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Dissolved Oxygen Monitoring Project Final Report 2005

Friends of Casco Bay

Final Report

2005 Dissolved Oxygen Monitoring Project

Prepared for the

CASCO BAY ESTUARY PARTNERSHIP

by

FRIENDS OF CASCO BAY

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Introduction

Quahog Bay has experienced reduced water quality, including low dissolved oxygen (DO), for at least the past twelve years. This bay is considered one of the most environmentally challenged in Casco Bay (Doan 2004). Previous Dissolved Oxygen Monitoring Projects have revealed hypoxic conditions at depth and high organic carbon concentrations in the sediment, suggesting high sediment oxygen demand. These conditions are present regardless of temperature or salinity stratification in the water column (Doan 2003). The 2005 Dissolved Oxygen Monitoring Project was designed to examine the underlying causes of these conditions by looking at how water moves into and out of the bay. Restricted water flow would contribute to increased sedimentation and accumulation of organic matter, resulting in high bacterial respiration and low DO. Building an understanding of the flushing rates in Quahog Bay may help to develop a clearer picture of why these hypoxic events occur.

In order to measure tidal variability and mean current flow, the project focused on a narrow restriction at the mouth of Quahog Bay. Flow measurements were taken on either side of Pole Island, which lies in the middle of this restriction. Data was collected over ten days with two Acoustic Doppler Current Profilers (ADCP's) secured to the bottom of the channels on either side of the island. During the same 10-day deployment period, three sites were sampled hourly for twelve hours to document temperature, salinity and dissolved oxygen over one full tidal cycle. This 3-site transect was comprised of one site at the mouth of the bay, one at the middle of the bay, and one at the head of the bay. Wind speed and direction were measured to determine how the tidal flushing rates were modified by the wind.

Collaboration with other institutions added valuable ancillary data in addition to the information provided by the ADCP and profile measurements. Southern Maine Community College designed and helped release two GPS drifters which were tracked by Woods Hole Oceanographic Institution. Bowdoin College designed and deployed a series of smaller, short-term drifters, collected weather data from a meterological station set up near the ADCP sites, collected temperature data through HoboTemp monitors and conducted a series of water column profiles for temperature, salinity, DO, dissolved inorganic nutrients, and chlorophyll.

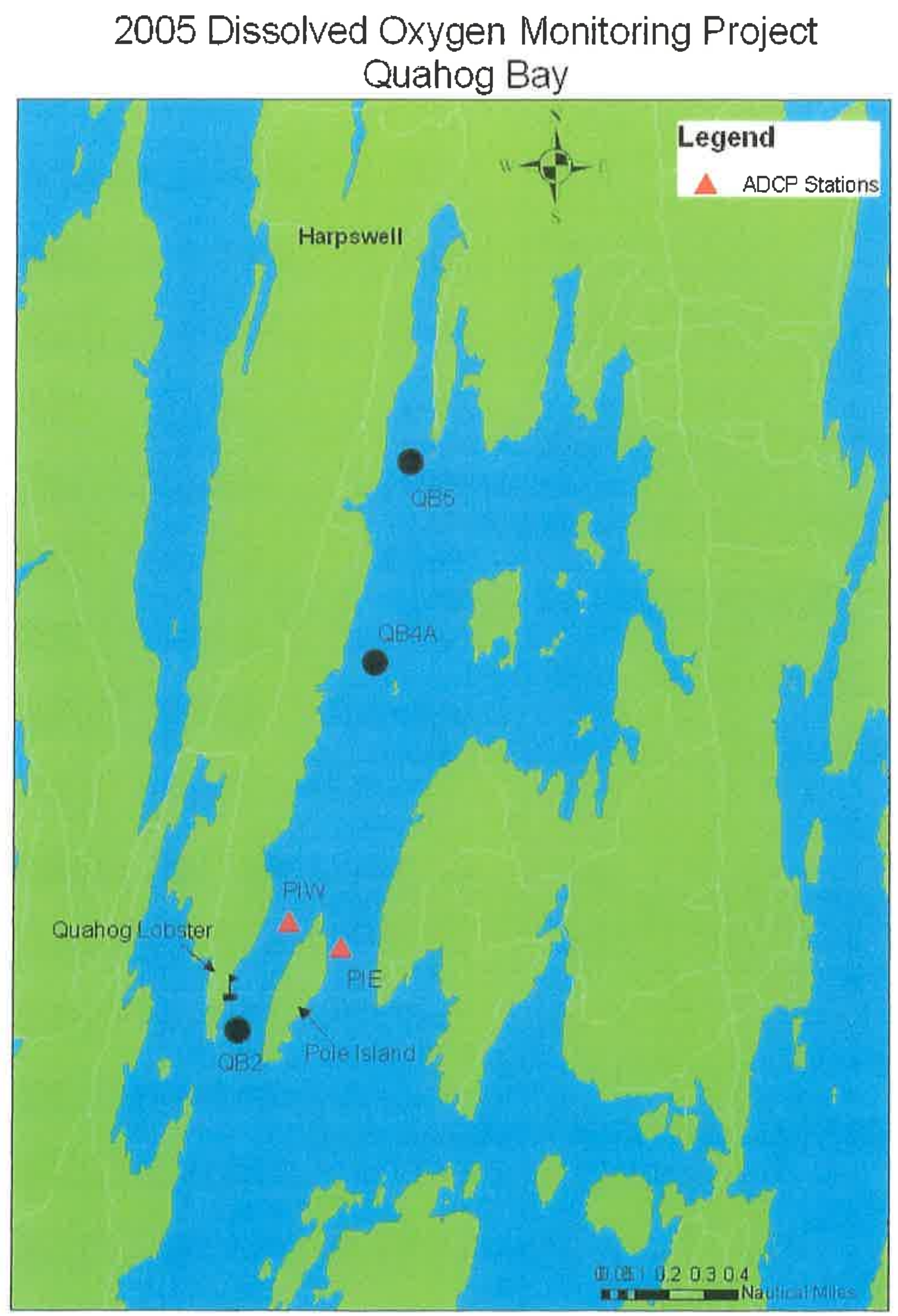
Methods

The accoustic doppler current profiler units were leased through ASL Environmental, Inc. These units were Nortek AquaDopp profilers designed for coastal applications. The profilers were fixed to the bottom and set to record current direction and velocity measurements throughout the water column every 10 minutes. A diver was hired to deploy the ADCP units firmly on the bottom substrate in the correct upward-facing position. Lobster traps were used as the mounting platforms, with the ADCP's secured to the top of the traps. These units were attached by 100 feet of horizontal line to a cinder block, which anchored another 50 feet of vertical line which was buoyed at the surface. This system allowed for easy retrieval of the units and provided assurance that the units would be adequately secured. The ADCP's were deployed on October 10 and retrieved on October 19, 2005.

The water column profiles for temperature, salinity, and dissolved oxygen were conducted by boat on October 12. The three sites included one below the ADCP stationed to the west of Pole Island (QB2), one north of that same ADCP (QB4A), and one near the upper end of Quahog Bay (QB5). Each site was monitored at least once per hour during the 12-hour series. At each site, a YSI 6600 data sonde was lowered from the surface to the bottom, recording data at the surface,

at one meter below the surface, at two meters below the surface, and then at every two meters down to the bottom. The sonde was calibrated against known standards prior to the first profile and was checked against the standards after the final profile. The ADCP units and data sondes were used in accordance with the Friends of Casco Bay Water Quality Monitoring Program Quality Assurance Project Plan. Figure 1 shows the locations of the two ADCP units (PIW and PIE) and the three water column profile sites (QB2, QB4A and QB5).

Figure 1.



The meteorological station was deployed on the main pier of Quahog Lobster Pound, on the western shore. Wind speed and direction data was collected hourly from October 10 to October 30. Rainfall data was also collected.

HoboTemp sensors were attached to vertical lines suspended from buoys and set to record hourly water temperature readings from October 6 to October 27. There were two strings of sensors, each string located just north of an ADCP unit. Each string had three of these units deployed in one-meter intervals along the top of the line and three more were attached in one-meter intervals along the bottom of the line, which was secured to a cinder block resting on the bottom. .

Additional water column profiles were conducted weekly by Bowdoin College using a YSI 600 data sonde. The sonde was deployed in a manner consistent with the FOCB protocols. During these profiles, water samples were collected at the surface and at depth for filtering and analysis of chlorophyll a, phaeopytin, and dissolved inorganic nutrients.

The drifters were designed by Southern Maine Community College and GPS-tracked through a collaborative effort with Woods Hole Oceanographic Institute. The drifters were released in the vicinity of the ADCP units and allowed to move with the current. Figure 2 shows one of the drifters about to be deployed. The GPS unit was contained in the box at the top of the unit. Once deployed, the four "wings" floated just below the surface of the water and allowed the unit to move with the surface current.

Figure 2. – Drifter deployment

Results

Water flow was consistent between stations on either side of Pole Island. The ADCP data revealed similarities in current velocity and direction on both sides of Pole Island. At each station, the water column was comprised of three distinct layers of water moving at varying speed and direction. For most of the deployment, the surface layer moved at a fairly high rate of speed, about 0.8 meters per second, and in a direction predicated by the prevailing wind. This layer was continually driven out of the Bay during the first seven days of the deployment period, moving independently of tidal influence. During this time, wind was predominantly out of the west. Over the final three days of the deployment period wind was much more variable in direction and the surface layer moved with the tide. Wind speed and direction data recorded by the meteorological station proved vital in interpreting the movement of the surface water layer. The middle layer of water was consistently tidally driven, and moved at a somewhat slower rate of speed. The bottom layer moved very little during this deployment, displaying minor tidal influence with only a slight rate of speed. Figure 3 is a representation of the ADCP data from the unit on the west side of Pole Island, and Figure 4 presents data from the east side. An example of current velocity data from the Pole Island West station is represented in Figure 5. The jagged light blue stripe indicates that the surface water in the channel was consistently moving faster than the rest of the water column, from October 10 through approximately October 17. After October 17, the layer of faster-moving water on the surface dissipated. However, there were short periods of time, generally at high tide, during which this layer reemerged. Wind direction data from the meteorological station is shown in Figure 6.

Figure 3 – Pole Island West ADCP station

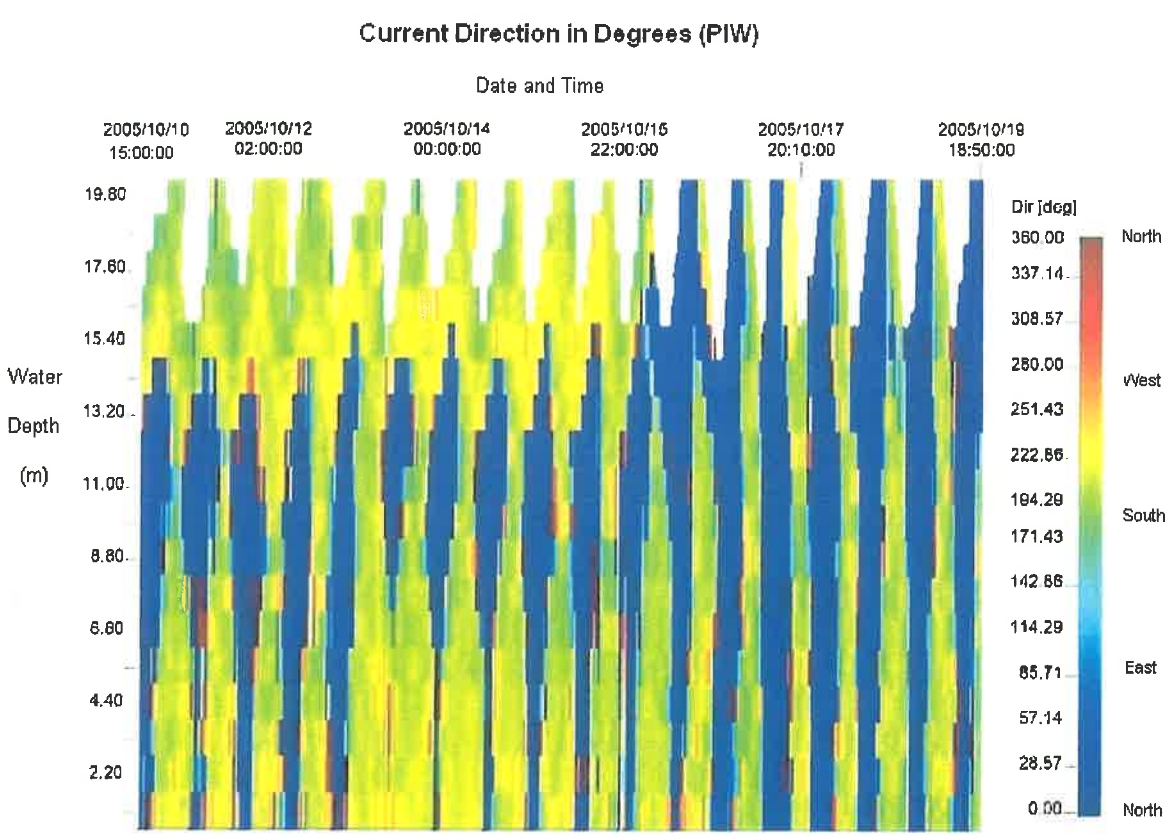


Figure 4 – Pole Island East ADCP station

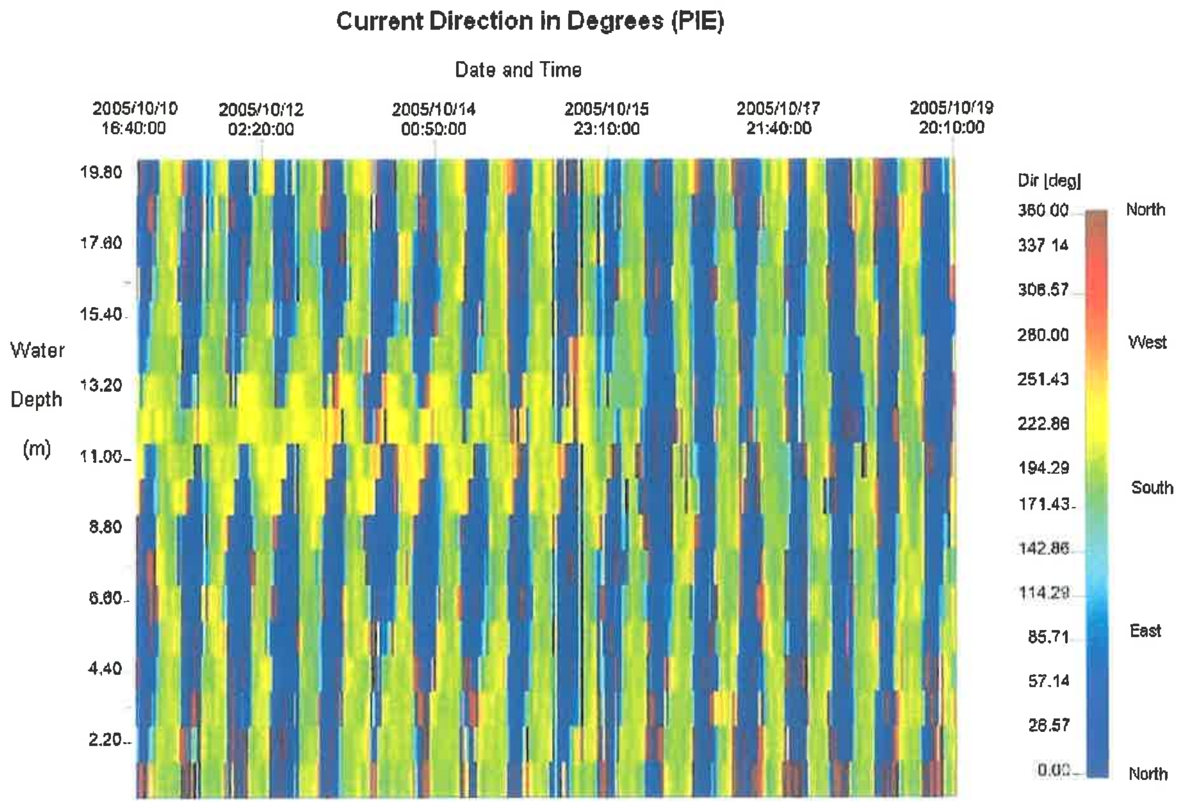


Figure 5 – Current Velocity at Pole Island West ADCP station

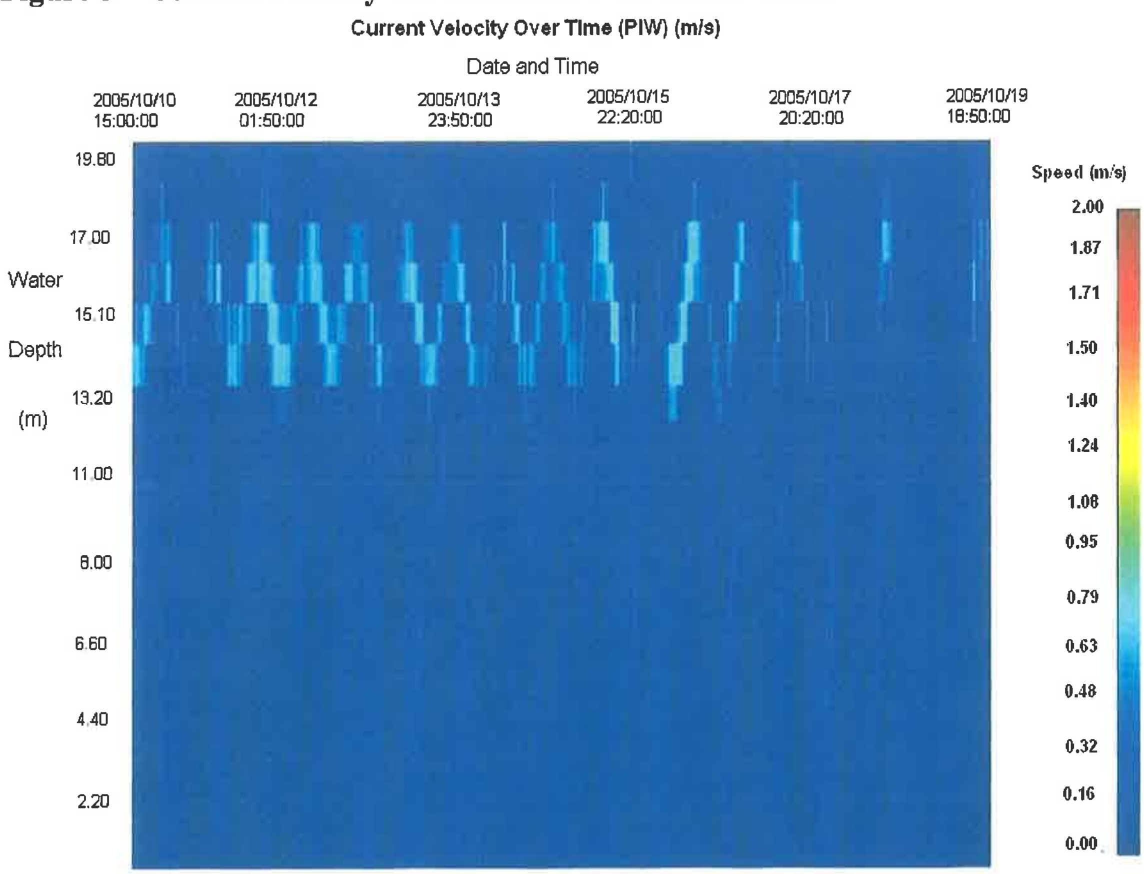
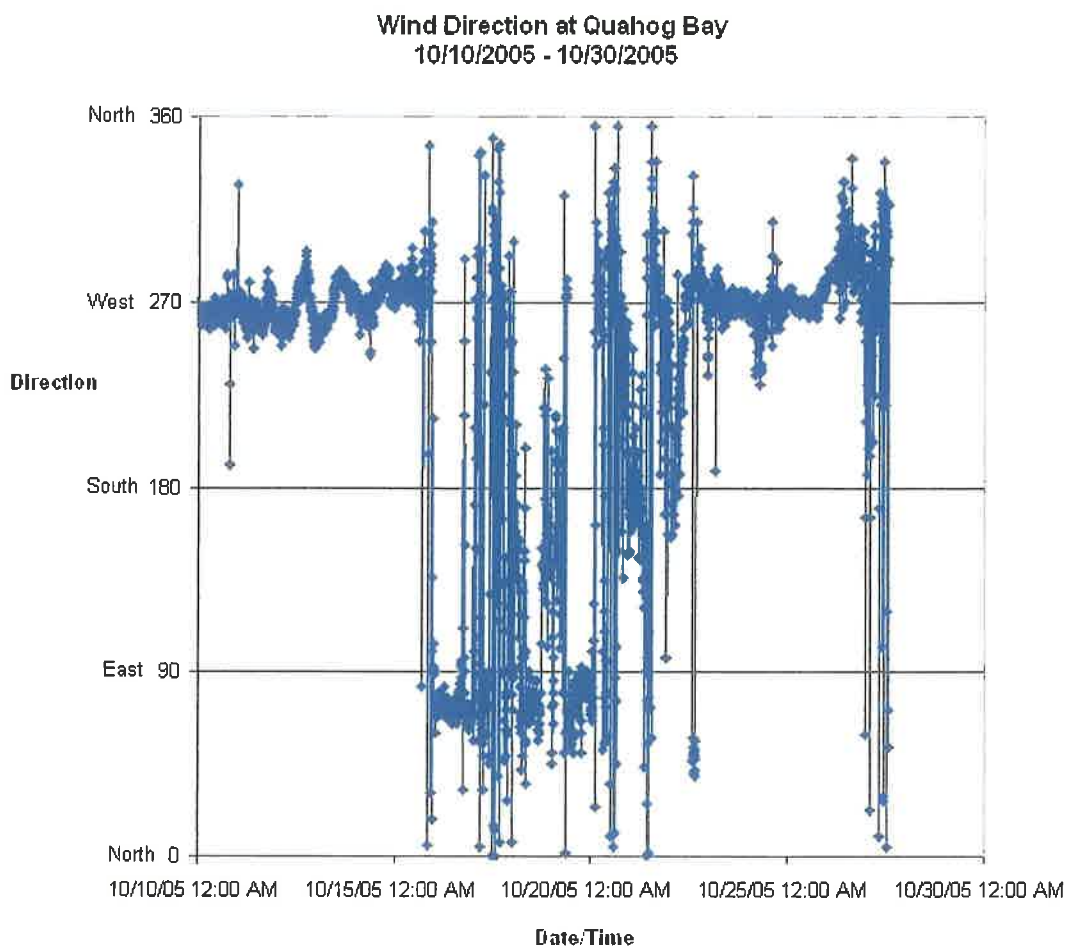


Figure 6 – Wind direction measured at Quahog Lobster, to the west of Pole Island.



During the ADCP deployment period, the water columns at all three profile stations were fairly homogeneous with regard to salinity and temperature, and the differences in water movement did not translate into stratification. Water column mean values for temperature were the same (11.8 C) at each profile site. The single highest temperature value from all of the profile data was 12.6 C and the lowest value was 11.5 C. Salinity mean values were nearly identical for each station at 30.3 parts per thousand (ppt) at QB2 and QB4A, and 30.2 ppt at QB5. The highest salinity value for all of the data collected was 30.7 ppt and the lowest overall value was 28.7 ppt.

There was a very sharp gradient in dissolved oxygen concentrations and percent saturation values, from lows of 6.3 mg/l and 70.7 percent saturation to highs of 9.1 mg/l and 101.8 percent saturation. The lowest values were always found at depth. These low bottom conditions could be considered unusual for late fall. We expected higher values and less of a gradation in water quality from surface to bottom. As seen with previous studies, the reduced water quality at depth was not a result of stratification. Evidence of high rates of organic matter accumulation on the bottom of Quahog Bay was also seen in the nutrient and chlorophyll data. See Figure 7 for summary statistics from the 12-hour series of water column profiles.

Figure 7 – Summary Statistics from 12-hour water column profile series.

Summary Statistics for October 12, 2005

	Temp C	*Salinity* ppt	*DO Conc* mg/L	*DO%* %	*pH*	*Chlorophyll* ug/L
QB2 - below ADCP station						
mean	11.8	30.3	7.7	86.1	7.6	10.8
standard deviation	0.2	0.3	0.5	5.6	0.0	8.0
maximum	12.2	30.8	8.4	94.6	7.7	64.9
minimum	11.5	30.0	6.8	75.7	7.6	8.1
QB4A - above ADCP station						
mean	11.8	30.3	7.8	87.4	7.6	9.6
standard deviation	0.1	0.2	0.4	4.2	0.0	0.7
maximum	12.0	30.7	8.4	94.5	7.6	11.5
minimum	11.6	30.1	6.9	76.9	7.6	8.1
QB5 - near top of bay						
mean	11.8	30.2	7.7	86.0	7.6	11.5
standard deviation	0.2	0.4	0.5	6.1	0.0	9.0
maximum	12.6	30.7	9.1	101.8	7.7	58.5
minimum	11.5	28.7	6.3	70.7	7.5	8.5

The drifter data reinforced the observation that the surface layer moved with the wind. This phenomenon was most apparent when winds were in excess of nine miles per hour (mph). This threshold was noted through an analysis of the drifter movements and the meteorological data, and supported by a literature search (Demers et al 1987). In Quahog Bay, wind speeds greater than nine mph moved the drifters, and therefore the surface water, with the general direction of the wind and against the influence of tidal currents.

The HoboTemp units provided long-term water temperature data. The most notable result from the deployment of these units was that the water column "turned over" during the project. A large drop in temperature occurred just after a large rain event, which preceded a steady shift from coldest temperatures at depth to coldest temperatures at the surface. Early in the deployment period, a two to three degree decrease in the temperature of the middle water layer occurred with every high tide. Low tide produced a two to three degree increase in water temperature in that same layer. This correlation provided further evidence that tidal influence was predominantly found in the middle layer of the water column. This situation occurred on both sides of Pole Island but was not so pronounced on the west. In addition to the fall "overturn" of the water column, water temperatures became colder in general as the project progressed. The surface water temperatures were influenced more by air temperature than by offshore water temperature.

Water column profiles that included measurements of chlorophyll and dissolved inorganic nutrients suggested that the bay was near the end of the fall phytoplankton bloom period. Chlorophyll levels decreased during the project and phaeophytin levels increased. High surface chlorophyll levels were evident during the initial profiles and high phaeophytin levels at depth

were found toward the end of the project. High surface chlorophyll values were also seen in the upper, northern part of the bay, and high bottom chlorophyll values were present in the lower, southern part of the bay, primarily in the deeper basin located at QB2. An overall increase in dissolved inorganic nutrients was reported, the result of reduced demand by the phytoplankton and more bacterial recycling of the decomposing phytoplankton. In addition, there was a significant difference between the bottom chlorophyll fluorescence values and fluorescence values of the upper water column. These very high values at depth indicate chlorophyll or phaeophytin (either living or decaying phytoplankton biomass) accumulating on the bottom of Quahog Bay.

Discussion

Two primary conclusions may be made from the data collected through this project:

First, weather dramatically influences the flushing of Quahog Bay. Wind-moderated flow of the surface water layer was clearly evident during this study. Prevailing winds generated a shear zone when the wind direction was contrary to the tidal movement of the water. During the period of October 10 through 15, surface water was always flowing out of the Bay. This would indicate that the surface layer of water was never refreshed by the flood tide during this period but relied on upwelling of deeper waters toward the northeast end of the Bay.

An earlier ADCP study conducted by Bowdoin College resulted in similar findings (Decoster 2005). During the afternoon of April 22, 2005Bowdoin students used similar methods to analyze the water currents and tides flowing in and out of Quahog Bay. Both studies show a distinct velocity shear zone at a depth of about 5 meters. On the east and west sides of Pole Island, the water below 5 meters flowed out of the bay in a southerly direction, due to the outgoing tide. However, the water above this depth did not leave the bay with the tide. Instead, it was pushed northward into the bay by the prevailing southerly wind. During the April 2005 study period, wind speed was measured at the Brunswick Naval Air Station at approximately 12 miles per hour.

Both of these studies confirm that a shear zone can develop below the surface layer of water when prevailing winds are opposite the tidal current. During these conditions, water enters the bay in the middle layer with the tide, under the surface layer. Wind direction and velocity are critically important in governing the exchange of water. A prevailing wind up into Quahog Bay might serve to slow the overall flushing of the bay.

Second, the bottom layer of the water column did not move much during the deployment period. This is a significant finding that warrants additional study. If this layer of water remains fairly stagnant during the late summer and fall, it may be concluded that poor flushing leads to a build up of organic matter at depth. Previous work has revealed very high concentrations of organic carbon in the sediment and perennially low dissolved oxygen readings at depth. A net heterotrophic system would account for the poor water quality that is a dominant feature of Quahog Bay. This situation, along with the possibility of slow flushing due to a prevailing wind into the bay, would certainly produce conditions that could degrade water quality and reduce DO.

The twelve-hour series of water column profile measurements did not reveal stratification or trends in water temperature or salinity. Sampling in the late fall diminished the use of these parameters to track mixing as influenced by water flow because the water column was fairly

homogenous with regard to both of these parameters during the twelve-hour period. The homogenous conditions were somewhat expected due to the season, but still remarkable given that the twelve-hour series of profiles took place just after the system received about nine inches of rain. This input of fresh water had little effect on salinity. However, there were substantial differences in DO levels between the surface and bottom of the water column. While the DO data was ancillary to the goals of the 2005 effort, the presence of low DO concentrations at depth, late in the season, highlights the perennially degraded water quality in Quahog Bay.

The water column profile measurements conducted by Bowdoin College took place outside of the ADCP deployment period and did show some variability in temperature, salinity, dissolved inorganic nutrients, and chlorophyll a/phaephytin ratios. Phaeophytin is a breakdown product of chlorophyll, which is released as phytoplankton decompose. The lower chlorophyll levels found as the project progressed, accompanied by the concomitant increase in phaeophytin at depth, suggest a buildup of recently deposited phytoplankton.

The data collected through the drifter deployments reinforced the finding that surface water moves with the wind. The movement of the drifters correlated with tidal currents while the winds were light and variable, but at a certain threshold (9 mph) wind velocity did influence the direction of surface water. A previous study (Geyer and Signell 1992) showed that the extent of tidal flushing between embayments and larger bodies of water, where tides enter through narrow channels, is generally dependent upon the strength of the tidal currents but can be reduced by strong wind-driven currents. Quahog Bay is an example of this type of morphology, and the movement of the drifters demonstrated that wind speed, perhaps above a threshold of nine mph, does diminish the effect of tidal currents. The drifter deployments took place after the ADCP units were retrieved, so a direct comparison of results cannot be made. It would seem that a sustained prevailing wind is capable of moving the surface layer even at low wind speeds, while variable winds need to exceed a threshold of nine miles per hour before dictating direction of surface currents.

Conclusion

The 2005 Dissolved Oxygen Monitoring Project provides insight into the causal mechanisms for reduced water quality in Quahog Bay. The preliminary understanding of water flow and tidal exchange that has been achieved through this project supports the hypothesis that degraded water quality in the bay is the result of poor flushing rates. Reduced water flow at depth in Quahog Bay would allow for increased sedimentation rates. Accumulation of organic matter in the sediment would then lead to a net heterotrophic condition and low dissolved oxygen levels.

Reduced flow at depth is most likely a natural morphologic feature. Further studies should be conducted during the summer when DO levels are lowest and prevailing winds are blowing into the bay. If the same shear effect is present, a case could be made that not only does the poorly-flushed lower water layer influence water quality, but so does a surface layer that is continually "pushed" into Quahog Bay. Tidal exchange essentially would be limited to the middle layer.

A critical element of any future study should involve a longer duration deployment of the ADCP unit. With the knowledge that water flow is similar on both sides of Pole Island, a single ADCP unit could be deployed in the deepest part of the bay near Quahog Lobster. We recommend a deployment period of ten to twelve weeks over late summer.

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