Blackstone River HSPF Model Scenario Report

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Table of Contents

Blackstone River HSPF Model Scenario Report i
Table of Contents ii
List of Tables iii
List of Figures iv
Executive Summary viii
1 Introduction 1
2 Background 2
3 Methodology 3
  3.1 Actual Flow Regime Scenario Set 5
    Baseline Conditions (Current Scenario) 5
    Upgrades in accordance with the 2001 NPDES permit (Upgrade 1) 6
    Proposed Upgrades in accordance with 2008 NPDES permit (Upgrade 2) 6
    Zero Load at UBWPAD (ZeroUB) 6
    NPS Reductions plus 2001 NPDES permit (UP1NPS) 7
  3.2 Design Flow (DF) Scenario Set 7
  3.3 Benthic Nutrient Release Concentration Adjustment 7
4 Evaluation of Water Quality and Loading Improvements 8
  4.1 Nutrient Inputs over the Simulation Period 8
  4.2 Average Annual Nutrient Inputs 11
  4.3 Along Stream Average Nutrient Concentrations 13
    Along Stream Average Summer Nutrient Concentration Results 14
    Along Stream Dissolved Oxygen Concentration Results 16
    Along Stream Chlorophyll a Concentration Results 17
  4.4 Cumulative Frequency Nutrient Concentrations and Loads 19
    Millbury 21
    MA/RI Border 24
    Blackstone River Outlet 27
  4.5 Delivery of Nutrients to Narragansett Bay 31
5 Discussion 33
  5.1 In-stream concentrations 33
  5.2 Load to Narragansett Bay 36
5 Summary & Future Work 37
6 References 40

Appendices

Appendix A: Comparison of PS and NPS scenarios, annual basis, actual flow regime ... 41
Appendix B: Along stream summer average concentrations, design flow regime 46
Appendix C: Along stream annual average concentrations, actual flow regime 49
Appendix D: Along stream annual average concentrations, design flow regime 52
Appendix E: Additional CDF Figures for the Actual Flow Regime 55
Appendix F: Cumulative Distribution Frequency Figures for Design Flow Regime 62
Appendix G: Blackstone River HSPF Water Quality Model Schematic 74

List of Tables

Table 1: UBWPAD 2001 and 2008 NPDES Permit Limits, mg/L 1
Table 2: WWTPs in Blackstone River Watershed 2
Table 3: Effluent Limits for the UBWPAD and Woonsocket used for Actual Flow Regime scenario analysis set, in mg/L 4
Table 4: Effluent Limits for the UBWPAD and Woonsocket used for Design Flow Regime scenario analysis set, in mg/L 4
Table 5: Summary of Scenarios Analyzed 5
Table 6: Benthic Release of Nutrient Parameters as Adjusted for the various Loading Scenarios 8
Table 7: Point source TN Load (10^6 kg) over simulation period, by scenario 9
Table 8: Point source TP load (10^3 kg) over simulation period, by scenario 9
Table 9: Percent of current scenario TN load under the actual flow regime 10
Table 10: Percent of current scenario TP load under the actual flow regime 10
Table 11: Percent of current scenario TN load under the design flow regime 11
Table 12: Percent of current scenario TP load under the design flow regime 11
Table 13: List of dams, impoundments, hydroelectric plants and WWTPs on the mainstem Blackstone River by rivermile, relative to the outlet 14
Table 14: Modeled average daily in-stream P25 concentrations for the studied scenarios at Millbury 22
Table 15: Modeled average daily in-stream P25 concentrations for the studied scenarios at the MA/RI border 25
Table 16: Modeled average daily in-stream P25 concentrations for the studied scenarios at the MA/RI border 29
Table 17: Modeled average daily loads, kg/day, from the basin for a range of frequencies 29
Table 18: Modeled average annual load to Narragansett Bay under the studied scenarios 33
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 33
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 33
Table 21: Phosphorus and Nitrogen Impairment Criteria used by the BRC 35
Table 22: TN flux to Narragansett Bay in kg/yr, adapted from Nixon *et al.* (1995, 2005) 36
Table 23: TP fluxes to Narragansett Bay in kg/yr, adapted from Nixon *et al.* (1995, 2005) 36

List of Figures

Figure 1: Point source TN load (10^3 kg) over simulation period 9
Figure 2: Point source TP load (10^3 kg) over simulation period 9
Figure 3: Annual TN external load comparison for studied scenarios 12
Figure 4: Annual TP external load comparison for studied scenarios 13
Figure 5: Along stream average summer TN concentrations for the actual flow regime. 15
Figure 6: Along stream average summer TP concentration for the actual flow regime ... 15
Figure 7: Along stream average summer DO concentrations for the actual flow regime 17
Figure 8: Along stream average summer Chl-a concentrations for the actual flow regime 18
Figure 9: Along stream maximum summer Chl-a concentrations for the actual flow regime 19
Figure 10: Locations for which cumulative frequency distribution plots are presented... 20
Figure 11: Cumulative frequency distribution of model average daily TN concentrations at Millbury (river mile 41.7) for the actual flow regime 22
Figure 12: Cumulative frequency distribution of model average daily TP concentrations at Millbury (river mile 41.7) for the actual flow regime 23
Figure 13: Cumulative frequency distribution of model average daily Chl-a concentrations at Millbury (river mile 41.7) for the actual flow regime 24
Figure 14: Cumulative frequency distribution of model average daily TN concentrations at the MA/RI border (river mile 16.6) for the actual flow regime 25
Figure 15: Cumulative frequency distribution of model average daily TP concentrations at the MA/RI border (river mile 16.6) for the actual flow regime 26
Figure 16: Cumulative frequency distribution of model average daily Chl-a concentrations at the MA/RI border (river mile 16.6) for the actual flow regime 27
Figure 17: Cumulative frequency distribution of model average daily TN concentrations at the basin outlet for the actual flow regime 28
Figure 18: Cumulative frequency distribution of model average daily TN loads at the basin outlet for the actual flow regime 28
Figure 19: Cumulative frequency distribution of model average daily TP concentrations at the basin outlet for the actual flow regime 30
Figure 20: Cumulative frequency distribution of model average daily TP loads at the basin outlet for the actual flow regime 30
Figure 21: Cumulative frequency distribution of model average daily Chl-a concentrations at the basin outlet for the actual flow regime 31
Figure 22: Variation in annual TN load from the Blackstone River to Narragansett Bay in millions of kg 32
Figure 23: Variation in annual TP load from the Blackstone River to Narragansett Bay in millions of kg 32
Figure 24: Relative contributions of annual TN external loads from point and nonpoint sources under the current scenario for the actual flow regime 42
Figure 25: Relative contributions of annual TN external loads from point and nonpoint sources under the UP1 scenario for the actual flow regime 42
Figure 26: Relative contributions of annual TN external loads from point and nonpoint sources under the UP2 scenario for the actual flow regime 43

Figure 27: Relative contributions of annual TN external loads from point and nonpoint sources under the ZeroUB scenario for the actual flow regime 43
Figure 28: Relative contributions of annual TP external loads from point and nonpoint sources under the current scenario for the actual flow regime 44
Figure 29: Relative contributions of annual TP external loads from point and nonpoint sources under the UP1 scenario for the actual flow regime 44
Figure 30: Relative contributions of annual TP external loads from point and nonpoint sources under the UP2 scenario for the actual flow regime 45
Figure 31: Relative contributions of annual Tp external loads from point and nonpoint sources under the ZeroUB scenario for the actual flow regime 45
Figure 32: Along stream average summer TN concentrations over the simulation period at design flow 47
Figure 33: Along stream average summer TP concentrations over the simulation period at design flow 47
Figure 34: Along stream average summer DO concentrations over the simulation period at design flow 48
Figure 35: Along stream average summer Chl-a concentrations over the simulation period at design flow 48
Figure 36: Along stream average year round TN concentrations over the simulation period at actual flow 50
Figure 37: Along stream average year round TP concentrations over the simulation period at actual flow 50
Figure 38: Along stream average year round DO concentrations over the simulation period at actual flow 51
Figure 39: Along stream average year round Chl-a concentrations over the simulation period at actual flow 51
Figure 40: Along stream average year round TN concentrations over the simulation period at design flow 53
Figure 41: Along stream average year round TP concentrations over the simulation period at design flow 53
Figure 42: Along stream average year round DO concentrations over the simulation period at design flow 54
Figure 43: Along stream average year round Chl-a concentrations over the simulation period at design flow 54
Figure 44: Cumulative frequency distribution for daily TN load under the actual flow regime at Millbury 56
Figure 45: Cumulative frequency distribution for daily TP load under the actual flow regime at Millbury 56
Figure 46: Cumulative frequency distribution for daily Chl-a load under the actual flow regime at Millbury 57
Figure 47: Cumulative frequency distribution for average daily DO concentration under the actual flow regime at Millbury 57
Figure 48: Cumulative frequency distribution for daily TN load under the actual flow regime at the MA/RI border 58
Figure 49: Cumulative frequency distribution for daily TP load under the actual flow regime at the MA/RI border 58

Figure 50: Cumulative frequency distribution for average daily DO concentration under the actual flow regime at the MA/RI border 59
Figure 51: Cumulative frequency distribution for daily Chl-a load under the actual flow regime at the MA/RI border 59
Figure 52: Cumulative frequency distribution for daily TN load under the actual flow regime at the basin outlet 60
Figure 53: Cumulative frequency distribution for daily TP load under the actual flow regime at the basin outlet 60
Figure 54: Cumulative frequency distribution for daily average DO concentration under the actual flow regime at the basin outlet 61
Figure 55: Cumulative frequency distribution for daily Chl-a load under the actual flow regime at the basin outlet 61
Figure 56: Cumulative frequency distribution for daily TN load under the design flow regime at Millbury 63
Figure 57: Cumulative frequency distribution for daily average TN concentration under the design flow regime at Millbury 63
Figure 58: Cumulative frequency distribution for daily TP load under the design flow regime at Millbury 64
Figure 59: Cumulative frequency distribution for daily average TP concentration under the design flow regime at Millbury 64
Figure 60: Cumulative frequency distribution for daily average DO concentration under the design flow regime at Millbury 65
Figure 61: Cumulative frequency distribution for daily Chl-a load under the design flow regime at Millbury 65
Figure 62: Cumulative frequency distribution for daily average Chl-a concentration under the design flow regime at Millbury 66
Figure 63: Cumulative frequency distribution for daily TN load under the design flow regime at the MA/RI border 66
Figure 64: Cumulative frequency distribution for daily average TN concentration under the design flow regime at the MA/RI border 67
Figure 65: Cumulative frequency distribution for daily TP load under the design flow regime at the MA/RI border 67
Figure 66: Cumulative frequency distribution for daily average TP concentration under the design flow regime at the MA/RI border 68
Figure 67: Cumulative frequency distribution for daily average DO concentration under the design flow regime at the MA/RI border 68
Figure 68: Cumulative frequency distribution for daily Chl-a load under the design flow regime at the MA/RI border 69
Figure 69: Cumulative frequency distribution for daily average Chl-a concentration under the design flow regime at the MA/RI border 69
Figure 70: Cumulative frequency distribution for daily TN load under the design flow regime at the basin outlet 70
Figure 71: Cumulative frequency distribution for daily average TN concentration under the design flow regime at the basin outlet 70
Figure 72: Cumulative frequency distribution for daily TP load under the design flow regime at the basin outlet 71

Figure 73: Cumulative frequency distribution for daily average TP concentration under the design flow regime at the basin outlet 71
Figure 74: Cumulative frequency distribution for daily average DO concentration under the design flow regime at the basin outlet 72
Figure 75: Cumulative frequency distribution for daily Chl-a load under the design flow regime at the basin outlet 72
Figure 76: Cumulative frequency distribution for daily average Chl-a concentration under the design flow regime at the basin outlet 73

Executive Summary

An HSPF water quality model of the Blackstone River was developed by the University of Massachusetts Amherst and CDM for the Upper Blackstone Water Pollution Abatement District (UBWPAD). A description of the model development and calibration is presented in the Blackstone River HSPF Water Quality Model Calibration Report (UMass and CDM, August 2008). The HSPF water quality model was used to simulate different UBWPAD effluent characteristics in order to evaluate potential improvements in water quality resulting from treatment plant upgrades at both UBWPAD and Woonsocket. Four scenarios were simulated:

- 2009 Plant Conditions (Upgrade 1). The new facilities at UBWPAD are being sized and constructed for 45 MGD average flow and 160 MGD peak flow, and to meet current permit limits. Upgrade 1 refers to the WWTF loading scenario that represents limits which will be achieved upon completion of upgrades underway at the UBWPAD facility. For evaluation purposes, these limits were applied to both the UBWPAD facility and the Woonsocket WWTF, the two largest (in terms of volume) WWTFs in the watershed.

- Proposed New NPDES Limits (Upgrade 2). Upgrade 2 refers to the effluent limits that will be required under the 2008 NPDES permit. As for upgrade 1, these limits were applied to both the UBWPAD facility and the Woonsocket WWTF.

- Zero Nutrient Loading at UBWPAD (ZeroUB). The Zero Nutrient Load scenario was developed by assuming the concentrations of all nutrients in the UBWPAD effluent are zero. In this way, the hydraulics of the system are preserved (effluent volume is accounted for) while allowing an evaluation of the "best case", although not feasible, scenario for effluent treatment. This scenario was only applied to the UBWPAD loadings.

- 2009 Plant Conditions plus a 20% Reduction in Nonpoint Source Loads (UP1NPS). The effluent quality conditions anticipated as a result of Upgrade 1, or the 2009 plant conditions, were paired with a twenty percent reduction in nonpoint sources, applied uniformly across the basin.

The discharge scenarios were simulated for two UBWPAD flow discharge conditions: observed historical effluent flows and design flow conditions. Design flow conditions assume the plant operates at its average daily design capacity over each calendar year while retaining day-to-day variations in flow. By inflating the volume treated at the plant, the design flow condition increase the mass loading to the river and represent a worse case load scenario for the river. Design flow conditions are typically used as the basis for Total Maximum Daily Load development. Observed historical effluent flows, referred to as the actual flow regime in this report, are those that were used in model calibration. Thus the actual flow regime scenario results are more indicative of the ultimate improvements that will be realized by the alternative management scenarios. The set of scenario results for the two flow conditions thus represent a range of potential improvements along the river resulting from WWTP upgrades. While results for both flow regimes are presented, the focus of this report is on scenario results under the actual flow regime. The studied scenarios are summarized in the table below.

Regime	Scenario Description	Abbreviation
Actual Flows	Baseline condition based on WWTP inputs developed during the model construction and calibration phases of the project.	Current
	WWTP inputs developed based on actual flow conditions and 2001 NPDES permits (Upgrade 1, Table 3).	UP1
	WWTP inputs developed based on actual flow conditions and 2008 NPDES permits (Upgrade 2, Table 3).	UP2
	No UBWPAD load; Woonsocket load based on actual flow and 2001 NPDES permits (Upgrade 1, Table 3).	ZeroUB
	WWTP inputs developed based on actual flow conditions and 2001 NPDES permits (Upgrade 1, Table 3) plus a 20% uniform reduction in NPS across the basin.	UP1NPS
Design Flows	WWTP inputs developed based on the observed effluent concentrations during the simulation period converted to a load based on daily design flow conditions.	Current DF
	WWTP inputs developed based on design flow conditions and 2001 NPDES permits (Upgrade 1, Table 3).	UP1 DF
	WWTP inputs developed based on design flow conditions and 2008 NPDES permits (Upgrade 2, Table 3).	UP2 DF
	No UBWPAD load; Woonsocket load based on design flow and 2001 NPDES permits (Upgrade 1, Table 3).	Zero UB
	WWTP inputs developed based on design flow conditions and 2001 NPDES permits (Upgrade 1, Table 3) plus a 20% uniform reduction in NPS across the basin.	UP1NPS DF

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 total nitrogen (TN) and total phosphorus (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, dissolved oxygen (DO) and Chlorophyll a (Chl-a). As noted in the Blackstone River HSPF Water Quality Model Calibration Report (UMass and CDM, August 2008), further refinement of the model calibration for DO and Chl-a is planned; the results for these parameters should thus be considered as interim. However, although model calibration refinement may alter specific values, trends and relative behavior under the studied scenarios are anticipated to be similar. The following observations are based on a review of the scenario simulation results:

- 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 suggested EPA Ecoregion nutrient criteria, even under the most stringent effluent levels associated with UP2 and the unrealistic ZeroUB scenario.
- Average summer Chlorphyll a (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 Chl-a under UP1, and to approximately 35 µg/L Chl-a under 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 sources of nutrients could be an effective mechanism for in-stream water quality improvement, particularly for downstream reaches.
- 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.

1 Introduction

The Upper Blackstone Water Pollution Abatement District (UBWPAD) was issued a NPDES permit in 2001 requiring more stringent effluent standards on BOD, TSS, nutrients and metals concentrations, Table 1. In order to meet the permit limits, the UBWPAD implemented a 4 phase improvement plan to be completed by 2009 with an estimated total cost of $180 million (UBWPAD, 2008; Walsh, 2008). Prior to the completion of upgrades for the 2001 permit, a new NPDES wastewater discharge permit was issued for the UBWPAD in the summer of 2008. The new NPDES permit calls for year round nitrification as well as more stringent biological oxygen demand (BOD), total suspended solids (TSS), phosphorous and metals limits, especially in the summer months. District members are expected to provide most of the funding, with sewer rates per household increasing between 300 and 500 percent in the next 5 years (Patterson, 2007). Increasingly stringent seasonal standards are being enacted at the Woonsocket WWTP as well.

Table 1: UBWPAD 2001 and 2008 NPDES Permit Limits, mg/L

Parameter	2001 Permit		2008 Permit	
	Summer	Winter	Summer	Winter
CBOD	20	25	10	25
TSS	15	30	10	30
NH3	2	12	2	12
TN	report	report	5	report
TP	0.75	report	0.1	1.0
Cd	0.001	0.001	0.0002	0.0002
Cu	0.0072	0.0072	0.0072	0.0072
Zn	0.0913	0.0913	0.0913	0.0913

Potential improvements in stream water quality resulting from the upgrades at both the UBWPAD and Woonsocket WWTPs were investigated utilizing the Blackstone River HSPF model. An overview of the development and calibration of the HSPF model is provided in the Blackstone River HSPF Water Quality Model Calibration Report (UMass and CDM, August 2008). Potential changes in loading from MA to RI and from the Blackstone River into Narragansett Bay resulting from different upgrade scenarios were investigated as well. The purpose of these analyses was to evaluate the effectiveness of on-going pollution management strategies for the Blackstone River watershed. Goals of the scenarios analysis included:

- Determine the impact that the ongoing and proposed point source (PS) upgrades will have on water quality and loading patterns in the Blackstone River.
- Determine the impact that the ongoing and proposed PS upgrades will have on loading from the Blackstone River into Narragansett Bay.
- Determine the relative improvement in water quality resulting from each of the above PS reduction scenarios.

2 Background

There are nine waste water treatment plants (WWTPs) that discharge into the Blackstone River watershed. The largest, in terms of average effluent flow volume, is the UBWPAD (Table 2, based on 1996 - 2007). Located in the headwaters of the Blackstone River, the UBWPAD WWTP treats sewage from Worcester and the surrounding area. The plant is currently undergoing a $180 million dollar upgrade to reduce its total nitrogen (TN) and total phosphorus (TP) effluent concentrations to 8 and 0.75 mg/L, respectively on a seasonal basis in response to the NPDES permit issued in 2001. The upgraded preliminary and primary treatment facilities are designed to treat a peak hour flow of 160 MGD; however, the new advanced treatment system is designed to handle a peak hour flow of 120 MGD and a maximum day flow of 80 MGD. The average day design flow is 45 MGD. While no specific total nitrogen (TN) limits are called for in the 2001 NPDES permit (Table 1) the limits placed on ammonia (NH_3) effluent concentrations encouraged the plant to achieve a TN effluent concentration of 8 mg/L on a seasonal basis. The preliminary and primary upgrades are now operational and the advanced treatment upgrades are expected to be online and operational in 2009.

In an effort to further reduce nutrient levels in the Blackstone River, a new NPDES permit was issued to the District in the summer of 2008 requiring TN and TP to be reduced to 5 and 0.1 mg/L on a seasonal basis, while achieving TP levels of 1.0 for the remainder of the year. Current estimates for the construction and implementation of the proposed upgrades are approximately $200 million (Walsh, 2006).

Table 2: WWTPs in Blackstone River Watershed

WWTP	Receiving Waters	Average Effluent Flow
		MGD
UBWPAD	Blackstone River	36.62
Woonsocket WWTP	Blackstone River	7.32
Grafton WWTP	Blackstone River	1.74
Northbridge WWTP	Blackstone River	1.13
Burrillville WWTP	Branch River	0.79
Uxbridge WWTP	Blackstone River	0.78
Hopedale WWTP	Mill River	0.40
Douglas WWTP	Mumford River	0.23
Upton WWTP	West River	0.16

The Woonsocket WWTF is the second largest wastewater treatment plant in the Blackstone River Watershed in terms of volume. The plant is designed to treat 16 MGD of wastewater and on average it treats approximately 7.3 MGD. In 2008, the Woonsocket WWTP was issued a NPDES permit that will require the plant to meet a seasonal TN effluent concentration of 5 mg/L and a seasonal TP effluent concentration of 0.1 mg/L. However, Woonsocket expects to achieve a seasonal TN effluent concentration of 3 mg/L. It is anticipated that the upgrades required to meet these standards will be online by 2014. An estimated cost for the required upgrades is not yet available.

3 Methodology

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. To simulate this, daily loading values under future conditions were estimated by multiplying the calculated observed WWTP effluent flow volume (1996 – 2007) by the constituent effluent concentrations mandated by both the 2001 (Upgrade 1) and 2008 (Upgrade 2) NPDES permits. Only nutrient load values at the two largest plants, UBWPAD and Woonsocket, were adjusted in this manner as sensitivity analyses suggest the model results are insensitive to changes in loadings from smaller WWTPs within the basin under current conditions. It should be noted that this may change as upgrades are brought on-line at the two major WWTPs. The HSPF model was then re-run for the period 1996-2007. To date only PS reductions have been simulated, however, in the future, NPS reduction simulations may also be conducted.

When developing effluent limits such as those contained in the NPDES permits, regulatory agencies use the design flow of the plant rather than the observed annual average daily effluent flow. Therefore, in addition to the set of scenarios run based on observed plant effluent flows from 1996 – 2007, a second set was run with plant flows inflated to design flow conditions at UBWPAD and Woonsocket. Under the 2001 and 2008 permits, the design flow for UBWPAD is 45 MGD while for Woonsocket it is 16 MGD. The design flow conditions at the plants are considerably larger than annual and average annual observed effluent flows at both plants (Table 2). Design flows were not applied at the smaller plants due to the documented lack of sensitivity of model results to these WWTP loadings.

In order to retain daily effluent flow fluctuations when accounting for design flow, rather then simply generating WWTP loading based on a constant daily flow, daily flows for the design flow scenarios were calculated using Equation 1,

$$Q_{DFd} = \left(Q_{Di} / Q_{Ai} \right) \cdot Q_{DF}$$

Equation 1

where Q_{DFd} is the calculated design flow scenario plant effluent flow for a given day, Q_{Di} is the reported daily flow on a given day during year i, Q_{Ai} is the average annual flow in year i and Q_{DF} is the design flow of the plant. Utilizing the above methodology, the relative magnitude in observed daily effluent volume fluctuations is maintained while inflating the average flow (both over the year and over the period of the study) to the plant design flow. The daily loading value for each constituent was calculated by multiplying the daily flow for design flow conditions by the constituent effluent concentrations mandated by the NPDES permits for nutrients. No changes were made to plant CBOD or TSS loadings. A simulation based on observed WWTP effluent nutrient concentrations and calculated daily flows for design flow conditions was used as the baseline for judging water quality improvements under design flow conditions.

The nutrient concentration adjustment to account for BOD associated phosphorus and nitrogen used during model calibration phase was also applied to the upgrade scenarios. This step eliminates double counting of nutrient loads from WWTPs and is necessary due to the HSPF model construct for BOD. A more detailed description of this adjustment is provided in the model calibration report (UMass and CDM, August 2008). To summarize this procedure, first the BOD associated TP is determined and subtracted from the reported plant TP concentration. The remaining TP concentration is then used to calculate the daily TP load from the plant used as input for the model. Next the daily BOD associated TN is determined and subtracted first from the daily NH_3 concentration values. If there is more BOD associated nitrogen then available NH_3, the daily NO_3 concentration is next reduced followed by daily NO_2 concentrations. Finally, if necessary, the daily OrgN concentration values are reduced to account for any remaining BOD associated N.

Water quality conditions and loading for three potential future scenarios were estimated for each of the two flow condition sets. As discussed above, the first set of scenarios utilizes the actual UBWPAD and Woonsocket effluent flow volumes from 1996 – 2007. The second set of scenarios simulates the higher design flow conditions. Observed concentration values provided a baseline for comparison for each set when paired with the flow values (actual or design flow). The NPDES permit values and their application periods used in the scenario analyses are summarized in Table 3 for the actual flow regime set and in Table 4 for the design flow regime set. The individual scenarios are described in more detail in the following sections and are summarized in Table 5. Subsequent figures utilize the scenario abbreviations presented in this table.

Table 3: Effluent Limits for the UBWPAD and Woonsocket used for Actual Flow Regime scenario analysis set, in mg/L

	UBWPAD				**Woonsocket**			
	TP	**TN**	**Org N**	**Dates**	**TP**	**TN**	**Org N**	**Dates**
Upgrade 1	0.6 or as is	8 or as is	1	Year Round	0.6 or as is	8 or as is	1	Year Round
Upgrade 2	0.09 or as is	4.5 or as is	1	Apr 1 - Oct 31	0.09 or as is	2.7 or as is	1	Apr 1 - Oct 31
	0.6 or as is	8 or as is	1	Nov 1 - Mar 31	0.6 or as is	8 or as is	1	Nov 1 - Mar 31

Table 4: Effluent Limits for the UBWPAD and Woonsocket used for Design Flow Regime scenario analysis set, in mg/L

	UBWPAD				**Woonsocket**			
	TP	**TN**	**Org N**	**Dates**	**TP**	**TN**	**Org N**	**Dates**
Upgrade 1	0.6	8	1	Annually	0.6	8	1	Annually
Upgrade 2	0.09	4.5	1	Apr 1 - Oct 31	0.09	2.7	1	Apr 1 - Oct 31
	0.6	8	1	Nov 1 - Mar 31	0.6	8	1	Nov 1 - Mar 31