Fact Sheet No. 5

# MASSACHUSETTS BAYS PROGRAM

UMASS/AMHERST
312066016608422
MASS. EA13.102: P56/2

# Physical Oceanography of Massachusetts and Cape Cod Bays

The circulation patterns of the bays control the transport of pollutants throughout the bays ecosystem. These patterns are influenced by a number of physical processes which occur on a local and a regional scale, including the wind, the rain and temperature. This fact sheet is a brief summary of a number of research projects which provide insight into the physical processes that influence the health of the entire bays ecosystem. It is one in a series of fact sheets published by the Massachusetts Bays Program. For more information, please call 1-800-447-BAYS.


- A New View of The Bays
- What Does the Bays' Water Column Look Like?
- Circulation Patterns of The Bays
- Significance of Findings


## A New View of The Bays

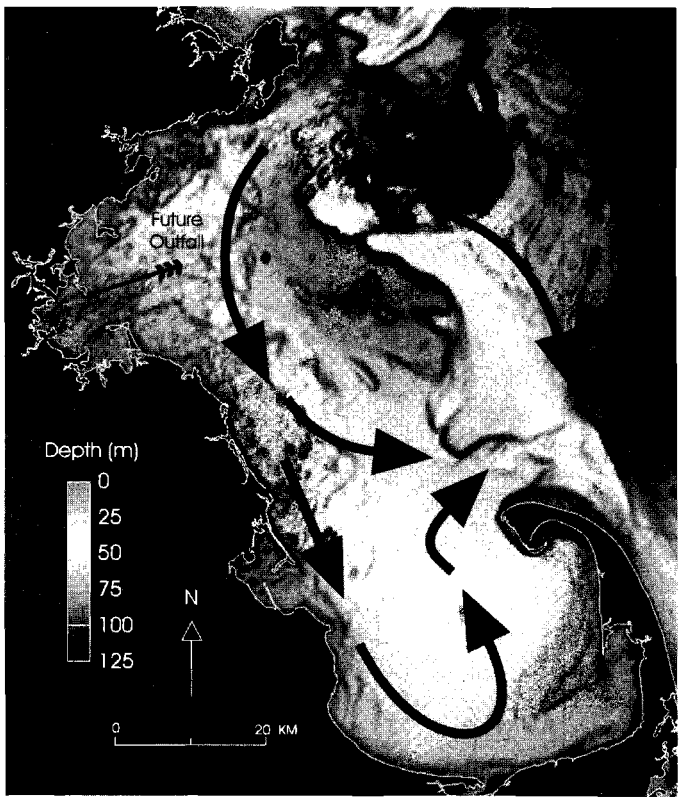
***Tumors in fish, advisories against consumption of lobster tomalley, and questions relating to the extension of the Massachusetts Water Resources Authority (MWRA) outfall pipe into Massachusetts Bay have made us begin to look at how pollutants are transported throughout the marine waters.***

For most of human history, people have used rivers, lakes and the ocean to dispose of their waste. There seemed to be no limit to the capacity of the ocean, especially, to absorb noxious materials that residents wanted to put out of sight and out of mind. People believed that currents carried the wastes far out to sea where they were diluted by seawater or sank to the bottom of the deep ocean, thought to be a silent, dark region that supported no important life.

Of course, those living along the shores of Massachusetts and Cape Cod Bays are realizing that this characterization of the ocean is wrong. Currents do indeed bear some of our pollutants into the open ocean, but we've learned that these substances frequently affect the estuaries through which they pass. We've learned, too, that some contaminants settle to the bottom but may be taken up by marine organisms. We are now seeing the cumulative effects of centuries of nearshore dumping and disposal, as well as contamination from the atmosphere, and runoff from a concentrated population along the coast.

As technology has made more of the marine environment accessible to us, we have learned that even the deep ocean supports a lively ecosystem.

**Figure 1 — Circulation Patterns**
*Overall circulation patterns in Massachusetts and Cape Cod Bays. Note the small* ***gyre*** *(pronounced "ji-er": a circular or spiral motion) in eastern Cape Cod Bay which may be a factor in the unusually intense phytoplankton blooms observed there.*




U.S. Geological Survey, Woods Hole, MA

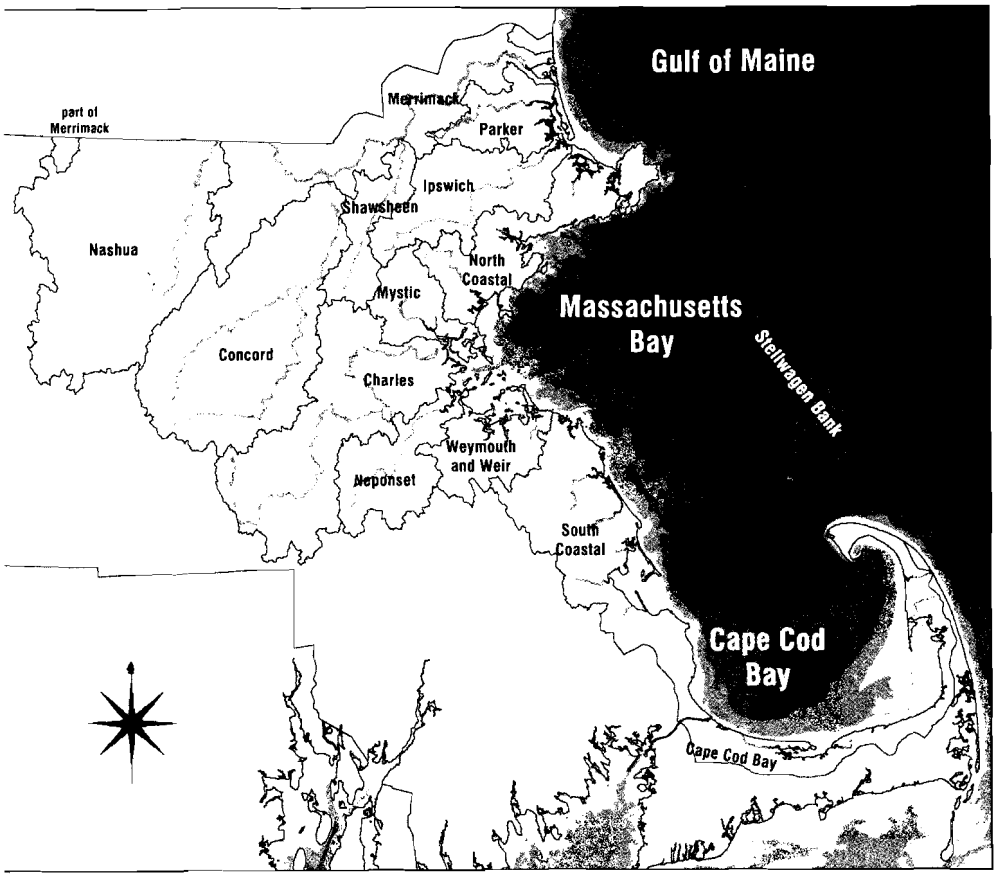



**Figure 2 — What is an Estuary?**
*Massachusetts and Cape Cod Bays form a large* ***estuary****, defined as a "semi-enclosed body of water, which has a free connection with the open sea and within which seawater is measurably diluted with freshwater from land drainage." This means that* ***freshwater*** *(primarily derived from rivers) mixes with seawater (from the Gulf of Maine) and that* ***circulation*** *of water is somewhat restricted within the bays. Estuaries are among the most productive ecosystems on earth because nutrients are retained and potentially recycled. However, retention has its drawbacks. Contaminants dissolved or attached to particles entering the bays tend to become trapped, resulting in accumulation of contaminated sediments or uptake by aquatic organisms.*

It has become clear that human activity is affecting the health of both the coastal and estuarine waters we enjoy and the less visible ecosystem further offshore. Tumors in fish and shellfish, and advisories against consumption of lobster tomalley in Boston Harbor, are the most visible consequences of this stress. Sediments are contaminated not only in Boston Harbor and Salem Sound, but also offshore in Massachusetts Bay where contaminants have been found in areas thought to be relatively unimpacted.

Preliminary work related to the clean-up of Boston Harbor and extension of the outfall pipe into Massachusetts Bay revealed how little we knew about the bays ecosystem and the effect this relocated discharge (an average of 550 million gallons per day) would have on the bays. With $1.6 million in settlement funds from the lawsuit against the Commonwealth over the pollution of Boston Harbor, the Massachusetts Bays Program launched the first integrated research program focused on the bays. This was done in coordination with related projects of the Massachusetts Water Resources Authority (MWRA), the U.S. Geological Survey (USGS), and the Massachusetts Institute of Technology Sea Grant Program.

## What Does The Bays' Water Column Look Like?

***Heated by the sun and mixed with freshwater and the air, the surface waters tend to be warmer, less salty and more oxygen-rich than the deep waters of the bays.***

We generally think of the water in the ocean as being uniformly cold and salty, not realizing that its many characteristics vary throughout the water column (from the surface to the bottom.) Studies of Massachusetts and Cape Cod Bays have found that temperature and salinity vary horizontally and vertically. Freshwater input and solar heating stratify, or separate, the water column into layers of varying water properties. Rivers provide freshwater which can form a brackish (moderately salty), less dense layer over the deeper, saltier (and therefore denser) water, and sunlight warms the upper part of the water column, making it less dense than the lower part. The relatively sharp change in density between layers is called a **pycnocline**. In Massachusetts Bays, the pycnocline is seasonal, lasting from roughly April to October, (see Figure 3).

Dissolved oxygen, important to the respiration of marine animals, is generally more concentrated in the upper parts of the water column because of mixing with the atmosphere and because phytoplankton living near the surface produce oxygen during photosynthesis. There is some dissolved oxygen in deep waters, which is used by bottom-dwelling animals during respiration, and by decaying organic matter. The pycnocline effectively isolates the deeper waters in Stellwagen Basin (west of Stellwagen Bank) resulting in levels of dissolved

oxygen which are among the lowest in the bays, but still adequate to support marine life.

The importance of each of these factors varies over the course of the year and from place to place. Nearshore regions, for instance, are more influenced by tides and freshwater input than are offshore waters. Though significant stratification occurs in some areas of Boston Harbor, in much of the Harbor the freshwater flow from rivers plus tidal action, combined with the shallow depth of the Harbor, result in a well-mixed water column. The picture is disrupted in nearshore and offshore regions by large events, such as hurricanes and other coastal storms.

## Circulation Patterns of The Bays

***Though surface water circulation in Massachusetts Bays is generally counter-clockwise it slows down through Cape Cod Bay, moves faster than deeper waters during the summer, and slows during the winter when the well-mixed water column flows more uniformly throughout the bays.***

***Depending on the direction, winds can cause "upwelling" and "downwelling" which can bring cold, deep waters up or push the warmer surface waters down.***

In order to better understand the rate of transport and the fate and movement of waterborne pollutants in the bays, the Massachusetts Bays Program funded a major study to gather information about the physical processes operating on the bays. The study addressed seasonal variations in circulation patterns and looked at how currents, tides, winds, and runoff influence circulation. Scientists from the Woods Hole Oceanographic Institution, the University of Massachusetts - Boston, the University of New Hampshire and the USGS used information gathered from moored instrument arrays, satellite-tracked surface drifters, shipboard surveys and satellite images to provide data on large-scale water movements and properties—the physical oceanography—of the bays.

The study confirmed that surface water circulation in Massachusetts Bays is generally counter-clockwise, entering from the Gulf of Maine near

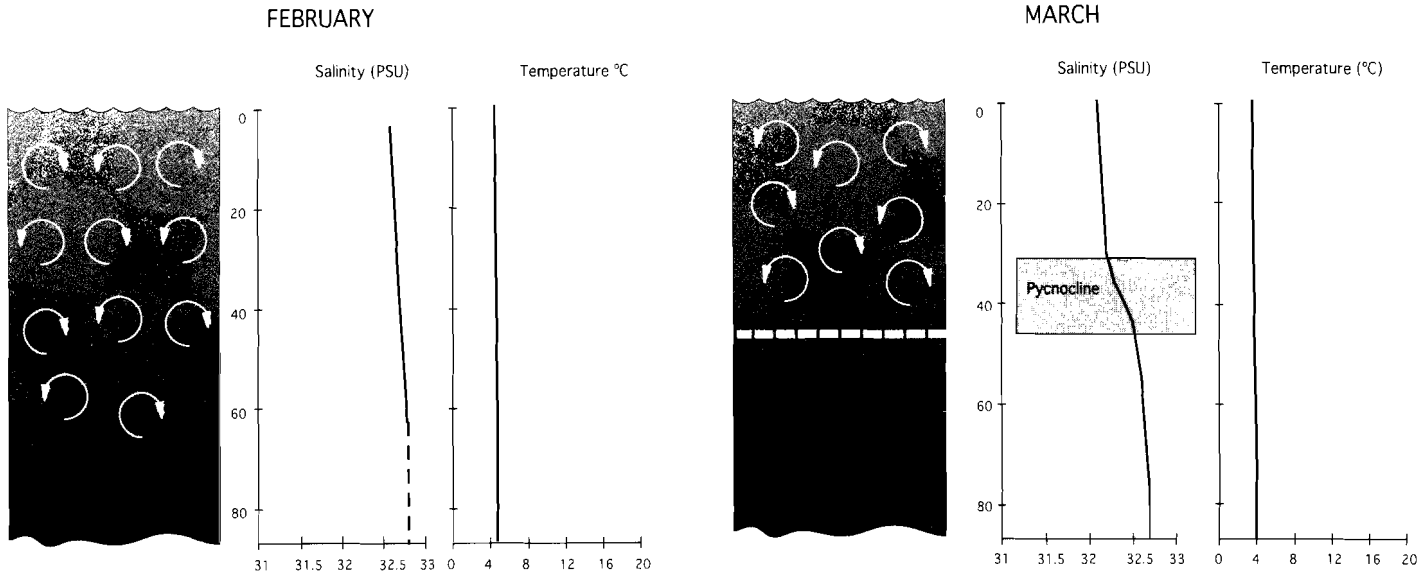



**Figure 3 — Seasonal Variations in the Water Column**
*Seasonal profiles of the water column in the offshore parts of Massachusetts Bays are depicted above. The depths are shown in meters. The profile for February is typical for winter, with salinity and temperature fairly constant from the surface to the bottom. These characteristics allow mixing throughout the water column because there is very little difference in water density from top to bottom. The profile for March shows little change in temperature, but does show a decrease in the salinity (and consequently the density) of surface water because of increased freshwater input from snowmelt and spring rains. The part of the water column where the change in density is most pronounced is called the* ***pycnocline****.*

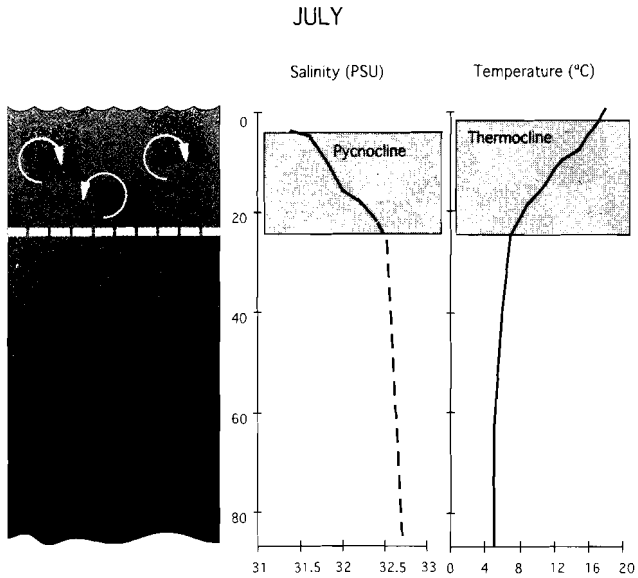
Cape Ann and moving first west, then south along the South Shore, travelling either directly east or through Cape Cod Bay and finally leaving the bays north of Race Point at the tip of Cape Cod, (see Figure 1). Contaminants may travel a considerable distance from their point of entry into the bays to other areas where they may accumulate in sediments or be taken up by marine organisms. The waters are influenced by the larger counterclockwise patterns in the Gulf of Maine, which are, in turn, driven by rivers, by circulation in the North Atlantic, and by large-scale atmospheric weather patterns.

Surface water (down to about 18 meters) takes anywhere from 20 to 40 days to complete its trip through the bays. A slow-moving eddy (a closed loop of recirculating flow separate from the main stream) in Cape Cod Bay sometimes results in the waters remaining there longer than in Massachusetts Bay. One drifter buoy released during the study remained in Cape Cod Bay for more than a month. This may help to explain the intense phytoplankton blooms observed there in early to mid-February. The longer residence time combined with the shallow depth allows the phytoplankton to begin growing early in the year when the overall light level is still low in the deeper waters.

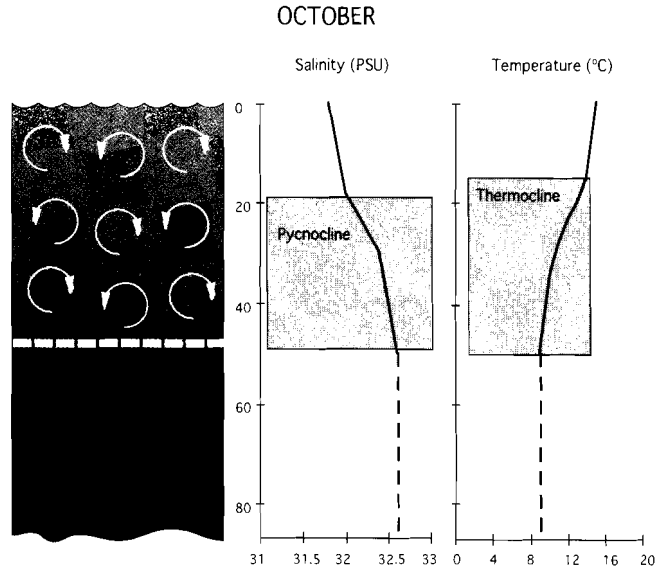
Generally, in large bodies of water, the deeper water is somewhat dependent on the surface water for its movement. The surface water creates a shear that drives the movement of deeper waters and "drags" it along its path. In Massachusetts and Cape Cod Bays, from late spring through fall, vertical variations in density tend to isolate the deeper water from the surface. In fact, there may be very little net flow of bottom waters (below about 60 meters) through the relatively shallow northern connection with the Gulf of Maine. However, in the winter the water column is well mixed and the flow through the bays is more nearly uniform with depth.

## How fast does the water move through the bays?

The study also found that current speed varies with the season. During the winter, surface currents proceed on their generally counterclockwise path through the bays more slowly than in the summer due to a well-mixed water column. Surface currents measured off the Scituate coast during the winter averaged only about 4.6 cm/sec, whereas




*By July, the pycnocline is stronger and higher in the water column because of reduced freshwater input and because the surface waters are warmed, and, hence, made less dense, by the sun. The warmer, less saline water is less dense than in March and the stronger gradients greatly reduce vertical mixing.*




*October's profile shows a weakening of the pycnocline. Surface cooling due to shorter days and cooler air temperatures reduce the surface layer temperature and the lower gradients result in increased mixing.*

during the summer currents averaged about 8.3 cm/sec. (These values reflect both the magnitude and direction of the current.) Intermediate waters (18 to 28 meters deep) flow more slowly, and, in general, follow the course of the surface currents throughout the year. Deep waters (below 30 meters) are especially sluggish during the summer months and are known to occasionally move in directions opposite the surface waters.

### What causes the vertical movement of water in the bays?

During the summer, strong southwesterly winds move the surface water offshore bringing colder, deeper water to the surface, and lifting or elevating the pycnocline (see Figure 2). This phenomenon, called **upwelling**, is most familiar to beachgoers on the North and South shores, as they are faced with cold water for swimming. It is important because the deeper water also brings nutrients (like nitrogen and phosphorus) into the upper part of the water column where the light-dependent phytoplankton can grow. Winds blowing from an offshore direction cause downwelling, forcing nearshore surface water to sink as offshore surface water is pushed inshore. Data suggest that during the three-month summer stratified period about one-eighth of the bottom water can be exchanged with the surface layer.

### Do the tides influence the circulation patterns of the bays?

Since tides move water back and forth with no net direction, they do not have a strong effect on the overall circulation patterns of the bays. However, the tides in Massachusetts Bays, which range from 8 to 12 feet, can have strong local effects. Tides are the major factor controlling the exchange of water between Boston Harbor and Massachusetts Bay. In shallow waters of the bays, tides create turbulence near the bottom which can resuspend sediments or disrupt stratification.

## Significance of These Findings

***The movement of waters within the bays, such as vertical mixing, circulation at various depths, upwelling and the length of time waters remain in a given area, will help researchers predict the fate of the effluent from outfall pipes, the distribution of large concentrations (blooms) of phytoplankton, and the movement of pollutants throughout the bays ecosystem.***

The findings of this project have significant implications for management strategies to reduce the effects of pollution on Massachusetts and Cape Cod Bays. They are especially important when one considers that decisions regarding the disposal of wastes from sewage treatment plants, industries, and dredging projects are often based upon very limited data. Data are usually limited to local circulation patterns, which restricts the decision-makers' ability to accurately predict the ultimate fate of pollutants discharged into the larger bays system.

Particularly important is the new information on vertical mixing of the water column, which provides clues to the fate of the effluent from the extended MWRA sewage outfall and how it could affect the production of phytoplankton. The study suggests that the fate of the effluent plume will be most affected by the circulation of mid-depth waters (between 18 and 28 meters deep) in the lower portion of the pycnocline, (see Figure 2), confirming the assumption scientists made when they recommended that site. Further measurements of currents at this depth were made by scientists at the Woods Hole Oceanographic Institution to determine the extent of this mixing and to better estimate the length of time the effluent will remain in the area of the outfall.

The data gathered on upwelling and residence time, in conjunction with information on nutrients (see Fact Sheet #7), are useful for predicting the distribution of phytoplankton blooms, which form the base of the food chain for marine animals. Circulation patterns may have an effect on the shellfishery when "red tide" seed populations are carried into the bays from waters north of Massachusetts. Blooms of these toxic organisms lead to extensive closures of shellfish beds. In addition, nutrient availability may indirectly affect the

endangered whale populations that inhabit Cape Cod Bay. The phytoplankton that serves as the primary food source for the tiny animals eaten by the whales depend upon nutrient availability to grow. The high residence time of water in Cape Cod Bay, and its relationship to productivity, are being clarified through further studies (Gardner & Villareal).

The value of this information is further enhanced by the results of related studies. For example, based upon sediment traps deployed near the planned MWRA outfall, the USGS has found that storms, especially during the fall and winter, periodically resuspend material from the sea floor. When combined with our new knowledge about the circulation patterns, we can begin to predict the fate of the contaminants in the bays. To that end, the USGS is using the MBP data to calibrate a three-dimensional model of circulation in Massachusetts and Cape Cod Bays which will help improve our ability to predict how particles, including those that reenter the water column during storms or other events, become transported to other locations. Taken together, this information provides a more complete characterization of the processes at work in the bays, and will greatly assist researchers in monitoring the effects of pollutant discharges to the bays.

## Resources

"Physical Oceanographic Investigation of Massachusetts and Cape Cod Bays," Geyer, et al, 1992; MBP-92-03.

"Biological and Physical Processes Controlling Nutrient Dynamics and Primary Production in Cape Cod Bay," Gardner and Villareal, UMass-Boston; Loder, University of New Hampshire-Durham; in prep.

## Contacts

Massachusetts Bays Program, 100 Cambridge Street, Room 2006, Boston, MA 02202; Diane Gould, 617-727-9530.

Massachusetts Institute of Technology, Dept. of Civil Engineering, 77 Massachusetts Avenue, Cambridge, MA 02139; Eric Adams, 617-253-6595.

Massachusetts Water Resources Authority, Charlestown Navy Yard, 100 First Avenue, Boston, MA 02129; Wendy Leo, 617-242-6000 x5501.

National Oceanic and Atmospheric Administration, JFK Federal Building, HEE-CAN6, Boston, MA 02203; Kenneth Finkelstein, 617-223-5537.

U.S. Environmental Protection Agency, Region 1, JFK Federal Building, WQE, Boston, MA 02203; Matthew Liebman, 617-565-4866.

U.S. Geological Survey, 384 Woods Hole Road, Quissett Campus, Woods Hole, MA 02543-1598; Richard Signell, 508-457-2229.

University of Massachusetts-Boston, Environmental Sciences Program, Harbor Campus, Boston, MA 02125; George B. Gardner, (617) 287-7454.

Woods Hole Oceanographic Institution, Applied Ocean Physics, Woods Hole, MA 02543; W. Rockwell Geyer, (508) 548-1400 x2868.

## The Estuary Program

The Massachusetts Bays Program is a joint effort of local, state, and federal governments, as well as citizens, scientists, educators and businesses to develop regional solutions to pollution problems in the Bays and their adjacent watersheds. The Program is funded under the Clean Water Act through the U.S. Environmental Protection Agency (#CE001534-01-4), and administered by the Massachusetts Executive Office of Environmental Affairs' Coastal Zone Management Office. In addition to developing a long-term plan to improve water quality management, the Program offers information on and technical assistance for innovative, locally-based pollution prevention and remediation projects, and sponsors a multi-faceted public outreach and education effort to heighten awareness of pollution problems and to enlist support for and participation in bays protection.

Massachusetts Bays Program Fact Sheets —Editor: Elizabeth McEvoy. Contributing Writers: Maxine Schmidt and Matthew Liebman. Design: Don Eunson.

For more information call 1-800-447-BAYS or write Massachusetts Bays Program, 100 Cambridge Street, Room 2006, Boston, MA 02202.

100% Recycled Fiber