Aquatic Ecosystem Sciences LLC

TECHNICAL MEMORANDUM

# Upper Klamath Lake Tributary Loading: 2009 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 a nutrient budget for UKL (Kann and Walker 1999). The UKL tributary water quality database was previously updated with 2009 data and appropriate quality assurance analyses (*see Excel spreadsheets: Klamath Tribes Inflow Nutrient Data 1991-2000.xls and Klamath Tribes Inflow Nutrient-Q Data 2001-2009.xls*). This report serves as an annual update to the UKL tributary water quality database, including a summary of 2009 data (basic summary statistics and graphical analysis), and limited comparison of graphical time-series trends of tributary data collected for the 1991-2009 period.

## 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 2009 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 (USGS Gages 11502500 and 11501000, respectively). Daily outflow volume for Upper Klamath Lake @ Link Bridge (UKL outflow) was obtained from both USGS discharge station 11507500 for the Link River and USBR A-Canal 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. 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 2009 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 after 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. Loading graphs and summaries are computed based on the October-September hydrologic water year (denoted HY in below plots).

**Table 1. Nutrient parameters colleted in Upper Klamath Lake tributaries, 2009.**

| 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 colleted in Upper Klamath Lake tributaries, 2009.**

| 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 2009 nutrient concentration pattern among inflow stations was similar to that of the 1991-2008 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 2003-2008) was consistently lower for all nutrient parameters 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 as in 2008, $NH_4$-N at Seven Mile Canal was similar to the UKL Outlet as well (Figure 1; Table 3). Of the inflow stations, 2009 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 1991-2008 period (Figure 1). As in 2008, ammonia was noticeably lower at the UKL outflow station in 2009 relative to previous years.

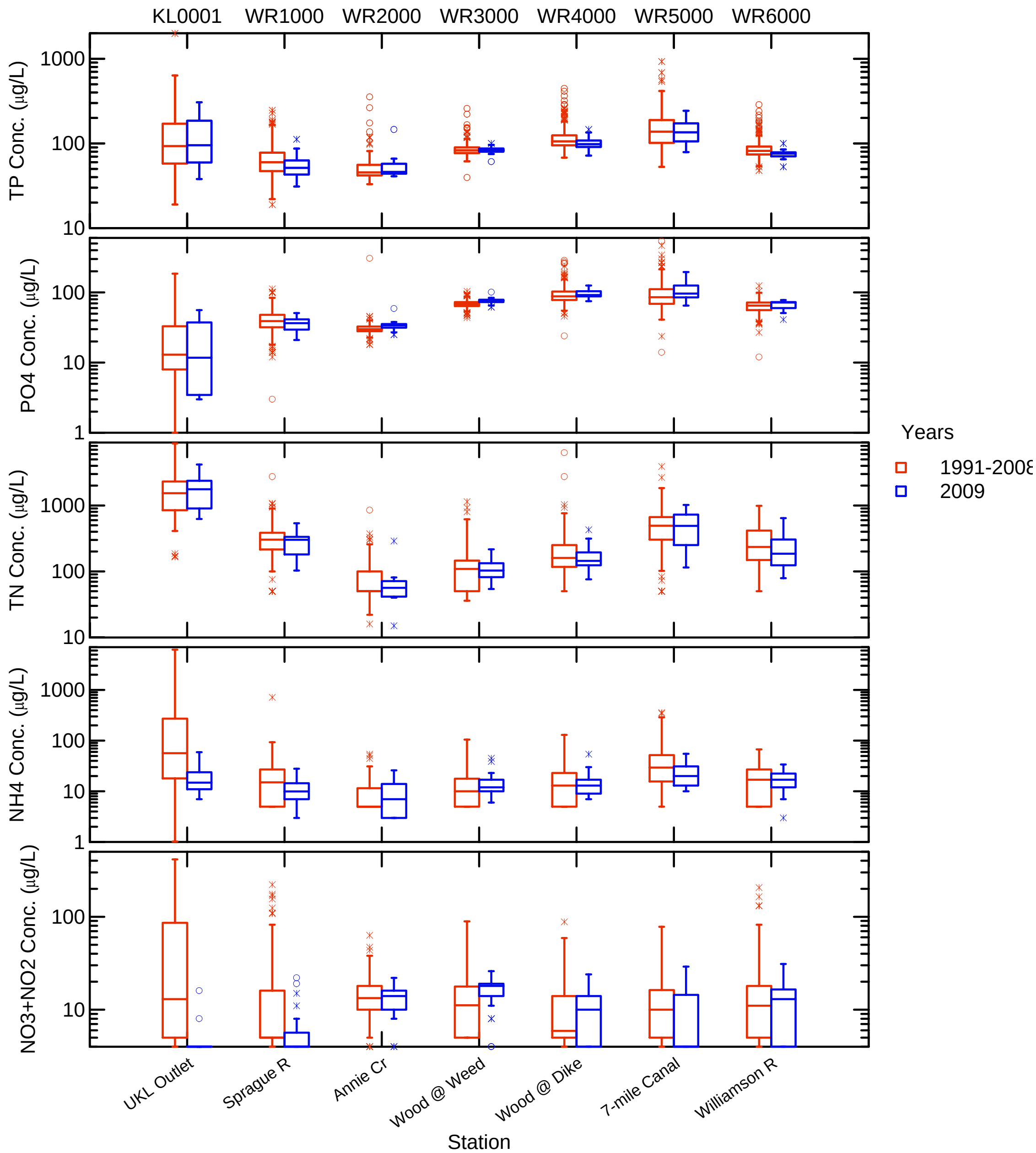



**Figure 1. Station distributions of TP, SRP, TN, NH4-N, and NO3+ NO2-N concentration (µg/L) compared between 1991-2008 (red) and 2009 (blue).**

**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 2009.**

| 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 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| KL0001 | UKL Outlet | Median | 96 | 15 | 1760 | 15 | 4 | 520 | 7973 |
| KL0001 | UKL Outlet | Mean | 130 | 21 | 1897 | 22 | 5 | 578 | 8384 |
| KL0001 | UKL Outlet | Pct25 | 60 | 4 | 904 | 11 | 4 | 199 | 3305 |
| KL0001 | UKL Outlet | Pct75 | 186 | 38 | 2375 | 24 | 4 | 858 | 11513 |
| WR1000 | Sprague R | N of cases | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| WR1000 | Sprague R | Median | 52 | 37 | 302 | 10 | 4 | 30 | 132 |
| WR1000 | Sprague R | Mean | 55 | 36 | 281 | 11 | 6 | 57 | 296 |
| WR1000 | Sprague R | Pct25 | 43 | 30 | 181 | 7 | 4 | 20 | 87 |
| WR1000 | Sprague R | Pct75 | 63 | 42 | 335 | 15 | 6 | 86 | 384 |
| WR2000 | Annie Cr | N of cases | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| WR2000 | Annie Cr | Median | 46 | 34 | 57 | 7 | 14 | 6 | 6 |
| WR2000 | Annie Cr | Mean | 53 | 34 | 64 | 9 | 13 | 8 | 10 |
| WR2000 | Annie Cr | Pct25 | 44 | 32 | 42 | 3 | 10 | 5 | 5 |
| WR2000 | Annie Cr | Pct75 | 58 | 36 | 72 | 14 | 16 | 8 | 9 |
| WR3000 | Wood @ Weed | N of cases | 25 | 25 | 25 | 25 | 25 | 24 | 24 |
| WR3000 | Wood @ Weed | Median | 83 | 77 | 103 | 12 | 18 | 60 | 63 |
| WR3000 | Wood @ Weed | Mean | 83 | 77 | 111 | 15 | 16 | 58 | 80 |
| WR3000 | Wood @ Weed | Pct25 | 80 | 73 | 82 | 10 | 14 | 39 | 48 |
| WR3000 | Wood @ Weed | Pct75 | 87 | 80 | 135 | 17 | 19 | 68 | 93 |
| WR4000 | Wood @ Dike | N of cases | 25 | 25 | 25 | 25 | 25 | 23 | 23 |
| WR4000 | Wood @ Dike | Median | 98 | 92 | 144 | 13 | 10 | 99 | 146 |
| WR4000 | Wood @ Dike | Mean | 103 | 96 | 174 | 15 | 11 | 105 | 179 |
| WR4000 | Wood @ Dike | Pct25 | 91 | 88 | 122 | 9 | 4 | 88 | 94 |
| WR4000 | Wood @ Dike | Pct75 | 110 | 105 | 201 | 17 | 14 | 116 | 218 |
| WR5000 | 7-mile Canal | N of cases | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| WR5000 | 7-mile Canal | Median | 136 | 97 | 490 | 20 | 4 | 28 | 70 |
| WR5000 | 7-mile Canal | Mean | 142 | 109 | 492 | 24 | 10 | 45 | 196 |
| WR5000 | 7-mile Canal | Pct25 | 106 | 85 | 257 | 13 | 4 | 12 | 26 |
| WR5000 | 7-mile Canal | Pct75 | 173 | 126 | 730 | 31 | 15 | 70 | 392 |
| WR6000 | Williamson R | N of cases | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| WR6000 | Williamson R | Median | 76 | 72 | 186 | 17 | 13 | 118 | 233 |
| WR6000 | Williamson R | Mean | 75 | 67 | 238 | 17 | 12 | 146 | 573 |
| WR6000 | Williamson R | Pct25 | 70 | 60 | 121 | 12 | 4 | 95 | 164 |
| WR6000 | Williamson R | Pct75 | 79 | 73 | 323 | 23 | 17 | 172 | 744 |

Time series plots of the 2009 concentration data consistently show Seven Mile Canal to have higher values for TP, $PO_4$, PP (particulate P which equals TP minus $PO_4$), TN, and $NH_4$-N (Figure 2). These 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.

The ratio of TN:TP at the UKL Outflow station was higher (TN:TP $\cong$ 10) than tributary stations in April of 2009, increased during June bloom development, declined through the bloom decline period (see Kann 2010), and then remained stable through October (Figure 2). In contrast, the TIN:SRP ratio increased slightly during the period of June bloom development and then declined through the summer growing season (Figure 3). Both TN:TP and TIN:SRP values in the 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 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 (*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 1991-2009 period, including a possible inverse relationship between the TN:TP ratios in the Williamson and those in the UKL outflow. Further analysis is required to explore these apparent trends.

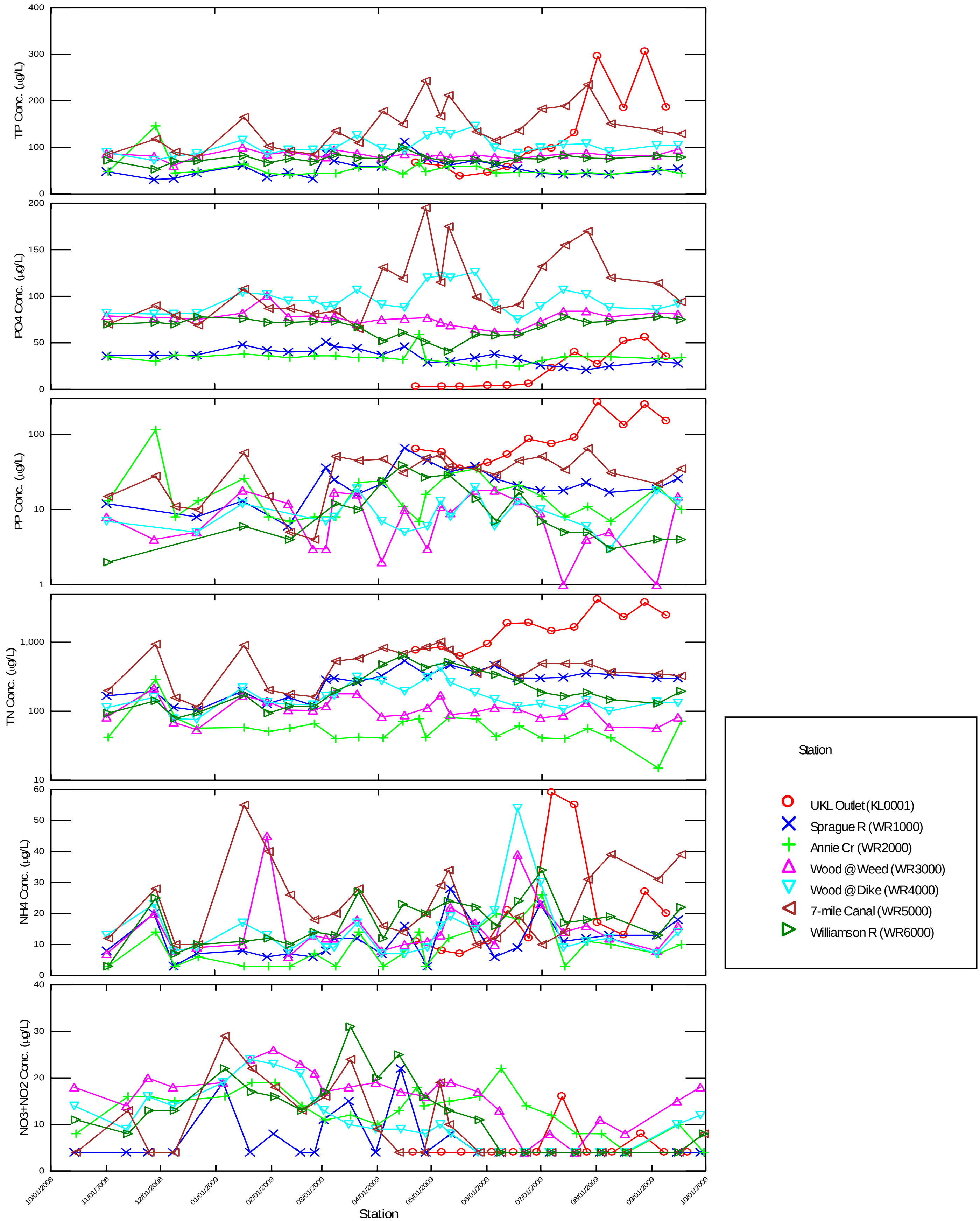



**Figure 2. Time-series plot of nutrient concentrations for Upper Klamath Lake tributaries and outflow, 2009.**

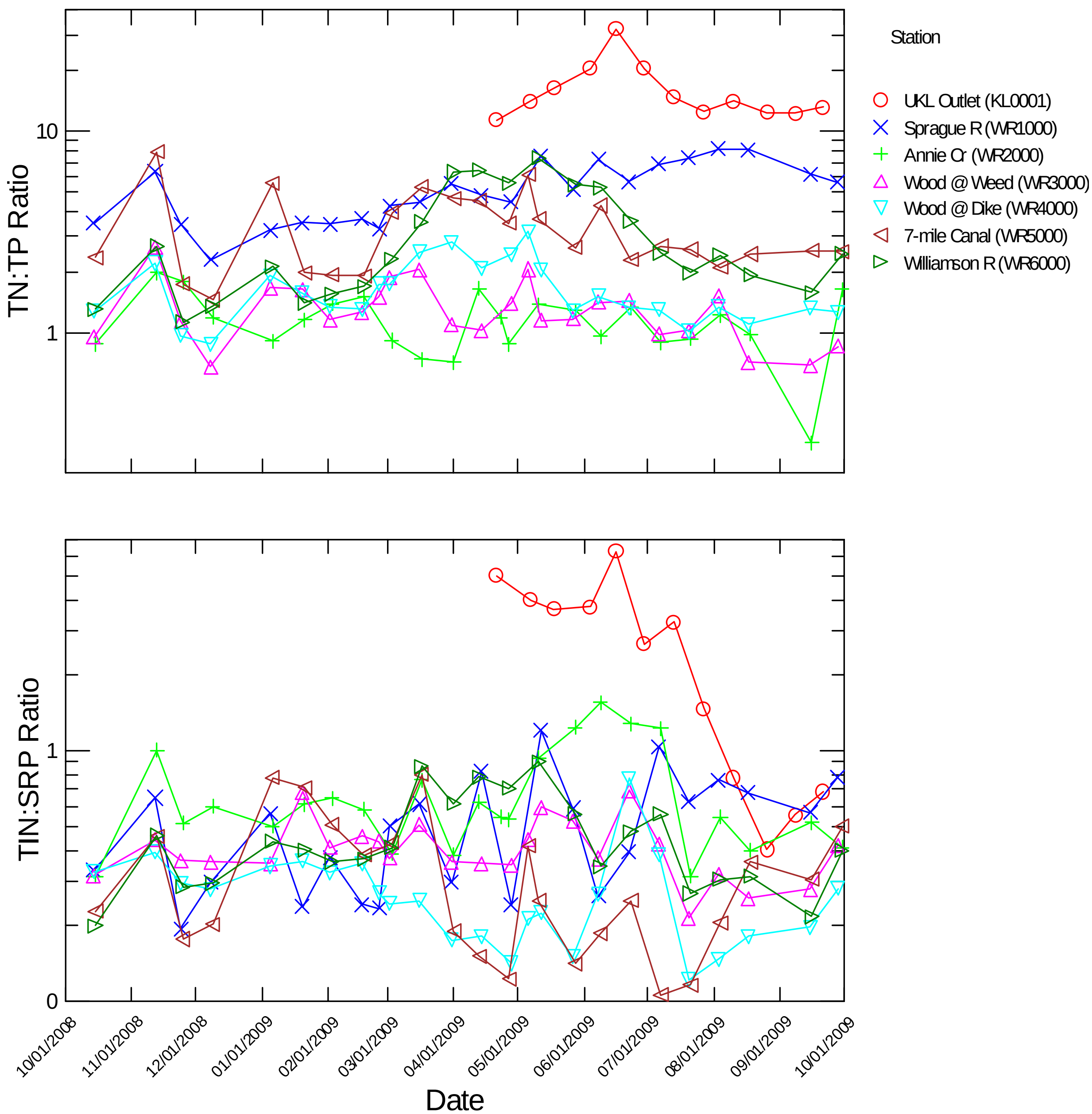
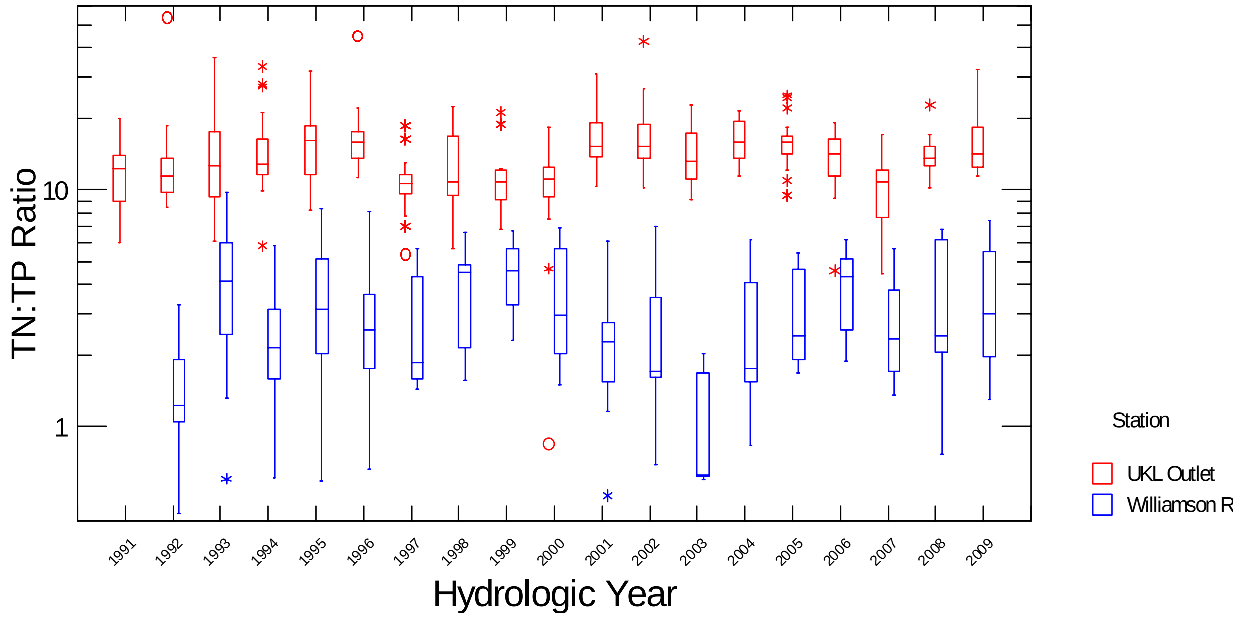



**Figure 3. Total nitrogen to total phosphorus (TN:TP) and total inorganic nitrogen (NOx-N+$NH_4$-N) to $PO_4$ (TIN:SRP) ratios in Upper Klamath Lake tributaries and outflow stations, 2009. Note that UKL Outflow is only sampled during April-October.**



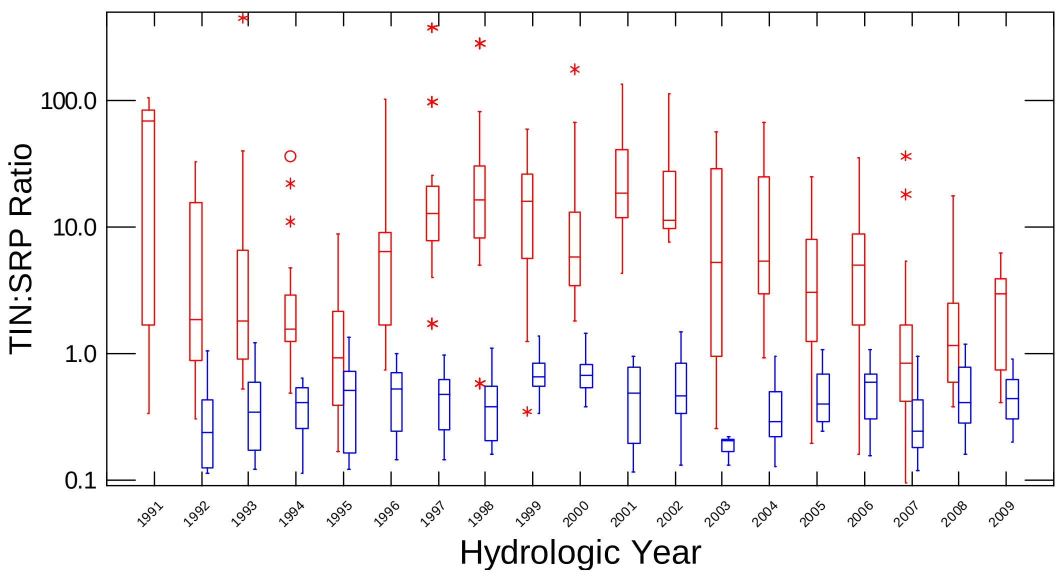




**Figure 4. Total nitrogen to total phosphorus (TN:TP) and total inorganic nitrogen (NOx-N+NH4-N) to PO4 (TIN:SRP) ratios in the Williamson River and UKL outflow stations, April-October: 1991-2009.**

### *TP and TN Loading*

2009 Seasonal Pattern

Similar to other years, the seasonal loading pattern for 2009 showed maximum tributary inflow loads of TP and TN occurring during the late-winter to early-spring period (Figure 5), and maximum UKL outflow loads occurring during the summer months when internal loading and nitrogen fixation takes place in UKL (e.g., see Kann 1998 and Kann and Walker 1999). Outflow loads were similar to Williamson and Wood River loading during the April-May period prior to the summer algal growing season.

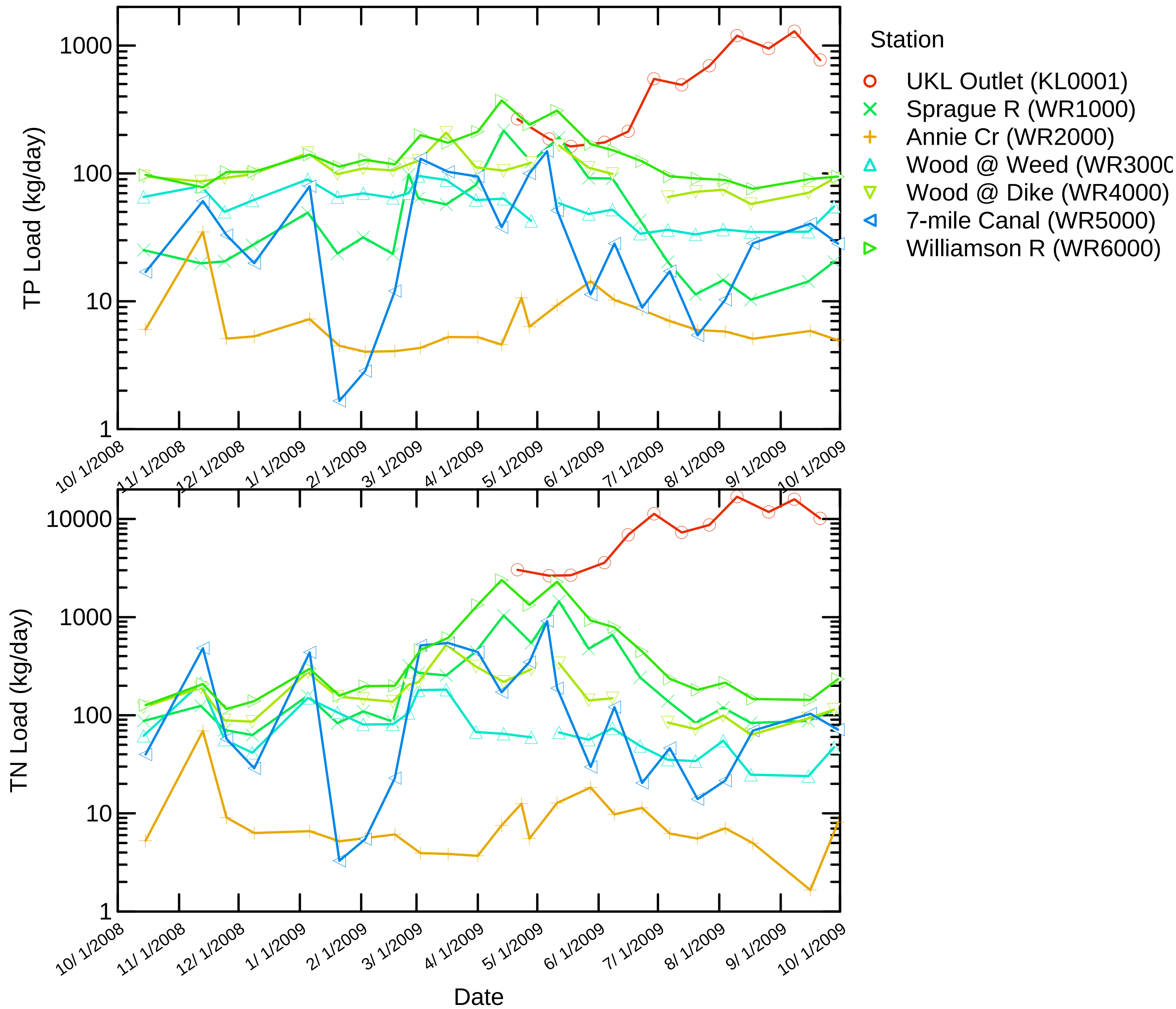



**Figure 5. Seasonal TP and TN loading trends by station, 2009.**

2009 Station Pattern

The 2009 nutrient loading pattern among stations was also similar to that of the 1991-2008 sampling period (Figure 6); both TP and TN loading were higher at the UKL outlet station. Of the inflow tributaries, the Williamson River (WR6000) showed highest overall loading due largely to its higher discharge, with the 2009 TP and TN loading distributions somewhat lower than previous years. Median TP loading at Wood River station WR4000 was similar to that of the Williamson River in 2009. As with concentration, Annie Creek at Snow Park was consistently lower for both loading parameters. High UKL outlet loads likely reflect internal loading and nitrogen fixation processes taking place in UKL. Sprague River TN load was more similar to the Williamson River load than it was for TP load (which was lower), 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).

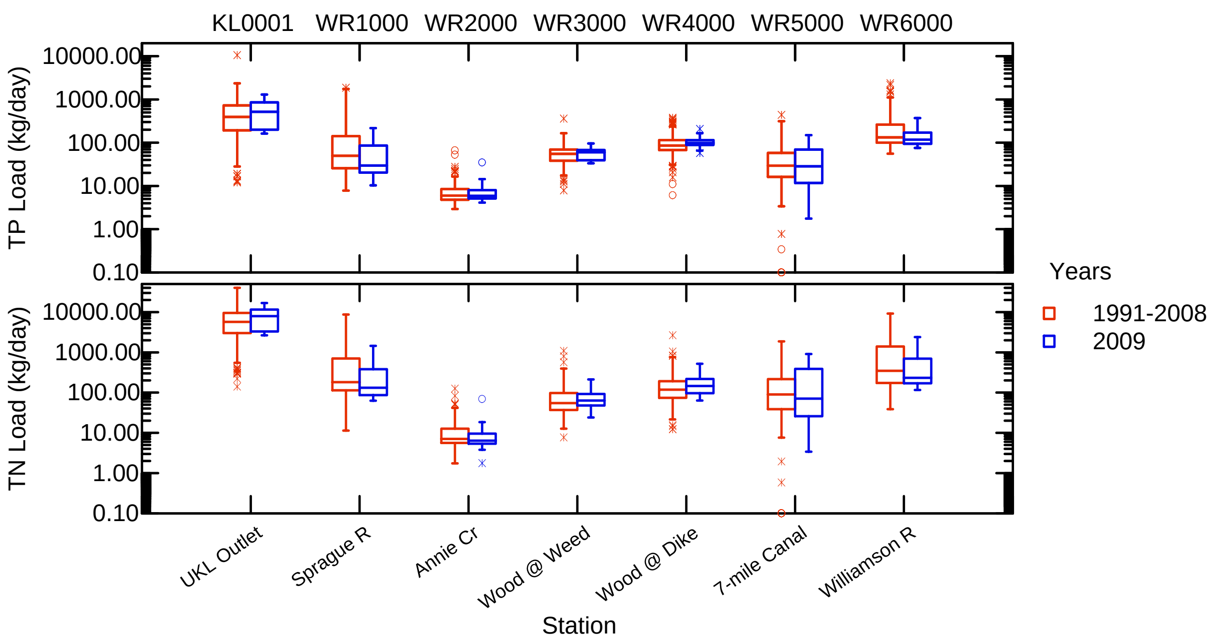



**Figure 6. Station distributions of TP and TN loading compared between 1991-2008 (red) and 2009 (blue). Note for station KL0001: in HY2006, there are no samples from January to mid-April and in HY2007-2008 there are no samples from November to mid-April.**

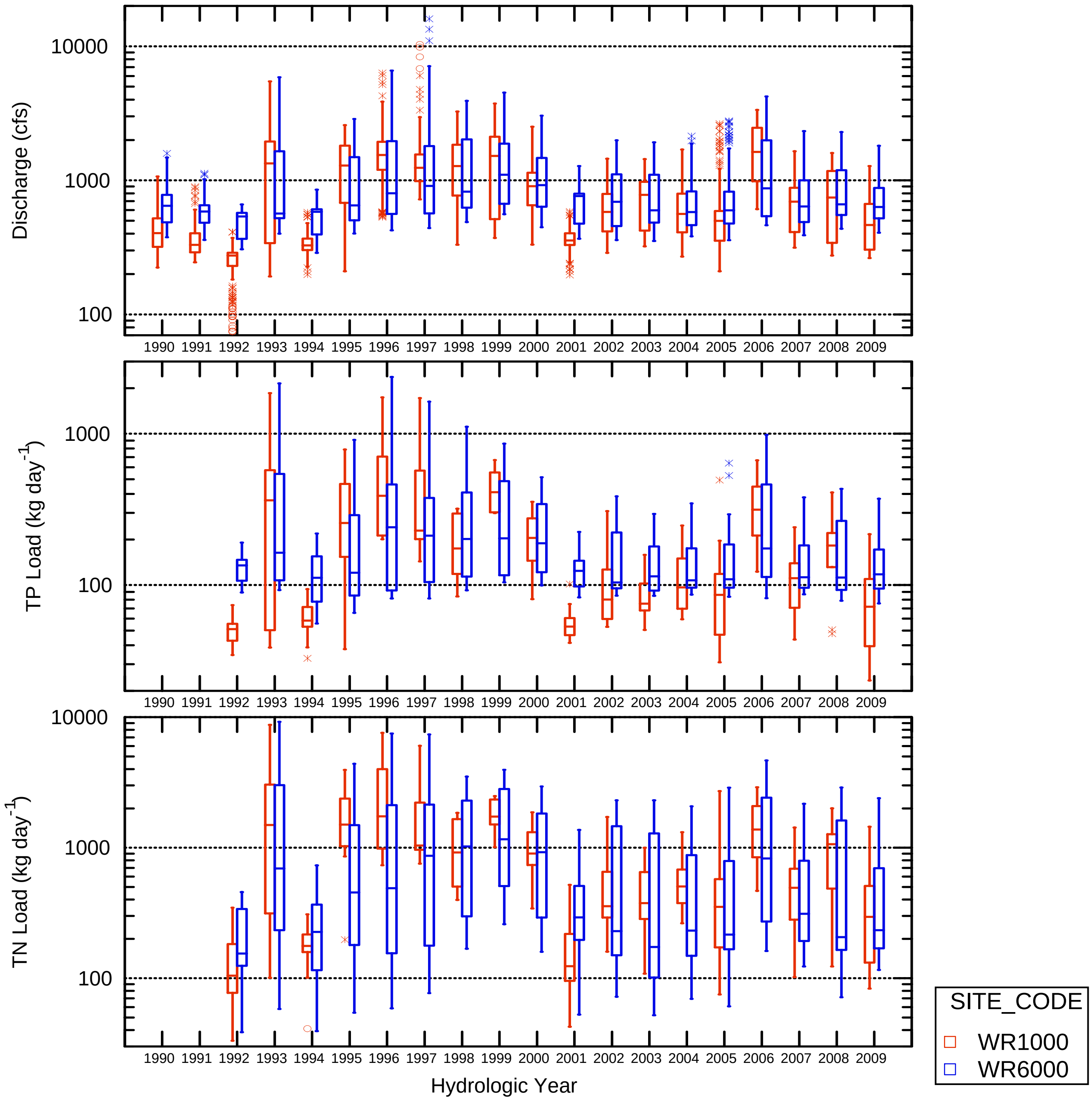



**Figure 7. Distribution of Williamson River (WR6000) and Sprague River (WR1000) daily discharge (top panel), TP load (middle panel), and TN load (bottom panel) for the January-May inflow period, 1990-2009.**

Inter-annual Patterns, 1991-2009

Although it is beyond the scope of this 2009 data summary report to analyze the inter-annual trends in detail, 1992-2009 comparisons for all sampling stations for three periods (all dates, the June-September period, and the Jan-May period) are shown in (Figures 8 to 21). UKL outflow TP and TN loads during Jun 1-Sep 30, 2009 were lower than the previous 3 years, but similar to 2003-2005 (Figure 8 and Figure 15). Note that for the UKL outlet station, only the June–September inter-annual graphical comparisons are valid due to changes in the winter and early spring sampling frequency over the period of record. The Sprague (Figure 9 and Figure 16) and Williamson Rivers (Figure 14 and Figure 21) in 2009 tended to show among the lowest TP and TN loading distributions for both the June-September and January-May periods when compared to the 1992-2009 period of record. Hydrologic loading as indicated by Williamson River discharge (Figure 9) 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 early 2011.

## SUMMARY

With the addition of 2009 data, the UKL tributary nutrient and loading database now includes 19 years of data and includes the years 1991-2009. 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.

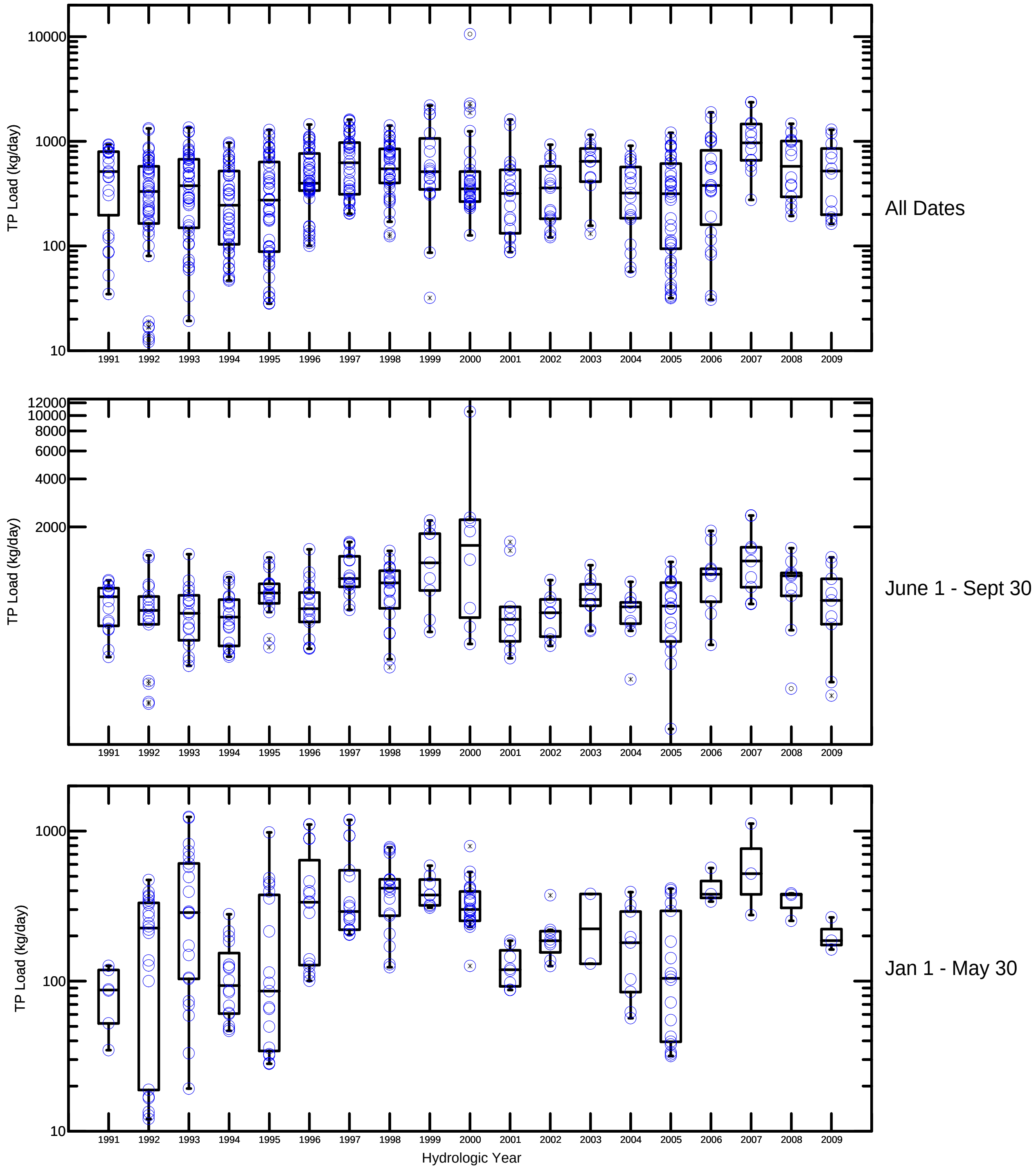



**Figure 8. Annual and seasonal distributions of UKL Outlet TP loading, 1991-2009. Note: in HY2006, there are no samples from January to mid-April and in HY2007-2008 there are no samples from November to mid-April.**

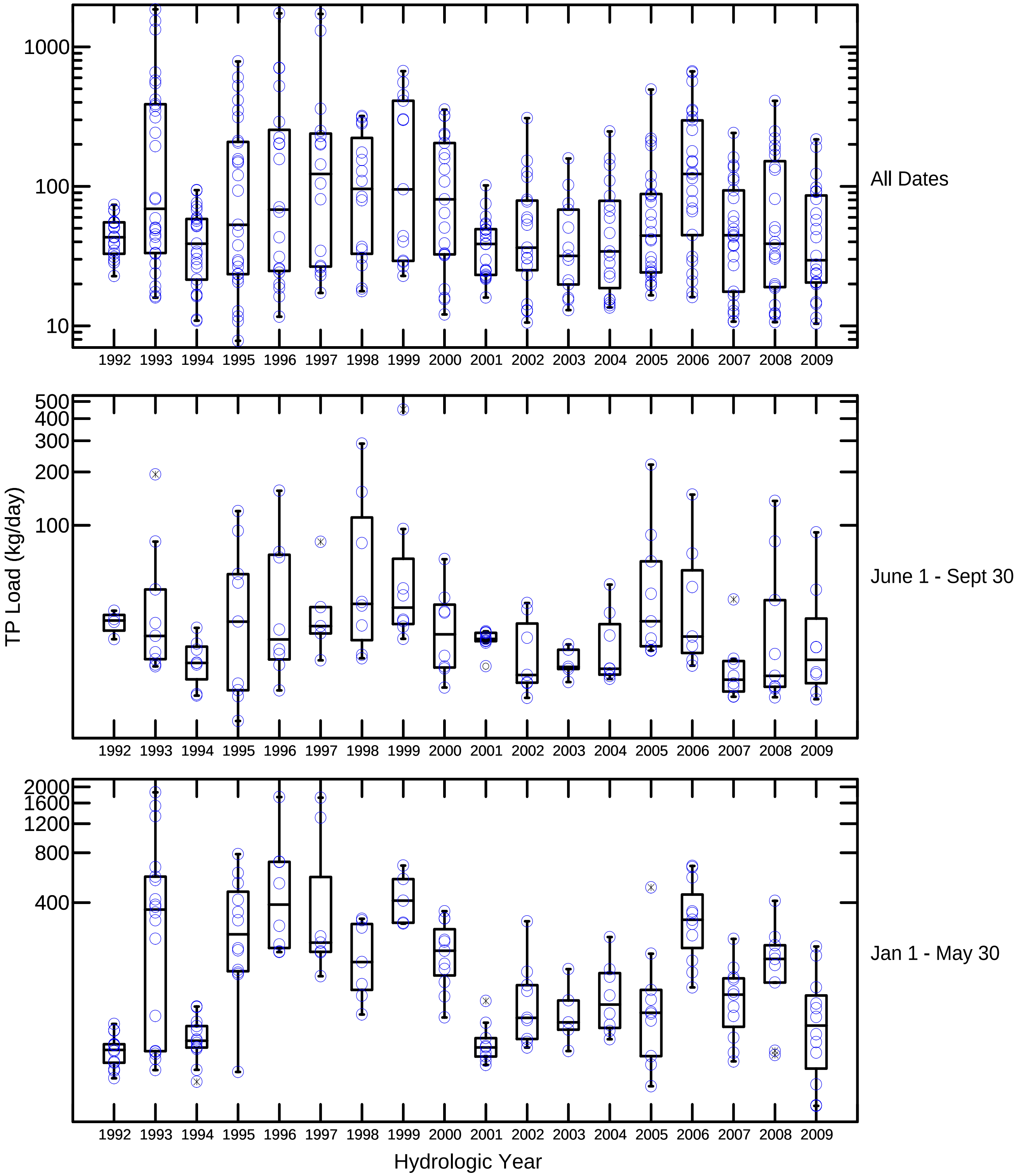



**Figure 9. Annual and seasonal distributions of Sprague River TP loading, 1991-2009.**

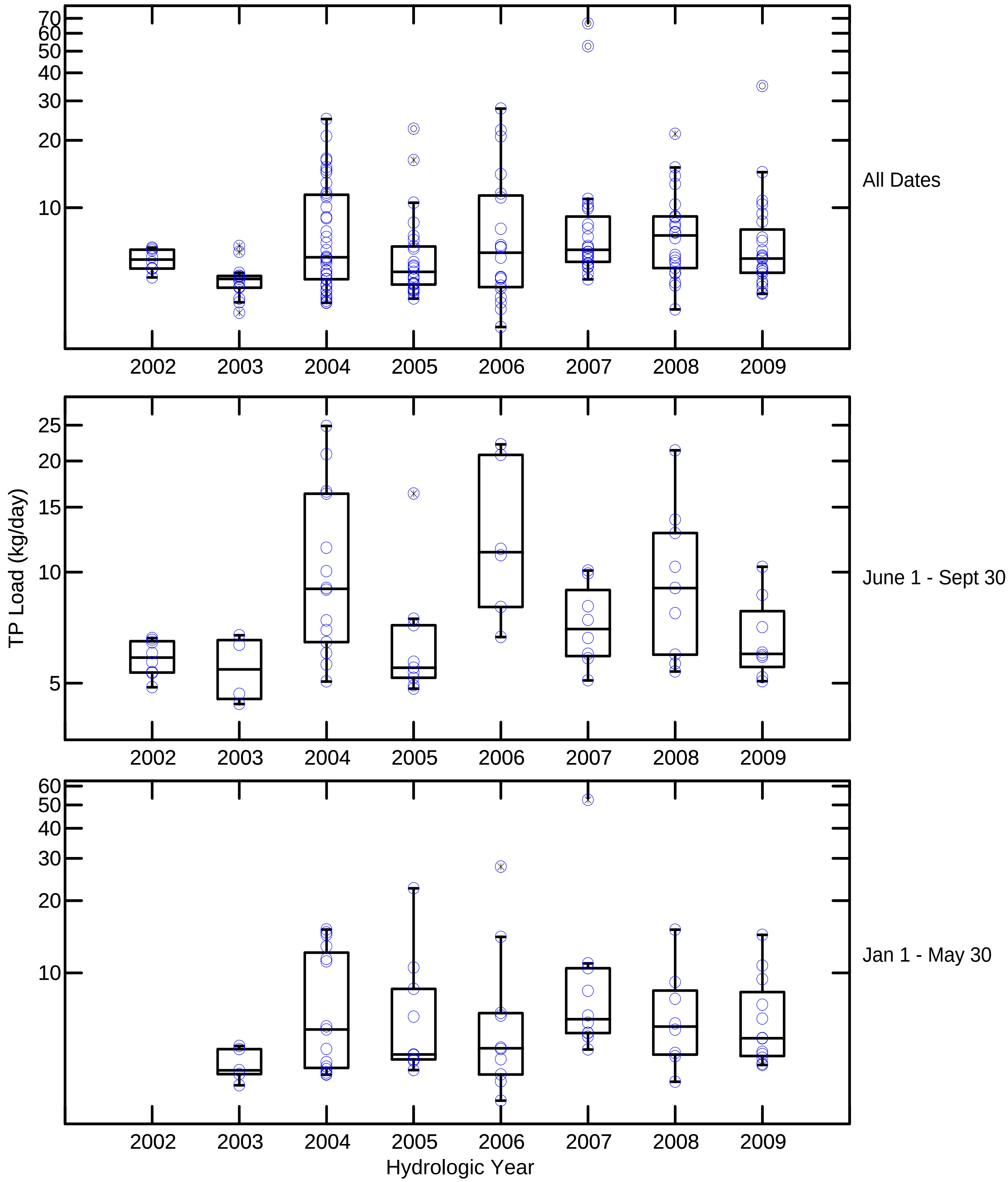



**Figure 10. Annual and seasonal distributions of Annie Creek TP loading, 2003-2009.**

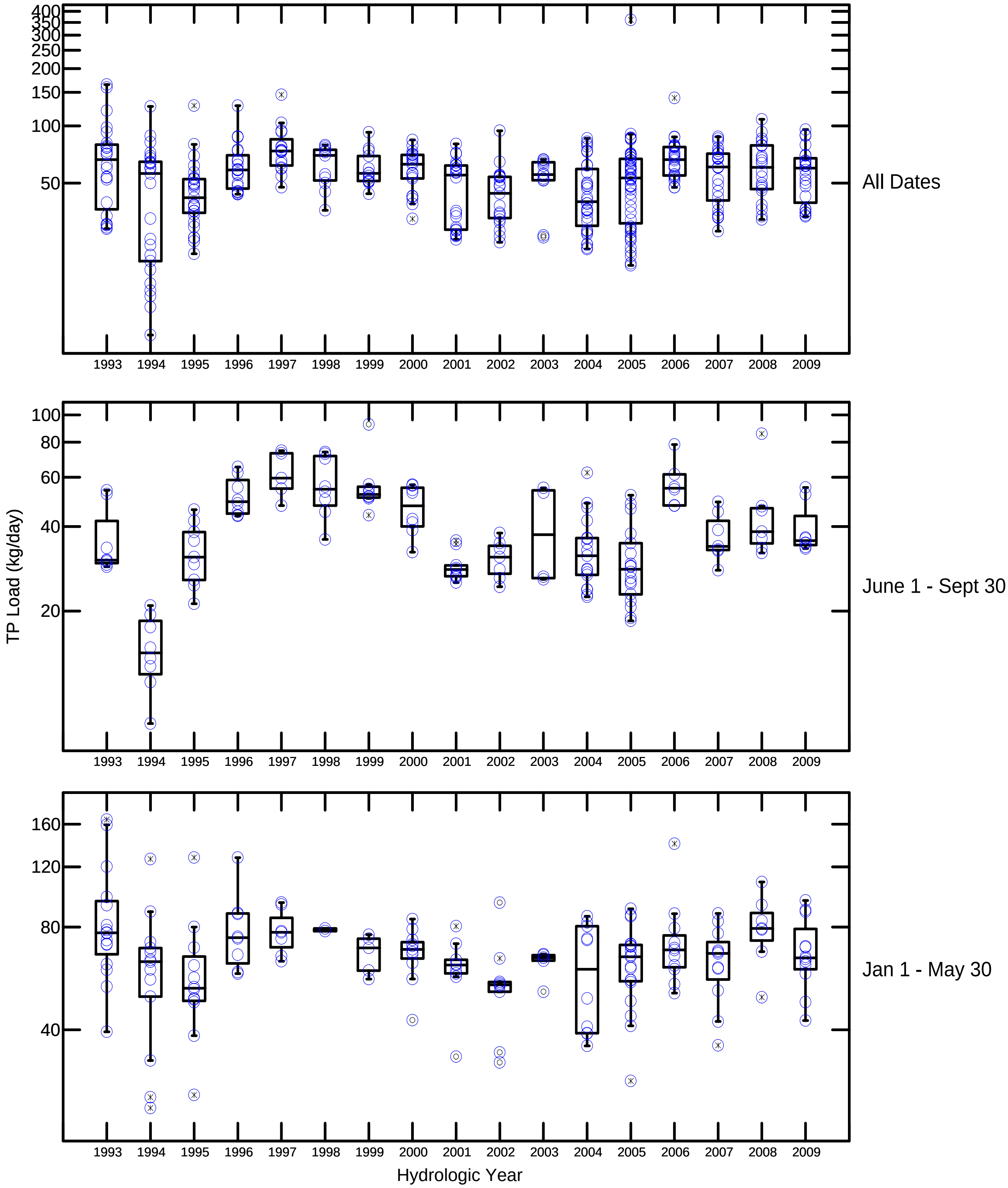



**Figure 11. Annual and seasonal distributions of Wood River at Weed Rd. TP loading, 1991-2009.**

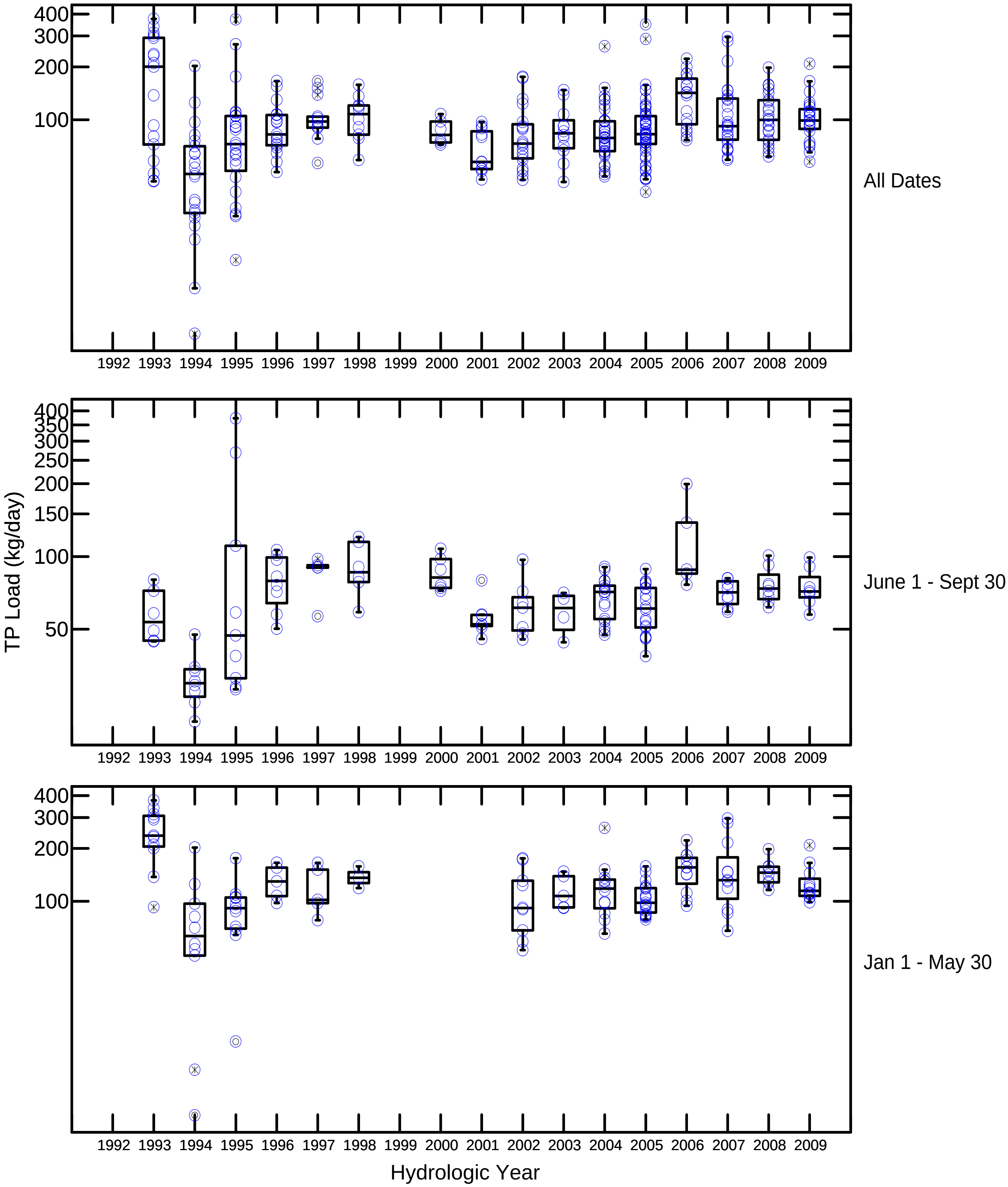



**Figure 12. Annual and seasonal distributions of Wood River at Dike Rd. TP loading, 1991-2009.**

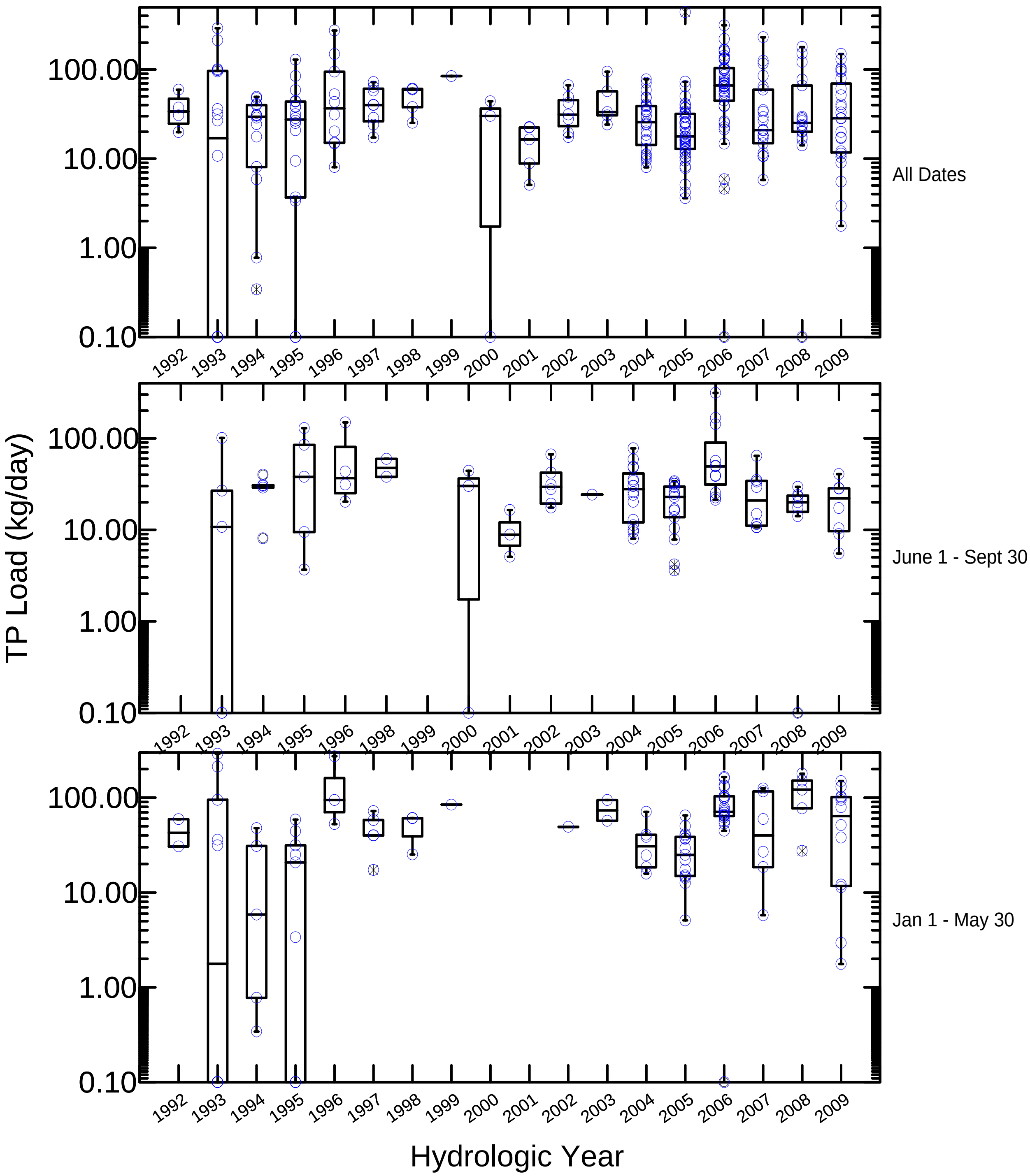



**Figure 13. Annual and seasonal distributions of Seven Mile Canal TP loading, 1991-2009.**

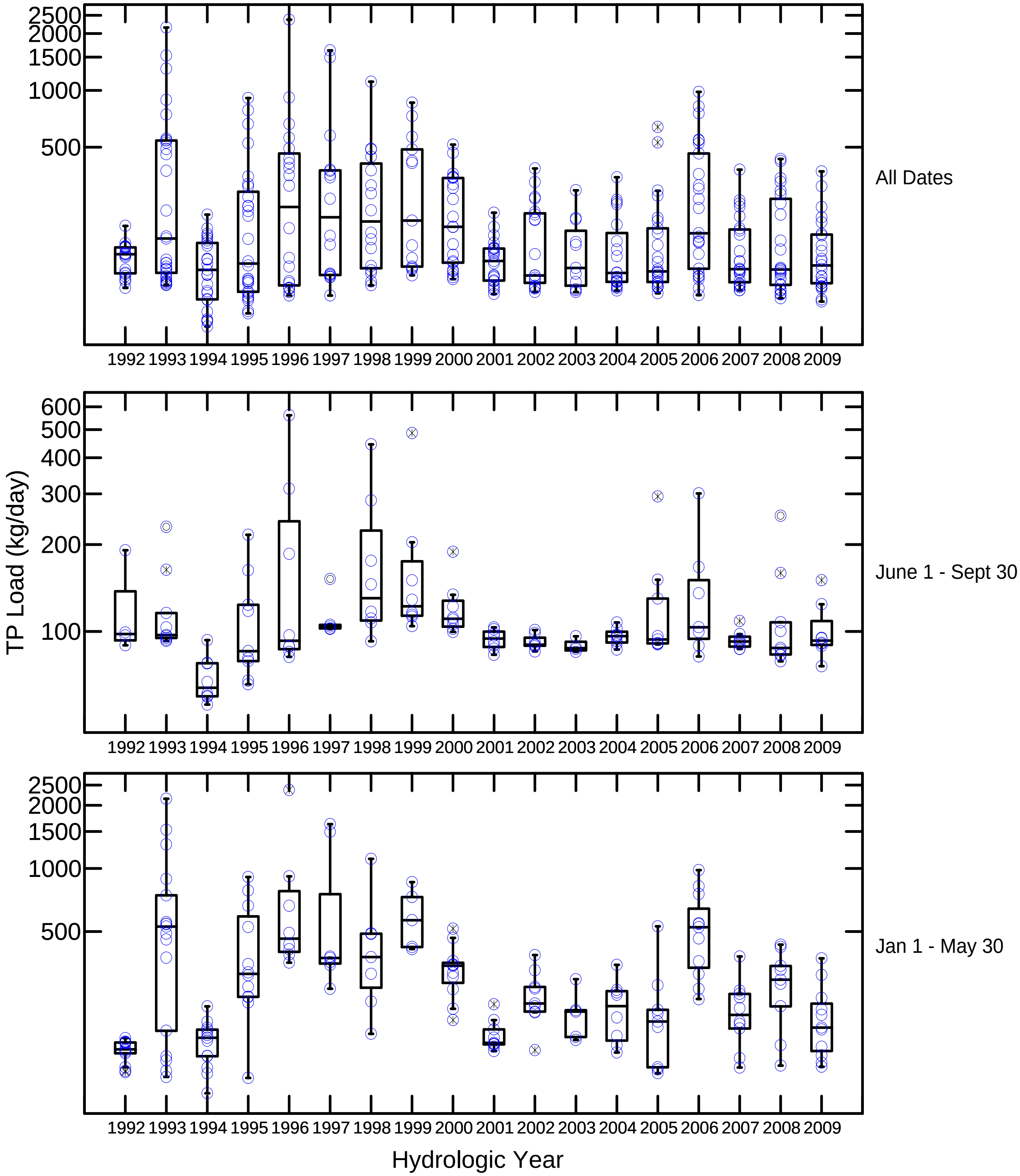



**Figure 14. Annual and seasonal distributions of Williamson River TP loading, 1991-2009.**

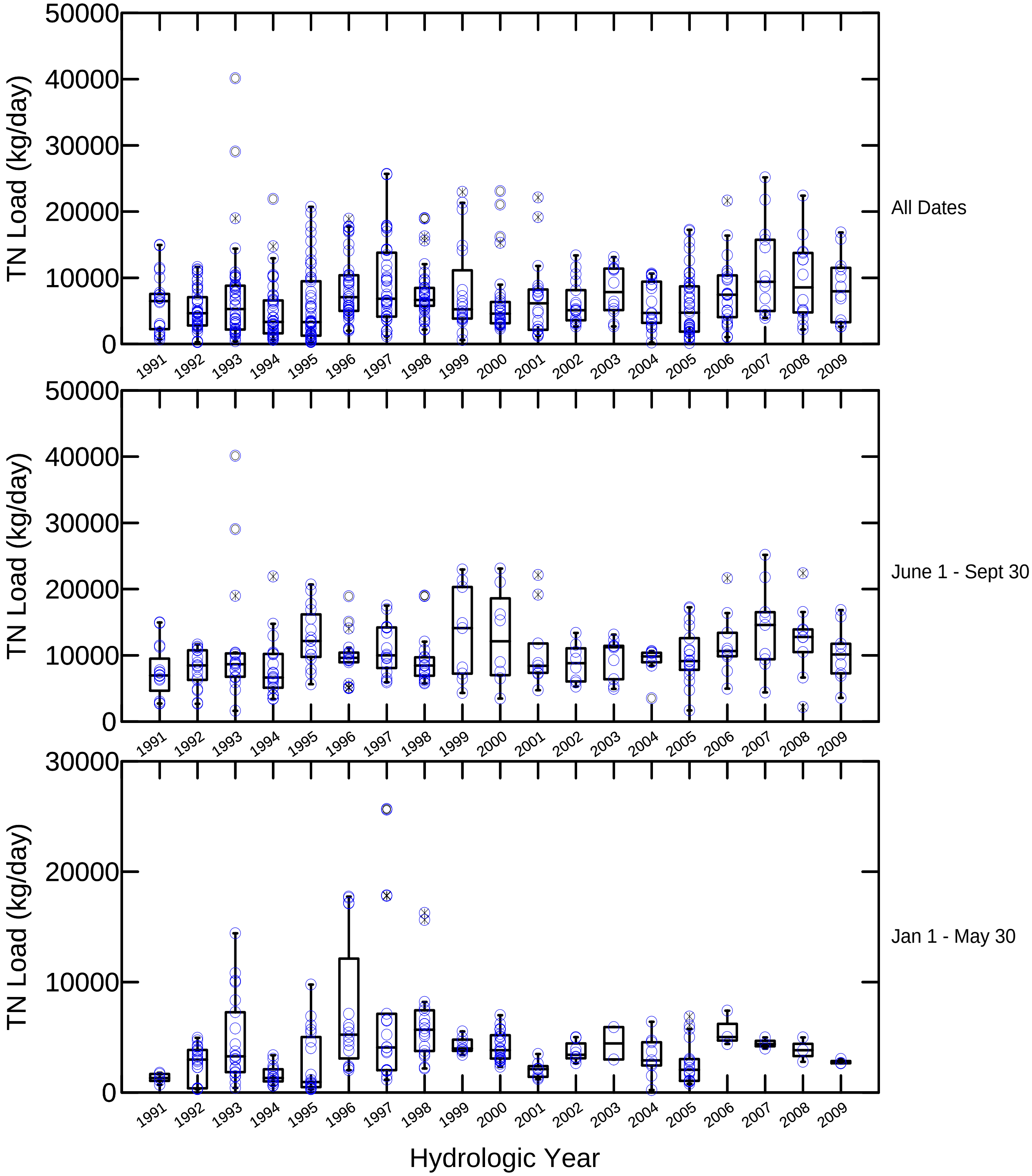



**Figure 15. Annual and seasonal distributions of UKL Outlet TN loading, 1991-2009. Note: in HY2006, there are no samples from January to mid-April and in HY2007-2008 there are no samples from November to mid-April.**

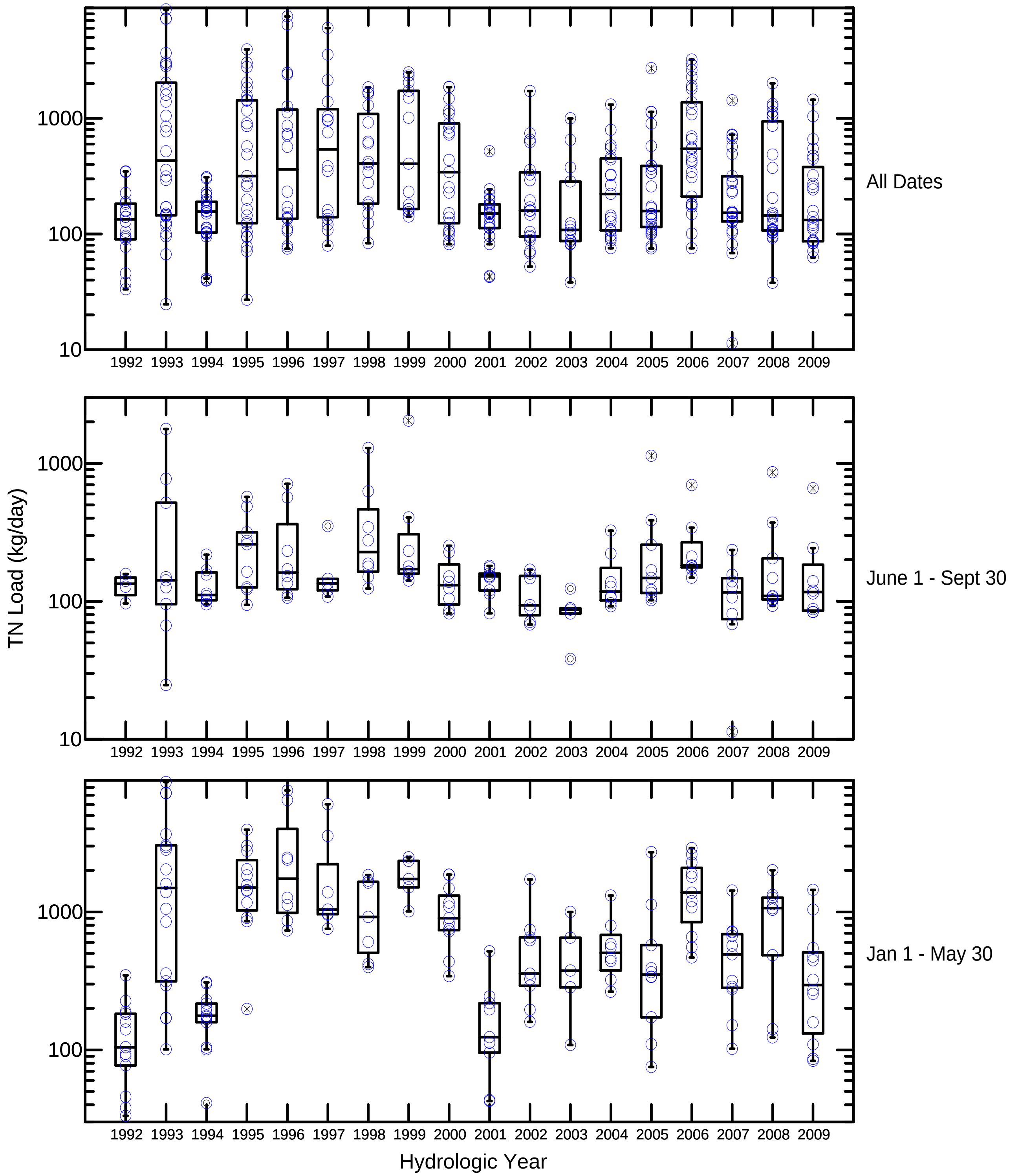



**Figure 16. Annual and seasonal distributions of Sprague River TN loading, 1991-2009.**

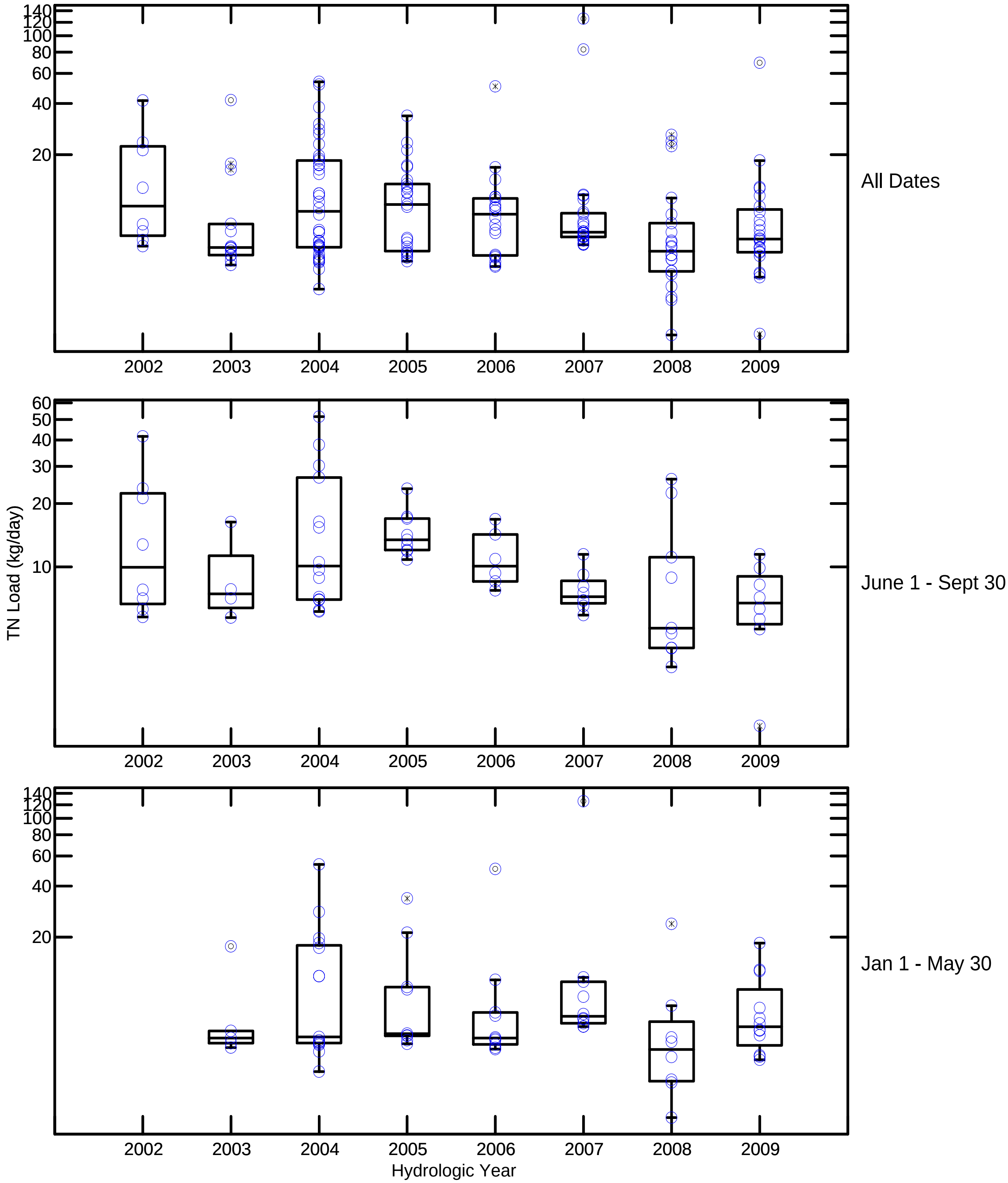



**Figure 17. Annual and seasonal distributions of Annie Creek TN loading, 1991-2009.**

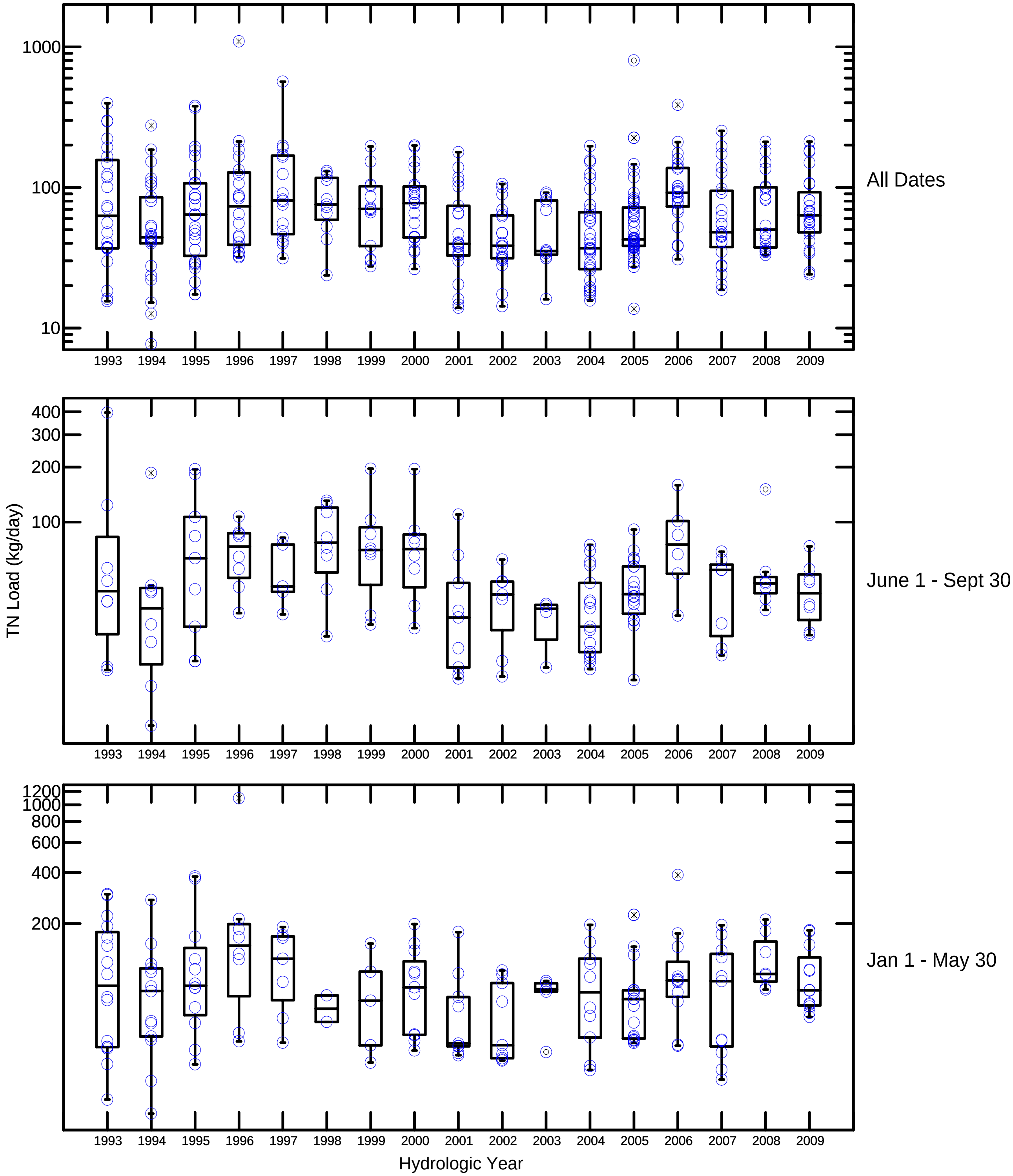



**Figure 18. Annual and seasonal distributions of Wood River at Weed Rd. TN loading, 1991-2009.**

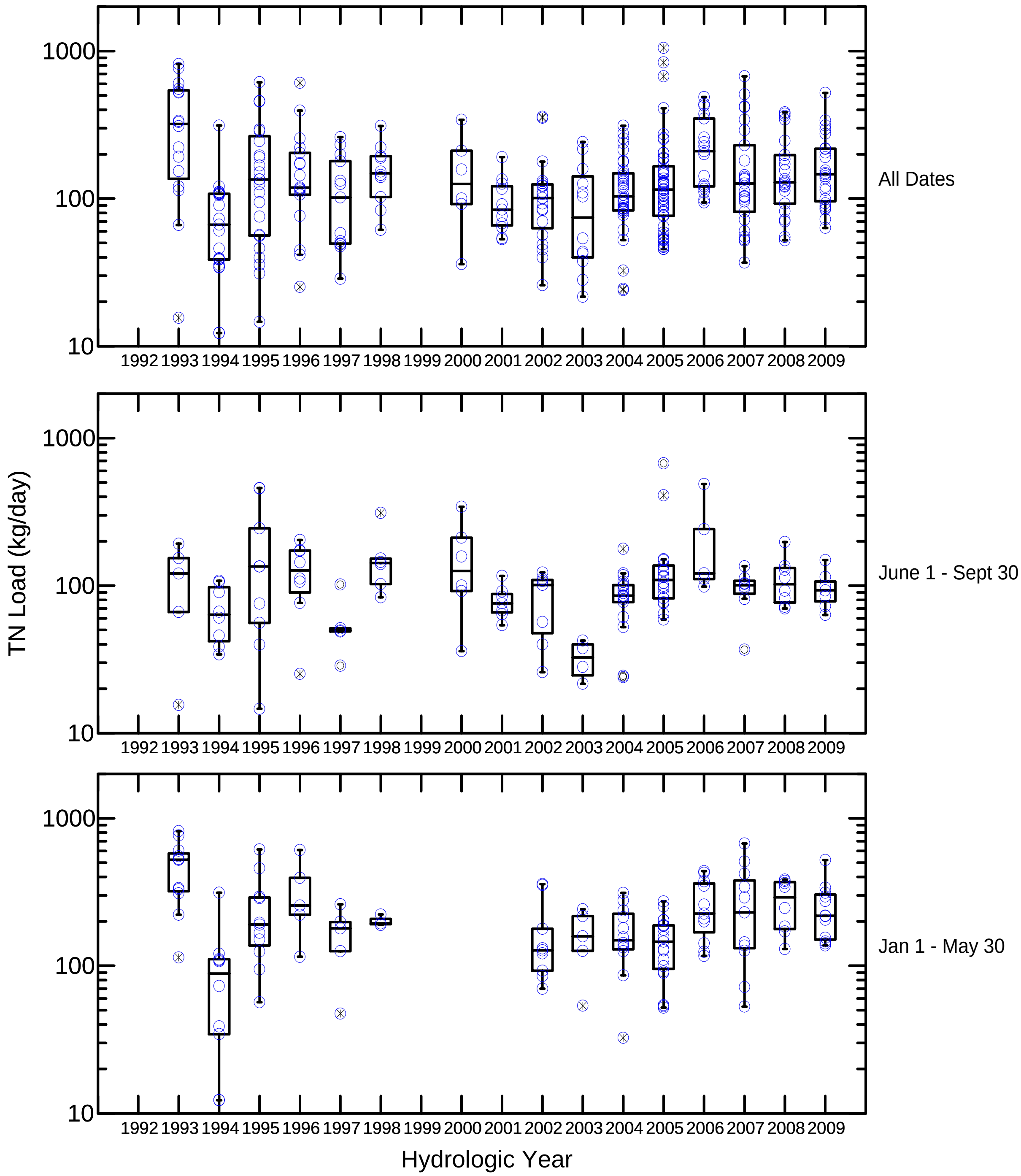



**Figure 19. Annual and seasonal distributions of Wood River at Dike Rd. TN loading, 1991-2009.**

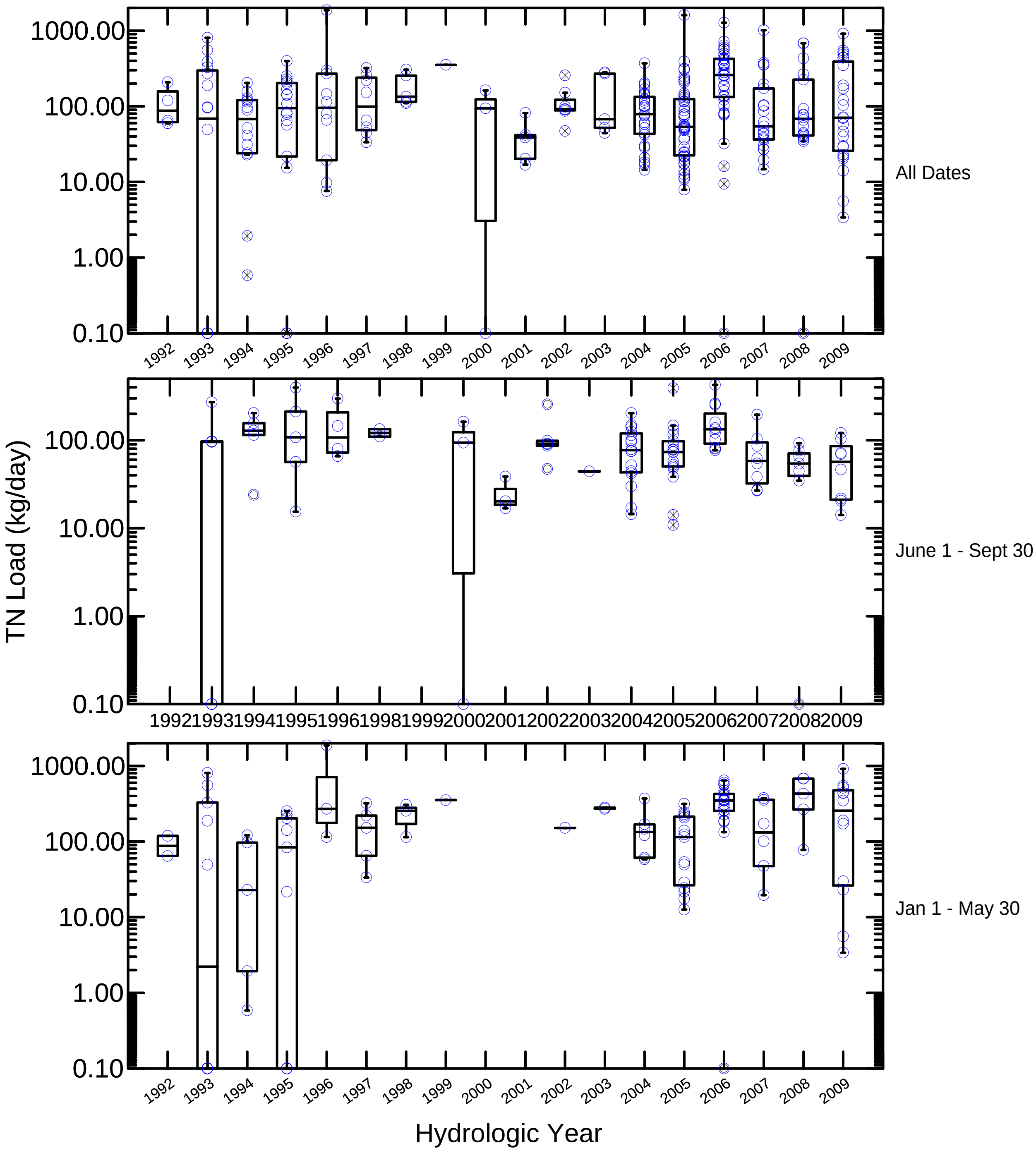



**Figure 20. Annual and seasonal distributions of Seven Mile Canal TN loading, 1991-2009.**

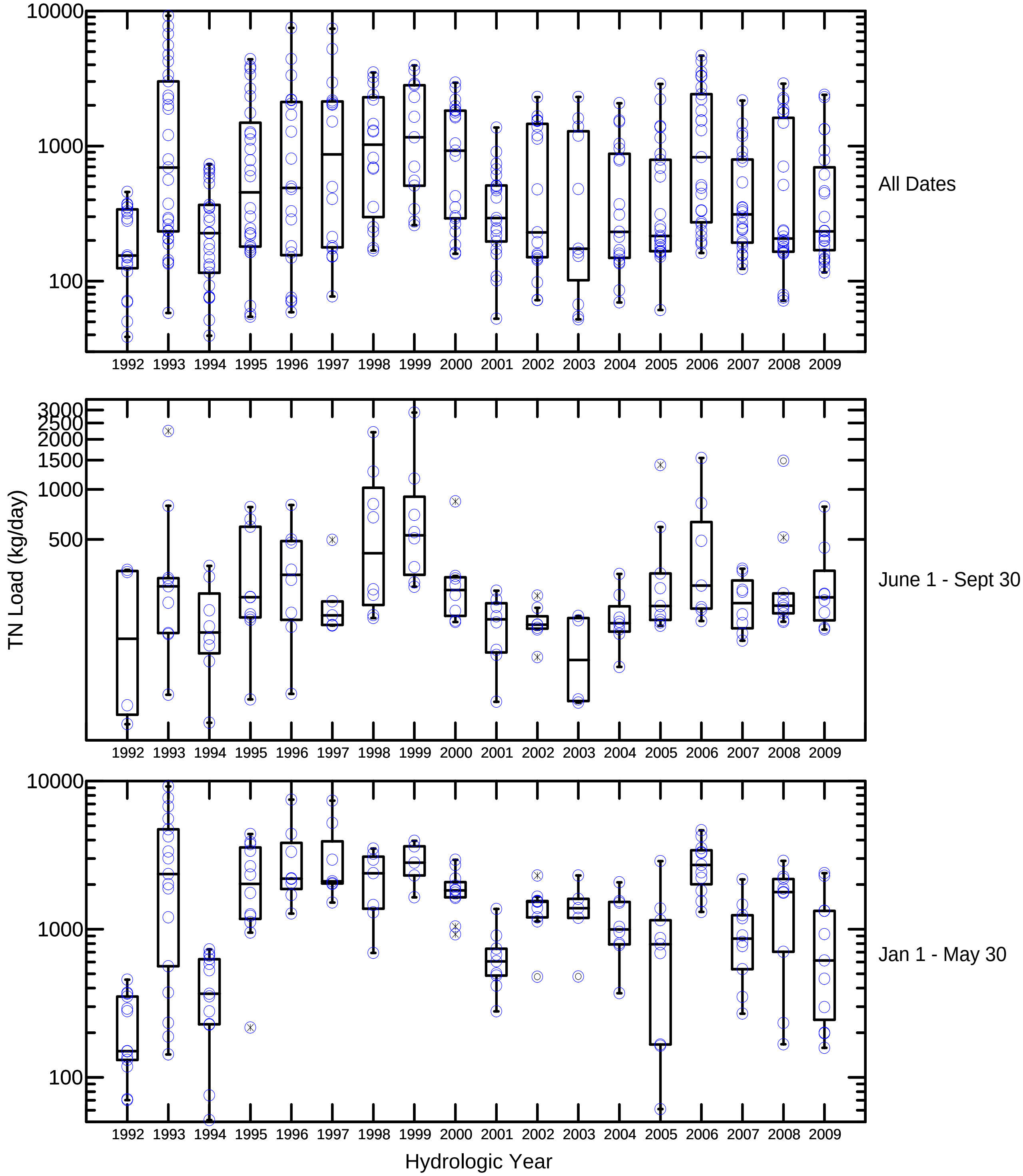



**Figure 21. Annual and seasonal distributions of Williamson River TN loading, 1991-2009.**

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