TECHNICAL MEMORANDUM

TO:	JOHN HALL, HALL & ASSOCIATES	DATE:	JANUARY 16, 2012
CC:	GREAT BAY MUNICIPAL COALITION	RE:	ESTIMATION OF DIN LOADS TO THE GREAT BAY ESTUARY SYSTEM
FROM:	THOMAS W. GALLAGHER CRISTHIAN MANCILLA	FILE:	HAAS – 174334

1.0 INTRODUCTION

New Hampshire Department of Environmental Services (NHDES) has proposed a total nitrogen (TN) criterion of 0.3 mg/L to allow the recovery of eelgrass in the tidal tributaries to the Great Bay Estuary system. It is now recognized that nitrogen loads to Great Bay are not stimulating excessive suspended algal levels and a concurrent significant reduction in water clarity. A study by J. Ru Morrison et al. (Using Moored Arrays and Hyperspectral Aerial Imagery to Develop Nutrient Criteria for New Hampshire's Estuaries, 2008) indicates that average suspended algal levels (3-5 ug/L Chlorophyll-a) reduce water clarity by approximately 10 to 15% during the growing season. The observed suspended algal levels in Great Bay are low (2000-2008 median ~3.4 ug/L) and cannot produce a significant reduction in water clarity. Furthermore, recent studies (algal level temporal figures generated by NHDES) have shown that significant changes in algal levels did not occur during the period of eelgrass decline. However EPA has issued draft NPDES permits for Newmarket and other sewage treatment plants with an effluent TN limit of 3.0 mg/L based on a proposed NHDES TN criterion of 0.30 mg/L that is intended to reduce suspended algal levels in Great Bay. Dr. Arthur Mathieson (Jackson Estuarine Laboratory) has indicated that it is likely that the growth of macroalgae in Great Bay is a major factor in eelgrass decline over the last 20 years but the level of nitrogen reduction required to reduce macroalgae growth to acceptable levels is unknown. In addition, Dr. Mathieson indicated that dissolved inorganic nitrogen (DIN), the readily available form of nitrogen for algal growth, is the primary form of nitrogen to initially regulate to control macroalgae growth (verbal presentation - Great Bay Municipal Coalition Nitrogen meeting).

This memorandum summarizes the estimation of point source (PS) and non-point source (NPS) DIN loads to the Great Bay Estuary System for the period extending from before the decline in eelgrass to present conditions. The results of this analysis can be used to compare DIN loads to Great Bay when eelgrass beds were abundant to expected future nitrogen loads with PS effluent TN at 8 mg/L. This effluent TN level (8 mg/L) is referenced in the Memorandum of Agreement (MOA) developed by the Great Bay Municipal Coalition in coordination with NHDES.

2.0 ESTIMATION OF TRIBUTARY RIVERS NPS DIN LOADS (EXETER, LAMPREY, AND OYSTER RIVERS)

The tributary rivers included in this study are the Exeter, Lamprey and Oyster. Nitrogen data for the rivers under consideration was provided by NHDES. The water quality station selected for each tributary is the head of tide monitoring station employed by NHDES to perform a similar load analysis for TN in the tidal tributaries using the USGS program LOADEST. Daily flow records were obtained from USGS for all three tributaries. The USGS stations are: 01073587 Exeter River at Haigh Road, 01073500 Lamprey River near Newmarket, and 01073000 Oyster River near Durham. Figures 1 to 3 present temporal plots of daily flow, NO_2+NO_3 and NH_3 (1990-2010) for each tributary. Initially, it was intended to develop a relationship between DIN concentrations and river flows and furthermore consider any seasonal dependency possibly produced by algal uptake, temperature, and others. However, after further analysis no relationship between DIN concentrations and river flows was identified. Figure 4 presents cross plots of measured DIN versus measured river flows for all three tributaries. Similar analysis was performed on a seasonal and monthly basis but no DIN concentration – flow dependency was observed. The limited availability of data could be one the reasons for the inability to identify monthly or seasonal DIN-flow patterns. As shown on Figures 1 to 3, NH_3 detection limit (DL) issues are present in the 2001-2007 time period. No attempts were performed on considering data flagged as DL in the DIN calculations as there are clearly at least three different detection limits over that period of time. It was considered that implementing any DL consideration approach would simply add unnecessary uncertainty to the calculation of a long term DIN average. In any case, no identifiable temporal trends are present in the dataset and therefore not considering nitrogen data flagged as DL (NH_3) in the calculation of DIN concentrations may not significantly affect the computed long term average DIN.

For the estimation of long term NPS DIN loads to the Great Bay Estuary System, it was necessary to identify a time period (season) when macroalgae growth is viable given the seasonal variability of temperature and available light. Two major factors were considered in isolating this time period: water temperature and river flow levels. Water temperature trends over a year are a key factor on macroalgae growth and therefore it is important to identify a season where such growth is possible and/or significant. River flow trends over a year are also important because during low flows the water turbidity and color is reduced thereby resulting in greater water clarity and available light for macroalgae growth. Water temperature for several stations in the Great Bay area was obtained from the Centralized Data Management Office (CDMO), part of NOAA's National Estuarine Research Reserve System (NERRS) program. The stations included are: GRBSQ on the Squamscott River, GRBLR on the Lamprey River, GRBOR in the Oyster River and GRBGB on the Great Bay area. Figure 5 (upper panel) presents the monthly average water temperature computed for all stations together (2000-2010). Similar analysis was performed for the tributary river flows. Figure 5 (bottom panel) presents the computed monthly average river flows for all three rivers under consideration (1990-2010). From considerations of possible macroalgae and eelgrass growing seasons and from the water temperature and river flow trends presented in Figure 5, the June to September time period was selected for estimation of NPS DIN loads being delivered into the Great Bay Estuary System.

Having established the time period of interest, June-September average river flows were computed for the 1990-2010 time period. Daily flow records for the Exeter River are available after 1996 only and therefore a relationship was developed between Exeter and Lamprey daily flows and employed for estimating the 1990-1995 Exeter River June-September average flows. Figures 6 to 8 (upper panel) present the computed June-September average river flows. The June-September average DIN concentration for each river was then computed from the available valid nitrogen data and employed in conjunction with the computed average river flows to calculate river DIN loads. Flow multipliers, as derived by NHDES, were employed in the calculation of river DIN loads to account for watershed drainage area not considered by the USGS stream gage. For each river under consideration, the computed NPS DIN loads (1990-2010) are shown on Figure 6 to 8 (bottom panel). A similar NPS load analysis was performed for the April-May time period and is presented in later sections in this document.

3.0 ESTIMATION OF CURRENT PS DIN LOADS (EXETER WWTP, NEWMARKET WWTP, AND DURHAM WWTP)

The PS loads considered in this analysis are tabulated in Table 1. The Newfields WWTP is also located on the Exeter River but for the purposes of this analysis it was ignored given its insignificant DIN load contribution as compared to the Exeter River and Exeter WWTP DIN loads. The PS effluent flows and DIN concentrations were based on available flow and total dissolved nitrogen (TDN) values as presented by NHDES and confirmed by limited data. The DIN concentration was computed with the assumption that 2 mg/L of the TDN was dissolved organic nitrogen (DON). For reference, the computed PS DIN loads are represented by the dotted red theoretical lines on Figures 6 to 8 (bottom panel).

Table 1. WWTP DIN Loads.

River	WWTP	Flow (MGD)	TDN (mg/L)	DIN (mg/L)	DIN (lb/d)
Exeter	Exeter	2.2	10	8	147
Lamprey	Newmarket	0.7	20	18	105
Oyster	Durham	1.0	7	5	42

4.0 EVALUATION OF LONG TERM RIVER FLOW CONDITIONS

In order to develop a NPS-PS DIN load balance being delivered to the Great Bay Estuary for the period of interest (1990-2010), it was necessary to examine the long term river flows to identify any bias in the flow conditions present in the time period under consideration for the load analysis. The Lamprey river flow was selected as a surrogate for long term hydrological conditions in the area of interest as it is a major freshwater input to the Great Bay system. Figure 9 presents Lamprey River daily and June-September average flows from 1934 to 2011. A probability distribution of June-

September average flows was also developed and is presented in Figure 10. From these figures it is apparent that the 2006, 2008 and 2009 June-September average flows were very infrequent occurrences during the last eighty years (1934-2011). It was considered that developing the NPS-PS DIN load balance from 1990 to 2005 would be a better representation of the long term river flow conditions in the area of interest.

5.0 ESTIMATION OF CURRENT AND FUTURE TOTAL DIN LOADS

For the estimation of future PS DIN loads, a monthly average effluent TN of 8 mg/L was assumed for all three WWTPs. This monthly effluent TN was assumed to correspond to a long term average TN of 6 mg/L and TON of 3 mg/L and therefore produce a long term average effluent DIN of 3 mg/L. The current effluent flows were employed for the calculation of future PS DIN loads. The computed current and future average PS and NPS DIN loads (1990-2005) are shown in Figure 11. Figure 11, upper panel, presents the DIN load NPS-PS split for each tributary river including current and future (TN=8mg/L) PS DIN loads. The estimated future total DIN load as a percent of the current total DIN load for each river is: Exeter River 56%, Lamprey River 60% and Oyster River 73%. Figure 11, bottom panel, presents the current and future total DIN load from all three tributaries under consideration. The estimated future total DIN load as a percent of the current total DIN load for all three rivers is approximately 60%. Figure 12 presents a similar analysis to the one presented in Figure 11 but the DIN load NPS-PS split was computed for the April-May time period. The effect of the higher river flows on the NPS loads is evident as well as the relatively small contribution of the PS DIN loads to the total DIN load as compared to the June-September time period. In this case, the estimated future total DIN load as a percent of the current total DIN load for all three rivers is approximately 85%.

All three rivers PS and NPS DIN loads under consideration were added to obtain the total DIN load delivered by these tributaries. Both, present and estimated future total DIN loads, are shown in Figure 13 (lower panel). For this analysis, the Durham WWTP present DIN load estimate was refined to reflect a treatment modification in 2005 and therefore the 1990-2004 DIN effluent concentration was specified as 18 mg/L. The post 2004 Durham DIN effluent concentration was specified as the previously employed 5 mg/L. Figure 13, upper panel, also presents a temporal plot of eelgrass area as quantified in the Great Bay area. If 1990-2001 is considered to be the pre-eelgrass decline period, the corresponding average total DIN load was about 582 lb/d. In comparison, the estimated average future total DIN load (1990-2010) is about 347 lb/d. As established before, 2006, 2008 and 2009 June-September average flows are very infrequent occurrences (extremely high June-September flows) and therefore, if ignored in the 1990-2010 future total DIN load estimation, the future average total load would be about 288 lb/d.

With the reduction of the Exeter, Newmarket, and Durham wastewater treatment plants effluent TN to 8 mg/L, total DIN loads to Great Bay during the growing season (June-September) will be less that the total DIN loads to Great Bay when eelgrass was abundant. It is recognized that although DIN is the form of nitrogen immediately available to macroalgae and eelgrass, some organic nitrogen will be converted to inorganic nitrogen in the Great Bay. The amount of organic nitrogen converted to inorganic nitrogen depends on the fraction of organic nitrogen that is labile (readily available) versus refractory and the residence time in Great Bay for this conversion to occur. As a first estimate, this level of point source nitrogen load reduction in conjunction with some non-point source nitrogen load reductions is a reasonable first step in an adaptive management approach to restore eelgrass in the Great Bay. The future point source effluent scenario under consideration (TN=8mg/L) will likely reduce nitrogen loads to Great Bay to levels experienced in the 1990s when eelgrass was present at a larger extent.

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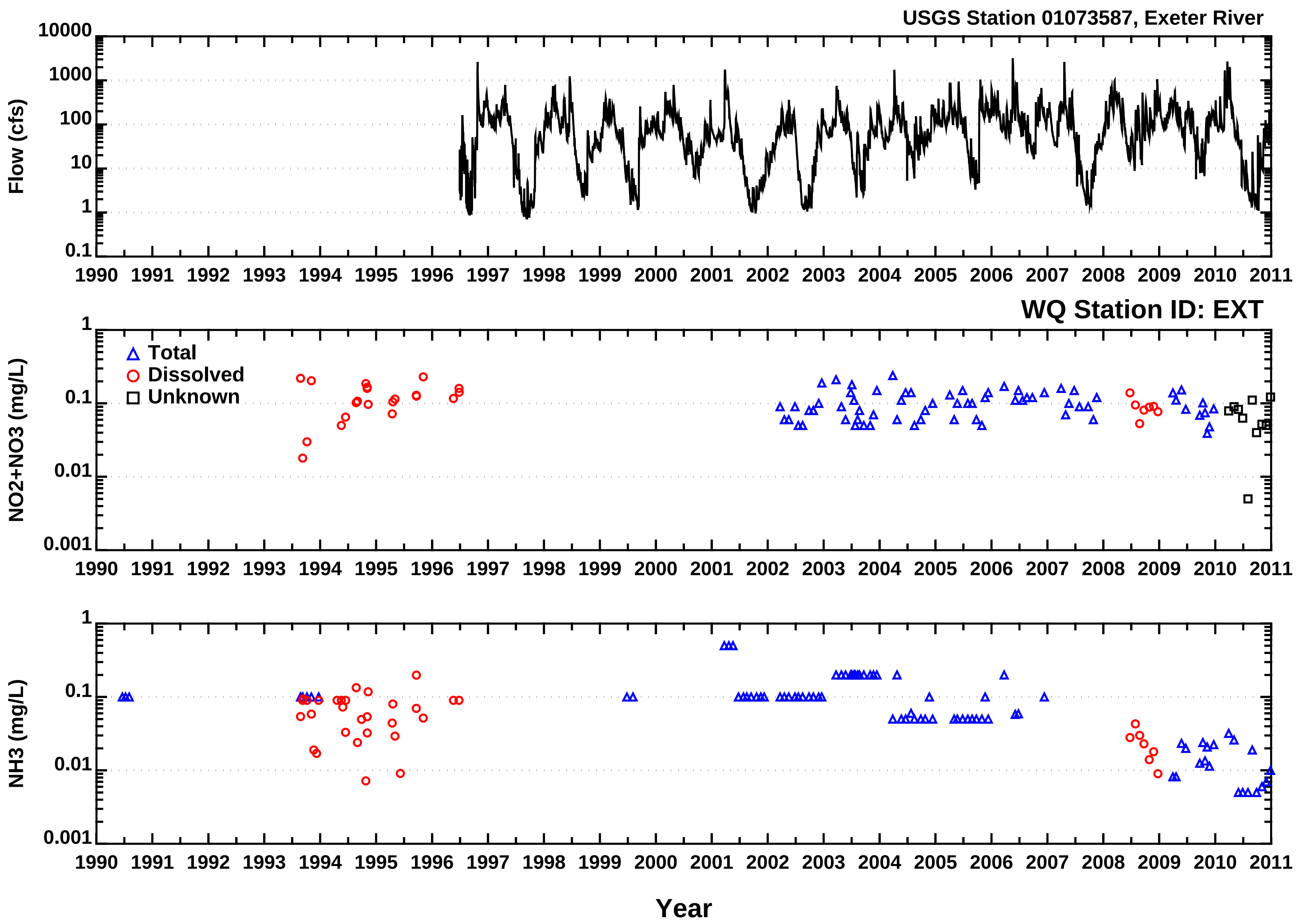


Figure 1. Exeter River: Available NO2+NO3 and NH4 Data for DIN Load Estimation (1990-2010)

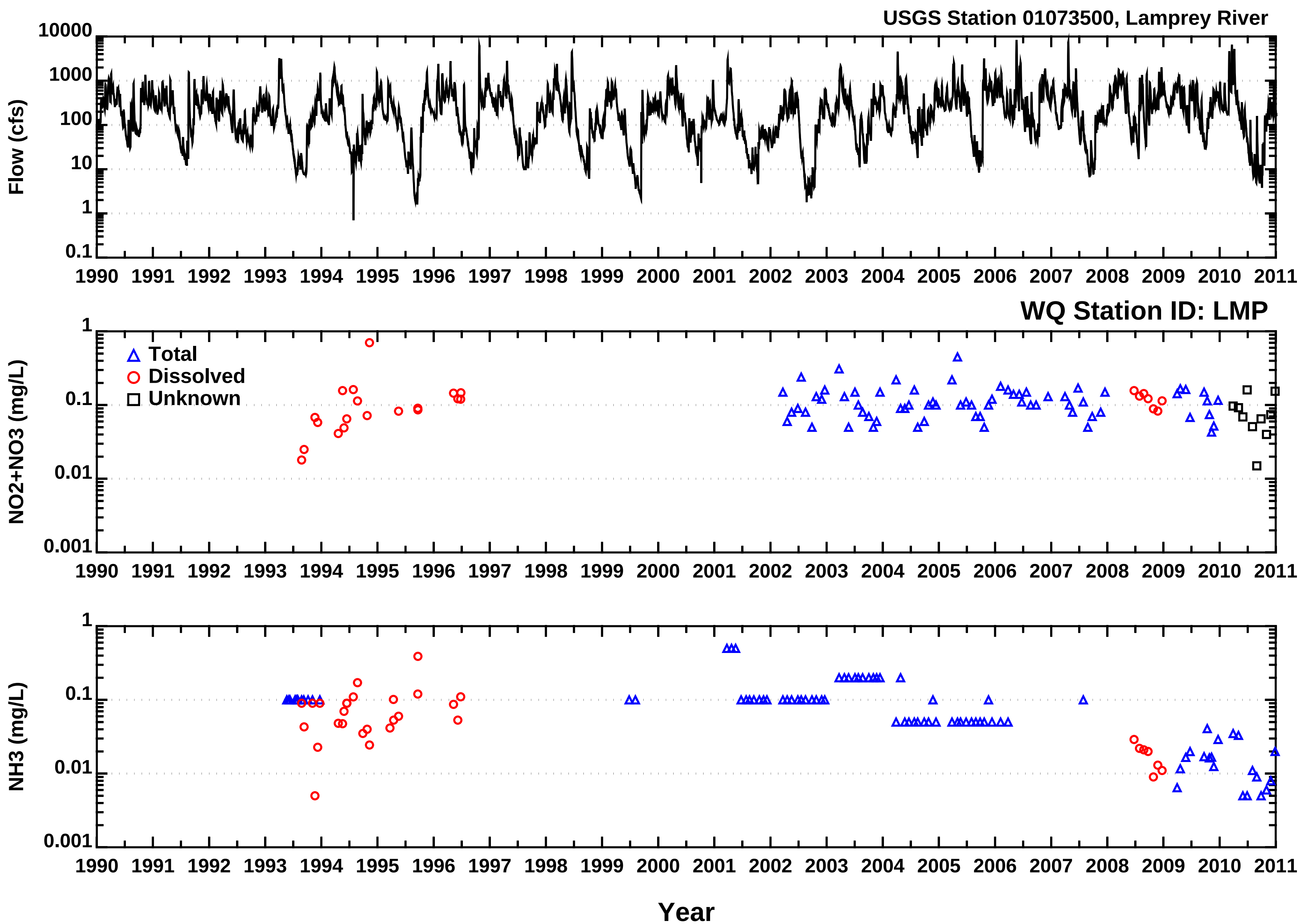


Figure 2. Lamprey River: Available NO2+NO3 and NH4 Data for DIN Load Estimation (1990-2010)

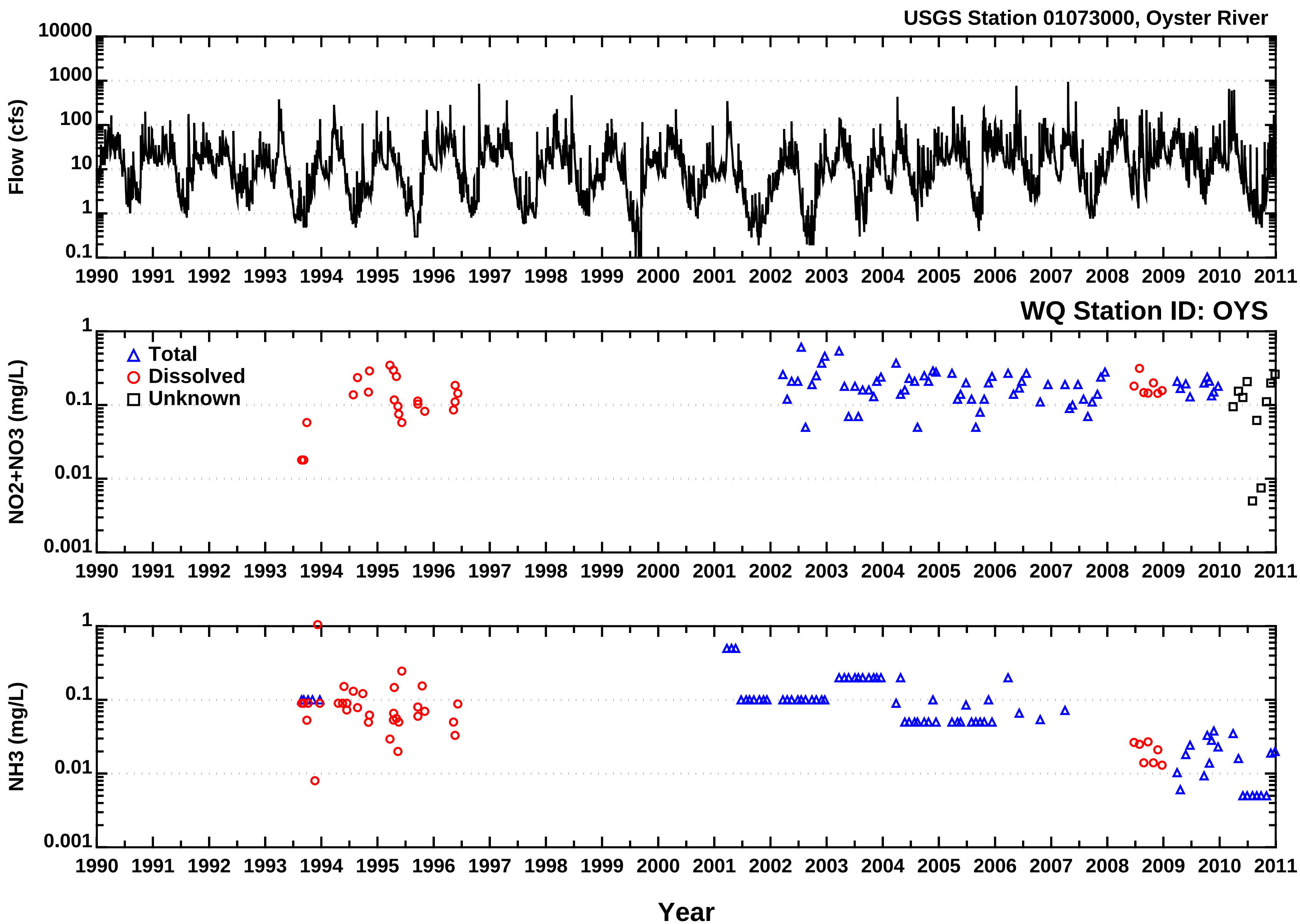


Figure 3. Oyster River: Available NO2+NO3 and NH4 Data for DIN Load Estimation (1990-2010)

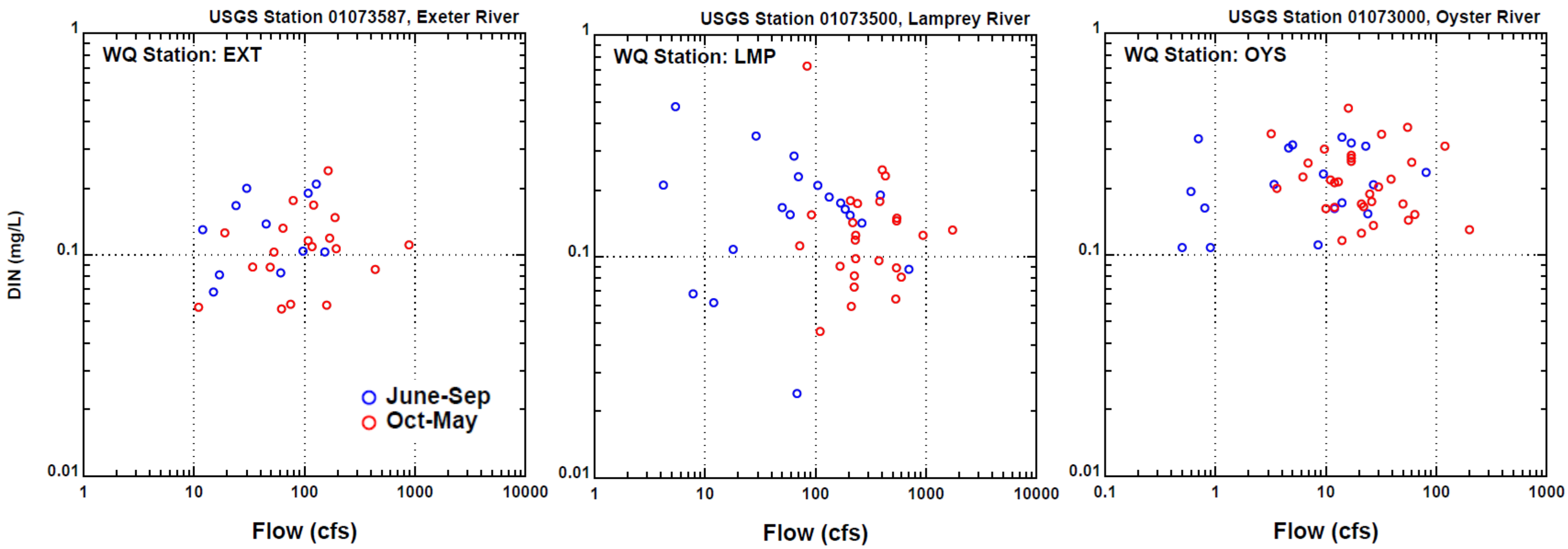
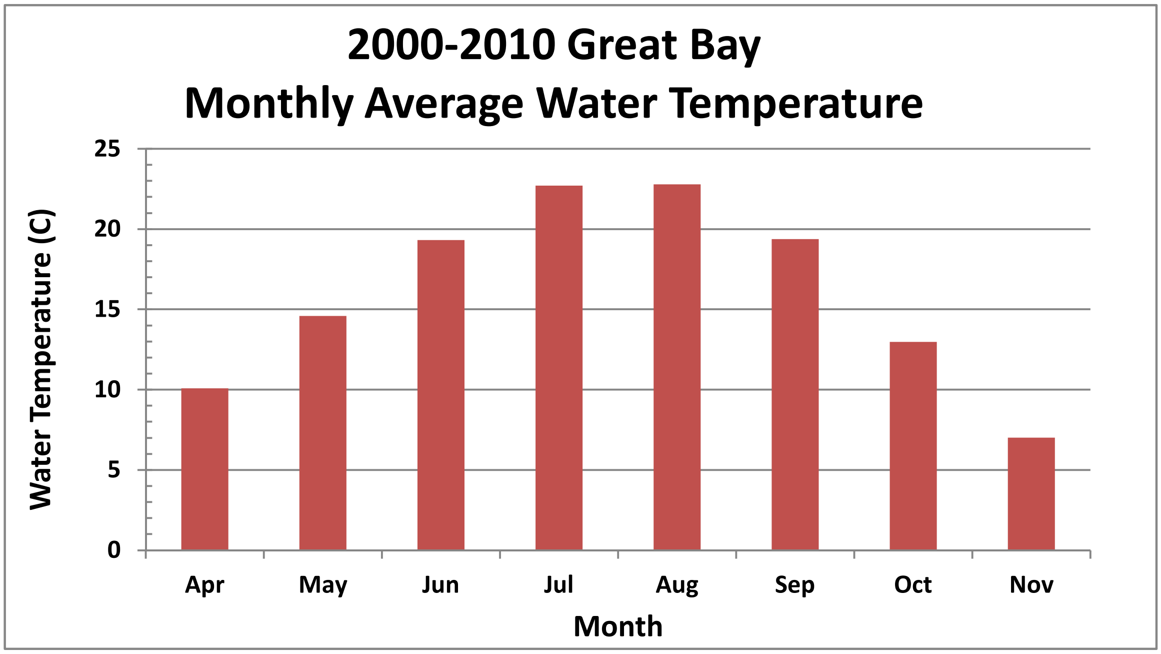


Figure 4. Measured River DIN Concentrations and Flows.



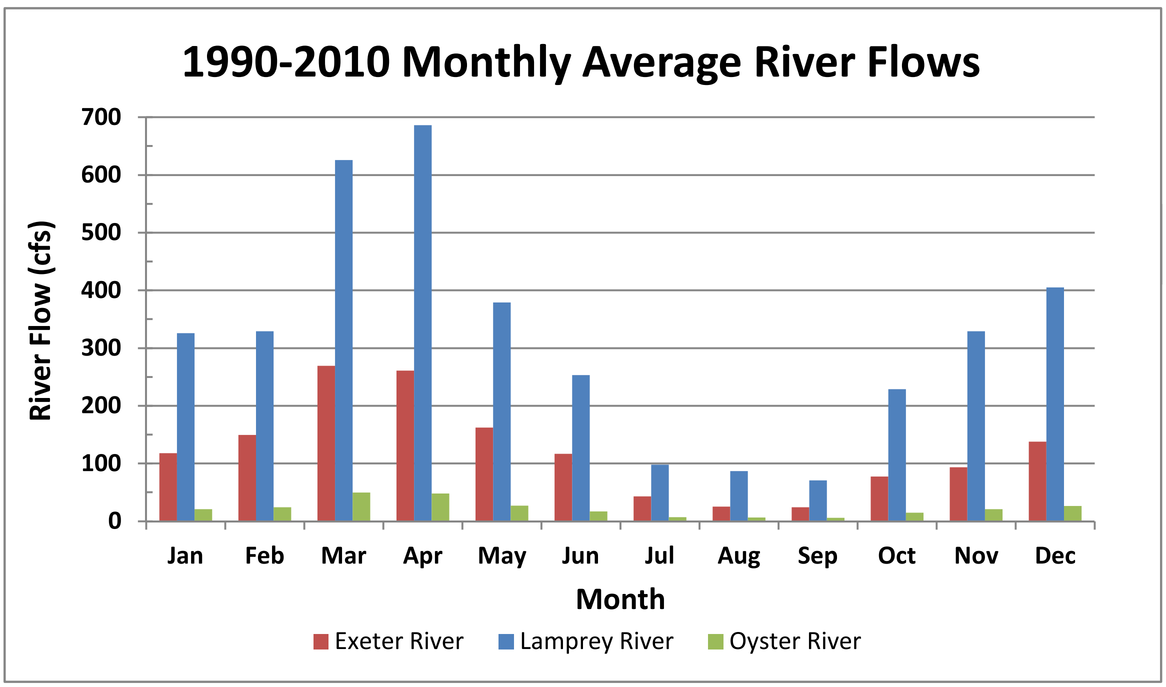


Figure 5. Great Bay Monthly Average Water Temperature and River Flows.

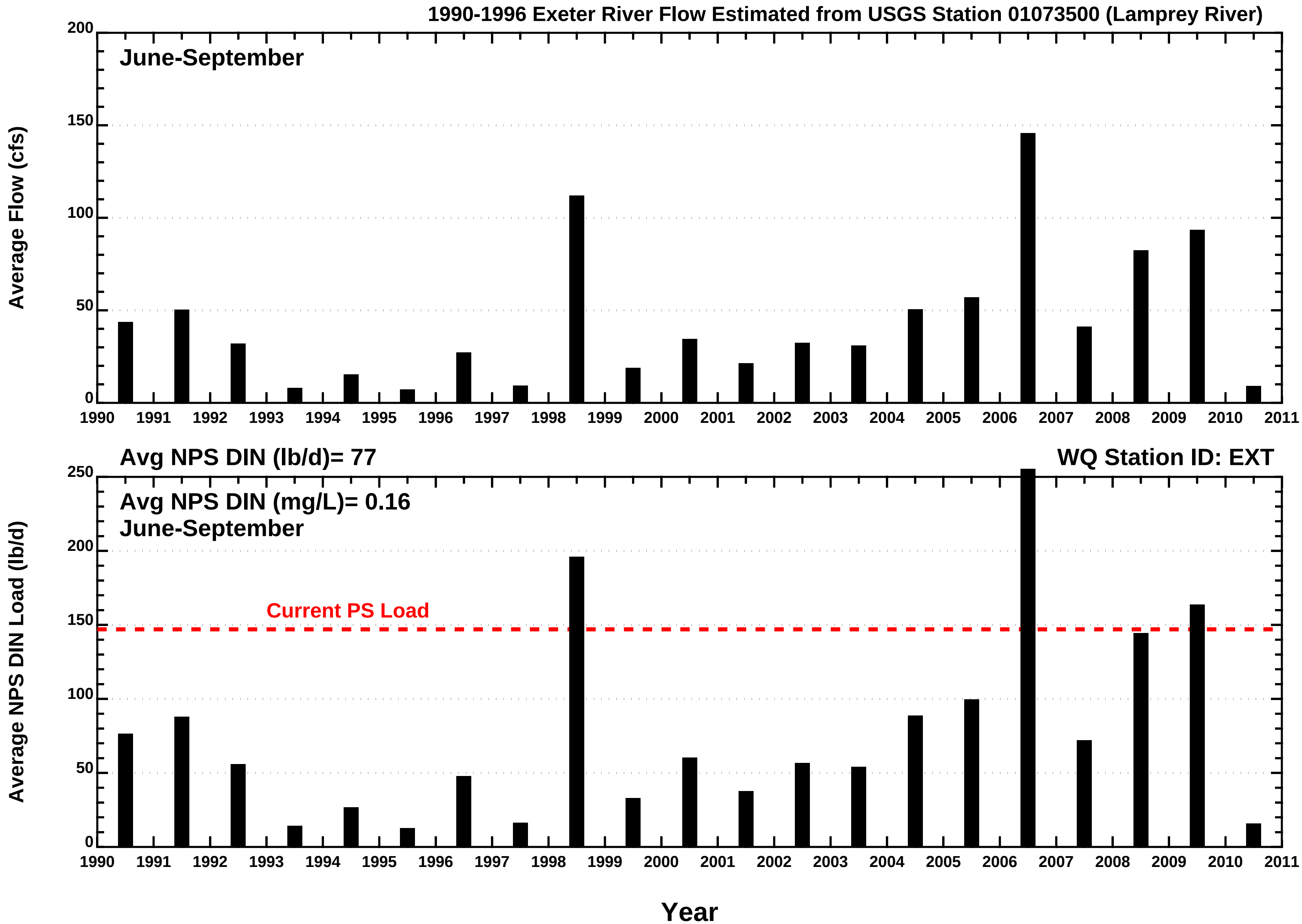


Figure 6. Estimation of Exeter River DIN Loads (1990-2010)

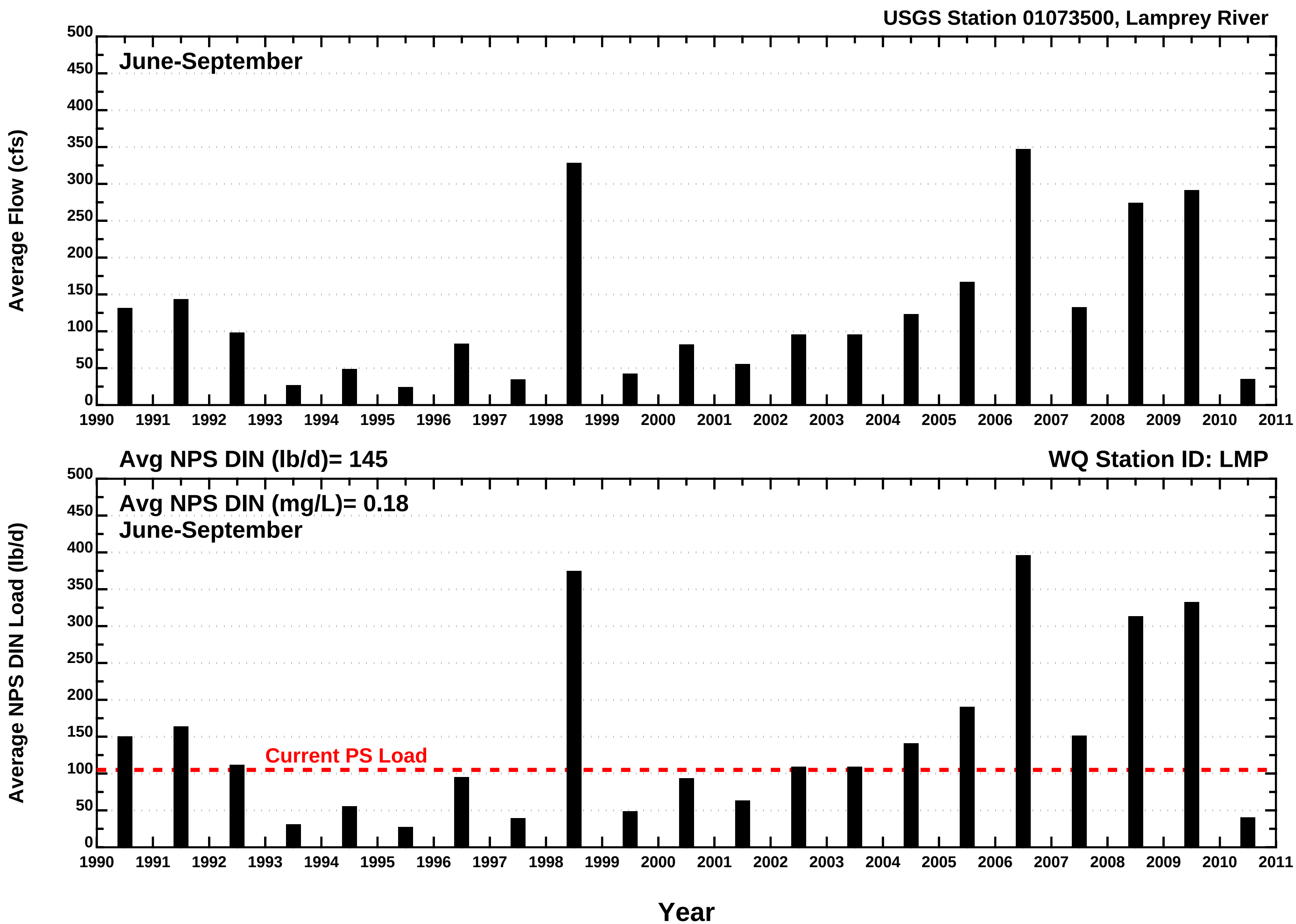


Figure 7. Estimation of Lamprey River DIN Loads (1990-2010)

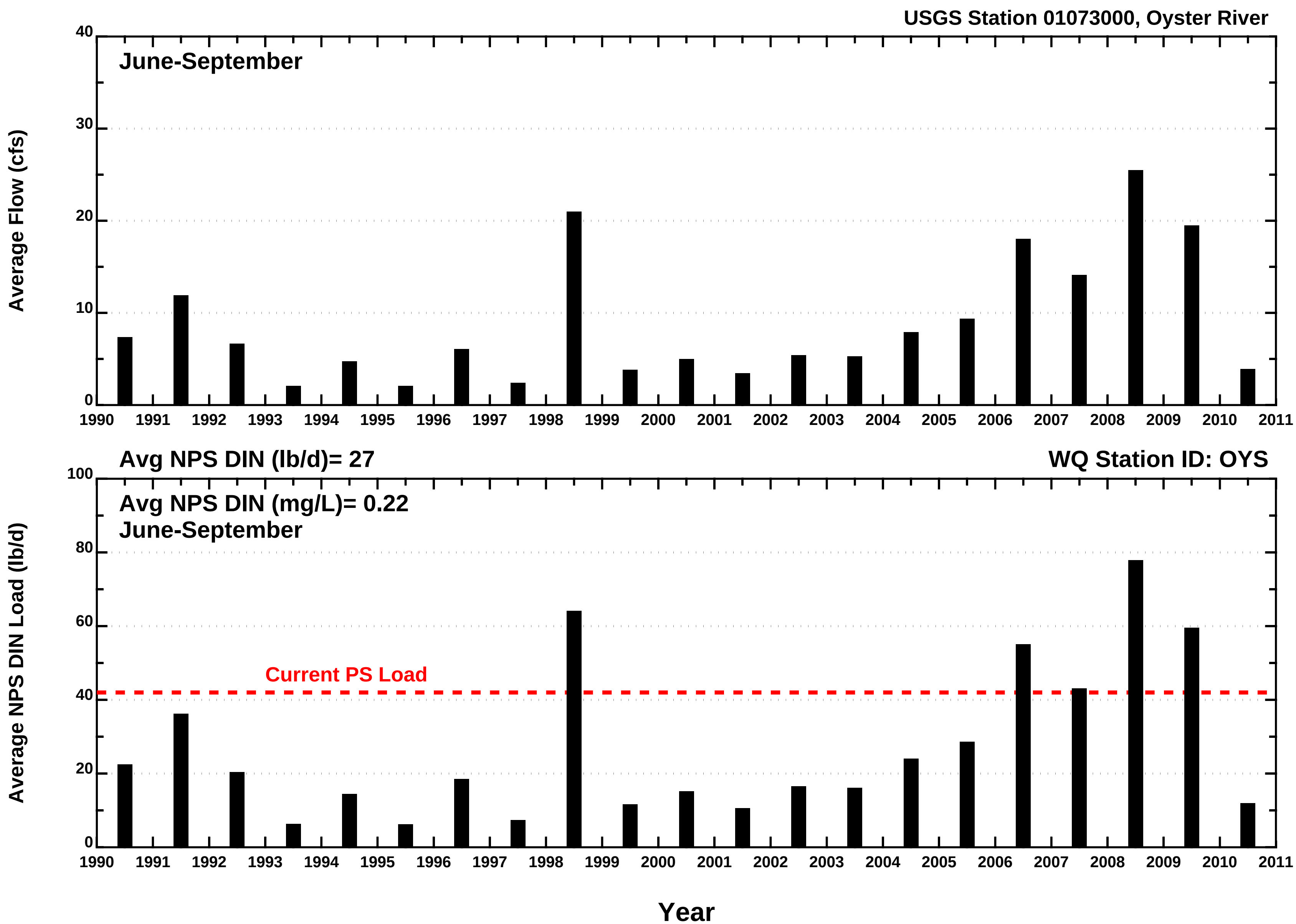


Figure 8. Estimation of Oyster River DIN Loads (1990-2010)

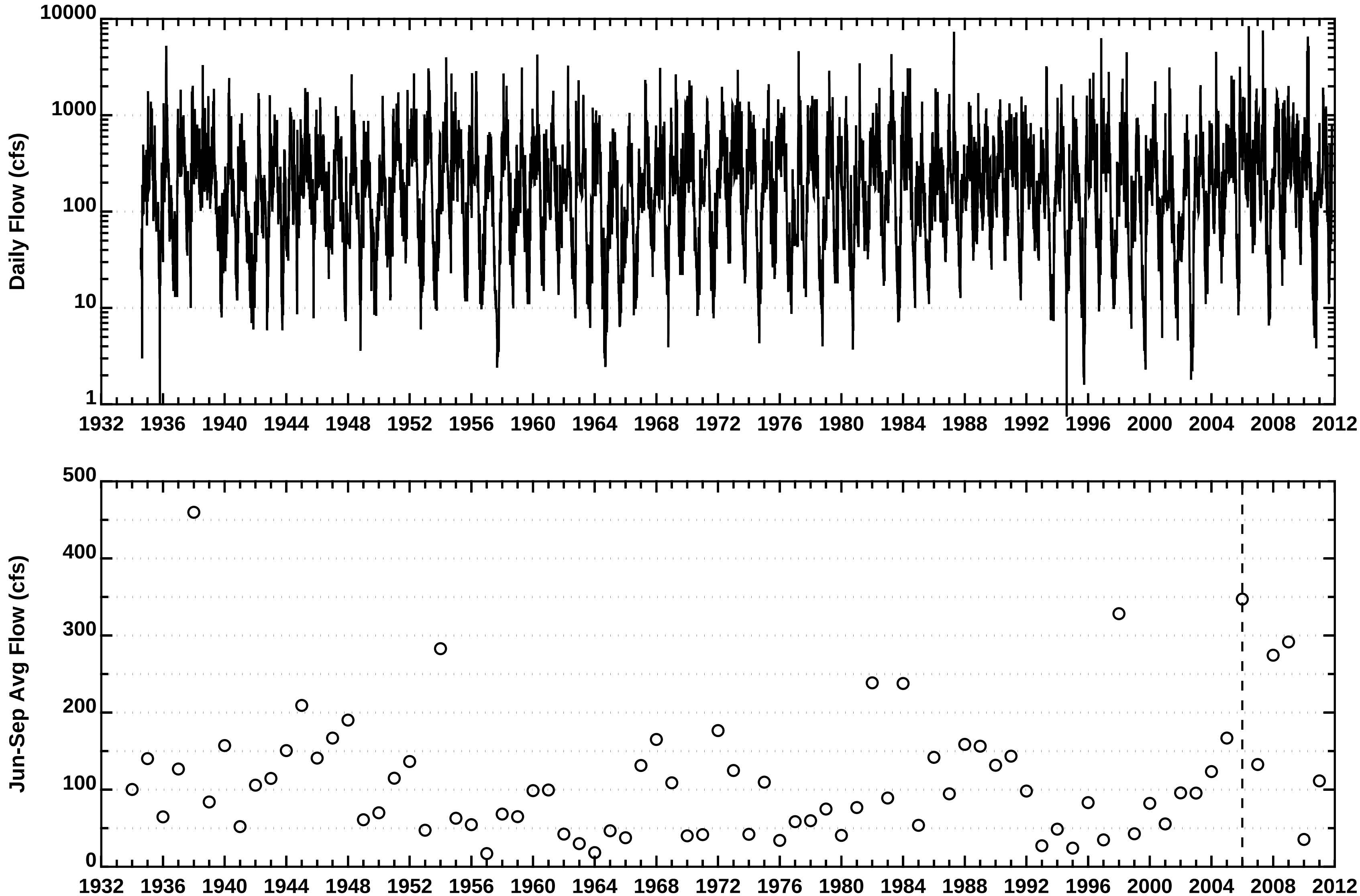


Figure 9. Jun-Sep Average Flow, USGS Station 01073500, Lamprey River (1934-2011)

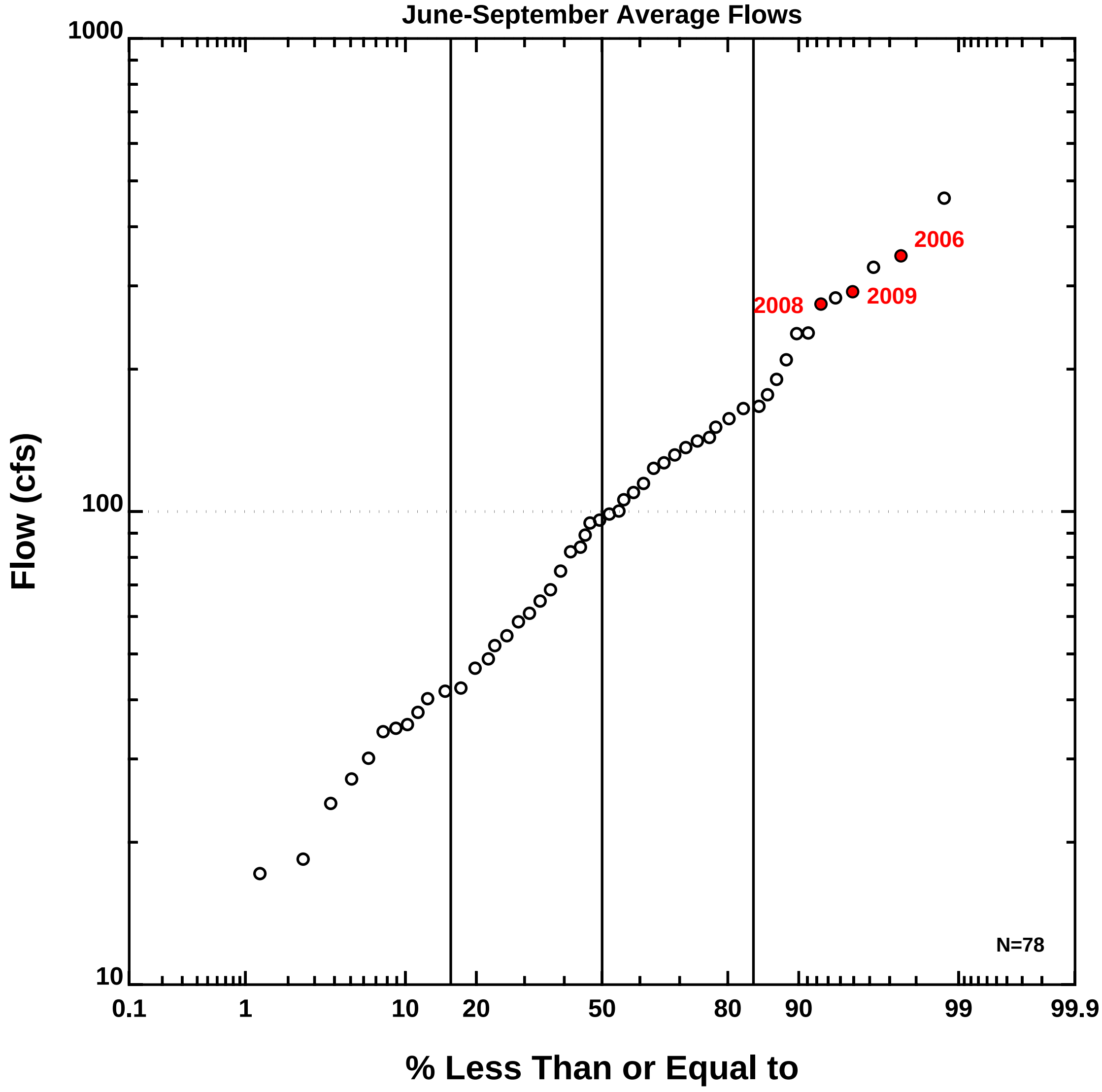


Figure 10. Jun-Sep Average Flows, USGS Station 01073500, Lamprey River (1934-2011)

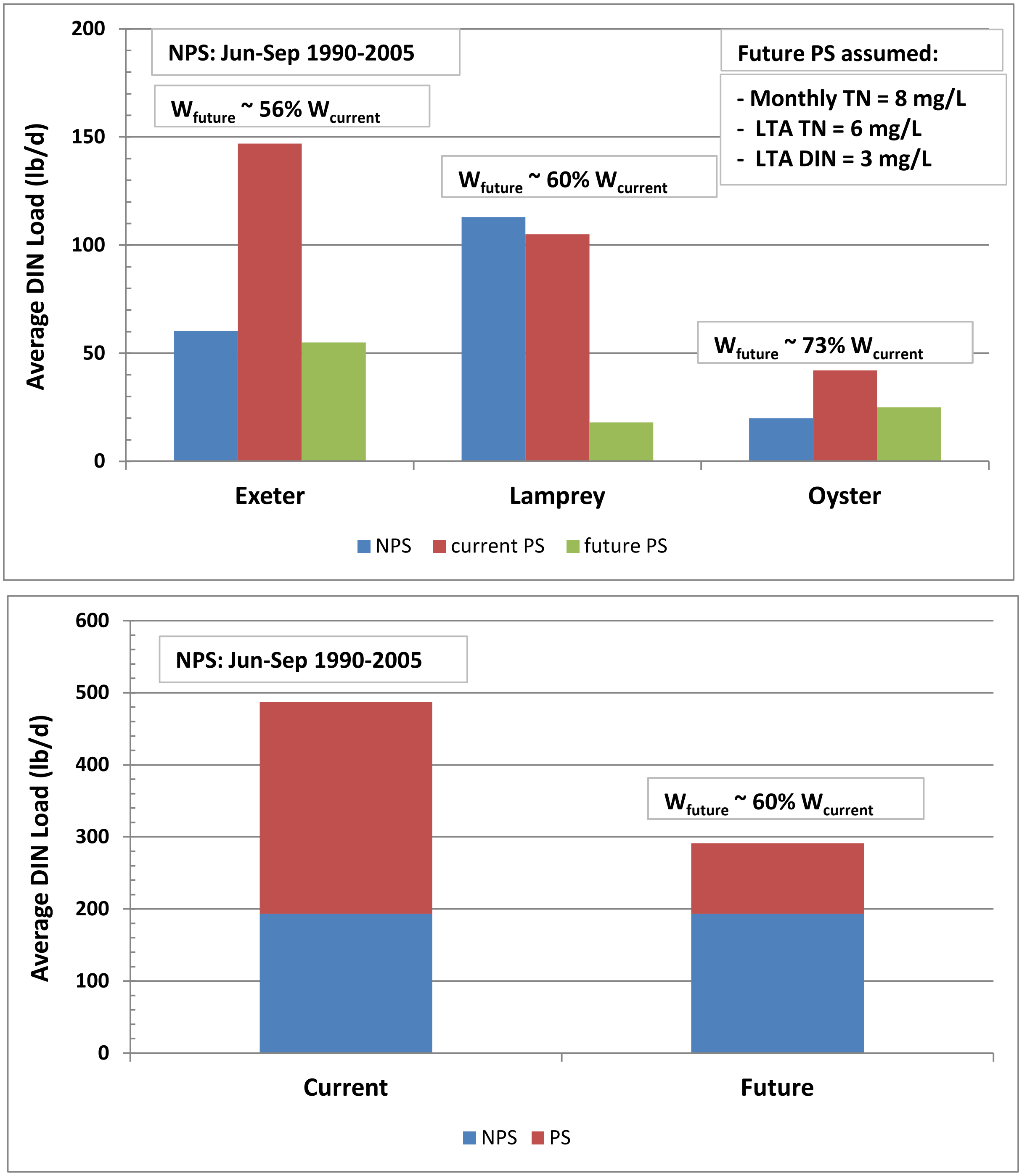


Figure 11. Estimated Current and Future NPS and PS DIN Loads (June-September 1990-2005).

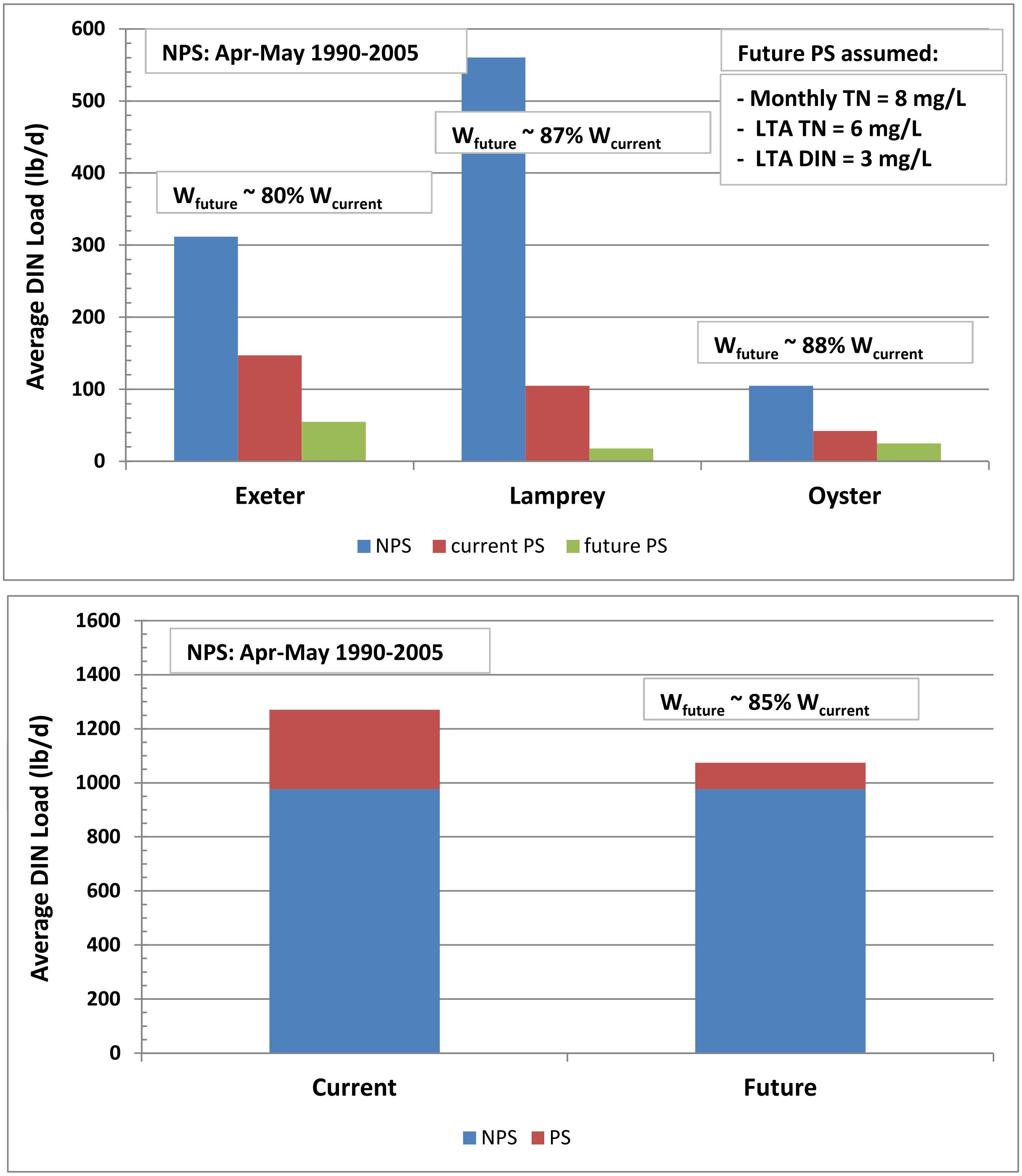


Figure 12. Estimated Current and Future NPS and PS DIN Loads (April-May 1990-2005).

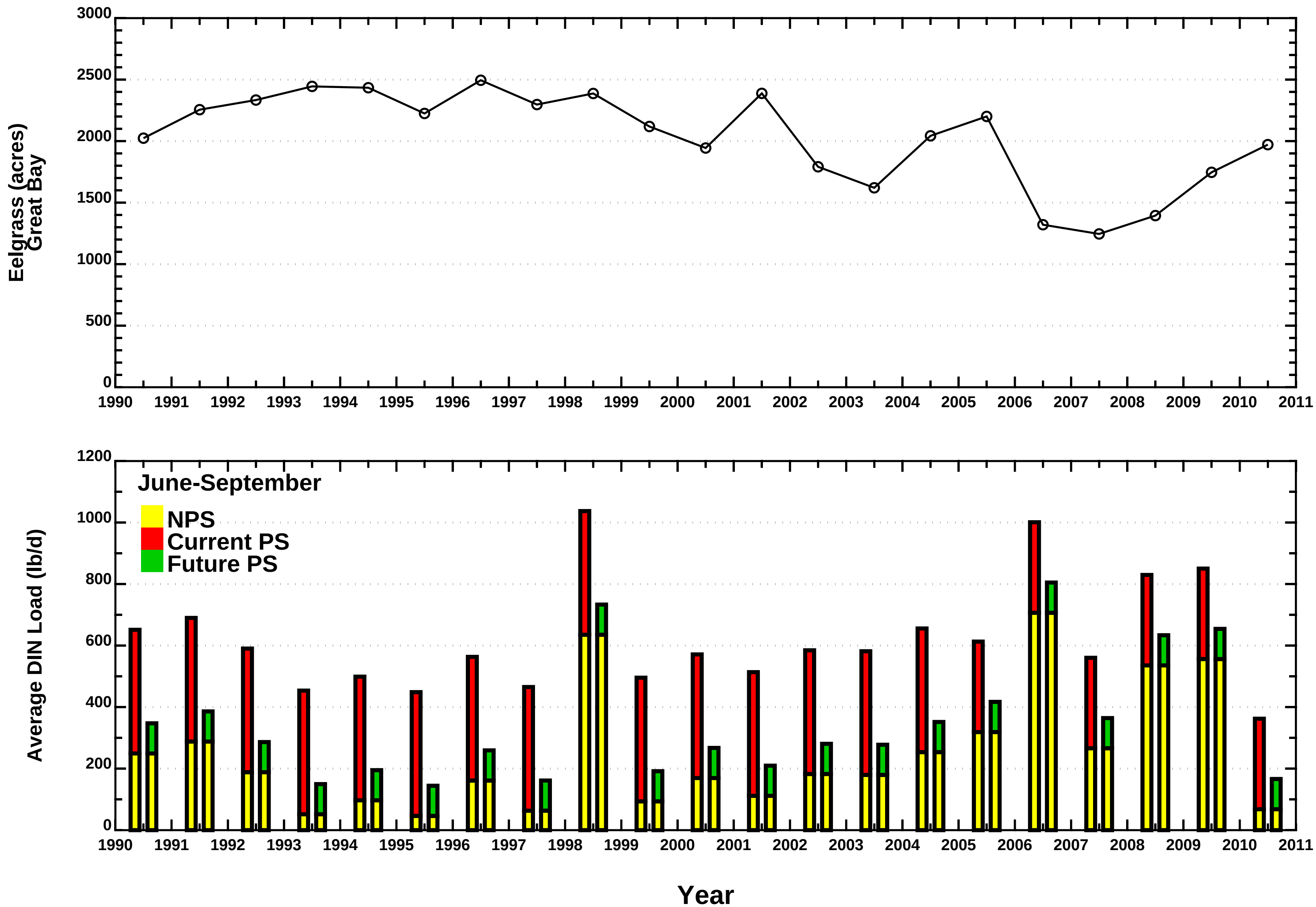


Figure 13. Exeter, Lamprey and Oyster River DIN Loads (1990-2010)