Sonar Bathymetry: Waquoit Bay NERR
Determining the Functional Shallow Water Limitation for an Arrival Based Sonar

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Introduction:

During previous survey operations, the Teledyne Benthos C3D-LPM has been able to collect accurate bathymetric data with less than 2 meters of water below the transducers, yet retain a swath width greater than 10 times the water depth. Extreme precision in survey methodologies is required to obtain quality data in this challenging environment. In this paper we endeavor to detail the specific requirements placed on the survey operations that are necessary to achieve adequate results, and to determine the minimum depth at which the system fails to produce satisfactory data.

The area chosen for the survey was a small portion of the Waquoit Bay area on the coast of Cape Cod Massachusetts. This area is part of Waquoit Bay National Estuarine Research Reserve. The 2600 acre Waquoit Bay Reserve encompasses open waters, barrier beaches, marshlands and uplands on the south shore of Cape Cod. We present the operational details required to achieve success. The variations in morphology make it difficult to obtain consistent results across the entire survey region. The results demonstrate that even in challenging extreme shallow water environments wide swath angle of arrival based systems are capable of providing high quality data sets useful for environmental assessment applications as well as coastal zone and habitat management.

Methods:

- Survey Area –

The 3000 acre Waquoit Bay area (Figure 1) was chosen as the survey site for several reasons. The first and most important site consideration for our testing, the bay has a maximum water depth of less than three meters and an average water depth of approximately 1.5 meters. This brought forth unique challenges for a swath bathymetric survey. The second reason the site was chosen is that it is part of the NOAA monitored National Estuarine Research Reserve estuary program where ongoing data has been and continues to be collected. This data is useful when combined with supporting acoustic data from the swath bathymetry and sidescan sonar. The last
factor in choosing this area was based on logistics and opportunity for involvement with the local research community.

**Figure 1** – Waquoit Bay Survey Area (Image taken from NOAA nautical chart 13229-4).

- **Vessel** –

  The survey was planned using a vessel supplied and operated by TG&B Marine Services. TG&B owns and operates six coastal survey / work boats engaged in oceanographic, geophysical and marine environmental surveys. The *Surveysa*, a 24 foot shallow draft privateer survey boat powered by a 200HP outboard was used for the survey of Waquoit Bay. It is primarily used for side scan, bathymetric and subbottom profiling surveys throughout New England. The *Surveysa* was outfitted with a number of survey sensors and three on board processors to run the software applications used for survey planning and operations, data acquisition and on board processing of the bathymetry data.
• **Sonar System Installation** –

**-Sonar System:**

The swath bathymetry system used was the Teledyne Benthos C3D-LPM. The system is designed for shallow water small vessel operations in depths to 50 meters. The LPM system comes with two 6-array transducers for receiving acoustic signals on both port and starboard for simultaneous operation collecting combined side scan and bathymetry data. It is also equipped with a streamlined cover for the pole mount, mounting bracket and design to fit standard 3-inch pipe flanges, and two 10-meter cables that connect directly into the C3D-LPM transceiver.

**-Motion Sensor:**

Motion data was collected using the IxSea Octans fixed mounted to the over the side bracket supporting the C3D-LPM sonar head. This configuration allowed for direct coupling to the sonar head and was independent of any motion or flexing of the fiberglass hull of the survey vessel during survey operations. The heading accuracy is on the order of 0.1 degree and dynamic pitch and roll accuracies are on the order of 0.01 degree. This helps to minimize the uncertainties due to platform motion. Motion data collected was at the rate of 25Hz. In the shallow water depths expected in the Waquoit Bay area, inaccuracies due to the effect of platform motion can be a very large percentage of the measured depths below the transducer. For this reason, careful consideration should be made in the choosing of a motion sensor (Figure 2).

![Figure 2](image)

**Figure 2** – The expected inaccuracies due to roll for a 1 degree sensor vs. a 0.1 degree sensor given a 20 meter swath (the expected swath width coverage for the survey area).
-Sound Velocity Sensor:

Real time sound velocity data was collected using the Odom Digibar Pro mounted to the pole slightly above the sonar head at a depth of 0.5 meter. The Digibar Pro velocity measurement automatically compensates for all influences -- including pressure, water salinity and temperature that were expected to vary in Waquoit Bay survey area. Sound velocity data was acquired at the rate of 1Hz

-Positioning and Tidal Corrections:

Positioning data was collected using an Ashtech Z-surveyor GPS using real time kinematic technology (RTK). The Z-Surveyor was chosen to provide precise centimeter positions in real-time and would allow for accurate vertical positioning throughout the survey area. Variations in the tidal corrections using tidal gauges alone would not support the vertical accuracies required throughout the very shallow coastal estuary survey area. The tide gauge at the mouth of the bay would have readings that were significantly offset from the actual tidal variations experienced directly at the vessel during the survey period. Pacific Crest radios were used to relay the corrections from the base station located at the USGS Marine Operations Facility (Figure 3).

Figure 3 – GPS Base Station and Tide Station Locations (Image taken from NOAA nautical chart 13229-4 overlayed with targets plotted by Hypack Survey).
A radio repeater was also used to ensure that the corrections would be received at the survey site. All position data was logged at a rate of 5Hz with positions logged in the Triton Isis acquisition software and Hypack Survey. Tidal data from the tide station was collected as backup and for verification.

-Survey Planning:

The survey operation was planned with an approximate average depth assumption of two meters and anticipated swath coverage of 10x altitude. The survey area and lines were planned using Hypack software (Figure 4).

![Figure 4](image)

Figure 4 – Planned survey lines using 20 meter line spacing (Image taken from NOAA nautical chart 13229-4 overlayed with line plan plotted by Hypack Survey).

-On Board Data Processing:

The majority of the data was acquired from March 12th to March 15th 2007, as soon as the winter ice cleared from the bay. Three processors were installed on board the Surveysa and they
were configured to support both real-time data acquisition and offline data processing. Various software applications were installed to support the real-time and offline processing functions. One processor was utilizing Triton Isis for C3D data acquisition and real time sound velocity, motion and positioning data. A Second Processor configured with Hypack Survey was used for survey planning and operations. While a third had CARIS HIPS & SIPS and Triton Suite installed for bathymetry processing and sidescan mosaicing.

**Results and Analysis:**

- **Survey Operations** –

  The total area covered (Figure 5) by the C3D-LPM system was nearly 3x the expected coverage area that a conventional multibeam sonar system having a 3.5x altitude swath would yield in the same time frame. The 3000 acre area of Waquoit Bay required over 40 hours of vessel time for the data collected (Figure 6).

*Figure 5 – The track lines logged for the 3000 acre survey area of Waquoit Bay (Image taken from NOAA nautical map 13229-4 overlayed with vessel positions plotted by Hypack Survey).*
Figure 6 – C3D at 10x Depth versus Multibeam at 3.5x Depth for 6 Tidal Cycles. The resulting area surveyed at a vessel speed of four knots versus the expected area that would be surveyed if a conventional multibeam system was used for the project. The figure plots the area covered over six tidal cycles.

• **Bathymetry** –

The sonar system consistently yielded the 10x altitude below the transducer swath coverage anticipated for the project throughout most of the survey operations in varying heights above the seabed from two meters to nearly 0.25 meters (Figure 7 & 8).

Figure 7 – The 2D bathymetry data plot shown is an example of the coverage at a depth that is approximately the average depth below the transducer for most of the survey operations. Note that there is a good representation of the bottom for greater than 10x the 1.25 meter altitude of the transducer above the seabed.
These results provided confidence that the sonar could get the 10x depth below the transducer swath coverage under a wide range of survey conditions.

Figure 8 – 2D Bathymetry Plot showing Swath Coverage in 50cm height above the seabed with sidescan. The data shown is an example of the swath bathymetry coverage along with the sidescan data which was collected in the shoaler areas of the survey area in little more than 50cm depth below the transducer.

The major area of interest for the Waquoit Bay project was the repeatability of the results of the bathymetry coverage (Figure 9). The results show that most of the data has 10cm standard deviation or less. This verifies that the sonar system, when equipped with well chosen associated survey sensors, is capable of providing repeatable wide swath bathymetry coverage in very shallow water.
Figure 9—Standard Deviation of intersecting lines at 10x Swath Coverage on Day 1 and Day 3 gridded to one meter. Some of the variance shown in the cross line was attributed to the wake of the survey vessel in the 1.5 meter water depths.

The full coverage bathymetry mosaic (Figure 10) was gridded to greater than 10m for the view presented. This was due to the data being sparser in some areas than planned. The sparse data in regions could be attributed to several factors. The first factor was the two meter depth assumption. Much of the survey area proved to be less than two meter in depth and our planned 20 meter line spacing did not give the full coverage required in the shoaler areas. The second factor was the depth of the transducer below the waterline was not taken into account when making the survey plan. This reduced our expected height above the seabed by 25%, thus our swath coverage was reduced be a proportional 25%. These first two factors were fixed variables that may have been able to be planned for at the onset of the project. Note that these factors would not have had a significant impact on a survey project in 10m of water.
Figure 10 – Preliminary results for Waquoit Bay Bathymetry, maximum depth 2.5 meter with 0.25 meter contours.
- Tidal Variations:

Tidal variations in shallow water also significantly affected survey operations (Figure 11). The tidal variations were 0.55 meters during the survey period. The tidal variation in shallow water represents a very significant percentage of the water depth in the survey area, which greatly affected the bathymetry coverage in the shoaler areas of the bay.

Figure 11– Filtered RTK Elevations logged during Day 2 of survey operations.
Properly planning for the tidal variations can greatly improve survey efficiencies (Figure 12). Planning the survey for high tidal cycle operations would reduce survey time by nearly 40% in this example.

![Coverage graph](image)

**Figure 12** – An example showing survey coverage at 10x water depth at a four knot vessel speed for the high tidal cycle versus the low tidal cycle for six tidal cycles given a one meter tidal variation and an average altitude of one meter above the seabed

-Sound Velocity:

Sound velocity measurements have large variations when the temperature and salinity fluctuate as expected throughout this coastal estuary. The sound velocity varied by greater than 50 meters per second during the course of a survey day (Figure 13).
Although the sound velocity probe was proportionally deep in the water column for much of the survey, we still had some regions where refraction effects from sound velocity could be seen in the swath data. A sound velocity profiler with sub-decimeter depth accuracy would be recommended for surveys of this type.
• **Amplitude Data** –

Ongoing investigation is underway to determine if there is any correlation between the backscatter amplitude data and the macro algae mats that are on the seabed in Waquoit Bay (Figure 14 & 15).

![Figure 14](image-url) – Preliminary results of backscatter amplitude data shown at a resolution of two meters. Higher intensity backscatter is shown as white with the darker regions being the low intensity backscatter areas.
Figure 14 – Map of Macro Algae Distribution Performed at the Waquoit Bay Reserve (Bio-Mapping 2006)

Conclusion:

The challenges for an acoustic bathymetric survey in an environment like those experienced in Waquoit Bay can be significant. The combination of sound velocity diversity and the ability to accurately measure tidal variations at the survey site can create operational difficulties in collecting a repeatable reasonable quality data set. In addition, vessel wake along tight survey lines and the narrow typical 3.5 to 1 swath width to depth below the transducer ratio of a conventional multibeam system, further degraded by the same transducer offsets below the water line merged with the local tidal variation and the goal of a 100% coverage survey in a shallow coastal estuary can present a daunting task. However, this study has produced data that demonstrates that careful survey planning and use of a wide swath angle of arrival based sonar system can drastically reduce the operational time required for a 100% coverage survey. This could also have a similar impact on the cost to perform such a survey.
In conclusion, angle of arrival based sonar systems and the additional ancillary sensor data can significantly enhance and be an efficient means of supporting coastal estuary monitoring and research.

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Citations:

Appendix A: Equipment and Software Information

Equipment Used

IxSea, Octans 1000 Motion Reference Unit
Magellen Ashtech ZSurveyor Dual Frequency Carrier Phase Differential GPS Receiver.
Odom Hydrographic Systems, Inc. Digibar Pro, Model #DB1200 Sound Velocity Sensor
Pacific Crest Radio Link Radios
Teledyne Benthos, Inc., C3D-LPM 200 Swath Bathymetry and Sidescan Sonar

Software Used

CARIS Field Sheet Editor Version Bathymetry Editing Software 6.1
CARIS HIPS/SIPS data processing software Version 6.1
Mathworks MATLAB Release 13
Hypack, Hypack Survey Version 6.2
Triton Imaging Inc., BathyPro data processing software Version 2.1.428.53
Triton Imaging Inc., DelphMap data processing software Version 3.1.428.53
Triton Imaging Inc. Isis Acquisition Software Version 7.1.428.53