BATHYMETRIC SURVEY
PADANARAM HARBOR, DARTMOUTH, MA
Report date: May 14, 2010
Data collection: January 12 and March 9, 2010

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Introduction

The Division of Marine Fisheries purchased a Biosonics split-beam sonar system in 2006 as part of the Cod Conservation Zone project to identify fish in the water column and near the seafloor. The instrument is extremely lightweight and portable, and has bathymetric and bottom-type capabilities, so the Fisheries Habitat Program was interested in exploring these other capabilities. The Town of Dartmouth is interested in re-mapping their mooring field to minimize impacts to eelgrass and maximize the number of moorings. The town harbormaster offered a vessel and data analysis support, so we entered into a partnership to conduct instrument development work.

Methods

The survey area was inner Padanaram Harbor (north of the Padanaram Swing Bridge) in Dartmouth, MA (Figure 1). Data was collected over two days: January 12 and March 9, 2010. Ice in the harbor limited the first survey day to only part of the harbor. The survey was conducted using the Dartmouth Harbormaster's 17' Boston Whaler. The Biosonics DT-X 200 kHz transducer was mounted off the starboard side of the boat, attached to a pole extended down from 2X4's that were bolted to both sides of the boat (Figure 2). The pole was custom designed to bolt to the aluminum frame of the transducer head. Both the front-end lead weights and tail were removed from the Biosonics towfish body. The antenna for a Garmin handheld GPS unit was attached to the transducer pole directly above the transducer, so no position offset was required. Both echosounder and GPS data were merged and recorded using Biosonics Visual Acquisition software. The ping rate was 5 pings per second and the range was set at 0.25 meters.

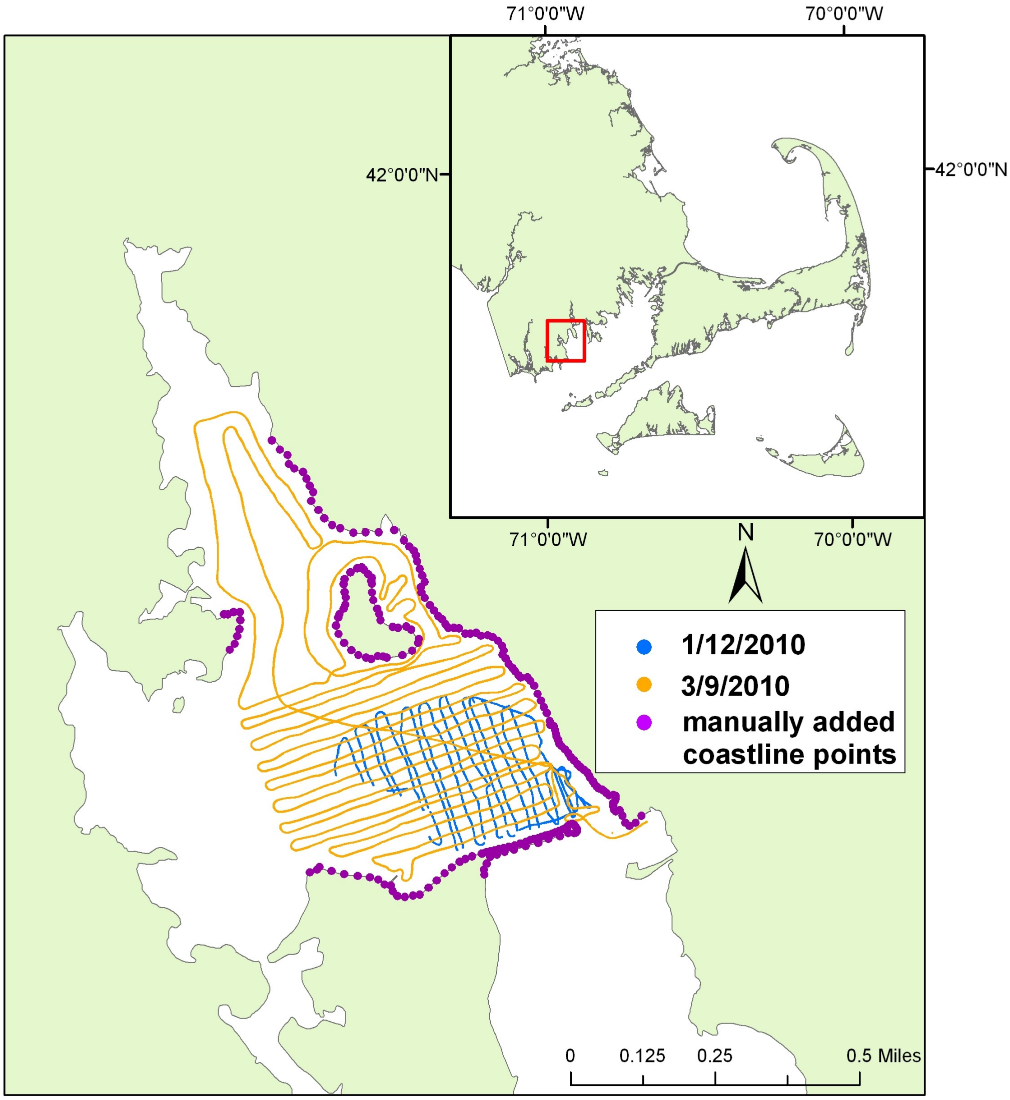


Figure 1. Survey location.

Survey lines were set up in ArcGIS software and a dedicated GPS and laptop was used for navigation. The navigation laptop recorded GPS position as a backup, but the data stream was not utilized.

On the first survey day the system was powered using an inverter from the vessel battery. However, because the survey was conducted at slow speeds, the engine alternator was not producing enough power to recharge the battery. After two hours of operation on the first day (which coincided with the end of the survey for the day), there was no battery power remaining. Therefore, on the second day of surveying the system was powered using a Honda suitcase generator.

Figure 2. Equipment configuration on the vessel.

Calibration

The transducer was depth-calibrated using a sphere extended 1 and 2 meters below the transducer face. The calibration sphere was hung from polyline at the target depths in a nylon harness (Figure 3) and data was recorded. The echograms were opened in Echoview 4 software and the calibration sphere data was examined to ensure the validity of the data values (e.g. TS, Sv values) derived from power data. No corrections were necessary.

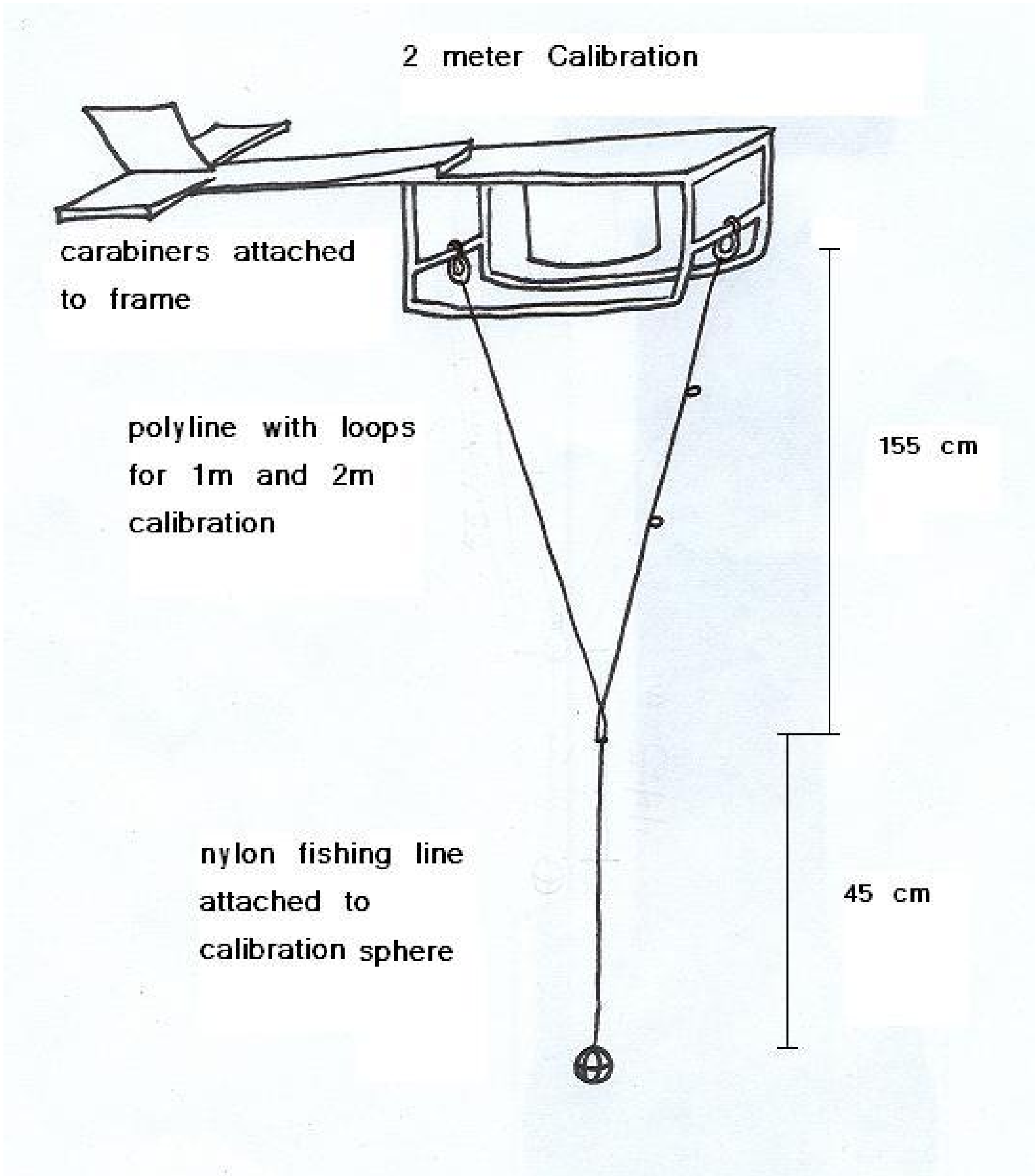


Figure 3. The depth calibration.

The depth below the water line was measured at the survey speed (~2 knots) with the boat load distribution in place as it would be during surveying. The tide was measured hourly on a meter stick affixed to a dock piling in the upper harbor. Tide correction was done using data from the nearest NOAA NOS Tide Station which was 8447368, Great Hill, MA. The verified six-minute data from the station was adjusted for time using the tide measurements taken at the survey site. The tide data was extrapolated using a linear assumption between each six minute interval in order to apply a more accurate correction to each depth measurement. The depths were corrected to the Mean Lower Low Water (MLLW) datum.

Data processing

Data was processed using Echoview 4 software. The Biosonics .dt4 datafile was imported into Echoview and the cruise track was opened to check navigation accuracy. No navigational spikes were present in the data. The echograms were then opened and used to select the bottom. The Best Bottom Candidate line pick tool was utilized on the Sv split beam pings (channel 1) as the operand 1 and converted into an editable line (see Table 1 for settings). The selected bottom was then reviewed and corrections were made by hand to remove spikes or hand-select bottom in areas where the tool incorrectly identified the bottom.

Table 1. Settings for bottom line pick in Echoview.

Basic settings	Start depth (m): 0.25 Stop depth (m): 10 Minimum Sv for good pick (dB): -70
Backstep settings	Use backstep: checked Discrimination level (dB): -42 Backstep range (m): 0
Advanced settings	Peak threshold (dB): -50 Maximum dropouts (samples): 2 Window radius (samples): 8 Minimum peak asymmetry: -1

The selected bottom was then exported to an x,y,z file using the CSV export file format for bathymetric data. Tide correction and transducer depth corrections were conducted in Excel.

Accuracy & Consistency

The horizontal accuracy of the WAAS-enable GPS receiver is assumed to be better than three meters 95 percent of the time (Garmin 2010).

The vertical accuracy is assumed to be ±5 cm. This measurement is based on the added error from measuring the depth of the transducer head, calibration-induced error, and tide error. These are outlined in Table 2.

Table 2. Error components.

Error component	**Approximate error**
Measuring depth of transducer head	±2 cm
Calibration-induced	±1 cm
Tide correction	±2 cm
Total	±5 cm

Samples co-located on both days were used to examine the survey's vertical consistency. There were 271 co-located samples. Basic correlation statistics were used to produce an assessment of the consistency between the samples. All calculations were done in Excel.

Bathymetric Mapping

All mapping was done in ArcGIS 9.3 using the 3D Analyst extension. Several methods, including triangulated irregular network (TIN), inverse distance weighted (IDW), natural neighbor, and kriging, were considered as interpolation tools. Natural neighbor and IDW were compared since both were rapid (as opposed to the computationally complex kriging) and were less sensitive to the distribution of the clustered data (as opposed to TIN). TINs are very commonly used in bathymetric and topographic mapping since they handle contoured data and widely distributed well. However, this dataset would have required data optimization to enable good TIN mapping since points were clustered and co-located. Therefore, the simpler weighted interpolation techniques were compared. Both natural neighbor and IDW are also used commonly in bathymetric mapping.

For the natural neighbor mapping, a 5-meter cell size was used. The IDW variables are listed in Table 3.

Table 3. Variables used for IDW interpolation.

Variable	Value	Notes
Output cell size	5.0	unit is meters, 5.0484 was default. 1 meter was also used, but did not substantially change the result at the scales we are using the maps.
Power	2	default – a higher power results in less influence from more distant points
Variable	*(selected as the method)*	default – the alternative is fixed, which defines a search radius by distance instead of number of points
Number of points	12	default – the number of nearest input sample points used to calculate the interpolation
Maximum distance	*(left blank)*	default – the number of nearest input sample points used to calculate the interpolation

Results & Discussion

Consistency

A linear regression was used to examine the correlation between the co-located samples. The resulting correlation coefficient of 0.99 is suggestive of a very strong correlation between the datasets. The linear relationship between the datasets was

$$\text{January depth} * 0.9637 = \text{March depth}$$

Therefore, a correction factor of 0.9637 was applied to the data prior to mapping. Some of the statistics associated with the corrected and uncorrected datasets are listed in Table 4.

Table 4. Error statistics computed by comparing co-located points.

Error component	**Uncorrected**	**Corrected**
Average difference (cm)	7.3 cm	4.4 cm
Standard deviation	6.8 cm	3.9 cm
Difference range (cm)	0-41 cm	0-21 cm
95% of points		
Average difference (cm)	6.2 cm	3.8 cm
Standard deviation	4.7 cm	2.9 cm
Difference range (cm)	0-20 cm	0-12 cm
75% of points		
Average difference (cm)	4.2 cm	2.7 cm
Standard deviation	2.7 cm	1.7 cm
Difference range (cm)	0-10 cm	0-6 cm

The correction factor greatly improves the confidence of the data. In future mapping efforts, it will be uncommon to have co-located samples to create correction factors. Also, it is impossible to resolve which dataset is truer than the other. Therefore, for future work we will describe the vertical accuracy as ±11 cm (average + 1 standard deviation for 95% of the uncorrected samples) plus the measurement error of ±5 cm for a total of ±16 cm (6.5 inches).

We also looked at whether or not the difference in the two datasets increased with respect to depth. There was a weak correlation coefficient of 0.45. However, the six greatest differences (0.25 meters and more) were all at sites >3.5 meters deep suggesting that depth or depth change is a variable influencing the differences between the datasets. 95% of the uncorrected data points had difference values within 8% of the total depth. This improved to 6% after correcting the data.

This methodology for bathymetric mapping is robust, repeatable, and simple. Therefore, it is a sound method for work where highly precise depth measurements are not needed.

Bathymetry

The goals for the bathymetric mapping were: 1) create a surface model that was as true as possible to the seafloor terrain in the harbor; 2) use ArcGIS tools since we already have access to them and are familiar with them; 3) be computationally quick; 4) be relatively small digitally, to preserve disk space and be easy to use in GIS projects; 5) be straightforward and repeatable, so multiple technicians could do such work when additional surveys are conducted; 6) be reproducible in a format the town can use.

Simply plotting the point data or generating raster grids from the point data are perhaps the most accurate means of producing data but they are not very user friendly unless extremely high data densities are available (Figure 4). Therefore, it is most common in bathymetric studies to interpolate point data. The goal of interpolations is to estimate values at points in space that have not been sampled in order to create a continuous surface model. ArcGIS with the 3D analyst extension has several tools for creating interpolated surface models. Each interpolation tool is designed for specific types of data (discrete or continuous, well-distributed or sparse). With bathymetric data, they are all robust enough that choosing a tool can also be heavily influenced by the intended use of the interpolated surface and logistical considerations such as ease of use and processing time. Techniques relying on geostatistical methods such a kriging can produce valuable error matrices, which have distinct benefits in situations where management decisions are being made but take more time to process. In contrast, deterministic techniques such as IDW frequently meet the needs of the user and are computationally simpler. Bathymetric data lends itself to any of the available interpolation techniques in ArcGIS. Therefore, ease of use, appearance of the product, and processing speed drove the decision regarding which interpolation method was most applicable. We also checked other examples of bathymetric data processing to ensure that the technique we selected had been used and tested in other studies. This led us to not consider Thiessen interpolations (also known as Voronoi diagrams). As described in the ESRI help manual, "Thiessen polygons have the unique property that each polygon contains only one input point, and any location within a polygon is closer to its associated point than to the point of any other polygon" (ESRI 2009). While this interpolation method can be used on bathymetric data, we could not easily find any examples of it being used in that way. Perhaps this is because elevation data is continuous and expected to change smoothly in most regions. Thiessen interpolations are particularly good with discrete data since they do not assign intermediate values to sample points. However, since bathymetric data is continuous and usually smoothly varying, other interpolation methods yield more realistic surface models.

Both triangulated irregular networks (TINs) and kriging were quickly ruled out. Kriging is a powerful interpolation algorithm that relies on assessments of the variability of point values across space to weight the influence of neighboring points on any given point, but we did not need an error surface, the process took a long time relative to other techniques, and it interpolated beyond the limit of the data, thereby requiring additional processing (such as use of a coastline mask or creation of a coastline with zero points). TINs are very commonly used with elevation data. They use the Delaunay criterion to draw edges between a point and its nearest neighbors to form triangles. The TIN was straightforward to create, but the product had very jagged edges and took considerable time to draw (Figure 5). The clustered points where N-S and E-W survey lines crossed were very apparent. In examining other research that generated TINs, namely the NOAA Estuarine

Bathymetric dataset, many processing steps were required to optimize the point data in the TIN model (NOAA 2007). This technique simply requires too much pre-processing of the data in order to create a realistic surface model. However, if the vector output is needed, the TIN could be generated from the a raster surface model interpolated using another interpolation technique.

The natural neighbor algorithm finds the closest subset of input samples to a query point and applies weights to them based on proportionate areas (based on Thiessen polygons) in order to interpolate a value (Sibson, 1981 as referenced by ESRI). Similarly, an IDW model weights sample points such that the influence of one point relative to another declines with distance from the unknown point you want to create. IDW is sensitive to the distribution of data points since the sample points will have the maximum and minimum values; natural neighbor does not infer trends nor is it sensitive to the distribution of the data (Watson 1992 as referenced by ESRI). IDW and natural neighbor techniques can be used to interpolate data sets with either continuous or discontinuous data. Since the map product needs in this project are relatively generic, of the multiple techniques utilized to create maps, IDW and natural neighbor offer good tradeoffs in terms of ease of use, time, and quality of the output product.

There were obvious artifacts as a result of the distribution of the data with the IDW technique (Figure 6). Also, IDW interpolated beyond the boundary of the dataset. Therefore, in confined coastal waters the use of a coastline mask or addition of coastline data points with zero depth is recommended. However, as with the TIN, some pre-processing of the data to eliminate co-located samples and minimize clustering are needed to create a more realistic surface model with the IDW technique.

The natural neighbor interpolation was the best technique for this application. It produced a reasonable and intuitive product, it did not interpolate beyond the bounds of the survey, thereby eliminating confusing edge effects and removing the need for a coastline mask (Figure 7). This technique met all of our goals in terms of ease of use and disk space usage. There were data distribution artifacts resulting from the processing of clustered and co-located samples resulting in “pockets” or “divets” in the surface. When points collected in January were excluded from the interpolation some areas were indeed smoother, but a few features were better delineated when interpolation was done using the points from both surveys. In particular, the wall toward the south end of the survey and the shoal in the middle of the harbor were better delineated using all of the data points. Additional processing of the data could be done to minimize impact of clustered points on the interpolation, but it is also easy to smooth the effect from end products simply by the proper color ramps and shading.

Addition of coastline data points with zero depth was not an essential processing step. However, two-hundred fourteen coastline zero points were added manually since they did improve the overall quality of the end product. These points primarily improved the surface around the island and along the southern wall. Lastly, 0.5 meter contours were added to the final map product (Figure 8).

References

Chang, K-T. 2006. Introduction to Geographic Information Systems. 3rd Edition. McGraw Hill.

DeMers, M.N. 2005. Fundamentals of Geographic Information Systems. 3rd Edition. Wiley.

ESRI. 2009. Create Thiessen Polygons. Desktop Help. Release 9.2.
_____ 2008. Natural Neighbor Interpolation. Desktop Help. Release 9.2.
_____ 2008. How Kriging Works. Desktop Help. Release 9.2.

Garmin 2010. What is WAAS? Web page.
http://www8.garmin.com/aboutGPS/waas.html

Johnston, Shelley. 2003 Uncertainty in Bathymetric Surveys. U.S. Army Corps of Engineers Environmental Research Data Center. Coastal and Hydraulics Engineering Technical Note, CHETN-IV-59.
http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-iv-59.pdf

Mitas, L., Mitasova, H. 1999. Spatial Interpolation. In: P.Longley, M.F. Goodchild, D.J. Maguire, D.W.Rhind (Eds.). Geographical Information Systems: Principles, Techniques, Management and Applications. Wiley.

NOAA. 2007. U.S. Estuarine Bathymetric Datasets. Metadata.
http://estuarinebathymetry.noaa.gov/metadata.html

Sibson, R.. 1981. A Brief Description of Natural Neighbor Interpolation. In: Interpolating Multivariate Data. John Wiley & Sons, New York. pp. 21-36.

Watson, D. 1992. Contouring: A Guide to the Analysis and Display of Spatial Data. Pergamon Press, London.

Figure 4. 10-m raster grid.

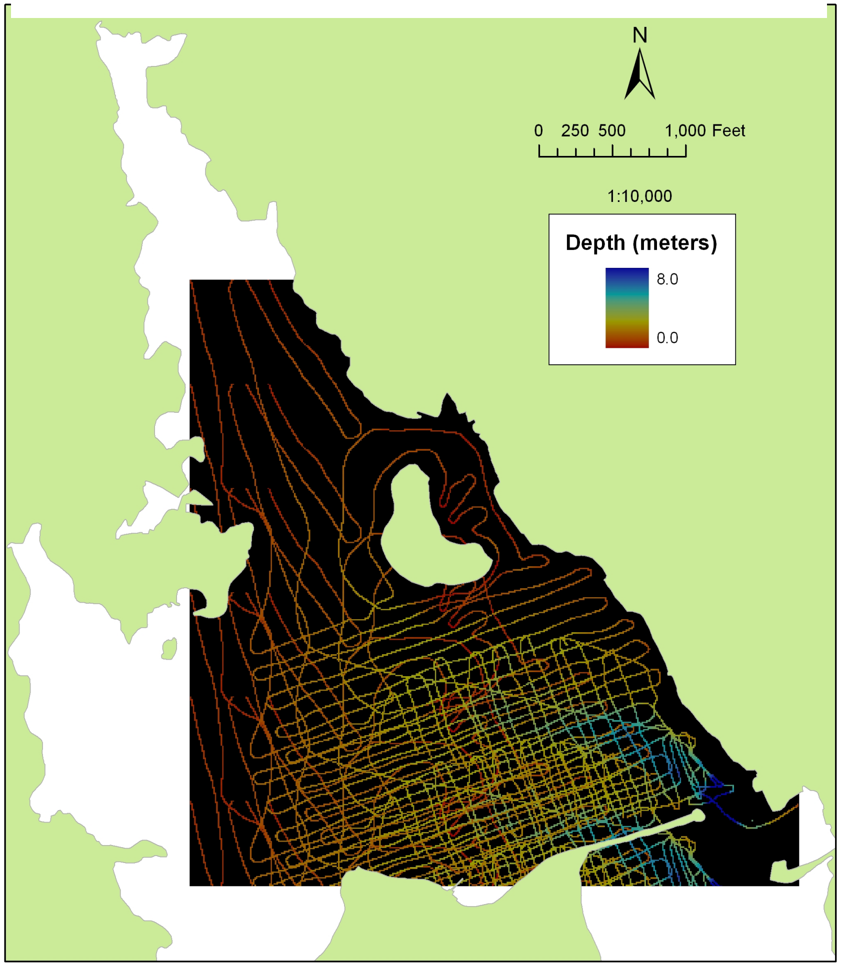
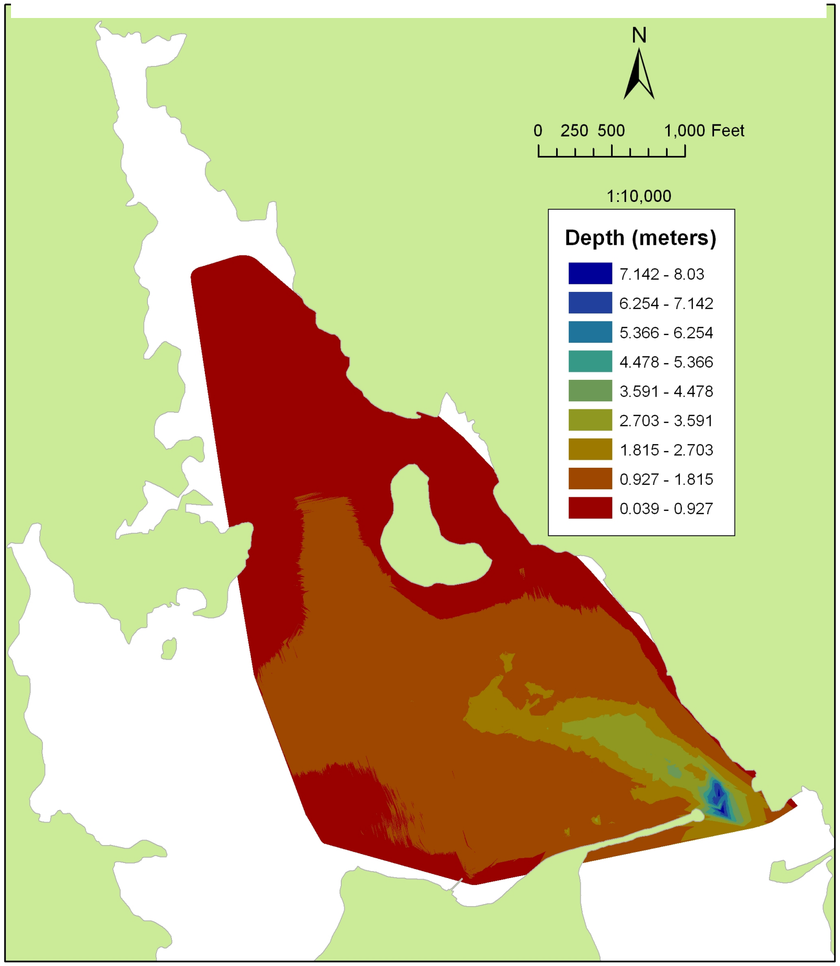


Figure 5. 5-m triangulated irregular network (TIN).



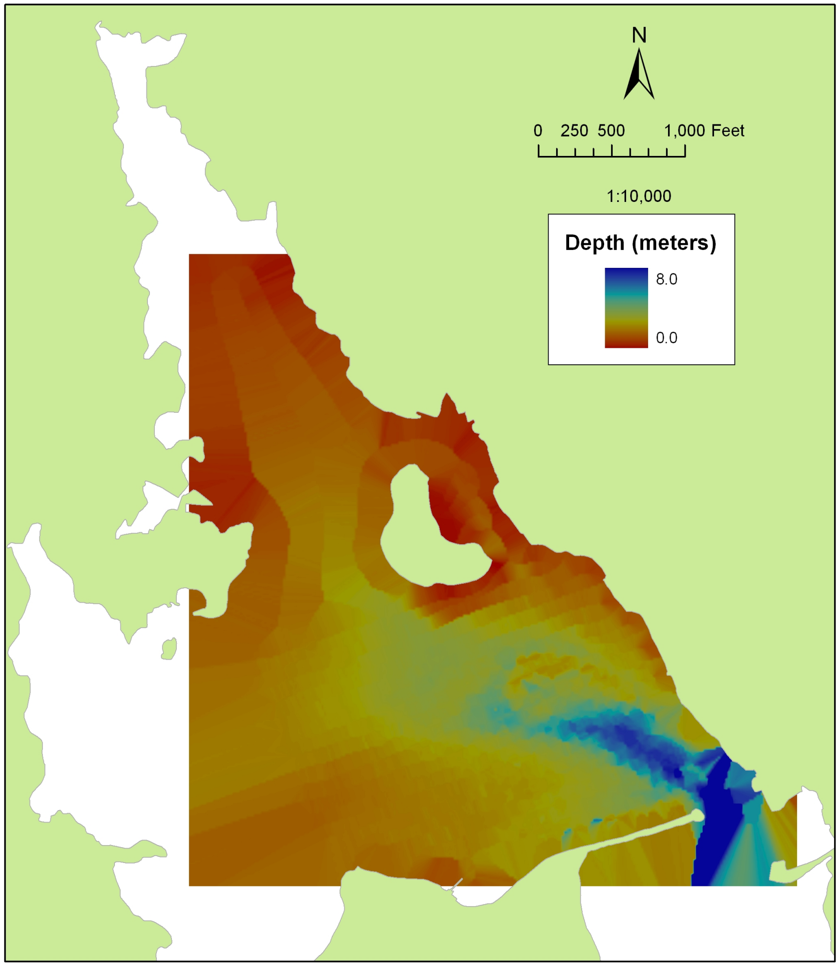


Figure 6. 5-m inverse distance weighted (IDW) interpolation.

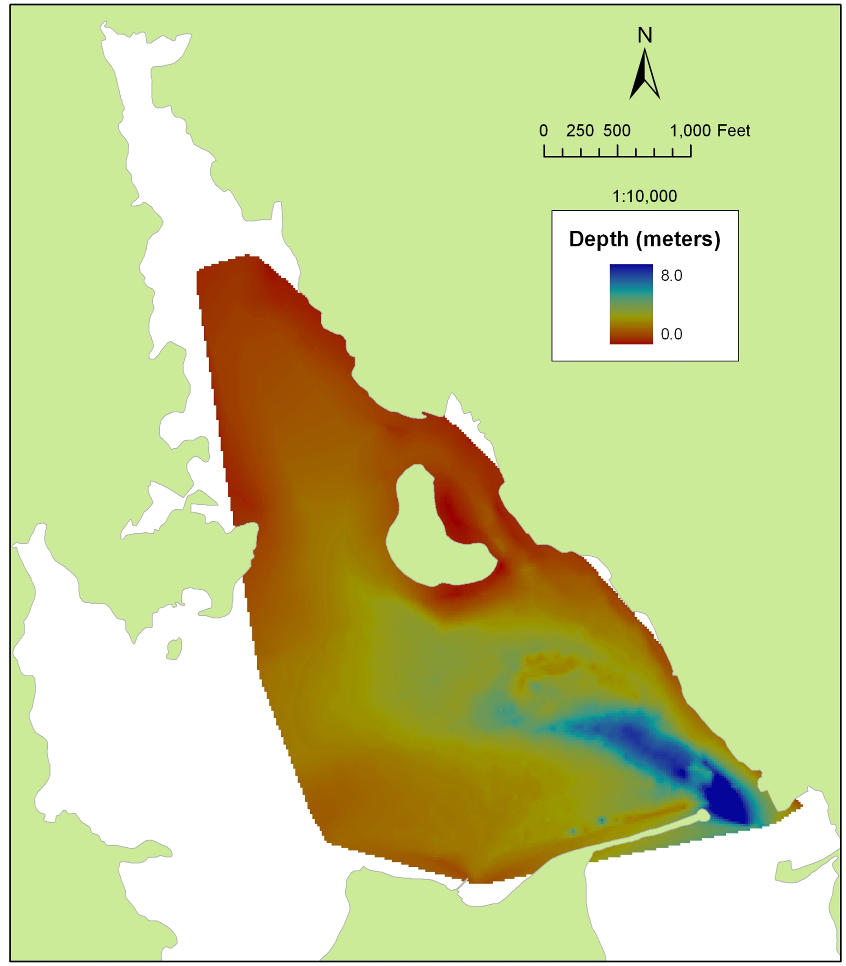


Figure 7. 5-m natural neighbor interpolation.

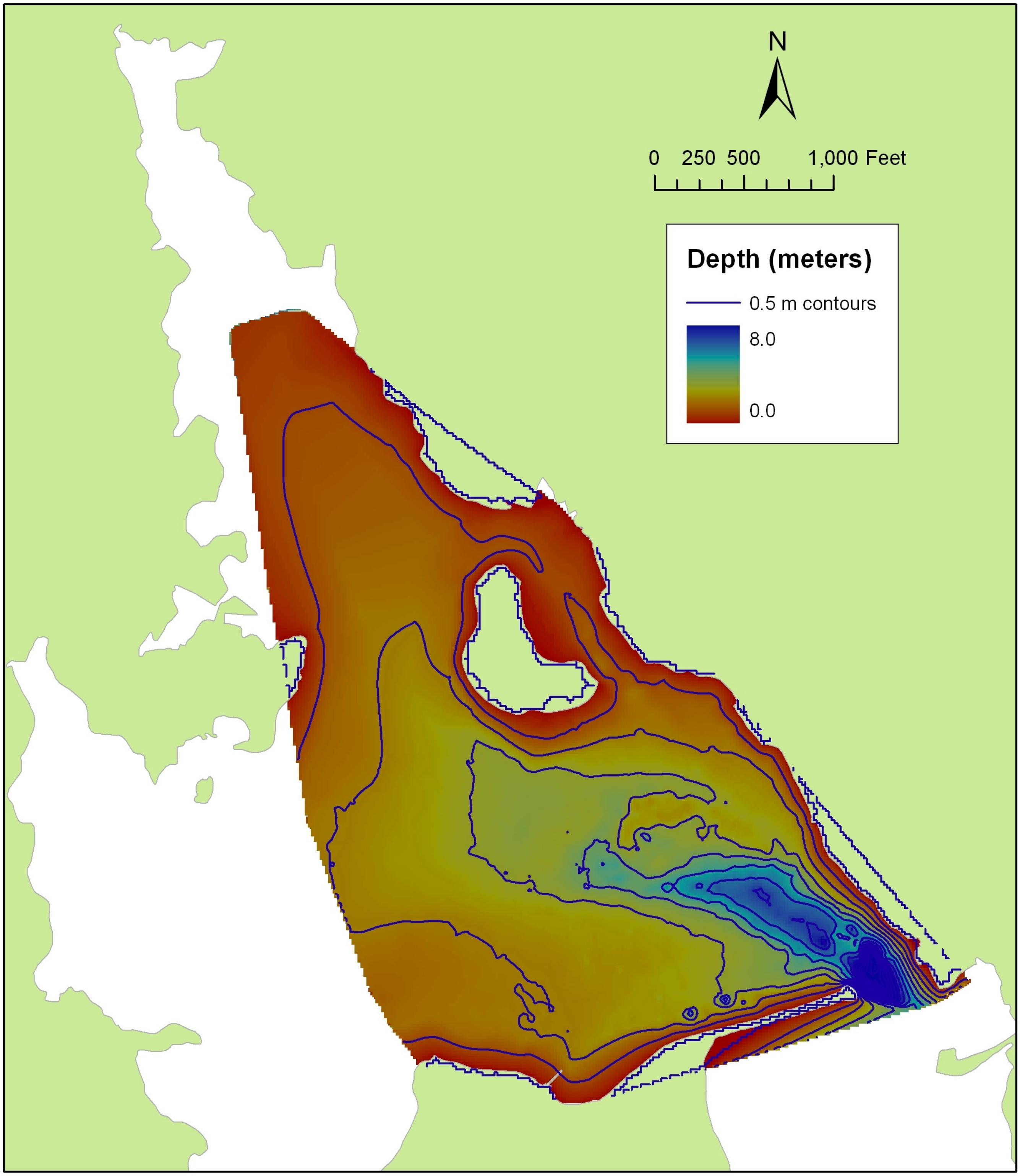


Figure 8. 5-m natural neighbor interpolation using manually added coastline points with a depth of zero. 0.5 meter contour intervals.