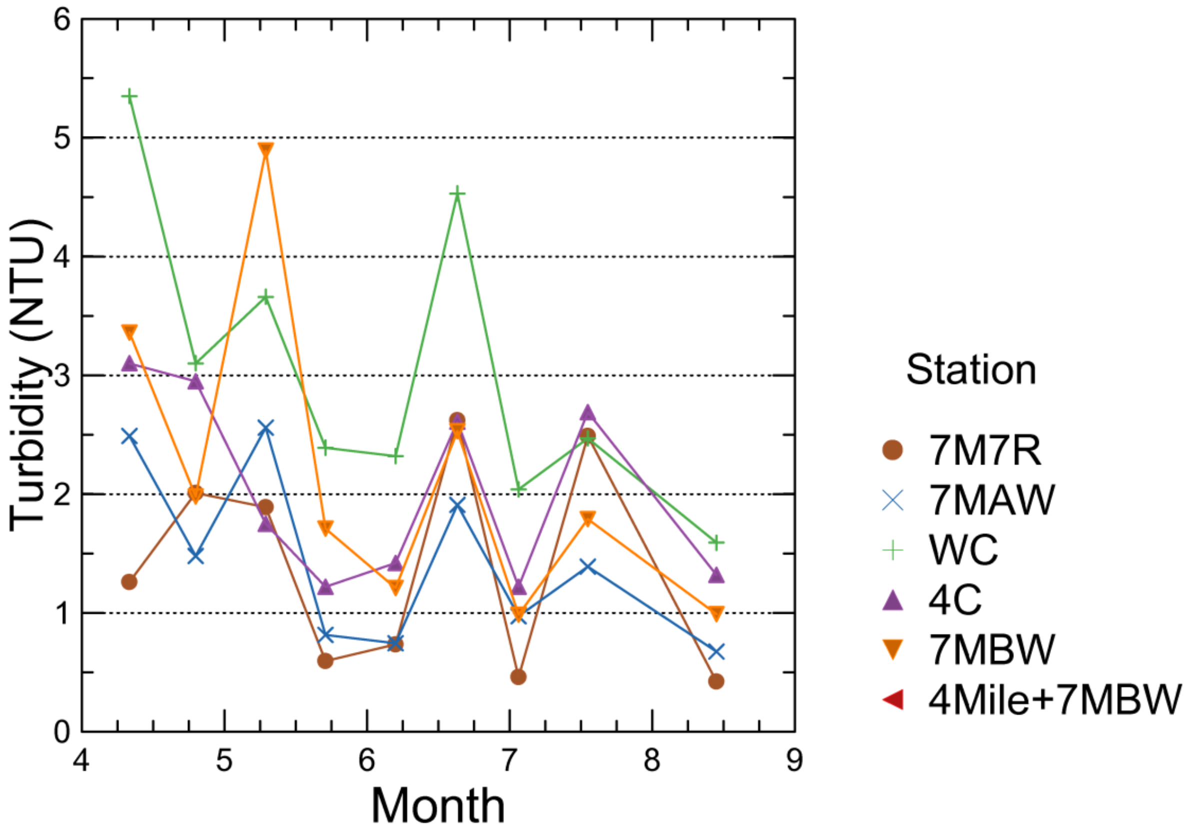

Figure 10. Biweekly time-series of Turbidity for Sevenmile Creek, 2019.

were at the detection limit during the summer months, TSS in WC was higher than those occurring at 7M7R, and appeared to influence concentrations below the confluence at times. Turbidity tended to track at all stations (i.e., although upstream stations 7M7R and 7MAW had lower values than WC, concentrations increased and decreased proportionally to those at WC; Figure 10). Turbidity concentration also increased between 7M7R and 7MAW, and below the confluence of WC, which showed the highest turbidity concentrations, both 4C and 7MBW had higher concentrations than 7MAW upstream Concentrations of SiO2 (important for diatom growth and also an erosional indicator) were substantially higher in WC than they were at both upstream stations (7M7R and 7MAW), this translated to concentrations below the WC confluence (4Mile+7MBW) that were highly elevated in comparison to stations upstream (Figure 11a). Silica concentrations also increased seasonally at all stations.

Temperature and conductivity were highest in WC while dissolved oxygen was lowest (Figure 12). West Canal influenced temperature, dissolved oxygen, and conductivity below its confluence with Sevenmile Creek, with temperature and conductivity higher at 4C and 7MBW and DO lower.

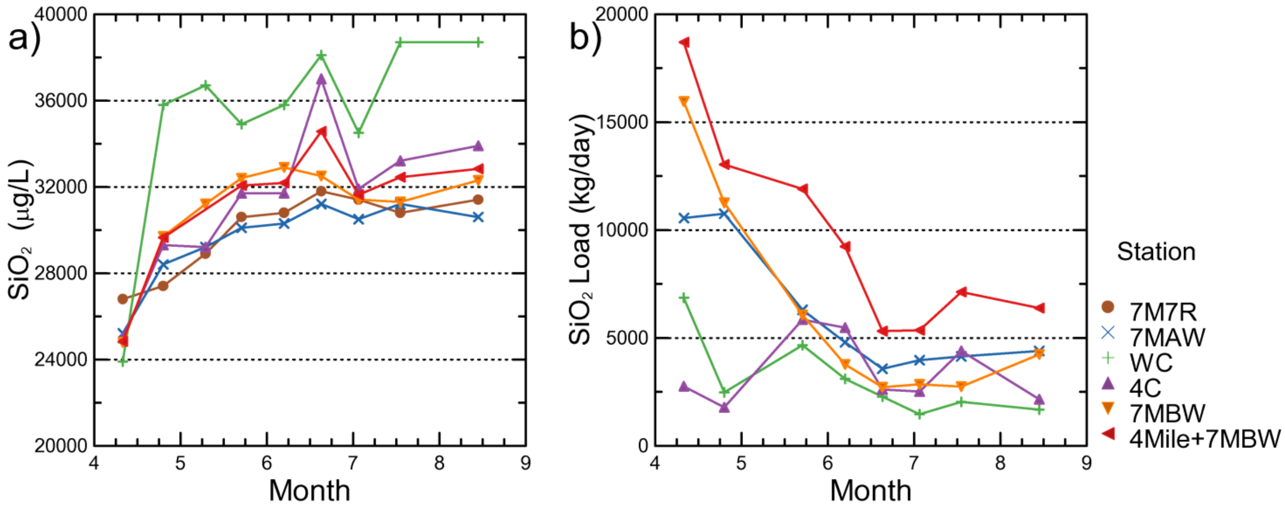

Figure 11. Biweekly time-series of silica concentration (a), and silica load (b) for Sevenmile Creek, 2019.

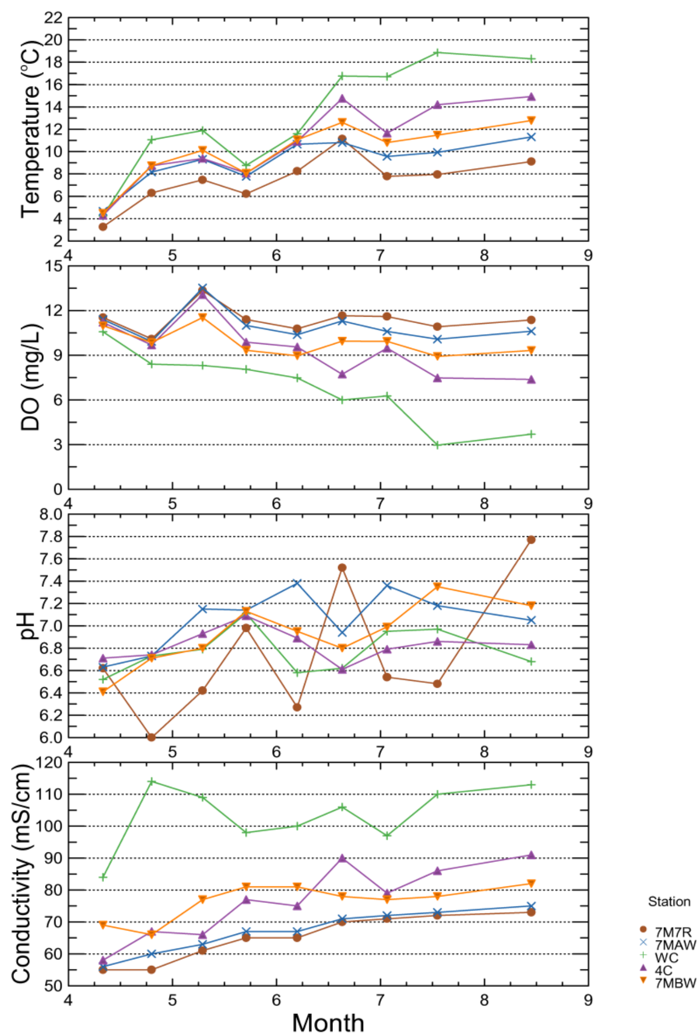

Figure 12. Biweekly time-series of YSI multi-parameter probe water quality measurements for Sevenmile Creek, 2019.

Nutrient loading time-series

Phosphorus and Nitrogen

Following the increased P concentrations and associated loads entering from WC, overall loads of TP, PO4, and PP were substantially higher entering Agency Lake (4Mile+7MBW) than they were in Sevenmile Creek directly upstream from WC (4Mile+7MBW vs. 7MAW; Figure 6b,d,f). For example, TP, PO4, and PP loads were generally 2 to 2.5x higher at 4Mile+7MBW than they were at 7MAW. Likewise, for all N species, 4Mile+7MBW loads were generally 2-4x higher than they were at 7MAW due to the direct effect of loading from WC. During the spring higher flow event, loading of NH4 and NO3+NO2 were 4x and 8x higher, respectively, than at 7MAW. These increased nutrient loads entering Agency Lake via Fourmile and West Canals, as demonstrated by all statistics (Appendix II), clearly show the impact of WC on Sevenmile Creek loading characteristics.

TSS and Silica

TSS load was elevated below the confluence of WC during the first spring higher flow sample event, but was then similar to 7MAW on the subsequent sample date due to a large decline in WC TSS concentration (Figure 9a,b). Following that late-April date, TSS loading continued to decline at all stations, and was generally higher by 1.5-2x downstream of WC compared to upstream. Silica loading showed a more muted seasonal decline for WC than 7MAW and there was a 1-1.5x increase in load at 4Mile+7MBW downstream from the WC confluence (Figure 11b).

Total seasonal load and FWMC

As noted in the methods, the total seasonal loads and flows for 2019 (April to mid-August) for the P, N, and TSS parameters were computed from the area under the time-series curves, which also allowed computation of seasonal FWMC for each parameter. On a seasonal basis the FWMC values for all P and N parameters were clearly higher in WC than other stations (Table 4; Figure 13a; Figure 14a). For example, TP in WC was 183 µg/L vs 68.5 µg/L for 7MAW, and in general FWMC values were >1.5x higher for P parameters and >2.25x higher for N parameters below the confluence of WC (4Mile+7MBW) compared to above the confluence at 7MAW. Likewise, for total seasonal loads, values were >2-2.5x higher for the P parameters and 2-3x higher for the N parameters (Figure 13b; Figure 14b). For TSS, the FWMC and load were more similar between 7MAW and 4Mile+7MBW, where the differences were 1.1x and 1.7x higher below the confluence of WC for FWMC and load, respectively (Figure 15a,b).

Since the total discharge and load to Agency Lake computed either as the sum of 7MAW and WC, or as the sum of 7MBW and 4C, should be equal, the difference between the two gives some idea of the combined error associated with discharge measurements, collection of grab samples, and laboratory analyses. The percent difference between the two for discharge was relatively low at -5.3%, meaning that measured flows were slightly higher when computed from 7MBW+4C as opposed to 7MAW+WC (Table 4).For nutrient loads, the percent error ranged from +0.3% to -7.9% (Table 4).Overall, the relatively low percent error provides confidence in the ability to characterize flows, concentrations and loads at the sampled Sevenmile stations.

Table 4. Total seasonal (April to mid-August) inflow, load, and FWMC for the Sevenmile system, 2019.

				Load (kg)							
Site Code	**Description**	**Days**	**Inflow (acre-ft)**	**TP**	**TN**	**PP**	**PN**	**PO4**	**NO3+ NO2**	**NH4**	**TSS**
4C	Fourmile Canal	126	152	1,550	3,508	377	3,095	1,172	131	283	24,101
4Mile+7MBW	4Mile+7Mile Below West	126	411	3,881	9,440	1,070	8,395	2,810	350	694	137,342
7MAW	Sevenmile Creek above West Canal	126	276	1,765	2,820	438	2,384	1,327	114	321	80,565
7MBW	Sevenmile Canal below West Canal	126	259	2,331	5,932	693	5,301	1,638	220	411	113,242
WC	West Canal	126	114	1,947	6,162	669	5,555	1,278	231	375	51,281
WC % Load	PP and PO4 as % of TP; PN, NO3+NO2, and NH4 as % of TN					34%	90%	66%	4%	6%	
				Flow-Weighted Mean Concentration (µg/L)							
4C	Fourmile Canal			109	248	27	218	83	9	20	1701
4Mile+7MBW	4Mile+7Mile Below West			101	246	28	219	73	9	18	3584
7MAW	Sevenmile Creek above West Canal			69	109	17	93	52	4	12	3127
7MBW	Sevenmile Canal below West Canal			97	246	29	219	68	9	17	4689
WC	West Canal			183	579	63	522	120	22	35	4821
	Sevenmile Load Difference Computed as: (7MAW+WC)-(4C+7MBW)		-20.6	-168.5	-458.8	36.9	-456.3	-205.4	-4.5	2.0	-5495.9
	Sevenmile Error Estimate or % Difference = ((7MAW+WC)-(4C+7MBW))/(7MAW+WC)		-5.3%	-4.5%	-5.1%	3.3%	-5.7%	-7.9%	-1.3%	0.3%	-4.2%
	WC Load as a % of Total 7Mile Load to Agency Lake (computed using 4Mile+7MBW)		27.8%	50.2%	65.3%	62.5%	66.2%	45.5%	66.0%	54.0 %	37.3%
	WC Load as a % of Total 7Mile Load to Agency Lake (computed using WC+7MAW)		29.2%	52.4%	68.6%	60.4%	70.0%	49.0%	66.9%	53.9 %	38.9%

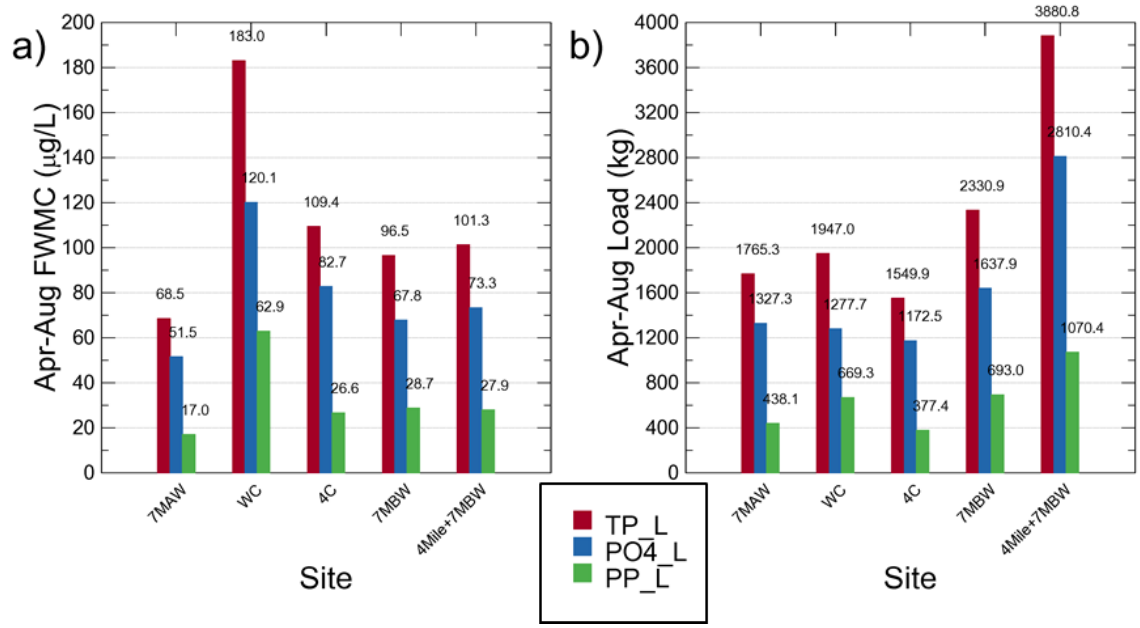

Figure 13. April to mid-August flow-weighted mean concentrations (FWMC; a) and total loads (b) for TP, PO4, and PP. Total loads computed as the area under the curves in Figure 6.

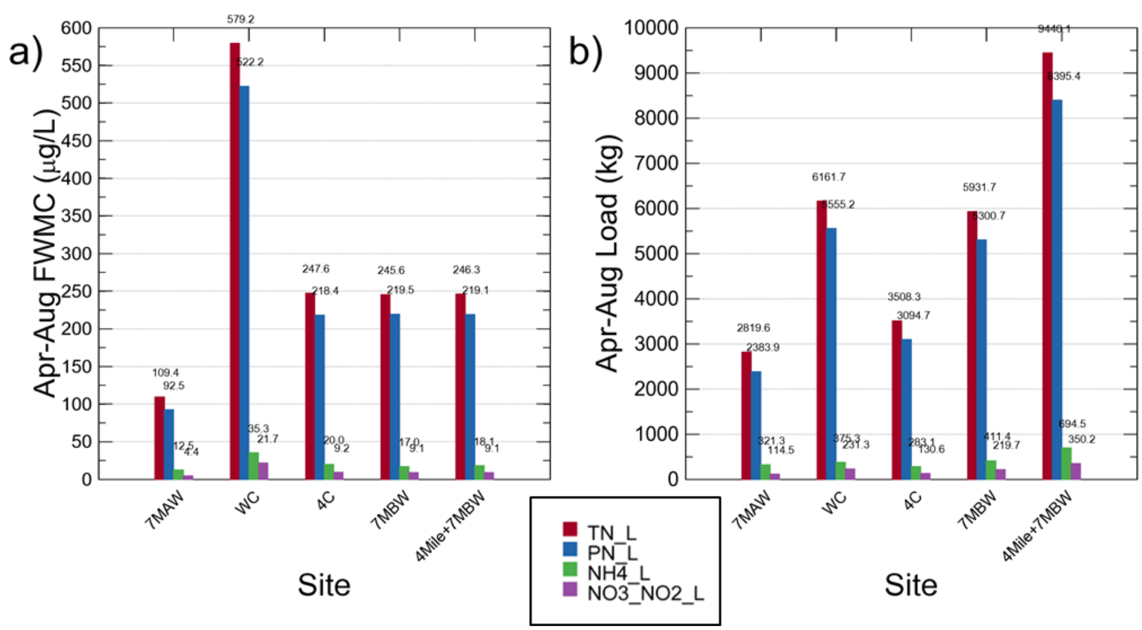

Figure 14. April to mid-August flow-weighted mean concentrations (FWMC; a) and total loads (b) for TN, PN, NH4, and NO+NO2. Total loads computed as the area under the curves in Figure 7.

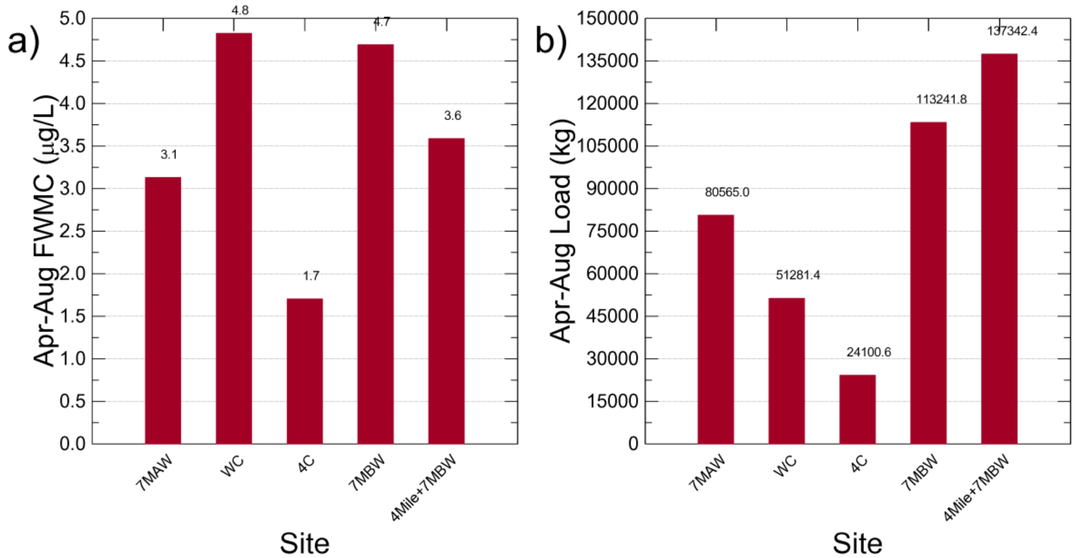

Figure 15. April to mid-August flow-weighted mean concentration (FWMC) (a) and total load (b) for TSS. Total load computed as the area under the curves in Figure 9.

On a seasonal basis, WC contributed 27.8% to 29.3% (depending on calculation method) of the total Sevenmile discharge to Agency Lake, but contributed >50% of the TP load, >60% of the PP load, and >45% of the PO4 load (Table 4). Overall, the N contribution from WC was higher relative to P, contributing >65% of the load for all parameters except NH4 (54%). As noted above, the increased N is also of concern since it may foster the growth of toxin-producing *Microcystis*, and can contribute to growth of N-fixing cyanobacteria as well[16]. As indicated above in Figure 8, the overall seasonal PO4 load accounted for 66% of the total P load in WC, while PP accounted for 34% (Table 4). It is important to note that of the 34% PP load that a portion is likely not true particulate P, but is comprised of dissolved organic P.

Plots of discharge vs. load for each of the nutrient parameters further reveals that at any given discharge, for all parameters except PO4, WC loads were higher than remaining stations (Figure 16). The resulting slope for WC is most divergent from 7MAW, and after WC combines with water from 7MAW, the slope for 4Mile+7MBW is more similar to that of 7MAW (with the exception of TIN[17]). However, at any given discharge the resulting load was greater for 4Mile+7MBW than it was for 7MAW. The higher slopes for WC indicate that as discharge increases, the load per unit discharge (kg/cfs) is disproportionally higher in WC than it is for 7MAW (i.e., the ratio of load to discharge is higher for WC than it is for 7MAW).

[16] Due to the relatively high energy required to convert N_2 gas to useable forms of N via fixation, inorganic forms of nitrogen in the water column (e.g., NH4) are preferentially used by nitrogen-fixing cyanobacteria when available.
[17] TIN is the sum of NH4 and NO3+NO2

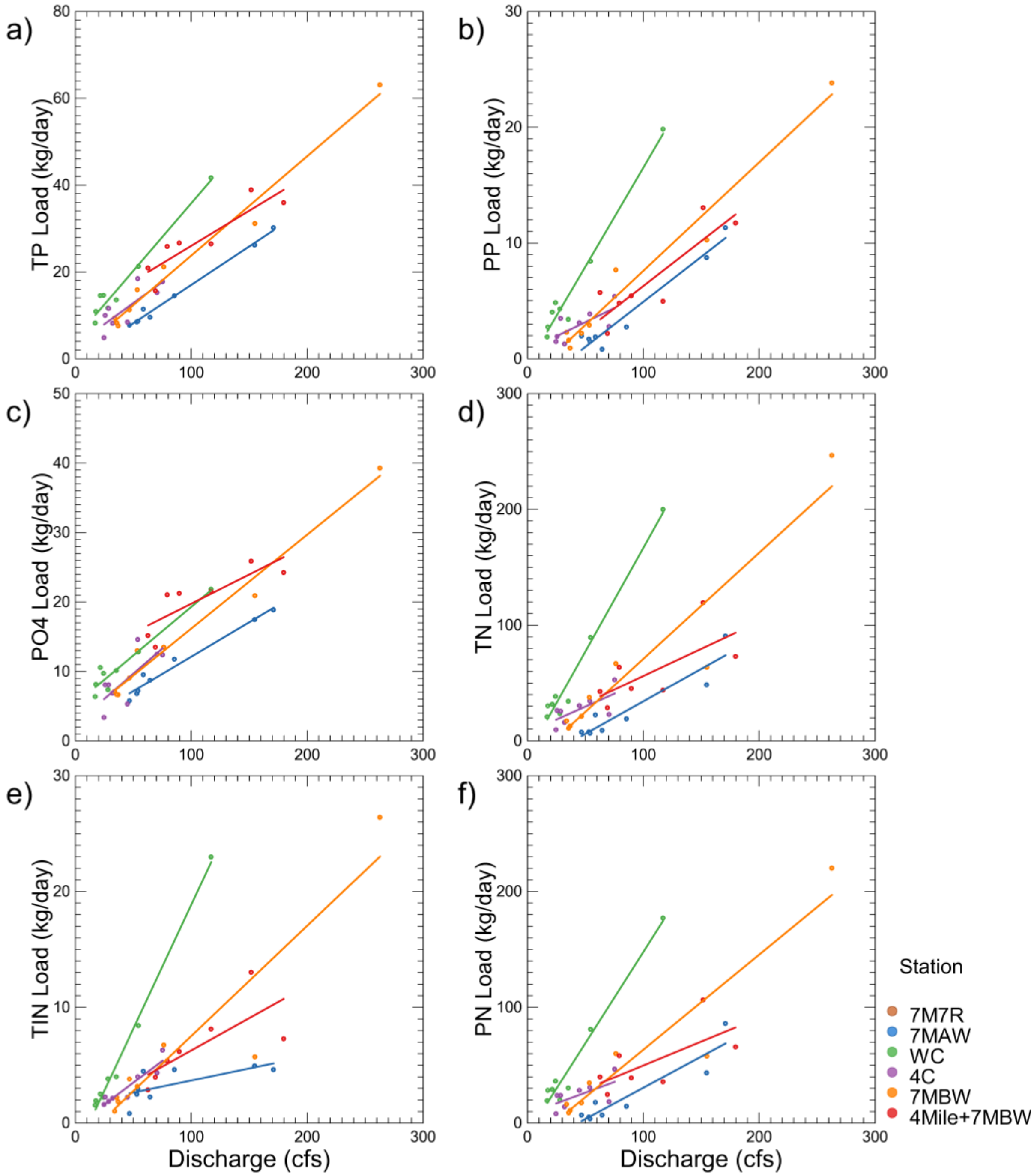

Figure 16. Discharge vs. load in the Sevenmile system, 2019. TP (a), PP (b), PO4 (c), TN (d), TIN (e), PN (f).

Comparison to 2016

In general, concentrations observed in this study were in the same range as those from the 2016 study (see Figures 17 and 18 in Kann 2017). However, the seasonal trajectories differed somewhat (especially for TP and PO4) with the 2016 trend for WC showing a more pronounced peak, and with loading continuing to occur well into the fall months in 2016 (Kann 2017). A comparison of two of the stations (WC and 7MAW) for discharge and TP load between the two years indicates that 2019 showed higher flow and load in April at both stations (Figure 17), but that discharge in WC in 2019 was similar to 2016 from late-April through June, while for 7MAW it was higher in 2019 through late June (Figure 17a,c). Accordingly, TP load at WC in 2019 was similar to 2016 in May and June, while for 7MAW load was higher in 2019 (Figure 17b,d). During the July-August period, TP load was higher in 2016 for WC but similar or lower for 7MAW.

Climatic and hydrologic data were used to explore whether differences in the 2016 vs. 2019 patterns may be attributable to different hydrologic conditions, or possibly Klamath Tribal water calls, which, by specifying minimum instream flows in the Wood River could reduce irrigation runoff that historically flowed to Sevenmile Creek via West Canal. Climate and inflow data show that April precipitation was higher, air temperature cooler, and that snow water equivalent and net inflow were higher in 2019 than they were in 2016 (Figure 18). This pattern was essentially reversed for March and is reflected in the discharge and TP load patterns where March discharge and load were high in 2016 (there are no March data for 2019), while April showed higher values in 2019 (Figure 17). May was also wetter and cooler in 2019, while June of 2019 was more similar to 2016 (Figure 18; precipitation was high in 2016, but SWE was higher in 2019 and net-inflow was similar). Thus, even though May of 2019 was wetter, the WC load was similar to 2016, while 7MAW followed the expected pattern of higher 2019 flow and load. During July and August when net-inflow (Figure 17d) was higher in 2019 than it was in 2016, WC showed generally lower TP loading in 2019, and again 7MAW loading was slightly higher or more similar to 2016. Although not conclusive[18], these patterns may reflect reduced irrigation return flow to WC due to Tribal water rights calls, since despite overall wetter conditions in 2019 it appears that WC flows and loads were relatively lower in WC, but not in 7MAW (which is not subject to tribal water calls).

It should be noted that the Klamath Tribes' 2019 sampling program was unable to capture any high flow events (e.g., due to increased precipitation, snowmelt runoff, or rain-on-snow events), which, given erosion potential in the Wood River Valley due to grazing-induced soil exposure, can cause intermittently high loads in the canal system. For example, a rain event of 1 inch in 24 hours during September of 2003 increased West Canal TP load by ~5x (GMA 2004).

[18]Since water calls were also made in 2016 a comparison of calls in 2016 and 2019 would need to be made to better understand the dynamics. Whether other factors such as water conservation activities were implemented in any of the years would also need to be evaluated, as would reduced irrigation need (especially in May and June) due to wetter climatic conditions.

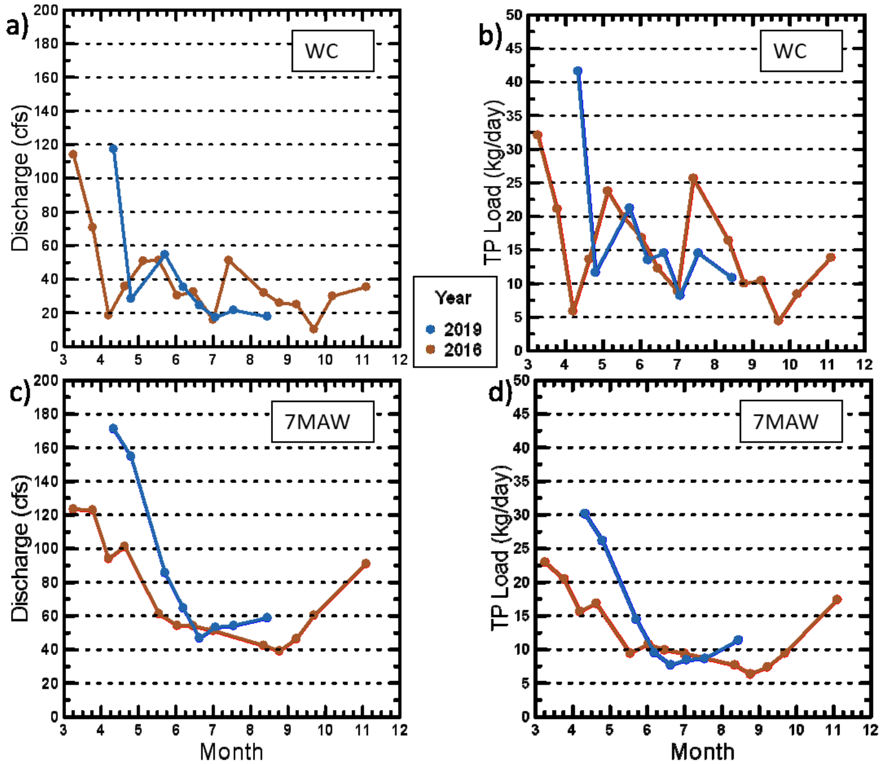

Figure 17. Comparison of discharge and load between 2016 (replotted from Kann 2017) and 2019 at West Canal (WC; a, b) and Sevenmile above West Canal (7MAW; c, d).

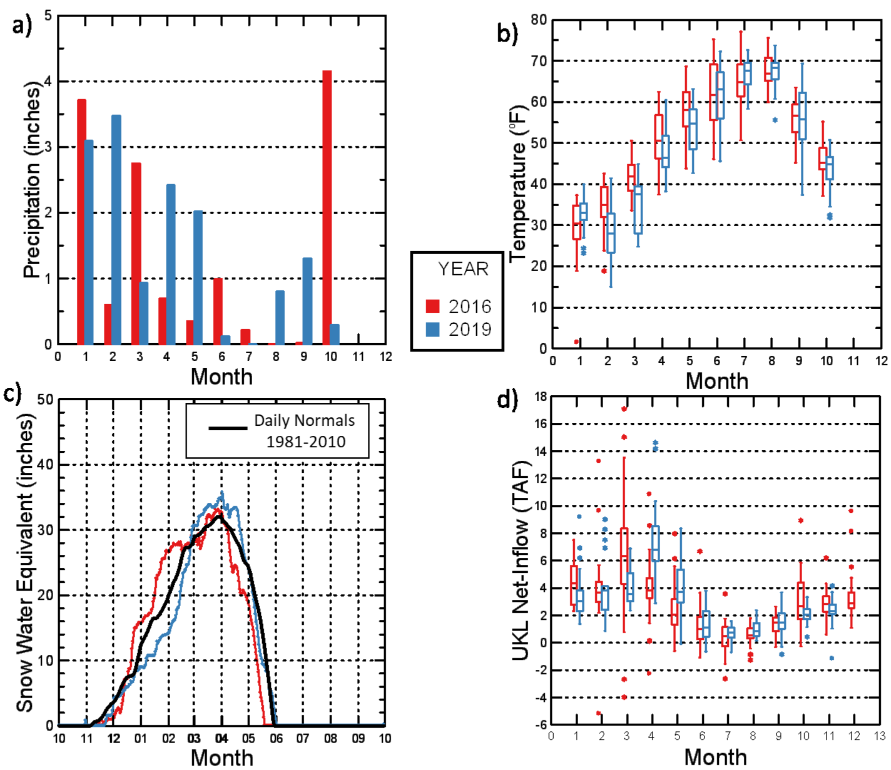

Figure 18. Climate and hydrology comparison between the 2016 and 2019 study periods. Agency Lake Ranch AgriMet station precipitation (a) and air temperature (b); Sevenmile Marsh SNOTEL station snow water equivalent (c); and UKL net-inflow (d).

SUMMARY

The Klamath Tribes' 2019 Sevenmile Creek monitoring program provides additional flow, concentration, and nutrient loading data that can be used to inform restoration activities intended to treat nutrients loads in the Sevenmile system. These analyses clearly show that FWMC and load of the major P and N nutrient parameters entering Agency Lake from the Sevenmile system greatly increase due to input via West Canal. In general, West Canal contributed ~28% of the total Sevenmile discharge to Agency Lake, but contributed >50% of the TP load, >60% of the PP load, and >45% of the PO4 load. Within West Canal, the overall seasonal PO4 load accounted for 66% of the total P load, while PP accounted for 34%. Since a portion of the PP load may be comprised of dissolved organic P, it is likely that not all of the 34% PP is in a true particulate form. Thus, in addition to wetland treatment options being evaluated for particulate P, treatment of West Canal discharge should also consider both its high PO4 contribution as well as its potentially high dissolved organic P contribution. Moreover, treatment options should consider potential seasonal changes in nutrient forms (e.g., TSS in WC was 4x higher during spring high flow than it was in summer). Overall the N contribution from WC was higher relative to P, contributing ~68% of the total Sevenmile load to Agency Lake. However, in contrast to P, where the PP fraction was 34%, the PN fraction of the total N in West Canal was ~90%. The TSS concentration tended to be higher at high discharge, indicating erosional processes are mobilizing sediment during high flow conditions.

Given the high load relative to land area in the Sevenmile system, and that much of the nutrient load is entering via a single source, treatment of West Canal nutrient loading should be a high priority to target for nutrient loading reduction to Upper Klamath and Agency Lake.

Acknowledgements
This work was funded by a grant from the National Fish and Wildlife Foundation (NFWF Grant # 0206.19.064927). I gratefully acknowledge the Klamath Tribes Aquatic Resources Water Quality Monitoring staff who were responsible for field data collection, and Megan Skinner of the Klamath Falls Office of the US Fish and Wildlife Service who provided review comments.

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APPENDIX I: Basic statistics by station for water qualtiy and nutrient concentrations in the Sevenmile system, 2019.

Note that concentrations for 4Mile+7MBW are the calculated flow-weighted mean concentrations.

Site	Statistic	T	pH	Cond (mS/cm)	DO (mg/L)	Q cfs	TP (µg/L)	PO4 (µg/L)	PP (µg/L)	TN (µg/L)	NH4 (µg/L)	NO3+NO2 (µg/L)	NO2 (µg/L)	PN (µg/L)	Turb-idity (NTU)	Sio2 (µg/L)	TSS (mg/L
4C	N of Cases	9	9	9	9	8	9	9	9	9	9	9	9	9	9	9	9
4C	Minimum	4.3	6.6	58	7.4	25	68	48	14	94	10	8.0	1	73	1.2	25000	1.0
4C	Maximum	14.9	7.1	91	13.1	75	163	127	49	409	24	11.0	1	374	3.1	37000	6.8
4C	Median	10.9	6.8	77	9.6	39	96	72	28	259	17	9.0	1	229	1.8	31700	1.0
4C	Arithmetic Mean	10.8	6.8	77	9.5	45	108	82	26	241	18	9.3	1	214	2.0	31433	2.1
4C	10th Percentile	5.8	6.7	61	7.4	25	71	50	15	109	10	8.0	1	86	1.2	26680	1.0
4C	25th Percentile	8.6	6.7	67	7.7	27	78	55	16	150	16	8.8	1	124	1.3	29275	1.0
4C	75th Percentile	14.3	6.9	87	10.2	62	144	111	29	304	22	10.0	1	274	2.8	33375	2.1
4C	90th Percentile	14.9	7.0	91	12.3	74	161	122	41	389	24	10.6	1	358	3.0	35760	6.2
4Mile+7MBW	N of Cases	0	0	0	0	8	8	8	8	8	8	8	0	8	0	8	8
4Mile+7MBW	Minimum					63	82	55	13	152	12	4.7		124		24834	1.0
4Mile+7MBW	Maximum					308	135	108	37	367	26	21.1		329		34570	9.3
4Mile+7MBW	Median					104	100	77	26	241	18	7.3		217		32122	1.6
4Mile+7MBW	Arithmetic Mean					132	107	80	27	248	18	8.9		221		31277	2.9
4Mile+7MBW	10th Percentile					65	85	56	14	156	12	5.0		130		26279	1.0
4Mile+7MBW	25th Percentile					74	92	64	21	167	14	6.1		147		30645	1.0
4Mile+7MBW	75th Percentile					166	127	97	35	323	21	9.3		292		32640	4.0
4Mile+7MBW	90th Percentile					269	135	105	37	355	24	17.6		320		34047	8.0

Site	Statistic	T	pH	Cond (mS/cm)	DO (mg/L)	Q cfs	TP (µg/L)	PO4 (µg/L)	PP (µg/L)	TN (µg/L)	NH4 (µg/L)	NO3+NO2 (µg/L)	NO2 (µg/L)	PN (µg/L)	Turb-idity (NTU)	Sio2 (µg/L)	TSS (mg/L
7M7R	N of Cases	9	9	9	9	0	9	9	9	9	9	9	9	9	9	9	9
7M7R	Minimum	3.3	6.0	55	10.1		58	42	2	15	3	4.0	1	0	0.4	26800	1.0
7M7R	Maximum	11.1	7.8	73	13.3		73	65	22	638	13	8.0	1	631	2.6	31800	3.5
7M7R	Median	7.8	6.5	65	11.4		64	58	10	45	10	4.0	1	29	1.3	30800	1.0
7M7R	Arithmetic Mean	7.5	6.7	65	11.4		65	55	10	124	10	4.4	1	110	1.4	29989	1.5
7M7R	10th Percentile	4.4	6.1	55	10.4		58	42	3	21	5	4.0	1	6	0.4	27040	1.0
7M7R	25th Percentile	6.3	6.4	60	10.9		61	46	6	33	9	4.0	1	17	0.6	28525	1.0
7M7R	75th Percentile	8.5	7.1	71	11.6		68	61	13	127	12	4.0	1	114	2.1	31400	1.5
7M7R	90th Percentile	10.3	7.7	73	12.7		71	64	20	442	13	6.4	1	432	2.6	31640	3.3
7MAW	N of Cases	9	9	9	9	8	9	9	9	9	9	9	9	9	9	9	9
7MAW	Minimum	4.7	6.6	56	9.9	47	60	45	5	48	3	4.0	1	26	0.7	25200	1.0
7MAW	Maximum	11.3	7.4	75	13.5	171	79	66	27	216	27	8.0	1	205	2.6	31200	6.4
7MAW	Median	9.6	7.1	67	10.6	62	67	52	13	64	10	4.0	1	57	1.4	30300	1.0
7MAW	Arithmetic Mean	9.1	7.1	67	11.0	86	68	53	15	97	12	4.9	1	80	1.4	29633	2.1
7MAW	10th Percentile	5.9	6.7	58	10.0	49	61	45	7	51	5	4.0	1	31	0.7	26480	1.0
7MAW	25th Percentile	8.1	6.9	62	10.3	54	64	49	11	58	8	4.0	1	41	0.8	29000	1.0
7MAW	75th Percentile	10.7	7.2	72	11.3	120	70	55	19	134	16	5.0	1	116	2.1	30750	2.2
7MAW	90th Percentile	11.1	7.4	74	12.7	166	76	62	25	191	23	8.0	1	172	2.5	31200	6.2
7MBW	N of Cases	9	9	9	9	8	9	9	9	9	9	9	9	9	9	9	9
7MBW	Minimum	4.5	6.4	66	8.9	34	82	55	10	123	8	4.0	1	98	1.0	24800	1.0
7MBW	Maximum	12.8	7.4	82	11.5	263	121	99	41	383	27	23.0	1	342	4.9	32900	9.7

Site	Statistic	T	pH	Cond (mS/cm)	DO (mg/L)	Q cfs	TP (µg/L)	PO4 (µg/L)	PP (µg/L)	TN (µg/L)	NH4 (µg/L)	NO3+NO2 (µg/L)	NO2 (µg/L)	PN (µg/L)	Turb-idity (NTU)	Sio2 (µg/L)	TSS (mg/L
7MBW	Median	10.8	7.0	78	9.9	50	98	76	27	205	16	9.0	1	193	1.8	31400	1.0
7MBW	Arithmetic Mean	10.0	6.9	77	9.9	88	102	77	26	240	17	9.0	1	213	2.2	30944	3.1
7MBW	10th Percentile	5.9	6.5	67	8.9	35	82	57	13	129	9	4.0	1	106	1.0	26760	1.0
7MBW	25th Percentile	8.6	6.8	75	9.2	36	91	69	19	160	15	4.0	1	142	1.2	30825	1.0
7MBW	75th Percentile	11.8	7.1	81	10.2	116	115	86	32	325	21	10.5	1	293	2.7	32425	4.8
7MBW	90th Percentile	12.7	7.3	82	11.3	231	120	95	39	372	26	19.8	1	333	4.3	32740	7.9
WC	N of Cases	9	9	9	9	8	9	9	9	9	9	9	9	9	9	9	9
WC	Minimum	4.2	6.5	84	3.0	17	145	76	39	338	22	11.0	1	283	1.6	23900	1.0
WC	Maximum	18.9	7.1	114	10.6	117	276	200	82	787	46	45.0	1	729	5.4	38700	13.4
WC	Median	11.9	6.7	106	7.5	26	194	150	63	642	32	15.0	1	605	2.5	35800	3.0
WC	Arithmetic Mean	13.1	6.8	103	6.9	40	205	141	64	589	33	19.0	1	537	3.1	35233	3.7
WC	10th Percentile	6.0	6.5	89	3.3	17	149	84	41	360	23	11.8	1	309	1.8	28140	1.0
WC	25th Percentile	10.5	6.6	98	5.4	20	158	104	58	465	30	13.8	1	426	2.3	34800	2.0
WC	75th Percentile	17.1	7.0	111	8.3	45	251	175	77	692	36	20.0	1	624	3.9	38250	3.5
WC	90th Percentile	18.6	7.1	114	9.7	98	267	195	82	751	43	36.2	1	696	5.0	38700	9.6

APPENDIX II: Basic statistics by station for nutrient loads (kg/day) in the Sevenmile system, 2019.

Site	Statistic	TP	PO4	PP	TN	NO3+NO2	NH4	PN	TSS	SiO2
4C	N of Cases	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
4C	Minimum	4.8	3.3	1.3	9.4	0.5	1.0	7.9	63.4	1773.4
4C	Maximum	18.4	14.6	5.4	52.6	1.8	4.4	46.3	747.3	5849.7
4C	Median	10.7	8.0	2.9	25.6	0.9	1.5	23.6	152.5	2678.4
4C	Arithmetic Mean	11.7	8.9	2.9	27.0	1.0	2.1	24.0	221.3	3437.4
4C	10th Percentile	5.8	3.9	1.3	11.4	0.6	1.0	9.6	65.5	1885.6
4C	25th Percentile	8.2	6.1	1.7	19.2	0.6	1.1	16.0	74.6	2327.4
4C	75th Percentile	16.5	12.4	3.6	32.2	1.3	2.9	29.1	252.7	4932.4
4C	90th Percentile	18.2	13.9	4.9	47.1	1.7	4.0	41.5	619.3	5736.0
4Mile+7MBW	N of Cases	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
4Mile+7MBW	Minimum	15.6	13.5	2.2	28.4	1.0	1.9	24.4	169.2	5317.9
4Mile+7MBW	Maximum	71.4	44.5	26.9	276.5	15.9	12.7	247.9	6986.3	18698.7
4Mile+7MBW	Median	26.5	21.3	5.6	54.2	2.0	4.7	48.8	312.1	8183.2
4Mile+7MBW	Arithmetic Mean	32.7	23.3	9.3	86.4	3.6	5.8	77.0	1439.1	9632.6
4Mile+7MBW	10th Percentile	17.2	14.0	2.9	32.6	1.0	2.2	27.7	176.7	5328.1
4Mile+7MBW	25th Percentile	23.3	18.1	4.9	43.0	1.1	3.5	37.2	207.1	5865.7
4Mile+7MBW	75th Percentile	37.4	25.0	12.4	96.0	3.0	7.6	85.8	1659.3	12473.1
4Mile+7MBW	90th Percentile	61.6	38.9	22.7	229.3	12.2	11.7	205.4	5567.0	17001.0
7MAW	N of Cases	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
7MAW	Minimum	7.7	5.7	0.8	6.4	0.5	0.3	3.4	114.3	3567.3
7MAW	Maximum	30.1	18.8	11.3	90.4	1.7	3.9	85.8	2679.0	10756.7
7MAW	Median	10.4	9.1	1.9	13.9	0.7	2.4	10.4	150.9	4594.5
7MAW	Arithmetic Mean	14.5	10.7	3.8	26.2	0.9	2.5	22.8	725.2	6058.1
7MAW	10th Percentile	7.9	6.0	1.0	6.6	0.5	0.7	3.9	119.0	3686.5
7MAW	25th Percentile	8.5	7.0	1.6	7.4	0.5	1.7	5.8	131.2	4049.1

Site	Statistic	TP	PO4	PP	TN	NO3+NO2	NH4	PN	TSS	SiO2
7MAW	75th Percentile	20.3	14.6	5.7	35.1	1.3	3.6	30.4	1222.1	8426.7
7MAW	90th Percentile	28.9	18.4	10.5	77.7	1.6	3.8	73.0	2545.7	10694.3
7MBW	N of Cases	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
7MBW	Minimum	7.5	6.6	0.9	10.8	0.3	0.7	8.6	87.4	2708.5
7MBW	Maximum	63.0	39.2	23.8	246.3	14.8	11.6	220.0	6239.0	15951.2
7MBW	Median	13.5	11.0	2.6	29.2	0.9	2.7	25.7	198.9	3998.4
7MBW	Arithmetic Mean	20.9	14.5	6.4	59.4	2.6	3.7	53.0	1217.8	6195.1
7MBW	10th Percentile	7.7	6.6	1.1	11.3	0.3	0.9	9.2	88.4	2717.0
7MBW	25th Percentile	8.8	6.9	1.9	14.8	0.4	1.4	13.4	102.5	2790.7
7MBW	75th Percentile	26.1	17.2	9.0	65.0	1.6	4.6	58.7	1406.6	8661.6
7MBW	90th Percentile	53.5	33.7	19.7	192.4	10.9	9.6	171.9	4947.7	14545.7
WC	N of Cases	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
WC	Minimum	8.2	6.3	1.9	20.6	0.5	1.1	19.0	42.1	1453.4
WC	Maximum	41.6	21.8	19.8	199.7	12.9	10.0	176.7	3844.2	6856.4
WC	Median	14.0	9.9	4.1	32.7	1.1	2.0	29.5	192.7	2371.8
WC	Arithmetic Mean	17.0	10.8	6.2	58.3	2.6	3.3	52.4	649.3	3064.5
WC	10th Percentile	9.0	6.6	2.1	21.4	0.5	1.1	19.2	42.5	1520.3
WC	25th Percentile	11.2	7.7	3.1	26.6	0.7	1.3	23.8	100.6	1856.7
WC	75th Percentile	17.9	11.7	6.6	63.7	1.9	4.5	58.4	360.7	3874.5
WC	90th Percentile	35.5	19.1	16.4	166.5	9.7	8.9	147.9	2827.0	6195.7