Estimates of nitrogen loads to Casco Bay

FINAL DRAFT December 21, 2012

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Introduction

The nationwide excess of reactive nitrogen (Nr) is causing impairment to one-third of U.S. streams and two fifths of U.S. lakes (EPA Science Advisory Board (SAB; 2011).[1] Although this is especially acute in the Mississippi River and Chesapeake Bay watersheds,other areas of the United States are also suffering the effects of increased nitrogen delivery to coastal waters. Between 5 and 10% of coastal waters in the Gulf of Maine exhibit elevated levels of nitrogen or chlorophyll *a* .[2] Specific areas of concern include nearshore estuaries such as Great Bay, Salem Sound, Boston Harbor, some Cape Cod embayments and to a smaller degree, parts of Casco Bay (see Figure 2 below).[3]

Recently, the EPA Science Advisory Board, with approval by Administrator Lisa Jackson, recommended that a 25% reduction of the reactive nitrogen introduced into the environment should be obtained in the next 10 to 20 years with available technology.[4] In parallel, EPA Region 1 has undertaken many projects and utilized many regulatory and non-regulatory tools, to reduce delivery of nitrogen to coastal waters. These include setting stricter permit limits for sewage treatment plants, promoting nitrogen removal in stormwater control structures, developing nutrient criteria for coastal waters, promoting habitat restoration in coastal watersheds within National Estuary Programs, removing sources of degradation using the EPA's "*Healthy Watershed*" framework, and promoting low impact development (LID) and agricultural best management practices.

Casco Bay, one of the NEPs, is experiencing potentially increased nutrient levels, as documented by the Friends of Casco Bay and the Casco Bay Estuary Partnership (CBEP) in the State of the Bay 2010 Report.[5] To evaluate the feasibility of nitrogen reductions, it is important to evaluate existing loadings of nitrogen, and the relative contribution of nitrogen from the different sources. These sources include wastewater treatment plants

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[1] SAB (Science Advisory Board to the US Environmental Protection Agency). 2011. Reactive Nitrogen in the United States; an analysis of inputs, flows, consequences, and management Options. US Environmental Protection Agency: Washington, DC. EPA-SAB-11-013.
[2] Liebman, M. Benoy, G., Latimer, J.S. and S. Bricker. 2012. Eutrophication: State of the Gulf of Maine Report. Gulf of Maine Council on the Marine Environment.
[3] There is concern that in the last decade some eelgrass habitat has been lost in Casco Bay, but no hard evidence supports this concern. An aerial survey is planned for 2013.
[4] SAB. 2011. Ibid.
[5] Casco Bay Estuary Partnership. 2010. State of the Bay 2010. Muskie School of Public Service, University of Southern Maine. http://www.cascobay.usm.maine.edu/sotb10.html

(WWTP), septic systems, urban stormwater, atmospheric deposition, and agricultural sources.

This paper presents results of our analysis of the estimated nitrogen loading to Casco Bay using the USGS SPARROW (SPAtially Referenced Regressions On Watershed attributes) model to Casco Bay for the 2000s time period. We compared these results to estimates of nitrogen loading from a mass balance model using 1990s era data and to the Simple Model[6] for calculating runoff from impervious surfaces.

Methods

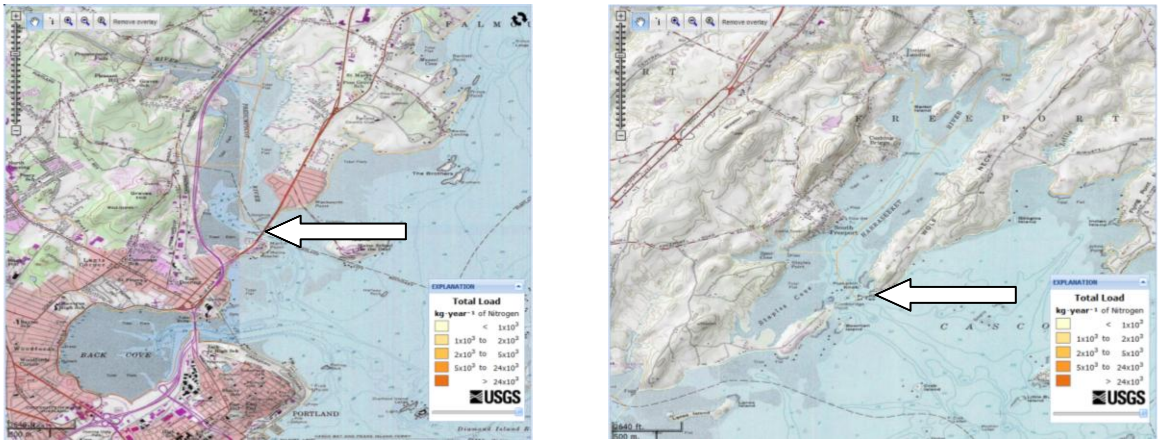
Nitrogen load predictions from the Northeast SPARROW model for NHDplus stream networks that drain to Casco Bay were retrieved from the USGS online SPARROW decision support system.[7] The Northeast SPARROW model is calibrated to USGS gauging stations and predicts long-term average annual nitrogen and phosphorus flux and water flow for the Northeast and Mid-Atlantic area based on 2002 landscape conditions. The model considers land to water delivery, as well as in-stream loss terms (e.g. nitrogen attenuation), and apportions estimates contribution to the total nutrient mass from the following sources: (1) permitted wastewater discharge; (2) runoff from developed land; (3) commercial fertilizer applied to agricultural land planted in corn, soybean, and alfalfa, plus, for nitrogen, estimates of nitrogen mass from nitrogen fixation by soybean and alfalfa; (4) commercial fertilizer applied to agricultural land in other crops; (5) manure from livestock production; (6) atmospheric (wet) deposition of inorganic nitrogen (nitrogen only); and, (7) runoff from forested lands (phosphorus only) (Moore *et al.*, 2011).[8]

Atmospheric deposition is modeled based on data from the National Atmospheric Deposition Program (NADP) but only includes wet deposition of regional sources, and may not fully account for dry deposition contributions, especially from local urban sources. The developed land source term, however, includes contributions from these urban sources. Developed, agricultural and forested land is defined by the 2001 National Land Cover Database (NLCD) available at 30 meter resolution. Developed land, as defined by the NLDC includes open space (e.g. golf course) and low density (about 20% impervious cover) up to high density residential and commercial settings (100% impervious cover). Therefore, developed land represents delivery of nitrogen from urban stormwater, localized atmospheric dry deposition, fertilizer use for suburban lawns and potentially septic systems.

[6] Schueler, T. 1987. Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments. Washington, DC.
[7] http://cida.usgs.gov/sparrow/
[8] Moore, Richard B., Craig M. Johnston, Richard A. Smith, and Bryan Milstead, 2011. Source and Delivery of Nutrients to Receiving Waters in the Northeastern and Mid-Atlantic Regions of the United States. *Journal of the American Water Resources Association* (JAWRA) 47(5):965-990. DOI: 10.1111/j.1752-1688.2011.00582.x

The stream network is based on the NHDplus network, a 1:100,000 scale network with an average stream segment of 2.3 km^2. Results are reported as the average total nitrogen in kilograms per year delivered to coastal waters at the most downstream segment of the reach, which is usually as it enters the bay (Figure 1).

Figure 1. Locations of the furthest downstream segments for the Presumpscot (left) and Harraseeket (right) rivers.



Results: Nitrogen loadings

Over 825,000 kg of nitrogen is estimated to be delivered to Casco Bay on an annual basis (Table 1). Four rivers, the Presumpscot, Royal, Stroudwater and Harraseeket, account for 88% of the total nitrogen delivered to the Bay. It is no surprise, then, that the highest ambient levels of nitrogen are observed at the mouths of these rivers in Casco Bay (Figure 2).[9] (These embayments also have less flushing than outer Bay stations.) The four rivers that discharge to Portland and the Fore River (Presumpscot, Stroudwater, Capisic Brook and Long Creek) account for about 72% of the total loads to the Bay.

It should be noted that the SPARROW model does account for instream losses in headwater streams and wetlands, but these losses are not expected to be high, especially loads delivered near the coast. On average, the total nitrogen attenuation predicted by the SPARROW model in this watershed is about 1%.[10] Most models of nitrogen retention, however, predict attenuation of 20% to 30%. The Northeast SPARROW model compensates for this underestimate of instream nitrogen attenuation by over estimating watershed attenuation (Bryan Milstead, personal communication). Nevertheless, most attenuation of nitrogen is expected to occur before the nitrogen is delivered to major rivers and streams.[11]

[9] Casco Bay Estuary Partnership. 2010. State of the Bay 2010. Muskie School of Public Service, University of Southern Maine. (http://www.cascobay.usm.maine.edu/sotb10.html

[10] Bryan Milstead calculation, December 5, 2012.

[11] Based on presentations by Michelle Daley, UNH for Lamprey River watershed studies.

Figure 2. From State of the Bay 2010 Report. CBEP, 2010. Based on data collected by the Friends of Casco Bay. Although the levels of nitrogen observed here are higher than levels proposed by New Hampshire DES as numeric nutrient criteria in Great Bay[12], no waters in Casco Bay have been officially listed as impaired.

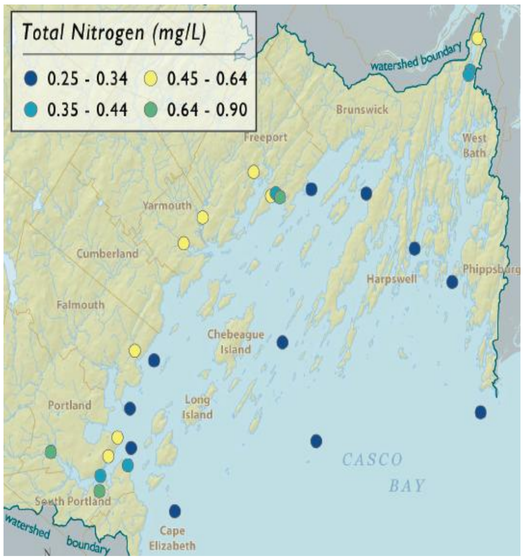


Table 1. Estimates of total nitrogen loads in kg per year from different sources identified in the SPARROW model.

SPARROW stream name	Location	Development	Atm Dep	WWTP	Other Fert	Manure	Corn Soy	Total	Flow_CFS
Presumpscot River	Portland	232351	151816	90446	31987	16467	15922	538989	1269
Royal River	Yarmouth	58557	35786	12293	13493	8198	6176	134503	321
Stroudwater River	South Portland/Fore River	19291	5971	0	3247	1634	1891	32033	52
Harraseeket River	S. Freeport	10536	4298	5251	647	364	232	21330	35
Capisic Brook	Portland	12718	1172	0	186	108	67	14251	9
Long Creek	Portland	8727	938	0	187	114	67	10033	7
New Meadows River	Harpswell/Phippsburg	5709	3253	0	318	245	66	9591	32
n/a	Brunswick/Naval Air Station	7230	1017	0	147	97	53	8544	11
Fall Brook	Back Cove	6515	448	0	3	2	1	6969	4
Mill Creek	Falmouth	5214	1299	0	106	60	38	6717	11
Barberry Creek	South Portland	5560	698	0	169	104	61	6592	5
Trout Brook	South Portland	4520	660	0	84	52	30	5346	5
Red Brook	South Portland	3689	835	0	238	134	85	4981	6
Bunganac Stream	Brunswick	1667	1307	0	597	332	214	4116	10

[12] New Hampshire Department of Environmental Services. 2009. Numeric Nutrient Criteria for the Great Bay Estuary prepared by Philip Trowbridge, P.E. June, 2009. Concord, NH.

Pasture Brook	Winnegance Bay/Phippsburg	1528	2106	0	5	23	0	3663	20
n/a	Cumberland Foreside	2125	356	0	64	38	23	2606	3
Pond Cove Brook	Cape Elizabeth	1858	425	0	33	18	12	2347	3
Alewife Brook	Cape Elizabeth	1293	538	0	78	44	28	1981	4
Miller Creek	Brunswick/Maquoit Bay	924	478	0	156	86	56	1700	4
n/a	Woodward Cove	1302	304	0	36	20	13	1674	2
n/a	Brunswick/Maquoit Bay	1161	325	0	51	37	18	1593	3
Little River	Freeport	682	652	0	120	67	43	1565	5
n/a	Brunswick/Maquoit Bay	545	275	0	238	139	85	1283	2
n/a	Buttermilk Cove	961	208	0	19	10	7	1205	1
North Creek	Phippsburg	588	601	0	1	1	0	1192	5
n/a	Delano Park	805	228	0	6	3	2	1043	2
n/a	Back Cove	980	61	0	0	0	0	1041	0
n/a	Harpswell Neck	295	98	0	0	5	0	398	1
n/a	Harpswell Neck/Clark Cove	212	111	0	0	7	0	329	1
Total		**397545**	**216265**	**107991**	**52213**	**28409**	**25190**	**827612**	**1833**

Sources of nitrogen to Casco Bay and comparison to other estimates

Within the watershed, developed land and atmospheric deposition, are the major sources of nitrogen to Casco Bay (Table 2). It should be noted, however, that septic systems are not separately calculated, and are considered part of the developed land component.

Table 2. Relative contribution of different sources of nitrogen to Casco Bay.

Source	Percentage
Developed land	48.0
Atmospheric Deposition	26.1
Wastewater Treatment Plant	13.0
Agricultural sources	12.7

How do these results compare to other estimates using different approaches? Bricker *et al., 2006*[13] reported nitrogen loadings to Casco Bay as 983,506 kg per year, based on the WATERSN mass balance based nitrogen loading model from Whitall *et al*., 2004.[14] The

[13] Bricker S, Lipton D, Mason A, Dionne M, Keeley D, Krahforst C, Latimer J, Pennock J (2006) Improving Methods And Indicators For Evaluating Coastal Water Eutrophication: A Pilot Study in the Gulf of Maine. NOAA National Ocean Service National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment, Silver Spring, MD. Also reported in Latimer, J.S. and Charpentier, M.A. 2010. Nitrogen inputs to seventy-four southern New England estuaries: Application of a watershed nitrogen loading model. Estuarine, Coastal and Shelf Science 89: 125-136.

[14] Whitall D, Castro M, and Drisoll C (2004) Evaluation of management strategies for reducing nitrogen oadings to four U.S.estuaries. Science of the Total Environment 333:25–36.

Whitall *et al*., 2004 mass loading approach, however, includes wastewater treatment plant discharges (based on population), while the SPARROW model results do not include discharges of wastewater treatment plants directly into Casco Bay. Maine Department of Environmental Protection estimated annual nitrogen loads from wastewater treatment plants that discharge directly to Casco Bay (Table 3). These loads are approximately the same as loads from rivers to Casco Bay. When you include these sources, wastewater treatment plants account for over 58% of the nitrogen loads to Casco Bay (Table 4). This proportion differs significantly from the results of Bricker *et al.*, 2006 which estimates higher values for atmospheric deposition and lower values for wastewater (Table 5). The rank order is still the same.

Table 3. Loads from Wastewater Treatment Plants (WWTP) to Casco Bay. Source: ME DEP, 2008[15]

Source	Total nitrogen loads (kg/year)
Portland Water District	546,134
South Portland	256,450
Falmouth	42,990
Yarmouth	36,211
Freeport	20,668
TOTAL	902,453

Table 4. Relative contribution of different sources of nitrogen accounting for coastal sewage discharges, based on the SPARROW model results and ME DEP (Table 3).

Source	Percentage
Developed land	22.9
Atmospheric Deposition	12.5
Wastewater Treatment Plant	58.4
Agricultural sources	6.1

Table 5. Relative contribution of nitrogen sources from Bricker *et al.*, 2006 using the WATERSN nitrogen loading model.

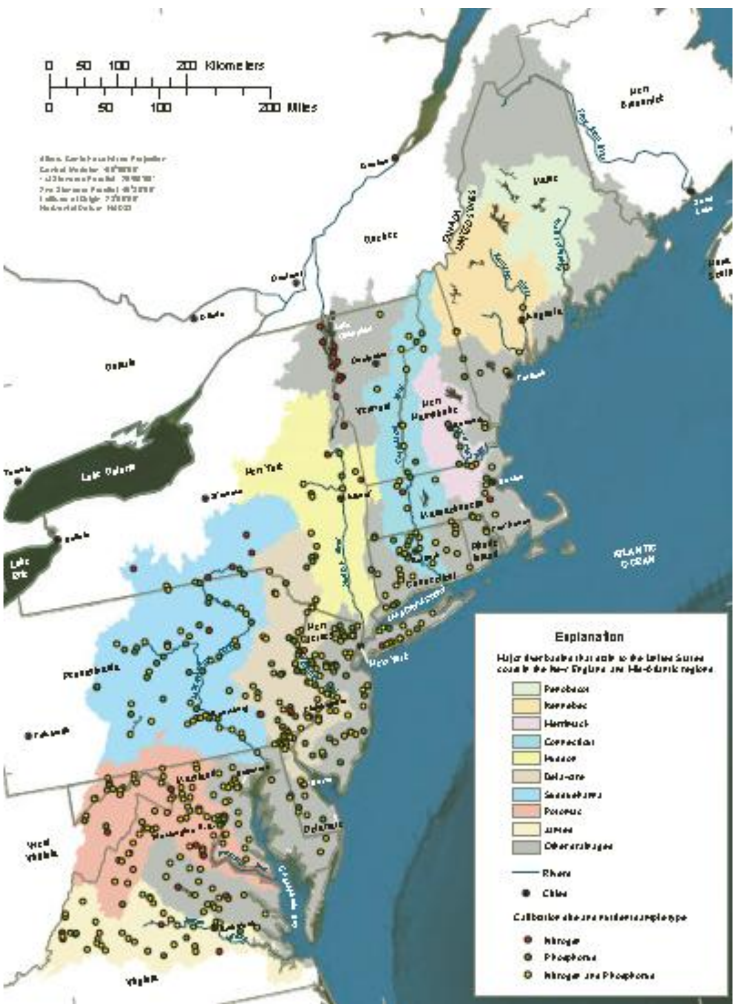
Source	Percentage
Developed land	17.8
Atmospheric Deposition	34.6
Waste Water Treatment Plant	41.2
Agricultural sources	5.3

[15] Maine Department of Environmental Protection. 2008. Development of Nutrient Criteria for Maine's Coastal Waters. Contact: Andrew Fisk, Director Bureau of Land and Water Quality.

Limitations of the model

The SPARROW nutrient model is an estimate, and based on a calibration of 363 river discharge datasets in New England and the mid-Atlantic, but only six stations are located in Maine (Figure 3).[16] Fewer are actually in the Casco Bay watershed. In addition, the input and stream discharge data are also calibrated for the early 2000s time period, about ten years ago. Land use and WWTP discharges have clearly changed since then. Finally, the estimates of the relative contribution of the different nitrogen sources should be considered with caution, as some parameters in the model are fit to better predict loadings.

Figure 3. Map of Northeastern and Mid-Atlantic Regions Study Area, Major Watersheds Within the Study Area, and Nutrient Load Calibration Points. From Moore *et al.*, 2011.



[16] Moore et al., 2011. Ibid.

Stormwater accounting and calculation of impervious surfaces

One of the CBEP priorities[17] is reducing impacts from storm water -- water that flows along the ground after a rainfall, or during snowmelt. Stormwater runoff carries sediments and nutrients such as nitrogen into streams and rivers that flow directly or indirectly into Casco Bay. This storm water mainly comes from nonpoint sources, often conveyed over impervious surfaces such as roads, parking lots, rooftops and compacted soils through a pipe into a water body. Recent research has established a linkage between the percent of impervious surface within a watershed and water quality impairment in streams. Watersheds that exceed 10% impervious cover tend to exhibit impairments in aquatic life due to effects of sedimentation, nutrient enrichment and loss of habitat.[18]

EPA Region 1 has focused significant attention on the role of percent impervious cover as a cause of or indicator of impairment of water quality. For example, EPA has encouraged and approved TMDLs for impervious cover; has exercised its residual designation authority (RDA) to reduce stormwater impacts in rivers or streams[19]; and have proposed that the Commonwealth of Massachusetts MS4 stormwater permits may require monitoring impervious cover to better control discharges to impaired streams. In order to implement these tools, we need to define or account for credits (estimates of pollutant removal performance) for a range of best management practices, to effectively remove the impacts of impervious surface.[20]

One approach to accounting for the effects of impervious cover is to estimate pollutant loading using a runoff model called the Simple Method. The Simple Method (as described in Schueler, 1987 and 2011) determines the pollutant load from stormwater derived from impervious land cover as a product of annual runoff volume and pollutant concentration.

$$L=0.226*R*C*A$$

where:
L = annual loads
R = annual runoff (inches)
C = pollutant concentration (mg/l)
A = watershed size (acres)
0.226 = unit conversion factor

[17] http://www.cascobay.usm.maine.edu/stormwater.html
[18] Shaver, E., Horner, R., Skupien, J., May, C. and G. Graeme Ridley. 2007. Fundamentals of Urban Runoff Management: Technical and Institutional Issues. 2nd Edition, 2007. North American Lake Management Society. Madison, WI 53703-0443.
[19] RDA can be implemented when EPA determines that stormwater permits are needed to control stormwater discharges causing or contributing to violations of water quality standards.
[20] Schueler, T. 2011. CSN TECHNICAL BULLETIN No. 9: Nutrient Accounting Methods to Document Local Stormwater Load Reductions in the Chesapeake Bay Watershed. Center for Watershed Protection. Version 1.0 REVIEW DRAFT Chesapeake Stormwater Network. August 15, 2011.

Annual runoff (inches) is calculated as a product of annual runoff volume, and a runoff Coefficient (Rv). Runoff is calculated as:

> $R = P * Pj * Rv$
> Where:
> R = annual runoff (inches)
> P = annual rainfall (inches)
> Pj = fraction of annual rainfall events that produce runoff (usually 0.9)
> Rv = Runoff coefficient

The runoff coefficient is calculated based on an established relationship to impervious cover in the subwatershed. This relationship has been established as follows:

$Rv=0.05+0.9Ia$
Where: Ia = percent impervious in the watershed

Thus, in order to calculate nitrogen loads from a watershed attributed to impervious surface, we need to know: the annual rainfall; typical concentrations of nitrogen discharges from stormwater; watershed size; and percent imperviousness in the watershed. We used ArcGIS to determine the percent imperviousness for the Casco Bay watershed (Figure 4).

Figure 4: Casco Bay Watershed. Source: CBEP, 2010.

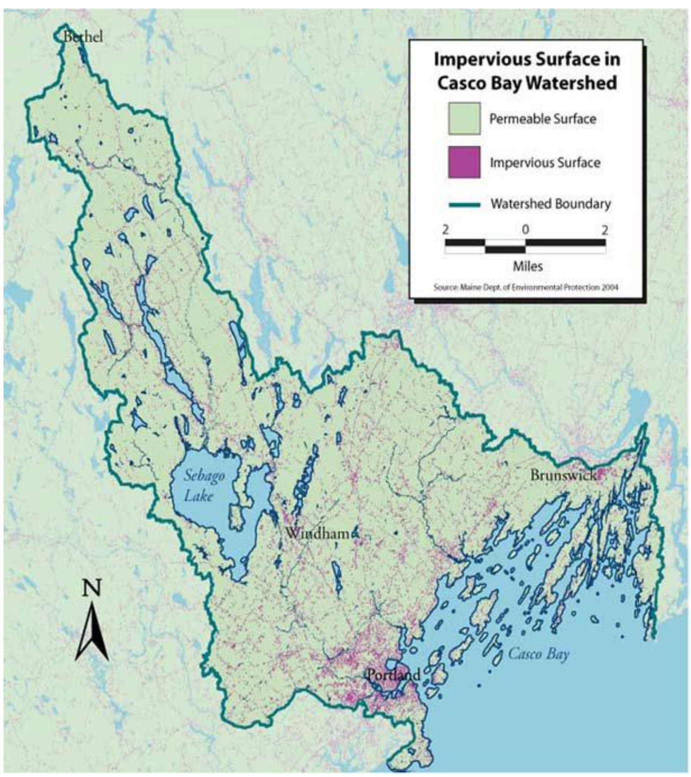


Table 6. Sources of data for calculation of runoff from impervious cover.

Data	Value	Source
Annual rainfall	50.809 inches per year	NOAA's rainfall data from various towns in Casco Bay. An average of available towns and then a total average was determined as an estimate for annual rainfall of Casco Bay watershed.
Nitrogen discharges in stormwater	1.88 mg/L	Concentration of pollutant (nitrogen) was provided by Mark Voorhees (EPA) based on a preliminary compilation of data.
Watershed size	682453.2 acres	ME GIS ArcGIS coverage (HUC 01060001). USDA Geospatial dataset.
Percent imperviousness	6.25%	ME GIS ArcGIS coverage IMPERV is a raster data set of impervious areas, derived from 5 meter SPOT imagery collected in the summer of 2004 over the State of Maine. Areas of imperviousness are characterized by anthropogenic features such as buildings, roads, parking lots, etc.

The resulting total nitrogen loading to Casco Bay from storm water based on the simple method was estimated at 639,034 kg per year. This compares **surprisingly** well to the estimate of 613,810 kg per year from combined developed land and atmospheric deposition in the SPARROW model. When you include the agricultural sources (i.e. total loads subtracting out WWTP), the result is 719,661 kg per year. Note that the simple method does not account for instream nitrogen attenuation (which Moore *et al.*, 2011 estimate as no more than 28%), so the estimate is expected to be higher than that which would reach the bay. This suggests that the SPARROW model estimates are probably realistic (i.e. they differ no more than 20% than other estimates).

Priorities for nitrogen reduction

One question that has been raised is whether it is feasible to remove impervious surface from nutrient runoff, by installing appropriate stormwater control measures (or BMPs) that effectively reduces the nitrogen loads. Given that the percent imperviousness is about 6.5%, a large scale effort to reduce impervious cover (IC) may not be feasible or effective. In smaller watersheds such as in Long Creek, which exhibit very high IC (in some places over 40%[21]) installation of major retrofits may result in improvements in aquatic life in the freshwater areas of the stream. Given the possible lack of significant nitrogen attenuation in this coastal stream close to Casco Bay, it is unlikely however, that these improvements would result in significant improvements to the estuarine area in nearshore Casco Bay. Therefore, because sewage treatment plants provide the highest

[21] Ziebler, C.R., Varricchione, J.T., Schofield, K., Norton, S.B. and S. Meidel. 2007. Causal Analysis of Biological Impairment in Long Creek: A Sandy-Bottomed Stream in Coastal Southern Maine. EPA/600/R-06/065F December 2007 . National Center for Environmental Assessment Office of Research and Development U.S. Environmental Protection Agency Washington, DC 20460.

loadings to Casco Bay, and in areas which are most sensitive to nutrient enrichment, it is recommended that consideration be provided to explore improvements in treatment at WWTP in the inner bay near Portland.

Recommendations

This report highlights the need for additional monitoring of nitrogen loads to Casco Bay, from both riverine and wastewater treatment plant sources. Most of the data used to make these estimates might be outdated or not well reported. Another data gap is direct runoff of nitrogen from impervious surfaces near waterfronts and in Combined Sewer Overflows, (e.g. in Portland), that are not captured in the SPARROW model. Finally, the role of instream nitrogen attenuation should be evaluated and better incorporated into these models.