Indicator: Nutrient loading to the Great Bay Estuary

Question
How much nitrogen is coming into the Great Bay Estuary?

(Currently, the only nutrient being quantified with regard to loading is nitrogen, although phosphorus may be added in the future. Therefore, this indicator may also be referred to as "nitrogen loading.")

Answer
Total nitrogen loading from 2012 to 2016 was 903 tons per year, which is 26% percent lower than the 2009 to 2011 levels (1224 tons per year). Low rainfall and corresponding stream flow during this period as well as significant reductions in nitrogen loading at municipal wastewater treatment facilities are the primary reasons for this decrease. Since the human population and impervious cover continue to increase, nitrogen management remains a high priority.

PREP Goal
Reduce nutrient loads to the estuaries and the ocean so that adverse, nutrient-related effects do not occur (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

Why This Matters
Nitrogen is one of many nutrients that are essential to life in the estuaries. However, high levels of nitrogen may cause problems like excessive growth of seaweed and phytoplankton. When these organisms die, bacteria and other decomposers use the available oxygen to break down the organic matter, decreasing oxygen availability for other organisms like fish. In addition, excessive algal growth can have negative impacts on sediment quality, seagrass, shellfish and benthic invertebrates.

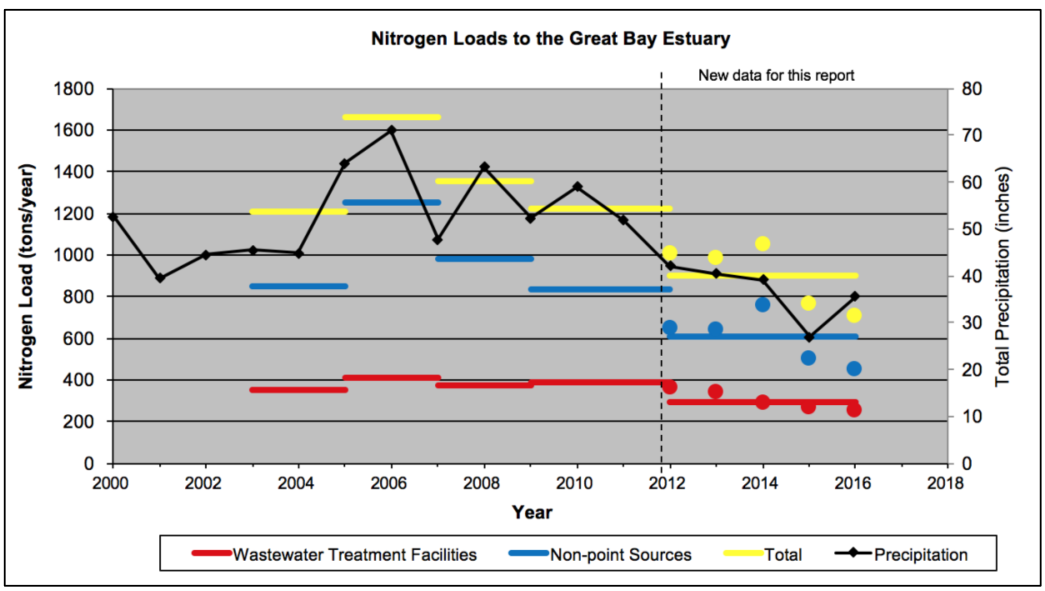


Figure NL-1. Nitrogen loads to the Great Bay Estuary. Precipitation data (indicated by the black line) are averaged between Portsmouth (Pease) and Greenland weather stations. Colored circles indicate annualized loads for 2012 through 2016. Data Source: NH Water Resources Research Center. Load estimates from 2003 - 2011 from NHDES (2010).

Explanation (from the 2018 State of Our Estuaries Report)
The average annual load of total nitrogen into the Great Bay Estuary from 2012 to 2016 was 903.1 tons per year (Figure NL-1). In 2016, the total nitrogen load was 707.8 tons per year, the lowest since consistent monitoring of loads began in 2003. Before 2003, there were three studies that assessed nitrogen loading to the Great Bay Estuary; they relied on data collected between 1987 and 1996

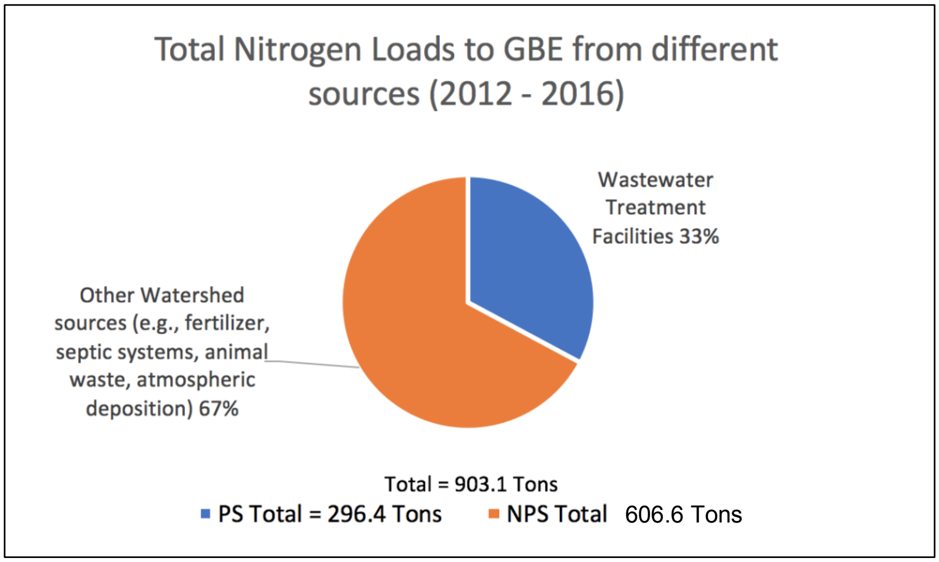


Figure NL-2. Total Nitrogen Loads from different sources (2012 to 2016). Data Source: NH Water Resources Research Center, UNH.

(NOAA/EPA 1988; Jones et al. 1992; Jones 2000) and estimated nutrient loading at approximately 715 tons per year. These three studies all used different methods from each other and from the current approach, but yielded very similar results (NOAA/EPA 1988; Jones et al., 1992; Jones 2000).

Figure NL-1 indicates that, since 2003, most of the variability relates to nitrogen from non-point sources. Non-point source nitrogen enters our estuaries in two major ways: 1) from stormwater runoff, which carries nitrogen from atmospheric deposition (including mobile transportation sources – cars, trucks, trains; and stationary stack emissions – smoke stacks), fertilizers, and animal waste to the estuaries; and 2) from groundwater contribution, which carries nitrogen from septic systems, sewer leakage and infiltrated stormwater runoff into streams, rivers and the estuary itself (NH DES 2014; Roseen et al. 2015). These non-point sources (NPS) accounted for 606.6 tons per year or 67% of the nitrogen load for 2012 – 2016 (Figure NL-2). It is important to understand that NPS loads are much more difficult to manage than point source loads because they come from a variety of sources, many of which are controlled by private land owners.

In addition, there are 17 municipal wastewater treatment facilities (WWTFs) that discharge treated wastewater into the bay or into rivers that flow into the bay. Point sources of nitrogen from these WWTFs account for 296.4 tons per year or 33% of the total nitrogen load for 2012-2016 (Figure NL-2). Of the 903.1 tons of total nitrogen entering the bay annually from 2012-2016, 506.0 tons were dissolved inorganic nitrogen (DIN), which is the most biologically available form of nitrogen. The DIN load was approximately evenly split between point and non-point sources (Figure NL-3). However, during the summer months when plant and algae growth is highest, point sources from WWTFs dominate DIN loading (Jones 2000; PREP 2012).

The highest loads since 2003 were seen in the 2005 to 2007 period (1,662.4 tons per year), a time that coincides with the highest total annual precipitation values (Figure NL-1). In comparison, the 2012 to 2016 period exhibited lower rainfall (Figure NL-1), a contributing factor to the 27% decrease in NPS loading since the 2009 – 2011 period. This underscores the association between nitrogen loading and run-off. Precipitation records (NH Climate Office 2014) and forecasts (Hayhoe et al. 2007) suggest that our region will continue to see periods of extreme highs and lows, which will continue to impact non-point source load.

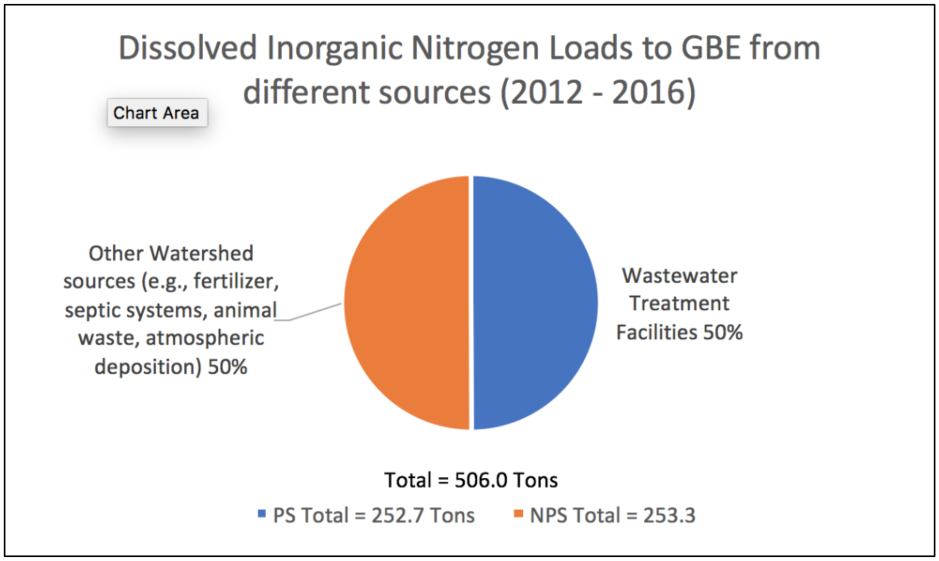


Figure NL-3. Dissolved Inorganic Nitrogen Loads from different sources (2012 to 2016). Data Source: NH Water Resources Research Center, UNH.

The nitrogen load from WWTFs for 2012 – 2016 was 296.4 tons, a decrease of 24% since the 2009 – 2011 period. In 2015 and 2016, the nitrogen load from WWTFs was 264.3 and 256.2 tons per year, respectively (Figure NL-1). Municipalities have made recent, substantial improvements to their WWTFs to reduce the amount of total nitrogen they discharge. Rochester, Dover, and Newmarket have recently completed major upgrades; Durham has reconfigured its facility and Portsmouth, Newington, and Exeter are in the process of upgrading their treatment plants. Each of these upgrades should result in less nutrients in wastewater effluent.

See the "*Estuary Health: Stress & Resilience*" section of the 2018 State of Our Estuaries Report (PREP 2017b) for more on how nitrogen loading relates to other indicators, such as phytoplankton, seaweed and eelgrass.

<u>Methods and Data Sources</u>

For the purposes of this analysis, the following sources were identified that contribute to the nitrogen load to the Great Bay Estuary (Figure NL-5). It is assumed that these represent a complete accounting of contributing sources.

- Municipal Wastewater Treatment Facilities (WWTFs)
- Non-Point Sources (NPS) in Watersheds
- Groundwater Discharge to the Estuary
- Atmospheric Deposition to the Estuary

Nitrogen loads were calculated for the portion of the Great Bay Estuary system north and west of Dover Point (Great Bay, Little Bay, and the Upper Piscataqua River – the "study area"). A complete analysis of nitrogen loads to the Lower Piscataqua River was not completed, although the delivered loads from WWTFs in the Lower Piscataqua River were included in the calculations. The methods for the nitrogen loading calculations follow the procedures in NHDES (2010, Appendix A). Brief summaries of the methods and any deviations from the procedures are described below.

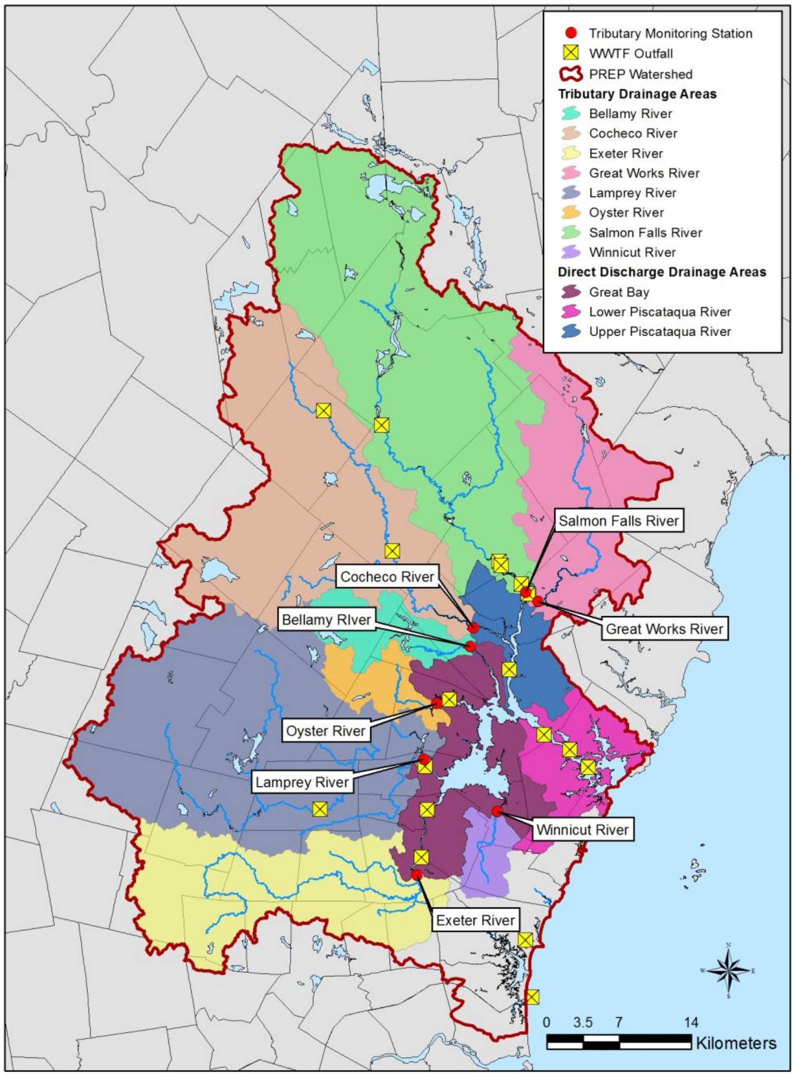


Figure NL-4. Watersheds draining to the Great Bay Estuary. Wastewater treatment plant facilities indicated with yellow markers.

Point Source Discharges from WWTFs

The annual and overall average TN and DIN load from each WWTF for 2012-2016 was estimated by multiplying the average concentration by the average effluent flow over the time period of interest (Table NL-2; Figure NL-7). If nitrogen data were not available for a WWTF, then the average TN and DIN concentrations from monitored WWTFs were compiled from facility operating reports and then averaged over the time period of interest. For WWTFs with intermittent discharges, the monthly average flow was calculated from the total volume of effluent discharged in the month, divided by the number of days in the month.

For WWTFs that discharge to rivers upstream of the estuary, some of the nitrogen discharged from the WWTF is lost during transit to the estuary. For WWTFs that discharge to the Lower Piscataqua River, some of the nitrogen discharged from the WWTF does not reach as far upstream as Dover Point due to the limits of the tidal water movement. For these WWTFs, the nitrogen load should be reported in terms of its “delivered load” to the Great Bay Estuary study area. The delivered load was calculated by multiplying the discharged load by a “delivery factor,” which represents the percent of the discharged load that is delivered to the study area (Table NL-2; Figure NL-8). The delivery factors for discharges to freshwater rivers were calculated based on travel time to the estuary following the methods of NHDES (2010). The delivery factors for WWTFs that discharge to the Lower Piscataqua River were calculated from particle tracking models used in NHDES (2010) or more recent models provided by Portsmouth and Kittery (ASA 2011a, ASA 2011b).

Non-Point Sources in Major Watersheds

The TN and DIN loads to the estuary from the eight major watersheds were calculated using measurements of TN and DIN concentrations and stream flow (Table NL-4). The U.S. Geological Survey (USGS) LOADEST model was used to develop a calibrated model relating TN and DIN concentrations and daily average stream flow (Runkel et al. 2004). The LOADEST model was set to select the optimal model based on the calibration dataset (Table NL-3) and all the parameters in the chosen model were included. The inputs to the LOADEST model were monthly measurements of TN and DIN concentrations and daily average stream flow at the tidal dam for each river. For TN and DIN concentrations, non-detected samples were represented by one-half of the reporting detection limit. Stream flow at the tidal dams was estimated from USGS stream gages in the watersheds and drainage area transposition factors (Table NL-1). The output of the LOADEST model was both the average load for the study period and the monthly loads during the study period. Monthly loads were summed to determine the annual loads during

Table NL-1: USGS stream gages and drainage area transposition factors for estimating stream flow at the tributary monitoring stations.

Tributary Monitoring Station	Watershed Area for Station (sq miles)	USGS Streamgage Number	Flow Multiplier for Transpositions	USGS Watershed Area for Stream Gage (sq miles)
Bellamy River[1]	27.26	Cocheco 01072800	0.341227	79.9
		Oyster 01073000	2.253228	12.1
Cocheco River	175.28	Cocheco 01072800	2.193704	79.9
Exeter River	106.90	Exeter 01073587	1.683529	63.5
Great Works River	86.69	Cocheco 01072800	1.085013	79.9
Lamprey River	211.91	Lamprey 01073500	1.145435	185
Oyster River	19.85	Oyster 01073000	1.640625	12.1
Salmon Falls River	235.00	Lamprey 01073500	1.270258	185
Winnicut River	14.18	Winnicut 1073785	1.005443	14.1

1. Flow in the Bellamy River was estimated by averaging cubic feet per square mile (cfsm) transpositions from the Cocheco and Oyster River gages.

the 2012-2016 time period. The NPS delivered load from watersheds was calculated by subtracting the delivered nitrogen load due to upstream WWTFs from the total measured load at each of the tidal dams (Table NL-4).

Non-Point Sources from Small Watersheds Adjacent to the Estuary

Runoff from land adjacent to the estuary was not captured in the load measurements at the tidal dams. Therefore, TN and DIN loads from these areas had to be estimated. Using the data from the major watersheds, relationships were developed between the percent of developed land and the TN and DIN yields (load per unit drainage area) after correcting for upstream WWTF discharges. The NPS loads from the small adjacent watersheds were estimated using the percent of developed land in the watershed and the corresponding regression equations (Figure NL-5). The regressions were developed for a range of land use from 9.6 to 27.5% developed. These small adjacent watersheds typically were more developed than this range (14.6 to 42.6%). Therefore, the use of these regressions is an extrapolation of a linear model outside the calibration range. For annual loading estimates from land adjacent to the estuary, annual NPS loading from the major watersheds was used in regression equations with % developed land use.

Groundwater Discharge

Some groundwater flow and nitrogen loading was accounted for in the NPS loading estimates for watersheds. However, regional groundwater flow was also expected to contribute some nitrogen to the estuaries. Ballestero et al. (2004) measured the nitrogen loading rate from groundwater seeps to be 0.13 tons N/yr per mile of tidal shoreline. This loading rate was applied to the length of tidal shoreline in the estuary to estimate the groundwater loading rate. The groundwater loading rate was assumed to be constant because no other information was available. All of the nitrogen contributed by this source was assumed to be in the DIN form (Table NL-5; Figure NL-7).

Atmospheric Deposition

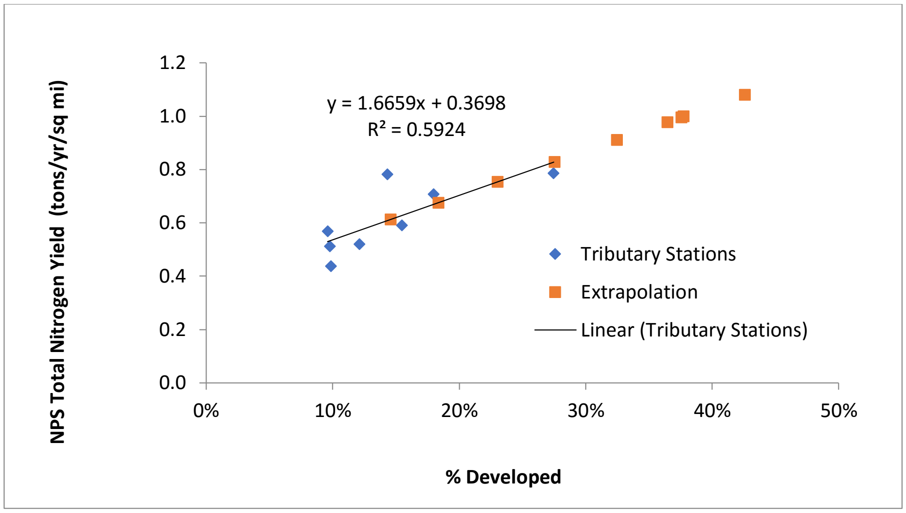
Atmospheric deposition of nitrogen directly to the estuary surface was estimated using wet deposition data provided by the University of New Hampshire Water Quality Analysis Laboratory (UNH WQAL). The UNH WQAL collected wet deposition (rain and snow) on a weekly basis at Thompson Farm (TF) in Durham, NH and analyzed the samples for total dissolved nitrogen (TDN) and DIN. Particulate nitrogen was assumed to be negligible in the wet deposition samples and therefore TDN in wet deposition was assumed to equal wet deposition TN. Volume weighted mean concentrations of TN and DIN in TF wet deposition were determined for the time period of interest and multiplied by the rainfall amount as recorded by the climate reference network (CRN) at TF (CRN station NH_Durham_2_SSW) over the same time period to determine wet deposition. Dry deposition was estimated as 58% of wet TN deposition (ClimCalc ratio of 0.58 dry to wet deposition for TF, Ollinger et al. 2001). Wet and dry deposition were summed to determine the total deposition of TN and inorganic N. For 2012-2016, this resulted in a wet deposition rate of 1.01 tons TN/sq mi/yr, a dry deposition rate of 0.60 tons TN/sq mi/yr and a total deposition rate of 1.63 tons TN/sq mi /yr. This loading rate was assumed to be constant over the 13.6 sq mi estuary resulting in 22.13 tons of TN load to the estuary per year. Atmospheric deposition of nitrogen to the land surface is accounted for in the NPS load contribution from the tributary watersheds and the land areas adjacent to the estuary. For annual estimates of deposition see Table NL-5.

Nitrogen Load Summary

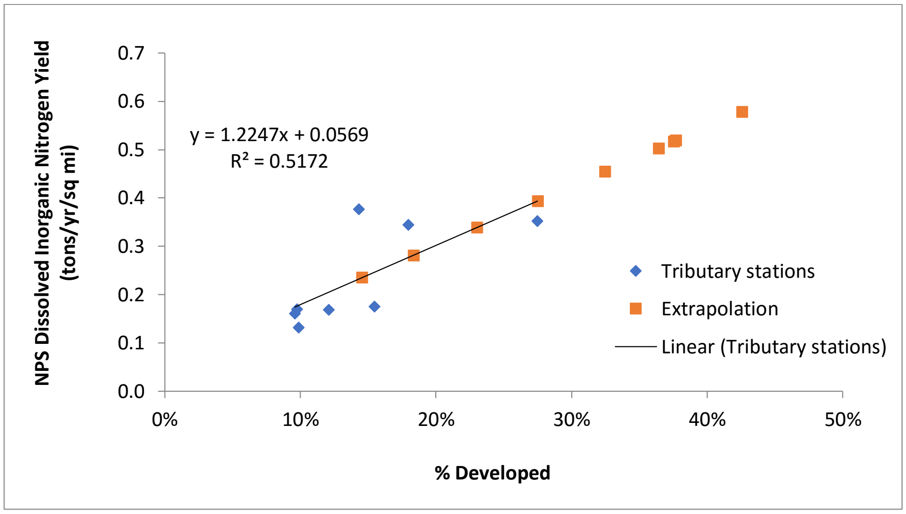
The 2012-2016 and annual TN and DIN loads were calculated by summing the individual components of the nitrogen load: Delivered WWTF loads, NPS loads from watersheds above the tidal dams, NPS loads from the land area below the tidal dams, groundwater loads, and atmospheric deposition to the estuary (Table NL-5). Subtotals for WWTFs and NPS were also calculated.

Figure NL-5. Relationship between non-point source nitrogen yields (2012-2016) and developed land use in major watersheds and extrapolations to small watersheds downstream of dams.

(A) Total Nitrogen



(B) Dissolved Inorganic Nitrogen



Data Sources
For the nitrogen load from WWTFs, flow data were obtained from monthly operating reports filed by the WWTFs. Nitrogen concentrations in WWTF effluent were obtained from the WWTFs and NHEP (2008).

The loading from the tidal tributaries was estimated from monthly (March-December) nutrient concentrations collected by the PREP Tidal Tributary Monitoring Program at the head of tide stations on the Winnicut, Exeter, Lamprey, Oyster, Bellamy, Cocheco, Salmon Falls and Great Works Rivers. Flow data for the Winnicut, Exeter, Lamprey, Oyster and Cocheco Rivers were obtained from the USGS Streamflow Monitoring Program.

Additional Results (Beyond What Was Reported in the SOOE)

The TN and DIN loads from the 17 WWTFs in the Great Bay Estuary watershed are shown in Table NL-2. The WWTF with the largest delivered nitrogen load was Dover followed by Rochester and Exeter. These three WWTFs accounted for 61% of the nitrogen delivered to the estuary by all WWTFs combined. Following these three WWTFs, Newmarket, Portsmouth, Durham and Somersworth have the highest delivered nitrogen loads. From 2012 to 2016, total nitrogen and DIN from WWTFs upstream of dams decreased by over 50% and 60%, respectively (Table NL-5).

The TN and DIN loads from the eight major tributaries are shown in Table NL-4 and Figure NL-8. The Cocheco, Salmon Falls and Lamprey River watersheds delivered the most NPS total nitrogen, but this is in part due to watershed size and the extent to which the watershed is developed. For example, the Salmon Falls watershed has the third highest delivery of total nitrogen, but it has the lowest level of "area-normalized" total nitrogen loading; at 235 sq mi, it is the largest watershed, and less than 10% of the watershed is developed (Table NL-4). On an area-normalized basis, the Winnicut, Cocheco and Oyster watersheds deliver the most total nitrogen to the estuary.

Technical Advisory Committee (TAC) Discussion Highlights
The Relationship Between Nitrogen Loading and Eelgrass Habitat Health
This topic was the focus of two consecutive TAC meetings on May 9-10, 2017; notes and presentations are available (PREP 2017). No votes were taken after the discussion but participants were asked to fill out a "matrix," which rated the probability of different stressors exerting negative pressure on eelgrass health. Figure NL-6 indicates that, of the 26 participants at the meeting, 22 rated nitrogen as a 3 or higher (on a scale of 1 to 5, 5 being highest) in terms of the probability that nitrogen is an important stressor on eelgrass habitat health in the Great Bay Estuary; four participants rated nitrogen lower than "2" as a stressor on eelgrass in the Great Bay Estuary.

One of the concerns about nitrogen is that it can fuel excessive blooms of phytoplankton and seaweeds (see individual "Phytoplankton" and "Seaweed" sections in this report.) At the May 9-10, 2017 meeting, the three external advisors to the TAC advocated that all light-attenuating components (e.g., seaweeds, TSS, colored dissolved organic matter (CDOM) and phytoplankton) be considered together, not separately, because these components act in an additive fashion.

Another concern about nitrogen is that it can lead to degraded sediment quality, which has impacts for eelgrass as well as benthic invertebrates such as shellfish. For more on the relationship between nitrogen loading and overall ecosystem health and resilience, see the "Stress and Resilience" section of the State of Our Estuaries Report (PREP 2017b) and the "External Advisors Statement Regarding Eelgrass Stressors in Great Bay Estuary" (Kenworthy et al. 2017).

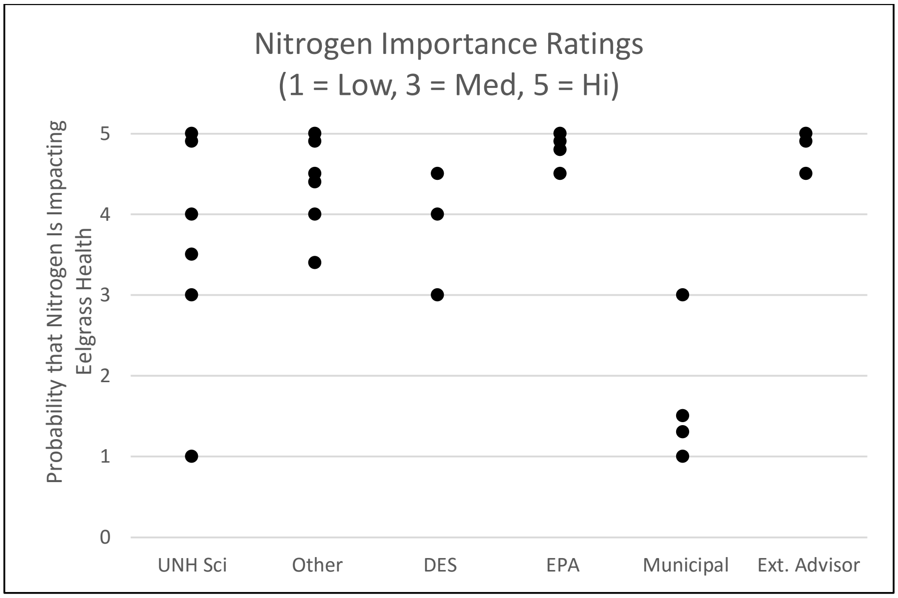


Figure NL-6. Results of "matrix" activity asking participants to rate the importance of nitrogen as a stressor on eelgrass. Results are categorized by segments of the community, from left to right: UNH Scientists, Other (e.g., non-profit organizations), NH DES, US EPA, Municipal Representatives, and External Advisors. Dots that are touching represent the same numeric rating, but are separated for visual clarity.

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Table NL-2: Estimated nitrogen loads from wastewater treatment facilities in 2012-2016

WWTF	Discharge Location (river)	Average Monthly Flow (mgd)	Data Source	Average TN (mg/L)	Average DIN (mg/L)	TN load (tons/yr)	DIN load (tons/yr)	Delivery Factor	Delivered TN load (tons/yr)	Delivered DIN load (tons/yr)
Rochester	Cocheco	3.0	City of Rochester Data	16.9	16.3	76.4	73.9	75.56%	57.7	55.9
Exeter	Exeter (tidal)	1.6	Town of Exeter Data for TN	22.6	19.0	55.5	46.6	100.00%	55.5	46.6
Newfields	Exeter (tidal)	0.1	2011 Town of Newfield Data for TN; 2002 data from Bolster et al. (2003) for DIN	21.5	19.0	2.9	2.6	100.00%	2.9	2.6
N Berwick	Great Works	0.2	Estimated	18.2	15.3	5.7	4.8	51.56%	2.9	2.5
Epping	Lamprey	0.2	Estimated	18.2	15.3	6.8	5.7	58.20%	4.0	3.3
Newmarket	Lamprey (tidal)	0.5	Town of Newmarket Data for TN	39.1	32.9	31.1	26.2	100.00%	31.1	26.2
Newington	Lower Piscataqua	0.1	Town of Newington Data	17.6	16.1	2.8	2.6	26.34%	0.8	0.7
Portsmouth	Lower Piscataqua	4.3	City of Portsmouth Data	30.0	21.7	194.9	141.0	12.50%	24.4	17.6
Kittery	Lower Piscataqua	0.9	NHEP 2008 and Kittery 2015 for TN	19.4	16.3	26.6	22.4	14.20%	3.8	3.2
Pease	Lower Piscataqua	0.6	2008 City of Portsmouth Data for TN	8.7	7.4	8.5	7.2	26.34%	2.2	1.9
Durham	Oyster (tidal)	0.9	Town of Durham Data	12.8	10.0	17.5	13.7	100.00%	17.5	13.7
Somersworth	Salmon Falls	1.4	City of Somersworth NH for TN Data	6.8	5.7	14.8	12.5	94.94%	14.1	11.8
Berwick	Salmon Falls	0.2	NHEP (2008) for TN Data	16.7	14.0	5.3	4.4	94.55%	5.0	4.2
Milton	Salmon Falls	0.1	Estimated	18.2	15.3	2.0	1.6	65.70%	1.3	1.1
Rollinsford	Salmon Falls	0.1	Estimated	18.2	15.3	2.1	1.8	98.96%	2.1	1.7
S Berwick	Salmon Falls (tidal)	0.3	2010 S Berwick Sewer District Data for TN; DIN Estimated using measured TN and DIN:TN at S Berwick in 2008	5.9	4.6	2.5	2.0	100.00%	2.5	2.0
Dover	Upper Piscataqua (tidal)	2.5	City of Dover Data	18.2	15.3	68.7	57.8	100.00%	68.7	57.8

1. Light grey cells: no data were available for this WWTF. For these WWTFs, TN was assumed to be the average TN concentration in monitored WWTFs (18.2 mg/L) and DIN was assumed based on the average TN and the average ratio of DIN to TN in monitored WWTFs (84.1%).
2. Dark grey cells: no DIN data were available and DIN was estimated as 84.1 % of TN for that WWTF.
3. The flows in this table are annual averages. The monthly average flows from NPDES discharge monitoring reports were averaged over the 60 months in the 5-year study period.
4. Delivery factor is the percent of the discharged load that is delivered to the GB/UPR estuary. For WWTFs in the watersheds, attenuation loss was estimated using the travel time for water between the WWTF outfall and the estuary and a first order loss coefficient. For the Lower Piscataqua River WWTFs, the delivery factor was estimated from the percent of particles in GB, LB, and Upper Piscataqua River at steady state in the Dartmouth particle tracking model (NHDES 2010) or particle tracking models provided by Portsmouth and Kittery (ASA 2011a, 2011b).
5. Italicized WWTFs are in Maine.

Table NL-3: LOADEST total nitrogen (TN) and Dissolved Inorganic Nitrogen (DIN) models for major tributaries in 2012-2016.

	LOADEST TN (tons/yr) Model			LOADEST DIN (tons/yr) Model		
Tributary	**R^2 (%)**	**PPCC**	**Model**	**R^2 (%)**	**PPCC**	**Model**
Bellamy	96.1	0.9921	1	86.4	0.9867	4
Cocheco	90.1	0.9839	9	83.1	0.9881	7
Exeter	99.0	0.9827	2	93.1	0.9822	6
Great Works	96.0	0.9892	2	89.2	0.9670	6
Lamprey	97.8	0.9934	3	91.4	0.9927	6
Oyster	98.2	0.9850	9	94.7	0.9667	9
Salmon Falls	97.2	0.9584	1	94.0	0.9874	8
Winnicut	98.8	0.9858	5	94.5	0.9936	9

1. TN loads estimated using USGS software "LOADEST" with water quality data from the PREP Tidal Tributary Monitoring Program and streamflow data from USGS.
2. R^2 is a measure of the quality of the loading regression model (0=worst, 1=best).
3. PPCC (probability plot correlation coefficient) is a measure of the normality of the residuals (0=worst, 1=best).
4. The model number refers to the specific model chosen. The models are defined in the LOADEST user's manual (Runkel et al. 2004).

Table NL-4: LOADEST, point (WWTFs) and non-point source nitrogen loads and yields from Great Bay Estuary watersheds 2012-2016.

Site	Area (mi^2)	TN Load (tons/yr)	DIN Load (tons/yr)	Area-Normalized TN Load (tons/yr/mi^2)	Area-Normalized DIN Load (tons/yr/mi^2)	Upstream WWTF Delivered TN (tons/yr)	Upstream WWTF Delivered DIN (tons/yr)	NPS TN Load (tons/yr)	NPS DIN Load (tons/yr)	Area-Normalized NPS TN Load (tons/yr/mi^2)	Area-Normalized NPS DIN Load (tons/yr/mi^2)	% Developed
Bellamy	27.26	16.10	4.79	0.59	0.18	0.00	0.00	16.10	4.79	0.59	0.18	15.46%
Cocheco	175.28	194.67	121.97	1.11	0.70	57.75	55.87	136.92	66.09	0.78	0.38	14.32%
Exeter	106.90	55.52	18.01	0.52	0.17	0.00	0.00	55.52	18.01	0.52	0.17	12.10%
Great Works	86.69	53.64	17.68	0.62	0.20	2.91	2.45	50.73	15.23	0.59	0.18	9.59%
Lamprey	211.91	112.51	39.39	0.53	0.19	3.97	3.34	108.55	36.05	0.51	0.17	9.77%
Oyster	19.85	14.05	6.84	0.71	0.34	0.00	0.00	14.05	6.84	0.71	0.34	17.98%
Salmon Falls	235.00	124.91	50.05	0.53	0.21	22.43	18.86	102.48	31.19	0.44	0.13	9.86%
Winnicut	14.18	11.13	5.00	0.79	0.35	0.00	0.00	11.13	5.00	0.79	0.35	27.48%
Total	**877**	**582.5**	**263.7**			**87.1**	**80.5**	**495.5**	**183.2**			

1. TN and DIN loads estimated using USGS software "LOADEST" with water quality data from the PREP Tidal Tributary Monitoring Program and streamflow data from USGS.
2. The following WWTFs are located upstream of the tributary monitoring stations. The Epping WWTF is upstream of the Lamprey River station. The Rochester and Farmington WWTFs are upstream of the Cocheco River station. The Milton, Berwick, Somersworth and Rollinsford WWTFs are upstream of the Salmon Falls River station. The North Berwick WWTF is upstream of the Great Works River station.
3. Upstream WWTF loads were reduced using an attenuation loss model to estimate the delivered load to the estuary.
4. Percent of watershed in developed land use classes are from the 2011 National Land Cover Dataset.

Table NL-5: Summary of nitrogen loads to the Great Bay Estuary from 2012-2016.

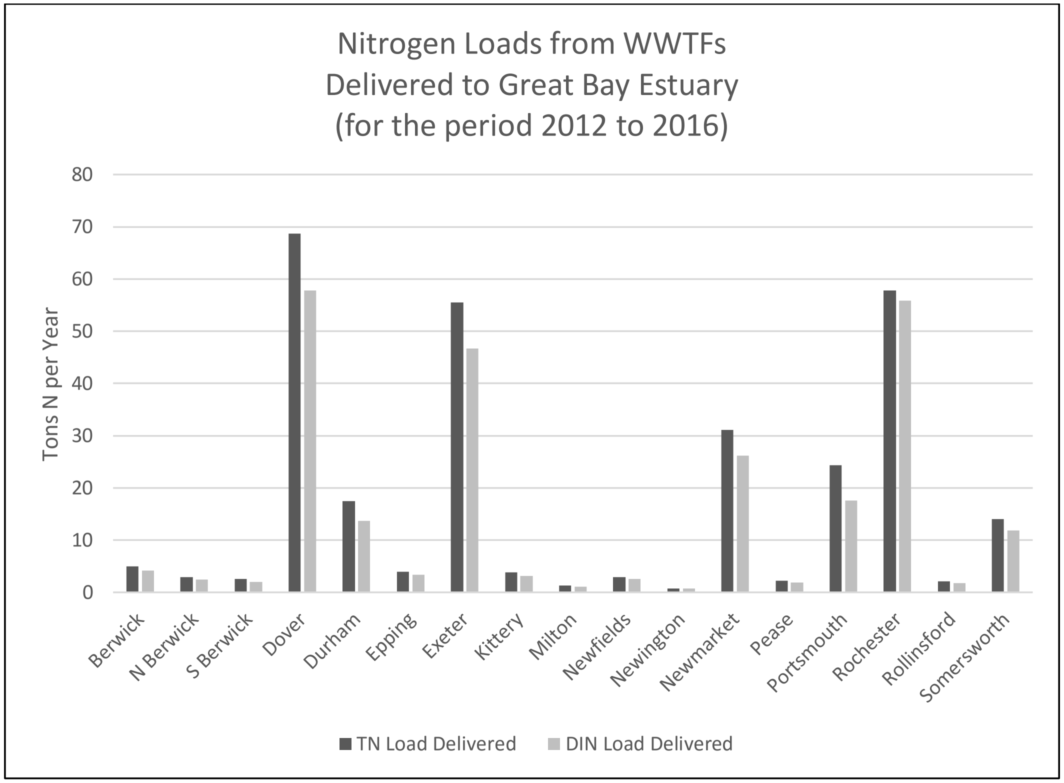
	2012-2016		2012		2013		2014		2015		2016	
Source	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**
WWTFs in Lower Piscataqua	31.1	23.4	33.1	25.5	34.0	22.8	26.7	21.3	27.0	21.7	35.3	25.6
WWTFs Downstream of Dam	178.2	148.8	177.7	150.4	174.3	148.3	208.9	174.3	176.8	149.8	151.7	120.8
WWTFs Upstream of Dam	87.1	80.5	153.2	154.6	133.0	127.1	53.3	44.8	60.5	52.6	69.2	61.9
NPS Upstream of Dam	495.5	183.2	535.1	162.4	528.7	172.9	628.9	249.6	394.8	158.8	355.8	133.9
NPS Downstream of Dam	74.51	35.36	74.5	35.4	71.6	28.3	94.3	46.4	67.3	36.3	63.8	39.5
NPS Groundwater	14.55	14.55	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
NPS Atmospheric Deposition to Tidal Waters	22.13	20.19	21.1	19.6	27.1	23.1	23.1	20.1	21.8	21.2	17.5	16.8
Subtotal - WWTF	**296.4**	**252.7**	364.0	330.4	341.3	298.2	288.9	240.4	264.3	224.1	256.2	208.3
Subtotal - Non-point sources	**606.6**	**253.3**	645.2	231.9	641.9	238.9	760.8	330.7	498.5	230.8	451.6	204.7
Total	**903.1**	**506.0**	1009.2	562.4	983.3	537.1	1049.7	571.1	762.8	455.0	707.8	413.1

1. WWTF = Wastewater Treatment Facility.
2. NPS = Non-Point Source.
3. Light grey highlighted values in 2012 – Regressions for TN and DIN NPS load vs. % developed for 2012 were not statistically significant. The average NPS downstream of dams for the entire 2012-2016 time period was used for 2012 instead.
4. Dark grey values in 2013 - Regressions for TN and DIN NPS load vs. % developed for 2013 approached significance ($p=0.060$, $R^2=0.47$ for both TN and DIN) and were used to estimate NPS load for 2013.
5. Dark grey value in 2014 - Regression for DIN NPS load vs. % developed for 2014 approached significance ($p=0.116$, R2=0.36) and was used to estimate NPS load for 2014. Other annual regressions for TN and DIN NPS load vs. % developed were significant at the $p<0.05$ level and model R^2 ranged from 0.69-0.86.

Table NL-6: Summary of nitrogen loads as percentages to the Great Bay Estuary from 2012-2016.

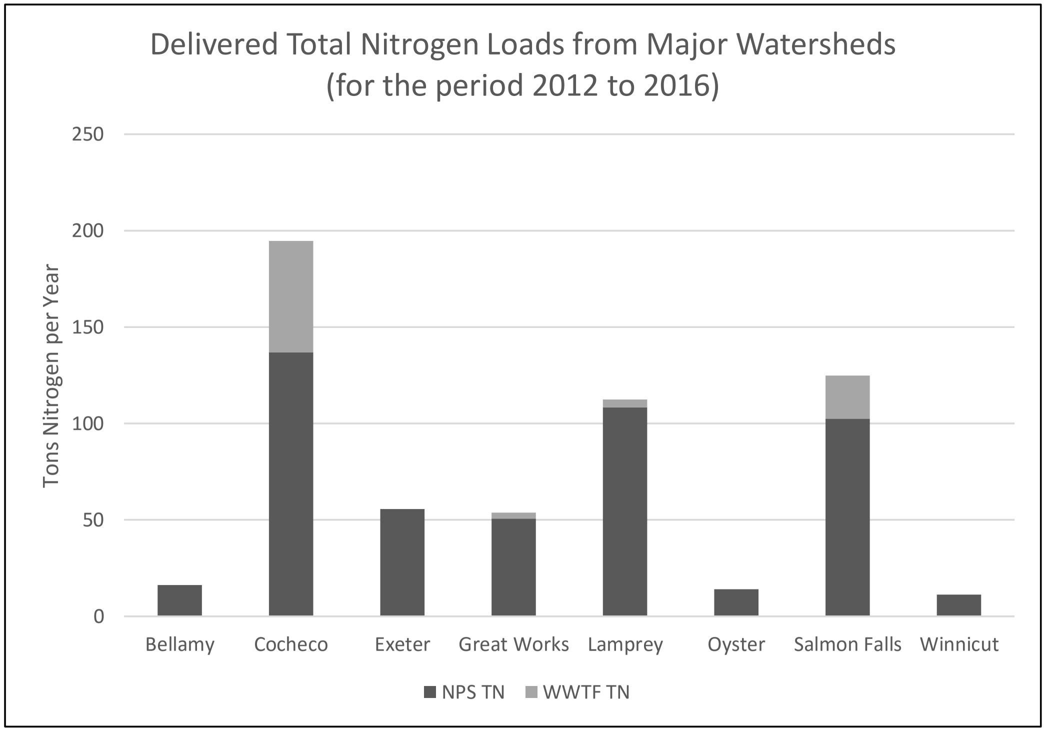
	2012-2016		2012		2013		2014		2015		2016	
Source	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**
WWTFs in Lower Piscataqua	3.4%	4.6%	3.3%	4.5%	3.5%	4.3%	2.5%	3.7%	3.5%	4.8%	5.0%	6.2%
WWTFs Downstream of Dam	19.7%	29.4%	17.6%	26.7%	17.7%	27.6%	19.9%	30.5%	23.2%	32.9%	21.4%	29.2%
WWTFs Upstream of Dam	9.6%	15.9%	15.2%	27.5%	13.5%	23.7%	5.1%	7.9%	7.9%	11.6%	9.8%	15.0%
NPS Upstream of Dam	54.9%	36.2%	53.0%	28.9%	53.8%	32.2%	59.9%	43.7%	51.8%	34.9%	50.3%	32.4%
NPS Downstream of Dam	8.3%	7.0%	7.4%	6.3%	7.3%	5.3%	9.0%	8.1%	8.8%	8.0%	9.0%	9.6%
NPS Groundwater	1.6%	2.9%	1.4%	2.6%	1.5%	2.7%	1.4%	2.5%	1.9%	3.2%	2.1%	3.5%
NPS Atmospheric Deposition to Tidal Waters	2.5%	4.0%	2.1%	3.5%	2.8%	4.3%	2.2%	3.5%	2.9%	4.7%	2.5%	4.1%
Subtotal - WWTF	**32.8%**	**49.9%**	**36.1%**	**58.8%**	**34.7%**	**55.5%**	**27.5%**	**42.1%**	**34.7%**	**49.3%**	**36.2%**	**50.4%**
Subtotal - Non-point sources	**67.2%**	**50.1%**	**63.9%**	**41.2%**	**65.3%**	**44.5%**	**72.5%**	**57.9%**	**65.3%**	**50.7%**	**63.8%**	**49.6%**

Figure NL-7: Estimated total nitrogen and dissolved inorganic nitrogen loads from wastewater treatment facilities in 2012-2016.



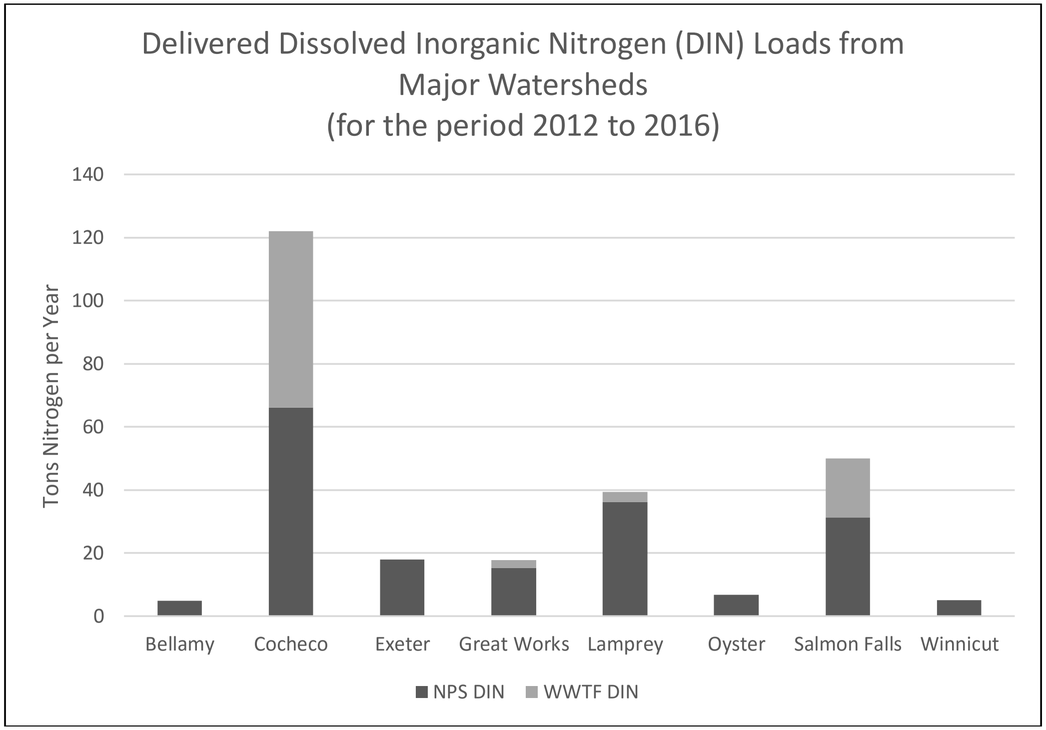
1. Values reported above combine data from 2012 through 2016, which does not reveal improvements made by WWTFs in the latter part of this period (e.g., for example, at Dover, Rochester and Durham.) Please see Table NL-5 to see changes by each year in this period in the amount of N delivered from WWTFs to the Great Bay Estuary.
2. Newmarket, in the summer of 2017, completed a major upgrade of their WWTF. Portsmouth, in 2017, broke ground on a major upgrade that should be completed by 2020. Also in 2017, Exeter broke ground on a major upgrade, slated for completion by the end of 2018. Newington, in 2016, broke ground on an upgrade of their system, which should be complete by early 2018.
3. Farmington's WWTF is not listed because the plant discharges to rapid infiltration basins so that the effluent does not reach the Cocheco River.

Figure NL-8a: Estimated total nitrogen loads from major tributaries in 2012-2016



1. Values reported above combine data from 2012 through 2016, which does not reveal improvements made by WWTFs in the latter part of this period (e.g., for example, at Dover, Rochester and Durham.) Please see Table NL-5 to see changes by each year in this period in the amount of N delivered from WWTFs to the Great Bay Estuary.
2. Newmarket, in the summer of 2017, completed a major upgrade of their WWTF. Portsmouth, in 2017, broke ground on a major upgrade that should be completed by 2020. Also in 2017, Exeter broke ground on a major upgrade, slated for completion by the end of 2018. Newington, in 2016, broke ground on an upgrade of their system, which should be complete by early 2018.

Figure NL-8b: Estimated total dissolved inorganic nitrogen (DIN) loads from major tributaries in 2012-2016



1. Values reported above combine data from 2012 through 2016, which does not reveal improvements made by WWTFs in the latter part of this period (e.g., for example, at Dover, Rochester and Durham.) Please see Table NL-5 to see changes by each year in this period in the amount of N delivered from WWTFs to the Great Bay Estuary.
2. Newmarket, in the summer of 2017, completed a major upgrade of their WWTF. Portsmouth, in 2017, broke ground on a major upgrade that should be completed by 2020. Also in 2017, Exeter broke ground on a major upgrade, slated for completion by the end of 2018. Newington, in 2016, broke ground on an upgrade of their system, which should be complete by early 2018.

Figure NL-9a: Total nitrogen loads to the Great Bay Estuary from different sources in 2012-2016. Total = 903.1 tons/year.

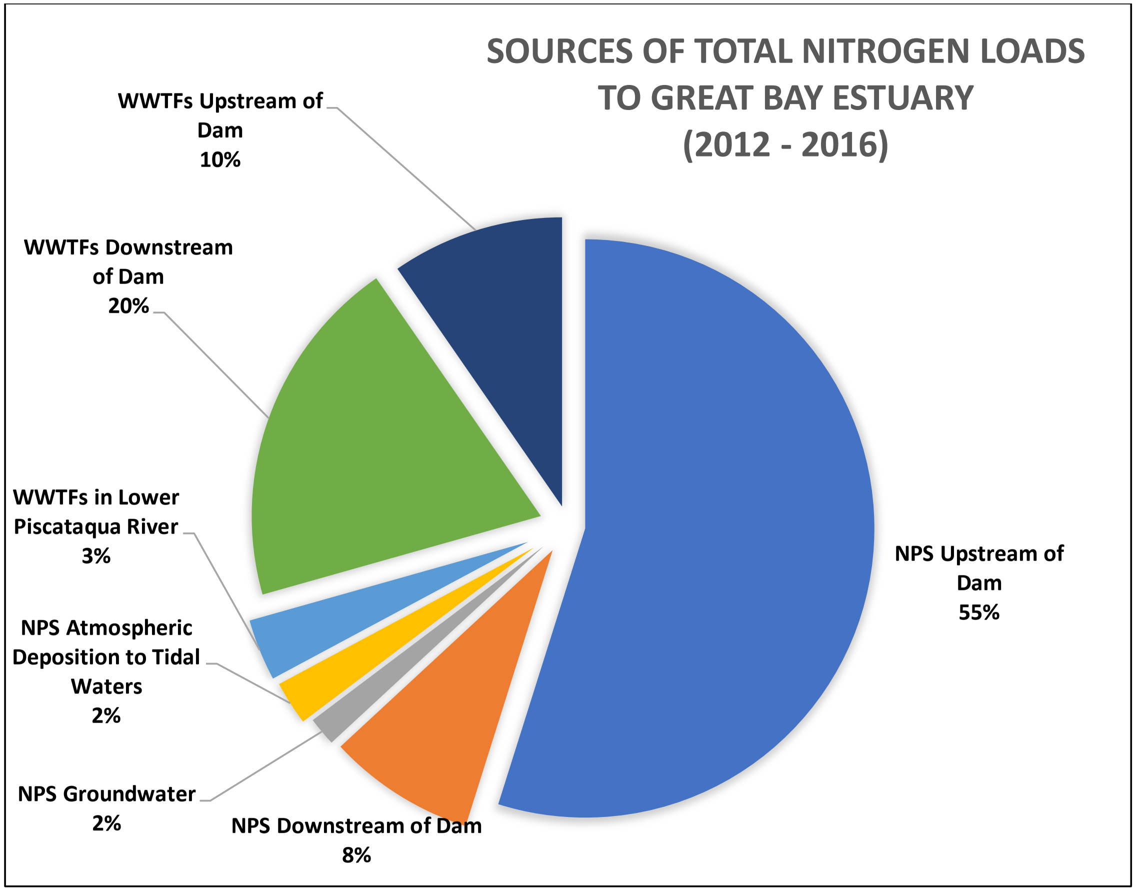


Figure NL-9b: Total dissolved inorganic nitrogen loads to the Great Bay Estuary from different sources in 2012-2016. Total = 506.0 tons/year.