Circulation Study of Blue Hill Bay

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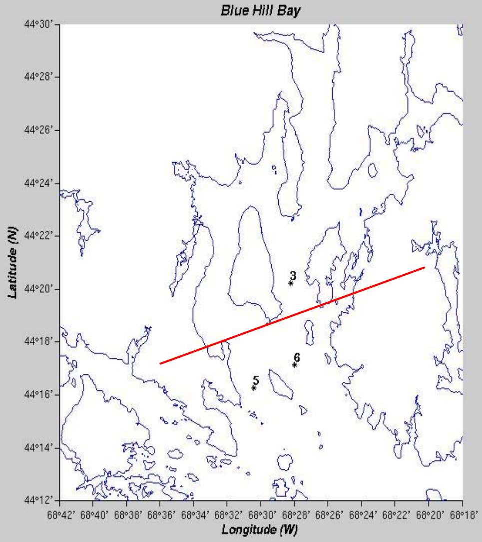


- Three Oceanographic Moorings were deployed in Blue Hill Bay. The buoys measured currents, temperature, salinity and winds.
- Preliminary results from the Princeton Ocean Model, a robust three-dimensional circulation model based on numerical solution of the fluid dynamical equation of motion. Model forced by winds, fresh water from the Union river, seasonal heating and cooling, friction, and exchange with the Gulf of Maine provided by a larger-scale model.
- General comments on the nitrogen budget of Blue Hill Bay.

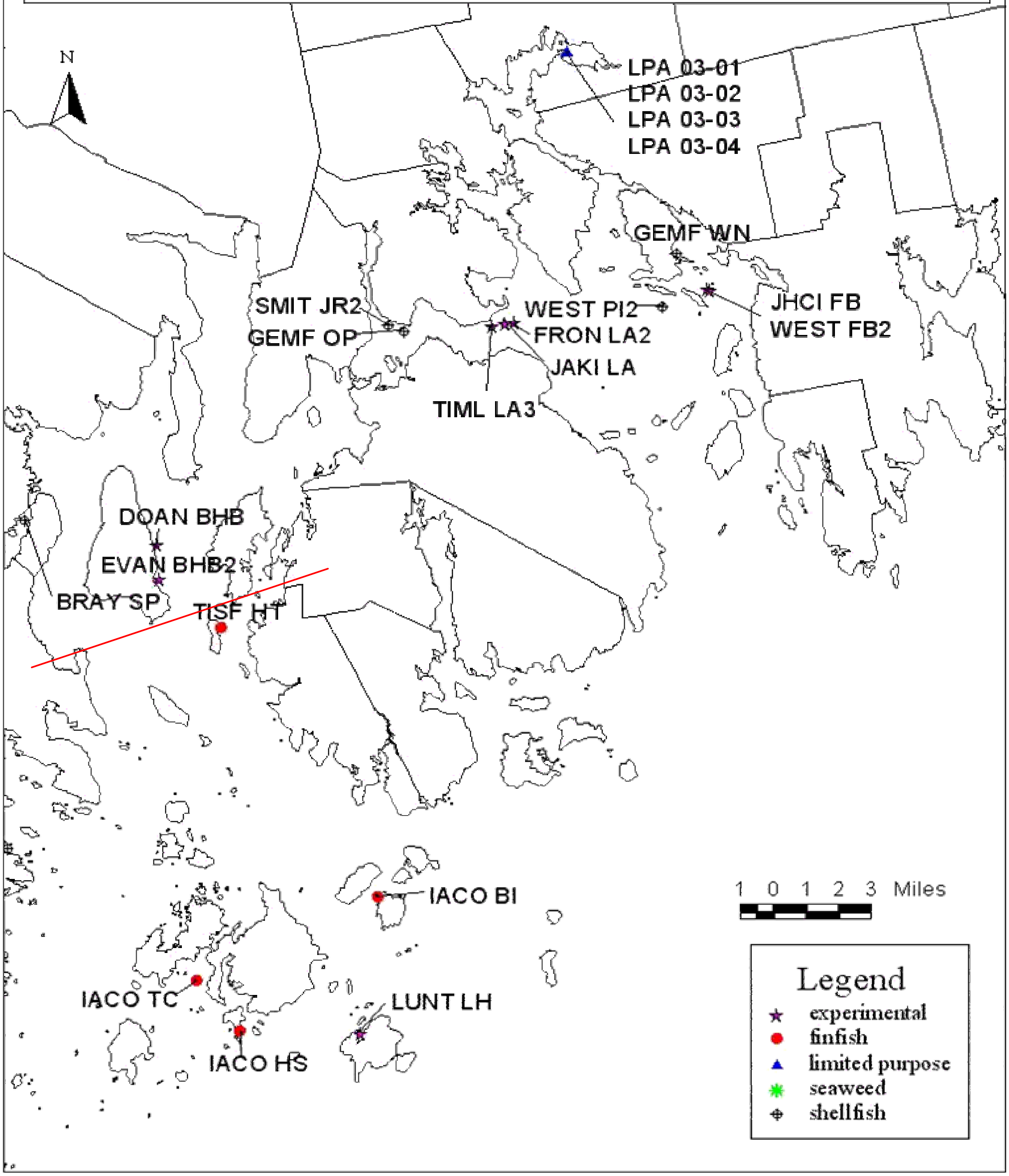
Circulation Study of Blue Hill Bay

The slide shown above is from a presentation Dr. Pettigrew made discussing the details and results from the circulation model of Blue Hill Bay that he and his colleagues have created. The results from this model are referenced in this presentation and have contributed greatly to the conclusions arrived at.

Current Blue Hill Bay Aquaculture Activity

The next page is a copy of the most current State of Maine's map of aquaculture sites in the Mount Desert Island area. A line has been drawn at the lower end of "Upper Blue Hill Bay" as defined in this bill. The only existing aquaculture sites in Upper Blue Hill Bay are a mussel farm on the Salt Pond in Brooklin and is labeled "BRAY SP" and two experimental mussel farms on the east side of Long Island labeled "DOAN BHB" and "EVAN BHB2". The only Salmon farm in the lower bay, located at Hardwood Island, is labeled "TISF HT". There are no known additional lease requests for Upper Blue Hill fin-fish aquaculture sites.

Figure 7. Aquaculture Lease Sites in the Mount Desert Island Area



Major Issues

Dissolved Oxygen

Importance of Seasonal Stratification
Geographical (East-West) differences in tidal mixing and seasonal stratification.
The Simpson-Hunter criterion as a predictor
Simpson-Hunter values for Upper Blue Hill Bay

Velocity of the Current

Resuspension and dispersion of net-pen wastes
Velocity values for Upper Blue Hill Bay

Residence Times and Nutrient Loading

DMR nitrogen study
Nitrogen impact of a salmon farm in upper Blue Hill Bay

Importance of Seasonal Stratification

Seasonal stratification (a warm, lighter layer of water at the top overlaying a cold layer on the bottom) develops when the heat of the sun is strong enough to offset the effects of tidal mixing and creates a temperature and density difference that produces a barrier to any significant exchanges of water between the layers. The addition of a fresh water source (fresh water is lighter than salt water) contributes to the probability and intensity of seasonal stratification. Upper Blue Hill Bay receives the significant fresh water output of the Union River.

When stratification occurs, water beneath the surface layer is cut off from any significant replenishment of oxygen until the stratification disappears when cold weather and winter storms arrive. Thus, in stratified waters, dissolved oxygen levels in the lower water level drop throughout the spring and summer periods as a result of naturally occurring increased organic activity. This causes deterioration in water quality that is not corrected until the stratification disappears. This natural oxygen depletion can become a severe problem and cause damage to the bottom dwelling (benthic) community when the lower water level is further burdened by additional organic discharges.

Effluents from fish pens exacerbate the dissolved oxygen decline through the decay of this organic material which is released into the lower layer.

Stratification also limits the replenishment of nutrients from the lower levels to the upper layer. These nutrients are used for phytoplankton growth in the upper layer. It is the development of stratification that ends the spring bloom conditions (when both light and nutrients are available) that lead to algal population growth.

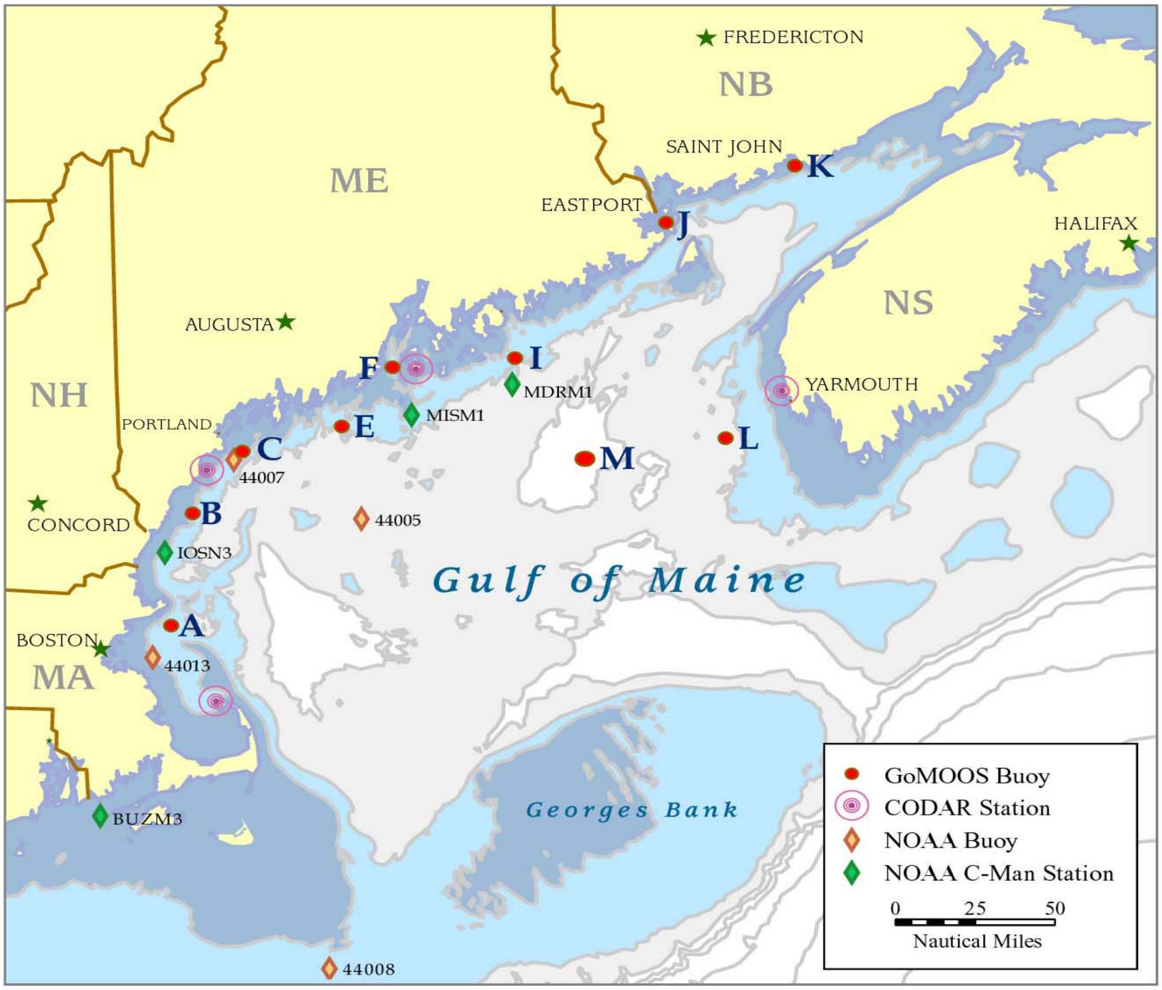
Penned fish release nutrients into the upper layer also. Blue Hill Bay would normally have low nutrient concentrations in the summer season. The disturbance of the natural state of a bay or estuary is potentially very significant in water bodies like Blue Hill Bay that have naturally low nutrient levels since, by definition, any increase is a major change from normal.

East – West gradient in tidal mixing

No seasonal stratification occurs in Cobscook Bay because vigorous tidal mixing results in contact between the deep waters and the atmosphere throughout the year. Thus, in these well-mixed regions dissolved oxygen can be renewed in the subsurface waters even during the summer months when organic loading, and thus oxygen demand, are high from both natural causes and net-pen operations.

Seasonal stratification begins to occur as one follows the coast from Cobscook Bay toward Schoodic Point. The map below shows the placement of buoys that Dr. Pettigrew is currently using in a larger study of the Gulf of Maine. Buoy “I” is off Schoodic Point and Buoy “J” is at Cobscook Bay. His detailed studies have shown that seasonal stratification begins about half-way between these two buoys and continues down the coast to the west to Blue Hill Bay and beyond.

The Gulf of Maine Ocean Observing System (GoMOOS):
GoMOOS real-time Monitoring in the Gulf of Maine Oceanography
Neal R Pettigrew**, Ph**ysical **O**ceanography **G**roup (**PhOG**)
School of Marine Sciences, University of Maine



Simpson – Hunter Criterion

A simple measuring formula known as the Simpson-Hunter criterion (SHC) was first published in 1974. The mixing effect of currents depends not only on the current but also the water depth. This formula relates them to each other to predict stratification. The formula is H/U3, where H is the water depth in meters and U3 is the tidal current speed in meters per second (m/sec) cubed.

It differentiates between areas that are vertically mixed by tidal currents, and thus don't seasonally stratify and areas where currents are too weak to overcome the stratification that results from solar heating. It should be noted that the formula ignores the impact of any fresh water source, in our case the Union River, on seasonal stratification. Fresh water (lighter than salt water) adds to the strength of the stratification since it magnifies the density difference between the two layers. Thus, the values presented in this material understate the stratification impact to some degree.

It is easy to compute and has been used successfully in shallow seas around the world. While it is a simple formula, it requires significant professional judgment to apply it in differing circumstances and can lead the less experienced to draw incorrect conclusions. Simpson-Hunter Criterion has been successfully applied in shallow seas around the world. Below are listed a few of the many published studies that have successfully used Simpson-Hunter to predict stratification.

- Tidal Mixing versus Thermal Stratification in the Bay of Fundy and Gulf of Maine. CJR Garrett, JR Keeley, and DA Greenberg, 1978. Atmosphere Ocean, 16 (4), 408-423.
- Tidal currents and mixing in the Gulf of St. Lawrence: an application of the incremental approach to data assimilation. Y Lu, KR Thompson, and DG Wright, 2001. Can J. Fish. Aquat. Sci. 58 (4) 723-735.
- Tidal mixing and summer plankton distributions in Hecate Strait, British Columbia. RI Perry, BR Dilke, and TR Parsons, 1983. Can J. Fish. Aquat. Sci. 40 (4) 871-887.
- Tidal Fronts in the southwestern Hwanghae (Yellow Sea). H-J Lie, 1989. Continental Shelf Res., 9 (6), 527-549.
- On the value of the mixing efficiency in the Simpson-Hunter H/U3 criterion. CJ Hearn, 1985. Deutsche hydrographische Zeitschrift, 38 (3) 133-145.
- Coastal Dynamics, Mixing and Fronts. CJR Garrett, 1983. Oceanography: The Present and Future, PG Brewer (Ed). Pp 70-86

In the Gulf of Maine and similar latitudes an SHC value of 70 has emerged as a rough guiding line between areas that seasonally stratify and those that do not.

Listed below are the Simpson-Hunter values for a few representative areas on the Maine coast and in Blue Hill Bay:

Cobscook (SHC of 10) experiences no stratification.

Shelf off Schoodic Point (SHC of 400-800) experiences stratification from May through October each year.

Toothacher Cove, Swans Island (estimated SHC of 100 to 200) is a marginal fish farm site that has had problems with environmental degradation including formation of extensive Beggiatoa mats and at least one incident of serious fish mortality associated with low dissolved oxygen.

Tinker Island (SHC of 1,000-3,000) would be expected to experience significant seasonal stratification.

Values of several hundred or greater should be considered good reason to reject a location as a potential fish-pen site. Areas with SHC values in the thousands should not even be considered as fish-pen sites.

The chart below shows the relationship between current flow and water depth and the resulting SHC values. It illustrates, for example, that at a depth of 131 feet a current of one knot produces an SHC of 320. SHC values in the 300-400 range have been highlighted to make clearer the velocities required at various depths to bring the SHC down to this level.

Simpson and Hunter
Criterion
Values

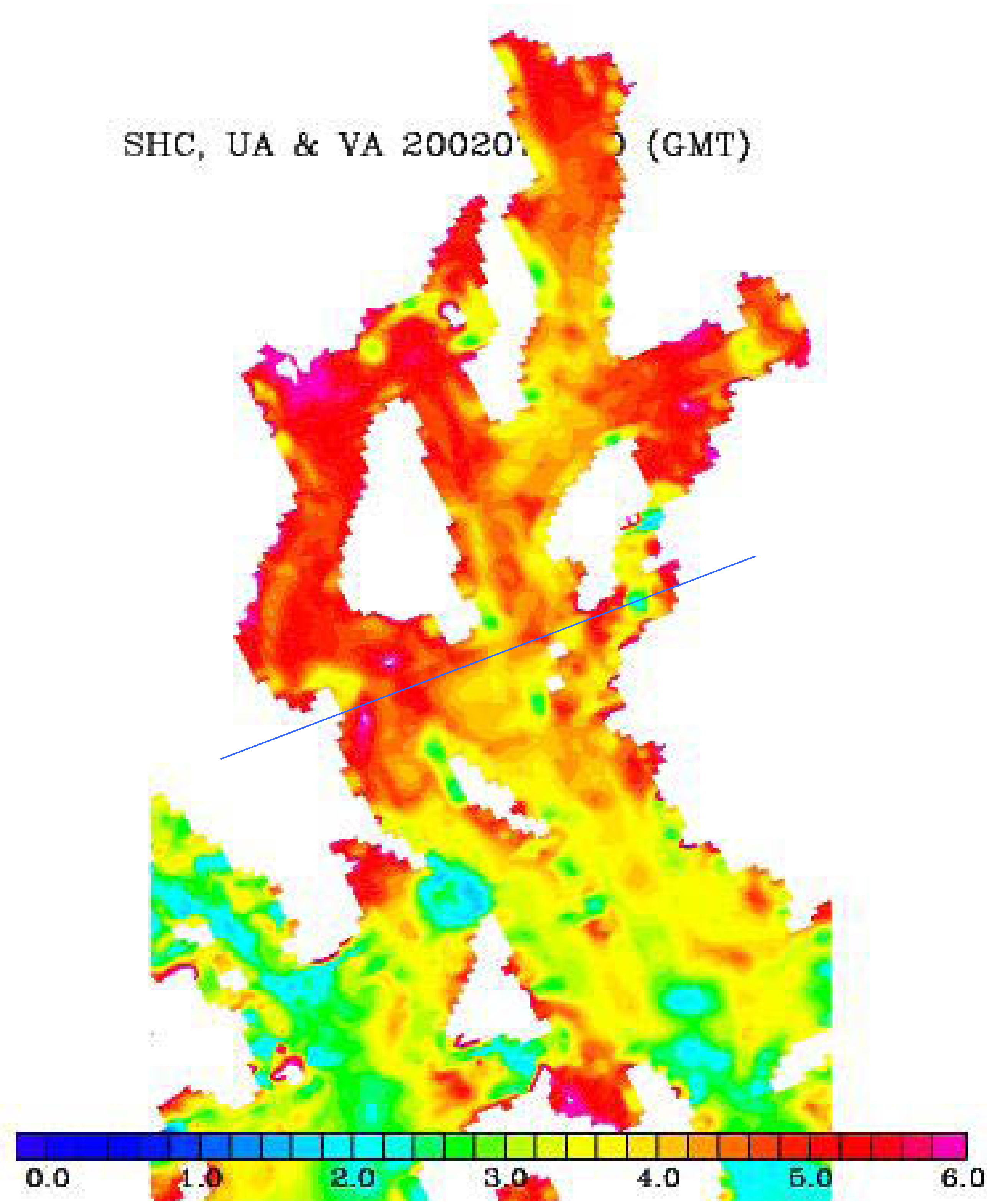
Depth Measured In											
Meters		1	5	10	20	30	40	50	60	70	80
Feet	3.281	3	16	33	66	98	131	164	197	230	262
Speed Measured In											
CM/Sec	Knots										
5	0.1	8,000	40,000	80,000	160,000	240,000	320,000	400,000	480,000	560,000	640,000
10	0.2	1,000	5,000	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000
15	0.3	296	1,481	2,963	5,926	8,889	11,852	14,815	17,778	20,741	23,704
20	0.4	125	625	1,250	2,500	3,750	5,000	6,250	7,500	8,750	10,000
25	0.5	64	320	640	1,280	1,920	2,560	3,200	3,840	4,480	5,120
30	0.6	37	185	370	741	1,111	1,481	1,852	2,222	2,593	2,963
40	0.8	16	78	156	313	469	625	781	938	1,094	1,250
50	1.0	8	40	80	160	240	320	400	480	560	640
60	1.2	5	23	46	93	139	185	231	278	324	370
80	1.6	2	10	20	39	59	78	98	117	137	156
100	1.9	1	5	10	20	30	40	50	60	70	80

A chart of Blue Hill Bay showing the SHC values for the Bay is displayed below. The scale is logarithmic. Thus the equivalent Simpson-Hunter values are shown below:

1.0	10 SHC
2.0	100 SHC
3.0	1,000 SHC
4.0	10,000 SHC
5.0	100,000 SHC
6.0	1,000,000 SHC

The line defining Upper Blue Hill Bay has been drawn on this exhibit.

SIMPSON-HUNTER CRITERION
Values for Blue Hill Bay



Simpson-Hunter Values	10	100	1,000	10,000	100,000	1,000,000

It can be clearly seen that yellows (5,000 SHC to 15,000 SHC) and reds (15,000 SHC to over 100,000 SHC) predominate in Upper Blue Hill Bay. **It has been regularly observed during the last several years that seasonal stratification in Blue Hill Bay is very strong. This observed seasonal stratification (as noted above) is entirely consistent with the high SHC values on Exhibit 4.**

Velocity Standards

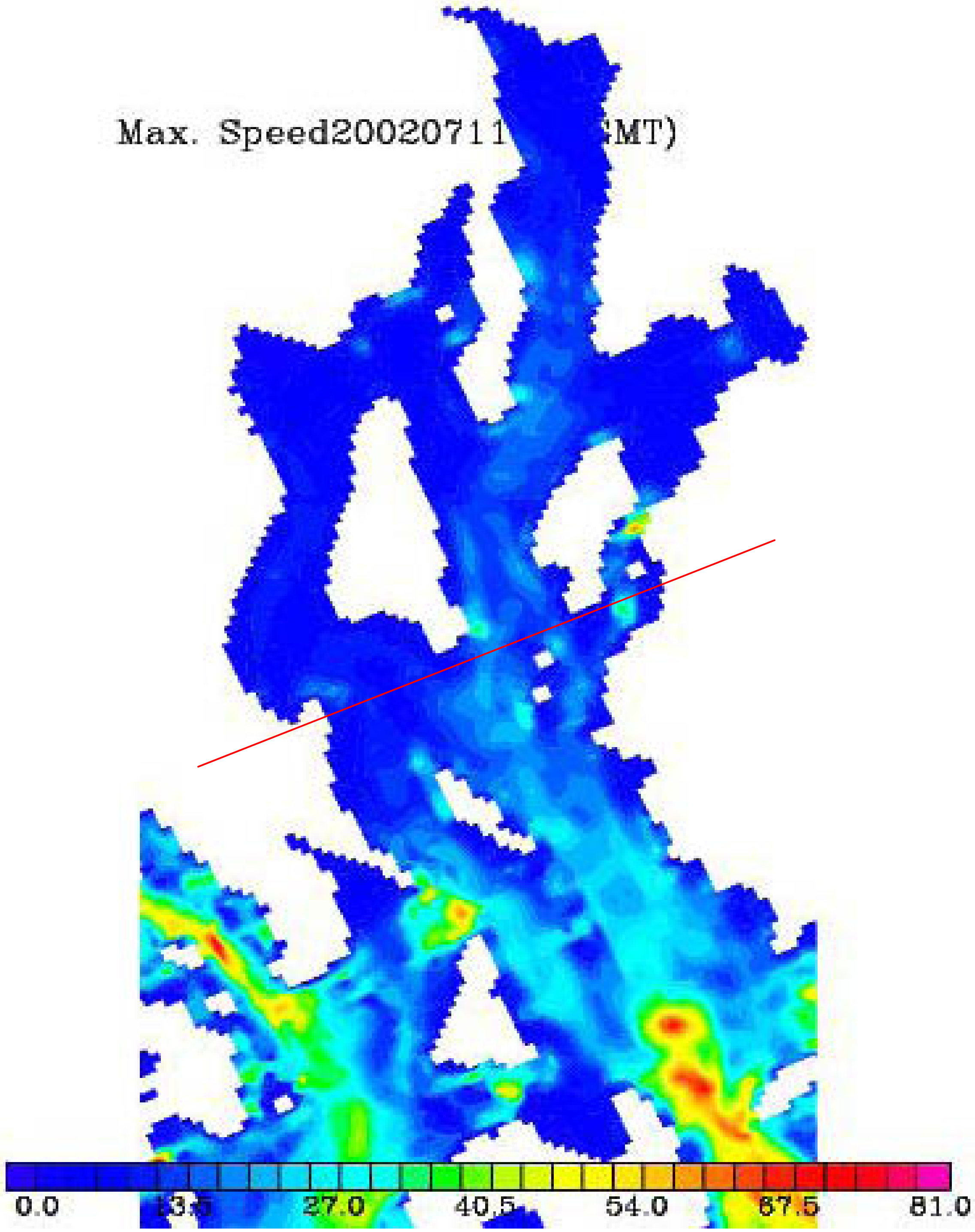
In addition to seasonal stratification, the maximum tidal velocities are very important. In order to remove sediment from the bottom under a finfish net-pen, the current at the bottom must be fast enough to cause particles on the bottom to rise back into the water column (resuspend) so they can be swept away to another location.

A "direct measurement" experiment by Dudley et al. was published in 2000. The work was done in Deep Cove Cobscook Bay to determine what minimum velocity is required to begin resuspending net-pen wastes. The tests indicated a required velocity of 42 cm/sec in April 1996 and 51 cm/sec in September 1996. More details regarding this study are shown below:

- Dudley *et al*., 2000, made **direct measurements** of the resuspension of net-pen wastes beneath a pen site in Deep Cove Cobscook Bay Maine using a Sea Carousel. The apparatus is an annular flume with controllable flow velocity that also takes turbidity measurements, water samples, and video of the erosional process. Using this instrument package they were able to determine the critical flow speeds (at one meter above the bottom) at which erosion and resuspension of net-pen wastes were initiated.
- The published results were that the **mean critical velocity** to initiate the erosion of net-pen wastes was **42 cm/sec April, 1996, and 51 cm/sec for September, 1996**. The increased velocity required at the end of summer was interpreted to indicate that higher speeds were required to initiate erosion and resuspension when greater quantities of waste material were on the benthos.

The current speed that is most important to resuspension is the maximum speed during the tidal cycle since that is the moment with the greatest potential to produce effective flushing. All current speed measurements used to prepare The above Simpson-Hunter Criterion chart and the chart below showing maximum tidal currents are the maximum speeds attained when the inherent natural flow and the tidal flow are moving in the same direction.

Blue Hill Bay
Maximum Tidal Currents



Centimeters per Second

The above charts shows that the MAXIMUM current velocities in Upper Blue Hill Bay are almost exclusively in the 0-13 cm per second range with none at the required resuspension rate of 42 cm per second except at Bartlett Island Narrows. Cobscook tides are approximately 10 times as strong as those in Blue Hill Bay.

Two questions regarding the validity of the Dudley study have recently been voiced. Dr. Pettigrew has addressed each:

1. “There has been some concern over the fact that the two control sites (outside the impact zone of the pens) used in this study showed very similar critical erosional speeds as the sites that were visually observed to contain a significant layer of pellets and feces. However, in my view this is not unexpected. Professor Findlay of Miami University, who has experience diving and deploying current meters beneath pens in Maine, offers anecdotal evidence that erosion begins at about 30 cm/sec (Findlay, personal.com.) Since the tidal flows in the Cove region are around 25-35 cm/sec (Dudley, personal.com.), it is to be expected that both the natural and net-pen sediments had been similarly winnowed. Thus it would be expected that the material remaining at each site would require similar velocity to initiate erosion.”

2. “A recent study by Cromey et al., (2002) has suggested that erosion may initiate at speeds closer to 10-15 cm/sec. However, these findings were primarily based on comparison of a model with the repeated survey of fluorescent particles. Furthermore, the model was not sensitive to increases in critical erosion stress (nor inferred critical velocity) and the model has another tunable coefficient referred to as an ‘erodability constant.’ On balance, the direct observations of Dudley et al., are by far the more compelling.”

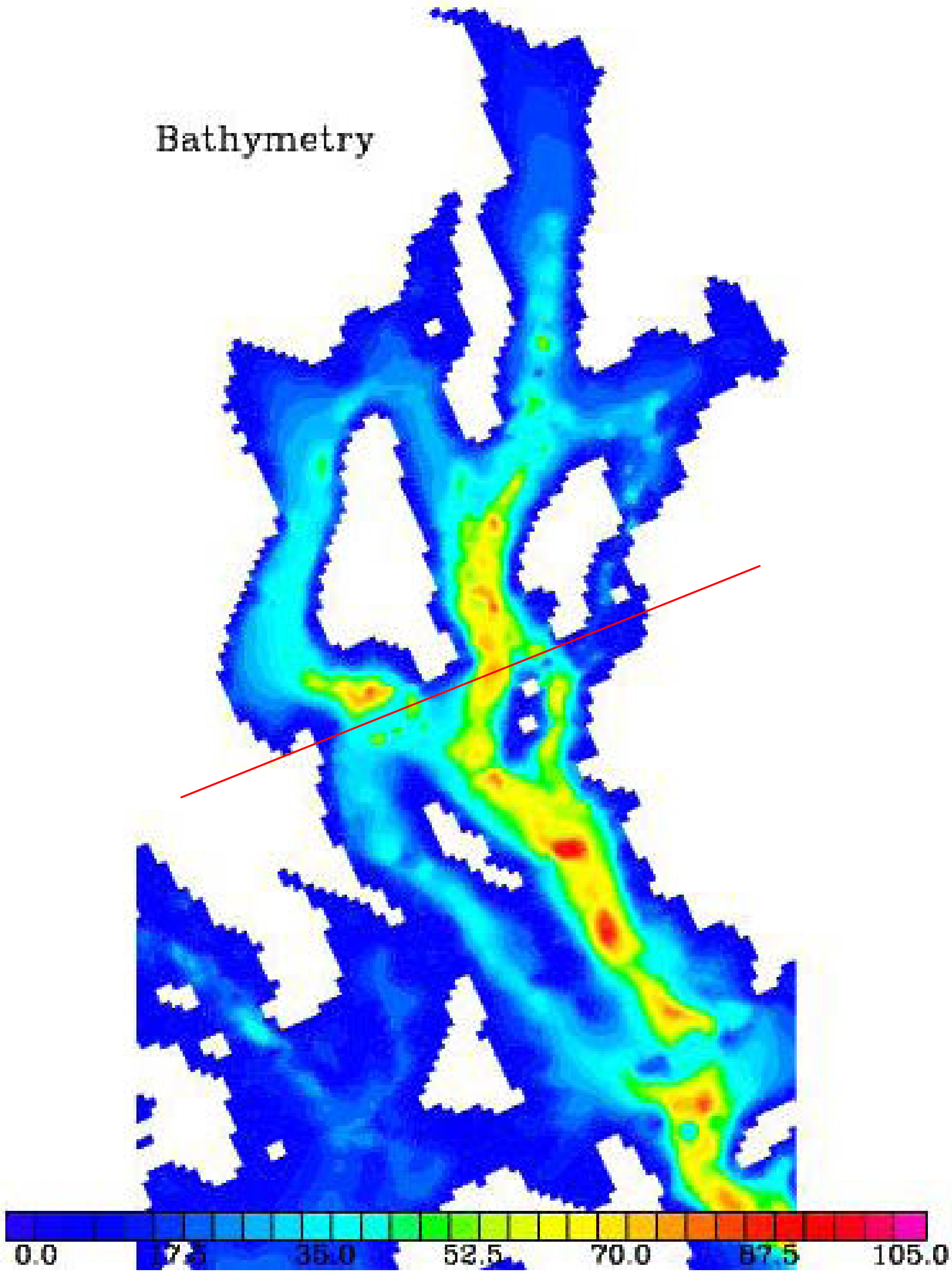
Page 14 illustrates the extremely slow currents in Upper Blue Hill Bay. Again, the line that defines the Upper Bay is drawn in. Keep in mind that these are MAXIMUM speeds. Purple and blue indicate speeds from zero to 15 cm/sec while green indicates speeds up to perhaps 20 cm/sec.

The maximum tidal currents in Blue Hill Bay are weak (as reflected in high SHC values). The maximum currents in Upper Blue Hill Bay are almost entirely on the order of 5-15 cm/sec., which is extremely sluggish. It is roughly only 1/3 the threshold

speed required to erode pen wastes. The weakness of the tidal currents make the benthos (bottom) of Upper Blue Hill Bay very sensitive to the impacts of organic loading, and the area will be very susceptible to the buildup of fish-pen waste products and sea bottom degradation.

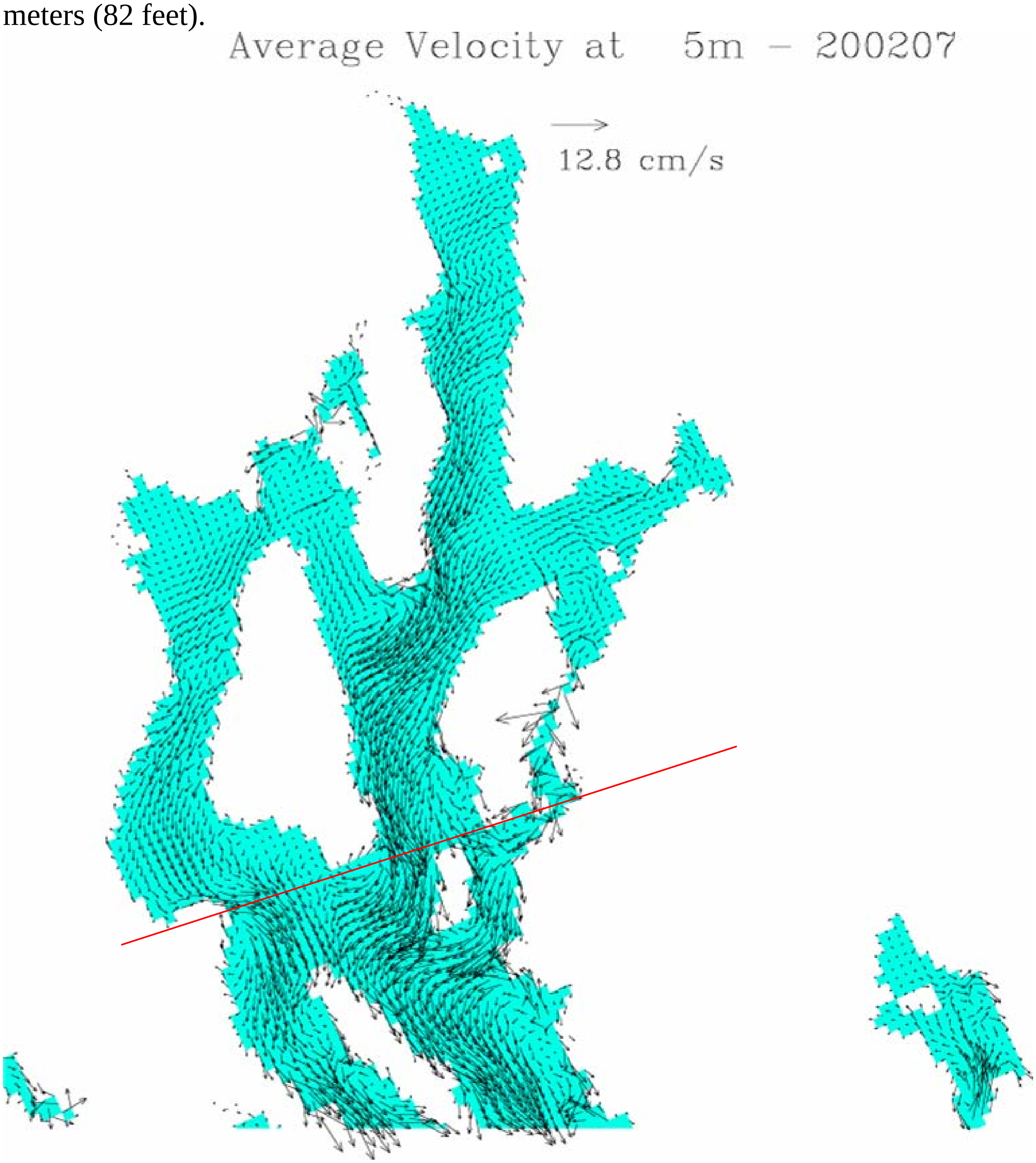
The chart below illustrates the depths in Blue Hill Bay. The extensive areas of light blue (75-125 feet), green (125-175 feet), yellow (175-250 feet) and red (250-300 feet) indicate that a large portion of the Bay is very deep. The deeper waters both require higher currents to deter seasonal stratification and, in fact in this Bay, exhibit slower and more complex currents than shallower waters.

Blue Hill Bay
Water Depths

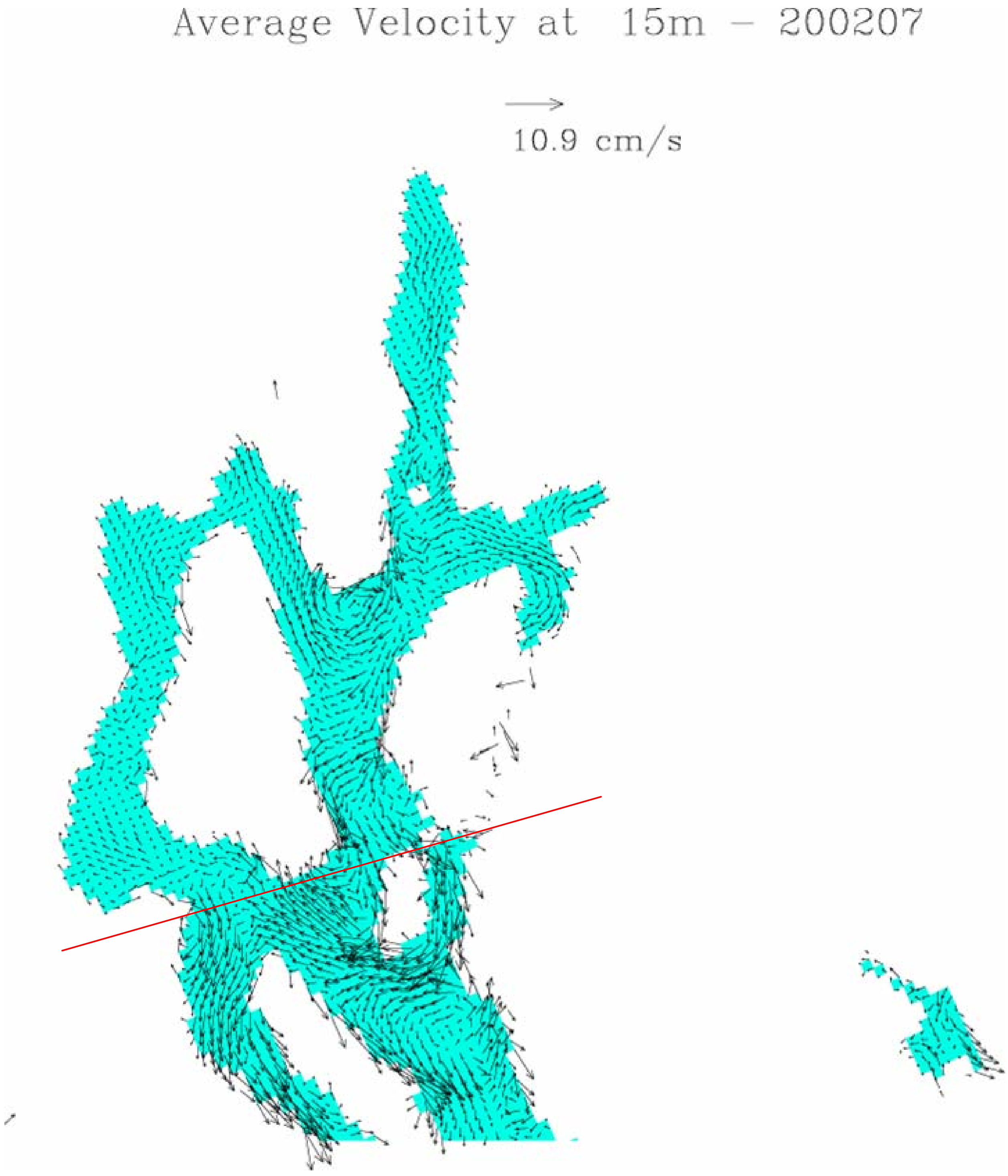


Meters
Feet 57 115 172 230 287 345

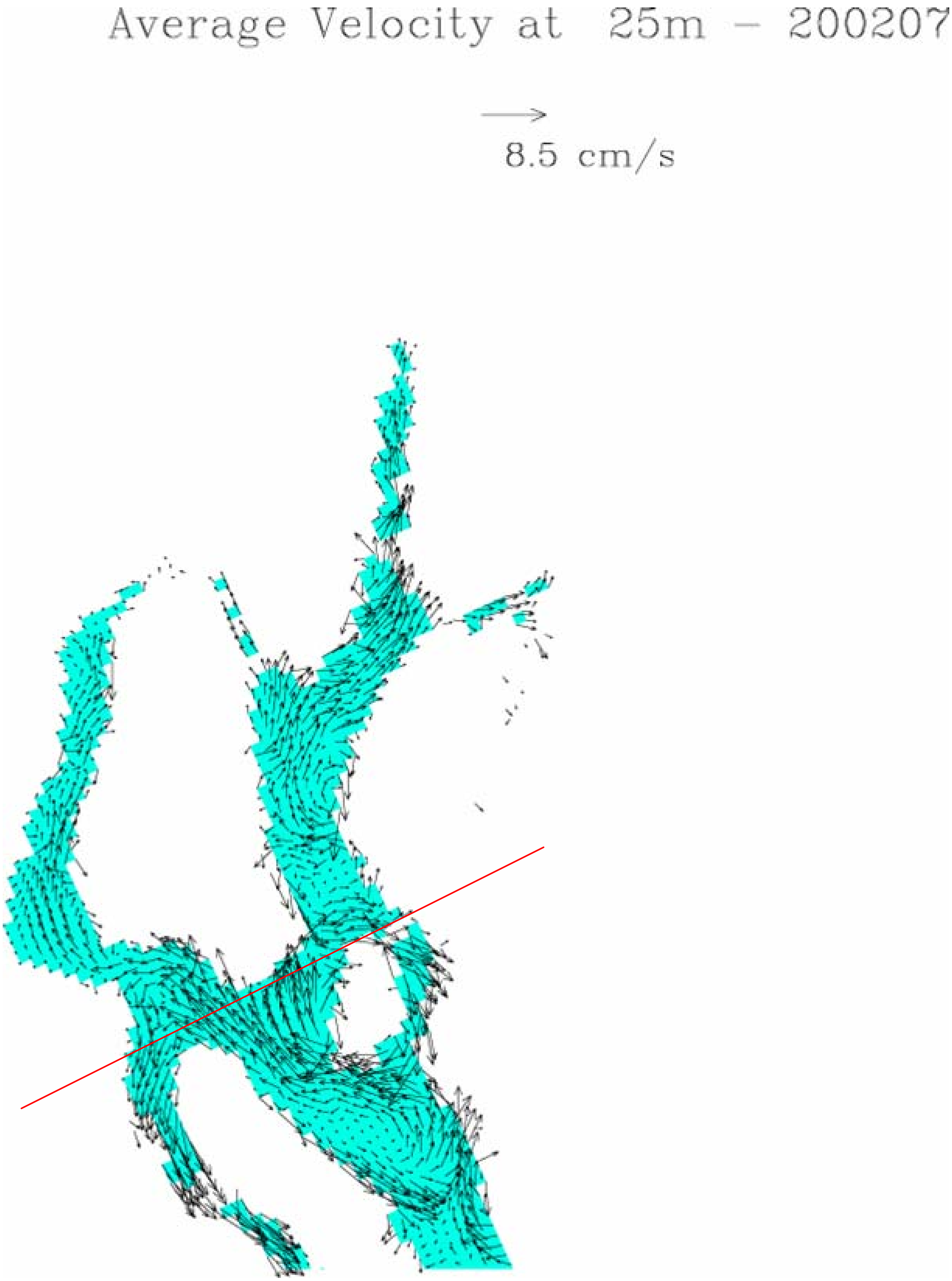
The following three charts illustrate the AVERAGE currents in both the upper and lower half of Blue Hill Bay. The first shows the currents at 5 meters (15 feet), the second shows currents at 15 meters (49 feet) and the third shows currents at 25 meters (82 feet).



5 meters (16 feet) down there is an orderly flow clearly influenced by the Union River although the currents in the lower half of the Bay are significantly reduced. Note that very few arrows equal even the length of the 12.8 cm/sec arrow shown.



15 meters (49 feet) down (EXHIBIT 10) the currents begin to become less orderly and more complex with eddies developing. In some areas the average current flows in rather than out. The velocities decrease even more with fewer and fewer long arrows even though the scale arrow is down to 10.9 cm/sec.



Finally, at 25 meters (82 feet) below the surface the currents become very complex with a number of eddies and significant areas where the average flow is up the Bay rather than out of the Bay. At this depth the Union River has produced an estuary effect with a large part of Upper Blue Hill Bay experiencing flows up the Bay rather than toward the ocean. Velocities have further slowed. Even with the scale arrow indicating only 8.5 cm/sec, the majority of the arrows are shorter than this and thus indicate even slower currents.

The average currents in Upper Blue Hill Bay become more complex and slower the deeper you go. With a significant number of eddies and "up the Bay" flows at 25 meters, combined with very slow currents, the ability of the Bay to clean itself by flushing out fish-pen waste products is very questionable. The risk of damaging the Bay is high and not worth the risk.

Nutrient Loading

Calculation of nitrogen inputs and effects

Municipal Wastewater	- 32 Metric Tonnes
Atmospheric	- 70 Metric Tonnes
Runoff	- 120 Metric Tonnes
Salmon Farm	- 55 Metric Tonnes (280,000 fish)

Once the seasonality of the inputs is recognized the following results are observed:

May to October

1. Using a 280,000 fish assumption the nitrogen input during this period is nearly 47 tons and 85% of the total year's input.
2. The input is more than twice the input from the municipal waste water treatment plants in Blue Hill and Ellsworth.
3. The fish pen input constitutes a 40% increase over the base inputs and is nearly 29% of the total for this period
4. Using 400,000 fish, the stated maximum desired for a typical salmon farm operation, the inputs jump to three times the treatment plant inputs, 36% of total inputs and a 57% increase over the non-fish pen inputs.

July and August

1. Using 280,000 fish, the nitrogen input during this short but by far most critical period is nearly 22 tons and 40% of the total year's input.
2. The input is twice the input from the municipal waste water treatment plants in Blue Hill and Ellsworth.
3. The fish pen input constitutes a 52% increase over the base inputs and is 34% of the total for this period
4. Using 400,000 fish, the inputs again jump to three times the treatment plant inputs, 42% of total inputs and a 74% increase over the non-fish pen inputs.

It must be noted that nitrogen deposited in the water within reach of phytoplankton in the top layer of water (approximately 10-15 meters deep) are consumed by them in a day or so. There can be no dispersion and the impact of the resultant phytoplankton growth is very local and occurs quickly.

Local Nitrogen Impact

The circulation model is able to receive nitrogen at a given point and illustrate the resulting dispersion pattern over time. The picture below shows the different patterns of dispersion and concentration at three key sites in Blue Hill Bay.

The red arrow points to the location off Tinker Island that has been selected by Erick Swanson for his salmon farm application.

The blue arrow highlights Hardwood Island, the site of Erick Swanson's current salmon farm.

The black arrow points to Rock Point, a site that Erick Swanson had indicated he had an interest in as a potential lease site. He has now indicated that he is no longer interested in that site.

The colors indicate the percentage of the originally deposited nitrogen that remains in the area. The colors represent the roughly following:

Red – 70% to 100% of the original nitrogen input still in the area
Yellow – 50% to 70%
Green – 30% to 50%
Light Blue – 10% to 30%
Dark Blue – 0% to 10%

The model shows the dramatic differences between the ability of the Lower Bay to handle nitrogen inputs and the ability of the Upper Bay to handle the same inputs.

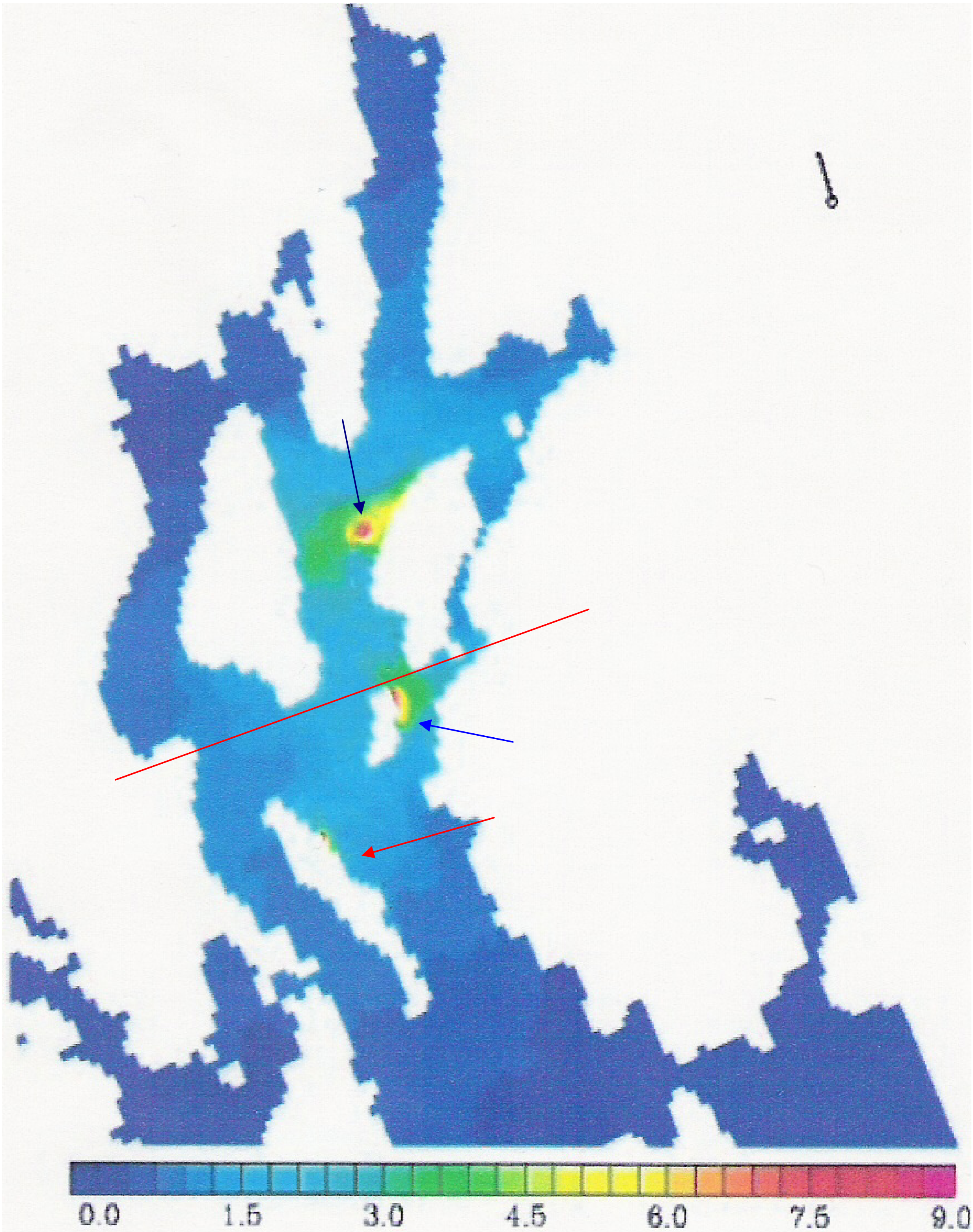
Tinker Island has, in fact a significant local impact that pales in comparison to the other sites but is still of concern.. Simpson-Hunter numbers illustrate a strong seasonal stratification which always indicates potential problems.

Hardwood Island, further up the Bay, shows somewhat worse nitrogen performance. Note the increased red and yellow patterns. Hardwood has had ecological problems in the past and was ordered by the DMR to prepare and execute a remediation plan for those problems.

Rock Point, now abandoned as a potential net-pen site by Swanson shows characteristics that are truly disturbing. Nitrogen inputs there show patterns of concentration and persistence that indicate significant risk. The currents are meager and bottom currents are predominantly in, not out. The potential for damage to the local ecology is high.

The west side of Long Island shows some of the slowest maximum currents of the entire Bay. The rest of Upper Blue Hill Bay is similar.

We believe that it is not wise to consider Upper Blue Hill Bay as at all suitable for fin fish aquaculture because of the potential ecological damage that can and probably would occur in such a sheltered and poorly flushing bay.


0.0
1.5
3.0
4.5
6.0
7.5
9.0

Residence Time

The flow patterns in Upper Blue Hill Bay determine the destination of any solids being moved by the tidal currents. They determine where the discharges go and how long it takes them to get there.

As detailed above, the maximum flows in Upper Blue Hill Bay are extremely slow and their pattern is chaotic. This sluggish circulation means that the residence times of the effluents within the Bay are undoubtedly long and flushing is poor for the system as a whole.

The completion of our Blue Hill Bay study will, by the fall, develop detailed residence times.

Summary Observations

Upper Blue Hill Bay is strongly stratified from mid-May through September. The "Simpson-Hunter Criterion" values (predictors of seasonal stratification) for these waters are extraordinarily high and clearly indicate the potential for significant oxygen depletion in these critically important waters.

The very slow maximum tidal current speeds throughout Upper Blue Hill Bay are not sufficient to lift waste materials off the bottom and flush them away.

A single salmon farm with 400,000 fish in Blue Hill Bay will deposit 79 metric tons of nitrogen in the Bay over the course of the year. 67 tons would be deposited during the period from May through October, the most sensitive time of the year.

31 tons would be deposited in July and August alone and would make up 42% of all nitrogen deposited during that period and a 74% increase over all other sources. This is three times the combined deposits from the Blue Hill and Ellsworth sewage treatment plants and will be deposited in a single location with significant local impact.

The potential impacts of such a nitrogen deposit at a location in upper Blue Hill Bay include (1) algal blooms in the upper stratified level including the possibility of the introduction of Red Tide and (2) serious depletion of oxygen in the lower stratified level.

As a result of these very slow currents and complex current patterns, the estimated time it takes for waste products deposited in Blue Hill Bay to eventually leave the Bay (residence time) is considered to be very long and is a further indication of the risk to the Bay from the addition of fish pen waste.

Conclusions

Upper Blue Hill Bay is not appropriate for the placement of fin fish pens. The Bay flushes very poorly and experiences significant seasonal stratification.

The addition of any fish pens would pose a great threat that dissolved oxygen in the lower water level would be overly depleted and algal blooms would occur in the upper water level, potentially introducing Red Tide to the Bay for the first time.

The extremely slow currents in Upper Blue Hill Bay would result in significant waste build up and the development of anaerobic bacterial mats under the fish pens and damage to the bottom dwelling (benthic) community.

The existing conditions and attendant risks appear to be so high that they should not be ignored.

Scientific Credit

Readers of this report should know that the presentation was put together using materials provided by Neal R. Pettigrew, Ph.D., Associate Professor of Physical Oceanography, School of Marine Sciences, University of Maine.

Dr. Pettigrew's academic credentials are as follows:

Dartmouth College – AB with Distinction in Physics,
Magna cum laude, Phi Beta Kappa
Louisiana State University – M.S. in Marine Sciences
Massachusetts Institute of Technology – Woods Hole Oceanographic Institution – Ph.D. in Physical Oceanography
23 Years of experience studying the circulation in the Gulf of Maine and coastal regions worldwide