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Strategic Assessment of Near Coastal Waters: Northeast Case Study

NOAA/EPA Team on Near Coastal Waters

Strategic Assessment of Near Coastal Waters

Northeast Case Study

Susceptibility and Status of Northeast Estuaries to Nutrient Discharges

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The Northeast Case Study has been undertaken to illustrate how data being developed in NOAA's program of strategic assessments can be used for resource assessments of estuaries and near coastal waters throughout the contiguous USA. It was designed as a pilot project to assist the U.S. Environmental Protection Agency (EPA) in developing its Strategic Initiative for the Management of Near Coastal Waters. As part of this initiative, the coastal states and EPA are to identify estuarine and coastal waters that require management action.

The project began in June 1987 as a cooperative effort by NOAA's Office of Oceanography and Marine Assessment and EPA's Office of Policy, Planning, and Evaluation and Office of Marine and Estuarine Protection. The Northeast was selected because NOAA's data bases were more complete for the estuaries of this region at the time. Offshore areas are not included since information to characterize them has not been organized for a consistently defined set of spatial units.

Preliminary and interim case study reports were completed in September and November 1987. In these reports, information was compiled by estuary for seven themes: (1) physical and hydrologic characteristics; (2) land use and population; (3) nutrient discharges; (4) classified shellfish waters; (5) toxic discharges and hazardous waste disposal sites; (6) coastal wetlands; and (7) public outdoor recreation facilities. Most of the information was compiled from NOAA's National Coastal Pollutant Discharge Inventory, National Estuarine Inventory (Volumes 1 and 2), National Coastal Wetlands Inventory, and Public Outdoor Recreational Facilities Inventory. However, with the exception of the toxic discharges chapter in the interim report, only cursory explanations of the data and no data analyses were provided in the previous reports.

Two chapters, nutrient and toxic discharges to estuaries, will be completed to illustrate fully the extent of available data, the methods used to develop the data, and the types of analyses that are possible. The data bases used to compile the information in the report are constantly being updated and improved. For example, during the course of the project, NOAA analyzed the susceptibility and status of all estuaries identified in its National Estuarine Inventory to nutrient and toxic discharges. This information, not in the preliminary and interim drafts of the case study, is emphasized in the chapters on nutrient and toxic discharges with special attention given to the estuaries in the Northeast. Case studies for other regions may be completed in the future depending on interest and available resources.

Additional information on NOAA's program of strategic assessments is available from:

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Strategic Assessment of Near Coastal Waters

Northeast Case Study

Chapter 3

Susceptibility and Concentration Status of Northeast Estuaries to Nutrient Discharges

NOAA/EPA Team on Near Coastal Waters
July 1988

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INTRODUCTION

This chapter of the Strategic Assessment of Near Coastal Waters: Northeast Case Study is an assessment of the susceptibility and concentration status of 17 Northeast estuaries to nutrient-related pollution problems. It is the final version of one of seven chapters in the Case Study and one of two chapters that will be completed. It first presents background information on the problems of nutrient overenrichment in estuaries followed by a screening analysis of the susceptibility and status of estuaries to nutrient discharges and sections on nutrient sources and discharge estimation methods. The final section is an overview of the region based on simple comparisons of discharge estimates across estuaries in the region. Appendix A contains one-page summaries for each estuary that include information on significant physical and hydrologic features, susceptibility and pollutant status, nutrient discharge estimates, and a narrative to assist the reader interpret the data. Summary estimates of particular interest are the changes in nitrogen and phosphorus inputs that would significantly alter the pollutant status of each estuary. Four additional appendices contain more detailed breakdowns of nutrient discharges by season and by source, an evaluation of the quality of the discharge estimates, and the method for determining an estuary's nutrient concentration status and susceptibility to nutrient-related pollution problems.

The susceptibility and concentration status of estuaries to nutrient-related pollutant problems are recent additions to NOAA's National Estuarine Inventory. They are the syntheses of several years of work to characterize comprehensively the physical and hydrologic features of the Nation's estuaries as they affect the retention and distribution of pollutant inputs. Susceptibility and concentration status are significant additions to the data included in the preliminary and interim drafts of this case study. This information serves as a screening device for evaluating the condition of estuaries relative to one another with respect to nutrient inputs and their potential effects. Public agencies responsible for managing resources, environmental quality, and activities in these areas can use this information to better direct resources toward estuaries that require management action. More detailed interpretation of this material is being developed in two forthcoming NOAA reports: "Estuarine Pollution Susceptibility" and "Estuarine Classification with Management Application."

Data in the case study are organized by estuarine drainage area (EDA), the land and water component of an entire watershed that most directly affects an estuary. EDAs are delineated based on the limits of tidal influence within an estuarine system and the boundaries of U.S. Geological Survey hydrologic cataloging units. A hydrologic cataloging unit is a geographic area representing all or part of a surface drainage basin or a distinct hydrologic feature. EDAs generally coincide with hydrologic cataloging unit(s) that contain the heads of tide and seaward estuarine boundaries. However, many of the EDAs in the Northeast bisect the hydrologic cataloging units.

The 17 estuaries in the region contain over 26,000 square miles of EDA of which about 3,900 square miles are estuarine surface waters with a volume of 6.5 trillion cubic feet. Fifty-seven counties fall entirely or in part within one or more of the EDAs. The estuaries receive over 95,000 tons per year of nitrogen and over 18,000 tons of phosphorus from point, nonpoint, and upstream sources. Only one of these estuaries is estimated to have high concentrations of both nitrogen and phosphorus based on its dissolved concentration potential and nutrient discharge received; seven are estimated to have low concentrations. The rest of the estuaries share a mix of high, medium, and low concentration values for nitrogen and phosphorus.

The information and analyses in this chapter are not definitive assessments of the condition of estuaries in the Northeast with respect to nutrient discharges and concentration. As screening devices, they can only suggest which estuaries are likely to be susceptible to nutrient-related pollution problems and the order-of-magnitude changes in nutrient discharges that are likely to affect the nutrient concentration status of these estuaries. This is important in program-level decision-making when determining which estuaries should receive a more detailed analysis of their condition or which estuaries should receive priority attention.

BACKGROUND

Estuaries make up less than one percent of the ocean environment, yet they are the most biologically productive. Part of this productivity is directly related to nutrient cycling that supports phytoplankton growth, the base of the food chain. The nutrients nitrogen and phosphorus are essential elements for the healthy growth of aquatic plants and generally stimulate the productivity of an estuarine system. However, excess discharges of either or both of these nutrients to receiving waters generally leads to eutrophication, particularly in estuaries with poor flushing characteristics, and can be a deterrent to growth and productivity of naturally occurring species. The most visible effect of eutrophication is the massive blooms of phytoplankton that can clog rivers, reduce light penetration, and emit noxious odors due to the decay of dead organisms. A major ecological impact of eutrophication is the depletion of dissolved oxygen (hypoxia) that can occur in bottom waters due to decay of algae as they die and sink. Hypoxia is a condition that occurs when levels of dissolved oxygen in bottom waters are less than 2 milliliters per liter. This, in turn, can lead to mass mortalities of finfish and shellfish. The most recent case in the Northeast occurred in Long Island Sound during the summer of 1987. Nutrient enrichment, combined with high temperatures, resulted in massive blooms of phytoplankton (green tide), bottom waters devoid of dissolved oxygen, and large fish kills. The flushing rate, circulation, stratification, and wind field are all important factors influencing the duration, magnitude, and extent of eutrophic conditions in estuaries.

Wastes, including excessive nutrients, have entered marine waters for centuries directly or indirectly by way of rivers, runoff, rainfall, atmospheric deposition, and end-of-pipe discharges. The magnitude of this problem for Northeast estuaries is illustrated by the nutrient discharge data presented in this chapter. Until recent years, the oceans seemed to have had the capacity to assimilate these wastes. While this may still hold true for the deep oceans, this is not the case for estuarine and coastal ocean waters. Increasing evidence of reduced fish catches, loss of habitats, and degradation in water and sediment quality resulting from nutrient overenrichment has shown that we are faced with hard management decisions concerning our ability to limit these discharges.

In a nationwide survey conducted in 1985 to identify the estuarine and coastal areas with eutrophic and hypoxic conditions around the country (Whitledge, 1985), the western end of Long Island Sound was classified as an area of priority concern, and Narragansett Bay was classified as a potential problem area. The western end of the Sound has a history of acute and persistent depressed oxygen, particularly near the East River. Heavy loading from municipal wastewater treatment plants (WWTPs) in the East River seems to be responsible for depressed oxygen values throughout the year. In the past, some of the bays in the western Sound have had serious eutrophication and hypoxic episodes because of the large amounts of nutrient runoff from the duck farm industry. These conditions have improved as the duck farm industry has declined. The upper end of Narragansett Bay in Rhode Island shows evidence of recurring low dissolved oxygen. Circulation is sluggish in this area, and nutrient input is high, but there were insufficient data to draw any conclusions about the persistence of hypoxic episodes. Other problems, such as fish kills or high bacteria counts that occurred in high nutrient areas, were also identified. Episodic events posing little potential for long term impacts, occurred throughout the region. A summary of the problems that have occurred in the estuaries of the Northeast is given in Table 1.

SCREENING ANALYSIS OF REGIONAL CONDITIONS

This section presents an assessment of the status and susceptibility of 17 estuaries in the Northeast to nutrient-related pollution problems. A classification scheme was developed for 82 estuaries nationwide identified in NOAA's National Estuarine Inventory (NEI) to assess the contribution of human activity to nutrient overenrichment, or eutrophication, in coastal and marine waters (Klein, et al, 1988). The classification scheme is comprised of three elements: 1) *dissolved concentration potential* (DCP), the ability of an estuary to concentrate dissolved substances; 2) *particle retention efficiency* (PRE), an estuary's ability to trap suspended particles and their associated pollutants; and 3) *concentration status*,

Table 1. Documented water quality problems related to nutrient discharge for the Northeast

Estuary	Problem			Probable Cause	Other Problems	Severity		
	High Nutrients	Low DO	Fish Kills			Episodic	Potential	Priority
Passamaquoddy Bay	X			Input from Ocean		X		
Narraguagus Bay	X			Combined sewage, high runoff	Coliform bacteria	X		
Penobscot Bay	X	X		WWTPs		X		
Casco Bay	X	X	X	WWTPs	High hydrogen sulfide		X	
Merrimack River	X	X		Industrial discharge WWTPs		X		
Massachusetts Bay	X	X	X	WWTPs			X	
Buzzards Bay		X	X	High runoff, high temperature	Excessive metals	X		
Narragansett Bay	X	X	X	High runoff, poor circulation			X	
Long Island Sound	X	X		WWTPs, stormwater, CSOs	High chlorophyll Coliform bacteria			X

Abbreviations: Dissolved oxygen, DO; Municipal wastewater treatment plants, WWTPs; Combined sewer overflows, CSOs.

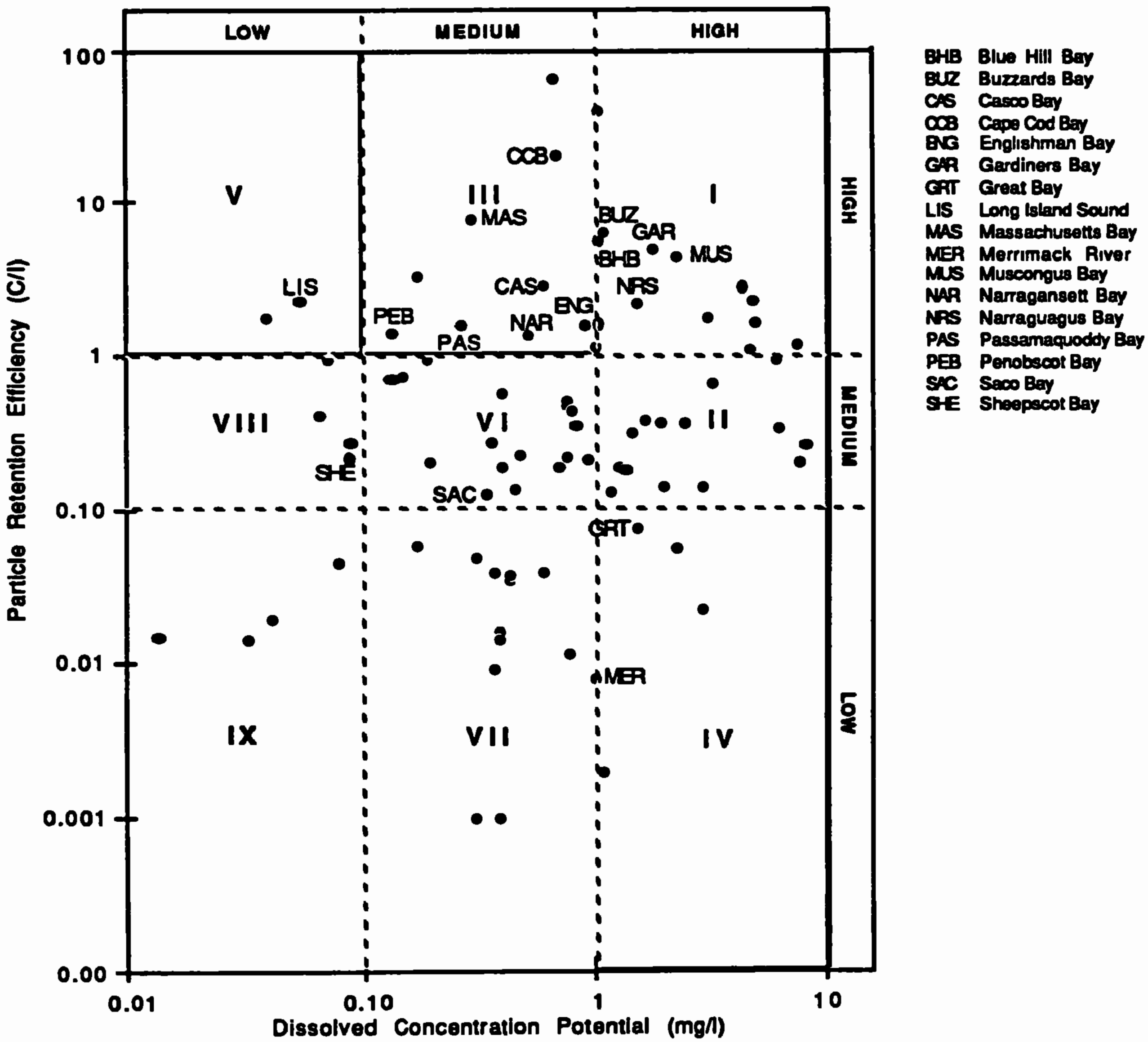
an inferred level of pollutants in an estuary. Comparisons of these characteristics among estuaries are valid in a relative sense only and do not reflect actual concentrations of nutrients that may be found in estuaries. They were derived by using physical and hydrologic data from NOAA's NEI and by using pollutant discharge estimates from NOAA's National Coastal Pollutant Discharge Inventory (NCPDI). Dissolved concentration potential, inferred nitrogen and phosphorus concentration status, total nitrogen and phosphorus discharges, and physical and hydrologic data for the 17 estuaries in the Northeast are summarized below.

Susceptibility of the Region's Estuaries to Pollutant Inputs. Pollutants exist in estuaries either in dissolved or particulate form in the water column or in bottom sediments. Nutrients are generally in dissolved form, although nitrogen and phosphorus can be associated with sediment particles. The pollutant susceptibility of an estuary is its relative ability to concentrate both dissolved and particulate substances. Pollutant susceptibility is plotted for each of 82 estuaries included in NOAA's NEI, including 17 in the Northeast region, based on their dissolved concentration potential and particle retention efficiency (Figure 1) (discussed below). Class I estuaries are the most susceptible to pollution problems because pollutants are not readily diluted or flushed and sediment-associated toxic substances are most likely to be trapped within the estuary. Five estuaries in the region, Muscongus, Gardiners, Narraguagus, Blue Hill, and Buzzards Bays, are Class I estuaries. Class IX estuaries (none in the Northeast) are the least susceptible to pollution problems. Other classes of susceptibility such as II and IV, which includes Great Bay and Merrimack River in the Northeast, have high dissolved concentration potential but low particle retention efficiency, suggesting that they are more susceptible to dissolved pollutants than sediment-attached pollutants.

Dissolved concentration potential characterizes the effect of dilution and flushing on a load of a dissolved pollutant to an estuary. It is interpreted as an average concentration potential throughout an estuary under steady-state conditions but does not reflect site-specific conditions. DCP values in conjunction with nutrient discharge estimates were used to determine the concentration status of nitrogen and phosphorus in the 17 Northeast estuaries.

DCP was calculated based on a fractional freshwater method for predicting the concentration of a pollutant (Ketchum, 1955). It was derived from the replacement of the freshwater component of the total estuary volume due to inflow. Computations for each estuary were based on average annual freshwater inflow and salinity. An equal pollutant load was assumed to be discharged to all estuaries. This provided a relative indicator for comparing an estuary's ability to concentrate a pollutant with others. Each nutrient was treated as a conservative pollutant and assumed to be uniformly distributed within each estuary. A high DCP indicates low dilution or flushing capability and high susceptibility to impacts from pollutant inputs. Values between 0.01 and 0.1 milligrams per liter indicates a low DCP; 0.1 to 1.0, medium; and 1.0 to 10.0 high. These categories are based on order-of-magnitude differences in DCP values. The method of calculating dissolved concentration potential is discussed in Appendix E.

Figure 1. Relative susceptibility classification



Abbreviations: C, Volume of estuary at mean sea level; I, annual volume of freshwater inflow; mg/l, milligrams per liter

Of the 17 estuaries in the region, seven have a high DCP; eight, medium; and two, low. Those with a high DCP, Narraguagus, Blue Hill, Muscongus, Great, Buzzards, and Gardiners bays and Merrimack River, receive about 18 percent of total nitrogen discharge and about 14 percent of the total phosphorus discharge in the region. They account for 18 percent of the estuarine resource base in the Northeast as measured by estuarine surface water area, or about 11 percent as measured by estuary.volume.[1] Those with a low DCP, Sheepscot Bay and Long Island Sound, receive 59 percent of the total nitrogen discharge and nearly 44 percent of total phosphorus discharge, and comprise over 33 percent of the estuarine resource base in the region. In general, the estuaries with a high DCP have less volume than those with medium or low DCP. For example, Muscongus Bay, with the eighth smallest volume, is estimated to have the highest dissolved pollutant concentration potential in the region, indicating that, on average, this estuary experiences a relatively low degree of flushing or dilution. Long Island Sound, by contrast, has the largest volume and a DCP that indicates a system with a high dilution capacity.

Particle retention efficiency (PRE) characterizes the ability of an estuary to trap suspended particles and their associated pollutants. Toxic substances are generally attached to suspended sediments, although some forms of nutrients also can be attached. The PRE estimate is based upon an empirical relationship developed for artificial freshwater impoundments that has been demonstrated to be applicable to estuaries (Biggs and Howell, 1984). It is inferred from the ratio of estuary volume to the total annual volume of freshwater that enters an estuary. A high particle retention efficiency indicates high susceptibility to retaining toxic inputs. The issue of toxic pollutants in estuaries of the Northeast is treated separately in the chapter on toxic discharges in this case study. The concept of PRE is presented here because it is an element in determining the overall pollutant susceptibility of estuaries.

The Nutrient Pollution Status of the Region's Estuaries. Figures 2 and 3 show the estimated nitrogen and phosphorus concentration status for the Northeast estuaries. Concentration status is interpreted as the relative condition of estuaries with respect to nutrient load and DCP and identifies those estuaries that would most likely benefit or suffer from changes in nutrient discharge. Both DCP and discharge are shown on a log-log scale. Diagonal lines on the figures show regions of relatively low, medium, and high concentrations. These concentrations are useful for describing potential nutrient problems from discharges from human activities. They do not account for nutrients made available by recycling within an estuary, atmospheric deposition, or oceanic inputs, which, in some cases, may be substantial. In each figure, the slope of the concentration zones demonstrates that estuaries with low nitrogen loadings, such as Gardiners Bay, can achieve medium concentrations given a high DCP. Estuaries with a relatively high nitrogen loading, like Sheepscot Bay, may exhibit low concentration if they have a low DCP. Concentration values of less than 0.1 milligram per liter of nitrogen and 0.01 of phosphorus indicate a low nutrient concentration status; 0.1 to 1.0 for nitrogen and 0.01 to 0.1 for phosphorus, a medium concentration status; and greater than 1.0 for nitrogen and 0.1 for phosphorus, a high concentration status.

These approximate the values developed for the Chesapeake Bay Environmental Quality Classification Scheme (U.S. EPA, 1983a). This scheme relates levels of nutrients (among other parameters) to observed resources. A low concentration status supports maximum diversity of benthic resources, submerged aquatic vegetation, and fisheries; medium concentration supports moderate diversity and results in reduction of submerged aquatic vegetation, and occasionally high chlorophyll levels; high concentration results in a significant reduction in resource diversity, loss of submerged aquatic vegetation, frequently high levels of chlorophyll and occasional red tide or algal blooms.

The best way to assess the condition of estuaries based on concentration status is to determine their relative position in Figures 2 and 3 and to estimate the approximate amount of discharge required to change their classification, keeping in mind the log-log scale used to show nutrient discharge and DCP. (The amount and percentage change in nitrogen and phosphorus discharge necessary to move each estuary in the region from one concentration status classification to the next higher or lower classification is given in the individual estuary summaries in Appendix A.)

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[1] Estuarine resource base can be measured by any number of estuarine characteristics. Estuarine surface area is used here because it is an easily understood and highly visible estuarine attribute.

Figure 2. Nitrogen concentration status

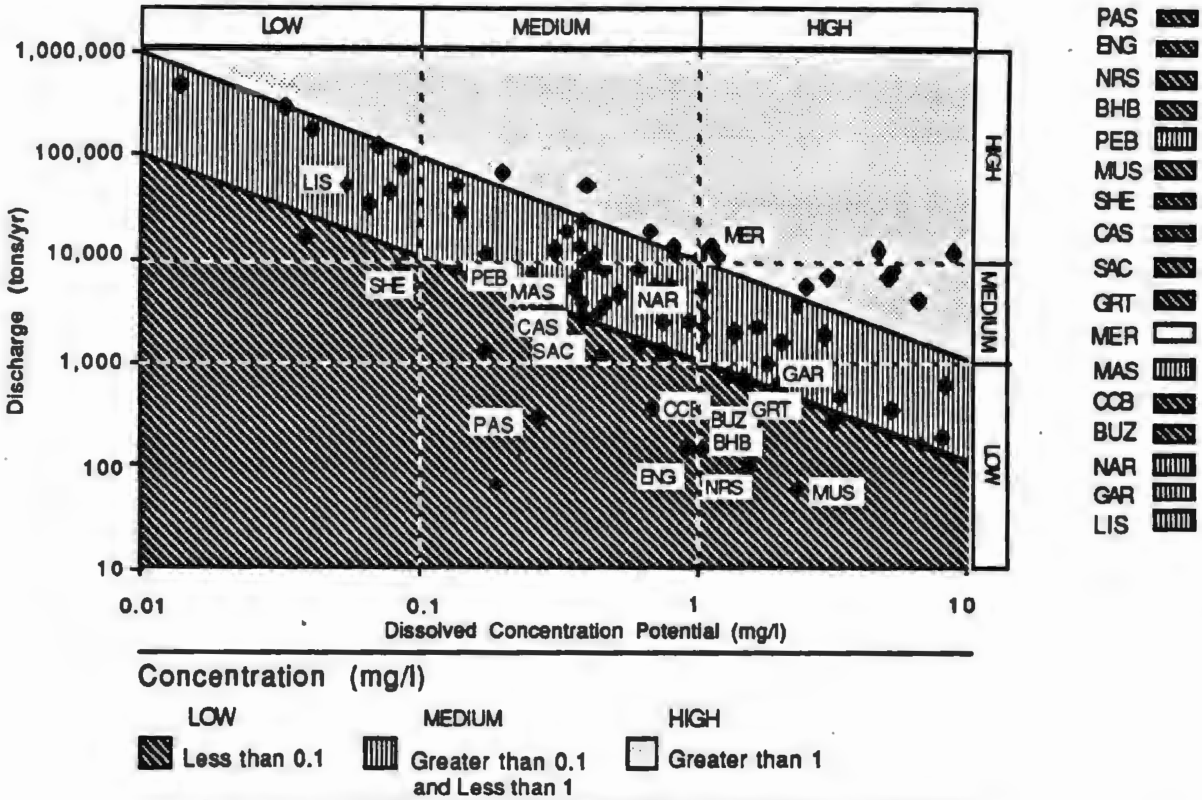
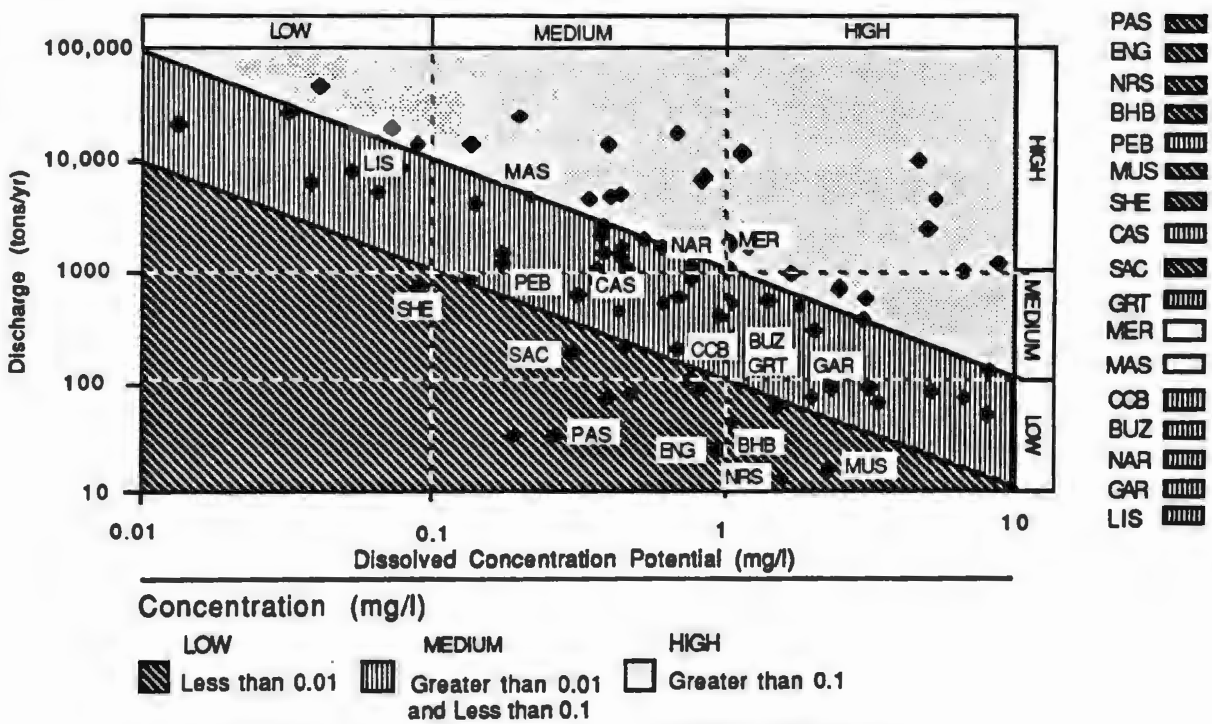


Figure 3. Phosphorus concentration status



Generally, estuaries with a low concentration status and low DCP require addition of nutrients significantly greater than estuaries with a medium or high DCP to achieve a high concentration. Sheepscot Bay, for example, would require an increased phosphorus load of more than 10,000 tons per year before it could be classified as an estuary with high concentration status according to this scheme. Estuaries with a low concentration status but high DCP, such as Blue Hill, Muscongus, and Narraguagus bays, are probably not experiencing systemic problems of overenrichment. However, each would require an increase of as little as 1,000 tons per year phosphorus to reach a high concentration status and perhaps experience an overenrichment condition. To change the nitrogen concentration status of Long Island Sound (low DCP) from medium to low would require a decreased discharge of nearly 32,000 tons per year. However, to change an estuary with a high DCP with the same concentration status, such as Gardiners Bay, would require a reduction of only about 400 tons per year. In general, estuaries with a low DCP are less sensitive to changes in concentration status due to changes in nutrient inputs.

The concentration status of most estuaries in the region is similar for both nitrogen and phosphorus (Table 2). Most estuaries that have a low nitrogen concentration status also have a low phosphorus concentration status. The Merrimack River is the only system with a high concentration status for both, accounting for nearly 9 percent of the phosphorus discharge and over 10 percent of the nitrogen discharge in the region. However, it comprises less than one percent of the estuarine resource base as defined by estuarine surface area. Massachusetts Bay is the only other system with a high concentration status for phosphorus and represents an additional 24 percent of the discharge from the region into this water body. Four estuaries with medium concentration status for nitrogen and phosphorus–Long Island Sound, Narragansett, Gardiners, and Penobscot bays–receive 65 percent nitrogen and 56 percent phosphorus discharge and account for nearly 52 percent of the estuarine resource base in the region. Seven estuaries–Saco, Sheepscot, Blue Hill, Muscongus, Englishman, Narraguagus, and Passamaquoddy Bays–share a low concentration status for both nitrogen and phosphorus. Collectively, they account for about 11 percent of the nitrogen discharge, 5 percent of phosphorus, and about 16 percent of the estuarine resource base in the region.

Table 2. Summary of physical and hydrologic characteristics, dissolved concentration potential, nutrient discharges, and concentration status

Estuary	Surface Area (sq.mi.)	Volume (cu ft.)	Average Daily Freshwater Inflow (1000 cfs)	Dissolved Concentration Potential	Nitrogen		Phosphorus	
					Total Discharge (tons/year)	Concentration Status	Total Discharge (tons/year)	Concentration Status
Passamaquoddy Bay	157	3 15E+11	6 2	M	294	L	32	L
Englishman Bay	78	7 97E+10	1 6	M	151	L	23	L
Narraguagus Bay	70	6 33E+10	0 9	H	106	L	12	L
Blue Hill Bay	115	2 41E+11	1 3	H	155	L	37	L
Penobscot Bay	381	7 25E+11	16 1	M	7,808	M	775	M
Muscongus Bay	72	8 55E+10	0 8	H	58	L	15	L
Sheepscot Bay	103	1 18E+11	17 8	L	8,741	L	641	L
Casco Bay	164	1.91E+11	2 1	M	1,418	L	471	M
Saco Bay	17	1.53E+10	3 8	M	1,254	L	195	L
Great Bay	15	4 75E+09	2 0	H	640	L	203	M
Merrimack River	6	2 08E+09	6 4	H	10,111	H	1,628	H
Massachusetts Bay	364	7 85E+11	2 9	M	7,995	M	4,091	H
Cape Cod Bay	548	1.18E+12	1.8	M	380	L	185	M
Buzzards Bay	228	2 15E+11	1 2	H	489	L	216	M
Narragansett Bay	165	1.39E+11	3 2	M	4,574	M	1,778	M
Gardiners Bay	197	1.11E+11	0 7	H	985	M	440	M
Long Island Sound	1,281	2 19E+12	30 0	L	50,148	M	7,527	M
Total	3,939	8 46E+12	100 2		95,267		18,289	

Abbreviations. L, low, M; medium; H, high

Anthropogenic contributions of nutrients alter the natural balance of the nutrient cycle and have become a major concern in coastal and estuarine waters. A serious problem in assessing the extent of eutrophication in these waters is the absence of quantitative and standardized long-term data on nutrient discharges to marine waters and long-term measurements of nutrient concentrations within waterbodies themselves. However, in absence of these data, pollutant susceptibility and inferred concentration status provide a reasonable first cut at ranking estuaries according to their susceptibility to pollution effects. This characterization distinguishes estuaries that have greater or lesser capacity to moderate pollutant inputs based upon dilution and flushing. This is important in establishing management strategies and program priorities for estuaries that exhibit various degrees of responsiveness to pollutant inputs.

The remainder of the chapter contains the nutrient discharge estimates to the 17 estuaries in the region and information on the sources of discharge and methods used to estimate discharge. This is important background information necessary to understand the data used in determining nutrient concentration status.

NUTRIENT SOURCES, ESTIMATION METHODS, AND DISCHARGES

Figure 4 shows estimated total nitrogen and phosphorus discharges by estuarine drainage area (EDA) for each estuary. The estimates include organic and inorganic forms of each nutrient and are estimated as "total nitrogen" and "total phosphorus" and are taken from NOAA's National Coastal Pollutant Discharge Inventory (NCPDI). The estimates are based on a combination of monitored and estimated data, circa 1982. Annual discharge estimates for each nutrient by source category are listed in Table 3; seasonal estimates are presented in Appendix B; estimates by source categories are listed in Appendix C. Discharge estimates by source categories are only for the coastal county portion of an EDA. Discharges for those portions of the EDA outside the coastal county boundary and for the area outside of the EDA are reflected in the upstream source discharge estimates. No estimates were made of nutrients contributed by atmospheric deposition or exchange between estuaries and ocean through surface transport seaward and bottom transport landward. For the 17 estuaries in the Northeast, 12 percent of the estimated nutrient discharges are from nonpoint sources; 41 percent are from point sources, and 46 percent are from upstream sources.

The methods used to estimate nutrient discharges for each category are described briefly below. Detailed explanations of the estimation methods are contained in the NCPDI Methods Documents available from NOAA's Strategic Assessment Branch (1987). Selected information used to estimate nutrient discharges such as land area, precipitation, fertilizer applications, and number of WWTPs is provided as background information in Table 4. An assessment of the quality of discharge estimates and background information is given in Appendix D.

Estimates represent "end-of-pipe" point source discharges and nonpoint runoff into rivers, streams, and creeks that eventually may enter the estuary. They do not take into account the transport, deposition, and chemical cycling of nitrogen and phosphorus in the water column which affect ambient levels of nutrients in estuaries. A direct connection is not made between nutrient discharge estimates and ambient concentrations in an estuary. However, the estimates do reflect the net addition of nutrients from human activities and are important for evaluating the relative contributions of different sources (Table 5).

Natural Sources. Natural sources of nitrogen and phosphorus are runoff from forests, wetlands, natural soil erosion, atmospheric and oceanic exchange, groundwater, and weathering. Both the nitrogen and phosphorus cycles are open systems in marine waters. Biological processes of uptake, decay, and regeneration determine the concentrations of these nutrient compounds, and physical factors, such as sinking of dead organisms and upwelling, determine the distribution. Phosphorus is generally the limiting nutrient in freshwater and nitrogen is the limiting nutrient in seawater; estuaries represent a transition zone from fresh to seawater.

Both nitrogen and phosphorus occur in organic and inorganic forms. Nitrogen is found in water as dissolved molecular nitrogen and as inorganic and organic compounds. The inorganic forms of nitrogen are nitrate, nitrite, and ammonia--nitrate being the most abundant. Organic nitrogen compounds are either dissolved or particulate forms. Inorganic phosphate occurs primarily as orthophosphate in sea water. Another inorganic form found only in estuarine waters is polyphosphate ions from detergents (Riley and Chester, 1971). Organic phosphorus in marine waters is also found in dissolved or particulate forms and is derived mostly from decomposition and excretion of marine organisms.

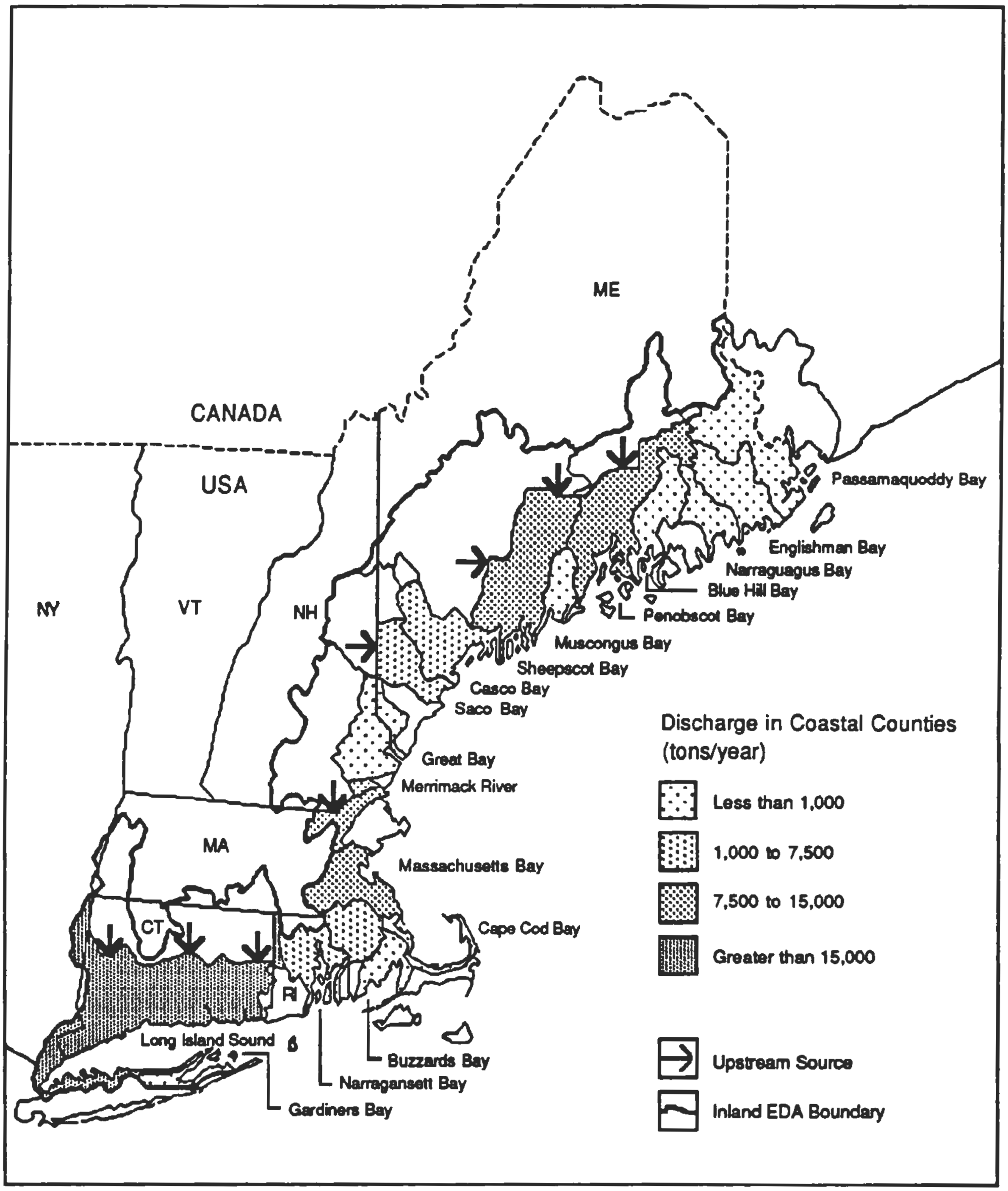


Figure 4. Nitrogen and phosphorus discharge in the coastal county portion of estuarine drainage areas, circa 1982

The methods used to calculate discharges from urban (NOAA, 1987d) and nonurban (NOAA, 1987a) sources are described briefly below. Land use data common to both categories were derived from the USGS Land Use and Land Cover (LU/LC) Classification System (Anderson et al, 1976) and the U.S. Department of Agriculture's (USDA) Soil Conservation Service 1982 National Resource Inventory (USDA, 1982). Precipitation and other weather data were obtained from the National Weather Service.

Table 3. Nutrient discharges to Northeast estuaries (tons per year) - circa 1982

Estuary	Nonpoint: Agriculture N	Agriculture P	Forest N	Forest P	Urban N	Urban P	Other N	Other P	Total N	Total P	Point: WWTPs N	WWTPs P	Industry N	Industry P	Total N	Total P	Upstream N	Upstream P	Totals N	Totals P	Totals N+P
Passamaquoddy Bay	88	5	19	0	66	14	1	0	192	19	18	13	84	0	102	13	0	0	294	32	326
Englishman Bay	65	3	15	0	42	7	2	0	124	10	17	12	10	1	27	13	0	0	151	23	174
Narraguagus Bay	62	3	8	0	20	3	3	0	93	6	8	6	5	0	13	6	0	0	106	12	118
Blue Hill Bay	16	1	10	0	77	13	4	0	107	14	30	21	18	2	48	23	0	0	155	37	192
Penobscot Bay	59	4	147	1	143	23	3	0	352	28	77	57	99	4	176	61	7,280	686	7,808	775	8,583
Muscongus Bay	27	2	0	0	17	3	0	0	44	5	13	10	1	0	14	10	0	0	58	15	73
Sheepscot Bay	253	14	32	0	188	32	1	0	474	46	67	52	10	0	77	52	8,190	543	8,741	641	9,382
Casco Bay	367	13	30	0	270	45	0	0	667	58	408	273	343	140	751	413	0	0	1,418	471	1,889
Saco Bay	58	2	2	0	133	22	0	0	193	24	149	101	37	15	186	116	875	55	1,254	195	1,449
Great Bay	166	7	4	0	227	36	0	0	397	43	230	153	13	7	243	160	0	0	640	203	843
Merrimack River	83	4	0	0	531	86	0	0	614	90	1,310	814	37	2	1,347	816	8,150	722	10,111	1,628	11,739
Massachusetts Bay	64	3	271	3	1,449	239	40	1	1,814	246	6,166	3,844	15	1	6,181	3,845	0	0	7,995	4,091	12,086
Cape Cod Bay	3	0	0	0	108	17	2	0	113	17	267	168	0	0	267	168	0	0	380	185	565
Buzzards Bay	38	3	0	0	124	20	1	0	163	23	306	193	0	0	306	193	0	0	469	216	685
Narragansett Bay	345	17	1	0	1,363	217	4	0	1,713	234	2,470	1,540	391	4	2,861	1,544	0	0	4,574	1,778	6,352
Gardiners Bay	158	4	0	0	183	29	0	0	341	33	628	391	16	16	644	407	0	0	985	440	1,425
Long Island Sound	1,827	38	61	1	3,639	589	1	0	5,528	628	18,922	4,980	1,071	20	19,993	5,000	24,627	1,899	50,146	7,527	57,675
Total	3,667	123	600	5	8,600	1,395	62	1	12,929	1,524	31,086	12,628	2,150	212	33,236	12,840	49,122	3,905	95,287	18,269	113,556

Abbreviations Nitrogen, N; Phosphorus, P; Municipal wastewater treatment plants, WWTPs

Table 4. Factors influencing nutrient discharges to Northeast estuaries - circa 1982

Estuary	Land Area (square miles): EDA	Coastal County (1)		Precipitation (inches): Winter	Spring	Summer	Fall	Long Term Avg Annual	WWTPs	Fertilizer Application in Coastal Counties (tons/year) (2): Coastal Counties in EDA N	Coastal Counties in EDA P	Total in EDA N	Total in EDA P
Passamaquoddy Bay (3)	1,328	1,220	(92)	11 2	8 2	14 0	8 6	44 2	6	179	79	185	83
Englishman Bay	799	799	(100)	10 5	8 6	12 3	8 7	44 2	1	122	55	122	55
Narraguagus Bay	372	372	(100)	10 5	8 6	12 3	8 7	44 2	1	113	51	113	51
Blue Hill Bay	608	587	(97)	9 6	9 1	10 4	8 9	----	2	74	33	74	33
Penobscot Bay	2,769	962	(35)	8 4	8 6	11 1	6 7	40 3	11	389	172	2,705	1,214
Muscongus Bay	404	404	(100)	10 2	9 3	13 1	6 8	----	5	226	100	226	100
Sheepscot Bay	5,838	926	(16)	8 8	8 8	17 8	7 1	----	7	672	298	3,859	1,704
Casco Bay	979	827	(84)	8 9	10 7	12 7	7 4	40 8	17	529	233	586	259
Saco Bay	1,723	536	(31)	8 8	8 7	13 7	7 5	41 6	10	516	227	655	290
Great Bay	880	838	(95)	8 4	8 3	13 8	8 0	40 9	19	480	156	160	653
Merrimack River	2,177	665	(30)	8 7	9 2	14 9	10 2	43 3	7	494	130	1,106	144
Massachusetts Bay	1,094	1,094	(100)	9 9	9 2	19 5	9 9	44 0	9	229	56	229	59
Cape Cod Bay	213	213	(100)	10 5	9 1	15 6	11 2	41 7	2	7	2	7	2
Buzzards Bay	354	354	(100)	11 0	6 9	14 4	12 1	42 3	3	459	113	459	113
Narragansett Bay	1,151	1,151	(100)	10 8	6 8	16 8	11 1	43 3	28	1,531	367	1,532	366
Gardiners Bay	203	203	(100)	12 4	11 3	16 9	6 7	43 9	4	256	93	255	94
Long Island Sound	5,693	2,773	(49)	10 0	10 5	16 7	7 7	----	72	5,945	1,661	5,945	1,661
Total (4)	26,173	13,497	-	9 4 (4)	8 6	13 6	8 2	42 7	201	12,221	3,826	18,220	6,876

Abbreviations Estuarine Drainage Area, EDA, Nitrogen, N; Phosphorus, P, WWTPs, Wastewater treatment plants

(1) Numbers in parentheses are percent of total EDA.
(2) Fertilizer Application is pro-rated for EDA not included in coastal counties
(3) EDA land area does not include Canadian portion of EDA.
(4) Precipitation values are average values

Nonpoint Sources. Nonpoint source discharge is the transport of dissolved and particulate materials to surface waters via surface runoff from precipitation. The nutrients are transported to surface waterbodies through direct overland flow, storm sewers, and stream channels. Nonpoint discharges are divided into four categories: agriculture, forest, urban, and other. Nonpoint source discharge has been estimated to account for 50 percent of water pollution in the USA (Barton, 1978). In addition to estimated discharges in the coastal county portion of Northeast estuaries, significant nonpoint source discharge is also reflected in the upstream source category. In the Northeast, six estuarine systems are estimated to receive more than 500 tons/year of nutrient discharges from nonpoint sources in coastal counties or about 89 percent of the total discharge. Three receive greater than 1,500 tons/year accounting for 70 percent of the total. Urban and agriculture lands are the major contributors to nonpoint source discharges, the estimated discharge from urban lands being approximately twice that of agriculture lands (Figure 5).

Table 5. Nutrient sources for marine waters

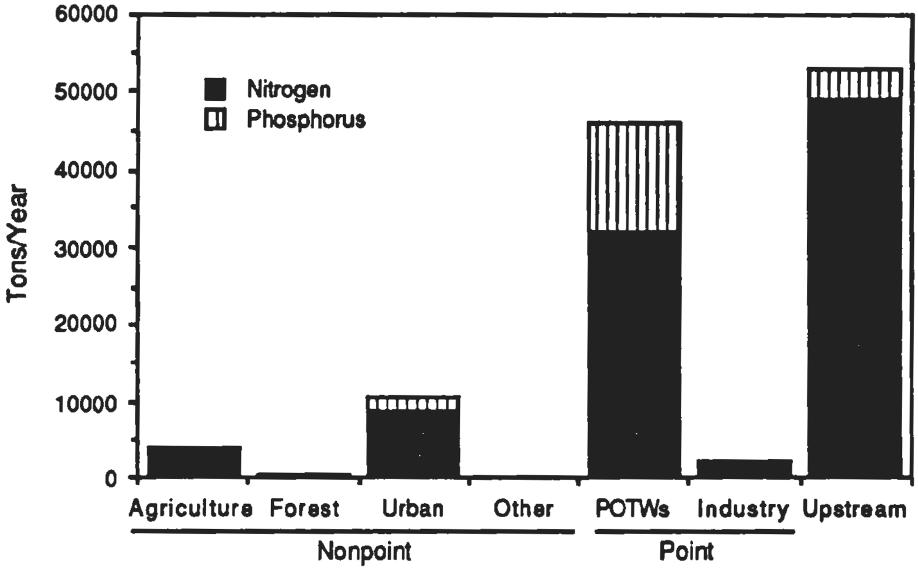
Nutrient	Species	Sources
Nitrogen		
Inorganic	Nitrate	Rain, fertilizers, nitrification of nitrite
	Nitrite	Bacterial nitrification from ammonia, nitrate reduction
	Ammonia	Rain, sewage, animal excretion, bacterial reduction
Organic	Dissolved	Sewage, plant tissue
	Particulate	Sewage, excretion, organism death
Phosphorus		
Inorganic	Orthophosphate	Sewage, autolysis, rock weathering, animal excretion, fertilizers
	Polyphosphate	Detergents (found in estuarine waters)
Organic	Dissolved	Sewage, plant tissue, excretion of extracellular metabolites
	Particulate	Organism death, excretion

Agriculture. Agriculture includes irrigated and non-irrigated cropland and pasture land. These areas are most likely to yield high nutrient discharges due to the exposure of soil for farming practices. In addition to the nutrients naturally occurring in the organic portion of the soils, fertilizers are applied to the land surfaces and are readily available for runoff. Factors that influence the amount of runoff and discharge of nutrients are soil cover, soil moisture and texture, mode of fertilizer application, management practices, precipitation pattern, and slope. These vary within a watershed between sites and may change with time for a single plot of land.

Nitrogen and phosphorus discharge estimates for agriculture lands are based on two sources: 1) soluble nitrogen and phosphorus from chemical fertilizers; and 2) organically bound nitrogen and phosphorus in sediment discharges. The predominant source of nutrient discharges from agriculture in the Northeast are from chemical fertilizers. Actual discharge data for these nutrients were estimated by determining the annual fertilizer use in each coastal county, based on information from state and county extension agents of the USDA and the percent of fertilizer applied each season. Total cropland acreage for each coastal county and corresponding USGS cataloging units were computed using USGS land use data. Fertilizer application was then distributed according to the percent of total cropland in each cataloging unit. Runoff for each nutrient was determined by multiplying the amount of fertilizer applied by an average runoff coefficient developed from field plot studies. Separate runoff coefficients were used for conventional and conservation tillage.

To estimate runoff of organically bound nitrogen and phosphorus from sediment discharges, the Simulator for Water Resources from Rural Basins model (SWRRB), developed by the USDA (Dalton, Dalton and Newport, 1984; Williams and Nicks, n.d.), was used. This is a daily simulation model used to estimate moisture accounting and applied to average site conditions by crop at the subbasin level to model runoff and soil erosion. It predicts tons per acre sediment yield by crop type under different soil erodibility, slope, cover, and management conditions. The sediment-attached nutrient discharges determined by calculating soil erosion using the SWRRB model were multiplied by an enrichment ratio (soils enriched with a pollutant and equal to the ratio of the concentration of the pollutant in the eroded soil to the concentration of the pollutant in situ) and the percent organic matter of dominant soil type being modeled.

Figure 5. Nutrient discharges by source category for the Northeast



Nutrient discharge from agricultural lands in the coastal counties make up about 26 percent of the nonpoint source estimates. For the coastal county portion of the EDAs, Long Island Sound receives the largest input of nutrients from agricultural lands. However, a closer look at those portions of the EDAs not contained within the coastal county and the fertilizer applications prorated to those agriculture lands outside the coastal counties (Table 4) shows that discharges from this category are potentially far greater than estimated and should be reflected in large upstream estimates. This appears to be the case for Penobscot Bay, Sheepscot Bay, and the Merrimack River. In each case, the prorated fertilizer applications outside the EDA is 7, 6, and 2 times that applied within the coastal county. Casco and Narragansett bays receive the second largest inputs from agriculture discharges from the coastal counties. The amounts are small compared to Long Island Sound. However, eutrophication problems are documented in both of these bays, particularly Narragansett Bay.

Forest. Forest lands can be either deciduous, coniferous, or mixed, with soil cover ranging from good to poor. Forests generally undergo very small amounts of natural erosion with little or no effects on estuarine environments. The nutrient contributions to surrounding waterbodies is small in comparison to agriculture or urban sources unless forests are intensely managed to produce wood products.

The SWRRB simulation model was used to calculate runoff for nutrient discharges from forest lands. The runoff is organic, sediment-attached nitrogen and phosphorus; these nutrients are bound to the soil particles and transported in the solid phase with eroded sediment. Nutrient discharge from forest land is low compared to the other nonpoint source categories. The heavy vegetation of forests stabilizes soils, reducing soil erosion and providing efficient forest nutrient cycling and low nutrient discharge from surface runoff.

Nutrient discharges from forest lands for the Northeast are small compared to other categories. The estimated total nutrient discharge from forest lands is only 2 percent of the total for the nonpoint source category, primarily from the EDAs in Maine. Runoff from forest lands is a minor source of nutrient discharges to Long Island Sound. Forest land constitutes the dominant land use for most of the EDAs in Maine, with less than 5 percent land area used for urban. The largest nutrient contribution from forest land is in the Penobscot Bay EDA.

Urban. Although urban runoff has been recognized for many years as a significant source of water degradation, pollution from this source remains difficult to measure. This is due to the intermittent and highly variable nature of storm events, the land use diversity in urban areas, and the varied sewer systems in an area. Urban areas greater than 2,500 population were considered in this analysis. There are five land use categories for urban areas: 1) commercial, 2) residential, 3) industrial, 4) mixed, and 5) open. The urban source category is divided into two subcategories: Combined sewer overflows (CSOs) and non-combined sewer overflows (Non-CSOs). Combined sewers convey both sanitary sewage and stormwater runoff. When the capacity of the WWTP and conveyance system serving these combined sewers is exceeded, the resultant overflow of untreated sewage and stormwater becomes an important discharge. CSO is a major problem in many older urban areas, particularly in the Northeast. Non-CSOs are those urban areas with separate storm sewers and sanitary systems.

Runoff from urban areas is a function of precipitation, the extent of impermeable surfaces, and the type of stormwater collection system. For each urban area, runoff coefficients were computed to estimate the amount of water that runs off the surface of an urban land use type given a unit of precipitation. Runoff coefficients were than applied to the time pattern and amount of precipitation to estimate the amount of stormwater runoff typically discharged to surface waterbodies in the spring, summer, fall, winter, and over the entire year. The amount of pollutants contained in the runoff were estimated using data obtained from EPA's National Urban Runoff Program (US EPA, 1983b). The discharge estimates of any given urban area equaled the seasonal runoff volume by land use type times the specific nutrient concentration value. The runoff volume was computed daily and aggregated by season. These were then summed for each EDA for each season to give an annual discharge.

CSO discharges are calculated as part of urban runoff, but are treated somewhat differently because stormwater entering a waterbody may be processed through a WWTP or may by-pass it and be discharged directly to receiving waters without treatment. It is this excess CSO volume and associated nutrient load that is considered as the CSO discharge. Discharge estimates are computed by multiplying the estimated volume of overflow by typical pollutant concentrations that are specific to CSOs. These concentrations were averaged from a number of regional studies. Because a sewer system receives flow over a time interval (depending on the intensity and duration of a rain event, precipitation, runoff) combined sewer stormwater flow and CSO are calculated in half-hour time steps instead of daily intervals for general urban runoff. These, in turn, are added for the day, season, and ultimately, the year.

Urban land nutrient discharge estimates are about 72 percent of the total nonpoint source estimate. The Long Island Sound EDA has the greatest input; 25 percent of the land use in this EDA is urban land area. Massachusetts Bay and Narragansett Bay rank second and third, respectively, in amount of nutrient discharge from urban land. Twenty five percent of the land use in the Narragansett Bay EDA is designated as urban, and 53 percent of the Massachusetts Bay EDA is urban lands.

Other. Other lands include rangeland and brushland. Nutrient discharges come from natural sources and from some fertilizer application. The discharge from this category is low and almost negligible in comparison to the other nonpoint sources in the region. This is due to the limited area of this land use type. Other lands make up approximately 1 percent of the total land area in the Northeast and nutrient discharges account for 0.1 percent of nonpoint estimates.

Range and brushland are treated similarly to agriculture and forest lands using the SWRRB daily simulation model to calculate nutrient discharge from runoff. Ground cover for other lands is basically grasses and brush, and less amounts of fertilizers are applied.

***Point Sources*.** Point sources are those WWTPs and industrial facilities that are land based and discharge wastewater directly to surface water through a pipe or similar conveyance on a regular basis. The discharge estimates in this category are marked by their low variability in both flow and pollutant concentration.

Point source discharge estimates for WWTPs and industrial facilities were based on measured or estimated flow data times a measured or estimated nutrient concentration (NOAA, 1987b). Estimating loads when monitored data were not available required development of: 1) a comprehensive list of point source discharges in the region and their associated wastewater flow volumes; 2) characteristic information, such as level of treatment, industry operation levels, and seasonal discharges (where available); and 3) typical nutrient concentrations based upon industry type.

Estimates of flow were obtained from the Discharge Monitoring Reports (DMR) or from regional and Federal data bases listing NPDES permitted flow, design flow, or estimated average flow for a facility. The Federal data base used for WWTPs was the 1982 EPA Construction Grants Needs Survey (U.S. EPA, 1985), and for industrial facilities, the EPA Permit Compliance System and the Industrial Facilities Discharge file was used.

Pollutant concentrations for WWTPs were obtained from: 1) EPA's Forty-City Study that presents data on the occurrence and fate of conventional and toxic pollutants collected from 1978 to 1980 for 50 WWTPs; 2) EPA's Four-City Study that presents pollutant concentrations from residential, commercial, and industrial sources; and 3) information supplied by EPA's Municipal Environmental Research Laboratory. Pollutant discharge concentrations for each industrial category were obtained from the EPA industry status sheets of effluent characteristics for selected industrial point source categories. For industries not covered in the status sheets, concentrations were derived from EPA Effluent Guideline Development Documents (U.S. EPA, 1986), studies of specific industrial categories, and concentration estimates developed by NOAA based on a survey of DMR data.

Wastewater Treatment Plants. WWTPs are facilities that receive and treat wastewater from residential, commercial, and industrial sources. Over 200 WWTPs account for 90 percent of point source nutrient discharges in coastal counties in Northeast estuaries. WWTPs can be either major or minor. Major plants discharge over one million gallons per day of wastewater, and minor plants discharge less that one million gallons per day. Long Island Sound, Massachusetts Bay, Narragansett Bay, and the Merrimack River basins have the largest inputs of nutrients from WWTPS. Population densities are also the greatest for these areas.

Sources of phosphorus in domestic wastewater are human excrement, synthetic laundry detergents, and water treatment chemicals. Industrial wastes that are typically high in phosphorous and generally discharged through WWTPs include fertilizer production plants, feedlots, meat processing and packing, milk processing, commercial laundries, and some food processing wastes. Primary sources of nitrogen are from urea, feces, and other organic matter. Industrial wastewater discharges that are high in nitrates are feedlots, fertilizer production, meat processing, milk processing, petroleum refineries, coking facilities, synthetic fiber plants, and industries that clean with ammonia containing compounds.

Industries. Industrial operations are defined by a series of four-digit Standard Industrial Classification (SIC) codes that classify industrial facilities according to their types of products and activities. These codes classify industrial facilities according to their types of products and activities. The four-digit SIC code is the basic classification unit used in NOAA's NCPDI to define typical pollutant concentrations. The pollutants are discharged directly to streams and rivers in the EDA and are separate from industrial pollutants discharged to WWTPs. The discharges come from production processes, contact cooling water, non-contact cooling water, or any combination of these. Industrial facilities are diverse and complex depending on the type of industry and are the largest overall contributor of pollutant discharges other than nutrients, such as petroleum hydrocarbons or metals. Nutrient discharges from industrial sources are small compared to WWTPs and nonpoint urban runoff. Industrial discharges total about 5 percent of point source discharges in coastal counties. The primary industrial contributions come from the Long Island Sound, Narragansett Bay, and Casco Bay EDAs.

Upstream Sources. Estimates were made for upstream riverine sources with an annual average flow in excess of 1,000 cubic feet per second. While all other sources of discharges in the NCPDI are located within the coastal counties, upstream sources, when present, account for that portion of the total point, nonpoint, and natural pollutant loads to the estuary that originates from outside the coastal counties. Upstream sources also reflect concentrations after transport, chemical transformations, and settling behind dams upstream of the coastal counties. For the Northeast, significant amounts of nitrogen are from upstream sources. They contribute less total phosphorus, ranking second to WWTPs (Figure 5). Five estuarine systems in the Northeast have significant nutrient discharges from upstream sources.

Nutrient discharges from upstream riverine sources are computed as the product of the seasonal flow and seasonal nutrient concentration (NOAA, 1987c). Stream discharge data were obtained from annual USGS State Water Resources Data Reports (Smith and Alexander, 1983). Ambient water quality data were obtained from the USGS National Stream Quality Accounting Network (NASQAN) and other USGS and state water quality monitoring stations. Ideally, flow and concentration data would be available for each stream at its point of entry to the coastal counties. In practice, gages were not always located at this point nor were complete water quality data always available. In some cases, estimates were based on values from nearby streams with similar flows and from land use characteristics, or were prorated using drainage area information.

SIMPLE COMPARISONS BY ESTUARY

Comparisons of pollutant discharge data among the estuaries in the Northeast can be made from several different perspectives to assess the extent of the nutrient problem. Figures 6 and 7 illustrate the relative contribution of point, nonpoint, and upstream sources to the total discharge to each estuary. Tables 6 and 7 emphasize the nitrogen and phosphorus discharge per unit of estuarine surface area ranked in descending order by estuary. Also, the cumulative regional percentage by estuary of the total nitrogen and total phosphorus discharge are presented along with the cumulative regional percentage of total estuarine surface area and population. Organized in this way, the data provide information on how much of the resource base and population in the study area is being affected by nutrient discharge. Tables 8 and 9 rank order the estuaries by the amount of estuarine surface area to illustrate how much of the estuarine resource base in the region is accounted for by discharges of nitrogen and phosphorus and population.

In the Northeast, 58 percent of the estuarine resource base receives approximately 96 percent of nitrogen loading and 93 percent of phosphorus loading from point, nonpoint, and upstream sources. Approximately 94 percent of the population lives in these areas. The most densely populated areas, the Massachusetts Bay, Narragansett Bay, and Long Island Sound EDAs, are included in the systems receiving large nutrient discharges. The greatest source of nitrogen discharges in the Northeast is from upstream sources, and for phosphorus, WWTPs (Figure 5). Urban runoff is the primary source of nitrogen loading for those estuaries without an upstream source. Due to its relatively large discharge and small surface area, the Merrimack River receives the largest annual load of nutrients per square mile. It represents 0.2 percent of the estuarine resource base and 10 percent of total loading. Long Island Sound, on the other hand, has the largest estuarine surface area and receives the largest nutrient loading, but ranks fifth in surface area affected by nitrogen loading and seventh for phosphorus. Even though this body of water is large with a large dilution, the loading is significant enough that eutrophication problems have been documented in the western portion of the Sound. Massachusets Bay, with a population density of 1,681 per square mile, ranks second in surface area affected by phosphorus discharge and sixth in nitrogen discharge. The land area around Massachusetts Bay is highly urbanized, and nutrient discharges come primarily from urban runoff and WWTPs. Urban runoff and WWTPs are also primary sources of nutrients in Narragansett Bay. Some of the other estuarine systems, such as Saco Bay and Great Bay, which fall in the top five for surface area affected by nutrient input, have relatively small nutrient discharges, but also small surface areas. Upstream sources for nitrogen and phosphorus discharges are important inputs to Penobscot and Sheepscot bays, the Merrimack River, and Long Island Sound. The remainder of the 17 estuaries receive less than 10 tons per year per square mile of nitrogen discharge and less than 2 tons per year per square mile of phosphorus discharge, which affects approximately 3 percent or less of the estuarine resource base.

Figure 6. Nitrogen discharges by source by estuary

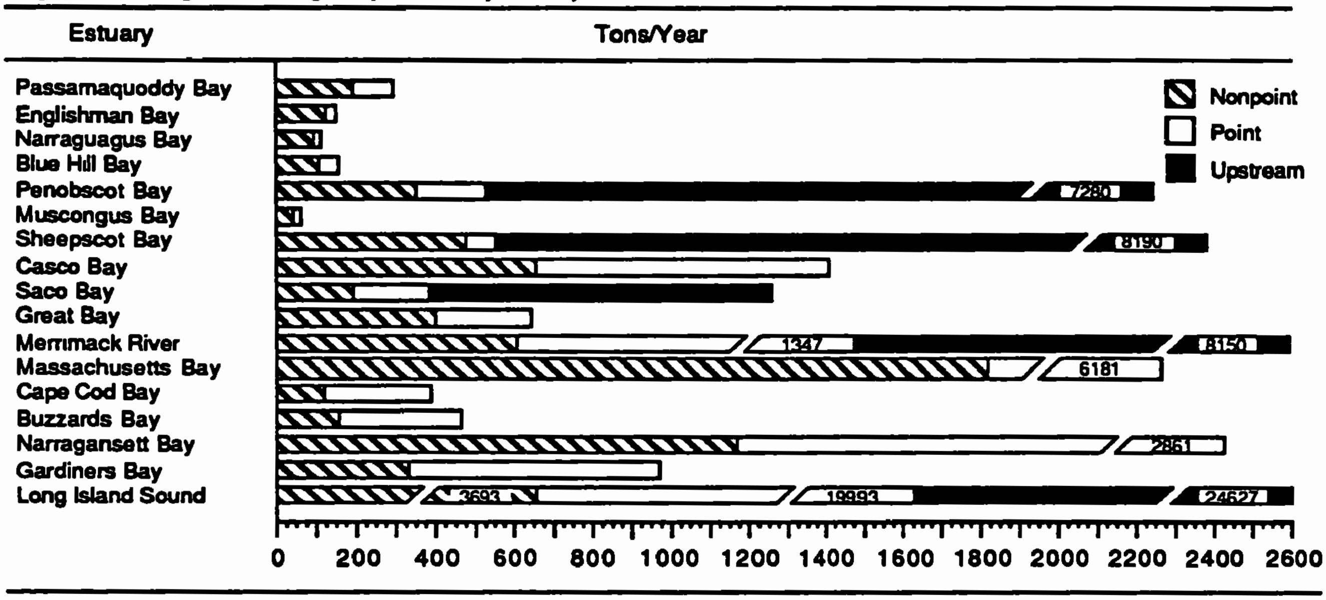


Figure 7. Phosphorus discharges by estuary

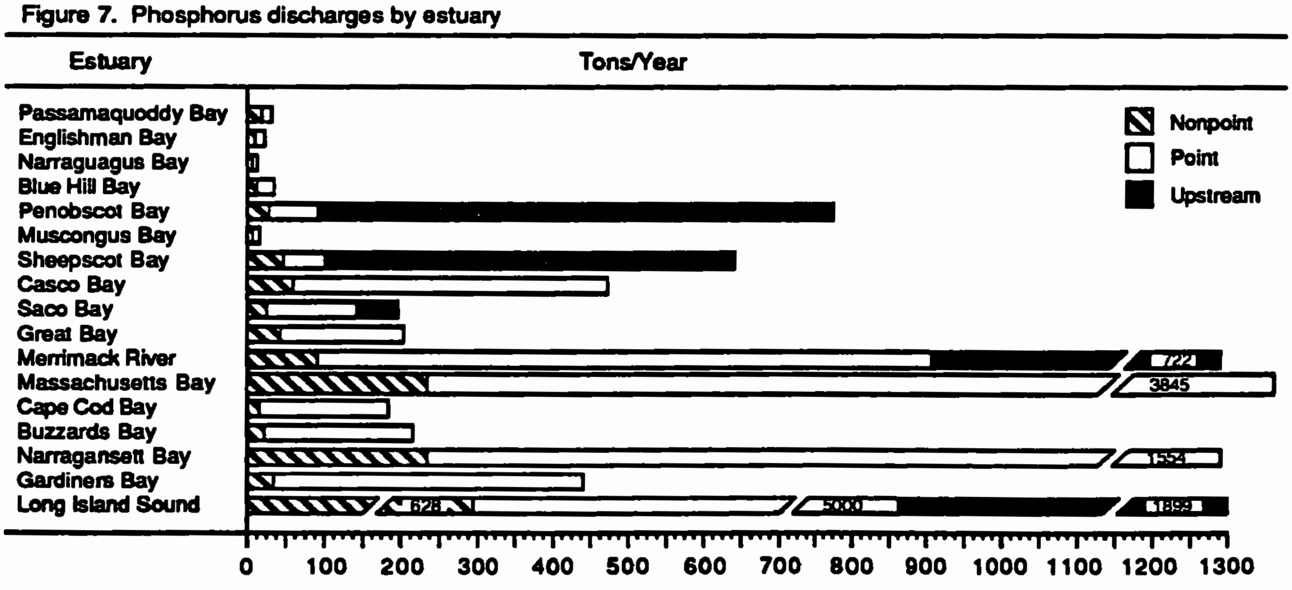


Table 6. Nitrogen discharge by estuary ranked by discharge per square mile of estuarine surface water

Estuary	Nitrogen Discharge				Estuarine Resource Base			Population			
	Discharge (tons/year)	Discharge (tons/yr /sq mi) (ESA)	Percent of Regional Total	Cumulative Total	Surface Area (sq mi)	Percent of Regional Total	Cumulative Total	Density (sq mi of EDA)	Total in EDA (thousands)	Percent of Regional Total	Cumulative Total
Merrimack River	10,111	1685 2	10 6	10 6	6	0 2	0 2	441	961	8 5	8 5
Sheepscot Bay	8,741	84 9	9 2	19 8	103	2 6	2 8	62	362	3 2	11 7
Saco Bay	1,254	73 8	1 3	21 1	17	0 4	3 2	61	105	0 9	12 7
Great Bay	640	42 7	0 7	21 8	15	0 4	3 6	227	200	1 8	14 4
Long Island Sound	50,148	39.1	52 6	74 4	1,281	32 5	36 1	963	5,485	48 6	63 1
Massachusetts Bay	7,995	22.0	8 4	82 8	364	9 2	45 3	1,681	2,021	17 9	81 0
Narragansett Bay	4,574	27.7	4 8	87 6	165	4 2	49 5	1,070	1,232	10 9	91 9
Penobscot Bay	7,808	21 6	8.2	95 8	361	9.2	58.7	62	171	1.5	93 4
Casco Bay	1,418	8.6	1 5	97 3	164	4 2	62 9	257	216	1 9	95 4
Gardiners Bay	985	5.0	1 0	98 3	197	5 0	67 9	681	138	1 2	96 6
Buzzards Bay	469	2.1	0 5	98 8	228	5 8	73 6	557	197	1 7	98 3
Englishman Bay	151	2.0	0 2	99 0	76	1 9	75 6	12	10	0 1	98 4
Passamaquoddy Bay	294	1.9	0 3	99 3	157	4 0	79 6	11	15	0 1	98 5
Narraguagus Bay	106	1.5	0 1	99 4	70	1 6	81 3	18	7	0 1	98 6
Blue Hill Bay	155	1 3	0 2	99 5	115	2 9	84 3	26	16	0 1	98 7
Muscongus Bay	58	0.8	0 1	99 6	72	1 8	86 1	60	24	0 2	99 0
Cape Cod Bay	380	0.7	0 4	100 0	548	13 9	100 0	552	117	1 0	100 0
Regional Totals	95,287	24	100		3,939	100		422	11,277	100	

Abbreviations sq mi , square miles, EDA, estuarine drainage area, ESA, Estuarine surface area.

Table 7. Nitrogen discharge by estuary ranked by percent of regional estuarine resource base

Estuary	Estuarine Resource Base			Nitrogen Discharge				Population			
	Surface Area (sq mi)	Percent of Regional Total	Cumulative Total	Discharge (tons/year)	Discharge (tons/yr /sq mi) (ESA)	Percent of Regional Total	Cumulative Total	Density (sq mi)	Total in EDA (thousands)	Percent of Regional Total	Cumulative Total
Long Island Sound	1,281	32 5	32 5	50,148	39	52 6	52 6	963	5,465	48 6	48 6
Cape Cod Bay	548	13 9	46 4	380	1	0 4	53 0	552	117	1 0	49 7
Massachusetts Bay	364	9.2	55 7	7,995	22	8 4	61 4	1,681	2,021	17 9	67 6
Penobscot Bay	361	9 2	64 8	7,808	22	8 2	69 6	62	171	1 5	69 1
Buzzards Bay	228	5 8	70 6	469	2	0 5	70 1	557	197	1 7	70 9
Gardiners Bay	197	5.0	75 6	985	5	1 0	71 1	681	138	1.2	72 1
Narragansett Bay	165	4.2	79 8	4,574	28	4 8	75 9	1,070	1,232	10 9	83 0
Casco Bay	164	4.2	84 0	1,418	9	1 5	77 4	257	216	1 9	84 9
Passamaquoddy Bay	157	4 0	88 0	294	2	0 3	77 7	11	15	0 1	85 1
Blue Hill Bay	115	2 9	90 9	155	1	0 2	77 9	26	16	0 1	85 2
Sheepscot Bay	103	2 6	93 5	8,741	85	9 2	87 1	62	362	3 2	88 4
Englishman Bay	76	1 9	95 4	151	2	0 2	87 2	12	10	0 1	88 5
Muscongus Bay	72	1.8	97 3	58	1	0 1	87 3	60	24	0 2	88 7
Narraguagus Bay	70	1.6	99 0	106	2	0 1	87 4	18	7	0 1	88 6
Saco Bay	17	0 4	99 5	1,254	74	1 3	88 7	61	105	0 9	89 7
Great Bay	15	0 4	99 8	640	43	0 7	89 4	227	200	1 8	91 5
Merrimack River	6	0 2	100 0	10,111	1,685	10 6	100 0	441	961	8 5	100 0
Regional Totals	3,939	100		95,287	24	100		422	11,277	100	

Abbreviations sq mi., square miles, EDA, estuarine dranage area, ESA, Estuarine surface area.

Table 8. Phosphorus discharge by estuary ranked by discharge per square mile of estuarine surface water

Estuary	Phosphorus Discharge				Estuarine Resource Base			Population			
	Discharge (tons/year)	Discharge (tons/yr /sq mi) (ESA)	Percent of Regional Total	Cumulative Total	Surface Area (sq mi)	Percent of Regional Total	Cumulative Total	Density (sq mi of EDA)	Total in EDA (thousands)	Percent of Regional Total	Cumulative Total
Merrimack River	1,628	271.3	8 9	8 9	6	0 2	0 2	441	961	8 5	8 5
Great Bay	203	13.5	1.1	10 0	15	0 4	0 6	227	200	1 8	10 3
Massachusetts Bay	4,091	11.2	22.4	32 4	364	9 2	9 8	1,681	2,021	17 9	28 2
Narragansett Bay	1,778	10.8	9 7	42 1	165	4 2	14 0	1,070	1,232	10 9	39 1
Saco Bay	195	11 5	1 1	43 2	17	0 4	14 4	61	105	0 9	40 1
Sheepscot Bay	641	6.2	3 5	46 7	103	2 6	17 0	62	362	3 2	43 3
Long Island Sound	7,527	5.9	41 2	87 9	1,281	32 5	49 5	963	5,485	48 6	91 9
Casco Bay	471	2 9	2 6	90 5	164	4 2	53 7	257	216	1 9	93 8
Gardiners Bay	440	2 2	2 4	92 9	197	5 0	58 7	681	138	1 2	95 1
Penobscot Bay	775	2.1	4 2	97 2	361	9 2	67 9	62	171	1 5	96 6
Buzzards Bay	216	0.9	1 2	98 3	228	5 8	73 6	557	197	1 7	98 3
Cape Cod Bay	185	0.3	1 0	99 3	548	13.9	87 6	552	117	1 0	99 4
Blue Hill Bay	37	0.3	0 2	99 6	115	2 9	90 5	26	16	0 1	99 5
Englishman Bay	23	0.3	0 1	99 7	76	1 9	92 4	12	10	0 1	99 6
Muscongus Bay	15	0 2	0 1	99 8	72	1 8	94 2	60	24	0 2	99 8
Passamaquoddy Bay	32	0 2	0 2	99 9	157	4 0	98 2	11	15	0 1	99 9
Narraguagus Bay	12	0.2	0 1	100 0	70	1 8	100 0	18	7	0 1	100 0
Regional Totals	18,269	4 6	100		3,939	100		422	11,277	100	

Abbreviations sq mi , square miles, EDA, estuarine drainage area, ESA, Estuarine surface area.

Table 9. Phosphorus discharge by estuary ranked by percent of regional estuarine resource base

Estuary	Estuarine Resource Base			Phosphorus Discharge				Population			
	Surface Area (sq. mi)	Percent of Regional Total	Cumulative Total	Discharge (tons/year)	Discharge (tons/yr /sq mi) (ESA)	Percent of Regional Total	Cumulative Total	Density (sq. mi)	Total in EDA (thousands)	Percent of Regional Total	Cumulative Total
Long Island Sound	1,281	32 5	32 5	7,527	5 9	41 2	41 2	963	5,485	48 6	48 6
Cape Cod Bay	548	13 9	46 4	185	0 3	1 0	42 2	552	117	1 0	49 7
Massachusetts Bay	364	9 2	55 7	4,091	11 2	22 4	64 6	1,681	2,021	17 9	67 6
Penobscot Bay	361	9.2	64 8	775	2 1	4 2	68 8	62	171	1 5	69 1
Buzzards Bay	228	5.8	70 6	216	0 9	1 2	70 0	557	197	1 7	70 9
Gardiners Bay	197	5 0	75 6	440	2 2	2 4	72 4	681	136	1 2	72 1
Narragansett Bay	165	4.2	79 8	1,778	10 8	9 7	82 2	1,070	1,232	10 9	83 0
Casco Bay	164	4 2	84 0	471	2 9	2 6	84 8	257	216	1 9	84 9
Passamaquoddy Bay	157	4.0	88 0	32	0 2	0 2	84 9	11	15	0 1	85 1
Blue Hill Bay	115	2.9	90 9	37	0 3	0 2	85 1	26	16	0 1	85 2
Sheepscot Bay	103	2.6	93 5	641	6 2	3 5	88 6	62	362	3 2	88 4
Englishman Bay	76	1.9	95 4	23	0 3	0 1	88 8	12	10	0 1	88 5
Muscongus Bay	72	1.8	97 3	15	0 2	0 1	88 8	60	24	0 2	88 7
Narraguagus Bay	70	1.8	99 0	12	0 2	0 1	88 9	18	7	0 1	88 8
Saco Bay	17	0 4	99 5	195	11 5	1 1	90 0	61	105	0 9	89 7
Great Bay	15	0 4	99 8	203	13 5	1 1	91 1	227	200	1 8	91 5
Merrimack River	6	0 2	100 0	1,628	271 3	8 9	100 0	441	961	8 5	100 0
Regional Totals	3,939	100		18,269	4 6	100		422	11,277	100	

Abbreviations sq mi, square miles, EDA, estuarine drainage area, ESA, Estuarine surface area.

CONCLUDING COMMENTS

This report illustrates that the "strategic level" information developed on the susceptibility of an estuary to pollutant concentration, nutrient discharge, and nutrient concentration status are useful for suggesting which of the 17 estuaries in the Northeast may be experiencing nutrient- related pollution problems and the predominant source of the nutrient discharge. With this type of information developed in a consistent and comprehensive manner across estuaries, it may now be possible to plan better which estuaries or sources of pollutant inputs should receive priority attention or emphasis in Federal and state programs designed to improve or maintain the quality of the Nation's estuarine waters.

However, this information is not designed to provide definitive answers on controls or management practices. It is important to emphasize that users review and understand the assumptions, methods, and accuracy of the information in this report. Developing this information for use on national and regional scales required the use of many simplifying assumptions to account for the behavior of estuaries and to estimate the levels of nutrient discharges to them. This report is only the first step in addressing the questions of how to improve or maintain water quality of the Nation's estuaries.

Appendix A. Summaries of the Susceptibility and Concentration Status of Northeast Estuaries to Nutrient Discharges

Strategic Assessment of Near Coastal Waters

Northeast Case Study

NOAA/EPA Team
on Near Coastal Waters

1.01 Passamaquoddy Bay
ME, NB

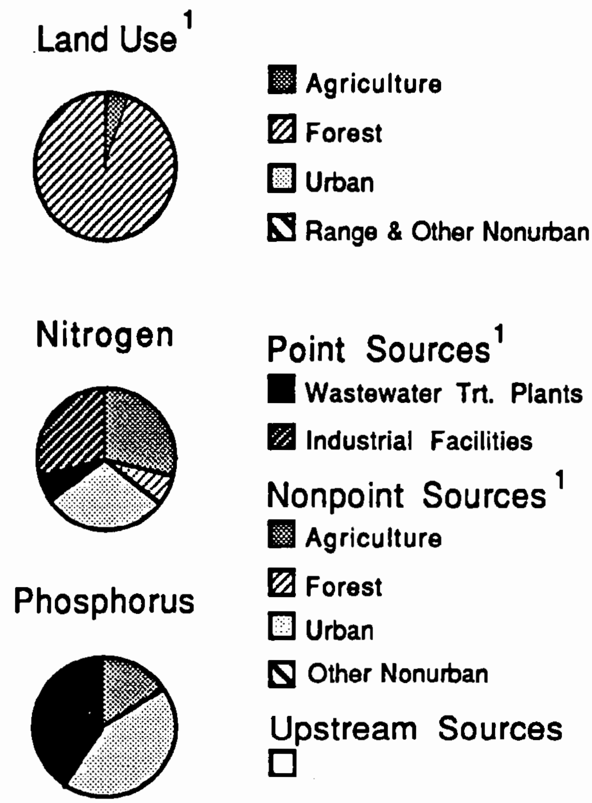
PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	3.15×10^{11}
Surface Area (sq. mi.)	157
Average Daily Inflow (cfs)	6,200
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	1,376
EDA outside coastal counties	1,824
EDA Total	3,200
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	3,200

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	0.27	(M)
Particle Retention Efficiency (C/I)	1.61	(H)



[1] Data based on coastal county portion of EDA.

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

	Nitrogen	Phosphorus
Point	102	13
Nonpoint	192	19
Upstream	0	0
Total	294	32

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class, Increase by		To Change Conc. Class, Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.008	(L)	3,471	1,181	NA	NA
Phosphorus	0.001	(L)	344	1,077	NA	NA

Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

INTERPRETATION

Passamaquoddy Bay is estimated to have a medium susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the low phosphorus loading should result in a low phosphorus concentration. Based upon its low nutrient loading, Passamaquoddy Bay should retain its present characteristics. The N/P molecular ratio of the loading (20.3) suggests the importance of phosphorus as a potential limiting nutrient in the system.

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1.02 Englishman Bay
ME

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	7.97 x 10^{10}
Surface Area (sq. mi.)	76
Average Daily Inflow (cfs)	1,600
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	883
EDA outside coastal counties	0
EDA Total	883
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	883

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	0.92	(M)
Particle Retention Efficiency (C/I)	1.58	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

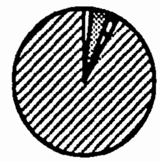
	Nitrogen	Phosphorus
Point	27	13
Nonpoint	124	10
Upstream	0	0
Total	151	23

Predicted Concentration Status
(load in tons/yr)

	Concentration		To Change Conc. Class. Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.014	(L)	939	622	NA	NA
Phosphorus	0.002	(L)	86	374	NA	NA

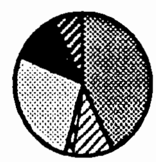
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]



Agriculture
Forest
Urban
Range & Other Nonurban

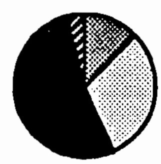
Nitrogen



Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Phosphorus



Upstream Sources

[1] Data based on coastal county portion of EDA.

INTERPRETATION

Englishman Bay is estimated to have a medium susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the low phosphorus loading should result in a low phosphorus concentration. Based upon its low nutrient loading, Englishman Bay should retain its present characteristics despite its medium to high susceptibility to concentrate dissolved substances. For N/P molecular ratios of in the range of 10-20, determination of the limiting nutrient is particularly difficult. However, the N/P molecular ratio of the loading (14.5) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

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1.03 Narraguagus Bay ME

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	6.33×10^{10}
Surface Area (sq. mi.)	70
Average Daily Inflow (cfs)	900
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	416
EDA outside coastal counties	0
EDA Total	416
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	416

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	1.54	(H)
Particle Retention Efficiency (C/I)	2.23	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

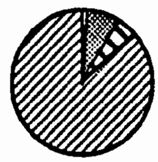
	Nitrogen	Phosphorus
Point	13	6
Nonpoint	93	6
Upstream	0	0
Total	106	12

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class, Increase by		To Change Conc. Class, Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.016	(L)	544	513	NA	NA
Phosphorus	0.002	(L)	53	442	NA	NA

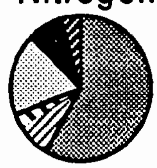
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]

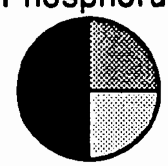


- Agriculture
- Forest
- Urban
- Range & Other Nonurban

Nitrogen



Phosphorus



Point Sources[1]
- Wastewater Trt. Plants
- Industrial Facilities

Nonpoint Sources[1]
- Agriculture
- Forest
- Urban
- Other Nonurban

Upstream Sources

[1] Data based on coastal county portion of EDA.

INTERPRETATION

Narraguagus Bay is estimated to have a high susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the low phosphorus loading should result in a low phosphorus concentration. Based upon its low nutrient loading, Narraguagus Bay should retain its present characteristics despite its high susceptibilty to concentrate dissolved substances. For N/P molecular ratios in the range of 10-20, determination of the limiting nutrient is particularly difficult. However, the N/P molecular ratioof the loading (19.6) suggests the importance of phosphorus as a potentially limiting nutrient in the system.

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1.04 Blue Hill Bay ME

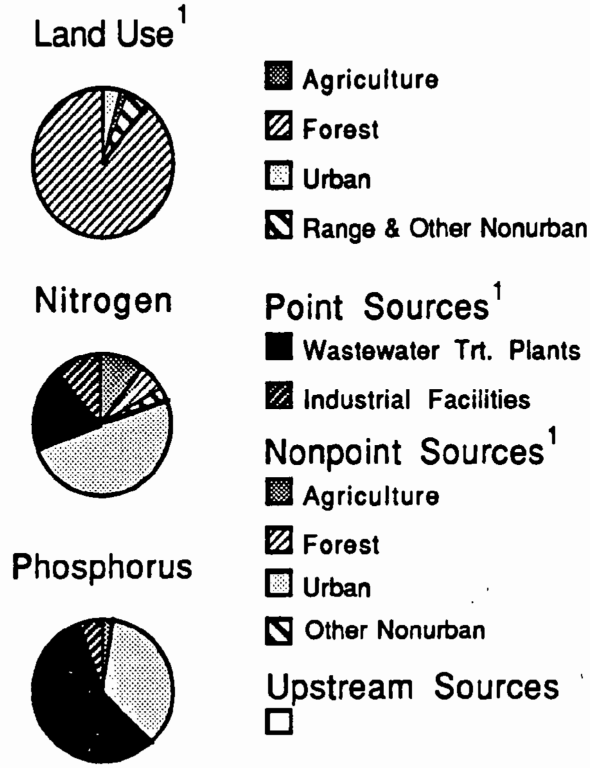
PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	2.41×10^{11}
Surface Area (sq. mi.)	115
Average Daily Inflow (cfs)	1,300
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	800
EDA outside coastal counties	25
EDA Total	825
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	825

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	1.03	(H)
Particle Retention Efficiency (C/I)	5.88	(H)



1 Data based on coastal county portion of EDA.

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

	Nitrogen	Phosphorus
Point	48	23
Nonpoint	107	14
Upstream	0	0
Total	155	37

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class. Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.016	(L)	815	526	NA	NA
Phosphorus	0.004	(L)	60	162	NA	NA

Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

INTERPRETATION

Blue Hill Bay is estimated to have a high susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the low phosphorus loading should result in a low phosphorus concentration. Based upon its low nutrient loading, Blue Hill Bay should retain its present characteristics despite its high susceptibility to concentrate dissolved substances. The N/P molecular ratio of the loading (9.3) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

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1.05 Penobscot Bay
ME

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	7.25×10^{11}
Surface Area (sq. mi.)	361
Average Daily Inflow (cfs)	16,100
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	1,106
EDA outside coastal counties	2,054
EDA Total	3,160
Fluvial Drainage Area (sq. mi.)	6,250
Total Drainage Area (sq. mi.)	9,410

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	0.13	(M)
Particle Retention Efficiency (C/I)	1.43	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

	Nitrogen	Phosphorus
Point	176	61
Nonpoint	352	28
Upstream	7,280	686
Total	7,808	775

Predicted Concentration Status (mg/l)

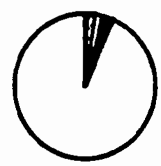
	Concentration		To Change Conc. Class. Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.104	(M)	67,091	859	318	4
Phosphorus	0.010	(M)	6,715	866	26	3

Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]

Agriculture
Forest
Urban
Range & Other Nonurban

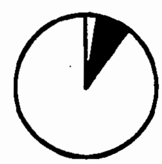
Nitrogen



Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Phosphorus



Upstream Sources

[1] Data based on coastal county portion of EDA.

INTERPRETATION

Penobscot Bay is estimated to have a medium susceptibility for concentrating dissolved substances. This concentration potential combined with a medium nitrogen loading should result in a medium nitrogen concentration within the estuary. Similarly, the concentration potential combined with the medium phosphorus loading should result in a medium phosphorus concentration. Based upon its present nutrient loading and its susceptibility to concentrate dissolved substances, Penobscot Bay should exhibit those characteristics associated with both low and medium nutrient concentration. The N/P molecular ratio of the loading (22.3) suggests the importance of phosphorus as a potentially limiting nutrient in the system.

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1.06 Muscongus Bay
ME

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	8.55×10^{10}
Surface Area (sq. mi.)	72
Average Daily Inflow (cfs)	600
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	346
EDA outside coastal counties	0
EDA Total	346
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	346

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	2.25	(H)
Particle Retention Efficiency (C/I)	4.52	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

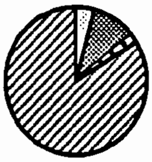
	Nitrogen	Phosphorus
Point	14	10
Nonpoint	44	5
Upstream	0	0
Total	58	15

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class. Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.013	(L)	387	667	NA	NA
Phosphorus	0.003	(L)	29	196	NA	NA

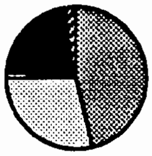
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]

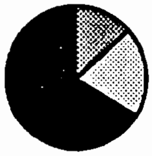


Agriculture
Forest
Urban
Range & Other Nonurban

Nitrogen



Phosphorus



Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Upstream Sources

[1] Data based upon coastal county portion of EDA.

INTERPRETATION

Muscongus Bay is estimated to have a high susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the low phosphorus loading should result in a low phosphorus concentration. Based upon its low nutrient loading, Muscongus Bay should retain its present characteristics despite its high susceptibility to concentrate dissolved substances. The N/P molecular ratio of the loading (8.6) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

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1.07 Sheepscot Bay
ME, NH

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	1.18×10^{11}
Surface Area (sq. mi.)	103
Average Daily Inflow (cfs)	17,600
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	984
EDA outside coastal counties	5,166
EDA Total	6,150
Fluvial Drainage Area (sq. mi.)	3,920
Total Drainage Area (sq. mi.)	10,070

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	0.09	(L)
Particle Retention Efficiency (C/I)	0.21	(M)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

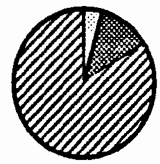
	Nitrogen	Phosphorus
Point	77	52
Nonpoint	474	46
Upstream	8,190	543
Total	8,741	641

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class. Increase by		To Change Conc. Class. Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.077	(L)	2,607	30	NA	NA
Phosphorus	0.006	(L)	494	77	NA	NA

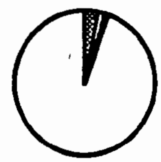
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]



Agriculture
Forest
Urban
Range & Other Nonurban

Nitrogen

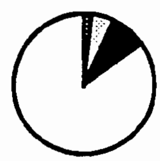


Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Upstream Sources

Phosphorus



1 Data based on coastal county portion of EDA.

INTERPRETATION

Sheepscot Bay is estimated to have a low susceptibility for concentrating dissolved substances. This concentration potential combined with a medium nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the medium phosphorus loading should result in a low phosphorus concentration. Based upon its present nutrient loading and its susceptibility to concentrate dissolved substances, Sheepscot Bay should exhibit those characteristics associated with both low and medium nutrient concentration. The N/P molecular ratio of the loading (30.2) suggests the importance of phosphorus as a potentially limiting nutrient in the system.

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1.08 Casco Bay
ME

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	1.91×10^{11}
Surface Area (sq. mi.)	164
Average Daily Inflow (cfs)	2,100
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	974
EDA outside coastal counties	185
EDA Total	1,159
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	1,159

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	0.61	(M)
Particle Retention Efficiency (C/I)	2.89	(H)

NUTRIENT CHARACTERISTICS

Loadings
(tons/year)

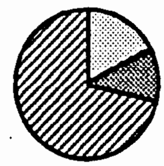
	Nitrogen	Phosphorus
Point	751	413
Nonpoint	667	58
Upstream	0	0
Total	1,418	471

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class.			
			Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.087	(L)	213	15	NA	NA
Phosphorus	0.029	(M)	1,160	246	308	65

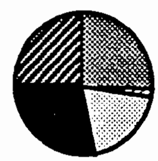
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]



Agriculture
Forest
Urban
Range & Other Nonurban

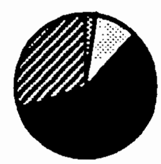
Nitrogen



Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Phosphorus



Upstream Sources

1 Data based on coastal county portion of EDA.

INTERPRETATION

Casco Bay is estimated to have a medium susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the medium phosphorus loading should result in a medium phosphorus concentration. Based upon its present nutrient loading and its medium susceptibility to concentrate dissolved substances, Casco Bay should exhibit those characteristics associated with both low and medium nutrient concentration and may be most sensitive to increased nitrogen loading. The N/P molecular ratio of the loading (6.7) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

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1.09 Saco Bay
ME, NH

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	1.53×10^{10}
Surface Area (sq. mi.)	17
Average Daily Inflow (cfs)	3,600
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	549
EDA outside coastal counties	1,221
EDA Total	1,771
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	1,771

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	0.45	(M)
Particle Retention Efficiency (C/I)	0.13	(M)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

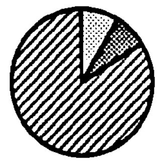
	Nitrogen	Phosphorus
Point	186	116
Nonpoint	193	24
Upstream	875	55
Total	1,254	195

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class. Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.057	(L)	949	76	NA	NA
Phosphorus	0.009	(L)	25	13	NA	NA

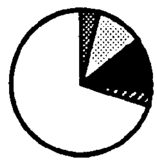
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]



Agriculture
Forest
Urban
Range & Other Nonurban

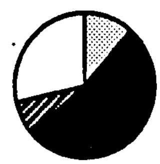
Nitrogen



Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Phosphorus



Upstream Sources

[1] Data based on coastal county portion of EDA.

INTERPRETATION

Saco Bay is estimated to have a medium susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the low phosphorus loading should result in a low phoshorus concentration. Based upon its susceptibility to concentrate dissolved substances and its present nutrient loading, Saco Bay should exhibit those characteristics associated with both low and medium nutrient concentration and be moderately sensitive to changes in nutrient concentration. For N/P molecular ratios in the range of 10-20, determination of the limiting nutrient is particularly difficult. However, the N/P molecular ratio of the loading (14.2) suggests the importance of nitrogen as a potential limiting nutrient in the system.

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1.10 Great Bay
ME, NH

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	4.75×10^9
Surface Area (sq. mi.)	15
Average Daily Inflow (cfs)	2,000
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	903
EDA outside coastal counties	47
EDA Total	950
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	950

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	1.54	(H)
Particle Retention Efficiency (C/I)	0.08	(L)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

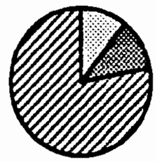
	Nitrogen	Phosphorus
Point	243	160
Nonpoint	397	43
Upstream	0	0
Total	640	203

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class.			
			Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.098	(L)	11	2	NA	NA
Phosphorus	0.031	(M)	448	221	138	68

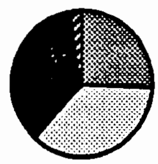
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]



Agriculture
Forest
Urban
Range & Other Nonurban

Nitrogen



Phosphorus

Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Upstream Sources

[1] Data for coastal county portion of EDA.

INTERPRETATION

Great Bay is estimated to have a high susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the medium phosphorus loading should result in a medium phosphorus concentration. Based upon its present nutrient loading and its high susceptibility to concentratedissolved substances, Great Bay should exhibit those characteristics associated with both low and medium nutrient concentration and should be sensitive to changes in that concentration. The N/P molecular ratio of the loading (7.0) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

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1.11 Merrimack River
NH, MA

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	2.08×10^9
Surface Area (sq. mi.)	6
Average Daily Inflow (cfs)	8,400
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	690
EDA outside coastal counties	1,610
EDA Total	2,300
Fluvial Drainage Area (sq. mi.)	2,680
Total Drainage Area (sq. mi.)	4,980

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	1.01	(H)
Particle Retention Efficiency (C/I)	0.01	(L)

NUTRIENT CHARACTERISTICS

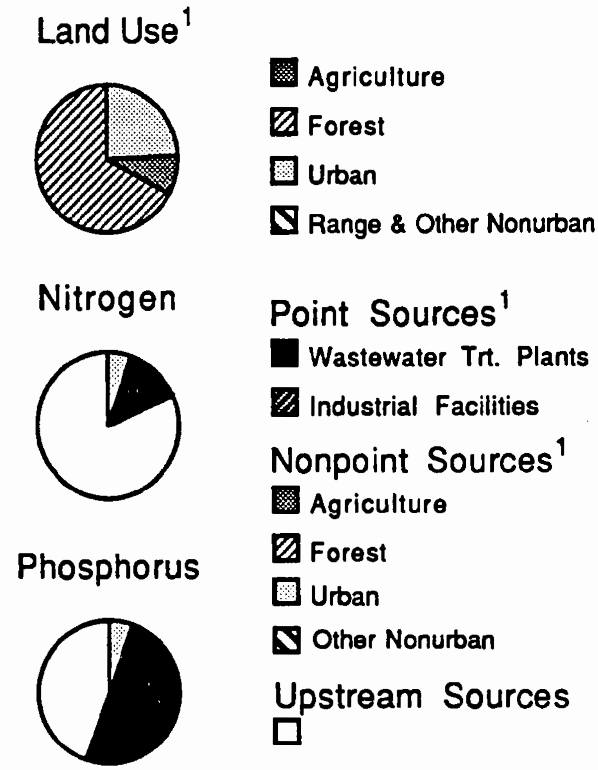
Estimated Loadings
(tons/year)

	Nitrogen	Phosphorus
Point	1,347	816
Nonpoint	614	90
Upstream	8,150	722
Total	10,111	1,628

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class			
			Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	1.022	(H)	NA	NA	222	2
Phosphorus	0.165	(H)	NA	NA	639	39

Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.



1 Data based on coastal county portion of EDA.

INTERPRETATION

Merrimack River has high susceptibility for concentrating dissolved substances. This concentration potential combined with a high nitrogen loading should result in a high nitrogen concentration within the estuary. Similarly, the concentration potential combined with the high phosphorus loading should result in a high phosphorus concentration. Based upon its high nutrient loading, Merrimack River should exhibit those characteristics associated with both high and medium nutrient concentration. However, due to its high concentration potential, the estuary should be sensitive to changes in nutrient concentrations. For N/P molecular ratios in the range of 10-20, determination of the limiting nutrient is particularly difficult. However, the N/P molecular ratio of the loading (13.8) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

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1.12 Massachusetts Bay
MA

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	7.85×10^{11}
Surface Area (sq. mi.)	364
Average Daily Inflow (cfs)	2,900
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	1,178
EDA outside coastal counties	24
EDA Total	1,202
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	1,202

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	0.27	(M)
Particle Retention Efficiency (C/I)	8.58	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

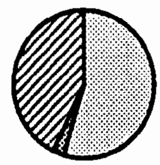
	Nitrogen	Phosphorus
Point	6,181	3,846
Nonpoint	1,813	245
Upstream	0	0
Total	7,994	4,091

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class. Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.215	(M)	28,636	358	4,331	54
Phosphorus	0.110	(H)	NA	NA	428	10

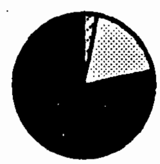
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1,2]

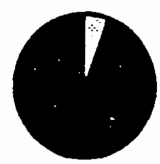


Agriculture
Forest
Urban
Range & Other Nonurban

Nitrogen



Phosphorus



Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1,2]
Agriculture
Forest
Urban
Other Nonurban

Upstream Sources

1 Data based on coastal county portion of EDA.
2 Data based on Boston Bay land use from National Estuarine Inventory, Volume 2.

INTERPRETATION

Massachusetts Bay is estimated to have a medium susceptibility for concentrating dissolved substances. This concentration potential combined with a medium nitrogen loading should result in a medium nitrogen concentration within the estuary. Similarly, the concentration potential combined with the high phosphorus loading should result in a high phosphorus concentration. Based upon its present nutrient loading, Massachusetts Bay should exhibit those characteristics associated with both medium and high nutrient concentration and may be somewhat less responsive to nutrient reduction due to its concentration potential. The N/P molecular ratio of the loading (5.3) suggests the importance of nitrogen as a potential limiting nutrient in the system.

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1.13 Cape Cod Bay MA

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	1.18×10^{12}
Surface Area (sq. mi.)	548
Average Daily Inflow (cfs)	1,800
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	771
EDA outside coastal counties	0
EDA Total	771
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	771

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	0.69	(M)
Particle Retention Efficiency (C/I)	20.75	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

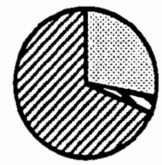
	Nitrogen	Phosphorus
Point	267	168
Nonpoint	113	17
Upstream	0	0
Total	380	185

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class. Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.026	(L)	1,074	283	NA	NA
Phosphorus	0.013	(M)	1,269	686	40	21

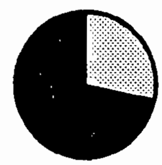
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]

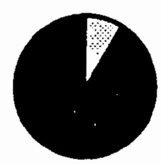


- Agriculture
- Forest
- Urban
- Range & Other Nonurban

Nitrogen



Phosphorus



Point Sources[1]
- Wastewater Trt. Plants
- Industrial Facilities

Nonpoint Sources[1]
- Agriculture
- Forest
- Urban
- Other Nonurban

Upstream Sources

[1] Data based on coastal county portion of EDA.

INTERPRETATION

Cape Cod Bay is estimated to have a medium susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the medium phosphorus loading should result in a medium phosphorus concentration. Based upon its ability to concentrate dissolved substances, Cape Cod Bay should retain those characteristics associated with medium and low concentration but should be sensitive to changes in concentration resulting from changes in nutrient loads. The N/P molecular ratio of the loading (4.6) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

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U.S. Environmental Protection Agency

1.14 Buzzards Bay MA

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	2.15×10^{11}
Surface Area (sq. mi.)	228
Average Daily Inflow (cfs)	1,200
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	576
EDA outside coastal counties	0
EDA Total	576
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	576

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	1.04	(H)
Particle Retention Efficiency (C/I)	5.68	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

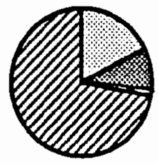
	Nitrogen	Phosphorus
Point	306	193
Nonpoint	163	23
Upstream	0	0
Total	469	216

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class.			
			Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.049	(L)	491	105	NA	NA
Phosphorus	0.023	(M)	744	344	120	56

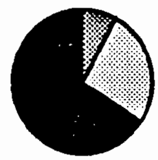
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]

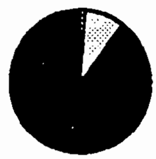


Agriculture
Forest
Urban
Range & Other Nonurban

Nitrogen



Phosphorus



Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Upstream Sources

1 Data based on coastal county portion of EDA.

INTERPRETATION

Buzzards Bay is estimated to have a high susceptibility for concentrating dissolved substances. This concentration potential combined with a low nitrogen loading should result in a low nitrogen concentration within the estuary. Similarly, the concentration potential combined with the medium phosphorus loading should result in a medium phosphorus concentration. Based upon its present nutrient loading and its high susceptibility to concentrate dissolved substances, Buzzards Bay should exhibit those characteristics associated with both low and medium nutrient concentration and should be sensitive to changes in that concentration. The N/P molecular ratio of the loading (4.8) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

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1.15 Narragansett Bay
MA, RI

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	1.39×10^{11}
Surface Area (sq. mi.)	165
Average Daily Inflow (cfs)	3,200
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	1,330
EDA outside coastal counties	0
EDA Total	1,330
Fluvial Drainage Area (sq. mi.)	451
Total Drainage Area (sq. mi.)	1,781

Pollution Susceptibility

	mg/l	Class
Dissolved Concentration Potential (mg/l)	0.52	(M)
Particle Retention Efficiency (C/I)	1.38	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

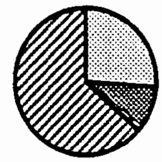
	Nitrogen	Phosphorus
Point	2,861	1,544
Nonpoint	1,713	234
Upstream	0	0
Total	4,574	1,778

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class. Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.239	(M)	14,563	318	2,660	58
Phosphorus	0.093	(M)	136	8	1,587	89

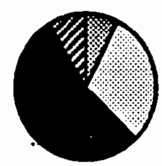
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]



- Agriculture
- Forest
- Urban
- Range & Other Nonurban

Nitrogen



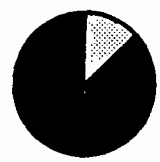
Point Sources[1]

- Wastewater Trt. Plants
- Industrial Facilities

Nonpoint Sources[1]

- Agriculture
- Forest
- Urban
- Other Nonurban

Phosphorus



Upstream Sources

[1] Data based on coastal county portion of EDA.

INTERPRETATION

Narragansett Bay is estimated to have a medium susceptibility for concentrating dissolved substances. This concentration potential combined with a medium nitrogen loading should result in a medium nitrogen concentration within the estuary. Similarly, the concentration potential combined with the medium phosphorus loading should result in a medium phosphorus concentration. Based upon its present nutrient loading, Narragansett Bay should retain those characteristics associated with medium concentration despite its susceptibility to concentrate dissolved substances. The N/P molecular ratio of the loading (5.7) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

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1.16 Gardiners Bay NY

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	1.11×10^{11}
Surface Area (sq. mi.)	197
Average Daily Inflow (cfs)	700
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	400
EDA outside coastal counties	0
EDA Total	400
Fluvial Drainage Area (sq. mi.)	NA
Total Drainage Area (sq. mi.)	400

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	1.77	(H)
Particle Retention Efficiency (C/I)	5.03	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

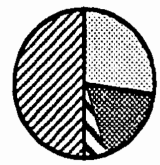
	Nitrogen	Phosphorus
Point	644	407
Nonpoint	341	33
Upstream	0	0
Total	985	440

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class.			
			Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.175	(M)	4,652	472	421	43
Phosphorus	0.078	(M)	124	28	384	87

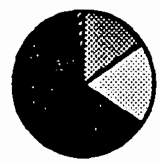
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]



Agriculture
Forest
Urban
Range & Other Nonurban

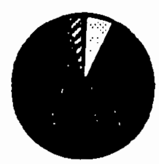
Nitrogen



Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Phosphorus



Upstream Sources

[1] Data based on coastal county portion of EDA.

INTERPRETATION

Gardiners Bay is estimated to have a high susceptibility for concentrating dissolved substances. This concentration potential combined with a medium nitrogen loading should result in a medium nitrogen concentration within the estuary. Similarly, the concentration potential combined with the medium phosphorus loading should result in a medium phosphorus concentration. Based upon its present nutrient loading, Gardiners Bay should retain its medium concentration status. However this status should be sensive to changes in nutrient loadings because of its high concentration potential. The N/P molecular ratio of the loading (5.3) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

Strategic Assessment Branch
Ocean Assessments Division
Office of Oceanography and Marine Assessment
National Ocean Service
National Oceanic and Atmospheric Administration

Office of Marine and Estuarine Protection
Office of Water
U.S. Environmental Protection Agency

1.17 Long Island Sound
NY, CT, MA

PHYSICAL CHARACTERISTICS

Dimensions

Volume (cu. ft.)	2.14×10^{12}
Surface Area (sq. mi.)	1,281
Average Daily Inflow (cfs)	30,000
Estuarine Drainage Area (sq. mi.)	
EDA within coastal counties	3,543
EDA outside coastal counties	3,687
EDA Total	7,230
Fluvial Drainage Area (sq. mi.)	10,010
Total Drainage Area (sq. mi.)	17,240

Pollution Susceptibility

	Conc	Class
Dissolved Concentration Potential (mg/l)	0.05	(L)
Particle Retention Efficiency (C/I)	2.32	(H)

NUTRIENT CHARACTERISTICS

Estimated Loadings
(tons/year)

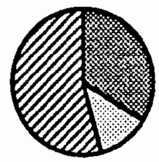
	Nitrogen	Phosphorus
Point	19,993	5,000
Nonpoint	5,528	628
Upstream	24,627	1,899
Total	50,148	7,527

Predicted Concentration Status
(load in tons/year)

	Concentration		To Change Conc. Class. Increase by		Decrease by	
	mg/l	Class	Load	%	Load	%
Nitrogen	0.273	(M)	133,728	267	31,760	63
Phosphorus	0.041	(M)	10,861	144	5,688	76

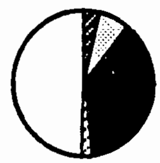
Abbreviations: cfs, cubic feet per second; mg/l, milligrams per liter; NA, not applicable; L, low; M, medium; H, high; C/I, volume/inflow.

Land Use[1]



Agriculture
Forest
Urban
Range & Other Nonurban

Nitrogen

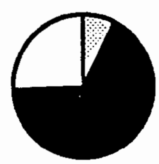


Point Sources[1]
Wastewater Trt. Plants
Industrial Facilities

Nonpoint Sources[1]
Agriculture
Forest
Urban
Other Nonurban

Upstream Sources

Phosphorus



1 Data based on coastal county portion of EDA.

INTERPRETATION

Long Island Sound has low susceptibility for concentrating dissolved substances. This concentration potential combined with a high nitrogen loading should result in a medium nitrogen concentration within the estuary. Similarly, the concentration potential combined with the high phosphorus loading should result in a medium phosphorus concentration. Based upon its low susceptibility to concentrate dissolved substances, Long Island Sound should exhibit those characteristics associated with medium nutrient concentration despite significant changes in nutrient loadings. For N/P molecular ratios in the range of 10-20, determination of the limiting nutrient is particularly difficult. However, the N/P molecular ratio of the loading (14.8) suggests the importance of nitrogen as a potentially limiting nutrient in the system.

Strategic Assessment Branch
National Ocean Service
National Oceanic and Atmospheric Administration

Office of Marine and Estuarine Protection
Office of Water
U.S. Environmental Protection Agency

Appendices B through E

Strategic Assessment of Near Coastal Waters

Northeast Case Study

NOAA/EPA Team
on Near Coastal Waters

Appendix B. Nutrient Discharges by Season by Estuary (tons per year) - circa 1982

Estuary	Source	Nitrogen					Phosphorus				
		Winter	Spring	Summer	Fall	Total	Winter	Spring	Summer	Fall	Total
Passamaquoddy Bay	Agriculture	31.8	40.1	12.5	0.5	84.8	0.3	4.0	0.3	0.0	4.5
	Forest	13.7	4.8	0.1	0.0	18.6	0.0	0.0	0.0	0.0	0.0
	Urban	22.1	24.8	24.4	15.0	86.3	3.8	3.7	2.5	2.5	12.5
	Other	0.3	0.2	0.1	0.0	0.6	0.0	0.0	0.0	0.0	0.0
	WWTPs	4.8	4.8	4.7	4.5	18.6	3.3	3.2	3.1	3.1	12.6
	Industry	19 4	22.3	21.3	20.8	83.6	0.1	0.1	0.0	0.0	0.3
	Upstream	0 0	0 0	0.0	0.0	0.0	0.0	0 0	0 0	0 0	0 0
	Total	91.9	96.9	63.2	40.8	292.8	7.4	11.0	5.8	5.6	29.8
Englishman Bay	Agriculture	24.8	30.8	8.9	0.5	65.0	0.2	2.8	0.2	0.0	3.3
	Forest	11.5	3.0	0.3	0.0	14.6	0.0	0.0	0.0	0.0	0.0
	Urban	12.5	11.7	10.9	7.3	42.4	2.0	1.9	1.6	1 2	6.8
	Other	1.0	0.6	0.3	0.1	2.0	0.0	0.0	0.0	0.0	0.0
	WWTPs	4.4	4.4	4.3	3.7	16.7	3.1	3.1	3.0	2.6	11.7
	Industry	1.1	3.3	3.1	1.9	9.3	0.1	0.2	0.2	0.1	0.7
	Upstream	0 0	0.0	0 0	0.0	0.0	0 0	0.0	0 0	0.0	0.0
	Total	55.3	53.6	27.6	13.5	150.1	5.4	8.0	5.2	3.9	22.5
Narraguagus Bay	Agriculture	23.3	29.0	6.4	0.4	61.2	0.2	2.8	0.2	0.0	3.1
	Forest	6.2	1.6	0.1	0.0	7.9	0.0	0.0	0.0	0.0	0.0
	Urban	8.0	20.2	17.6	2.1	46.1	4.0	1.0	3.0	1.6	9.8
	Other	1.4	0.6	0.4	0.2	2.7	0.0	0.0	0.0	0.0	0.0
	WWTPs	2.1	3.0	2.6	1.8	9.6	3.6	0.5	0.7	0.8	5.5
	Industry	0.5	1 3	1.1	0.1	3.0	0.1	0.0	0.0	0.0	0.1
	Upstream	0 0	0 0	0 0	0.0	0 0	0 0	0 0	0 0	0 0	0.0
	Total	39.5	55 9	30.6	4.5	130.6	7.9	4.2	4.0	2.4	18.5
Blue Hill Bay	Agriculture	6.2	7.7	2.2	0.1	16.2	0.1	0.7	0.1	0.0	0.8
	Forest	7.7	2 0	0.2	0.0	9.8	0.0	0.0	0.0	0.0	0.0
	Urban	22.7	21.2	19.7	13.3	76.9	3.6	3.4	3.2	2.1	12.4
	Other	2.0	1.1	0.8	0.3	4.0	0.0	0.0	0.0	0.0	0.0
	WWTPs	7.9	7.9	7.7	6.8	30.2	5.6	5.6	5.4	4.7	21.2
	Industry	1.9	6.0	5.6	3.4	18.9	0.2	0.4	0.4	0.2	1.3
	Upstream	0.0	0 0	0.0	0.0	0.0	0 0	0.0	0 0	0 0	0 0
	Total	48.4	46.0	36.0	23.8	154.2	9.5	10.1	9.1	7.1	35.7
Penobscot Bay	Agriculture	18.6	31.1	7.7	0.4	57.7	0.2	4.1	0.2	0 0	4.5
	Forest	82.0	58.8	5.2	0.0	148.0	1.0	1.0	0.0	0.0	2 0
	Urban	40.5	39.9	36.4	25.5	142.3	3.0	3.8	2.8	1.8	11.2
	Other	1.8	1.0	0.5	0.3	3.6	0.0	0.0	0.0	0.0	0.0
	WWTPs	20.4	20.4	20.1	16 3	77.2	9.8	10.6	9.4	6 9	36.4
	Industry	18.3	29.2	27.4	22.8	97.7	0.2	0.4	0.4	0.2	1.1
	Upstream	1,310 0	3,550 0	905 0	1,520 0	7,285 0	36 0	243 0	79 0	327.0	685.0
	Total	1,491.5	3,730.5	1,002.2	1,585.2	7,809.4	49.9	262.8	91.5	337.6	742.0
Muscongus Bay	Agriculture	7.8	13.7	4.9	0.2	26.6	0.0	2.0	0.2	0.0	2.2
	Forest	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	Urban	5.0	5.0	2.4	16.9	29.4	0.7	0.6	0.8	0.3	2.7
	Other	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	WWTPs	3.5	3.5	3.4	2.9	13.3	2.7	2.7	2.5	2.2	10.1
	Industry	0.0	0.1	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0
	Upstream	0 0	0.0	0 0	0.0	0 0	0.0	0.0	0 0	0.0	0 0
	Total	16.5	22.4	10.6	20.1	69.8	3.4	5.4	3.6	2.5	14.9

Abbreviation: WWTPs, Wastewater treatment plants.

Appendix B (continued)

Estuary	Source	Nitrogen					Phosphorus				
		Winter	Spring	Summer	Fall	Total	Winter	Spring	Summer	Fall	Total
Sheepscot Bay	Agriculture	79.0	100.4	70.2	3.6	253.1	1.0	12.5	1.6	0.0	15.0
	Forest	20.6	9.0	3.0	0.0	32.6	0.0	0.0	0.0	0.0	0.0
	Urban	41.1	57.5	59.5	28.6	186.6	6.4	10.1	10.1	3.4	29.9
	Other	0.5	0.5	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	WWTPs	16.0	16.0	17.3	15.3	68.6	13.9	13.9	13.2	11.9	52.9
	Industry	2.0	2.7	2.7	2.0	9.4	0.0	0.0	0.0	0.0	0.0
	Upstream	1,459 0	3,950 0	1,231 0	1,555 0	6,195.0	131.0	217.0	64.0	112.0	544.0
	Total	1,620.1	4,138.0	1,383.7	1,604.4	6,746.2	152.3	253.5	108.9	127.2	641.9
Casco Bay	Agriculture	184.9	102.0	77.2	3.8	367.9	1.9	10.5	1.0	0.0	13.3
	Forest	23.4	4.9	2.9	0.0	31.3	0.0	0.0	0.0	0.0	0.0
	Urban	79.0	67.0	76.0	40.0	262.0	13.0	11.0	13.0	7.0	44.0
	Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WWTPs	103.0	104.0	100.0	67.0	394.0	69.0	70.0	67.0	56.0	264.0
	Industry	81.0	84.0	83.0	81.0	329.0	33.0	33.0	33.0	33.0	132.0
	Upstream	0.0	0 0	0 0	0 0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	471.4	361.9	339.1	211.8	1,384.2	116.9	124.5	114.0	96.0	453.3
Saco Bay	Agriculture	23.9	20 4	13.9	0.4	56.6	0.2	2.1	0.1	0.0	2.4
	Forest	1.8	0.4	0.2	0.0	2.4	0.0	0.0	0.0	0.0	0.0
	Urban	26.6	42.5	43.5	21.5	134.3	4.5	6.2	6.5	2.8	19.9
	Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WWTPs	39.5	39 6	38.2	32.7	150.1	26.7	26.6	25.5	21.5	100.6
	Industry	9.1	9.4	9.3	9.1	36.6	3.7	3.7	3.7	3.7	14.6
	Upstream	216.0	453 0	103 0	103 0	875 0	5 0	40.0	4 0	6 0	55.0
	Total	317.2	565.3	208.1	166.7	1,257.3	40.1	78.8	39.7	34 0	192.6
Great Bay	Agriculture	96.2	37.9	28.6	1.4	164.2	0.7	5.6	0.7	0.0	7.0
	Forest	3.2	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0
	Urban	63.5	53.0	71.2	40.3	227.9	10.5	8.3	11.0	6.1	35.9
	Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0.0
	WWTPs	80.2	60.7	58.5	50.2	229.8	40.3	40.3	39.2	33.7	153.4
	Industry	2.8	2.8	2.8	2.8	11.0	1.7	1.7	1.7	1.7	6.6
	Upstream	0.0	0 0	0 0	0 0	0 0	0 0	0.0	0.0	0 0	0 0
	Total	225.6	154.4	161.2	94.7	636.0	53.1	55.8	52.6	41.4	202.9
Merrimack River	Agriculture	36.0	31.0	15.0	2.0	84.0	0.0	4.0	0.0	0.0	4.0
	Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Urban	153.0	86.0	175.0	116.0	530.0	26.0	13.0	28.0	19.0	86.0
	Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WWTPs	342.0	345.0	333.0	266.0	1,306.0	213.0	215.0	207.0	178.0	613.0
	Industry	9.0	10.0	9.0	9.0	37.0	0.0	0.0	0.0	0.0	0.0
	Upstream	2,340.0	3,490 0	1,640 0	684 0	8,154 0	172 0	303 0	134.0	113 0	722.0
	Total	2,880.0	3,982.0	2,172.0	1,097.0	10,111.0	411.0	535.0	369.0	310.0	1,625.0
Massachusetts Bay	Agriculture	7.9	22.2	19.1	4.8	53.8	0.0	3.1	0.0	0.0	3.1
	Forest	123.3	2.7	142.7	2.5	271.2	1.5	0.0	1.3	0.0	2.8
	Urban	449.2	316.7	447.7	235.3	1,446.9	78.8	54.5	69.1	36.4	238.6
	Other	14.4	2.7	20.0	2.3	39.4	0.0	0.0	0.0	0.0	0.0
	WWTPs	1,603.1	1,603.1	1,603.1	1,356.4	6,165.7	999.5	999.5	999.5	645.6	3,644.3
	Industry	4.0	3.7	4.4	3.4	15.5	0.3	0.3	0.3	0.3	1.2
	Upstream	0.0	0 0	0.0	0 0	0.0	0 0	0.0	0 0	0.0	0 0
	Total	2,201.9	1,951.1	2,237.0	1,604.5	7,994.5	1,079.9	1,057.4	1,070.2	662.5	4,090.0

Appendix B (continued)

Estuary	Source	Nitrogen					Phosphorus				
		Winter	Spring	Summer	Fall	Total	Winter	Spring	Summer	Fall	Total
Cape Cod Bay	Agriculture	0.5	1.4	0.4	0.2	2.6	0.0	0.2	0.0	0.0	0.2
	Forest	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
	Urban	33.8	18.2	30.5	25.4	107.9	5.6	2.9	4.9	4.2	17.6
	Other	1.4	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
	WWTPs	70.1	70.5	68.1	58.5	267.2	44.1	44.5	42.9	36.9	168.4
	Industry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Upstream	0 0	0 0	0 0	0 0	0.0	0 0	0 0	0 0	0 0	0 0
	Total	105.9	90.2	99.0	84.1	379.2	49.6	47.6	47.8	41.2	186.2
Buzzards Bay	Agriculture	6.6	21.7	6.2	3.7	38.4	0.0	2.5	0.0	0.0	2.5
	Forest	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
	Urban	38.8	20.9	35.0	29.1	123.8	6.4	3.3	5.6	4 8	20.2
	Other	1 1	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0
	WWTPs	80.4	80.9	78.1	67.1	306.5	50.5	51.0	49.3	42.4	193.2
	Industry	0.0	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Upstream	0.0	0.0	0.0	0 0	0.0	0.0	0 0	0 0	0 0	0.0
	Total	127.4	123.5	119.2	99.9	470.1	56.9	56.6	54.9	47 2	215.6
Narragansett Bay	Agriculture	90.0	156.0	74.0	26.0	346.0	1.0	15.0	1.0	0.0	17.0
	Forest	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	Urban	431.0	206.0	452.0	278.0	1,367.0	70.0	33.0	72.0	43 0	216.0
	Other	2.0	0.0	1.0	0.0	3.0	0.0	0.0	0.0	0 0	0.0
	WWTPs	646.0	651.0	629.0	540.0	2,466.0	403.0	406.0	392.0	336.0	1,537 0
	Industry	97.0	97.0	97.0	97.0	388.0	1.0	1.0	1.0	1.0	4.0
	Upstream	0 0	0.0	0 0	0 0	0 0	0.0	0.0	0 0	0.0	0.0
	Total	1,267.0	1,110.0	1,253.0	941.0	4,571.0	475.0	455.0	466.0	360.0	1,776 0
Gardiners Bay	Agriculture	69.5	34.0	52 8	1.7	158.0	0.6	2.3	0.9	0 0	3.7
	Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Urban	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Other	81.7	42.5	52.6	23.6	180.5	10.2	6.8	8.5	3 7	29.2
	WWTPs	164.6	165.4	159.6	137.4	627.3	102.3	103.1	99.9	85.5	390.9
	Industry	3.6	3.9	4.1	3.7	15.3	3.8	3.8	3.6	3.6	15.3
	Upstream	0.0	0 0	0 0	0.0	0 0	0.0	0.0	0 0	0 0	0 0
	Total	299.4	245.9	269.4	166.5	981.1	116.9	116.1	113.1	93.0	439 2
Long Island Sound	Agriculture	693.0	421.0	670.0	43.0	1,827.0	6.0	23.0	6.0	0.0	35.0
	Forest	18.0	5.0	38.0	0.0	81.0	0.0	0.0	0.0	0.0	0.0
	Urban	1,050.0	760.0	1,306.0	527.0	3,843.0	173.0	121.0	215.0	86.0	595.0
	Other	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	WWTPs	4,512.0	5,126.0	4,934.0	4,344.0	16,916.0	1,187.0	1,479.0	1,263.0	1,022.0	4,971.0
	Industry	236.0	269.0	276.0	281 0	1,064.0	4 0	4.0	4.0	4.0	16.0
	Upstream	7,060.0	9,491 0	5,579 0	2,522 0	24,652.0	527 0	653.0	424 0	295 0	1,899.0
	Total	13,571.0	16,072.0	12,604.0	7,717.0	50,164.0	1,697.0	2,280.0	1,932.0	1,407.0	7,516.0

Appendix C. Nitrogen and Phosphorus Discharges by Source Category

Table C1 Nitrogen discharge by nonpoint, point, and upstream source category by estuary (tons per year) - circa 1982

Estuary	Total	Nonpoint		Point		Upstream		Estuarine Resource Base	
		Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Surface Area (sq mi)	Percent of Regional Total
Passamaquoddy Bay	294	192	65	102	35	0	0	157	4 0
Englishman Bay	151	124	82	27	18	0	0	76	1 9
Narraguagus Bay	106	93	88	13	12	0	0	70	1 8
Blue Hill Bay	155	107	69	48	31	0	0	115	2 9
Penobscot Bay	7,808	352	4	176	2	7,280	94	361	9 2
Muscongus Bay	58	44	76	14	24	0	0	72	1 8
Sheepscot Bay	8,741	474	5	77	1	8,190	94	103	2 6
Casco Bay	1,418	667	47	751	53	0	0	164	4 2
Saco Bay	1,254	193	15	186	15	875	70	17	0 4
Great Bay	640	397	62	243	38	0	0	15	0 4
Merrimack River	10,111	614	6	1,347	13	8,150	81	6	0 2
Massachusetts Bay	7,995	1,814	23	6,181	77	0	0	364	9 2
Cape Cod Bay	380	113	30	267	70	0	0	548	13 9
Buzzards Bay	469	163	35	306	65	0	0	228	5 8
Narragansett Bay	4,574	1,713	37	2,861	63	0	0	165	4 2
Gardiners Bay	985	341	35	644	65	0	0	197	5 0
Long Island Sound	50,148	5,528	11	19,993	40	24,627	49	1,281	32 5
Regional Totals	95,287	12,929	14	33,236	35	49,122	52	3,939	100

Table C2 Nitrogen nonpoint discharge by category by estuary (tons per year)

Estuary	Total	Agriculture		Forest		Urban		Other		Estuarine Resource Base	
		Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Surface Area (sq mi)	Percent of Regional Total
Passamaquoddy Bay	192	86	45	19	10	86	45	1	0	157	4 0
Englishman Bay	124	65	52	15	12	42	34	2	2	76	1 9
Narraguagus Bay	93	62	67	8	9	20	22	3	3	70	1 8
Blue Hill Bay	107	16	15	10	9	77	72	4	4	115	2 9
Penobscot Bay	352	59	17	147	42	143	41	3	1	361	9 2
Muscongus Bay	44	27	61	0	0	17	39	0	0	72	1 8
Sheepscot Bay	474	253	53	32	7	188	40	1	0	103	2 6
Casco Bay	667	367	55	30	4	270	40	0	0	164	4 2
Saco Bay	193	58	30	2	1	133	69	0	0	17	0 4
Great Bay	397	166	42	4	1	227	57	0	0	15	0 4
Merrimack River	614	83	14	0	0	531	86	0	0	6	0 2
Massachusetts Bay	1,814	54	3	271	15	1,449	80	40	2	364	9 2
Cape Cod Bay	113	3	3	0	0	108	96	2	2	548	13 9
Buzzards Bay	163	38	23	0	0	124	76	1	0	228	5 8
Narragansett Bay	1,713	345	20	1	0	1,363	80	4	0	165	4 2
Gardiners Bay	341	158	46	0	0	183	54	0	0	197	5 0
Long Island Sound	5,528	1,827	33	61	1	3,639	66	1	0	1,281	32 5
Regional Totals	12,929	3,667	28	600	5	8,600	67	62	0	3,939	100

Table C3 Nitrogen point source discharge by category by estuary (tons per year)

Estuary	Total	Wastewater Treatment Plants		Industry		Estuarine Resource Base	
		Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Surface Area (sq mi)	Percent of Regional Total
Passamaquoddy Bay	102	18	18	84	82	157	4 0
Englishman Bay	27	17	63	10	37	76	1 9
Narraguagus Bay	13	8	62	5	38	70	1 8
Blue Hill Bay	48	30	63	18	37	115	2 9
Penobscot Bay	176	77	44	99	56	361	9 2
Muscongus Bay	14	13	93	1	7	72	1 8
Sheepscot Bay	77	67	87	10	13	103	2 6
Casco Bay	751	408	54	343	46	164	4.2
Saco Bay	186	149	80	37	20	17	0 4
Great Bay	243	230	97	13	3	15	0 4
Merrimack River	1,347	1,310	97	37	3	6	0 2
Massachusetts Bay	6,181	6,166	100	15	0	364	9 2
Cape Cod Bay	267	267	100	0	0	548	13 9
Buzzards Bay	306	306	100	0	0	228	5 8
Narragansett Bay	2,861	2,470	86	391	14	165	4 2
Gardiners Bay	644	628	98	16	2	197	5 0
Long Island Sound	19,993	18,922	95	1,071	5	1,281	32 5
Regional Totals	33,236	31,086	94	2,150	6	3,939	100

Appendix C (continued)

Table C4 Phosphorus discharge by nonpoint, point, and upstream source category by estuary (tons per year) - circa 1982

Estuary	Total	Nonpoint		Point		Upstream		Estuarine Resource Base	
		Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Surface Area (sq mi)	Percent of Regional Total
Passamaquoddy Bay	32	19	59	13	41	0	0	157	4 0
Englishman Bay	23	10	43	13	57	0	0	76	1 9
Narraguagus Bay	12	6	50	6	50	0	0	70	1 8
Blue Hill Bay	37	14	38	23	62	0	0	115	2 9
Penobscot Bay	775	28	4	61	1	686	89	361	9 2
Muscongus Bay	15	5	33	10	67	0	0	72	1 8
Sheepscot Bay	641	48	7	52	1	543	85	103	2 6
Casco Bay	471	58	12	413	88	0	0	164	4 2
Saco Bay	195	24	12	116	59	55	28	17	0 4
Great Bay	203	43	21	160	79	0	0	15	0 4
Merrimack River	1,628	90	6	816	50	722	44	8	0 2
Massachusetts Bay	4,091	246	6	3,845	94	0	0	384	9 2
Cape Cod Bay	185	17	9	168	91	0	0	548	13 9
Buzzards Bay	216	23	11	193	89	0	0	228	5 8
Narragansett Bay	1,778	234	13	1,544	87	0	0	165	4 2
Gardiners Bay	440	33	8	407	92	0	0	197	5 0
Long Island Sound	7,527	628	8	5,000	66	1,899	25	1,281	32 5
Regional Totals	18,269	1,524	8	12,840	70	3,905	21	3,939	100

Table C5 Phosphorus nonpoint discharge by category by estuary (tons per year)

Estuary	Total	Agriculture		Forest		Urban		Other		Estuarine Resource Base	
		Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Surface Area (sq mi)	Percent of Regional Total
Passamaquoddy Bay	19	5	26	0	0	14	74	0	0	157	4 0
Englishman Bay	10	3	30	0	0	7	70	0	0	76	1 9
Narraguagus Bay	6	3	50	0	0	3	50	0	0	70	1 8
Blue Hill Bay	14	1	7	0	0	13	93	0	0	115	2 9
Penobscot Bay	28	4	14	1	3	23	82	0	0	361	9 2
Muscongus Bay	5	2	40	0	0	3	60	0	0	72	1 8
Sheepscot Bay	46	14	30	0	0	32	70	0	0	103	2 6
Casco Bay	58	13	22	0	0	45	78	0	0	164	4 2
Saco Bay	24	2	8	0	0	22	92	0	0	17	0 4
Great Bay	43	7	16	0	0	36	84	0	0	15	0 4
Merrimack River	90	4	4	0	0	86	96	0	0	8	0 2
Massachusetts Bay	246	3	1	3	1	239	97	1	0	364	9 2
Cape Cod Bay	17	0	0	0	0	17	0	0	0	548	13 9
Buzzards Bay	23	3	13	0	0	20	87	0	0	228	5 8
Narragansett Bay	234	17	7	0	0	217	93	0	0	165	4 2
Gardiners Bay	33	4	12	0	0	29	88	0	0	197	5 0
Long Island Sound	628	38	6	1	0	589	94	0	0	1,281	32 5
Regional Totals	1,524	123	8	5	0	1,395	92	1	0	3,939	100

Table C6. Phosphorus point source discharge by category by estuary (tons per year)

Estuary	Total	Wastewater Treatment Plants		Industry		Estuarine Resource Base	
		Discharge	Percent of Estuary Total	Discharge	Percent of Estuary Total	Surface Area (sq. mi.)	Percent of Regional Total
Passamaquoddy Bay	13	13	100	0	0	157	4.0
Englishman Bay	13	12	92	1	8	76	1.9
Narraguagus Bay	6	6	100	0	0	70	1.8
Blue Hill Bay	23	21	91	2	9	115	2.9
Penobscot Bay	61	57	93	4	7	361	9.2
Muscongus Bay	10	10	100	0	0	72	1.8
Sheepscot Bay	52	52	100	0	0	103	2.6
Casco Bay	413	273	66	140	34	164	4.2
Saco Bay.	116	101	87	15	13	17	0.4
Great Bay	160	153	96	7	4	15	0.4
Merrimack River	816	814	100	2	0	8	0.2
Massachusetts Bay	3,845	3,844	100	1	0	364	9.2
Cape Cod Bay	166	166	100	0	0	546	13.9
Buzzards Bay	193	193	100	0	0	226	5.8
Narragansett Bay	1,544	1,540	100	4	0	165	4.2
Gardiners Bay	407	391	96	16	4	197	5.0
Long Island Sound	5,000	4,980	100	20	0	1,281	32.5
Regional Totals	12,640	12,626	98	212	2	3,939	100

Appendix D. Accuracy of the Discharge Estimates

Inherent in any data set are limitations on quality and accuracy. The nutrient discharge data presented in this report were based on a number of factors and assumptions discussed below. Source categories differ in their complexity and in the amount and accuracy of data available to verify discharge estimates. Discharge estimates will vary by season, precipitation, terrain, land use, and economic activity. Point sources are generally less complex and variable than nonpoint and upstream sources. Nutrient concentrations from point source discharges are easier to obtain and measure, and hence, have higher quality estimates. Within the point source categories, wastewater treatment plants are easier to characterize than industrial facilities, and within the industrial category, simple industries (such as cement or glass) are easier to characterize than more complex industries (such as petrochemicals). In nonpoint source categories, better estimates are available for crop land than forestland. Urban storm runoff and combined sewer overflows are highly variable, have limited data, and are difficult to characterize. Upstream sources have the most variability, and the relationship between flow and pollutant load is not well captured in the NCPDI estimates.

The data range in quality from excellent to highly speculative and are a function of discharge variability and data availability. A five-point scale was used covering certain ranges of accuracy to assess data quality, as shown in Table D1. The discharge variability ranges from low to high depending on whether it is from an end-of-pipe constant discharge (low) or from land runoff (high).

Table D1. Data Quality Assessment - Accuracy of nutrient discharge data

Data Quality	Discharge Variability	Error Range (%)	Data Availability
(1) Excellent	Low	± 10 - 20	Good
(2) Good	Moderate	± 20 - 50	Good to Moderate
(3) Fair	Moderate to High	± 50 - 100	Limited
(4) Poor	High	100	Limited to None
(5) Unknown	High	100	Limited to None

Depending upon the type of source discharges within an estuarine system, the quality of the estimates may vary. For example, a system whose nutrient loads were dominated by WWTPs and agriculture may have more accurate discharge estimates than one dominated by upstream riverine inputs and urban runoff. Table D2 shows the relative differences in data quality between source categories and nutrient discharge data, and Table D3 shows the relative quality of the factors used in estimating nutrient loadings.

The quality of background data in Table 4 ranges from excellent to fair depending on the accuracy of records, age of data, and minor variations that occur at the site-specific level. These are reliable data and are easily measured. These data are used in calculating nutrient discharge by source category. Some errors are introduced when the data may be averaged or prorated for input to the estimation procedure. For example, rainfall may be averaged over a time interval of occurrence, or population or fertilizer application may be prorated over a given land area. The accuracy of the estimates will depend on the reliability of the background data in combination with the source category, pollutant, and the time and space scale considered.

Table D2. Data Quality Assessment - Discharges by source category for the Northeast

Source Category		Nitrogen		Phosphorus		Comments
		Annual	Seasonal	Annual	Seasonal	
Nonpoint						
	Agriculture	2 - 3	3 - 5	2 - 3	3 - 4	Flow and erosion modeled, daily simulation, nitrogen and phosphorus data from fertilizer, discharge highly variable
	Forest	3 - 4	3 - 5	3 - 4	3 - 4	Modeled soil erosion similar to cropland, runoff less known or studied than agriculture land
	Urban	3 - 4	3 - 5	3 - 4	3 - 5	Flow is modeled, daily simulation and WWTP capacity, bypass assumptions are conservative, nutrient load highly variable
	Other	2 - 3	3 - 5	2 - 3	3 - 5	Modeled similar to agriculture and forest land, erosion a function of ground cover, highly variable
Point						
	WWTPs	1 - 2	1 - 2	1 - 2	1 - 2	Flow and nutrient levels fairly constant by treatment levels, nitrogen and phosphorus often not permitted, actual discharge may vary
	Industry	1 - 3	2 - 3	2 - 3	2 - 3	Greater variation in seasonal flow, nutrient levels, and treatment performance, nitrogen and phosphorus often not permitted
Upstream						
	Upstream	2 - 5	3 - 5	2 - 5	3 - 5	Flow data more regularly collected than nutrient concentrations, high short term variability, monitoring often misses major storm activity

Numerical Ratings: 1, Excellent; 2, Good; 3, Fair; 4, Poor; 5, Unknown
Abbreviation: WWTPs, wastewater treatment plants.

Nonpoint Source Discharges. The quality of data for nonpoint sources ranges from good to unknown and is a function of the accuracy of the various parameters used in calculation discharges. Site-specific variations in land use types, soils, fertilizer applications, precipitation, and runoff coefficients are represented by basin drainage. This assumes implicitly that for such an area, the factors most important for the calculation of sediment and nutrient discharges do not vary significantly and are well represented by average values. This may not always be valid because of the variability in soil type, topography, management practices, and ground cover. Hence, discharge estimates for these categories vary in quality as a result site variability.

Agriculture. Fertilizer application rates were based on the best available data to date. Soluble nitrogen and phosphorus discharges were generalized based on state records of use and fertilizer sales. Lands such as nurseries, golf courses, and urban lawns were excluded. A fixed percentage of applied nutrients was assumed lost to surface runoff. Actual percentages vary and are not well represented by a single value. Variability, resulting from application rates and timing, mode of application, fertilized crop types, storm events, and physical characteristics of the fertilized areas, was not considered. However, conservation versus conventional tillage was considered.

The validity of the SWRRB model was tested using several watersheds in a study conducted by the Chesapeake Bay Program. The model was found to be accurate to ±30 - 100 percent for runoff and ±30 - 150 percent for soil erosion. While this is within the state-of-the-art for nonpoint source modeling, it indicates that these estimates are highly variable and difficult to model accurately .

Forest. The data quality range from fair to unknown. Less detailed information is available for forestland, and little is known about runoff or erodibility. The amount of ground cover in a deciduous forest will vary and will affect the amount of rainfall energy reaching the ground due to the presence of forest litter. Little has been done on the leaching of nutrients from decaying plants. The process is slow and can be considered negligible in relation to nutrient discharges from eroding of soil.

Table D3. Data Quality Assessment - Background data

Background Data Category	Annual	Seasonal	Comments
Precipitation	1	1	Orographic differences between sites in hilly areas, especially in New England
Land Use	2 - 3	N/A	Variations in age of data and population changes in region since data collected (particularly Maine and Cape Cod)
Population	1 - 2	N/A	Some errors in proration to estuarine drainage areas and in rapidly growing areas
Fertilizer Use	2 - 3	N/A	Variations between states in accuracy of records; errors introduced in prorating sales to crop acreage
Fertilizer Seasonality	2	2 - 3	Runoff coefficient based on average of field studies; some errors introduced at site-specific level
Number of WWTPs	1	N/A	Publicly owned facility characteristics contained in EPA Needs Survey
Number of Industrial Plants	1	N/A	Plants listed through NPDES permit programs; some minor or intermittent dischargers may have been omitted
Planting and Harvesting dates	1	1	Determined by regional temperature regimes; some annual variation between sites or crops

Numerical Ratings: 1, Excellent; 2, Good; 3, Fair
Abbreviations: WWTPs, Wastewater treatment plants; NPDES, National pollution discharge elimination system; N/A, not applicable

Urban. The estimate of runoff volumes depends upon the quality of the land use data, precipitation data, and runoff coefficients. The accuracy of the calculated estimates of urban storm runoff volumes and loadings depends upon the overall accuracy of the runoff volume estimates and the use of average pollutant concentrations. The amount of urban areas served by CSOs was taken from the Needs Survey (EPA, 1982), is up to date, and is the best single source of these data.

Precipitation and weather data are from NOAA. Readings are taken continuously with state-of-the-art instrumentation, and the data are considered good quality with a good density of weather stations. Land use data from the USGS LU/LC program are 6 to 12 years old and are the best available on a national basis. Runoff coefficients are based on EPA-conducted studies on runoff/rainfall relationships for impervious areas. A 90 percent confidence interval was determined for each area, and a median runoff coefficient calculated (EPA, 1983b). These data are considered good quality. Some error is introduced when different runoff coefficients are applied to site-specific land use mixes. Certain land uses, such as construction and mining operations, were not accounted for by urban definition and are not included in nonurban runoff methodology. Even though construction work is temporary, large sediment loads are nearly always associated with it.

Nutrient concentration estimates are the weakest link in urban runoff discharge estimates. The data do not reflect local storm variability. The variation within storms is not reflected in the calculated discharge. However, use of averaged concentrations is an accepted technique to avoid overestimation of the initial discharge.

Point Source Discharges. Point source data are the most accurate and range in quality from excellent to fair. The accuracy and completeness of these data are a function of the quality of flow and concentration data. Estimated flows and permit limits produce less accurate estimates than measured values.

Wastewater Treatment Plants. Flow data from WWTP discharge pipes are generally accurate and more easily measured. WWTPs receive fairly constant inflows and have storage facilities for flow equalization. The discharge estimation procedure assumes the same number of operating days and similar discharge patterns for all facilities for all seasons. Nitrogen and phosphorus concentrations are generally estimated based on similar treatment efficiency and technology for WWTPs. They are not subject to discharge permits so that detailed information is not available. The data, however, are considered generally good, with the best available for major WWTPs.

Industry. Industrial flow from major facilities is usually measured, and hence, the data are generally accurate. Flow data from minor facilities is either estimated or based on design flow. These data are considered a good estimate of wastewater discharge volumes. Nutrient discharges are either monitored or estimated based on similar facilities with similar flow volumes. Industrial discharges, however, vary seasonally and between industries and may introduce some error.

Upstream. Loadings calculated from this source category are classed in the good to unknown range. Flow from upstream sources is highly variable and seasonal. Nutrient data are also not always available, and in some cases, no flow or discharge data were available. Estimates were made for these streams based on values from nearby streams with similar flows and land use characteristics for which monitored data were available.

Flow information is generally collected on a regular basis but not always at the point of entry into an EDA. A problem with respect to the accuracy of upstream discharge estimates is the spatial overlap between the NCPDI study area and the NEI study area. In cases where the EDA extends beyond the coastal county boundary, nutrient discharge data may be underestimated. The EDA extends beyond ten estuarine systems in the Northeast. In cases where the EDA is fully within the coastal county, the nutrient discharge data may be overestimated. This would apply to seven estuarine systems for the region. Although this may only slightly affect overall nutrient discharge totals for a particular estuary, these spatial considerations need to be taken into account when using these data.

Appendix E. Computing Dissolved Concentration Potential

The approach used to develop the dissolved concentration potential estimates (Ketchum, 1955) assumes that pollutant behavior can be inferred by the knowledge of how freshwater inflow is flushed from the estuary and diluted by seawater. The average salinity concentration in an estuary is assumed to be indicative of the concentration of a conservative pollutant in the system. The physical forces of tide, freshwater inflow, and wind affect the distribution of a pollutant in an estuary as they do in freshwater.

The DCP estimate assumes that an initial concentration of a pollutant is equal to the pollutant load per unit time divided by total average daily freshwater inflow. This initial concentration is multiplied by the ratio of the volume of freshwater to seawater in an estuary to arrive at a DCP estimate. This is represented as:

$$DCP = C_{init} \times \text{Freshwater Fraction } (f_o)$$

where: C_{init} = pollutant loading rate / freshwater inflow
f_o = volume of freshwater / volume of seawater.

For purposes of comparison, an equal pollutant load is assumed to be discharged to all estuaries identified in NOAA's National Estuarine Inventory (NEI), including the 17 in the Northeast. This enables a direct comparison of the flushing and dilution characteristics as they affect potential pollutant concentrations. The same approach is used with actual loadings to estimate concentrations to characterize present status.

The DCP estimate is determined for average annual conditions of freshwater inflow and salinity. The latter represents the mix of fresh and salt water within an estuary as it is affected by freshwater inflow, wind, tide, and adjacent shelf dynamics. Volumes of fresh and salt water are estimated for the three salinity zones (tidal fresh: 0-0.5ppt, mixing zone: 0.5-25ppt; seawater zone: > 25ppt) as depicted for each estuary in the NEI Volume 1 and summed to obtain system totals.

The method assumes vertical and lateral mixing. The DCP estimate has limited utility in estuaries where salinity stratification persists for significant periods. In addition, the DCP calculation is highly dependent on the existence and accuracy of a freshwater signal in the average annual salinity structure. As a consequence, the DCP estimate has little meaning in systems where average annual salinity approaches that of seawater such as in Cape Cod Bay. Table 1 shows the DCP estimate, volume, average daily freshwater inflow, average annual salinity, intra-annual salinity variability (as per NEI Vol.1), and degree of stratification

The DCP estimate is most sensitive to the average annual salinity, and is dependent on the accuracy to which average salinity can be estimated. In addition, sensitivity increases as the average annual salinity of the system increases. Figure 1 shows the proportionately greater effect that a percent increase in the average annual salinity will have on a percent change in DCP. For example, an estuary having a 25ppt average annual salinity with a 10 percent over estimation in average annual salinity would have a corresponding 30 percent change in DCP. In contrast, a system with the same 10 percent error but whose average annual salinity is 20ppt would realize only a 10 percent change in its DCP. The percent change in the DCP estimate is depicted for increases in salinity, since this provides a greater effect on DCP estimates when compared to similar percent decreases. This is due to overall sensitivity of the DCP calculation to higher average annual salinities as mentioned previously.

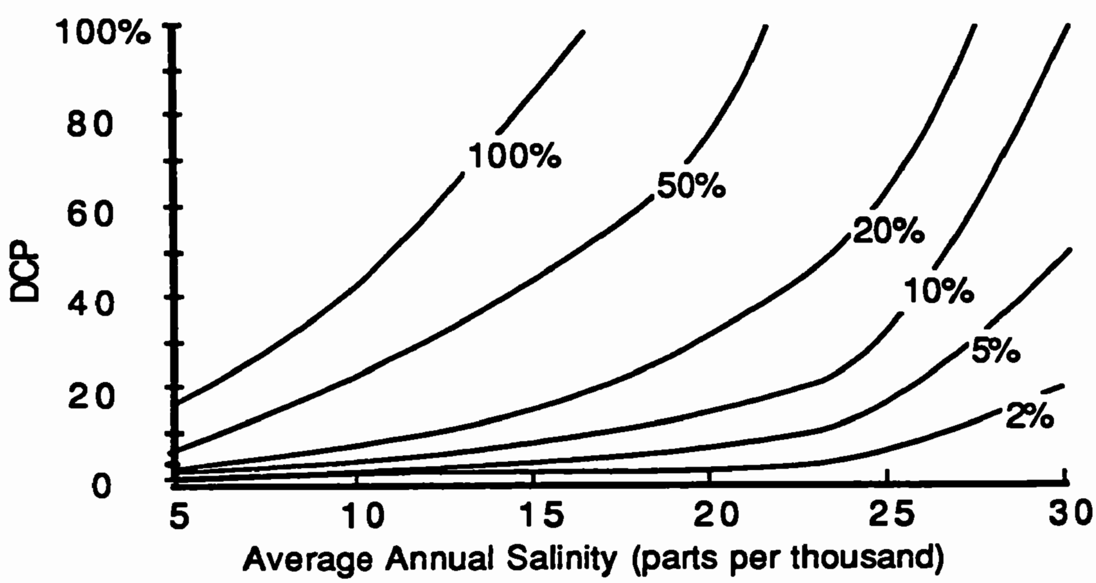
Estuaries whose average annual salinities are in excess of 25ppt, however, tend to be more stable and less susceptible to errors in salinity. This is because the overriding influences on salinity are oceanic (i.e. tidal). They exhibit a greater degree of predictability compared to estuaries dominated by freshwater inflows. Errors in estimating the average annual salinity for these estuaries in excess of 10% are unlikely. In comparison, estuaries with an average annual salinity of less than 15ppt are less stable and are susceptible to greater errors in salinity determination. However, the overall effect on the DCP estimate in these cases is minimized because the DCP estimate is not as sensitive to average annual salinities at the lower ranges.

Table E1. Selected physical charateristics and dissolved concentration potential for the Nation's estuaries.

Estuary	Dissolved Concentration Potential mg/l	Volume 10^9 cubic feet	FW Inflow Avg. Daily 1000 cfs	Salinity: Average Annual ppt	Salinity: Intra-annual variability	Stratification: 3-Mo. Hi Flow Strat. Class.	Stratification: 3-Mo. Lo Flow Strat. Class.
Passamaquoddy Bay	0.266	315.3	6.2	27.7	M	MS	MS
Englishman Bay	0.918	79.7	1.6	28.2	M	HS	MS
Narraguagus Bay	1.538	63.3	0.9	28.5	H	HS	HS
Blue Hill Bay	1.031	241.1	1.3	28.7	H	HS	HS
Penobscot Bay	0.134	724.6	16.1	26.1	H	HS	MS
Muscongus Bay	2.249	85.5	0.6	28.6	M	HS	MS
Sheepscot Bay	0.088	118.4	17.6	28.0	H	HS	MS
Casco Bay	0.613	191.3	2.1	28.8	M	MS	VH
Saco Bay	0.454	15.3	3.6	27.7	H	HS	HS
Great Bay	1.536	4.7	2.0	23.2	H	MS	VH
Merrimack River	1.011	2.1	8.4	5.6	M	MS	VH
Massachusetts Bay	0.273	785.0	2.9	30.5	L	VH	VH
Cape Cod Bay	0.688	1177.8	1.8	29.0	L	VH	VH
Buzzards Bay	1.042	215.0	1.2	28.9	M	VH	VH
Narragansett Bay	0.523	139.1	3.2	27.6	M	VH	VH
Gardiners Bay	1.774	111.1	0.7	29.0	L	VH	VH
Long Island Sound	0.054	2190.0	30.0	27.7	M	VH	VH

Abbreviations: mg/l, milligrams per liter; cfs, cubic feet per second; FW, freshwater; ppt, parts per thousand; 3-Mo., 3 month; strat. class., stratification classification

Figure E1. Sensitivity of DCP estimate



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