# Integration of dense, time-varying water column information with high-resolution swath bathymetric data

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## *Abstract*

Hydrographic surveys have tended to focus primarily on the sediment–water interface. This is, after all, the surface that is of most concern for safety of navigation. An additional component of hydrographic survey, however, has always been the collection of supporting current and oceanographic information. Our ability to measure the current field has recently undergone a massive advance with the widespread acceptance of acoustic doppler current profilers (ADCP's).

Hull-mounted ADCP's now allow us to simultaneously view the watermass current field both in space and in time. Such high spatial resolution however needs to be coupled with matching high-resolution views of the seabed. By combining swath bathymetric surfaces and the information about the sediment distribution on that surface (revealed from acoustic backscatter) with the time-varying current field, new insights into the coupling of coastal circulation and sedimentation can be revealed.

Examples of combined dense ADCP surveys, water column scattering surveys and swath sonar bathymetry and backscatter surfaces are presented for two particularly dynamic coastal environments. The first is the Kennebecasis Estuary where the mixing of salt and fresh water is restricted and predominantly controlled by short wavelength topography not previously known from charting. The second example, from Saint John harbour, reveals the interaction of the local current field and fine scale topography around an active offshore disposal site in a high current area.

Both these examples show the value of integration of high-resolution oceanographic and seabed data. Such data sets, however, which are truly four dimensional (both the current field and the seabed are observed to change with time), provide a particular challenge to visualise and interpret. Coastal hydrographic operations that include simultaneous dense physical oceanographic observations can better address the growing demand for environmental management in the increasingly stressed coastal zone.

## *Introduction*

As multibeam bathymetric sonar gains wider acceptance within both the hydrographic and geophysical community, an increasing number of applications are being discovered (Hughes Clarke et al., 1996). As the usable angular sector has increased (due to advances in bottom detection and motion sensing), so has the sensitivity of those systems to the spatial and temporal heterogeneity of the water column. Refraction errors, due to imperfect knowledge of the sound velocity profile in the water column, can dominate the error budget for low grazing angle solutions (Kammerer et al., 1998, Kammerer and Hughes Clarke, 2000).

To address this problem, newly emerging oceanographic instrumentation is being applied that involves towed oscillating sensors (Furlong et al., 2000, de Silva et al., 2000, Hughes Clarke et al. 2000). Even these physical sampling methods however, have limitations in resolution and thus acoustic methods such as volume scattering profiles (Munk and Garrett 1973, Proni and Appel, 1975) and acoustic doppler current profilers (Rowe and Young, 1973, Geyer, 1993) could be employed to view finer detail.

What one is seeing in the very natural convergence of the increasingly sophisticated water mass monitoring tools with the seabed surface mapping tools. By combining data outputs from the two instruments, one can simultaneously increase the benefits to both user groups: providing better oceanographic data for the seabed mappers, and providing better seabed constraints for the oceanographers. This paper presents two applications where the two data sets are complimentary and shows some of the potential as well as problems pertaining to this sort of data integration.

## *Available dense oceanographic instrumentation*

To look at the water column from underway platforms, oceanographers have employed two prime acoustic methods: multifrequency scattering and acoustic doppler current profiling. Both of these methods can be performed from moving vessels and, with care, can be used to infer changes in the water mass structure along a survey line.

The acoustic scattered intensity field is responding to the effect of a variety of scatterers in the water column including biological signatures, bubbles and temperature and salinity microstructure. The biological signatures are commonly due to shrimp-like zooplankton (Stanton et al., 1998) and the temperature and salinity (which control density and sound velocity) microstructure is controlled by turbulent mixing (Thorpe and Brubaker, 1983; Oakey and Cochrane, 1998). Experiments in this field have been conducted with equipment that take advantage of simultaneously used multiple frequencies (e.g.: 43 kHz, 120 kHz, 200 kHz, 420 kHz, and 1 MHz, Stanton et al., 1998 and 12, 50.5, 121 and 250 kHz, Oakey and Cochrane, 1998).

Acoustic Doppler current profilers provide information on the vertical velocity structure of the water column, indicating levels of velocity shear that are often associated with rapid gradients in water mass physical properties (haloclines or thermoclines). These measurements may also be made from moving vessels allowing a view of the water column from near the sea surface (within a minimum blanking distance of the transducer) to within ~6% of the water depth from the seabed. These measurements are usually derived from 3 or 4 tilted beams so they represent spatial averages over lengths scales of ~ 70% of the observation depth. Nevertheless, in shallow water (5-35m in the studies discussed) this corresponds to horizontal scales of a few tens of metres or less.

By collecting simultaneous cross sections of the multi-frequency scattering and current velocity structure one can infer oceanic processes over length scales of a few metres vertically and several 10’s of metres horizontally. By correlating with less frequent ground truth (static or towed CTD’s), variations in the water mass property distribution can thus be mapped at length scales comparable to the seabed bathymetric and backscatter information provided by the new generation of swath sonars.

## *Justification for Research*

Whilst the thrust of hydrographic charting (bathymetry) surveys has traditionally been to best depict the seabed relief, ancillary measurements of the regional oceanography (tides and spot currents) have always been an important component. Increasingly, however, the surveyor is tasked with investigations that extend beyond safety of navigation.

In dynamic coastal environments both the bathymetry and the seabed backscatter signature have a time varying component which often reflects the local oceanographic conditions. As the accuracy and resolution with which we can map the sediment water interface has increased (in part due to improved vertical position methods (deLoach et al., 1995)) we are better able to quantify the location and rate of seabed change. As part of this we also should characterise the water mass conditions both spatially and temporally in the vicinity of the active seabed change.

Of more immediate concern to the bathymetric survey however, is the effect to which the oceanography impinges on the accuracy of depth measurements, especially for very wide swath systems (which are finding particular favour in the shallow dynamic coastal zone due to increased survey efficiency). These changes impact precipitously on the final data fidelity. Thus any method that provides improved confidence in the depiction of the local watermass will be of benefit for charting surveys.

## *Instrumentation*

For these operations, the multibeam bathymetry data were collected using a Simrad EM3000S provided by the Canadian Hydrographic Service. The multibeam bathymetry system is integrated with a POS/MV 320 motion sensor and all data were post-processed using the OMG/UNB SwathEd software. The EM3000S is capable of resolving features of as small as 20 cm or ~0.5% in elevation as long as they are over ~ 5% of water depth in width. The spatial component of this resolution, however, significantly degrades from the inner to the outer beams. Near 200 % coverage was obtained using a 130 degree swath. Data were gridded at a 1m bin size using weighted filters reflecting the local beam footprint (and further weighted toward the near nadir beams). The system was operated in conjunction with the University of New Brunswick for the studies in Kennebecasis Estuary, and in conjunction with the Geological Survey of Canada for the studies of the Saint John offshore disposal site.

Subsequent to these surveys, simultaneous, 200 kHz and 600 kHz acoustic backscatter imagery was obtained of the water column. The 200 kHz data were obtained using a Knudsen 320 B/P with a 6° beamwidth. The digital echo envelope data were logged in 8 bit resolution with all source level, gain, and pulse length information retained. The 600 kHz backscatter data were obtained from an RDI Monitor Workhorse series ADCP which uses four 30° beams mounted at 20° off the vertical. Current vector and backscatter data were obtained simultaneously from the same ADCP at 1 m bins in the Kennebecasis and 0.3 m bins for the disposal site. All current data were reduced to absolute vectors using the bottom tracking capability. Azimuthal biases were calibrated by comparing DGPS course made good with bottom tracking dead reckoning.

The Knudsen scattering and Monitor ADCP data were logged simultaneously (both were mounted from a single rigid pole) and subsequently integrated with DGPS positioning and water level information. The vertical cross section data were all then projected onto a common vertical plane (Figure 1) to coregister the three information sources (200 and 600 kHz backscatter and the ADCP velocities).

In support of the Kennebecasis operations, manually lowered CTD information were collected at the start and end of each line, and for a subsequent tidal cycle, a moored profiling CTD (Ocean Sensors, OS500-APV) was employed to look at the time variation of the vertical structure at a single point location.

## *Kennebecasis Estuary*

The Kennebecasis Estuary is a fjord-like bay that is offset from the lower St. John River system. In this area, the salt water that passes through the restriction of the Reversing Falls interacts with the variable discharge of the Saint John River system. Because of the tidal damping at the Reversing Fall gorge and the absence of significant wind mixing, the two water masses do not heavily mix. As the denser, normally colder salt water enters the river system (already blended at the falls to ~23 ppt), it slides under the fresh water layer (between 5 and 13m thick depending on the state of the river flow and the tide) and penetrates over 20 km upstream (Trites, 1960).

This phenomenal water mass boundary, which corresponds to an abrupt sound speed gradient, provides a particular challenge to hydrographic surveys as it is a source of significant refraction. If known and stable, the layer would be inconsequential, but as observations as part of these study show, the interface varies in depth about 5-7m over length scales of a kilometre and time scales of a few hours. It thus represents an extreme case of the refraction problem observed on the open shelf.

A manually lowered CTD was used to obtain absolute sound speed calibration. In subsequent experiments, the change in the depth of the halocline as a function of space and time was monitored using the pattern of the in-water acoustic backscatter at 200 and 600 kHz, together with the velocity shear indicated by the ADCP current field.

As part of the oceanographic study of the exchange of fresh and salt water, the bathymetry and surficial sediment character of the constraining sill has been investigated using a combination of EM3000S multibeam, 28 kHz single beam bathymetry, shallow subbottom profiler, and 200 kHz pole-mounted sidescan sonar. Historic surveys, whilst noting occasional apparent isolated depressions had failed to recognise continuous narrow channels that cut across the sill. These investigations reveal that these channels (Figure 2) are conduits through which salt water exchange is enhanced. Only by the combined use of near 100 % bathymetric and seabed backscatter data together with ADCP and water mass scattering data were we able to recognise the control that the short wavelength morphology has on the intensified exchange within these channels.

Shipboard mounted ADCP's are now a commonly used tool (Geyer, 1993). By steaming a transect, a 2D vertical cross-section of the current field can be obtained. Displaying the vector information on a 2D plot provides a problem however. Herein, a combination of colour to indicate azimuth and intensity to indicate magnitude is used (Figure 1). A third variable, the scattering strength is also separated out. In this case, the 200kHz scattering was found to provide more information about the water column structure than the 600 kHz data and thus is shown in the upper panel. Using this display method, one can interactively rotate through a tidal cycle watching the evolution of the current field as observed from this 2D cross section. Using this method in Figure 1 one can see that there is clear current intensification associated with a short wavelength depression. The next step obviously is to relate the water mass movements see in the 2D cross-section to the high-density bathymetric and surficial backscatter mapping.

In Figure 2, the current data is broken up into depth ranges and presented as plan view vectors overlain on the high-density seabed acoustic data. In order to represent the depth variation in the current field, a crude selection is made, examining the current above and below 5m depth separately.

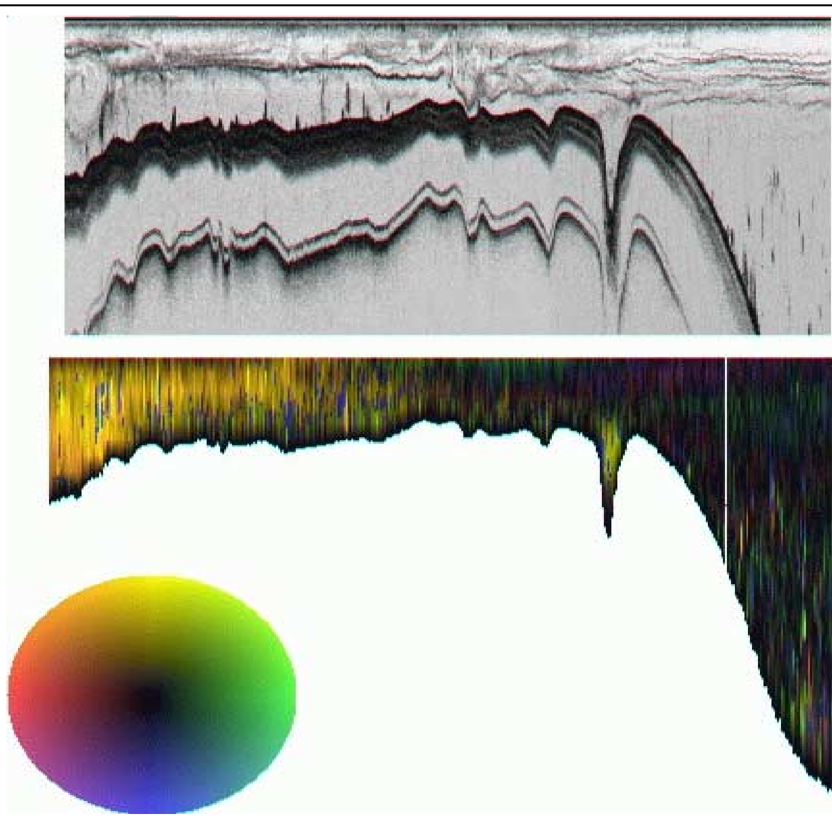


**Figure 1A**: 200 kHz water column acoustic backscatter image (depth range 0-20m) showing snapshot of halocline(s) location along a 2000 m W-to-E transect across the sill separating Grand Bay (on the left) from the Kennebecasis.

**Figure 1B**: simultaneous ADCP transect (depth range 0-30m) showing current magnitude and direction. Yellow areas are currents flowing into the page.

Note main body of water movement northward through Grand Bay and a lesser highly-intensified flow constrained within the incised channel .

For a complete animation of the full tidal sequence see:

http://www.omg.unb.ca/~jhc/kenneb/adcp_anim.html

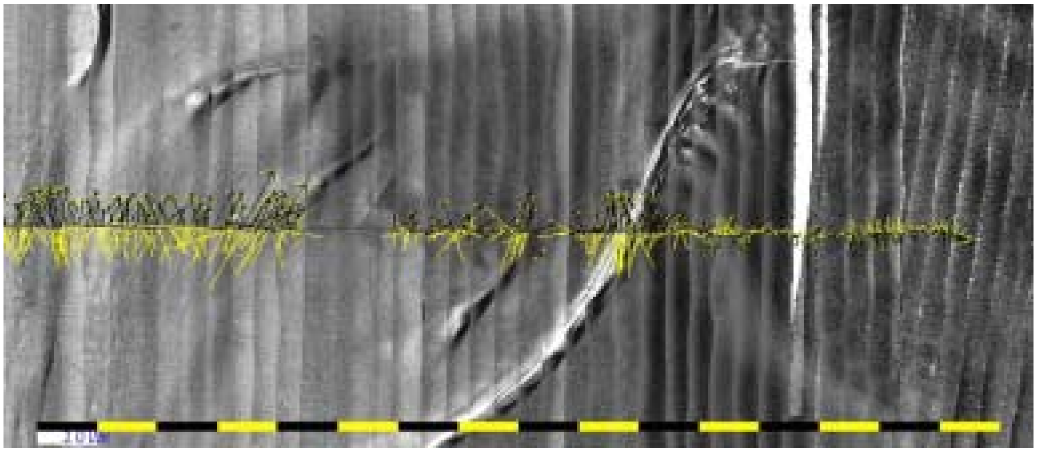


**Figure 2A:** ADCP current vectors averaged between 5-10m depth, indicating the N-NE direction of movement of the underlying salt water intrusion across the sill. Note the pronounced current intensification within the main (and lesser) incised channels (30 minutes after high water, Brothers Cove). The underlying image is a mosaick of 200kHz sidescan sonar data over the sill that clearly delineates the narrow channels and zones of varying surficial backscatter character.

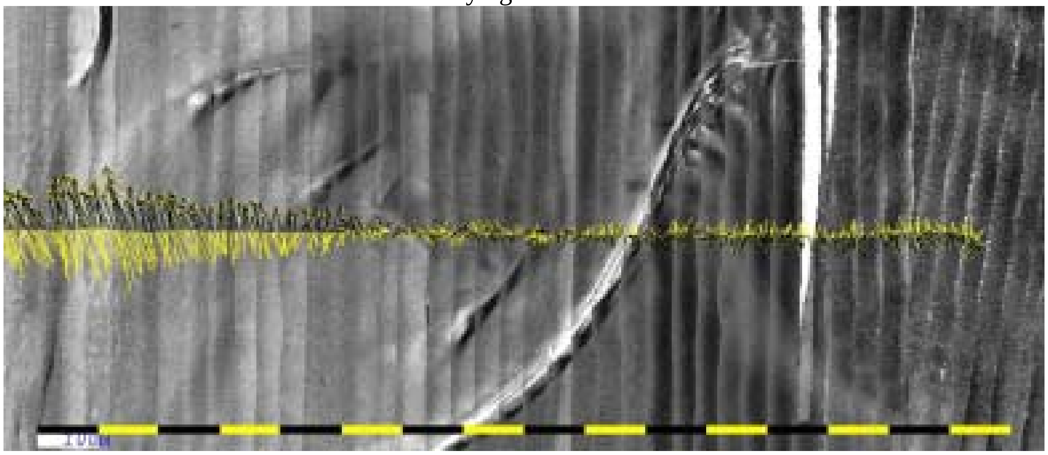


**Figure 2B:** currents averaged in the 0-5m depth range for same time period. Showing the main flux of the surface fresh water layer NNW into Grand Bay (left side) and the weaker return flow within the Kennebecasis (right side). Note that the surface currents show no indication of the localised subsurface density flow moving northward in the incised channel.

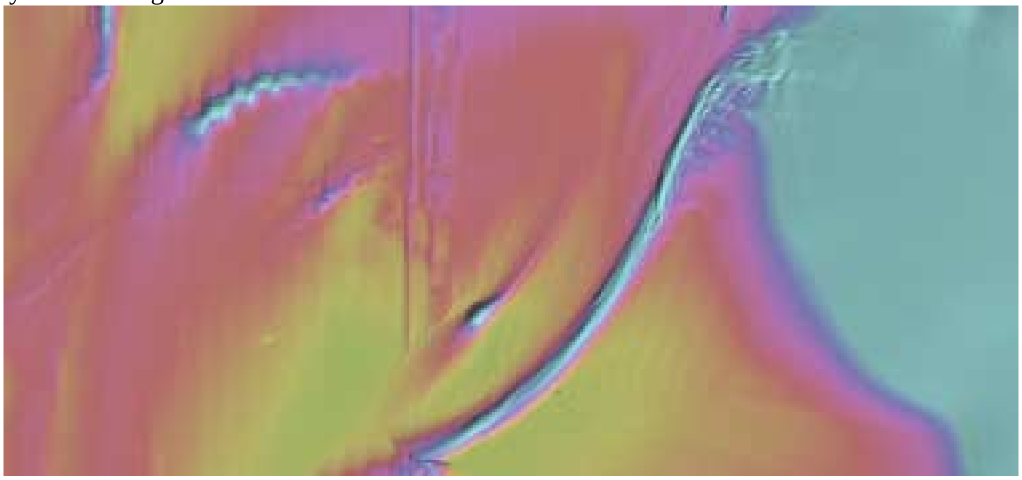


**Figure 2C:** Constraining bathymetry revealed from a combination of EM3000S multibeam and Knudsen 320 single-beam data (20m line spacing, interpolated). Depth ranges from 5m (yellow) to > 12m (blue green ).

## *Saint John Disposal Site*

The Saint John offshore disposal site is situated near Black Point at the mouth of Saint John harbour. There is active dumping of dredge spoil at this location at different times during the year. The site is currently the focus of an Environment Canada investigation into the state and suitability of the dumpsite (Parrott et al., 2001). Repetitive multibeam surveys have been carried out along with complimentary sidescan, subbottom and physical sampling programs. A critical component of this project is to estimate the level of sediment remobilisation either as bed or suspended load. As part of this the oceanographic conditions (including the current field over a typical tidal cycle) are critical to study.

The challenge here is to tie together the spatial and temporal variations of the current field with the time varying nature of the dumpsite (as revealed from repetitive multibeam surveys). For this area, little vertical velocity shear was observed, so it is possible to reduce the problem to viewing the time varying depth averaged current field. The plan view current field could be superimposed either over the short wavelength topography (as viewed through sun-illumination, Figure 3A) or over the surface differenced obtained from subsequent multibeam surveys (Figure 3B).

**Figure 3 A**

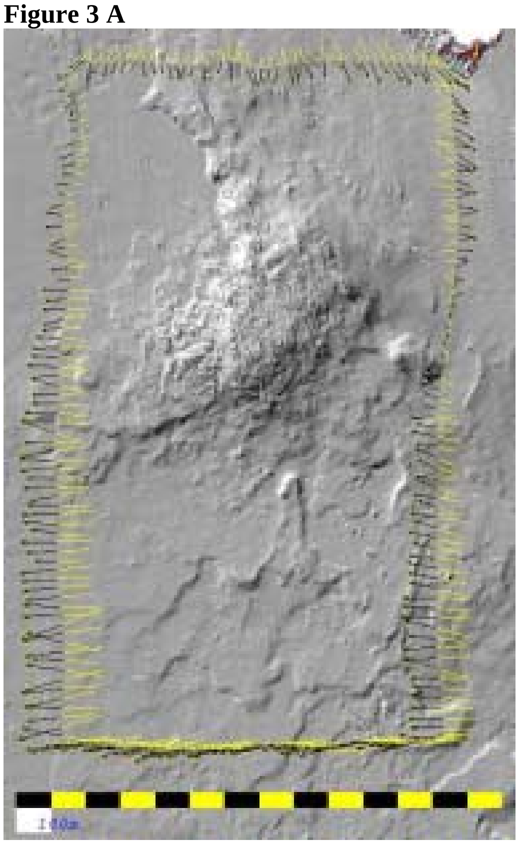
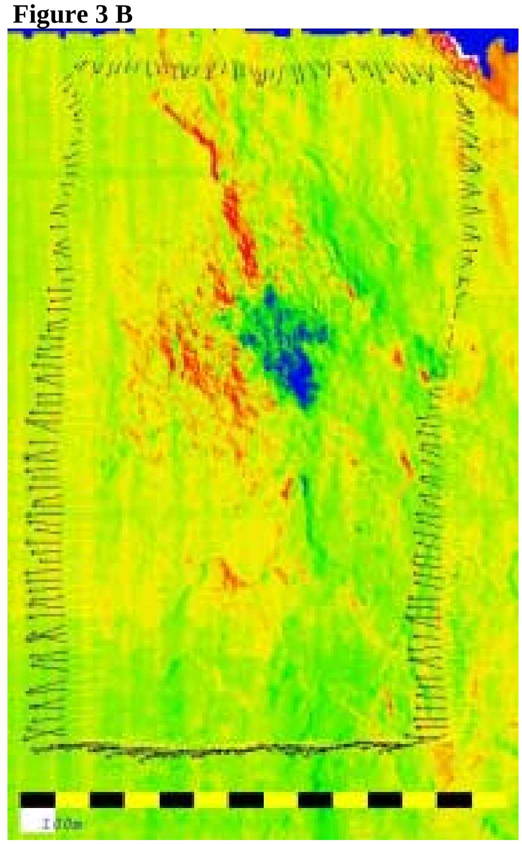


**Figure 3 B**



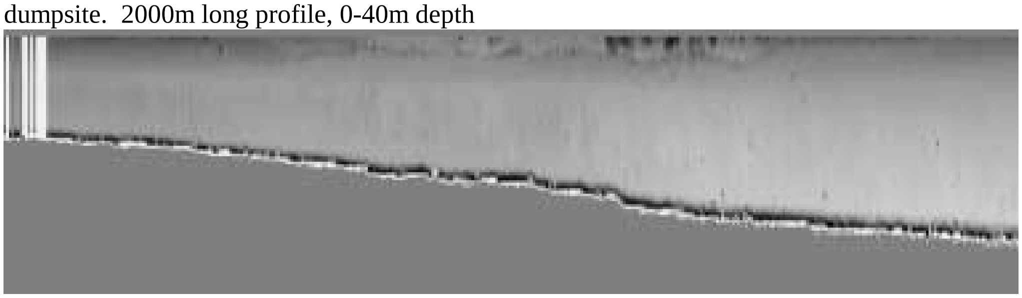
**A:** single image of an animation showing the vertically averaged currents collected over a 35 minute ADCP box transect around the disposal site at Black Point (this image, just after high water is one of 19 transects collected over one tidal cycle). ( the largest vector represents ~ 1.2 knots). Underlying image is a NW - sun-illuminated representation of the April 2000 multibeam bathymetry. Depths range from 8m to 32m.

**B :** equivalent representation where the underlying image represents the surface changes from April to October 2000. Blue represents a maximum of 80cm accretion of sediment over the summer (due to dumping). Reds represent areas where ~ 20-40 cm of sediment has been removed.

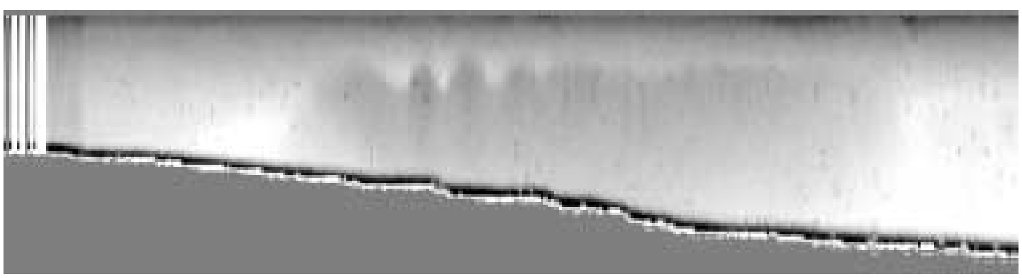
On the ebb tide, significant masses of fresh water are advected out of the Saint John River and move around the outer harbour separated by fronts visible as surface slicks (Neu, 1960). Below this surface layer, the water is generally very well mixed. This near-surface interface however provides significant complications for hydrographic surveys in the form of refraction errors. Although, the lenses do not have significantly different current velocity properties with respect to other underlying watermasses, the presence and extent of these lenses can be recognized from the 600 kHz volume backscatter (Figure 4A) derived from the ADCP.

Of particular interest at this open water site was the identification of soliton internal wave packets (Figure 4B), previously unreported in this area. Interfaces are perturbed by up to 6m over a length scale of just 100m. With conventional sound speed monitoring methods, such anomalies would go unreported. The internal waves could potentially act as a mechanism for enhanced sediment resuspension, as they exist at the depth of the shallowest area of the dumpsite where the most remobilisation is predicted.

**Figure 4:** 600 kHz, volume backscatter cross-sections along the west flank of the Saint John dumpsite. 2000m long profile, 0-40m depth



**A:** Imaging of the surface lens of freshwater advected out of the St. John River.



**B:** Passage of a soliton internal wave packet through the west side of the dumpsite.

## *Discussion*

The two test areas differ strongly in the nature of the water mass variations. For the more offshore, disposal site location, the watermass is vertically much more homogenous, so that little current velocity shear (other than a bottom boundary layer) is observed. Under these circumstances, the data may be treated as layer averaged solutions and thus the optimal method of presenting this data is in plan view. Whilst in this case a dedicated repetitive survey geometry was employed to examine the water column over a tidal cycle, data collected during the conduct of a regular hydrographic operation could be equivalently presented as a series of plan view images showing near instantaneous current vector fields during small sections of the tidal window.

For the Kennebecasis area of operations, significant velocity shear with depth was observed and thus the data needs to be differentiated by layer. The presentation of this data provides a significant challenge. For the purposes of correlating the flow patterns with the sediment distribution on the sill top, near seabed currents need to be isolated. The seabed was alternately affected by the salt and fresh water layers as the interface migrated. Conventional displays using a fixed depth range are inadequate as the seabed surface is undulating. Furthermore, trying to separate the movement of the salt and fresh water is compounded by the fact that this interface migrates vertically 5m over a tidal cycle.

## *Summary*

Multibeam bathymetric sonar has revolutionised the way coastal hydrography is undertaken. This new source of data, taken together with existing methods of acoustically imaging the water mass, provides a new opportunity for understanding the temporal and spatial variations occurring in the seabed and waters around our coasts. Such an approach has applications both in oceanographic investigations and in improving the fidelity of bathymetric survey measurements.

Future work in the integration of swath sonar and dense water column data scheduled for 2001 include:

- Investigation of the coupling between the current dynamics and sand wave migration in the Mispec Bay sand wave field, located about 5 km east of the Black point disposal site.
- Tracking haloclines at the Fraser River/ Georgia Basin (British Columbia) confluence to improve multibeam refraction errors.
- Providing constraints on 3D hydrodynamic modeling of the salt and fresh water exchange in the Lower Saint John River.

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