Merrymeeting Bay Current Study- Read This First Please

Intro
In order to run our drifter animations download Adobe Flash Player from the animation folder on our web site if your computer doesn't already have it. Once installed, you can play any of the animations. Six drifter deployments from 2005 [low-flow] and 2006 [medium flow] have been completely animated as have animations from two high flow deployments in 2008. Deployments are posted in two speeds, one slower [Chops-60 frames/sec] than the other [system-wide-90 frames/sec]. Also posted are two jpeg LANDSAT images showing extent of ground-truthing deployments done in 2006 on each river at medium flows and an animation of ground-truthing deployments at high flows in 2008 [see dedicated ground-truthing section with links].

Animation Controls
Control buttons for the animation are from left to right: 1. Reset, 2. Fast Rewind, 3. Stop, 4. Play, 5. Fast Forward. You can zoom in or out on a section of the image with the slider at lower left or zoom in drawing a rectangle with your cursor. Maximizing the image with the middle tab at upper right will give best results. Drifters can be checked on or off individually in the table. Clicking a left column check box either for hourly deployment or river, will short-cut clicking on or off that entire row of drifters. New for 2007 is an auto-zoom feature retrofitted to all previous deployments. The auto zoom will follow active drifters. As drifters stop, they will no longer be tracked by this feature. Due to internal GPS problems with our 2008 outgoing deployment, many tracks were not recorded. A link at the lower right in this animation series brings up mapped locations where drifters were recovered and the table documents how long they were out.

Reference Flows and Ground-truthing
The closest USGS river gauge to Merrymeeting Bay is at North Sidney on the Kennebec. While there is also a gauge in Auburn on the Androscoggin, this river is so obstructed by dams that flows can be very artificial. There are at least three dams between Auburn and Merrymeeting Bay and three just above the gauge at Auburn. There are no dams on the Kennebec between North Sidney and the Bay.

Ground-truthing has its own link but images and animations in the section show tracking results monitored in real-time for full tide cycles in 2006 and 2008 at low-medium and high flows.

Deployments
<u>System-wide deployments</u> cover a very large area and can be quite lengthy, setting 4 drifters out on the same falling tide at head-of-tide for each of the 6 tributaries [Kennebec, Androscoggin, Eastern, Abbagadassett, Muddy and Cathance Rivers]. These deployments last about 10 days.

<u>Incoming or Chops Up</u> deployments last about 1 ½ days. We set 4 drifters into the Chops every hour for the 6 hours of an incoming tide. We let them go up, come down and go upstream again to get a sense of net upstream movement, and then we recovered them on the next falling tide.

<u>Outgoing or Chops Down</u> deployments are the opposite of Incoming. The cycle here is down, up, down, recover. In the case of outgoing high flow deployments, some drifters were not recovered for a long time as they were flushed from the system, some traveling as far as Cape Cod Bay.

Acknowledgements
Thanks to field volunteers Simon Beirne [also our intern for some of the time], David W. Chipman, Andy Ellis, Ed Friedman, Jim & Susan Gillies, Barry Goodman, Kathleen McGee, Dick Nickerson, Owen & Brandon Pierce, Leonard Skelton, Kermit Smyth, Bob Weggel, David Whittlesey, Elisa Vandervort, Tom Walling, Mary Earle Rogers, Odin Anderson, Peter & Noreen Ryan, Norman Anderson and Steve Dexter and for animation to Carey Phillips of Bowdoin College and Geno Carpentier of Woodlot Alternatives [now Stantec].

For acoustic Doppler current profiling, thanks to folks at the US Geologic Survey in Augusta: Bob Lent, Greg Stewart and especially field crew Laura Flight and Charlie Culbertson. Thanks also to Point of View Helicopter Services, Ben Magro of Coastal Helicopters for helping us out of a jam, Mike Chelminski of Stantec, Marinna Martini of USGS-Woods Hole, Peter Milholland & Friends of Casco Bay, and especially to Scott Allen of DeLorme for his troubleshooting and technical expertise.

Thanks also to our major funder: The Merrymeeting Bay Trust, to our sometime host; Chop Pt. School, to Hancock Lumber for donation of some buoy materials and to Downeast Building Supply, DeLorme Mapping, and Tracker Radio Systems for discounts on various materials. Special thanks are due to David W. Chipman who performed extensive R&D on possible GPS units and means of extending their battery life in the field. David also researched battery types, designed the battery packs and machined the fixtures holding GPS and transmitter units. In addition, David has processed all of the data from 2005 and 2006 loggers prior to creation of final animations, which we contracted out to Woodlot Alternatives/Stantec.

Background
See separate documents included here: Merrymeeting Bay Current Study, Summary and Links.

Materials/Methods
Drifters were fabricated from 3" PVC pipe and are 32" long. Only the top 6" or so extends out of the water to minimize wind effect yet provide a visual for recovery and avoidance. Inside at the bottom of pipe there is a foam donut [from pipe insulation] cushioning PVC base from battery pack. Battery pack consists of 12 NiMH rechargeable batteries that provide double duty as ballast and extend the life of the DeLorme Blue Logger GPS unit to approximately 10 days. Above the battery pack is a foam pipe insulation spacer to minimize component shifting and at the top is a nylon plate with GPS unit and radio transmitter attached with cable ties. Transmitters are Tracker Lites from Tracker Radio Systems and receivers used to locate units are the Tracker Maxima. Drifters were sealed with standard threaded cap using several wraps of Teflon tape. After encountering some leakage in the first deployment we used the boot waterproofing "Snow Seal" as an additional sealant around the top of the threads. Drifters had a small surveyor flag taped to the top of their shaft and extending another 6" above the drifter. This helped immensely in spotting the units. Photos of all equipment may be found in the accompanying PowerPoint slides.

Tracking of drifters was done by air, car and boat. An external yagi antenna from Telonics was helpful in mitigating interference when tracking from car or fixed wing aircraft but was of no significant help when in an open boat or helicopter bubble cabin. The Maxima receivers have their own very effective integral antenna. We used these stock receivers successfully for tracking and recovery in both boat and helicopter applications.

Results
Previous Acoustic Doppler Current Profiler [ADCP] work by FOMB with a contractor and then with the Augusta office of the USGS had established that, for the most part, flows in the Bay are pretty uniform from top to bottom. This has been confirmed through ADCP work done by Peter Lea and his Bowdoin College students in the last few years. An exception to this might be during very low river flow conditions with high tides that occasionally allow a salt wedge to extend into the Bay towards Swan Island. A salt wedge at these times could create stratification and counter-flows within a depth profile. The overall ADCP data made us quite comfortable with using a drifter near the surface as a surrogate for what might also happen at depth.

Our study plan called for simultaneously deploying drifters at the head of each tributary during low, medium and high river flow conditions. Our point of reference for flows has been the USGS Kennebec River gauge at North Sidney. We hypothesized once drifters got to the Chops we would need to quickly recover them or they would rapidly move down and out the Kennebec to the sea.

2005
What we found was during low flow conditions [3000-5000 cubic feet per second (cfs)] typical of summer and winter at least, drifters only very slowly managed to work their way down through the system. They did often hang up in grass or on the bottom and we would free them up, but these hang ups not withstanding it was still clear that progress was slow as they oscillated their way with incoming and outgoing tides down each river. After awhile on this big deployment we had to physically move drifters far down in the smaller tributaries to ensure they would reach the Bay during the 10 day life of their batteries. It needs to be emphasized when the drifters are aground they tell nothing about the flow of WATER through the system. It is obvious water gets out faster than our drifters, which get can get hung up in mud or grass or in eddies, while the water does not (or does in eddies, for limited periods). In the future we or others may attempt to develop a circulation model of the Bay based on our data and to supplement it, rather than using drifter data alone to describe flows through the system.

The Bay Boundaries. For purposes of this study we consider the Kennebec tributary input to end at the Richmond Bridge where it becomes the upper Bay. The Androscoggin meets the middle Bay on a line between Pleasant Pt. in Topsham and Butler Head in North Bath. We consider the lower Bay to be between Chops Pt. and Thorne Head. Smaller tributaries meet the Bay at the following locations:

- Muddy and Cathance Rivers: at their junction
- Abbagadassett River: the old Warden's Camp cabins and boat launch off Centers Pt. Road
- Eastern River: Rte. 128 or the Lower Bridge

When the length of time to descend the rivers became clear [and batteries were exhausted], we decided to do some shorter deployments from the Chops as well. Assuming our drifters [or actual water] got to the Chops, what would happen if they arrived there at various levels of the tide?

Here again, we found in low flow conditions no matter at what tide level a drifter arrived at the Chops, getting out of the system was by no means assured. In fact most of the time drifters continued back and forth through the Chops a number of times before being picked up either somewhere upstream or not far downstream. On the 2005 low flow downstream deployment, only 2 drifters of 24 made it as far as Bath and the next day one of those was recovered immediately below the Chops and the other well above the Chops, just south of Abbagadassett Point.

On the upstream deployment we had drifters go up the Kennebec as far as the north end of Little Swan Island [where they grounded out] and we recovered them on an incoming tide. Had they not gotten stuck they might have continued further upstream. Also evident in all deployments was "cross pollination" between the tributaries-Androscoggin drifters coming out through the Chops in a pair and then coming back up and splitting between the Kennebec and Cathance; Eastern River drifters coming down and then splitting upstream on either side of Swan Island. All of these patterns can be studied in depth in the animations.

Under all flow conditions our results indicate mostly high residence times for tributary waters coming into the system and extensive mixing once in the Bay. In FOMB's yellow booklet on the Bay we have long referred to the Bay as a "mixing bowl" and these data bear this out. Most estuaries are linear in nature. Merrymeeting Bay has its two main tributaries entering the Bay in opposition. Four additional smaller tributaries and the added restraint of the 280 meter bedrock restriction known as the Chops further magnify residence time and spatial mixing. This goes a long way to making the Bay a very unique body of water worldwide. It may make a lot of sense to think of the four small tributaries under these conditions more as embayments than rivers as they really tend to mostly move up and down with the tide and height of the Bay and have relatively low volume inputs themselves.

Table 1

River	Distance	Net Downstream/24 hrs [Rate]	Lo Flow Time	Hi Flow
Cathance	8 miles [14,080yds]	300 yards	50 days	No Change [NC]
Muddy	3.5 mi. [6,160yds]	0 yards [200 min]	31 days	Presumed NC
Abby	6 miles [10,560]	0 yards [200 min]	53 days	No Change
Eastern	12 miles [21,120]	0 yards [200 min]	106 days	Presumed NC
Kennebec	15 mi. [Aug-Richmond]	8.5 miles	2 days	1 day
Andro	8 mi. [to Pleasant Pt.]	7.5 miles	1 day	½ day

The table above only looks at rate, time and distance from head-of-tide to the Bay [Time=Distance/Rate]. Where there appeared to be no net downstream gain, we still assumed at least 100 yards per tide to err on the side of at least some movement. Even with this assumption, [minimal] residence times are astoundingly long particularly when one considers any benefits derived from regular tidal exchanges or flushing. While the residence times are impressive one needs to remember these are calculated times from the head of tide.

On each river there is a "point of no return" [PNR], specifically a point where a water particle [or something carried in the water] will make it to the open Bay on one outgoing tide. If the PNR is known [and these can be measured from the red track lines in our LANDSAT ground-truthing plots], one should be able to calculate approximate residence time for any point on the river. PNR for tributaries with very little net downstream movement will be at the upstream limit of our ground-truthing drift from the river mouths. [We drift back to the river mouth in one ebb tide.] If for example there is an overboard sewage discharge from an outdated building one mile above the PNR on the Eastern River and we know the net downstream movement in 24 hours is 200 yards; we can take distance above PNR in yards [1760] and divide by net downstream movement in yards per 24 hrs. to find days to the PNR. 1760/200=8.8 days to PNR. We then add .5 [representing 12 hours containing one ebb tide to Bay] to arrive at a time of 9.3 days for pollutants or particulates to reach the Bay.

Once in the Bay the future of a particle is uncertain and a return to the confines of the channel from where it just emerged is not assured. In the open Bay spatial and temporal characteristics become harder to track because of short deployment periods necessitated in part by extensive tidal flats and depth of our drifters. Still, our animated data indicate thorough mixing even in the short-term.

What enters the Bay under these flow regimes appears to stay here a long time, for better or worse with more time to act on or be acted on by the Bay's sediments, vegetation, fish and wildlife. Consider the effects of phosphorus, dissolved oxygen, wastewater discharges, nitrogen, aquaculture operations, etc. Consider too how multiple exposures at the Chops to the same water and whatever is carried by it or in it may affect for example seal predation or proposed hydro projects in this area.

2006

In spring 2006, with no snowpack or early rain we didn't have a spring freshet of high water. We did however, towards the end of April, think we could do a medium flow deployment with levels in the 7000-10,000cfs range [we considered any levels at our North Sidney reference point above 10-12,000 to be high flows]. Shortly after we deployed system-wide the flows nose-dived. We ended up with a flow regime fairly similar to 2005 but for the absence of grass in the river as an obstruction. In some respects this was good in that we were able to eliminate one variable. In fact we did see some evidence of slightly faster transit times downstream without grass.

Flow levels at the end of May did pick back up to the 10,000-11,000cfs range giving us solid mid flow data for our Chops deployments. We did see our drifter travel extended downstream on the Sasanoa and Kennebec. One drifter was recovered in Hockomock Bay, one at Upper Hell Gate and several in the Fiddlers Reach/Doubling Point areas. Upstream drifters did not ascend as far as they did under low-flow conditions.

Super high flood flows arrived in June of 2006 but we were not in a position to redeploy so quickly due to a combination of motor trouble, other duties, and battery charging. Unfortunately with our current charging system we need about a 9 day lead time to get all the rechargeables ready.

Ground-truthing data [Table 1] from drifters deployed at the head of the tributaries and near their mouths confirmed, with the exception of the Kennebec and to some extent the Androscoggin, very little net downstream gain under the medium flows present. So, while our drifters did hang up in mud and plants, these delays [until we would free them] did not appear to influence the end result appreciably on the four smaller rivers while the opposite was true on Kennebec and Androscoggin rivers.

2008

In 2008, having completed the high flow portion of our multi-year current study there are several important things to report. The spring freshet does not have much impact in the smaller tributaries. How's that?? Two years ago in medium flows, we ground-truthed remote drifter data by actually following drifters up and down the various rivers for complete tide cycles. While on the Kennebec and, to a lesser extent, the lower mouth of the Androscoggin, there was substantial net downstream movement. On the four small tributaries we ended up usually within a hundred yards or so of where we started.

Traditional thinking might indicate in high spring flows we would pick up more net downstream movement even on the smaller rivers. However, with further thought we hypothesized the Bay-proper might control flows in these tributaries. In fact, this is what we found. Despite high flow inputs to the Cathance and Abbagadassett [the Eastern and Muddy don't have high volume inputs], after twelve hours on the water, we still ended up close to where we began. [For ground-truthing we would ride the tide up from the mouth of a river and then back towards the Bay and from the head of tide we would ride the outgoing flow and then come back upstream].

Levels of inflow on the tributaries were no match for higher water levels in the Bay, raised largely from Kennebec flows, and regulated in downstream movement by constriction at the Chops. High levels in the Bay appear to dampen tributary outflow and since water seeks its own level, Bay water acts as a dam preventing river outflow and/or actually backs up the rivers with the rising tides. These results confirm our thoughts and findings based on earlier work at lower flows.

Residence time of water in the tributaries is substantial although there is movement back and forth. Limited river output, even at high flows, means continual sensitivity and vulnerability to harmful inputs whether wastewater from overboard discharges, phosphorus, petroleum or other pollutants from increasing marina activity, or sedimentation from forestry, agricultural or development activities without adequate vegetated buffers.

Because ground-truthing in 2006 and 2008 indicated little change in the small tributaries, we did not deploy system-wide again. Of special note in the upper Kennebec animation is the dramatic increase in river speed just below Hallowell in the reach running down to Farmingdale.

One of the unique features of the Bay are "reversing tides", really a function of river water backing up in the vicinity of the Chops and Thorne Head in the face of a rising tide from the lower Kennebec. We found reversing flows ceased at the Chops when flows at our North Sidney reference point were somewhere between 33,000cfs and 38,000cfs. At levels above a point in this range there was no inflow on incoming tides. According to Bath area river-users, below Thorne Head the river current always shows some tidal regardless of flow. There appears to be a level where the rising tide comes up past Thorne Head into the lower Bay but does not have the strength to overcome high flows still pouring through the Chops where waters do not reverse. A net result is an abundance of flotsam and jetsam in this lower section around Lines Island as water flows in from the north on "high and low" tides but can only get by Thorne Head on an outgoing tide.

Below a certain volume, but still at very high flows, waters in the Chops continue to reverse, The importance of this fact is illustrated by a poorly thought out 2006 proposal to install a 50 unit underwater installation of hydro-electric turbines. Extremely high flows and large amounts of debris in the river are two physical challenges any structures here would be subject to. Turbines in this case would face multiple exposures and likely suffer cumulative adverse effects from these natural and sometimes anthropogenic [like residual pulp wood or smelt camps] forces.

At 70,000cfs our outgoing deployment from the Chops sent two drifters as far as Cape Cod. We also retrieved a number of drifters in Casco Bay and one down the Sasanoa River near Lower Hell's Gate. Unfortunately, after couple of years without use, internal batteries in many of our GPS units failed while they appeared to be working, so no location data were recorded enroute. Using our receiver and transmitter system we were able to recover all but one drifter in Maine. Helpful citizens in MA recovered the two in Cape Cod Bay. Of twenty-four drifters, one remains at large.

Acoustic Doppler current profiles, made on several transects between Abbagadassett Pt. and Lines Island when reference flows were at 38,000cfs, confirmed outgoing flows to full depth at all tide stages. During this time, water levels in the Bay continued to rise indicating even when the tide was ebbing, inflow exceeded capacity of the Chops to exhaust the high volumes.

It should be noted the Androscoggin also contributes substantial flow to the Bay although much less volume than the Kennebec. The closest USGS Androscoggin river gauge to the Bay is in the Auburn area. Because there are five dams influencing flows from not far above Auburn to the Bay, discharges can and do fluctuate wildly making the Auburn gauge unreliable as a reference point.

Conclusions

While there are very few other inland major confluences in the world, we know of no other tidal riverine-inland delta areas where major tributaries enter in opposition and are constrained by geologic constriction from draining freely.This study offers empirical evidence supporting FOMB's previous intuitive description that Merrymeeting Bay is a veritable soup bowl of mixing currents.

Drifter tracks show intermixing of waters from the various rivers both as they join the Bay and as they flow out the Chops and back upstream into different rivers from whence they came. As might be expected in a complicated deltaic system like this, residence time of water is extensive. At lower flows, water may take anywhere from 24 hours or so to reach the Bay from a short wide tributary, like the lower Androscoggin, to perhaps over a month from the head of tributaries like the Eastern, Cathance or Abbagadassett Rivers. Once in the middle Bay [between Abbagadassett Pt. and the Chops], timely, permanent outflow is still not likely. At low and medium flows there is extensive back and forth through the Chops as water only very gradually makes its way through the lower Bay [between the Chops and Thorne Head] and down the Kennebec. Even at high flows, up to somewhere in the mid 30,000cfs range at North Sidney, water continue to oscillate through the Chops. At extreme flows above this range tidal oscillation stops in this area and residence time lessens as movement of water accelerates down both the Kennebec and Androscoggin rivers to the Bay and from the Chops to the sea. At extreme high flows, limiting factors to outflow from the Bay are only bedrock constrictions of the Chops and Thorne Head and rising tide below Thorne Head.

While high flows shorten residence time of water in the large tributaries, residence time for water in the small rivers shows little change with only a gradual net movement to the Bay. Water levels in the Bay, rising faster than water can drain through the Chops, constrain and govern flows in the minor rivers preventing any substantive flushing from these water bodies. Also at high flows, water accelerating out the mouth of the Kennebec meets westerly long-shore and offshore currents moving into eastern and central Casco Bay and beyond. With the boost of ultra high flows, water of Kennebec origin can move to points well beyond the midcoast Maine area as evidenced by our Cape Cod drifters.

Our river water acts to transport or effect transport of many constituents including nutrients, fish, contaminants, sediment, phytoplankton, marine mammals, debris, oxygen and plant materials. This fundamental FOMB hydrologic study of the Bay enables us to better understand how our complex river/Bay system acts as a moveable matrix. In so doing, we are presented the opportunity to better care for it, understand the spatial extent of its effects and be aware of challenges to its integrity. In keeping with our mission statement, this circulation study acts to help us all better preserve, protect and improve the unique ecosystems of Merrymeeting Bay.

For more information please contact Ed Friedman at edfomb@suscom-maine.net . This study is also posted in the "Cybrary" section of the FOMB web site at: www.friendsofmerrymeetingbay.org .