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NHEP Environmental Indicator Report: Water Quality 2006

Phil Trowbridge
New Hampshire Department of Environmental Services

New Hampshire Estuaries Project

2006

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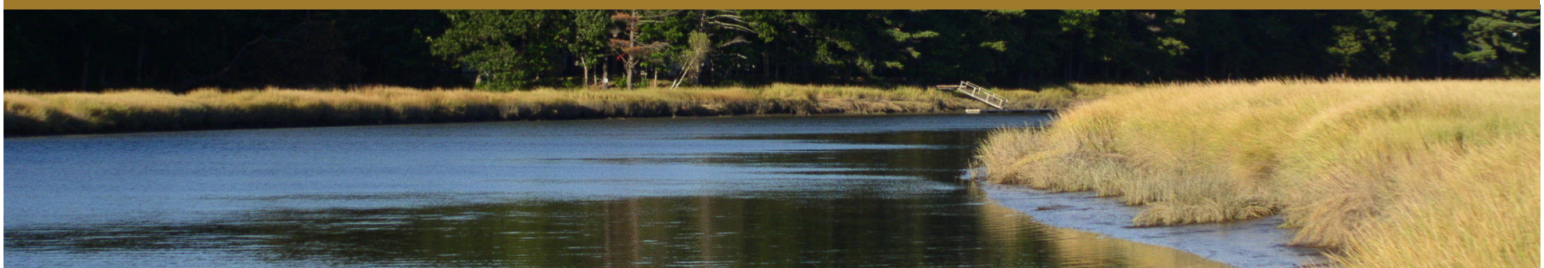

Environmental Indicator Report: Water Quality

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March 2006

ENVIRONMENTAL INDICATOR REPORT

WATER QUALITY

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ACKNOWLEDGMENTS

This report was peer-reviewed by the NHEP Technical Advisory Committee. The members of this committee deserve thanks for their time and thoughtful input.

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INTRODUCTION

The New Hampshire Estuaries Project (NHEP) is part of the U.S. Environmental Protection Agency's National Estuary Program, which is a joint local/state/federal program established under the Clean Water Act with the goal of protecting and enhancing nationally significant estuarine resources. The NHEP is funded by the EPA and is administered by the University of New Hampshire.

The NHEP's Comprehensive Conservation and Management Plan for New Hampshire's estuaries was completed in 2000 and implementation is ongoing. The Management Plan outlines key issues related to management of New Hampshire's estuaries and proposes strategies (Action Plans) that are expected to preserve, protect, and enhance the State's estuarine resources. The NHEP's priorities were established by local stakeholders and include water quality improvements, shellfish resources, land protection, and habitat restoration. Projects addressing these priorities are undertaken throughout NH's coastal watershed, which includes 42 communities.

Every three years, the NHEP prepares a State of the Estuaries report with information on the status and trends of a select group of environmental indicators from the coastal watershed and estuaries. The report provides the NHEP, state natural resource managers, local officials, conservation organizations, and the public with information on the effects of management actions and decisions.

Prior to developing each State of the Estuaries report, the NHEP publishes four technical data reports ("indicator reports") that illustrate the status and trends of the complete collection of indicators tracked by the NHEP. Each report focuses on a different suite of indicators: Shellfish, Water Quality, Land Use and Development, and Habitats and Species. All of the indicators are presented to the NHEP Technical Advisory Committee, which selects a subset of indicators to be presented to the NHEP Management Committee and to be included in the State of the Estuaries report. The Management Committee reviews the indicators and finalizes the list to be included in the report. Between 10 and 20 indicators are included in each State of the Estuaries report. The 2006 Water Quality Indicator Report is the second NHEP indicator report for water quality. Data from this report will be used in the 2006 State of the Estuaries report.

The following sections contain the most recent data for the 17 water quality indicators tracked by the NHEP. In some cases the NHEP funds data collection and monitoring activities; however data for the majority of indicators are provided by other organizations with monitoring programs. The details of the monitoring programs and performance criteria for the indicators are listed in the NHEP Monitoring Plan (NHEP, 2004).

The results and interpretations for the indicators presented in this report have been peer reviewed by the NHEP Technical Advisory Committee and other experts in relevant fields. The Technical Advisory Committee consists of university professors, researchers and state and federal environmental managers from a variety of disciplines and perspectives. The conclusions of this study represent the current scientific consensus regarding conditions in New Hampshire's estuaries.

BAC1 - ACRE-DAYS OF SHELLFISH HARVEST OPPORTUNITIES IN ESTUARINE WATERS

Monitoring Objective

The objective of this indicator is to report on how much of the year the shellfish beds are closed to harvesting due to high bacteria concentrations. The DES Shellfish Program measures the opportunities for shellfish harvesting using "acre-days," which is the product of the acres of shellfish growing waters and the number of days that these waters are open for harvest. The acre-days indicator is reported as the percentage of the total possible acre-days of harvesting for which the shellfish waters are actually open. In most cases, the reason why a shellfish growing area is closed to harvesting is somehow related to poor bacterial water quality (although closures due to PSP or "red-tide" do occur). Therefore, this acre-day indicator is a good integrative measure of the degree to which water quality in the estuary is meeting fecal coliform standards for shellfish harvesting. This indicator answers the following monitoring question:

Do NH tidal waters meet fecal coliform standards of the National Shellfish Sanitation Program for 'approved' shellfish areas?

Measurable Goal

The goal is to have 100% of all possible acre-days in estuarine waters open for harvesting.

Data Analysis and Statistical Methods

Data on shellfish harvesting classifications and acre-days of harvesting were provided by the DES Shellfish Program. Growing areas on the Atlantic Coast were not included in the classification summary or the acre-day trends because the size of these growing areas would dwarf changes in the estuarine waters. Moreover, the purpose of this indicator is to report on estuarine water quality, rather than coastal water quality. For reporting purposes, data on acre-days was split into the results for Great Bay, Little Bay, Little Harbor, and Hampton-Seabrook Harbor. The acre-days statistics are only for the "Approved" or "Conditionally Approved" waters in each growing area; therefore, areas that are delineated as "safety zones" around wastewater treatment facility outfalls and marinas were not included in the statistics. For each area, the reported indicator is the percent of the total possible acre-days for which the area was open, in order to take into account changes in growing area acreage that occur from year to year. NH Fish and Game Department closures for species conservation (June 1 to Labor Day for clams, July 1 to August 31 for oysters) were not included in the acre-days calculations

Results

Shellfishing classifications and acre-days of shellfishing opportunities have been tracked from 2000 through 2004. Table 1 shows that in 2000 and 2001, approximately 36 to 38% of the 13,718 acres of estuarine waters were classified as "Approved" or "Conditionally Approved" for shellfishing by the DES Shellfish Program. By 2004, the percentage of waters in the "Approved" or "Conditionally Approved" classifications had grown to 46%. However, some of the increased percentage was due to a reduction in the total area of estuarine waters being considered for shellfish classifications. In 2003, the DES Shellfish Program removed all of the estuarine waters on the Maine side of the border from its classification database.

Table 2 shows the trends in shellfish harvesting acre-days the major growing areas of NH's estuarine waters. Shellfishing opportunities in the open portions of the estuaries varied by location. In Great Bay, the shellfishing acre-days remained nearly 90% of the possible amount in 2000-2004.In Hampton-Seabrook Harbor and Little Harbor, the acre-day percentage was only slightly above 40% for the same period. In both of these harbors, poor water quality (i.e., elevated bacteria concentrations) occurs after even small rain storms. Therefore, these areas are often closed. There has been an improving trend in the Little Harbor growing area. This area was closed to shellfishing in before 2001. By 2004, it was open 44% of the possible acre-days. The growing areas in Upper and Lower Little Bay were closed more often in 2003 and 2004 than previously because of heavy rainfall and wastewater treatment facility overflows and the presence of boats in the mooring fields longer than usual.

The goal for the acre-days indicator is for all estuarine waters to be open for harvesting 100% of the time. This goal is not being met. Only approximately half of the estuarine waters are classified as "Approved" or "Conditionally Approved" for shellfishing. Of these areas, the best areas are only open for 93% of the possible acre days. Key growing areas such as Hampton-Seabrook Harbor are often closed due to poor water quality after rain storms. Stormwater runoff is the predominant cause for the closures in all areas. Direct runoff of bacteria from the land surface and the occasional wastewater treatment plant overflow

Table 1: Percent of NH estuarine waters in each shellfish classification

CLASSIFICATION	2000	2001	2002	2003	2004
Approved or Conditionally Approved	36.3%	37.8%	38.4%	48.5%	46.6%
Restricted or Prohibited	10.5%	11.2%	11.2%	13.6%	5.8%
Safety Zone	3.8%	7.5%	6.9%	9.3%	23.6%
unclassified	49.4%	43.5%	43.6%	28.6%	24.0%
Total Acres	13,718	13,718	13,739	11,355	11,452

Source: DES Shellfish Program Annual Reports

Figure 1: Percent of NH estuarine waters that are open for shellfish harvesting

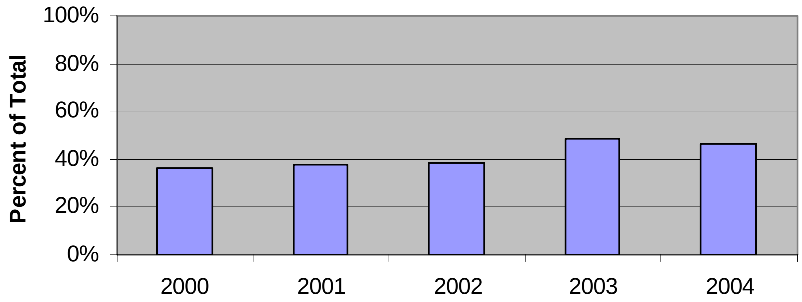
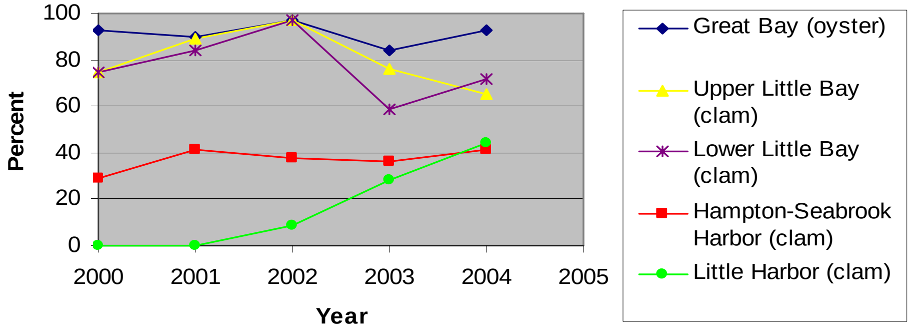


Table 2: Percent of possible acre-days during which shellfish harvesting was allowed in approved or conditionally approved estuarine waters

AREA	2000	2001	2002	2003	2004
Great Bay (oyster)	93	90	97	84	93
Hampton-Seabrook Harbor (clam)	29	41	38	36	65
Upper Little Bay (clam)	75	89	97	76	72
Lower Little Bay (clam)	75	84	97	59	72
Little Harbor (clam)	0*	0*	9	28	44
Goal	100	100	100	100	100

Source: NHDES Shellfish Program
***The Little Harbor growing area was closed to shellfishing in 2000 and 2001.**

Figure 2: Percent of possible acre-days during which shellfish harvesting was allowed in approved or conditionally approved estuarine waters



BAC2 - TRENDS IN DRY-WEATHER BACTERIAL INDICATORS CONCENTRATIONS

Monitoring Objective

The objective of this indicator is to identify long-term trends in bacteria concentrations during dry weather periods. Concentrations of the traditional bacteria indicators species (fecal coliforms, enterococci, and *Escherichia coli*) are measured monthly at fixed stations in the estuary and tributaries. This indicator answers the following monitoring question:

Has dry-weather bacterial contamination changed significantly over time?

Measurable Goal

The goal is to have statistically significant, decreasing trends in bacteria concentrations at stations in the tidal tributaries to the estuary.

Data Analysis and Statistical Methods

Samples that were collected from trend monitoring stations at low tide during dry weather were queried from the dataset. For sites in the middle of Great Bay/Little Bay, "dry weather" samples were those collected when there had been less than 2 inches of rain in the previous 4 days. For all other sites, a sample was considered to be dry if there had been less than 0.5 inches of rain in the previous 2 days. The two different criteria were used to identify "dry weather" samples because water quality at stations in the middle of the bay responds slower to rainfall runoff than at stations in the tidal tributaries.

Trends in low-tide dry weather samples were assessed using linear regression of natural log transformed concentrations versus year. Trends were considered significant if the coefficient of the year variable was significant at the $p<0.05$ level. The percent change in concentrations was calculated following Helsel and Hirsch (1992). Specifically, the coefficient of the year variable, b1, was converted to a percent change per year by $(e^{b1}-1)*100$. The overall change over the period of record was determined from the percent change per year and a first order differential equation.

Statistical trend analysis was only completed for the four trend stations with more than 5 years of data. For the other 13 trend stations that have been monitored by the National Coastal Assessment since 2002, the results for the stations with similar salinities were grouped together to illustrate spatial patterns across the estuary. The stations were grouped based on their average salinity. Each measurement was classified as either "dry" or "wet" using the criteria explained previously. Median values were calculated for the dry and the wet samples collected between 2002 and 2004 from all the stations within the same salinity group. The results were not standardized by tide stage. Data from the four long term trend sites were also included in this analysis.

Results

The results of the trend analysis at the four stations are summarized in Table 3. Graphs of the bacteria indicator species over time at each station are shown in Figure 3 through Figure 6. For each station, the graphs show the trends over the full period of record on the left and for the most recent 10 years on the right.

Fecal coliform and *Escherichia coli* concentrations decreased at the four long-term trend sites for the full period of record. The most dramatic decreases were observed in the tidal tributaries, the Lamprey and Squamscott rivers, where the concentrations fell by at least 75%. There were also decreases in concentrations at Adams Point in Great Bay and Fort Point in Portsmouth Harbor. However, the absolute bacteria concentrations are low at these sites so the effect of the trend is less significant than at the tributary sites. There were no statistically significant, increasing trends at any of the long-term trend sites.

In the most recent 10 years (see Table 3B), only two statistically significant trends were observed. The concentrations of fecal coliforms and *E. coli* in the Lamprey River fell by 73 and 80%, respectively. Bacteria concentrations were generally decreasing in the Squamscott River but the trends were not statistically significant. No significant trends were observed at the Adams Point or Portsmouth Harbor sites. However, this observation is not surprising because the concentrations are low at these sites already, possibly approaching background levels.

Therefore, for the full period of record (1988-2004) the goal of observing decreasing trends in the tidal tributaries is being met. WWTF upgrades and NHEP-funded stormwater management projects are likely major contributors to the decreasing trends. However, only two of the seven tributaries to the Great Bay Estuary have been monitored for long enough to allow for trend analysis. All of the trend conclusions are based on data from only four stations in the estuary. Moreover, most of the trends became non-significant in the last decade. The observed trends may have been driven by large decreases in the late 1980s and early 1990s, with smaller changes occurring in the past decade. Alternatively, continued population growth in coastal watershed may be counteracting the ongoing pollution control efforts.

For illustration, concentrations of bacteria indicator species at all of the trend stations from around the estuary (Figure 10) were combined to show the relationships between estuarine dilution, precipitation and bacteria concentrations. The stations were grouped according to the average salinity at the site in 2004, which is a measure of mixing with ocean waters. The median concentrations of fecal coliforms, enterococci and *E. coli* for each salinity regime under dry and wet conditions are shown in Figure 7, Figure 8 and Figure 9. In general, the bacteria concentrations increased as salinity decreased (less dilution) and as precipitation increased (wet weather).

Table 3: Trends in dry weather bacteria concentrations at low tide at long-term monitoring stations

A. Trends for full period of record

Station	Parameter	Period of Record	Median (cts/100ml)	Trend	Percent Change
GRBAP (Adams Point)	Fecal coliforms	1989-2004	8	**Decreasing**	-73%
	Enterococcus		3	No significant trend	
	E. coli		7	**Decreasing**	-63%
GRBLR (Lamprey River)	Fecal coliforms	1992-2004	70	**Decreasing**	-91%
	Enterococcus		35	No significant trend	
	E. coli		64	**Decreasing**	-93%
GRBCL (Squamscott River)	Fecal coliforms	1989-2004	72	**Decreasing**	-79%
	Enterococcus		32	No significant trend	
	E. coli		50	**Decreasing**	-74%
GRBCML (Portsmouth Harbor)	Fecal coliforms	1991-2004	6	**Decreasing**	-57%
	Enterococcus		2	No significant trend	
	E. coli		4	**Decreasing**	-57%

B. Trends for the most recent 10 years

Station	Parameter	Period of Record	Median (cts/100ml)	Trend	Percent Change
GRBAP (Adams Point)	Fecal coliforms	1995-2004	7.5	No significant trend	
	Enterococcus		3	No significant trend	
	E. coli		5	No significant trend	
GRBLR (Lamprey River)	Fecal coliforms	1995-2004	65	**Decreasing**	-73%
	Enterococcus		35	No significant trend	
	E. coli		41	**Decreasing**	-80%
GRBCL (Squamscott River)	Fecal coliforms	1995-2004	62	No significant trend	
	Enterococcus		30	No significant trend	
	E. coli		41	No significant trend	
GRBCML (Portsmouth Harbor)	Fecal coliforms	1995-2004	6	No significant trend	
	Enterococcus		2	No significant trend	
	E. coli		4	No significant trend	

Source: Great Bay NERR Monitoring Program and NH National Coastal Assessment

Figure 3: Long-term trends in bacteria indicators at Adams Point in Great Bay

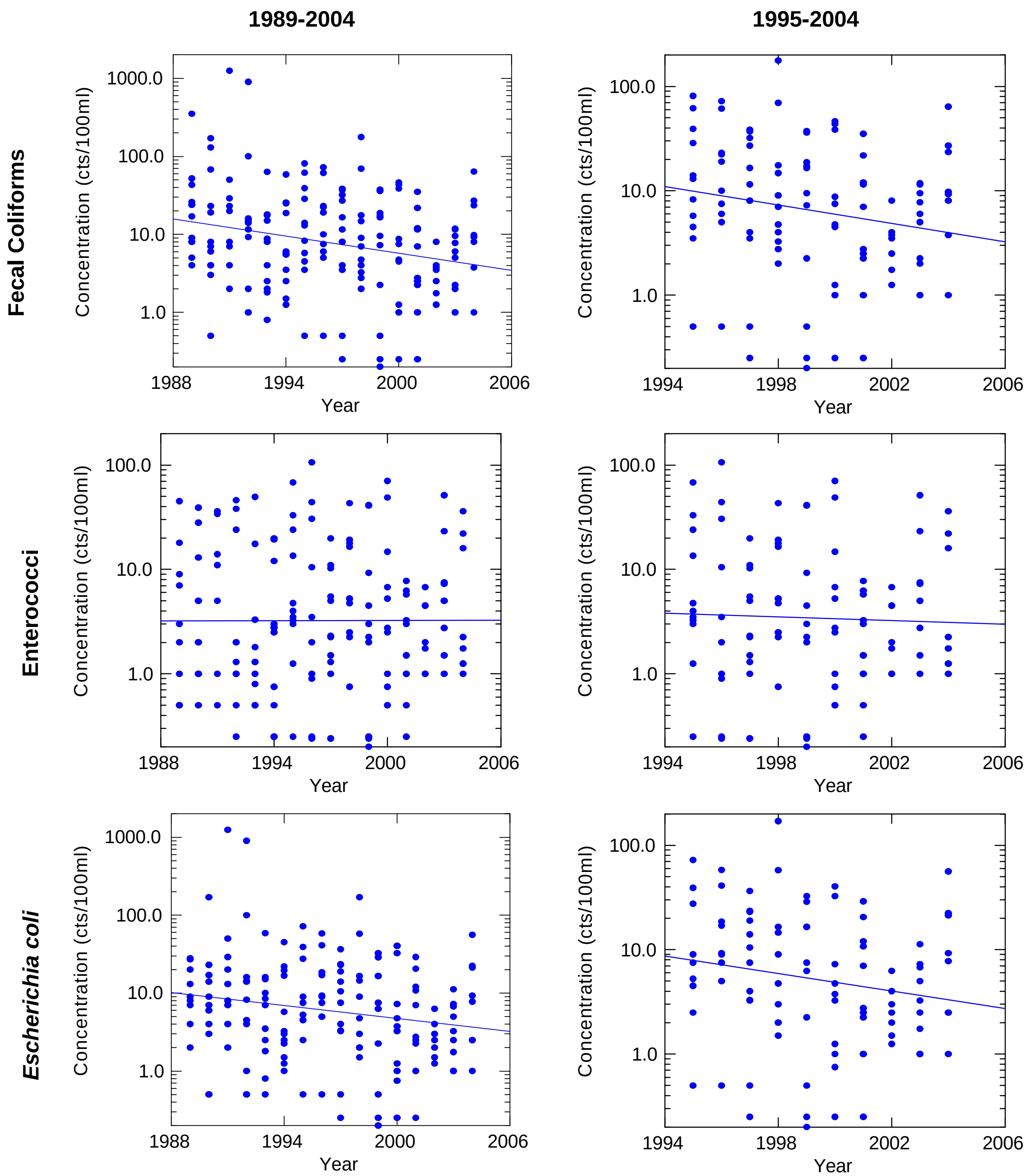


Figure 4: Long-term trends in bacteria indicators at the Newmarket Town Landing on the Lamprey River (tidal portion)

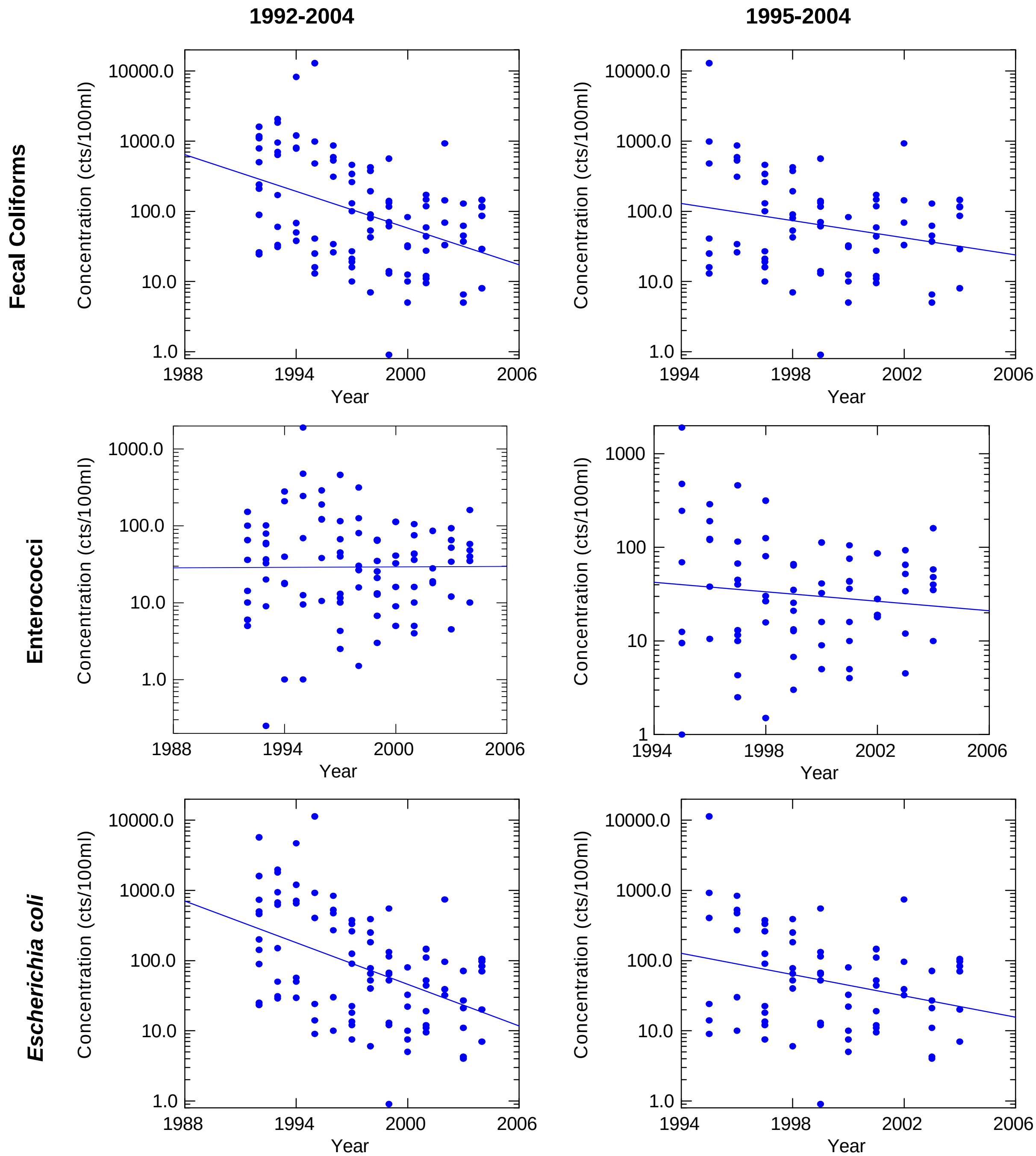


Figure 5: Long-term trends in bacteria indicators at Chapmans Landing on the Squamscott River

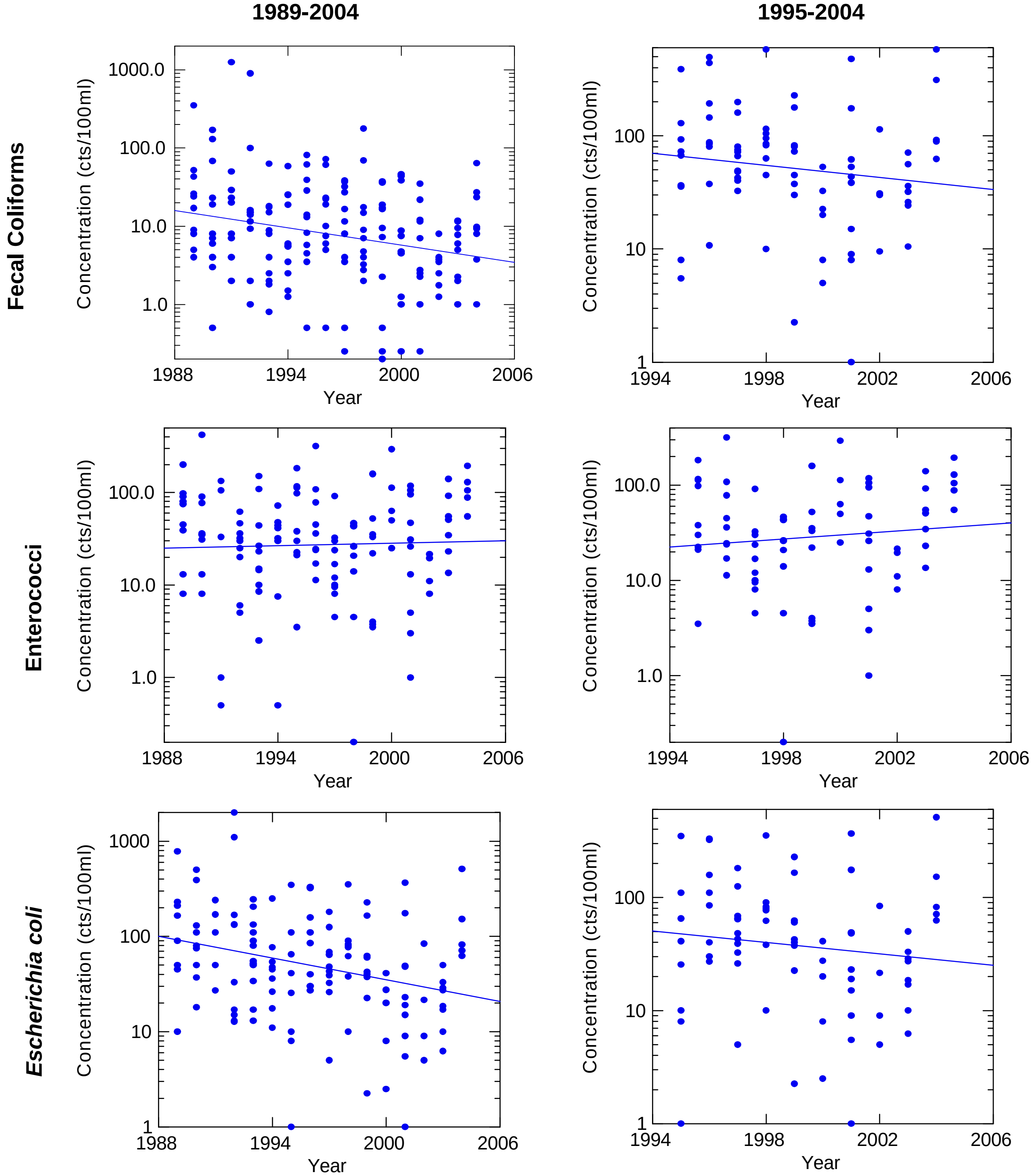


Figure 6: Long-term trends in bacteria indicators at Fort Point in Portsmouth Harbor

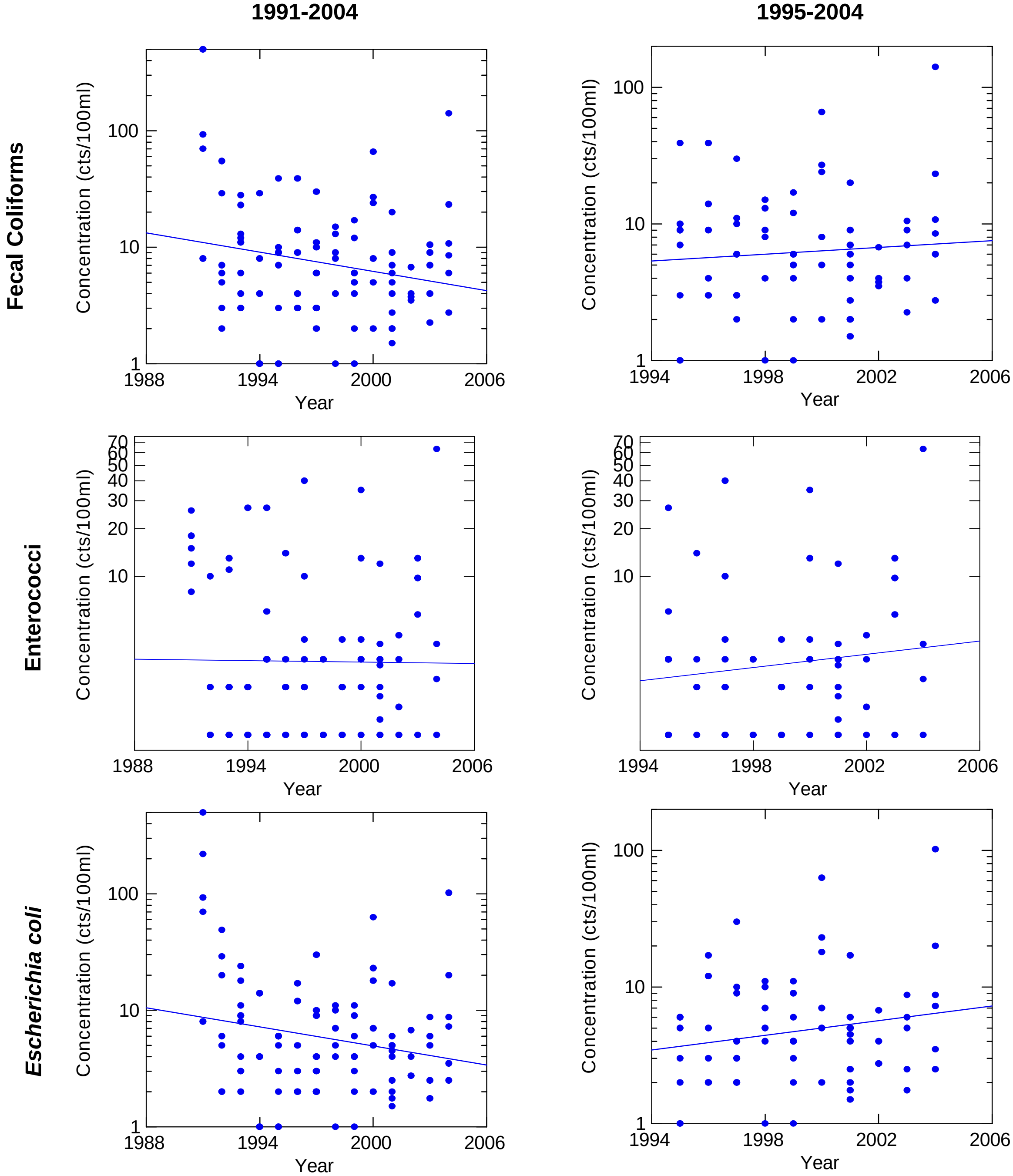


Table 4: Median bacteria concentrations at stations for different salinity and precipitation regimes

Salinity	Condition	Fecal coliforms	Enterococcus	E. coli
25-30 ppt	DRY	9.0	5.8	7.3
18-25 ppt	DRY	6.9	3.3	5.0
5-18 ppt	DRY	31.5	20.0	21.8
0.5-5 ppt	DRY	56.5	35.5	34.5
25-30 ppt	WET	11.9	14.8	7.6
18-25 ppt	WET	31.3	13.3	16.5
5-18 ppt	WET	83.5	39.0	42.5
0.5-5 ppt	WET	67.8	56.0	59.0

Source: NH National Coastal Assessment

Figure 7: Median fecal coliform concentrations at estuarine trend monitoring stations in 2002-2004

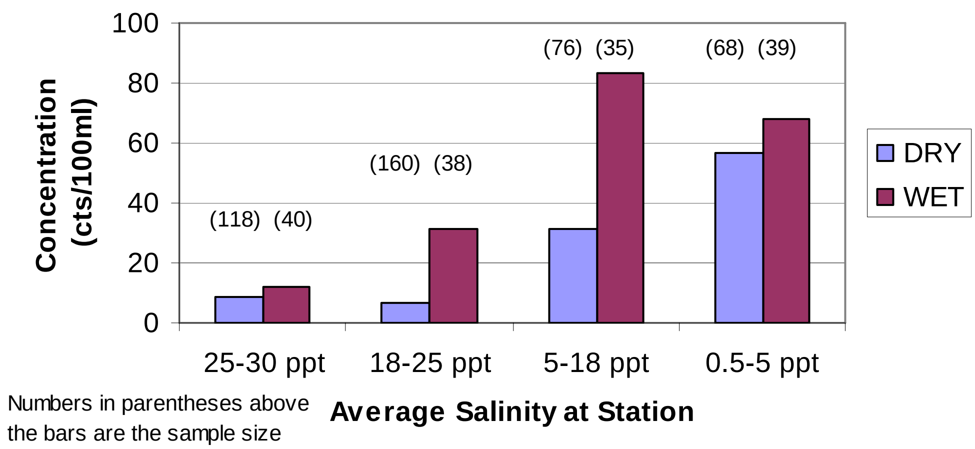


Figure 8: Median enterococci concentrations at estuarine trend monitoring stations in 2002-2004

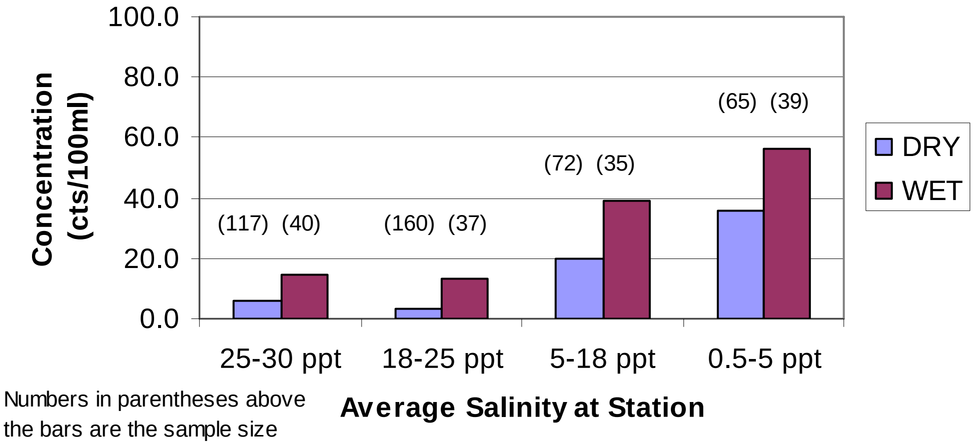


Figure 9: Median *E. coli* concentrations at estuarine trend monitoring stations in 2002-2004

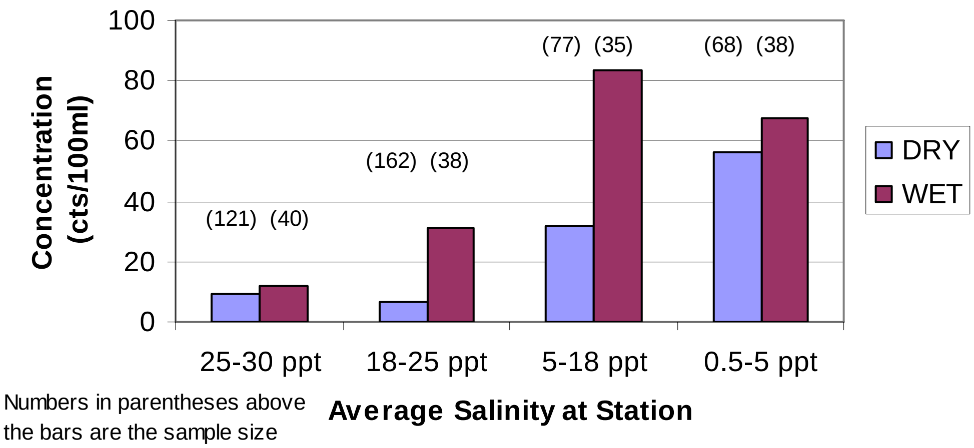
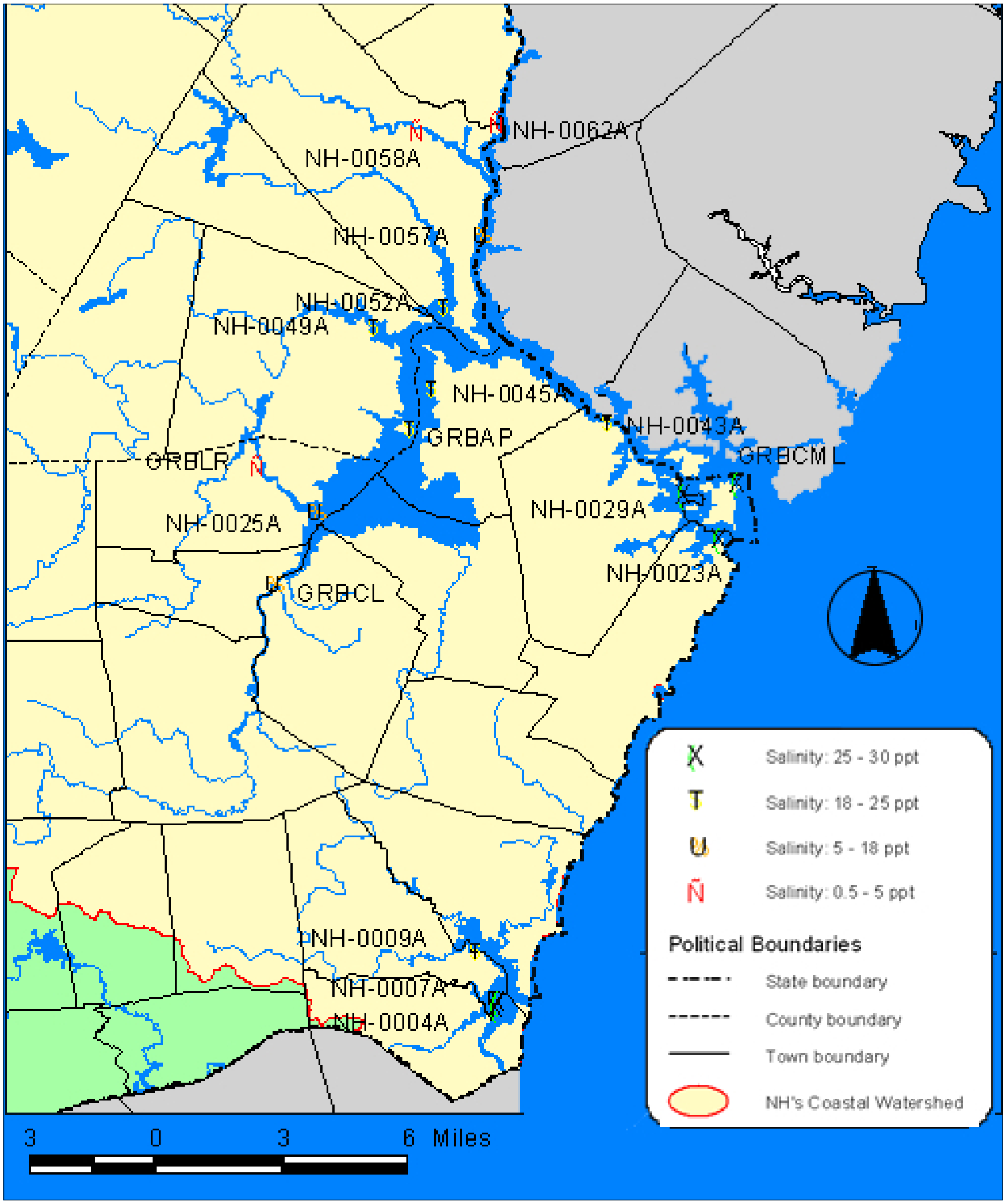


Figure 10: Stations for monthly bacteria monitoring in NH's estuaries (2002-2004)



Source: U.S. Army Corps of Engineers

BAC4 - TIDAL BATHING BEACH POSTINGS

Monitoring Objective

The objective for this indicator is to track the number of advisories at designated tidal bathing beaches in NH waters. The DES Beach Program monitors designated tidal bathing beaches along the Atlantic Coast of NH during the summer months (Memorial Day to Labor Day). If the concentrations of enterococci in the water do not meet state water quality standards for designated tidal beaches (104 cts/100 ml in a single sample), DES recommends that an advisory be posted at the beach. Therefore, the number of advisories at tidal beaches should be a good indicator of bacterial water quality at the beaches. This indicator partially answers the following monitoring question:

Do NH tidal waters, including swimming beaches, meet the state enterococci standards?

Measurable Goal

The goal is to have 0 advisories at the tidal bathing beaches over the summer season.

Data Analysis and Statistical Methods

The advisories at each coastal beach were obtained from the DES Beach Program. In 2005, there were 16 beaches in the program (Table 5). Most of these beaches have never been posted for bacterial pollution. Therefore, the total postings at all of the beaches were charted together.

Results

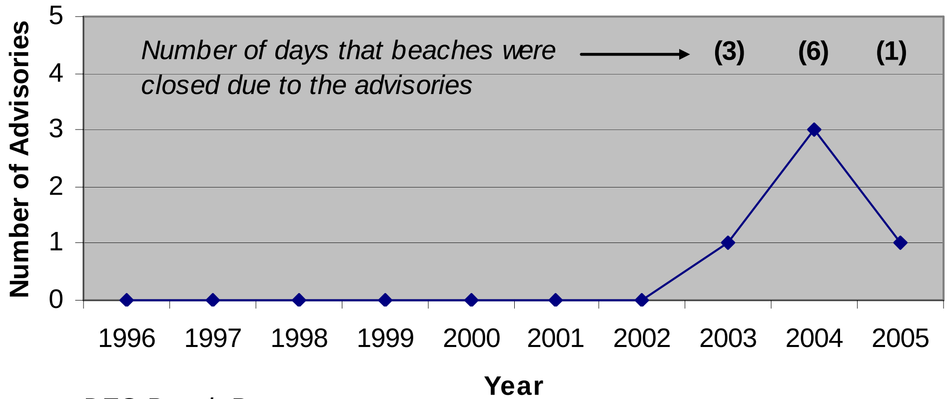
Before 2003, there had never been any advisories issued for the tidal bathing beaches in New Hampshire. In 2003, one beach (New Castle Town Beach) was posted. In 2004, three beaches (Bass Beach, Foss Beach, and Sawyer Beach) were all posted. In 2005, an advisory was issued for Seabrook Harbor Beach. The affected beaches were closed for a total of 3, 6 and 1 days in 2003, 2004 and 2005, respectively. The NHEP goal is zero advisories at tidal beaches. The current value of the indicator is one posting in 2005. Therefore, the goal is not currently being met.

It is significant that advisories have been issued for NH's tidal beaches for the first time. This trend may indicate a decline in water quality in near coastal areas. However, there is another possible explanation. The DES Beach Program changed its monitoring protocols in 2002. First, the number of beaches in the program increased from 9 in 2001 to 16 by 2005. Of the five advisories issued, three have been for beaches added to the program since 2002. Second, the sampling season was expanded to cover the period of June 1 to Labor Day. Third, the sampling frequency increased at some of the beaches. Therefore, the trends in beach advisories must be interpreted with caution until the effects of the new protocols are better understood.

Table 5: Tidal beaches monitored by the DES Beach Program

BEACH	TOWN	MONITORED SINCE
Hampton Beach S.P.	Hampton	1996
North Beach	Hampton	1996
New Castle Town Beach	New Castle	1996
Cable Beach	Rye	1996
Jenness State Beach	Rye	1996
Pirates Cove Beach	Rye	1996
Sawyer Beach	Rye	1996
Wallis Sands S.P.	Rye	1996
Seabrook Beach	Seabrook	1996
Northside Park	Hampton	2002
North Hampton State Beach	North Hampton	2002
Bass Beach	Rye	2002
Foss Beach	Rye	2002
Seabrook Harbor Beach	Seabrook	2003
Sun Valley Beach	Hampton	2004
Star Island	Rye	2004

Figure 11: Number of advisories at NH tidal beaches 1996-2005



Source: DES Beach Program.

BAC5 - TRENDS IN BACTERIA CONCENTRATIONS AT TIDAL BATHING BEACHES

Monitoring Objective

The objective of this indicator is to determine whether the bacterial concentrations at tidal bathing beaches are increasing or decreasing over time. The DES Beach Program systematically monitors designated tidal bathing beaches along the Atlantic Coast of NH for enterococci during the summer months (Memorial Day to Labor Day). These measurements can be used to assess trends in water quality at the beaches over time. This indicator answers the following monitoring question:

Are bacteria concentrations at tidal bathing beaches changing over time?

Measurable Goal

The goal is for no tidal beaches to have significantly increasing trends in enterococci concentrations.

Data Analysis and Statistical Methods

Routine monitoring data for each beach was extracted from the DES Beach Program database. Samples taken for bacteria source tracking investigations and field duplicates were excluded. Many of the results were reported as below the analytical detection limit. The analytical detection limit has changed over time as methods have changed. Therefore, it was not possible to evaluate trends in bacterial concentrations at each beach. To do so would have required assuming a value equal to one-half the method detection limit for non-detected samples which would have biased the results. Instead, each sample was classified as being either above or below the water quality standard of 104 cts/100ml of enterococci. Then, the percent of samples above the standard in each year was calculated. Finally, the Mann-Kendall Test was used to assess the significance of changes in the percentage between years. A level of 0.1 was used to determine statistical significance for a two-sided test.

Results

Enterococci concentrations are generally very low at all the tidal beaches. There was a statistically significant, increasing trend at one of the beaches: the New Castle Town Beach. This beach also had the highest percentage of samples above the water quality standard in 2003-2005, 6.1%. The DES Beach Program posted an advisory at this beach in 2003. In 2004, the percentage of samples from this beach that were greater than the standard peaked at 11%. However, by 2005, the percentage had fallen to 2%. Starting in 2002, the DES Beach Program increased the number of samples collected from this beach from approximately 15 to approximately 40 per year. The change in the sampling design may be responsible for some of the observed trend.

The goal for this indicator is for no beaches to have statistically significant, increasing trends. The data through 2005 show that one beach has an increasing trend. Therefore, the NHEP management goal is not being met. The following table and figure illustrate the trends at each of the beaches.

Please note that it is possible for a beach to have a small percentage of samples higher than the standard but not to have an advisory. Advisories are issued if two samples (collected on the same day) exceed the standard or if one sample exceeds the standard by 70 cts/100ml. In addition, advisories are only posted during the swim season. High concentrations of enterococci measured before or after the swim season would not result in an advisory.

Table 6: Summary of water quality trends at tidal bathing beaches

Beach	Town	Period of Record	Percent of samples above standard[1] in 2003-2005	Trend
Hampton Beach State Park	Hampton	1996-2005	1.6%	No significant trend
North Beach	Hampton	1996-2005	1.5%	No significant trend
Northside Park	Hampton	2002-2005	1.2%	Not evaluated[2]
Sun Valley Beach	Hampton	2004-2005	0.0%	Not evaluated[2]
New Castle Town Beach	New Castle	1996-2005	6.1%	**Increasing**
North Hampton State Beach	North Hampton	2002-2005	2.0%	Not evaluated[2]
Bass Beach	North Hampton	2002-2005	2.3%	Not evaluated[2]
Cable Beach	Rye	1996-2005	1.5%	No significant trend
Foss Beach	Rye	2002-2005	1.5%	Not evaluated[2]
Jenness State Beach	Rye	1996-2005	0.0%	No significant trend
Pirates Cove Beach	Rye	1996-2005	0.0%	No significant trend
Sawyer Beach	Rye	1996-2005	2.8%	No significant trend
Star Island	Rye	2002-2004[3]	0.0%	Not evaluated[2]
Wallis Sands State Park	Rye	1996-2005	0.0%	No significant trend
Seabrook Town Beach	Seabrook	1999-2005	0.8%	No significant trend
Seabrook Harbor Beach	Seabrook	2003-2005	3.4%	Not evaluated[2]

Source: DES Beach Program

1. The water quality standard for tidal beaches is 104 cts/100ml of enterococcus.

2. Trends were not evaluated at beaches with less than 5 years of data.

3. The Star Island beach was not monitored in 2005.

Figure 12: Water quality trends at tidal bathing beaches

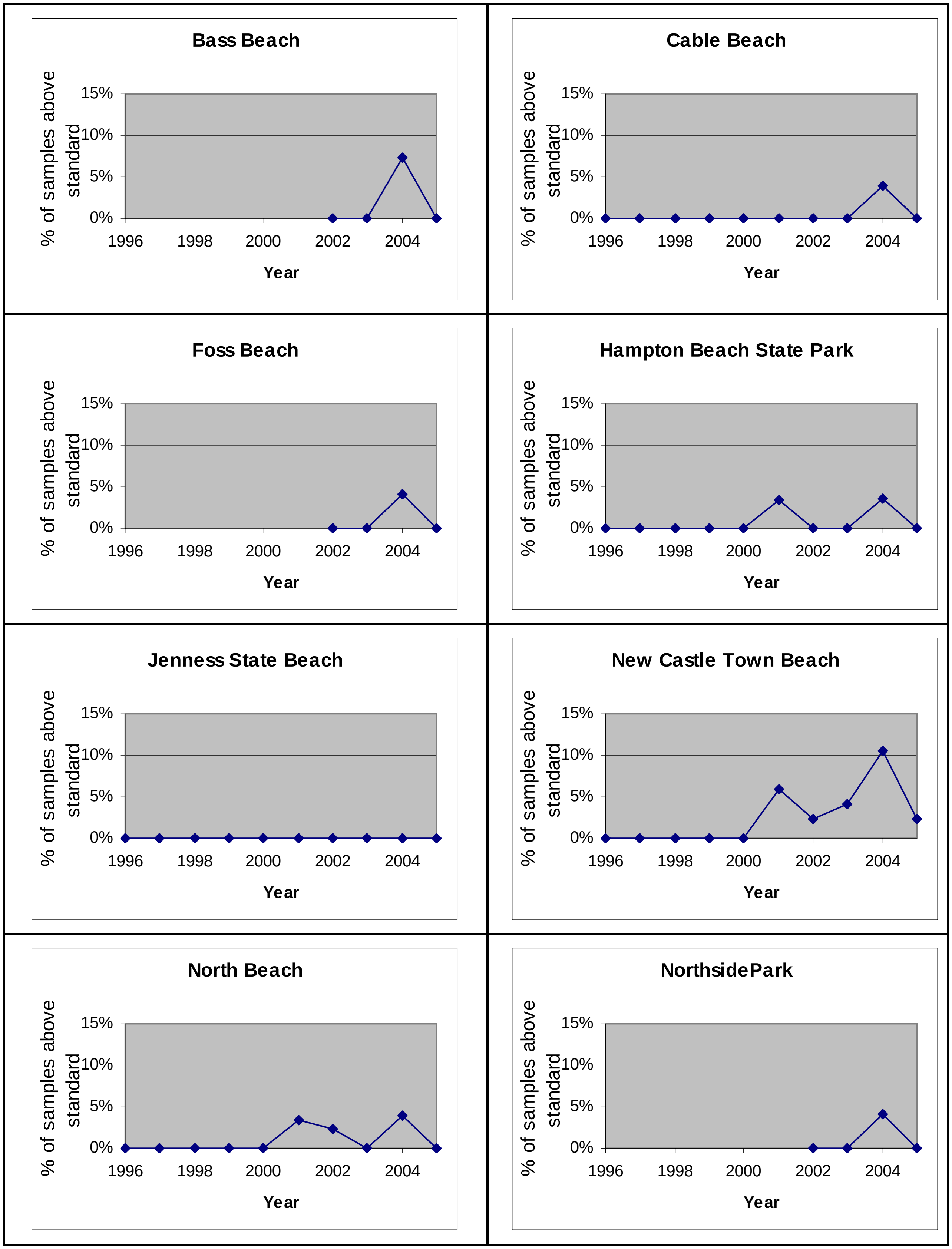
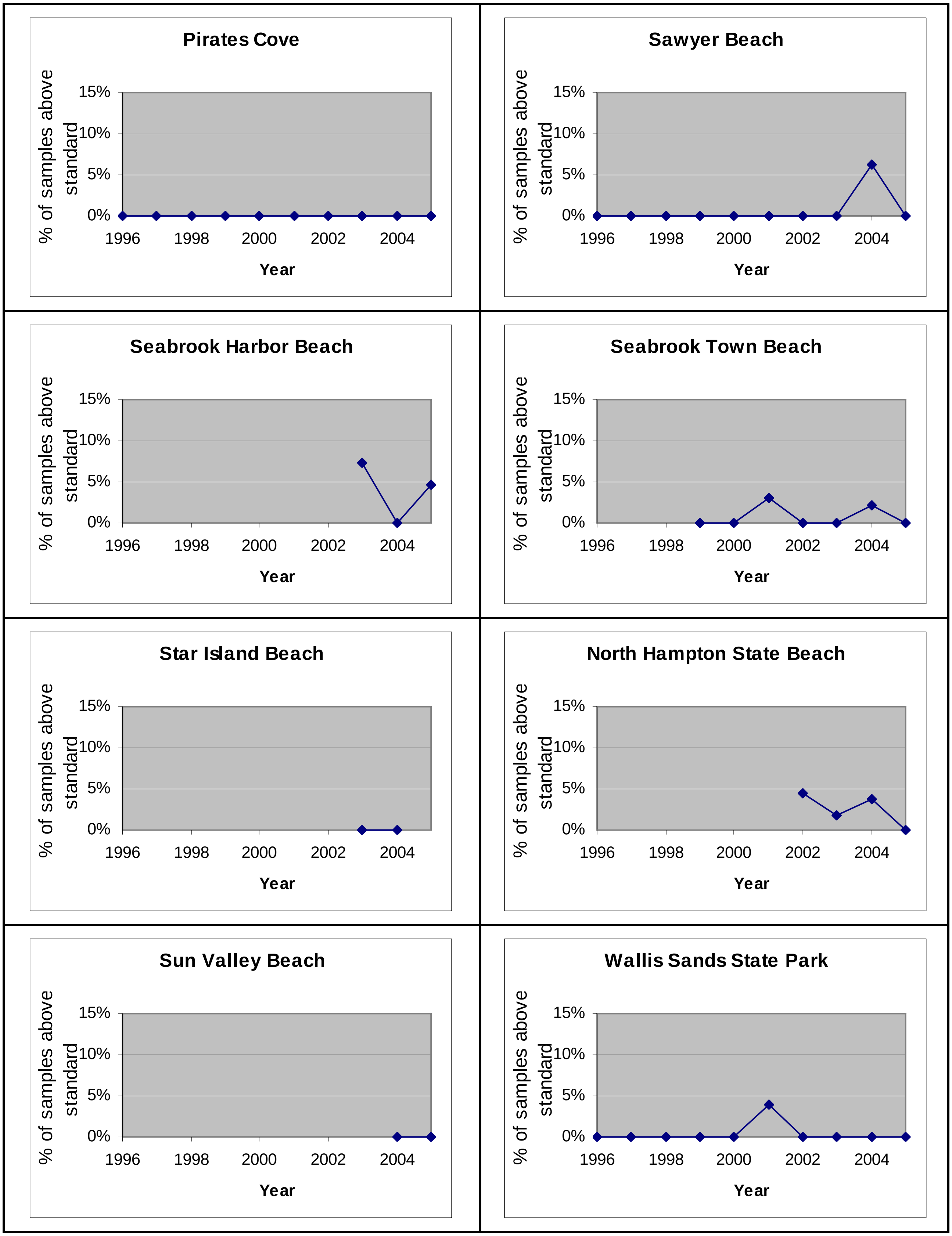


Figure 12 (con't): Water quality trends at tidal bathing beaches



BAC6 - VIOLATIONS OF ENTEROCOCCI STANDARD IN TIDAL WATERS

Monitoring Objective

The objective of this indicator is to track the violations of the state swimming standards for estuarine waters. Every two years, DES assesses the quality of the State's surface waters in the §305(b) Report to Congress. A standardized assessment methodology, based on the state laws and regulations, is used to determine areas of the estuaries that do not meet standards for swimming in tidal waters (RSA 485-A:8). This indicator is distinct from the preceding indicators on tidal beaches because it reports on the suitability of all estuarine waters for swimming. Therefore, this indicator answers the following monitoring question:

Do NH tidal waters, including swimming beaches, meet the state enterococci standards?

Measurable Goal

The goal is to have 0% of the estuarine area in violation of RSA 485-A:8.

Data Analysis and Statistical Methods

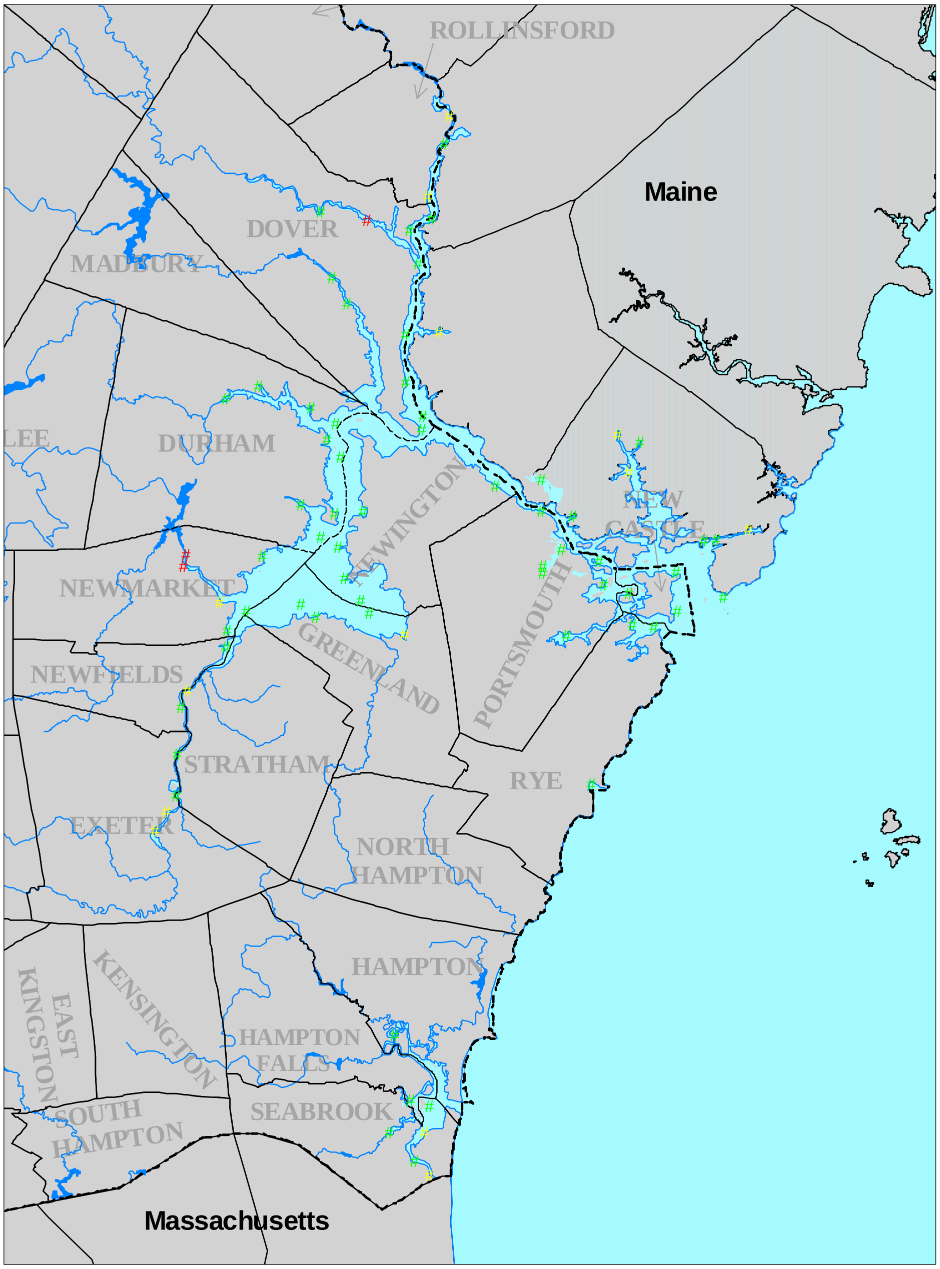
In 2002-3, the University of New Hampshire measured enterococci in 75 samples from the NHEP study area as part of the National Coastal Assessment. The stations were randomly assigned and spread throughout the estuaries following the probability-based monitoring procedures of the EPA's Environmental Monitoring and Assessment Program. The objective of a probability based monitoring program is to remove bias from the station locations so that the results can be used to draw conclusions about the entire study area. The individual enterococci measurements at each station were analyzed using the Horvitz-Thompson Estimator Method for a known subpopulation size (EPA, 1996) in order to generate the cumulative distribution function for enterococci in the estuaries. Ninety-fifth percentile confidence limits were calculated using a binomial method for the estimated percentage of the estuary with enterococci concentrations greater than 104 cts/100ml. These confidence limits were used to test the hypothesis that the estimated percentage was significantly different from zero.

In effect, a probabilistic monitoring program is a "poll" of water quality the estuary. In a typical public opinion poll, a subset of the population is chosen at random and then asked questions about a topic. The responses of this group are taken to be representative of the overall public opinion within a known margin of error. The same general process was followed for the probabilistic monitoring program in NH's estuaries. Out of the all the possible sampling locations in the estuaries, a subset of stations were chosen randomly. Since the stations were chosen at random, it was assumed that the water quality at the chosen stations was representative of water quality in the entire estuary. A margin of error was assigned when the results were extrapolated to the entire estuary.

Results

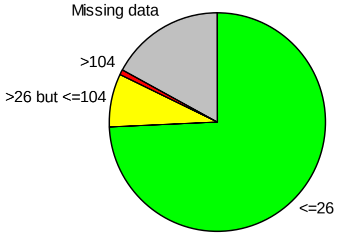
The probabilistic survey revealed that 82.3% of the estuarine area was expected to have enterococci concentrations less than 104 cts/100ml (Figure 13). In contrast, only 0.5% of the estuarine area was expected to have concentrations greater than 104 cts/100ml, which would be a violation of the water quality standard. The samples with >104 cts/100ml were located in the Lamprey River and the Cocheco River. Data were missing for 17.2% of the estuary. The goal for this indicator is for zero percent of estuarine waters to be in violation of the standard. The error bars on the estimate show that the result is not significantly different from zero. Therefore, the goal is currently being met.

Figure 13: Distribution of enterococci concentrations from the 2002-2003 National Coastal Assessment



Enterococci (cts/100ml)

Range	% of Estuarine Area	Error (+/-)
<=26	74.1	9.7
>26 but <=104	8.2	6.1
>104	0.5	1.6
Missing data	17.2	



BAC7 - FRESHWATER BATHING BEACH ADVISORIES

Monitoring Objective

The objective for this indicator is to track the number of advisories at designated freshwater bathing beaches in NH's coastal watershed. The DES Beach Program monitors designated freshwater bathing beaches in the coastal watershed during the summer months (Memorial Day to Labor Day). If the concentrations of *E. coli* in the water do not meet state water quality standards for designated freshwater beaches (88 *E.coli*/100ml in a single sample), DES recommends that an advisory be posted at the beach. Therefore, the number of postings at freshwater beaches should be a good indicator of bacterial water quality at the beaches. This indicator answers the following monitoring question:

Do NH freshwater beaches in the coastal watershed meet the state *E. coli* standards?

Measurable Goal

The goal is to have zero advisories at the freshwater bathing beaches in the coastal watershed over the summer season.

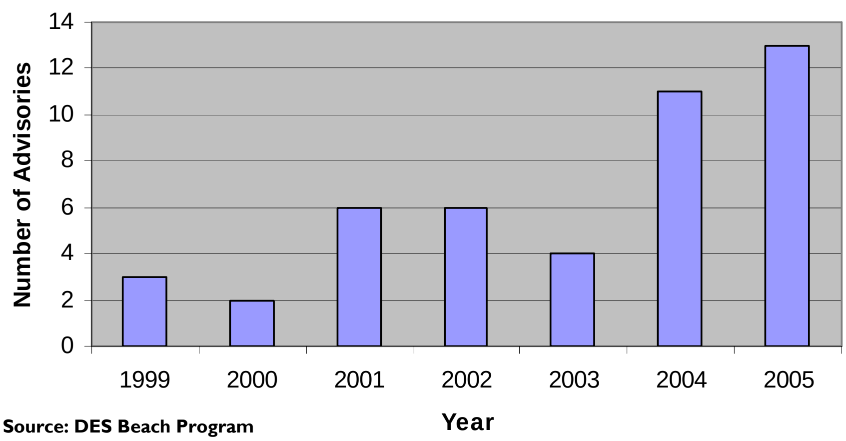
Data Analysis and Statistical Methods

The advisories at freshwater beaches in the coastal watershed were queried from the DES Beach Database. The number of advisories were summed for each year and then compared to the goal of zero.

Results

Since 1999, there have always been at least two advisories issued for freshwater beaches in the coastal watershed. The number of advisories has grown to 13 in 2005. Therefore, the goal of zero advisories is not being met. The number of beaches in the program since 1999 has not changed significantly. The total has remained between 158 and 163.

Figure 14: Number of advisories posted at freshwater beaches in the coastal watershed



Source: DES Beach Program

TOX1 - SHELLFISH TISSUE CONCENTRATIONS RELATIVE TO FDA STANDARDS

Monitoring Objective

The objective of this indicator is to determine whether shellfish from the estuaries contain toxic contaminants in their tissues at concentrations greater than FDA guidance values, and, if they do, how much of the estuary is affected by this contamination. For this indicator, the concentrations of toxic contaminants in mussel, oyster, and clam tissue from various locations in the estuary are measured. The chemicals that are measured in the tissue are: heavy metals, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and chlorinated pesticides. The result of this indicator partially answers the following monitoring question:

Are shellfish, lobsters, finfish, and other seafood species from NH coastal waters fit for human consumption?

Measurable Goal

The goal is for 0% of sampling stations in the estuary to have mean shellfish tissue concentrations greater than FDA guidance values.

Data Analysis and Statistical Methods

The data for this indicator were collected between 1993 and 2004. However, some data from this period were not available for this report. Mercury data from 1993 to 2002 were not available. These data were generated by the former Gulfwatch laboratory, whose methods have been questioned. The laboratory was reviewing the data at the time of this report. Copper data for three stations monitored in 2003 (NHDP, NHHS and NHLH) and chromium data for the Portsmouth Harbor station in 2003 were anomalous and, therefore, were not used. Data from 2004 on pesticides and PCBs at two Portsmouth Harbor stations (MECC and NHPI) were not available from the laboratory in time for this report.

NH Gulfwatch procedures for aggregating congeners, testing for normality, and calculating descriptive statistics were followed (Chase et al., 2001). In particular, to calculate total PCBs, PAHs, DDTs and pesticides, the concentrations of detected congeners were summed. Results that were below the analytical detection limit were excluded from the total. Non-detected results were not used for calculating averages and standard deviations of samples.

Each mussel tissue sample consisted of four measurements from replicate subsamples. Clam and oyster samples consisted of two replicate subsamples. The maximum concentration for each toxic contaminant in each tissue type was calculated and compared to the FDA guidance values. If the maximum concentration of a contaminant was higher than the screening value, then the results from the subsamples were averaged and the 95^{th} percentile concentration of the mean was estimated using a t-value of 2.776 (appropriate for a sample size of 4). Then, the mean value and the 95^{th} percentile of the mean was compared to the relevant FDA guidance value. Only if the lower confidence limit of the mean was greater than the FDA guidance value was the result considered to be higher than the FDA guidance values. If a result was found to be above the FDA guidance value, then the database was checked to determine if the result was from the most recent sample at that station.

FDA guidance values were used as reference values to conform with the NHEP management objective (WQ2-1A) and NSSP guidance.

Results

Between 1993 and 2004, 13 stations in NH's estuaries have been tested for toxic contaminants in blue mussel tissue under the Gulfwatch Program. The stations cover all of the major shellfish growing areas in the estuaries. Two stations each have been tested for clam (NHYC, NHMG) and oyster tissue (NHNI, NHAP). The station locations are shown in Figure 16.

Table 7 shows that lead was the only compound with a maximum value in a replicate sample above its FDA guidance value for mussels. The concentrations of contaminants in clam and oyster tissue were all below FDA values. For mussels, one result for lead from station NHSM (South Mill Pond) in 2003 was close to but still below the FDA value. The 95^{th} percentile error bars show that the mean value was not statistically different from the FDA guidance value. The average values for lead in all mussel samples are shown in Figure 15. Therefore, the goal of having no stations with average concentrations greater than FDA values was met for the period 1993-2004.

The results in Table 7 illustrate the differences in tissue concentrations between the three shellfish species. Copper concentrations tend to be higher in oyster tissue relative to the tissue of other species due to differences in metabolism.

Table 7: Maximum concentrations of toxic contaminants measured in clam, mussel and oyster tissue between 1993 and 2004

Parameter	Clam Tissue	Mussel Tissue	Oyster Tissue	FDA Screening Value	Units
ALUMINUM	860	778	170		mg/kg-dw
CADMIUM	0.9	3.6	2.1	25	mg/kg-dw
CHROMIUM	3.4	24	3.1	87	mg/kg-dw
COPPER	13	12	160		mg/kg-dw
IRON	4600	1200	440		mg/kg-dw
LEAD	4.1	11.6	0.9	11.5	mg/kg-dw
MERCURY		0.4		6.7	mg/kg-dw
NICKEL	2.2	4.5	2.2	533	mg/kg-dw
SILVER	0.2	0.8	9.4		mg/kg-dw
ZINC	100	240	6100		mg/kg-dw
PAH, TOTAL	160.1	977.7	341.4		ug/kg-dw
PCB, TOTAL	2.7	93.8	106.7	13000	ug/kg-dw
PESTICIDES, TOTAL	3.5	76.3	46.1		ug/kg-dw
DDT, TOTAL	0	76.3	40.8	33000	ug/kg-dw

Source: NH Gulfwatch Program

1. Cells with results higher than the screening value are shaded.

2. FDA screening values were converted from wet-weight to dry-weight basis by dividing the value by 0.15 (the average fraction of solids in tissue samples).

Figure 15: Distribution of lead concentrations in NH mussel tissue samples

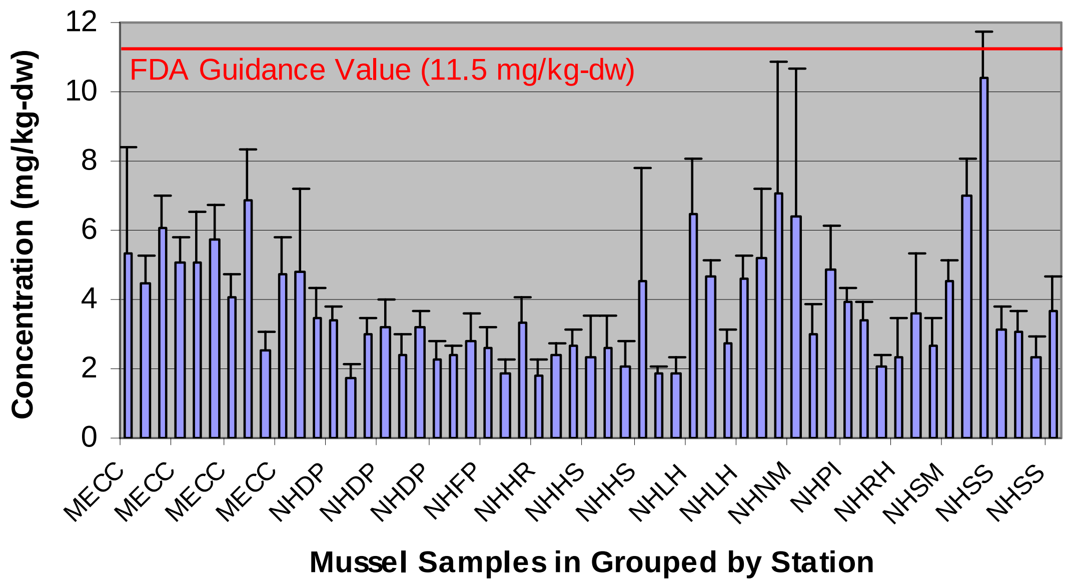
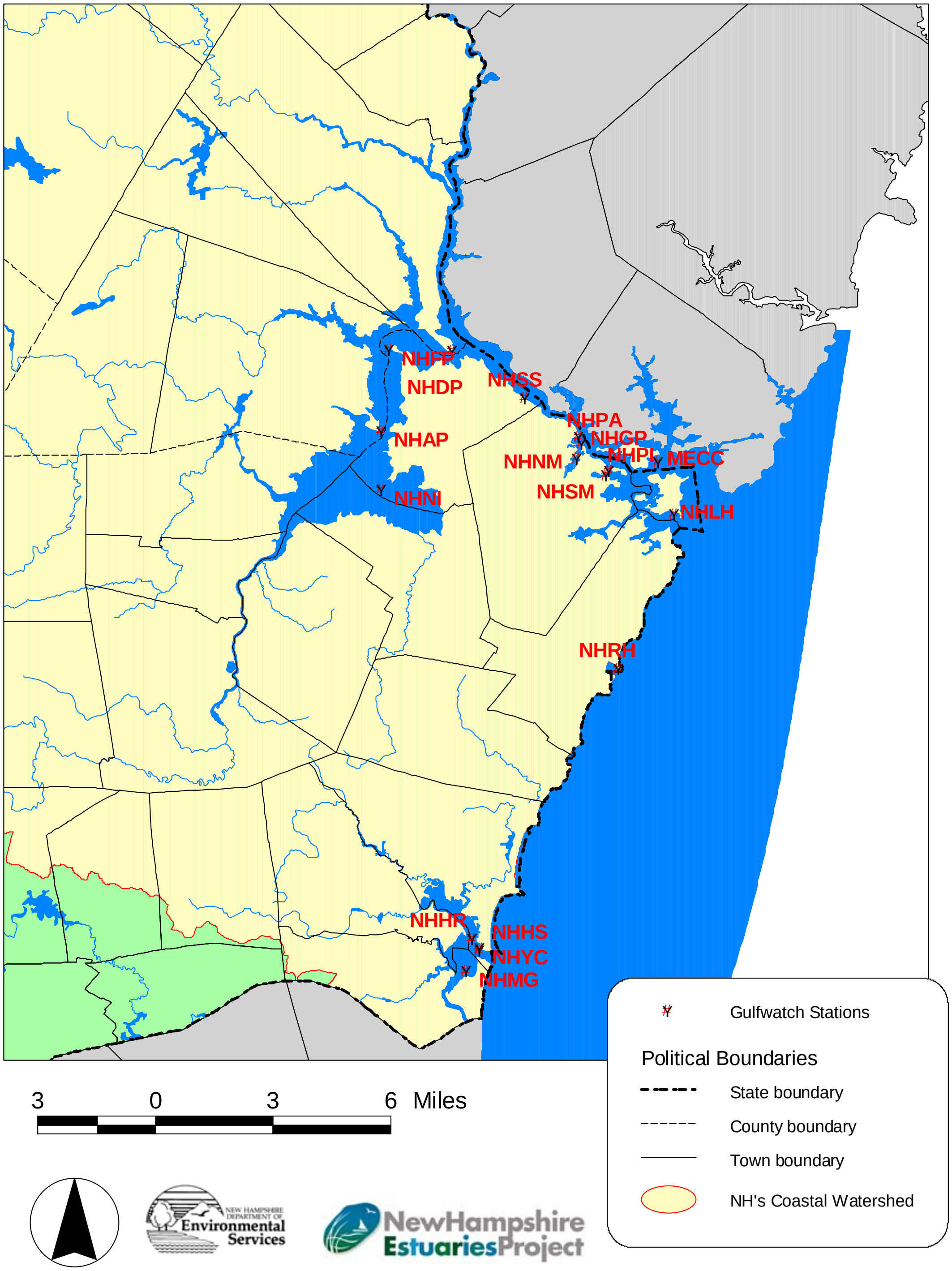


Figure 16: Gulfwatch stations in coastal New Hampshire



TOX3 - TRENDS IN SHELLFISH TISSUE CONTAMINANT CONCENTRATIONS

Monitoring Objective

The objective of this indicator is to track the trends of concentrations of toxic contaminants in shellfish from New Hampshire's estuaries over time. In order to achieve this objective, the concentrations of toxic contaminants (metals, PCBs, PAHs, pesticides) in mussel tissue are measured at three benchmark sites each year. This indicator partially answers the following monitoring question:

Have the concentrations of toxic contaminants in estuarine biota significantly changed over time?

Measurable Goal

The goal is to have no increasing trends for any toxic contaminants.

Data Analysis and Statistical Methods

The data preparations for this indicator were the same as for TOX1 because both indicators rely on the same dataset.

Trends were evaluated at the three benchmark sites in the estuary: MECC (Portsmouth Harbor), NHDP (Dover Point) and NHHS (Hampton-Seabrook Harbor). At each site, the four replicate results for each parameter were regressed against the year of collection using a linear model. Linear coefficients with a probability of <0.05 of being different from zero were considered to be statistically significant.

Results

For the period between 1993 and 2004, mussel tissue has been analyzed 12, 8, and 8 times in Portsmouth Harbor, Dover Point and Hampton-Seabrook Harbor, respectively. Statistically significant linear trends were apparent at one or more stations for lead, zinc, DDT and PCBs. The significant trends are listed on Table 8 and shown in Figure 17 through Figure 20. All of the trends are decreasing. Lead concentrations have decreased by 23% in Portsmouth Harbor. At all three stations, the zinc concentrations have fallen between 17% and 28%. The concentrations of DDT and PCB decreased at two of the three stations by 33-35% and 39-68%, respectively. Therefore, the NHEP goal of having no increasing trends is being met.

Table 8: Trends in contaminant concentrations in mussel tissue in Portsmouth Harbor ("MECC"), Dover Point ("NHDP") and Hampton-Seabrook Harbor ("NHHS"), 1993-2004

Station	Parameter	Trend for 1993-2004	Regression Equation	Percent Change
MECC	ALUMINUM	No significant trend		
	CADMIUM	No significant trend		
	CHROMIUM	No significant trend		
	COPPER	No significant trend		
	IRON	No significant trend		
	LEAD	**Decreasing**	[PB] = -0.125*YEAR + 255	-23%
	MERCURY	Not evaluated		
	NICKEL	No significant trend		
	SILVER	Not evaluated		
	ZINC	**Decreasing**	[ZN] = -1.89*YEAR + 3890	-17%
	DDT, TOTAL	**Decreasing**	[DDT] = -0.404*YEAR + 818	-35%
	PAH, TOTAL	No significant trend		
	PCB, TOTAL	**Decreasing**	[PCB] = -2.38*YEAR + 4810	-39%
NHDP	ALUMINUM	No significant trend		
	CADMIUM	No significant trend		
	CHROMIUM	No significant trend		
	COPPER	No significant trend		
	IRON	No significant trend		
	LEAD	No significant trend		
	MERCURY	Not evaluated		
	NICKEL	No significant trend		
	SILVER	Not evaluated		
	ZINC	**Decreasing**	[ZN] = -3.34*YEAR + 6790	-28%
	DDT, TOTAL	**Decreasing**	[DDT] = -0.523*YEAR + 1060	-33%
	PAH, TOTAL	No significant trend		
	PCB, TOTAL	No significant trend		
NHHS	ALUMINUM	No significant trend		
	CADMIUM	No significant trend		
	CHROMIUM	No significant trend		
	COPPER	No significant trend		
	IRON	No significant trend		
	LEAD	No significant trend		
	MERCURY	Not evaluated		
	NICKEL	No significant trend		
	SILVER	Not evaluated		
	ZINC	**Decreasing**	[ZN] = -2.81*YEAR + 5730	-24%
	DDT, TOTAL	No significant trend		
	PAH, TOTAL	No significant trend		
	PCB, TOTAL	**Decreasing**	[PCB] = -0.871*YEAR + 1750	-68%

Source: NH Gulfwatch Program

Note: Trends for silver and mercury could not be evaluated because of missing data.

Figure 17: Lead concentrations in mussel tissue at benchmark stations between 1993 and 2004

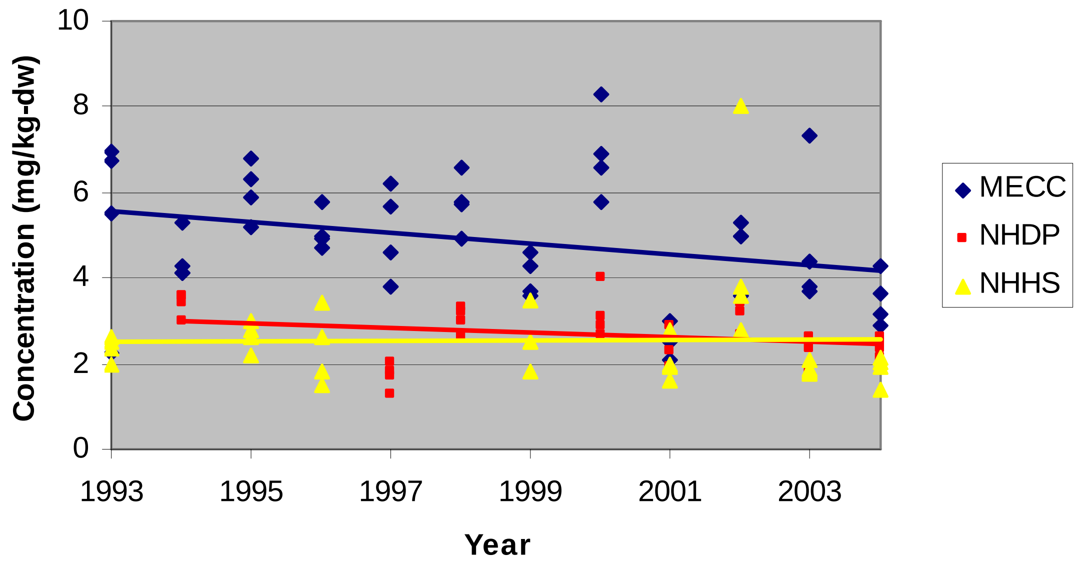


Figure 18: Zinc in mussel tissue concentrations at benchmark stations between 1993 and 2004

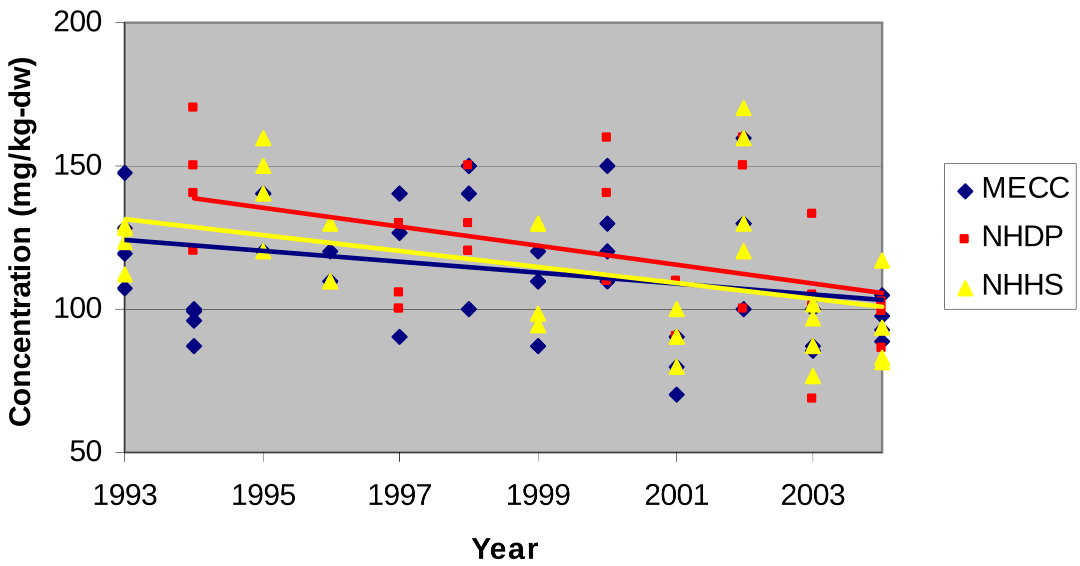


Figure 19: DDT concentrations in mussel tissue at benchmark stations between 1993 and 2004

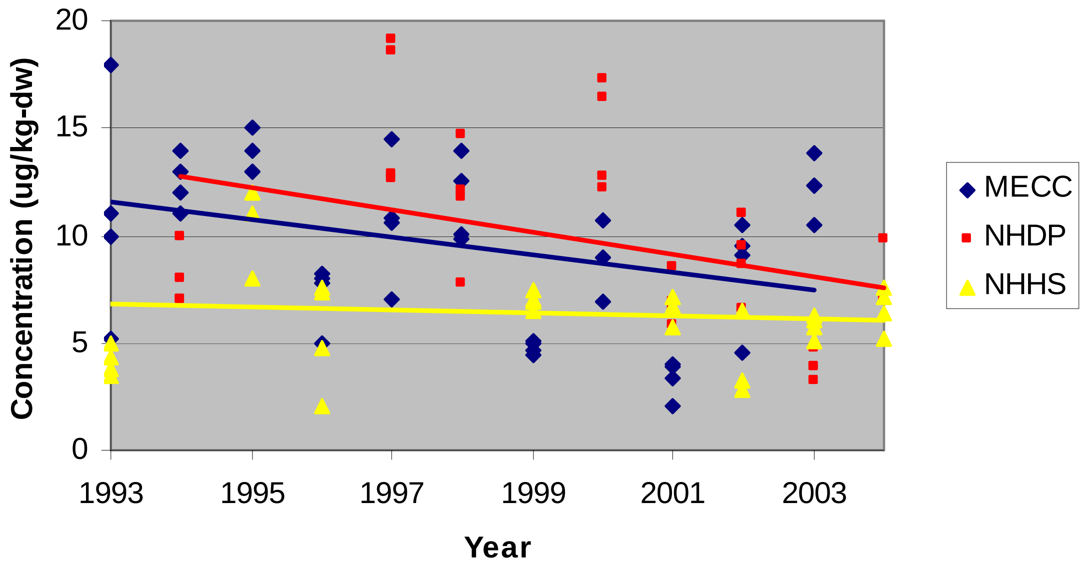
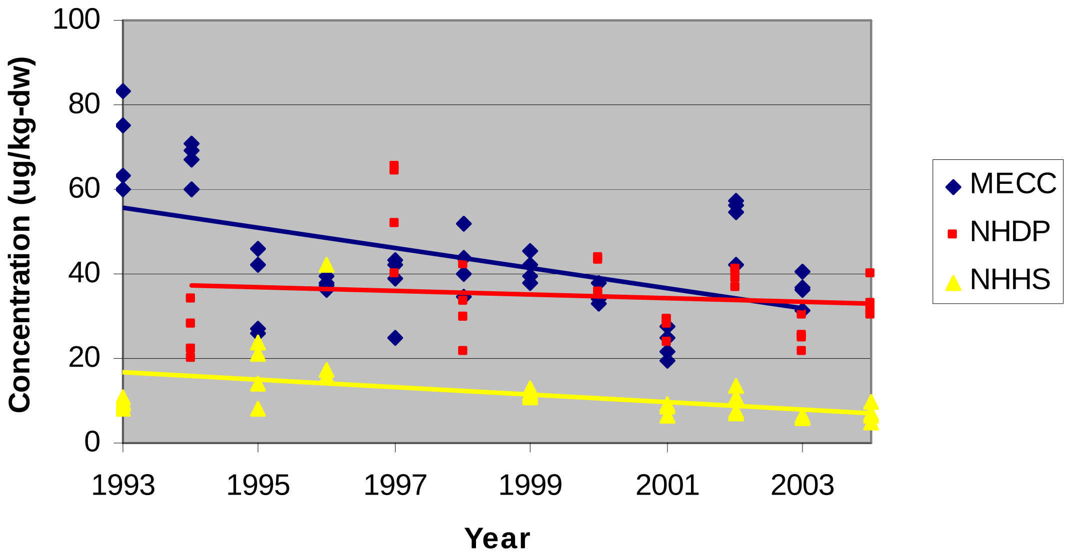


Figure 20: PCB concentrations in mussel tissue at benchmark stations between 1993 and 2004



TOX5 - SEDIMENT CONTAMINANT CONCENTRATIONS RELATIVE TO NOAA GUIDELINES

Monitoring Objective

The objective of this indicator is to provide information on the extent and severity of sediment contamination in the estuaries. In order to achieve this objective, the concentrations of toxic contaminants in surface sediment were measured throughout the two estuaries. The target contaminants were metals, PCBs, PAHs, and pesticides. This indicator answers the following monitoring question:

Do NH tidal sediments contain heavy metals, PCBs, PAHs, chlorinated pesticides, and other toxic contaminants that are harmful to humans, animals, plants, and other aquatic life?

Measurable Goal

The goal is for 0% of estuarine area to have sediments containing one or more compounds higher than Probable Effect Concentrations (PEC) or 5 times Threshold Effect Concentrations (TEC) as defined in the DES Sediment Policy. DES uses TEC and PEC values to determine if contaminants in sediment have the potential to impact the benthic community. TEC values are screening thresholds below which adverse effects are unlikely. TECs are typically derived from studies with sensitive species in laboratory exposures. PEC values are screening thresholds above which adverse effects are likely (NHDES, 2005). This indicator had originally used NOAA's Effects Range Low (ER-L) and Effects Range Medium (ER-M) as screening values. The TEC and PEC values were adopted instead because they are a compilation of screening values from many sources, including ER-L/ER-M values. For many parameters, the TEC/PEC values are identical to ER-L/ER-M values. The TEC/PEC values are updated periodically after new studies on species toxicity have been completed.

Data Analysis and Statistical Methods

In 2000-2001, the University of New Hampshire collected sediment samples from 70 stations in the NHEP study area as part of the National Coastal Assessment. The samples were tested in the laboratory for toxic contaminants. The stations were randomly assigned and spread throughout the estuaries following the probability-based monitoring procedures of the EPA's Environmental Monitoring and Assessment Program. The objective of a probability based monitoring program is to remove bias from the station locations so that the results can be used to draw conclusions about the entire study area.

In effect, a probabilistic monitoring program is a "poll" of water quality the estuary. In a typical public opinion poll, a subset of the population is chosen at random and then asked questions about a topic. The responses of this group are taken to be representative of the overall public opinion within a known margin of error. The same general process was followed for the probabilistic monitoring program in NH's estuaries. Out of the all the possible sampling locations in the estuaries, a subset of stations were chosen randomly. Since the stations were chosen at random, it was assumed that the water quality at the chosen stations was representative of water quality in the entire estuary. A margin of error was assigned to the results as they were extrapolated to the entire estuary.

For each station, the total PAHs, total DDT, and total PCB concentrations were calculated by summing the detected concentrations of the individual congeners. The totals for these classes of compounds were added to the database of results for individual heavy metals and pesticides. Then, the concentrations of toxic contaminants in the sediment sample from each station were compared to DES sediment screening values. Each station was characterized by the number of samples higher than TEC and PEC values. The results from all the stations were combined into a cumulative distribution function using the Horvitz-Thompson Estimator Method for a known subpopulation size (EPA, 1996). The cumulative distribution function was stratified into different categories relative to the number of TECs or PECs that were exceeded at the station. Ninety-fifth percentile confidence limits on the estimated percentages were calculated using binomial method. These confidence limits were used to test the hypothesis that the estimated values were significantly different from zero. Additional details of this assessment are presented in Trowbridge and Jones (2005).

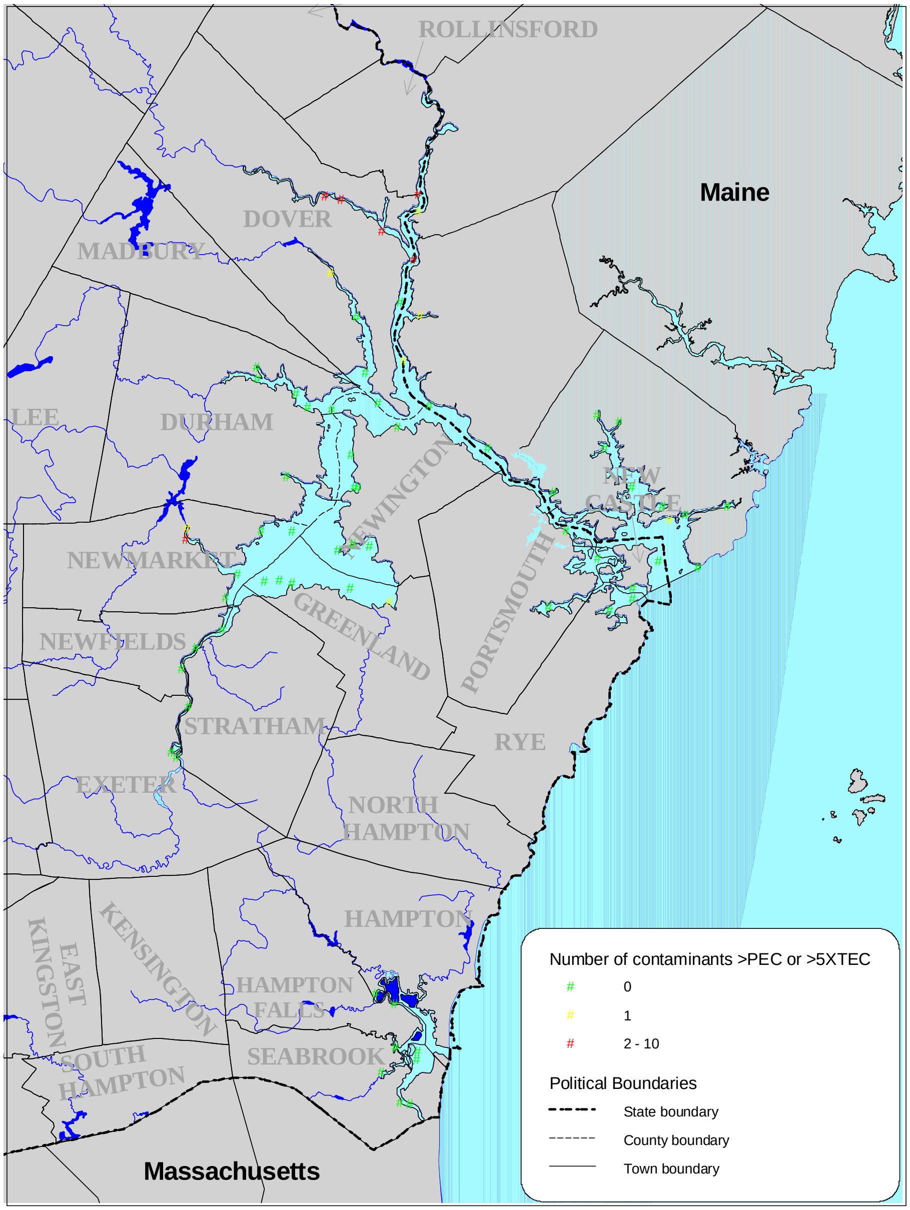
Results

The presence of chemicals in sediments is widespread throughout NH's estuaries. However, elevated levels of contamination occur mainly in the tidal rivers, especially the Cocheco River. The sites with the highest chemical concentrations relative to screening values (a "hazard index") are in the Cocheco River, at the most upstream sites in the Lamprey River, at the confluence of the Cocheco and Salmon Falls rivers, and Portsmouth Harbor (Figure 22). The chemicals that have concentrations greater than PECs or five times TECs are: chromium, lead, silver, PAHs, and total DDTs. Another important observation is the consistently low levels of almost all contaminants at sites in Little Harbor, Little Bay, Hampton-Seabrook Harbor and in the outer portion of Portsmouth Harbor. These sites also generally had relatively coarse sediment grain sizes so the capacity of the sediments to adsorb contaminants is low.

Trace metal concentrations range from 11 to 489 ug/g dry weight (DW) for chromium, 0.005 to 0.55 ug/g DW for mercury, and 14.8 to 120 ug/g DW for lead. Organic chemical contaminants are present over wider concentration ranges than for trace metals. Total polycyclic aromatic hydrocarbons (PAH) concentrations ranged from 13 to 54,394 ng/g DW, total polychlorinated biphenyls (PCB) from 2 to 86 ng/g DW, and total pesticides from 2 to 158 ng/g DW. This suggests New Hampshire estuaries have areas with minimal levels of toxic organic chemicals as well as areas with much greater levels.

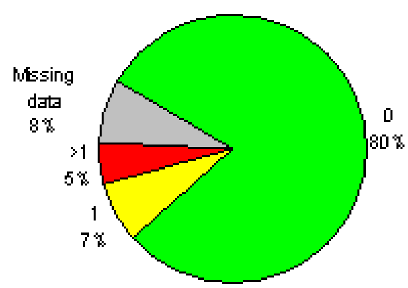
Approximately 12% of the estuarine sediments had at least one contaminant with concentrations greater than a PEC value or five times a TEC value. Therefore, the NHEP goal of having zero percent of the estuary affected by sediment contamination was not attained. The impact of the contamination on the benthic community is discussed in the next indicator. Additional details are presented in Trowbridge and Jones (2005).

Figure 21: Toxic contaminants in sediment compared to screening values



Number of Chemicals >5xTEC or >PEC Values

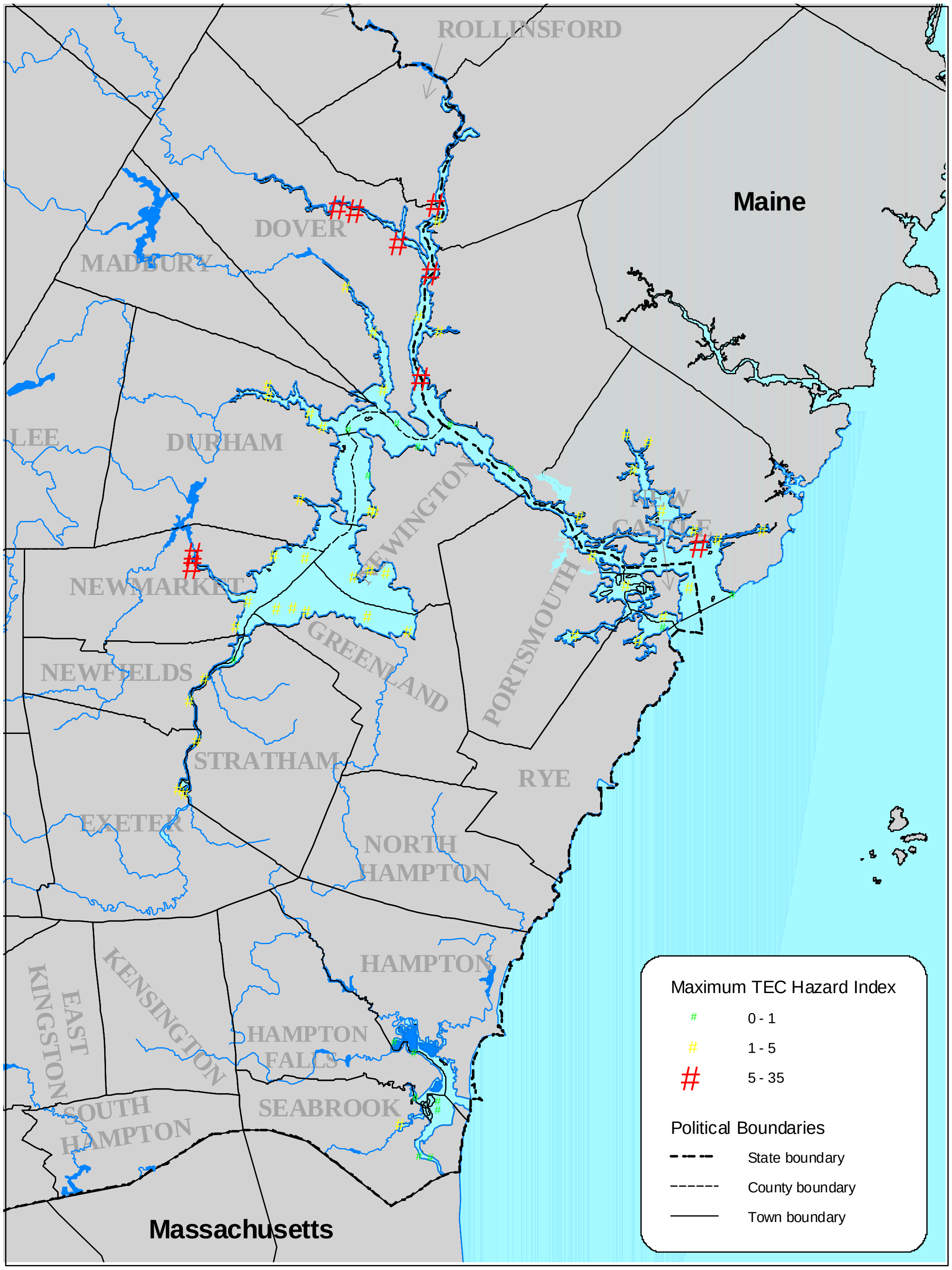
Range	Percent of Estuarine Area	Error (+/-)
0	80.0	8.9
1	7.3	5.8
>1	4.8	4.7
Missing data	7.9	6.0



Notes: The map shows how many contaminants exceeded screening values at each station. The table and pie chart summarize the results for all the stations

Source: NH National Coastal Assessment

Figure 22: Maximum hazard index based on TEC values for each sediment sample



TOX7 - BENTHIC COMMUNITY IMPACTS DUE TO SEDIMENT CONTAMINATION

Monitoring Objective

The objective of this indicator is to provide information on whether the benthic community has been impacted by toxic contaminants in the sediments. In order to achieve this objective, the abundance of benthic species were enumerated and whole sediment toxicity tests were performed throughout the estuaries. This indicator answers the following monitoring question:

Is there evidence of toxic effects of contaminants in estuarine biota?

Measurable Goal

The goal is for 0% of estuarine area to have apparent impacts to the benthic community due to sediment contamination.

Data Analysis and Statistical Methods

In 2000-2001, the University of New Hampshire collected sediment samples from 70 stations in the NHEP study area as part of the National Coastal Assessment. The samples were analyzed in the laboratory for sediment toxicity and benthic community assemblage. The stations were randomly assigned and spread throughout the estuaries following the probability-based monitoring procedures of the EPA's Environmental Monitoring and Assessment Program. The objective of a probability based monitoring program is to remove bias from the station locations so that the results can be used to draw conclusions about the entire study area.

In effect, a probabilistic monitoring program is a "poll" of water quality the estuary. In a typical public opinion poll, a subset of the population is chosen at random and then asked questions about a topic. The responses of this group are taken to be representative of the overall public opinion within a known margin of error. The same general process was followed for the probabilistic monitoring program in NH's estuaries. Out of the all the possible sampling locations in the estuaries, a subset of stations were chosen randomly. Since the stations were chosen at random, it was assumed that the water quality at the chosen stations was representative of water quality in the entire estuary. A margin of error was assigned to the results when they were extrapolated to the entire estuary.

Sediment impairments were determined using a combination of sediment chemistry, sediment toxicity and benthic community data. Sediment chemistry data were evaluated using screening values from the DES Sediment Policy (TOX5, NHDES, 2005). Sediment toxicity was assessed using the test organism *Ampelisca abdita,* a small shrimp-like amphipod. A sediment sample was considered to have significant toxicity if the percent survival of organisms exposed to the sediment was statistically lower (<80%)

compared to an unexposed control group. Benthic community data was evaluated using a benthic index for Gulf of Maine sediments developed by the Atlantic Ecology Division of EPA. The index was calculated as follows:

Benthic Index = 0.494 * Shannon + 0.670 * MN_ES50.05 – 0.034 * PctCapitellidae
where:
Shannon = Shannon-Wiener H' diversity index
MN_ES50.05 = Station mean of 5th percentile of total abundance frequency distribution of each species in relation to its ES50 value, where ES50 is the expected number of species in a sample of 50 individuals
PctCapitellidae = percent abundance of capitellid polychaetes
The benthic index was considered poor for values less than 4

A sediment sample was considered impaired if the concentration of a chemical was higher than a Probable Effect Concentration or five times a Threshold Effect Concentration screening value (see indicator TOX5) and either the sediment toxicity test indicated significant toxicity or the benthic index was poor. A sample was considered to be in fair condition if the sediment contamination was higher than the screening values and the benthic index was fair. The remaining samples were considered to be in good condition relative to benthic community impacts.

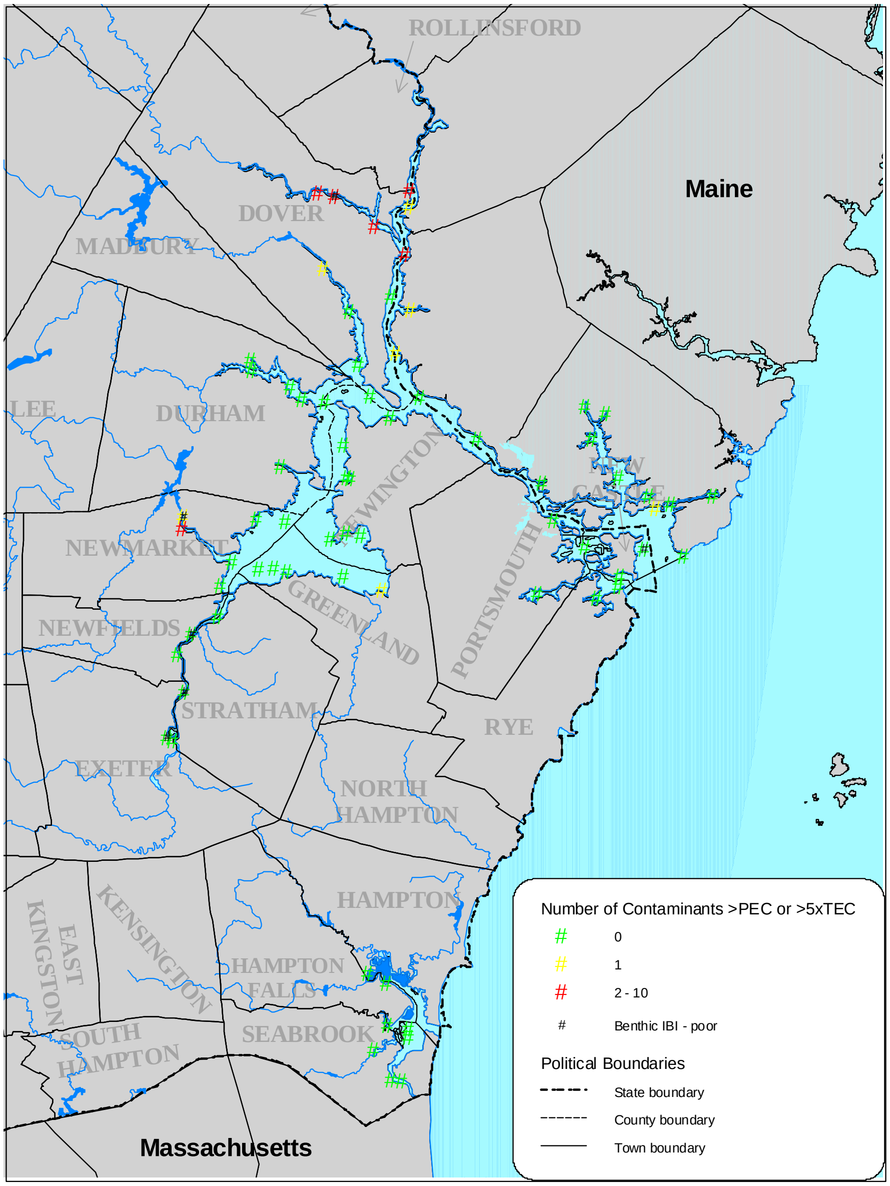
The results from all the stations were combined into a cumulative distribution function using the Horvitz-Thompson Estimator Method for a known subpopulation size (EPA, 1996). The cumulative distribution function was stratified into different categories relative to impacts. Ninety-fifth percentile confidence limits on the estimated percentages were calculated using a binomial model with the sample size and assuming equal station weights. These confidence limits were used to test the hypothesis that the estimated values were significantly different from zero. Additional details of this assessment are presented in Trowbridge and Jones (2005).

Results

Sediment toxicity results are shown in Figure 23. Only two stations comprising 0.3% of the estuary were classified as "poor". These stations were located in the Lamprey River and the Cocheco River in areas with relatively high sediment contamination. There were four other stations that failed either the sediment toxicity test or the benthic index but were not co-located with toxic contaminants. One of these stations was in Portsmouth Harbor. It appears that the sandy sediments at the location were not compatible with the test organism for the sediment toxicity test. However, in general, the Ampelisa sediment toxicity test is considered an appropriate test for northeastern estuaries. The three other stations were in the Squamscott River. This area often experiences low dissolved oxygen, which may be the cause of the benthic impairments. However, the results may also be due to the low salinity environment found in the Squamscott River. The benthic index may not be applicable in low salinity environments because very few low salinity sites were used to create the index. It should be noted that the two stations that were classified as "poor" were also low salinity environments.

The extent of benthic impacts due to toxic contaminants is 0.3% of the estuary with an uncertainty of 1.2%. Therefore, the result is not statistically different from zero. The NHEP goal is being met. However, the absence of apparent effects on the benthic infauna community does not necessarily mean that there are no effects on all aquatic species. Benthic infauna are just one of many possible aquatic species groups. For bioaccumulative compounds, such as mercury and PCBs, species in higher trophic levels could be at risk.

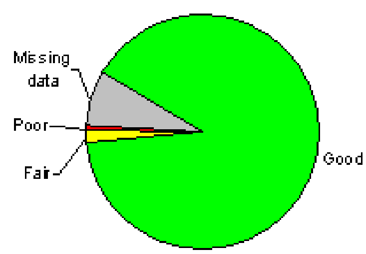
Figure 23: Benthic community impacts due to toxic contaminants in sediment



Toxic Impacts to the Benthic Community

Range	Percent of Estuarine Area	Error (+/-)
Good	90.1	6.6
Fair	1.7	2.9
Poor	0.3	1.2
Missing data	7.9	

Units: n/a



Notes: A station was considered poor if the concentrations of toxic contaminants were >PEC or >5x TEC screening values and either the sediment toxicity test was positive or the benthic index was poor.

NUT1 - ANNUAL LOAD OF NITROGEN TO GREAT BAY FROM WWTF AND WATERSHED TRIBUTARIES

Monitoring Objective

The objective of this indicator is to estimate the annual load of nitrogen to the Great Bay Estuary from the major tributaries and the wastewater treatment facilities (WWTF) in the coastal watershed. Available information on atmospheric and groundwater loading of nitrogen was also compiled. This indicator answers the following monitoring question:

Has the total nitrogen load to Great Bay significantly changed over time?

Measurable Goal

This report will provide the baseline information on this indicator. Future reports will compare the total nitrogen load from WWTFs and major tributaries to the Great Bay and Upper Piscataqua River estuaries to the values measured in 2002-2004 (as documented in this report). Atmospheric deposition, groundwater and direct nonpoint source loads will be excluded from the goal (but reported as part of a total nitrogen load) because these pathways are estimated, not measured.

Data Analysis and Statistical Methods

Five major sources of nitrogen were estimated for Great Bay: point source discharges from wastewater treatment facilities (WWTFs), discharge from major tributaries, direct discharges from nonpoint sources and small tributaries, atmospheric deposition and groundwater discharge. Nitrogen loads were calculated for the Great Bay and Upper Piscataqua River portions of the entire Great Bay Estuary system. A complete analysis of nitrogen loads to the lower portion of the Piscataqua River was not completed, although the loads from WWTFs were quantified.

<u>Point Source Discharges from WWTFs</u>

The total nitrogen load from each WWTF was estimated by multiplying the average total nitrogen (TN) concentration by the annual average flow. In 2002, Bolster et al. (2003) measured total dissolved nitrogen (TDN) in the effluent of WWTFs that discharge directly to the estuary or ocean. If data were missing for a plant, then it was assumed that the TDN concentration was 15 mg/L, the average value for the WWTFs that were monitored, which was probably an overestimate. To estimate the TN concentration, the TDN values were increased by 10% for WWTFs with secondary treatment and 40% for the Portsmouth WWTF which uses advanced primary treatment (George Neill, DES, pers. comm.). Flow from the plants was taken to be the annual average effluent discharge rate for 2002 reported by the WWTFs in their discharge monitoring reports.

Discharges from Major Tributaries

There are seven major tributaries to Great Bay and the Piscataqua River: the Winnicut, Exeter, Lamprey, Oyster, Bellamy, Cocheco and Salmon Falls rivers. The total nitrogen load from each tributary was estimated using measurements of TN concentrations in the rivers, measurements of flow and a loading model from the U.S. Geological Survey.

DES has monitored nitrogen species at the head of tide on each of the seven rivers on a monthly basis since at least 2002. The nitrogen data were queried from the DES Environmental Monitoring Database for the period between January 1, 2002, and December 31, 2004. Total nitrogen concentrations were calculated by adding the results for total Kjeldahl nitrogen to nitrate and nitrite. For non-detected samples, one-half of the reporting detection limit was substituted for the value. This assumption was valid because only 3% of the total Kjeldahl nitrogen and less than 20% of the nitrate/nitrite results were reported as below the detection limit. Total Kjeldahl nitrogen accounted for nearly 75% of the TN.

Flow in each of the tributaries was estimated for the period between January 1, 2002, and December 31, 2004, from USGS streamgaging records in the watershed. For the period between October 1, 2004 and December 31, 2004, the final, quality-assured data were not available; therefore, provisional data from the USGS were used. If the flow data were missing for a day, the result was estimated using linear interpolation between the two closest measurements. Average daily flow in the Lamprey, Exeter, Oyster, Cocheco, and Salmon Falls rivers was estimated from USGS stream gages 01073500, 01073587, 01073000, 01072800, and 01072100, respectively. For these rivers, flow at the tributary monitoring station was estimated by multiplying the flow at the gage by the ratio of the watershed area upstream of the gage to the watershed area upstream of the station. There are no USGS streamgages on the Bellamy River. Flows in the Bellamy River were estimated using area transpositions from the Oyster and Cocheco river streamgages. Specifically, the average flow per square mile at the Oyster River streamgage was multiplied by the watershed area for the Bellamy River to obtain one estimate of the flow in the Bellamy. The average flow per square mile at the Cocheco River streamgage was also multiplied by the Bellamy watershed area to obtain another estimate of the flow. Finally, the two estimates of flow were averaged. Flows in the Winnicut River were estimated using the average flow per square mile from the Oyster River multiplied by the area of the Winnicut River watershed because these two watersheds are similar in size. There is a streamgage on the Winnicut River but it was installed in July 2002 and, therefore, does not have a sufficient period of record for this analysis. For the period for which data were available from the Winnicut gage, the estimated and measured flows were well correlated (r=0.95). The watershed areas for the streamgages and tributary monitoring stations for each of the tributaries are shown in Table 9. The locations of the contributing watersheds for flow calculations are shown in Figure 24.

The TN concentration and flow measurements were combined to estimate the TN loads using a USGS computer model: LOADEST (Runkel et al, 2004). For each tributary monitoring station, the measured TN concentrations between January 1, 2002 and December 31, 2004 (30 samples) were all matched with the flow that was measured on the day that the sample was collected. These data were run through LOADEST to calibrate a model that related TN concentrations to flow, season and time. Next, the calibrated model was used to estimate the daily TN loads based on the daily average flows between January 1, 2002, and December 31, 2004. The output of the model was the annual average TN load for the 2002-2004 period, seasonal loading estimates, and the error in the result. LOADEST was allowed to select the optimal model based on the calibration dataset. Following advice from the USGS, all the parameters in the chosen model were used, even if the coefficient was not statistically significant.

Direct Discharges from Nonpoint Sources and Small Tributaries

Table 10 and Figure 24 show that between 13.9 and 21.6% of the watershed areas draining to the Great Bay and Upper Piscataqua River estuaries were downstream of the tributary monitoring stations (head of tide). Therefore, TN loads from these areas (except for WWTF point source loads) would not be captured by the DES tributary monitoring. The TN loads from these small watersheds would be through non-point source stormwater runoff and discharges from small streams. An estimate of the TN load from these areas was made using the watershed area and the estimated nonpoint source nitrogen yield (tons N per year per square mile of watershed area). The nonpoint source yield was estimated by subtracting any upstream WWTF loads from the tributary loads estimated in the previous section and then dividing by the watershed area (Table 13). The nitrogen yield coefficient was taken to be the average yield observed in the seven larger tributaries (0.78 tons N/year/sq. mile).

Atmospheric Deposition

Wet and dry deposition of nitrogen from the atmosphere directly to estuarine waters was estimated using the ClimCalc model from UNH's Complex Systems Research Center (Ollinger et al., 1993, http://www.pnet.sr.unh.edu/climcalc/). The predicted total nitrogen deposition for the center of the Great Bay at zero elevation was 6.12 kg/year/ha. This value was multiplied by the area of estuarine waters in Table 10 to estimate the annual deposition to the surface of the estuary. Loads due to atmospheric deposition on the land surface of the watershed were captured in the tributary loading estimates and in the direct discharges from nonpoint sources/small tributary loading estimates. The deposition rate from ClimCalc was three times lower than reported in a previous study (Mosher, 1996). However, the UNH researchers believe that the ClimCalc results better reflect the current state of the science for atmospheric deposition of nitrogen.

Groundwater Discharge (Great Bay only)

Groundwater discharge to the Great Bay Estuary was estimated by Ballestero et al. (2004). The results from this report have been adopted without alteration in this indicator. The results cannot be extrapolated to any other locations. Therefore, the load from groundwater discharge to the Upper Piscataqua River Estuary has not been quantified.

Nitrogen Load Summary

The total nitrogen loads from each of the sources listed above were combined to estimate the total load to the Great Bay and the Upper Piscataqua River Estuary. The seaward boundary for these two estuaries was chosen to be the Route 4/16 bridge at Dover Point. The choice of this boundary was somewhat arbitrary, but was influenced by the strong, tidal currents that occur in the Lower Piscataqua River Estuary downstream of this point. For each estuary, the individual point and non-point sources of nitrogen were listed. For the tributaries, if there were WWTFs upstream of the monitoring station, the nitrogen loads from the WWTFs were subtracted from the tributary load and included in the WWTF point source load so that the tributary load only represented nonpoint sources of nitrogen in the watershed.

Results

The TN loads from WWTFs in the coastal watershed are shown in Table 11 and Figure 25. The WWTFs have been grouped according to their discharge locations. The WWTF with the largest TN load was Portsmouth, followed by Hampton, Dover and Rochester. However, the Portsmouth and Hampton WWTFs do not discharge to the Great Bay or Upper Piscataqua River estuaries. Therefore, these loads do not contribute to the total loading estimates presented later. Under some flooding tides, nitrogen from the Portsmouth WWTF can enter Great Bay and the Upper Piscataqua River estuaries.

The total nitrogen loads from major tributaries are shown in Table 12 and Figure 26. The Cocheco River produced the highest annual load. The loads from the Salmon Falls and Lamprey rivers were slightly lower. The remaining four rivers delivered considerably less nitrogen. In Table 12, the model statistics for each river are shown. Overall, the models fit the data satisfactorily. The R-squared statistic for all the models was greater than 0.9.

The results from all the loading estimates are combined in Table 14, Figure 27, Figure 28 and Figure 29. The total nitrogen loads to the Great Bay Estuary and the Upper Piscataqua River Estuary were 449 and 556 tons per year, respectively (1,005 tons per year combined). WWTF point sources contributed 19% of the total load to the Great Bay Estuary, while these sources were responsible for 35% of the load to the Upper Piscataqua River Estuary. For the two estuaries combined, the largest sources of nitrogen were the major tributaries (54%). WWTFs contributed 28% of the total nitrogen. Finally, direct nonpoint sources/small tributaries, atmospheric deposition and groundwater were responsible for 13.5%, 3% and 2% of the total load, respectively.

Nitrogen loads from three WWTFs in the lower Piscataqua River were not included in the estimates provided above. While these facilities are outside of the study area for this indicator, they still are likely to contribute some nitrogen to the overall budget. On a flooding tide, some of the discharge from the WWTFs will be carried up into the estuary. Therefore, the most that these plants could contribute to the estuary would be 50% of their nitrogen load. Figure 30 shows how the nitrogen budget for the estuaries would change if 50% of the nitrogen load from these WWTFs were included. The total load would be increased to 1,097 tons/year (compared to 1,005 tons/yr). Nonpoint source tributary loads would still be the largest source (49%), followed by WWTFs (34%).

Similarly nitrogen loads from direct discharges (nonpoint sources and small tributaries) to the lower Piscataqua River were not included in the loading estimates provided above. Through stormwater runoff, this highly developed area of the watershed likely yields higher per acre nutrient loads to the estuary system than less developed areas of the watershed. For incoming tides nitrogen loads from direct discharge to this portion of the river could be carried into to the upper portions of the estuary. However, this estimated load was not calculated for the lower Piscataqua River and is not part of the nitrogen load for Great Bay and the Upper Piscataqua River Estuary presented for this indicator.

It is important to note that the atmospheric deposition term only reflects deposition to the estuary surface. Export of nitrogen deposited to the land surface has been captured by the tributary and direct nonpoint source categories. In fact, if the atmospheric deposition rate of 6.12 kg N/yr/ha were applied to the land surface of the watersheds, then we would predict that 1,678 tons per year of nitrogen are delivered annually to the watershed from the atmosphere. This value is greater than the total load to the two estuaries. Moreover, the import of nitrogen from the Gulf of Maine on incoming tides has not been considered.

The USGS has predicted nitrogen loads using the New England SPARROW model (Moore et al., 2004). The model predicted total loads to the Great Bay Estuary and the Upper Piscataqua River Estuary to be 692 and 841 tons per year, respectively (1,533 tons per year combined). The predicted values from SPARROW are approximately 50% higher than the measured loads presented in this report. Valiela et al. (2004) used a "Nitrogen Loading Model" to estimate total nitrogen loads to the Great Bay and Upper Piscataqua River estuaries. This paper predicted a total load of 1,198 tons per year based on land use for just the New Hampshire portion of the watershed (700.13 sq. miles). Assuming that the nitrogen yield per square mile would be the same for the Maine portion of the watershed, the model would have predicted a total load for both estuaries of 1650 tons per year (1,198 tons per year/700.13 sq miles * 964.07 sq mile). This value is similar to the output from SPARROW, but is more than 50% greater than the measured load in this report.

The loading estimate presented in this report will be the baseline for future comparisons which will use the same methodology.

Table 9: Watershed areas and area transposition factors for tributary flow estimates

Tributary Monitoring Station	Watershed Area for Station (sq miles)	USGS Streamgage Number	Watershed Area for Streamgage (sq miles)	Flow Multipier for Transpositions	Comments
Lamprey (05-LMP)	211.56	01073500	183	1.156052	
Exeter (09-EXT)	106.92	01073587	63.5	1.683844	
Oyster River (05-OYS)	19.83	01073000	12.1	1.638450	
Cocheco (07-CCH)	175.23	01072800	85.7	2.044650	
Salmon Falls River (05-SFR)	235.00	01072100	106.5	2.206573	
Bellamy (05-BLM)	27.30	01072800		0.1592940	50% of flow from cfsm transposition with Cocheco River streamgage
		01073000		1.1282227	50% of flow from cfsm transposition with Oyster River streamgage
Winnicut (02-WNC)	14.24	01073000		1.1764778	Cfsm Transposition with Oyster River streamgage
Total for Great Bay Tributary Watersheds	379.85				Lamprey, Exeter, Oyster, Bellamy, and Winnicut rivers
Total for Upper Piscataqua Tributary Watersheds	410.23				Cocheco and Salmon Falls rivers
Total	**790.07**				

Source: USDA Natural Resource Conservation Service HUC12 Watershed Divides (modified by NH DES)

Table 10: Watershed areas for the Great Bay and Upper Piscataqua River estuaries

Great Bay		
Definition	Estuarine waters south and west of the Route 4/16 Bridge to the head of tide of the Winnicut, Squamscott/Exeter, Lamprey, Oyster and Bellamy rivers	
Total watershed area	441.13	sq. miles
Watershed area upstream of tributary monitoring stations	379.85	sq. miles (86.1%)
Watershed area downstream of tributary monitoring stations	61.28	sq. miles (13.9%)
Estuarine suface area	11.36	sq. miles (2.6%)
Upper Piscataqua River Estuary		
Definition	Estuarine waters in the Piscataqua River north from the confluence with the Great Bay outlet at the Route 4/16 Bridge to the head of tide for the Cocheco and Salmon Falls rivers	
Total watershed area	522.94	sq. miles
Watershed area upstream of tributary monitoring stations	410.23	sq. miles (78.4%)
Watershed area downstream of tributary monitoring stations	112.72	sq. miles (21.6%)
Estuarine suface area	4.65	sq. miles (0.9%)

Source: USDA Natural Resource Conservation Service HUC12 Watershed Divides (modified by NH DES)

Figure 24: Contributing watersheds for total nitrogen load calculations

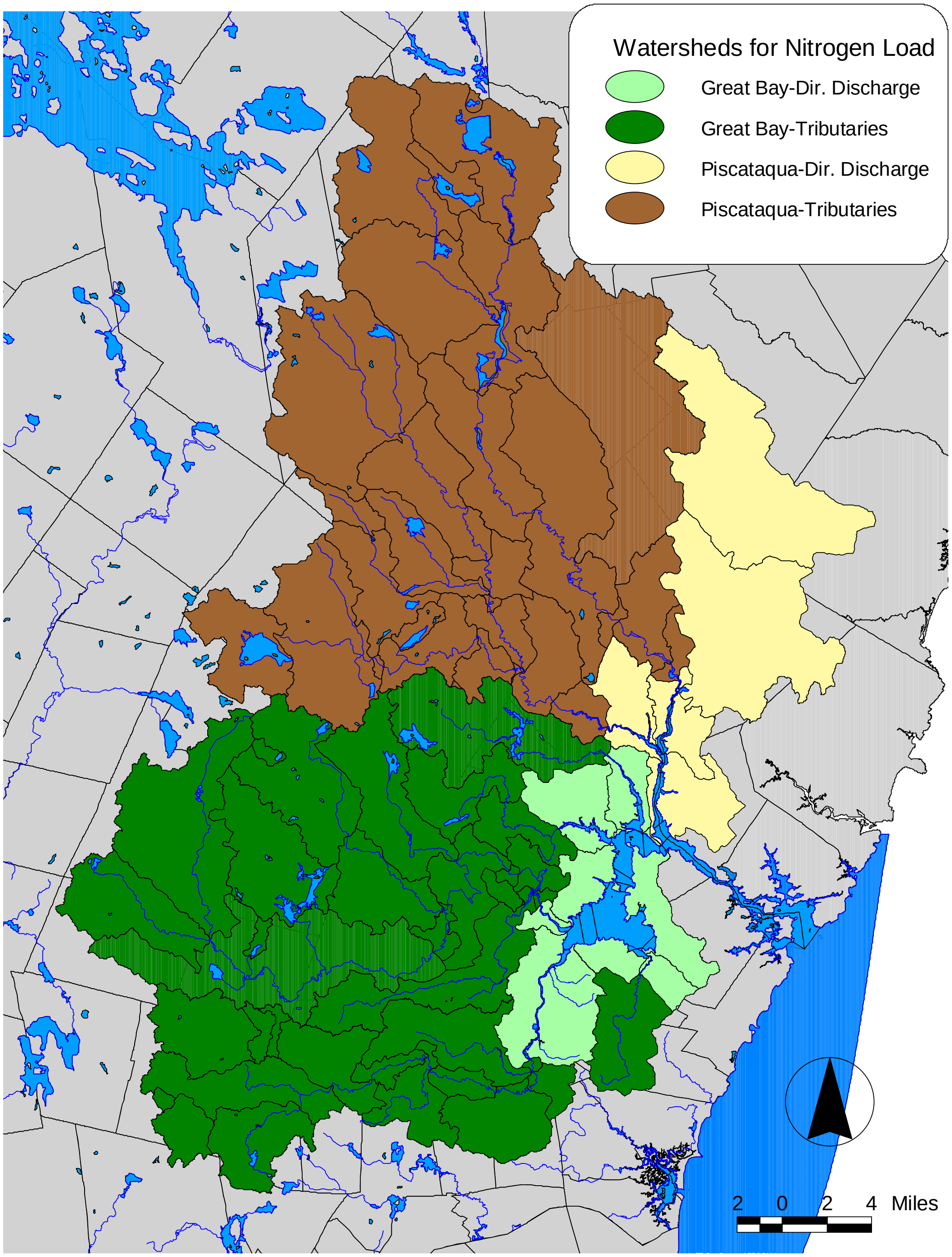


Table 11: Estimated total nitrogen loads from wastewater treatment facilities for 2002

WWTF	Treatment Type	Discharge Location	[TDN] (mg/L) from Bolster[1]	TDN to TN Conversion Factor[2]	Estimated [TN] (mg/L)	Annual Ave. Flow (MGD)[3]	TN Load in 2002 (tons/yr)
Durham	Secondary	Great Bay	16.0	1.1	17.60	0.939	25.16
Exeter	Secondary	Great Bay	13.6	1.1	14.96	1.500	34.15
Newfields	Secondary	Great Bay	15.0	1.1	16.50	0.170	4.27
Newmarket	Secondary	Great Bay	16.0	1.1	17.60	0.701	18.78
Dover	Secondary	Upper Piscataqua Estuary	16.9	1.1	18.59	2.694	76.22
South Berwick	Secondary	Upper Piscataqua Estuary	15.0	1.1	16.50	0.332	8.34
Kittery	Secondary	Lower Piscataqua Estuary	8.6	1.1	9.48	1.067	15.40
Newington	Secondary	Lower Piscataqua Estuary	13.3	1.1	14.63	0.122	2.71
Portsmouth	Advanced Primary	Lower Piscataqua Estuary	15.4	1.4	21.56	5.029	165.04
Hampton	Secondary	Hampton/Seabrook Estuary	19.2	1.1	21.12	2.542	81.70
Farmington	Secondary	Cocheco River	15.0	1.1	16.50	0.174	4.37
Rochester	Advanced	Cocheco River	15.0	1.1	16.50	2.585	64.92
Epping	Secondary	Lamprey River	15.0	1.1	16.50	0.161	4.04
Berwick	Advanced	Salmon Falls River	15.0	1.1	16.50	0.396	9.95
Milton	Secondary	Salmon Falls River	15.0	1.1	16.50	0.061	1.53
Rollinsford	Secondary	Salmon Falls River	15.0	1.1	16.50	0.089	2.24
Somersworth	Secondary	Salmon Falls River	15.0	1.1	16.50	1.108	27.83
Seabrook	Secondary	Atlantic Ocean	9.2	1.1	10.12	0.946	14.57

Total TN Load from WWTFs to estuaries	**432**
Total TN Load to from WWTFs to watershed rivers	**115**
Total TN Load from WWTFs to the ocean	**15**
Total TN Load from WWTFs	**561**

1. Average of monthly TDN measurements from Bolster et al. (2003). Values of "15.0" in red are assumptions for WWTFs that were not sampled. The average TDN concentration for WWTFs with secondary treatment from Bolster et al (2003) was 15 mg/L. The TDN data from Bolster et al. (2003) were colllected in 2002.
2. The conversion factor between TDN and TN was assumed based on advice from the DES Wastewater Engineering Bureau.
3. The flows in this table are annual averages for 2002. The monthly average flows from NPDES discharge monitoring reports were averaged.

Figure 25: Total nitrogen load from coastal wastewater treatment facilities

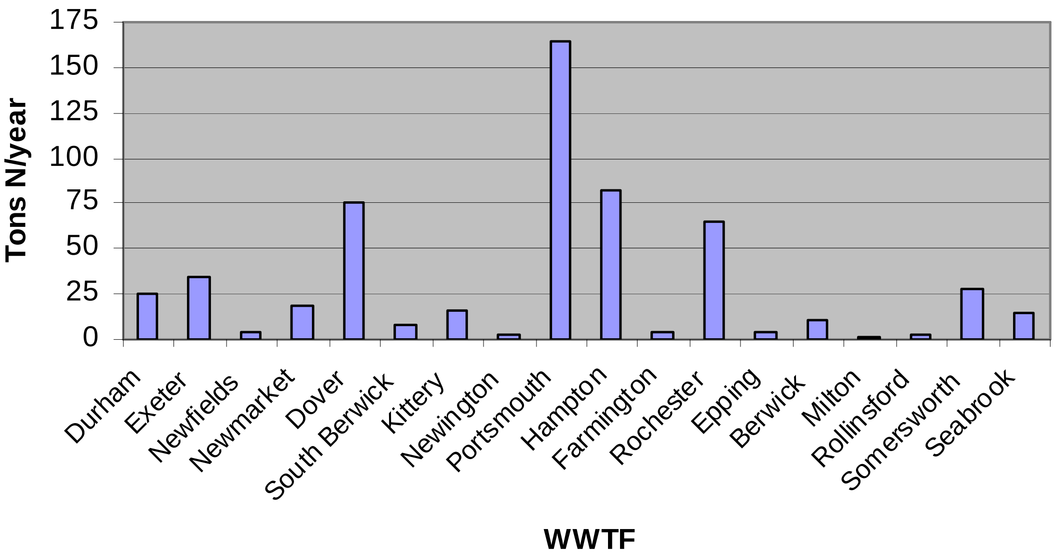


Table 12: Estimated average total nitrogen loads from major tributaries for 2002-2004

Tributary	Station	TN Load (tons/yr)	Standard Error (tons/yr)	R^2	PPCC	Model
Exeter River	09-EXT	74.21	3.39	0.985	0.937	9
Cocheco River	07-CCH	193.09	10.22	0.954	0.985	7
Lamprey River	05-LMP	151.35	8.22	0.972	0.996	4
Salmon Falls River	05-SFR	182.32	10.95	0.914	0.946	6
Bellamy River	05-BLM	20.84	1.80	0.927	0.928	1
Oyster River	05-OYS	18.79	1.26	0.975	0.973	6
Winnicut River	02-WNC	14.72	1.13	0.959	0.978	1

1. TN loads estimated using USGS software "LOADEST" with water quality data from the NH DES Ambient Rivers Monitoring Program and streamflow data from USGS.
2. R^2 is a measure of the quality of the model (0=worst, 1=best)
3. PPCC is a measure of the normality of the residuals (0=worst, 1=best)
4. The model number refers to the specific model chosen. The models are defined in the LOADEST users manual (Runkel et al, 2004).

Figure 26: Total nitrogen loads from tributaries in 2002-2004

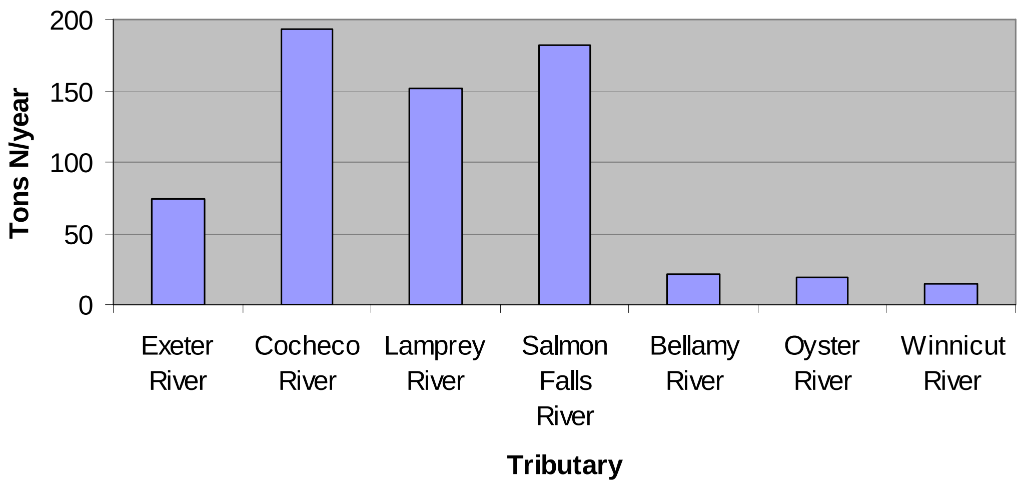


Table 13: Nonpoint source nitrogen yield from Great Bay watersheds

Tributary	Station	TN Load[1] (tons/yr)	Upstream WWTF TN Load[2] (tons/yr)	NPS TN Load (tons/yr)	Area (mi^2)	NPS TN Yield (tons/yr/mi^2)
Exeter River	09-EXT	74.21	0.00	74.21	106.92	0.69
Cocheco River	07-CCH	193.09	69.29	123.80	175.23	0.71
Lamprey River	05-LMP	151.35	4.04	147.31	211.56	0.70
Salmon Falls River	05-SFR	182.32	41.54	140.78	235.00	0.60
Bellamy River	05-BLM	20.84	0.00	20.84	27.30	0.76
Oyster River	05-OYS	18.79	0.00	18.79	19.83	0.95
Winnicut River	02-WNC	14.72	0.00	14.72	14.24	1.03
Average						0.78

1. TN loads estimated using USGS software "LOADEST" with water quality data from the NH DES Ambient Rivers Monitoring Program and streamflow data from USGS.
2. The following WWTFs are located upstream of the tributary monitoring stations. The Epping WWTF is upstream of 05-LMP on the Lamprey River. The Rochester and Farmington WWTFs are upstream of 07-CCH on the Cocheco River. The Milton, Berwick, Somersworth and Rollinsford WWTFs are upstream of 05-SFR on the Salmon Falls River.

Table 14: Summary of total nitrogen loads to the Great Bay and Upper Piscataqua River estuaries

Great Bay

SourceType	Source	TN Load (tons/yr)	Comments
NPS	Lamprey River	147.51	Note 1
NPS	Groundwater Discharge	19.3	
NPS	Atmospheric Deposition	19.8	
NPS	Direct Discharge Runoff	47.8	
NPS	Bellamy River	20.8	
NPS	Exeter River	74.2	
NPS	Oyster River	18.8	
NPS	Winnicut River	14.7	
Point	Durham WWTF	25.16	
Point	Exeter WWTF	34.15	
Point	Newfields WWTF	4.27	
Point	Newmarket WWTF	18.78	
Point	Epping WWTF	4.04	
Subtotal Point Sources (WWTFs)		*86.40*	(19.2%)
Subtotal Non-Point Sources		*362.91*	(80.8%)
Total		*449.31*	

Upper Piscataqua River Estuary

NPS	Cocheco River	123.8	Note 2
NPS	Salmon Falls River	140.78	Note 3
NPS	Direct Discharge Runoff	87.9	
NPS	Atmospheric deposition	8.1	
Point	Dover WWTF	76.22	
Point	So. Berwick WWTF	8.34	
Point	Rochester WWTF	64.92	
Point	Farmington WWTF	4.37	
Point	Milton WWTF	1.53	
Point	Berwick WWTF	9.95	
Point	Somersworth WWTF	27.83	
Point	Rollinsford WWTF	2.24	
Subtotal Point Sources (WWTFs)		*195.39*	(35.1%)
Subtotal Non-Point Sources		*360.58*	(64.9%)
Total		*555.97*	

Great Bay and Upper Piscataqua Estuaries Combined

Subtotal Point Sources (WWTFs)		*281.79*	(28%)
Subtotal Non-Point Sources		*723.49*	(72%)
Total		*1005.28*	

1. TN load from Epping WWTF was subtracted from measured tributary load.
2. TN load from Rochester and Farmington WWTF was subtracted from the measured tributary load.
3. TN load from Milton, Berwick, Somersworth, and Rollinsford WWTF was subtracted from the measured tributary load.

Figure 27: Total nitrogen loads in tons N per year to the Great Bay Estuary by source category

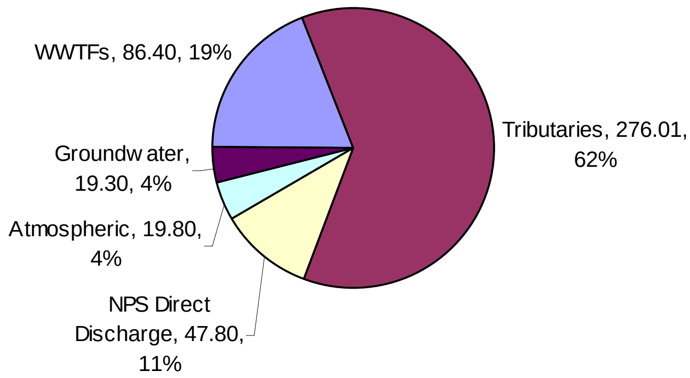


Figure 28: Total nitrogen loads in tons N per year to the Upper Piscataqua River Estuary by source category

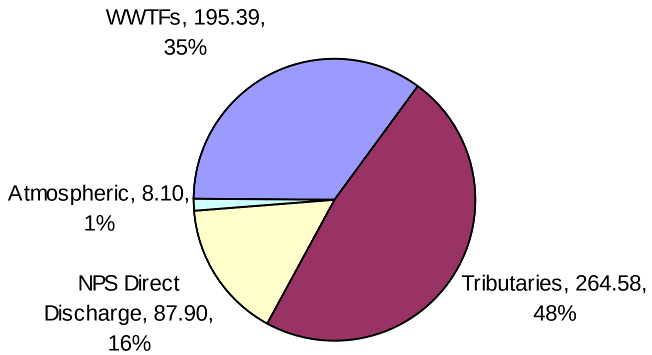


Figure 29: Total nitrogen loads in tons N per year to the Great Bay and Upper Piscataqua River estuaries by source category

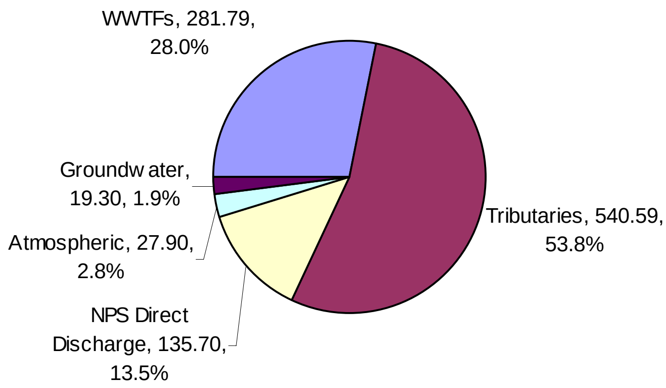
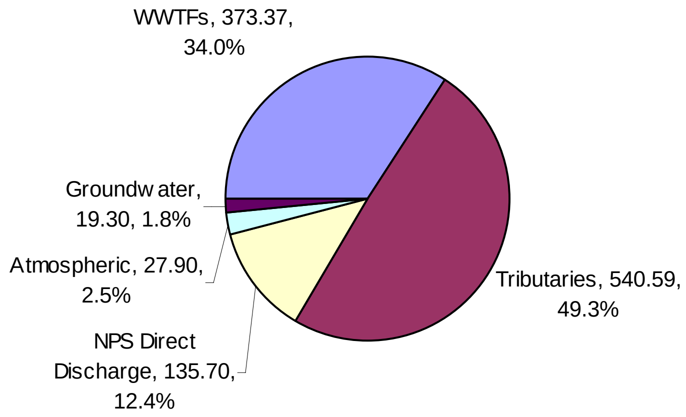


Figure 30: Total nitrogen loads to the Great Bay and Upper Piscataqua River estuaries by source category assuming 50% of WWTF loads in the lower Piscataqua River enter



NUT2 - TRENDS IN ESTUARINE NUTRIENT CONCENTRATIONS

Monitoring Objective

The objective of this indicator is to quantify long-term trends in nutrient concentrations (nitrogen and phosphorus) in estuarine waters. This indicator answers the following monitoring question:

Have levels of nitrogen and phosphorous significantly changed over time?

Measurable Goal

The goal is to have no increasing trends for any nitrogen or phosphorus species.

Data Analysis and Statistical Methods

Trends for nitrogen and phosphorus species were assessed at the three long-term trend stations at Adams Point in Great Bay ("GRBAP"), Squamscott River at Chapmans Landing ("GRBCL"), and Lamprey River at the Newmarket Town Landing ("GRBLR"). These three stations were the only stations in the estuary with at least five years of monthly data for nitrogen and phosphorus species. Nitrogen has been measured as nitrate plus nitrite (NO23) and ammonia (NH4). These two species were added together to calculate the dissolved inorganic nitrogen (DIN). Phosphorus was measured as orthophosphate (PO4). Less than 2% of the NO23 and NH4 measurements and less than 5% of the PO4 measurements were reported as "below the detection level". These results were excluded from the trend analysis. If either NO23 or NH4 were below detection, then the DIN concentration was not calculated. (Note that non-detected samples were treated differently for the NUT1 indicator because the dataset for NUT1 was much smaller than for NUT2.) The results from high and low tides on the same day and any station replicate samples were averaged prior to trend analysis.

The concentrations of nitrogen changed seasonally with the highest concentrations occurring in the winter. Winter measurements of nitrogen and phosphorus were not collected in 2002 to 2004 (Figure 31). Therefore the peak nitrogen concentrations were not captured for these years. Without these annual peak values, trend analysis on the full dataset would be biased low. Therefore, the trends were assessed using data from only the non-winter months (April to December) so that missing values from the winter season would not affect the overall trend.

Trends were assessed using linear regression of un-transformed concentrations versus year. Trends were considered significant if the coefficient of the year variable was significant at the $p<0.05$ level. The overall change over the period of record was determined by calculating the value of the regression line for the first and last years of the period of record. The difference between the two values divided by the first value was assumed to represent the average percent change over the period of record.

Results

The trends for the nitrogen and phosphorus species at Adams Point in Great Bay, the Squamscott River and the Lamprey River are shown in Figure 32, Figure 33 and Figure 34, respectively. Any statistically significant, linear trends are listed at the bottom of the graphs.

Statistically significant, increasing trends were observed for nitrogen (as NO23 and DIN) at only the Squamscott River station. The NO23 and DIN concentrations have increased by 63% and 39% between 1991 and 2004. No other statistically significant trends were observed. The goal for this indicator is to have no statistically significant increasing trends. This goal was not met because of the increasing trends in the Squamscott River. However, given that trends were not observed at the other two trend sites, there is not strong evidence for increasing nitrogen or phosphorus concentrations in the estuary between 1991 and 2004 (15 year period).

By using historical datasets, it is possible to investigate whether nitrogen or phosphorus concentrations have changed over a longer period. Norall et al (1982) and Loder et al (1983) monitored nitrogen and phosphorus species at Adams Point in Great Bay between 1974 and 1981 (Mathieson and Henre, 1986; Short, 1992). The measured concentrations from 1974-1981 were compared to more recent measured concentrations at this same location. For both datasets, a query was run to extract the samples collected at Adams Point at low tide. Non-detected results were a small fraction of the dataset and were removed. Both datasets were truncated so that they only covered full calendar years. For the recent dataset, the most recent 8 year period (1997-2004) was used to match the 8 year length of the Loder dataset (1974-1981).

Differences between the two datasets were analyzed using a parametric t-test and the non-parametric Kruskall-Wallis test with $p<0.05$ as the significance level. In effect, these tests compare the "populations" of concentrations measured in each study. It was not possible to complete another type of trend analysis because there were no data collected for more than a decade between the two studies.

Graphs of the data from each study are shown in Figure 35 through Figure 38. There has been a statistically significant increase in DIN and NH4 and a decrease in PO4. The DIN concentration increased from an average value of 0.107 mg N/L to 0.169 mg N/L (59% increase). The NH4 concentrations increased from 0.034 mg N/L to 0.079 mg N/L (132%). Finally, the PO4 concentration fell from 0.027 mg P/L to 0.023 mg P/L (-15%). These changes occurred over an approximately 25 year period.

The results of this historical analysis provide clear evidence that dissolved inorganic nitrogen concentrations have increased in the estuary in the past quarter century, even though more recent trends are equivocal. The DIN trend appears to be largely driven by increasing NH4 concentrations, which are often difficult to measure. However, even if the three highest NH4 values from the 1997-2004 dataset are removed, the statistical tests still indicate an increasing trend.

Figure 31: Dissolved inorganic nitrogen at Adams Point in the winter

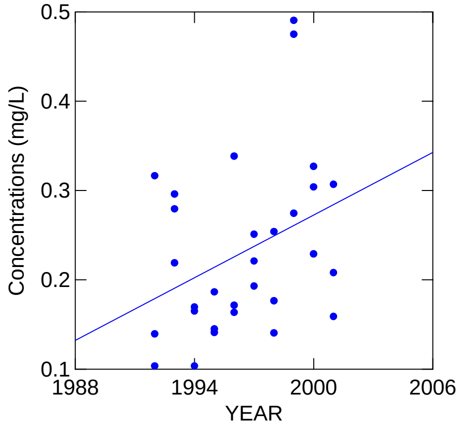
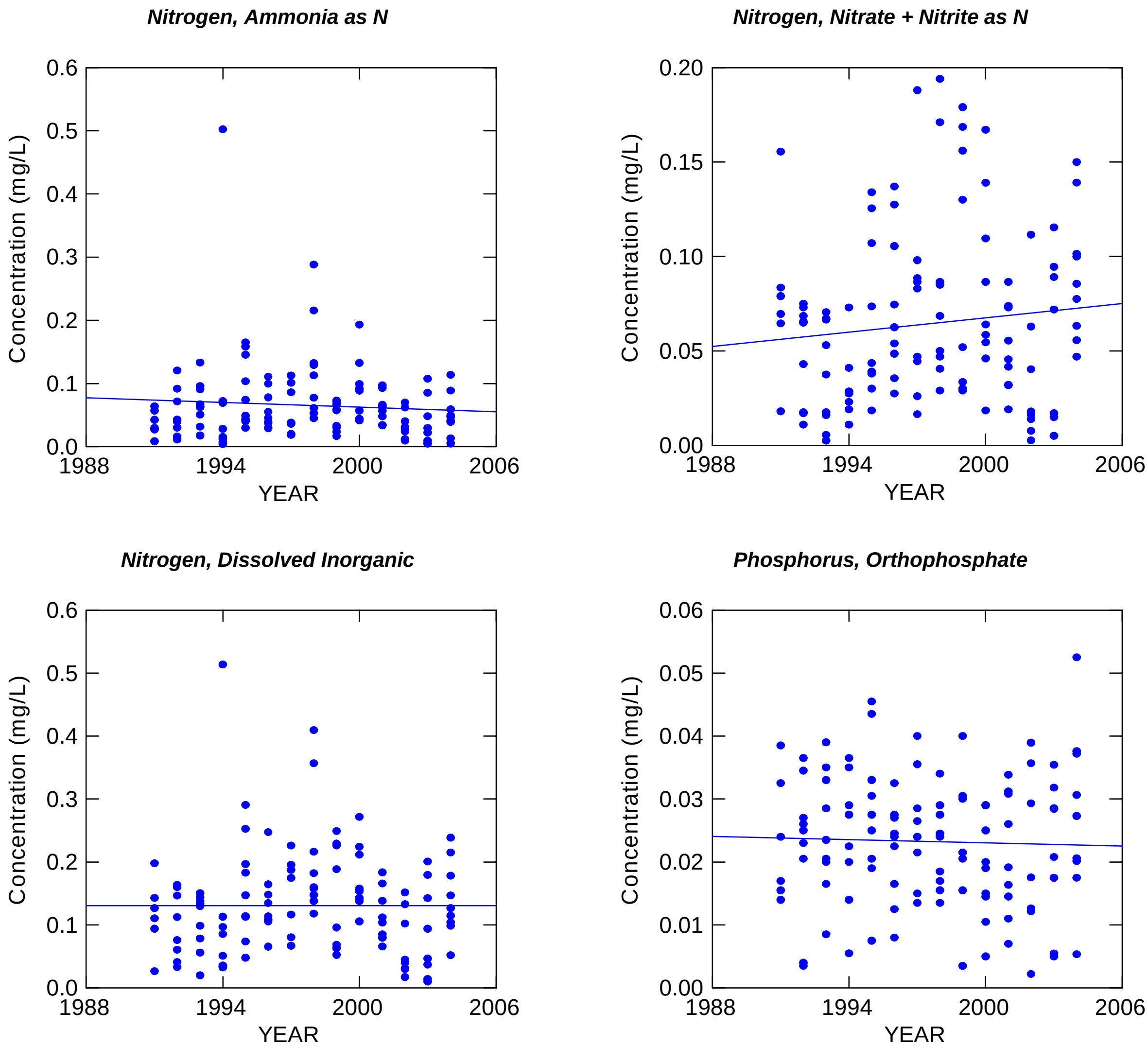


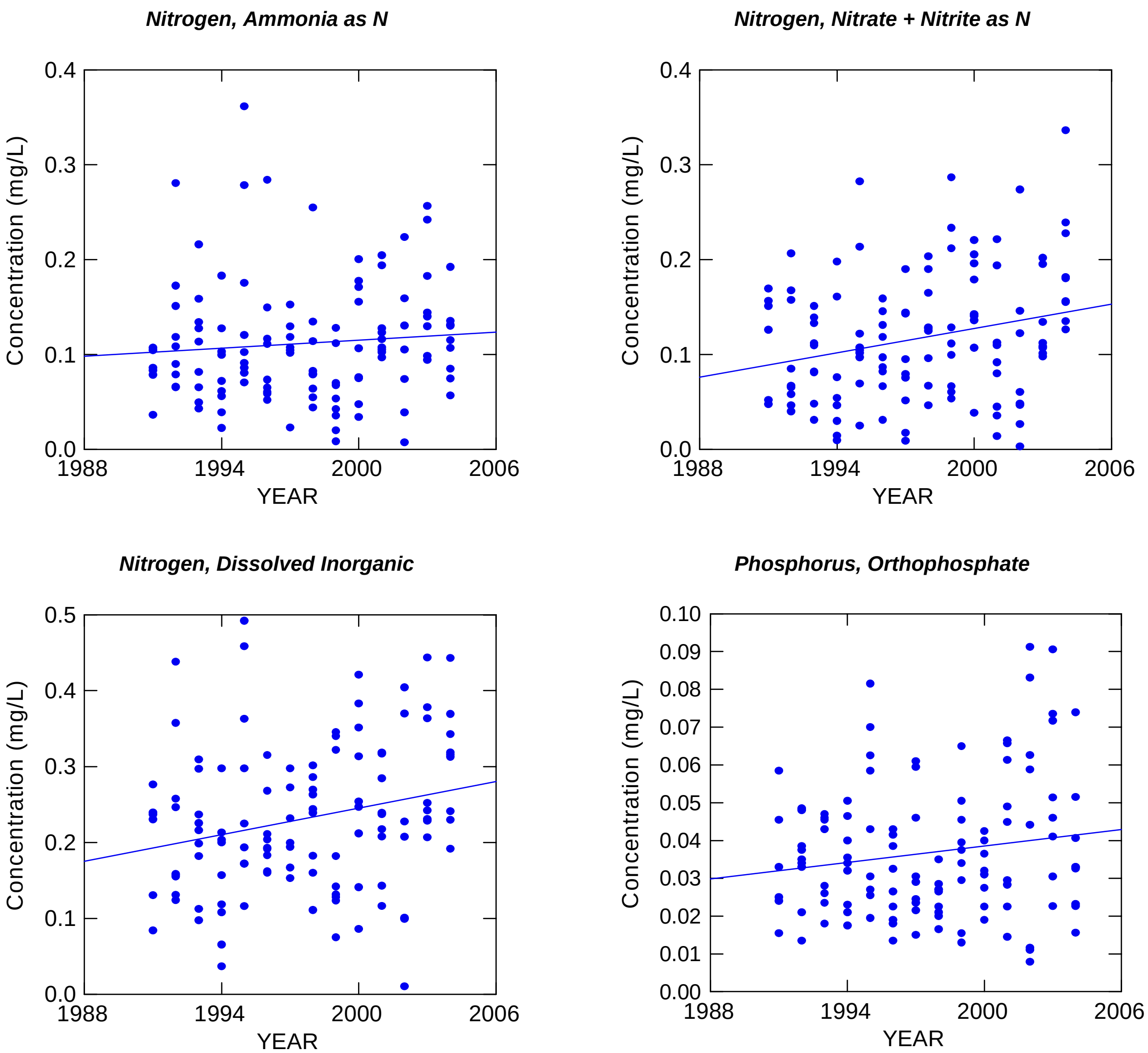
Figure 32: Long-term trends for nitrogen and phosphorus concentrations measured monthly from April through December at Adams Point in Great Bay



<u>*Statistically Signficant Trends*</u>

None

Figure 33: Long-term trends for nitrogen and phosphorus concentrations measured monthly from April through December at Chapmans Landing in the Squamscott River

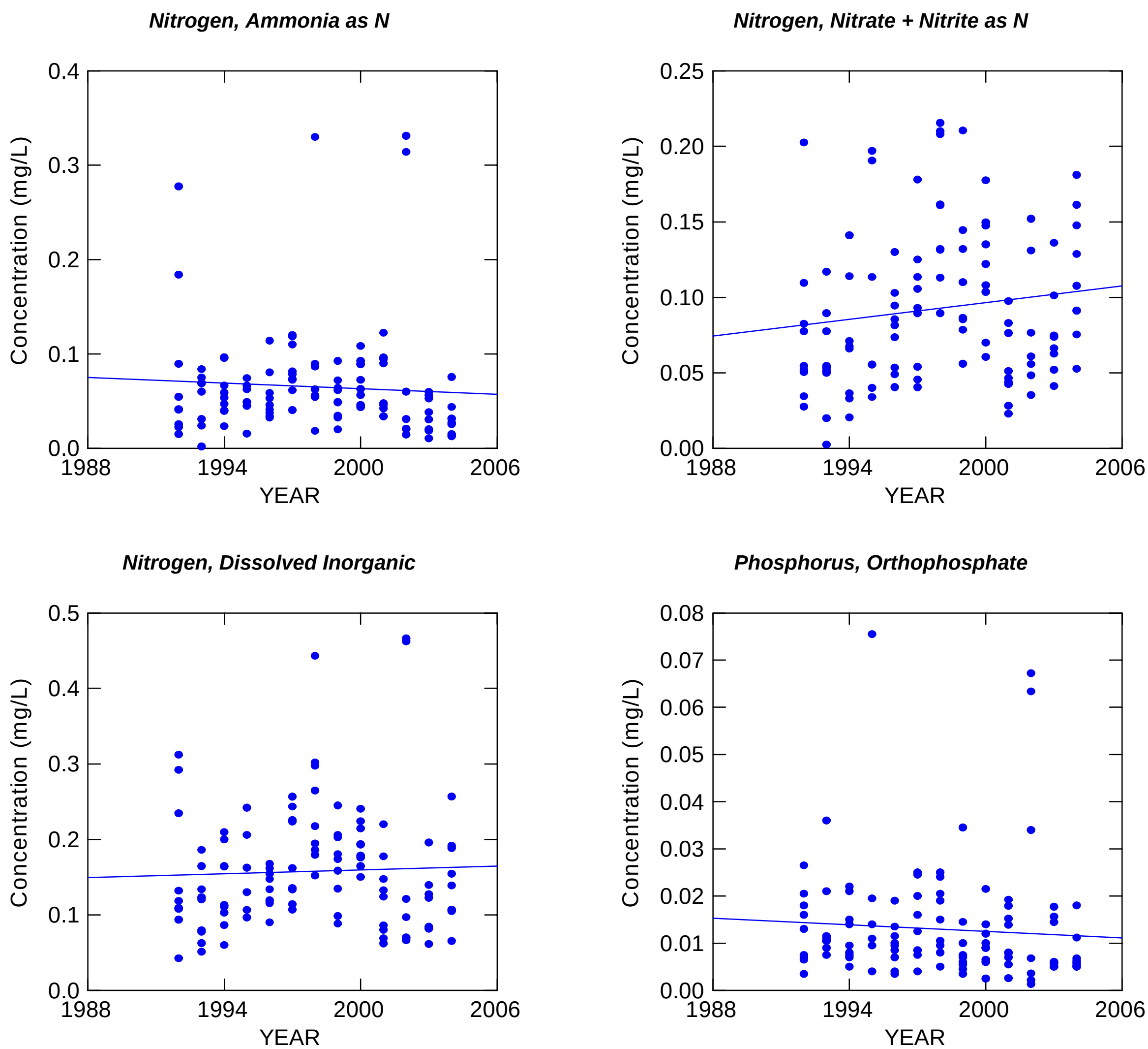


Statistically Signficant Trends

Nitrogen, Nitrate+Nitrite as N = 0.00428 * YEAR - 8.440 (P=0.005) Percent Change 1991-2004 = 63%

Nitrogen, Dissolved Inorganic = 0.00585 * YEAR - 11.448 (P=0.00 Percent Change 1991-2004: 39%

Figure 34: Long-term trends for nitrogen and phosphorus concentrations measured monthly from April through December at the Town Landing in the Lamprey River



Statistically Significant Trends: none

Figure 35: Comparison of nitrate+nitrite concentrations at Adams Point at low tide between 1974-1981 and 1997-2004

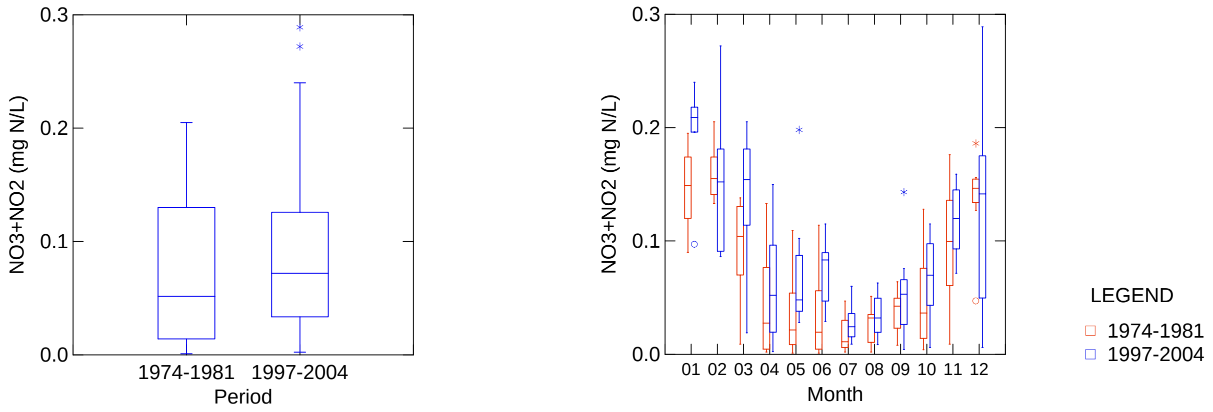


Figure 36: Comparison of ammonia concentrations at Adams Point at low tide between 1974-1981 and 1997-2004

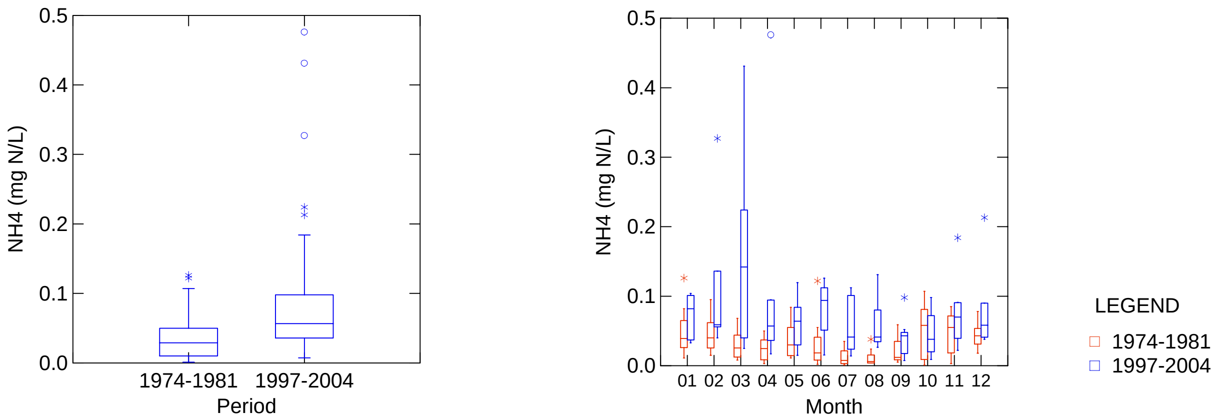


Figure 37: Comparison of dissolved inorganic nitrogen concentrations at Adams Point at low tide between 1974-1981 and 1997-2004

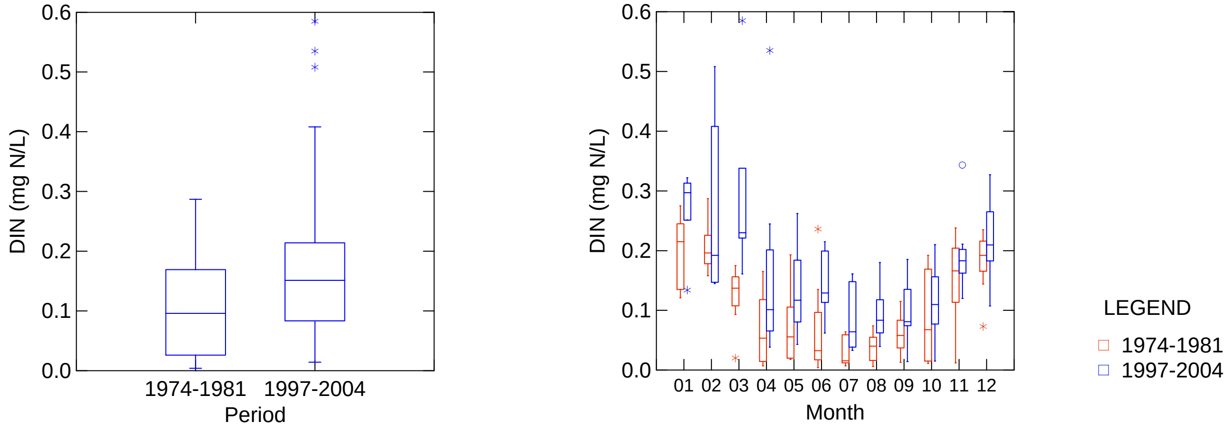
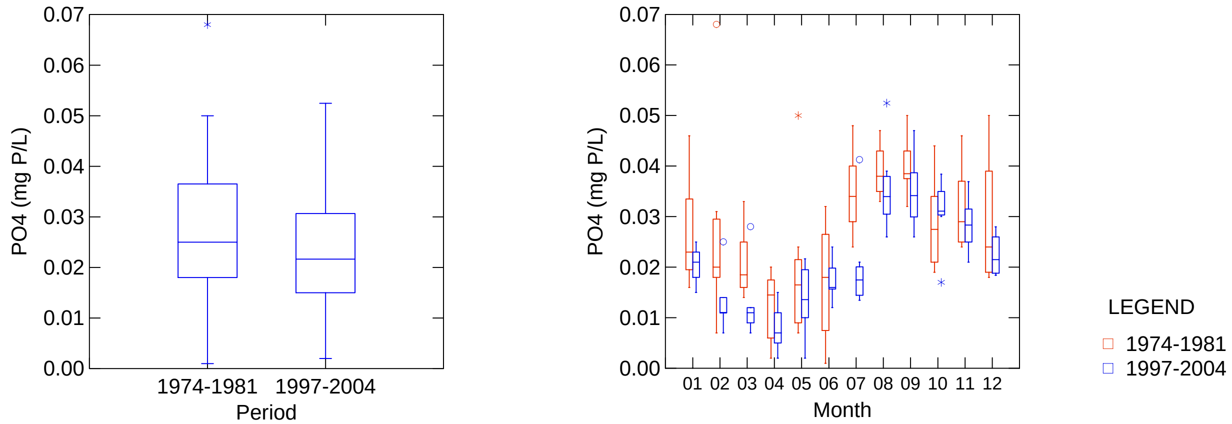


Figure 38: Comparison of orthophosphate concentrations at Adams Point at low tide between 1974-1981 and 1997-2004



NUT3 - TRENDS IN ESTUARINE PARTICULATE CONCENTRATIONS

Monitoring Objective

The objective of this indicator is to quantify long-term trends in particulate concentrations in estuarine waters. This indicator answers the following monitoring question:

Have surface tidal or freshwaters shown a significant change in turbidity over time?

Measurable Goal

The goal is to have no increasing trends for particulate matter in estuarine waters.

Data Analysis and Statistical Methods

Trends for particulate concentrations were assessed at the three long-term trend stations at Adams Point in Great Bay ("GRBAP"), Squamscott River at Chapmans Landing ("GRBCL"), and Lamprey River at the Newmarket Town Landing ("GRBLR"). These three stations were the only stations in the estuary with at least five years of monthly data for particulates. Particulates were measured as chlorophyll-a and total suspended solids (TSS). Less than 1% of the chlorophyll-a and TSS measurements were reported as "below the detection level". These results were excluded from the trend analysis. The results from high and low tides on the same day and any field replicate samples were averaged prior to trend analysis.

As discussed for indicator NUT2, the dataset is missing values from the 2002-2004 winter seasons. However, the peak values for TSS and chlorophyll-a do not occur in the winter. Therefore, these missing values are not expected to affect trend analysis using data from all the seasons.

Trends were assessed using linear regression of un-transformed concentrations versus year. Trends were considered significant if the coefficient of the year variable was significant at the $p<0.05$ level. The overall change over the period of record was determined by calculating the value of the regression line for the first and last years of the period of record. The difference between the two values divided by the first value was assumed to represent the average percent change over the period of record.

Results

Plots of the particulate concentrations over time are shown in Figure 39, Figure 40 and Figure 41. At Adams Point, chlorophyll-a concentrations increased by 76% between 1988 and 2004. Despite the large percent increase, the actual chlorophyll-a concentrations were low at this site, 2.6 ug/L in 1988 and 4.6 ug/L in 2004. A statistically significant trend for TSS was observed in the Lamprey River. The TSS concentrations at this site increased by 76% between 1992 and 2004 but the baseline concentrations were already low (5.8 mg/L in 2004).

There was no significant trend for TSS at Adams Point for the whole dataset (1988-2004). However, Figure 39 shows that TSS concentrations have been increasing since 1993. Given the high TSS concentrations observed in 1988-1992, it is clear that the TSS trend is not monotonic. Many factors are possibly related to changes in TSS concentrations at Adams Point including variability in rainfall, wind speed and tidal amplitude, localized erosion, loss of eelgrass due to wasting disease in the early 1990s and loss of filter feeders such as oysters. Figure 42 shows the rainfall totals for the four days before each TSS sample was collected at Adams Point. There is no significant trend in antecedent rainfall corresponding to the TSS trend from 1993 to 2004. Therefore, changes in rainfall patterns do not explain the increasing TSS trend.

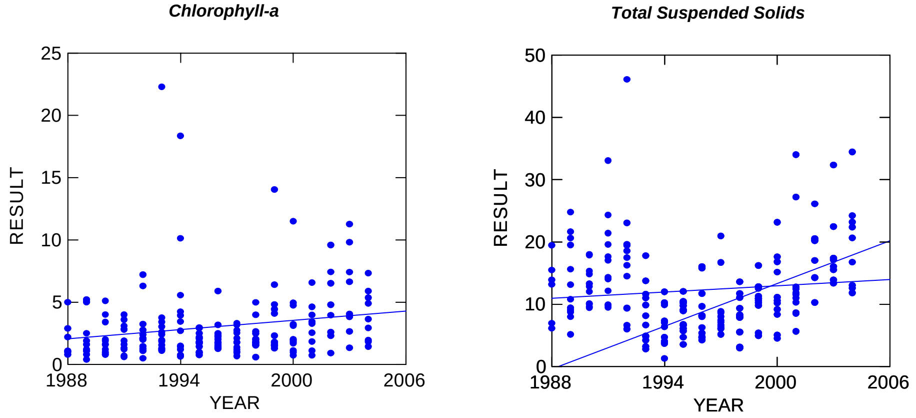
The NHEP goal for this indicator is to have no statistically significant, increasing trends for particulates. This goal is currently not being met; however, several of the increasing trends were observed at stations with very low concentrations.

By using historical datasets, it is possible to investigate whether particulate concentrations have changed over a longer period. Norall et al (1982) and Loder et al (1983) monitored chlorophyll-a and TSS at Adams Point in Great Bay between 1974 and 1981 (Mathieson and Henre, 1986; Short, 1992). The measured concentrations from 1974-1981 were compared to more recent measured concentrations at this same location. For both datasets, a query was run to extract the samples collected at Adams Point at low tide. Non-detected results were a small fraction of the dataset and were removed. Both datasets were truncated so that they only covered full calendar years. For the recent dataset of chlorophyll-a, the most recent 8 year period (1997-2004) was used to match the 8 year length of the older dataset (1974-1981). The older dataset only contains six years of TSS data between 1976 and 1981. Therefore, the most recent six years of data from the newer dataset were used for TSS comparisons.

Differences between the two datasets were analyzed using a parametric t-test and the non-parametric Kruskall-Wallis test with $p<0.05$ as the significance level. In effect, these tests compare the "populations" of concentrations measured in each study. It was not possible to complete another type of trend analysis because there were no data collected for more than a decade between the two studies.

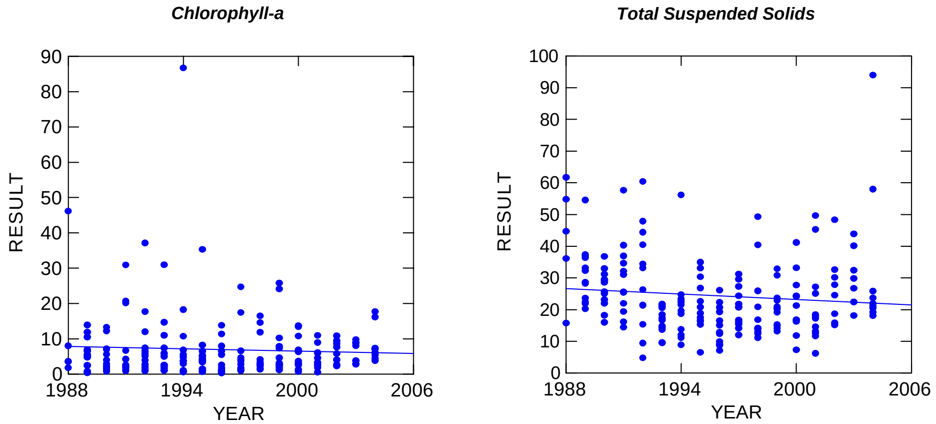
Graphs of the data from each study are shown in Figure 43 and Figure 44. There was no statistically significant difference in chlorophyll-a concentrations between the two studies, despite the increasing dissolved inorganic nitrogen concentrations during the same period (reported for indicator NUT2). However, TSS concentrations increased from an average value of 8.8 mg/L to 15.9 mg/L (an 81% increase) between 1976-1981 and 1999-2004. The choice of dates for the comparison is important for the TSS trend analysis. The 1999-2004 period was chosen for the TSS trend analysis because it is the most recent data available and it overlaps with the period used for trend analysis for the other parameters. However, if the 1976-1981 data are compared to data from 1993-1998, there is no significant trend for TSS. Therefore, the observed change in TSS between 1976-1981 and 1999-2004 should be interpreted with caution.

Figure 39: Long-term trends for particulate concentrations measured monthly at Adams Point in Great Bay



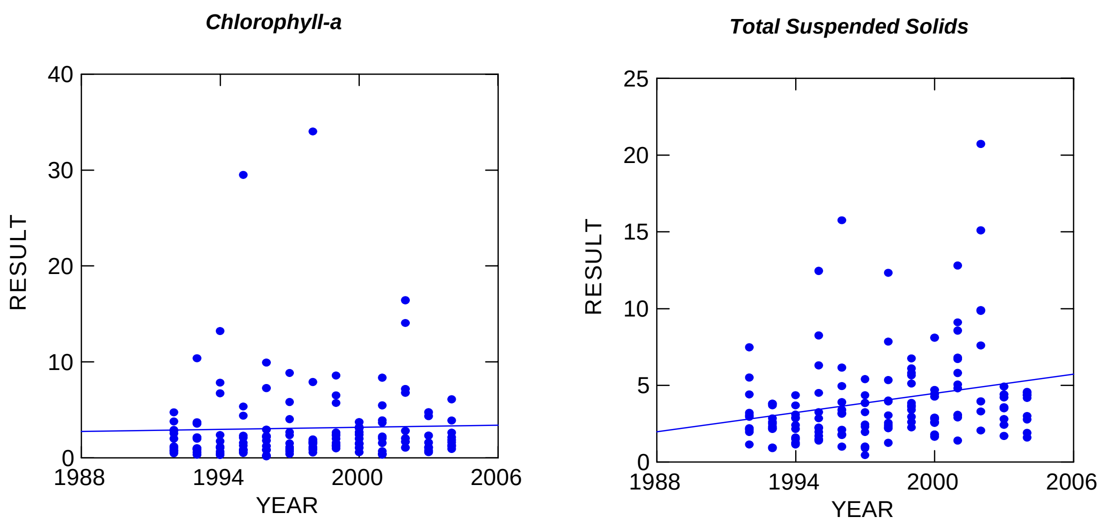
Statistically Significant Trends
Chlorophyll-a = 0.124 * YEAR –243.9
Percent Change 1988-2004 = 76%
TSS = 1.143 * YEAR—2273 (1993-2004 period)
Percent Change 1993-2004 = 2004%

Figure 40: Long-term trends for particulate concentrations measured monthly at Chapmans



Statistically Significant Trends
None

Figure 41: Long-term trends for particulate concentrations measured monthly at the Town Landing in the Lamprey River



Statistically Significant Trends
TSS = 0.209 * YEAR -413
Percent Change 1992-2004 = 76%

Figure 42: Four-day antecedent rainfall for TSS samples collected at Adams Point

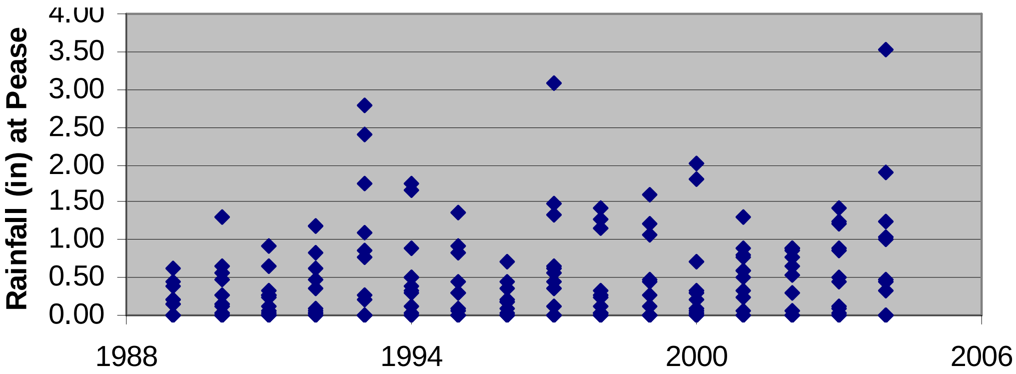


Figure 43: Comparison of chlorophyll-a concentrations at Adams Point at low tide between 1974-1981 and 1997-2004

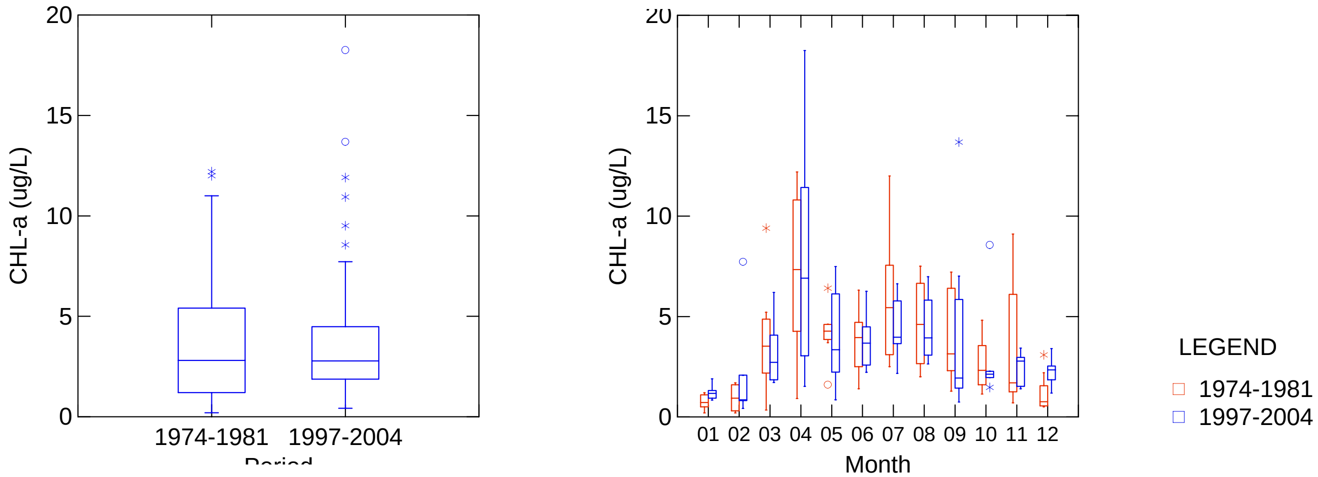
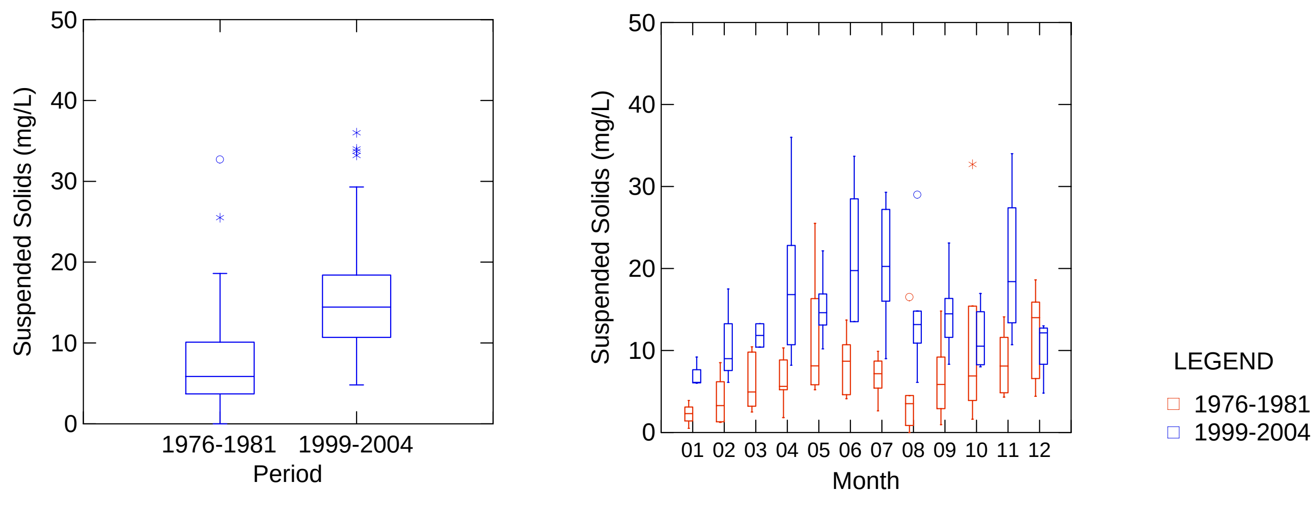


Figure 44: Comparison of suspended solids concentrations at Adams Point at low tide between 1976-1981 and 1999-2004



NUT5 - EXCEEDENCES OF INSTANTANEOUS DISSOLVED OXYGEN STANDARD

Monitoring Objective

The objective of this indicator is to document the number of exceedences of the state water quality standard for instantaneous dissolved oxygen concentrations in the estuary each year. Low dissolved oxygen (DO) concentrations are a common manifestation of eutrophication. In a system as well mixed as the Great Bay, low DO events are not likely to last longer than one tidal cycle. Therefore, DO measurements taken at a high frequency by in-situ sondes deployed near the sediments in the tidal tributaries (where low DO is the most likely) have the best chance of capturing these events in the Great Bay. This indicator partially answers the following monitoring question:

Do any surface tidal or freshwaters contain less than the state standard for dissolved oxygen? For what period of time?

Measurable Goal

The State water quality standard for dissolved oxygen has two components: (1) the *daily average* concentration must remain above 75% saturation, and (2) the *instantaneous* dissolved oxygen concentration must remain above 5 mg/l. This indicator will track the number of exceedences of the instantaneous standard. The goal is to have 0 days with exceedences of the instantaneous standard.

Data Analysis and Statistical Methods

The daily minimum dissolved oxygen concentration was calculated for each sonde for each date with complete (i.e., 48 valid measurements) dissolved oxygen data. If the minimum value was less than 5 mg/L, then that date was counted as a having a exceedence of the instantaneous dissolved oxygen standard. For each sonde, the number of days per year with at least one exceedence of the standard was tabulated and compared to the goal of zero days. Inter-annual trends were assessed qualitatively using the frequency of days with exceedences relative to the number of days with complete, valid data during July, August, and September.

The data used for this indicator were quality assured by staff from the Great Bay National Estuarine Research Reserve and DES. For 2004 data, the dissolved oxygen measurements were validated by pre- and post-deployment checks with an independently calibrated dissolved oxygen sensor. For earlier years, for which quality control data were not available, only measurements from the first 96 hours of the sonde deployment were used.

Results

The number of exceedences of the dissolved oxygen instantaneous standard that were recorded at each station is summarized in Table 15. A greater number of results passed the quality assurance reviews in 2004; therefore, there is better data coverage for this year. Trends over time in the percentage of days with exceedences are shown in Figure 46. The locations of the datasonde stations are shown in Figure 45.

In Great Bay (GRBAP) and Portsmouth Harbor (GRBCML), the dissolved oxygen almost never fell below 5 mg/L. The standard was exceeded at these stations only once out of 160 days between 2000 and 2004. Therefore, the NHEP goal of zero exceedences is essentially being met for the well mixed areas of Great Bay and Portsmouth Harbor.

In contrast to the open bays, there were persistent exceedences of the standard at the stations in the tidal tributaries. In the Lamprey River (GRBLR), the dissolved oxygen concentration fell below 5 mg/L on 21, 9 and 33 days during the summer months in 2002, 2003 and 2004, respectively. For the 2002-2004 period, there were exceedences of the dissolved oxygen standard in the Lamprey River on 69% of the days. While the greatest number of exceedences was observed in the Lamprey River, all of the other tidal tributaries also experienced dissolved oxygen concentrations below the standard. The daily minimum dissolved oxygen concentration in the Squamscott River (GRBSQ), the Oyster River (GRBOR) and the Salmon Falls River (GRBSR) fell below the standard on 38%, 27% and 18% of the time during 2002 through 2004.

Based on these data, the tidal tributaries do not meet the goal of having zero days with dissolved oxygen less than 5 mg/l. The Lamprey River exhibits the most persistent signs of low DO than the other rivers. Pennock (2005) studied dissolved oxygen in the Lamprey River and found that, in some cases, the episodes of low dissolved oxygen were caused by a salinity stratification that set up in the bottom waters. Dissolved oxygen concentrations in the middle of Great Bay and at the mouth of Portsmouth Harbor consistently meet the water quality standard.

In addition to knowing whether the water quality standard is exceeded, it is useful to know the frequency and duration of the exceedences. In Figure 47 through Figure 50, two graphs are presented for each datasonde where the dissolved oxygen fell below 5 mg/L in 2004. The first graph shows the percent of each day with dissolved oxygen less than 5 mg/L between July 1 and September 30 (only calculated for days with 48 valid dissolved oxygen measurements). The second graph is a histogram of the durations for "low DO episodes", periods when the dissolved oxygen fell below 5 mg/L. Dissolved oxygen concentrations less than 5 mg/L are not technically hypoxia but will be considered "low DO" for the purposes of discussion.

For most datasondes, the median duration of a DO episode was less than 4 hours. The only significant departure from this trend was observed at the Lamprey River datasonde. At this location, the histogram was bimodal with peaks at <4 hours and 12 hours. Despite the short duration of the typical "low DO" event, there can be multiple events in a single day if the dissolved oxygen fluctuates near the standard. The most persistent occurrence of low dissolved oxygen was in the Lamprey River. At his site, the datasonde documented a period of five days when the dissolved oxygen did not get above 5 mg/L (this period is not shown on the histogram).

While the 5 mg/L water quality standard for DO provides an objective reference point by which to judge measurements in the estuary, there are questions about whether the standard correctly identifies impairments of the aquatic life in tidal waters. Excursions of DO concentrations below 5 mg/L may be natural in tidal rivers and creeks. Biological data on anadromous fish returns (NHEP, 2006) and benthic invertebrates (TOX7) do not indicate widespread biological impairments in the tidal tributaries, despite episodes of low DO in these areas.

Table 15: Measurements of dissolved oxygen concentrations less than 5 mg/L at in-situ datasondes in the estuary

Station	Year	# days with DO measurements in July, August and September	# of days with daily minimum DO < 5 mg/L in July, August and September	Percent
GRBCML	2002	16	0	0
GRBCML	2003	20	0	0
GRBCML	2004	21	0	0
GRBGB	2000	9	0	0
GRBGB	2001	20	0	0
GRBGB	2002	30	1	3.3
GRBGB	2003	24	0	0
GRBGB	2004	20	0	0
GRBLR	2000	7	0	0
GRBLR	2001	20	3	15
GRBLR	2002	25	21	84
GRBLR	2003	15	9	60
GRBLR	2004	52	33	63.5
GRBOR	2002	25	9	36
GRBOR	2003	19	1	5.3
GRBOR	2004	52	21	40.4
GRBSF	2002	10	0	0
GRBSF	2003	17	6	35.3
GRBSF	2004	60	12	20
GRBSQ	2000	15	4	26.7
GRBSQ	2001	20	0	0
GRBSQ	2002	20	8	40
GRBSQ	2003	22	12	54.5
GRBSQ	2004	92	19	20.7

Source: Great Bay NERR Monitoring Program

Figure 45: Locations of in-situ datasondes in the Great Bay estuary

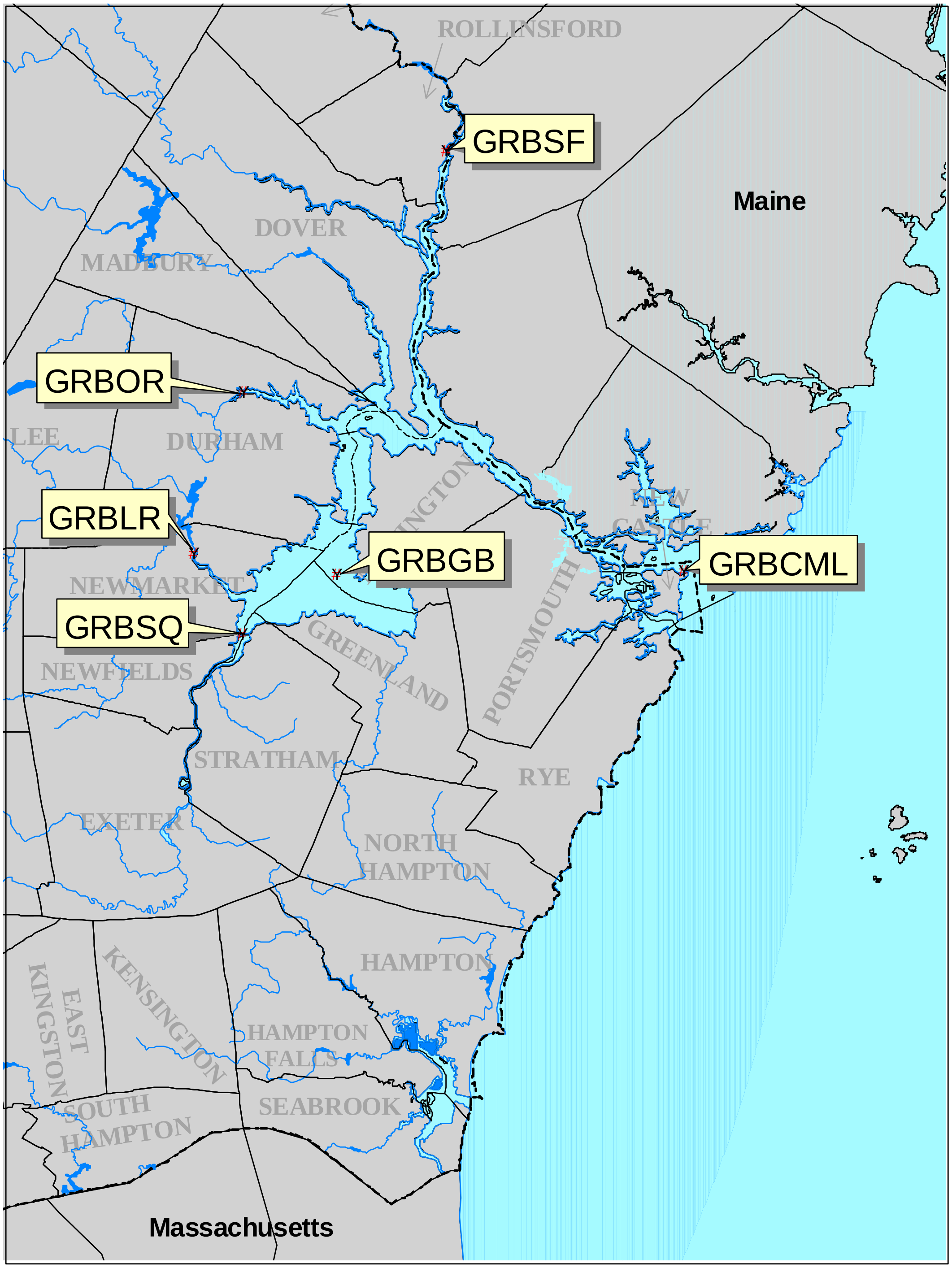


Figure 46: Trends in the occurrence of dissolved oxygen <5 mg/L as measured by in-situ datasondes

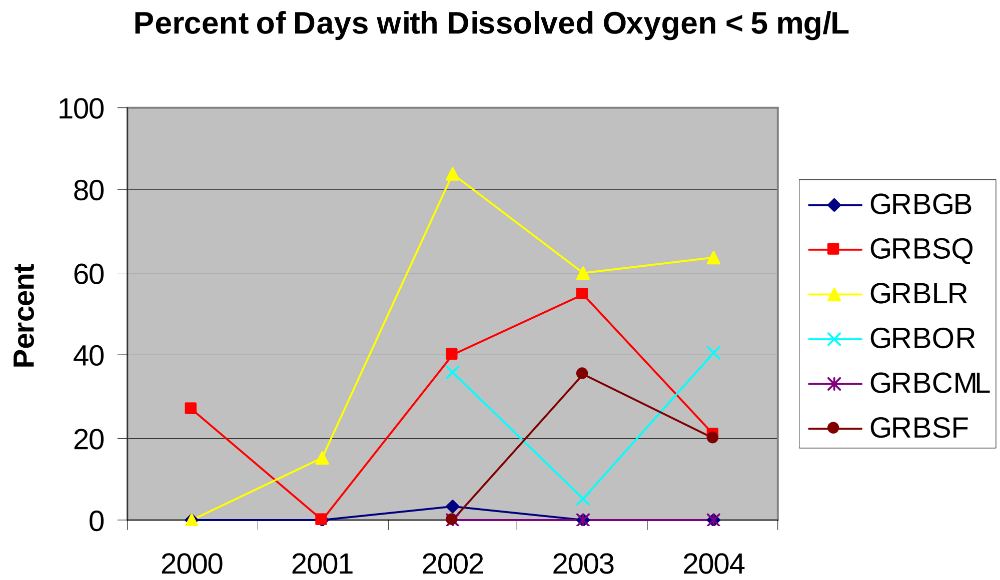


Figure 47: Frequency and duration of dissolved oxygen less than 5 mg/L at the Squamscott River datasonde

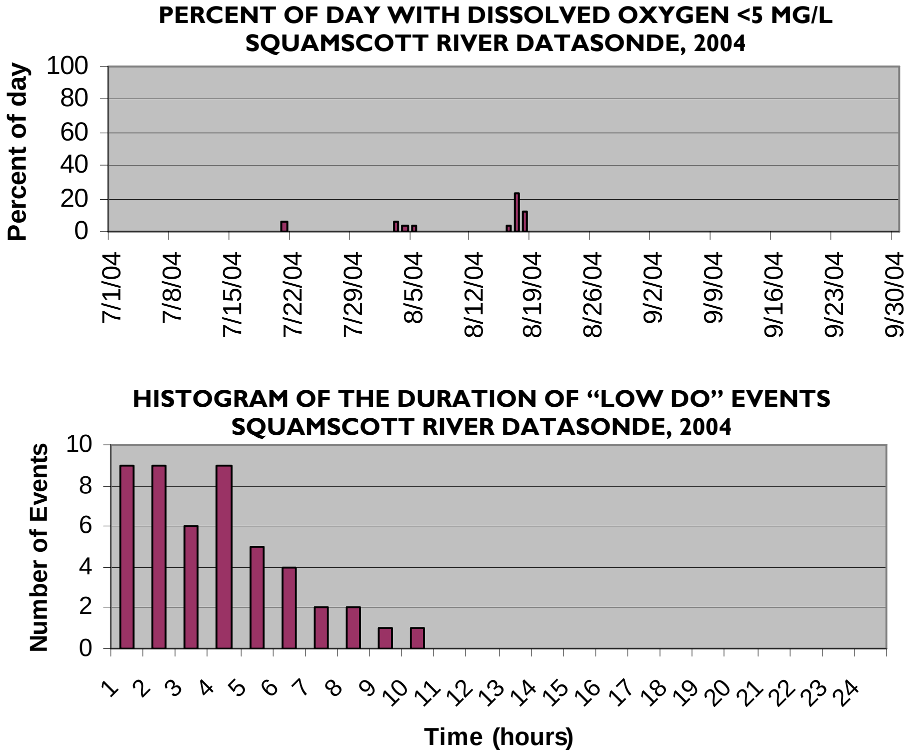


Figure 48: Frequency and duration of dissolved oxygen less than 5 mg/L at the Lamprey River datasonde

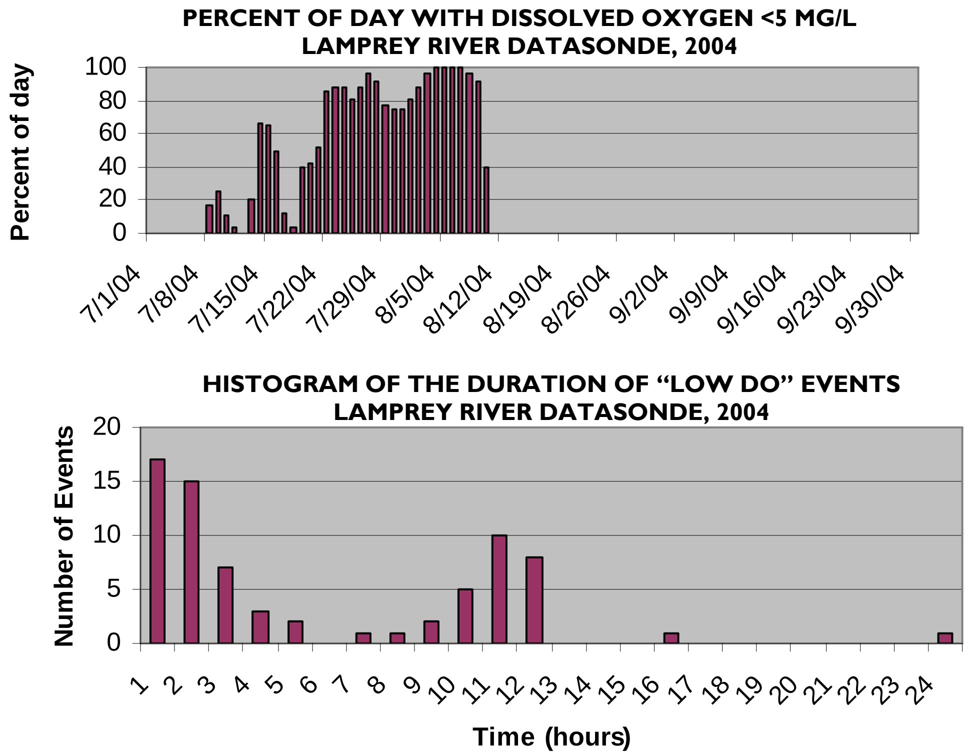


Figure 49: Frequency and duration of dissolved oxygen less than 5 mg/L at the Oyster River datasonde

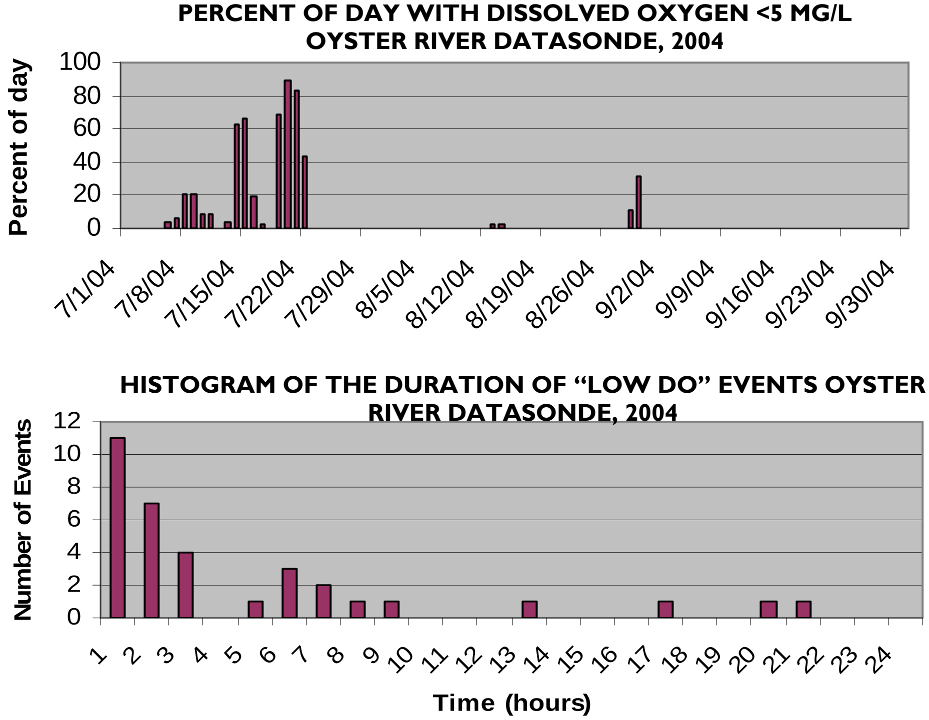
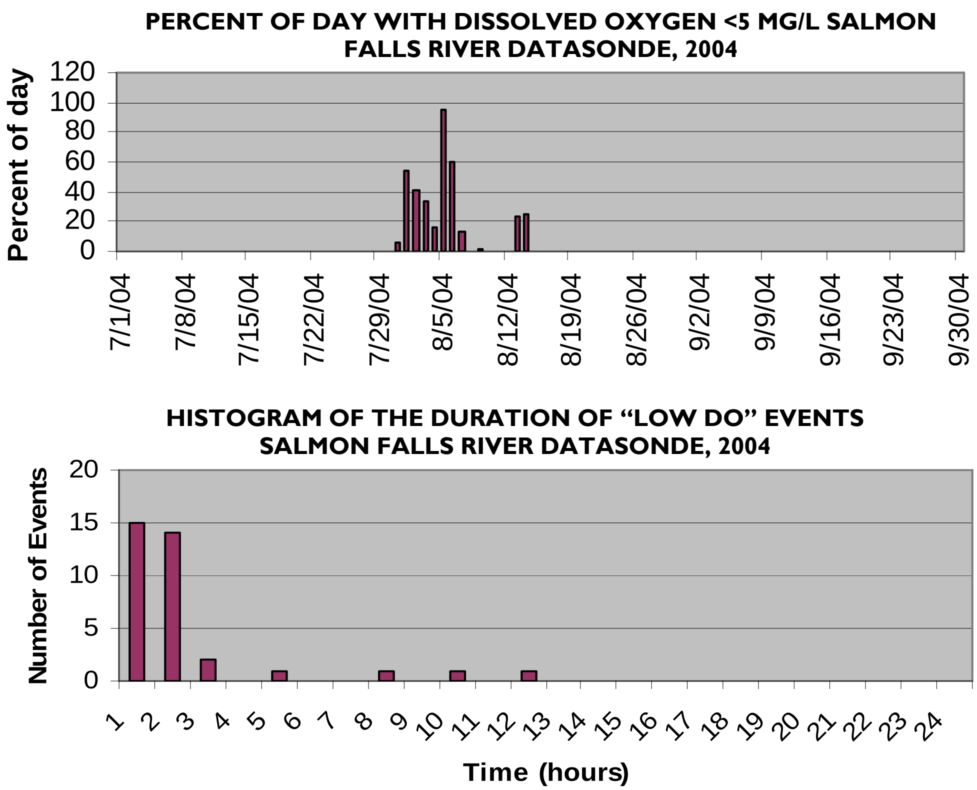


Figure 50: Frequency and duration of dissolved oxygen less than 5 mg/L at the Salmon Falls River datasonde



NUT6 - EXCEEDENCES OF THE DAILY AVERAGE DISSOLVED OXYGEN STANDARD

Monitoring Objective

The objective of this indicator is to estimate the number of exceedences in the estuary each year of the state water quality standard for daily average dissolved oxygen concentrations. This indicator partially answers the following monitoring question:

Do any surface tidal or freshwaters contain less than the state standard for dissolved oxygen? For what period of time?

Measurable Goal

The State Water Quality Standard for dissolved oxygen has two components: (1) the *daily average* concentration must remain above 75% saturation, and (2) the *instantaneous* dissolved oxygen concentration must remain above 5 mg/l. This indicator will track the number of violations of the daily average standard. The goal is to have 0 days with violations of the daily average standard.

Data Analysis and Statistical Methods

The data analysis methods for this indicator were the same as for Indicator NUT5, except that the measurements of dissolved oxygen saturation were averaged for each day. The average concentration was compared to the standard of 75%. If the average concentration was less than the standard, then the day was counted as exceeding the standard.

Results

Table 16 summarizes the number of exceedences of the daily average dissolved oxygen standard at the different datasondes. Trends in the frequency of occurrence for the exceedences are shown in Figure 51.

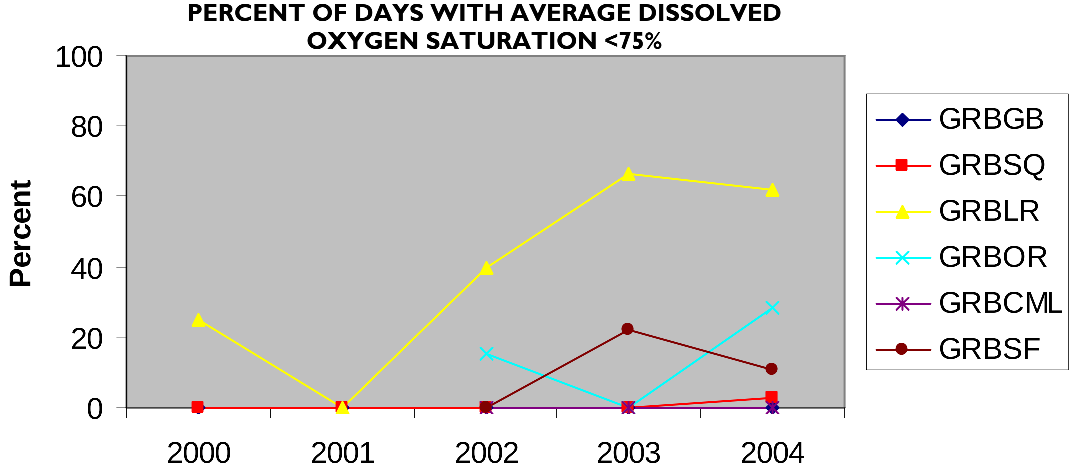
The results for this indicator are similar to those for NUT5. The dissolved oxygen concentrations in the Great Bay and Portsmouth Harbor consistently meet the 75% saturation standard, while exceedences of the standard have been observed in the tidal tributaries. The most exceedences have been observed in the Lamprey River (56% of the time on average in 2002-2004). Relatively few exceedences of the standard have been observed in the Squamscott River, despite the fact that the dissolved oxygen concentration often fell below 5 mg/L (see NUT5). These results indicate large diurnal swings of dissolved oxygen in the Squamscott River system.

Table 16: Measurements of daily average dissolved oxygen saturation less than 75% at in-situ datasondes in the estuary

Station	Year	# days with complete data in July, August and September	# of days with daily average DO <75% in July, August and September	Percent
GRBCML	2002	9	0	0
GRBCML	2003	12	0	0
GRBCML	2004	16	0	0
GRBGB	2000	5	0	0
GRBGB	2001	12	0	0
GRBGB	2002	18	0	0
GRBGB	2003	15	0	0
GRBGB	2004	18	0	0
GRBLR	2000	4	1	25
GRBLR	2001	11	0	0
GRBLR	2002	15	6	40
GRBLR	2003	9	6	66.7
GRBLR	2004	50	31	62
GRBOR	2002	13	2	15.4
GRBOR	2003	6	0	0
GRBOR	2004	46	13	28.3
GRBSF	2002	6	0	0
GRBSF	2003	9	2	22.2
GRBSF	2004	55	6	10.9
GRBSQ	2000	8	0	0
GRBSQ	2001	12	0	0
GRBSQ	2002	12	0	0
GRBSQ	2003	10	0	0
GRBSQ	2004	76	2	2.6

Source: Great Bay NERR Monitoring Program

Figure 51: Trends in the occurrence of daily average dissolved oxygen saturation <75% as measured by in-situ datasondes



NUT7 - TRENDS IN BIOLOGICAL OXYGEN DEMAND LOADING TO GREAT BAY

Monitoring Objective

One factor that can lead to hypoxia in the estuary is the biological oxygen demand (BOD) load from WWTFs and tidal tributaries. This indicator tracks the monthly loading from the tributaries to Great Bay and the WWTFs that discharge directly to the tidal waters to determine if the loads are changing over time. This indicator answers the following monitoring question:

Do any surface tidal or freshwaters show a significant change in biological oxygen demand?

Measurable Goal

The goal is for no WWTF or tributary to have significantly increasing trends in BOD loading. This is a goal for the NHEP but it is not legally binding for WWTF operators. Many WWTFs are allowed under their existing permits to discharge more BOD than they currently do. WWTF discharges cannot be required to be less than permitted levels unless the discharge can be shown to cause a water quality impact.

Data Analysis and Statistical Methods

Monthly average flow BOD loads from each WWTF were taken from NPDES Discharge Monitoring Reports filed by the facility. The long-term trend in monthly flow and BOD load was determined by the Seasonal Kendall Test using $p<0.10$ as critical value and two tailed test to determine significance.

Monthly BOD loads from the major tributaries could not be estimated because 235 of 263 (89%) of the BOD measurements at the tributary monitoring stations were below detection.

Results

The statistically significant trends for flow and BOD loading are shown in Table 17 and Table 18, respectively. For most of the WWTFs, flows have increased by 30% over the 15 year period between 1989 and 2004. This trend roughly parallels the population growth in Rockingham and Strafford counties between 1990 and 2005 (from 359,254 to 432,528 or 20% increase). The one exception was Newington WWTF, which has reduced its flow by 33% over the same period.

Despite the increasing flows, the BOD load was actually reduced at the Durham and Hampton WWTFs. BOD loading from the Newfields and Portsmouth WWTFs increased at approximately the same rate as the flow at these WWTFs. For the Newmarket WWTF, the BOD load increased by 86% while the flow only increased by 27%. The large BOD increase at this plant was caused by equipment malfunction during cold weather. The issue has been resolved.

The NHEP goal for this indicator is for no WWTF to have statistically significant, increasing trends. This goal is not being met. However, without a water quality model, it is not possible to determine the effect of the increased BOD loads on dissolved

Table 17: Trends in flow from wastewater treatment facilities discharging to estuarine waters

Facility	Flow (MGD)*	Period of Record	Trend	Percent Change
Dover WWTF	2.789	10/89 to 9/04	Increasing	25%
Durham WWTF	0.949	10/89 to 9/04	No significant trend	
Exeter WWTF	1.694	10/89 to 9/04	Increasing	32%
Hampton WWTF	2.741	10/89 to 9/04	Increasing	29%
Newfields WWTF	0.178	10/96 to 9/04	Increasing	29%
Newington WWTF	0.112	10/93 to 9/04	Decreasing	-33%
Newmarket WWTF	0.680	10/89 to 9/04	Increasing	27%
Portsmouth WWTF	4.934	10/89 to 9/04	Increasing	33%

** Average for 2002-2004*

Source: NPDES Discharge Monitoring Reports

Table 18: Trends in biological oxygen demand (BOD) loading from wastewater treatment facilities discharging to estuarine waters

Facility	BOD Load (lb/day)*	Period of Record	Trend	Percent Change
Dover WWTF	299	10/89 to 9/04	No significant trend	
Durham WWTF	60	10/89 to 9/04	Decreasing	-53%
Exeter WWTF	140	10/89 to 9/04	No significant trend	
Hampton WWTF	107	10/89 to 9/04	Decreasing	-59%
Newfields WWTF	10	10/96 to 9/04	Increasing	42%
Newington WWTF	10	10/93 to 9/04	Decreasing	-65%
Newmarket WWTF	176	10/89 to 9/04	Increasing	82%
Portsmouth WWTF	4434	10/89 to 9/04	Increasing	46%

** Average for 2002-2004*

Source: NPDES Discharge Monitoring Reports

NUT8 - PERCENT OF THE ESTUARY WITH CHLOROPHYLL-A CONCENTRATIONS GREATER THAN STATE CRITERIA

Monitoring Objective

The objective of this indicator is to track the spatial extent of elevated chlorophyll-a concentrations in the estuary. Chlorophyll-a is one symptom of nutrient enrichment and eutrophication. Increasing nutrient loads to the estuary may result in increasing areas of the estuary with elevated chlorophyll-a concentrations. In the DES §305(b) water quality assessments, chlorophyll-a concentrations greater than 20 ug/L are considered to impair swimming use in estuaries. This indicator answers the following monitoring question:

Do any surface waters exhibit chlorophyll-a levels that do not support swimming standards?

Measurable Goal

The goal for this indicator is for 0% of estuarine waters to be listed in State §305(b) reports as impaired for swimming due to elevated chlorophyll-a concentrations (i.e., >20 ug/L).

Data Analysis and Statistical Methods

In 2002-2003, the University of New Hampshire measured chlorophyll-a in water samples from 68 stations in the NHEP study area as part of the National Coastal Assessment. The stations were randomly assigned and spread throughout the estuaries following the probability-based monitoring procedures of the EPA's Environmental Monitoring and Assessment Program. The objective of a probability based monitoring program is to remove bias from the station locations so that the results can be used to draw conclusions about the entire study area.

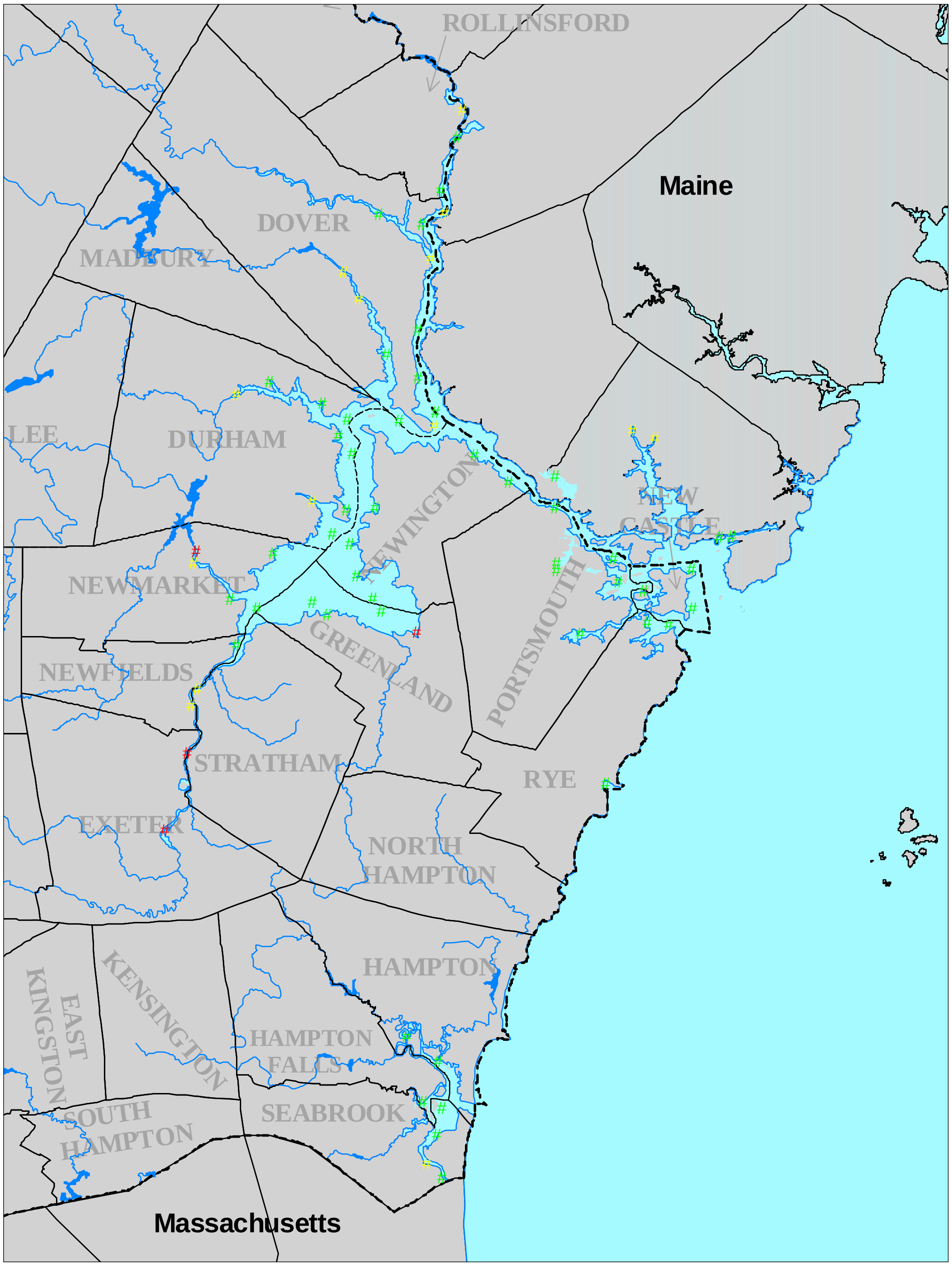
In effect, a probabilistic monitoring program is a "poll" of water quality the estuary. In a typical public opinion poll, a subset of the population is chosen at random and then asked questions about a topic. The responses of this group are taken to be representative of the overall public opinion within a known margin of error. The same general process was followed for the probabilistic monitoring program in NH's estuaries. Out of the all the possible sampling locations in the estuaries, a subset of stations were chosen randomly. Since the stations were chosen at random, it was assumed that the water quality at the chosen stations was representative of water quality in the entire estuary. A margin of error was assigned to the results when they were extrapolated to the entire estuary.

The chlorophyll-a results from all the stations were combined into a cumulative distribution function using the Horvitz-Thompson Estimator Method for a known subpopulation size (EPA, 1996). The cumulative distribution function was stratified into different categories according to the chlorophyll-a concentration: <5, >5 and <20, and >20 ug/L. Ninety-fifth percentile confidence limits on the estimated percentages were calculated using a binomial model. These confidence limits were used to test the hypothesis that the estimated values were significantly different from zero.

Results

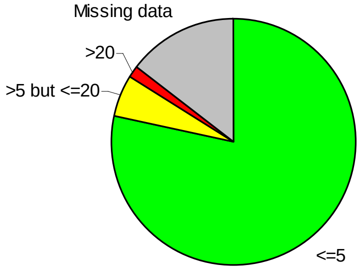
The distribution of chlorophyll-a concentrations during the summer season are shown on Figure 52. The majority of the estuary (78.4%) had chlorophyll-a concentrations less than 5 ug/L. The chlorophyll-a concentrations were greater than 20 ug/L in only 1.6% of the estuary. The uncertainty in this estimate was +/-2.8%, which means that the result is not statistically different from zero. Therefore, the NHEP goal to have zero percent of the estuary with elevated chlorophyll-a concentrations is being met.

Figure 52: Distribution of chlorophyll-a in NH's estuaries



Chlorophyll-a (ug/L)

Range	% of Estuarine Area	Error (+/-)
<=5	78.4	9.1
>5 but <=20	5.5	5.0
>20	1.6	2.8
Missing data	14.6	



WATER QUALITY INDICATORS MISSING FROM THIS REPORT

Several of the water quality indicators from the NHEP Monitoring Plan (NHEP, 2004) were not included in this report. The main reason for these omissions was insufficient data because of delays at EPA contract laboratories for the National Coastal Assessment. Table 19 contains a list of the missing indicators.

Table 19: Water quality indicators that are missing from this report

INDICATOR	REASON FOR ABSENCE
BAC8 – Bacteria load from wastewater treatment plants	All of the wastewater treatment facilities that discharge directly to estuarine waters renewed their permits and changed their bacteria indicators in the past 5 years. Therefore, none of the facilities have a sufficiently long record of bacteria discharges to support trend analysis.
TOX8: Finfish and lobster edible tissue concentrations relative to risk based standards.	Edible tissue samples were collected in 2004 as part of the National Coastal Assessment. The samples were shipped to EPA for processing and analysis. As of the date of this report, EPA has not released the results from these samples.
TOX4: Trends in finfish tissue contaminant concentrations	This indicator is based on edible tissue concentrations. These data are not available. See the explanation for TOX8.
TOX2: Public health risks from toxic contaminants in shellfish tissue	The NHDES Bureau of Environmental and Occupational Health must make any determination of public health risks. NHEP will request an evaluation of public health risk after data on toxic contaminants in the edible tissue of finfish and lobster are received from EPA. See explanation for TOX8.
TOX6 – Trends in sediment contaminant concentrations	Five stations in the estuary have been monitored five times in between 2000 and 2005. The samples were shipped to EPA for processing and analysis. As of the date of this report, the results from only two of the sampling events are available. Trend analysis cannot be performed until all five years of data are available.

CONCLUSIONS

Of the 17 NHEP water quality indicators in this report, six indicated environmental goals are being met, ten indicated environmental goals were not being met, and one could not be evaluated due to lack of a current goal. In general, the majority of the toxic contaminant indicators were meeting their goals, while the majority of the bacteria and nutrient indicators were not. Cross-cutting observations relevant to NHEP management objectives are summarized below and in Table 20, Table 21and Table 22.

- Shellfish harvesting opportunities are still restricted due to bacteria concentrations in the estuary, particularly after rain storms. Dry-weather bacteria concentrations have decreased over the past 17 years. However, the concentrations have remained relatively constant for the past decade. Trend data are only available for a handful of stations during dry weather and, therefore, should not be considered representative of all areas of the estuary.
- The number of advisories at tidal and freshwater beaches in the coastal watershed is increasing. Several more years of data are needed to determine if the increasing trends are the result of new protocols adopted by the DES Beach Program in 2002. In contrast, a probabilistic survey of non-beach tidal waters does not indicate significant violations of the enterococci water quality standard in the estuary.
- The number of advisories issued for freshwater bathing beaches in the coastal watershed continues to increase. Local bacteria sources, including bathers themselves, are presumed to be the cause of the impairments.
- Available data on shellfish tissue (mussels, clams, oysters) show that the concentrations of toxic contaminants in the tissue are below FDA guidance values. All of the statistically significant trends for toxic contaminants in shellfish tissue are decreasing. However, there were no new data available for toxic contaminants in the edible tissues of finfish and lobster. Therefore, the DES fish consumption advisories for ocean finfish and lobster tomalley due to mercury, PCB and dioxin contamination (http://des.nh.gov/ARD/EHP/HRA/index.html) remain in effect.
- A small percentage (12%) of the sediments of the estuary contains toxic contaminants at concentrations that might affect the benthic community; however, impacts to the benthos have been observed in only 0.3% of the estuary.
- Comparisons to historical data show that dissolved inorganic nitrogen concentrations have increased in Great Bay by 59% in the past 25 years. During the same period, suspended solids concentrations increased by 81%, although there are some questions about the appropriateness of the comparison. Trends over the past 15 years since the current monitoring program began are equivocal, with increasing trends evident at only a few stations for a few parameters. Any increase in nitrogen concentrations has apparently not resulted in increased phytoplankton blooms. The only increasing trend for chlorophyll-a was observed at a station with very low concentrations already. Moreover, a probabilistic survey of the estuary in 2002-2003 found only 1.6% of the estuary to have chlorophyll-a concentrations greater than 20 ug/L. The total nitrogen load to the estuary in 2002-2004 was determined to be between 1,005 and 1,097 tons/year. This estimate is 30% lower than modeled values from the USGS SPARROW model.

- Dissolved oxygen concentrations consistently fail to meet the State water quality standards in the tidal tributaries but not in the larger embayments.
- The biological oxygen demand loading from several coastal wastewater treatment plants is increasing. However, without a water quality model, it is not possible to determine the effect of the increased BOD loads on dissolved oxygen concentrations in the estuary.

RECOMMENDED CHANGES TO THE NHEP MONITORING PLAN

Analyzing the data for this report brought to light some problems with the NHEP Monitoring Plan. The following changes would save the NHEP resources and improve the quality of the indicators.

- Bacteria loads from WWTFs (BAC8) could not be reported because all of the WWTFs recently changed permit monitoring requirements. It is expected that each time the WWTFs update their permits, the monitoring requirements will change. Therefore, it will not be possible to use NPDES permit reporting data to track trends in bacteria loads over the long term. This indicator does not report on any specific NHEP Management Objective and should be removed from the NHEP Monitoring Plan.
- Indicator NUT7 was intended to report on biological oxygen demand loading from WWTFs and tributaries. High quality information is available for BOD loads from WWTFs. However, the BOD concentration in the tributary samples was consistently below the analytical method detection level. Tributary loads could not be calculated as a result. The cost per sample for BOD analysis is already $35/sample. Changing laboratories to use a more sensitive method would increase the cost even more. Approximately $3,500 per year could be saved if BOD was removed from the tributary sampling and the indicator changed to only track BOD loads from WWTFs. The NHEP Monitoring Plan should be changed accordingly.
- In order to update the nitrogen loading indicator (NUT1), total nitrogen measurements from WWTF effluent will need to be taken every three years. The samples should be taken monthly for at least 8 months of the year at all of the WWTFs (in New Hampshire and Maine) which discharge to the Great Bay or Piscataqua River estuaries.
- The accuracy of the nitrogen loading indicator (NUT1) would be improved with monthly sampling for total nitrogen on the Great Works River in South Berwick, Maine. The Great Works River discharges to the Salmon Falls River downstream of the tidal dam. Therefore, nitrogen loads from this watershed are not captured by the monthly DES monitoring at the tidal dam. The USGS does not have a stream gage on this river. However, as of 2005, there was an active group of volunteers, the Great Works River Watershed Coalition, who monitored the river water quality for dissolved oxygen, phosphorus and *E. coli*. The samples should be collected in 2006-2007 so

Table 20: NHEP water quality goal 1 and its associated objectives, monitoring questions and indicators

Water Quality Goal #1:
Ensure that NH's estuarine waters and tributaries meet standards for pathogenic bacteria including fecal coliform, E. coli, and Enterococci

Management Objective	Monitoring Question	Environmental Indicator	Indicator Type	Goal	Goal Met?	Overall Conclusion
WQ1-1: Achieve water quality in Great Bay and Hampton Harbor that meets shellfish harvest standards by 2010.	Do NH tidal waters meet fecal coliform standards of the National Shellfish Sanitation Program for 'approved' shellfish areas?	BAC1: Acre-days of shellfish harvesting opportunities in estuarine waters	Environmental Indicator	100% of possible acre-days	No. 2004 acre days: 63% (average of all growing areas)	Shellfish harvesting opportunities are still restricted due to bacteria concentrations in the estuary, particularly after rain storms. Dry-weather bacteria concentrations have decreased over the past 17 years. However, the concentrations have remained relatively constant for the past decade. Trend data are only available for a handful of stations during dry weather and, therefore, should not be considered representative of all areas of the estuary.
	Have fecal coliform, enterococci, and *E. coli* levels changed significantly over time?	BAC2: Trends in dry weather bacterial indicators concentrations	Environmental Indicator	Significantly decreasing trends at tributary stations	Yes. Decreasing trends observed for tributary stations	
	Has dry weather bacterial contamination changed significantly over time?					
	Has wet weather bacterial contamination changed significantly over time?	Trends in wet weather bacterial indicators concentrations	Research Indicator	TBD	NA	
WQ1-2: Minimize beach closures due to failure to meet water quality standards for tidal waters.	Do NH tidal waters, including swimming beaches, meet the state enterococci standards?	BAC4: Tidal bathing beach postings	Environmental Indicator	0 postings per year	No. One posting in 2005	The number of advisories at tidal and freshwater beaches in the coastal watershed is increasing. Several more years of data are needed to determine if the increasing trends are the result of new protocols adopted by the DES Beach Program in 2002. In contrast, a probabilistic survey of non-beach tidal waters does not indicate significant violations of the enterococci water quality standard in the estuary.
		BAC6: Violations of enterococci standard in estuarine waters	Environmental Indicator	0% of estuarine area in violation of standard	Yes.	
	Are bacteria concentrations at tidal bathing beaches changing over time?	BAC5: Trends in bacteria concentrations at tidal bathing beaches	Environmental Indicator	No increasing trends at any beaches	No. One beach with an increasing trend	
WQ1-3: Increase water bodies in the NH coastal watershed designated 'swimmable' by achieving state water quality standards.	Do NH freshwater beaches in the coastal watershed meet the state *E. coli* standards?	BAC7: Freshwater bathing beach postings	Environmental Indicator	0 postings per year	No. 13 postings in 2005	The number of advisories issued for freshwater bathing beaches in the coastal watershed continues to increase. Local bacteria sources, including bathers themselves, are presumed to be the cause of the impairments.
	Do NH surface freshwaters meet the state *E. coli* standards?	None. The TAC determined that the monitoring needed to accurately answer this question was not cost-	NA	NA	NA	

Table 21: NHEP water quality goal 2 and its associated objectives, monitoring questions and indicators

Water Quality Goal #2:

Ensure that New Hampshire's estuarine waters, tributaries, sediments, and edible portions of fish, shellfish, other aquatic life, and wildlife will meet standards for priority contaminants such as metals, PCBs, PAHs, and oil and grease.

Management Objective	Monitoring Question	Environmental Indicator	Indicator Type	Goal	Goal Met?	Overall Conclusion for Management Objective
WQ2-1A: Reduce toxic contaminants levels in **indicator species** so that no levels persist or accumulate according to FDA guideline levels.	Are shellfish, lobsters, finfish, and other seafood species from NH coastal waters fit for human consumption?	TOX1: Shellfish tissue concentrations relative to FDA standards.	Environmental Indicator	0% of stations with concentrations greater than FDA standards	Yes	Available data on shellfish tissue (mussels, clams, oysters) show that the concentrations of toxic contaminants in the tissue are below FDA guidance values. All of the statistically significant trends for toxic contaminants in shellfish tissue are decreasing. However, there were no new data available for toxic contaminants in the edible tissues of finfish and lobster. Therefore, the DES fish consumption advisories for ocean finfish and lobster tomalley due to mercury, PCB and dioxin contamination (http://des.nh.gov/ARD/EHP/HRA/index.html) remain in effect.
		TOX8: Finfish and lobster edible tissue concentrations relative to risk-based standards.	Environmental Indicator	Average concentrations of Hg and PCBs in target species less than risk-based standards	NA - Data not available	
		TOX2: Public health risks from toxic contaminants in fish and shellfish tissue	Supporting Variable	NA	NA - Data not available	
	Have the concentrations of toxic contaminants in estuarine biota significantly changed over time?	TOX3: Trends in shellfish tissue contaminant concentrations	Environmental Indicator	No increasing trends for any toxic contaminants at any locations	Yes	
		TOX4: Trends in finfish and lobster tissue contaminant concentrations	Environmental Indicator	No increasing trends for any toxic contaminants in target species	NA - Data not available	
WQ2-1B: Reduce toxic contaminants levels in water so that no levels persist or accumulate according to State WQS in Ws 1700.	Do NH tidal waters contain heavy metals, PCBs, PAHs, chlorinated pesticides, and other toxic contaminants that are harmful to humans, animals, plant, and other aquatic life?	Toxic contaminants in stormwater runoff and receiving waters	Research Indicator	NA	NA	There are no data available to report on this management objective.
WQ2-1C: Reduce toxic contaminants levels in **sediment** so that no levels persist or accumulate according to ER-M levels.	Do NH tidal sediments contain heavy metals, PCBs, PAHs, chlorinated pesticides, and other toxic contaminants that are harmful to humans, animals, plant, and other aquatic life?	TOX5: Sediment contaminant concentrations relative to NOAA guidelines	Environmental Indicator	0% of the estuaries with sediment concentrations greater than NOAA ERM values or five times NOAA ERL values	No. 12% of estuarine sediments above screening values.	A small percentage (12%) of the sediments of the estuary contain toxic contaminants at concentrations that might affect the benthic community; however, impacts to the benthos have been observed in only 0.3% of the estuary.
	Have the concentrations of toxic contaminants in sediment significantly changed over time?	TOX6: Trends in sediment contaminant concentrations	Environmental Indicator	No increasing trends for any toxic contaminants at any locations	NA - Data not available	
	Is there evidence of toxic effects of contaminants in estuarine biota?	TOX7: Benthic community impacts due to sediment contamination	Environmental Indicator	0% of estuarine area with impacts to the benthic community due to sediment contamination.	Yes	

Table 22: NHEP water quality goal 3 and its associated objectives, monitoring questions and indicators

Water Quality Goal #3:

Ensure that NH's estuarine waters and tributaries will meet standards for organic and inorganic nutrients, especially nitrogen, phosphorus, chlorophyll-a, dissolved oxygen, and biological oxygen demand.

Management Objective	Monitoring Question	Environmental Indicator	Indicator Type	Goal	Goal Met?	Overall Conclusion
WQ3-1: Maintain inorganic nutrients, nitrogen, phosphorus, and chlorophyll-a in Great Bay, Hampton Harbor, and their tributaries at 1998-2000 baseline levels. WQ3-2: Maintain organic nutrients in Great Bay, Hampton Harbor, and their tributaries at 1994-1996 baseline levels.	Has the total nitrogen load to Great Bay significantly changed over time?	NUT1: Annual load of nitrogen to Great Bay from WWTF and watershed tributaries	Environmental Indicator	WWTF and tributary loads to be less than or equal to 2002-2004 loading estimates (900 tons/yr)	NA - Goal established in this report.	Comparisons to historical data show that dissolved inorganic nitrogen concentrations have increased in Great Bay by 59% in the past 25 years. During the same period, suspended solids concentrations increased by 81%, although there are some questions about the appropriateness of the comparison. Trends over the past 15 years since the current monitoring program began are equivocal, with increasing trends evident at only a few stations for a few parameters. Any increase in nitrogen concentrations has apparently not resulted in increased phytoplankton blooms. The only increasing trend for chlorophyll-a was observed at a station with very low concentrations already. Moreover, a probabilistic survey of the estuary in 2002-2003 found only 1.6% of the estuary to have chlorophyll-a concentrations greater than 20 ug/L. The total nitrogen load to the estuary in 2002-2004 was determined to be between 1,005 and 1,097 tons/year. This estimate is 30% lower than modeled values from the USGS SPARROW model.
	Have levels of nitrogen and phosphorus significantly changed over time?	NUT2: Trends in estuarine nutrient concentrations	Environmental Indicator	No increasing trends for any nutrients at any location	No. Increasing DIN and NO23 concentrations observed in the Squamscott River	
		Eelgrass Nutrient Pollution Index (NPI)	Research Indicator	TBD	NA	
	Do any surface freshwaters exhibit chlorophyll-a levels that do not support swimming standards	NUT8: Percent of estuary with Chlorophyll-a Concentrations greater than State Criteria	Environmental Indicator	0% of estuarine waters listed as impaired for swimming due to chlorophyll-a in 305(b) reports.	Yes	
	Have surface tidal or freshwaters shown a significant change in turbidity over time?	NUT3: Trends in estuarine particulate concentrations	Environmental Indicator	No increasing trends for any particulates at any location	No. Increasing trends for TSS and chlorophyll-a observed.	
	Have levels of phytoplankton (chlorophyll-a) in NH waters changed significantly over time?					
	Is there evidence of proliferation of nuisance species associated with elevated nutrient loading?	Distribution of nuisance macroalgae	Research Indicator	N/A	NA	
WQ3- 3: Maintain dissolved oxygen levels at: >4 mg/L for tidal rivers; >6 mg/L for embayments (Great Bay and Little Bay); >7 mg/L for oceanic areas (Hampton Harbor and Atlantic Coast).	Do any surface tidal or freshwaters contain less than the state standard for dissolved oxygen? For what period of time?	NUT5: Exceedences of the instantaneous dissolved oxygen standard in tidal waters	Environmental Indicator	0 days/year with violations of standard	No. 85 days in 2004	Dissolved oxygen concentrations consistently fail to meet the State water quality standards in the tidal tributaries but not in the larger embayments.
		NUT6: Exceedences of the daily average dissolved oxygen standard in tidal waters	Environmental Indicator	0 days/year with violations of standard	No. 52 days in 2004.	
WQ3-4: Maintain NPDES permit levels for BOD at wastewater facilities in the NH coastal watershed.	Do any surface tidal or freshwaters show a significant change in biological oxygen demand?	NUT7: Trends in BOD loading to Great Bay	Environmental Indicator	No signficantly increasing trends in BOD loads from WWTF or tributaries	No. Increasing trends at three WWTFs	The biological oxygen demand loading from several coastal wastewater treatment plants is increasing. However, without a water quality model, it is not possible to determine the effect of the increased BOD loads on dissolved oxygen concentrations in the estuary.

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