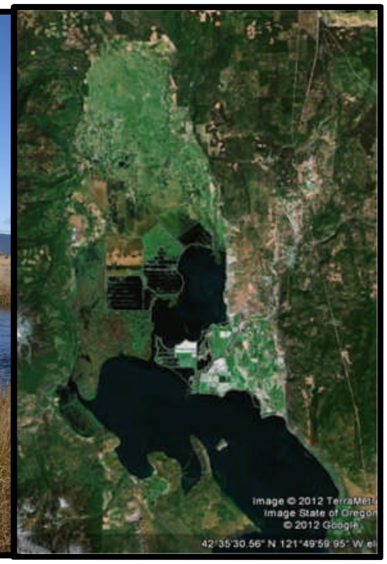
TECHNICAL MEMORANDUM

Upper Klamath Lake Tributary Loading: 2011 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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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 entire 1991-2010 database was evaluated for seasonal and inter-annual dynamics, long term trends, and both water and nutrient balances were computed (Walker et al. 2012). This report serves as an annual update to the UKL tributary water quality database, including a summary of 2011 data (basic summary statistics and graphical analysis), and limited comparison of graphical time-series trends of tributary data collected for the 1991-2011 period. Included in this summary is an update of previous UKL tributary water quality databases with data collected during 2011, including appropriate quality assurance analyses (*see Excel spreadsheets: Klamath Tribes Inflow Nutrient Data 1991-2000.xls and Klamath Tribes Inflow Nutrient-Q Data 2001-2011.xls*).

METHODS

Methods followed the Klamath Tribes established procedures for field collection and laboratory analysis of water quality parameters (see Klamath Tribes 2003 and Klamath Tribes 2006 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. Nutrient parameters (Table 1) were collected at seven tributary stations during the 2011 sampling season at an approximately biweekly frequency (Table 2; Figure 1). Specific nutrient loading methodology 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, 2011.

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, 2011.

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 @ Pelican Marina (UKL Outflow)	KL0002

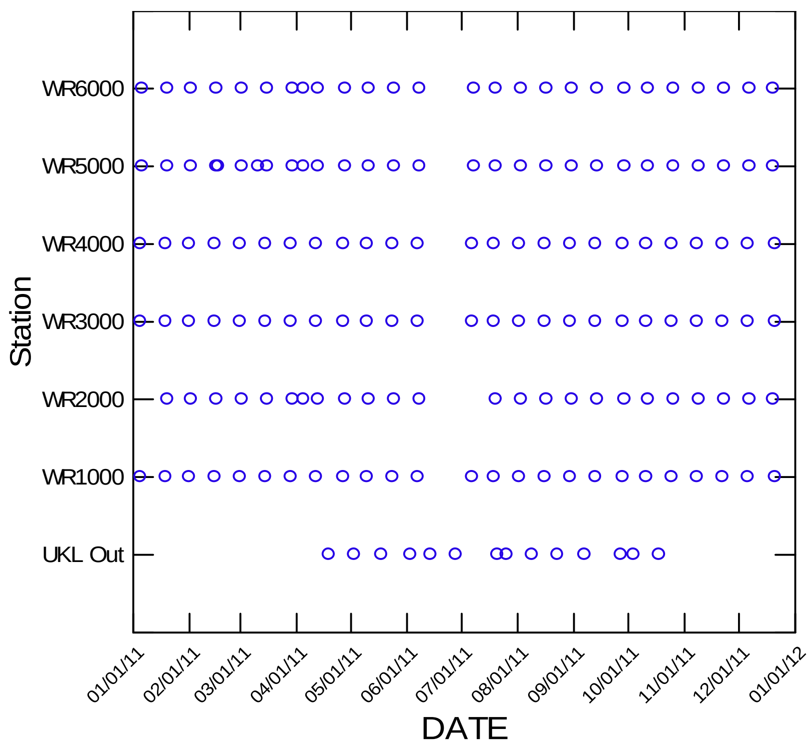

Figure 1. Spatial-temporal sampling matrix for Upper Klamath Lake tributaries, 2011.

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; 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 (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 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 and GMA (2004a; 2011a). Flow measurements coinciding with nutrient sample collection dates are shown in Figure 2. 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.

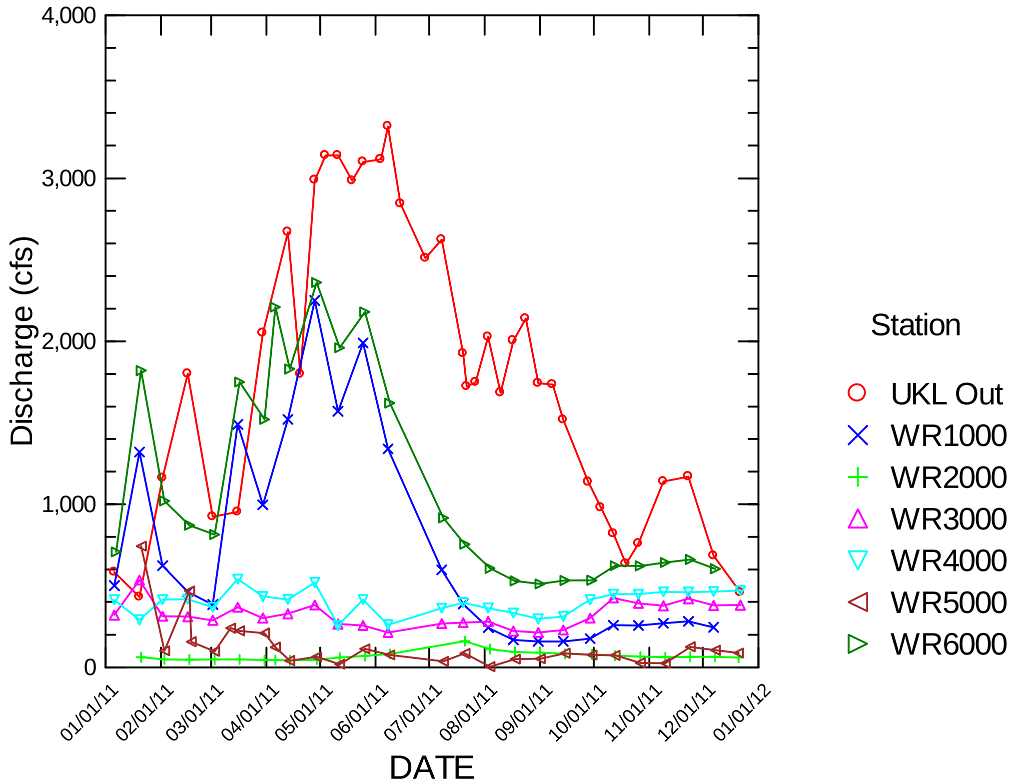

Figure 2. Flow (cfs) measurements coinciding with nutrient sample collection dates, 2011. Flow shown only for dates that nutrient data exist with the exception of UKL Out because nutrient data during the winter months were not available (flow values are shown for dates corresponding to nutrient collection at other stations).

The total phosphorus (TP) and total nitrogen (TN) mass (kg/day) for each 2011 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 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 @ Link Bridge are not available, this caused significant 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 USBR along with limited data collected by PacifiCorp during the winter of 2009 and 2010 (Excel spreadsheets: *KRWQ2007-2010KLLD.xls* and *Pacificorpdata2009-2010.xlsx*). However, 2011 winter outflow data have not yet been provided by USBOR; as of WY 2012 the Klamath Tribes are again sampling the outflow. Loading graphs and summaries are computed based on the October-September hydrologic water year (denoted HY in below plots).

RESULTS/DISCUSSION

Nutrient Concentration

The 2011 nutrient concentration pattern among inflow stations was similar to that of the 1991-2010 sampling period (Figure 3); total P and PO_4-P tended to be slightly 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 2003-2010) was consistently lower for all nutrient parameters except nitrate/nitrite among the inflow stations (Figure 3; Table 3).

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). Upper quartile values for NO_3-N were also higher at the UKL Outlet station than for inflow stations. Although in 2010 NH_4-N at the UKL Outlet was substantially higher than Seven Mile Canal, during 2011 and 2009 the UKL Outlet was similar to Seven Mile Canal (Kann 2011) (Figure 3; Table 3).

Although in 2011 the inter-quartile range for TP concentration was somewhat higher at Annie Creek, the Wood River stations, and the Williamson River, there were fewer extreme values when compared to the long-term 1991-2010 distribution (Figure 3). The distributions of Outflow and Sprague River SRP concentration were noticeably lower in 2011, and although other stations were similar to the long-term distribution, as with TP there were fewer extreme values. Other notable departures from the long-term distribution include overall lower Outflow TN, higher Sevenmile Canal TN and lower Outflow NH_4-N (Figure 3). Comparisons of ammonia and nitrate-nitrite between 2011 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[1]. 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.

Similar to 2010, time series plots of the 2011 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 4). 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; a pattern similar to 2010. However, for PP, Sprague River concentrations were often among the highest, but declined during the low-flow summer period (Figure 4). TP, PO_4, PP, TN, and NH_4 at the UKL Outflow station all increased relative to the inflow stations during the summer algal growing season. However, the increase in nutrients was most predominant in August, whereas in 2010 nutrients increased at the UKL Outflow station mainly in July.

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[1] Aquatic Research Inc. indicated a reporting limit of 10 µg/L; the SRWQL utilizes a reporting limit of 12 µg/L.

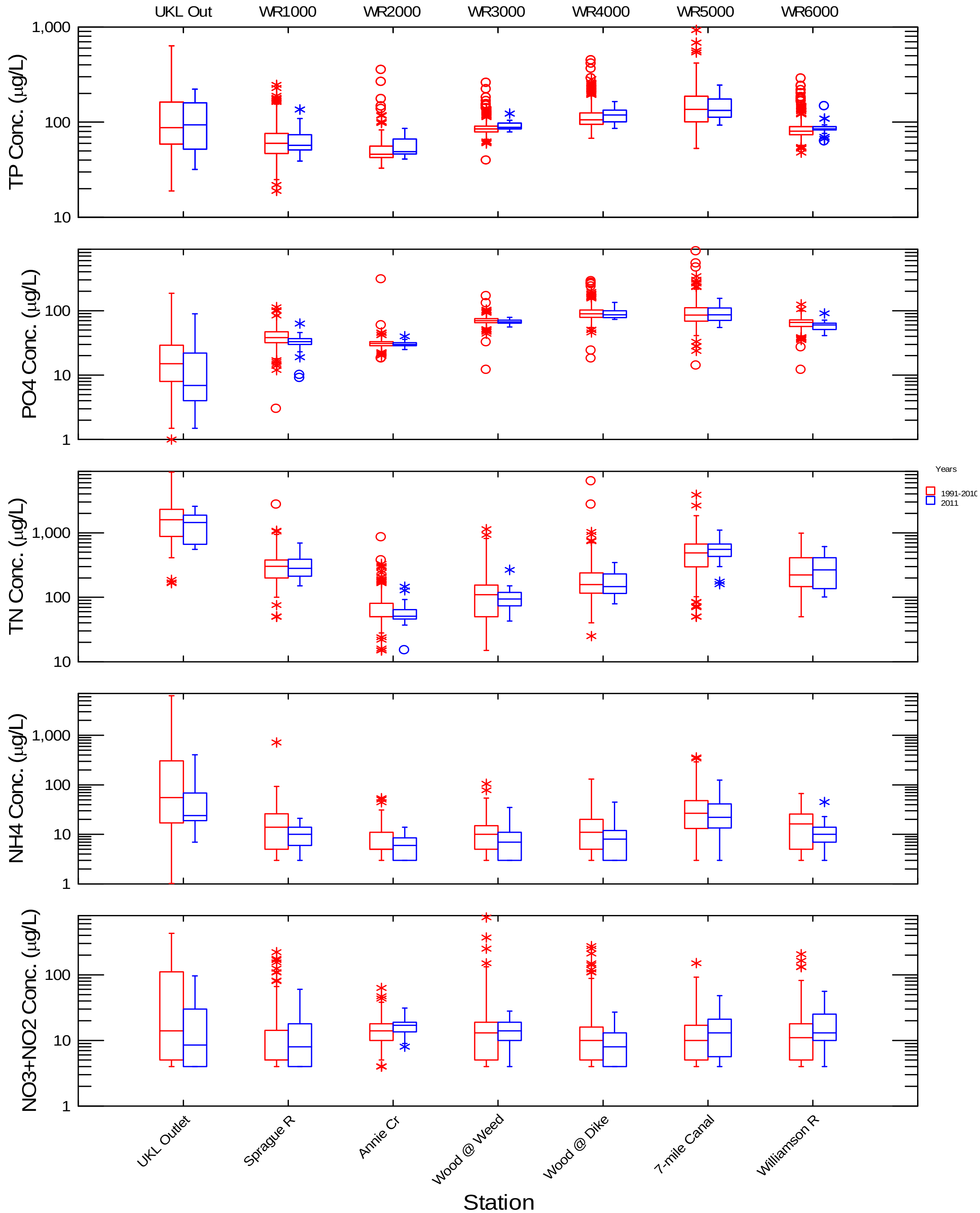

Figure 3. Station distributions of TP, SRP, TN, NH4-N, and NO3+ NO2-N concentration (µg/L) compared between 1991-2010 (red) and 2011 (blue).

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 2011.

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)
UKL Out	UKL Outlet	N of Cases	14	14	14	14	14	14	14
UKL Out	UKL Outlet	Median	95	7	1450	24	9	360	5056
UKL Out	UKL Outlet	Arithmetic Mean	107	21	1375	85	27	462	5824
UKL Out	UKL Outlet	Pct25	52	4	663	19	4	291	4072
UKL Out	UKL Outlet	Pct75	160	22	1870	68	30	723	6704
WR1000	Sprague R	N of Cases	25	25	25	25	25	25	25
WR1000	Sprague R	Median	57	33	280	10	8	64	245
WR1000	Sprague R	Arithmetic Mean	65	33	320	10	16	139	716
WR1000	Sprague R	Pct25	51	30	211	5	4	32	115
WR1000	Sprague R	Pct75	75	37	398	14	19	238	1197
WR2000	Annie Cr	N of Cases	23	23	23	23	23	23	23
WR2000	Annie Cr	Median	49	30	51	6	17	6	7
WR2000	Annie Cr	Arithmetic Mean	57	31	61	6	17	10	11
WR2000	Annie Cr	Pct25	46	28	46	3	13	5	5
WR2000	Annie Cr	Pct75	67	32	66	9	19	13	10
WR3000	Wood @ Weed	N of Cases	25	25	25	25	25	24	24
WR3000	Wood @ Weed	Median	88	67	94	7	14	66	65
WR3000	Wood @ Weed	Arithmetic Mean	92	67	100	8	15	67	79
WR3000	Wood @ Weed	Pct25	85	64	74	3	10	59	50
WR3000	Wood @ Weed	Pct75	98	71	119	11	19	72	89
WR4000	Wood @ Dike	N of Cases	25	25	25	25	25	24	24
WR4000	Wood @ Dike	Median	119	86	147	8	8	104	152
WR4000	Wood @ Dike	Arithmetic Mean	118	91	182	10	10	111	175
WR4000	Wood @ Dike	Pct25	99	78	115	3	4	95	123
WR4000	Wood @ Dike	Pct75	135	101	244	12	14	123	198
WR5000	7-mile Canal	N of Cases	27	27	27	27	27	26	26
WR5000	7-mile Canal	Median	133	86	555	22	13	30	101
WR5000	7-mile Canal	Arithmetic Mean	147	92	546	31	15	43	189
WR5000	7-mile Canal	Pct25	112	70	427	13	5	21	55
WR5000	7-mile Canal	Pct75	177	111	677	42	22	59	217
WR6000	Williamson R	N of Cases	25	25	25	25	25	25	25
WR6000	Williamson R	Median	85	60	267	10	13	177	651
WR6000	Williamson R	Arithmetic Mean	88	59	287	12	19	255	1000
WR6000	Williamson R	Pct25	82	51	136	7	10	117	204
WR6000	Williamson R	Pct75	90	64	420	14	28	367	1739

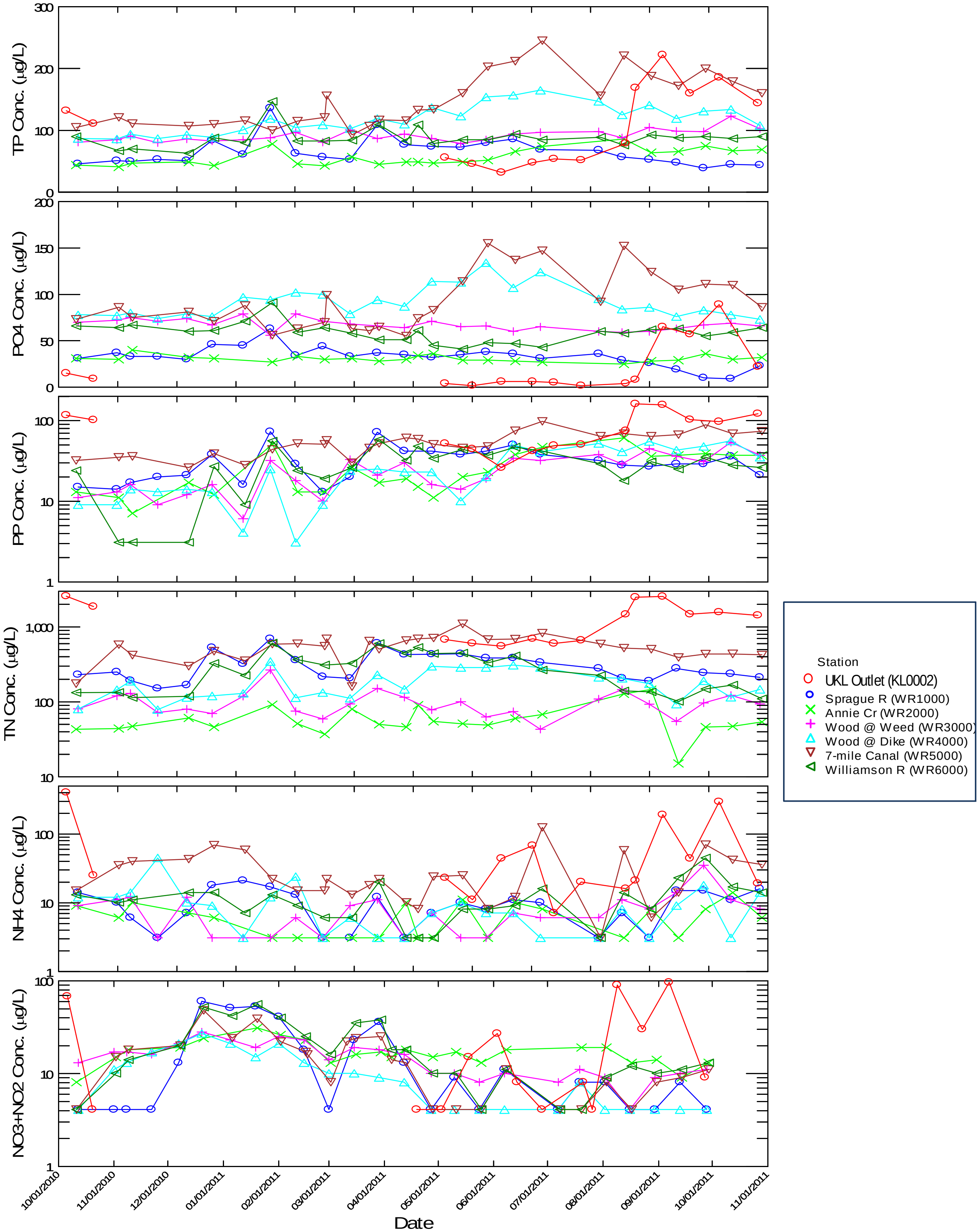

Figure 4. Time-series plot of nutrient concentrations for Upper Klamath Lake tributaries and outflow, 2011.

The TN:TP ratio at the UKL Outflow station was relatively high (TN:TP ≥ ~20) during the late fall of 2010, and similar to water year 2010 (see Kann 2011) ratios remained higher (TN:TP ≅ 10) than tributary stations through the season (Figure 5). Although winter data are missing for WY 2011, the overall pattern appears similar to 2009 and 2010 when the TN:TP ratio at UKL Outflow was higher (TN:TP ≅ 10) than tributary stations in April, increased during early summer bloom development, and declined through the bloom decline period before increasing again in September (Figure 5). The TIN:SRP ratio in the Outflow decreased from ~30 to ~3 during October of 2010, and aside from a decline to ~3 in early-June values were ~10-15 from April to mid-June, when values then declined somewhat through the summer growing season (Figure 5). 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 in particular showed very low TIN:SRP ratios (<0.3).

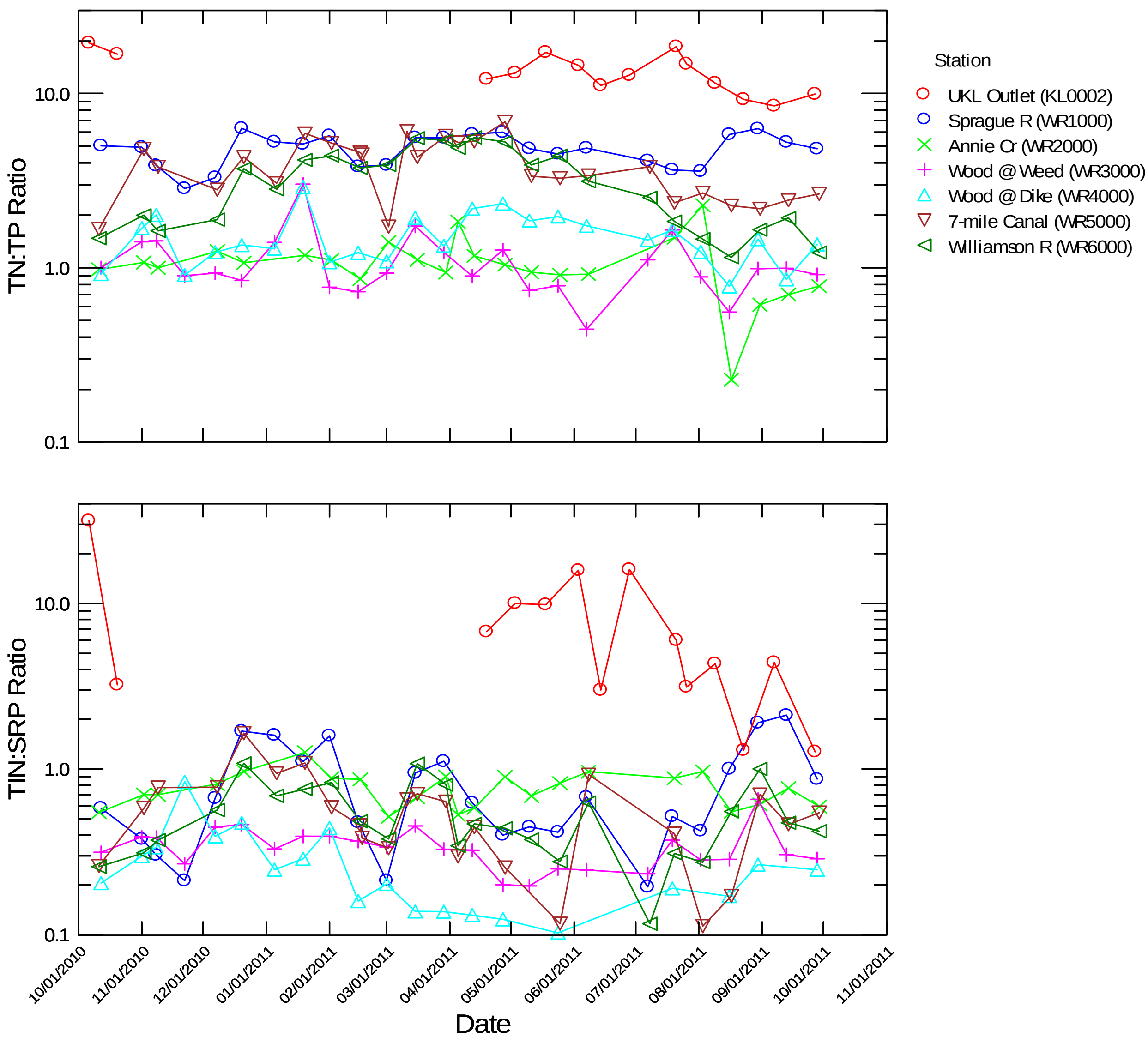

Figure 5. Total nitrogen to total phosphorus (TN:TP) and total inorganic nitrogen (NOx-N+NH_4-N) to PO_4 (TIN:SRP) ratios in Upper Klamath Lake tributaries and outflow stations, 2011.

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 available) show that both ratios (TP:TN and TIN:SRP) were always higher leaving UKL than they were in the Williamson River inflow (Figure 6). 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). Ratios rose in the outflow relative to inflow 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 trends over the 1991-2011 period. Further analysis is required to explore these apparent trends.

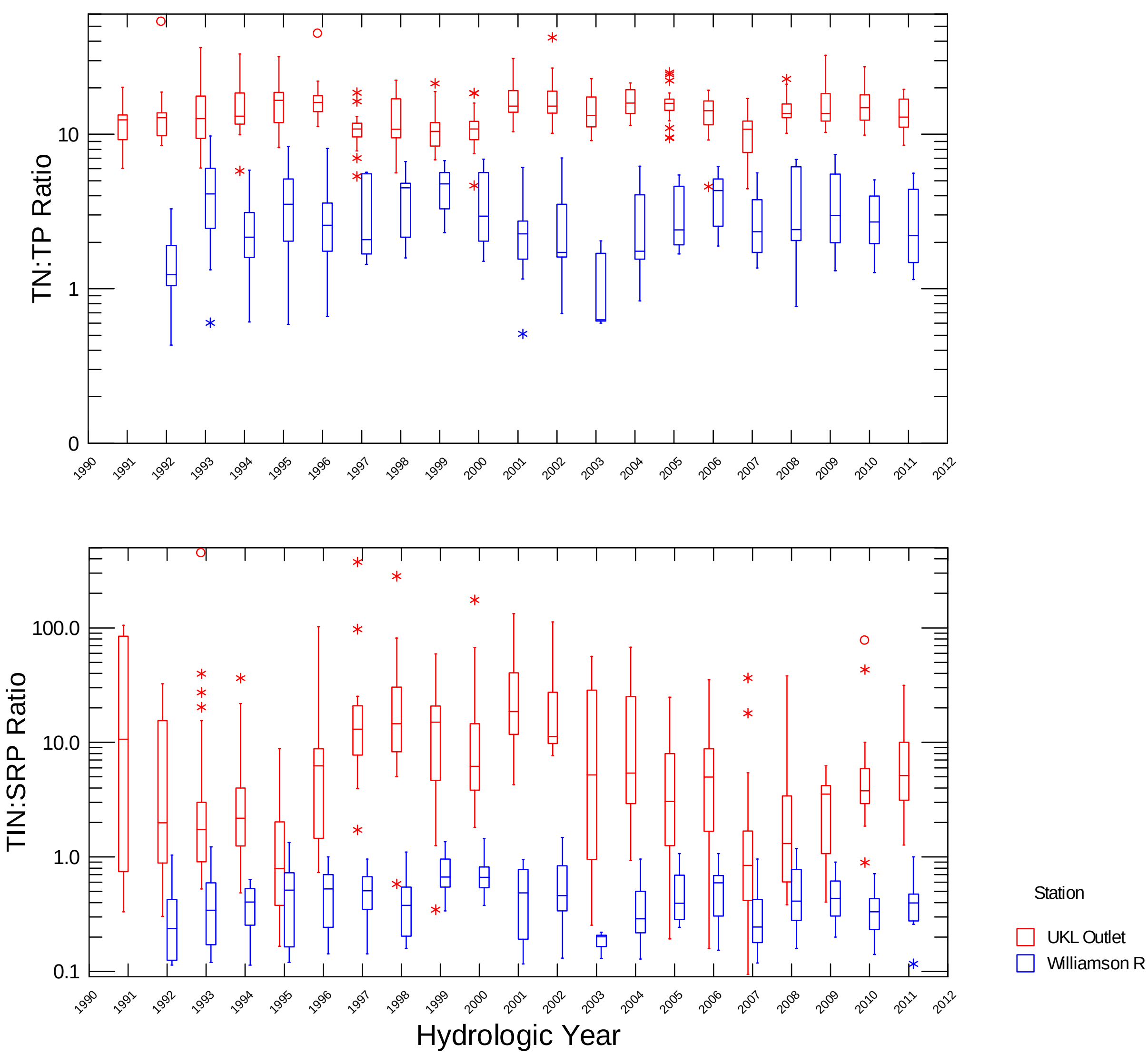

Figure 6. Total nitrogen to total phosphorus (TN:TP) and total inorganic nitrogen (NOx-N+NH_4-N) to PO_4 (TIN:SRP) ratios in the Williamson River and UKL outflow stations, April-October: 1991-2011.

TP and TN Loading

2011 Seasonal Pattern

The 2011 seasonal pattern of tributary loads for TP and TN showed a peak in January and increasing loads during the early-spring to early-summer period, with loading for both TP and TN showing a second peak during late-May, particularly for the Sprague and Williamson Rivers (Figure 7). UKL outflow loads of both TP and TN began increasing in July and 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). Typically the increase in Outflow TP and TN loading occurs in June, but initiation of the algal bloom was delayed by about a month during 2011 (Kann 2012). Outflow TP loads were similar to or slightly lower than Williamson River and Sprague River loading during the spring period prior to the summer algal growing season, while outflow TN loads generally remained higher than those for the Williamson River over this same period (Figure 7).

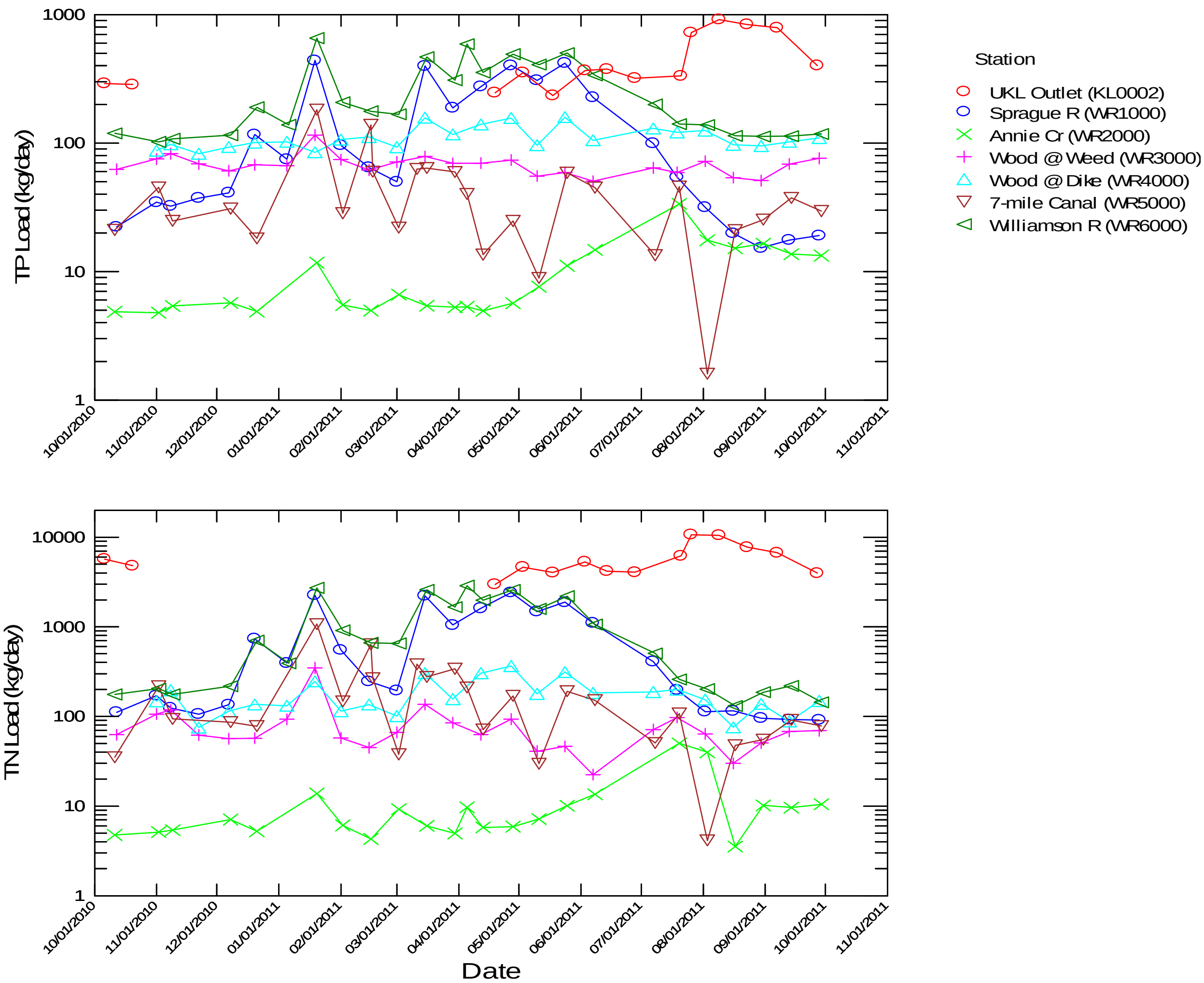

Figure 7. Seasonal TP and TN loading trends by station, HY 2011.

2011 Station Patterns

The 2011 nutrient loading pattern among stations was similar to that of the 1991-2010 sampling period (Figure 8). Also, as indicated above, TP and TN outflow loads tended to be higher than any individual inflow tributary loads during both 2011 and for the overall time period (1991-2010). Unlike 2010, when outflow TP and TN loads were lower overall than they were for the previous 1991-2009 period, in 2011 outflow loads were more similar to the 1991-2010 period. However, comparisons are somewhat confounded by the lack of winter data for the outflow during 2011. As noted above, high UKL outlet loads reflect sediment regeneration and nitrogen fixation processes taking place in UKL.

Of the inflow tributaries, the Williamson River (WR6000) showed highest overall loading, with the 2011 TP and TN loading distributions somewhat higher 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 appears to be more closely linked to discharge in the Sprague River than in the Williamson River (Figure 9).

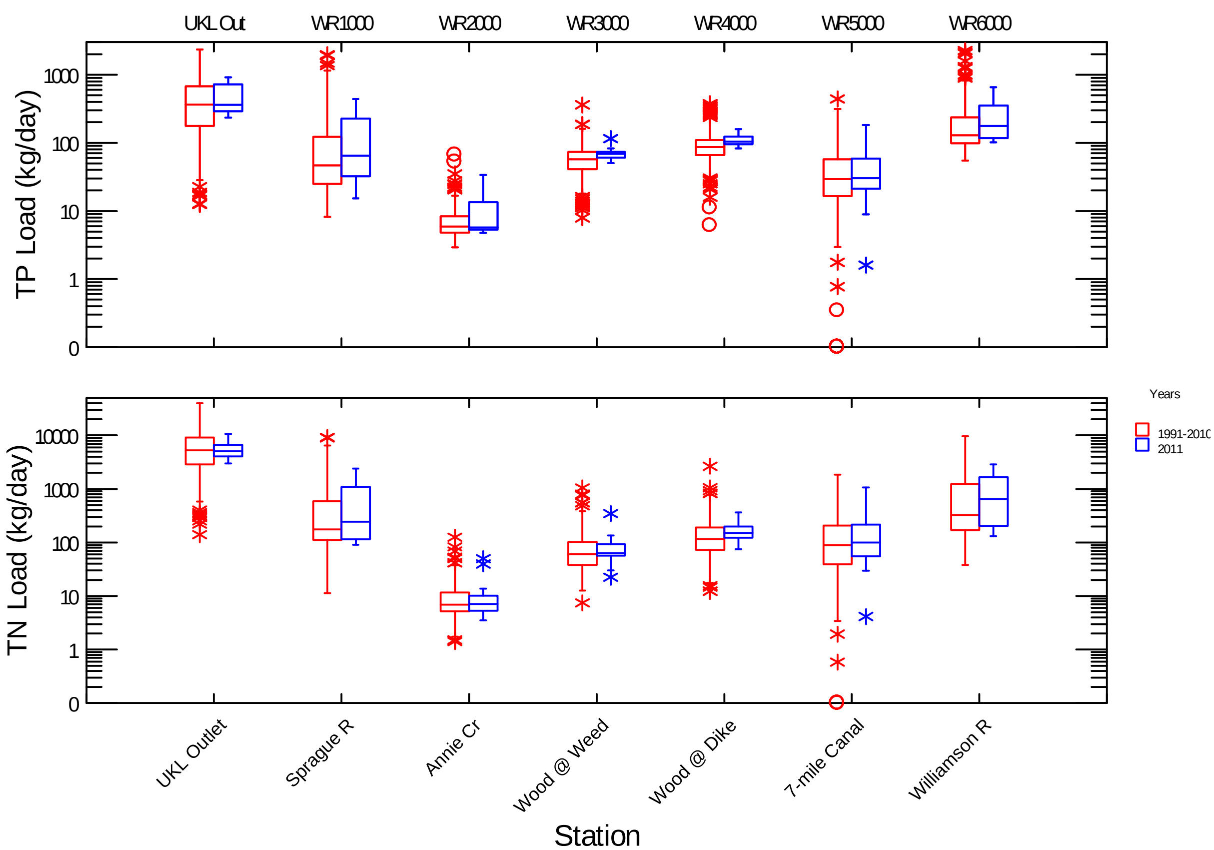

Figure 8. Station distributions of TP and TN loading compared between 1991-2010 (red) and 2011 (blue). Note: for the outflow station KL0001 there are no samples from January to mid-April in HY2006, and for HY2007-2009 and HY2011 samples are missing between November and mid-April.

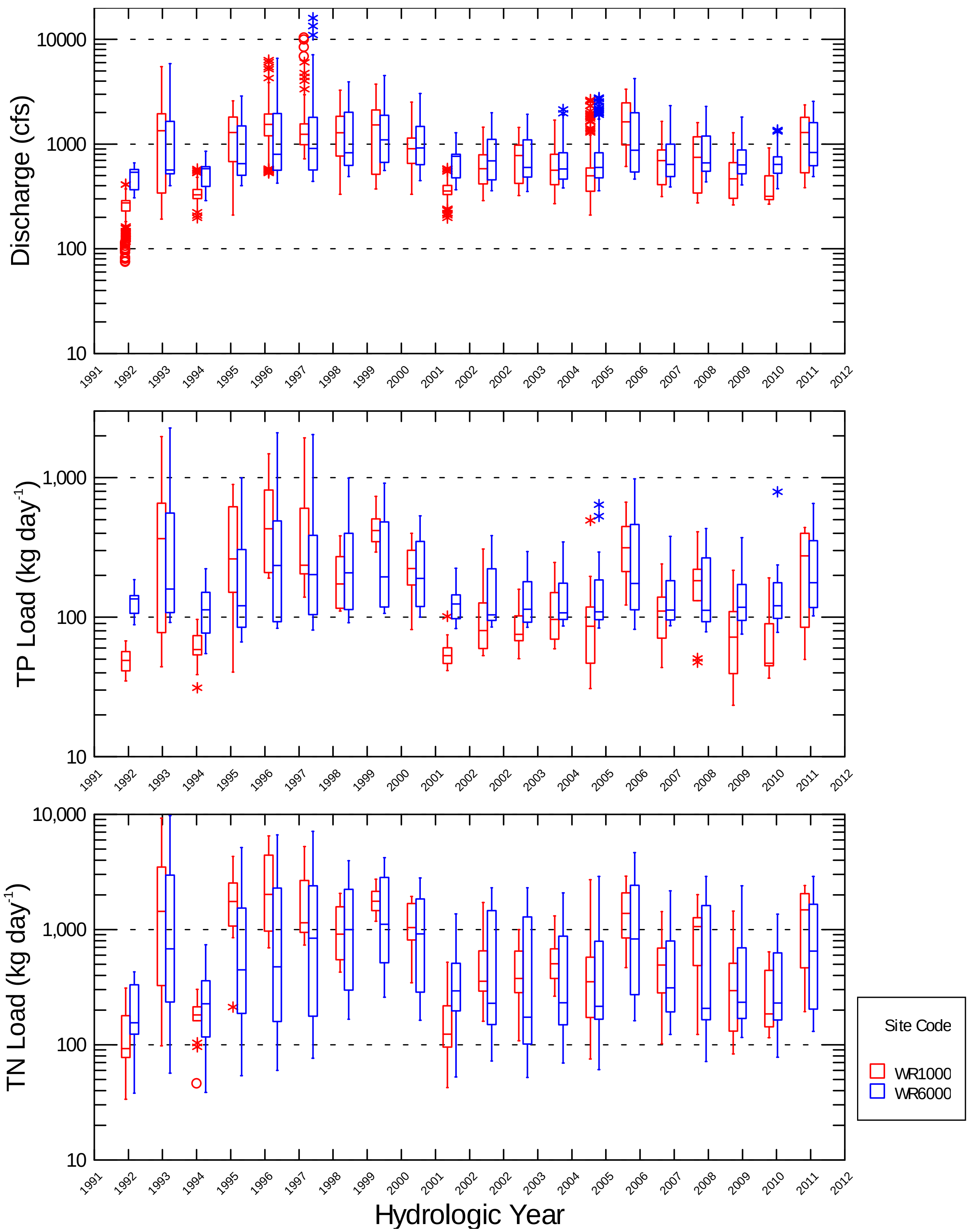

Figure 9. Distribution of Williamson River (WR6000) and Sprague River (WR1000) daily discharge (top panel), TP load (middle panel), and TN load (bottom panel) for the January-May inflow period, 1992-2011.

Inter-annual Patterns, 1991-2011

Although it is beyond the scope of this 2011 data summary report to analyze the inter-annual trends in detail, 1991-2011 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 10 to 23. Briefly, in 2011 the June -September UKL outflow TP loads were higher than 2010 but still generally lower than previous years (Figure 10). Similarly, TN loads were somewhat higher than 2010 but were also lower than previous years (Figure 17). 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 were similar to 2010 during the June-September period, but tended to be higher both overall and during the winter (Figure 11and Figure 18). The January-May Sprague River TP and TN loading distributions tended to be higher than the previous four years. Williamson River TP and TN loading distributions were intermediate for the June-September and January through May periods, and were higher overall than 2010 (Figure 16 and Figure 23). TN loading distributions for the Wood River stations during 2011 tended to be intermediate for the period of record for all periods (Figure 20 and Figure 21). The Wood River TP loading distribution for 2011tended to be among the highest when compared to previous years (Figure 13 and Figure 14). However, Seven Mile Canal TP and TN loading during 2011 was similar to previous years (Figure 15 and Figure 22) and overall loads for Annie Creek during the Jan-May period were higher than 2010 but tended to be intermediate compared to previous years (Figure 12 and Figure 19). Annie Cr. TP loads also tended to be higher than other years for the June-September period (Figure 12). In general, hydrologic loading as indicated by Williamson River discharge (Figure 9) appears to account for much of the inter-annual variability in nutrient loading.

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., Walker and Havens 2003). A comprehensive analysis of time-series trends as well as hydrologic and nutrient budgets for UKL has been completed for water years through 2010 (Walker et al. 2012).

SUMMARY

With the addition of 2011 data, the UKL tributary nutrient and loading database now includes 21 years of data and includes the years 1991-2011. 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 2011 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 entire 1991-2010 dataset (Walker et al. 2012).

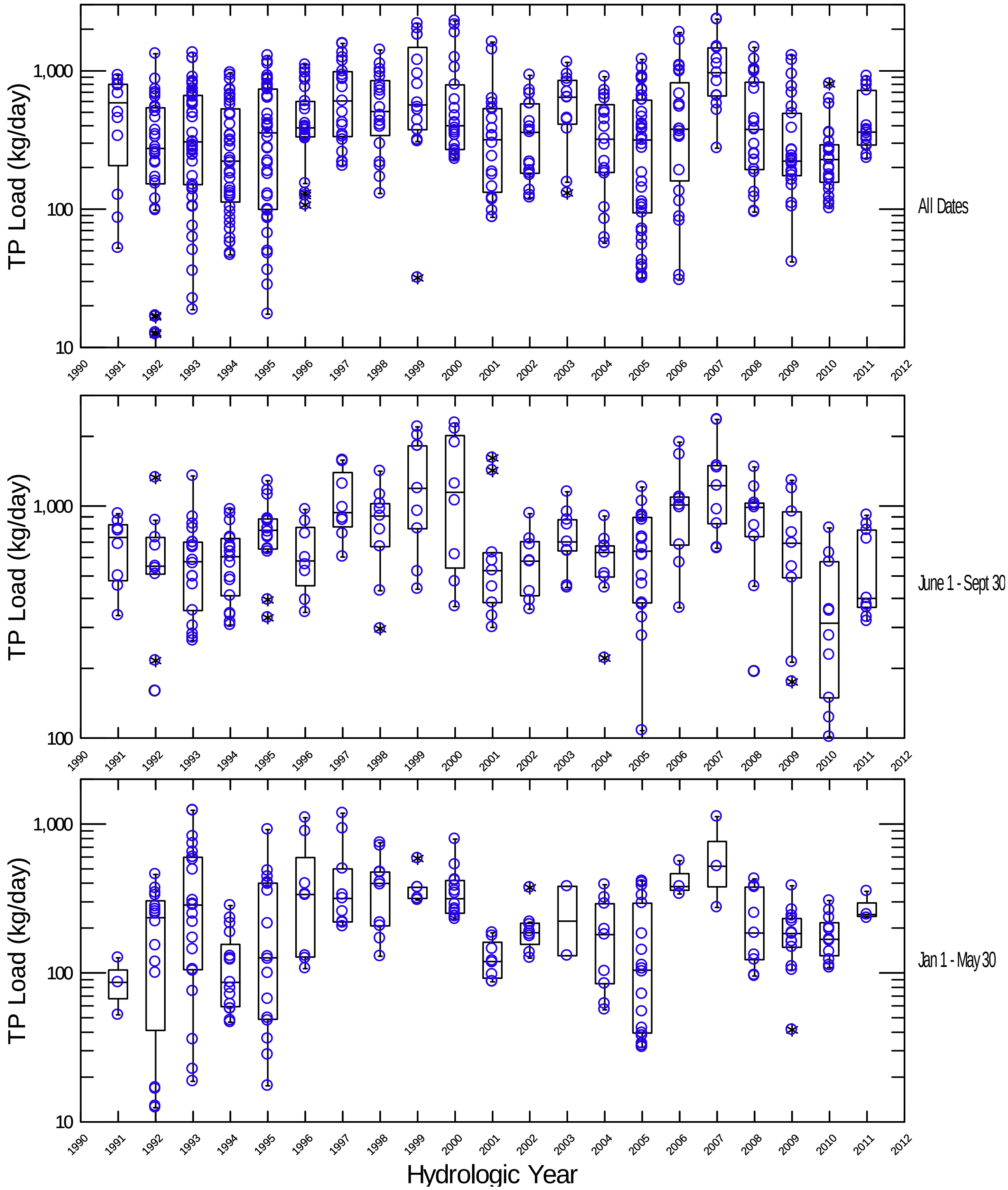

Figure 10. Annual and seasonal distributions of UKL Outlet TP loading, 1991-2011. Note: in HY2006, there are no samples from January to mid-April and in HY2007-2008 and 2011 there are no samples from November to mid-April.

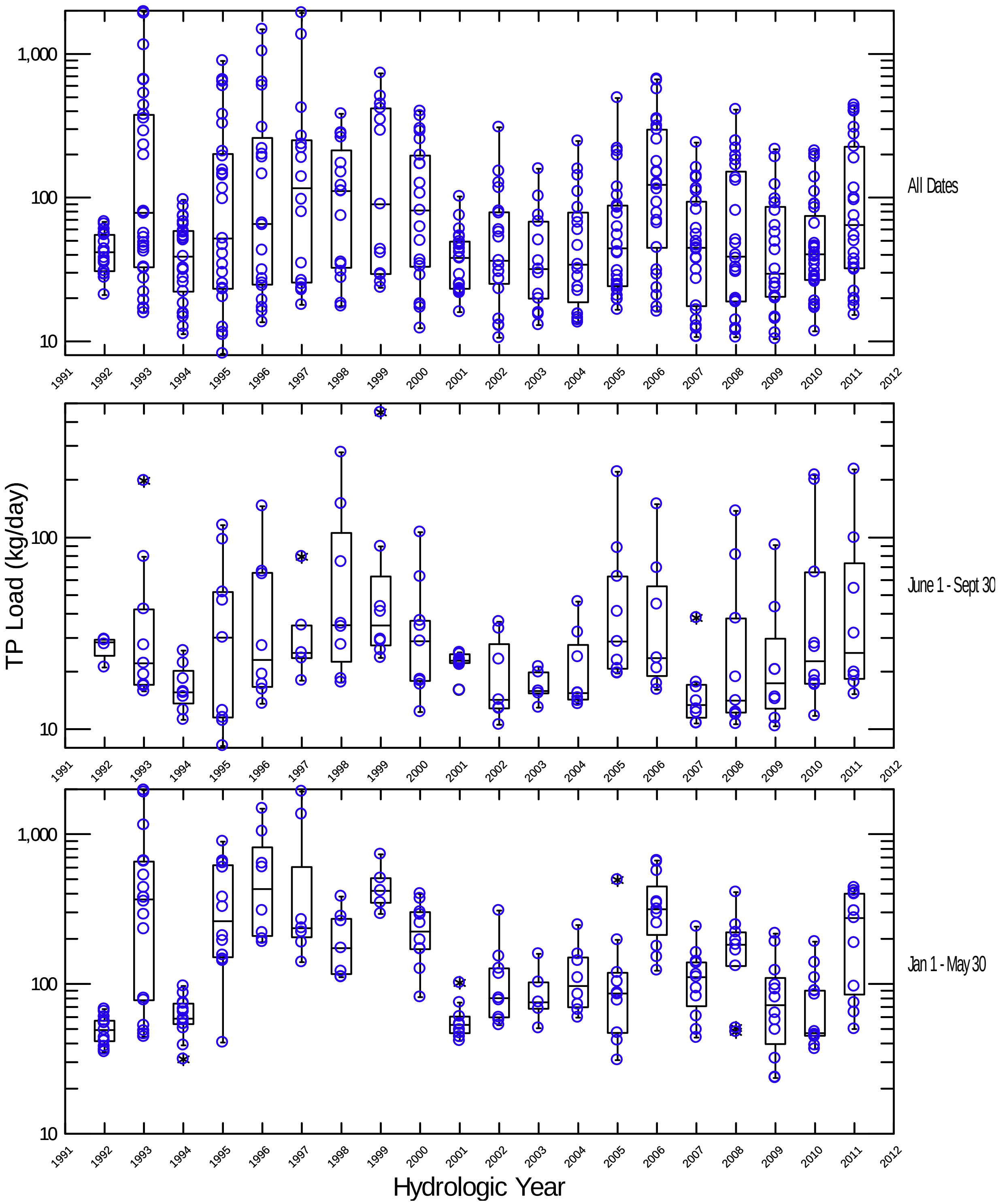

Figure 11. Annual and seasonal distributions of Sprague River TP loading, 1992-2011.

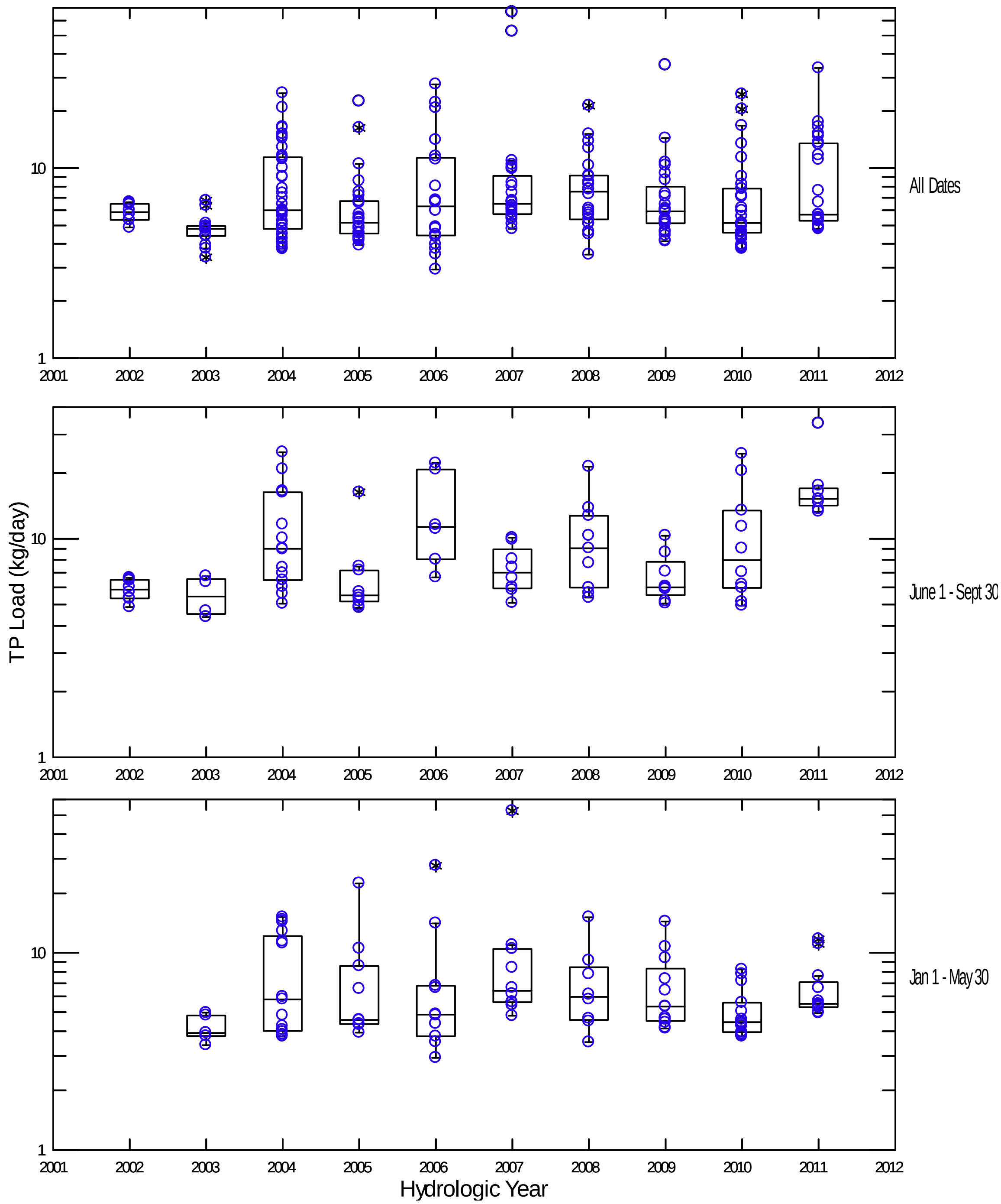

Figure 12. Annual and seasonal distributions of Annie Creek TP loading, 2002-2011.

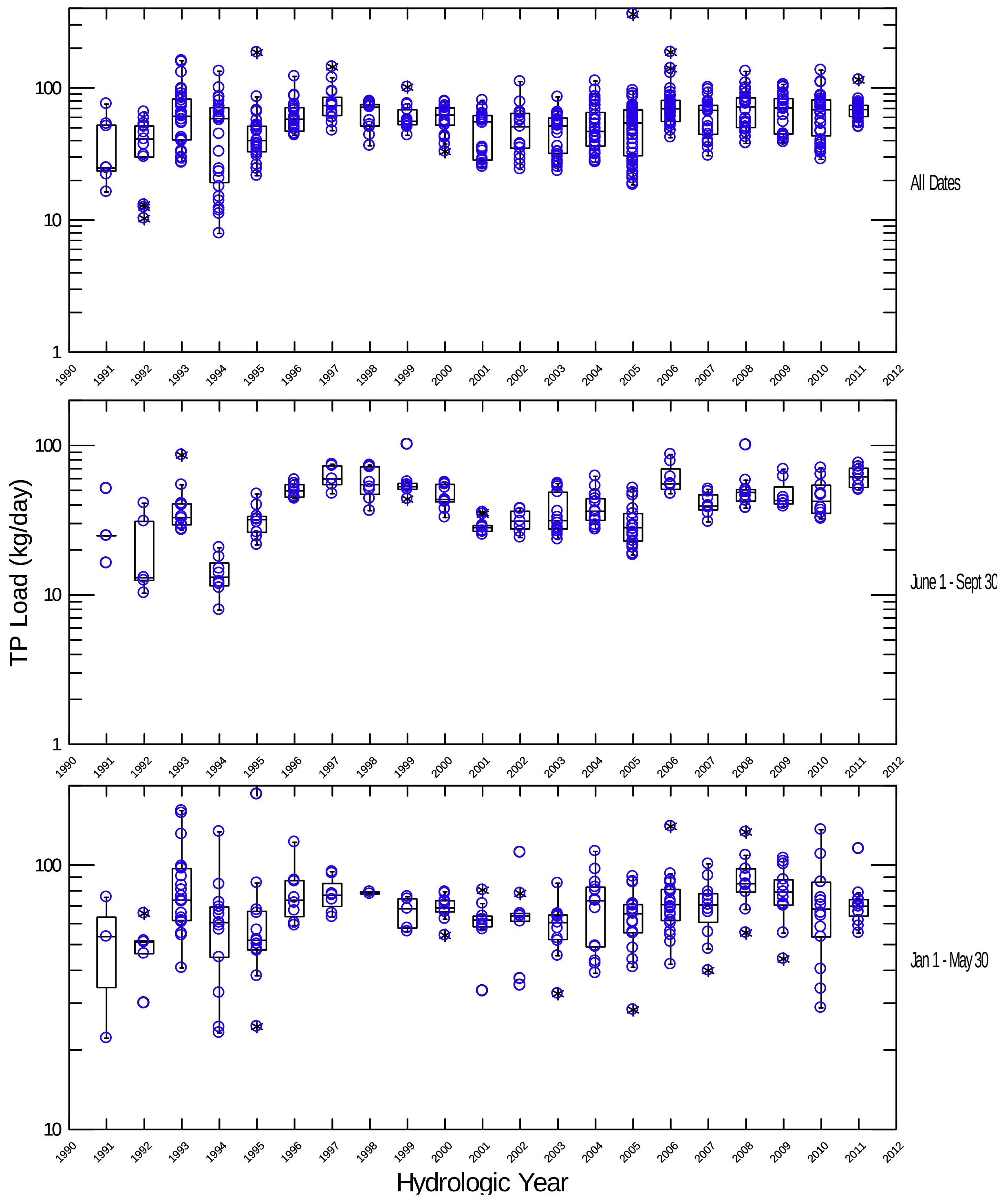

Figure 13. Annual and seasonal distributions of Wood River at Weed Rd. TP loading, 1991-2011.

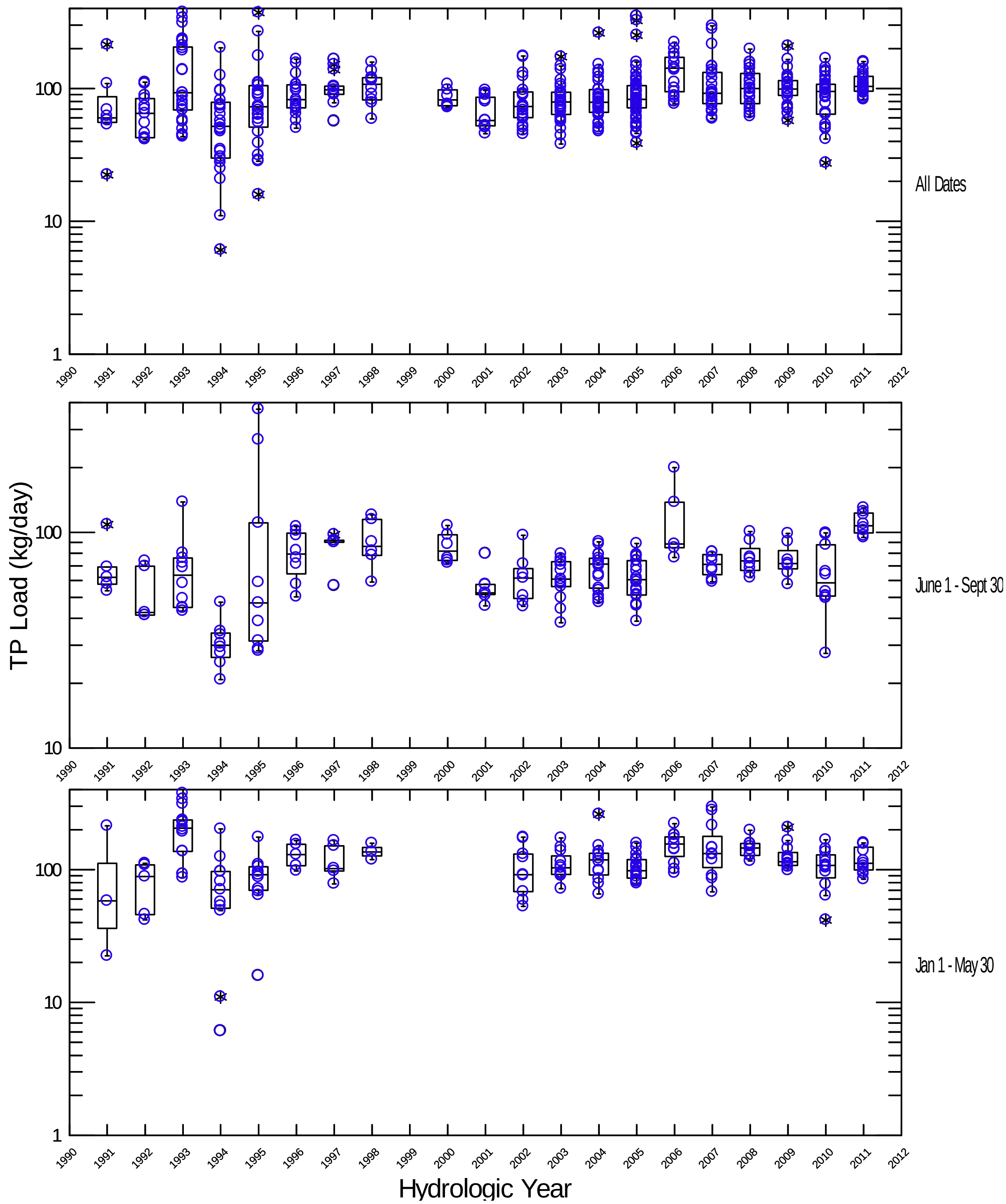

Figure 14. Annual and seasonal distributions of Wood River at Dike Rd. TP loading, 1991-2011.

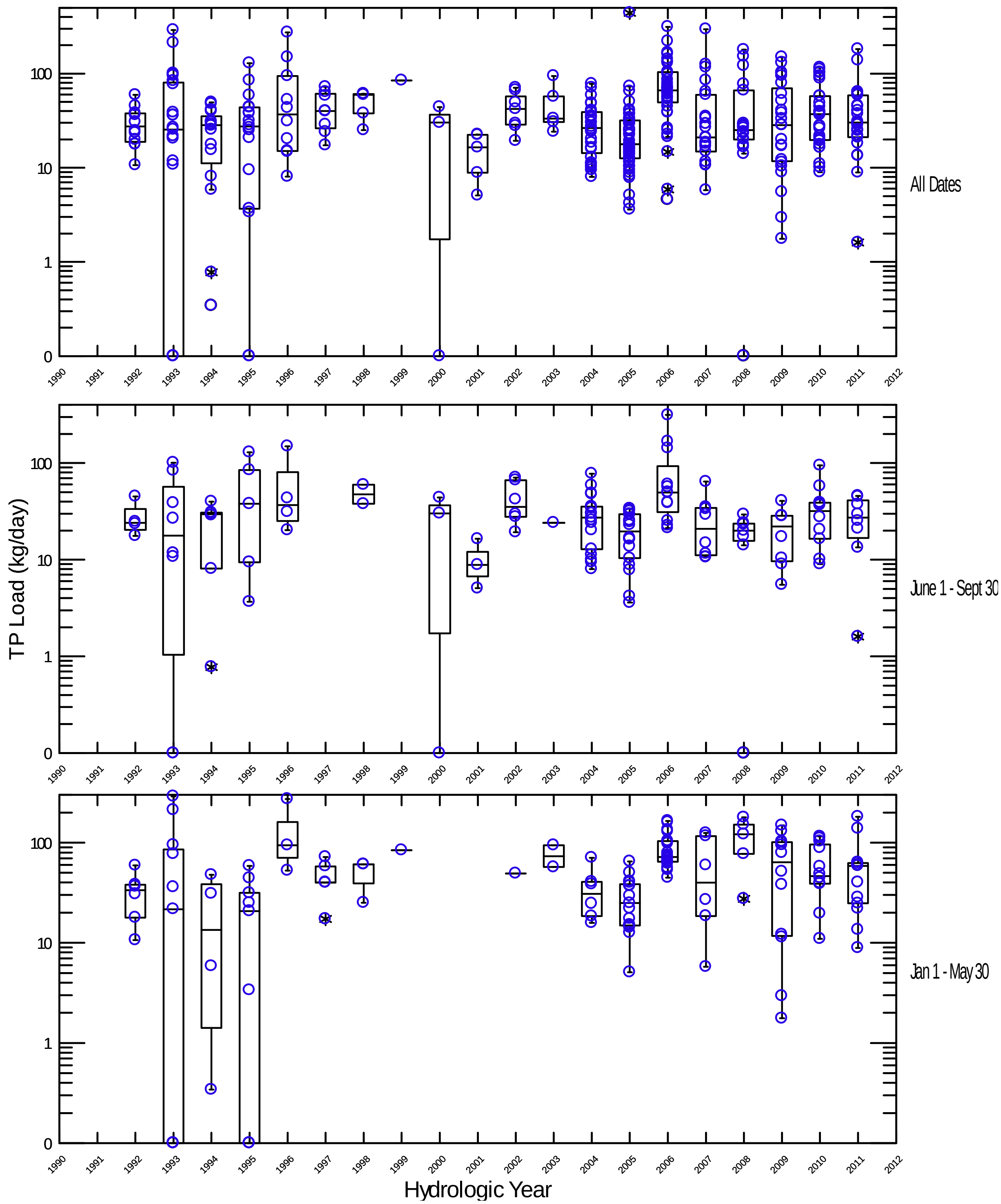

Figure 15. Annual and seasonal distributions of Seven Mile Canal TP loading, 1992-2011. Note that occurrences of zero load are due to lake-backwater effects when no flow is measured at the sampling location

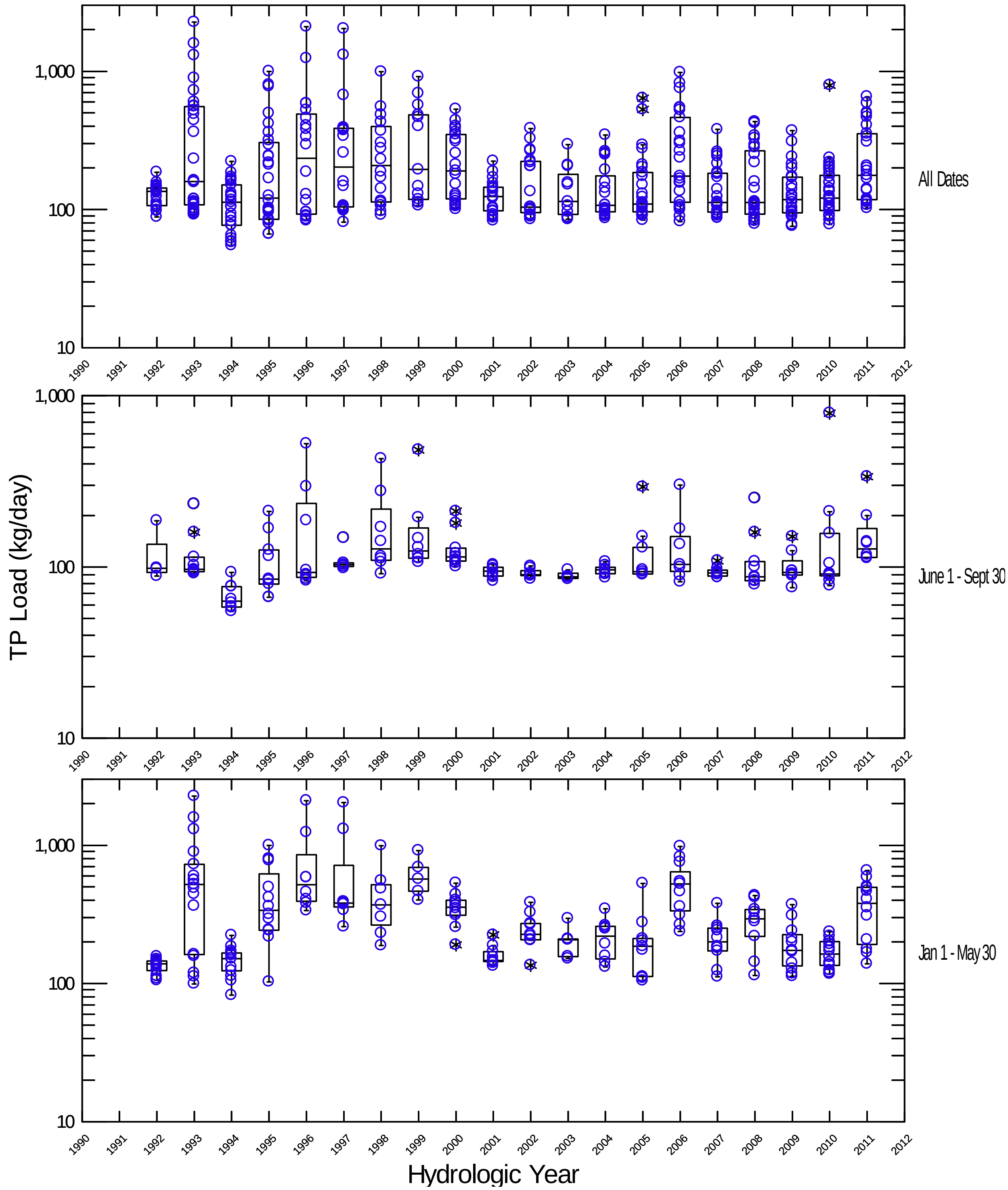

Figure 16. Annual and seasonal distributions of Williamson River TP loading, 1992-2011.

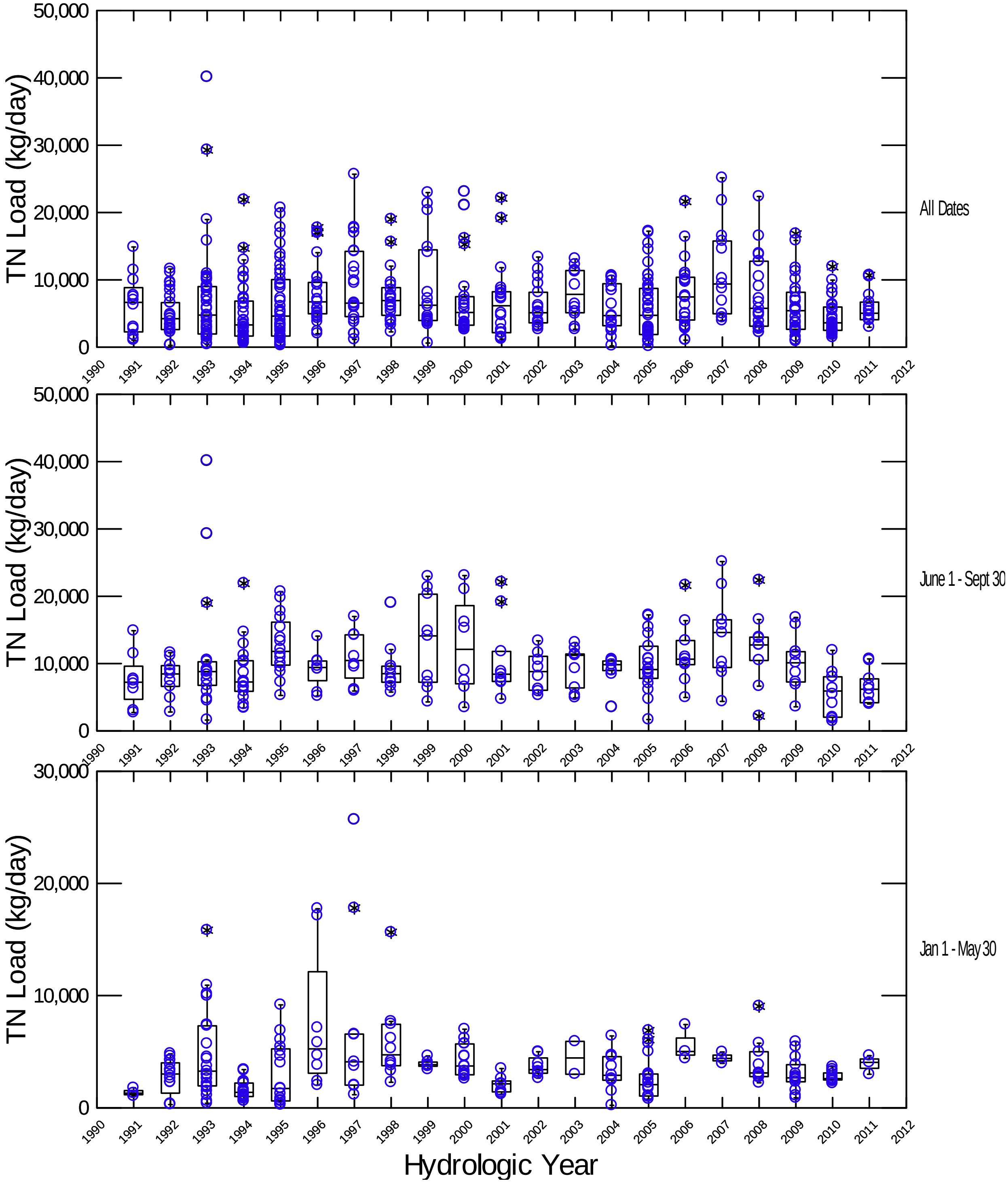

Figure 17. Annual and seasonal distributions of UKL Outlet TN loading, 1991-2011. Note: in HY2006, there are no samples from January to mid-April and in HY2007-2008 and 2011 there are no samples from November to mid-April.

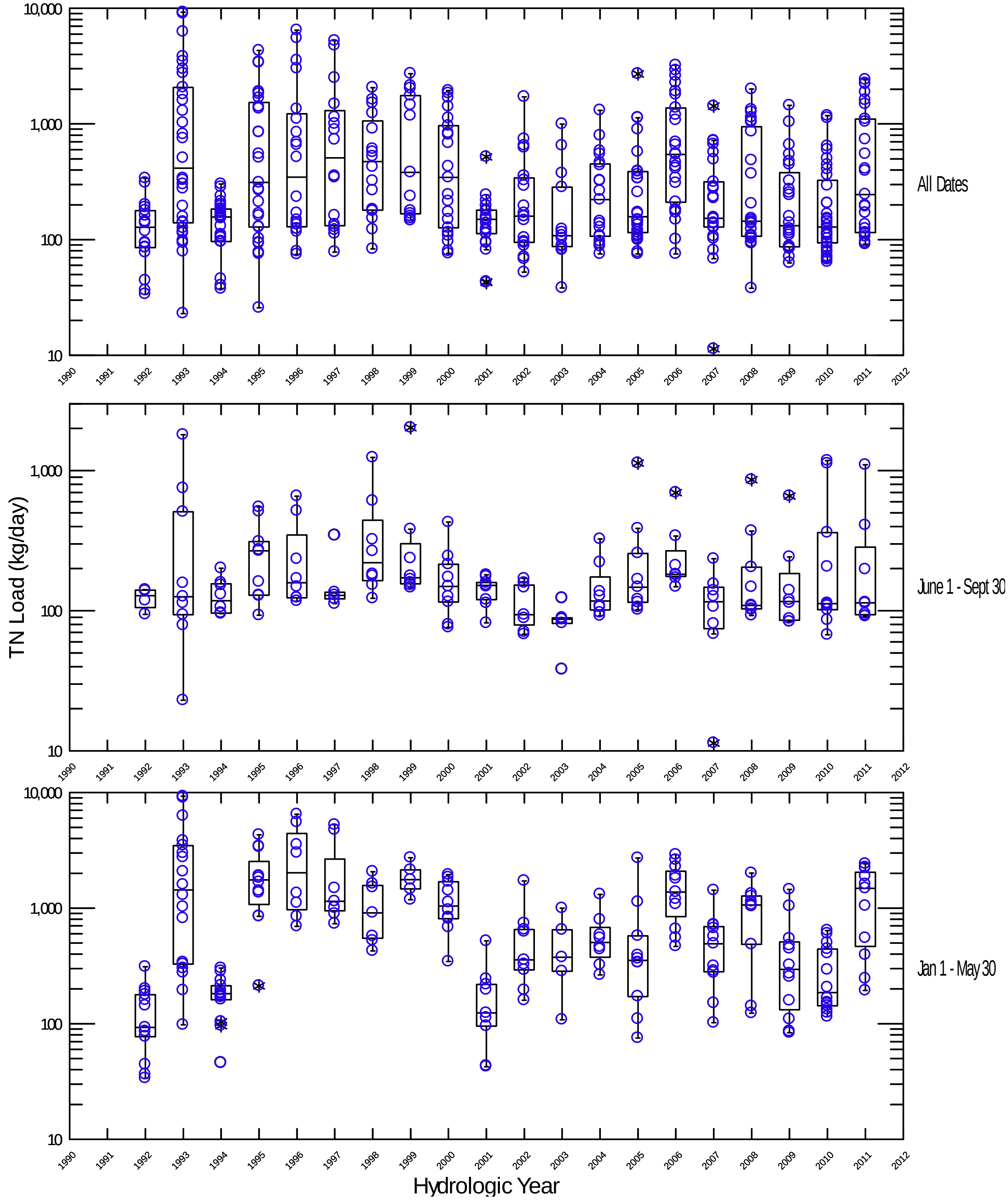

Figure 18. Annual and seasonal distributions of Sprague River TN loading, 1992-2011.

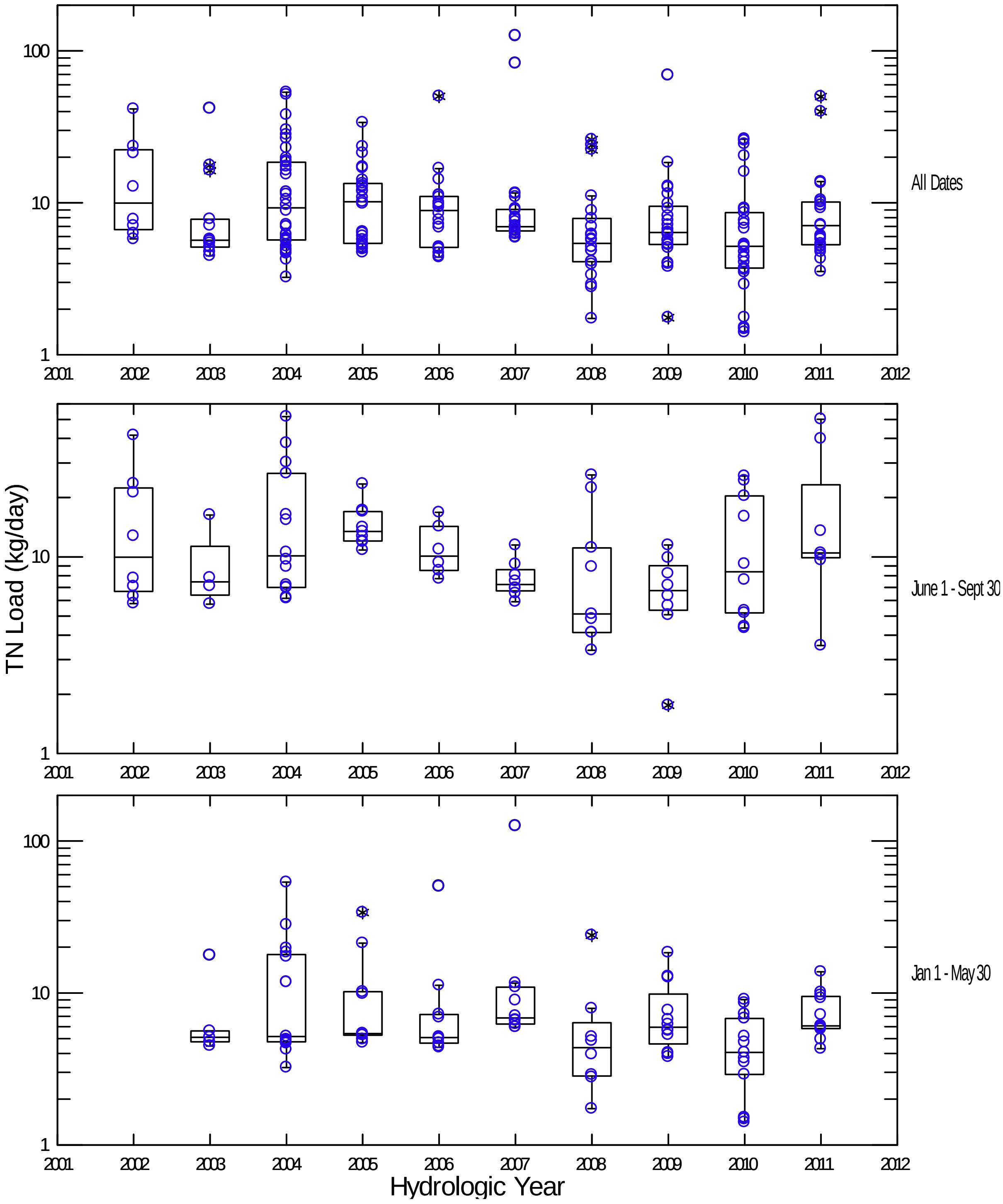

Figure 19. Annual and seasonal distributions of Annie Creek TN loading, 2002-2011.

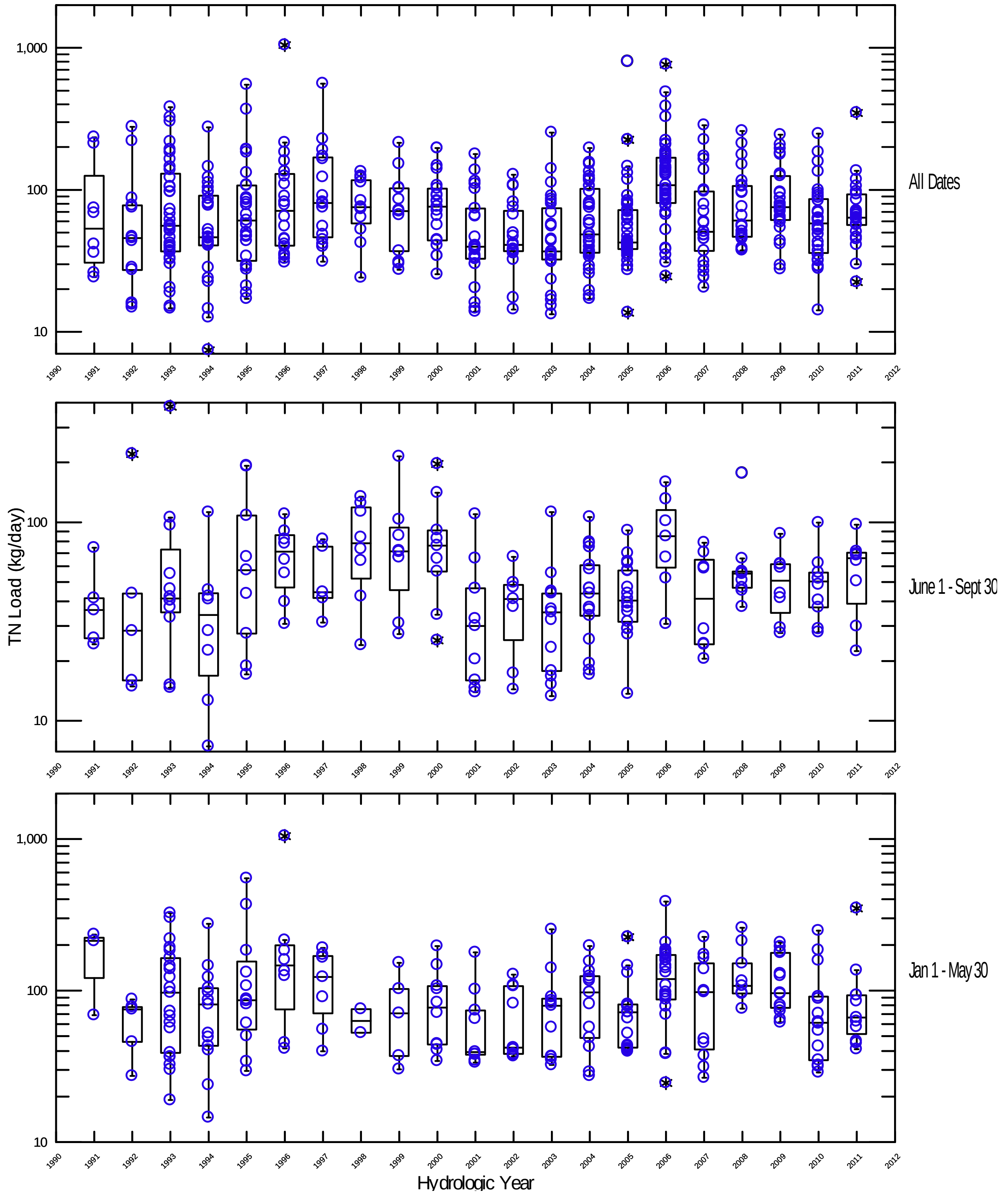

Figure 20. Annual and seasonal distributions of Wood River at Weed Rd. TN loading, 1991-2011.

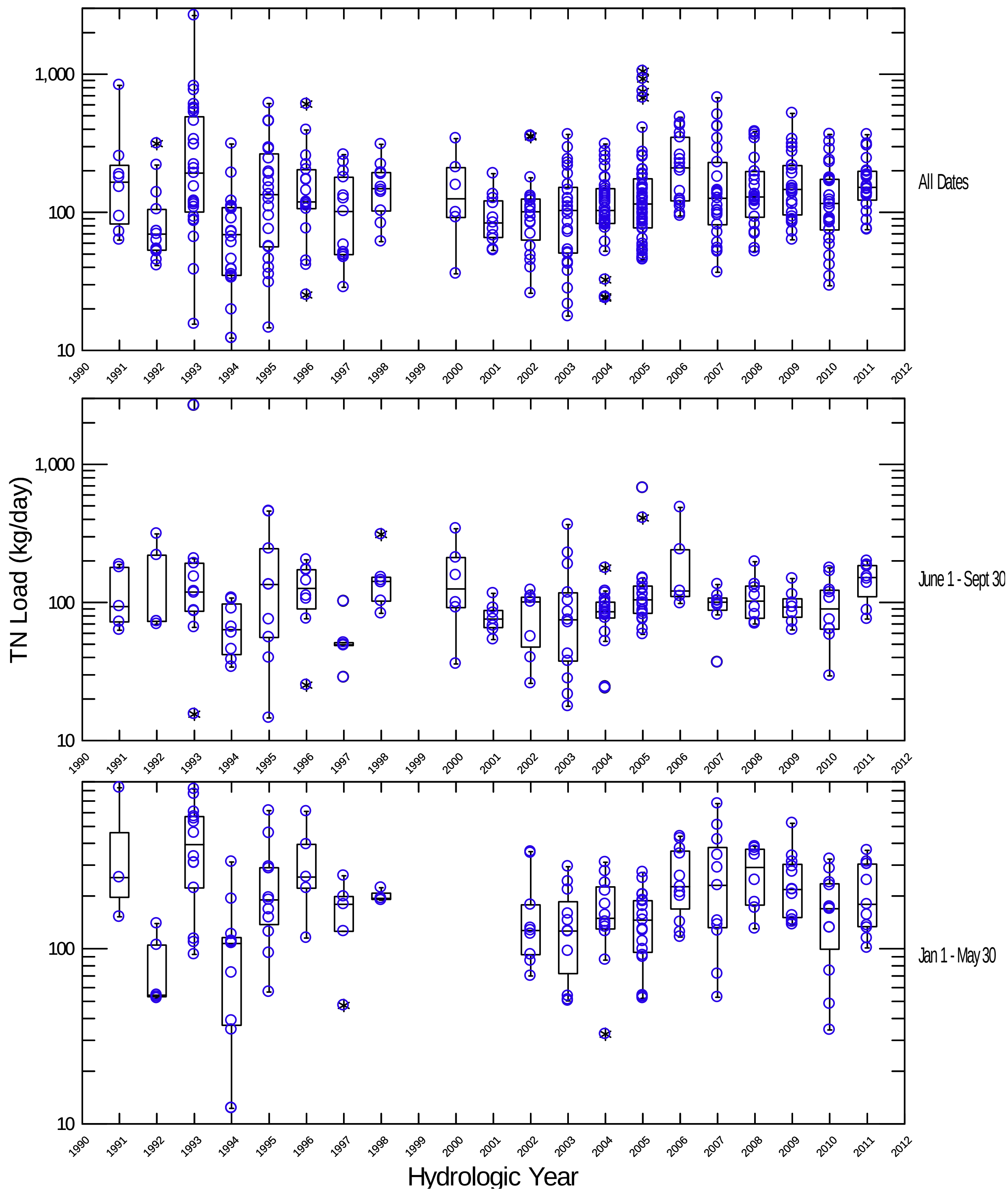

Figure 21. Annual and seasonal distributions of Wood River at Dike Rd. TN loading, 1991-2011.

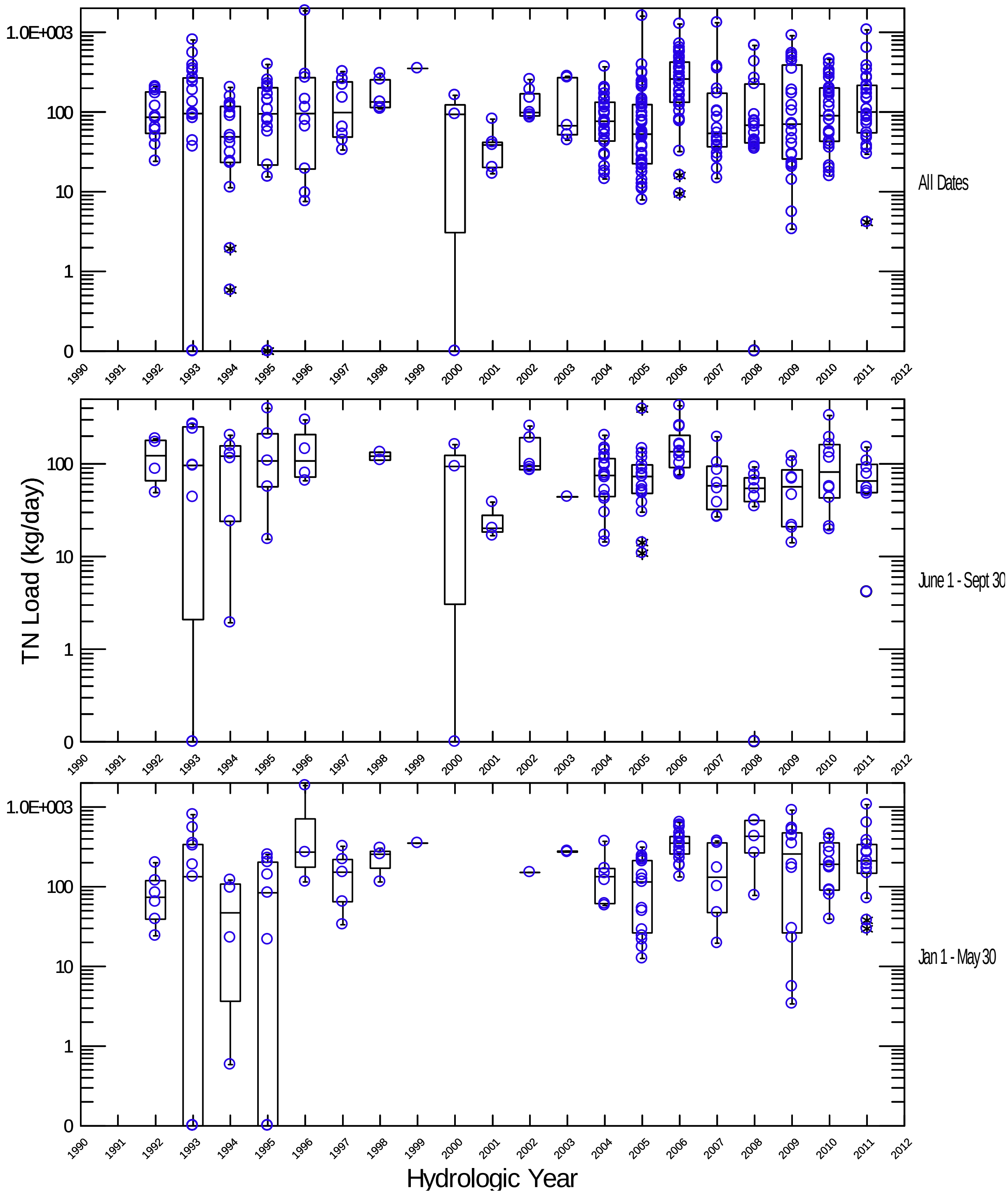

Figure 22. Annual and seasonal distributions of Seven Mile Canal TN loading, 1992-2011. Note that occurrences of zero load are due to lake-backwater effects when no flow is measured at the sampling location.

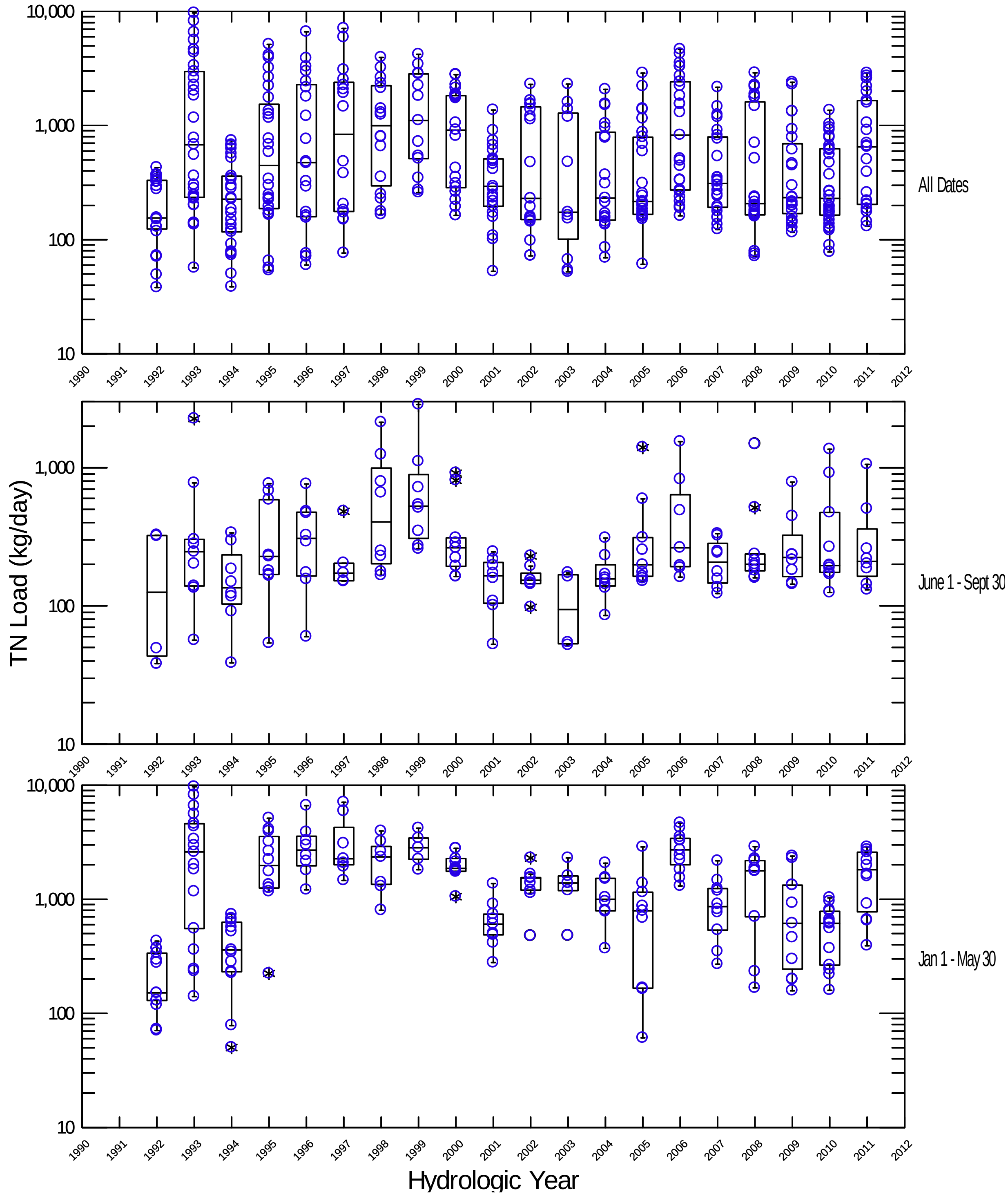

Figure 23. Annual and seasonal distributions of Williamson River TN loading, 1992-2011.

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