Analysis of Nitrogen Loading Reductions for Wastewater Treatment Facilities and Non-Point Sources in the Great Bay Estuary Watershed

Appendix D:

<u>Quality Assurance</u>

NEW HAMPSHIRE DEPARTMENT OF Environmental Services

DRAFT

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1 Introduction

In 2009, the New Hampshire Department of Environmental Services (DES) published a proposal for numeric nutrient criteria for the Great Bay Estuary (DES, 2009). These criteria were developed over a four-year period through an open process that involved local experts from universities, state agencies, federal agencies, municipalities, and non-governmental organizations. The report found that total nitrogen concentrations in most of the estuary needed to be less than 0.3 mg/L to prevent loss of eelgrass habitat and less than 0.45 mg/L to prevent occurrences of low dissolved oxygen. Eelgrass habitat and dissolved oxygen are both critical for supporting aquatic life in the Great Bay Estuary.

Based on these criteria and an analysis of a robust compilation of data from multiple sources, DES concluded that 11 of the 18 assessment zones in the Great Bay Estuary did not meet surface water quality standards and specifically did not comply with Env-Wq 1703.14, the narrative standard for nutrients (DES, 2009b). These impairments were added to New Hampshire’s 2008 303(d) list on August 14, 2009, approved by EPA on September 30, 2009, and have subsequently been retained on the 2010 303(d) list. Nine of the 11 impaired assessment zones were the subestuaries of Great Bay, Little Bay, Upper Piscataqua River, and the tidal rivers that flow into these areas. The other two impaired assessment zones were Portsmouth Harbor and Little Harbor/Back Channel at the mouth of the estuary.

Under the Clean Water Act, if a water body is placed on the 303(d) list, a study must be completed to determine the existing loads of the pollutant and the load reductions that would be needed to meet the water quality standard. To satisfy this requirement, DES has developed models to predict the existing nitrogen loads to the estuary (Appendix A) and the watershed nitrogen load thresholds that would be needed to meet the new criteria (Appendix B).

For this analysis, the precision, accuracy, and sensitivity of the DES models have been determined. Precision was evaluated using Monte Carlo simulations to propagate uncertainty in model input variables to output values. Accuracy was assessed by comparing measured total nitrogen concentrations to predicted values from the model. Two sensitivity tests were employed. The first was a rank correlation assessment of input and output variables from the Monte Carlo simulations. The second sensitivity test determined what effect changes in the numeric nutrient criteria would have on the model outputs.

2 Methods

Four quality assurance tests were used to understand uncertainty in the DES models of existing nitrogen loads and watershed nitrogen loading thresholds. These tests quantified the precision, accuracy, and sensitivity of the models.

2.1 Precision

Precision is a measure of variability. It is often expressed in terms of error bars on a modeled variable. Due to the large number of input variables for the models, DES used Monte Carlo simulations to propagate uncertainty in the input variables through the model to predict the error bars in the model output variables. Distributions representing the uncertainty for input variables for the 2003-2004 models were defined using Crystal Ball® (version 2000.2) software. These distributions are described in detail in Table 1. The only input variables that were assumed to not have uncertainty were dimensional parameters such as watershed drainage areas, stream flow measured by USGS gages, wastewater treatment facility effluent discharge volumes, and the numeric nutrient criteria. For the Monte Carlo simulations, the distributions for input variables were substituted for point values in the DES models. Crystal Ball® software was then used to generate 1,000 iterations of the models and to capture distribution in the output variables due to the variability in the input variables. Error bars in output variables were calculated by calculating the difference between the 5th and 95th percentile values and the median value. The error bars were represented as a percent by dividing the larger of the two differences by the median value.

2.2 Accuracy

Accuracy is a measure of how well the model predicts actual conditions. Measured nitrogen concentrations in the subestuaries were used as the benchmark to test the accuracy of the models. This approach tested both the model to predict existing nitrogen loads and the model to predict watershed nitrogen loading thresholds from nitrogen concentrations in the subestuaries. As described in the previous section, DES used Monte Carlo simulations with Crystal Ball® software to predict the distribution of median nitrogen concentrations in each subesutary for the 2003-2004 period. If the measured median nitrogen concentration in each subestuary was between the 5th and 95th percentiles of the predicted values, the modeled and measured results were considered to match. In addition, the relative percent differences between the median predicted concentration and the measured median concentration were calculated.

2.3 Sensitivity

Sensitivity is a measure of how much individual input variables control the output of the model. Two tests of sensitivity were performed. First, to quantify the sensitivity of watershed nitrogen load thresholds to input variables, the rank correlation of input variables to the predicted thresholds were calculated using the Monte Carlo simulations. To clarify the results, variables with trivial impacts on the model outputs (i.e., having a rank correlation coefficient with absolute value greater than 0.1) were filtered out of the results.

The second sensitivity test determined the sensitivity of the model to the numeric nutrient criteria. Uncertainty in the criteria was not included in the precision and first sensitivity tests in order to isolate uncertainty in the models, not the modeling targets. However, it is important to also understand how changes in the numeric criteria would affect the model results. In the DES models, the predicted watershed nitrogen loading threshold is linearly related to the difference between the nutrient criteria and the concentration of nitrogen in the subestuary from ocean water. The concentration of nitrogen due to ocean water in a subestuary is linearly related to the salinity of the subestuary. Therefore, the sensitivity of the models to the nutrient criteria will be a function of salinity. DES developed a generalized relationship using the equations from the models to show the effect of a 20% increase in the numeric criteria for the range of salinities in the modeled subestuaries.

3 Results

3.1 Precision

The uncertainty in the model outputs for the existing watershed nitrogen loads and the watershed nitrogen load thresholds to meet the criteria to protect eelgrass and prevent low dissolved oxygen are shown on Tables 2, 3, and 4, respectively. The uncertainty was different for the tidal river subestuaries compared to the downstream areas (Great Bay, Little Bay, and Upper Piscataqua).

For the existing watershed nitrogen loads, the error bars for the tidal river subestuaries were +/-10% on average. In the downstream areas, the error bars were +/-6% on average. The decreased error in downstream areas makes sense because the existing nitrogen load is essentially the sum of multiple nitrogen sources. As the number of sources increases, the errors in individual sources cancel each other out, which improves the precision of the sum.

For the watershed nitrogen load thresholds, the error bars for the tidal river subestuaries were +/-12% on average. In the downstream areas, the error bars were +/-29% on average. The error bars were the same for the load thresholds to meet both criteria (protecting eelgrass and preventing low dissolved oxygen). The uncertainty in the load thresholds was higher in the downstream subestuaries with higher salinity. As will be shown in the following sections, the model is sensitive to changes in salinity, particularly in subestuaries with salinities approaching ocean water salinity. Consequently, the DES model for determining watershed nitrogen load thresholds is more precise for lower salinity subestuaries.

3.2 Accuracy

In Table 5, the distribution of median nitrogen concentrations in each subestuary, generated by Monte Carlo simulations, have been compared to the measured median nitrogen concentrations from 2003-2004. Overall, five of the ten subestuaries pass the data quality objective that the measured nitrogen concentration fall between the 5^{th} and 95^{th} percentiles of the simulated distribution. The model under-predicts the nitrogen concentration for the Exeter River, Salmon Falls River, Great Bay and Upper Piscataqua subestuaries. The Winnicut River subestuary did not have enough measurements of nitrogen in 2003-2004 to make the comparison. The relative percent difference between the measured concentration and the median value of the predicted concentrations was -11% on average and ranged from -27% to 8%.

These results indicate that the model is reasonably accurate but that there is the potential for under-predicting nitrogen concentrations in some subestuaries. Internal sources and sinks of nitrogen within the subestuaries, both in the water column and the sediments, are not part of the model and may explain the under-predictions. Another explanation is that the measured nitrogen concentrations in subestuaries may not be representative of the modeled locations. All nitrogen data in the subestuaries were compiled to calculate the median values, not just samples collected at the modeled location. Regardless, if the model does under-predict nitrogen concentrations, this would mean that the watershed nitrogen loading thresholds would be biased high.

3.3 Sensitivity to Model Input Variables

The sensitivity of the watershed load threshold model to the input variables was assessed by calculating the rank correlation coefficients for input variable relative to output variables from the Monte Carlo simulations. The variables with rank correlation coefficients greater than or equal to 0.1 (absolute value) are listed on Table 6.

There were three types of variables for which the model was sensitive. First, there was a negative correlation between the watershed nitrogen load threshold and the nitrogen concentration in the ocean. This correlation was observed in the models for each of the subestuaries and ranged from -0.69 to -0.32. Second, stream flow, often expressed as cubic feet per second per square mile (CFSM), was positively correlated with the watershed nitrogen load thresholds. The correlation coefficients ranged from 0.14 to 0.76 for these variables. Finally, all of the subestuary models were sensitive to the salinity of the subestuary. The correlation coefficients ranged from 0.53 to 0.90. Therefore, the watershed load threshold models were most sensitive to the input variables of ocean nitrogen concentration, stream flow in tributaries, and salinity in the subestuaries.

3.4 Sensitivity to Numeric Nutrient Criteria

In the watershed nitrogen load threshold model, there is a linear relationship between the threshold and the difference between the numeric nutrient criteria and the nitrogen concentration due to ocean water in the subestuary. The nitrogen concentration due to ocean water in the subestuary is a linear function of the salinity in the subestuary.

Therefore, the sensitivity of the watershed nitrogen load threshold model to the numeric nutrient criteria should be a function of salinity in the subestuary. Figure 1 shows this relationship across a range of salinities expressed as the percent increase in the watershed nitrogen load threshold given a 20% increase in the numeric nutrient criteria.

For the theoretical subestuary with zero salinity, there would be a 20% increase in the watershed nitrogen load threshold for a 20% increase in the numeric nutrient criteria. For the tidal river subestuaries with an average salinity of 13 ppt, the watershed nitrogen load threshold to protect eelgrass would increase by 28% for a 20% increase in the numeric nutrient criteria. If the nutrient criteria for preventing low dissolved oxygen were used, the watershed load threshold would only increase by 24%. Finally, for the downstream areas, such as Great Bay, Little Bay, and the Upper Piscataqua, with an average salinity of 23 ppt, a 20% increase in the nutrient criteria would result in a 39% increase in the watershed nitrogen load threshold if the criteria to protect eelgrass were used and a 30% increase if the criteria to prevent low dissolved oxygen were used.

There are two key points from this analysis. First, as salinity increases, the watershed nitrogen load threshold model becomes more sensitive to numeric nutrient criteria value. Second, the model is more sensitive to the numeric nutrient criteria to protect eelgrass than to the criteria to prevent low dissolved oxygen. This is because the criteria to prevent low dissolved oxygen (0.45 mg N/L) is much higher than the predicted nitrogen concentration due to ocean water in subestuaries (0.08-0.15 mg N/L). Therefore, the model is least sensitive to the choice of the numeric nutrient criteria when applied to the tidal river subestuaries with low salinity and when using the criteria for preventing low dissolved oxygen.

4 Summary

The quality assurance tests confirm that the DES models have reasonable precision and accuracy for their intended purpose. In the tidal river subestuaries, the modeled watershed nitrogen load thresholds have error bars of +/-12%. The error for downstream subestuaries was higher, +/-29%. The models accurately predict nitrogen concentrations in half of the subestuaries. The most important input variables for the models were ocean nitrogen concentration, stream flow in tributaries, salinity in the subestuaries, and the numeric nutrient criteria. The model was most sensitive to the choice of the numeric nutrient criteria when applied to the higher salinity subestuaries and when using the criteria for protecting eelgrass habitat. In combination, the quality assurance tests indicate that the models have the least error and are less sensitive to the nutrient criteria when applied to the tidal river subestuaries.

5 References

DES. 2009. Nutrient Criteria for the Great Bay Estuary. New Hampshire Department of Environmental Services, Concord, NH. Published online: http://www.prep.unh.edu/resources/nutrient/20090601_nutrient_criteria.pdf (Accessed September 23, 2009)

DES. 2009b. Amendment to the New Hampshire 2008 Section 303(d) List Related to Nitrogen and Eelgrass in the Great Bay Estuary. R-WD-09-14. New Hampshire Department of Environmental Services, Water Division, Concord, NH.

6 Tables and Figures

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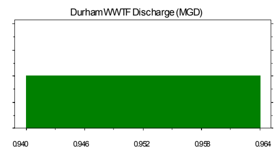
Table 1: Probability Distribution Functions for Input Parameters for the Watershed Nitrogen Loading Model (2003-2004)

WWTF Effluent Discharge

Explanation: Uniform distribution with min/max defined by the average flows in 2003 and 2004, i.e. the smaller of the two annual average flows was the min and the larger was the max.

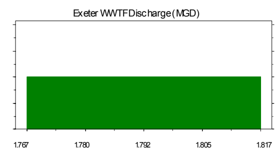
Durham WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	0.940
Maximum	0.964



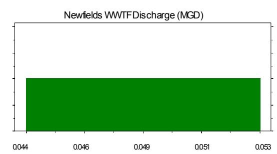
Exeter WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	1.767
Maximum	1.817



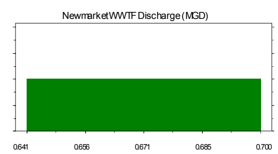
Newfields WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	0.044
Maximum	0.053



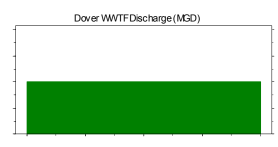
Newmarket WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	0.641
Maximum	0.700



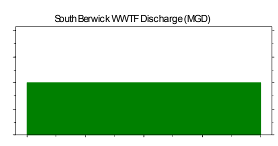
Dover WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	2.762
Maximum	2.912

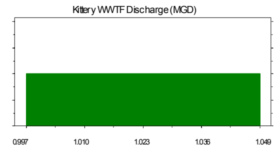


South Berwick WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	0.322
Maximum	0.332



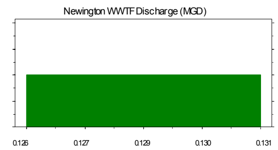
Kittery WWTF Discharge (MGD)



Uniform distribution with parameters:

Minimum	0.997
Maximum	1.049

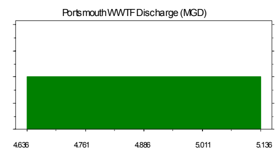
Newington WWTF Discharge (MGD)



Uniform distribution with parameters:

Minimum	0.126
Maximum	0.131

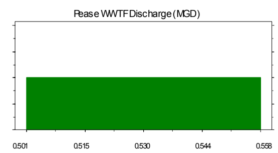
Portsmouth WWTF Discharge (MGD)



Uniform distribution with parameters:

Minimum	4.636
Maximum	5.136

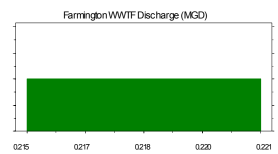
Pease WWTF Discharge (MGD)



Uniform distribution with parameters:

Minimum	0.501
Maximum	0.558

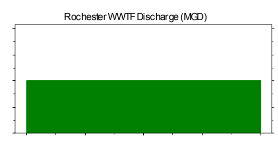
Farmington WWTF Discharge (MGD)



Uniform distribution with parameters:

Minimum	0.215
Maximum	0.221

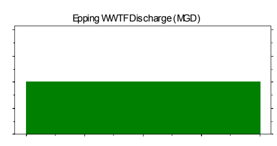
Rochester WWTF Discharge (MGD)



Uniform distribution with parameters:

Minimum	3.420
Maximum	3.504

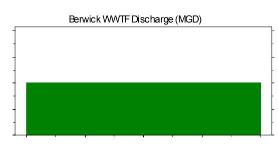
Epping WWTF Discharge (MGD)



Uniform distribution with parameters:

Minimum	0.213
Maximum	0.256

Berwick WWTF Discharge (MGD)

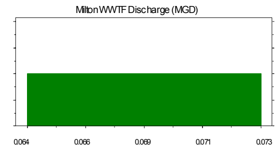


Uniform distribution with parameters:

Minimum	0.383
Maximum	0.392

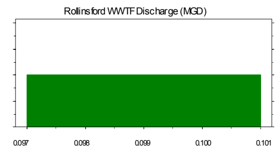
Milton WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	0.064
Maximum	0.073



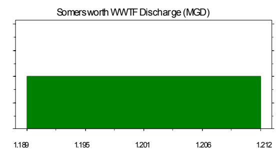
Rollinsford WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	0.097
Maximum	0.101



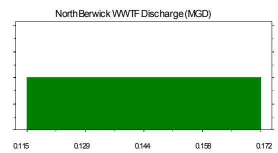
Somersworth WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	1.189
Maximum	1.212



North Berwick WWTF Discharge (MGD)

Uniform distribution with parameters:	
Minimum	0.115
Maximum	0.172



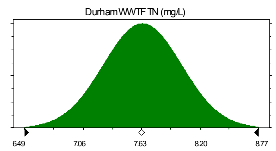
Nitrogen Concentration in WWTF Effluent

Explanation: Normal distribution with mean and stdev calculated from monitoring data for each WWTF. For the six plants without monitoring data (Newfields, Newington, Epping, Milton, Rollinsford, North Berwick), the distribution was assumed to be normal with a mean value of 17.78 and a stdev of 5 mg/L. The mean value was calculated using data from the WWTFs which were monitored. The stdev was assumed. The highest stdev calculated for a WWTF was 4.2 mg/L. The overall average stdev of the monitored WWTFs was 3.7 mg/L. Therefore, by selecting a stdev of 5 mg/L, the assumed error for the WWTFs that were not monitored was inflated to account for the lack of data.

Durham WWTF TN (mg/L)

Normal distribution with parameters:

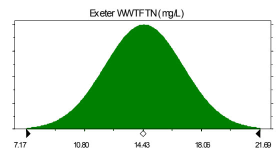
Mean	7.63
Standard Dev.	0.38



Exeter WWTF TN (mg/L)

Normal distribution with parameters:

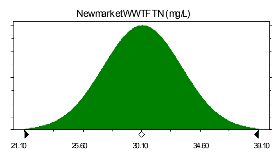
Mean	14.43
Standard Dev.	2.42



Newmarket WWTF TN (mg/L)

Normal distribution with parameters:

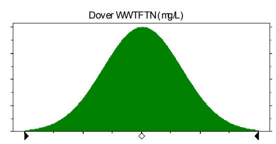
Mean	30.10
Standard Dev.	3.00



Dover WWTF TN (mg/L)

Normal distribution with parameters:

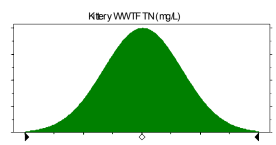
Mean	22.33
Standard Dev.	2.49



Kittery WWTF TN (mg/L)

Normal distribution with parameters:

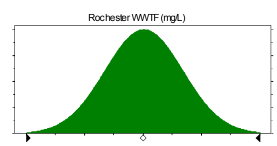
Mean	15.99
Standard Dev.	2.16



Rochester WWTF (mg/L)

Normal distribution with parameters:

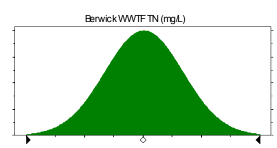
Mean	30.11
Standard Dev.	4.20



Berwick WWTF TN (mg/L)

Normal distribution with parameters:

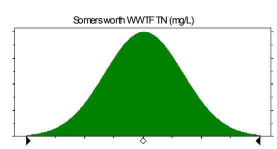
Mean	16.68
Standard Dev.	2.72



Somersworth WWTF TN (mg/L)

Normal distribution with parameters:

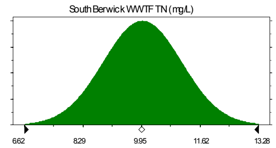
Mean	4.95
Standard Dev.	0.55



South Berwick WWTF TN (mg/L)

Normal distribution with parameters:

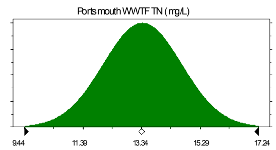
Mean	9.95
Standard Dev.	1.11



Portsmouth WWTF TN (mg/L)

Normal distribution with parameters:

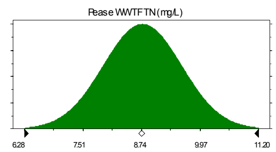
Mean	13.34
Standard Dev.	1.30



Pease WWTF TN (mg/L)

Normal distribution with parameters:

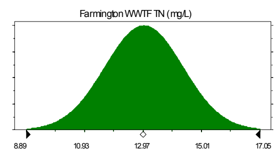
Mean	8.74
Standard Dev.	0.82



Farmington WWTF TN (mg/L)

Normal distribution with parameters:

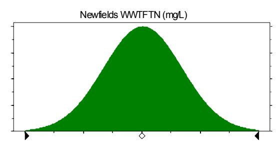
Mean	12.97
Standard Dev.	1.36



Newfields WWTF TN (mg/L)

Normal distribution with parameters:

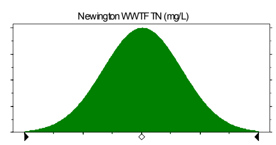
Mean	17.78
Standard Dev.	5.00



Newington WWTF TN (mg/L)

Normal distribution with parameters:

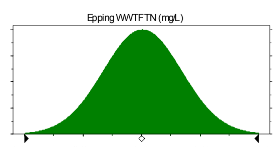
Mean	17.78
Standard Dev.	5.00



Epping WWTF TN (mg/L)

Normal distribution with parameters:

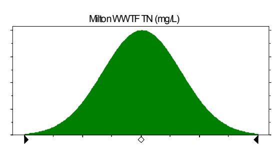
Mean	17.78
Standard Dev.	5.00



Milton WWTF TN (mg/L)

Normal distribution with parameters:

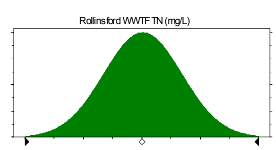
Mean	17.78
Standard Dev.	5.00



Rollinsford WWTF TN (mg/L)

Normal distribution with parameters:

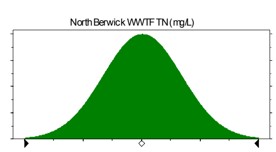
Mean	17.78
Standard Dev.	5.00



North Berwick WWTF TN (mg/L)

Normal distribution with parameters:

Mean	17.78
Standard Dev.	5.00



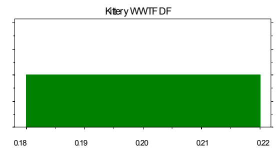
Nitrogen Delivery Factor for WWTFs Discharging to Freshwater Rivers

Explanation: Uniform distribution with min/max defined by assuming 10% error in chosen value. Distributions truncated at 1. No uncertainty was assumed for WWTFs with delivery factors of 1 because these WWTFs discharge directly to tidal waters.

Kittery WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

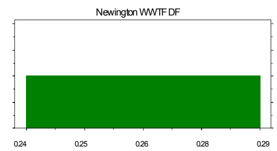
Minimum	0.18
Maximum	0.22



Newington WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

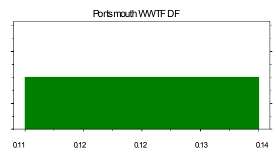
Minimum	0.24
Maximum	0.29



Portsmouth WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

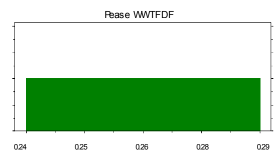
Minimum	0.11
Maximum	0.14



Pease WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

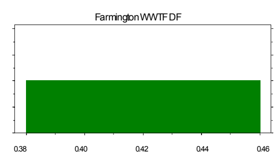
Minimum	0.24
Maximum	0.29



Farmington WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

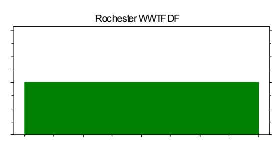
Minimum	0.38
Maximum	0.46



Rochester WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

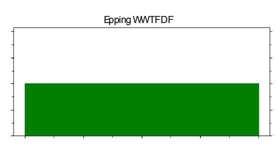
Minimum	0.68
Maximum	0.83



Epping WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

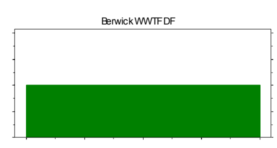
Minimum	0.52
Maximum	0.64



Berwick WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

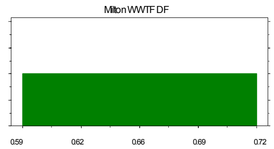
Minimum	0.85
Maximum	1.00



Milton WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

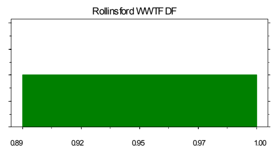
Minimum	0.59
Maximum	0.72



Rollinsford WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

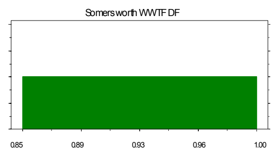
Minimum	0.89
Maximum	1.00



Somersworth WWTF Nitrogen Delivery Factor

Uniform distribution with parameters:

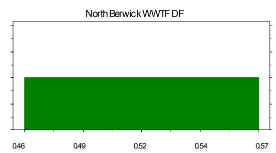
Minimum	0.85
Maximum	1.00



North Berwick WWTF Nitrogen Delivery Factor

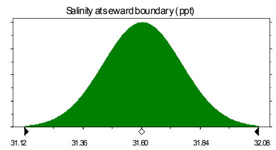
Uniform distribution with parameters:

Minimum	0.46
Maximum	0.57



Global Variables for the Watershed Nitrogen Loading Model

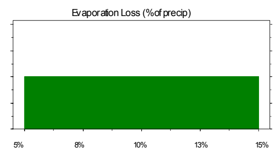
Salinity at seaward boundary (ppt)



Normal distribution with parameters:	
Mean	31.60
Standard Dev.	0.16

Explanation: Normal distribution with a mean value of 31.6 ppt and a stdev of 0.16 ppt. >700 observations in dataset. Standard deviation is the standard deviation of the distribution (0.864) divided by the square root of the sample size. Using the minimum sample size for Central Limit Theorem to apply (n=30).

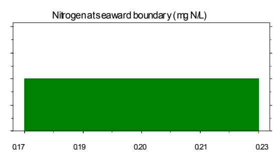
Evaporation Loss (% of precip)



Uniform distribution with parameters:	
Minimum	5%
Maximum	15%

Explanation: Uniform distribution between 5 and 15%. The 10% value was already an assumption..

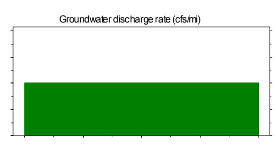
Nitrogen at seaward boundary (mg N/L)



Uniform distribution with parameters:	
Minimum	0.17
Maximum	0.23

Explanation: Uniform distribution with mean of 0.2 mg/L and error bars of +/-0.026 mg/L. The TN concentration in the ocean was pulled from multiple studies. The closest station with all nitrogen species measured is GRBCML. At this station, the 44 samples have a mean of 0.306 mg/L and a standard deviation of 0.072 mg/L. The stdev of the mean is 0.072 divided by sqrt(44) = 0.01 mg/L. The median of the samples from GRBCML is 0.303 mg/L which is very close to the mean. This indicates that a normal distribution may be appropriate but a uniform distribution was used to be conservative. The variability in TN at GRBCML will be larger in absolute terms than the variability for TN in the ocean because the concentrations are higher. Therefore, a conservative approach would be to use the stdev for GRBCML and apply it to the ocean median value. Using a stdev of 0.072 mg/L, the 95th percentile CI of the mean would be 2*stdev/sqrt(30) (assuming the minimum sample size for Central Limit Theorem to apply), which equals 0.026 mg/L. This is a conservative estimate of the 95th percentile CI.

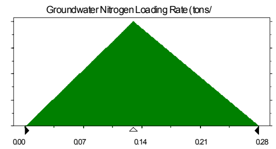
Groundwater discharge rate (cfs/mi)



Uniform distribution with parameters:	
Minimum	0.12
Maximum	0.17

Explanation: Uniform distribution between 0.12 and 0.17. Ballestero et al. used two methods to estimate overall groundwater discharge. The range of the results from the two methods was used to bracket this parameter.

Groundwater Nitrogen Loading Rate (tons/mi/yr)

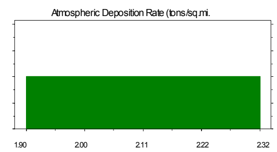


Triangular distribution with parameters:

Minimum	0.00
Likeliest	0.13
Maximum	0.28

Explanation: Triangle distribution, min=0, likeliest=0.13, max=0.28. Ballestero reported the loading rate to be 0.13 +/-0.15 tons/mi/yr. The value cannot be negative so it was truncated at 0. A triangle distribution was used instead of a uniform distribution because of the very large spread.

Atmospheric Deposition Rate (tons/sq.mi./yr)

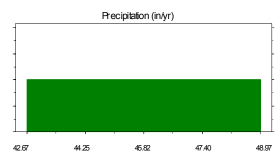


Uniform distribution with parameters:

Minimum	1.90
Maximum	2.32

Explanation: Uniform distribution with uncertainty of 10%.

Precipitation (in/yr)



Uniform distribution with parameters:

Minimum	42.67
Maximum	48.97

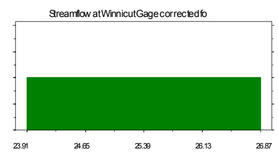
Explanation: Uniform distribution between 42.67 and 48.97 in/yr. This is the range of annual precipitation across the four met stations in the watershed over the two years.

Streamflow Corrected for Upstream Withdrawals

Explanation: Measured streamflow was assumed to be accurate. However, the correction for upstream withdrawals adds uncertainty. The distribution was assumed to be uniform with min/max calculated using the average of the upstream withdrawals in 2002-2008. This would be the maximum possible error that could be introduced by the upstream withdrawal estimates. The error bars for each of the rivers were: Winnicut (+/-1.48 cfs), Lamprey (+/-0.21 cfs), Oyster (+/-0.38 cfs), Cocheco (+/-3.55 cfs), and Exeter (0 cfs, no upstream withdrawals).

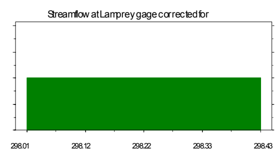
Streamflow at Winnicut River gage (cfs, corrected)

Uniform distribution with parameters:	
Minimum	23.91
Maximum	26.87



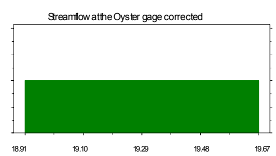
Streamflow at Lamprey gage (cfs, corrected)

Uniform distribution with parameters:	
Minimum	298.01
Maximum	298.43



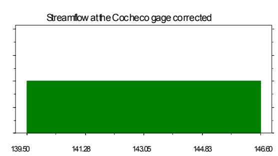
Streamflow at the Oyster River gage (cfs, corrected)

Uniform distribution with parameters:	
Minimum	18.91
Maximum	19.67



Streamflow at the Cocheco River gage (cfs, corrected)

Uniform distribution with parameters:	
Minimum	139.50
Maximum	146.60



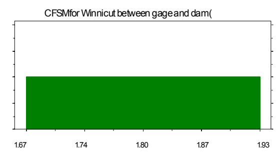
Runoff Coefficients for Area Transposition Calculations

Explanation: Measured streamflow at gages was assumed to be accurate. However, the use of area transposition calculations (cubic feet per second per square mile or CFSM) to estimate streamflow in other watersheds adds uncertainty. This uncertainty was accounted for using a uniform distribution with an error of +/-0.13 CFSM for each of the corrected CFSM values. The magnitude of the error was estimated by calculating the CFSM for the five stream gages in 2003-2004. The difference between the largest and smallest CFSM was 0.13 cfsm (1.56, 1.69). This difference was used as the maximum potential error in the CFSM values. This amount was subtracted from the calculated CFSM value for each watershed, corrected for upstream withdrawals. For the typical CFSM values in 2003-2004, the error is roughly equivalent to +/-8%.

CFSM for Winnicut River watershed

Uniform distribution with parameters:

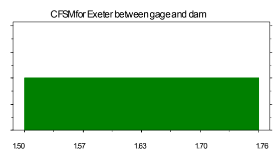
Minimum	1.67
Maximum	1.93



CFSM for Exeter River watershed

Uniform distribution with parameters:

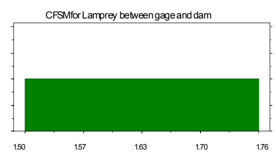
Minimum	1.50
Maximum	1.76



CFSM for Lamprey River watershed

Uniform distribution with parameters:

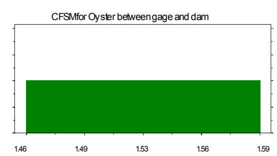
Minimum	1.50
Maximum	1.76



CFSM for Oyster River watershed

Uniform distribution with parameters:

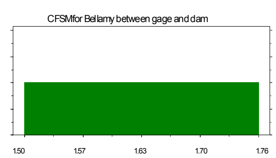
Minimum	1.46
Maximum	1.59



CFSM for Bellamy River watershed

Uniform distribution with parameters:

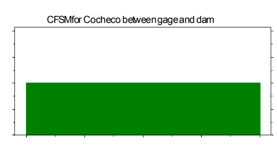
Minimum	1.50
Maximum	1.76



CFSM for Cocheco River watershed

Uniform distribution with parameters:

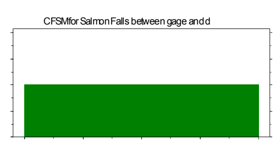
Minimum	1.54
Maximum	1.80



CFSM for Salmon Falls River watershed

Uniform distribution with parameters:

Minimum	1.51
Maximum	1.77



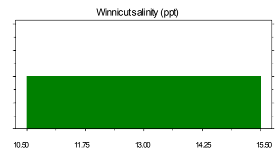
Salinity in Subestuaries

Explanation: Uncertainty in the salinity in each subestuary was modeled using a uniform distribution with chosen value +/- the 95th %ile confidence interval of the mean. The 95th %ile confidence intervals of the mean were calculated by 2*stdev/sqrt(30) based on all data from each zone in 2003-2004 (station visit maxes). A sample size of 30 was used to calculate the confidence intervals, which is smaller than the actual samples size for all areas except the Winnicut subestuary (n=16). This assumption increased the size of the confidence intervals and the uncertainty. The distribution of possible values accounts for uncertainty in the mean salinity value in both space and time. For most subestuaries, the uniform distribution is the chosen value +/-2 ppt.

Winnicut salinity (ppt)

Uniform distribution with parameters:

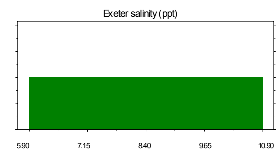
Minimum	10.50
Maximum	15.50



Exeter salinity (ppt)

Uniform distribution with parameters:

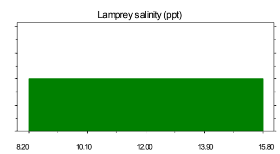
Minimum	5.90
Maximum	10.90



Lamprey salinity (ppt)

Uniform distribution with parameters:

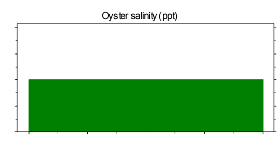
Minimum	8.20
Maximum	15.80



Oyster salinity (ppt)

Uniform distribution with parameters:

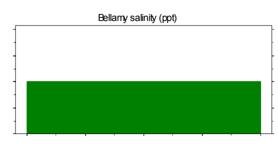
Minimum	18.20
Maximum	21.80



Bellamy salinity (ppt)

Uniform distribution with parameters:

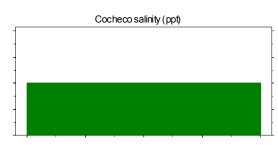
Minimum	20.00
Maximum	24.00



Cocheco salinity (ppt)

Uniform distribution with parameters:

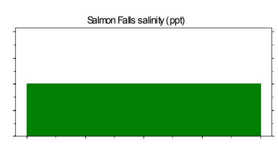
Minimum	6.40
Maximum	11.60



Salmon Falls salinity (ppt)

Uniform distribution with parameters:

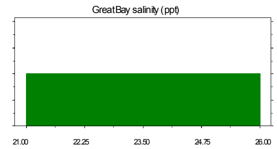
Minimum	7.20
Maximum	12.80



Great Bay salinity (ppt)

Uniform distribution with parameters:

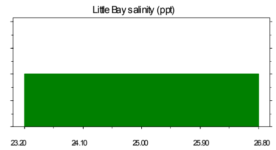
Minimum	21.00
Maximum	26.00



Little Bay salinity (ppt)

Uniform distribution with parameters:

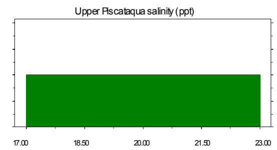
Minimum	23.20
Maximum	26.80



Upper Piscataqua salinity (ppt)

Uniform distribution with parameters:

Minimum	17.00
Maximum	23.00



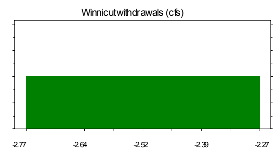
Cumulative Water Withdrawals

Explanation: The accuracy of measurements of individual water withdrawals is supposed to be +/-10%. Summing individual withdrawals to calculate cumulative withdrawals will improve the accuracy to less than +/-10% due to random error propagation methods.However, there are likely to be errors in reporting and, more likely, undocumented withdrawals. Therefore, an overall error of 10% with a uniform distribution was assumed for this parameter.

Winnicut withdrawals (cfs)

Uniform distribution with parameters:

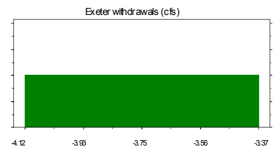
Minimum	-2.77
Maximum	-2.27



Exeter withdrawals (cfs)

Uniform distribution with parameters:

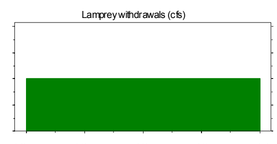
Minimum	-4.12
Maximum	-3.37



Lamprey withdrawals (cfs)

Uniform distribution with parameters:

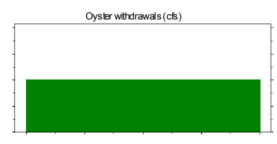
Minimum	-2.12
Maximum	-1.73



Oyster withdrawals (cfs)

Uniform distribution with parameters:

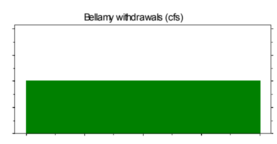
Minimum	-2.43
Maximum	-1.99



Bellamy withdrawals (cfs)

Uniform distribution with parameters:

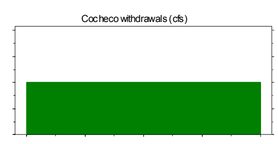
Minimum	-6.11
Maximum	-5.00



Cocheco withdrawals (cfs)

Uniform distribution with parameters:

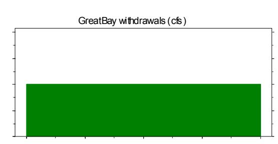
Minimum	-4.73
Maximum	-3.87



Great Bay withdrawals (cfs)

Uniform distribution with parameters:

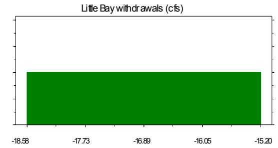
Minimum	-10.04
Maximum	-8.22



Little Bay withdrawals (cfs)

Uniform distribution with parameters:

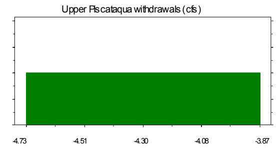
Minimum	-18.58
Maximum	-15.20



Upper Piscataqua withdrawals (cfs)

Uniform distribution with parameters:

Minimum	-4.73
Maximum	-3.87



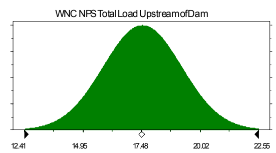
Non-Point Source Nitrogen Load Upstream of Dams

Explanation: Nitrogen loads upstream of tidal dams was estimated using the USGS LOADEST Model. The model output includes the mean load and the standard error the estimate. To isolate the non-point source load, the delivered load from upstream WWTFs was subtracted from the mean. The overall uncertainty in the non-point source load was assumed to follow a Normal distribution with a standard deviation equal to the standard error from the LOADEST output. For the Great Works River, non-point source loads were not estimated using LOADEST because of insufficient data. Instead, a regression of land use versus non-point source nitrogen yields was used. The standard error of this regression multiplied by the drainage area was used as the standard deviation for the Great Works River distribution.

Winnicut NPS Load Upstream of Dam (tons N/yr)

Normal distribution with parameters:

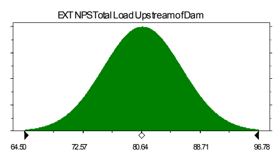
Mean	17.48
Standard Dev.	1.69



Exeter NPS Load Upstream of Dam (tons N/yr)

Normal distribution with parameters:

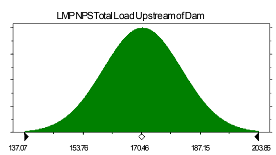
Mean	80.64
Standard Dev.	5.38



Lamprey NPS Load Upstream of Dam (tons N/yr)

Normal distribution with parameters:

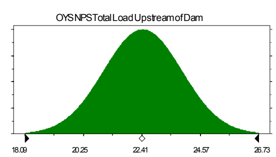
Mean	170.46
Standard Dev.	11.13



Oyster NPS Load Upstream of Dam (tons N/yr)

Normal distribution with parameters:

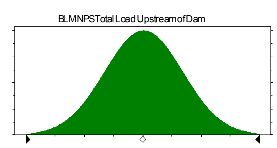
Mean	22.41
Standard Dev.	1.44



Bellamy NPS Load Upstream of Dam (tons N/yr)

Normal distribution with parameters:

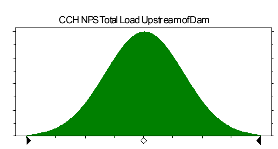
Mean	24.20
Standard Dev.	2.45



Cocheco NPS Load Upstream of Dam (tons N/yr)

Normal distribution with parameters:

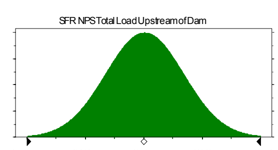
Mean	246.56
Standard Dev.	18.62



Salmon Falls River NPS Load Upstream of Dam (tons N/yr)

Normal distribution with parameters:

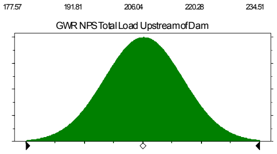
Mean	206.04
Standard Dev.	9.49



Great Works NPS Load Upstream of Dam (tons N/yr)

Normal distribution with parameters:

Mean	71.51
Standard Dev.	12.24



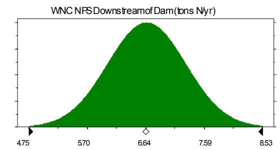
Non-Point Source Nitrogen Load Upstream of Dams

Explanation: Nitrogen loads in drainage areas downstream of tidal dams were estimated using a regression of land use versus non-point source nitrogen yields was used. The standard error of this regression multiplied by the drainage area was used as the standard deviation for the estimate for each of the drainage areas.

Winnicut NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

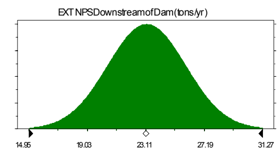
Mean	6.64
Standard Dev.	0.63



Exeter NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

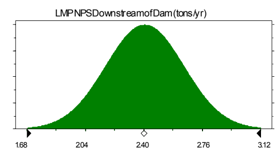
Mean	23.11
Standard Dev.	2.72



Lamprey NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

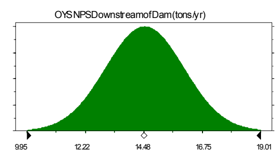
Mean	2.40
Standard Dev.	0.24



Oyster NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

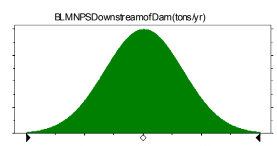
Mean	14.48
Standard Dev.	1.51



Bellamy NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

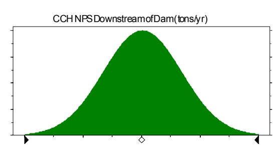
Mean	10.08
Standard Dev.	0.82



Cocheco NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

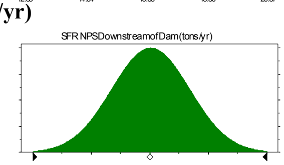
Mean	16.85
Standard Dev.	1.34



Salmon Falls River NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

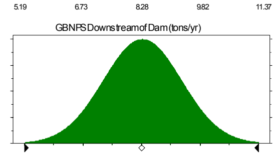
Mean	8.28
Standard Dev.	1.03



Great Bay NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

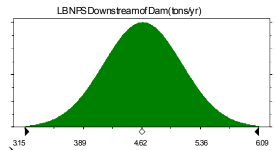
Mean	18.71
Standard Dev.	2.20



Little Bay NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

Mean	4.62
Standard Dev.	0.49



Upper Piscataqua NPS Load Downstream of Dam (tons N/yr)

Normal distribution with parameters:

Mean	12.19
Standard Dev.	1.63

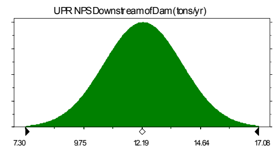


Table 2: Uncertainty in Existing Watershed Nitrogen Loads as Determined from Monte Carlo Simulations

Subestuary	5th %ile of Simulated Threshold	Median of Simulated Threshold	95th %ile of Simulated Threshold	CI (max)	CI (%)
Winnicut River	22.19	25.11	28.20	3.09	12.3%
Exeter/Squamscott River	133.00	147.56	161.26	14.56	9.9%
Lamprey River	185.03	204.87	223.98	19.84	9.7%
Oyster River	46.65	50.56	54.17	3.91	7.7%
Bellamy River	33.04	37.53	41.90	4.50	12.0%
Cocheco River	236.14	265.18	295.39	30.21	11.4%
Salmon Falls River	267.75	295.41	319.07	27.66	9.4%
Great Bay	390.64	414.88	440.37	25.49	6.1%
Little Bay	505.90	531.65	557.78	26.13	4.9%
Upper Piscataqua River	629.75	674.82	717.25	45.07	6.7%

Units: tons of nitrogen per year
CI = Confidence interval. The CI was calculated as the difference between the 5^{th} percentile or the 95^{th} percentile and the median. The value shown is the larger of the two differences. The CI expressed as a percent was calculated by dividing the CI (in tons/year) by the median value.

Table 3: Uncertainty in Watershed Nitrogen Loading Thresholds to Meet the Nutrient Criteria to Support Eelgrass as Determined from Monte Carlo Simulations

Subestuary	5th %ile of Simulated Threshold	Median of Simulated Threshold	95th %ile of Simulated Threshold	CI (max)	CI (%)
Winnicut River	9.83	10.53	11.47	0.95	9.0%
Exeter/Squamscott River	58.51	62.05	65.97	3.92	6.3%
Lamprey River	103.04	111.06	124.43	13.37	12.0%
Oyster River	18.63	20.94	24.17	3.22	15.4%
Bellamy River	20.60	24.55	29.94	5.40	22.0%
Cocheco River	86.48	91.93	98.96	7.03	7.7%
Salmon Falls River	150.94	166.17	183.36	17.19	10.3%
Great Bay	270.45	331.72	433.41	101.68	30.7%
Little Bay	365.05	452.09	589.49	137.40	30.4%
Upper Piscataqua	313.59	365.81	455.28	89.47	24.5%

Units: tons of nitrogen per year
CI = Confidence interval. The CI was calculated as the difference between the 5th percentile or the 95th percentile and the median. The value shown is the larger of the two differences. The CI expressed as a percent was calculated by dividing the CI (in tons/year) by the median value.

Table 4: Uncertainty in Watershed Nitrogen Loading Thresholds to Meet the Nutrient Criteria to Prevent Low Dissolved Oxygen as Determined from Monte Carlo Simulations

Subestuary	5th %ile of Simulated Threshold	Median of Simulated Threshold	95th %ile of Simulated Threshold	CI (max)	CI (%)
Winnicut River	16.40	17.88	19.53	1.64	9.2%
Exeter/Squamscott River	92.80	99.83	107.43	7.60	7.6%
Lamprey River	166.85	185.84	212.90	27.06	14.6%
Oyster River	34.86	39.12	44.58	5.45	13.9%
Bellamy River	40.02	47.45	57.95	10.50	22.1%
Cocheco River	137.94	148.89	162.30	13.40	9.0%
Salmon Falls River	242.52	271.04	305.45	34.42	12.7%
Great Bay	531.91	662.45	873.05	210.60	31.8%
Little Bay	761.50	933.35	1201.82	268.48	28.8%
Upper Piscataqua River	573.83	686.29	863.05	176.77	25.8%

Units: tons of nitrogen per year
CI = Confidence interval. The CI was calculated as the difference between the 5th percentile or the 95th percentile and the median. The value shown is the larger of the two differences. The CI expressed as a percent was calculated by dividing the CI (in tons/year) by the median value.

Table 5: Comparison of Measured and Predicted Nitrogen Concentrations, 2003-2004

Winnicut River Subestuary

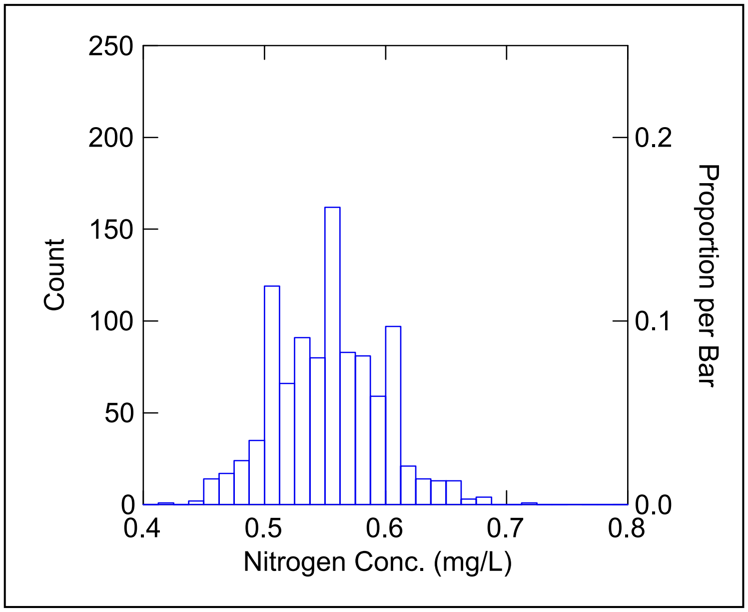
Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.48	NA
Median	0.55	NA
95th %ile	0.62	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median



Exeter River Subestuary

Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.52	NA
Median	0.58	0.74
95th %ile	0.65	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median

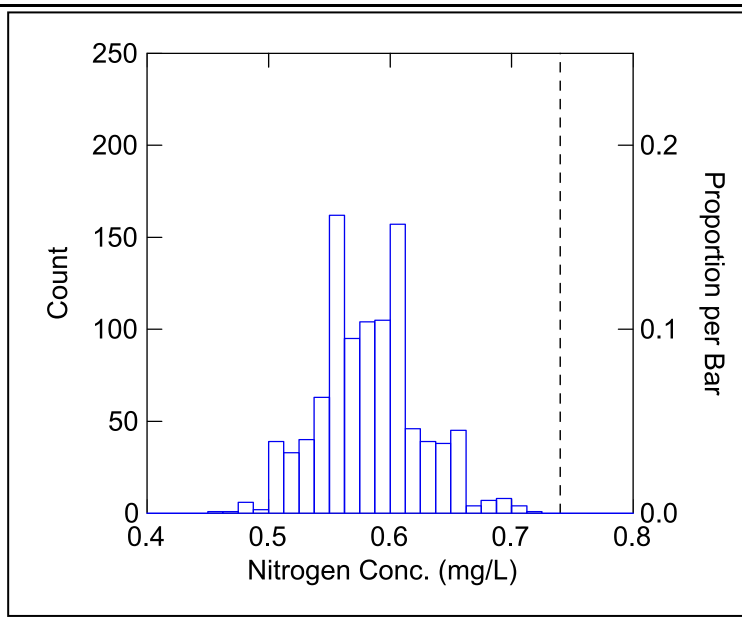


Table 5: Continued

Lamprey River Subestuary

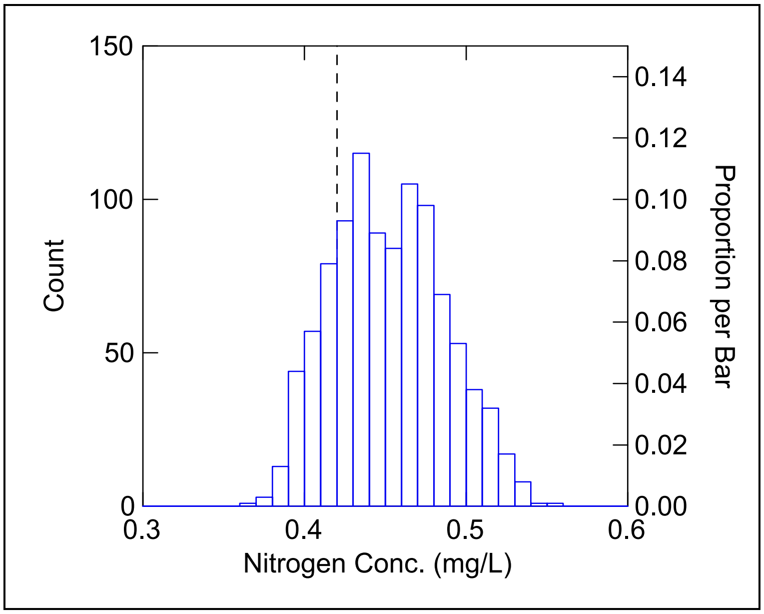
Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.39	NA
Median	0.45	0.42
95th %ile	0.50	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median



Oyster River Subestuary

Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.45	NA
Median	0.50	0.47
95th %ile	0.56	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median

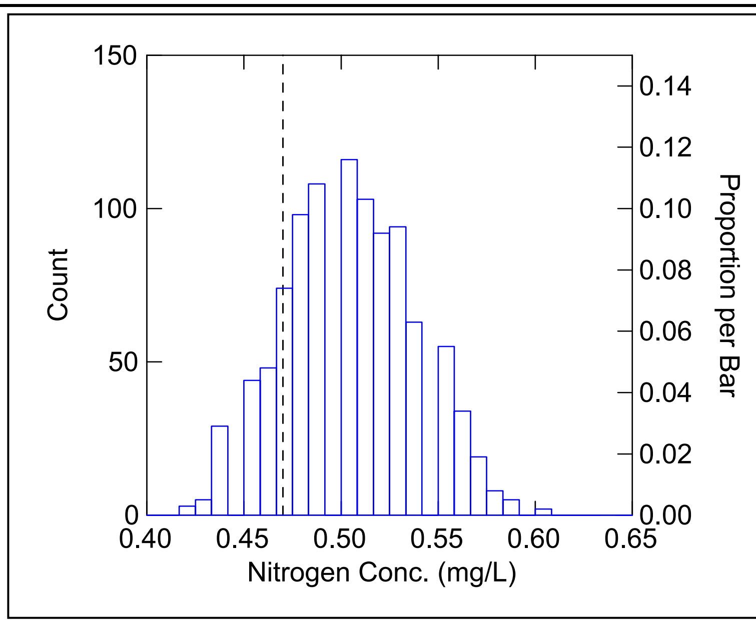


Table 5: Continued

Bellamy River Subestuary

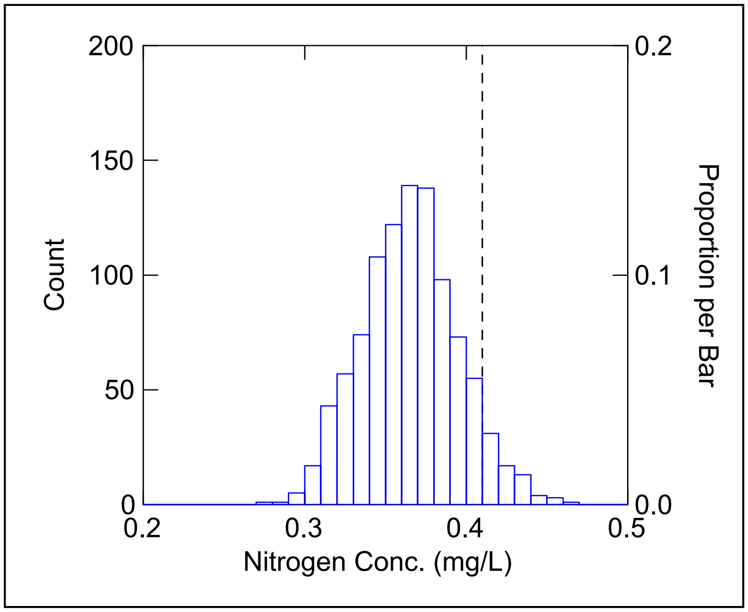
Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.31	NA
Median	0.36	0.41
95th %ile	0.41	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median



Cocheco River Subestuary

Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.60	NA
Median	0.69	0.76
95th %ile	0.78	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median

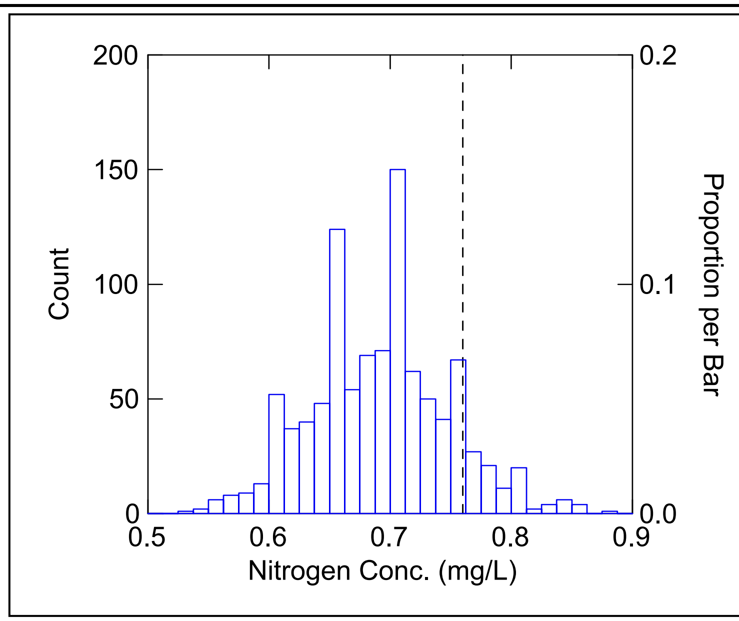


Table 5: Continued

Salmon Falls River Subestuary

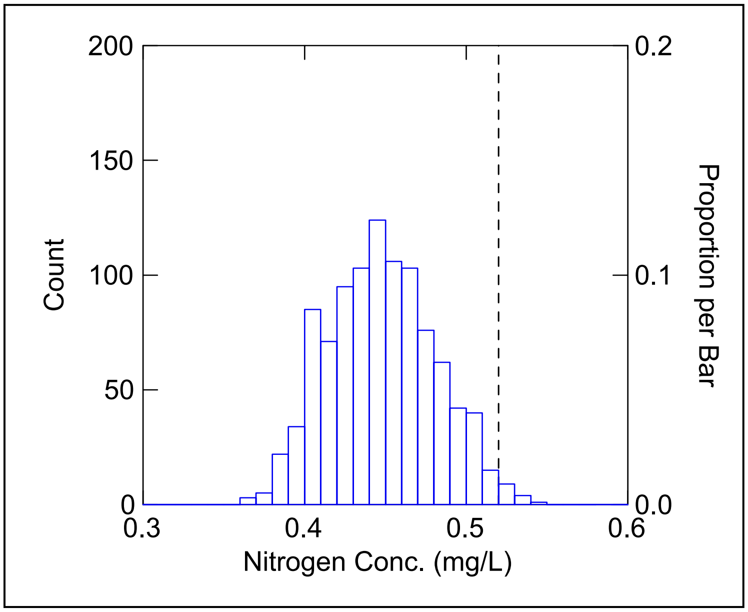
Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.39	NA
Median	0.44	0.52
95th %ile	0.50	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median



Great Bay Subestuary

Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.28	NA
Median	0.32	0.43
95th %ile	0.36	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median

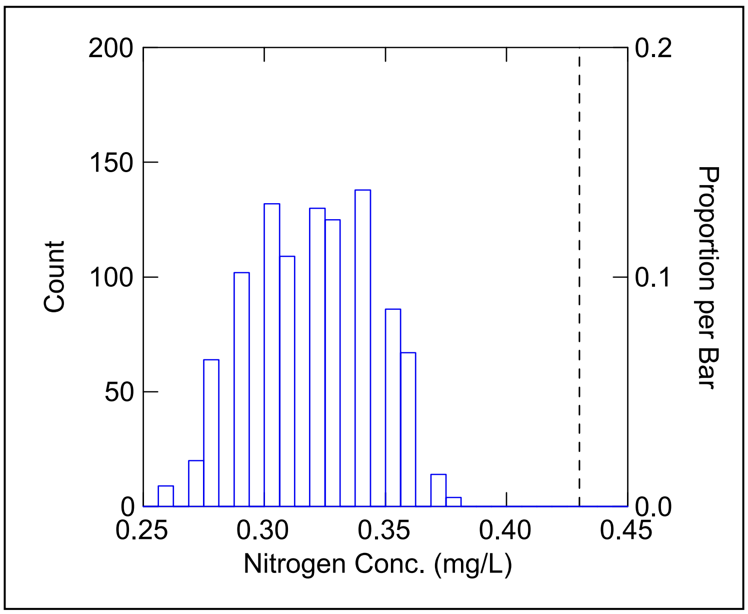


Table 5: Continued

Little Bay Subestuary

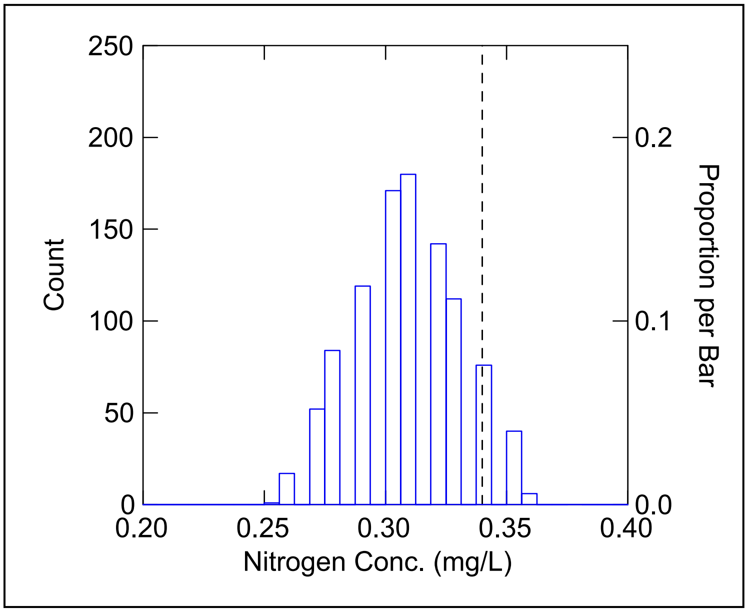
Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.27	NA
Median	0.31	0.34
95th %ile	0.34	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median



Upper Piscataqua Subestuary

Median TN Concentrations (mg/L)

	Predicted (bars)	Measured (dashed line)
5th %ile	0.35	NA
Median	0.41	0.51
95th %ile	0.47	NA

Key for graph:

Bars = Histogram of predicted values

Dashed line = Measured median

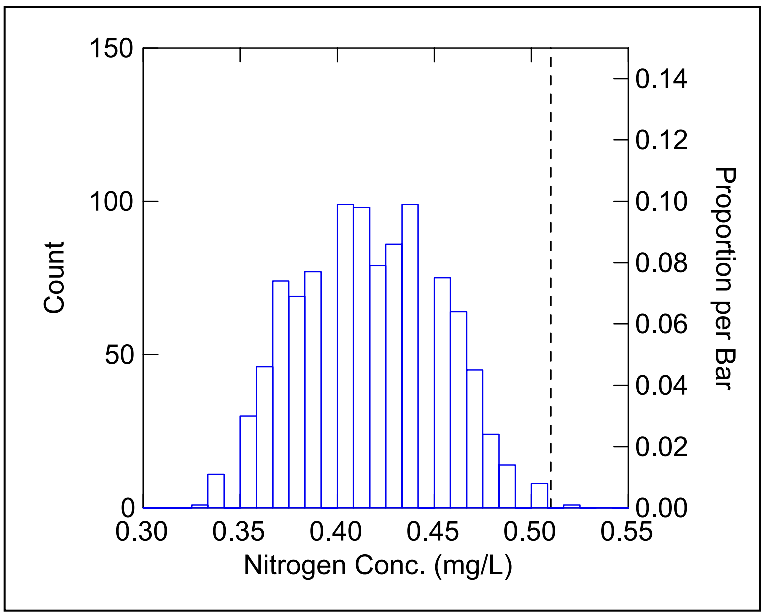


Table 6: Rank Correlation Coefficient Between Input Variables and Predicted Nitrogen Load Thresholds for Each Subestuary from Monte Carl Simulations.

Variable	Winnicut	Exeter	Lamprey	Oyster	Bellamy	Cocheco	Salmon Falls	Great Bay	Little Bay	Upper Piscataqua
Nitrogen at seaward boundary (mg N/L)	-0.62	-0.42	-0.45	-0.69	-0.61	-0.40	-0.32	-0.49	-0.60	-0.49
CFSM for Bellamy between gage and dam					0.42					
CFSM for Cocheco between gage and dam						0.56				
CFSM for Exeter between gage and dam		0.54								
CFSM for Lamprey between gage and dam			0.15							
CFSM for Salmon Falls between gage and dam							0.76			0.25
Streamflow at the Cocheco gage corrected						0.14				
Winnicut salinity (ppt)	0.78									
Exeter salinity (ppt)		0.74								
Lamprey salinity (ppt)			0.90							
Oyster salinity (ppt)				0.65						
Bellamy salinity (ppt)					0.68					
Cocheco salinity (ppt)						0.68				
Salmon Falls salinity (ppt)							0.53			
Great Bay salinity (ppt)								0.84		
Little Bay salinity (ppt)									0.80	
Upper Piscataqua salinity (ppt)										0.83

This table only contains variables with rank correlation coefficients greater than or equal to 0.1 (absolute value).

Figure 1: Effect of 20% Increase in Numeric Nutrient Criteria on Watershed Nitrogen Load Thresholds at Different Salinities