Aquatic Ecosystem Sciences LLC

TECHNICAL MEMORANDUM

Upper Klamath Lake Tributary Loading: 2010 Data Summary Report

Prepared By:

Jacob Kann, Ph.D.
Aquatic Ecosystem Sciences LLC
295 East Main St., Suite 7
Ashland, OR 97520

Prepared For:

Klamath Tribes Natural Resources Department
PO Box 436
Chiloquin, OR 97624

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Table of Contents

List of Figures

List of Tables

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 a nutrient budget for UKL (Kann and Walker 1999). This report serves as an annual update to the UKL tributary water quality database, including a summary of 2010 data (basic summary statistics and graphical analysis), and limited comparison of graphical time-series trends of tributary data collected for the 1991-2010 period. Included in this summary is an update of previous UKL tributary water quality databases with data collected during 2010, including appropriate quality assurance analyses (*see Excel spreadsheets: Klamath Tribes Inflow Nutrient Data 1991-2000.xls and Klamath Tribes Inflow Nutrient-Q Data 2001-2010.xls*).

METHODS

Similar to previous years, data collection methods followed the Klamath Tribes established procedures for field collection and laboratory analysis of water quality parameters (see Klamath Tribes 2003 for a complete description of these methods). Nutrient parameters (Table 1) were collected at seven tributary stations during the 2010 sampling season (Table 2). Specific nutrient loading methodology is outlined in Kann and Walker 1999, but is briefly summarized here.

Daily inflow volume for the Williamson and Sprague Rivers on a given sample date was computed from continuous daily discharge data obtained from U.S. Geological Survey (USGS) stream-flow discharge stations. These data were obtained online; Williamson River Gage 11502500:
http://waterdata.usgs.gov/nwis/dv/?site_no=11502500&agency_cd=USGS&referred_module=sw,
and Sprague River Gage 11501000:
http://waterdata.usgs.gov/or/nwis/dv/?site_no=11501000&agency_cd=USGS&referred_module=sw).
Daily outflow volume for Upper Klamath Lake @ Link Bridge (UKL outflow) was computed from the sum of USGS discharge station at Link River 11507500:
http://waterdata.usgs.gov/or/nwis/dv/?site_no=11507500&agency_cd=USGS&referred_module=sw, and USBR A-Canal daily discharge measurements:
http://www.usbr.gov/mp/kbao/operations/water/korep1.cfm?lakeid=ukldata3.

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. 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 and GMA (2004a). Additional nutrient concentration data were collected by GMA (2004b) and incorporated into tributary loading calculations for years when such data were available.

The total phosphorus (TP) and total nitrogen (TN) mass (kg/day) for each 2010 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 @ Link Bridge) was discontinued due to funding limitations during 2006. Although the UKL sampling station PM was used as a surrogate for UKL outflow for intervals when data for Upper Klamath Lake @ Link Bridge were not available, this caused significant gaps for the October-March period during 2006 and 2007. Beginning in 2008, USBR began monitoring nutrients during the winter months at Link River Dam and near the mouth of the Link River. These data were provided by USBR along with limited data collected by PacifiCorp during the winter of 2009 and 2010 (Excel spreadsheets: *KRWQ2007-2010KLLD.xls* and *Pacificorpdata2009-2010.xlsx*). Loading graphs and summaries are computed based on the October-September hydrologic water year (denoted HY in below plots).

Table 1. Nutrient parameters collected in Upper Klamath Lake tributaries, 2010.

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

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

Table 2. Station location and Site ID Code for data collected in Upper Klamath Lake tributaries, 2010.

Location	Site ID Code
Sprague R. @ Kirchers Bridge	WR1000
Annie Ck @ Snow Park	WR2000
Wood R @ Weed Rd	WR3000
Wood R @ Dike Rd	WR4000
7-mile canal @ Dike Rd	WR5000
Williamson R @ Bridge on Modoc Pt. Road	WR6000
Upper Klamath Lake @ Link Bridge (UKL Outflow)	KL0001

RESULTS/DISCUSSION

Nutrient Concentration

The 2010 nutrient concentration pattern among inflow stations was similar to that of the 1991-2009 sampling period (Figure 1); total P and PO_4-P tended to be higher at the Wood River and Seven Mile stations (WR3000, WR4000, and WR5000); total N tended to be lower for the Wood River stations (WR3000 and WR4000) but higher for Seven Mile (WR5000); values for the Williamson River (WR6000) tended to be intermediate relative to other stations for most parameters, but values for the Sprague River (WR1000) tended to be lower for TP and PO_4-P. In addition, Annie Creek at Snow Park (previously sampled between 2003-2009) was consistently lower for all nutrient parameters except nitrate/nitrite among the inflow stations (Figure 1; Table 1). With the exception of Seven Mile Canal, the UKL outlet (KL0001) tended to be higher than inflow stations for TP, lower for PO_4, and substantially higher for TN and ammonia (NH_4-N). Although in 2009 NH_4-N at Seven Mile Canal was similar to the UKL Outlet, during 2010 the UKL Outlet was substantially higher than Seven Mile Canal (Figure 1; Table 3). Of the inflow stations, 2010 showed somewhat lower TP and TN at the Williamson and Sprague River stations, noticeably lower NH_4-N at Seven Mile Canal, and higher nitrate at the Wood River stations, when compared to the previous 1991-2009 period (Figure 1). Dissimilar to 2008 and 2009 when ammonia was noticeably lower at the UKL outflow station relative to previous years, values in 2010 were similar to or slightly higher than the previous period of record (Figure 1).

Time series plots of the 2010 concentration data show Seven Mile Canal to have among the highest values for TP, PO_4, PP (particulate P which equals TP minus PO_4), TN, and NH_4-N (Figure 2). Phosphorus values seasonally peaked during both the spring runoff period and the summer irrigation season. With respect to PO_4, the Wood River stations also showed high values, followed by the Williamson and then the Sprague River, which showed values consistently lower than 40 µg/L. However, for PP, Sprague River concentrations were often among the highest, particularly during the low-flow summer period (Figure 2). TP, PP, TN, and NH_4 at the UKL Outflow station all increased relative to the inflow stations during the summer algal growing season. However, PO_4 only increased slightly during that time, remaining lower than the major inflow stations. Of note is the consistently higher NH_4 and NO_3+NO_2 at the UKL Outflow station during the late fall, winter, and early-spring months (Figure 2).

TN:TP at the UKL Outflow station was high (TN:TP $\geq$ ~20) during the late fall of 2009 and the winter of 2010 (Figure 3). Similar to spring 2009, the ratio of TN:TP at the UKL Outflow station was higher (TN:TP $\cong$ 10) than tributary stations in April of 2010, increased during early summer bloom development, declined through the bloom decline period (see Kann 2010), and then remained stable through October before increasing (Figure 3). The TIN:SRP ratio was elevated (TIN:SRP $\geq$ 40) during late fall 2009 and early winter 2010, declined to values < 3 during April, increased slightly during the period of bloom development and then declined somewhat through the summer growing season (Figure 3). Both TN:TP and TIN:SRP values in the inflow tributary stations indicate nitrogen limiting conditions (<10 for TN:TP and <1 for TIN:SRP) that would favor nitrogen-fixing algae such as the *Aphanizomenon* prevalent in UKL.

Time-series plots of these ratio data that compare the Williamson River and UKL Outflow (summarized for the April-October period when data for both stations were consistently

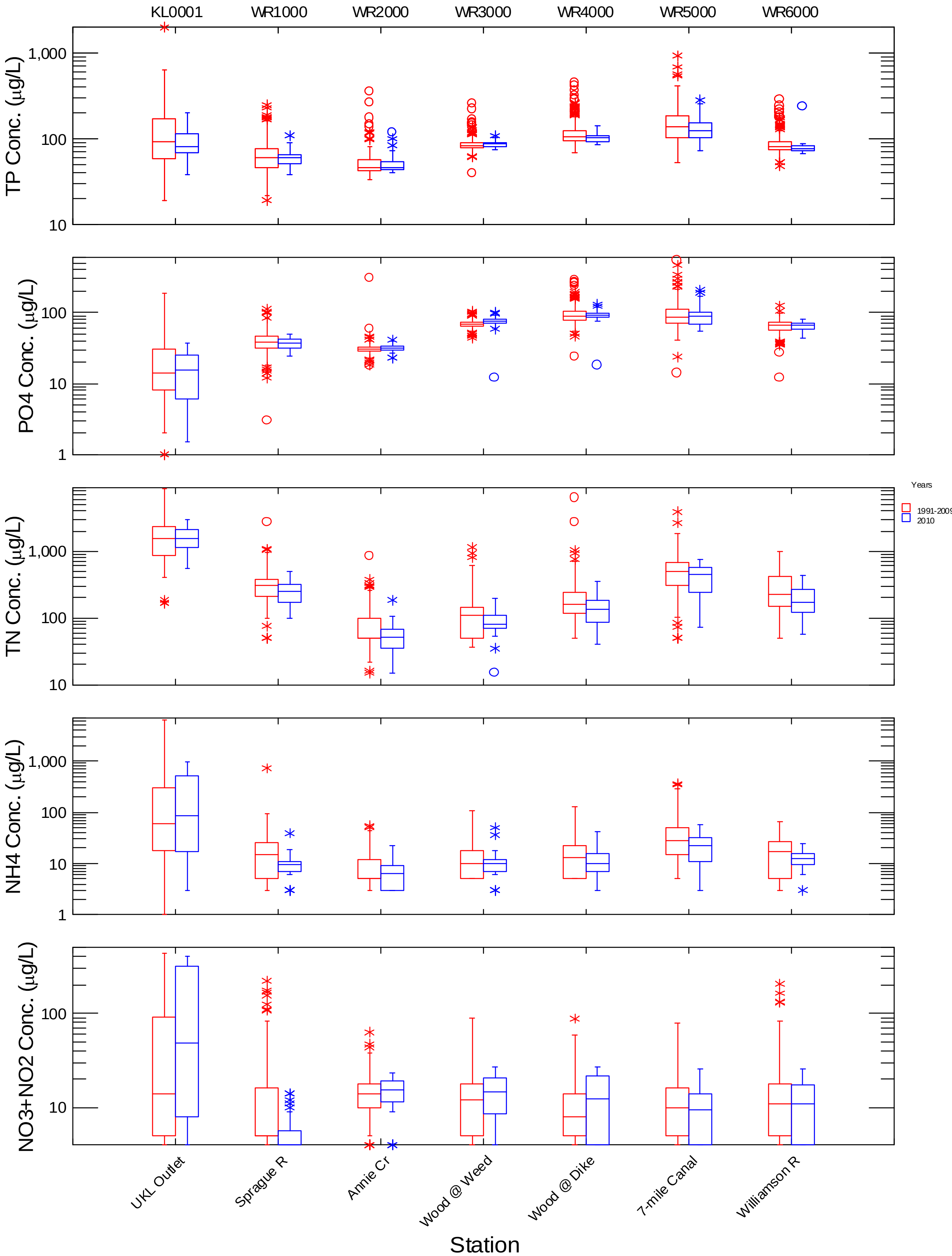


Figure 1. Station distributions of TP, SRP, TN, NH4-N, and NO3+ NO2-N concentration (µg/L) compared between 1991-2009 (red) and 2010 (blue).

Table 3. Basic statistics by station for TP, SRP, TN, NH_4-N, and NO_3+ NO_2-N concentration, and TP and TN load, Water Year 2010.

Station Code	Station Name	Parameter	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	Total Phosphorus Load (kg/d	Total Nitrogen Load (kg/d)
KL0001	UKL Outlet	N of Cases	27	22	27	27	25	27	27
KL0001	UKL Outlet	Median	81	16	1540	86	49	228	3629
KL0001	UKL Outlet	Arithmetic Mean	92	16	1589	267	156	271	4606
KL0001	UKL Outlet	Pct25	68	6	1113	17	8	153	2502
KL0001	UKL Outlet	Pct75	118	25	2090	527	320	299	6081
WR1000	Sprague R	N of Cases	32	32	32	32	32	32	32
WR1000	Sprague R	Median	60	38	251	10	4	40	128
WR1000	Sprague R	Arithmetic Mean	61	37	253	10	6	60	256
WR1000	Sprague R	Pct25	51	32	173	7	4	27	94
WR1000	Sprague R	Pct75	66	43	315	11	6	75	328
WR2000	Annie Cr	N of Cases	32	32	32	32	32	29	29
WR2000	Annie Cr	Median	46	32	52	7	16	5	5
WR2000	Annie Cr	Arithmetic Mean	53	32	55	7	15	7	8
WR2000	Annie Cr	Pct25	44	30	36	3	12	4	4
WR2000	Annie Cr	Pct75	55	34	67	9	19	8	9
WR3000	Wood @ Weed	N of Cases	32	32	32	32	32	32	32
WR3000	Wood @ Weed	Median	87	76	80	10	15	60	48
WR3000	Wood @ Weed	Arithmetic Mean	87	75	90	12	15	57	60
WR3000	Wood @ Weed	Pct25	81	72	71	7	9	34	33
WR3000	Wood @ Weed	Pct75	90	81	111	12	21	70	73
WR4000	Wood @ Dike	N of Cases	32	32	32	32	32	30	30
WR4000	Wood @ Dike	Median	102	91	133	10	13	95	116
WR4000	Wood @ Dike	Arithmetic Mean	104	91	146	11	14	91	135
WR4000	Wood @ Dike	Pct25	92	85	88	7	4	64	75
WR4000	Wood @ Dike	Pct75	110	98	182	16	22	107	174
WR5000	7-mile Canal	N of Cases	32	32	32	32	32	31	31
WR5000	7-mile Canal	Median	125	90	453	23	10	37	89
WR5000	7-mile Canal	Arithmetic Mean	138	99	422	24	10	43	143
WR5000	7-mile Canal	Pct25	103	69	239	11	4	19	41
WR5000	7-mile Canal	Pct75	154	103	578	33	14	55	199
WR6000	Williamson R	N of Cases	32	32	32	32	32	32	32
WR6000	Williamson R	Median	77	67	169	13	11	121	231
WR6000	Williamson R	Arithmetic Mean	82	65	200	13	11	155	407
WR6000	Williamson R	Pct25	72	59	121	10	4	98	164
WR6000	Williamson R	Pct75	82	72	270	16	18	177	626

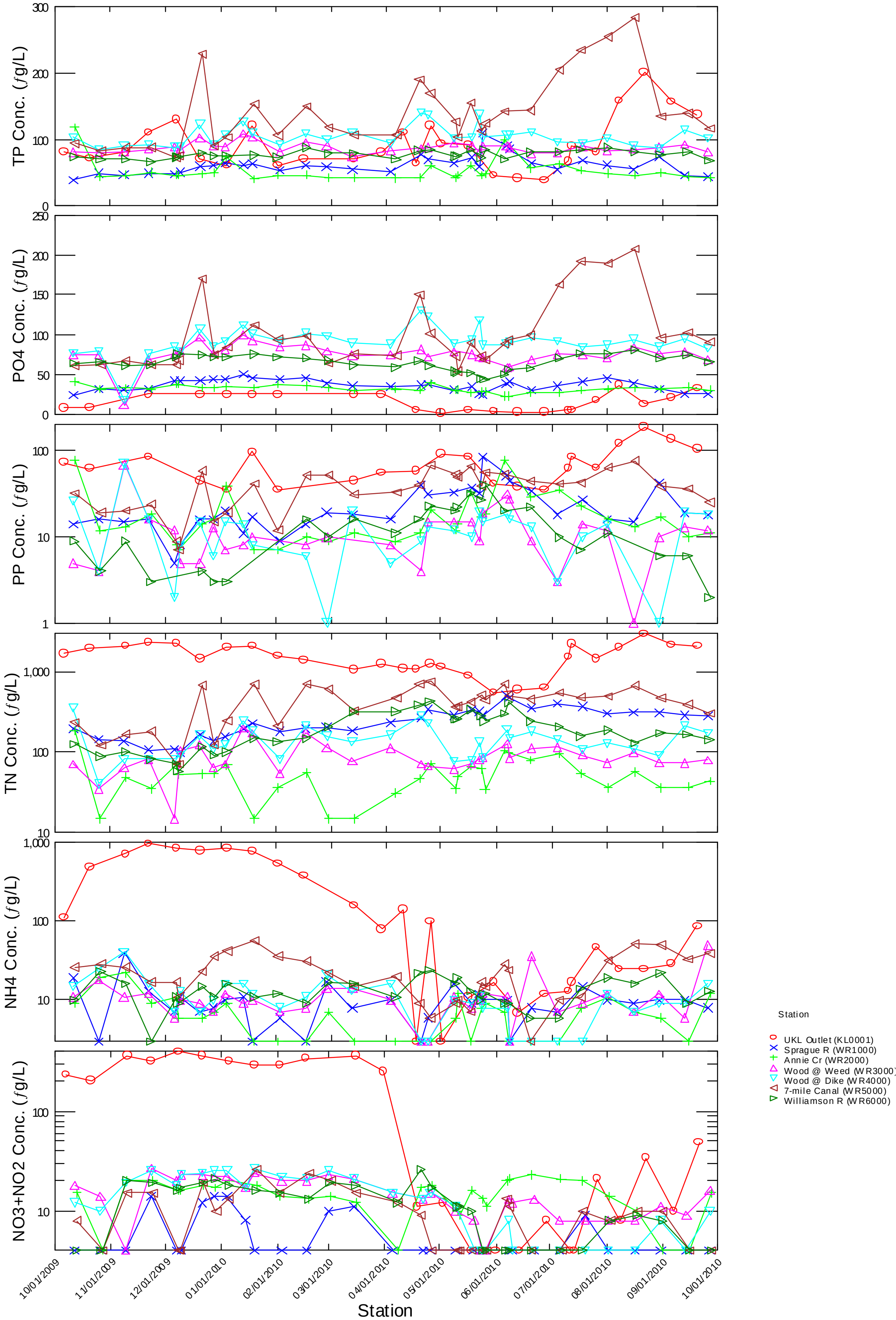


Figure 2. Time-series plot of nutrient concentrations for Upper Klamath Lake tributaries and outflow, 2010.

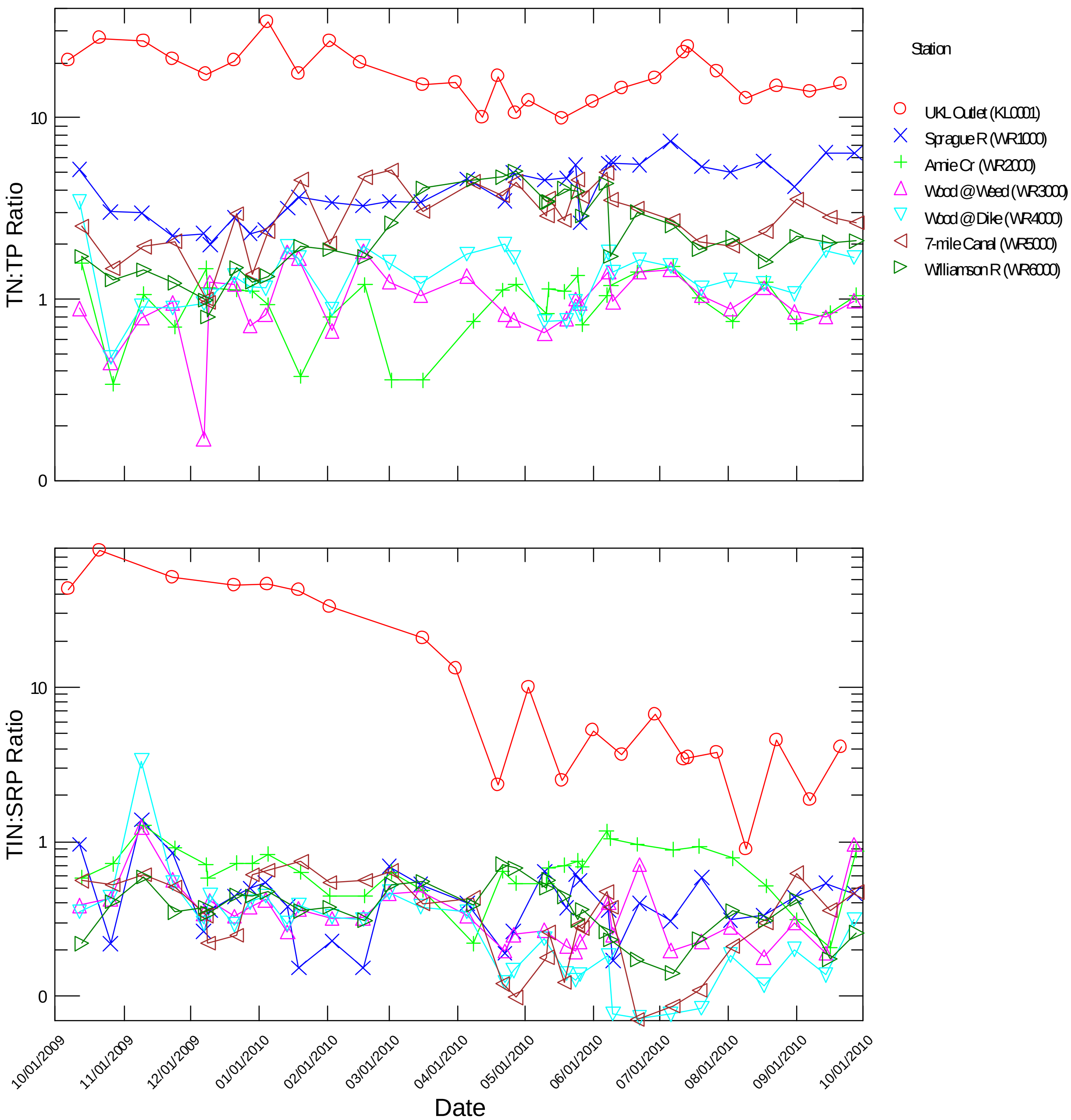
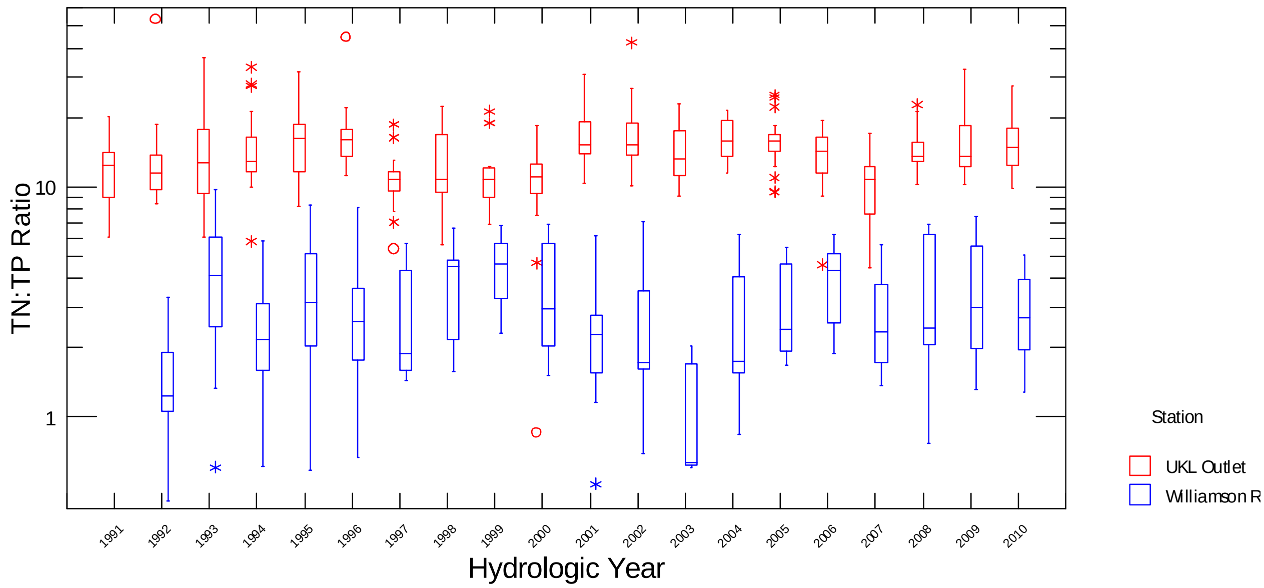


Figure 3. Total nitrogen to total phosphorus (TN:TP) and total inorganic nitrogen (NOx-N+NH_4-N) to PO_4 (TIN:SRP) ratios in Upper Klamath Lake tributaries and outflow stations, 2010.



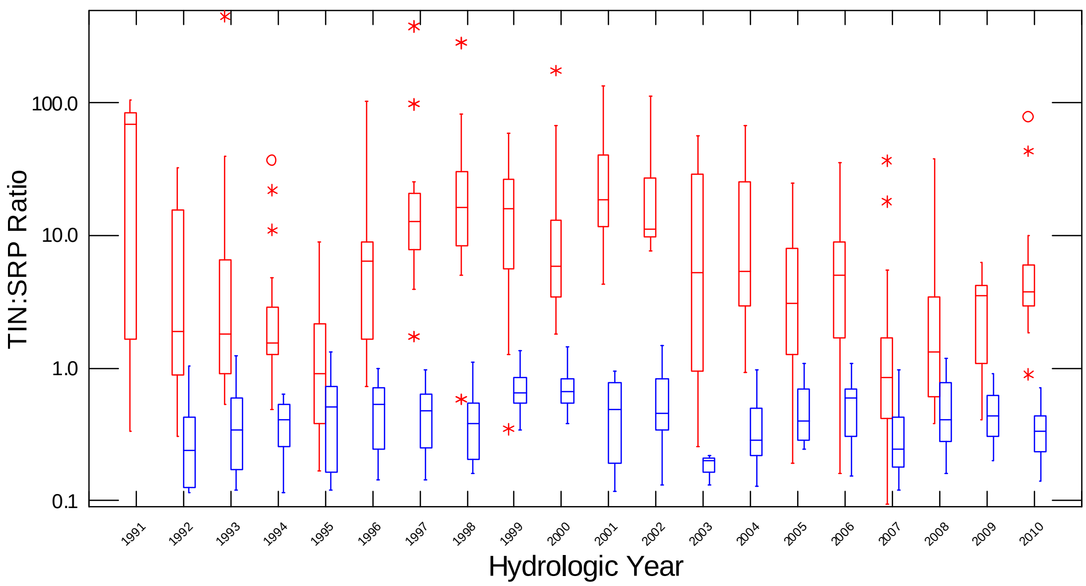


Figure 4. Total nitrogen to total phosphorus (TN:TP) and total inorganic nitrogen (NOx-N+NH4-N) to PO4 (TIN:SRP) ratios in the Williamson River and UKL outflow stations, April-October: 1991-2010.

available) show that both ratios (TP:TN and TIN:SRP) were always higher leaving UKL than they were in the Williamson River inflow (Figure 4). 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. Ratios rose in the outflow relative to inflow despite additional internal or sediment loading of phosphorus, which would tend to drive ratios downward. There is also indication of cyclical trends over the 1991-2010 period. Further analysis is required to explore these apparent trends.

TP and TN Loading

2010 Seasonal Pattern

The seasonal loading pattern for 2010 showed increasing tributary inflow loads of TP and TN occurring during the early-spring to early-summer period, with loading for both TP and TN peaking during late-May to early-June, particularly for the Sprague and Williamson Rivers (Figure 5). UKL outflow loads of both TP and TN began increasing in June when internal nutrient loading from sediments and nitrogen fixation takes place in UKL (e.g., see Kann 1998 and Kann and Walker 1999), and tended to peak in late-August. Outflow loading levels remain elevated during the fall months before declining in the winter. Outflow TP loads were similar to Williamson River loading during the January-May period prior to the summer algal growing season, while outflow TN loads generally remained higher than those for the Williamson River over his same period (Figure 5)

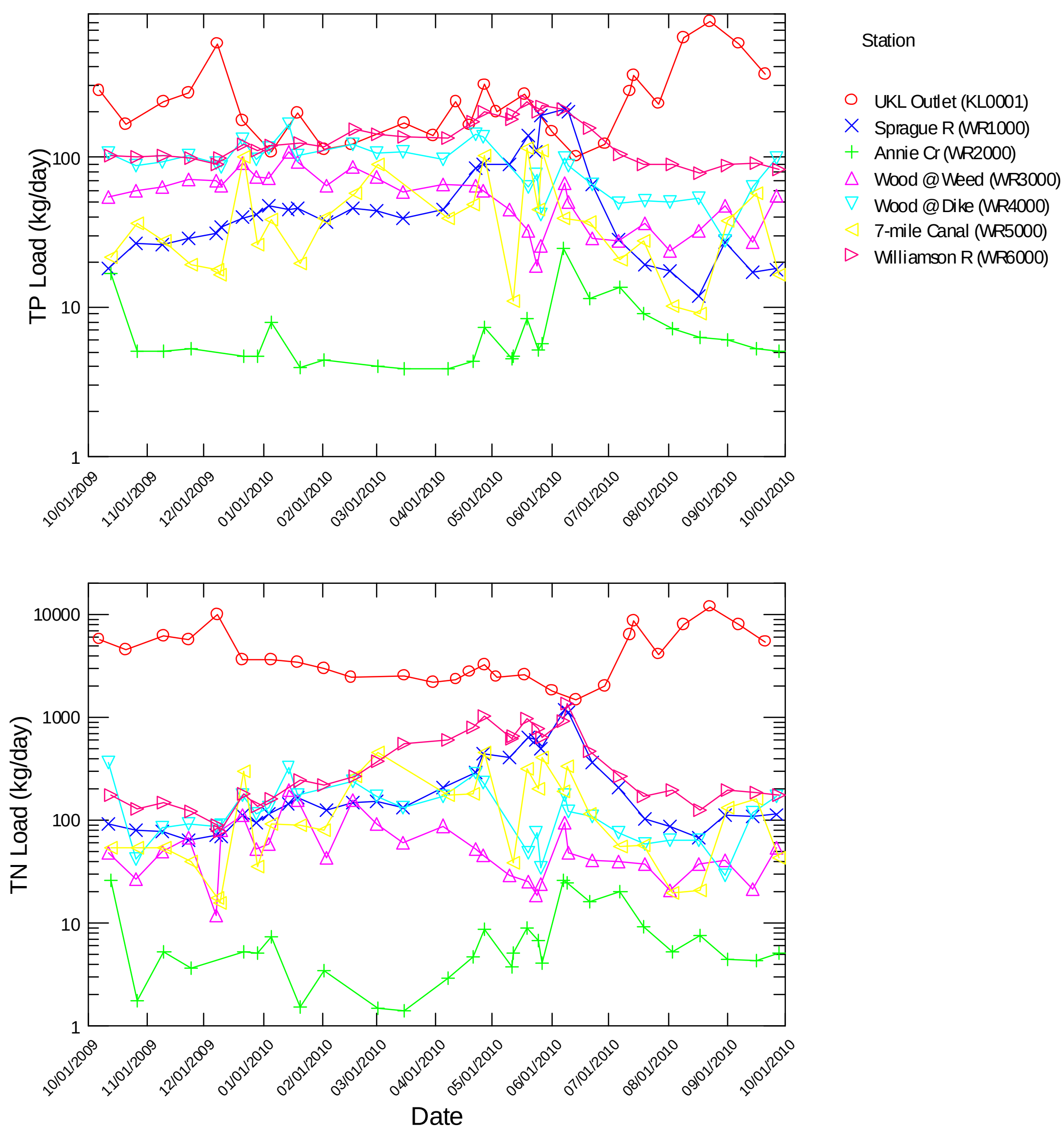


Figure 5. Seasonal TP and TN loading trends by station, HY 2010.

2010 Station Patterns

The 2010 nutrient loading pattern among stations was also similar to that of the 1991-2009 sampling period (Figure 6). Also, as indicated above, TP and TN outflow loads were higher than any individual inflow tributary loads during both 2010 and for the overall time period (1991-2009). Outflow TP and TN loads were lower overall during 2010 than they were for the previous 1991-2009 period. As noted above, high UKL outlet loads likely reflect internal loading and nitrogen fixation processes taking place in UKL.

Of the inflow tributaries, the Williamson River (WR6000) showed highest overall loading due largely to its higher discharge, with the 2010 TP and TN loading distributions somewhat lower than previous years. As with concentration, Annie Creek at Snow Park was consistently lower for both loading parameters. Sprague River TN load was more similar to the Williamson River TN load than it was for TP load (which was lower in the Sprague when compared to the Williamson), indicating that the Sprague River is contributing proportionally more nitrogen to the overall load. TP and TN loading patterns in both the Williamson and Sprague Rivers tended to follow the general pattern in discharge; however, loading was more closely linked to discharge in the Sprague River than in the Williamson River (Figure 7).

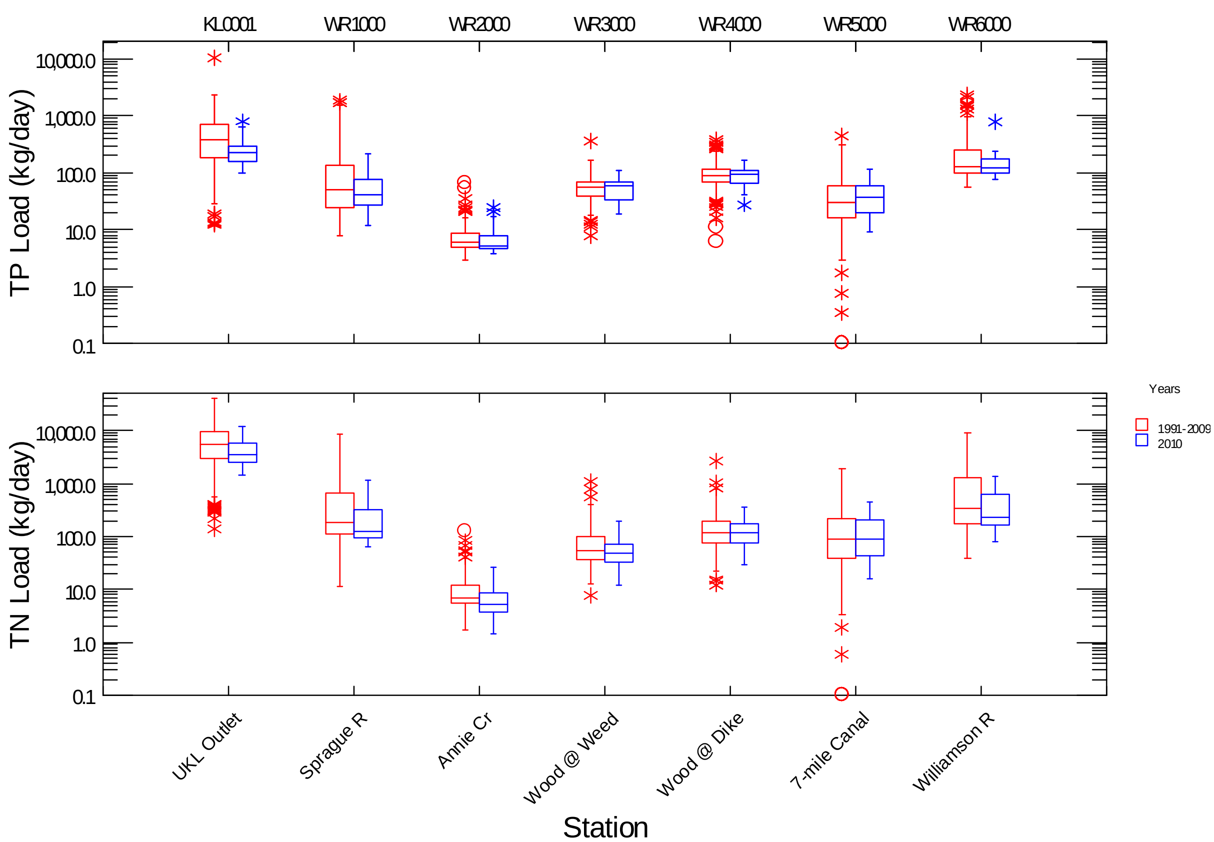


Figure 6. Station distributions of TP and TN loading compared between 1991-2009 (red) and 2010 (blue). Note for station KL0001: in HY2006, there are no samples from January to mid-April and in HY2007-2009 there are no samples from November to mid-April.

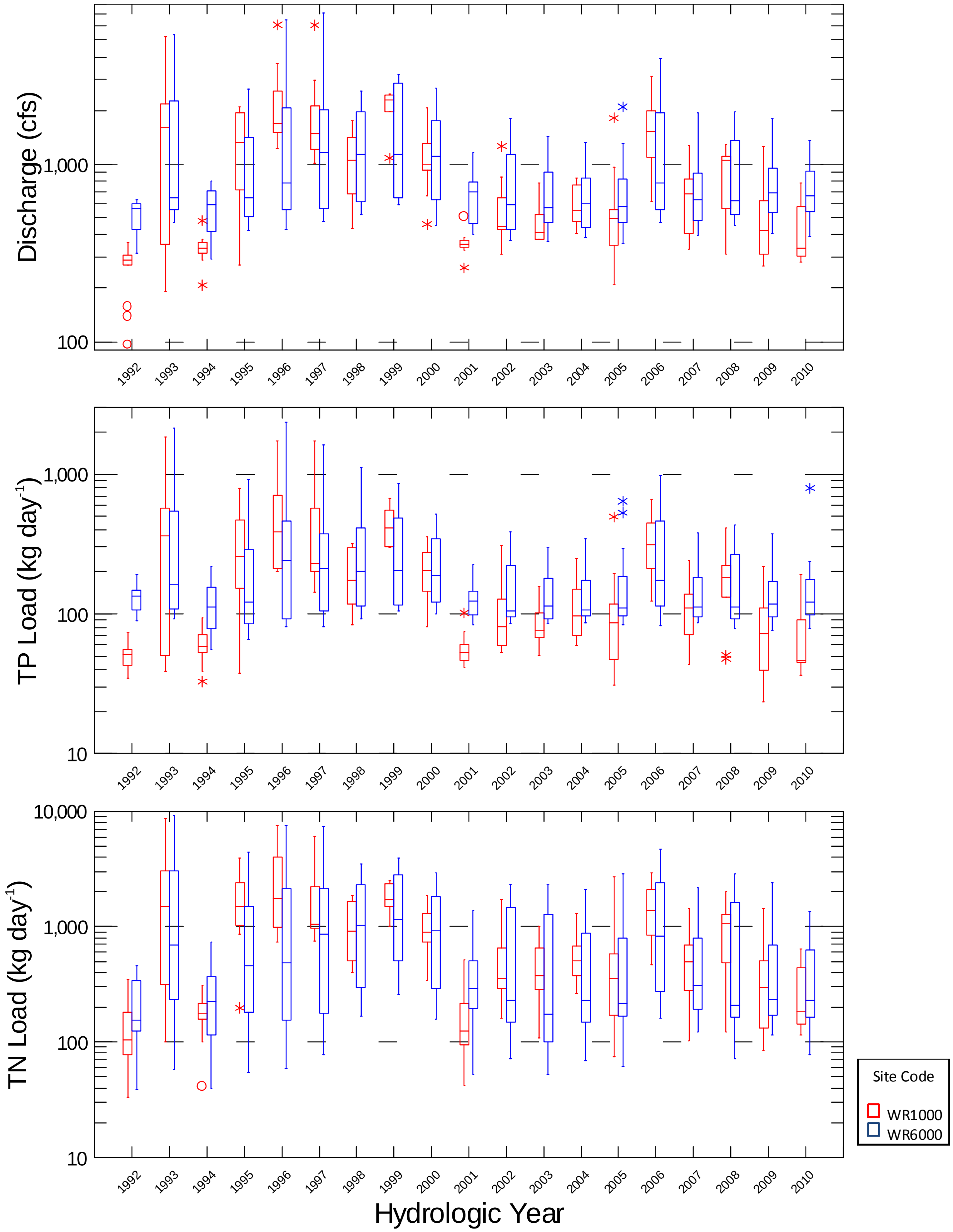


Figure 7. Distribution of Williamson River (WR6000) and Sprague River (WR1000) daily discharge (top panel), TP load (middle panel), and TN load (bottom panel) for the January-May inflow period, 1990-2010.

Inter-annual Patterns, 1991-2010

Although it is beyond the scope of this 2010 data summary report to analyze the inter-annual trends in detail, 1992-2010 comparisons for all sampling stations for three periods (all dates, the June-September period, and the Jan-May period) are shown for reference in Figures 8 to 21.

UKL outflow TP and TN loads during Jun 1-Sep 30, 2010 were noticeably lower than all previous years (Figure 8 and Figure 15). 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. June-September TP and TN loading distributions for the Sprague River (Figure 9 and Figure 16), although higher in 2010 than in 2009, were among the lower end of distributions for the period of record. The January-May Sprague River TP and TN loading distributions were also among the lowest for the period of record. Williamson River TP and TN loading distributions were intermediate for the June-September period, and among the lowest for the January through May period (Figure 14 and Figure 21).

TP and TN loading distributions for the Wood River stations during 2010 also tended to be among the lowest for the period of record for all periods (Figure 11, Figure 12, Figure 18, Figure 19). In contrast, Seven Mile Canal loading during 2010 was similar to previous years (Figure 13 and Figure 20). Over all loads for Annie Creek during the Jan-May period also tended to be lower than previous years (Figure 10 and Figure 17). In general, hydrologic loading as indicated by Williamson River discharge (Figure 7) appears to account for much of the inter-annual variability in nutrient loading.

Further inter-annual comparisons 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., Walker and Havens 2003). A comprehensive analysis of time-series trends as well as hydrologic and nutrient budgets for UKL is currently funded with completion scheduled for summer 2011.

SUMMARY

With the addition of 2010 data, the UKL tributary nutrient and loading database now includes 20 years of data and includes the years 1991-2010. 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. As noted above, a comprehensive analysis of the long-term UKL tributary database including statistical time series, an assessment of the relationship between controlling variables (e.g., climate) and loading parameters, and construction of hydrologic and nutrient budget updates for UKL is forthcoming.

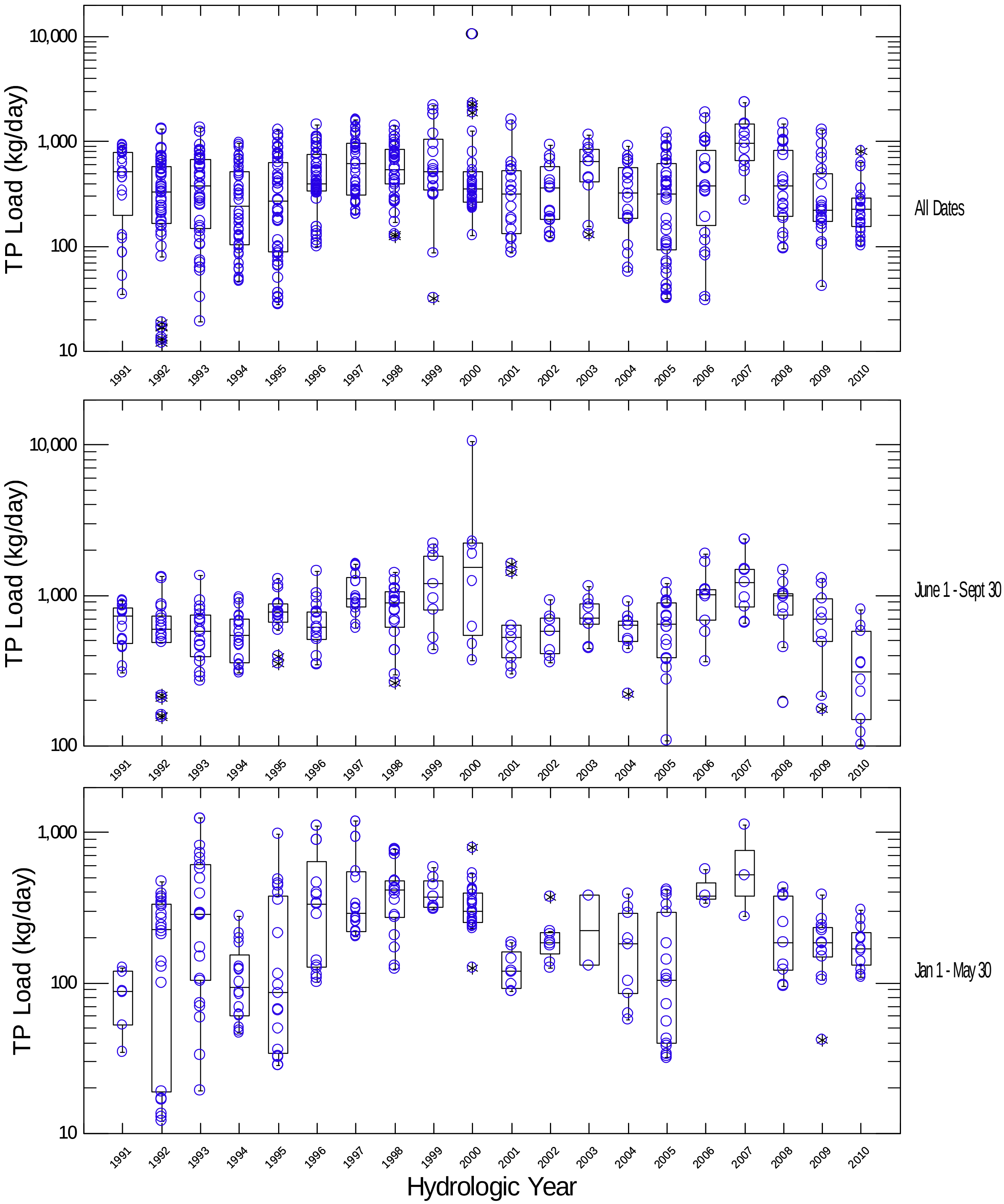


Figure 8. Annual and seasonal distributions of UKL Outlet TP loading, 1991-2010. Note: in HY2006, there are no samples from January to mid-April and in HY2007-2008 there are no samples from November to mid-April.

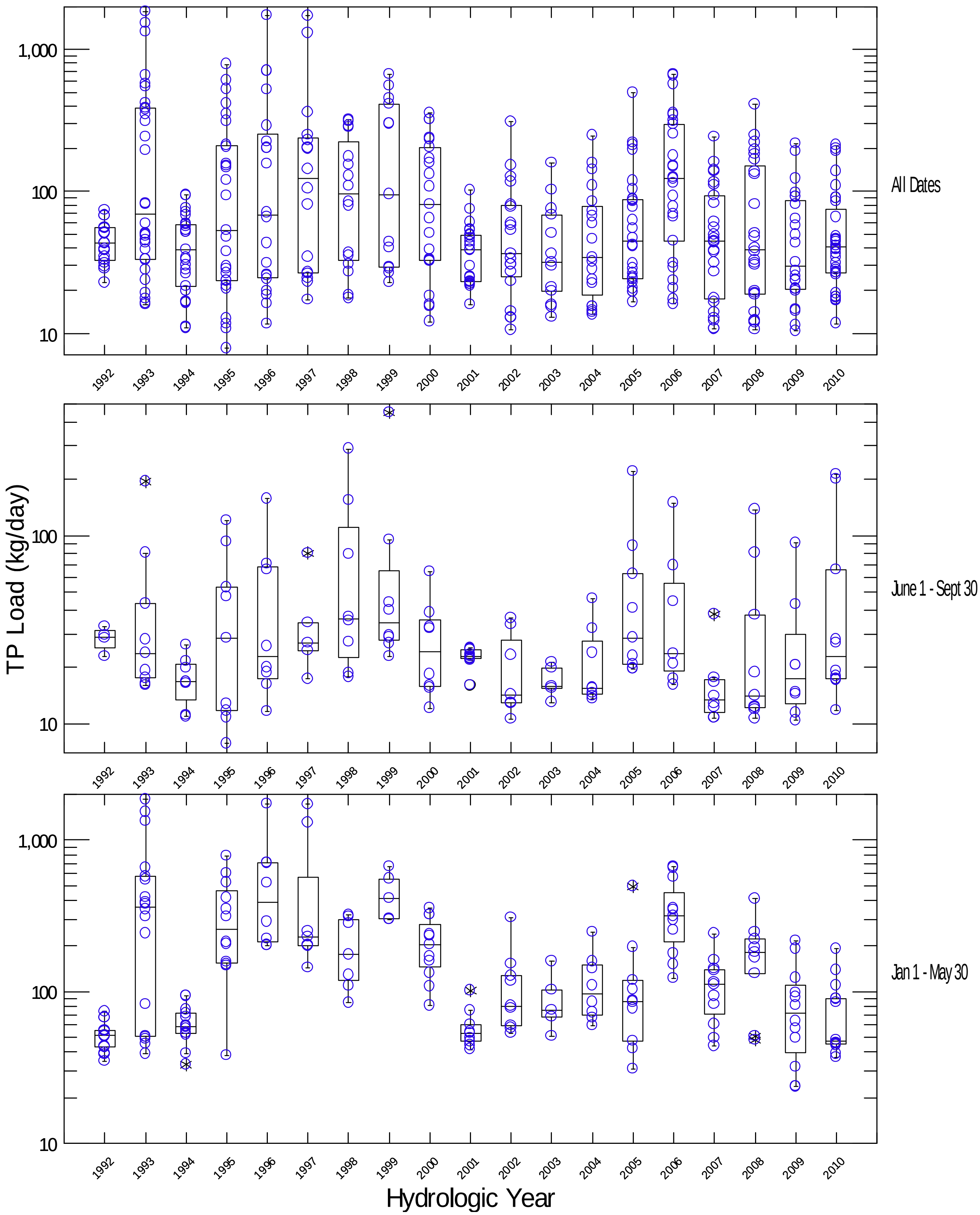


Figure 9. Annual and seasonal distributions of Sprague River TP loading, 1991-2010.

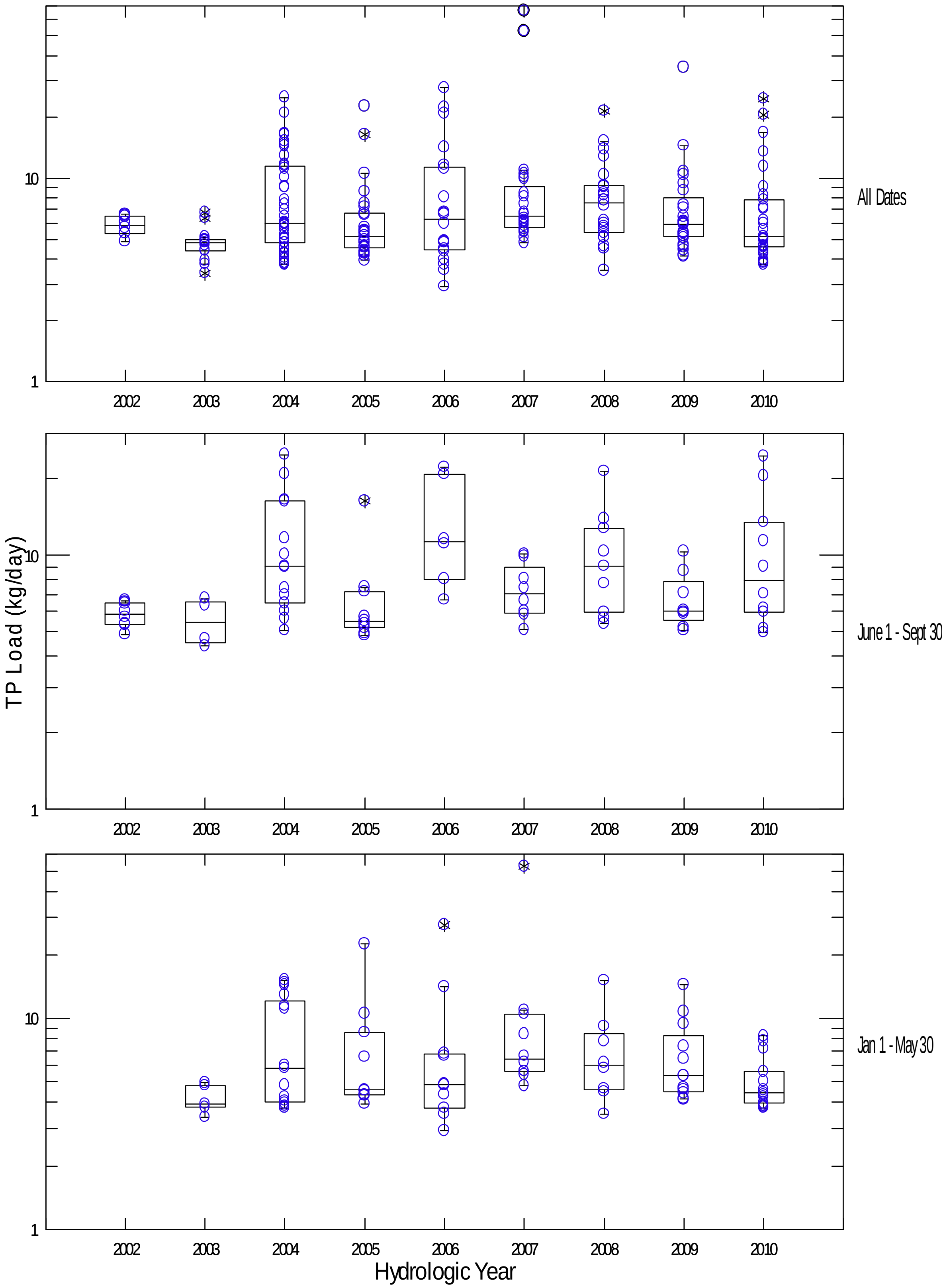


Figure 10. Annual and seasonal distributions of Annie Creek TP loading, 2003-2010.

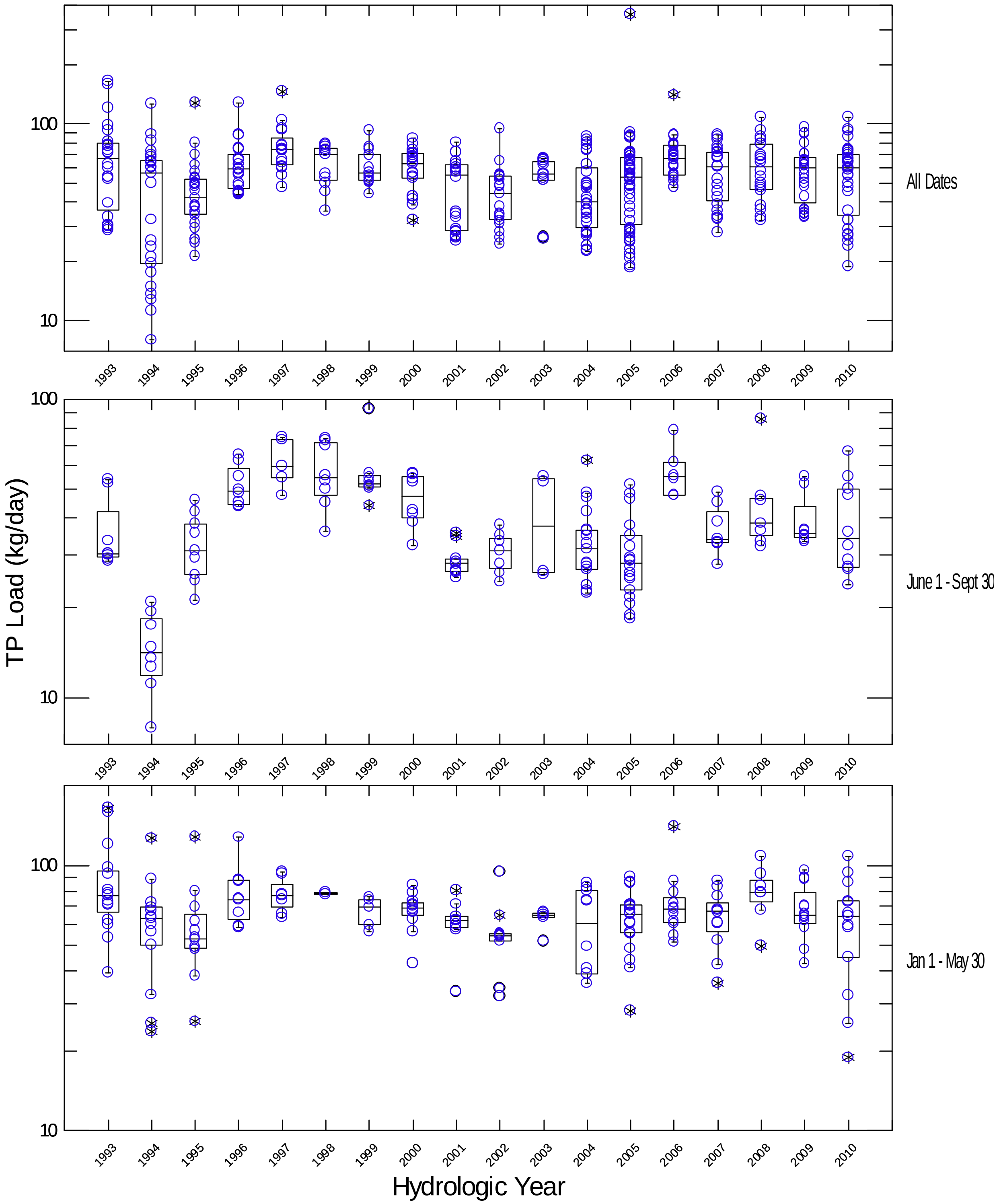


Figure 11. Annual and seasonal distributions of Wood River at Weed Rd. TP loading, 1991-2010.

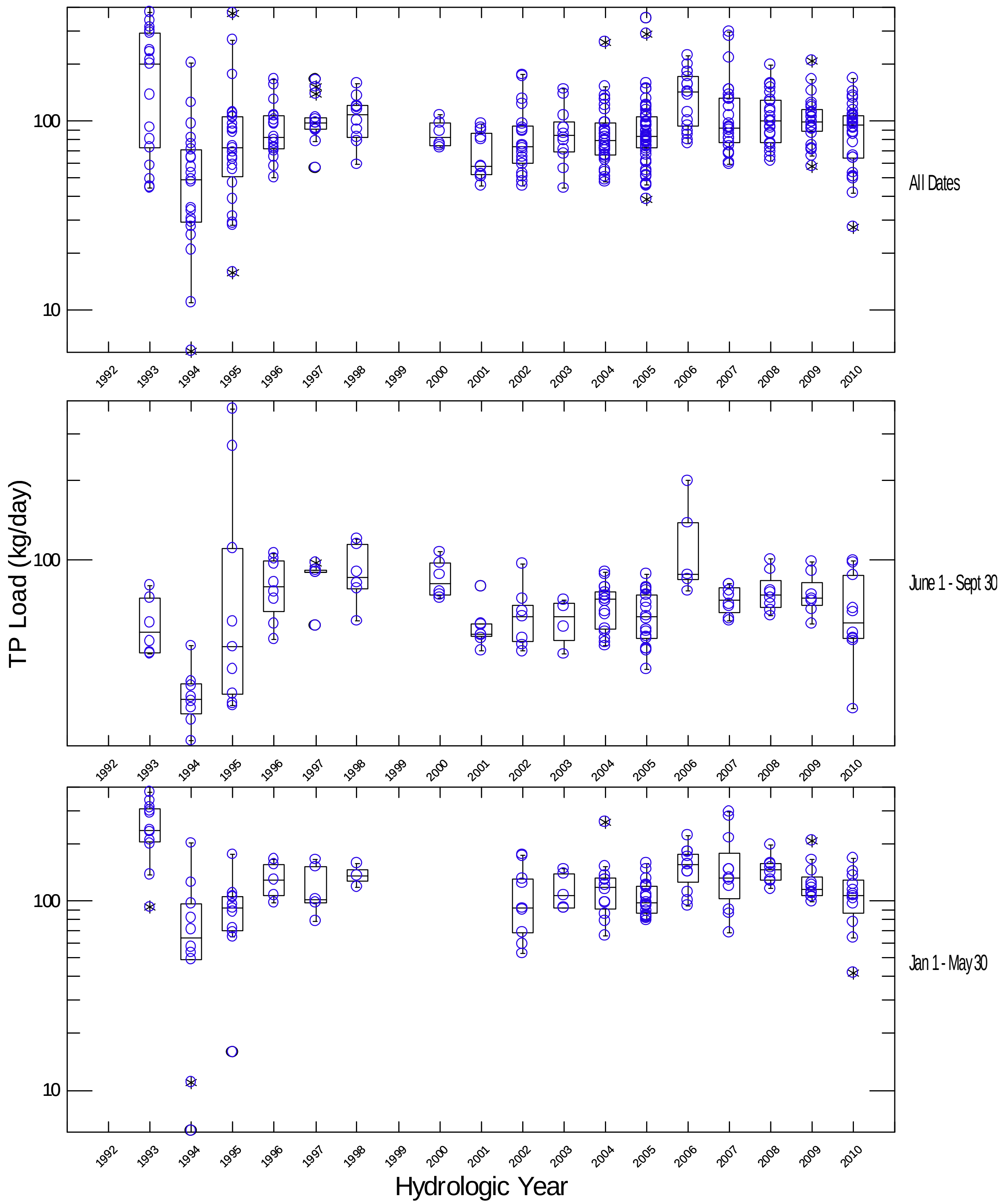


Figure 12. Annual and seasonal distributions of Wood River at Dike Rd. TP loading, 1991-2010.

TP Loads at Seven-Mile Canal at Dike Rd (WR5000) HY1991-2010

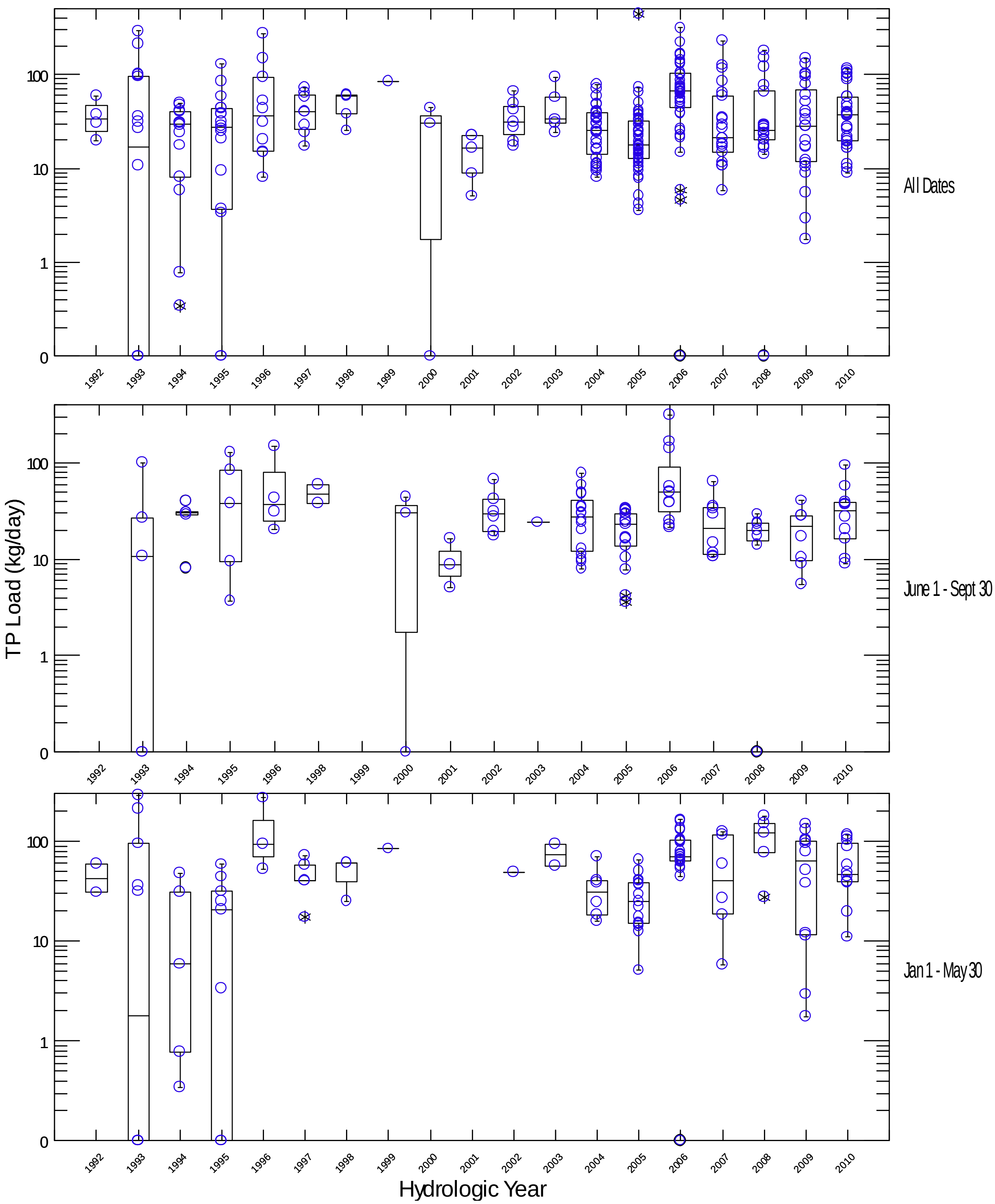


Figure 13. Annual and seasonal distributions of Seven Mile Canal TP loading, 1991-2010. Note that occurrences of zero load are due to lake-backwater effects when no flow is measured at the sampling location

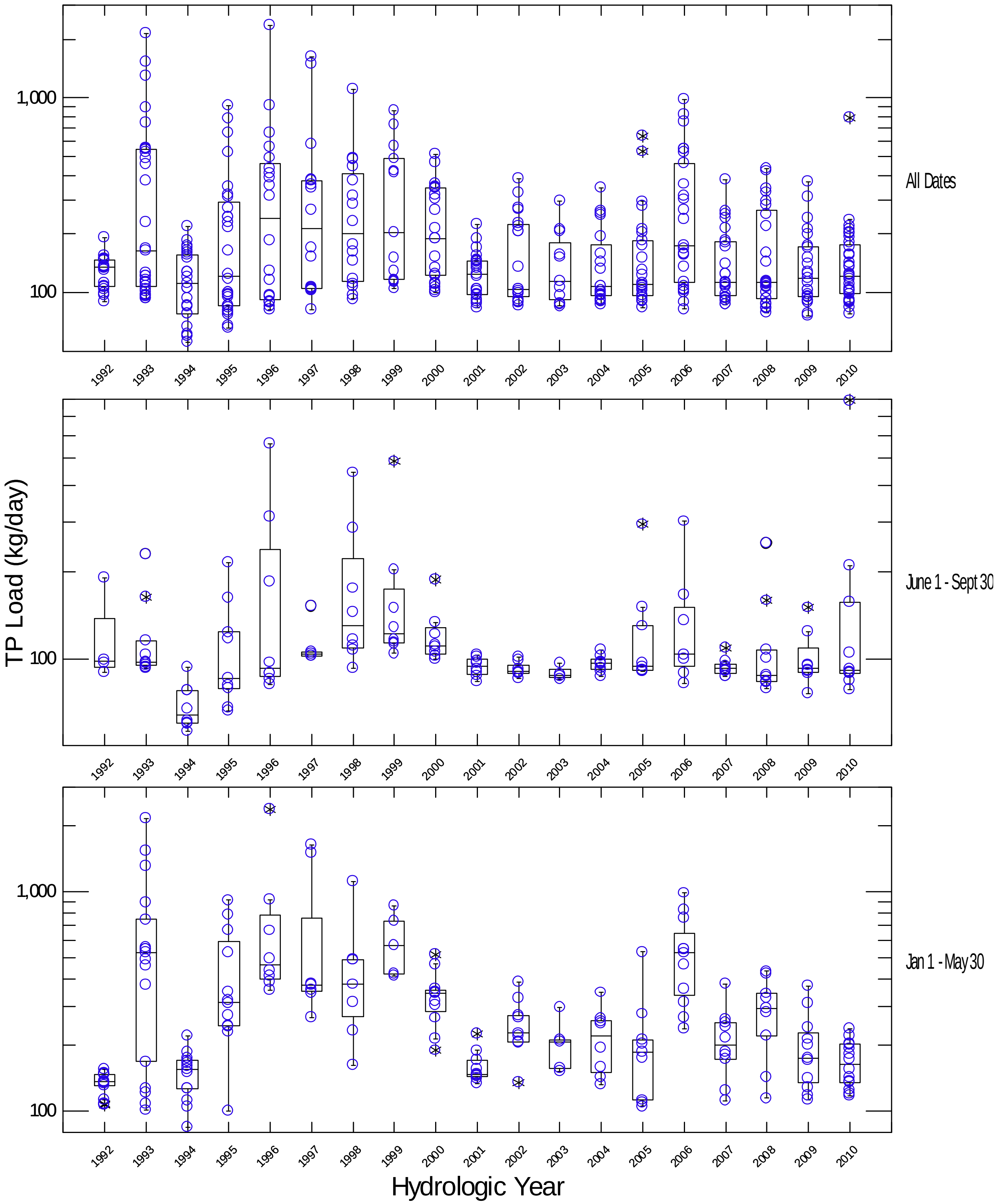


Figure 14. Annual and seasonal distributions of Williamson River TP loading, 1991-2010.

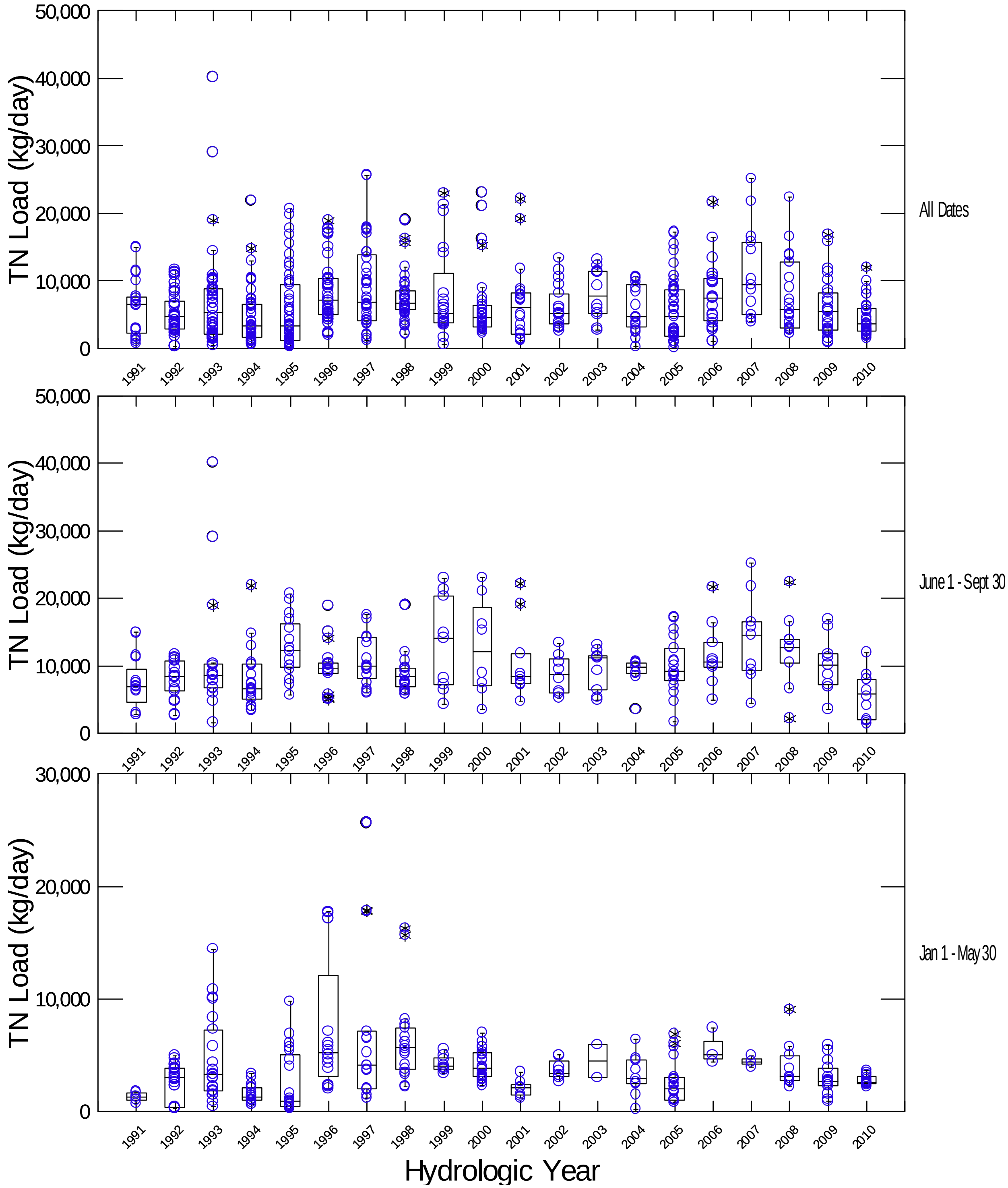


Figure 15. Annual and seasonal distributions of UKL Outlet TN loading, 1991-2010. Note: in HY2006, there are no samples from January to mid-April and in HY2007-2008 there are no samples from November to mid-April.

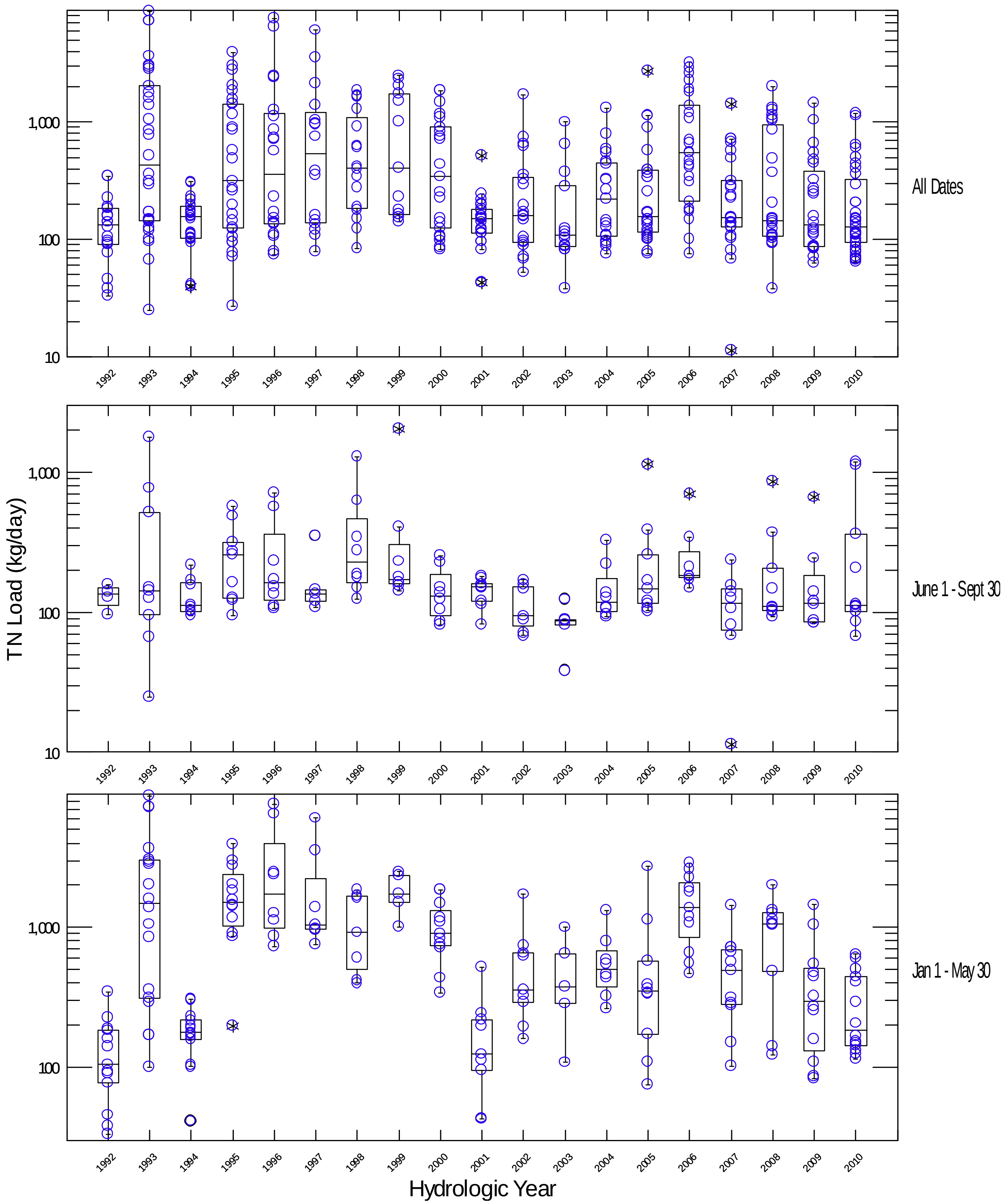


Figure 16. Annual and seasonal distributions of Sprague River TN loading, 1991-2010.

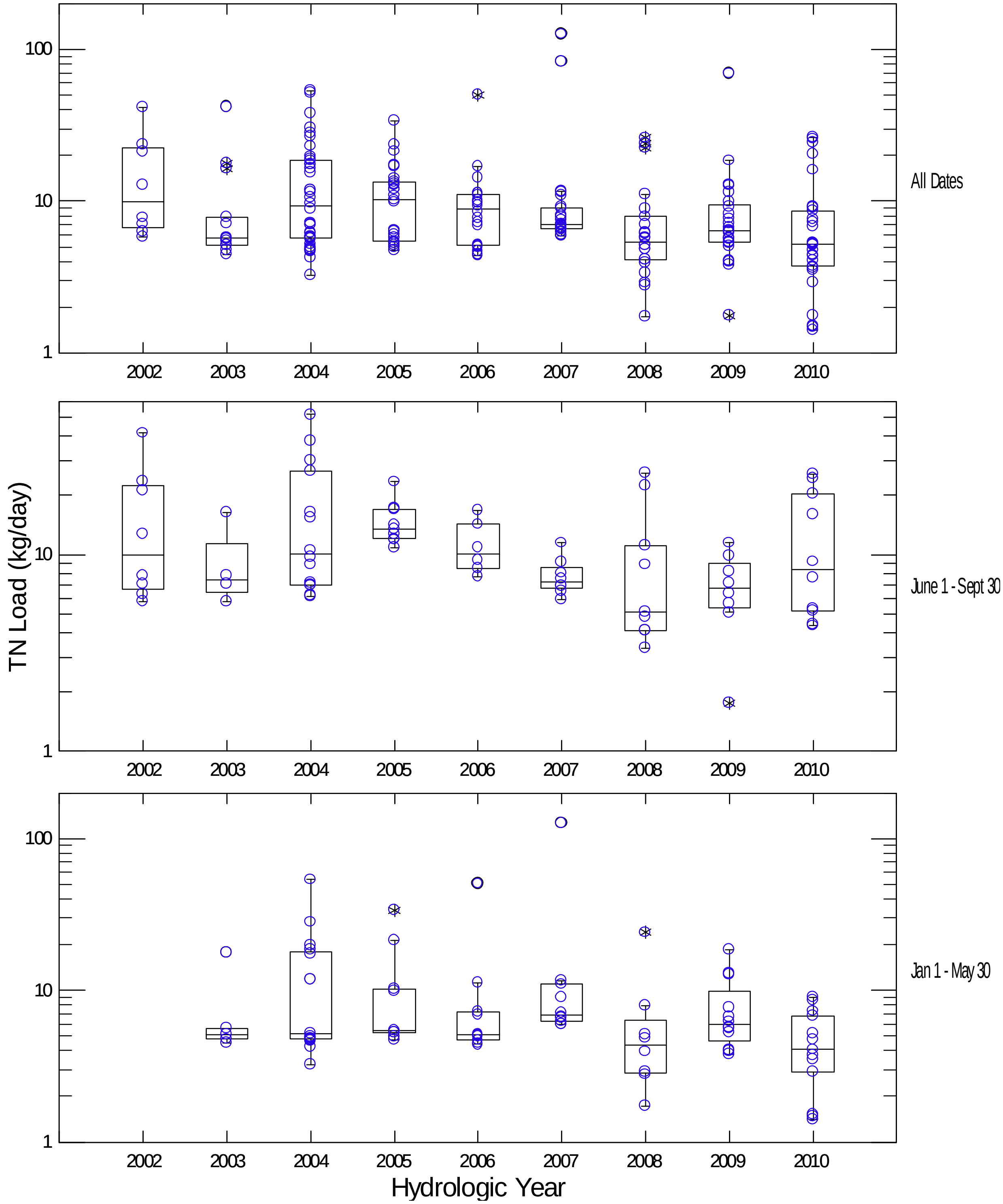


Figure 17. Annual and seasonal distributions of Annie Creek TN loading, 1991-2010.

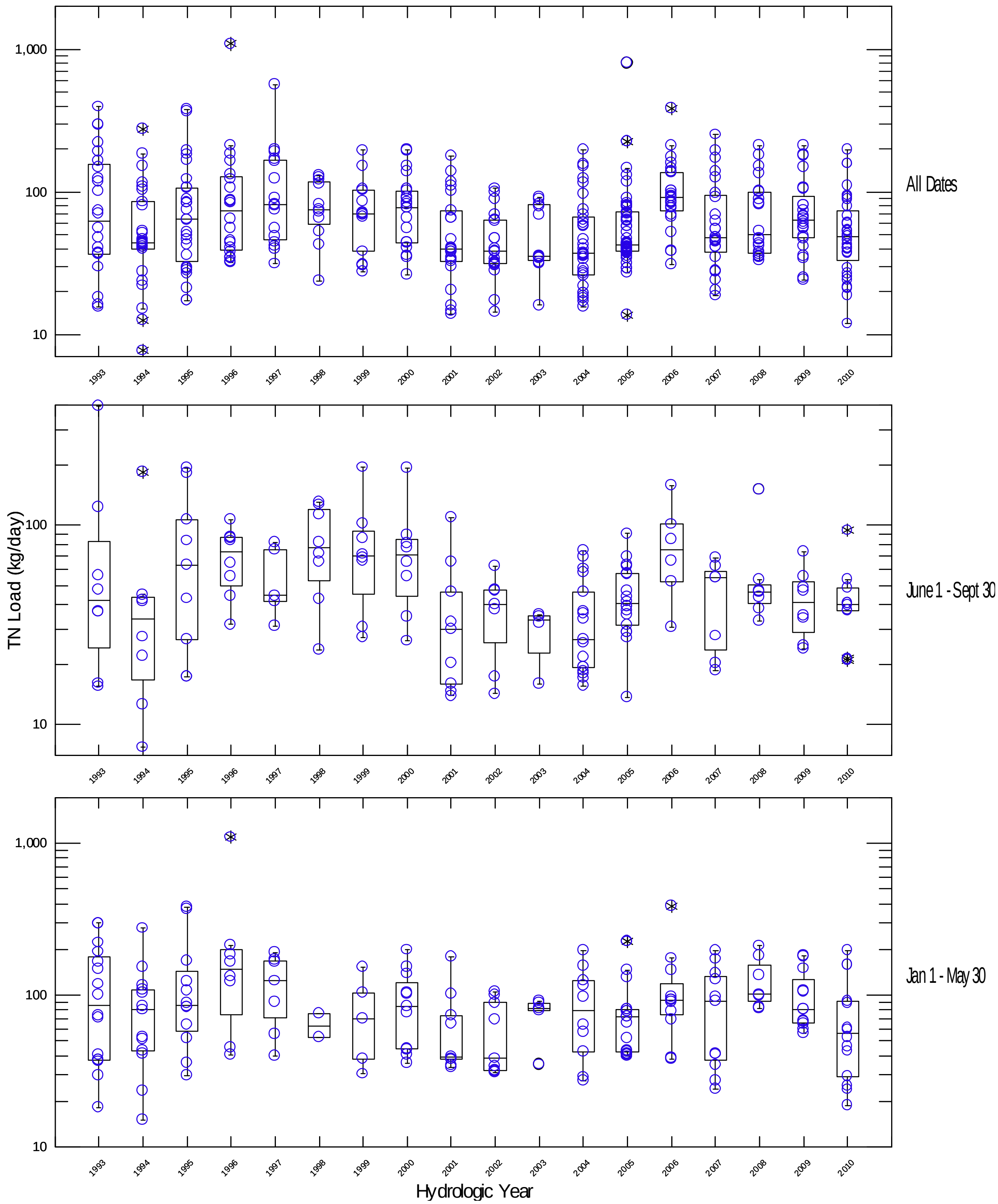


Figure 18. Annual and seasonal distributions of Wood River at Weed Rd. TN loading, 1991-2010.

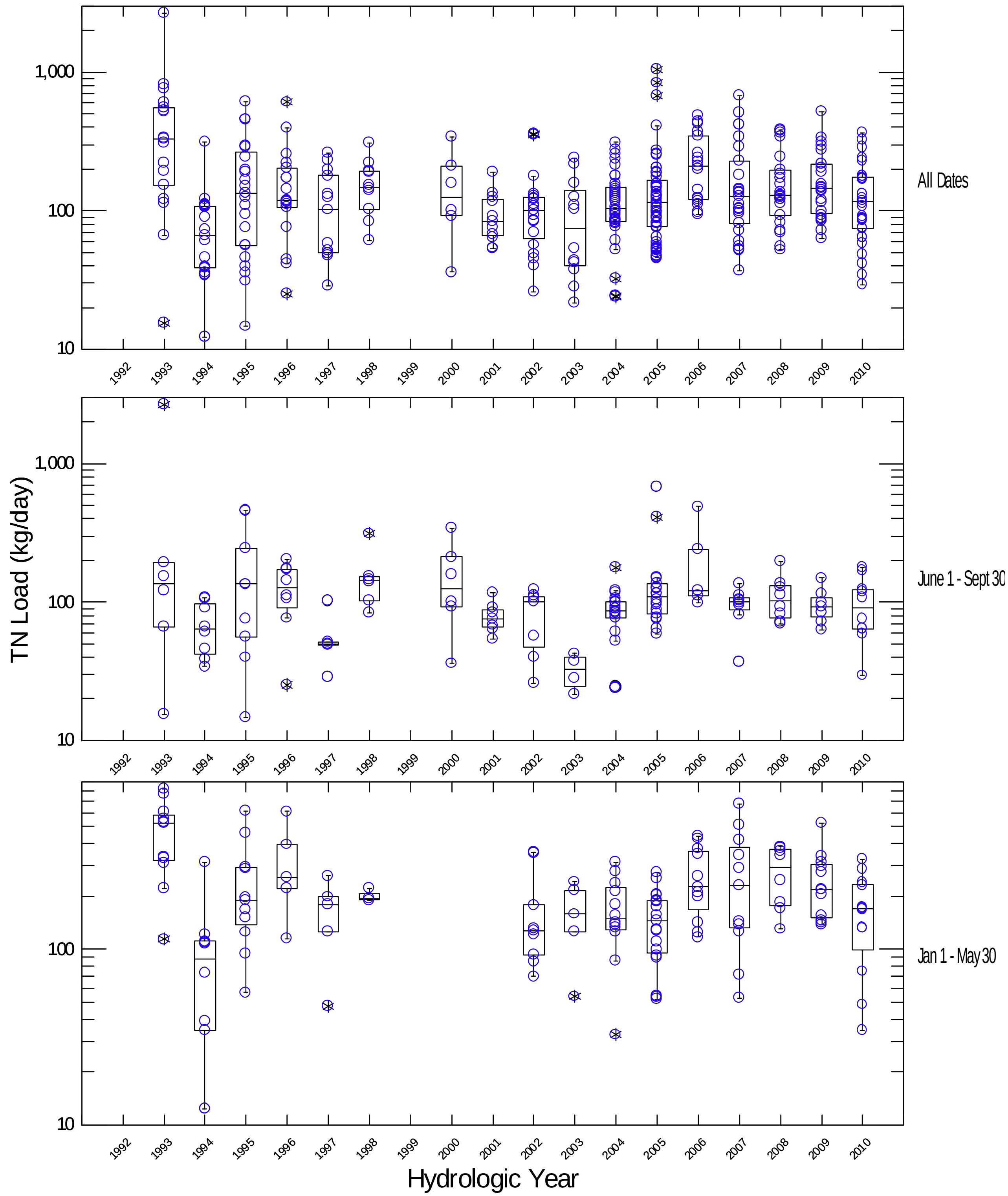


Figure 19. Annual and seasonal distributions of Wood River at Dike Rd. TN loading, 1991-2010.

TN Loads at Seven-Mile Canal at Dike Rd (WR5000) HY1991-2010

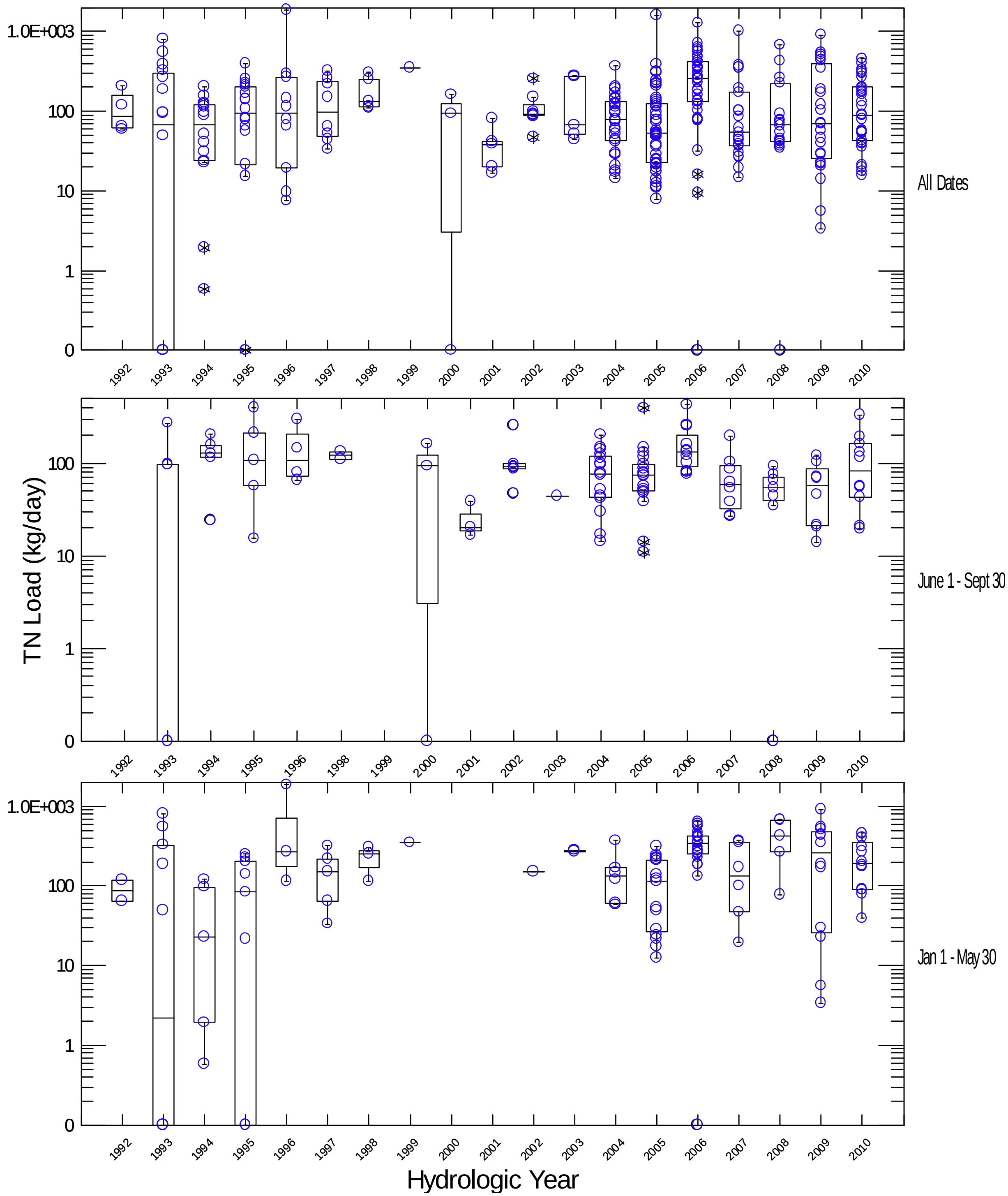


Figure 20. Annual and seasonal distributions of Seven Mile Canal TN loading, 1991-2010. Note that occurrences of zero load are due to lake-backwater effects when no flow is measured at the sampling location.

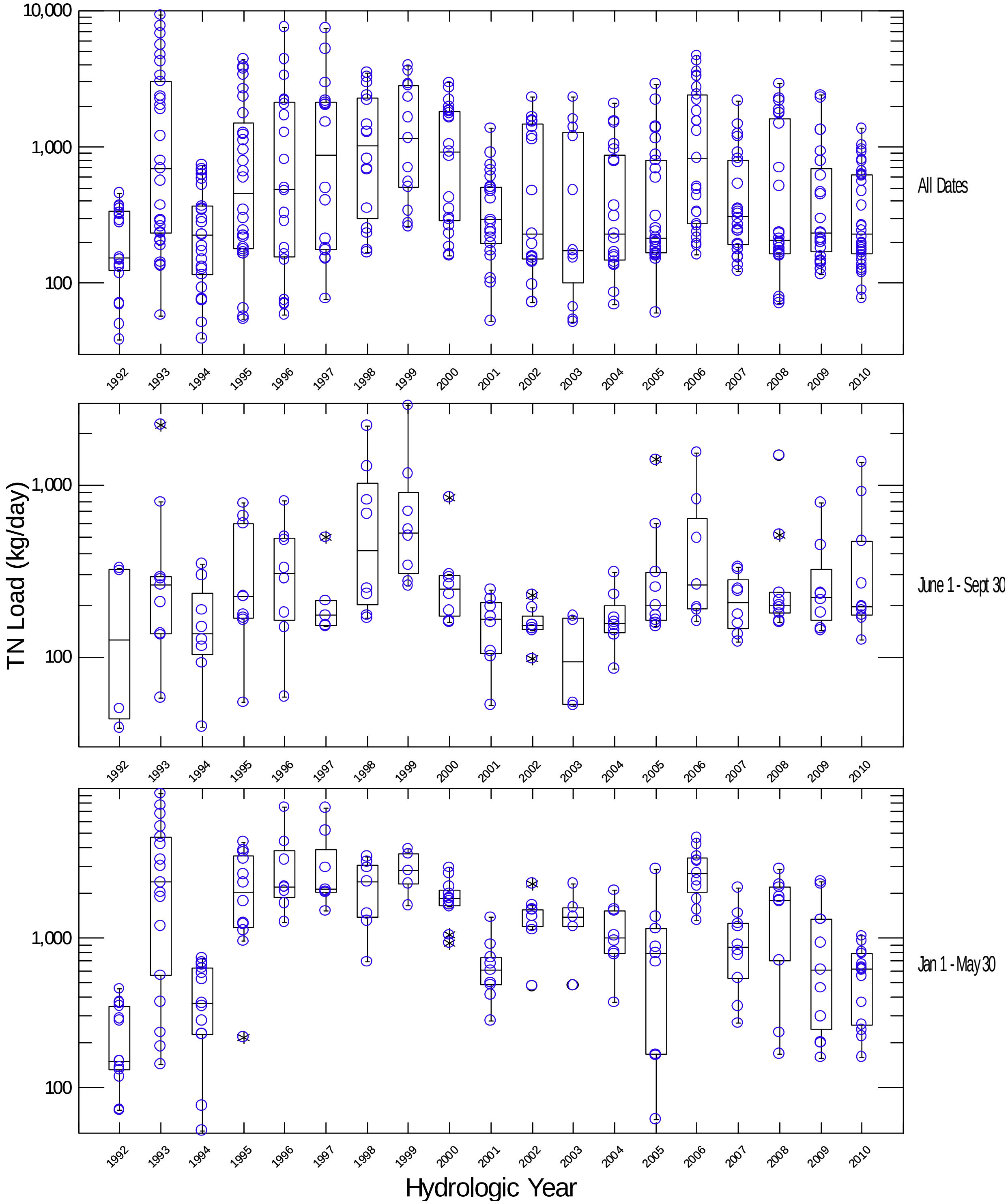


Figure 21. Annual and seasonal distributions of Williamson River TN loading, 1991-2010.

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