Neponset River Watershed Assessment Phase 1: Nutrient fluxes

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In any ecosystem, the chemical and physical processes of the environment affect the biological communities (Evans 1956). In turn, the metabolic processes of the biological organisms, such as respiration, photosynthesis, and decomposition, determine the cycling of nutrients and energy transfer. Oxygen, carbon, nitrogen and phosphorous are key elements in the biochemical cycle that occurs in marine systems (Evans 1956; Redfield 1958). The autotrophic growth of organic matter is stimulated, via photosynthesis, by the input of carbon dioxide, energy (sunlight), and the vital nutrients of nitrogen and phosphorous (Redfield 1958; Valiela 1997b). Moderate amounts of nitrogen and phosphorous are, therefore, essential to the maintenance of a healthy ecosystem, but can be dangerous to biodiversity if under or over represented. Excessive amounts of nitrogen and phosphorous stimulate primary production at an unsustainable rate, a process called eutrophication, disrupting the complex balance of the ecosystem as a whole (Kemp *et. al.* 2005; Officer *et. al.* 1984).

Eutrophication of coastal marine ecosystems can be a natural process and be caused or accelerated by anthropogenic influences. Dangerous levels of eutrophication, in some cases, have been caused by the massive expansion of human populations across the globe (Bricker *et. al.* 1999; Bricker *et. al.* 2008). The anthropogenic effects of urbanization, industrialization, and agriculture have resulted in nutrient loading of estuarine systems that can stimulate the overproduction of organic matter, in the form of dangerous algal blooms. Unregulated growth from primary production can have negative cascading effects on the trophic system and can result in the loss of biodiversity and in some cases the hypoxia (reduction of oxygen) or anoxia (absence of oxygen) of the water body (Kemp *et. al.* 2005; Officer *et. al.* 1984; Martinetto *et. al.* 2006; McClelland & Valiela 1997a).

Anthropogenic nutrient loading of a water system can occur from three main sources: fertilizers, wastewater and atmospheric deposition (wet and dry) (Valiela *et. al.* 1997a; Bricker *et.al.* 2008). Fertilizers used in agriculture (e.g. farmlands, golf courses, residential lawns, landscaping, and ball fields) are high in nitrates and phosphates that can seep into the groundwater and contribute to the overall nutrient content of a watershed. Wastewater from septic systems, faulty sewage lines, cesspools, and urban runoff can also contribute to nutrient loading of a coastal system. This can result from seepage into the groundwater, which will eventually flow to the mainstream or through direct input into the system. Atmospheric deposition is more difficult to quantify, but combustion of fossil fuels from industry and automobiles release nitrogen into the air, which will later rain down directly onto the water surface (wet deposition) or onto the land surfaces surrounding the watershed (dry deposition) that may eventually wash into the river system (Howes *et. al.* 2010; Bowen *et. al.* 2007). Quantifying the level at which these inputs occur in a particular geographic area can be difficult, as every system has its own physical, biological, and geological parameters that interact with each other and its anthropogenic surroundings differently.

The Neponset River watershed is located on the eastern coast of Massachusetts, southwest of Boston. It drains an area of roughly 300 square miles that includes 14 towns and cities composed of both suburban and urban demographics. The Neponset River itself runs for 30 miles, starting in Foxboro and ending in Dorchester Bay, right next to UMass Boston campus (NRWA website: http://www.neponset.org/). The estuary at Dorchester Bay is showing signs that increased population densities of neighboring towns and cities have impacted the waterway. In years past, the estuary was comprised of thick eelgrass (*Zostera marina*) meadows providing habitat to a vast array of species and acting as a buffer between land and sea. Presently, there is little to no eelgrass left.

The loss of vital seagrass beds, in the Neponset River estuary may be an indicator that eutrophication has occurred. The Neponset River watershed runs through many developed areas and the estuary itself is located in an extremely urbanized locale of Massachusetts. Anthropogenic activity and its related nutrient inputs, such as wastewater, fertilizers, impervious runoff, and fossil fuel combustion (atmospheric deposition) are presumably high in the area. In a eutrophic system, nutrient enrichment of the water body encourages the growth of primary producers, such as phytoplankton and algae. Algal blooms can result in reduction of light and dissolved oxygen depletion that will likely stifle other vegetative growth (Bricker *et. al.* 1999; Martinetto *et. al.* 2006). Eelgrass (*Z. marina)* is a rooted, vascular plant that can only grow in the photic zone in aerobic conditions, and is extremely vulnerable to eutrophic conditions (Heck *et. al.* 2008).

Citizen scientists working with the Neponset River Watershed Association (NRWA) found dangerous levels of nutrients (total nitrogen and organophosphates, nitrates and nitrites, ammonia, and total phosphorous) in 24 out of 25 sites sampled between 2001 and 2003. These results encouraged the NRWA to request from the DEP (Department of Environmental Protection) that 18 stream segments be added to the 303(d) list of impaired waters (NRWA Assessment Report 2004). It is clear, then, that the Neponset River watershed is susceptible to contamination and nutrient loading.

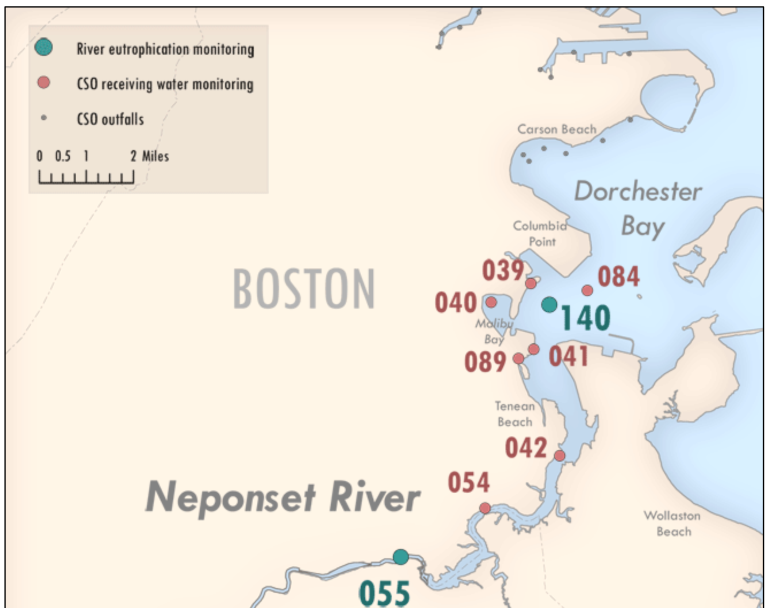


Figure 1: MRWA Sampling Sites (source: MRWA.state.ma.us)

In this report, a rudimentary attempt to quantify nutrient inputs in the Neponset River watershed was made using the web-based nitrogen loading model, NLOAD (http://nload.mbl.edu/index.php), and a dataset of actual nutrient measurements made available by the MRWA Environmental Quality Department on their website (http://www.mwra.state.ma.us/harbor/html/nr_wq.htm). The MRWA's Environmental Quality Department manages water quality data on Boston Harbor and its tributaries, including the Neponset River. The organization supplies the nutrient data (along with data on bacteria, dissolved oxygen, water quality, algae, and total suspended solids) collected from sample sites in the Neponset River and at the river mouth. There is data starting in 1994 and ending in 2011. The most complete data set is of bottom and surface nitrate/nitrite concentrations at site 055 and 140 (see Figure 1). Unfortunately, there is no nutrient data at intermediate sites downstream of 055 to the mouth.

Where data could not be found for model inputs, assumptions were made based on local and state census data, various literature sources, and visual estimations using GIS as detailed.

Results and Analysis

MRWA data

Certain considerations are applicable to all of the MRWA data. Firstly, although it spans over 15 years, this is a relatively short-term dataset in atmospheric and nutrient cycling terms. Therefore it may not elucidate long-term terms in nitrate and phosphate concentrations. The data includes some extremely suspect readings that seem unlikely to be accurate even considering the potential effects of episodic events. Nothing has been omitted from the data-set, but it is possible that some outliers are the product of sampling technique or equipment calibration.

The dataset was also noisy, and defied easy import and analysis in R. There were no null values included, with many records including blank data fields. In cases where both nitrate/nitrite and phosphate data-fields were blank, the records were omitted on the assumption that the sampling or analysis techniques prevented obtaining of data. There is a single record including a value for nitrate/nitrite and a blank cell for phosphate that slipped through the net and appears on the figures as a false zero value. The final consideration is that intervals between samples varied, and presented on scatter plots this creates a false impression of clustering. Samples taken with shorter intervals between are intuitively likely to have more similar values than those with longer intervals between.

Upstream site (Station 55)

There has been no discernible change in the concentration of either nitrates/nitrites (Figure 2) or phosphates (Figure 3) since sampling began in 1997. The variance also appears unchanged. This implies there has been no net rise or fall in input from atmospheric, wastewater and fertilizers that contribute to the upstream nutrient loads. There has also not been any substantial increase in episodic events that cause nutrient fluctuations. This also implies that upstream nutrient input is not a dampening or compounding factor on downstream nutrient loads during the study period. This data contributes little in terms of recommendations for management. It is possible that the various inputs into the upstream portion of the system have changed, but without a net effect on nutrient loads.

Downstream site (Station 140)

There has been no discernible change in the concentration of either nitrates/nitrites (Figure 4) or phosphates (Figure 5) since sampling began in 1994. The variance also appears unchanged. This implies that there has been no net rise or fall in input from atmospheric, wastewater and fertilizers that contribute to downstream nutrient loads. There has also not been any substantial increase in episodic events that cause nutrient fluctuations.

In figure 5 it can be seen that surface concentrations of nitrates/nitrites (typically taken at 0.1-0.2m of depth) are consistently higher than concentrations from bottom sediment (depth varies 0.5m-5m). However, phosphate concentrations (Figure 5) remain relatively consistent between surface and sediment levels. It is possible that this provides evidence for nitrogen being the limiting nutrient in the Neponset system as it is relatively abundant at the surface then is extensively utilized through the water column, resulting in a lower concentration in the sediment. Phosphate on the other hand, if not the limiting factor, is not extensively utilized through the water column and so are present in roughly equal concentrations in surface waters and the sediment. The lack of a depth gradient for concentrations of phosphate in the sediment also supports this.

Upstream vs. Downstream

As there was no substantial change observed in nitrates/nitrites and phosphate concentrations over the study period, values for upstream (station 55) and downstream (station 140) were averaged over the study period and compared. The upstream concentration of nitrates/nitrites was 34.57µM, and the downstream concentration was an average of 6.21µM. This represents a considerable loss over the downstream progress of the Neponset, possibly due to exploitation of the nitrates/nitrites by organisms. The volume of water also increases greatly downstream, and if the volume increase simply outpaced the rate of nitrate/nitrite input then the concentration would drastically decrease.

Phosphate, on the other hand, increased from the upstream site to the downstream site from 0.61 µM to 0.91µM. This net gain could be attributed to anthropogenic activities over the course of the river. Since nitrogen lowered and phosphate rose from upstream to downstream this may imply that nitrogen is the limiting nutrient in the system and therefore is used at a higher rate, while phosphate accumulates. Considering the previously described effect of the increase in water volume on concentration of nitrates/nitrites, either the phosphate input greatly outpaces this dilution, or the nitrate/nitrites are being exploited.

Figure 2: Nitrate/Nitrite Concentrations Upstream (Station 55) Neponset River

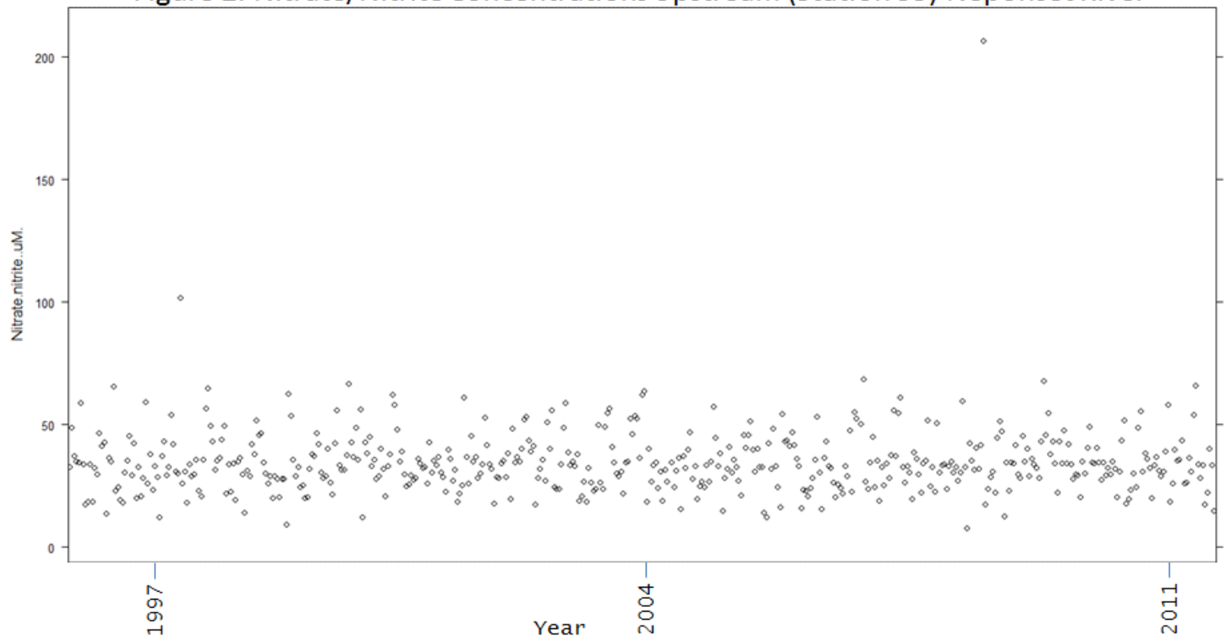


Figure 3: Phosphate Concentration in Upstream Neponset River (Station 55)

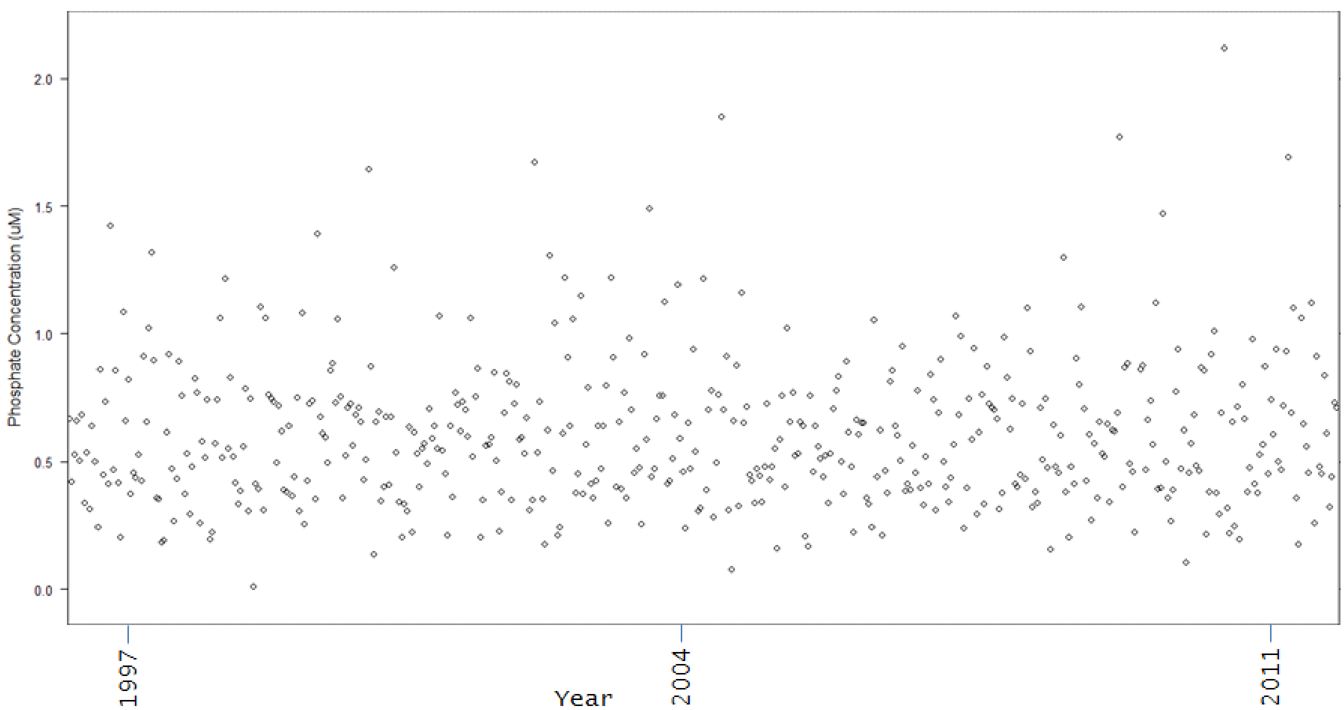


Figure 4: Nitrate/Nitrite Concentrations Downstream (Station 140) Neponset River

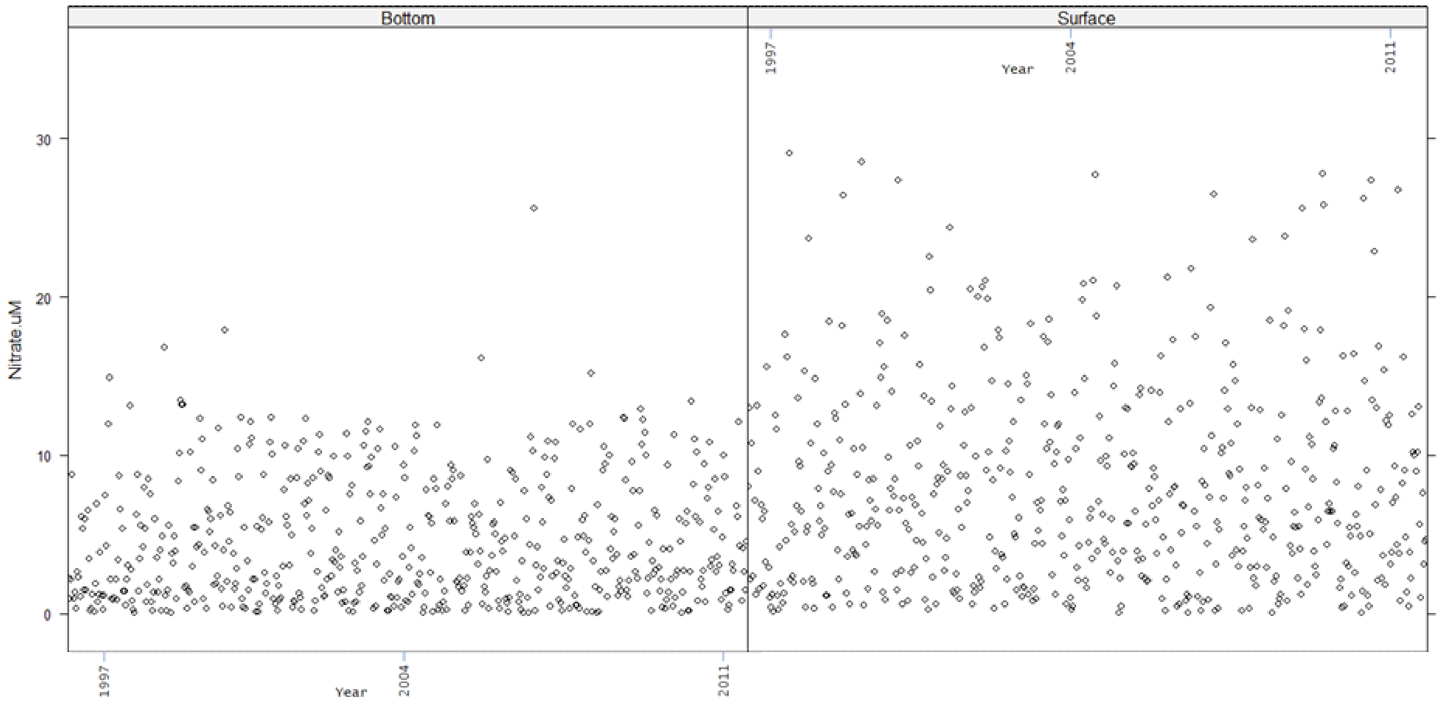
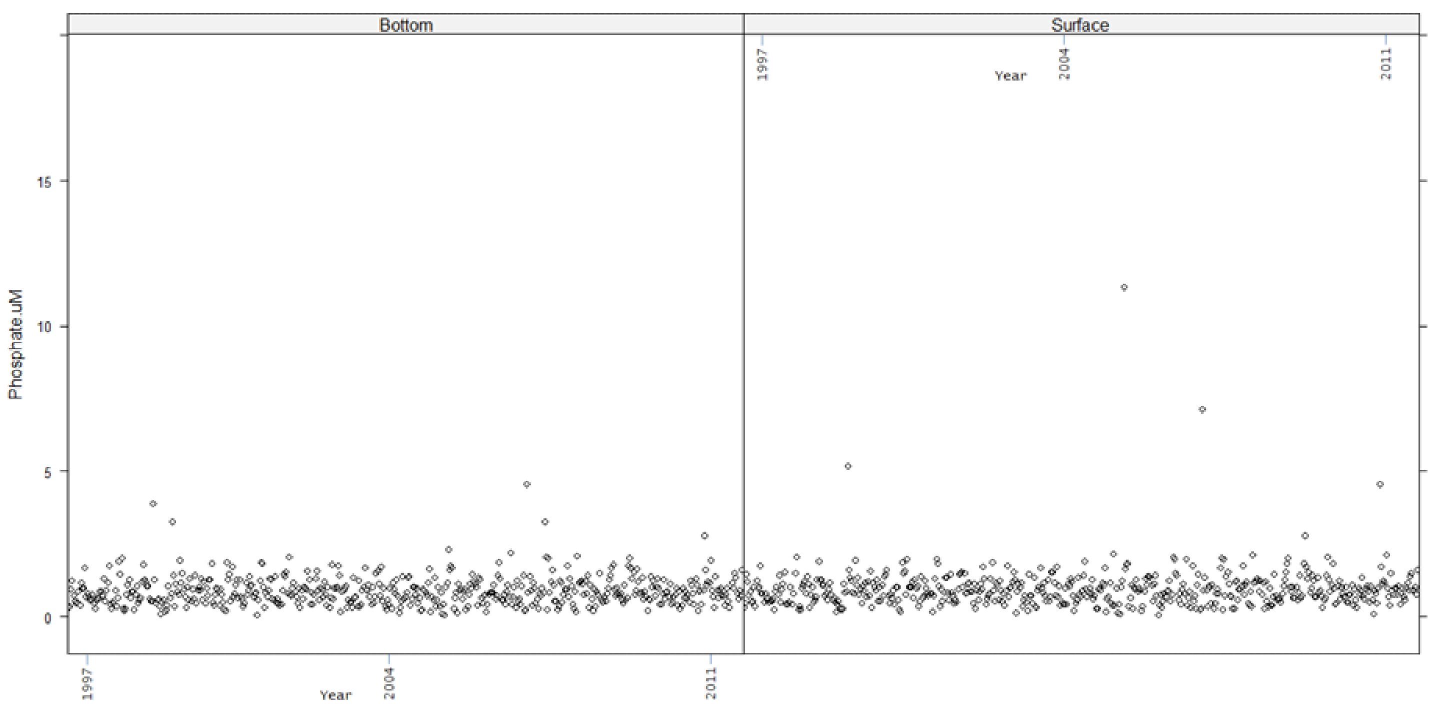


Figure 5: Phosphate Concentrations Downstream (Station 140) Neponset River



NLoad Model

The NLoad Model considers inputs (see Table 1) and calculates the Total Dissolved Nitrogen (TDN) input from a watershed to a river. The specific task carried out through the web-based NLoad model was the estimation of contributions to TDN load from wastewater, fertilizer, and atmospheric deposition. It assumes nitrogen outputs in various forms from each land-use type and amalgamates the results into TDN derived from wastewater, atmospheric and fertilizer (see Table 2). The inputs in Table 1, used to model the Neponset river TDN load, were assumptions constructed from local and state census data, various literature sources, and GIS.

Figure 6 shows the proportional contribution of nitrogen sources to TDN load in the Neponset River according to the NLoad Model. It suggests that wastewater is by far the most substantial input of nitrogen. This would make it an obvious target for management recommendations aimed at reducing TDN in the Neponset. However, it is possible that the contribution of wastewater is being overestimated as much of the wastewater generated in the Neponset River watershed enters a sewage system and is actively pumped out to Deer Island after secondary treatment, beyond the geographical boundaries of the system. It is possible that the model is based on infrastructures where septic tanks are more prevalent and therefore there is much higher direct nitrogen input through seepage.

Figure 6: Total Nitrogen Delivered to Watershed (kg N/year)

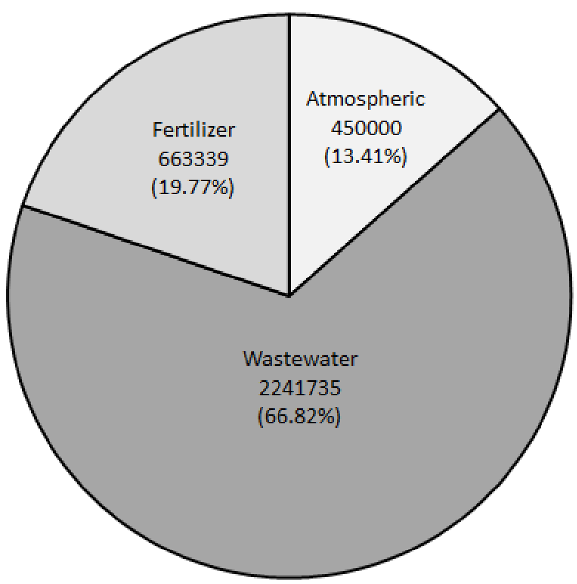


Table 1: Neponset River Watershed NLOAD Input Data			
Parameter	Value	Method	Source/Reference
Total Area of Watershed	300 km^2	NRWA Website	http://www.neponset.org/Watershed.htm
River length	47 km^2	NRWA Website	http://www.neponset.org/Watershed.htm
Total Number of People	300, 000	NRWA Website	http://www.neponset.org/Watershed.htm
Housing Density	334.4 houses/mi^2	MA Census Data	http://www.census-charts.com/Density/Massachusetts.html
Total number of Houses	259,827	334.4 houses per square mile (1), converted to square km, multiplied by 300 km^2	http://www.census-charts.com/Density/Massachusetts.html
Houses 200m from shore	16,282	Multiplied length of river (47km) by 200m (x2 for both sides), then took housing density converted to km2 over that area	Reference table
Impervious Cover	72 km^2	Converted percentage listed in the literature (24%) to km2	NRWA 2004 Assessment Report
Pond Area	5.29 km^2	Used Adobe Photoshop to estimate the pond area verses land area (counted pixels)	Map used courtesy of Ian Cooke. Posted on course wiki
Land uses:			
Residential area	114 km^2	Converted percentage listed in the literature (38%) to km^2	Huang & Chen 2009
Forest area	102 km^2	Converted percentage listed in the literature (34%) to km^2	Huang & Chen 2009
Industry	15 km^2	Converted percentage listed in the literature (5%) to km^2	Huang & Chen 2009
Wetland	12 km^2	Converted percentage listed in the literature (4%) to km^2	Huang & Chen 2009
Golf Course	6 km^2	Converted percentage listed in the literature (2%) to km^2	Huang & Chen 2009
Baseball fields	0.15 km^2	Estimated using GIS: 15 baseball fields in the watershed each 9800 $m^{2,}$ equals 147,000 m^2 or 0.147 km^2	https://maps.google.com/
Cranberry Bogs	0 km^2	Estimated using GIS: no visible bogs in the watershed	https://maps.google.com/

Table 2: NLoad Model Results

Output	Value	Unit
Total atmospheric N delivered to watershed	450000	*kg N per yr*
Total wastewater N delivered to watershed	2241735.39	*kg N per yr*
Total fertilizer N delivered to watershed	663338.83	*kg N per yr*
Total N load to watershed	3355074.22	*kg N per yr*
Percent of N load to watershed from atmospheric sources	13.41	*percent*
Percent of N load to watershed from wastewater sources	66.82	*percent*
Percent of N load to watershed from fertilizer sources	19.77	*percent*
Total atmospheric N delivered to estuary	66132.38	*kg N per yr*
Total wastewater N delivered to estuary	651237.96	*kg N per yr*
Total fertilizer N delivered to estuary	103416.18	*kg N per yr*
Total N delivered to estuary	820786.52	*kg N per yr*
Percent of N delivered to estuary from atmospheric sources	8.06	*percent*
Percent of N delivered to estuary from wastewater sources	79.34	*percent*
Percent of N delivered to estuary from fertilizer sources	12.6	*percent*

Future Directions

The ultimate aim of this investigation is to make management recommendations with an aim to create the ecological conditions necessary for a repopulation of eelgrass in the Neponset River estuary. There are likely multiple environmental conditions that currently make Neponset River estuary an unsuitable habitat for eelgrass. On the broad scale, establishing causation for environmental parameters that fall outside of the suitable conditions for eelgrass is a big step. Those resulting from anthropogenic influences could be altered by management and policy, but those resulting from global environmental change are less malleable. Understanding whether the reintroduction of eelgrass is possible given ideal management conditions is the next logical step in the assessment process.

On the fine scale, the adjustment of nutrient load models in terms of their inputs and their relative weighting will give a more accurate picture of the nutrient fluxes in the system. Estimations of parameters can certainly be improved. Priority should be given to those that the model is deemed to be most sensitive to. A variety of techniques and sources of data exist, especially GIS-based, that would greatly refine model input estimations. However, these techniques tend to be extremely labor-intensive and possibly beyond the scope of a preliminary study.

Any management plan recommended by this study should include proposed sampling schemes that would allow proper evaluation and adaptation of management approaches. In particular, partitioning the Neponset River by monitoring nutrients at more of the MWRA stations along its course would greatly improve both the accuracy of models and also the targeting of management.

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