Table 18: Modeled average annual load to Narragansett Bay under the studied scenarios

	Scenario				
Parameter	***Current***	***UP1***	***UP2***	***ZeroUB***	***UP1NPS***
TN (10^6 kg)	1.49	1.28	1.17	.934	1.13
TP (10^4 kg)	17.2	10.7	9.32	8.10	9.23

Table 19: Percent reduction of TN external sources in comparison to the percent reduction in average annual load to Narragansett Bay under the studied scenarios

	Scenario				
Source	***Current***	***UP1***	***UP2***	***ZeroUB***	***UP1NPS***
PS	100	74	61	28	74
NPS	100	100	100	100	80
PS+NPS	100	85	77	58	77
Load to Bay	100	85	78	62	76

Table 20: Percent reduction of TP external sources in comparison to the percent reduction in average annual load to Narragansett Bay under the studied scenarios

	Scenario				
Source	***Current***	***UP1***	***UP2***	***ZeroUB***	***UP1NPS***
PS	100	43	29	43	19
NPS	100	100	100	100	80
PS+NPS	100	64	56	57	49
Load to Bay	100	62	54	54	47

5 Discussion

5.1 In-stream concentrations

In Massachusetts, there is no numerical nutrient criterion that classifies a stream as being impaired or meeting its designated use. According to the Massachusetts Surface Water Quality Standards, nutrient concentrations in lakes and streams "shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication." Rhode Island also has no specific numerical criterion for nutrients in flowing waters. According to Rhode Island Water Quality Regulations, nutrient concentrations shall not exist "in such concentration that would impair any usages specifically assigned to said Class, or cause undesirable or nuisance aquatic species associated with cultural eutrophication." However, Rhode Island does specify that "average Total Phosphorus shall not exceed 0.025 mg/l in any lake, pond, kettle hole or reservoir."

Numerical criterion in the form of Total Maximum Daily Loads (TMDLs) will be used in the Blackstone to eliminate designated use impairment. Currently 20 phosphorus (TMDLs) are under development for several lakes in the Blackstone watershed. As part of these TMDLs, target concentrations and attainment strategies are proposed. TMDLs are developed for lakes prior to their development for rivers due to the publicly perceived aesthetic issues associated with eutrophication in lakes. As mandated by the EPA, TMDLs will eventually be developed for all identified use impaired ponds, lakes, and river reaches along the Blackstone. The MassDEP proposes to develop a phosphorus TMDL for the Blackstone River over the next few years.

Target concentrations for nitrogen and phosphorus TMDL development are typically based upon estimates of ambient concentrations for the region. In 1994, the EPA determined ambient phosphorus concentrations in lakes and rivers across Massachusetts as part of the Massachusetts Ecoregions Project (Griffith *et al.*, 2004). Data on more than 10 pristine lakes in the Blackstone watershed, considered to be relatively unaffected by human influence, were included the study. However, due to its extensive urbanization, only one riverine station for the study was situated within the Blackstone River watershed. Ambient phosphorus concentrations in the Blackstone River were estimated to be in the range of 71-100 µg/L. Earlier work by Rohm *et al.* (1995) also evaluated phosphorus concentrations in the lakes of the Blackstone watershed. Values for ambient N concentrations were not provided in either Griffith *et al.* (2004) or Rohm *et al.* (1995).

Using the findings of reports such as Griffith *et al.* (2004) and Rohm *et al.* (1995), the EPA has adapted an ecoregion based approach for developing ambient water quality criteria recommendations for streams and rivers, lakes and reservoirs, estuarine systems and wetlands (EPA, 2000b). The EPA has chosen to use the 25th percentile value (P25) of all of the available water quality data to develop its ambient nutrient criteria. P25 values were developed for Ecoregion 14 (which contains Massachusetts and Rhode Island) as a whole as well as each sub-ecoregion within it. This value is used whenever possible because it represents minimally impacted stream conditions, provides protection of designated uses and also allows for flexibility in reduction management strategies (EPA, 2000b).

In Ecoregion 14, reference TP concentrations ranged from 1.25 to 1525 µg/L with a P25 of 31.25 µg/L. TN concentrations ranged from 0.07 to 10.68 mg/L with a P25 of 0.44 mg/L. In Ecoregion 14-59, where the Blackstone watershed is located, TP concentrations ranged from 2.5 to 907.5 µg/L with a P25 of 23.75 µg/L and a P75 of 90 µg/L while TN concentrations ranged from 0.15 to 5.57 mg/L with a P25 of 0.61 mg/L and a P75 of 0.94 mg/L. Differences between ambient water quality concentrations between this study and previous studies lie within their analyzed data sets. Previous studies such as Griffith *et al.* (2004) and Rohm *et al.* (1995) utilized all data for the region, as far back as the 1970's. The EPA (2000b) study, however, only took data from 1990 to 1998 into consideration when developing their water quality recommendations. These values provide a reference for analyzing the in-stream water quality under the studied scenarios. In earlier sections of the report, values were compared against the Ecoregion 14-59 values for P75.

Observed water quality concentrations have been used as a gauge of water use impairment for the Blackstone River watershed. As part of their water quality monitoring program, the BRC, a volunteer watershed group detailed in a later section, creates a water quality report card based upon the concentrations observed during their water quality monitoring efforts. The BRC water quality criteria are based on guidance from the MADEP and are on the basis of nitrate and orthophosphate rather then TN and TP due to their sampling protocols. The phosphorus and nitrogen impairment criterion are shown in Table 21. The impairment criterion used by the EPA is typically more stringent for phosphorus than those used by the BRC. The EPA recommends a TP concentration no greater than 0.024 mg/L, while the BRC allows for a PO4 concentration of 0.025 mg/L, not accounting for the impacts of other forms of phosphorus on the water quality of the river or stream. Comparison of the nitrogen criterion is more difficult. The EPA calls for TN concentrations of 0.61 mg/L or less, while the BRC calls for NO3 concentrations of less than 0.31 mg/L. This may be more or less stringent depending on the presence of other nitrogen species.

Table 21: Phosphorus and Nitrogen Impairment Criteria used by the BRC

Nitrate as N		OrthoPhos as P	
Concentration (mg/L)	Classification	Concentration (mg/L)	Classification
<0.31	Standard	<0.025	Standard
<0.3	Excellent	<0.025	Excellent
0.3 - 0.599	Good	0.025 - 0.049	Good
0.6 - 0.9	Fair	0.05 - 0.1	Fair
> 0.9	Poor	> 0.1	Poor

Current regulatory focus in the Blackstone is on phosphorus reduction. Like the majority of freshwater systems, biological activity in the Blackstone is believed to be a phosphorus limited system. Previous regulatory efforts in the Blackstone have been focused on point source reduction strategies for all pollutants. The construction of WWTPs and decreases in NPDES permit limits have substantially increased the health of the river. As late as 1994, Shanahan reported that the water quality of the Blackstone was "considerably improved." He surmised that the improvement was due to continual WWTP investment to meet increasingly stringent federal laws (NPDES program) as well as the control of industrial dischargers. Work by Nixon *et al.* (2005) estimates that there has been a 20 percent decrease in total nitrogen (TN) loading and 50 percent decrease in total phosphorus (TP) from the Blackstone since the 1970's. Nixon *et al* (2005) attribute the majority of the load reduction to a decrease in WWTP effluent concentrations. Additional reduction from atmospheric sources is also cited as a cause of TN reduction to the river and subsequently the bay.

Modeling results for the five scenarios suggest that while reductions in in-stream TN and TP concentrations will occur as more stringent effluent controls are mandated, concentrations will remain above the EPA Ecoregion 14-59 reference P75 values for a majority of the days, even under the most stringent effluent levels associated with UP2 and the unrealistic ZeroUB scenario. While results for nitrate and phosphate have not been presented, model TN and TP results suggest that most stretches of the mainstem river would be classified as "poor" under the BRC criteria. These findings suggest that nonpoint source loads alone result in higher in-stream concentrations than deemed desirable. Further model scenario studies are necessary to more fully understand these dynamics and to study the impacts of additional management scenarios.

5.2 Load to Narragansett Bay

Nixon *et al.* (1995) developed a mass balance of nitrogen and phosphorus into Narragansett Bay based on historical data collection efforts in the watershed, including atmospheric deposition rates, in-stream water quality concentrations and WWTP effluent concentrations. Their goal was to develop a better understanding of the relative magnitudes of various sources of nutrients to the Bay. A follow up study was conducted in 2005. Sources of nutrients to the Bay include rivers (including the impacts in inland WWTPs), atmospheric deposition, urban runoff, unmeasured surface drainage, and direct sewage (including inputs from the three major treatment plants that discharge directly into Narragansett Bay). A summary of their findings for nitrogen are shown in Table 22 and for phosphorus in Table 23.

Table 22: TN flux to Narragansett Bay in kg/yr, adapted from Nixon *et al.* (1995, 2005)

SOURCE	1983	% of Total	2003-2004	% of Total
Blackstone R	1,845,200	21.8	1,380,820	17.1
Pawtuxet River	945,980	11.2	830,060	10.3
Woonasquatucket R	105,840	1.2	120,260	1.5
Moshassuck R	82,740	1.0	66,780	0.8
Ten Mile R	196,980	2.3	196,980	2.4
Taunton River	1,624,000	19.1	1,918,000	23.8
Atmosphere	420,000	5.0	420,000	5.2
Urban Runoff	518,000	6.1	518,000	6.4
Direct Sewage	2,520,000	29.7	2,394,000	29.7
Unmeasured Surface Drainage	224,000	2.6	224,000	2.8
TOTAL	8,482,740	100	8,068,900	100

Table 23: TP fluxes to Narragansett Bay in kg/yr, adapted from Nixon *et al.* (1995, 2005)

SOURCE	1983	% of Total	2003-2004	% of Total
Blackstone R	175,460	17.4	119,970	14.5
Pawtuxet River	191,270	18.9	111,910	13.5
Woonasquatucket R	8,680	0.9	9,920	1.2
Moshassuck R	5,580	0.6	4,030	0.5
Ten Mile R	25,110	2.5	25,110	3.0
Taunton R	139,190	13.8	164,300	19.9
Atmosphere	4,030	0.4	4,030	0.5
Urban Runoff	124,000	12.3	124,000	15.0
Direct Sewage	325,500	32.2	251,100	30.4
Unmeasured Surface Drainage	11,780	1.2	11,780	1.4
TOTAL	1,010,600	100	826,150	100

Model estimates of annual loads to Narragansett Bay from the Blackstone River under current conditions, Figures 22-23 and Table 18, fall within the range of estimates by Nixon *et al.* (1995, 2005) for both TN and TP. Model average annual estimates for TN are about 5% higher than the 2003-2004 Nixon *et al.* (2005) estimates while average annual model estimates for TP are almost equivalent to the 1983 Nixon *et al.* (2005) TP estimates. Based on the 2003-2004 Nixon estimates for TN and the model average annual predictions, the total TN load to Narragansett Bay is reduced by approximately 2.5% under the UP1 scenario and by approximately 4% under the UP2 scenario. Based on the 1983 Nixon estimates for TP and the model average annual predictions, the total TP load to Narragansett Bay is reduced by approximately 6.5% under the UP1 scenario and by approximately 8% under the UP2 scenario.

5 Summary & Future Work

In order to determine the impacts that the ongoing and proposed WWTP upgrades will have on water quality and nutrient loading budgets in the Blackstone River, several simulations were conducted using the HSPF model constructed and calibrated during the Blackstone River Water Quality Study. For the scenario simulations, observed WWTP loadings from 1996 – 2007 were adjusted to simulate potential improvements resulting from the NPDES mandated reductions in effluent nutrient concentrations. Two additional scenarios were evaluated, one where NPS loads were reduced by 20% uniformly across the basin and one where all nutrient load from the UBWPAD was eliminated. Nutrient inputs from external sources were determined and compared for the studied scenarios both over the simulation period and on an annual basis. Several techniques were used to evaluate anticipated improvements in in-stream water quality due to WWTP upgrades. These included along stream plots of average TN and TP concentrations as well as concentration cumulative frequency duration curves for select reaches along the mainstem. Load reductions to Narragansett Bay were also examined. Results were presented for TN, TP, DO and Chl-a. The results presented for DO and Chl-a are interim pending further calibration of the HSPF model for these parameters. However, although model calibration refinement may alter specific values, trends and relative behavior under the studied scenarios are anticipated to be similar.

For comparative purposes, resulting in-stream concentrations were compared against the suggest EPA nutrient criteria for Ecoregion 14-59, within which the Blackstone lies. Nutrient loads to Narragansett Bay were compared with the Nixon *et al.* (1995, 2007) mass balance estimates for the Bay. The following is a list of key findings for the study:

- Modeling results for the five scenarios suggest that while reductions in in-stream TN and TP concentrations will occur as more stringent effluent controls are mandated, concentrations will remain above the EPA Ecoregion 14-59 reference P75 values for a majority of the days, even under the most stringent effluent levels associated with UP2 and the unrealistic ZeroUB scenario.
- Average summer Chl-a remains low, typically less than 5 μg/L, upstream of Fisherville Pond. Downstream of this point, Chl-a values increase steadily along the river.

- Average summer Chl-a levels along the Rhode Island portion of the river are typically above 20 μg/L. These levels drop from over 60 μg/L at the outlet under current conditions to approximately 45 μg/L under UP1, and to approximately 35 μg/L under UP2.
- Under current conditions in the river, model results suggest maximum summertime Chl-a concentrations as high as 160 μg/L may occur during the summer in the Rhode Island portions of the river. Available data support the existence of high Chl-a values in these reaches; the highest measured chlorophyll value in the river is 137μg/L and was measured at Lonsdale Avenue (Reach 218), near the river outlet. As more stringent nutrient effluent limits are applied, maximum levels along the stream drop to approximately 120 μg/L for UP1 and 90 μg/L for UP2.
- Under the UP2 scenario, maximum Chl-a summer concentrations predicted at the outlet are comparable to the ZeroUB scenario value of about 60 μg/L.
- Reductions of nonpoint source of TN could be an effective mechanism for water quality improvement, particularly for downstream reaches. Targeted reductions may be more effective, although these have not been studied to date.
- Under the UP1 limits, PS load contributions to the river are reduced by 26% for TN and by 57% for TP. However, due to NPS contributions, annual TN load to the Bay is reduced by 15% on average while annual TP load is reduced by 38% on average.
- Under the UP2 limits, PS load contributions to the river are reduced by 39% for TN and by 71% for TP. However, due to NPS contributions, annual TN load to the Bay is reduced by 22% on average while annual TP load is reduced by 46% on average.
- Under both the UP1 and UP2 scenarios, point source controls are about 60% as effective on a percent basis at the basin outlet. For example, a reduction of 100 kg at a point source results in approximately a 60 kg reduction at the basin outlet.
- The UP1NPS scenario results suggest that targeted NPS reductions may be a more efficient mechanism for reducing overall loads to Narragansett Bay. For example, average annual TN loads to Narragansett Bay are reduced to 78% of the Current conditions under the UP2 scenario and to 76% of the Current conditions under the UP1NPS scenario. Similarly, average annual TP loads are reduced to 54% of the Current conditions under the UP2 scenario and to 47% of the Current conditions under the UP1NPS scenario. Recall that the UP1NPS scenario applies a 20% reduction in NPS loads uniformly across the basin. Potential NPS reduction scenarios should be considered further.
- Based on the 2003-2004 Nixon estimates for TN and the model average annual predictions, the total TN load to Narragansett Bay is reduced by approximately 2.5% under the UP1 scenario and by approximately 4% under the UP2 scenario.
- Based on the 1983 Nixon estimates for TP and the model average annual predictions, the total TP load to Narragansett Bay is reduced by approximately 6.5% under the UP1 scenario and by approximately 8% under the UP2 scenario.

Further calibration of the model for DO and Chl-a is anticipated; scenario results for these parameters should be re-examined when calibration is finalized. However, although model calibration refinement may alter specific values, trends and relative behavior under the studied scenarios are anticipated to be similar. Additional work is necessary to evaluate along stream attenuation under the various scenarios. These analyses will also provide insight into the magnitude of NPS inputs to the river from benthic sources. Targeted NPS reductions may be an effective management scheme and should be explored. In addition, scenarios considering dam removal or management along the river should be analyzed to measure their relative effectiveness. In general, the impacts of NPS loads to the river should be evaluated. This is particularly important considering that even under the ZeroUB scenario, in-stream concentrations do not achieve EPA recommended Ecoregion criteria.

6 References

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Appendix A: Comparison of PS and NPS scenarios, annual basis, actual flow regime

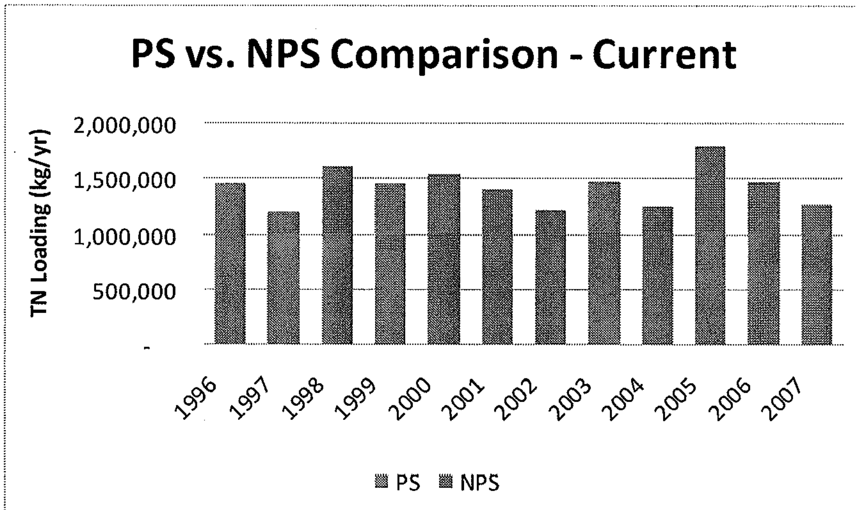

Figure 24: Relative contributions of annual TN external loads from point and nonpoint sources under the current scenario for the actual flow regime

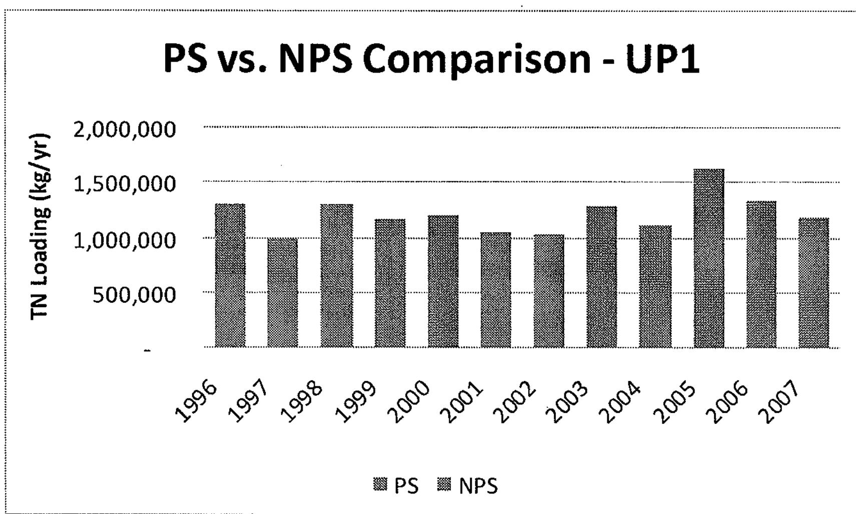

Figure 25: Relative contributions of annual TN external loads from point and nonpoint sources under the UP1 scenario for the actual flow regime

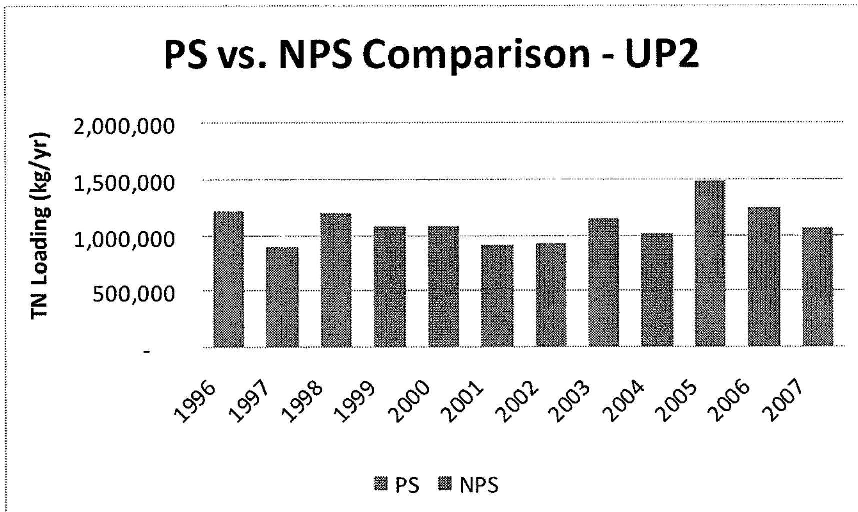

Figure 26: Relative contributions of annual TN external loads from point and nonpoint sources under the UP2 scenario for the actual flow regime

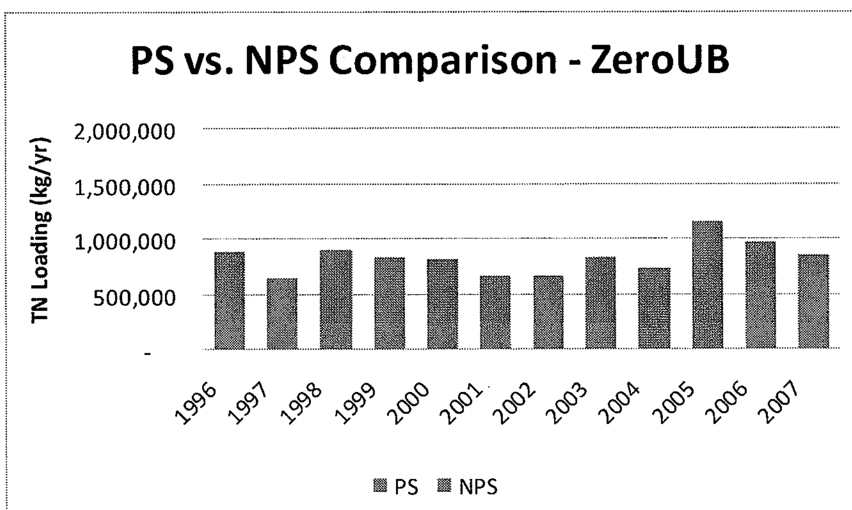

Figure 27: Relative contributions of annual TN external loads from point and nonpoint sources under the ZeroUB scenario for the actual flow regime

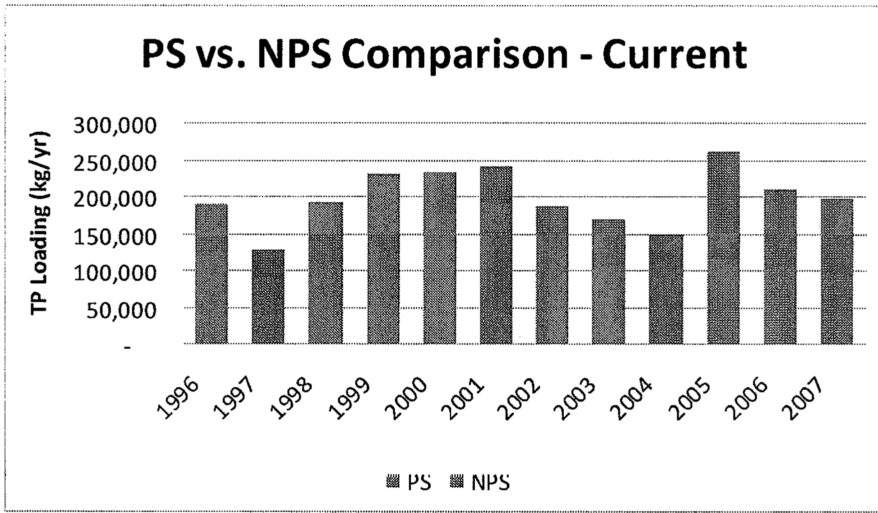

Figure 28: Relative contributions of annual TP external loads from point and nonpoint sources under the current scenario for the actual flow regime

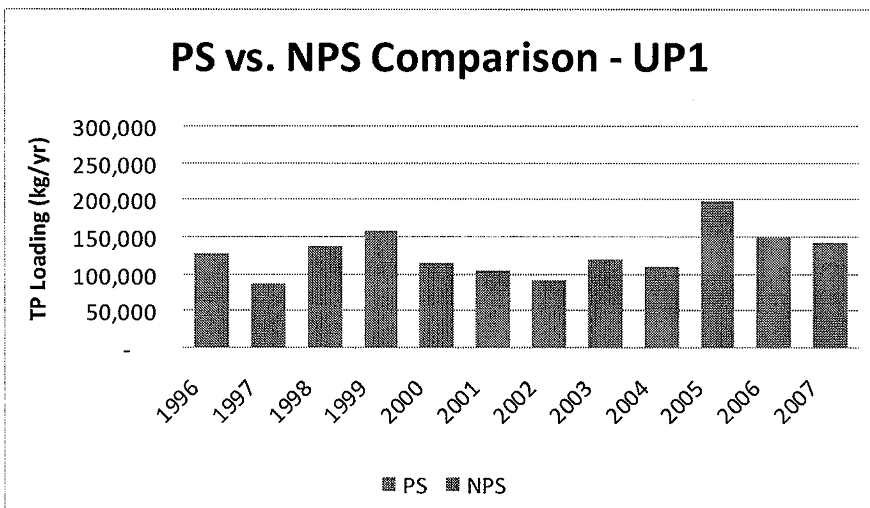

Figure 29: Relative contributions of annual TP external loads from point and nonpoint sources under the UP1 scenario for the actual flow regime

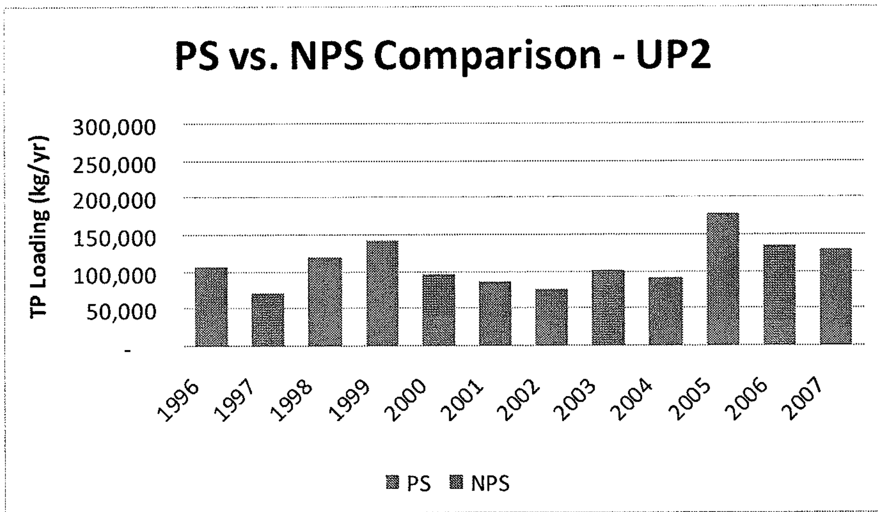

Figure 30: Relative contributions of annual TP external loads from point and nonpoint sources under the UP2 scenario for the actual flow regime

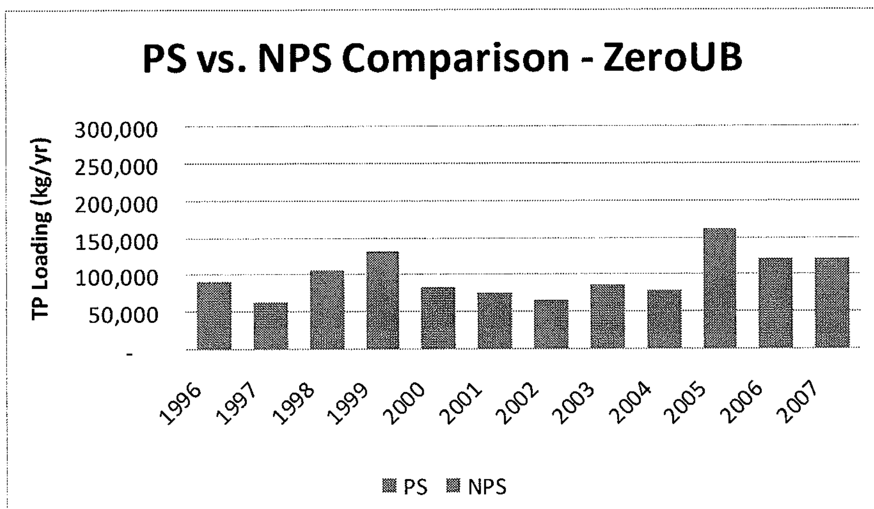

Figure 31: Relative contributions of annual Tp external loads from point and nonpoint sources under the ZeroUB scenario for the actual flow regime

Appendix B: Along stream summer average concentrations, design flow regime