Improving Methods And Indicators For Evaluating Coastal Water Eutrophication:

A Pilot Study in the Gulf of Maine

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Improving Methods And Indicators For Evaluating Coastal Water Eutrophication:

A Pilot Study in the Gulf of Maine

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Coastal and Estuarine
Environmental Technology

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Kennebec/Androscoggin River

The Kennebec Androscoggin Bay is made up of a narrow, shallow estuary consisting of the Kennebec River and Androscoggin River. Freshwater inflow from both rivers dominates this estuary and is the largest source of freshwater to Maine estuaries. Circulation is affected by strong tidal and non-tidal currents. Vertical mixing of salinity occurs in this estuary. The tidal range is 1.95 m near the city of Bath (NOAA, 1997).

Data availability

There were not enough available water quality data for the ASSETS application for the Kennebec and Androscoggin Rivers. However, what data were available came from the University of Maine's Department of Oceanography (Mayer, 1996). The data cover an average of eight stations per month for September 1993, February 1994, and May-August 1994. For Chl a there were a total of 168 samples for all months and years of available data. There were no available data for DO for any of the stations.

Pressure – Overall Human Influence

Kennebec Androscoggin Bay is classified as having Low susceptibility to eutrophic conditions because its flushing potential is High and its dilution potential is Moderate.

At the time of this study there was no estimate of land-based nitrogen load available for the Kennebec Androscoggin Bay area, and thus no new OHI calculation was derived. Nitrogen loading to the system was documented as Moderate in the original National Estuarine Eutrophication Assessment (NEEA) (Bricker, 1999).

OHI for the Kennebec Androscoggin Bay was Low in the early 1990s, based on the original NEEA (Bricker, 1999).

State – Overall Eutropic Condition

Insufficient data were available to make OEC calculations. More years of data are required or more samples within a given year.

OEC for the Kennebec Androscoggin Bay was Low in the early 1990s, based on the original NEEA report (Bricker, 1999).

Response – Determination of Future Ooutlook

Future trends for the Kennebec and Androscoggin Rivers are unknown at this time. DFO was not calculated or projected in the original NEEA report.

ASSETS Synthesis

No ASSETS value can be assigned to Kennebec Androscoggin Bay because of lack of data.

References

Bricker S.B., C.G. Clement, D. E. Pirhalla, S.P. Orlando, and D.R.G. Farrow. 1999. National Estuarine Eutrophication Assessment. Effects of Nutrient Enrichment in the Nation's Estuaries. NOAA, National Ocean Service, Special Projects Office and National Centers for Coastal Ocean Science, Silver Spring. MD.

Mayer, L. et al., 1996. Kennebec, Sheepscot and Damariscotta River Estuaries: Seasonal Oceanographic Data. University of Maine, Department of Oceanography Technical Report #9601.

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Casco Bay

Casco Bay, located in the northeast U.S., supports industries including shipping, petroleum transport, commercial fish and shellfish harvesting, and tourism. Maine's largest city, Portland, is located on the south-east shore of Casco Bay and is the third largest oil-handling port on the East Coast. The port of Portland supports $314 million in sales, $70 million in wages and $9 million in taxes per year from these industries (Casco Bay Plan).

Data availability

Water quality data used for the ASSETS application for the Casco Bay come from the Friends of Casco Bay (http://www.cascobay.org/) for 10 stations and represents about 1,760 monthly samples for 2001-02 for DO and 1,154 samples for Chl a. Physical and hydrologic data are from CADS (http://cads.nos.noaa.gov). Nutrient-loading estimates are from USGS SPARROW model (Smith et al., 1997). Land use is from Banner and Libby (1995).

Figure 1
Chl a and DO in Casco Bay used for ASSETS and human use assessment (http://www.cascobay.org/).

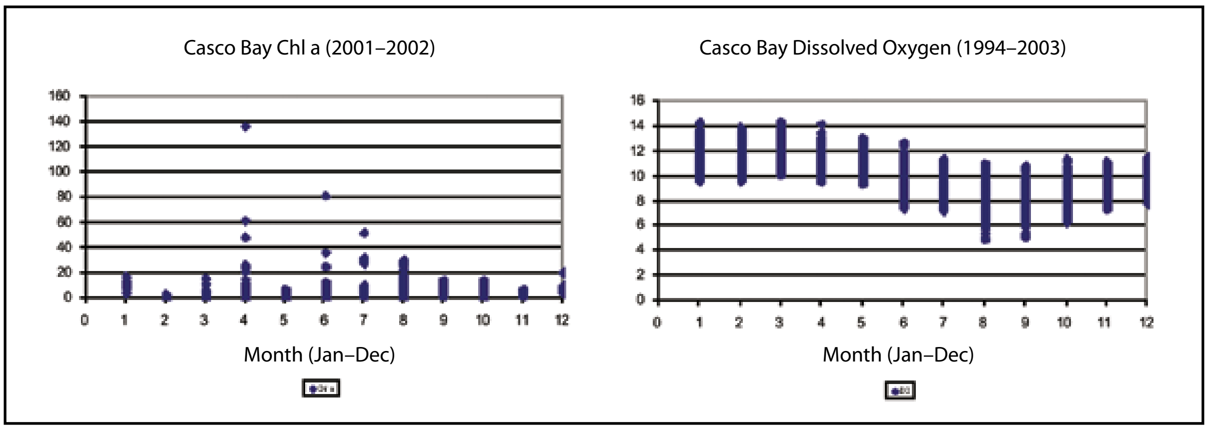
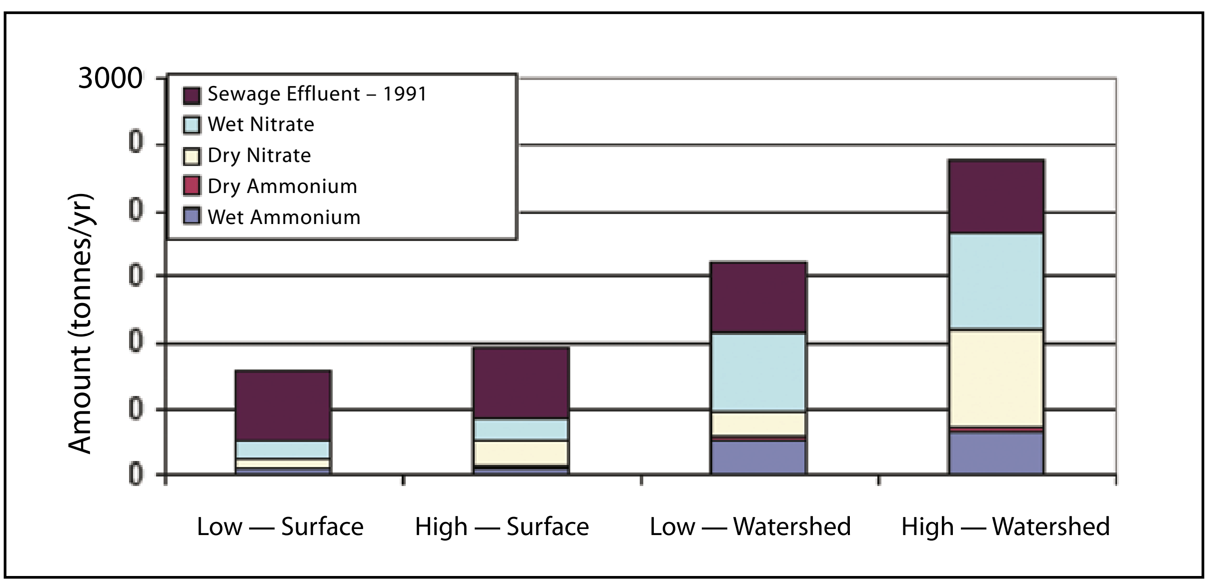


Figure 2
Summary of sewage effluent discharges, estimates of dry deposition, and wet deposition of inorganic nitrogen to Casco Bay from 1998 to 2000. Low and High signify deposition estimate ranges. "Surface" refers to the surface of Casco Bay while "watershed" refers to the entire watershed surface area. (Ryan et al. 2003)



Pressure – Overall Human Influence

Casco Bay estuary consists of Casco Bay and East Bay with several rocky islands interspersed. Freshwater to this system is limited (3.21 x10^6 m^3 d^{-1}, CADS) and enters from the east through the Presumpscot and Royal Rivers. The system is large (427 sq km) and deep (mean depth 12 m) and the mean tide height is 2.7 m (CADS). Circulation is dominated by strong tidal mixing, especially around shoal areas (Bricker et al., 1997). Limited freshwater input combined with High tidal range results in a Moderate residence time (125 days; CADS) in this well-mixed system. Casco Bay is classified as having a Low susceptibility to nutrient inputs because the system has a High capacity to both dilute and to flush nutrients.

The watershed of Casco Bay is mostly forested, with the main center of population in and surrounding the city of Portland. Like many northeast systems, the system includes extensive rocky shores (200 sq km) and boasts 758 rocky islands that provide habitat for a range of inter-tidal plant and animal species.

Total loading (dry plus wet) of inorganic nitrogen deposition to the Casco Bay surface ranged from 255 to 428 metric tons/yr (Figure 2). Over the 2551 square km watershed surface area total (dry plus wet) inorganic nitrogen deposition ranged from 1,097 to 1,842 metric tons/yr. This means atmospheric (dry plus wet) deposition of inorganic nitrogen into Casco Bay is estimated to have ranged from 225 to 1,842 metric tons/yr from 1998 to 2000 (Casco Bay Plan; Table 1). The factor of 8 range in the inorganic nitrogen atmospheric deposition total is primarily the result of uncertainty about the fraction/amount of atmospheric deposition to the watershed that reaches the Bay. Future work should be performed to refine this range by investigating and estimating the role and/or percentage of atmospheric deposition to the watershed that reaches the Bay. Total (dry plus wet) inorganic nitrogen deposition is predominately in the form of nitric acid plus nitrate (70-80%) with the remainder in the form of ammonium (20-30%).

Table 1
Load estimates to Casco Bay.

Source	1000s metric tons/yr	Timeframe
Atmospheric	0.225 to 1.842	1998 - 2000
Sewage	0.540	1991
Total	0.765 – 2.387	

Ryan et. al, 2003

Mosher (2000) reported that point-source discharges in 1991 from sewage treatment effluent introduced roughly 540 metric tons/yr of nitrogen into Casco Bay. The 1991 data were used because more recent data are lacking. Based on this information and atmospheric deposition estimates, results show that a range of 30% to 70% of the total amount of inorganic nitrogen pollution entering Casco Bay comes from atmospheric deposition. For comparison, 21% of the nitrogen pollution entering Chesapeake Bay comes from the air (e.g., U.S. Environmental Protection Agency, 2000a). Thus, atmospheric deposition is estimated to be a greater source of inorganic nitrogen input to Casco Bay (30-70%) than it is to Chesapeake Bay (21%).

The level of nitrogen load is considered Low, based on model calculations (see Bricker et al. 2003 for OHI calculation) giving a value of 0.3 using the highest of the estimates (Table 1). Low loads and Low susceptibility give an overall human influence rating of Low.

State – Overall Eutrophic Condition

Chl a concentrations vary seasonally ranging in 2001-02 from less than 0 to 136.8 micrograms/l with highest concentrations observed in the spring and summer months. The Chl a 90th percentile for Casco Bay is 10 micrograms/l, which gives a rating of Medium. Spatial coverage is High and frequency of occurrence is Periodic. The overall rating for Chl a in this system is High.

No data were found for epiphytes or macroalgae for Casco Bay and these parameters were not included in the index calculation.

The overall primary expression value for the Casco Bay is High.

DO varies seasonally from 4.9 to 14.3 mg/l but rarely goes below 5 mg/l. The 10^{th} percentile is 7.9 mg/l, which gives a rating of No Problem. There are small areas in Maquiot Bay, a part of Casco Bay, (Casco Bay Plan) that are suspected to have low-DO problems; however, there are no data available to support this suspicion. This gives an overall rating of No Problem for DO in Casco Bay.

SAV in Casco Bay at present has a very low spatial coverage, having been lost to wasting diseases in the 1940s. There have been small increases in SAV coverage in recent years (Casco Bay Plan). This variable is given a rating of Increased SAV coverage.

Several species of toxic blooms are known to occur annually in Casco Bay, including Alexandrium sp., Dinophysis sp., Prorocentrum lima, and Pseudonitzchia sp. In addition, Gymnodinium sp., and Prorecentrum micans also occur, and while they are not toxic, can cause low-DO events and smother benthic organisms when they occur in large abundance or form dense algal mats. There is usually a spring bloom and sometimes a fall bloom where Alexandrium (PSP) is involved. PSP events can occur in spring, summer, or fall, lasting for a whole season. Where Pseudonitzschia is concerned, problems always occurred in the colder months (fall and winter) (L. Bean, Maine Department of Marine Resources, personal communication).

The spatial coverage is High and the frequency of occurrence is Periodic for nuisance and toxic blooms and duration is seasonal. However, these typically originate offshore and then are advected into the estuary (L. Bean, Main Department of Marine Resources, personal communication). Thus, the rating for nuisance and toxic blooms for Casco Bay, while High, is recorded here as Low because they are not triggered by in-estuary nutrients.

The overall rating for secondary symptoms for Casco Bay is Low because there is No Problem with DO, SAV is increasing, and nuisance and toxic blooms originate offshore and are considered Low.

The final classification for State (OEC) falls within the Moderate category due to High expression values for primary symptoms and Low/No Problem expression values for secondary symptoms.

Response – Determination of Future Outlook

The expected response of this system was examined by considering future changes in nutrient loading by looking at watershed population growth, potential management measures to be implemented, and other land-use changes that will influence water quality within the Casco Bay. Watershed population growth from 1970 to 1990 was 25% and is expected to increase in the future (Casco Bay Plan Chapter 1: State of the Bay, http://www.cascobay.usm.maine.edu/Chapter1.pdf). While Casco Bay does not appear to have major nutrient-enrichment problems at present, the potential for problems will increase as population and development continue. However, the population increase is balanced by management actions that have already been implemented or proposed. Because Casco Bay was selected for inclusion in the National Estuary Program in 1990, a preliminary management plan for the Bay has been developed, and a final Comprehensive Conservation and Management Plan with recommendations for priority corrective actions to restore and maintain the estuarine resources was produced in 1995. To date, a series of implementation and demonstration projects have been undertaken. (Casco Bay Plan Chapter 1: State of the Bay http://www.cascobay.usm.maine.edu/Chapter1.pdf). These include:

- The Agricultural Stabilization and Conservation Service distributed over $200,000 in cost-share funds in Casco Bay watershed to address agricultural nonpoint source pollution.
- A public education campaign provided information on the need to restore eroding stream banks along the Pleasant River. Volunteers performed the restoration work.
- A training program for municipal officials was developed to provide information on nonpoint source pollution and best management practices.
- Administrative structures to ensure the inspection and maintenance of septic systems are being evaluated.
- A storm water management plan for a town center is under development to demonstrate storm water control planning in areas designated as growth areas under local zoning ordinances (from EPA http://www.epa.gov/ecoplaces/part2/region1/site3.html).

The planned or implemented management measures, in combination with the Low susceptibility of Casco Bay, results in a future outlook forcast of Improve High.

ASSETS Synthesis

Casco Bay is given an overall classification of Moderate, which reflects an OHI of Low, Moderate OEC, and Improve Low for future outlook (Table 2).

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Table 2
ASSETS Synthesis for Casco Bay.

<table>
<tr><th>Indices</th><th>Methods</th><th colspan="3">Parameters/ Values / EAR</th><th>Index category</th><th>ASSETS grade</th></tr>
<tr><td rowspan="3">Pressure
OHI index</td><td rowspan="2">Susceptibility</td><td>Dilutionpotential</td><td>High</td><td rowspan="2">Low
Susceptibility</td><td rowspan="3">Low</td><td rowspan="9">OHI = 5
OEC = 3
DFO = 5

Moderate</td></tr>
<tr><td>Flushingpotential</td><td>High</td></tr>
<tr><td>Nutrient inputs</td><td colspan="3">Low</td></tr>
<tr><td rowspan="5">State
OEC index</td><td rowspan="2">Primary
Symptom
Method</td><td>Chlorophyll a</td><td>High</td><td rowspan="2">High</td><td rowspan="5">Moderate</td></tr>
<tr><td>Macroalgae</td><td>No Data</td></tr>
<tr><td rowspan="3">Secondary
Symptom
Method</td><td>Dissolvedoxygen</td><td>No Problem</td><td rowspan="3">Low</td></tr>
<tr><td>Submerged
aquaticvegetation</td><td>Increase</td></tr>
<tr><td>Nuisance and
Toxic Blooms</td><td>Low</td></tr>
<tr><td>Response
DFO index</td><td>Future nutrient
pressures</td><td colspan="3">Future nutrient pressures decrease</td><td>Improve
Low</td></tr>
</table>

Saco Bay

Saco Bay is a highly stratified, saltwedge-type of estuary. Freshwater inflow is dominated by the Saco River. Salinity stratification is more pronounced during periods of high freshwater inflow. The estuary begins below the Cataract Dam on the Saco River. Tidal range is 2.62 m near the mouth of the estuary (NOAA, 1997).

Data availability

There were not enough available water quality data for the ASSETS application for the Saco River. However, what data were available came from the Maine Department of Marine Resources. These data cover an average of eight stations per month for July and August 1992, and August-September 1993. For Chl a there was a total of 75 samples for all months and years of available data. For DO there were 1,688 samples for all months and all years of available data. The limiting factor for being unable to produce an ASSETS application was the lack of a significant number of representative months in a given year.

Pressure – Overall Human Influence

Saco River is classified as having a Low susceptibility to eutrophic conditions because its flushing potential is High and its dilution potential is Moderate.

At the time of this study, there was no estimate of land-based nitrogen load available for the Saco River area. As such, no new OHI calculation was derived. Nitrogen loading to the system was documented as Low in the original National Estuarine Eutrophication Assessment (NEEA) (Bricker, 1999).

OHI for the Saco River was Low in the early 1990s, based on the original NEEA (Bricker, 1999).

State – Overall Eutrophic Condition

Insufficient data were available to make OEC calculations. More years of data or more samples within a given year are required.

OEC for the Saco River was Moderate, based on the original NEEA report (Bricker, 1999).

Response – Determination of Future Outlook

Future trends for the Saco River are unknown at this time. DFO was not calculated or projected in the original NEEA report.

ASSETS Synthesis

No ASSETS value can be assigned to Saco River due to lack of data.

References

Bricker S.B., C.G. Clement, D. E. Pirhalla, S.P. Orlando, and D.R.G. Farrow. 1999. National Estuarine Eutrophication Assessment. Effects of Nutrient Enrichment in the Nation's Estuaries. NOAA, National Ocean Service, Special Projects Office and National Centers for Coastal Ocean Science, Silver Spring, MD.

National Oceanic and Atmospheric Administration (NOAA). 1997. NOAA's Estuarine Eutrophication Survey. Volume 3: North Atlantic Region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 45 p.

Wells Bay

Wells National Estuarine Research Reserve (NERR), located in Southern Maine, is composed of two barrier-built marsh systems, the Webhannet River Estuary and the Little River Estuary (Ward, 1993). The Webhannet River watershed is approximately 35 sq km (Ward, 2004) and the watershed of Little River is almost twice the size of the Webhannet at 67.3 sq km (WNEER, 2002), for a total watershed area of 102 sq km. The Webhannet River contributes 50% and the Blacksmith Brook about 25% to the daily freshwater inflow (~49 x10^3 m^3/day; Ward, 2004). Although the discharge from Little River is not known, it is predicted to be three to four times the flow from the Webhannet River and Blacksmith Brook (WNEER website http://www.wellsreserve.org).

Wells NERR is a tide-dominated system with a mean semi-diurnal tide range of 2.6 m and spring tidal range of 2.9 m (Ward, 1993). Depth varies throughout the system, but averages about 2.5 m at the head of tide and about 4.5 m near the mouth of the estuary (Ward, 2004).

The land in Wells Bay watershed is primarily forested, with the Webhannet watershed showing the greatest development at about 20% (Table 2).

Data availability

Water quality data for the ASSETS application for Wells NERR come from the NERR system's System-wide Monitoring Program (SWMP) for Chl a, DO, and nutrients. SWMP data is controlled and housed by the NERR system's Centralized Data Management Office (CDMO) and was accessed through the web at CDMO Data Dissemination page (CDMO, 2005). Chl a data for 2002 were not available online and had to be directly requested from the Wells NERR contacts. The data represent samples from four stations in 2002, including 262 samples for Chl a and 12,781 samples for DO. The nutrient data for the calculation of overall human influence are from DIN data, also for 2002.

Pressure – Overall Human Influence

Wells NERR is classified as having a Low susceptibility to development of eutrophic conditions because it has a High capability to both flush and dilute incoming pollutant loads, with a flushing rate of 5 hours (M. Dionne, personal communication – Webhannet Morphometrics.doc).

The estimated land-based nitrogen load for Wells NERR OHI calculation was derived using the 2002 median DIN value of the head-of-tide station located in the Webhannet River and the 2002 median DIN value of the inlet station as the ocean-end member. The results show an OHI ratio of 0.074, which is in the Low category. Combined with the Low susceptibility, the OHI to Wells NERR is estimated to be Low.

State – Overall Eutrophic Condition

Chl a concentration data for all four stations and for all months sampled in 2002 range from 0.26 to 9.11 micrograms/l. The 90th percentile for all data is 4.85 micrograms/l which falls into the Low category. When analyzed by station, the Low values have High spatial coverage seen on an annual basis. As such, the Chl a expression value is 0.25, or Low.

There were no available data for macroalgal abundance.

The primary symptoms in Wells NERR are Low, based on Chl a only, because there are no data for macroalgal abundance.

DO concentration data for the four stations for all months in 2002 ranged from 2.2 to 16.7 mg/l. The 10th percentile value for all data is 5.6 mg/l, which falls into the category of No Problem. No occurrences of hypoxia or anoxia were observed, and the expression value is 0, or No Problem.

There is no SAV information for Wells Bay.

PSP (paralytic shellfish poison toxin) was detected at an average of approximately 50 micrograms of toxin per 100 grams of shellfish tissue from April to June of 2002 (Bean, 2004, unpublished). The duration of the toxic bloom is Months and the frequency is Periodic, giving a rating for nuisance and toxic blooms or HABs as a Problem. However, it is likely that these blooms begin offshore and advect into the system, and therefore they are not included in the assessment formulation.

The secondary-symptom indicators in Wells NERR are Low, despite the occurrence of toxic blooms.

The overall eutrophic condition for Wells NERR is Low, due to the Low primary and Low secondary-symptom expression.

Table 3
Land use in Wellls Bay watershed (as percent; WNERR,2002).

	Webhannet River	Merriland River	Branch Brook	Little River
Wetlands	0.3	2.1	0.2	1.3
Fresh Water	3.4	0.2	0.1	0.3
Tidal Marsh	10.2	0	0.2	0.9
Beach	1.1	0	0	0.1
Total water + wetland	15	2.3	0.5	2.6
Hardwood, mix	22.1	36	42.6	38.1
softwood	40.1	50.1	40.4	45.8
> 30% harvested	1.5	0	0	0
Total woodland	63.7	86.1	83	83.9
Total agriculture (Hay, pasture, mowed)	2.8	5.8	10.6	7.9
Developed, low density	6.2	4.4	2.6	3.5
Developed, high density	10.1	0	0	0
Commercial	2	0.1	2.5	1.1
Sand & Gravel pit	0.1	1.3	0.8	1.1
Dump	0.2	0	0	0
Total developed land	18.6	5.8	5.9	5.7

Table 4
ASSETS Synthesis for Wells Bay.

<table>
<tr><th>Indices</th><th>Methods</th><th colspan="3">Parameters/ Values / EAR</th><th>Index category</th><th>ASSETS grade</th></tr>
<tr><td rowspan="3">Pressure
OHI index</td><td rowspan="2">Susceptibility</td><td>Dilutionpotential</td><td>High</td><td rowspan="2">Low
Susceptibility</td><td rowspan="3">Low</td><td rowspan="9">OHI = 5
OEC = 5
DFO = 2

Good</td></tr>
<tr><td>Flushingpotential</td><td>High</td></tr>
<tr><td>Nutrient inputs</td><td colspan="3">Low</td></tr>
<tr><td rowspan="5">State
OEC index</td><td rowspan="2">Primary
Symptom
Method</td><td>Chlorophyll a</td><td>Low</td><td rowspan="2">Low</td><td rowspan="5">Low</td></tr>
<tr><td>Macroalgae</td><td>No Data</td></tr>
<tr><td rowspan="3">Secondary
Symptom
Method</td><td>Dissolvedoxygen</td><td>No Problem</td><td rowspan="3">Low</td></tr>
<tr><td>Submerged
aquaticvegetation</td><td>N Data</td></tr>
<tr><td>Nuisance and
Toxic Blooms</td><td>Low</td></tr>
<tr><td>Response
DFO index</td><td>Future nutrient
pressures</td><td colspan="3">Increase in nutrient loading in the future</td><td>WL</td></tr>
</table>

Response – Determination of Future Outlook

Land use in the Merriland, Branch Brook, and Little Mouth Rivers is mostly undeveloped, with an approximate 83% forest coverage (WNERR, 2002; Table 2). However, the whole region has been experiencing an increase in development pressure over the past few years. In 1991, only about 6% of the watershed was developed, but between 1990 and 2000 the Webhannet River watershed had an increase in new housing growth of about 50% (WNERR, 2003). This trend in development points to increases in land-based nitrogen inputs to the system. Management practices overall for the region are lax, allowing development of the shoreland zone to occur with virtually no enforcement of the laws pertaining to vegetated shoreland buffers. Positive management practices in the region include government ownership of land for preservation purposes, continued monitoring of multiple water quality variables, and identification and remediation of probable problem areas. Management has had some successes, notably the reopening of clam beds in 1996 after a 10-year closure. As such, the determination of future outlook for Wells NERR is Worsen Low, because of an increase in nutrient loading with Low susceptibility.

ASSETS Synthesis

The combination of Low overall human influence, Moderate High overall eutrophic conditions, and Worsen Low for future outlook forecast gives an ASSETS synthesis classification of Moderate (Table 3).

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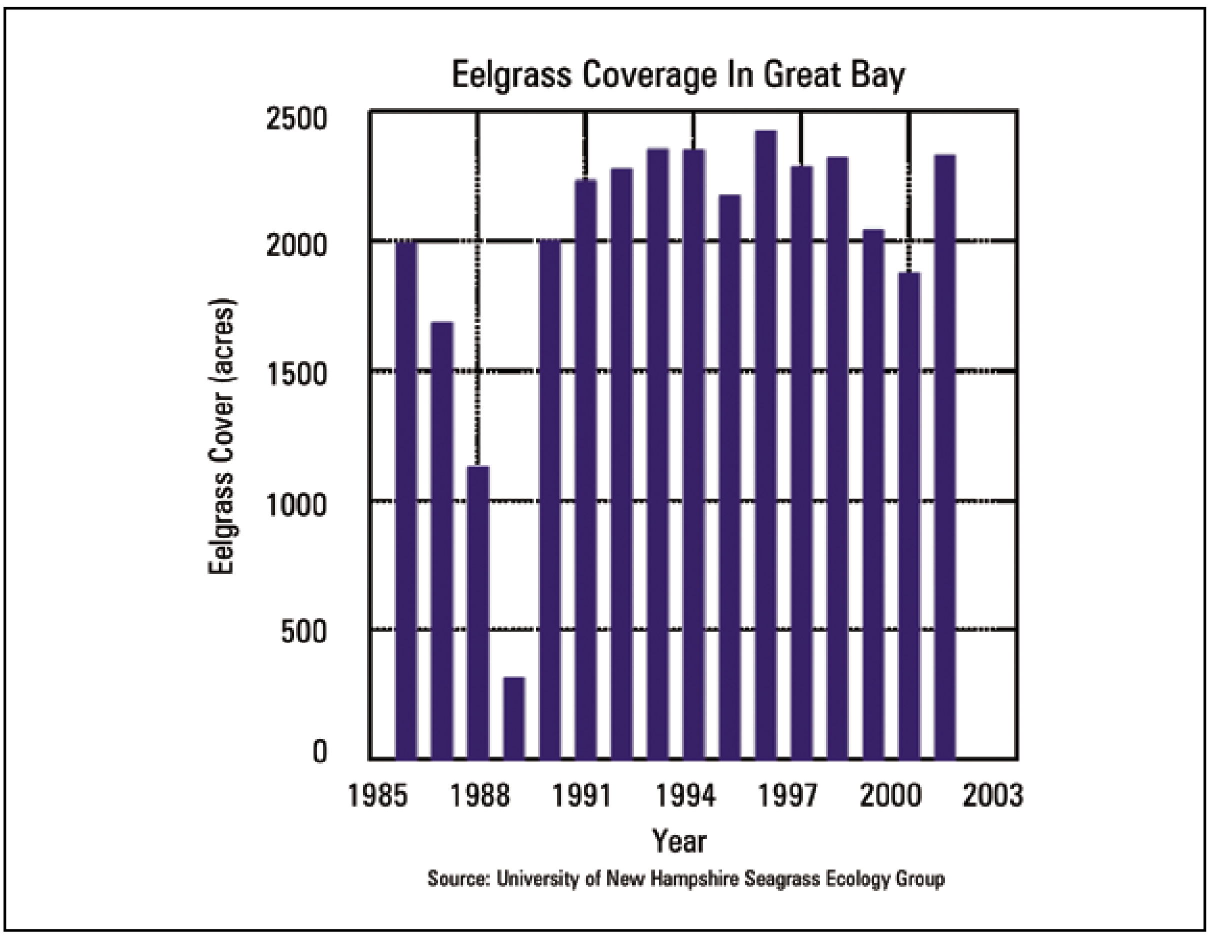
Great Bay

Great Bay is a relatively small estuary of 53.9 sq km, located between New Hampshire and Maine (NOAA, 1997). The estuary itself is tidally dominated and composed of the Piscataqua River, Little Bay and Great Bay areas. Seven major rivers as well as several small creeks and their tributaries also drain into the Bay. Within the Great Bay estuary is the Great Bay National Estuarine Research Reserve (NERR) which is composed of 21.4 sq km of tidal waters and mudflats, as well as about 77.2 km of shoreline (GBNERR, 2005). The Great Bay NERR has five component stations – Adams Point/Crommet Creek, Lubberland Creek, Squamscott River, Wilcox Point, and Sandy Point – as well as stations in the Lamprey and Oyster Rivers. Along with these stations, there is also a coast lab inlet station for which data are collected.

Data availability

Water quality data for the ASSETS application for Great Bay came from the NERR system's System-wide Monitoring Program (SWMP) for Chl a, DO, and nutrients. SWMP data are controlled and housed by the NERR system's Centralized Data Management Office (CDMO) and was accessed through the web at CDMO Data Dissemination page (CDMO, 2005). Data for the additional coast lab inlet station were acquired via direct request to the University of New Hampshire's (UNH) Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET). The data represent samples from three stations in 2002 representing 645 samples for Chl a and samples from five stations in 2002 that include 36,156 samples for DO. The nutrient data for the calculation of overall human influence come from DIN data, also for 2002.

Figure 3
Changes in eelgrass coverage in Great Bay. (NHEP, 2003).



Pressure – Overall Human Influence

Great Bay is classified as having a Moderate susceptibility to eutrophic conditions because its flushing potential is High and its dilution potential is Low.

The estimated land-based nitrogen load for the Great Bay OHI calculation was derived using the 2002 median DIN value of the head-of-tide station (a weighted average of the Lamprey and Oyster River stations for 2002) and the 2002 median DIN value of the coast lab inlet station as the ocean-end member. The results show an OHI ratio of 0.131, which is in the Low category. Combined with the Moderate susceptibility, the overall human influence to Great Bay is estimated to be Low.

State – Overall Eutrophic Condition

Chl a concentration for three stations and all months sampled in 2002 ranged from 0.581 to 28.756 micrograms/l. The 90th percentile for all data is 14.138 micrograms/l, which falls into the Medium category. When analyzed by station, the Medium values have High spatial coverage seen on an annual basis. As such, the Chl a expression value is 1, or High.

There were no available data for macroalgal abundance.

The primary symptoms in Great Bay are High, based on Chl a. There are no data for macroalgal abundance.

DO concentration data for five stations for all months in 2002 ranged from 1.2 to 19.6 mg/l. The 10th percentile value for all data is 5.5 mg/l, which falls into the category of No Problem. Fifteen occurrences of hypoxia were recorded, and no anoxia was observed. As such, DO has an expression value of 0, or No Problem.

Eelgrass coverage for Great Bay increased from approximately 1,800 acres in 2000 to approximately 2,300 acres in 2001. In 2001, there was an increase in SAV coverage of approximately 500 acres (NHEP, 2003; Figure 3).

There were no available HAB data for Great Bay.

The secondary symptom indicators in Great Bay are Low because of the DO indicator.

The overall eutrophic condition for Great Bay is Moderate due to the High primary-symptom and Low secondary-symptom expression.

Response – Determination of Future Ooutlook

Land use in the Great Bay drainage area has been changing over the past 10 years. According to Trowbridge (2003), the percent of impervious surfaces for the Great Bay alone increased 46.4% between 1990 and 2000 (Fig. 4). Most of the major river systems draining into Great Bay, such as the Lamprey, Oyster, and Squamscott Rivers, showed percent increases in impervious surfaces in the range of approximately 46-60%. Trowbridge (2003) also discovered a strong linear relationship between population increases and impervious surface increases. Management practices in the region are good, but it has been determined that reducing the amount of impervious surfaces in the watershed is not currently feasible (Trowbridge, 2003). As of 2002, the

Table 5
ASSETS Synthesis for Great Bay.

<table>
<tr><th>Indices</th><th>Methods</th><th colspan="3">Parameters/ Values / EAR</th><th>Index category</th><th>ASSETS grade</th></tr>
<tr><td rowspan="3">Pressure
OHI index</td><td rowspan="2">Susceptibility</td><td>Dilution potential</td><td>Low</td><td rowspan="2">Moderate Susceptibility</td><td rowspan="3">Low</td><td rowspan="9">OHI = 5
OEC = 3
DFO = 1

Moderate</td></tr>
<tr><td>Flushing potential</td><td>High</td></tr>
<tr><td>Nutrient inputs</td><td colspan="3">Low</td></tr>
<tr><td rowspan="5">State
OEC index</td><td rowspan="2">Primary Symptom Method</td><td>Chlorophyll a</td><td>High</td><td rowspan="2">High</td><td rowspan="5">Moderate</td></tr>
<tr><td>Macroalgae</td><td>?</td></tr>
<tr><td rowspan="3">Secondary Symptom Method</td><td>Dissolved oxygen</td><td>No Problem</td><td rowspan="3">Low</td></tr>
<tr><td>Submerged aquatic vegetation</td><td>Increase</td></tr>
<tr><td>Nuisance and Toxic Blooms</td><td>Low</td></tr>
<tr><td>Response
DFO index</td><td>Future nutrient pressures</td><td colspan="3">Increase in population and impervious surfaces</td><td>Worsen High</td></tr>
</table>

New Hampshire Estuaries Program (NHEP) had acquired 172.3 sq km of land in the coastal watershed for environmental protection, representing 8.4% of the total watershed area (NHEP, 2003). Their goal is to acquire a total of 15% of the total coastal watershed land area. Even with the good management practices in the region, it will be difficult to counteract the increasing population and subsequent increases in impervious surfaces. As such, the DFO for Great Bay is Worsen Low, because of an increase in population and impervious surfaces, with Moderate susceptibility.

ASSETS Synthesis

The combination of Low overall human influence, Moderate overall eutrophic conditions, and a Worsen Low forecast for future outlook gives an ASSETS synthesis classification of Moderate (Table 5).

References

Centralized Data Management Office (CDMO). 2005. National Estuarine Research Reserve (NERR) System-Wide Monitoring Program Data Dissemination website. (http://cdmo.baruch.sc.edu/data_dissemination.html, viewed 05-04-05).

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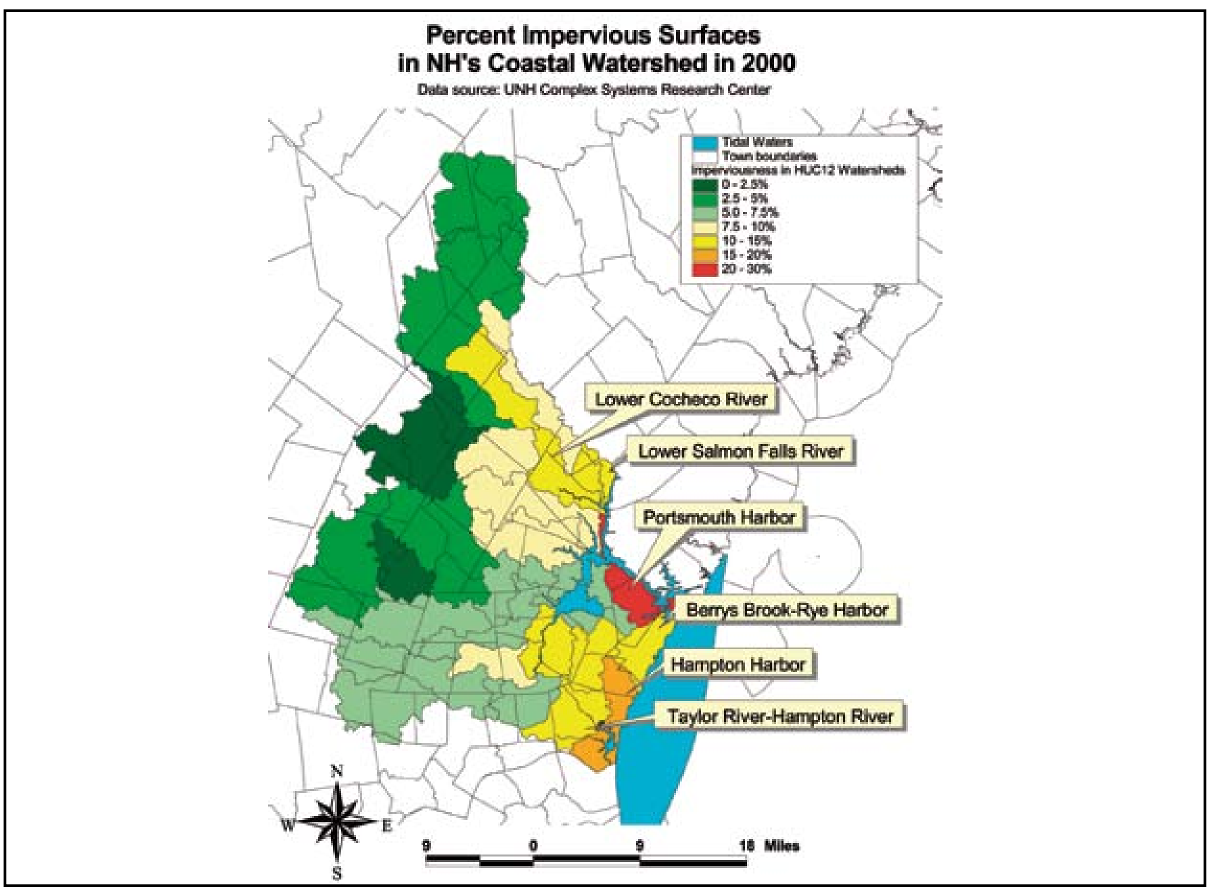
Trowbridge, Phil. 2003. Environmental Indicator Report: Land Use and Development. New Hampshire Estuaries Project, New Hampshire Department of Environmental Services.

Figure 4
Percent Impervious Surface, New Hampshire's Coastal Watershed in 2000. (Trowbridge, 2003).



Plum Island Sound

Plum Island Sound is a relatively small estuary of approximately 60 sq km with three main river drainage basins: the Parker (155 sq km), the Rowely (26 sq km), and the Ipswich (404 sq km) River basins (PIE-LTER, unpublished). Part of the watershed falls in the Greater Boston metropolitan area, and as such development pressures are high. The watershed also contains the largest saltmarsh-dominated estuary in New England (PIE-LTER, unpublished).

Data availability

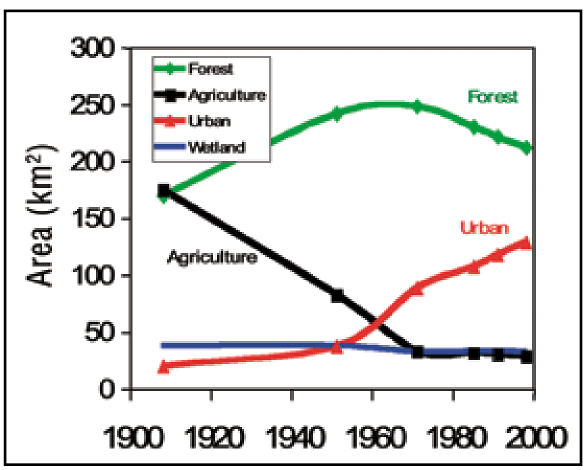
Data for the ASSETS application came from the Plum Island Sound Long-Term Ecological Research website (http://ecosystems.mbl.edu/pie/data.htm). The data cover 23 stations for Chl a and represent 274 samples for nine years of a 10-year span, 1994-2003. There are data for DO for three stations, representing 95,189 samples from 2001-02.

Pressure – Overall Human Influence

Plum Island Sound is classified as having a Moderate susceptibility to eutrophic conditions because its flushing potential is High and its dilution potential is Low.

The estimated land-based nitrogen load for the Plum Island Sound OHI calculation was derived using the 2000-01 median DIN concentration at the head-of-tide station and the 2000-01 median DIN concentration at the Audubon station as the ocean-end member. The results show an OHI ratio of 0.43, which is in the Moderate category. Combined with the Moderate susceptibility, the overall human influence to Plum Island Sound is estimated to be Moderate.

Figure 5
Changes in Land Use of Plum Island Sound from 1900-2000 (from Schneider and Pontius, 2001).



State – Overall Eutrophic Condition

Chl a concentration for 23 stations and all months (sampled in April-October of 2000-02) ranged from 0 to 114.9 micrograms/l. The 90th percentile for all data is 26.1 micrograms/l, which falls into the High category. When analyzed by station, the High values have Moderate spatial coverage when seen on an annual basis. As such, the Chl a expression value is 1, or High.

There were no available data for macroalgal abundance.

The primary symptoms in Plum Island Sound are High, based on Chl a only. There are no data for macroalgal abundance.

DO concentration data for three stations for all available months (June-November) in 2001-02 ranged from 0.24 to 15.8 mg/l. The 10th percentile value for all data is 5.43 mg/l, which falls into the category of No Problem. Multiple occurrences of hypoxia were recorded, and no anoxia was observed. As such, DO has an expression value of 0, or No Problem.

No SAV data were found.

HAB data for Plum Island Sound came from the Plum Island Estuary Long Term Ecological Research Site's (PIE-LTER) unpublished Summary of Research Findings. HABs are observed periodically for one to two weeks where the Parker River enters the estuary. As such, the expression for HABs is Moderate and gets a value of 0.5.

The secondary symptom indicators in Plum Island are Moderate, due to the HAB indicator.

The overall eutrophic condition for Plum Island Sound is Moderate High, due to the High primary and Moderate secondary symptom expression.

Response – Determination of Future Outlook

As of 1991, land use in the Plum Island Sound basin was approximately 32% urban/suburban, 7% agriculture, 15% open water and marsh, and 46% forest (PIE-LTER, unpublished; Figures 5 and 6). Population is expected to continue to increase, and thus the nutrient loads are also expected to increase. The future outlook is rated "Worsen High", based on the combination of increased nutrient loads and Moderate susceptibility.

ASSETS Synthesis

The combination of Moderate overall human influence, Moderate High overall eutrophic conditions and an outlook rating of Worsen Low gives an ASSETS synthesis classification of Poor (Table 6).

References

Plum Island Estuary Long Term Ecological Research Site (PIE-LTER), unpublished. Summary of Research Findings. National Science Foundation's (NSF) Long Term Ecological Research (LTER) Network. The Ecosystems Center at the Marine Biological Laboratory, the University of South Carolina, the Massachusetts Audubon Society, the Wells National Estuarine Research Reserve, the University of New Hampshire and Clark University. (http://ecosystems.mbl.edu/pie/ResSumm.pdf, viewed 05-05-05). Schneider, L. and J. R. G. Pontius. 2001. Modeling land-use change in the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems & Environmental 85(1-3): 83-94

Figure 6
Population growth in the Ipswich River Basin 1870—2000 (C. Hopkinson, personal communication).

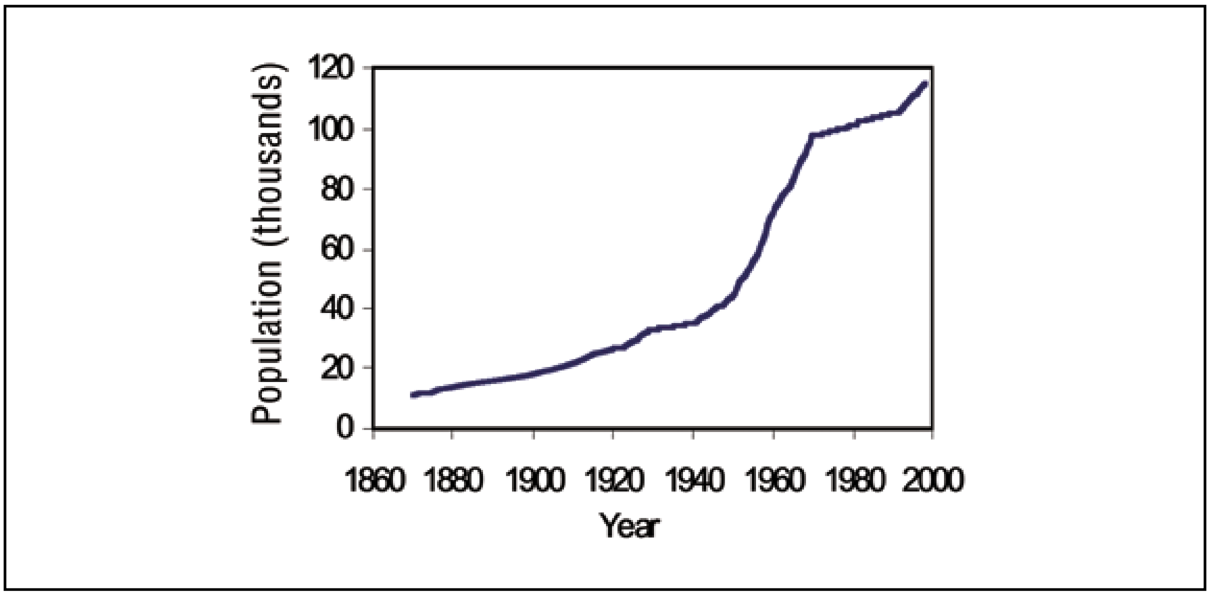


Table 6
ASSETS Synthesis for Plum Island Sound.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilutionpotential	Low	Moderate Susceptibility	Moderate	OHI = 3 OEC = 2 DFO = 1 Poor
		Flushingpotential	High			
	Nutrient inputs	Moderate				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate High	
		Macroalgae	?			
	Secondary Symptom Method	Dissolvedoxygen	No Problem	Moderate		
		Submerged aquaticvegetation	?			
		Nuisance and Toxic Blooms	Moderate			
Response DFO index	Future nutrient pressures	Increase due to population and development			Worsen High	

Boston Harbor

Boston Harbor is an urban system consisting of Boston Harbor and several smaller coastal embayments. Gulf of Maine salinities exist within the main harbor. Freshwater inflow is dominated by the Neponset River, but there are also contributions from two other rivers, the Mystic and the Charles. Salinity is vertically homogeneous throughout the Bay. Circulation is strongly affected by tidal influences and non-tidal surface currents. Tidal range is approximately 2.76 m near the mouth of Boston Harbor (Bricker et al., 1997b). It is a relatively shallow system with an average depth of about 4.6 m and is well-flushed by strong tides. Average residence time in the harbor is short, Massachusetts Bay and river waters replace the harbor water in 5 to 7 days though the channels flush more quickly and inner harbor and shoreline areas flush more slowly (Hornbrook et al., 2002).

The most notable characteristic of Boston Harbor is the recent change in the location of the sewage outfall. Sewage discharges ended in 1991, today it is landfilled.

Before July 1998, poorly treated wastewater was discharged into the harbor. Between 1998 and 2000 several improvements were made: sewage treatment in the two main plants discharging to the harbor was upgraded to secondary treatment and a new outfall was built that now transports cleaner effluent out of the harbor completely and into Massachusetts Bay. The Bay outfall became operational on September 6, 2000. Today, no treatment plants discharge directly to the Bay (Libby et al., 2003).

Noted improvements in Boston Harbor include increases in water clarity, decreases in ammonium concentration in the Harbor, decreases in indicator bacteria, decreases in Chl a, and Harbor beaches are swimmable most of the time (Rex et al., 2002).

Data availability

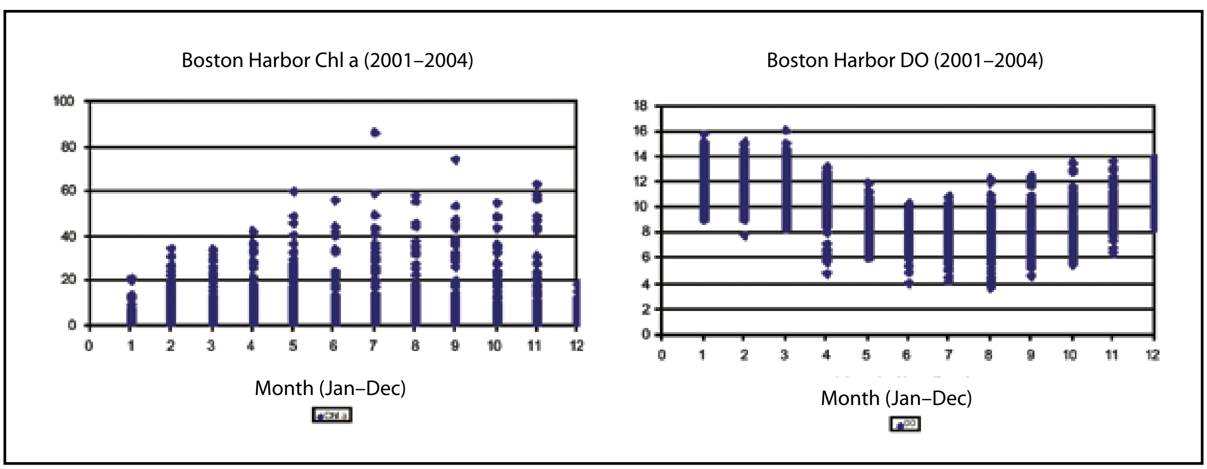
Water quality data for the ASSETS application for Boston Harbor are derived from the Environmental Monitoring and Mapping System (EM&MS), an Oracle database maintained by the Massachusetts Water Resources Authority (MWRA) Environmental Quality Department (ENQUAD) for Chl a, DO, and nutrients. The 2003 data represent samples from 23 stations with 1,142 samples for Chl a and 1,137 samples for DO (Figure 7). The nutrient data for the calculation of overall human influence are for nitrogen concentrations, specifically DIN, and are also for 2003.

Pressure – Overall Human Influence

Boston Harbor is classified as having a Moderate susceptibility to development of eutrophic symptoms because the system has Moderate capacity to both dilute and flush nutrients.

Neither the SPARROW (Smith et al., 1997; Alexander et al., 2001) nor the WATERSN (Whitall et al., 2004; Castro et al., 2003; Castro and Driscoll, 2002) model provide load estimates for Boston Harbor. For the OHI calculation, a flow weighted average of DIN concentration was used to estimate the land-based nutrient sources from the Charles, Neponset, and

Figure 7
Chl a and DO data for Boston Harbor used for ASSSETS and Human Use Assessment (MWRA).



Mystic Rivers. A station in Massachusetts Bay was used to represent the oceanic-end member. The results show an OHI ratio of 0.37, which is in the Moderate Low category. Combined with the Moderate susceptibility, the overall human influence to Boston Harbor is estimated to be Moderate.

State – Overall Eutrophic Condition

Chl a concentration data for all 23 stations and for all months sampled in 2003 range from 0.32 to 60 micrograms/l. The 90th percentile for all data is 9.38 micrograms/l, which falls into the Moderate category. Analyzed by station, the Moderate values show High spatial coverage and these concentrations are seen on an annual basis. The Chl a expression value is 1, or High.

No data or information are available for macroalgal abundance.

The primary symptoms in Boston Harbor are High, based on Chl a only, because there are no data for macroalgal abundance.

DO concentration data for the 23 stations for all months of 2003 ranged from 4.88 to 14.9 mg/l. The 10th percentile value for all data is 7.18 mg/l, which falls into the category of No Problem. No occurrences of hypoxia or anoxia were observed and the expression value is 0, or No Problem.

At present, Boston Harbor has only small areas of submerged aquatic grasses. The grasses had died out almost completely by the late 1980s because of high turbidity, viral diseases, and excessive epiphytic growth due to high nutrient levels (Hornbrook et al., 2002). Since the loss of the grass meadows in the 1980s, turbidity has not decreased to the point of regrowth of the grasses. The expression value for SAV loss is given a value of 0.25, because the losses occurred previously but the water quality is such that regrowth has not occurred.

There were no records of nuisance or toxic bloom occurrences in Boston Harbor during this time and thus this indicator receives a score of No Problem.

The secondary symptom indicators in Boston Harbor are Low due to the SAV indicator.

The overall eutrophic condition for Boston Harbor is Moderate, based on the High primary and Low secondary symptom expression.

Response – Determination of Future Outlook

Loads to Boston Harbor have decreased significantly since September 2000, when the Massachusetts Water Resources Authority transferred the wastewater discharges from the Deer Island treatment facility to Boston Harbor, 16 km offshore, for diffusion in the bottom waters of Massachusetts Bay (Figure 8). This "offshore transfer" ended the bulk of the discharges of wastewater from the City of Boston and surrounding communities to Boston Harbor (Taylor, 2004). This has led to decreases in nutrient concentrations and in summertime Chl a concentrations, as well as to increases in summertime DO concentrations (Figure 8). While the analysis here shows that Chl a is considered High, the trends noted are encouraging and the expectation is that additional improvements will be seen in the

Table 7
ASSETS Synthesis for Boston Harbor.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	Moderate	Moderate Susceptibility	Moderate	OHI = 3 OEC = 3 DFO = 4 Moderate
		Flushing potential	Moderate			
	Nutrient inputs	Moderate Low				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate	
		Macroalgae	No Data			
	Secondary Symptom Method	Dissolved oxygen	No Problem	Low		
		Submerged aquatic vegetation	Low			
		Nuisance and Toxic Blooms	No Problem			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease			Improve Low	

future (Hornbrook et al., 2002). The combination of an expected decrease in nutrient loads to Boston Harbor with Moderate susceptibility leads to a classification for determination of future outlook of Improve Low.

ASSETS Synthesis

The combination of Moderate overall human influence, Moderate overall eutrophic conditions, and Improve Low rating for future outlook gives an ASSETS synthesis classification of Moderate (Table 6).

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Figure 8
Noted changes in Boston Harbor chemical, biological and physical measures from 2000-2003 (from Taylor, 2004).

Summary of differences in Harbor water-quality between the 36-months and baseline.

VARIABLE	CHANGE DURING 36-MONTHS	
TN (umoll^{-1})	F	-10.0 (-32%)
DIN (umoll^{-1})	F	-7.0 (-59%)
DIN as % TN	F	-14 (-37%)
TP (umoll^{-1})	F	-0.58 (-28%)
DIP (umoll^{-1})	F	-0.4 (-38%)
DIP as % TP	F	-7 (-14%)
TN:TP	F	-1.3 (-9%)
DIN:DIP	F	-3.8 (-33%)
TOTAL CHL-A (ugl^{-1}) (summer)	F	-3.4 (-35%)
'ACTIVE' CHL-A (ugl^{-1}) (summer)	F	-2.5 (-36%)
PHAEOPHYTIN (ugl^{-1}) (summer)	F	-1.0 (-36%)
POC (umoll^{-1})	F	-12.1 (-28%)
TSS (mgl^{-1})	FC	+0.25 (+7%)
POC as % TSS	F	-6.0 (-42%)
k (m^{-1})	–	-0.01 (-2%)
SECCHI DEPTH (m)	C	+0.1 (+4%)
DO CONC (mgl^{-1}) (mid-summer)	C	+0.5 (+7%)
DO % SAT (mid-summer)	C	+5.0 (+6%)
SALINITY (ppt)	g	+4.0 (+1%)

Up-facing arrows indicate increases, down-facing arrows, decreases. Blue arrows indicate changes that might be interpreted as 'improvements'.
Red arrows indicate changes that might not be viewed as improvements. Gray hatched arrows denote differences that cannot at this time be assessed as beneficial or not.

Massachusetts Bay

Massachusetts Bay comprises a large coastal bay with multiple smaller coastal embayments. Gulf of Maine salinities exist within the main Bay. Circulation is strongly influenced by tides and non-tidal surface currents. Tidal range is approximately 2.74 m near Beverly Harbor. (Bricker et al., 1997b). There is a general counterclockwise circulation in the Gulf of Maine, with inflow from the Scotian shelf and flow to the southwest along the coast of Maine towards Massachusetts Bay. Some of the water sweeping past Cape Ann enters Massachusetts Bay and contributes to a counterclockwise circulation (Geyer, 1999). The main Bay is approximately 100 km long from north to south, 50 km wide from east to west, and 35 m deep on average. The Bay is closed in the north, west and south, and is open to the Gulf of Maine in the east at Stellwagen Bank, which is approximately 20 m deep. Freshwater from Boston Harbor tributaries and the Massachusetts Water Resources Authority (MWRA) effluent at the outfall site provide point sources of fresh water and nutrients. Thus, the Massachusetts Bay is a semi-enclosed embayment (Jiang and Zhou, 2003).

Data availability

Water quality data for the ASSETS application for Massachusetts Bay are derived from the Environmental Monitoring and Mapping System (EM&MS), an Oracle database maintained by the MWRA Environmental Quality Department (ENQUAD) for Chl a, DO, and nutrients. The data represent samples from 31 stations during 2001-04; 6,062 samples for Chl a and 5,888 samples for DO. The nutrient data for the calculation of overall human influence are for nitrogen concentrations, specifically DIN, for 2003.

Pressure – Overall Human Influence

Massachusetts Bay is classified as having Low susceptibility to eutrophic conditions because its dilution potential is High and its flushing potential is Moderate.

The estimated land-based nitrogen load for the Massachusetts Bay OHI calculation was derived using the 2003 median DIN concentration of the head-of-tide station, which in this situation was the station closest to land, and the 2003 median DIN concentration of the ocean-end member, or the station farthest from land. The results show an OHI ratio of 0.019, which is in the Low category. Combined with the Low susceptibility, the overall human influence to Massachusetts Bay is estimated to be Low.

State – Overall Eutrophic Condition

Chl a concentration for 31 stations and all months sampled in 2003 ranged from 0.001 to 20.9 micrograms/l. The 90th percentile for all data is 7.53 micrograms/l, which falls into the Medium category. When analyzed by station, the Medium values have High spatial coverage seen on an annual basis. As such, the Chl a expression value is 1, or High.

There were no available data for macroalgal abundance.

The primary symptoms in Massachusetts Bay are rated High, based on Chl a only since there are no data for macroalgal abundance.

DO concentration data for 31 stations for all months in 2003 ranged from 5.67 to 13.1 mg/l. The 10th percentile value for all data is 7.71 mg/l, which falls into the category of No Problem. There were no occurrences of hypoxia recorded, and no anoxia observed. As such, DO has an expression value of 0, or No Problem.

At the time of this publication no SAV data were available.

A minor Phaeocystis pouchetii bloom was observed throughout most of Massachusetts Bay in April 2002. These blooms did not deplete nutrient levels in the surface waters until June, as the waters were weakly stratified until this survey (Libby et al., 2003). There are annual occurrences of the dinoflagellate Alexandrium tamarense in the Gulf of Maine and as a result this region has annually recurrent outbreaks of paralytic shellfish poisoning (PSP) caused by this and other closely-related species (Anderson undated 1, 2; Anderson, 1997; Figure 9). As such, HABs are given an expression of High and a value of 1.

The secondary symptom indicators in Massachusetts Bay are High due to the HAB indicator.

The overall eutrophic condition for Massachusetts Bay is High due to the High primary and High secondary symptom expression.

Response – Determination of Future Outlook

Land-based inputs to the Massachusetts Bay come from a wide variety of sources. The Merrimack River and rivers further north in the Gulf of Maine provide most of the freshwater inflow to Massachusetts Bay (MWRA, 2003). Although they do not empty directly into the Bay, their flow is much greater than the Charles River and other Massachusetts Bay rivers. Another important source of inputs to Massachusetts Bay is the new Boston Harbor outfall pipe, which releases waste treatment plant water directly into the center of the Bay. Increases in population over time, as well as increases in impervious surfaces, will cause small increases in land-based nitrogen inputs to the system. As such, the DFO forecast for Massachusetts Bay is Worsen Low because of an increase in land-based nitrogen loading with Low susceptibility.

ASSETS Synthesis

The combination of Low overall human influence, High overall eutrophic conditions, and a Worsen Low forecast for future outlook gives an ASSETS synthesis classification of Moderate (Table 8).

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Figure 9
Alexandrium bloom 1993. (Modified from Geyer, 1999).

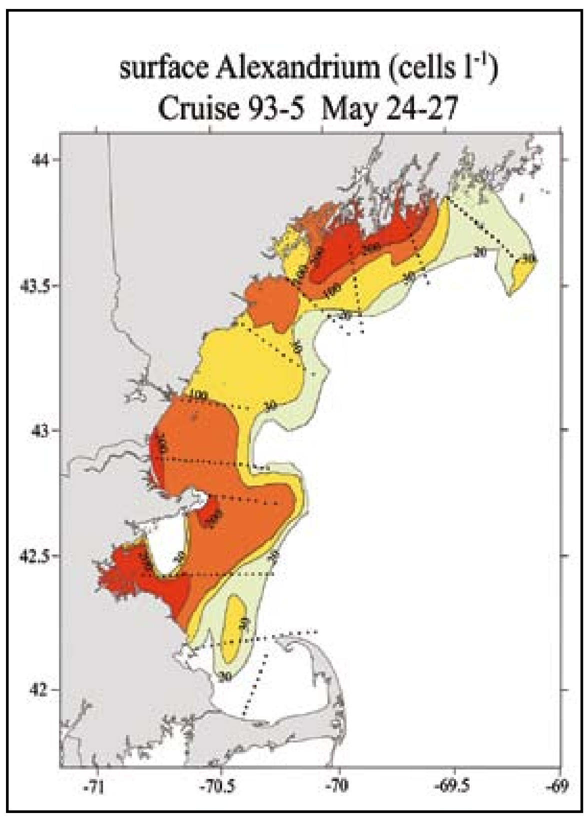


Table 8
ASSETS Synthesis for Massachusetts Bay.

<table>
<tr><th>Indices</th><th>Methods</th><th colspan="3">Parameters/ Values / EAR</th><th>Index category</th><th>ASSETS grade</th></tr>
<tr><td rowspan="3">Pressure
OHI index</td><td rowspan="2">Susceptibility</td><td>Dilutionpotential</td><td>High</td><td rowspan="2">Low
Susceptibility</td><td rowspan="3">Low</td><td rowspan="9">OHI = 5
OEC = 3
DFO = 2

Moderate</td></tr>
<tr><td>Flushingpotential</td><td>Moderate</td></tr>
<tr><td>Nutrient inputs</td><td colspan="3">Low</td></tr>
<tr><td rowspan="5">State
OEC index</td><td rowspan="2">Primary
Symptom
Method</td><td>Chlorophyll a</td><td>High</td><td rowspan="2">High</td><td rowspan="5">Moderate</td></tr>
<tr><td>Macroalgae</td><td>?</td></tr>
<tr><td rowspan="3">Secondary
Symptom
Method</td><td>Dissolvedoxygen</td><td>No Problem</td><td rowspan="3">Low</td></tr>
<tr><td>Submerged
aquaticvegetation</td><td>?</td></tr>
<tr><td>Nuisance and
Toxic Blooms</td><td>Low</td></tr>
<tr><td>Response
DFO index</td><td>Future nutrient
pressures</td><td colspan="3">Increase in population and impervious surfaces</td><td>Worsen Low</td></tr>
</table>

Cape Cod Bay

This system consists of a large coastal bay (the largest in the North Atlantic region) that is partially enclosed by Cape Cod, a ridge on the Coastal Plain consisting of glacial deposits. Four smaller bays and harbors make up the rest of the system. Circulation is strongly affected by tidal influences and non-tidal surface currents. Salinity is vertically homogeneous throughout the Bay. Tidal range is approximately 2.74 m near Wellfleet Harbor (Bricker et al., 1997b).

Data availability

Water quality data for the ASSETS application for Cape Cod are derived from the Environmental Monitoring and Mapping System (EM&MS), an Oracle database maintained by the Massachusetts Water Resources Authority (MWRA) Environmental Quality Department (ENQUAD) for Chl a, DO and nutrients. The data from 2001–2004 represents samples from four stations with 420 samples for Chl a and 397 samples for DO. The nutrient data for the calculation of overall human influence are for nitrogen concentrations, specifically DIN for 2003.

Pressure – Overall Human Influence

Cape Cod Bay is classified as having Moderate susceptibility to eutrophic conditions since its dilution potential is High and its flushing potential is Moderate.

The estimated land-based nitrogen load for the Cape Cod Bay OHI calculation was derived using the 2003 median DIN concentration of the head-of-tide station, which in this situation was the station closest to land, and the 2003 median DIN concentration of the ocean-end member, or the station farthest from land. The results show an OHI ratio of 0.007, which is in the Low category. Combined with the Moderate susceptibility, the overall human influence to Cape Cod Bay is estimated to be Moderate Low.

State – Overall Eutrophic Condition

Chl a concentration for four stations and all months sampled in 2003 ranged from 0.022 to 19.8 micrograms/l. The 90th percentile for all data is 7.68 micrograms/l, which falls into the Medium category. When analyzed by station, the Medium values have High spatial coverage seen on an annual basis. As such, the Chl a expression value is 1, or High.

The Natural Resources Department has long been aware of an enormous and growing quantity of sea lettuce Ulva lactuca in Round Cove. Throughout the Cove, this floating macroalgae, which consume oxygen through respiration, have formed large mats, at present often 0.61 to 0.91 m thick. In addition, the decaying material releases nitrogen back into the water (Office of Harwich Harbormaster, 1998) Macroalgae abundance receives a Low Value since data is spatially limited.

The primary symptoms in Cape Cod are rated High based on Chl a and limited macroalgal abundance data.

DO concentration data for four stations for all months in 2003 ranged from 5.819 to 12.431 mg/l. The 10th percentile value for all data is 7.975 mg/l, which falls into the category of No Problem. There were no occurrences of hypoxia recorded, and no anoxia observed. As such, DO has an expression value of 0, or No Problem.

A minor Phaeocystis pouchetii bloom was observed throughout most of Cape Cod Bay in April 2002. These blooms did not deplete nutrient levels in the surface waters until June, as the waters were weakly stratified until this survey (Libby et al., 2003). There are annual occurrences of the dinoflagellate Alexandrium tamarense in the Gulf of Maine and as a result this region has annually recurrent outbreaks of paralytic shellfish poisoning (PSP) caused by this and other closely related species (Anderson undated 1, 2; Anderson, 1997). As such, HABs are given an expression of High and a value of 1.

The secondary symptom indicators in Cape Cod Bay are High due to the HAB indicator.

The overall eutrophic condition for Cape Cod Bay is High due to the High primary and High secondary symptom expression.

Response – Determination of Future Outlook

Land use in the Cape Cod Bay drainage area has changed dramatically, almost doubling over the last 40 years (Figure 10). Increases in population density as well as increases in impervious surfaces (Figure 11) have been noted in recent decades (WHRC, 2005). These increases, along with the addition of the Boston Harbor/Massachusetts Bay water treatment outfall pipe, have continued to increase nitrogen loading to Cape Cod Bay. As such, the DFO for Cape Cod Bay is Worsen Low, due to an increase in population and impervious surfaces, with Moderate susceptibility.

Figure 10
Population change in Barnstable County, MA,1765 to 2003 (CCC, 2003).

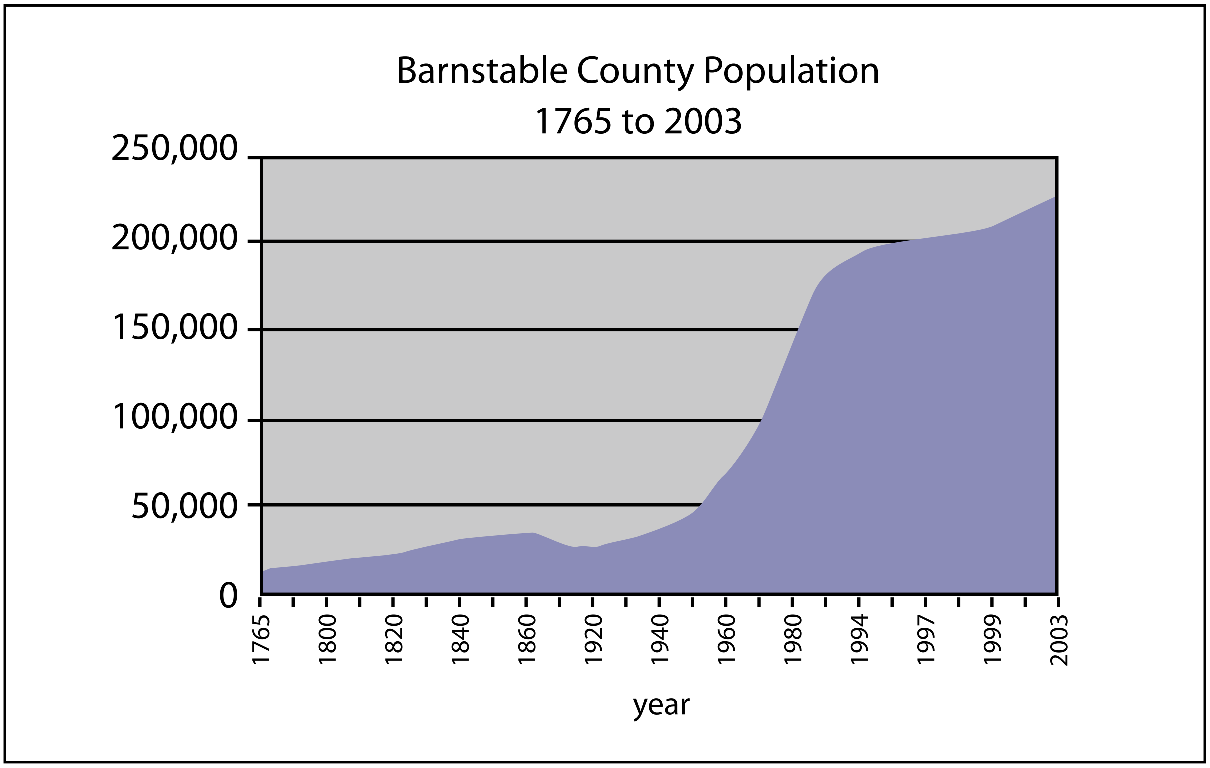
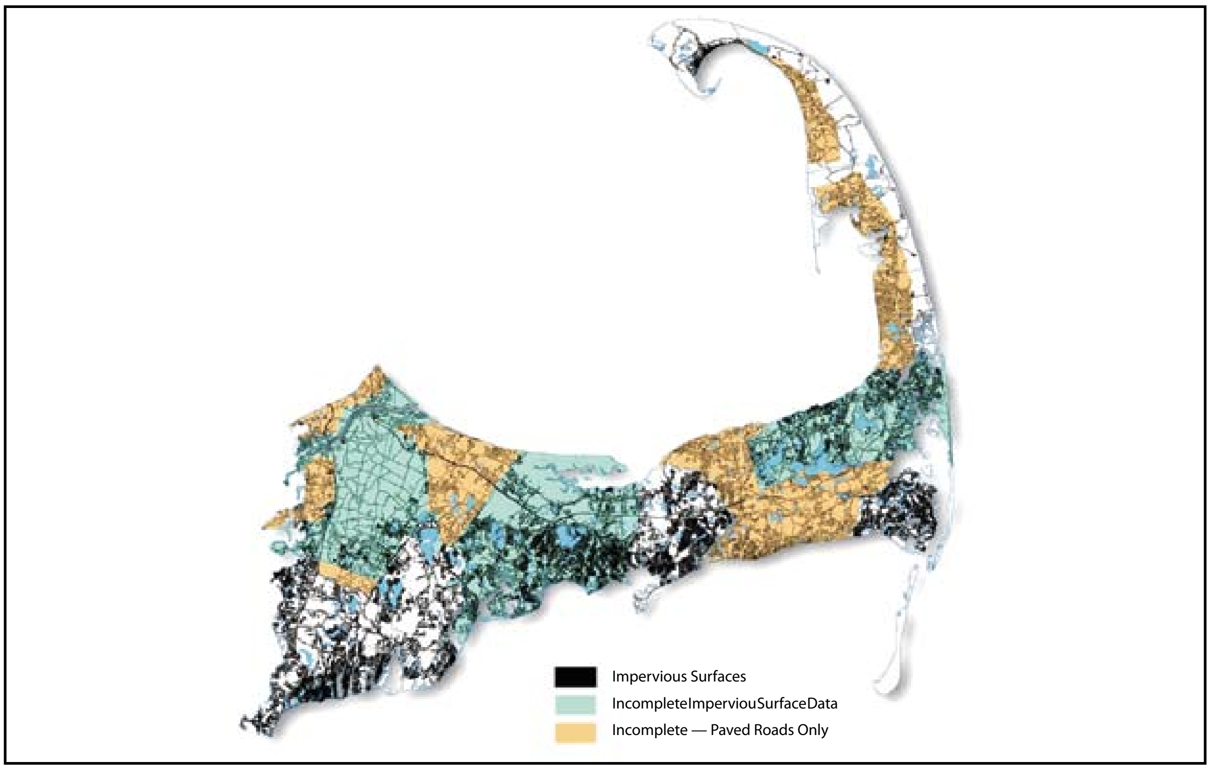


Figure 11
Impervious surfaces on the Cape Cod peninsula (WHRC, 2005).



ASSETS Synthesis

The combination of Moderate Low overall human influence, Moderate overall eutrophic conditions, and a Worsen Low forecast for future outlook gives an ASSETS synthesis classification of Moderate (Table 9).

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Table 9
ASSETS Synthesis for Cape Cod Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	Moderate Susceptibility	Moderate Low	OHI = 4 OEC = 3 DFO = 2 Moderate
		Flushing potential	Moderate			
	Nutrient inputs	Low				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate	
		Macroalgae	Low			
	Secondary Symptom Method	Dissolved oxygen	No Problem	Low		
		Submerged aquatic vegetation	?			
		Nuisance and Toxic Blooms	Low			
Response DFO index	Future nutrient pressures	Increase in population and impervious surfaces			Worsen Low	

Buzzards Bay

Buzzards Bay is located on the southwestern end of Cape Cod between the Elizabeth Islands and the Southeast Massachusetts coastline. The Bay has an open water surface area of approximately 590 sq km and drains a total area of approximately 1120 sq km (US EPA, 1991). Tidal range is about 1.2 m throughout the bay (Bricker et al., 1997b). The basin includes all or parts of 17 municipalities in both Massachusetts and Rhode Island. Population increases in the region have been dramatic in recent years; over the past five decades there has been a 50% increase (Howes, 1996). Current estimates place the population at approximately 373,000 people, with 40% of these living in the Greater New Bedford area (http://www.savebuzzardsbay.org/).

There are 11 primary rivers that empty into Buzzards Bay; seven on the western shore and four on the eastern shore. All are tidally influenced, however they differ in their nutrient inputs based on their respective land usage (Howes, 1996). For example, in Buzzards Bay as a whole, sewage treatment facilities account for 45-55% of nitrogen released into the Bay, but in the sub-embayment Buttermilk Bay (a typical embayment as far as land use), private septic tank systems account for about 74% of nitrogen inputs (Costa, 2003).

Data availability

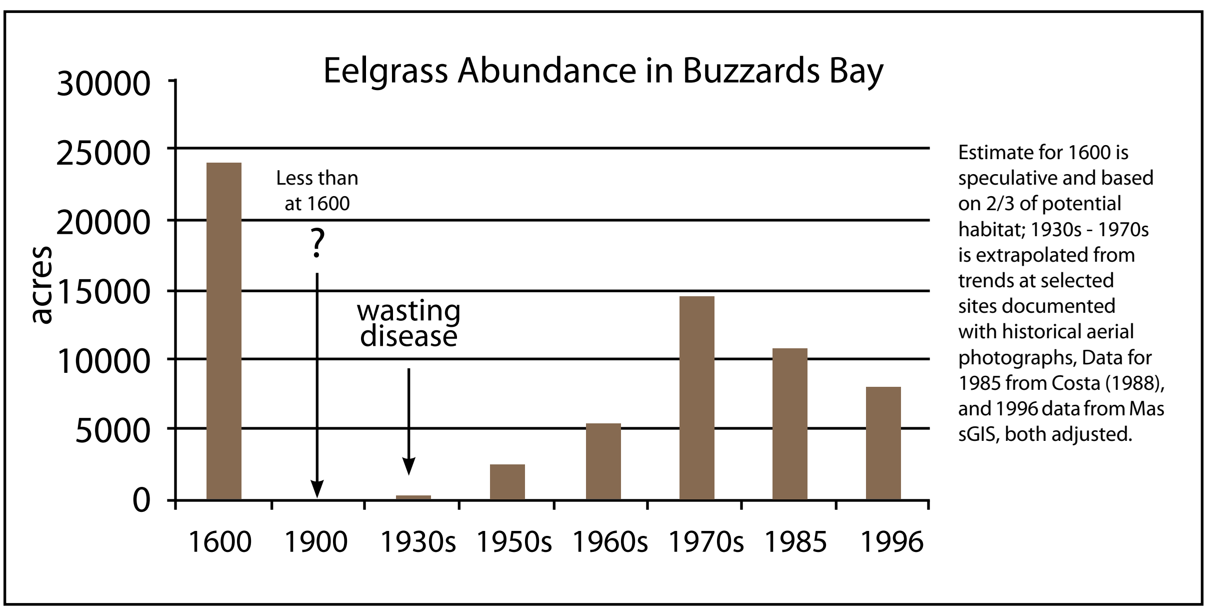
Water quality data for the ASSETS application for Buzzards Bay came from both the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP) database and the Coalition for Buzzards Bay (CBB). The EMAP database includes data for DO, Chl a, salinity, and temperature. The data represent samples from approximately 217 stations (varies depending on water-quality variable) in 1990-93, 2000-01 and 38 samples for Chl a and 86 samples for DO. The part of the CBB database retrieved for this study had data only from 2002-03. The CBB database had a total of 1,326 Chl a samples and 3,773 DO samples.

Pressure – Overall Human Influence

Buzzards Bay is classified as having Moderate susceptibility to eutrophic conditions because its dilution potential is High and its flushing potential is Low.

The Buzzards Bay nitrogen loading estimate of 2.18 x 10^6 kg of nitrogen per year is from estimates of riverine loading WATERSN model (Whitall, 2004; Castro, 2002, 2003). OHI model results show a ratio of 0.176, which is in the Low category. Combined with the Moderate susceptibility, the overall human influence to Buzzards Bay is estimated to be Moderate Low.

Figure 12
Historical Summary of eelgrass in Buzzards Bay (Adapted from Costa 2003 State of Buzzards Bay presentation).



State – Overall Eutrophic Condition

Chl a concentration data were available only for the months July-August 2002-03. These 1,350 samples range from 0.04 to 100.69 micrograms/l. The data for surface samples were averaged because the 90th percentile calculation would significantly bias the assessment results toward a falsely High value. The average is 5.33 micrograms/l, which falls into the Low range. The assessment for Chl a is Low.

Macroalgae in Buzzards Bay was observed in the middle portion of the Slocums River in 2003. There was High abundance of macroalgae, but because the spatial coverage was Low, macroalgae is categorized as Low.

The primary symptoms in Buzzards Bay are Low, based on the Chl a and macroalgae data.

DO concentration data were available for only the months July-August in 2002-03. These data range from 1.5 to 15.5 mg/l. The data for bottom samples were averaged because the 10th percentile calculation would bias the data toward a falsely Low assessment. The average for July and August 2002-03 is 6.4, or No Problem.

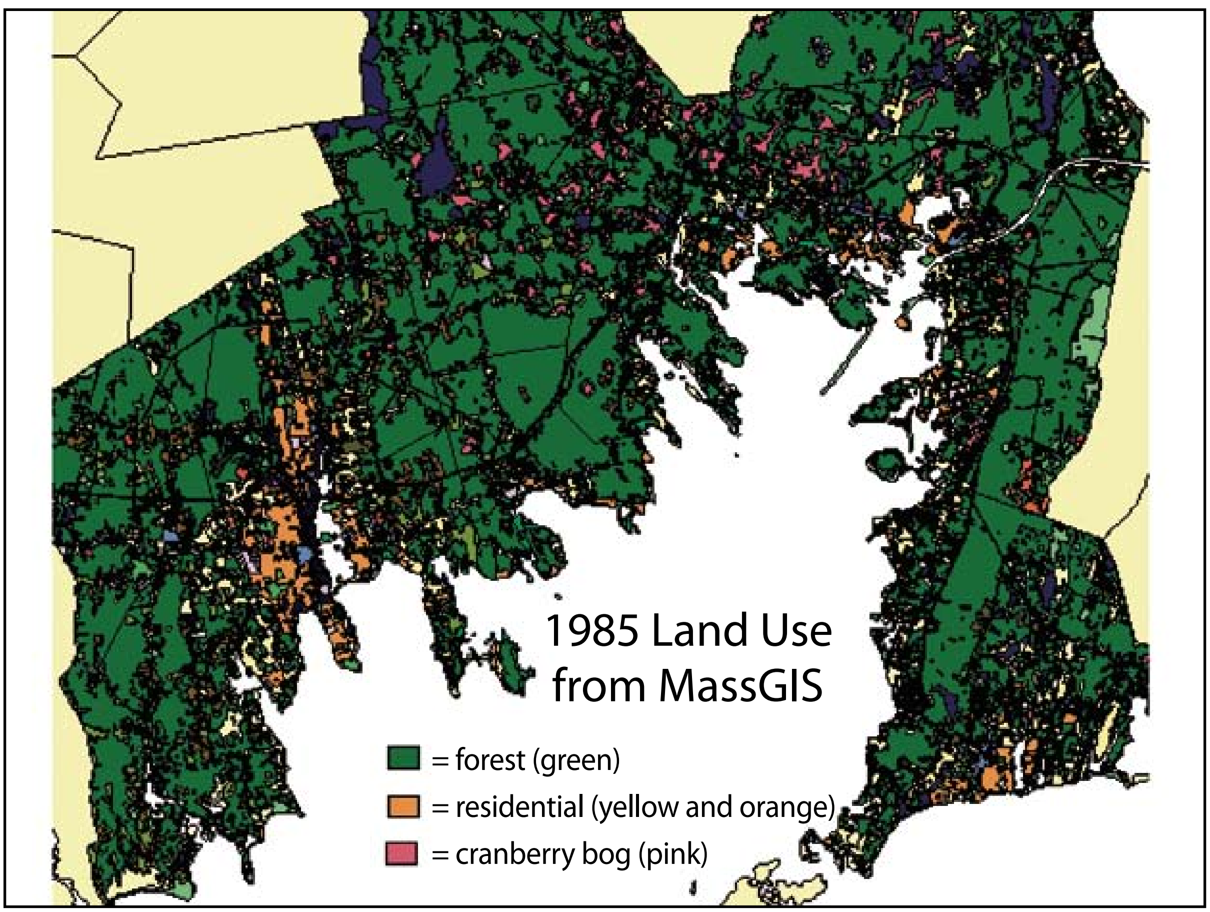
Buzzards Bay experienced an overall loss of SAV between 1985 and 1996 (Costa, 2003; Figure 12). The observed loss is estimated to be Low and receives an ASSETS expression of Low.

HABs were not a problem in Buzzards Bay during the timeframe of our assessment.

The secondary symptoms in Buzzards Bay are Low, as all three of the subcategories are Low or No Problem.

The overall eutrophic condition for Buzzards Bay is Low due to the Low primary and Low secondary symptom expression.

Figure 13
Land use in Buzzards Bay (1985).



Response – Determination of Future Outlook

Land use in Buzzards Bay varies tremendously, from highly developed sub-bays like Clark's Cove (5% forest coverage, 92% developed) to relatively undeveloped sub-bays like Widow's Cove (88% forest coverage, 11% developed) (Costa, 1999; Figure 13). Forest coverage in Buzzards Bay as a whole has been on the decline in the 21st century. This loss of forestation is primarily caused by development along the coastal region. The trend toward increasing development points to increases in land-based nitrogen inputs to the system. Management of the coastal areas of Buzzards Bay is ongoing, but with such a diverse range of potential problem areas spread over such a large area, the DFO for the Bay is Worsen Low because of an increase in nutrient loading with Moderate susceptibility.

ASSETS Synthesis

The combination of Moderate Low overall human influence, Low overall eutrophic conditions, and Worsen Low for future outlook gives an ASSETS synthesis classification of Good (Table 10).

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Table 10
ASSETS Synthesis for Buzzards Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilutionpotential	High	Moderate Susceptibility	Moderate Low	OHI = 4 OEC = 5 DFO = 2 Good
		Flushingpotential	Low			
	Nutrient inputs	Low				
State OEC index	Primary Symptom Method	Chlorophyll a	Low	Low	Low	
		Macroalgae	Low			
	Secondary Symptom Method	Dissolvedoxygen	No Problem	Low		
		Submerged aquaticvegetation	Low			
		Nuisance and Toxic Blooms	No Problem			
Response DFO index	Future nutrient pressures	Future nutrient pressures increase			Worsen Low	

Narragansett Bay

Narragansett Bay is a medium-sized (370 sq km), relatively well-mixed temperate latitude estuary that includes several smaller embayments such as Greenwich Bay and Mount Hope Bay. The watershed is about 4,714 sq km with three major river basins – the Taunton, Blackstone and Pawtuxet – with 60% of the drainage basin found within the boundaries of Massachusetts (Deacutis, 2004). It has relatively low input of freshwater, receiving the majority of freshwater from the Blackstone and Taunton Rivers. Circulation is affected largely by tidal mixing and wind currents and is generally well mixed, but seasonal stratification occurs in the upper Bay and in some embayments. Ocean water intrudes further up the East Passage than the West Passage. It has an average depth of 9 m with tides ranging from 0.91 m at the mouth of the bay to approximately 1.52 m near Warwick, Rhode Island (Bricker et al., 1997a). Average flushing rate is 26 days (Pilson, 1985).

Data availability

Water quality data used for the ASSETS application for Narragansett Bay are from several sources, although none represent an annual cycle. In this case, means were used instead of 90th and 10th percentiles since that would bias the results, given that the samples were taken only in the summer months. DO data for 1,356 samples from 65 stations for three sampling dates in 2002 and 2003 are from the Insomniacs Nighttime Cruises, a multidisciplinary team including academic, State, and Federal partners (http://www.geo.brown.edu/georesearch/insomniacs/index.html). The data were sorted to include only samples from 4.5 m depth and below, assuming an average depth of 9 m, since there was no identification of the relative depth, only the actual depth measure. Additional DO data for 104 samples and 127 samples for Chl a from 51 stations from July and August came from the EPA EMAP program for 2000-01 (EMAP). National Estuarine Research Reserve (NERR) program automatic sampler results are continuous measures (10th and 90th percentile was determined from these data) from 1995 to1998, including 51,000 samples for DO and 65,500 samples for Chl a from four locations. Other NERR data from 2002 include 104 Chl a samples from three stations from March through December, and 16,009 samples for DO from two locations (T-Wharf and Potter's Cove) from an autosampler (i.e., annual data were collected). Physical and hydrologic data come from CADS (http://cads.nos.noaa.gov). Nutrient-loading estimates are from Nixon et al. (2004).

Pressure – Overall Human Influence

The susceptibility for Narragansett Bay is Moderate because of Low flushing and High dilution potentials.

The 2003-04 estimated land-based nitrogen load to Narragansett Bay is 7.07 x10^{3} metric tons/yr (Nixon et al., 2004) which includes atmospheric deposition (0.24 metric tons/yr) but excludes estimated oceanic input (0.21 metric tons/yr). The OHI calculation included an oceanic NO_3 concentration from Smith (CADS improved). The results show an OHI ratio of 0.53, which is in the Moderate category. Combined with the Moderate susceptibility, the overall human influence to Narragansett Bay is estimated to be Moderate.

State – Overall Eutrophic Condition

Chl a concentration for the July and August samples from EMAP 2000-2001 ranged from 0.81 to 95 micrograms/l. Averages were used instead of the 90th percentile due to the limited timeframe of the samples. Because there was no significant difference between surface, mid-depth and bottom concentrations, they were used together to give a summertime mean of 9.23 micrograms/l. This falls within the Moderate category. The NERR data from two sampling stations (Potters Cove and T-Wharf) range from 0.23 to 7.48 micrograms/l. (Nags Creek data were not used because the location in a creek could potentially bias the results.) The 90th percentile of all data is 1.91 micrograms/l, which falls into the Low category. Because the NERR data are limited spatially, the EMAP data were used and produced a result of Moderate for Chl a concentration for Narragansett Bay. The spatial coverage and frequency cannot be determined from this data, and thus the overall value is 0.5, or Moderate for this indicator.

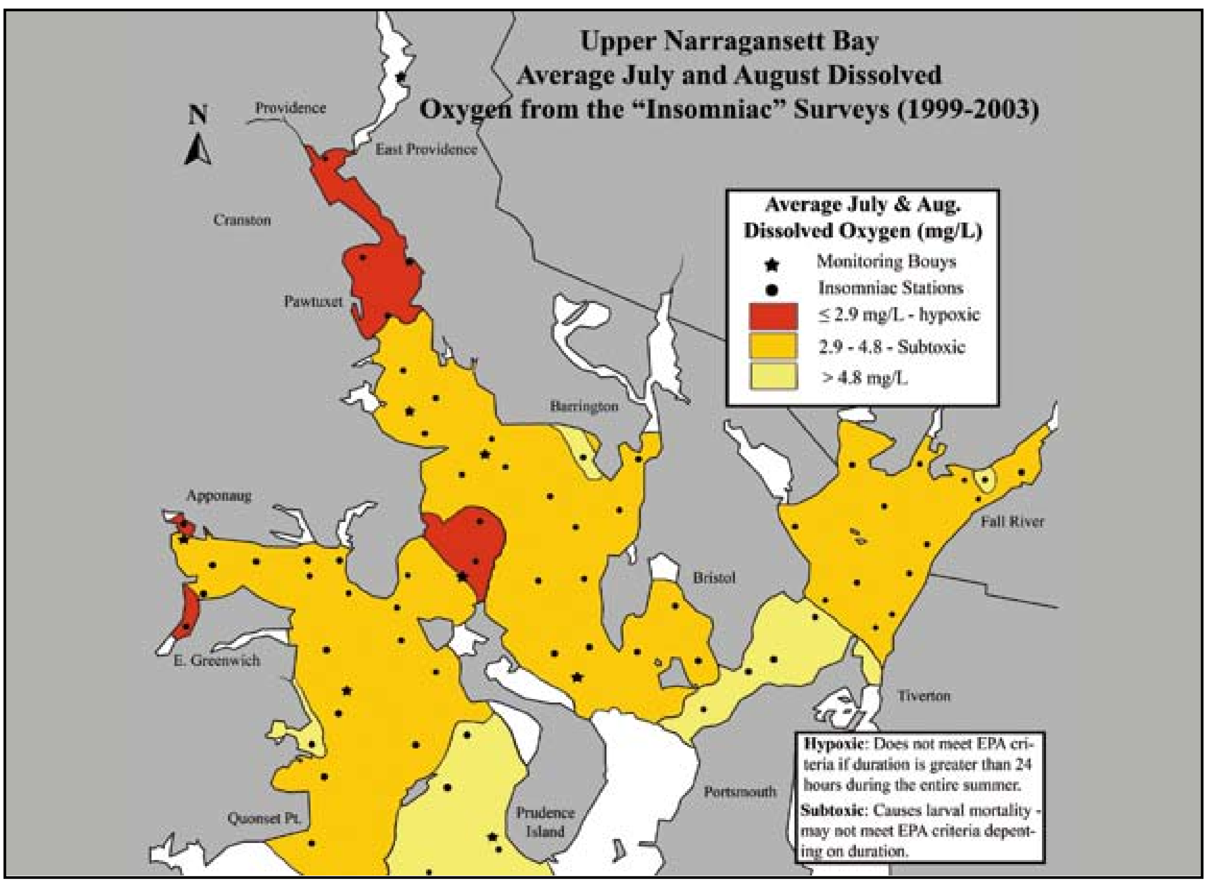
Macroalgae problems have been common for the past 10-15 years in the Providence River, and they appear to be spreading down the Bay and into many shallow coves (RISG, 2005). Macroalgal populations have become so dense and lush in the upper Bay that the Rhode Island Department of Environmental Management can no longer conduct fish survey trawls there because the algae clog the trawls, making sampling impossible. The abundance of macroalgae appears to have increased over time, but the data are limited. In some embayments, such as Greenwich Bay and other shallow embayments in the upper Bay, large Ulva mats have been observed for some time (RISG, 2005). The assessment value for this indicator is 1, or High, due to observed problems with a Periodic frequency.

The overall primary expression value is High, due to the combination of High macroalgal and Moderate Chl a assessment values.

When seasonal stratification occurs, it is stronger in the Providence River relative to the rest of the estuary, making this portion of the system more prone to hypoxia and more likely to maintain hypoxic conditions longer. Water column stratification is set up by river flow to the head of the Bay and strengthened by the depth of the dredged channel, which is difficult to mix vertically during summer conditions. In Bullock Reach, for instance, stratification is a major forcing function in the development of low oxygen concentrations. Because of this, hypoxia is common in the upper Bay, short-term anoxia events have been observed (Figure 14; RISG, 2005), and fish kills have been recorded in 1999 and 2003 (Deacutis, 1999; RIDEM, 2003).

EMAP 2000-01 data for DO ranges from 0.9 to 11.1 mg/l, with an average of 5.72 mg/l for the July and August samples. But one sample (2%) falls within the hypoxic range and 34% fall within the biologically stressful DO range. Data results from the multi-agency Insomniacs team, sampled June-August 2002-03, show a range from 0.08 to 10.83 mg/l, with an overall average of 4.7 mg/l. When averaged per station, there are two of 65 stations (3%) that have means falling within the hypoxic range and 32 stations, or almost 50%, where averages fall within the biologically stressful concentration range. The value for this indicator is Moderate, based on Moderate concentration, Moderate spatial coverage, and Periodic frequency (http://www.geo.brown.edu/georesearch/insomniacs/).

Figure 14
Average Dissolved oxygen concentrations compiled from five summers of nocturnal, neap tide monitoring surveys. (Modified from RISG, 2005; summarized from Saarman, 2005)



Eelgrass is now found only in the lower Bay; it is completely absent in the upper Bay. It is believed that present nutrient-loading levels preclude the return of eelgrass in upper Bay areas. Restoration of eelgrass has been successful only around Prudence Island (RISG, 2005; Deacutis, 1999). The expression value for SAV is Low (0.25), given that losses have already occurred but nutrient conditions prevent recolonization.

Nuisance and toxic blooms (including benthic macroalgae) are observed in the upper Bay (lower Providence River) and in western Greenwich Bay (RISG, 2005). Because of the limited data and information about these blooms, this indicator receives a Low expression value.

The overall secondary expression is Moderate, due to the Moderate values for DO concentrations.

Combined with the High primary symptom expression, the overall eutrophic condition assessment expression for Narragansett Bay is Moderate High.

Table 11
ASSETS Synthesis for Narragansett Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilutionpotential	High	Moderate Susceptibility	Moderate	OHI = 3 OEC = 2 DFO = 3 Poor
		Flushingpotential	Low			
	Nutrient inputs	Moderate				
State OEC index	Primary Symptom Method	Chlorophyll a	Moderate	High	Moderate High	
		Macroalgae	High			
	Secondary Symptom Method	Dissolvedoxygen	Moderate	Moderate		
		Submerged aquaticvegetation	Low			
		Nuisance and Toxic Blooms	Low			
Response DFO index	Future nutrient pressures	Inputs will remain the same due to STP improvements despite population increase			No Change	

Response – Determination of Future Outlook

Nixon et al. (2005) report that total nitrogen loads have remained fairly constant from the 1980s, and that phosphorus loads have decreased by more than half. In projections to 2010, nitrogen loads are expected to remain the same, based on full realization of reductions of nitrogen from sewage treatment plants. These decreases are expected despite a projection of a population increase of 5-10% by 2008 (Crosset et al., 2004). With the Moderate susceptibility and a No Change in nutrient loading, the determination of future response is No Change.

ASSETS Synthesis

The combination of Moderate overall human influence, Moderate High overall eutrophic conditions, and No Change for future outlook gives an ASSETS synthesis classification of Poor (Table 11).

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Long Island Sound

Long Island Sound is a large (3,400 sq km) estuary with connections to the ocean at its western end via Block Island Sound and via the East River and New York Harbor to the east. The major tributaries, the Housatonic and Connecticut Rivers, enter from the north, with the Connecticut River accounting for about 70% of total freshwater inflow (Wolfe et al., 1991). The East River promotes stratification in the western Sound, particularly during the spring runoff period (Bricker et al., 1997). Average tidal range is about 2 m.

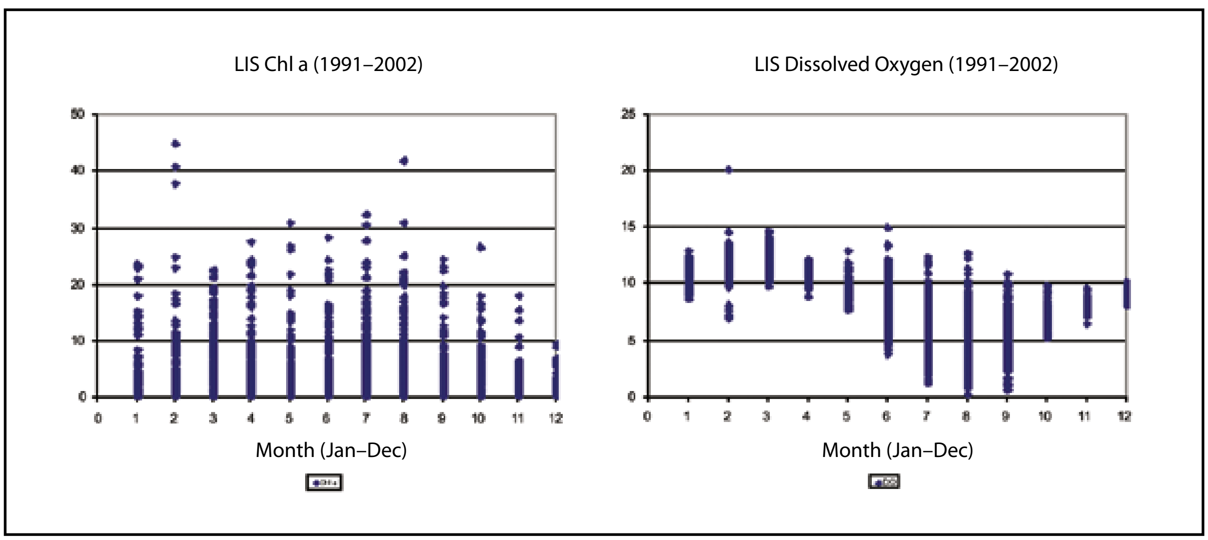
The NEEA/ASSETS method was applied to Long Island Sound to see if there have been noticeable changes between 1991 and 2002, a decade after the implementation of management measures designed to limit nitrogen inputs to the Sound.

Pressure – Overall Human Influence

The most significant feature of this system is its location adjacent to one of the most heavily populated regions of the United States: the New York metropolitan area and Bridgeport and New Haven, two of Connecticut's largest cities. The total population in the basin is greater than 8 million, with the majority residing in New York and Connecticut (U.S. Census Bureau, 2002). Although Long Island Sound receives some input from Massachusetts, Vermont, and New Hampshire, New York and Connecticut account for more than 80% of total inputs. The total nitrogen loading to Long Island Sound is 60.7 X 10^3 ton yr^{-1}, primarily from point sources (NYSDEC and CTDEP, 2000). Since 1990, about 25 of the 105 sewage treatment plants in Connecticut and New York have been upgraded to biological nutrient removal of nitrogen and more are under construction or are being proposed. These upgrades have led to a 30% decrease in nitrogen loading from wastewater treatment plants since 1990 (LISS, 2003) and it is expected that these improvements will continue (NYCDEP, 2000; NYSDEC and CTDEP, 2001).

The combination of High dilution potential and Low flushing potential gives this system a susceptibility rating of Moderate.

Figure 15
Chl a and DO in Long Island Sound used for ASSETS and Human Use assessment (LIS Study).



Data availability

Water quality data used for the ASSETS application to Long Island Sound are from the Long Island Sound Study (undated; Figure 15) and represent more than 111 monthly samples for seven stations in 1991 and 387 monthly samples for 17 stations in 2002. Physical and hydrologic data are from CADS (1999). Nutrient-loading estimates are from NYSDEC and CTDEP (2000).

Application of the loading-susceptibility model using a conservative re-entrainment value of 50% gives a human level of influence of 59% in 1991 and 51% in 2002, both falling within the Moderate category. With Moderate inputs and Moderate susceptibility, the rating for OHI is Moderate for both years.

State – Overall Eutrophic Condition

Chl a data for Long Island Sound show a decrease in the 90th percentile concentration from 18 micrograms/l to 9 micrograms/l, between 1991 and 2002. Additionally, average Chl a concentrations at the winter/spring bloom have decreased from 17 micrograms/l to about 2 micrograms/l in Western Long Island Sound (LISS, 2001). For both years, the frequency of occurrence is Periodic, the spatial coverage is High and the rating for Chl a is High.

Epiphytes were identified as a Moderate problem and macroalgae were identified as a High-level problem in Long Island Sound in the early 1990s (Bricker et al., 1999). However, there are no data for comparison to conditions in 2002. These variables were not used in the assessment.

The primary symptom expression value for Long Island Sound is High for both years.

DO 10th percentile for all stations together shows an increase from 3.9 mg/l in 1991 to 6.4 mg/l in 2002. However, biologically stressful concentrations are seen in both years, with a spatial coverage of High for 1991

Table 12
ASSETS Synthesis for Long Island Sound 1991.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	Moderate Susceptibility	Moderate	OHI = 3 OEC = 1 DFO = 4 Bad
		Flushing potential	Low			
	Nutrient inputs	Moderate				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	High	
		Macroalgae	?			
	Secondary Symptom Method	Dissolved oxygen	Moderate	High		
		Submerged aquatic vegetation	High			
		Nuisance and Toxic Blooms	No Data			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease, significant population/ development increases – Improve Low			Improve Low	

Table 13
ASSETS Synthesis for Long Island Sound 2002.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	Moderate Susceptibility	Moderate	OHI = 3 OEC = 3 DFO = 4 Moderate
		Flushing potential	Low			
	Nutrient inputs	Moderate				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate	
		Macroalgae	?			
	Secondary Symptom Method	Dissolved oxygen	Low	Low		
		Submerged aquatic vegetation	Low			
		Nuisance and Toxic Blooms	No data			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease, significant population/ development increases – Improve Low			Improve Low	

and Moderate for 2002. This is concurrent with an observed decrease in hypoxic area from almost 800 sq km in 1987 to about 330 sq km in 2002 (LISS, 2003). Although the duration is highly variable, there is a trend toward a decreasing duration of Low-DO events over the same time period. The rating for DO in 1991 is Moderate and for 2002 is Low.

Nuisance and toxic blooms were identified as a Moderate-level problem in the early 1990s (Bricker et al. 1999) but there are no data for 2002 for comparison. This variable was not used in the assessment.

SAV was lost in the 1970s and 1980s due to High Chl a concentrations in the water column (LISS, 2003). SAV spatial coverage is Very Low for both 1991 and 2002, however, there has been a small increase in SAV from 1991 to 2002. In Mumford Cove, Connecticut eelgrass has increased by 0.2 sq km from 1987 to 2002 (LISS, 2003). The rating for SAV for 1991 is High and the rating for 2002 is Low.

The overall secondary symptom expression for Long Island Sound is High for 1991 and Low for 2002.

The overall eutrophic condition for Long Island Sound 1991 is High, and for 2002 is Moderate.

Response – Determination of Future Outlook

Although the population is expected to increase in the Long Island Sound watershed over the next 20 years, the EPA-approved TMDLs and the agreement to reduce nitrogen by 58.5% by 2014 (LISS, 2003) are likely to result in continued declines in loadings. The expected decrease in inputs, combined with the Moderate susceptibility, gives a response rating of Improve Low for expected eutrophic conditions in Long Island Sound.

ASSETS Synthesis

The combination of Pressure-State-Response results for Long Island Sound for 1991 result in an ASSETS rating of Bad. The improvements in conditions within the system that resulted from the decreases in loadings during 1990s are reflected in the ASSETS score of Moderate for Long Island Sound for 2002 (Table 12, 13).

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Patuxent River

The Patuxent River is a smaller estuary with a surface area of approximately 140 sq km. It is the largest river that falls completely within the state of Maryland and drains a total basin area of around 2,270 sq km. The median salinity of the Patuxent River was 11.3 for 2002. Tidal range is about 0.3 m at the mouth (Bricker et al., 1997a).

Land use in the Patuxent River Basin is varied, with nearly equal areas of urban (30%), agriculture (26%), and forest (44%) (Figure 16).

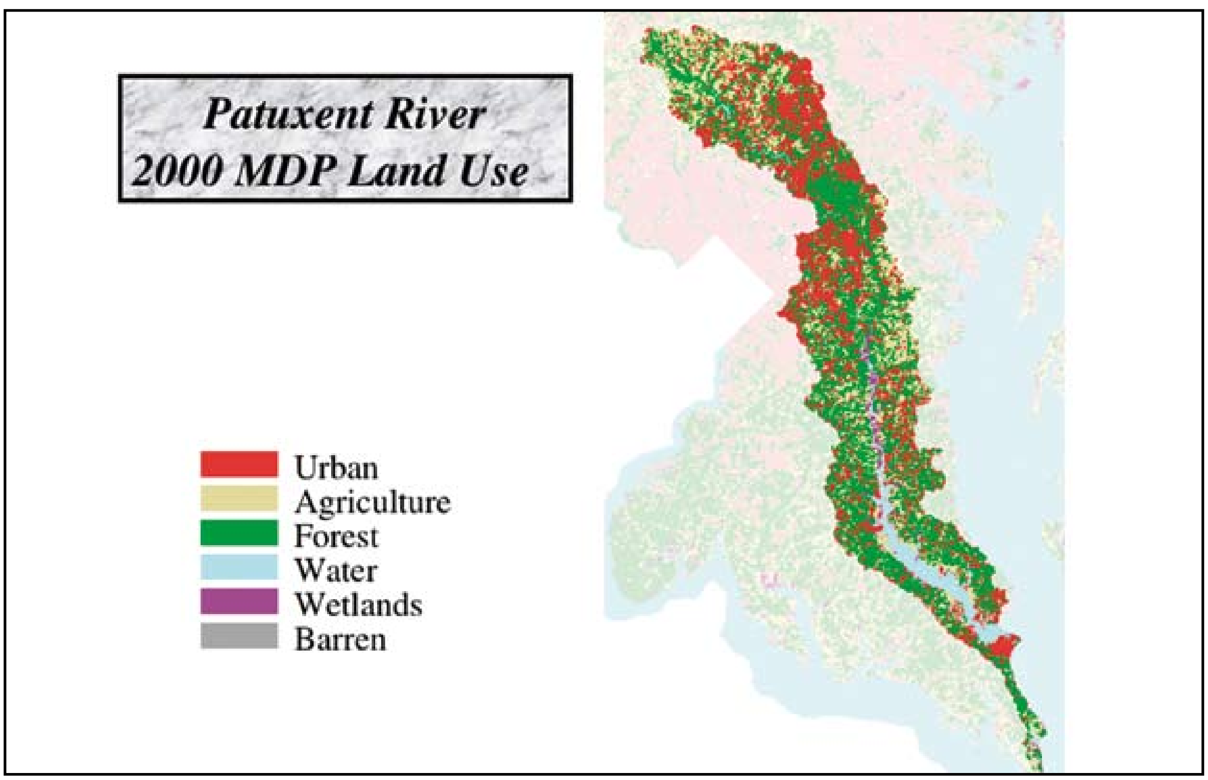
Data availability

The data used for the Patuxent River NEEA/ASSETS assessment is from a number of different sources. The water quality data (Chl a, DO, and salinity) and nutrient data (DIN) comes from the Chesapeake Bay Program's online database (http://www.chesapeakebay.net). Chl a 90th percentile for 2002 was calculated from nine stations and represents 582 individual samples. DO 10th percentile for 2002 was calculated from nine stations and represents 795 individual samples. A median salinity was calculated for the estuary using the Chesapeake Bay Program's data for the years 1997-2002. DIN median for 2002 was also calculated from the Chesapeake Bay Program's database.

The change in SAV coverage in 2002 was calculated using the 2001 and 2002 SAV coverage dataset that was produced at the Virginia Institute of Marine Science from aerial photography taken in 2001 and 2002. Areal SAV coverage (square meters) in 2001 and 2002 was calculated using ArcMAP. The change in SAV coverage was then calculated by subtracting the areal coverage of 2001 from the areal coverage for 2002.

Harmful algal bloom (HAB) data were collected from the Eyes On the Bay website (http://mddnr.chesapeakebay.net/hab/, 2002 HAB report search). Physical, hydrological, and land-use data for the Patuxent River came from both the original NEEA database and from the Patuxent River Basin Summary (MDDNR, 2004).

Figure 16
Land use in the Patuxent River Basin 2000 (Basin Summary Team and Chesapeake Bay Program Tidal Monitoring and Analysis Workgroup, 2004).



Pressure – Overall Human Influence

The Patuxent River drains part of the large agricultural area of Maryland as well as some of the newly developed areas near Columbia, Maryland. Along with these large agricultural and suburban nutrient sources, the Patuxent lies between the two major metropolitan centers of Washington, DC and Baltimore. Land use for the Patuxent watershed is 44% forest/wetlands, 26% agriculture, and 30% urban (MDDNR, 2004). The 2000 population estimate for the Patuxent River basin was 618,000, with significant increases expected in the future. Nitrogen, phosphorus, and sediment inputs to the Patuxent River have all decreased since 1985, however there have been significant increases in population and development over that same period.

The Patuxent River has a Moderate dilution potential but a Low flushing potential. This gives the system an overall susceptibility rating of High. Nitrogen-loading for the system calculated the human influence to be 82.2% for 2002, which corresponds to a value of High. With High inputs and High susceptibility, the OHI value is High for 2002.

State – Overall Eutrophic Condition

Chl a 90^{th} percentile concentrations in the Patuxent River estuary during 2002 ranged from Medium to Hypereutrophic in the following approximate spatial coverage: Medium, 90%; High, 4%; and Hypereutrophic, 5%. The overall 90^{th} percentile value for all 2002 data and all stations was 35.14 micrograms/l, which corresponds to a value of High. The highest spatial coverage above (which is for Medium Chl a) is adopted for the overall Chl a value for the Patuxent River estuary for 2002, and as such the system gets an expression of High.

Macroalgae for the Patuxent River in 2002 was No Problem (Peter Tango, MDDNR, personal communication).

DO levels in the Patuxent River estuary during 2002 ranged from No Problem to Biological Stress in the following approximate spatial percentages: No Problem, 14% and Biological Stress, 85%. The overall combined 10^{th} percentile for all stations in 2002 was 3.8 mg/l, which corresponds to Biological Stress. This spatial coverage and DO level correspond to an overall rating of Moderate, with a value of 0.5.

Table 14
ASSETS Synthesis for Patuxent River.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	Moderate	High Susceptibility	High	OHI = 1 OEC = 3 DFO = 4 Moderate
		Flushing potential	Low			
	Nutrient inputs	High				
State OEC index	Primary Symptom Method	Chlorophyll a	High	Moderate	Moderate	
		Macroalgae	No Prob			
	Secondary Symptom Method	Dissolved oxygen	Moderate	Moderate		
		Submerged aquatic vegetation	Small Increase			
		Nuisance and Toxic Blooms	Problem			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease, significant population/ development increases – Improve Low			Improve Low	

In 2001, SAV in the Patuxent River had a spatial coverage of approximately 1,341,822.21 sq m, whereas in 2002 there was a slight increase to 1,344,817.18 sq m.

HABs had only minor appearances during 2002. On April 15, 2002, there was a single recorded event of low levels of Dynophysis accuminata in the Patuxent River. The low duration gives HABs an overall Low value of 0.25.

Secondary symptoms are Moderate. The overall eutrophic condition is Moderate due to Moderate primary and secondary symptoms.

Response – Determination of Future Outlook

For the Patuxent River basin, nitrogen loading, phosphorus loading, and sediments all decreased between 1985 and 2002 (Patuxent River Basin Summary, 2004). In contrast, however, population growth in Maryland is projected to increase at an approximately 1% every year, and the Patuxent River basin itself includes many new suburban communities that are expected to continue to experience rapid suburban growth.

Therefore, even though nitrogen, phosphorus, and sediment loading are decreasing, significant population increases and development may mask the decreases in loading and cause there to be only small positive changes in future nutrient pressures. Thus, with High susceptibility and only small improvements in future nutrient pressures, the overall calculation for DFO forecast in the Patuxent River is Improve Low for 2002.

ASSETS Synthesis

The pressure to the system (OHI) was High, and the state of the system (OEC) was Moderate. There are only small expected improvements in the future nutrient pressures (DFO). These three values combine for an overall ASSETS rating of Moderate (Table 12).

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Potomac River

The Potomac River is a medium-sized estuary (1,267 sq km) with a low median salinity around 11.3. It drains parts of Maryland and Virginia (7,200 sq km) as well as parts of West-Virginia, Pennsylvania and Washington, D.C. before emptying out into the main stem of the Chesapeake Bay. The river is tidally influenced with the head-of-tide just beyond the upstream limits of Washington, DC. The Potomac River contributes approximately 20% of the total freshwater to the Chesapeake Bay (MDDNR website). Tidal range is about 0.4 m near the mouth (Bricker et al., 1997a).

Data availability

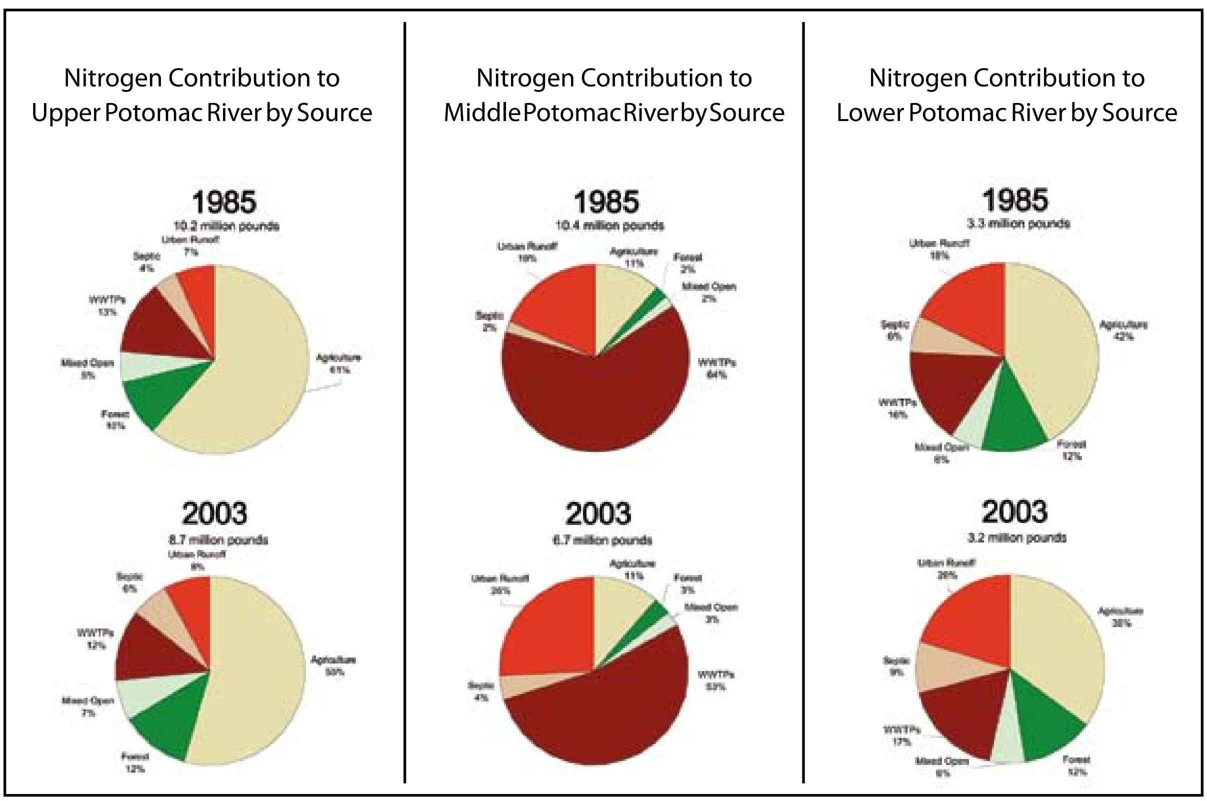
The data used for the Potomac River NEEA/ASSETS assessment are from a number of different sources. The water quality data (Chl a, DO, and salinity) and nutrient data (DIN) come from the Chesapeake Bay Program's online database (www.chesapeakebay.net). Chl a 90th percentile for 2002 was calculated from 12 stations and represents 645 individual samples. DO 10th percentile for 2002 was calculated from 11 stations and represents 1,329 individual samples. A median salinity was calculated for the estuary using the Chesapeake Bay Program's data for the years 1997-2002. DIN median for 2002 was also calculated from the Chesapeake Bay Program's database.

The change in SAV coverage in 2002 was calculated using the 2001 and 2002 SAV coverage dataset, produced at the Virginia Institute of Marine Science from aerial photography taken in 2001 and 2002, using ArcMAP (part of the ArcGIS program). Areal SAV coverage (in square meters) in both 2001 and 2002 was calculated. The change in SAV coverage for the Potomac was then calculated by subtracting the areal coverage of 2001 from the areal coverage for 2002.

HAB data were collected from the Eyes On the Bay website (http://mddnr.chesapeakebay.net/hab/, 2002 HAB report search).

Physical, hydrological, and land-use data for the Potomac River came from both the original NEEA database and the Potomac River Basin Summary (MDDNR, 2004).

Figure 17
Nitrogen Loading to the Upper, Mid and Lower Potomac 1985 and 2003 (Basin Summary Team and Chesapeake Bay Program Tidal Monitoring and Analysis Workgroup, 2004).



Pressure – Overall Human Influence

The Potomac River basin drains large agricultural areas in Maryland, Virginia, Pennsylvania and West Virginia as well as the Washington DC metropolitan area. The estimated total population for the Maryland side of the basin alone (excluding DC) is 643,000 (MDDNR, 2004). The River can be classified into upper and lower segments, with the delineation being the head-of-tide. The upper Potomac River is made up of 48% forest/wetlands, 38% agriculture, and 14% urban. Land use for the lower Potomac River is 60% forest/wetlands, 24% agriculture, and 16% urban (MDDNR, 2004). Nitrogen, phosphorus, and sediment loading to the Potomac River decreased between 1985 and 2003, while the population, along with development, significantly increased (Figure 17). However, there is new evidence that nutrient inputs are now increasing (B. Romano, Personal Communication).

The Potomac River has a High dilution potential but a Low flushing potential, giving the system an overall susceptibility rating of High. Nitrogen loading for the system calculated the human influence to be 94.8% for 2002, which corresponds to a value of High. With High inputs and High susceptibility, the OHI value for 2002 is High.

Medium, 59% and High, 9%. The overall 90th percentile value for all 2002 data and all stations was 16.42 micrograms/l. The highest spatial coverage (which is for Medium Chl a) was adopted for the overall Chl a value for the Potomac River estuary for 2002, and as such the system gets an expression of High.

Macroalgae for the Potomac River in 2002 was No Problem (Peter Tango, MDDNR, personal communication, August 23, 2005)

DO levels in the Potomac River estuary during 2002 ranged from No Problem to Hypoxia in the following approximate spatial percentages: No Problem, 23%; Biological Stress, 28%; Anoxia, 19%. The overall combined 10th percentile for all stations in 2002 was 4.2 mg/l, which corresponds to Biological Stress.

In 2001, SAV in the Potomac River had a spatial coverage of approximately 529,557.04 sq m, whereas in 2002 there was an increase of approximately 34 million sq m, to 34,479,090.57 sq m.

HABs were a large problem during 2002. There were multiple different blooms throughout the year, however the largest and longest bloom was that of Dinophysis accuminata from February until around April of 2002 (Eyes on the Bay website, viewed 6-04). During the three months of the bloom, shellfish beds were closed and no harvesting was allowed. HABs carried the largest NEEA/ASSETS secondary symptoms value and were combined with the overall primary symptom value to calculate the OEC.

Table 15
ASSETS Synthesis for Potomac River.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	High Susceptibility	High	OHI = 1 OEC = 1 DFO = 4 Bad
		Flushing potential	Low			
	Nutrient inputs	High				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	High	
		Macroalgae	No Prob			
	Secondary Symptom Method	Dissolved oxygen	Low	High		
		Submerged aquatic vegetation	Large Increase			
		Nuisance and Toxic Blooms	Problem (1)			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease, significant population/development increases – Improve Low			Improve Low	

State – Overall Eutrophic Condition

Chl a 90th percentile concentrations in the Potomac River estuary during 2002 ranged from Low to High in the following approximate spatial coverage: Low, 1%, The overall eutrophic condition for the Potomac River in 2002 was High and was calculated from a primary symptoms value of High and a secondary symptoms value of High.

Response – Determination of Future Outlook

For the Potomac River basin, nitrogen loading, phosphorus loading, and sediments all decreased between 1985 and 2002 (Potomac River Basin Summary, 2004). In contrast, however, population growth in Maryland alone is projected to increase at an approximate 1% every year, while the Potomac River basin itself includes many new suburban communities that are expected to continue to experience rapid suburban growth.

As a result, even though nitrogen, phosphorus, and sediment loading are decreasing, significant population increases and development may mask the decreases in loading and cause there to be only small positive changes in future nutrient pressures. Thus, with High susceptibility and only small improvements in future nutrient pressures, the overall calculation for DFO in the Potomac River is Improve Low for 2002.

ASSETS Synthesis

The ASSETS synthesis for the Potomac River in 2002 resulted in a value of Bad. Both the pressure to the system (OHI) and the state of the system (OEC) were rated High. There are only small expected improvements in the future nutrient pressures (DFO), giving a rating of Improve Low. These three values combine for an overall ASSETS rating of Bad (Table 15).

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