Maine Geologic Facts and Localities
May, 2008

Coastal Circulation in the
Vicinity of the Kennebunk River and Goochs Beach

43° 20′ 51.31″ N, 70° 28′ 54.18″ W

Text by
Peter A. Slovinsky
Introduction

In order to better understand and predict coastal circulation in and around beaches in southern Maine, the Maine Geological Survey (MGS) conducted surveys of ocean currents in the vicinity of swimming beaches in support of the Maine Healthy Beaches Program. The MHB Program monitors water quality at swimming beaches and is part of a national initiative of the U.S. Environmental Protection Agency to monitor public health threats and to improve recreation at beaches around the United States. Surveys were conducted as part of an agreement between the MGS and the State Planning Office as part of the Healthy Maine Beaches Program.

To date, MGS has conducted surveys at four different locations.
Maine Healthy Beaches Program

These include (from north to south): Old Orchard Beach, Goose Rocks Beach, Goochs Beach, and Ogunquit Beach (Figure 1). The goal of each survey was to capture nearshore circulation near any nearby river and along the beach in order to characterize flow during an ebbing tide when currents near the river are expected to be strongest. This was done at most locations since the rivers have been thought to be the source of pollutants.

Figure 1. The Maine Geological Survey completed coastal circulation surveys at four locations along the southern Maine coast to support the Maine Healthy Beaches program. Base imagery from MEGIS.
Goochs Beach

We attempted to complete the surveys on days with a mild southwesterly breeze similar in direction and speed to a "sea breeze" that is common during many days in summer when the beach is heavily used for recreation. For this site of the month, we report on our methodology and findings for a survey completed at Goochs Beach, Kennebunk, on August 9, 2007 (Figure 2).

Figure 2. The Goochs Beach and Kennebunk River study area. Base imagery from MEGIS.
Beach Morphology

Goochs Beach is an approximate 1.3 km east-west trending pocket barrier beach and dune system located adjacent to the mouth of the Kennebunk River and bound by bedrock headlands of Oaks Neck and Old Fort Point. Approximately 90% of Goochs Beach is fronted with a wooden seawall, though a very small active frontal dune is located adjacent to a jetty at the river mouth. The beach profile is generally flat and low and, due to the lack of sand exchange with most of the dune system and repeated wave action on the seawall, has a minimal summer berm (Slovinsky and Dickson, 2007).
Tides

Predicted tides for the survey day, based on the Portland tide gauge, were for a high tide of 8.4 ft MLLW, at 8:45 a.m. EDT. The current survey was completed between 09:56 and 11:52 EDT, when ebbing currents from the Kennebunk River were expected to be well established and flowing the fastest along the beach. During the survey, measured tides from the Portland tide gauge were close to predicted tides (Figure 3).

Figure 3. The ADP survey occurred from 09:56 a.m. - 11:52 a.m. during an ebbing tide (inset box). Observed tides follow those predicted so the survey collected data unaffected by unusual weather systems. Tidal data courtesy of the NOAA Center for Operational Oceanographic Products and Services.
Wind

During the ADP survey, winds were from the north and northwest for the first half of the study period, before switching to the south. Wind speeds started near 8 mph, then receded through the study (Figure 4).

Figure 4. Winds during the study were slightly stronger during the start and receded (red inset box). They were directed from the west-northwest (offshore) near the start of the study, and about half-way through, shifted out of the south. Wind data from buoy BO1 (Western Maine Shelf) courtesy of GoMOOS.
Waves

Waves offshore at GoMOOS Buoy BO1 were less than 2 feet in height, with periods in the 4-8 second range (Figure 5). The wave periods indicated the influence of the offshore winds, which produced shorter period wind-waves during the first part of the study. The period lengthened to 8 seconds near the end of the survey, indicating longer period groundswell coming from farther offshore in the Gulf of Maine. Observations during the survey noted that swell was present, directed from the southeast. Breaking waves in the surf zone measured roughly 1-2 feet, with some larger sets.

Figure 5. Wave data indicates that wave heights averaged 1.4 feet during the study (red inset box). Periods ranged from 4-8 seconds. Wind data from buoy BO1 (Western Maine Shelf) courtesy of GoMOOS.
Equipment

The MGS **Nearshore Survey System (NSS)**, a personal watercraft-based survey platform, was utilized to complete the survey (Figure 6). The NSS is outfitted with an Ashtech Z-Xtreme Real Time Kinematic Global Positioning System (RTK-GPS), which is capable of producing positioning accuracy on the order of 2-3 cm.

**Figure 6.** The MGS Nearshore Survey System is comprised of a personal watercraft platform outfitted with a Real Time Kinematic Global Positioning System, a precision depth sounder, and an Acoustic Doppler Profiler. Navigation is followed using set tracklines shown on the helm display.
Equipment

To measure current magnitudes and directions, the NSS is equipped with a SonTek 1500 KHz Mini Acoustic Doppler Profiler (ADP, Figure 7). The NSS is equipped with a precision depth sounder, and a helm display which aids in navigation on set track lines.

Figure 7. The SonTek mini-ADP.
The ADP measures the velocity of water using the principle of Doppler shift. If a source of sound is moving relative to the receiver, the frequency of the sound at the receiver is shifted from the transmit frequency.

\[ F_{\text{doppler}} = -2F_{\text{source}}\frac{V}{C} \]

where \( V \) is the relative velocity between source and receiver (i.e., motion that changes the distance between the two), \( C \) is the speed of sound, \( F_{\text{doppler}} \) is the change in the received frequency at the receiver (i.e., the Doppler shift), and \( F_{\text{source}} \) is the frequency of the transmitted sound.

The SonTek ADP is equipped with 3 transducer heads that generate pulses of sound at a known frequency. As the sound travels through the water, it is reflected by particulate matter, and a portion of the reflected energy travels back along the transducer axis toward the transducer where the processing electronics measure the change in frequency. The Doppler shift measured by a single transducer reflects the velocity of the water along the axis of the acoustic beam. The ADP includes an internal compass and tilt sensor to report 3D velocity data in Earth (East-North-Up or ENU) coordinates, independent of instrument orientation.
Currents: Bottom Track Mode

Thus, the overall current velocity is a combination of the vessel speed and the current velocity relative to the ADP at depth $z$.

$$U_m(z) = U_b + U(z);$$  where $U_m$ is the current velocity, at depth $z$.

**Figure 8.** A conceptual diagram of the three beams emitted from the ADP mounted on a vessel and directed down through the water column. The measured water motion $U_m(z)$ at a given depth, $z$, is the sum of the vessel velocity, $U_b$, and the current velocity at a given depth, $U(z)$. 
**Currents: Methods**

**SonTek Current Surveyor**
SonTek CurrentSurveyor software was used to determine the track for each survey line using GPS waypoints. This software is capable of receiving input strings from the RTK-GPS input so that precise coordinates for the position of the survey vessel can be provided. During the survey, GPS positional data is stored, along with bottom track data, data quality, and calculated current magnitudes and directions.

**Data Collection**
The ADP was mounted on the port side of the NSS at a depth of 1 m below the water surface in order to remove the influence of surface turbulence in the data. With a default blanking distance of 0.4 m, the ADP was set to record its first currents in a bin starting at 1.4 m. The ADP is equipped with an internal thermometer which records water temperature throughout a survey. The speed-of-sound through water is a function of the water temperature, salinity, and depth. Changes in temperature and salinity have a major impact on accurate acoustic Doppler measurements. Salinity measurements were conducted during ADP surveys using an YSI-30-M salinity meter so that collected data could be post-processed to correct for the speed of sound (and calculated currents) due to changes in temperature and salinity.

**Data Processing and Analysis**
Collected ADP data was post-processed using SonTek's CurrentSurveyor and ViewADP (SonTek, 2007) software. Data was corrected for measured salinities and local magnetic declination (-15.87°). Resultant depth averaged and surface current magnitudes and directions were then converted into shapefiles and projected in ESRI ArcMap (ESRI, 2007) software for data display, mapping, and analysis.
Results

A total of 11 transect lines were surveyed (Figure 9). Transects were named based on the respective starting time.

Figure 9. A total of 11 ADCP survey transects were completed during the study (1002 through 1152). Each transect name marks the starting time for that transect.
Results

An example of the corrected current data along an individual transect from a "fish eye view," that is, through the water column, is shown in Figure 10. This view shows different aspects of the data along the transect, including velocities recorded through the water column, the surface velocity, water temperatures, and depth. The example was taken from a transect that went into the mouth of the Kennebunk River. The colder river water, along with higher velocities, is clearly noted.

**Figure 10.** Example of current data in the "fish eye view" showing variations in magnitude throughout the water column. The lower images show the surface current velocity (noted by the horizontal arrow in the upper image), while the bottom shows the depth and changes in temperature along the transect.
Results

Along each transect, both surface and depth-averaged current magnitudes and directions were recorded. The results of all transects combined are shown in Figure 11 and Figure 12.

Figure 11. Surface currents, as measured during the survey conducted on August 9, 2007 during an ebbing tide. Surface currents are defined by the first measured bin from the Acoustic Doppler Profiler.
Results

Figure 12. Depth-averaged currents, as measured during the survey conducted on August 9, 2007 during an ebbing tide. Depth-averaged currents are calculated by averaging all of the current magnitudes and directions from each bin throughout the water column.
Discussion and Analysis

In general, surface currents tend to show more influence from local wind conditions, while depth-averaged currents capture more of the overall flow of the entire water body (from surface to bottom). However, at Goochs Beach, portions of the surveyed area offshore of Goochs Beach are shallow enough that depth-averaged currents can be influenced by wave orbitals. In particular, swell waves (8 seconds or more) moving towards shore can create a shore-directed current in open water as the waves shoal and "feel the bottom." Water that "piles up" along the beach due to breaking surf will then generate currents along or parallel to the beach that then exit either by the jetty or the western rock headland. However, both wind and waves can each influence current magnitude and direction separately or together. This survey was characterized by generally low waves and calm wind, so both wind and wave influence is relatively minimal. These conditions were optimal for measuring the direction and magnitude of ebbing tidal circulation.
Discussion and Analysis

Both surface and depth-averaged currents indicate that during the ebbing tide, there is a relatively strong seaward flow that extends from the river channel southwards and offshore (Figure 13). This condition can be expected with all outgoing tides twice a day. It appears that the ebbing flow entrains (or pulls in) nearby "beach" water. This influence of the ebbing river current leads to a slight onshore flow in the middle of the survey area.

**Figure 13.** Surface current patterns clearly show an entrainment zone, associated with the ebbing flow from the Kennebunk River. There is an area of weaker currents, and current activity along the center of the beach. The western edge of the study area has a net seaward-flowing current.
Discussion and Analysis

The area of highest entrainment appears to be just west of the apparent river flow, several hundred meters (on the order of 1000 feet) seaward of the jetties. Figure 14 shows the overall generalized current trends within the Goochs Beach study area *during an ebbing tide*. The area of water entrainment discussed above has been termed the **Entrainment Current Zone (ECZ)**, and entrains water from both west and east of the river channel during the ebbing tide.

**Figure 14.** Interpretation of ebbing current patterns allowed for the designation of several current zones in the study area.
Discussion and Analysis

The central portion of the study area exhibits little discernible current directions and velocities are low; this has been characterized as a Slack Current Zone (SCZ). This is due to an area of relatively deep water with generally flat bottom, and acts as an effective boundary between offshore-directed currents associated with the ECZ, and currents along Goochs Beach itself.

Along the beach is the Nearshore Current Zone (NCZ). This zone is separated from offshore waters and currents by the SCZ, and appears to be characterized by the influence of wind- and wave-driven currents. The NCZ appears to show a slightly dominant westerly flow along the beach, although nearer to the jetties, it appears that flow is directed towards the jetties (likely a result of the proximity to the entrainment current zone). It is important to mention that it does not appear that currents coming directly from the mouth of the river would direct pollutants right at the beach during an ebbing tide, mainly due to the strength of the ebbing current.

However, it appears that some of the water that has ebbed into the offshore as part of the ECZ could become entrained and move back towards the beach and be pushed ashore by wave orbitals into the NCZ, then moved eastward back into the ECZ, or westward, along Goochs Beach.
Discussion and Analysis

At the western end of Goochs Beach is the **Western Fringe Current Zone (WFCZ)**, which is basically an offshore extension of the NCZ, with currents to the southwest and offshore, parallel to a series of rock outcrops that form the western terminus of the beach. This pattern is a result of water moving westward, along the beach, then being forced offshore.

At the eastern end of the study area, in an area termed the **Eastern Fringe Current Zone (EFCZ)** currents appear to be directly influenced by the entrainment current zone. Along the headland, currents appear to be directed onshore (towards the small pocket beach) likely due to entrainment by the ECZ, which pulls the nearshore water offshore, requiring the offshore water to move along the headland and towards the beach. In the offshore portion of the study area, it appears that currents associated with the ECZ generally disperse and continue in a southern and southwestern direction, and may potentially travel westward, around the submerged ledges within the WFCZ.
Summary

The field conditions were selected to provide a "worst-case-scenario" when tidal currents could carry water from the Kennebunk River most directly to Goochs Beach. A large, single gyre forming a clockwise circulation cell was expected but not found. Instead, river outflow (ECZ) extended quite far offshore from the beach. As river water flows seaward it entrains beach water from either side (NCZ and EFCZ) that may act to dilute any pollutants. It is possible that the river water will flow back to the beach via an area of slack flow located seaward of the center of the beach (SCZ). This circulation, however, will lead to increased mixing and thus dilution of polluted water.

Onshore flow could be more rapid during periods of onshore wind (summer sea breezes) and even more reduced during periods of offshore wind (westerlies). Large surf will tend to move water from directly offshore of the beach onshore and this flow is expected to return offshore by moving out both along the westerly ledge area and the easterly jetty area at speeds faster than measured in this study. On days with surf, the current along Goochs Beach may be enhanced to the east by a southwesterly wind or to the west by a southeasterly or easterly wind. Immediately along the beach the direction of wave shoaling and breaking can also generate increased flows parallel to Goochs Beach.
References and Additional Information

Environmental Systems Research Institute, 2007, ArcGIS and ArcMap.

NOAA Center for Operational Oceanographic Products and Services, 2007, Tides Online.

