TECHNICAL MEMORANDUM

Upper Klamath Lake Tributary Sampling: 2018 Data Summary Report

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INTRODUCTION

The Klamath Tribes have been monitoring nutrient concentration and loading in Upper Klamath Lake (UKL) tributaries since 1991. Data from 1991-1998 were summarized and incorporated into water and nutrient balances for UKL (Kann and Walker 1999). More recently the longer term 1991-2010 database was evaluated for seasonal and inter-annual dynamics, long term trends, and both water and nutrient balances were computed for UKL (Walker et al. 2012). This report serves as an annual update to the UKL tributary water quality database, including a summary of 2018 data (basic summary statistics and graphical analysis), and limited comparison of graphical time-series trends of tributary data collected for the 1991-2018 period. Included in this summary is an update of previous UKL tributary water quality databases with data collected during 2018 (*see Excel spreadsheets: Klamath Tribes Inflow Nutrient Data 1991-2000.xls* and *UKL_tributaries_2001_2018_data_ver_6_26_2019.xls*).

METHODS

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). Beginning in 2008 for nutrient parameters, laboratory analyses transitioned from Aquatic Research, INC. in Seattle WA to the Sprague River Water Quality Laboratory (SRWQL) in Chiloquin OR. During the transition period duplicate samples were analyzed by both laboratories to confirm parameter reproducibility. Specific nutrient methodology and field collection protocol are contained in the SRWQL QAPP (Klamath Tribes 2013) and SOP (2013). Nutrient parameters (Table 1) were collected at seven tributary stations during the 2018 sampling season at an approximately biweekly frequency (Figure 1; Figure 2). Specific computation of nutrient loading is outlined in Kann and Walker (1999) and Walker et al. (2012), but is briefly summarized here.

Table 1. Nutrient parameters collected in Upper Klamath Lake tributaries, 2017.

Parameter	Abbreviation/Unit	Grab [a]
Total Phosphorus	TP (µg/L)	X
Soluble Reactive Phosphorus	SRP or PO_4 (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
Silica	SiO_2 (µg/L)[1]	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.

[1] Silica measurements were initiated in 2008, NO_2 in 2013, and TSS and Turbidity in 2016 and are now included as a regularly measured parameter.

Table 3. Station location and Site ID Code for data collected in Upper Klamath Lake tributaries, 2018.

Location	Site ID Code	Latitude/Longitude
Sprague R. @ Kirchers Bridge	WR1000	N42.567806° W121.864472°
Annie Ck @ Snow Park	WR2000	N42.763685° W122.058362°
Wood R @ Weed Rd	WR3000	N42.646461° W121.994959°
Wood R @ Dike Rd	WR4000	N42.581460° W121.941536°
7-mile canal @ Dike Rd	WR5000	N42.581970° W121.970898°
Williamson R @ Bridge on Modoc Pt. Road	WR6000	N42.514355° W121.916714°
Upper Klamath Lake @ Pelican Marina/Fremont Bridge (UKL Outflow)	KL0001/KL0002	N42.238472° W121.805557°

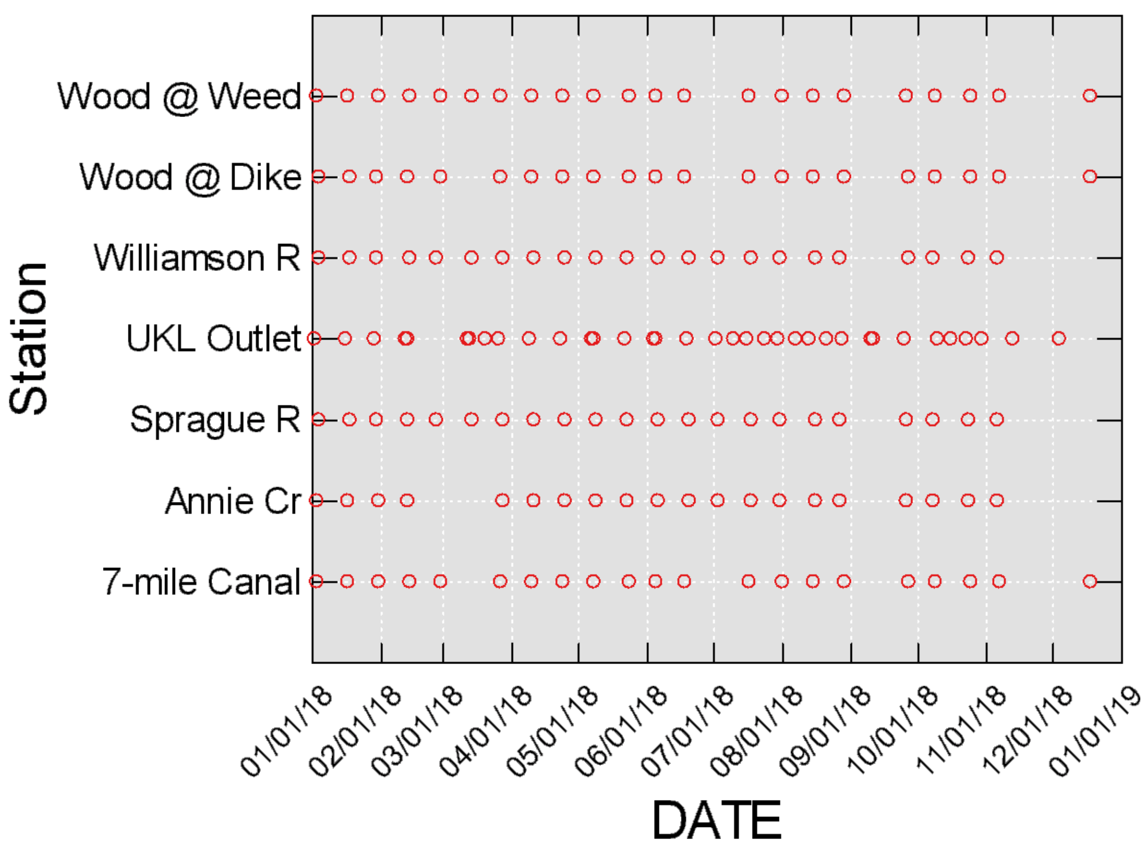

Figure 1. Spatial-temporal sampling matrix for Upper Klamath Lake tributaries, 2018.

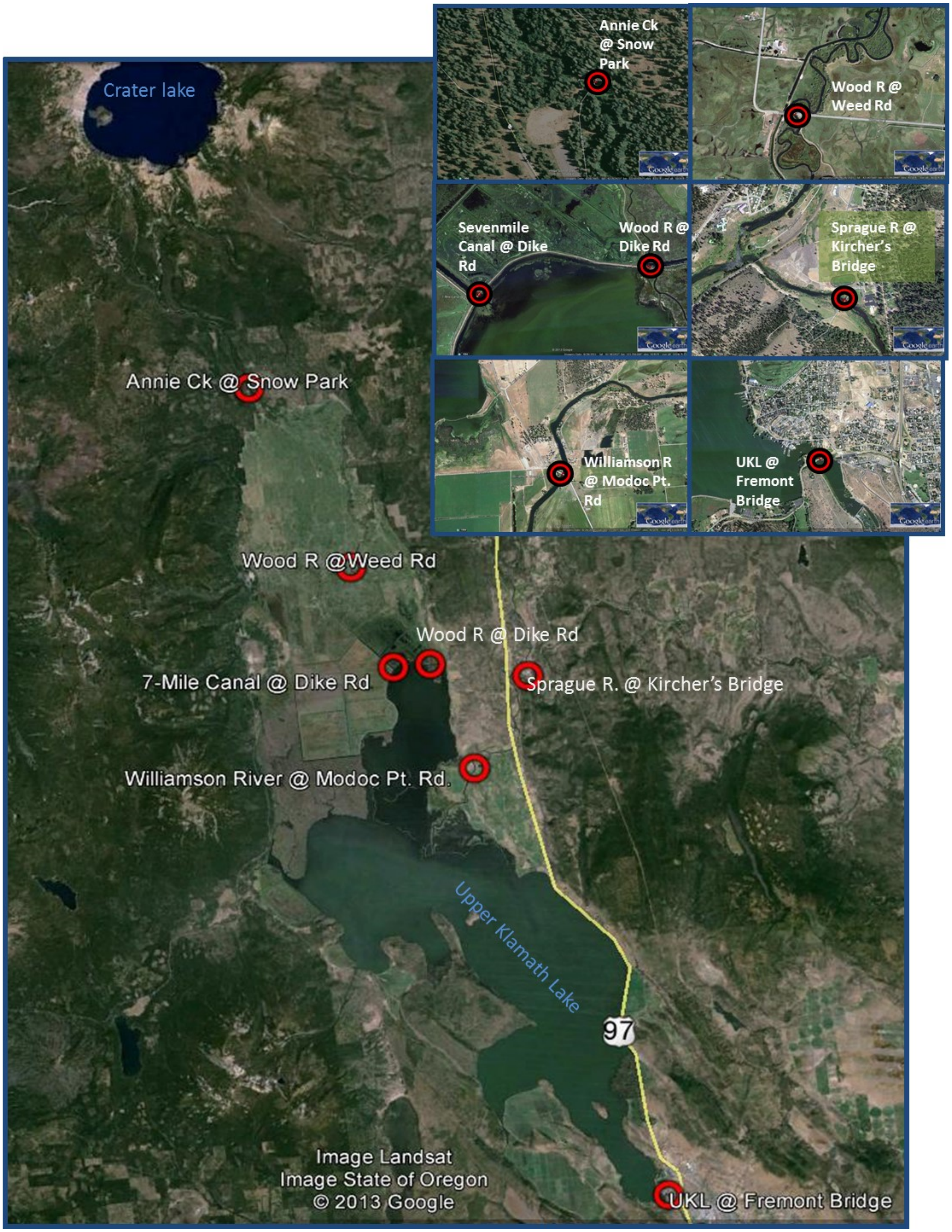

Figure 2. Location of Klamath Tribes Upper Klamath Lake tributary sampling stations.

Daily inflow volume for the Williamson and Sprague Rivers on a given sample date was extracted from continuous daily discharge data obtained from U.S. Geological Survey (USGS) stream-flow discharge stations. These data were obtained online for the Williamson River Gage 11502500[2] and Sprague River Gage 11501000[3]. Daily outflow volume for Upper Klamath Lake (UKL outflow) was computed from the sum of USGS discharge station at Link River 11507500[4] and USBR A-Canal[5] daily discharge measurements:.

For the Wood R. @ Weed and Wood R. @ Dike stations, continuous daily discharge measurements were generated by Graham Matthews and Associates (e.g., see GMA 2004) for 1992-2006, but these data were not available after 2006 for Dike Road. However, instantaneous discharge continued to be measured at Wood R. @ Weed, Wood R. @ Dike, 7-mile canal @ Dike Rd and Annie Cr. @ Snow Park stations by both the Klamath Tribes[6] and GMA (2004a; 2011a). Beginning in 2013, USGS implemented a continuous flow monitoring station at Wood R. @ Dike (USGS 11504115 Wood River Near Klamath Agency, OR[7]). With the exception of late-January and late-April, the Klamath Tribe biweekly instantaneous measurements of discharge generally showed good agreement with the USGS daily values (Figure 3). Flow measurements coinciding with nutrient sample collection dates are shown in Figure 4. Although additional nutrient concentration data were collected by GMA (e.g., 2004b; 2011b) and these data were incorporated into tributary loading calculations for the overall 1991-2010 analysis (Walker et al. 2012), only data collected by the Klamath Tribes are presented in this annual data update report.

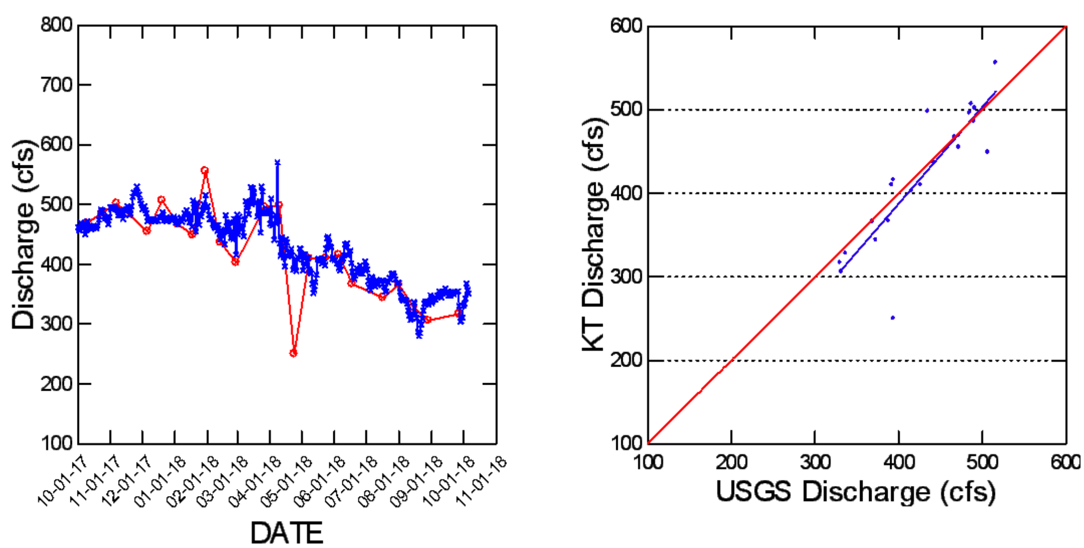

Figure 3. Comparison of USGS and Klamath Tribes discharge measurements at Wood River @ Dike Road. Red line on the scatter plot is the 1:1 line; blue line is the linear regression line.

[2] http://waterdata.usgs.gov/nwis/dv/?site_no=11502500&agency_cd=USGS&referred_module=sw
[3] http://waterdata.usgs.gov/or/nwis/dv/?site_no=11501000&agency_cd=USGS&referred_module=sw).
[4] http://waterdata.usgs.gov/or/nwis/dv/?site_no=11507500&agency_cd=USGS&referred_module=sw
[5] http://www.usbr.gov/mp/kbao/operations/water/korep1.cfm?lakeid=ukldata3
[6] Note that in 2017 logistical issues precluded flow measurements at Annie Creek on several dates, and difficulty obtaining velocity measurements at Sevenmile Canal precluded discharge calculation for most dates (see Figure 4).
[7] http://waterdata.usgs.gov/usa/nwis/uv?11504115

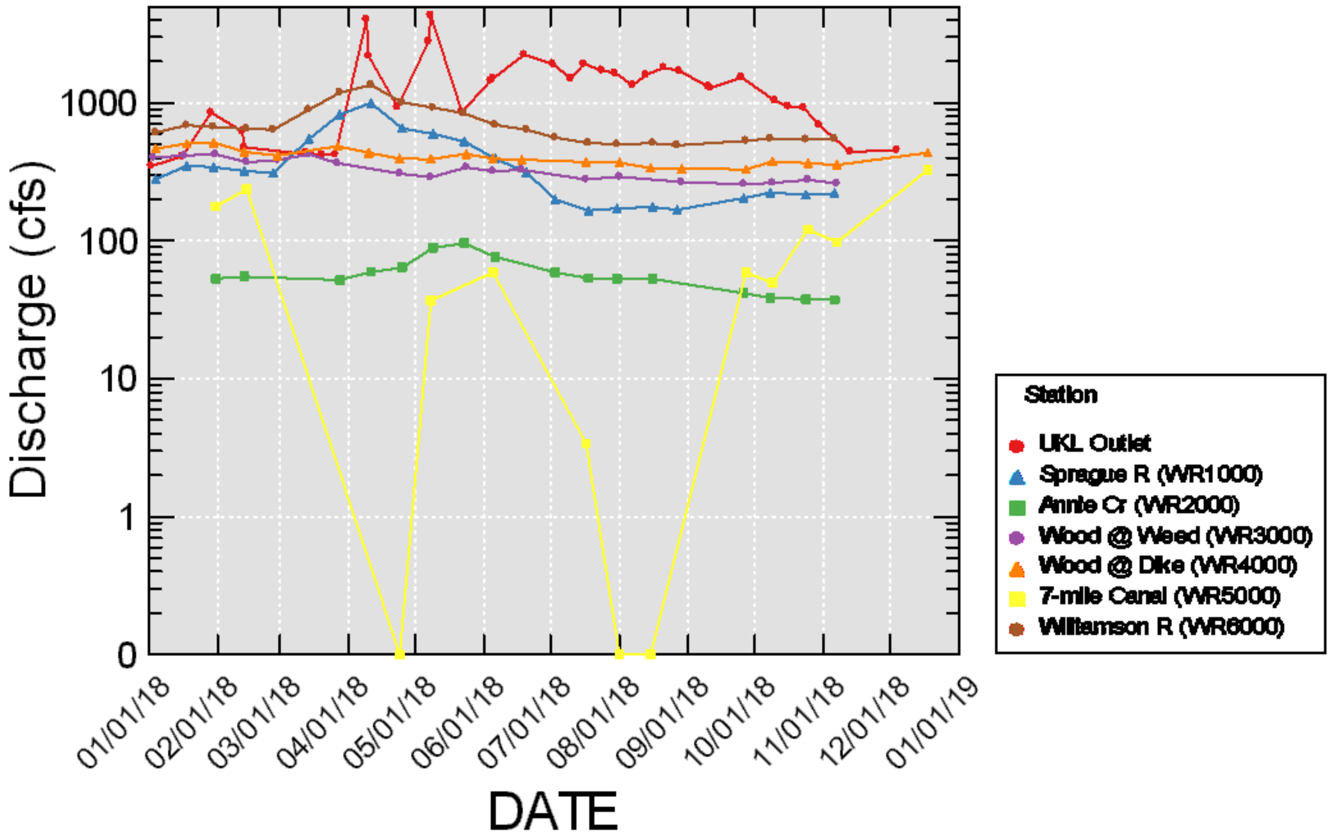

Figure 4. Flow (cfs) measurements coinciding with nutrient sample collection dates, 2018. Flow shown only for dates that nutrient data exist.

The total phosphorus (TP) and total nitrogen (TN) mass (kg/day) for each 2018 sample station and date were computed as the product of daily water volume and measured TP or TN concentration. Nutrient data collection at the UKL outflow station (Upper Klamath Lake @ Fremont Bridge) was discontinued by the Klamath Tribes during 2006-2011 due to funding reductions. Although the UKL sampling station PM is used as a surrogate for the UKL outflow for intervals when data for Upper Klamath Lake @ Fremont Bridge are not available, this caused data gaps for the October-March period during 2006 and 2007.

Beginning in 2008, the U.S. Bureau of Reclamation (USBOR) began monitoring nutrients during the winter months at Link River Dam and near the mouth of the Link River. These data were provided by USBOR along with limited data collected by PacifiCorp during the winter of 2009 and 2010 (Excel spreadsheets: *KRWQ2007-2010KLLD.xls* and *Pacificorpdata2009-2010.xlsx*). Outflow data provided by USBOR for 2011 and 2012 also included additional data for 2009 and 2010 that had not been previously provided (Excel spreadsheets: *KRWQ2007-2012KLLD.xls*[8])

[8] sources: http://www.kbmp.net/collaboration/klamath-hydroelectric-settlement-agreement-monitoring, and spreadsheet "UKL-FreemontBridge-WQ-2012-13-BOR.xlsx" provided by Rick Carlson, Physical Scientist, Bureau of Reclamation Klamath Basin Area Office, racarlson@usbr.gov. The latter file includes additional data collected at Fremont Bridge as part of a 3-year nutrient budget study of the Klamath Project.

In addition, the Klamath Tribes again began sampling Upper Klamath Lake @ Fremont Bridge in 2012. Additional nutrient data were incorporated from data provided by both USGS and USBR in 2013- 2018 leading to greater sampling frequency at this station. Only Klamath Tribes data for 2018 are included in this data summary report. Station names for the various outflow stations were standardized by renaming them UKL-Outlet. When stations were sampled on the same date a mean was taken. Loading graphs and summaries are computed based on the October-September hydrologic water year (denoted HY in below plots).

Additional tributary sampling on the Sevenmile system that took place in 2016 and 2017 did not occur in 2018. The intent of the additional sampling was to determine longitudinal nutrient concentrations and loads between Sevenmile Creek at Sevenmile Rd. and Sevenmile Creek just below the confluence of West Canal. See Kann 2017 for a write-up of the 2016 results.

RESULTS/DISCUSSION

Nutrient Concentration

The 2018 among-station nutrient concentration pattern was generally similar to the 1991-2017 sampling period (Figure 5). For the inflow stations, total P and PO4-P concentration tended to be toward the lower end of the 1991-2017 distribution at all stations except Sevenmile; total N tended to be lower for all stations; NH4-N was intermediate at most stations but lower for the Williamson and Sprague river stations. Comparisons of inflow ammonia and nitrate-nitrite between 2018 and the long-term distribution are confounded by levels near method detection limits and by a change in detection limits when the SRWQL began processing samples in 2008[9]. However, Outflow, Williamson River, and Sevenmile values for these parameters are affected to a lesser degree because values tend to be above method detection limits. Although beyond the scope of the annual data report, long-term comparisons can be facilitated by constraining values to be no less than the higher detection limits used prior to 2008.

With the exception of Seven Mile Canal, the UKL outlet (KL0001) tended to be higher than inflow stations for TP, lower for PO4, and substantially higher for TN and ammonia (NH4-N). Long-term upper quartile values for NO3-NO2-N were also higher at the UKL Outlet station than for inflow stations, and were substantially higher in 2018. Outflow NO3-NO2-N was also notably higher than inflow stations during 2012-2018. Similar to some previous years (e.g., 2010 and 2013), when NH4-N at the UKL Outlet was notably higher than Seven Mile Canal, the pattern in 2018 also showed higher upper quartile (and median) values at UKL Outlet (Figure 5). In contrast, in 2009, 2011, and 2014, the UKL Outlet NH4-N values were more similar to Sevenmile Canal. The 2018 UKL-Outflow TP and NH4-N distributions were comparable to the long-term distributions, while those for TN and NO3-NO2-N were somewhat higher.

Higher Outflow nitrate values also occurred during 2013-2017 and may be due to the increased sampling frequency during winter months when NO3-NO2-N is usually higher overall than other seasons. This is somewhat confirmed by the comparison of seasonal June-October distributions, where the 2018 NO3-NO2-N distribution is similar to the long-term distribution when winter

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[9] Aquatic Research Inc. indicated a reporting limit of 10 µg/L for NH4 and NO23; the SRWQL utilizes a reporting limit of 6 µg/L for NH4 and 8 µg/L for NO23.

months are excluded (Appendix II). In general, 2018 nutrient concentrations for the inflow stations were also lower relative to the long-term distributions for the June-October period (Appendix II).

Similar to previous years, time series plots of the 2018 concentration data show Seven Mile Canal (WR5000) to have among the highest inflow values for TP, PO_4, PP (particulate P which equals TP minus PO_4), and TN (Figure 6). Although in previous years values at Sevenmile Canal tended to be higher during the summer irrigation season (Kann 2017), as in 2017, values in 2018 peaked during the spring runoff period (Figure 6)[10]. TP, PP, and TN at the UKL Outflow station were generally low in the spring and then increased substantially relative to the inflow stations during the summer algal growing season (primarily June-August).

Ammonia (NH_4-N) and nitrate-nitrite (NO_3-NO_2-N) at the Outflow station increased seasonally (during the fall and winter months) until they started to decline during the late-winter (Figure 7). Outflow NH4-N and NO3-NO2-N patterns are tied to algal uptake and nitrogen fixation dynamics in UKL, as well as ammonification/nitrification (see Kann 2016). In general, ammonia in Sevenmile Cr. tends to be among the highest relative to other inflow stations, especially during the irrigation season.

Dissolved silica concentration at the Wood River and Annie Cr. Stations tended to be higher than the Sevenmile, Sprague, and Williamson stations during the spring; the Sprague River tended to show the lowest silica concentrations, followed by 7-Mile and the Williamson River (Figure 7). The UKL Outflow station showed a clear seasonal pattern where silica values were depressed during the spring and early summer before increasing sharply in June to higher levels that remain high through the winter (Figure 7). The spring silica depression at the Outflow station coincides with diatom blooms occurring in Upper Klamath Lake, summer increases are likely due to decline of diatoms as well as release of sediment P-bound silica due to high summer pH levels.

[10] This trend may be due to reduced irrigation return flows into Sevenmile Canal due to Klamath Tribal water calls in 2017 and 2018

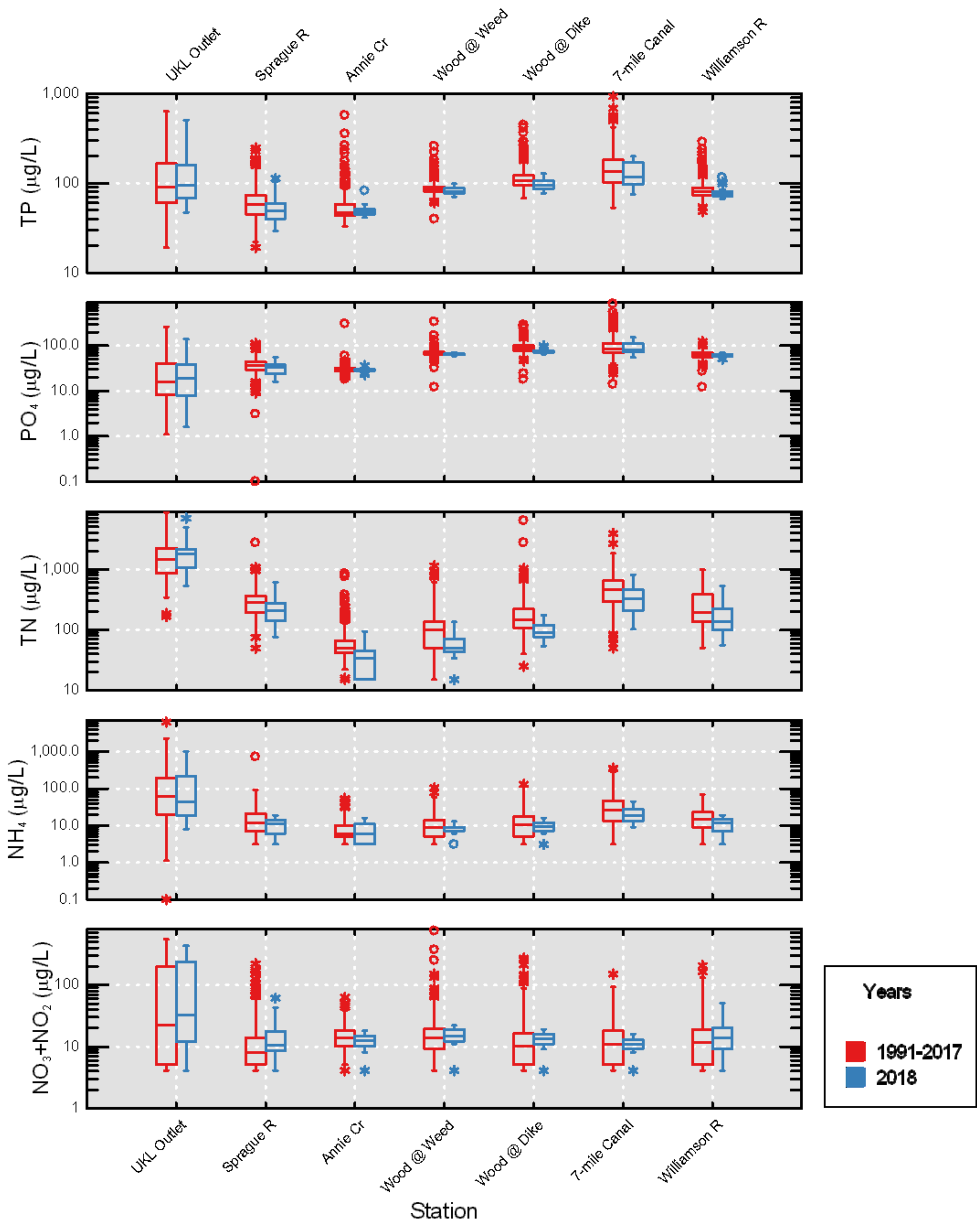

Figure 5. Station distributions of TP, SRP, TN, NH4-N, and NO3+ NO2-N concentration (µg/L) compared between 1991-2017 (red) and 2018 (blue).

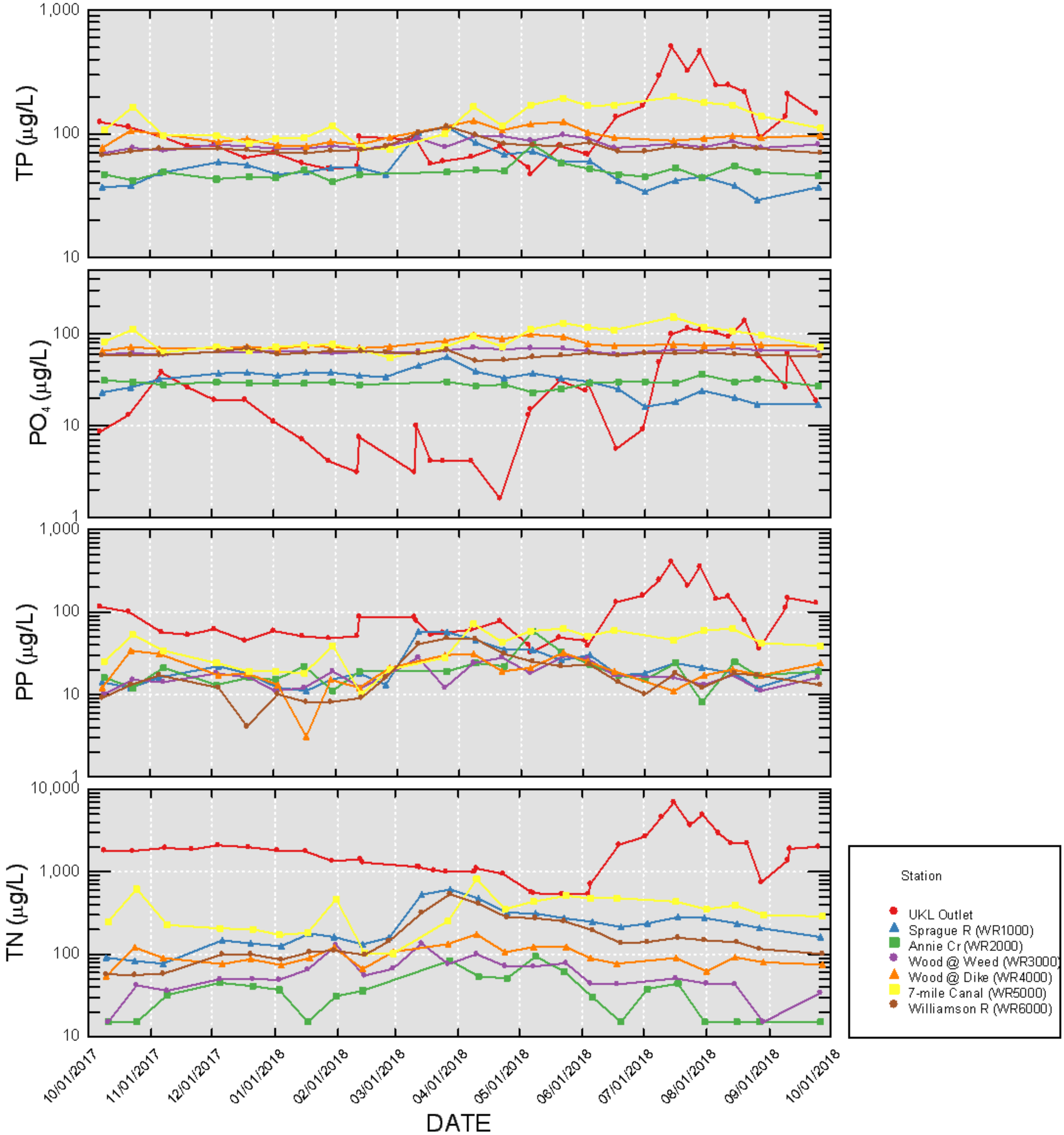

Figure 6. Time-series plot of TP, SRP, PP and TN concentrations for Upper Klamath Lake tributaries and outflow, HY 2018.

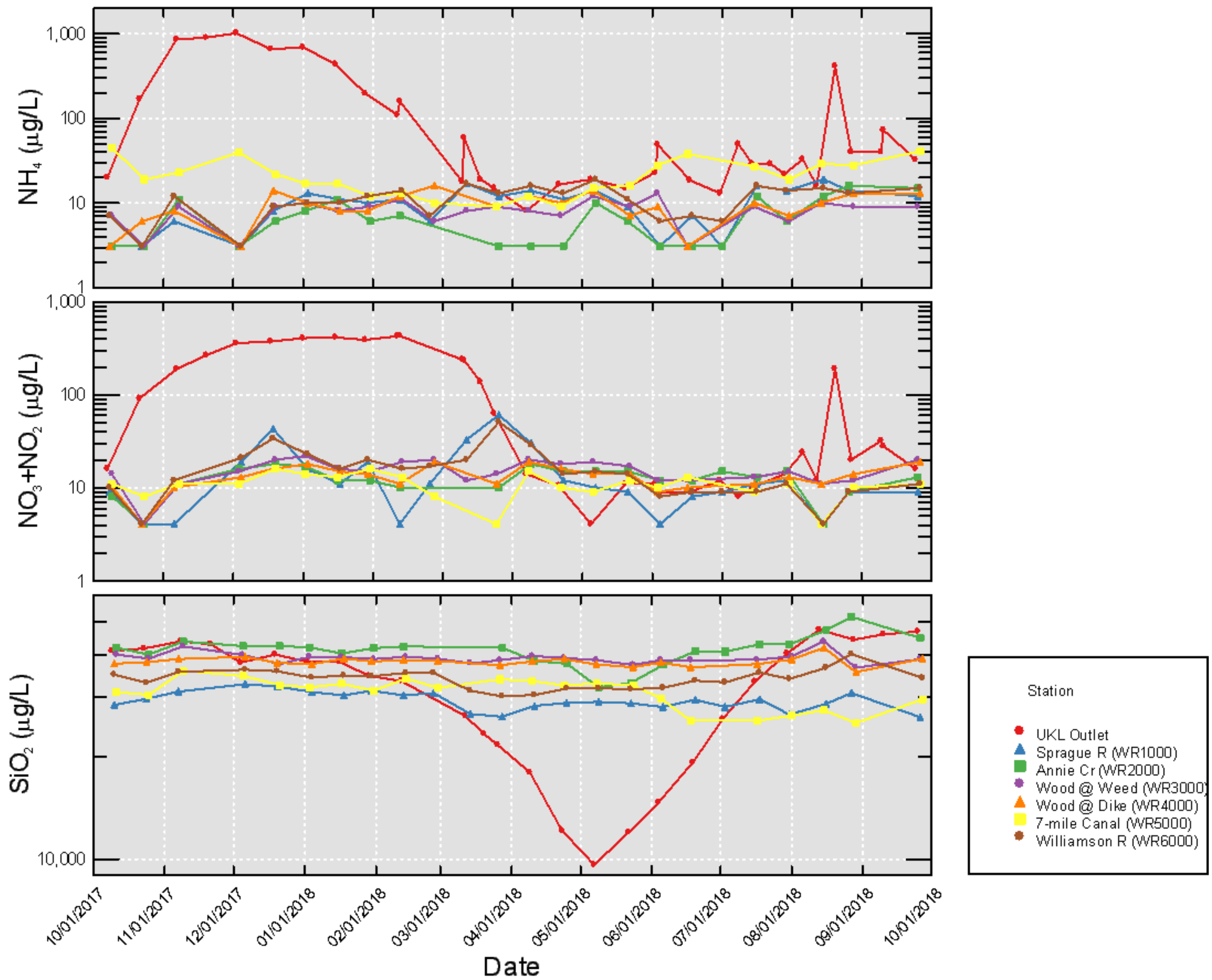

Figure 7. Time-series plot of NH_4-N, NO_3+ NO_2-N and SiO_2 concentrations for Upper Klamath Lake tributaries and outflow, HY 2018.

The TN:TP ratio at the UKL Outflow station was relatively high (TN:TP > ~15) during the late fall and early winter (2014-2018), and similar to earlier years (see Kann 2016), ratios then declined but remained higher than tributary stations through the season (Figure 8). The lowest values of the year (~7) occurred during late-May and June. The overall pattern appears similar to earlier years when the TN:TP ratio at UKL Outflow was higher (TN:TP ≅ 10) than tributary stations in April, declined during May and June, increased during early summer UKL bloom development, and declined through the bloom decline period before increasing again in August (Figure 8). In 2018 the TIN:SRP ratio in the Outflow decreased from peak values of ~200 (they were ~600 in 2017) during winter-spring, to ~5-20 in mid-spring, and then declined to seasonal low values in in late-May (~1)and again mid-July to mid-August (~0.2), before increasing again in September (~10) (Figure 8). Both TN:TP and the majority of TIN:SRP values in the inflow tributary stations indicate nitrogen limiting conditions (<10 for TN:TP and <1 for TIN:SRP) that would tend to promote nitrogen-fixing algae such as the *Aphanizomenon* prevalent in UKL. The Wood River and Sevenmile in particular showed very low TIN:SRP ratios (<0.3).

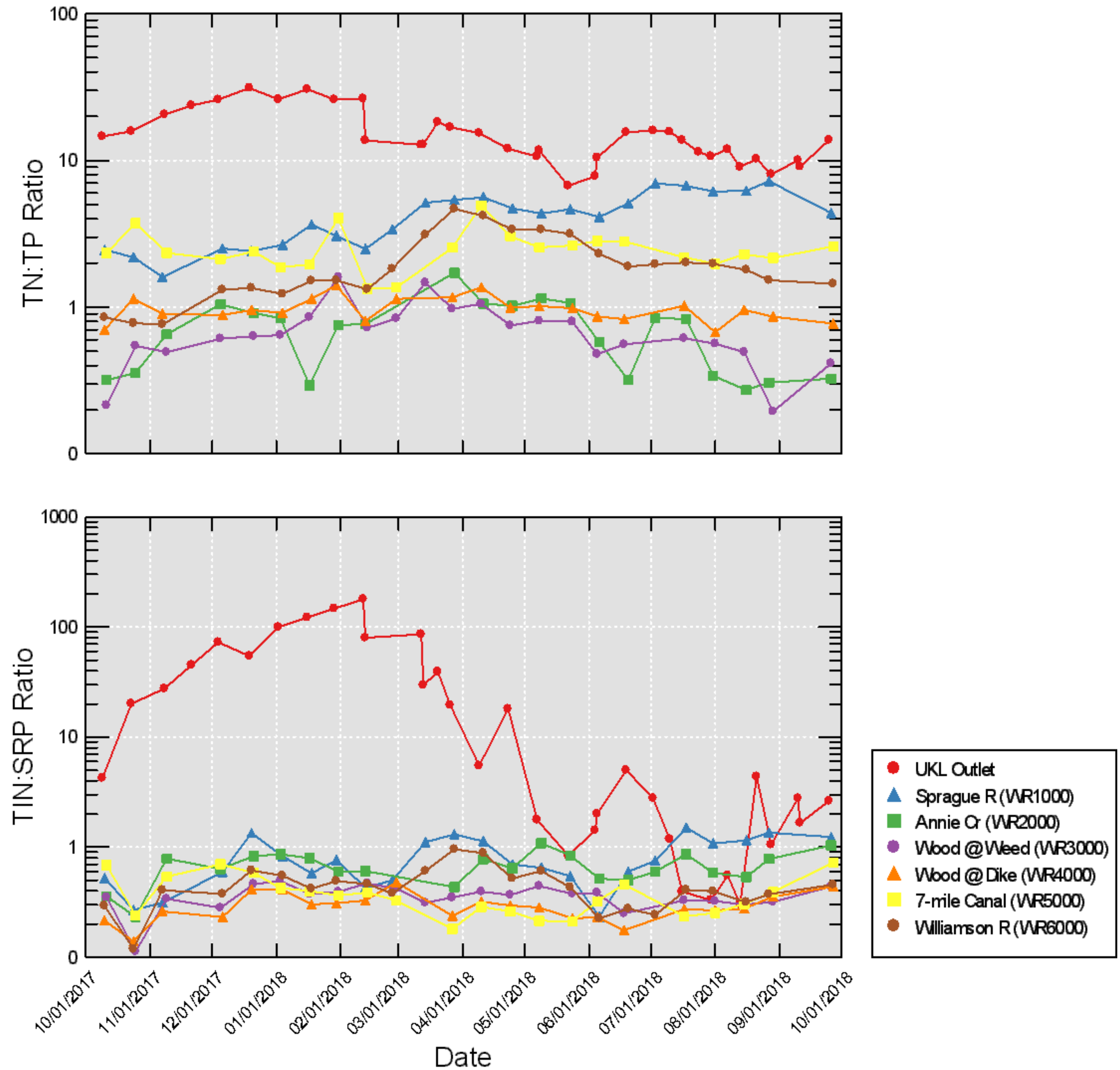

Figure 8. Total nitrogen to total phosphorus (TN:TP) and total inorganic nitrogen (NOx-N+NH_4-N) to PO_4 (TIN:SRP) ratios in Upper Klamath Lake tributaries and outflow stations, HY 2018.

Time-series plots of these ratio data comparing the Williamson River and UKL Outflow (summarized for the April-October period when data for both stations were consistently available) show that both ratios (TP:TN and TIN:SRP) were always higher leaving UKL than they were in the Williamson River inflow (Figure 9). Much of this increase is likely due to increases in UKL nitrogen due to both nitrogen-fixation by blue-green algae (particularly the dominant *Aphanizomenon flos-aquae*) and sediment regeneration of ammonia to the water column (although the ultimate source of the sediment nitrogen is also derived from settled algal biomass). These higher outflow ratios relative to inflow ratios occur despite additional internal loading or sediment recycling of phosphorus (Walker et al. 2012), which would tend to drive ratios downward. There is also indication of cyclical sub-decadal trends, particularly for the TIN:SRP ratio, over the 1991-2018 period. Further analysis is required to explore these apparent trends.

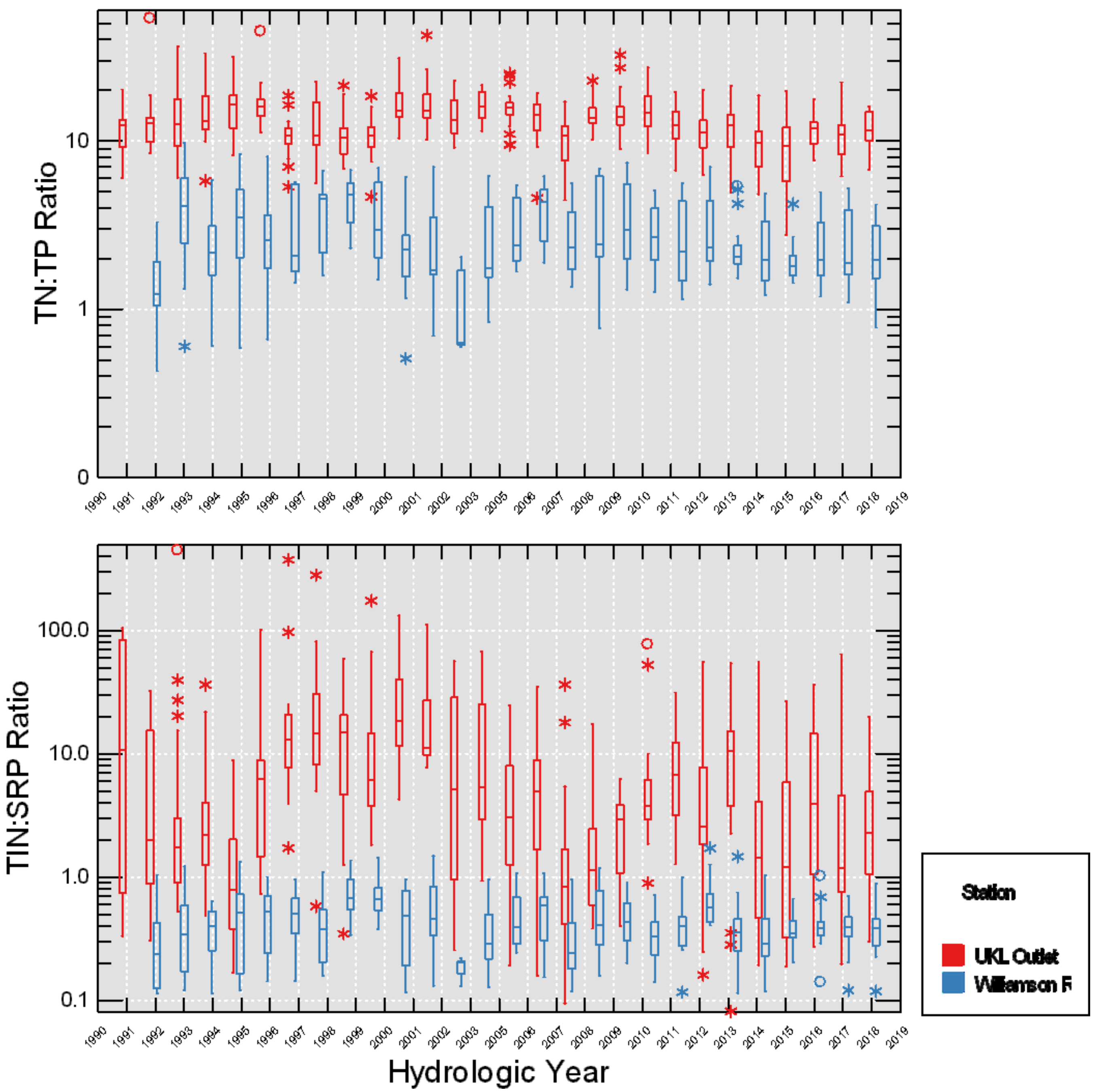

Figure 9. Total nitrogen to total phosphorus (TN:TP) and total inorganic nitrogen (NOx-N+NH_4-N) to PO_4 (TIN:SRP) ratios in the Williamson River and UKL outflow stations, April-October: 1991-2018.

TP and TN Loading

2018 Seasonal Pattern

Similar to previous years the 2018 seasonal TP and TN tributary loading pattern showed several peaks in the winter and spring, with loading generally increasing during the March-May period coinciding with peak discharge (Figure 4; Figure 10). This was in contrast to 2014 and 2015 when loading was relatively constant during that period[11]. The winter-spring increase in TP load was more evident for the Sprague and Williamson Rivers than for the Wood River system. Missing flows for Sevenmile precluded delineating 2018 seasonal loading trends. Williamson and Sprague loading then declined through mid-July before leveling off through the late-summer period. UKL outflow loads of TN and TP declined in late-fall before increasing again late-spring, with a secondary and larger increase beginning in June is tied to internal nutrient recycling from sediments and nitrogen fixation in UKL (e.g., see Kann 1998; Kann and Walker 1999; Walker et al. 2012). Peak outflow load occurred in mid-July in 2018. Outflow TP loads were similar to or lower than Williamson, Sprague, and Wood River loading during the late-winter to early-spring spring period, but were then higher through the remainder of the year. With the exception of early-spring, outflow TN loads remained higher than all other stations over this same period (Figure 10).

2018 Station Patterns

The 2018 nutrient loading pattern among stations was similar to that of the 1991-2017 sampling period (Figure 11). Also, as indicated above, TP and TN outflow loads tended to be higher than any individual inflow tributary loads during both 2018and for the overall time period (1991-2017). In contrast to the previous four years (2013-2016), when outflow TP and TN loads were lower overall than they were for the previous long-term period, 2017 outflow loads were higher than the long term 1991-2016 distribution (a similar trend occurred in 2010) (see Kann 2018). In 2018 outflow TP and TN loads were again slightly lower than the long-term distribution. Since comparisons can be somewhat confounded by the lack of consistent winter data for the outflow during earlier years, a comparison of the core irrigation and summer algal growing season when measurements are consistent indicates that 2018 outflow loads were similar to the long term distribution (Appendix II). As noted above, high UKL outlet loads reflect sediment regeneration and nitrogen fixation processes taking place in UKL. The TP and TN loads were lower for all inflow stations relative to the outflow station.

Of the inflow tributaries, the Williamson River (WR6000) showed highest overall loading, followed by the Wood River, with the 2018 TP loading distributions lower for the Williamson and Sprague Rivers but somewhat higher for the Wood River (Figure 11). Sprague River TN load was more similar to the Williamson River TN load than it was for TP load (which was noticeably lower in the Sprague when compared to the Williamson), indicating that the Sprague River is contributing proportionally more nitrogen to the overall load. Wood River 2018 TP load was somewhat higher when compared to the long-term distribution, but Wood River TN was lower (Figure 11). TP and TN loading patterns in both the Williamson and Sprague Rivers tended to follow the general pattern in discharge (although loading appears to be more closely linked to discharge in the Sprague River than in the Williamson River), and as noted above for

[11] 2014 was among the driest years on record with low precipitation and snowpack, and 2015 was also a dry year.

Outflow concentration, there is indication of cyclical trending over the period of record (Figure 12). Flows and loads in 2018 were noticeably lower than the previous 2 years for both the Sprague and Williamson Rivers, and were more similar to the drought years of 2013-2015 (Figure 12). A low frequency of discharge measurements at Annie Creek at Snow Park and Sevenmile Canal in 2018 precluded long-term comparisons.

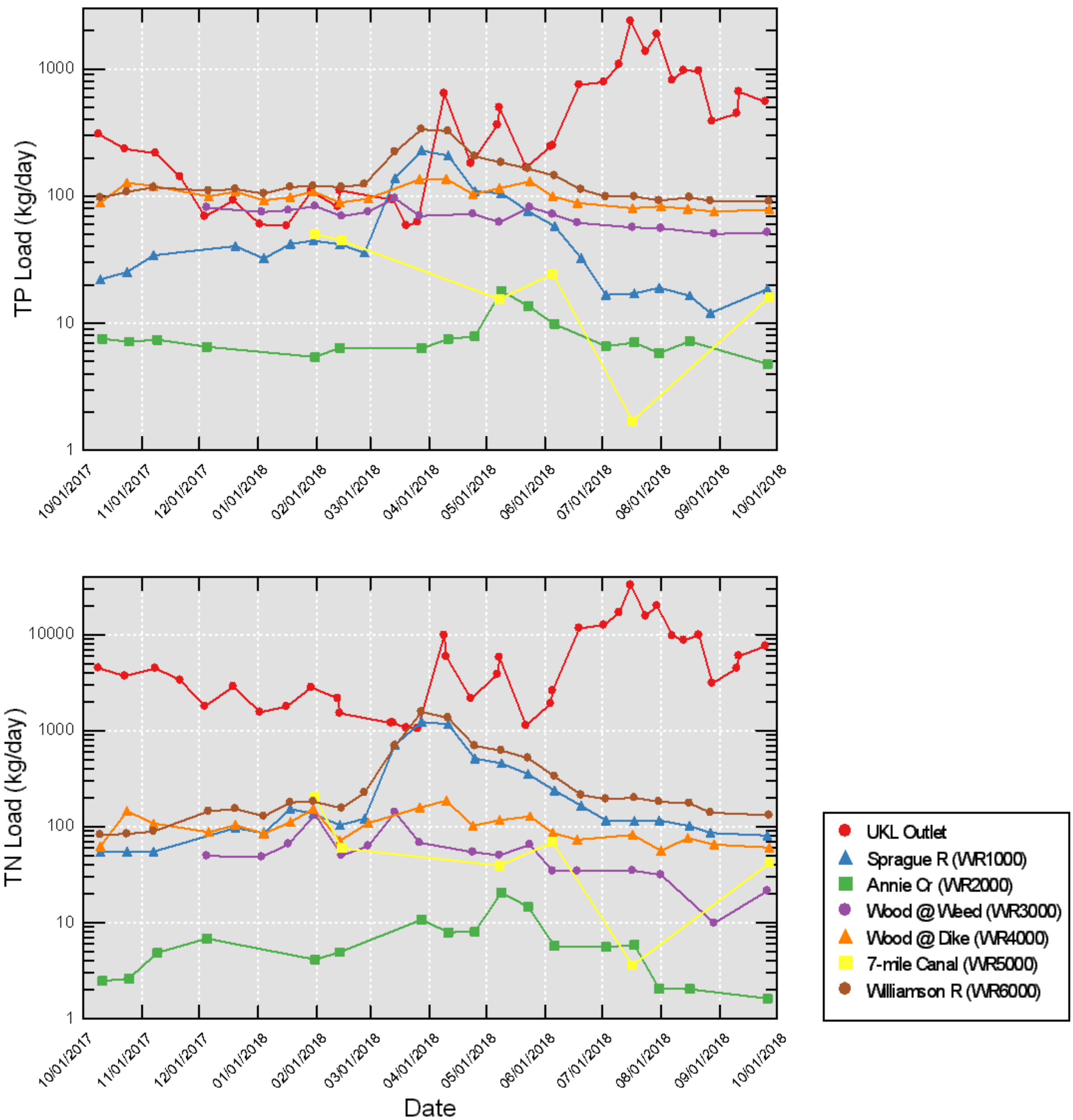

Figure 10. Seasonal TP and TN loading trends by station, HY 2018.

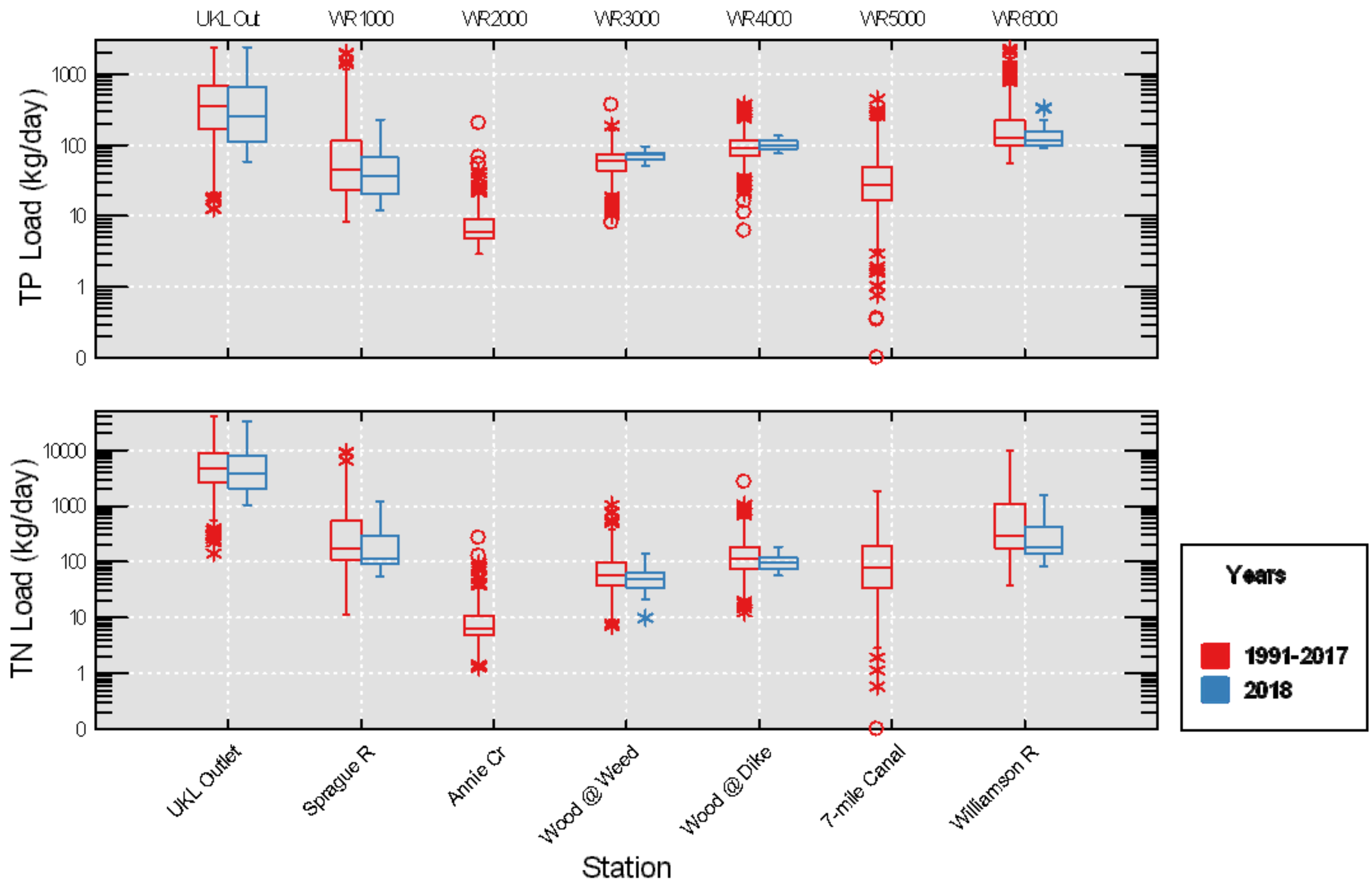

Figure 11. **Station distributions of TP and TN loading compared between 1991-2017 (red) and 2018 (blue). Note: for the outflow station KL0001 there are no samples from January to mid-April in HY2006, and for HY2007-2009 and HY2011 samples are missing between November and mid-April.**

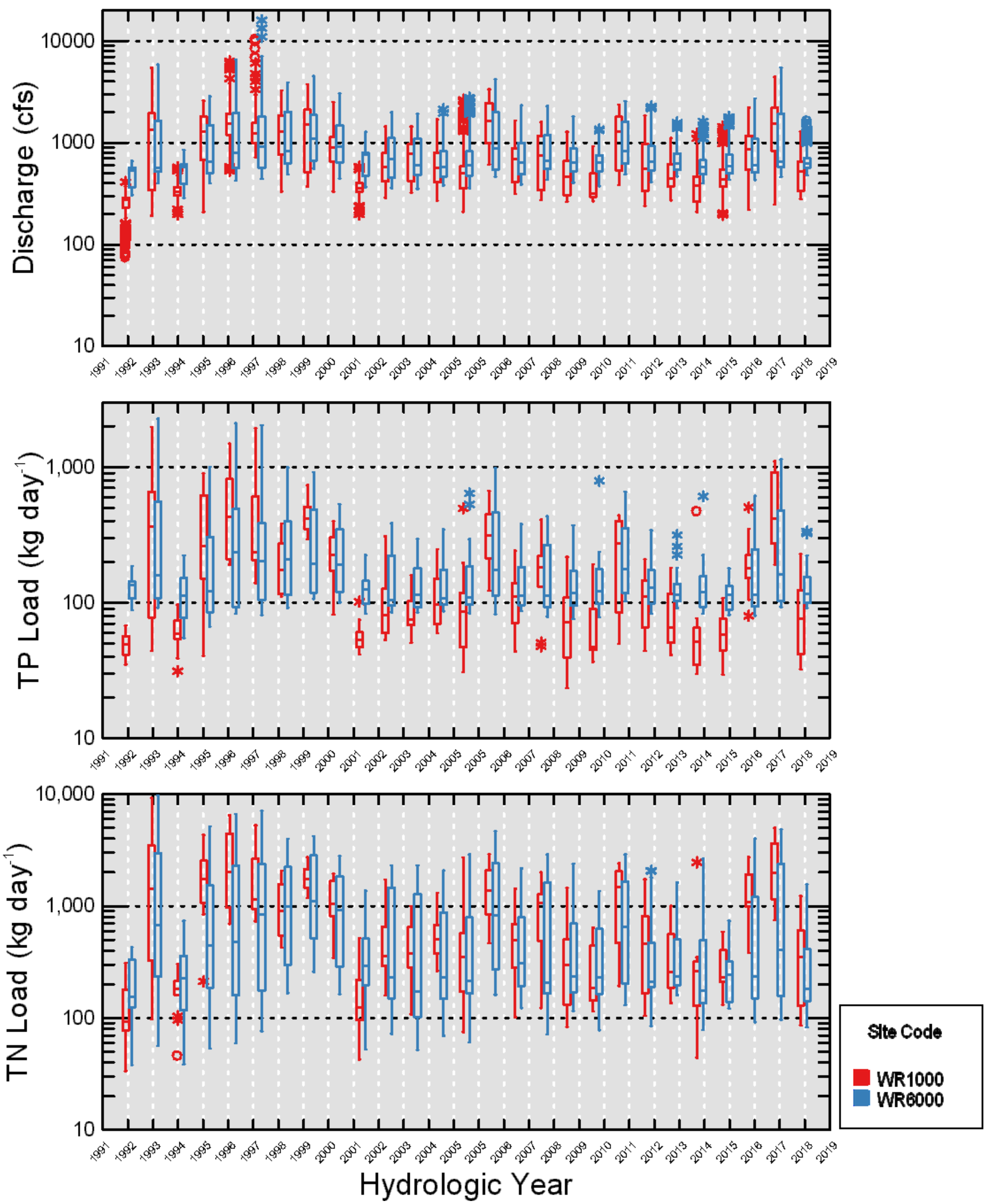

Figure 12. Distribution of Williamson River (WR6000) and Sprague River (WR1000) daily discharge (top panel), TP load (middle panel), and TN load (bottom panel) for the January-May inflow period, 1992-2018.

Sonde, TSS and Turbidity

Seasonal and spatial patterns in temperature, specific conductance, dissolved oxygen, and pH are shown in Figure 13. Peak temperatures generally occurred in June for the Wood and Williamson River stations, and July for Annie Creek, Sprague, and Sevenmile stations. The Annie Cr. and Wood River stations showed cooler overall temperatures than the Sevenmile, Sprague and Williamson stations. Among the inflows, dissolved oxygen decreased seasonally at several stations, but was most apparent at the Sevenmile Canal, Wood Dike, and Williamson/Sprague River stations. Aside from UKL Outlet, which is controlled by productivity dynamics in Upper Klamath Lake, pH was showed moderate fluctuations over the season (generally ranging between 7 and 8.5), but peaked at values ~9.0 during mid-summer in the Williamson and Sprague Rivers (likely tied to attached algae and macrophyte productivity). Specific Conductance slightly increased during spring runoff for Sevenmile and was noticeably lower for Annie Creek.

TSS concentrations and loads in the winter and spring were highest for the Sprague and Williamson stations in 2018 (Figure 14). Annie Creek TSS concentrations tended to be higher than other stations from May-July. Turbidity also tended to be higher in Annie Creek during late-May and early-summer, and again the Sprague and Williamson stations showed highest seasonal turbidity concentrations in the winter and spring months (Figure 14). Peak snowmelt in May and June are likely driving the Annie Creek increases in TSS and Turbidity, especially given the loose pumice material that much of the Annie Creek streambed is composed of. The Wood River tended to show higher TSS loading than other stations during the summer months.

Inter-annual Patterns, 1991-2018

Although it is beyond the scope of this 2018 data summary report to analyze the inter-annual trends in detail, 1991-2018 comparisons for all sampling stations for three periods (all dates, the June-September period, and the Jan-May period) are shown for reference in Appendix I. Briefly, in 2018 Outflow TP loading for all dates was lower than 2017 but similar to 2013-2015, the June-September inter-quartile range for Outflow TP load showed a similar trend, and the 2017 winter distribution was among the lowest of the period of record (Appendix I Figure 1). A similar pattern to TP load was observed for TN load over all dates and in winter, but June to September TN load was not noticeably different than the previous 7-year period and also showed an elevated lower quartile (Appendix I Figure 8). However, the pattern of lower overall TN loading in more recent years (2010 to 2018) compared to 1991-2009 continues to be observed. Note that for the UKL outlet station, the June-September period provides the most consistent inter-annual comparison due to changes in the winter and early spring sampling frequency over the period of record. While the distribution of overall loads (and concentrations) can be similar within a given time period among years, there is considerable variability in monthly timing among years. June-September TP and TN loading distributions for the Sprague River in 2018 were lower than 2016 and 2017, but were similar to 2013-2015 (Appendix I Figures 2 and 9). The pattern for Williamson River TP and TN loading distributions was similar to that of the

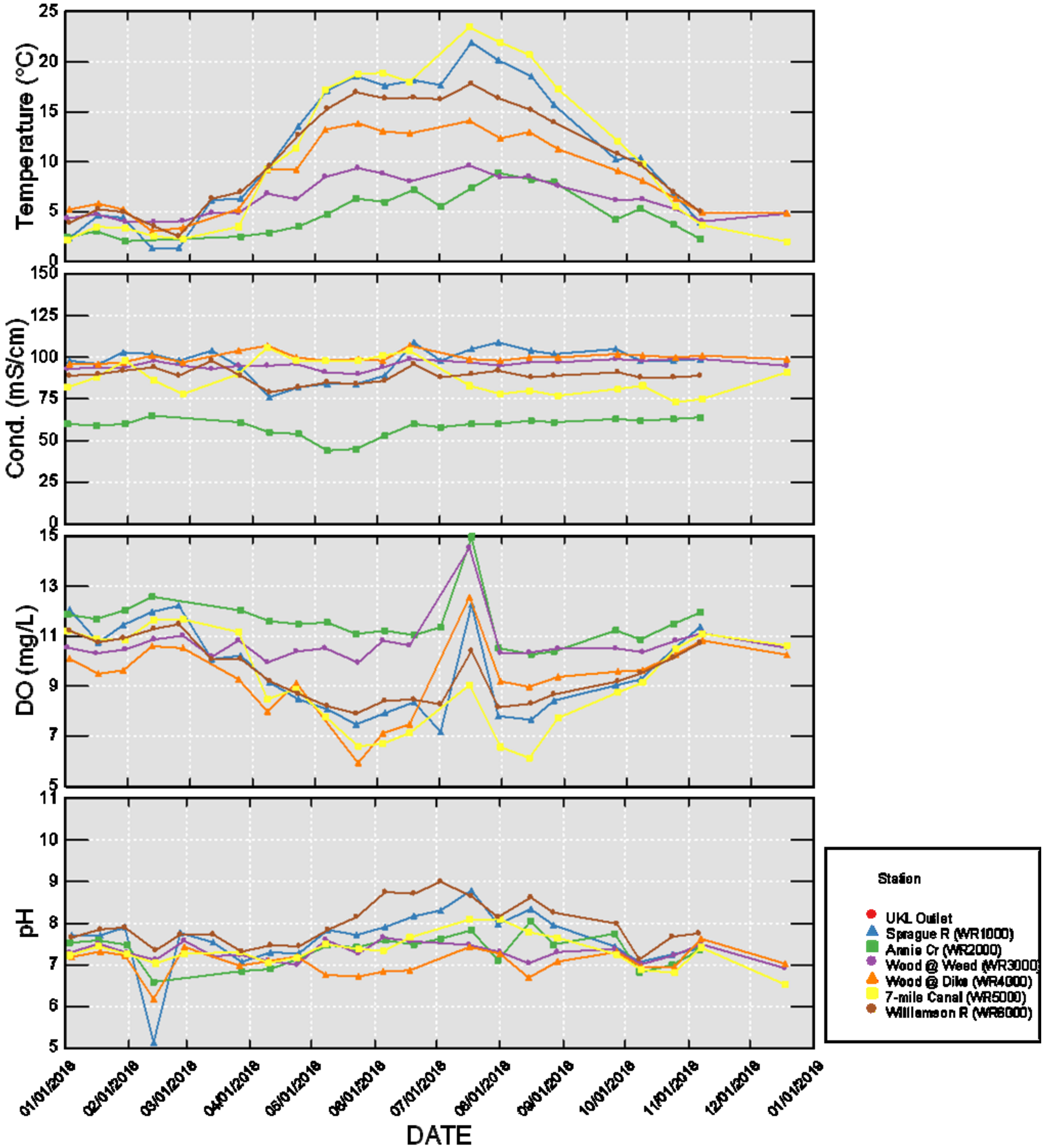

Figure 13. Time series plot of YSI multi-parameter probe water quality measurements for Upper Klamath Lake tributaries and outflow, 2018.

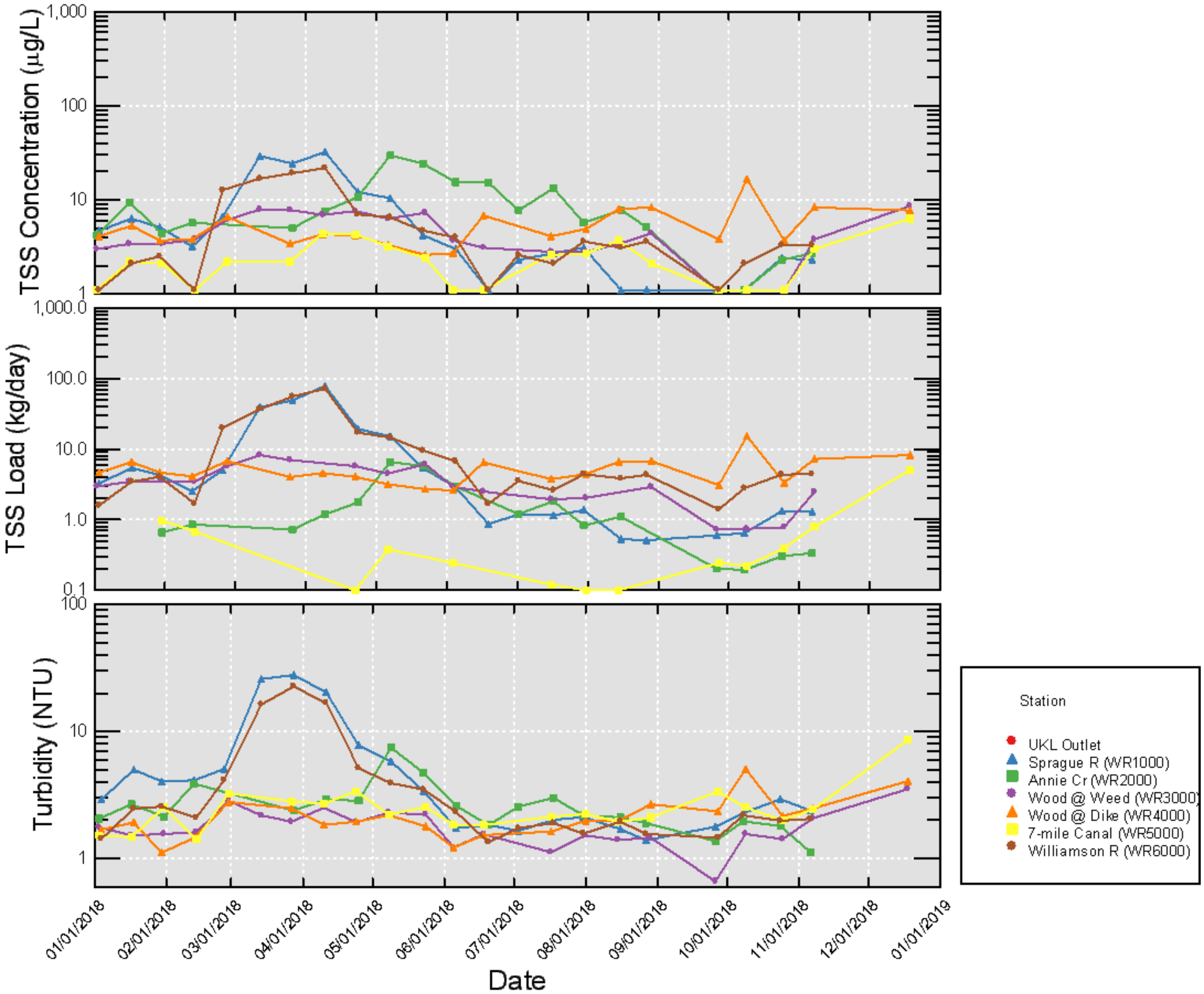

Figure 14. Time series plot of TSS Concentration, load and Turbidity for Upper Klamath Lake tributaries and outflow, 2018.

Sprague River (Appendix I Figures 7 and 14). The Wood River TP loading distribution for 2018 tended to be intermediate relative to previous years. (Appendix I Figures 4 and 5). TN loading distributions for the Wood River stations during 2018 tended to be in the lower range relative to previous years (Appendix I Figures 11 and 12). Too few measurements were available for Sevenmile Canal to evaluate trends for 2018 (Appendix I Figures 3, 10, 6, and 13).

Although the analyses described above provide a relative comparison among years, inter-annual comparisons of nutrient concentration and loading at the various UKL inflow stations requires refined estimation of loading using multiple regression based-algorithms that represent concentration variations associated with flow (i.e., magnitude as well as ascending/descending limb of hydrograph), season (i.e., Julian day), and year (e.g., see Walker et al. 2012; 2015). A comprehensive analysis of time-series trends as well as hydrologic and nutrient budgets based on estimated daily data were completed for UKL through 2010 (Walker et al. 2012). Future comprehensive analyses should be undertaken for additional data collected between 2011-2018.

SUMMARY

With the addition of 2018 data, the UKL tributary nutrient and loading database now includes 28 years of data and includes the years 1991-2018. As with the UKL water quality database, such a long-term monitoring program is essential for assessing change relative to management programs, as well as for understanding inter-annual dynamics. Also similar to recommendations for the UKL water quality database, continued monitoring is recommended to accommodate the restoration time-frame for Klamath Basin activities and to increase statistical power (sample size) for inter-variable analyses. While this data summary report is intended to provide an update of the long-term data base with 2017 tributary and outflow data, Walker et al. (2012) provide a more detailed and comprehensive analysis of the long-term UKL tributary database including statistical trend analyses and construction of hydrologic and nutrient budgets for UKL using the 1991-2010 dataset (Walker et al. 2012). A similar comprehensive treatment of the data is recommended at five year intervals, which is now at 8 years with the addition of 2018 data.

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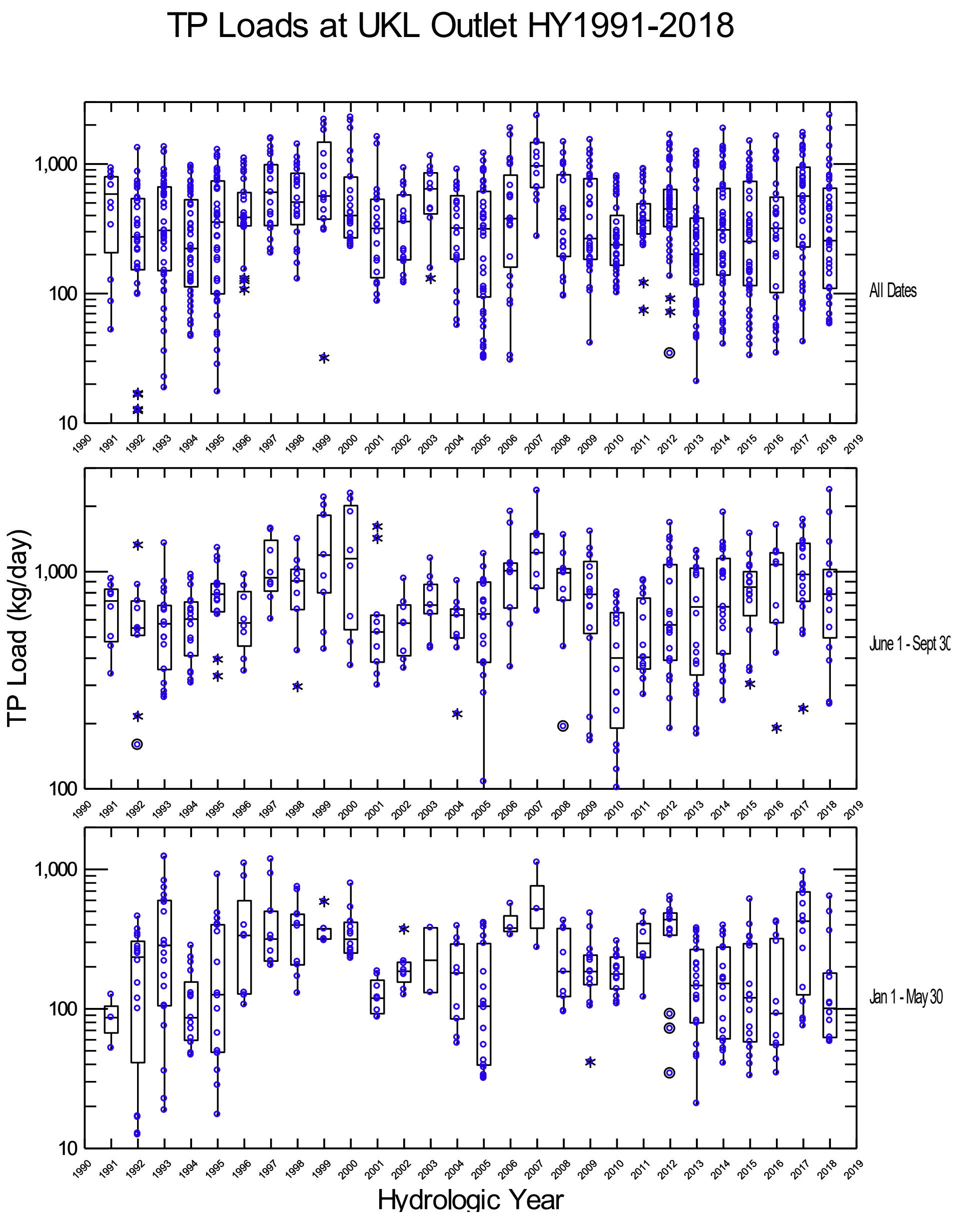
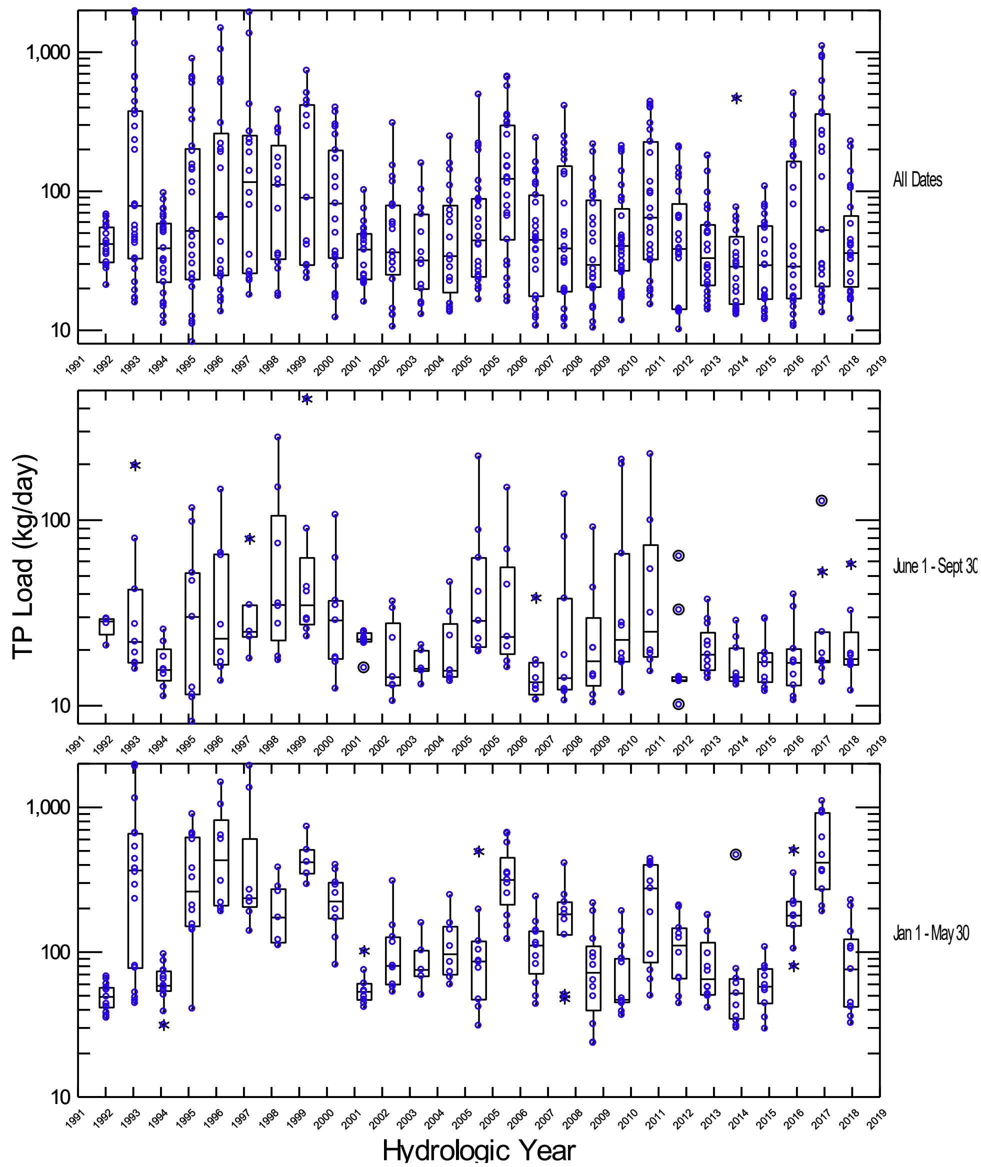
APPENDIX I: Annual and seasonal distributions of TP and TN loading of Upper Klamath Lake Tributaries and outflow.

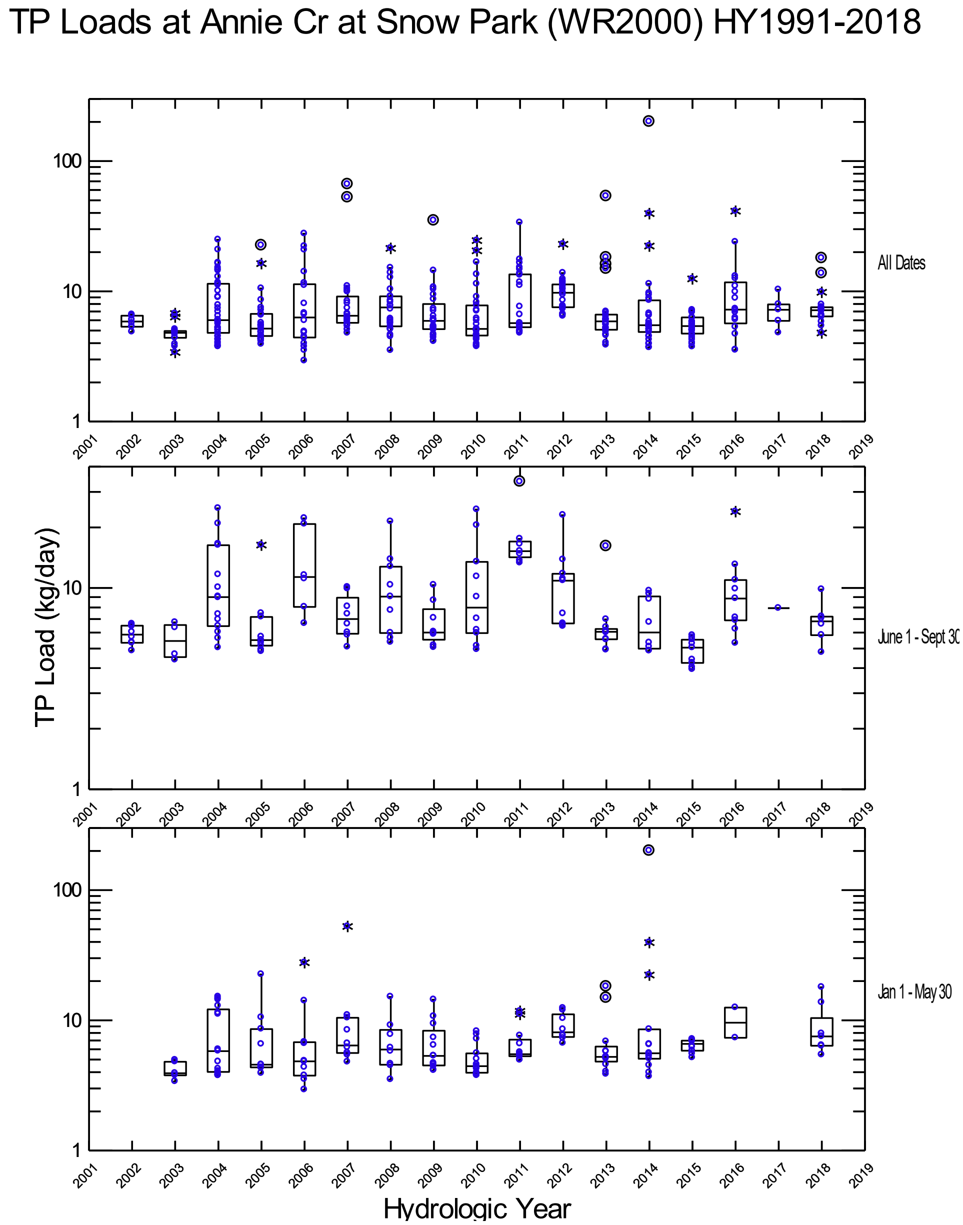


Appendix I Figure 1

TP Loads at Sprague R. @ Kirchers Bridge (W1000) HY1992-2018

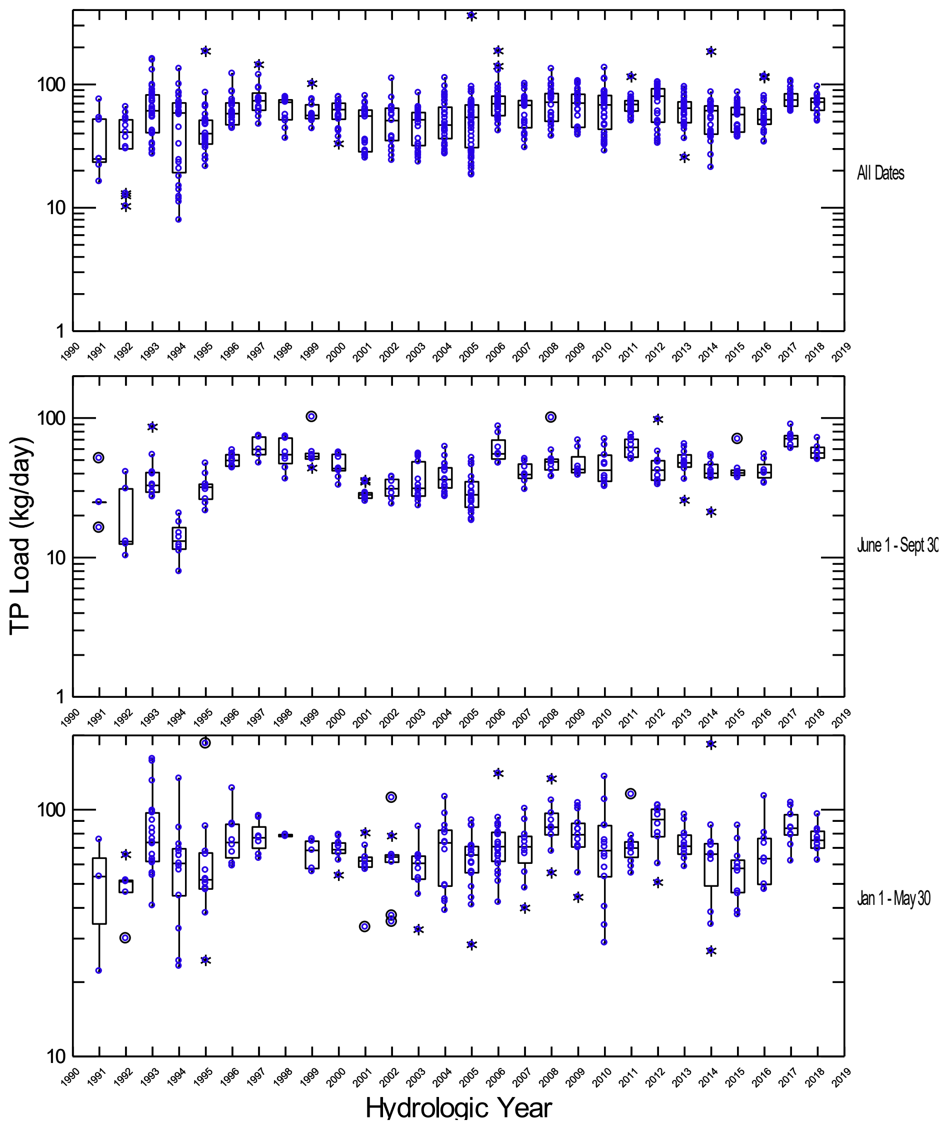


Appendix I Figure 2

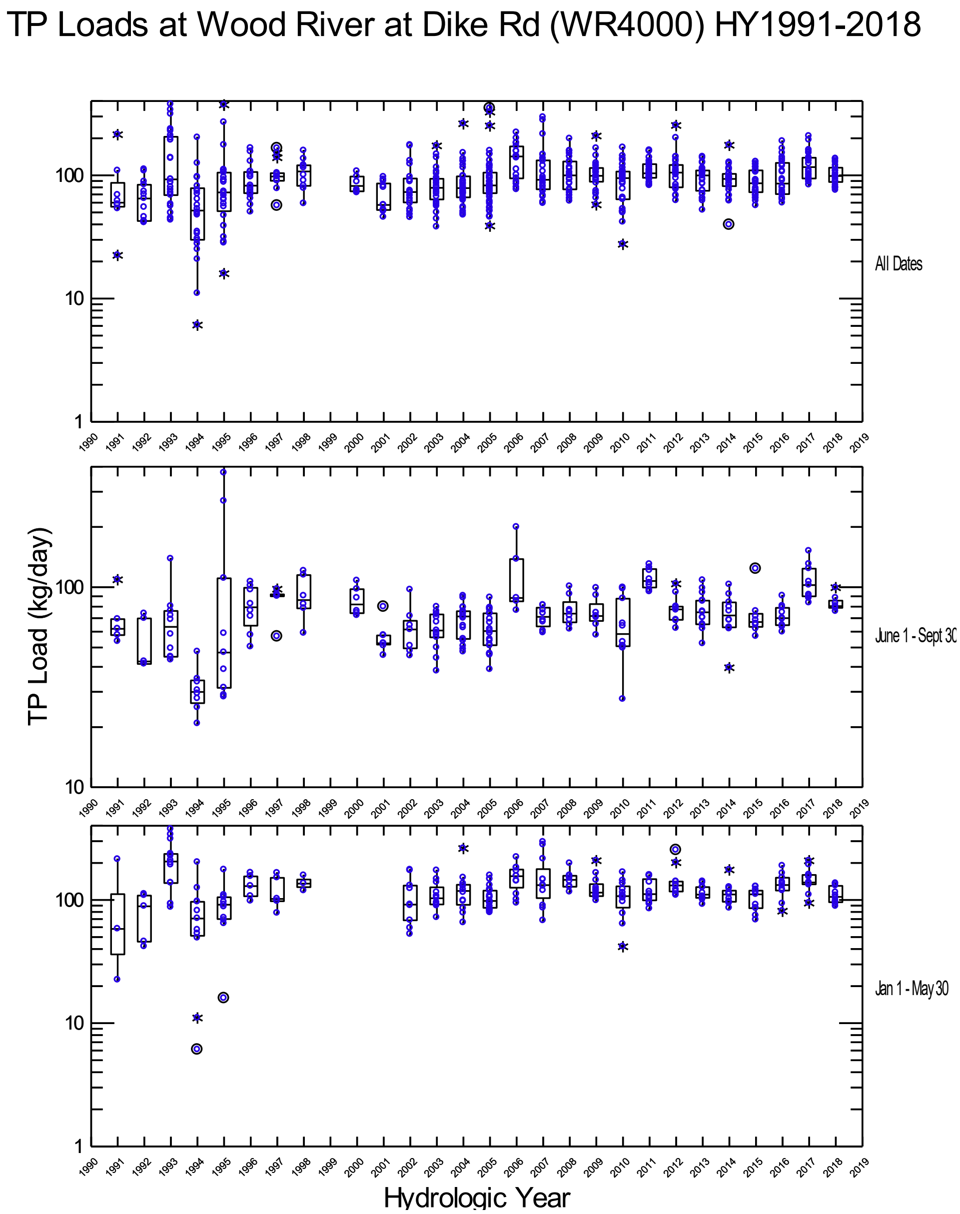


Appendix I Figure 3

TP Loads at Wood River at Weed Rd (WR3000) HY1991-2018

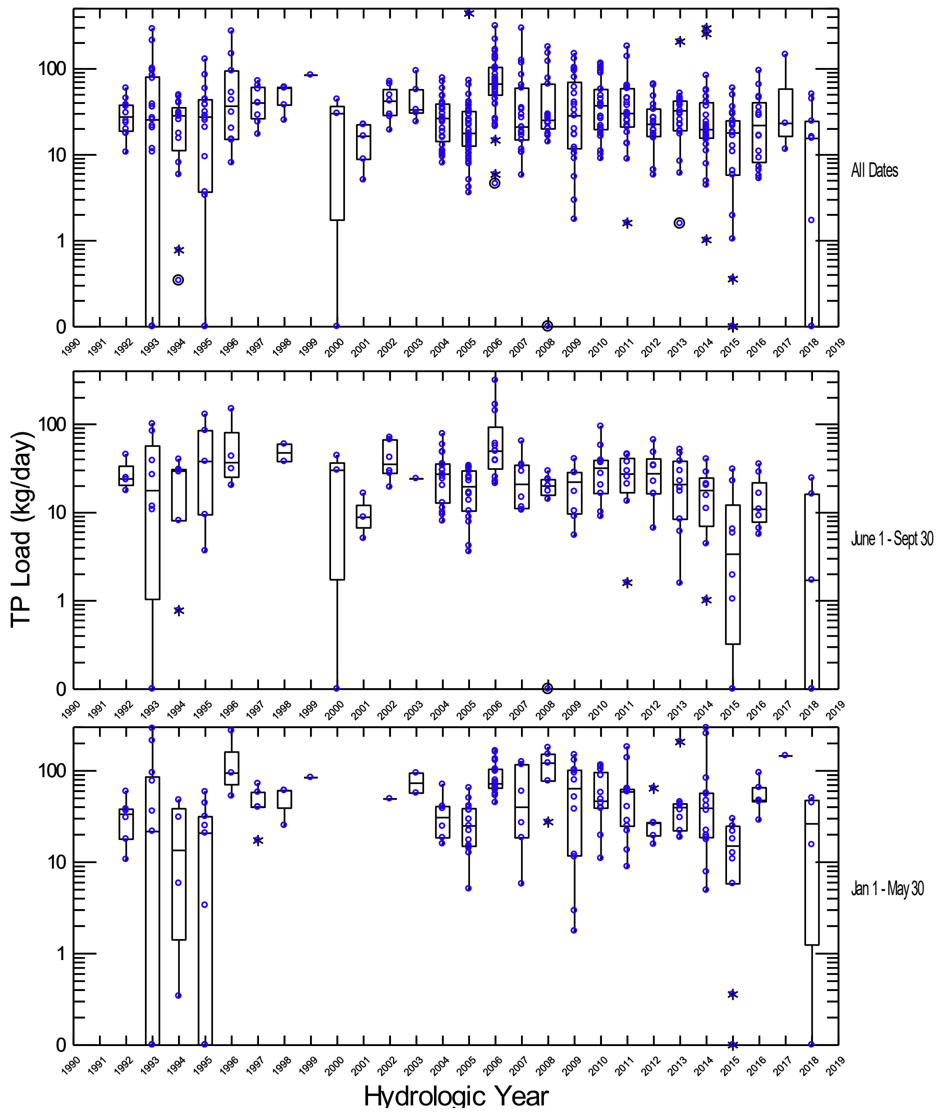


Appendix I Figure 4



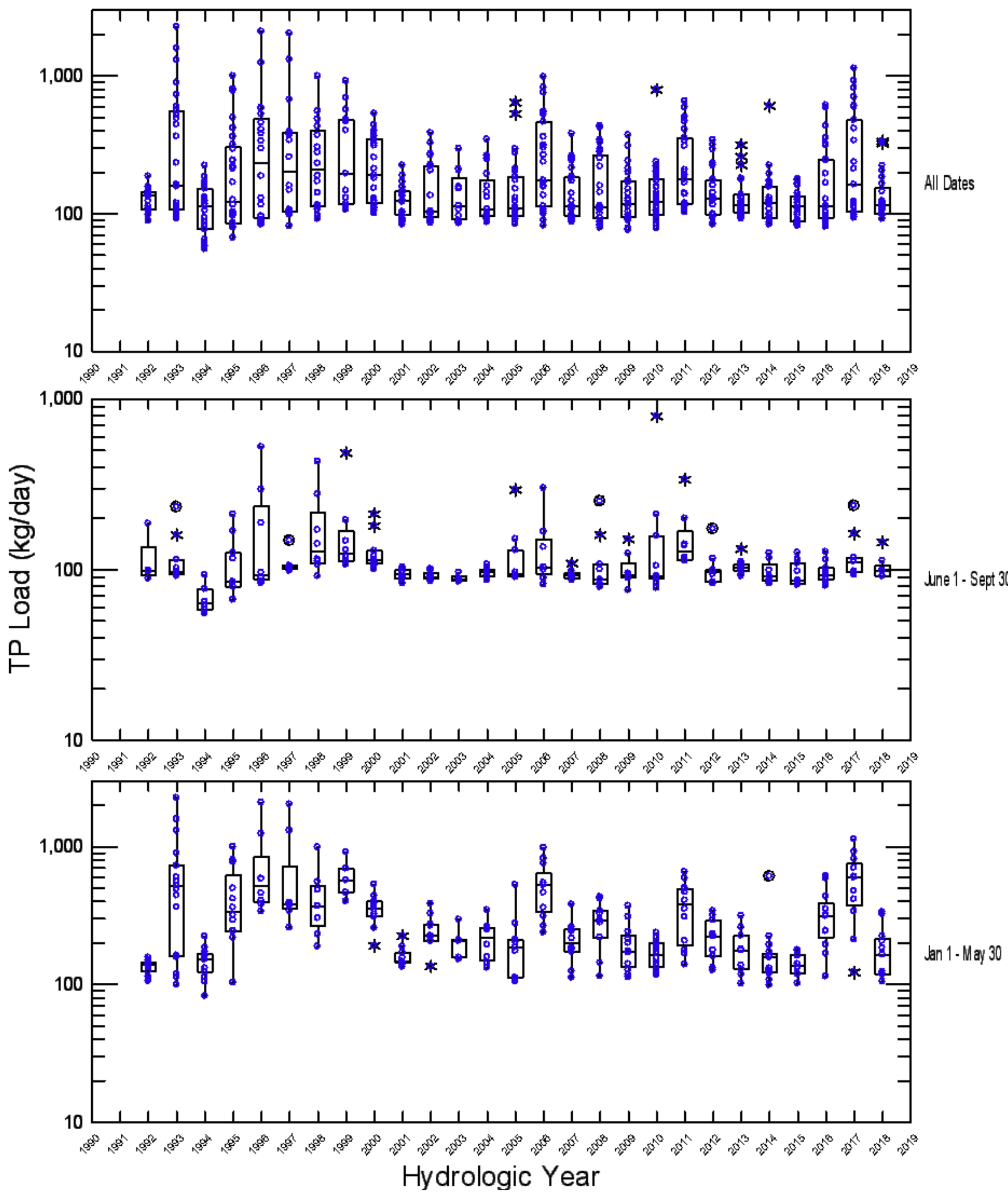
Appendix I Figure 5

TP Loads at Seven-Mile Canal at Dike Rd (WR5000) HY1991-2018

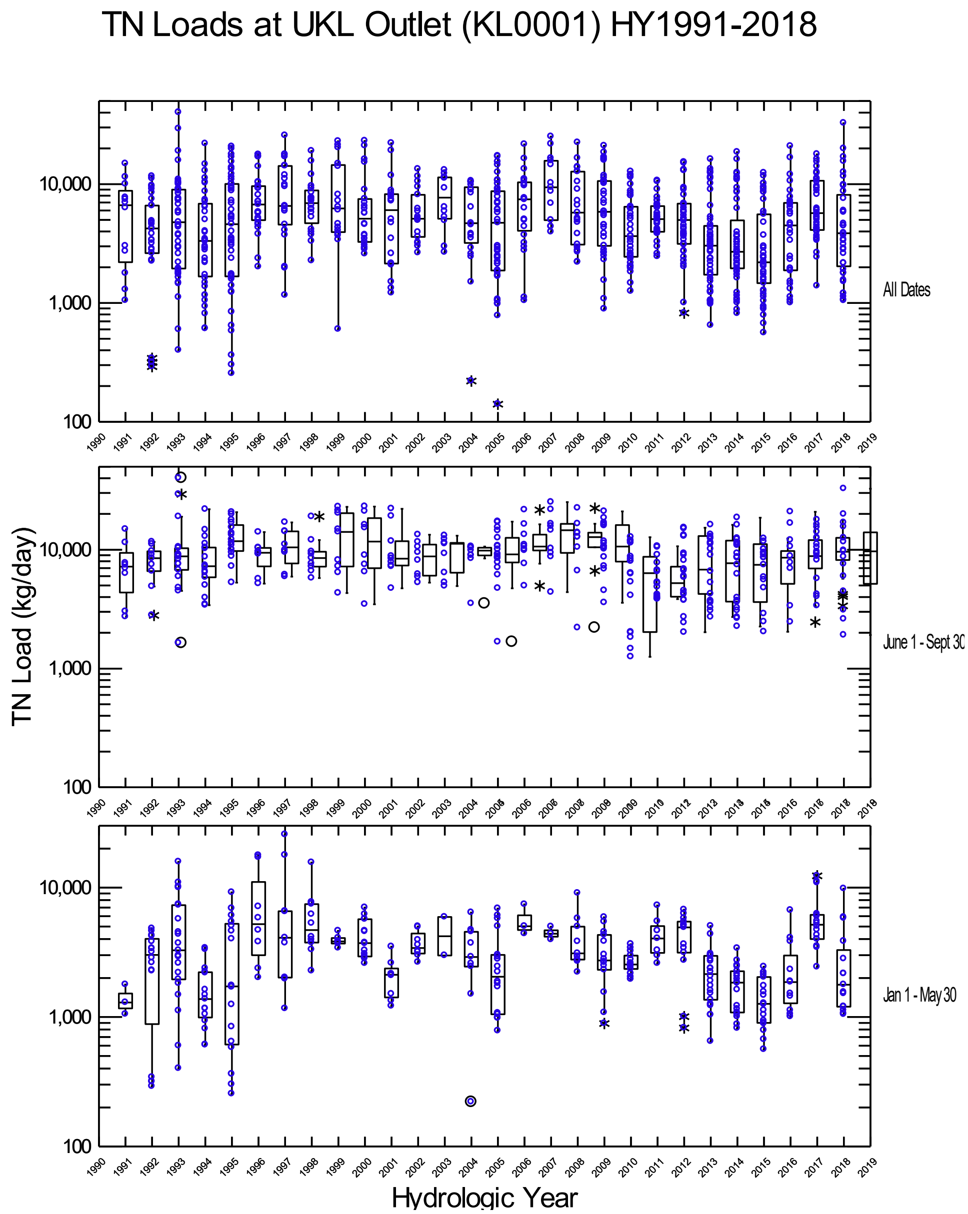


Appendix I Figure 6

TP Loads at Williamson R at Bridge on Modoc Pt. Road (WR6000) HY1991-2018

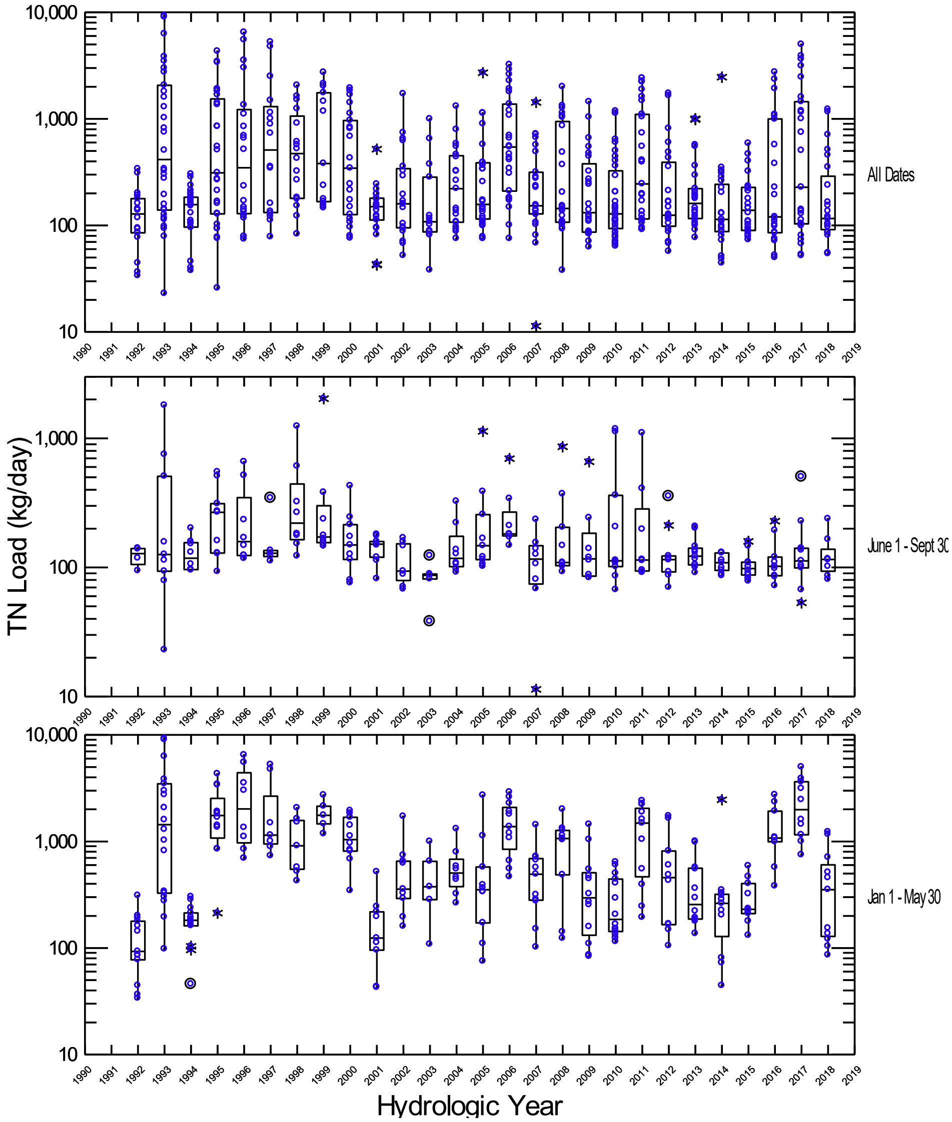


Appendix I Figure 7



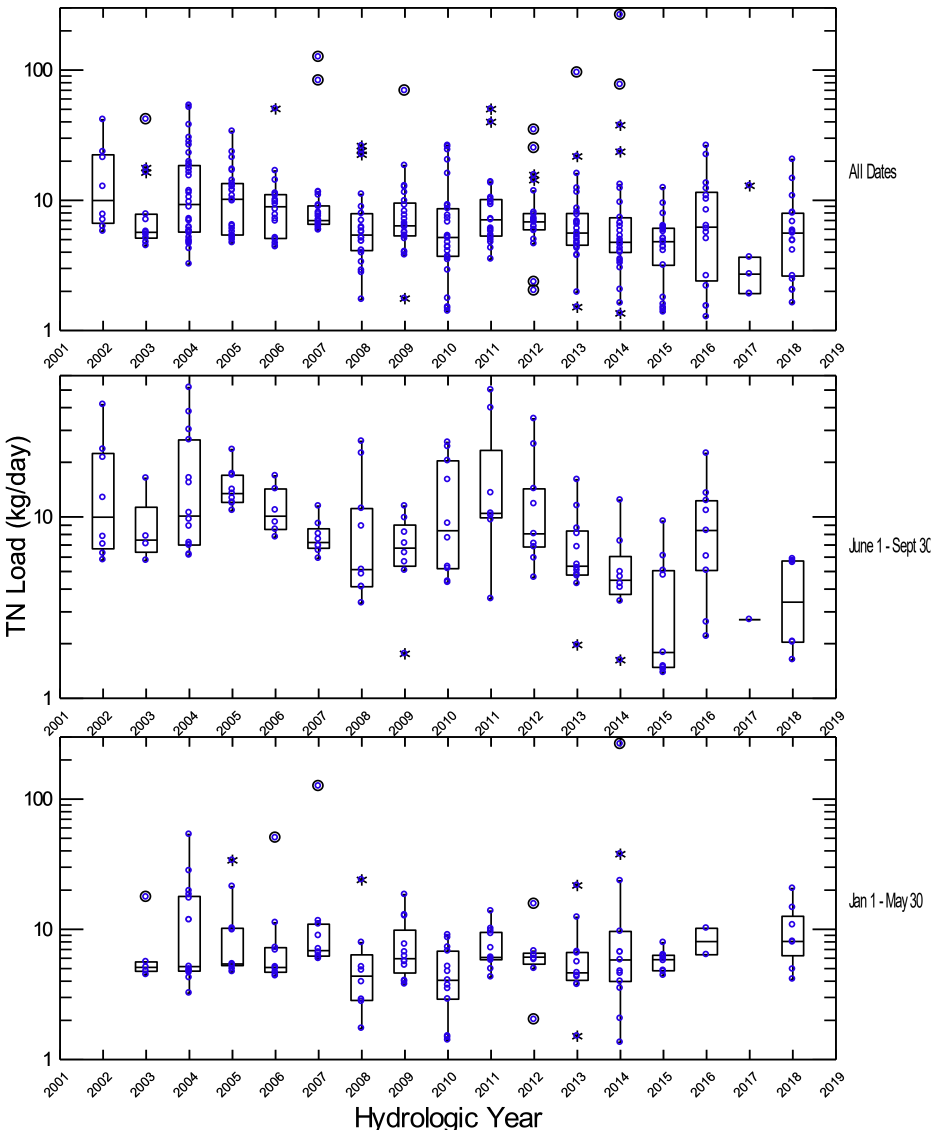
Appendix I Figure 8

TN Loads at Sprague R. @ Kirchers Bridge (W1000) HY1991-2018



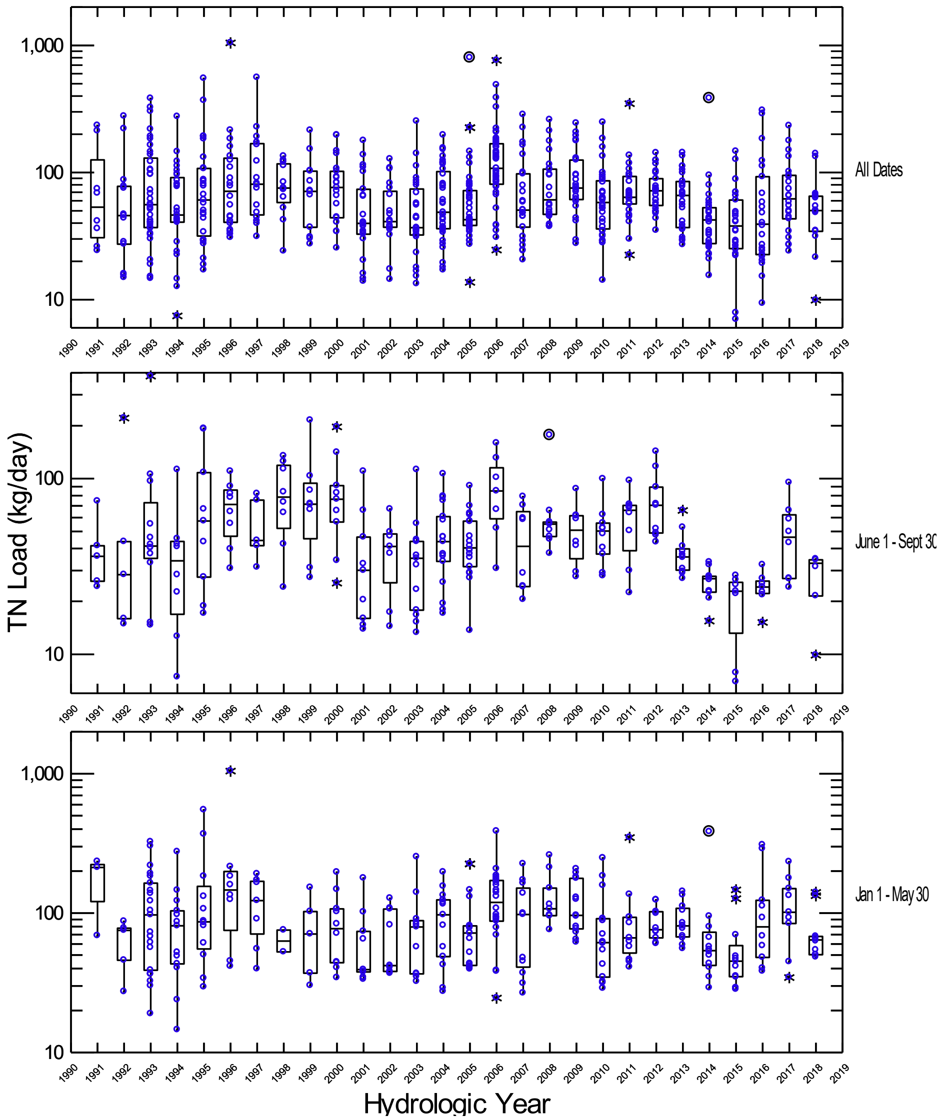
Appendix I Figure 9

TN Loads at Annie Cr at Snow Park (WR2000) HY1991-2018



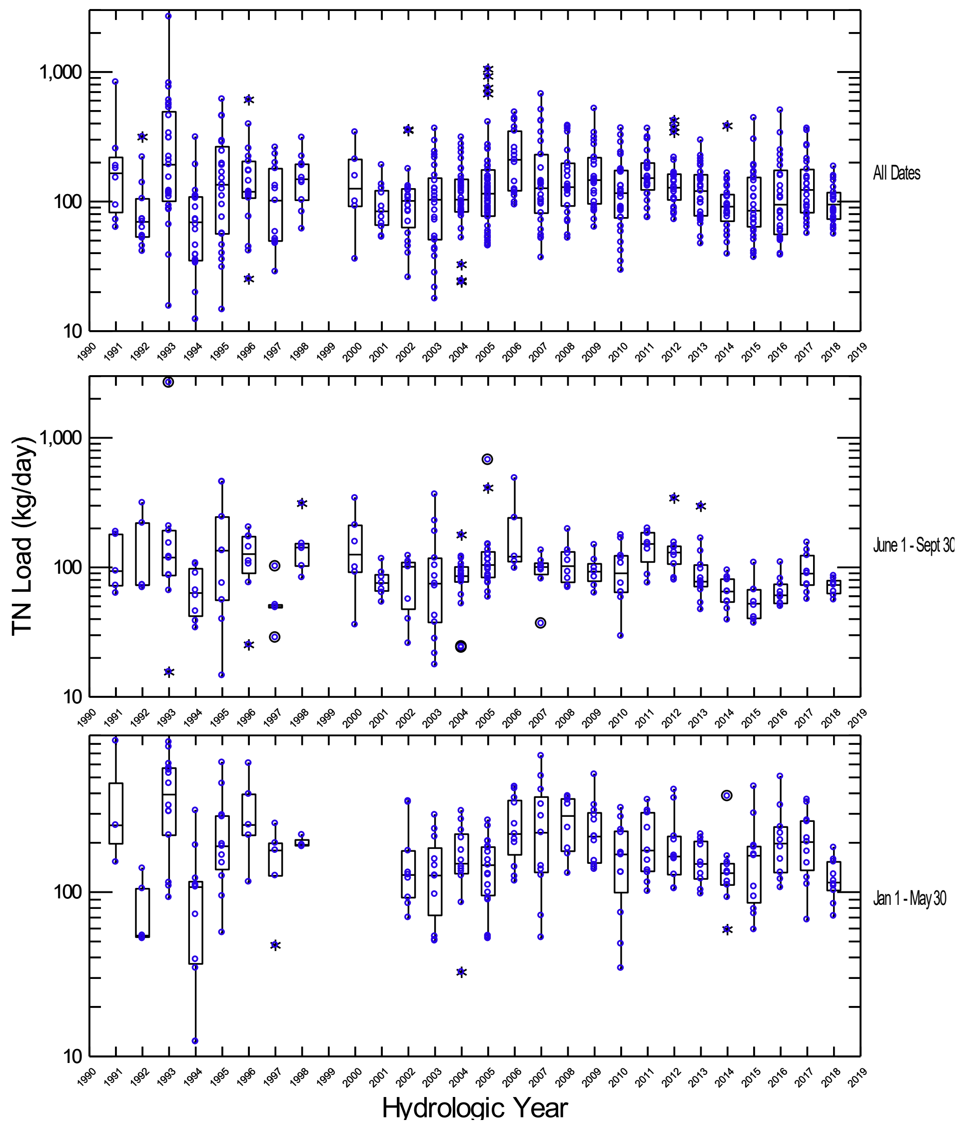
Appendix I Figure 10

TN Loads at Wood River at Weed Rd (WR3000) HY1991-2018



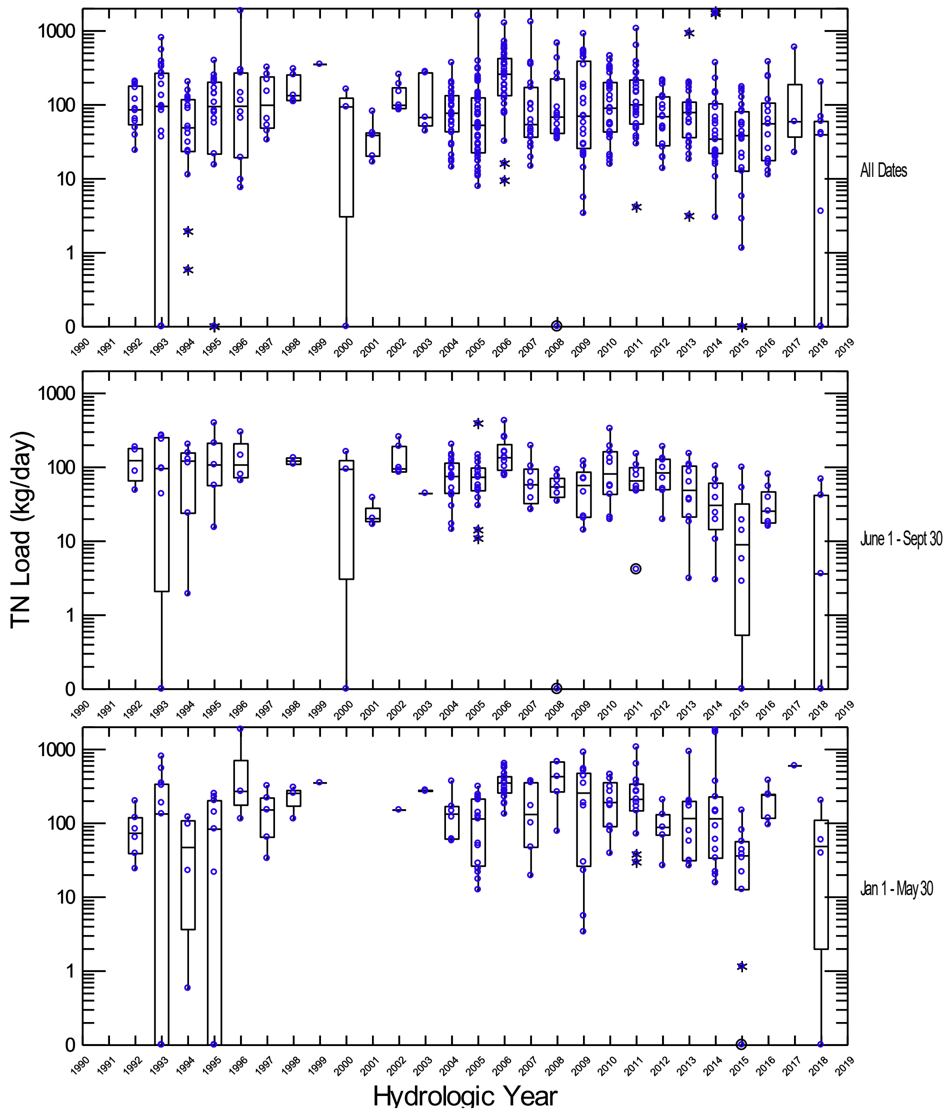
Appendix I Figure 11

TN Loads at Wood River at Dike Rd (WR4000) HY1991-2018



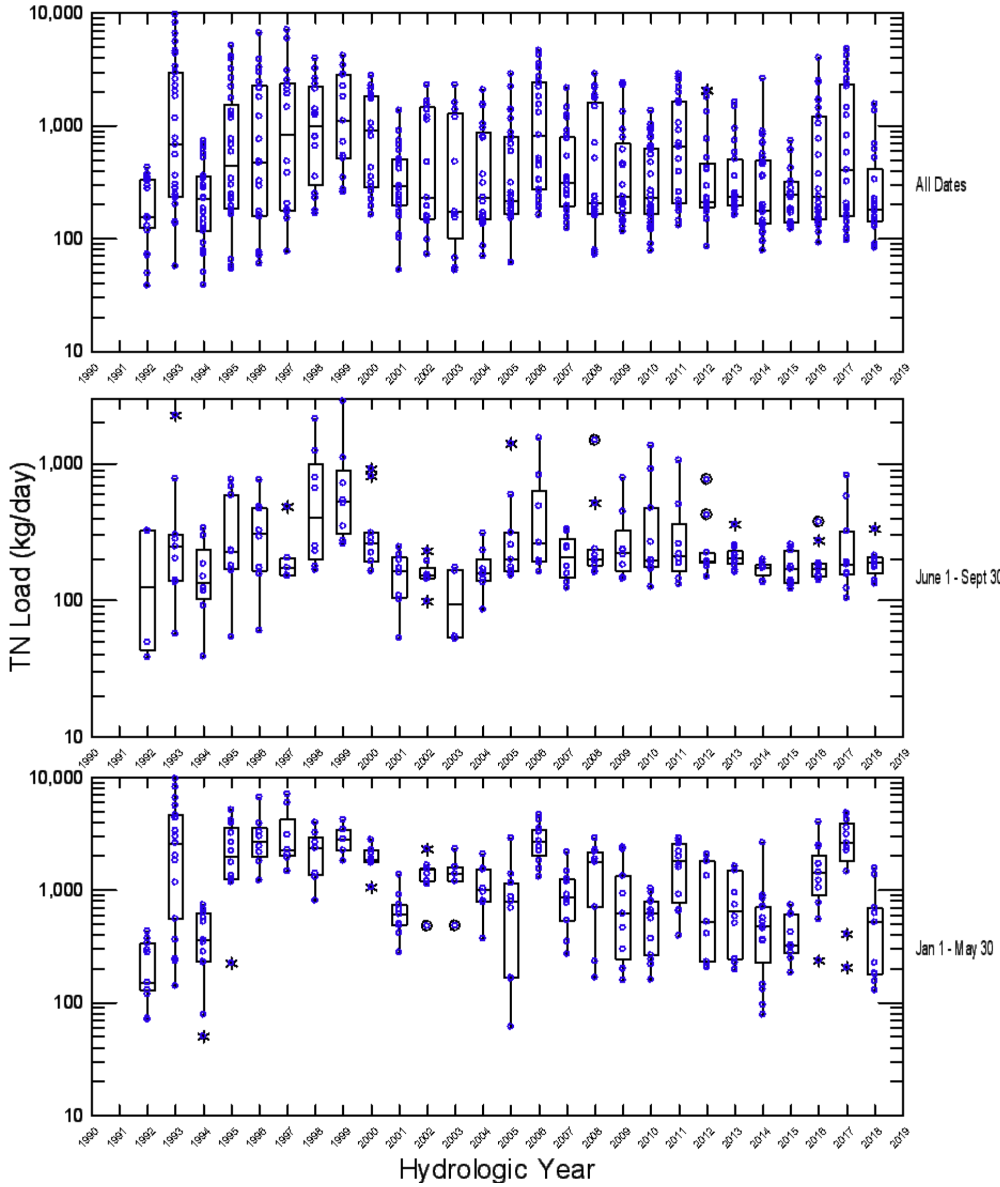
Appendix I Figure 12

TN Loads at Seven-Mile Canal at Dike Rd (WR5000) HY1991-2018



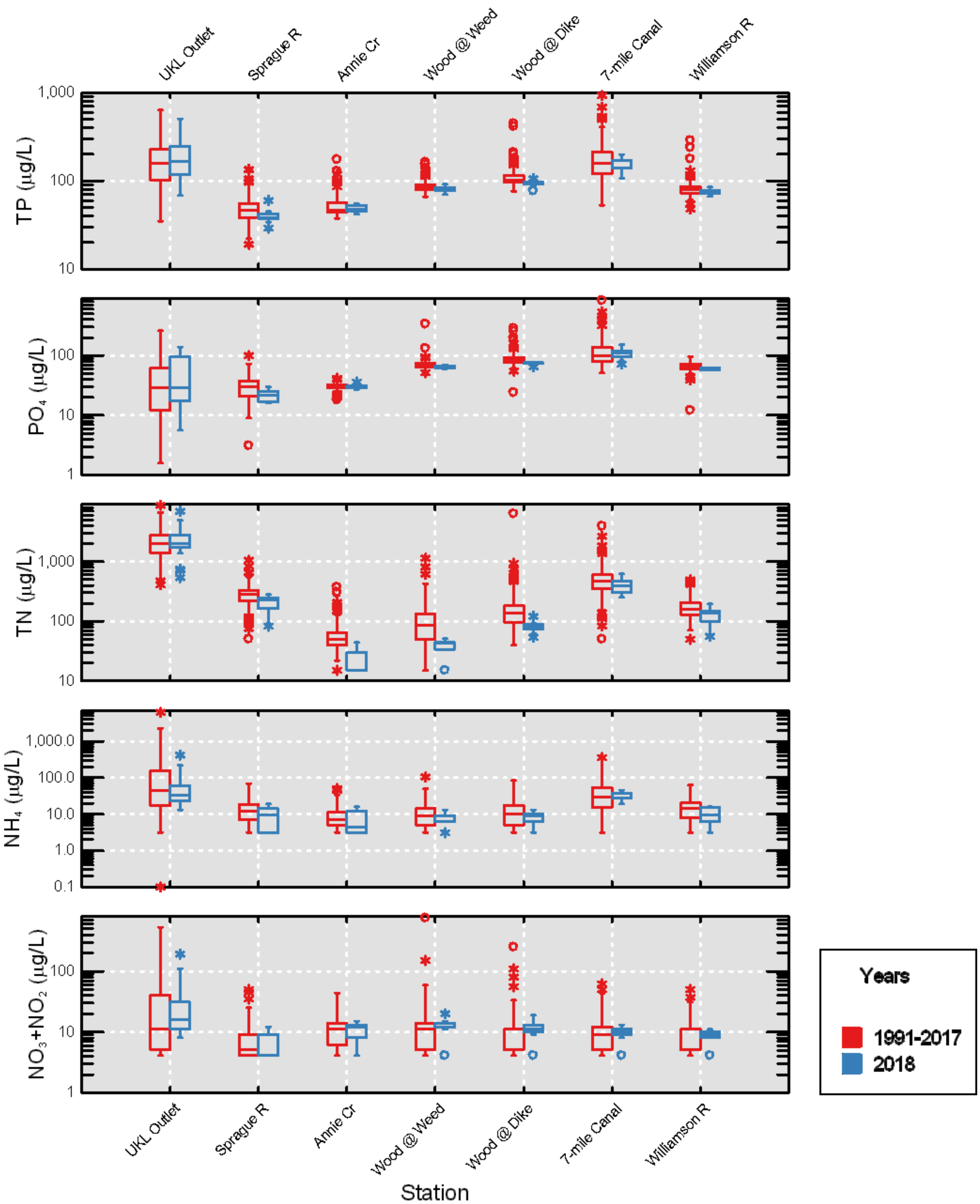
Appendix I Figure 13

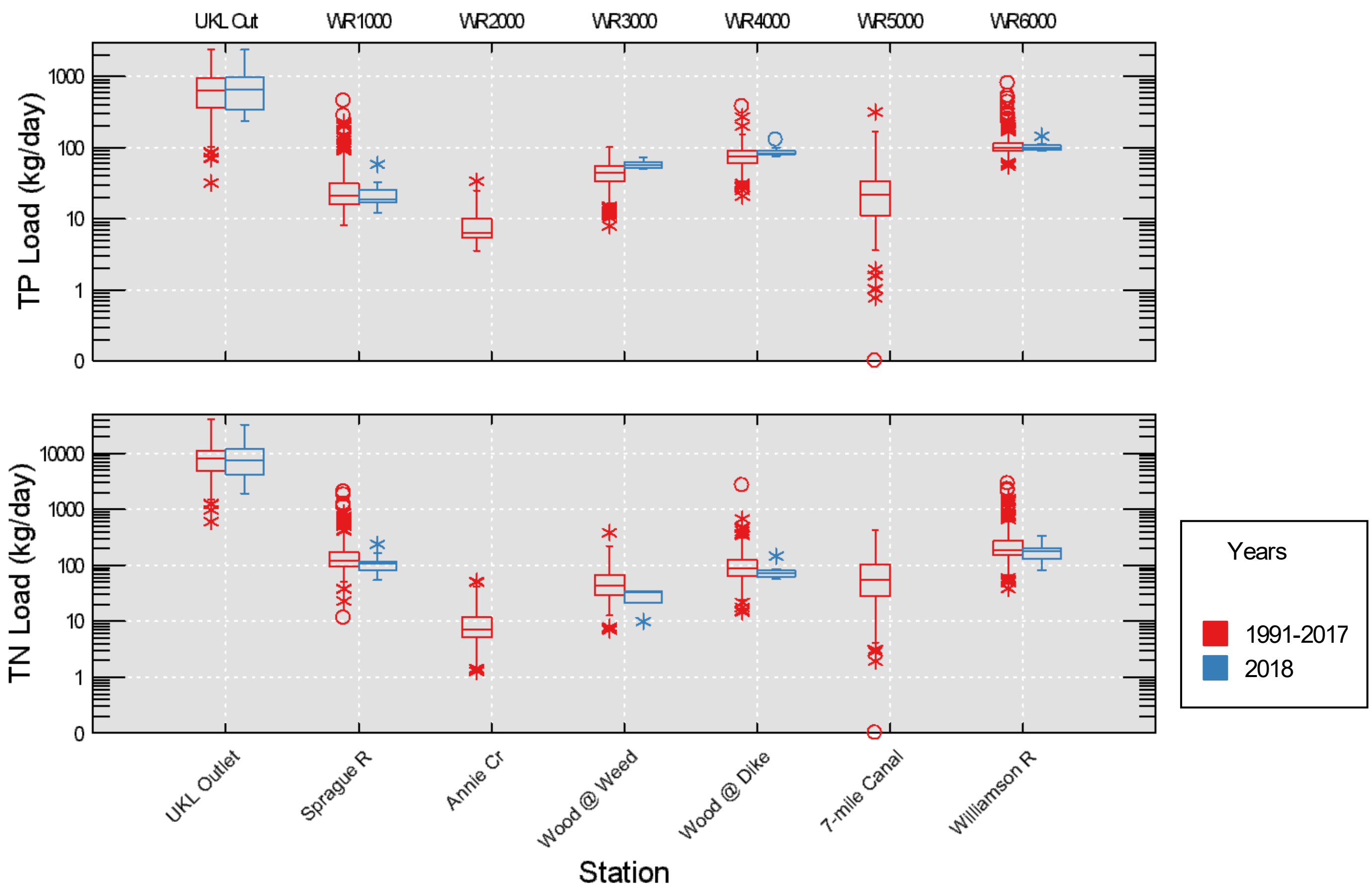
TN Loads at Williamson R at Bridge on Modoc Pt. Road (WR6000) HY1991-2018



Appendix I Figure 14

APPENDIX II: Station distributions of TP, SRP, TN, NH4-N, NO3+ NO2-N concentrations (µg/L) and TP and TN loading (kg/day) during the irrigation season of June-October




UKL Out
WR1000
WR2000
WR3000
WR4000
WR5000
WR6000
TP Load (kg/day)
TN Load (kg/day)
1000
100
10
1
0
10000
1000
100
10
1
0
UKL Outlet
Sprague R
Annie Cr
Wood @ Weed
Wood @ Dike
7-mile Canal
Williamson R
Station
Years
1991-2017
2018