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Understanding Casco Bay: A Circulation Study Factsheet

Casco Bay Estuary Project

Understanding Casco Bay: A Circulation Study

The waters of Casco Bay are in constant motion, carrying microscopic plants and animals, nutrients, dissolved oxygen, and pollutants throughout the bay. Knowing how these waters circulate helps to answer many questions about the bay.

Currents influence where fish will feed, where clam larvae will settle, where algal blooms are a threat, and what happens to pollutants discharged into the bay. Understanding how and where water moves provides the framework for comprehending, managing, and working with the natural systems found in Casco Bay.

Scientists, managers, and citizens alike have questioned how pollution moves through the waters that make up Casco Bay, and yet little background information has been available. As interest in protecting the bay from pollution and degradation has increased, the Casco Bay Estuary Project formulated these questions:

• What happens to pollutants in the bay? Do polluted discharges into Portland Harbor find their way to the eastern part of the bay? If you drop something in the water in Portland, will it wash ashore in Harpswell?

• Does fresh water from the Kennebec River affect Casco Bay? The Kennebec River is not part of the Casco Bay watershed, yet unexplained contaminants are found in the eastern portion of the bay. Are these pollutants carried down the Kennebec River and transported and deposited into Casco Bay?

• Does poor water circulation magnify the effects of algal blooms in Maquoit Bay, in Casco Bay's northern reaches? In 1988, an algal bloom depleted oxygen levels in Maquoit Bay, resulting in a devastatingly high mortality of marine organisms.

To answer these questions and to better understand how water moves in the bay, the Casco Bay Estuary Project commissioned a study to model water circulation. Dr. Bryan Pearce, Dr. Neal Pettigrew, and Bin Gong from the University of Maine Department of Civil and Environmental Engineering developed the Casco Bay Circulation Model. This model characterizes the influences and patterns of water circulation in Casco Bay. This fact sheet explains some of the factors affecting circulation and how the model helps us grasp the way water moves in the bay.

How Water Moves in Casco Bay

The tides, wind, temperature, salinity, and the earth's gravity all influence how water circulates in Casco Bay. Water circulation is dominated by the tides, although other forces are interrelated and work together to strengthen or dampen the currents.

A message in a bottle

If you put a note in a bottle and throw it into the bay, will it wash up in Freeport, Cape Cod, Nova Scotia, or Europe? It all depends on where and when you throw your bottle into the bay and how long it stays afloat.

If you toss your bottle off the shore of Maquoit Bay during a dry spell, chances are it will wash ashore in Freeport or Brunswick without much fanfare.

On the other hand, if during an outgoing tide, you toss your bottle off a dock on the exposed shore of one of Casco Bay's islands, it will likely be carried out to the Gulf of Maine. Once in the Gulf it will slowly circulate counterclockwise in the Gulf of Maine Gyre, coming close to Cape Cod but turning eastward out to sea and then northward toward Nova Scotia and the Bay of Fundy. It may turn westward and continue down the Maine coast toward Casco Bay again, making a loop in about three months.

If your bottle tracked more southerly near Cape Cod, it could float across Georges Bank and get picked up by the Gulf Stream. The trip across the Atlantic Ocean would be much warmer than the float within the Gulf of Maine, and with luck, in six or seven weeks the bottle may turn up in Ireland, or maybe even Portugal.

This assumes your bottle is floating on the surface, but if your bottle could float 100 meters below the surface in the Gulf of Maine, it would follow a different track. At that depth, temperature, salinity, and the character of the bottom play a large role in dictating currents and water flow. Your bottle may take up to a year to complete its tour of the Gulf of Maine. And if the bottle is deeper yet and makes its way to the open ocean, it may be carried off to Arctic waters.

Tides

A nine-foot tidal range in Casco Bay provides a tremendous influence on water circulation and currents. Tides are caused by the gravitational effect of the moon and sun on the ocean. Heavy rainfall, low barometric pressure, and strong onshore winds increase tides, while the opposite will decrease them. Casco Bay has a semidiurnal tidal cycle, meaning that there are usually two high tides and two low tides each day. Each tide cycle is 12 hours and 25 minutes long, so that high and low tides are 50 minutes later each day.

The speed and direction of tidal currents change constantly during the tidal cycle. Currents have the greatest energy when water is pushed in and out of bays and channels during their highest and lowest points. Tidal levels fluctuate during the month depending on how the earth, moon, and sun line up (Figure 1).

Tidal currents across Casco Bay's rough bottom stir up the water in the bay. This bottom friction creates turbulence and mixes microscopic plants, animals (phytoplankton and zooplankton), nutrients, and pollutants throughout the water column (a cross-section of water from the surface to the ocean bottom). In the deeper parts of Casco Bay, turbulence does not mix the entire water column, and a layer of water warmed by the sun remains at the surface during the summer months.

Wind

Wind plays an important role in moving surface water and can influence currents in the upper portion of the water column. However, wind is not as important as tide in affecting the currents of Casco Bay. Although the wind can create a rough "chop" and whitecaps which appear to be moving, in fact it is the waves themselves that are moving and not the water.

The predominant winds in Casco Bay are from the southwest in summer and from the northwest in winter. On the southeast side of Casco Bay's islands, surface wave action and turbulence can be quite severe when the winds are high.

Temperature

When water is warmed, it becomes lighter and tends to rise; when it is cooled, it tends to sink. Throughout the year, changing water temperatures from seasonal heating and cooling mix the water column. Casco Bay also has several large rivers flowing into it. River water may be warmer than sea water, creating thermal currents as the warmer (and less saline) water flows above the cooler sea water.

Salinity

The more salty or saline the water, the heavier it is. Salt water sinks under fresh water, allowing the less saline fresh water to flow above. This phenomenon is seen near the mouths of rivers and downstream where freshwater pools may persist. Where the Kennebec River flows into the ocean, a weak current system is created with a flow parallel to the coast in a southerly direction along outer Casco Bay. This flow fluctuates with changes in river volume or discharge, onshore movement of oceanic water, and wind.

Upwelling

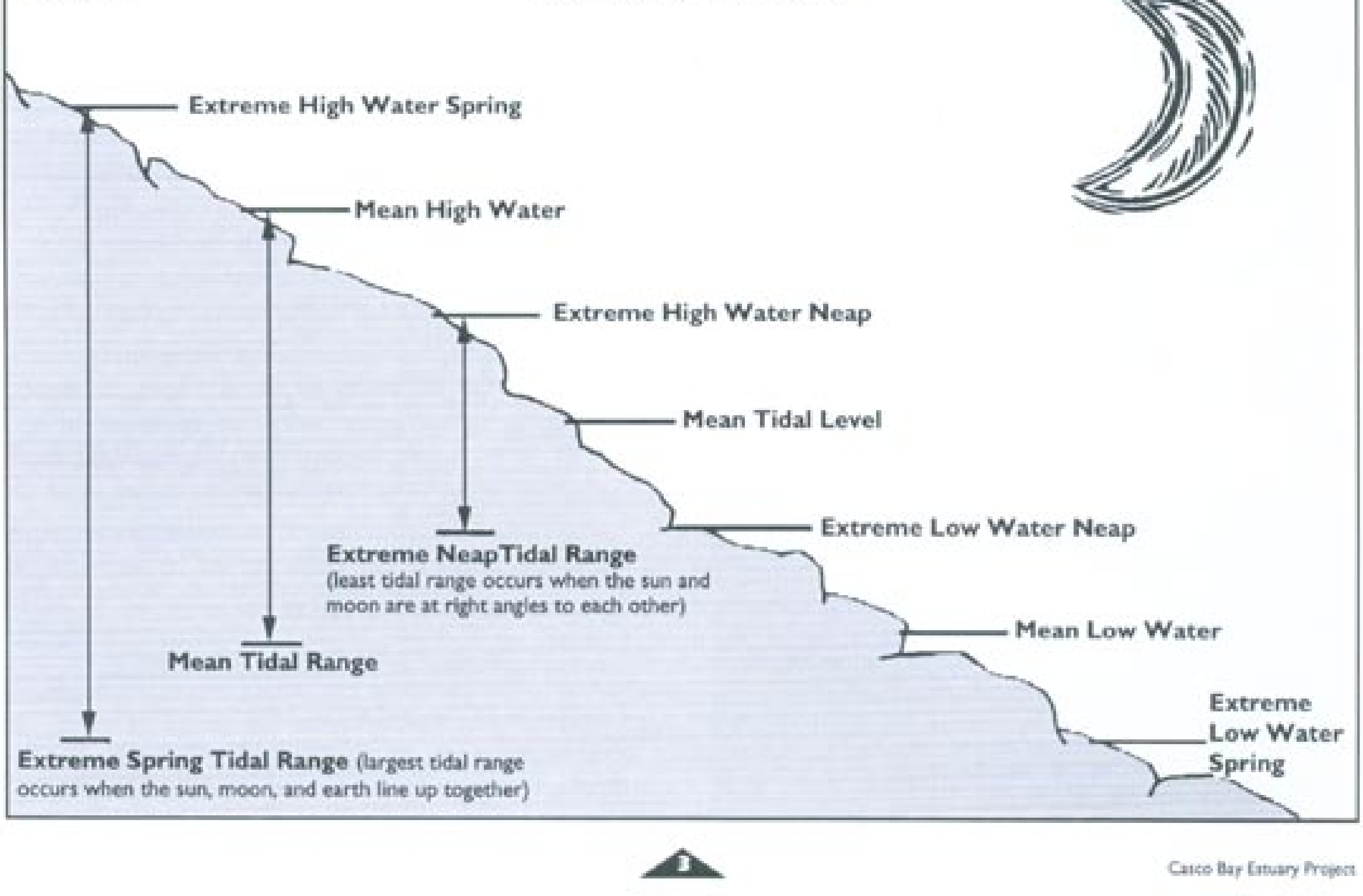
Strong tides and other currents can pull water up from deep channels and basins below the surface. This upwelling can create colder, more saline pools of water. Since cold water holds more dissolved oxygen and nutrients, these areas support rich planktonic communities that are more productive than the surrounding areas. Casco Bay's rough bottom, full of constricting channels and basins, contributes to this phenomenon.

What is Known About Casco Bay's Currents?

While very little actual data has been gathered on water circulation in Casco Bay, we do understand what factors influence the currents, the most dominant being tides. Coupled with the numerous linear islands that create constrictions across the bay, the tides create strong currents through the channels.

While currents are strong near the center of the bay, the upper reaches of its shallow inner bays (i.e., Maquoit and Middle Bays) experience very little "flushing" or exchange of water. When the weather is dry and there is little fresh water flowing into these bays, the water sloshes back and forth, much like in a bathtub. This makes these bays more susceptible to algal blooms, because there is little exchange of water

FIGURE 1 **Tidal ranges and levels**



to dilute and mix with the nitrogen from runoff or wastewater. Nitrogen acts as a fertilizer to stimulate algal growth to nonsustainable levels. Algal blooms then crash, or die off, and decompose, quickly depleting dissolved oxygen in the water column and creating problems for other organisms in the bay.

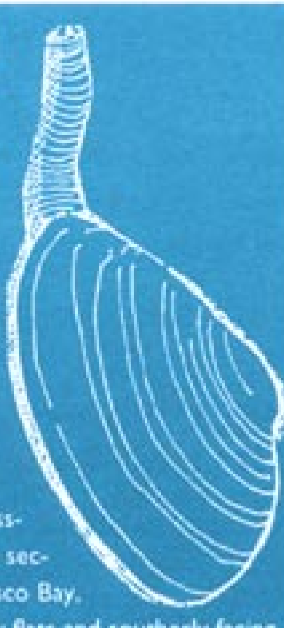
The rugged bottom of Casco Bay also has many constricting narrow channels, isolated edges, and shoals that control the flow of water at those depths and consequently the movement of materials within the water. In channels below thirty meters, deep water currents are slow. West Cod Ledge sits off Casco Bay and controls water flow in the entire area. Seaward of West Cod Ledge is an area where currents slow and important fishing grounds are found near Hue and Cry and East Cod Ledges.

Persistent upwelling pulls deep, cold water up toward the surface and into the heads of major channels and the edges of the inner bays. This cold water is apparently from two bottom areas, one southwest of Cape Elizabeth and the other to the east of Halfway Rock. Another large cool pool is found just south of Jewell Island where incoming tides diverge to flow into the Portland Harbor Channel, Luckse Sound, and Hussey Sound.

The Casco Bay Estuary receives vast quantities of fresh water from the Kennebec, Royal, Fore, Stroudwater, and Presumpscot Rivers. This fresh water can affect the distribution of marine organisms living on the bottom and carry toxic contaminants into the bay. Pollutants that are dissolved in fresh river water can precipitate out in the very different chemical environment of salt water. It appears that a pool of fresh water from the Kennebec River hooks around Small Point and enters Quahog Bay near Harpswell. Researchers speculate that this freshwater flow is responsible for the unexplained presence of toxic contaminants in Quahog Bay and the New Meadows River.

The outer reaches of Casco Bay are affected by the Gulf of Maine Gyre, a slow, counterclockwise flow of cool water circulating throughout the Gulf. This gyre, in part, sets off a clockwise recirculation gyre near West Cod Ledge.

Circulation and Clam Larvae



One example of how the Casco Bay Circulation Model can help researchers understand natural processes within Casco Bay is illustrated by connecting circulation patterns with the greater settlement of clam larvae in specific locations in the bay.

Clam sets are most successful in the north-northeastern sections of the finger bays of Casco Bay, particularly on the head-of-bay flats and southerly facing coves. Researchers speculate that tidal currents and wind may be responsible.

Clam spat, or microscopic larvae, are suspended for two to three weeks in the surface layer of the water column, between May and September. During the summer months, the wind is predominantly out of the southwest, depositing surface-carried materials on shores of the north-northeastern bays. The tidal currents disperse the larvae, bringing them into the bays and coves while the wind pushes them to shore. The warm, south-facing flats encourage settlement in these areas.

The Casco Bay Circulation Model

Building on efforts to model water circulation in other bays and estuaries, the research team from the University of Maine used the Model for Estuarine and Coastal Circulation Assessment (MECCA) as a starting point for its work. Originally developed by the National Oceanic and Atmospheric Administration, MECCA provided the basic tool to begin the enormous job of calculating Casco Bay's currents. Like Casco Bay, the driving forces for MECCA are tide, wind, water density, and air pressure.

The model itself is exceedingly complex. The formulas and commands fill an appendix over an inch thick. To run the Casco Bay Circulation Model, the researchers broke the bay into a grid of 5,520 cells, each measuring 600 by 600 meters. For each of these grid cells, the model has another ten layers of cells to reflect how circulation is influenced by depth. Parameters in the grid cells change over time, and interact with, and are influenced by, the cells around them. The calculations needed to predict how current velocities and other variables change are time-consuming even for the fastest computer. Because there are 5,520 cells with ten layers of water depths, the computer has to calculate several variables for 55,200 cells for every thirty seconds of simulated time! A computer run to plot water circulation for several weeks takes twenty days to complete.

The model uses as inputs tidal elevations, current measurements, salinity and temperature data, wind and atmospheric pressure, and bottom topography. Each of the 55,200 cells in the Casco Bay Circulation Model contains these data. The cells also account for interaction and friction between grid cells and for lower velocities in deeper layers of water, due to friction along the ocean floor. Another model (3DENS) was used to predict the values for many of these parameters on the open ocean boundary, where little or no information was available. This information was then incorporated into MECCA.

Model Findings

After correcting glitches in MECCA and letting the model run calculations to cover several weeks, the researchers provided us the clearest picture yet as to how water circulates in the bay. Four distinct regions were characterized by the model (Figure 2):

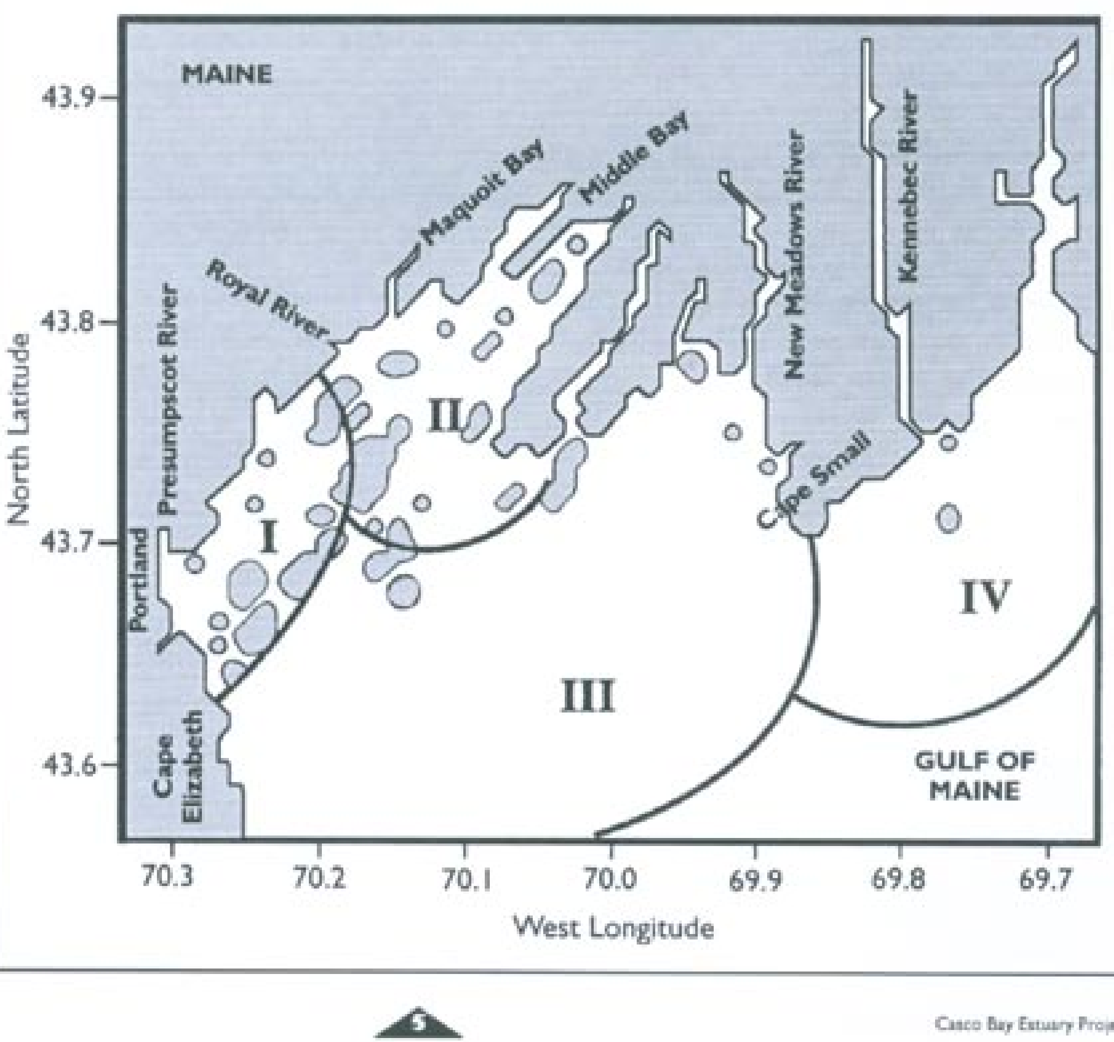
Section I has relatively small currents, except for the Portland Harbor Channel and Hussey Sound.

Section II includes Maquoit and Middle Bays and Broad Sound. Most of the water exchange between Maquoit and Middle Bays and the Gulf of Maine is forced through Broad Sound. The abrupt topography, coastal islands, and convoluted shoreline in this region create strong currents through Broad Sound. At 40 centimeters per second, they are the fastest currents in Casco Bay. The coastline in this section strongly influences the flow of ebb and flood tide, and these flows generally run parallel to the shore.

Section III is the open estuarine region affected mainly by processes in the Gulf of Maine. Water flow is predominantly north and south, depending on the tide.

Section IV is influenced by the Kennebec River. Other currents in this area are relatively small.

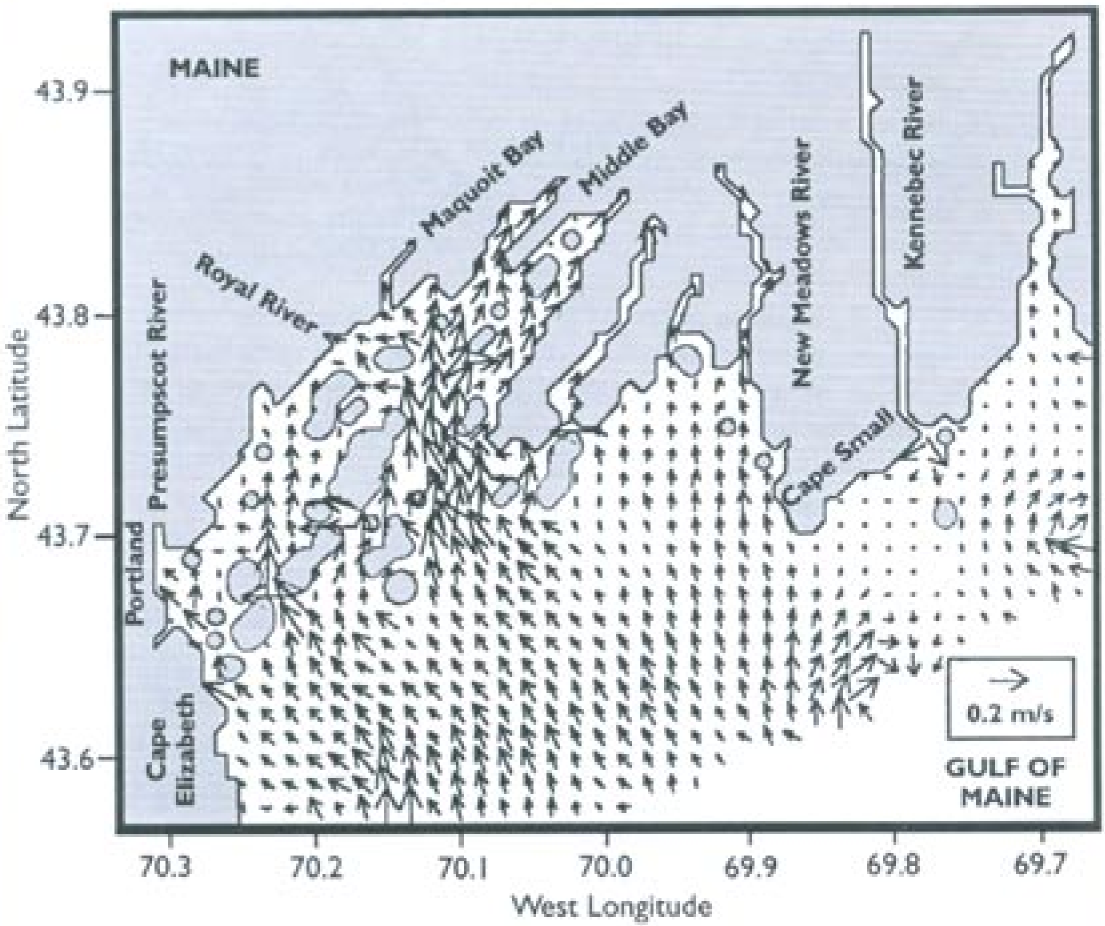
FIGURE 2 **A division of the Casco Bay region according to the flow patterns**



Figures 3 and 4 display the intensity of Casco Bay's currents during ebb and flood tide. The values of the surface, middle, and bottom currents have been averaged in these figures. The strong currents through Broad Sound and the constrictions of the islands can easily be seen in these figures.

The Casco Bay Circulation Model verifies that there is a drift that tends to move water northeast to southwest within the bay. This drift could be due to several interrelated factors, including bottom friction, overall circulation in the Gulf of Maine, or spring runoff along the shore.

FIGURE 3 **Vertically averaged flood currents**



The maximum value is 0.41 m/s

Another finding from the model and some of the fieldwork is that fresh water from the Kennebec River pools near Cape Small and the mouth of the New Meadows River during flood tides. Pulses of this fresh water then move down the coast as the current flows southwest toward New Hampshire and Massachusetts Bay.

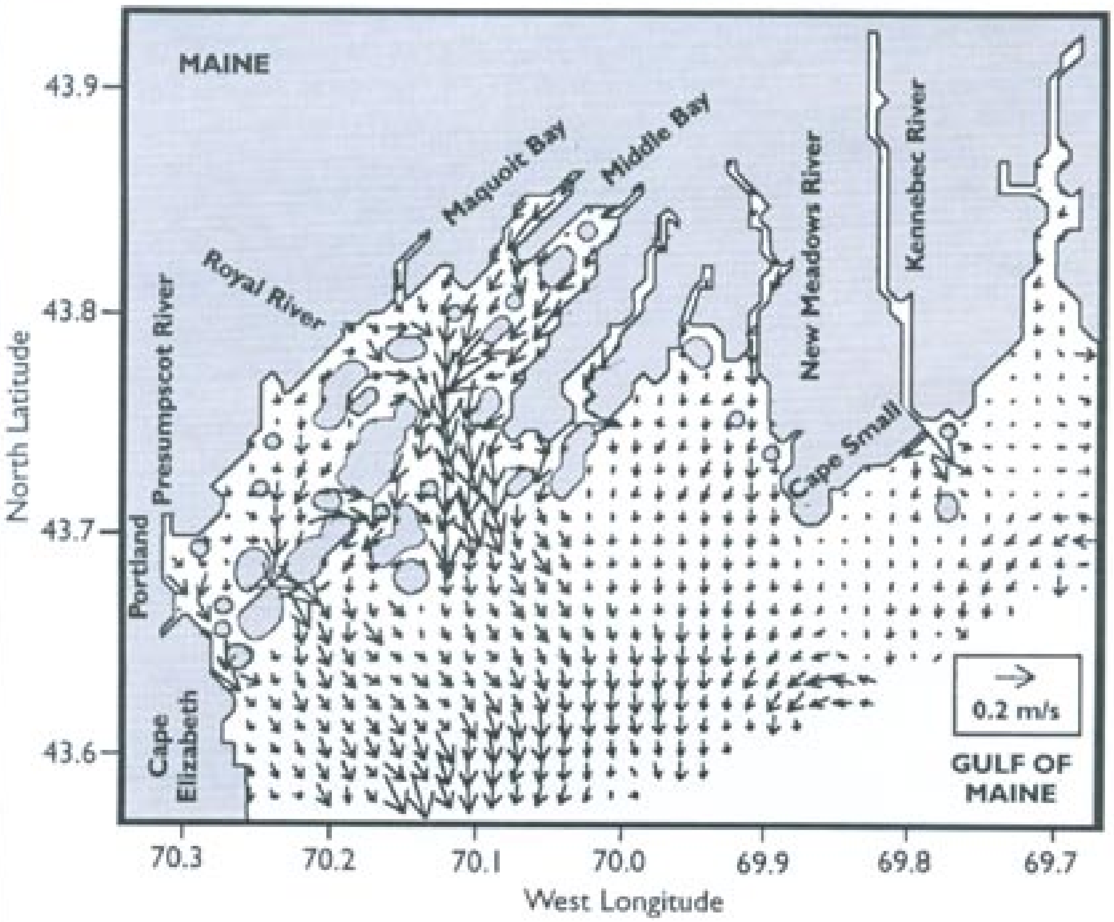
While the model provides important insights into the bay's circulation, it should be seen as a work in progress. More comprehensive field data is needed to fine-tune and field-check its accuracy, and work is needed to better integrate the influence of salinity and temperature on circulation patterns.

Maquoit and Middle Bays

In 1988, Maquoit and Middle Bays in Brunswick experienced low oxygen and a severe kill of aquatic life that have been attributed to low rates of flushing or water exchange. To understand the role of flushing rates in these two shallow embayments, the circulation research team took a closer look at water circulation within these two bays with a finer-scale submodel.

The submodel predicted that flushing rates were indeed low in these wide, shallow bays. Water sloshes back and forth with little exchange over the tidal cycles, confirming the notion that very little new water flows into the bays with each

FIGURE 4 **Vertically averaged ebb currents**



The maximum value is 0.43 m/s

tide. These findings support the theory that low flushing rates contributed to the low-oxygen event in 1988. Hot, dry summer weather magnifies these problems. Fresh water flowing into the bay from heavy rains or spring runoff increases circulation in the bays, improving their overall health.

DETMOD

To display how water circulates within Casco Bay, the research team translated data and findings from the Casco Bay Circulation Model into an animated computer program. DETMOD (Desktop Estuarine Transport Model) uses an oil spill as an example of how particles move on the water surface. The user defines where a spill occurs, how much is spilled, and over what time period (i.e., whether it is a one-time event or a continuous discharge). Wind and changing tide cycles profoundly influence how the oil plume moves across the bay. Changing the model's values for wind speed or direction dramatically affects the plume's size and orientation. The shift from ebb to flood tide also affects a plume's character, often reversing its previous direction. Plumes typically curve around and continue to spread after a change of tide.

Figures 5, 6 and 7 (see next page) illustrate time-series graphics from a DETMOD simulation covering several hours. Figure 5 simulates a slick from a continuous oil spill off the tip of Bailey's Island with a light west wind and an incoming tide. In Figure 6, the effect of tide changes can be seen on the plume ten hours after the initial spill. After fifteen hours (Figure 7), the oil disperses and is carried inland with the incoming tide.

The direction and strength of water currents anywhere in the bay can be displayed in DETMOD, as well as the bathymetry or characteristics of the bottom. The program also can calculate how much oil remains within a grid cell, to see how much oil is left in the area after a spill.

While DETMOD was developed to illustrate and predict oil spill movement, it can also be used to track the movement of other floating or weightless particles in Casco Bay, such as pollutants or marine organisms. The animated computer program can be run for Casco Bay or just Maquoit Bay. The Maquoit Bay submodel can track how long a particle remains in the bay, to examine the role of flushing.

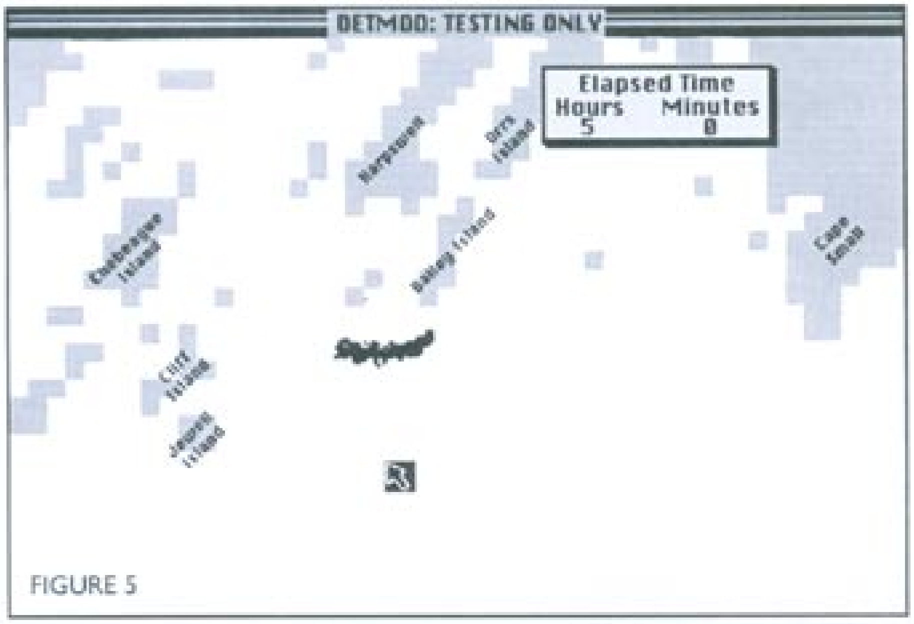


FIGURE 5

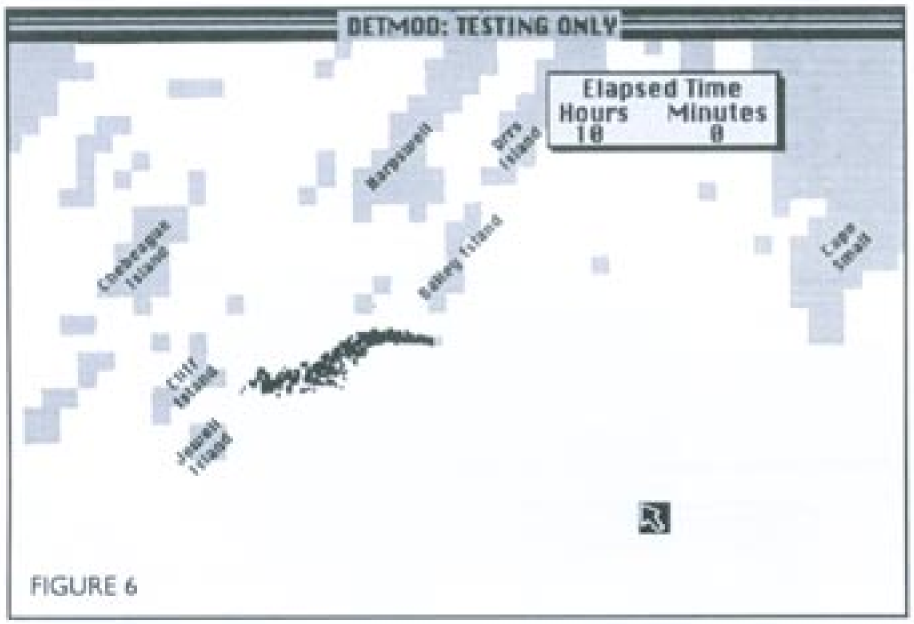


FIGURE 6

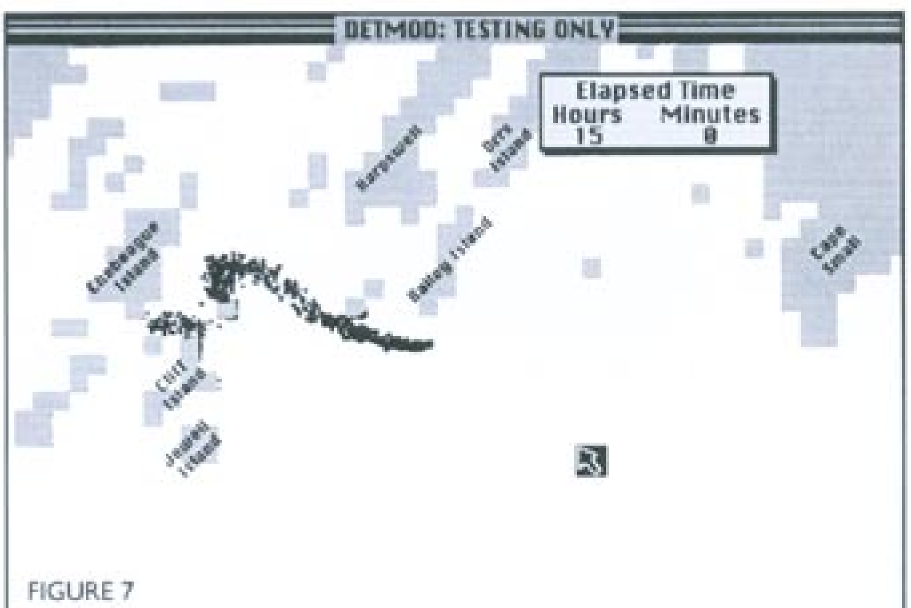


FIGURE 7

How The Model Can Be Used

The Casco Bay Circulation Model provides a valuable tool for predicting and comprehending water circulation patterns and currents within the bay. With little actual field data, it is one of the few tools available to us. The uses for this model are myriad, including:

- Providing baseline information to predict water currents
- Predicting and tracking the distribution of microscopic marine organisms such as clam larvae or phytoplankton
- Predicting locations that are susceptible to degradation from stormwater runoff or non-point source pollution, based on low flushing rates
- Tracking pollutants from sources, once they have been detected in the bay

All in all, the model integrates all the information we currently have on Casco Bay's circulation. It provides an important link to our understanding of the bay and is a vital component of the overall framework for understanding and managing it.

Want to know more?

The mission of the Casco Bay Estuary Project is to preserve the ecological integrity of Casco Bay and ensure the compatible human uses of the bay's resources through public stewardship and effective management. For more information, call or write:

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