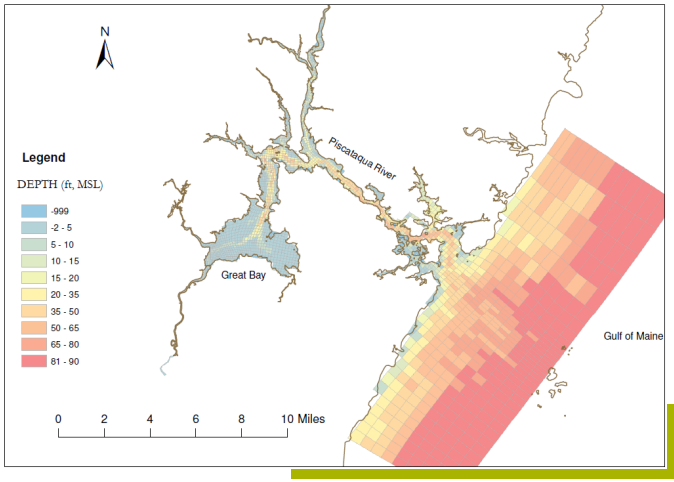
Great Bay Estuary TN Model

Development of TN Model and Evaluation of NPS & PS TN Load Reductions

August 13, 2019



HDR

DOVER 001311

Study Goal

- Calibrate the Great Bay Estuary System (GBES) hydrodynamic model against total nitrogen (TN) data at multiple estuary locations and then employ the hydrodynamic model to develop various combinations of point source (PS) and nonpoint source (NPS) TN loads that achieve various GBES target TN concentrations.

Scope of Work

- **Task 1. Develop GBES NPS TN Loads.** Years 2010-2011 and 2017. Lamprey River, Cocheco River, Squamscott River, Oyster River, Salmon Falls River, Winnicut River and Bellamy River. Use annual average TN concentrations from existing reports.
- **Task 2. Develop GBES Annual or Monthly Average PS TN Loads.** Employ effluent data (of very limited frequency) to develop either annual or monthly average effluent TN loads for the simulation years. WWTFs: Dover, Rochester, Pease, Peirce Island, Newmarket, Newfields, Exeter and Durham.

Scope of Work (Cont.)

- **Task 3. Calibrate the GBES 3D Hydrodynamic Model to Measured TN Levels.**
  - A calibrated 3D, time-variable hydrodynamic model of the GBES for the years 2010 and 2011 is available. Extend the hydrodynamic model simulation to include the year 2017.
  - Model TN as a conservative substance. Compare computed TN concentration against measured TN in the GBES.
  - For this phase of the project, no consideration was given to the exchange of TN between the water column and the bottom of GBES associated with eelgrass nitrogen uptake and the diffusion of nitrogen between GBES sediments and overlying water.

Scope of Work (Cont.)

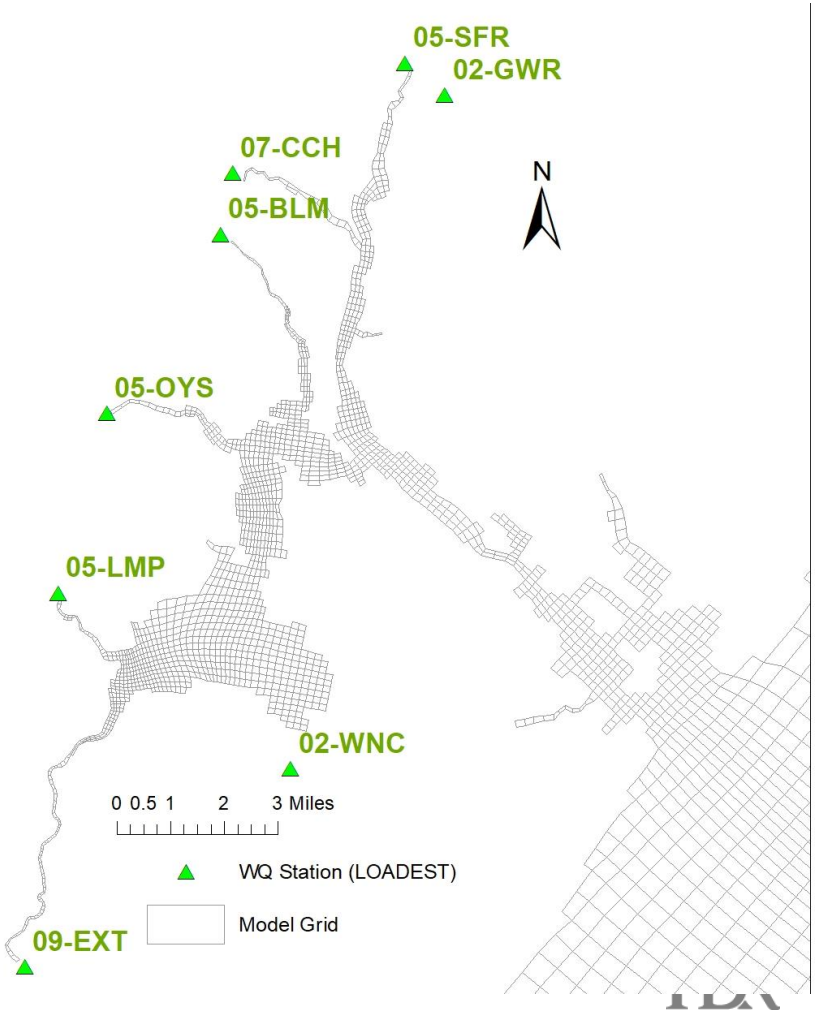
- **Task 4. Evaluate TN Loads and Resulting GBES TN Concentrations.** Use the calibrated model to develop various combinations of PS and NPS TN loads that achieve various GBES target TN concentrations.

Development of NPS TN Loads

- Due to limited funding, initial scope considered the use of simple annual average TN concentrations from existing reports.
- An effort was performed to define NPS loads in a more realistic way by employing LOADEST (USGS load model), within the approved budget.
- Daily NPS TN loads for all GBES tributaries were developed by employing LOADEST. Model inputs are river daily flows and limited head-of-tide measured TN data.

Development of NPS TN Loads (Cont.)

- Head of tide stations



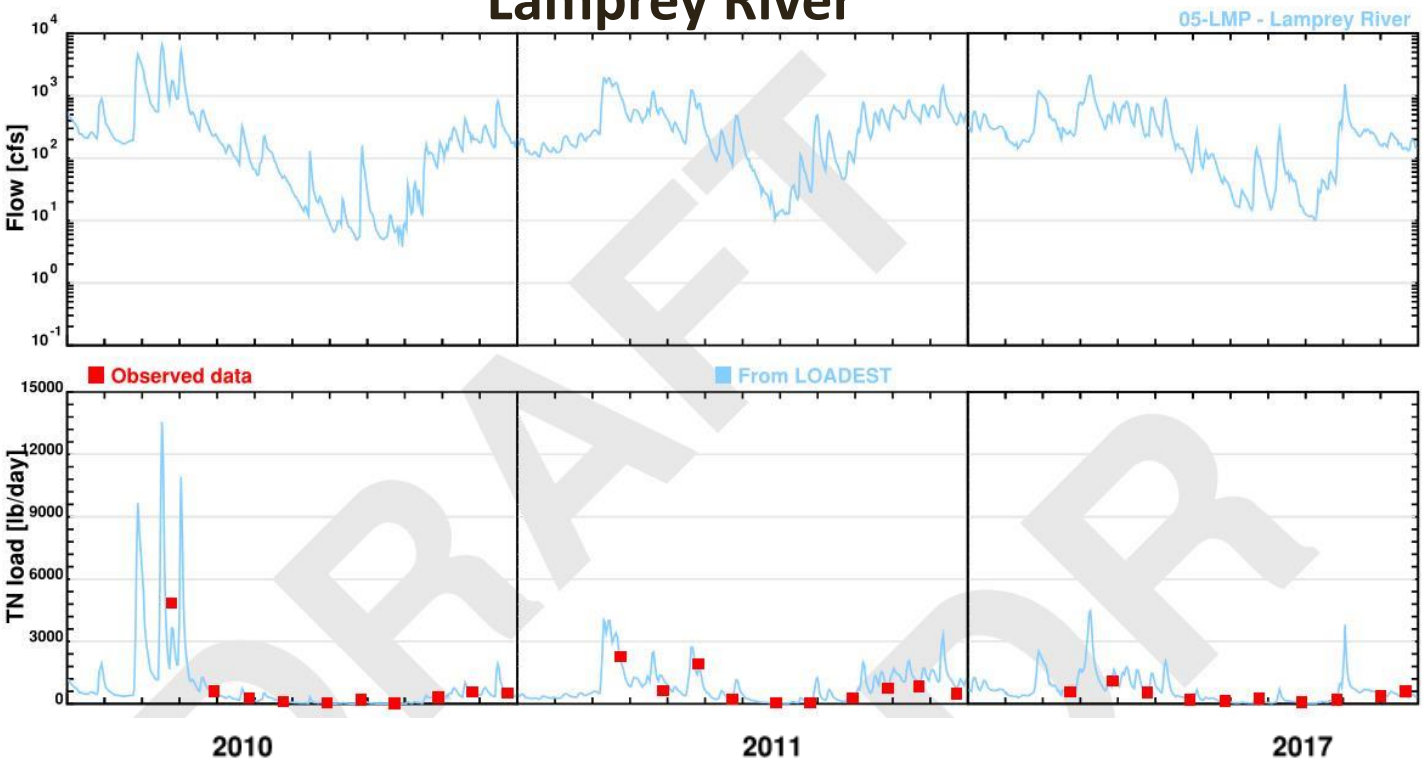
Development of NPS TN Loads (Cont.)

- Head of tide TN data available for the years 2008 to 2017.

Head of Tide Area	Station ID	# TN measurements
COCHECO RIVER	07-CCH	98
LAMPREY RIVER	05-LMP	98
SALMON FALLS RIVER	05-SFR	92
EXETER RIVER	09-EXT	101
BELLAMY RIVER	05-BLM	99
OYSTER RIVER	05-OYS	100
WINNICUT RIVER	02-WNC	96
GREAT WORKS RIVER	02-GWR	98

Development of NPS TN Loads (Cont.)

Lamprey River



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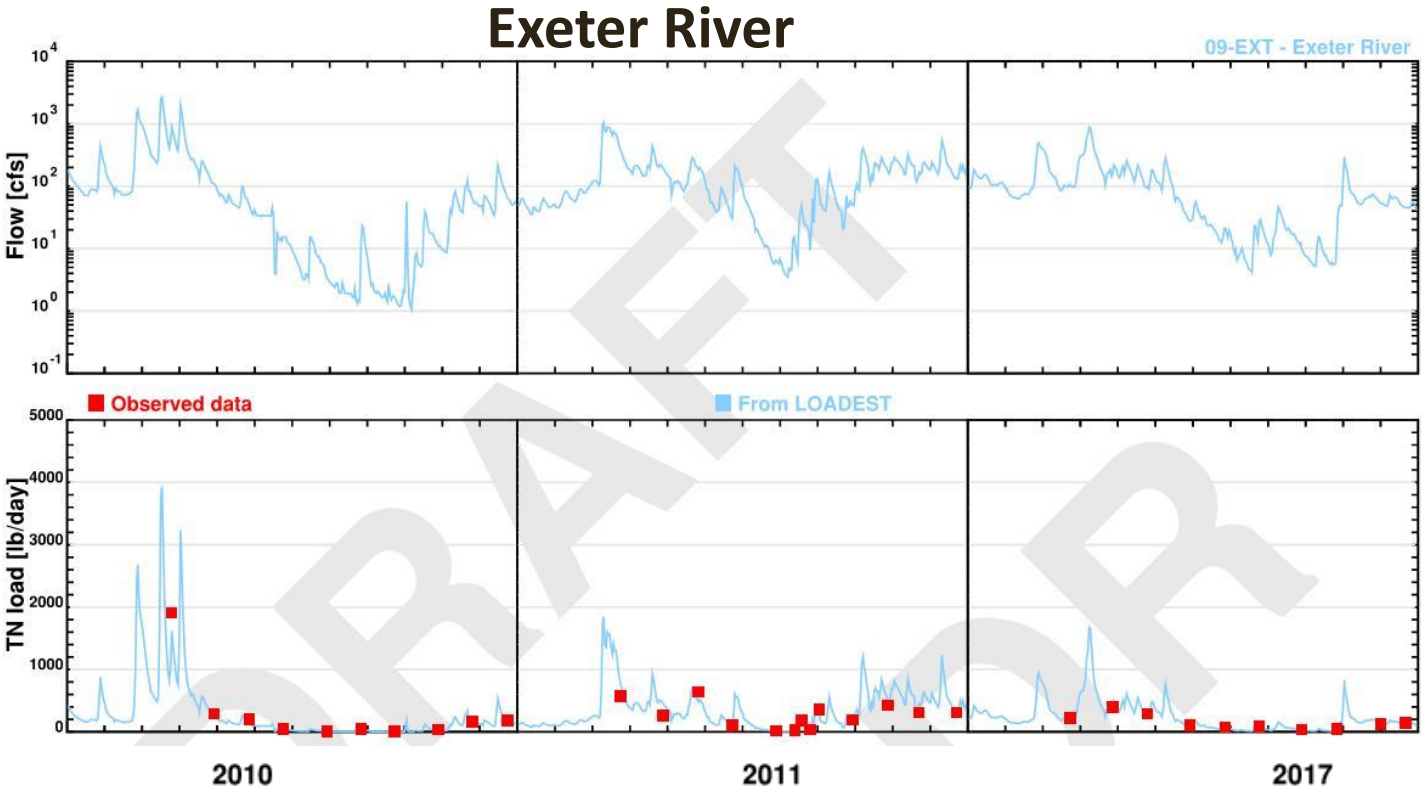
Development of NPS TN Loads (Cont.)



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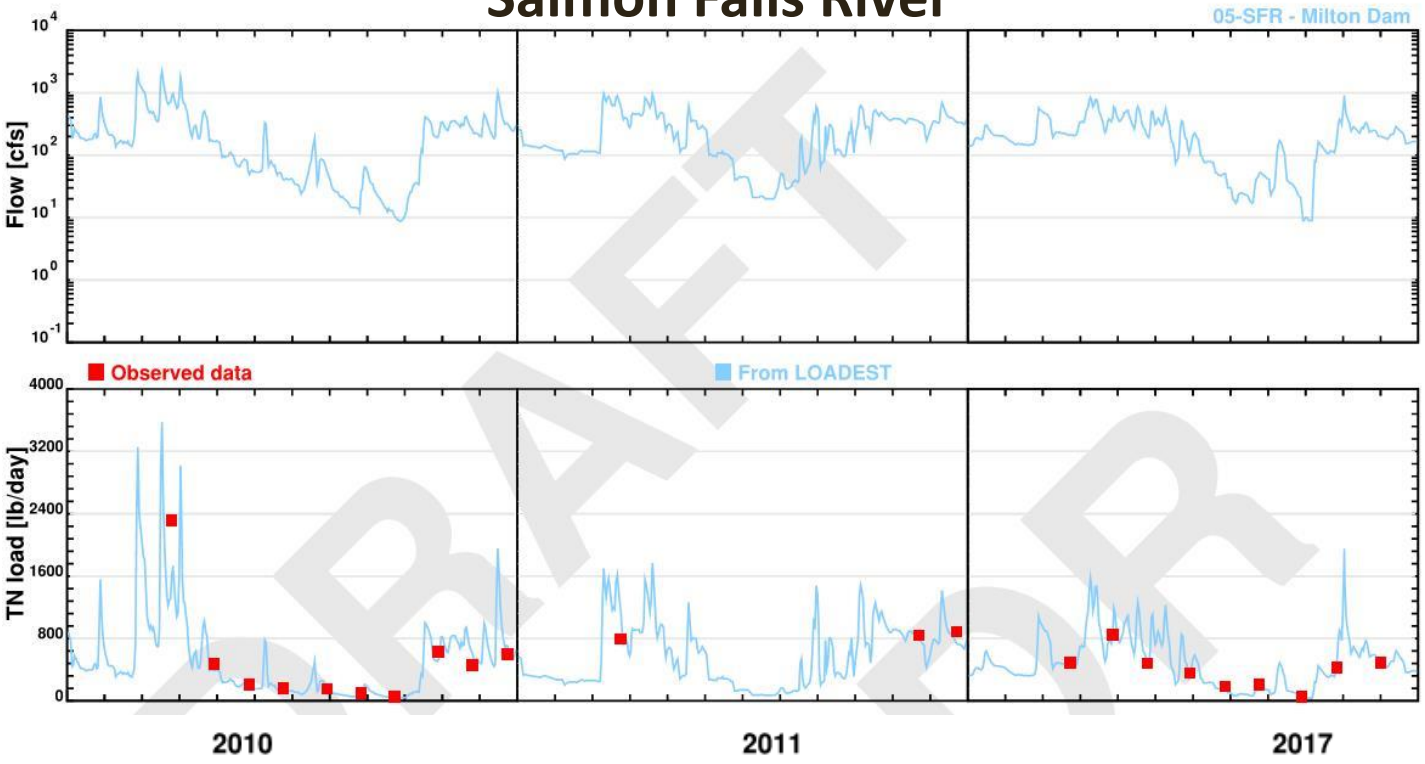
Development of NPS TN Loads (Cont.)

Salmon Falls River



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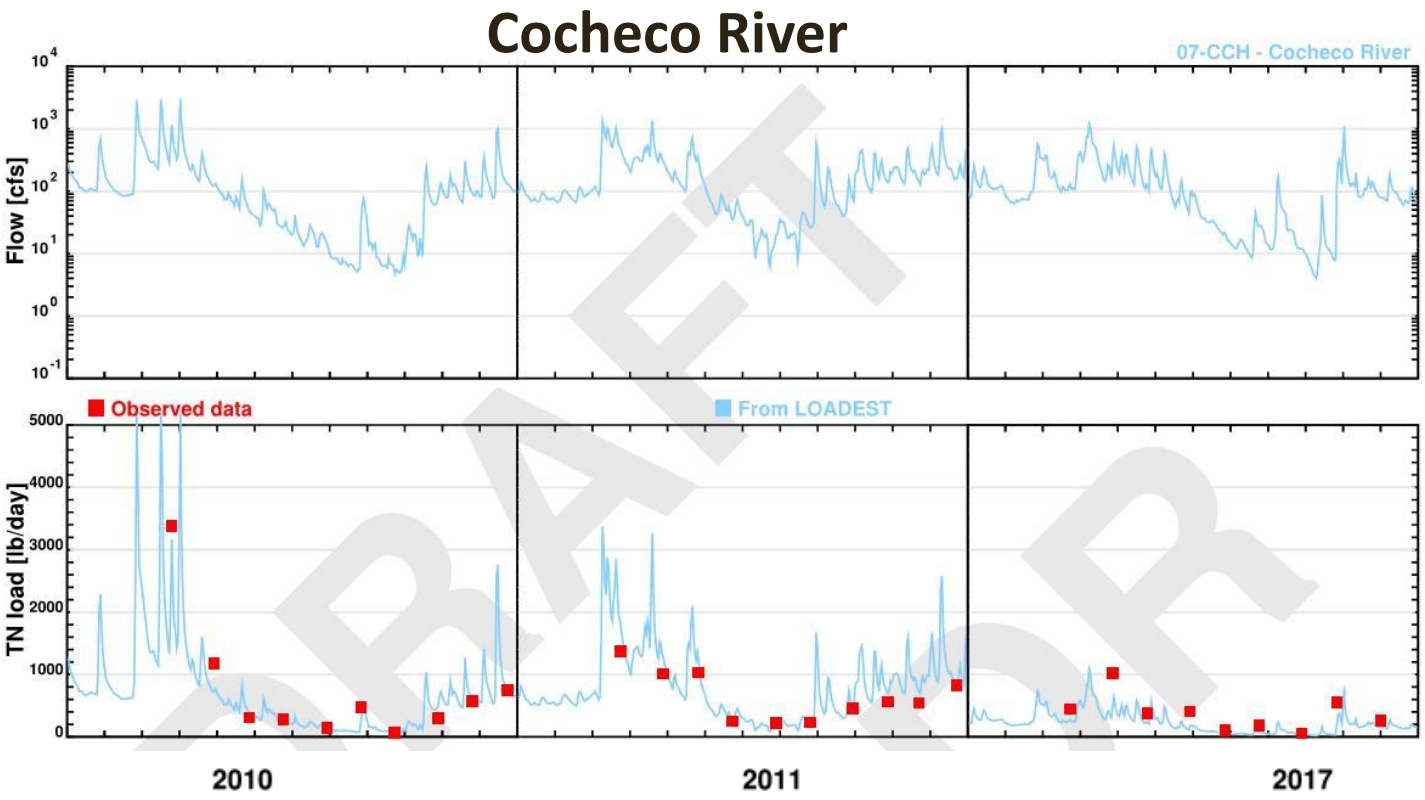
Development of NPS TN Loads (Cont.)



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Development of NPS TN Loads (Cont.)

- Salmon Falls River head of tide TN was employed for defining Salmon Falls and Great Works rivers NPS TN loads.
- The Cocheco River head of tide TN data reflects both background river and Rochester WWTF TN loads. Previous data analyses performed by HDR in the Cocheco River indicate that a portion of Rochester WWTF TN load is attenuated in the river before reaching the estuary; this attenuation is dependent on river flow and temperature conditions. For this phase of the study, based on previously performed Cocheco River TN mass balance analyses, a background river TN concentration of 0.5 was employed.

Development of NPS TN Loads (Cont.)

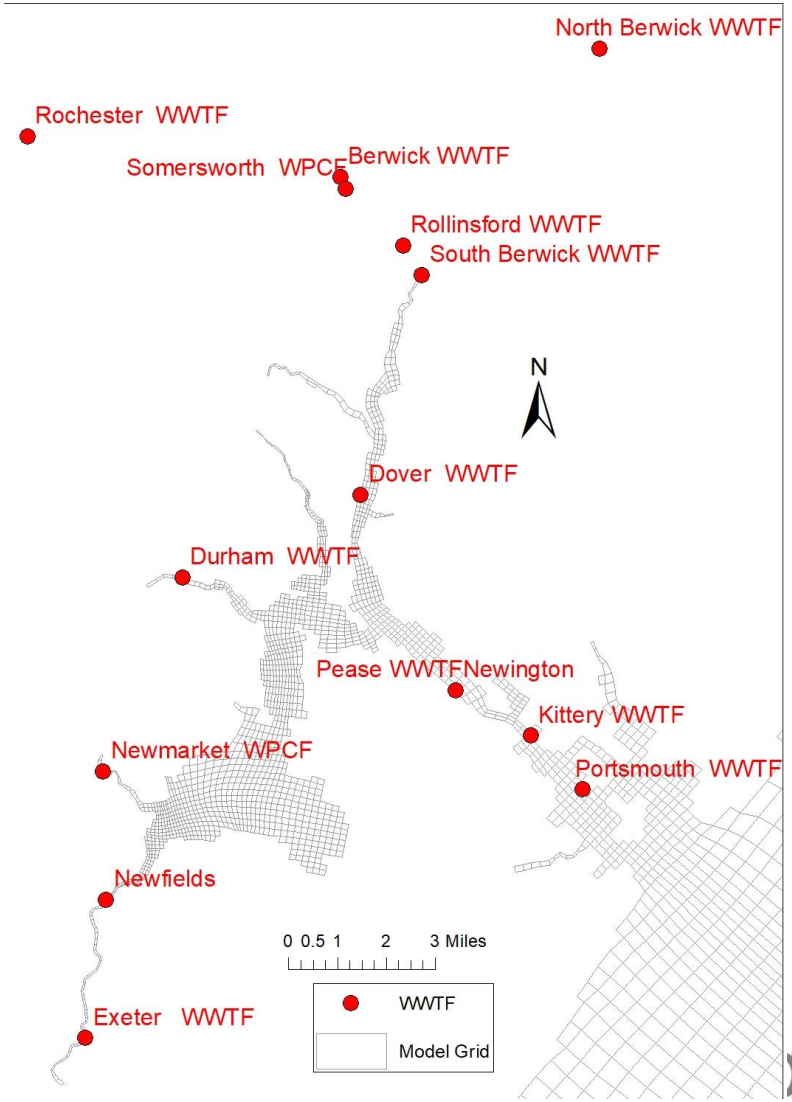
- Annual average NPS TN loads:

Average Loading Rate (lb/day)*			
	2010	2011	2017
Lamprey	952	992	762
Squamscott	571	721	467
Oyster	107	112	91
Cocheco	988	1,146	802
Salmon	1,598	1,806	1,524
Winnicut	138	131	96
Bellamy	64	61	47

*Scaled up from Head of Tide Station

Development of Annual or Monthly Average PS TN Loads

- WWTFs



Development of Annual or Monthly Average PS TN Loads (Cont.)

- Monthly or annual average TN loads developed for the following WWTFs: Dover, Rochester, Pease, Peirce Island, Newmarket, Newfields, Exeter and Durham. Years 2010, 2011 and 2017.
- Methodology employed for deriving WWTF TN loads specific to each WWTF available TN data.
- Derivation methodologies tried to capture seasonal variability, flow dependency and treatment changes over time specific to each WWTF.
- Based on Cocheco River TN mass balance analyses performed by HDR in the past as well as NHDES estimates, a 75% delivery factor was employed for Rochester WWTF TN load.

Development of Annual or Monthly Average PS TN Loads (Cont.)

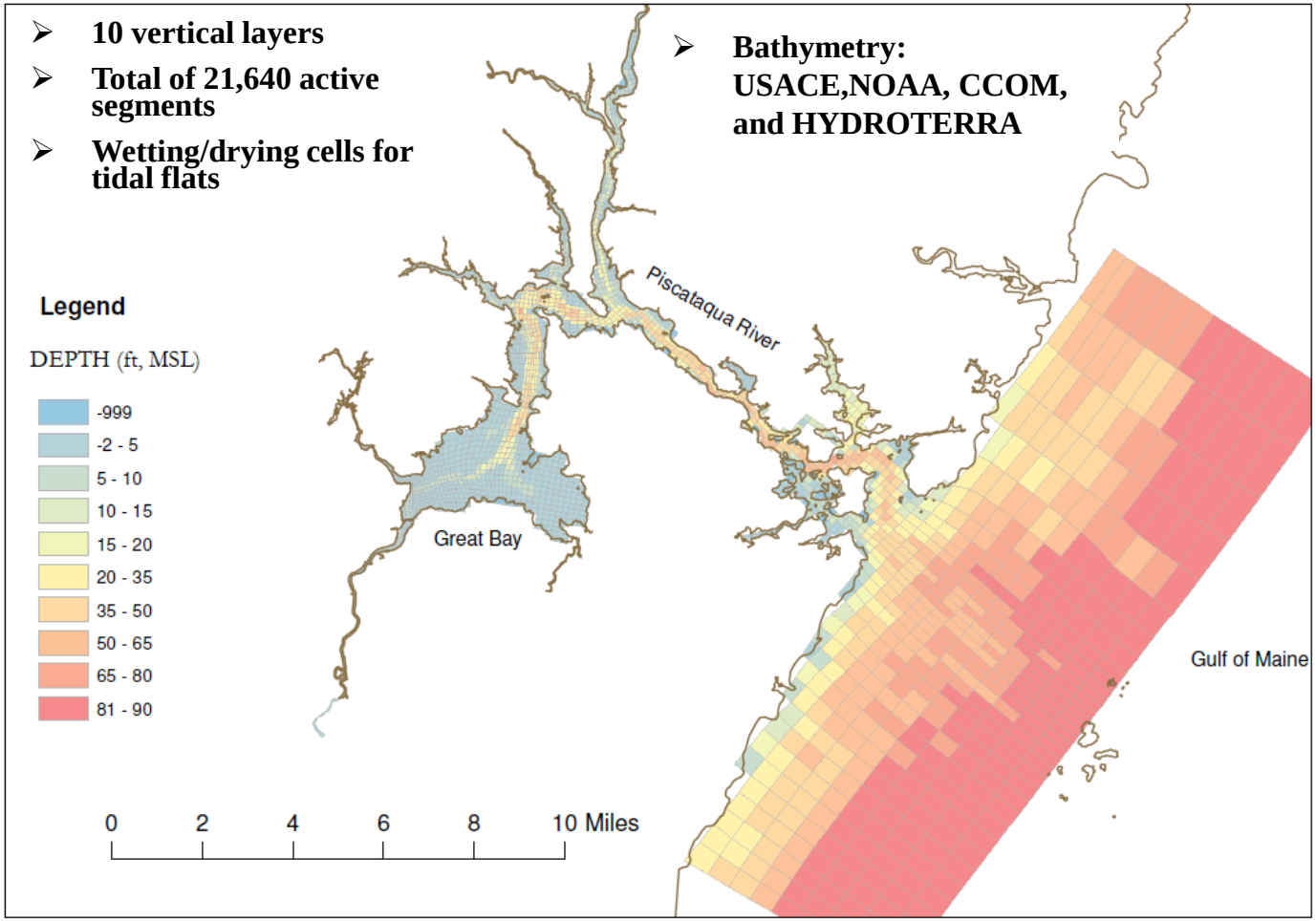
- Annual average PS TN loads:

Average Loading Rate (lb/day)			
	2010	2011	2017
Durham	85	77	115
Exeter	271	271	661
Newfields	10	10	10
Newmarket	124	124	100
Dover	359	359	185
Portsmouth	896	956	1,014
Rochester	665	707	266
Pease	146	145	145

Note: Rochester WWTF load is the load delivered to the estuary at a delivery efficiency factor of 75%

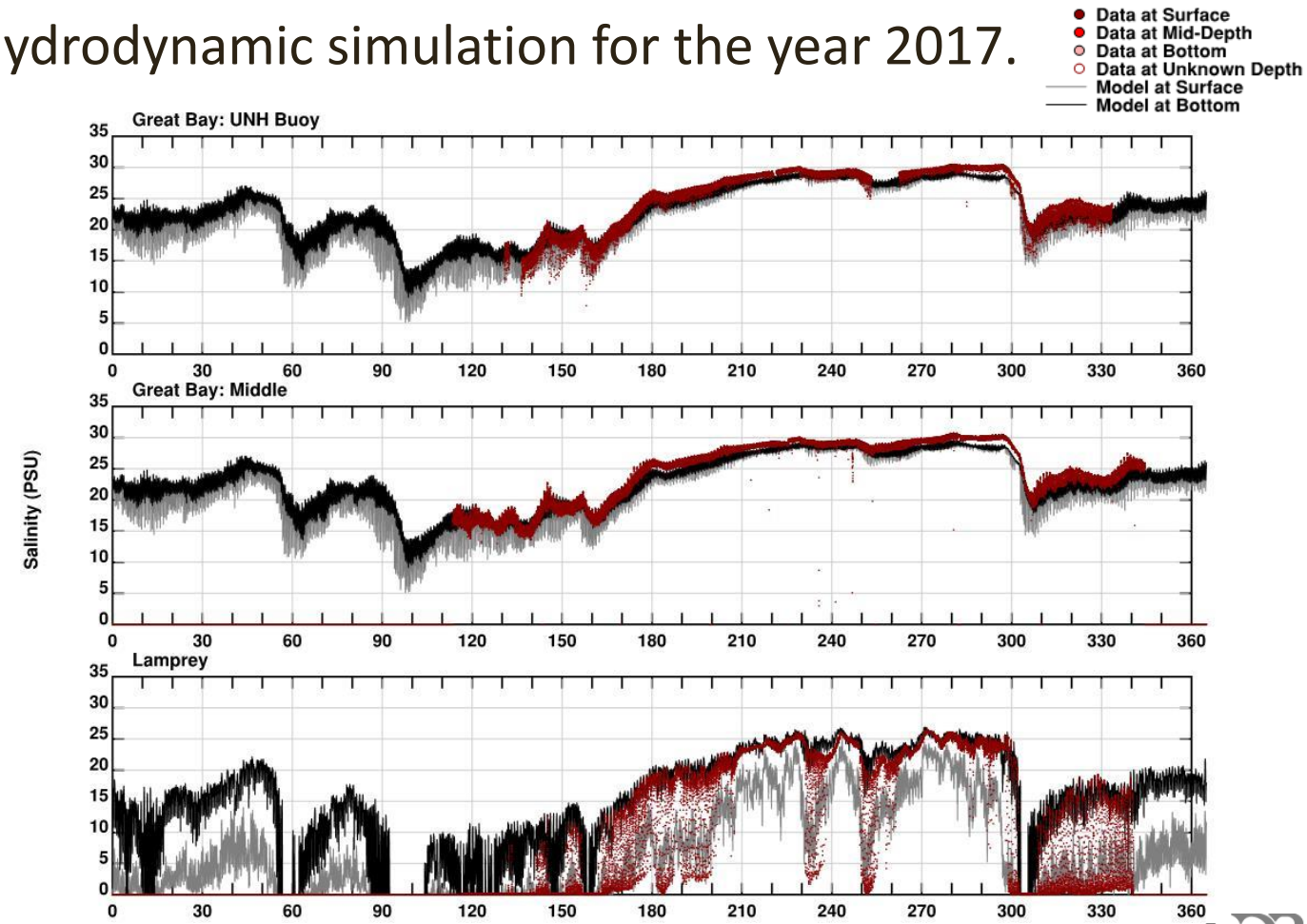
Development of GBES TN Model

- 10 vertical layers
- Total of 21,640 active segments
- Wetting/drying cells for tidal flats
- Bathymetry: USACE,NOAA, CCOM, and HYDROTERRA



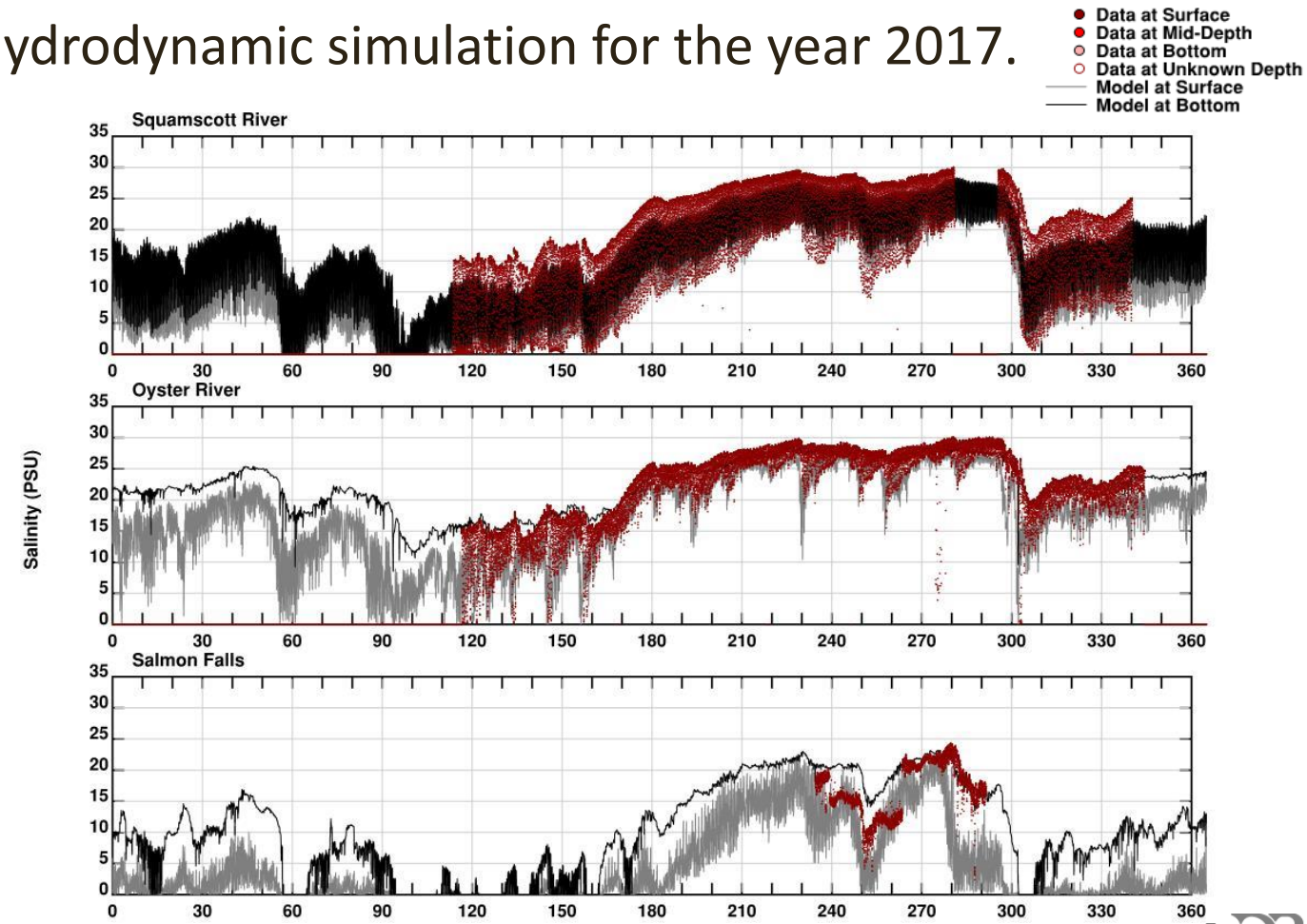
Development of GBES TN Model (Cont.)

- Hydrodynamic simulation for the year 2017.



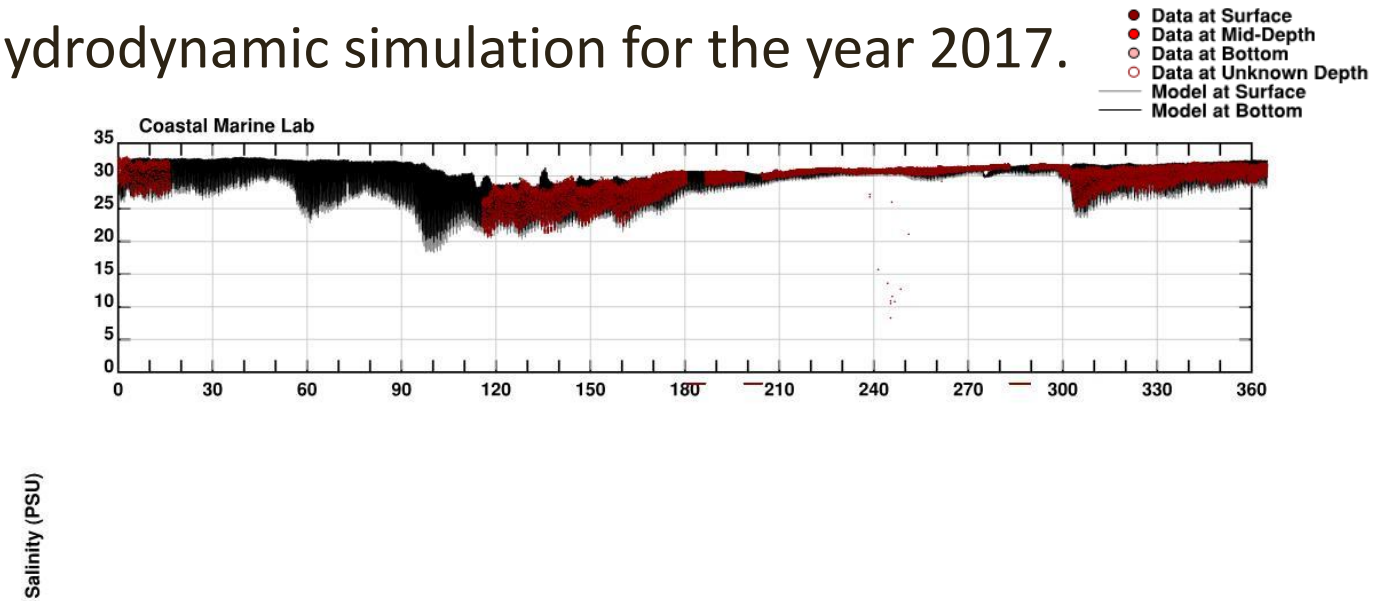
Development of GBES TN Model (Cont.)

- Hydrodynamic simulation for the year 2017.



Development of GBES TN Model (Cont.)

- Hydrodynamic simulation for the year 2017.

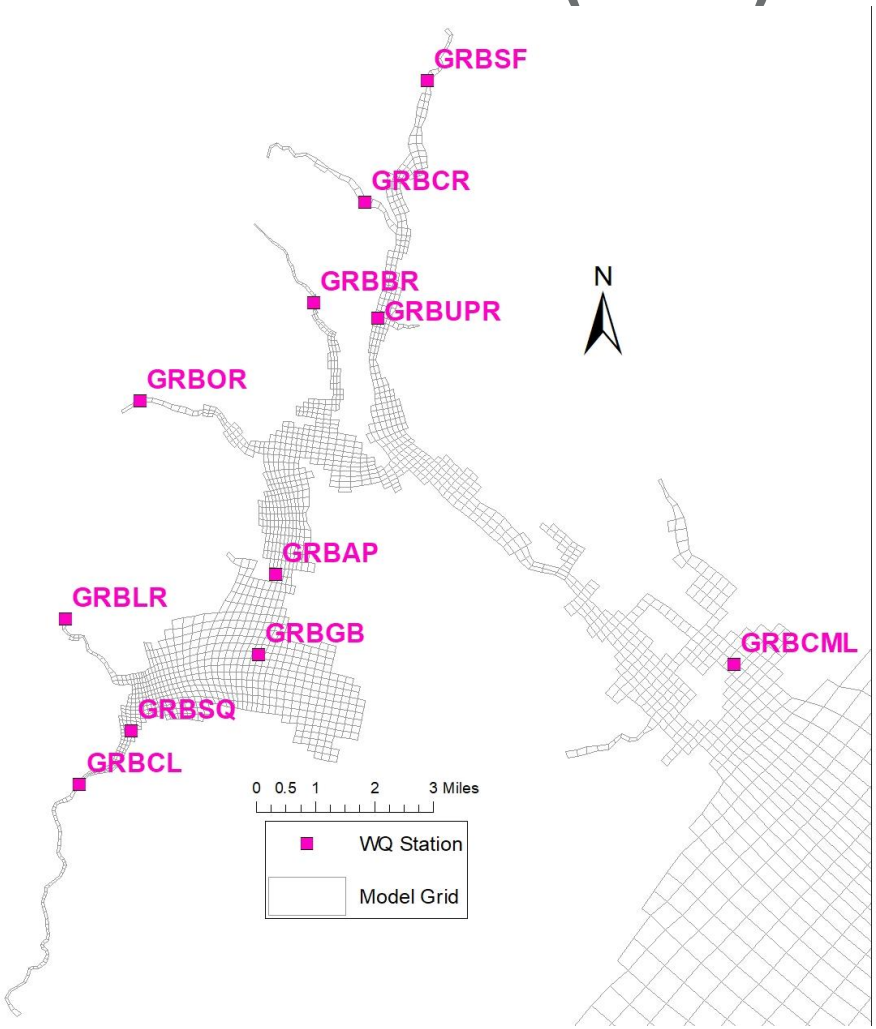


Development of GBES TN Model (Cont.)

- Modeled TN as a conservative substance.
- Daily TN NPS loads input to hydrodynamic model.
- Monthly TN PS loads input to hydrodynamic model.
- Based on CML TN data and analysis performed by NHDES, an oceanic TN boundary of 0.2 mg/L was specified.
- TN model results compared to measured TN data at selected stations.

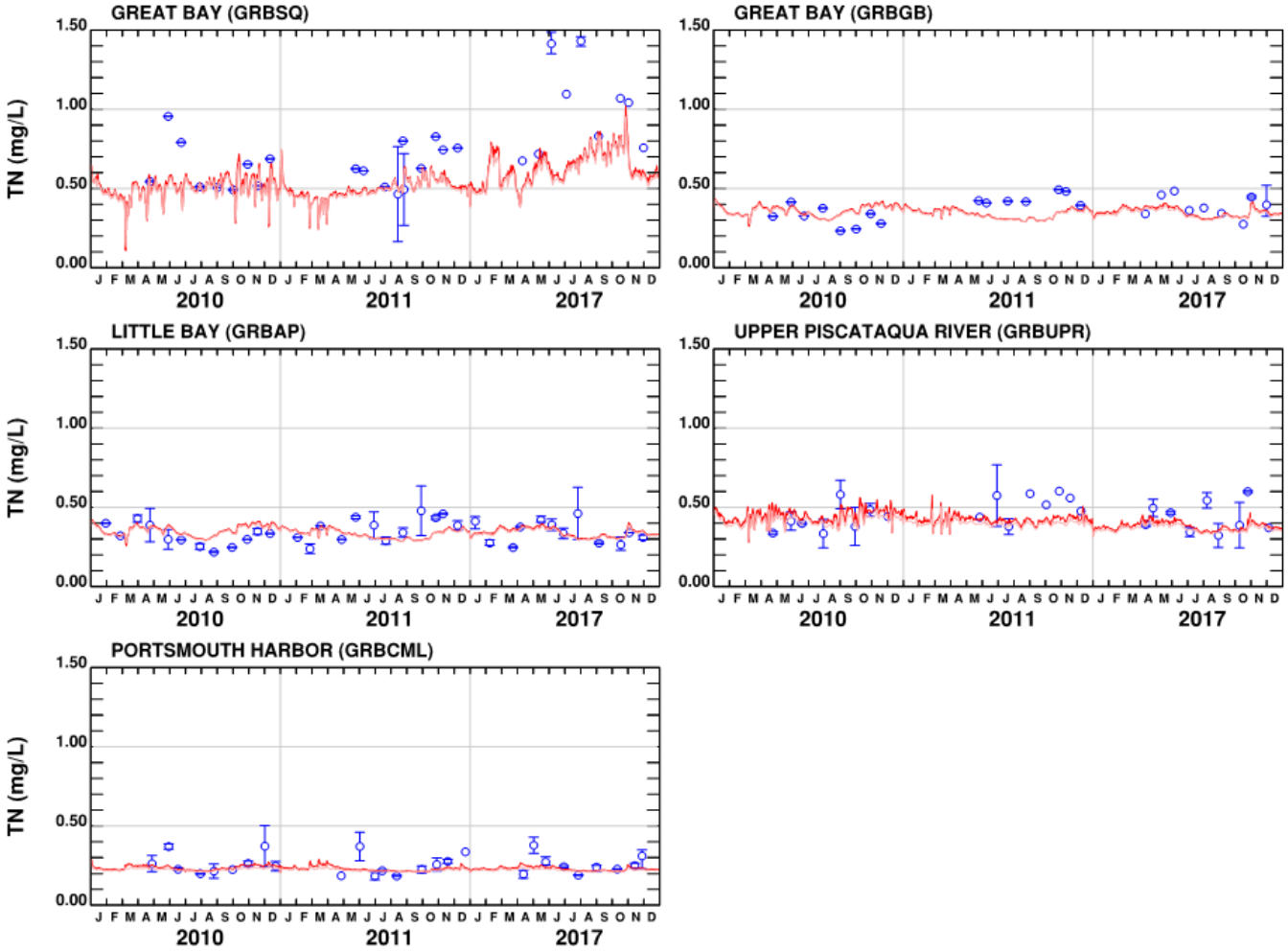
Development of GBES TN Model (Cont.)

- TN calibration stations



Development of GBES TN Model (Cont.)

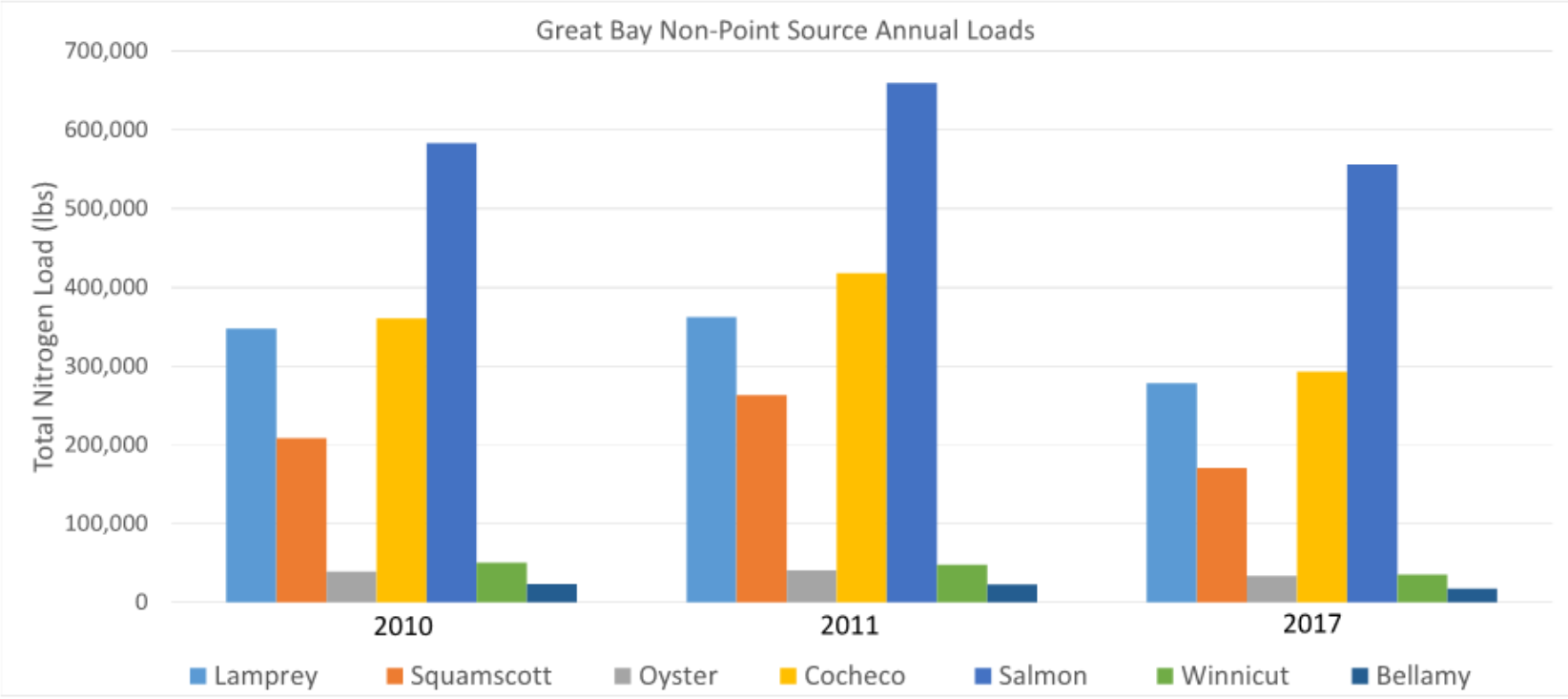
- Model-data comparison



Evaluation of PS & NPS TN Load Reductions and Resulting GBES TN Concentrations

- Employed the calibrated model to develop various combinations of PS and NPS TN loads and assess resulting Great Bay TN concentrations.
  - Oceanic TN boundary at 0.20 mg/L for all scenarios.
  - Point source TN at 6.0 mg/L represents a TN monthly limit of 8.0 mg/L.
  - Point source TN at 3.0 mg/L represents limit of technology.
  - Point sources at design flows.
  - Nonpoint Sources at reductions of 20%, 30% and 40%.

GBES NPS TN Annual Loads



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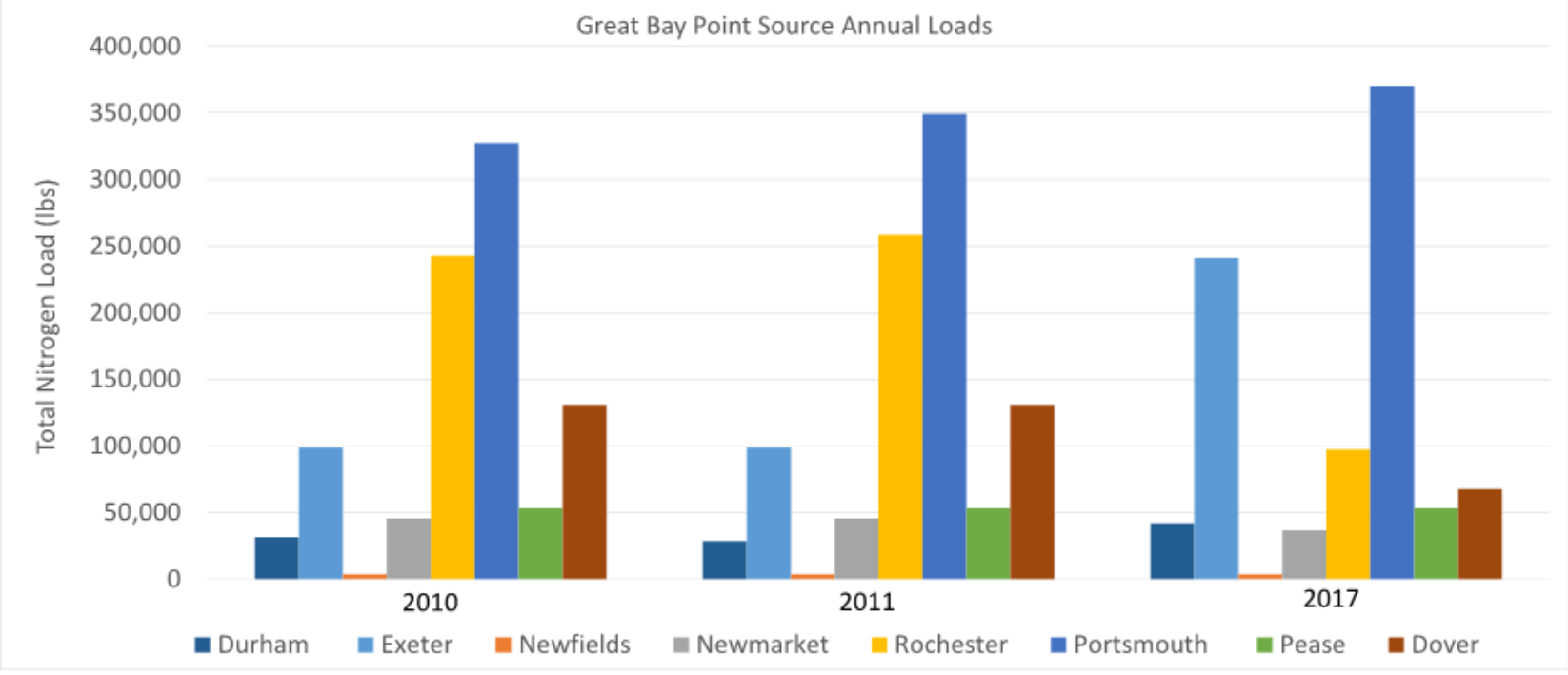
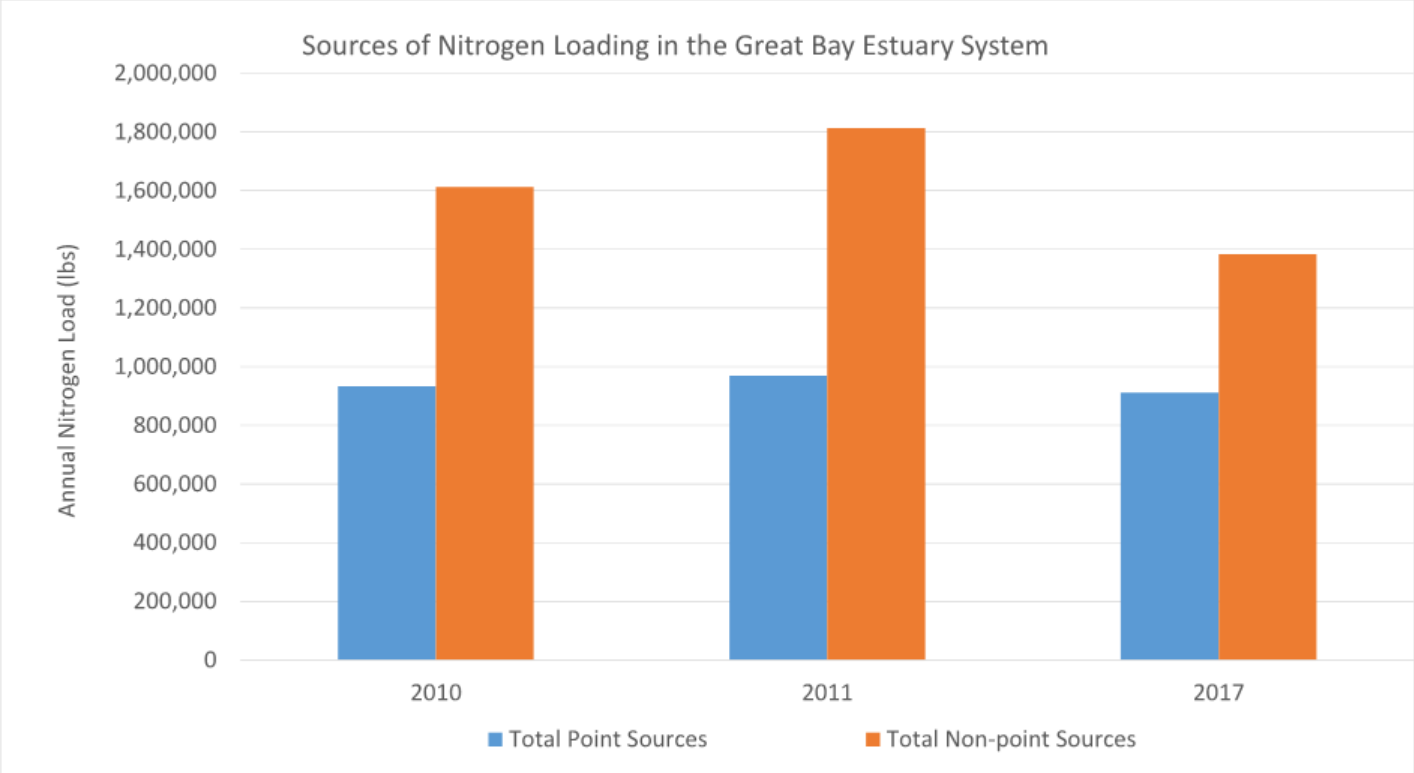
GBES PS TN Annual Loads



Note: Rochester WWTF load is the load delivered to the estuary at a delivery efficiency factor of 75%

GBES Annual Loads



Loading Scenarios (Annual)

			2010		2011		2017	
	Scenario description [1]	Location	Average TN concentration (mg/L)	TN Load to Great Bay Estuary System (kg/ha/yr)	Average TN concentration (mg/L)	TN Load to Great Bay Estuary System (kg/ha/yr)	Average TN concentration (mg/L)	TN Load to Great Bay Estuary System (kg/ha/yr)
Scenario 1	NPS Calibration PS[4] at 6 mg/L [2]	Adam's Point Great Bay Piscataqua	0.31 0.32 0.36	166	0.33 0.34 0.39	183	0.32 0.32 0.37	147
Scenario 2	NPS 20% Reduction PS[4] at 6 mg/L [2]	Adam's Point Great Bay Piscataqua	0.28 0.29 0.32	139	0.3 0.31 0.34	153	0.29 0.29 0.33	124
Scenario 3	NPS 30% Reduction PS[4] at 6 mg/L [2]	Adam's Point Great Bay Piscataqua	0.27 0.28 0.31	126	0.28 0.29 0.32	138	0.28 0.28 0.31	112
Scenario 4	NPS 40% Reduction PS[4] at 6 mg/L [2]	Adam's Point Great Bay Piscataqua	0.26 0.26 0.29	112	0.27 0.27 0.29	122	0.26 0.26 0.29	101
Scenario 5	NPS Calibration PS[4] at 3 mg/L [3]	Adam's Point Great Bay Piscataqua	0.29 0.3 0.34	150	0.31 0.32 0.37	167	0.3 0.3 0.35	131
Scenario 6	NPS 20% Reduction PS[4] at 3 mg/L [3]	Adam's Point Great Bay Piscataqua	0.26 0.27 0.3	123	0.28 0.29 0.32	137	0.27 0.27 0.3	108
Scenario 7	NPS 30% Reduction PS[4] at 3 mg/L [3]	Adam's Point Great Bay Piscataqua	0.25 0.25 0.28	110	0.26 0.27 0.29	122	0.26 0.26 0.28	97
Scenario 8	NPS 40% Reduction PS[4] at 3 mg/L [3]	Adam's Point Great Bay Piscataqua	0.24 0.24 0.26	97	0.25 0.25 0.27	107	0.24 0.24 0.26	85
Calibration	NPS Calibration PS Calibration	Adam's Point Great Bay Piscataqua	0.36 (0.32[5]) 0.36 (0.32[5]) 0.45 (0.42[5])	212	0.33 (0.37[5]) 0.34 (0.43[5]) 0.42 (0.52[5])	232	0.34 (0.34[5]) 0.35 (0.39[5]) 0.38 (0.44[5])	191

[1] Oceanic TN boundary Condition = 0.20 mg/L for all scenarios
[2] Point Source TN at 6.0 mg/L represents a TN monthly limit of 8.0 mg/L
[3] Point Source TN at 3.0 mg/L represents limit of technology
[4] Point Source Flow is at Design Flow
[5] Average of Monthly data

Loading Scenarios (Growing Season)

			2010 Growing Season (April-September)		2011 Growing Season (April-September)		2017 Growing Season (April-September)	
	Scenario description [1]	Location	Average TN concentration (mg/L)	TN Load to Great Bay Estuary System (kg/ha/yr)	Average TN concentration (mg/L)	TN Load to Great Bay Estuary System (kg/ha/yr)	Average TN concentration (mg/L)	TN Load to Great Bay Estuary System (kg/ha/yr)
Scenario 1	NPS Calibration PS at 6 mg/L [2]	Adam's Point Great Bay Piscataqua	0.28 0.29 0.34	166	0.31 0.32 0.37	183	0.3 0.31 0.36	147
Scenario 2	NPS 20% Reduction PS at 6 mg/L [2]	Adam's Point Great Bay Piscataqua	0.27 0.27 0.31	139	0.28 0.29 0.33	153	0.28 0.28 0.32	124
Scenario 3	NPS 30% Reduction PS at 6 mg/L [2]	Adam's Point Great Bay Piscataqua	0.26 0.26 0.3	126	0.27 0.27 0.31	138	0.26 0.27 0.3	112
Scenario 4	NPS 40% Reduction PS at 6 mg/L [2]	Adam's Point Great Bay Piscataqua	0.25 0.25 0.29	112	0.25 0.26 0.29	122	0.25 0.25 0.28	101
Scenario 5	NPS Calibration PS at 3 mg/L [3]	Adam's Point Great Bay Piscataqua	0.27 0.27 0.31	150	0.29 0.3 0.35	167	0.29 0.29 0.34	131
Scenario 6	NPS 20% Reduction PS at 3 mg/L [3]	Adam's Point Great Bay Piscataqua	0.25 0.25 0.28	123	0.27 0.27 0.31	137	0.26 0.26 0.3	108
Scenario 7	NPS 30% Reduction PS at 3 mg/L [3]	Adam's Point Great Bay Piscataqua	0.24 0.24 0.27	110	0.25 0.26 0.28	122	0.25 0.25 0.28	97
Scenario 8	NPS 40% Reduction PS at 3 mg/L [3]	Adam's Point Great Bay Piscataqua	0.23 0.23 0.26	97	0.24 0.24 0.26	107	0.23 0.24 0.26	85
Calibration	NPS Calibration PS Calibration	Adam's Point Great Bay Piscataqua	0.34 (0.28[5]) 0.35 (0.32[5]) 0.44 (0.41[5])	212	0.32 (0.37[5]) 0.32 (0.42[5]) 0.42 (0.50[5])	232	0.34 (0.38[5]) 0.35 (0.39[5]) 0.39 (0.43[5])	191

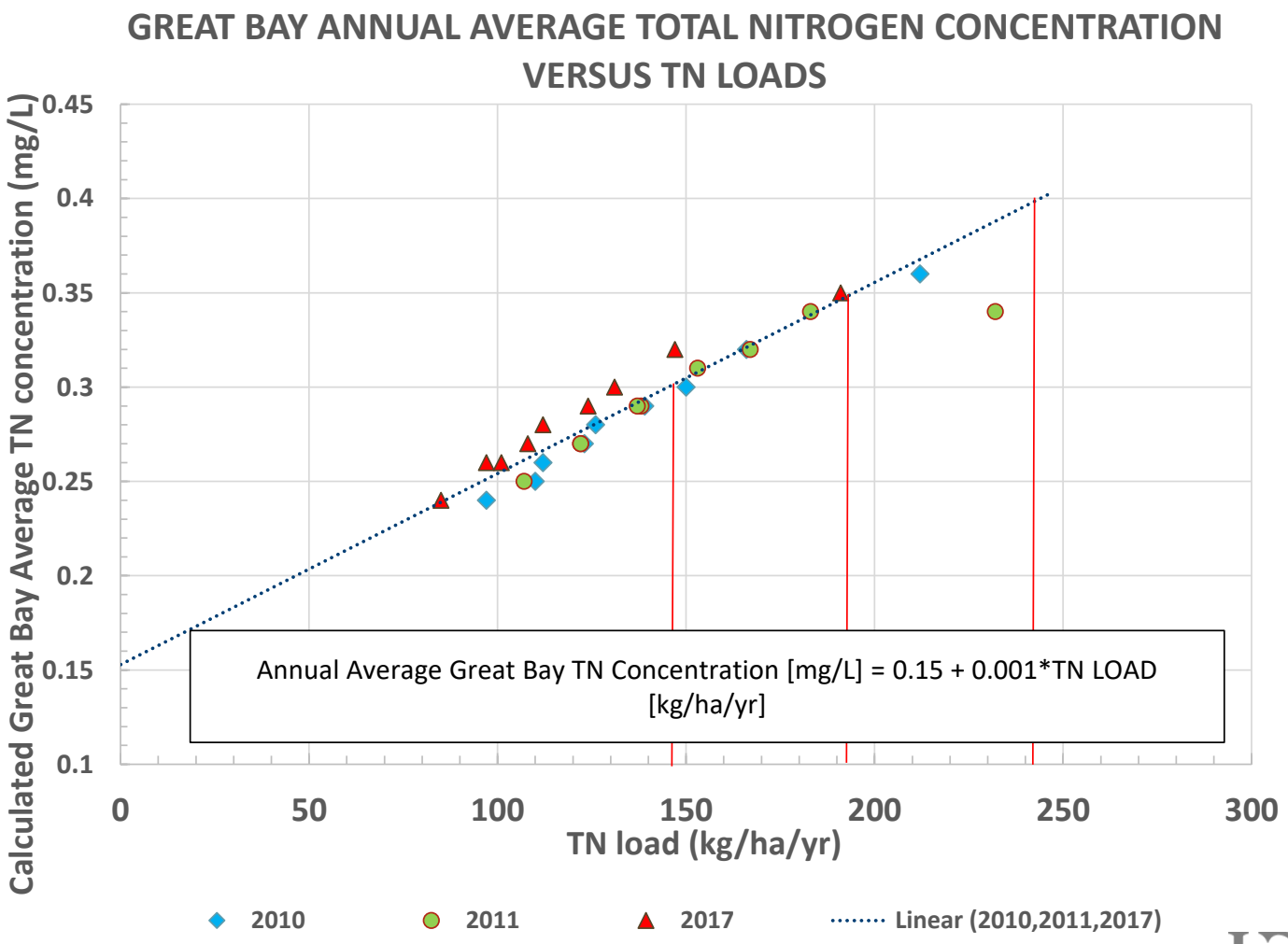
[1] Oceanic TN boundary Condition = 0.20 mg/L for all scenarios
[2] Point Source TN at 6.0 mg/L represents a TN monthly limit of 8.0 mg/L
[3] Point Source TN at 3.0 mg/L represents limit of technology
[4] Point Source Flow is at Design Flow
[5] Average of Monthly data

Loading Scenarios (Annual)

Loading Scenarios at Great Bay Estuary System (Average of 2010, 2011 &2017)[1]			
PS concentration (mg/L) [2][3][4]	NPS % Load Reduction	Average TN concentration (mg/L)	TN Load to Great Bay Estuary System (kg/ha/yr)
6	0	0.33	165
6	20	0.30	139
6	30	0.28	125
6	40	0.26	112
3	0	0.31	149
3	20	0.28	123
3	30	0.26	109
3	40	0.24	96
Actual[5]	0	0.35	212

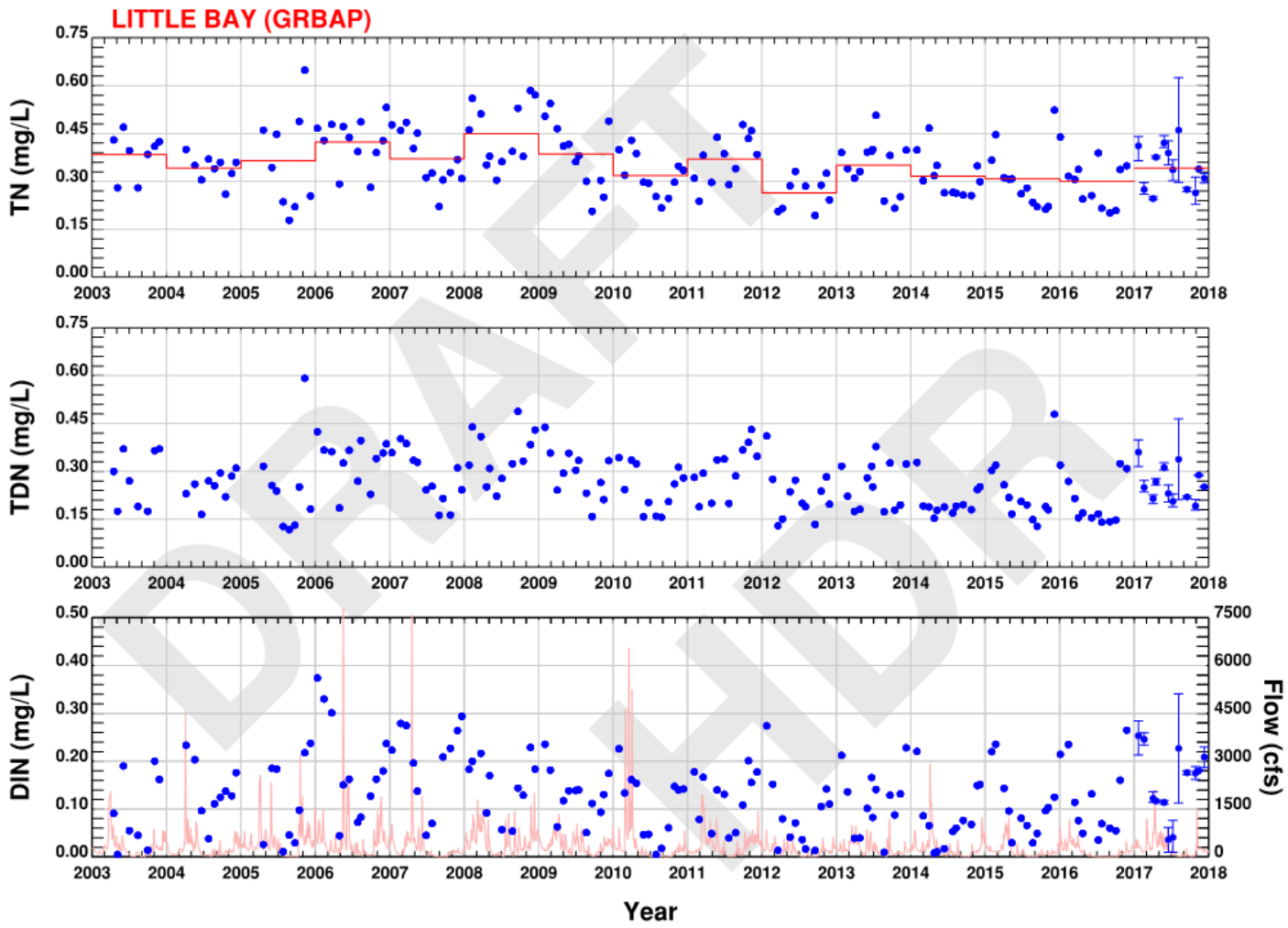
[1] Oceanic TN boundary Condition = 0.20 mg/L for all scenarios
[2] Point Source TN at 6.0 mg/L represents a TN monthly limit of 8.0 mg/L
[3] Point Source TN at 3.0 mg/L represents limit of technology
[4] Point Source Flow is at Design Flow
[5] Point Source Flow is at actual flow

Great Bay TN vs. TN Loads (Station GRBGB)



Summary

- An oceanic TN concentration of 0.20 mg/L produces an average Great Bay background (no PS & NPS loads) TN concentration of 0.15 mg/L
- A 100 kg/ha/yr TN load to the GBES increases the annual average Great Bay TN concentration by 0.10 mg/L
- Under current conditions (2010, 2011, 2017), PS TN loads are 38% of the PS + NPS loads to the GBES. This percentage decreases to 26% without the Portsmouth Pierce Island WWTF load
- At design wastewater flows, a reduction in PS effluent concentration from 6 mg/L to 3 mg/L decreases the annual average Great Bay TN concentration by 0.02 mg/L


LITTLE BAY (GRBAP)
TN (mg/L)
TDN (mg/L)
DIN (mg/L)
Flow (cfs)
Year
0.75
0.60
0.45
0.30
0.15
0.00
0.50
0.40
0.30
0.20
0.10
0.00
7500
6000
4500
3000
1500
0
2003
2004
2005
2006
2007
2008
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