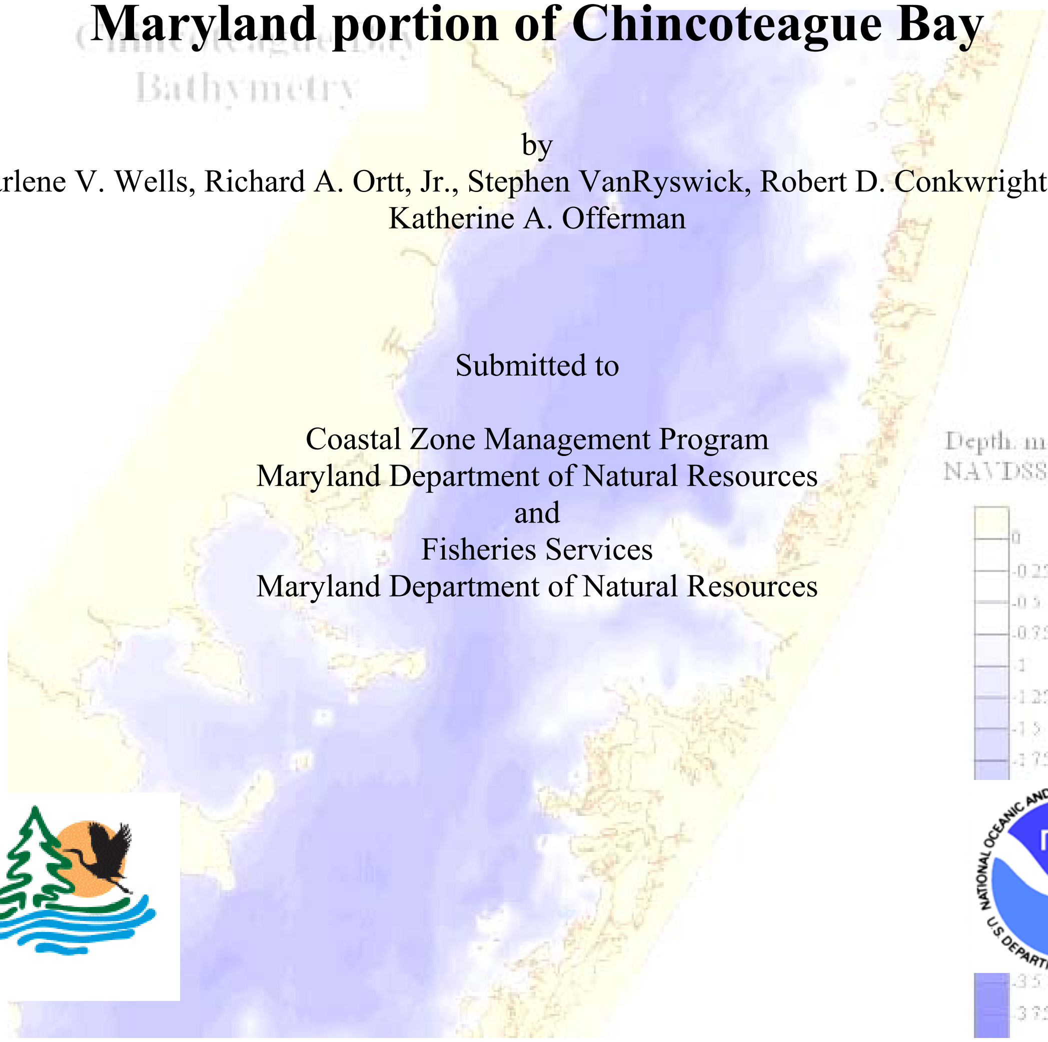
Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY
Emery T. Cleaves, Director

COASTAL AND ESTUARINE GEOLOGY
FILE REPORT NO. 04-04

Bathymetric Survey of the Maryland portion of Chincoteague Bay



by
Darlene V. Wells, Richard A. Ortt, Jr., Stephen VanRyswick, Robert D. Conkwright, and
Katherine A. Offerman

Submitted to

Coastal Zone Management Program
Maryland Department of Natural Resources
and
Fisheries Services
Maryland Department of Natural Resources

Financial assistance provided by the Coastal Zone Management Act of 1972, as amended, administered by the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration (NOAA). A report of the Maryland Coastal Zone Management Program, Department of Natural Resources, pursuant to NOAA Award No. NA17OC2689. This award was provided to the Maryland Department of Natural Resources by the NOAA Coastal Services Center.

July, 2004

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Table of Contents

List of Figures

List of Tables

Bathymetric Survey of the
Maryland portion of Chincoteague Bay

Executive Summary

The Maryland Geological Survey, through funding from NOAA, conducted hydrographic surveys in the Maryland portion of Chincoteague Bay. The purpose of the study was to provide a consistent bathymetry data set that may be used in other scientific studies. The hydrographic surveys were collected in May through September 2003, using differential global positioning service (DGPS) techniques and digital dual-frequency echo sounding equipment. Hydrographic survey lines were spaced 400 meters apart and extended from shore to shore. Six hundred kilometers of hydrographic records were surveyed and over 600,000 discrete soundings were recorded. In addition to the hydrographic surveys, water level data were collected at four different sites within the study area. The water level data were used to correct the echo sounding data for tide and wind offsets.

Sounding depths were adjusted to North America Vertical Datum of 1988 (NAVD88). The data are listed in ASCII XYZ (northing, easting, depth, time) ASCII format. Location coordinates are in UTM, NAD83. The adjusted sounding data were used to generate 10-meter, regularly spaced grid for the study area and a bathymetry (depth contour) map was created from the gridded data. The XYZ data, metadata, and map are presented on CD-ROM.

Introduction

The coastal bays of Maryland are environmentally sensitive areas that deserve the efforts and studies of the scientific community. Until recently, these studies were being conducted without a current and complete knowledge of the bathymetric framework of the bays. Hydrographic surveying determines the depths of the water from which a bathymetric model may be created. This model can serve as an integrating factor for various other studies and monitoring efforts such as sedimentation and sediment budget studies, sub-aquatic vegetation surveys and monitoring, water quality and pollutant transport modeling, and aquatic habitat studies. The bathymetric model can be a useful guide in the management of navigation channels and boating activities.

In 1999, the State Water Use Workgroup implemented a new set of management guidelines for Maryland's coastal bays. These new water use management guidelines, which differ from those of the Chesapeake Bay, would facilitate fulfillment of a number of goals outlined in *A Comprehensive Conservation and Management Plan for Maryland's Coastal Bays* (MCBP, 1999). With the implementation of the management plan, the need for better, up-to-date bathymetric data had been identified.

Prior to 2000, the only detailed, up-to-date bathymetric data available in the coastal bays were restricted to the navigation channels and the vicinity of the Ocean City Inlet. In the spring/summer of 2000, the Maryland Geological Survey (MGS) completed hydrographic surveys in Assawoman Bay, St. Martin River, Sinepuxent Bay, and Newport Bay, using standard digital hydrographic methods (Wells and Ortt, 2001). Because of cost and time constraints, MGS did not survey Chincoteague Bay.

Purpose

In response to the need for more complete and up-to-date bathymetric data in Chincoteague Bay, the Maryland Geological Survey, part of Maryland Department of Natural Resources' (DNR) Resource Assessment Service, conducted hydrographic surveys in the Maryland portion of Chincoteague Bay, using standard digital bathymetric methods (IHO, 1998). The objectives for this survey were to:

1. Provide current, consistent, and systematic hydrographic coverage of the study area;
2. Produce a bathymetric data set to complement the bathymetry data for the northern coastal bays (Assawoman Bay, St. Martin River, Sinepuxent Bay, and Newport Bay);
3. Develop a baseline digital bathymetric data set that may be expanded and/or used for comparison with surveys conducted in the future; and
4. Provide a digital bathymetric data set applicable for model development for various purposes such as circulation models, and water quality models.

Previous Bathymetric Studies

A listing of historical hydrographic surveys conducted by NOAA's National Ocean

Service (NOS) in Maryland's coastal bays is given in Table 1. These surveys, using several different sounding methods and datums, represent the extent of NOAA bathymetric data available in the coastal bays. The line spacings of the NOAA surveys are approximately 1000 meters apart, providing only very general coverage of the coastal bay bottom. The data from these surveys are included in NOAA's GEODAS database, information of which may be found at the NOAA web site.

Table 1. NOAA hydrographic data summary.

NGDC #	Survey	Date*	Area	Datum		Sounding Method	# of Soundings
				Horizontal	Vertical +		
03581004	H05714	12/79	Pope Is. to Chincoteague Inlet	NAD27	MLW	Lead line assumed	11543
03F12118	H09715	12/79	Sinepuxent Bay and Ocean City	NAD27	MLW	Digital echosounder assumed	1866
03NG1001	H01455A	12/94	Chincoteague Bay, lower parts	NAD27	MLW	Lead line assumed	7040
03NG1107	H01455B	6/94	Chincoteague Bay, upper parts	NAD27	MLW	Lead line assumed	3583
03NG1109	H01816	06/94	Millers Creek, DE to Sinepuxent Bay, MD	NAD 1913	MLW	Lead line assumed	2278

* Date when data was added to database. Surveys were conducted prior to that date but date was not given in database.
+ Tidal epoch was not given in NOAA summary of database.

Study Area

Chincoteague Bay is the southern-most of seven coastal bays located on the Atlantic coast of the Delmarva Peninsula (Figure 1). Assateague Island separates Chincoteague Bay from the Atlantic Ocean. The northern two-thirds of Chincoteague Bay lie in Maryland. Chincoteague Bay is contiguous with both Sinepuxent and Newport Bays at its northern boundary. The bay is connected to the Atlantic Ocean through two outlets: Ocean City Inlet located at the northern end of Sinepuxent Bay; and Chincoteague Inlet in Virginia to the south.

The Maryland coastal bays are microtidal (less than 2 meter tidal range) coastal lagoons. Circulation patterns and tidal ranges in the Chincoteague Bay are dependent on proximity to Ocean City and Chincoteague Inlets and wind conditions. Near the inlets, currents are primarily an effect of tidal cycles. Tidal influence diminishes rapidly with increasing distance from the inlets. For a large portion of the study area, wind conditions often have a greater effect than tides on water levels.

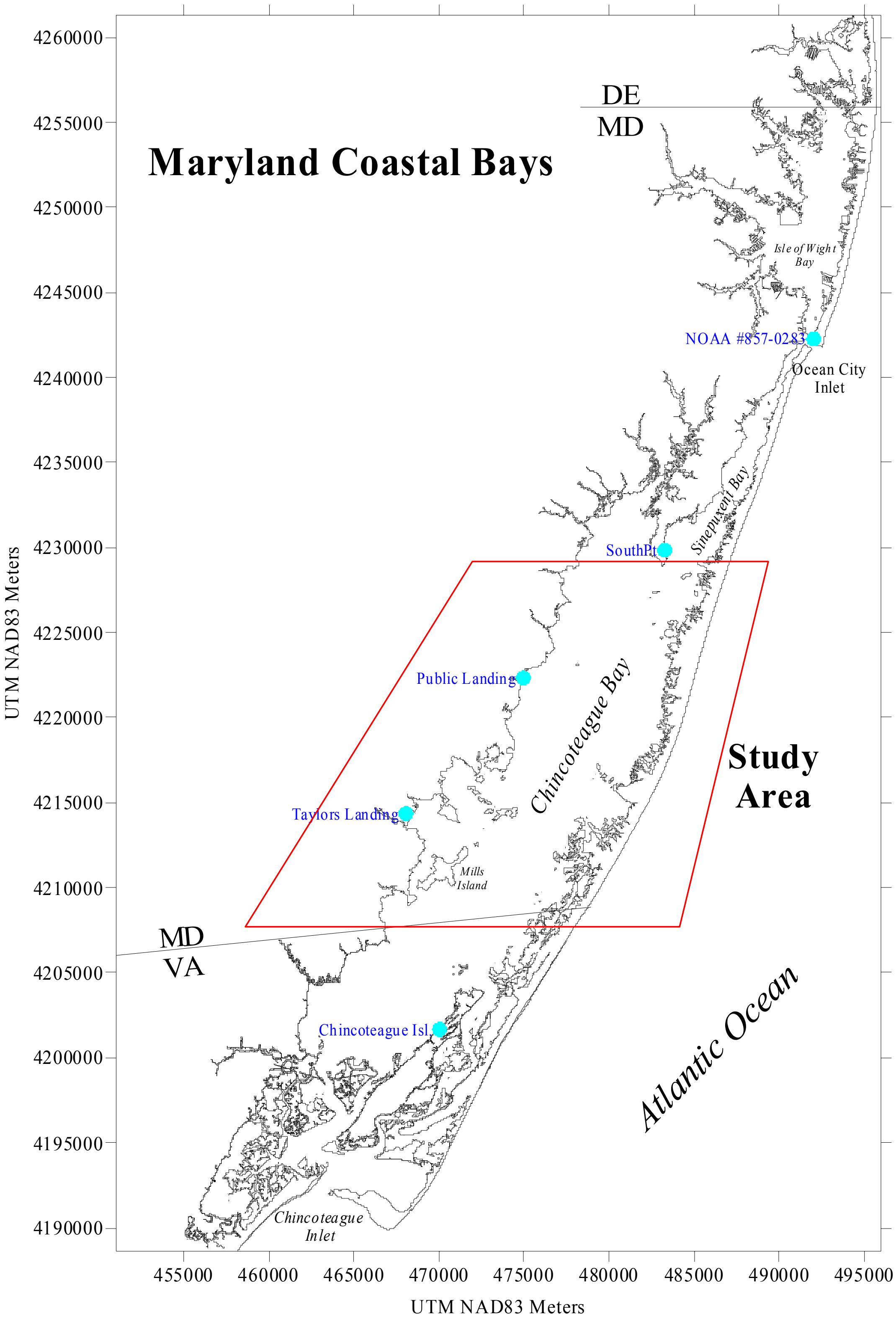

Figure 1. Study area (red polygon). Locations of water level recorders and NOAA Tide Station are indicated in blue.

Methods

Study Approach

Obtaining quality bathymetric data for the Maryland coastal bays is an enormous challenge, for several reasons. First, the bays are very shallow. This shallowness creates navigational difficulties during hydrographic surveys, and has the potential to enhance any error in the sounding data. The second reason why it is difficult to obtain good bathymetric data is related to the tidal characteristics of Maryland's coastal bays. Due to restricted access to the open ocean, the tidal range within the bays varies significantly depending on proximity to the inlet. For most areas in the bay, water level fluctuations are often more wind-driven rather than tidally induced. Water levels cannot be predicted and have to be measured at the same time and in the immediate vicinity of the hydrographic surveys.

Table 2. IHO Classification of Surveys (IHO,1998)

Order	Special	1	2	3
Examples of Typical Areas	Harbors, berthing areas, critical channels with minimum under-keel clearances	Harbors, harbor approach channels, some coastal areas with depths up to 100m	Areas not described in Special Order and Order 1, or areas up to 200m depth	Offshore areas not described in Special Order or Orders 1 and 2.
Horizontal Accuracy (95% confidence level)	2m	5m + 5% of Depth	20m +5% of Depth	150m +5% of Depth
Depth Accuracy for Reduced Depths (95% Confidence Level)	0.25m	0.5m +1% of Depth	1.0m + 2% Depth	1.0m + 2% Depth
100% Bottom Search	Compulsory	Required in select Areas	May be required in select areas	Not required
System Detection Capability	Cubic features >1m	Cubic features > 2m in depths up to 40m 10% of depth beyond 40m	Same as Order 1	N / A
Maximum Line Spacing	Not applicable, as 100% search is compulsory	3x average depth or 25m, whichever is greater	3-4x average depth or 200m, whichever is greater	4 x average depth

The number of transects and spacing required for hydrographic surveys depends on the techniques used and the level of coverage desired. Hydrographic surveys are traditionally associated with navigation. Due to the need to have thorough coverage for safety of ship passage and for the safety of the environment, several classifications have been created. Table 2 outlines these various classifications (IHO, 1998). First order hydrographic surveys require 100% coverage of the bay bottom, which is almost impossible to attain given the shallow depths found in the coastal bays. Since navigation was not the primary purpose for obtaining bathymetric data for most of the Maryland coastal bays, we conducted surveys at a track line spacing of 400 meters, a coverage we considered adequate to develop a preliminary bathymetric framework for the Chincoteague bays.

This study was conducted in two phases. The first was the collection of field data which consisted of three tasks: 1) conducting hydrographic surveys to obtain a systematic grid of discrete soundings in x, y, z format (geographic location and water depths); 2) installing and operating water level recorder to record water level (tide) data needed to adjust sounding data to a common datum; and 3) determining elevations (referenced to a common datum) of the water level recorders. The second phase involved the reduction and adjustment of the data to produce a bathymetric data set.

Hydrographic Surveys

Hydrographic surveys of the study area were collected using a 17 ft Boston Whaler equipped with a 70 horsepower outboard engine. Track lines follow UTM northing gridlines or easting gridlines, which facilitates navigation of the survey vessel and allows survey lines to be easily retraced for quality control and quality assurance (QA/QC) purposes and for future surveys. Track lines were spaced 400 meters apart and extended from shore to shore (generally east-west). Tie-in track lines, used primarily for QA/QC reasons, were run every 1000 meters perpendicular to the shore to shore tracks lines. Perimeter surveys, following the shoreline, were also conducted to establish boundary (near-shore) conditions. Figure 2 shows the actual boat track lines for the hydrographic surveys collected within the study area. All surveys were conducted between May 31 and September 30, 2003.

Bathymetric data were collected using an Ashtech Reliance Precision GPS (model SCA-12S; L1 code and carrier) and a Knudsen 320B/P dual frequency echosounder with sounding frequencies of 200 KHz and 28 KHz. The echosounder transducer is a KEL771 dual frequency transducer with a 200 KHz beam angle of 4 degrees and a 28 KHz beam angle of 29 degrees. The echosounder generated acoustic pulses for bottom recognition at a rate of 2 Hz. The pulse width was set to automatically change between *0.2 mS and 0.8 mS* depending on the depth of the water. The transmitted acoustic wave reflected off the density gradient separating the water column from the bottom sediment. The returned acoustic wave is received by the transducer, and the time separation between the sent and the returned wave is recorded. This time separation is directly proportional to distance. The recordings were then filtered for points that were outside of the gate window *(2 meters)* and integrated within the echosounder to produce an accurate measurement from the transducer to the water/sediment interface. At an average vessel speed of 4 knots, a depth sounding was collected approximately every 1.0 m (3.3 ft) along the survey track-lines. To minimize pitch and roll, the transducer, used for both transmitting the pulse and receiving the echo signal, was mounted off the port side of the whaler, slightly aft of the vessel's center. Because of the size of the boat and safety considerations, surveys were collected during "calm" conditions (waves ≤ 1 ft).

The sounding data was stored along with the GPS location and positional latency in a laptop computer. Navigation was provided through a Lowrance GlobalNav 212 GPS interfaced to a Lowrance DGPS beacon receiver. A Starlink MRB-2 DGPS receiver provided DGPS signals to the Ashtech Reliance GPS system. The Ashtech unit was programmed to output location coordinates only if the following criteria were met: 1) position derived from at least six satellites with positions of 15 ° or greater above the horizon; 2) Position dilution of precision (PDOP) less than 5; and 3) DGPS signal less than 30 seconds old. DGPS differential corrections broadcast by the United States Coast Guard provided a real-time horizontal accuracy of 1 to 2 m [3 to 6 feet] using the Cape Henry, Virginia, and Cape Henlopen, Delaware, DGPS sites. The Ashtech GPS, the Lowrance GPS, and the echosounder were checked against known horizontal and vertical measurements during the survey. The echosounder was calibrated to obtain speed of sound correction and transducer offset (Appendix C).

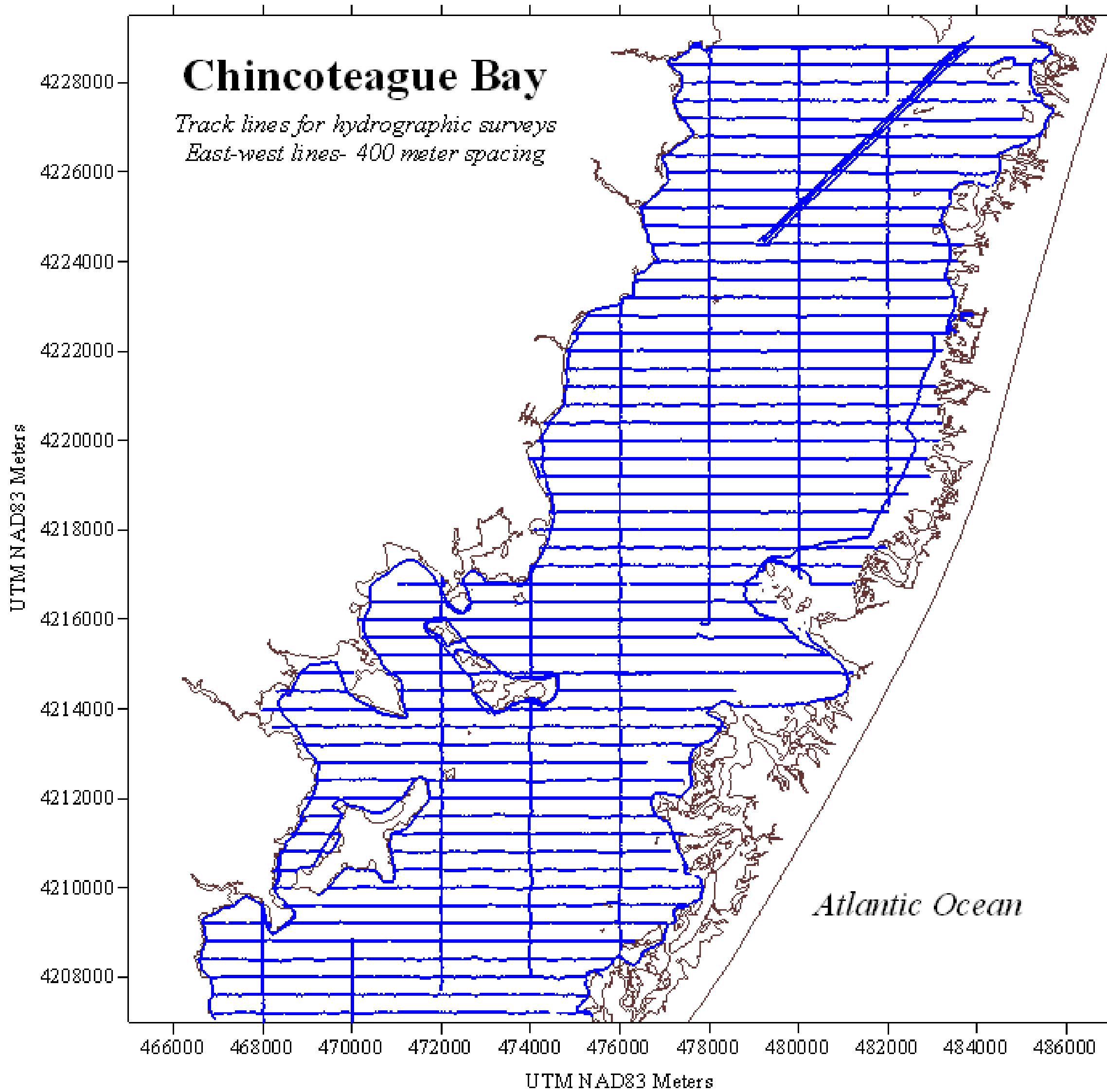

Figure 2. Track lines for hydrographic surveys collected in the Maryland portion of Chincoteague Bay. Surveys were conducted between May 30 and September 30, 2003.

Data recording

A laptop computer with Windows Online SCSI Echo Control Software (Knudsen Engineering Limited (KEL), 1999) was used to control operating parameters, to synchronize the GPS with the echosounder, and to record data from echosounder via the sounder's SCSI (Small

Computer System Interface) port. The parameters settings used are presented in Table 8 (Appendix B). Project ID, Time fix flag, Date, time, high frequency (HF) depth, HF depth valid flag, low frequency (LF) depth, LF depth valid flag, sound speed used, position (latitude and longitude), and position latency were output as ASCII comma-delimited text files (kea files). Horizontal position was recorded in Latitude and Longitude, using the North American Datum of 1983 (NAD83). HF and LF depths reflecting the distance from transducer to either the water-sediment interface (bay bottom) or sub-bottom interface were recorded in meters. The HF and LF depth flags and position latency were used to filter out “bad” data (See discussion under **Depth data filtering**). Because the GPS updated location every second while the Knudsen recorded a depth sounding every 0.5 seconds, two depth soundings were recorded for every unique location coordinate pair.

The Knudsen software permitted the display, in real-time, of a gray-scale graphic (echogram) on the PC monitor (similar to a hard-copy record), annotation of the record, and storage of the raw data as binary files for use by post-processing software. Each frequency had a separate display/record. An example of an echogram is shown in Figure 3.

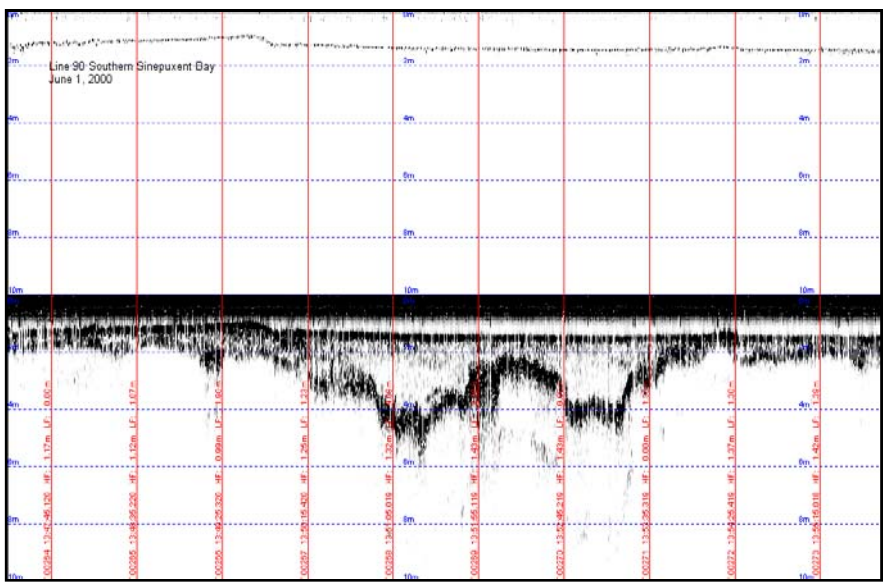

Figure 3. Example of echogram produced by Knudsen software. This echogram was collected in southern Sinepuxent Bay (west to east) in 2000. Record outputs for both frequencies are shown. The high frequency (200 kHz) record is on top, showing the position of the bay bottom. The bottom record represents the low frequency (28 kHz) output. A paleochannel is seen in the low frequency record.

Water Level Measurements

The soundings (depth data) collected by the echosounder are measurements of the distance between the transducer and the top of the water-sediment interface (or whichever interface recognized). The level of the water surface (and the level of the whaler) fluctuated depending on the tide stage and degree of wind setup, both factors of which will vary depending on exact location in the coastal bays. To determine the actual water level during the time the hydrographic surveys were conducted, four (4) water level recorders were installed and operated at several locations within the areas being surveying (Figure 1). Information such as UTM coordinate location, times of deployment and elevations for each water level recorder site are listed in Table 3.

Additional water level observations were obtained from the tide gauge at the U.S. Coast Guard station in Ocean City. The tide gauge at the Coast Guard Station is included in the NOAA tide gauge network (Sta. No. 857-0283).

The water level recorder systems used consisted of a data recorder interfaced with a level sensor. The level sensor is a submersible pressure transducer consisting of a solid-state pressure sensor encapsulated in a stainless steel submersible 3/4'" diameter housing. The sensor is connected to the data logger by a molded-on waterproof cable that is vented to the atmosphere. The vent to the atmosphere minimized offsets caused by barometric changes.

To minimize noise from wave activity, the sensor was mounted in a "stilling well" which consisted of a 5-foot length of 3-inch PVC pipe. The sensor was affixed to the inside wall of the pipe. The level of the sensor and a second level corresponding to 48 inches (1.22 m) above the sensor were marked on the outside of the pipe. The top and bottom of the PVC pipe were capped. To allow slow passage of water between the inside and outside of the pipe, four 1/8" holes were drilled through the PVC wall near the bottom of the pipe and two 1/8" holes at the top of the pipe. The PVC pipe was securely mounted on a piling, with the bottom of the pipe positioned on or near the bay bottom.

The manufacturer calibrated the water level recorders prior to shipping. Calibrations were confirmed in the field prior to deployment and again at the end of the study. The data loggers were programmed to take a set of six readings every six minutes, recording the average of those readings. Time of day was synchronized with GPS time when water level data were transferred from loggers to the laptop and data loggers reset. Data output from the loggers included date, time of day, and water level in comma-delimited ASCII format.

Elevation determinations of water level recorders

Given that the bathymetric data collected for this study is to be used primarily for scientific application rather than navigation, the North American Vertical Datum of 1988 (NAVD88) was used as the common vertical reference instead of Mean Lower Low (MLLW) datum that is traditionally used for navigation charts. NAVD88 is a fixed plane of reference for elevations on the North American continent and is independent of tidal datums, which may vary significantly within a geographical area. Surface models developed from sounding data referenced to NAVD88 provide a true depiction of the bay bottom surface, whereas, surfaces derived from data adjusted to MLLW are "warped."

Table 3. Information on water level recorders and tide stations used in this study. Station locations are shown in Figure 1. Elevations for water level sensors were derived by differential leveling surveys (see Appendix A).

Sta #	Sta ID	Water Lever Recorder Serial #	Date installed (Date put on-line)	Date removed	UTM NAD83-meters		Elevation of Water Level Sensor NAVD88-meters (feet)	Location-description/ Comments
					Northing	Easting		
1	NOAA #8570283	----	Permanent		4242265	492034	(See footnote [1])	NOAA tide station at US Coast Guard Station, Isle of Wight Bay
2	South Pt.	5577	5/27/03	7/10/03	4229840	483271	-0.668 ± 0.015 (-2.19± 0.05)	South Pt. Boat Ramp, Sinepuxent Bay
3	Public Landing	5576	5/27/03	7/10/03	4222334	474964	-0.808 ± 0.009 (-2.65 ± 0.03)	WLR on public pier at end of Route 365, Public Landing
	Public Landing [2]	5577	7/10/03	9/30/03	4222334	474964	--	WLR on public pier at end of Route 365, Public Landing
4	Taylors Landing	5150	7/17/03	9/30/03	4214365	468052	-0.750 ± 0.009 (-2.46 ± 0.03)	County public boat ramp at end of Taylors Landing Road, Johnson Bay; WLR on bulkhead
5	N. Chincoteague Island, Va.	5576	7/11/03	10/02/03	4201668	470042	-0.396 ± 0.006 (-1.30 ± 0.02)	WLR on end of private dock, 1000 meter north of Blake Cove; northeast shore of Chincoteague Island, Va.

[1]Water levels (MLLW) for #857-0283 were corrected to NAVD88 by subtracting 0.518 m (1.7 ft). The correction was derived from a comparison of published tidal datums (Tidal epoch 1983-2001) for NOAA Stations 857-0282 and 857-0283. The tidal datums for Sta 0282 are tied to NAVD88.

[2]Due to a problem with the sensor (#5576), it was replaced with the one pulled from South Point. The sensor was repaired and installed at Chincoteague Island.

To adjust the water level data to NAVD88, each water level recorder site was surveyed to determine elevation of the water level sensor relative to NAVD88. One or more benchmarks (BM) were used at each recorder site and relative elevations between the BMs and 4 ft reference marks on the stilling well of the recorders were determined by differential leveling. Elevations (NAVD88) of the water level recorder (water level sensors) are listed in Table 3.

Hydrographic Survey Data Processing

Depth data filtering

The sounding data from the hydrographic surveys were processed to remove noise and invalid depth readings. The ASCII comma-delimited text files (kea files) outputted by the Knudsen echosounder were imported into spreadsheets. A series of sorting routines were used to filter out invalid HF depth data (invalid HF flag), depths less than 0.35 meters (detection limit of the Knudsen), "out of sequence" depths (*e.g.*, fish, water column noise, multiples, etc.), and invalid location coordinates (GPS latency values > 1000 msec). For soundings having the same geographic coordinates, the sounding with the higher latency was removed.

Sounding depth adjustments

Sounding depth values were adjusted to account for the offset of the transducer below the water surface. The offset value was derived from the calibration of the echosounder (See Appendix A). The following equation was used:

$$Depth_{adj} = 0.9945 \times depth_{measured} + 0.2052$$

Where: the value ***0.2052*** is the transducer offset in meters, and ***0.9945*** is a correction factor for the speed of sound (set at 1500 m/s during data collection). Both $depth_{adj}$ and $depth_{measured}$ are in meters.

The adjusted sounding depth values were then corrected to account for tide stage and/or wind effects. Using a MathCAD splining algorithm (Wells and Ortt, 2001), water levels from the specific recorder were interpolated to the exact times depth soundings were taken, and the interpolated water levels were subtracted from the adjusted depth soundings, obtaining depths corrected to NAVD88. Tidal corrections were calculated using a two-step process. 1.) Water levels from each recorder were interpolated for exact times soundings were collected. 2.) From the time-interpolated water levels, a water level for each sounding location was interpolated using a weighted factor based on the distance the sounding location was between two closest bounding water level recorders. The method assumes that the water level change between stations is a linear relationship.

Due to equipment failure, there were gaps in water level data recorded at several stations (Appendix C, Table 9). For those times, soundings were adjusted using water levels interpolated between next closest bounding stations, or, water levels from the closest station. Hydrographic surveys by date and which water level stations were used for adjustment are listed in Appendix C.

Bathymetric Modeling

Final adjusted bathymetric data were interpreted with Surfer ® 8 software package. In Surfer, the adjusted data was processed using Triangulation with Linear Interpolation (TLI) method (Golden Software, Inc., 1999). Using a vector shoreline digitized from rectified 1989 and 1999 aerial photography to define the land-water interface (0 depths), a 10 meter regularly spaced grid was calculated from the bathymetric data. The TLI method is an exact interpolator and honors every data point, creating a surface that best represents the original data and shoreline. The regularly spaced grids were used to create the bathymetry model and contour map (Figure 4).

The validity of the model was analyzed using residuals. After the model was generated, it was compared to the original data set. The amount that the actual raw data differed from the model at the data point's location is the residual for that data point. Residuals were calculated at all measured data points and statistical quantification was performed on these residuals (Table 4).

Table 4. Residual analysis of the comparison of the raw hydrographic data to that of the gridded data.

Number of Raw Data Points Observed:	255648
Minimum Residual:	-1.72m
Maximum Residual:	1.89m
Mean:	0.003m
Median:	0.0017m
Standard Error:	0.0002m
Root-Mean-Square (all data):	0.124m
Root-Mean-Square (border conditions removed)	0.084m

It is expected that the minimum and maximum would be roughly equivalent to the upland surface (for gridding purposes it was fixed at 0.3 meters) and the near-shore depth since the grid was generated at a 10-meter interval and the water depth changes drastically at that interface. The averaging of all of the offsets yields a 3 mm offset with a standard error of 0.2mm throughout the generated surface. A root mean square analysis looks at absolute error rather than averaged error. Due to the errors caused by our rapid depth changes at shorelines, this value is biased due to that boundary condition. By removing all errors associated with the shoreline conditions, the root mean square is 0.084 meters.

Data accuracy

The Ashtech GPS-Starlink DGPS system provides for ± 1.5-meter accuracy. The accuracy of the post-processed horizontal GPS data is ±3.5 meters. The figure takes in account of the average boat speed (4 knots or 2 m/sec) and GPS coordinate update latency (maximum of

1000 msec). The accuracy of the post-processed bathymetry data is estimated to be ± 0.2 meters (0.7 ft). This estimate takes in account of the error introduced with the water level adjustments and elevation accuracy of the water level recorders.

Discussion

Bathymetric Grid

The bathymetry maps were not produced from the original soundings, but from a gridded data set that consists of data points interpolated from the original data and the shoreline. Any feature missed by the original data (*i.e*., features less than 400 meters in size and lying between hydrographic survey lines, or features outside of surveyed areas) would not show up on the grid. Also, some "bulls-eye" contour patterns seen in the maps are an artifact of the gridding technique. An example of this may be seen around several small islands lying between survey lines (Figure 4).

Bathymetry of the Maryland Portion of Chincoteague Bay

The bathymetry map shows that most areas surveyed are shallow, less than 2.0 meters NAVD88 (6.5 ft) deep. The mean depth is 0.9 meters. Most of the deeper areas (greater than 2 meters) are restricted to the central axis of the bay. However, depths rarely exceed 2.5 meters. A depth greater than 3.0 meters was measured in an un-named slough or gut located on the bay side of Assateague Island just south of Tingles Island.

Tides

Based on the water level data collected in the study, some general observations may be made regarding the tide patterns in Chincoteague Bay. Preliminary tidal datums for the water level stations are presented in Table 5. Although some of these datums are based on observations for time intervals of less than 30 days (*i.e.,* not a full lunar cycle), the datums are somewhat similar to published and unpublished datums from NOAA. Any significant deviations from published datums are attributed to effects of wind setup skewing short-term data. Hurricane Isabel occurred during the time the water level recorders were deployed. Although the storm passed west of Baltimore, Maryland, it produced a 0.75 m (2-ft) surge in water levels in the bays (Figure 5).

Mean tide range in Chincoteague Bay is 10 to 20 cm (4 to 8 inches). The tide range increases slightly toward Chincoteague Island in Virginia. Based on the time delay of tides from NOAA Station #857-0283, Taylors Landing and N. Chincoeague Island area are more influenced by Chincoteague Inlet. Tides at Chincoteague Inlet are approximately 30 minutes to an hour behind Ocean City Inlet tides.

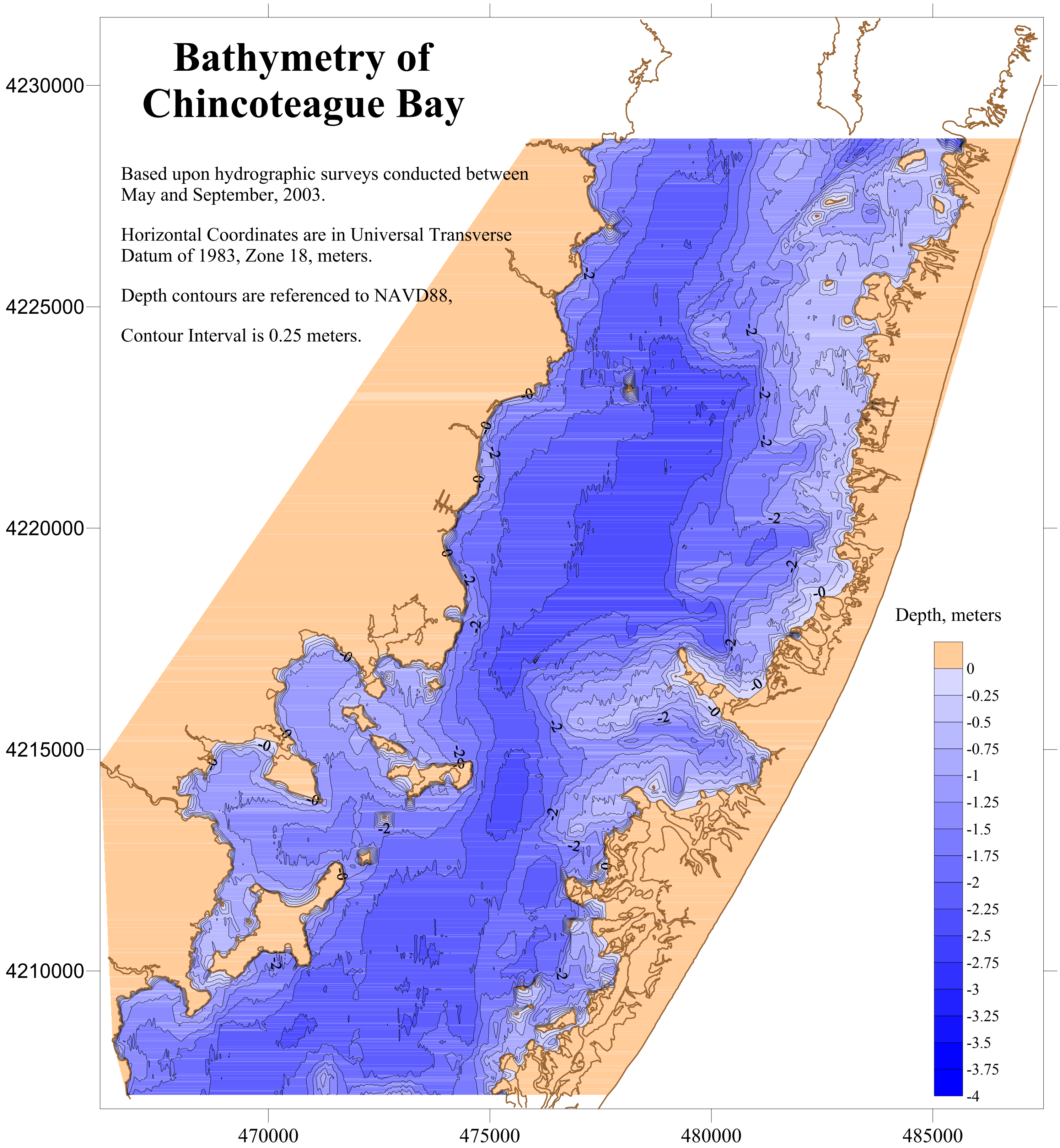

Figure 4. Bathymetry map of Chincoteague Bay.

Table 5. Comparison of preliminary tide datums calculated from water level data collected for this study (2003). Elevations are in meters NAVD88.					
		South Pt.	Public Landing	Taylors Landing	North Chincoteague Island
Time interval (2003)		6/5-7/2	7/30-8/30	8/27-9/16	7/30-8/25
Mn*		0.094	0.114	0.153	0.219
MTL		0.093	0.020	0.078	-0.016
DHQ		0.058	0.041	0.044	0.052
DLQ		0.040	0.048	0.028	0.046
Gt		0.192	0.202	0.225	0.317
DTL		0.103	0.017	0.086	-0.013
Time lag from NOAA Sta. #857-0283	High tide	4 hr 21 m	4 hr 23 m	3 hr 27 m	1 hr 40 m
	Low tide	4 hr 21 m	5 hr 2 m	4 hr 13 m	2 hr 24 m

* Mean Range (Mn) = MHW-MLW
Mean Tide Level (MTL) = Avg(MHW + MLW)
Diurnal High Water Inequality (DHQ)= MHHW - MHW
Diurnal Low Water Inequality (DLQ)= MLW- MLLW
Gross Mean Range (Gt) = MHHW - MLLW
Diurnal Tide Level (DTL) = Avg(MHHW + MLLW)

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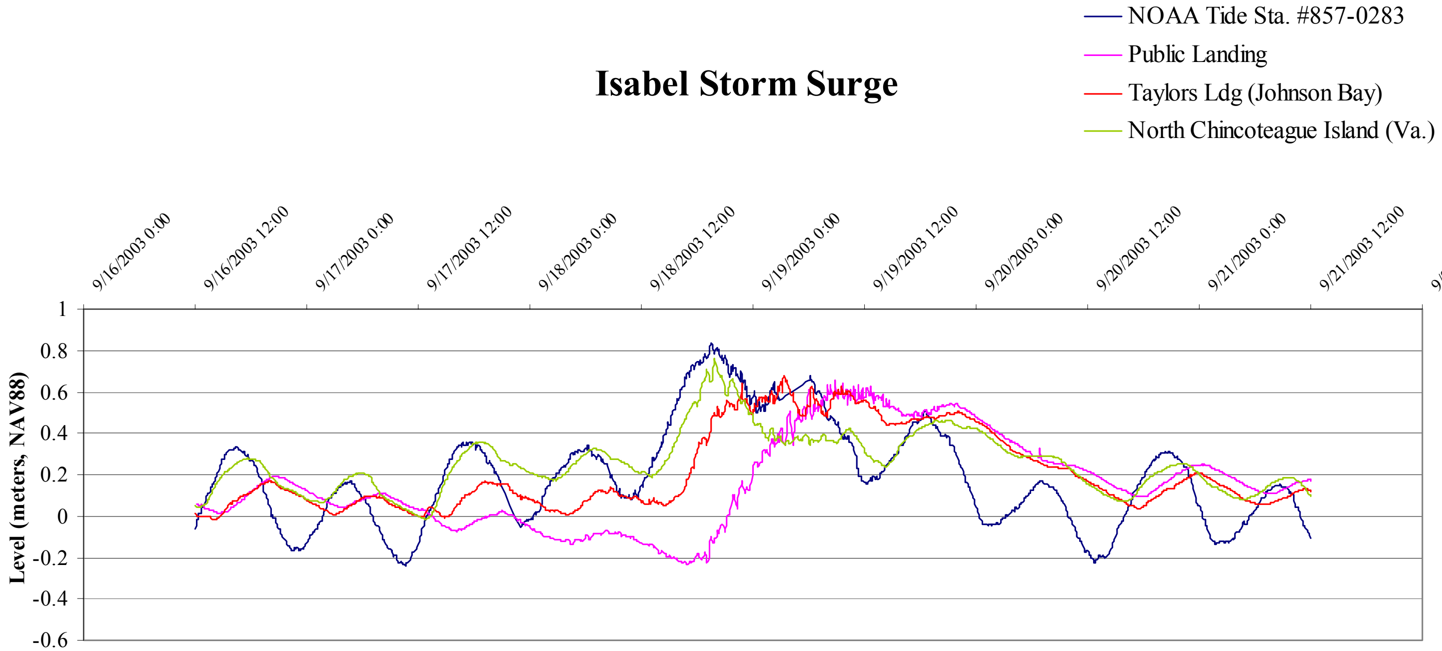

Figure 6. Plot of water levels in Chincoteague Bay during Hurricane Isabel. At 1:00 pm (UTC), September 18, 2003, the storm made landfall east of Cape Lookout, North Carolina, and tracked NNW. At 1:00 am, September 19th, the storm passed approximately 75 miles west of the mouth of the Chesapeake Bay. Water levels in Isle of Wight Bay at Ocean City Inlet (NOAA #857-0283) peaked at 7:30 pm on Sept. 18th, reaching 0.84 meters (2.7 ft) above NAVD88.

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Appendix A- Quality Assurance/Quality Control

1. Echosounder depth calibration

The Knudsen echosounder was checked against known depths to determine keel offset and reduce errors. The echosounder was calibrated throughout the entire range of water depths measured. The calibration data and the regression curve are presented in Table6. All initial depth recordings were made assuming a speed of sound of 1500 meters per second. The recorded depths were adjusted after collection using a calibration equation derived from the calibrations conducted in the field (Figure 6).

Table 6. Calibration data for Knudsen echosounder.

Known Depth		Knudsen reading (200 kHz)
feet	meters	Depth (m)
4.62	1.41	1.20
4.63	1.41	1.24
5.56	1.69	1.67
4.96	1.51	1.27
9.2	2.80	2.70
9.3	2.83	2.70
2.13	0.65	0.44
2.54	0.77	0.57
3.8	1.16	0.92
3.59	1.09	0.84
6.64	2.02	1.83
6.64	2.02	1.74
5.8	1.77	1.74
7.04	2.15	2.14
5.82	1.77	1.54
6.18	1.88	1.58
6.84	2.08	1.83
7.26	2.21	1.97
7.52	2.29	2.11
11.88	3.62	3.34
11.82	3.60	3.37
12.52	3.82	3.43
12	3.66	3.56
17.9	5.46	5.20
17.95	5.47	5.26
16	4.88	4.70
16.3	4.97	4.94

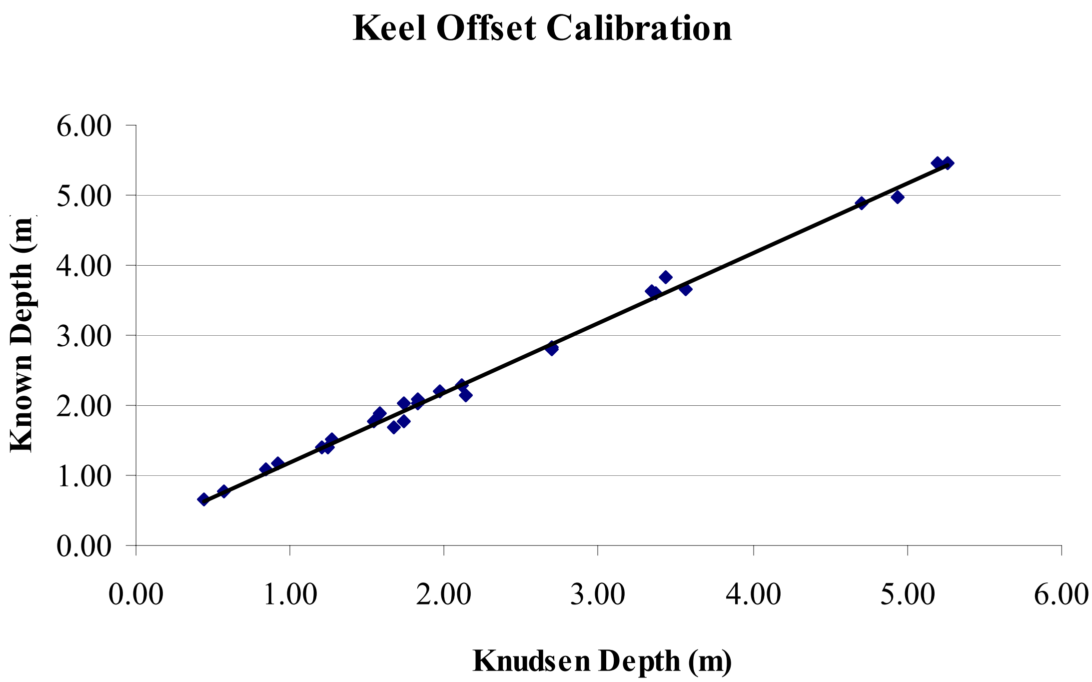

Figure 6. Plot of the calibration data for the Knudsen. Based on regression analysis, equation used to adjust depth sounding: Actual depth=0.9945*Knudsen Depth +0.2052; $R^2 = 0.9956$.

2. Elevation determinations of water level sensors

Table 7 contains leveling data for the water level recorders installed by MGS for this study. All elevations are orthometric elevations, NAVD88, in feet (meters, if indicated, in parentheses).

Table 7. Vertical control data for elevations determination for water level recorders.

Station	Point Description	Elevation NAVD88 feet	Comments
South Point	NOS BM 857 0536 A	1.65±0.05	Elevation (NAVD88) determined by DNR Engineerin in 2000 (Wells and Ortt, 2001); Bench mark loose; suspect
	NOS BM 857 0536 B	3.26 ±0.05	Elevation (NAVD88) determined by DNR Engineerin in 2000 (Wells and Ortt, 2001)
	NOS BM 857 0536 D	2.50 ±0.01	Elevation (NAVD88) determined by DNR Engineerin in 2000 (Wells and Ortt, 2001)
	4 ft nail on piling	1.81 1.81	Surveyed on 5/27/03 and 10/2/03, calculated elevation
	Water level sensor	-2.19 +/- 0.01 -2.19 +/- 0.00	Surveyed on 5/27/03 and 10/2/03, calculated elevation
Public Landing	NOS BM 857 0649 A	9.70	Used SHA elevations: Md State Highways surveyed to NAVD88; submitted preliminary elevations to NGS [1]
	OC9 #531	9.09	Surveyed on 5/27/03, calculated elevation
	NOS BM 18 WDK 1963	9.05	Used SHA elevations: Md State Highways surveyed to NAVD88; submitted preliminary elevations to NGS [1]
	NOS BM 857 0649 C	10.89	Used SHA elevations: Md State Highways surveyed to NAVD88; submitted preliminary elevations to NGS [1]
	NW corner of light post	3.97	Surveyed on 9/29/03, calculated elevation
	BM Property marker	8.735	Surveyed on 5/27/03 and 9/29/03, calculated elevation
	Top of Dock	3.97	Surveyed on 5/27/03 and 9/29/03, calculated elevation

Table 7. Vertical control data for elevations determination for water level recorders.

Station	Point Description	Elevation NAVD88 feet	Comments
Public Landing (cont.)	3-ft Nail	0. 35 0.26	3-ft nail is 44.5 inches below top of dock, measured with tape
	4-ft Nail	1.262	4-ft nail is 32.5 inches below top of dock, measured with tape
	Sensor	-2.65 -2.68	Surveyed on 5/27/03 and 9/29/03, calculated elevation
Taylors Landing	MGS 527 (PID MD0013)	2.28	Surveyed on 10/9/03; used SHA elevations: Md State Highways surveyed to NAVD88; submitted preliminary elevations to NGS [1]
	Grate (NE corner)	0.745	Surveyed on 7/17/03 before establishing MGS 527 and on10/9/03; calculated elevation
	4-ft nail	1.54	calculated elevation
	Sensor	-2.46	calculated elevation
N. Chincoteague Island	Mid Platform-heat pump	9.20	Surveyed on 10/2/03; elevation (NGVD adj 1977 provided by Jim West [2], adjusted to NAVD88 by subtracting 0.81 ft.
	9-ft nail	9.0	Elevation provided by Mr. West [2]
	4-ft nail	2.71	Surveyed on 10/2/03
	Sensor	-1.29	Surveyed on 10/2/03

[1] Personal communication with Malcolm Archer-Shee, Surveys and Plats, SHA: NGS final adjustments to elevation will be +/- 2 mm or 0.07 inches).

[2] Jim West [2], Town of Chincoteague City manager and professional surveyor provided elevations, in ft, NGVD adj. 1977, for temporary benchmarks surveyed for house construction to meet FEMA requirements. Elevation pulled from NOS BM D 258 1942 (PID# FW0146).

Appendix B
Knudsen operating parameter settings

Table 8. Knudsen echosounder system control settings used for the hydrographic surveys conducted for this study.

Global control settings		**Low frequency (LF) settings**		**High frequency (HF) settings**	
Range	0	Power	1	Power	1
Phase	1	AGC	On	AGC	On
Autophase	Off	GAIN	32	GAIN	48
Timed event marks	On	Processing Gain	5	Processing Gain	0
Interval	50 seconds	Sensitivity	Off	Sensitivity	Off
Units	Meters	Tx Blank	9	Tx Blank	3
TVG	Off	Pulse	1	Pulse	0
Gatewidth	2				
Primary Channel	HF				
Ping interval	500 millisec. (ms)				

The setting parameters are defined as follows:

Range- sets the transmit blanking distance used by the echosounder's internal digitizer to avoid false triggering on transmit reverberation.

Phase- selects the depth, or location in the water column, of the active window

Autophase- If ON, the phase changes are performed automatically in response to information provided by the primary channel bottom tracking algorithm.

Timed event marks- if ON, allows the user to select the echosounder's internally timed event marks. The echosounder will cause internally generated event mark at the time interval selected in the **Timed Event Interval** box.

Interval- Sets interval (seconds) for timed event marks on the echogram.

Units- Operating units, can be meters, feet, or fathoms

TVG- Time varied gain on the analog receivers. The **OFF** setting provides constant receive gain throughout each pulse-echo cycle (note that receive gain will vary from ping to ping if AGC is on).

Gatewidth- The gate width is a depth variability tolerance value used by the bottom tracking algorithm to determine the validity of the current depth value. The value is defined as a distance above or below the bottom depth trend established by the current and several previous readings. If the most

	current depth reading falls within this range, it is considered valid. If a depth return falls outside of this range, it is deemed invalid and “0.0" is displayed in all the dialogue boxes with depth displays.
Primary Channel-	The **Primary Channel** parameter defines the frequency channel used as the reference depth for the auto phasing algorithm. The **Primary Channel** designation only has effect when both channels of a dual-channel echosounder are ON.
Ping interval-	Sound pulse rate in milliseconds
Power-	Specifies the transmit power level of the pulse being transmitted.
AGC-	Invokes automatic gain control of the analog receive gain
Gain-	Controls the analog receiver gain of the relevant channel.
Processing Gain-	Provides for additional gain in the digital signal processing software which can be used with very low level signals.
Sensitivity-	Parameter that controls the minimum echo strength acceptable by the bottom detection software. This parameter is useful in areas where soft sediments overlay harder materials, and where buried layers may often produce stronger echoes than the real bottom. If **Sensitivity** is **OFF** (the default condition), the bottom detection software will always select the strongest echo in the *window* . Increasing the **Sensitivity** causes the bottom detection software to accept a weaker but shallower echo. The higher the **Sensitivity**, the weaker the echo, relative to the strongest echo in the *window*, that will be selected.
Tx Blank-	Sets the transmit blanking distance used by the echosounder's internal digitizer to avoid false triggering on transmit reverberation.
Pulse-	Pulse type

Appendix C

Table 9. Water level data time period and missing data for each water level site. Times are UTC.					
WLR Location	**Time Start**		**Time End**		**Missing Data/ Comments**
	Date	**Time**	**Date**	**Time**	
South Point	05/27/03	20:29:31	07/08/03	18:56:42	5/29/03 17:50 – 6/4/03 17:37
Public Landing	05/27/03	22:38:57	09/30/03	20:23:30	6/27/03 16:09 – 7/5/03 07:02 7/7/03 13:47 – 7/10/03 18:08
Taylors Landing	7/17/03	14:39:05	10/01/03	14:45:36	7/18/03 15:57 – 8/20/03 14:17
N. Chincoteague Island	7/11/03	16:18:24	09/30/03	20:49:20	9/3/03 17:26 – 9/9/03 22:35

Table 10. Summary information on hydrographic survey lines. File name for survey lines are identified by date collected and time started (**e.g.,** May31_1542). Tidal adjustments to soundings were based on water level data from recorders located at South Pt. (SP), Public Landing (PL), Johnson Bay (JB), and N. Chincoteague Island (CI). Refer to Table 3 for exact station locations.			
File Name	**Date**	**UTM Line And/or Designation**	**Tidal Adjustment (water level data used)**
May31_1541.xls	31-May-03	N4228800	SP
June13_1402.xls	13-Jun-03	N4224000	SP, PL
June13_1454.xls	13-Jun-03	N4223600	SP, PL
June13_1554.xls	13-Jun-03	N4223200	SP, PL
June13_1726.xls	13-Jun-03	N4222800	SP, PL
June16_1333.xls	16-Jun-03	N4222800	SP, PL
June16_1411.xls	16-Jun-03	N4222400	SP, PL
June23_1517.xls	23-Jun-03	N4222400	SP, PL
June23_1622.xls	23-Jun-03	Perimeter	SP, PL
June6_1339.xls	6-Jun-03	N4225600	SP, PL
June6_1429.xls	6-Jun-03	N4225200	SP, PL
June6_1526.xls	6-Jun-03	N4224800	SP, PL
June6_1721.xls	6-Jun-03	N4224400	SP, PL
June6_1719.xls	6-Jun-03	N4224400	SP, PL
June6_1643.xls	6-Jun-03	N4224400	SP, PL

Table 10. Summary information on hydrographic survey lines. File name for survey lines are identified by date collected and time started (**e.g.,** May31_1542). Tidal adjustments to soundings were based on water level data from recorders located at South Pt. (SP), Public Landing (PL), Johnson Bay (JB), and N. Chincoteague Island (CI). Refer to Table 3 for exact station locations.

File Name	Date	UTM Line And/or Designation	Tidal Adjustment (water level data used)
June6_1543.xls	6-Jun-03	N4224800	SP, PL
June6_1655.xls	6-Jun-03	N4224400	SP, PL
June05_1425.xls	5-Jun-03	N4227200	SP, PL
June05_1522.xls	5-Jun-03	N4226800	SP, PL
June05_1624.xls	5-Jun-03	N4226400	SP, PL
June05_1722.xls	5-Jun-03	N4226000	SP, PL
June24_1454.xls	24-Jun-03	N4227600	SP, PL
June24_1601.xls	24-Jun-03	N4227600	SP, PL
June24_1635.xls	24-Jun-03	NW Perimeter	SP, PL
June24_1809.xls	24-Jun-03	E478000	SP, PL
June25_1223.xls	25-Jun-03	E480000	SP, PL
June25_1317.xls	25-Jun-03	E482000	SP, PL
June25_1415.xls	25-Jun-03	East Perimeter	SP, PL
June25_1559.xls	25-Jun-03	Navigation channel-Center	SP, PL
July07_2025.xls	7-Jul-03	Navigation channel-Center Redo]	SP
July07_2119.xls	7-Jul-03	NW edge of Channel	SP
July08_1540.xls	8-Jul-03	N422880	SP
July08_1452.xls	8-Jul-03	SE side of Channel	SP
July08_1647.xls	8-Jul-03	N4228400	SP
July08_1752.xls	8-Jul-03	N4228000	SP
July15_1035.xls	15-Jul-03	N4222000	PL
July15_1234.xls	15-Jul-03	N4221600	PL
July15_1310.xls	15-Jul-03	N4221600	PL
July15_1318.xls	15-Jul-03	N4221200	PL
July15_1412.xls	15-Jul-03	N4220800	PL
July15_1521.xls	15-Jul-03	N4220400	PL
July17_1141.xls	17-Jul-03	N4220000	PL,JB,CI
July17_1241.xls	17-Jul-03	N4219600	PL,JB,CI
July17_1344.xls	17-Jul-03	N4219200	PL,JB,CI
July25_1025.xls	25-Jul-03	N4218800	PL,CI
July25_1130.xls	25-Jul-03	N4218400	PL,CI
July25_1223.xls	25-Jul-03	N4218000	PL,CI
July25_1322.xls	25-Jul-03	N4217600	PL,CI
July25_1419.xls	25-Jul-03	N4217200	PL,CI
July25_1515.xls	25-Jul-03	N4216800 East end	PL,CI
July31_0220.xls	31-Jul-03	N4216800 West end	PL,CI

Table 10. Summary information on hydrographic survey lines. File name for survey lines are identified by date collected and time started (**e.g.,** May31_1542). Tidal adjustments to soundings were based on water level data from recorders located at South Pt. (SP), Public Landing (PL), Johnson Bay (JB), and N. Chincoteague Island (CI). Refer to Table 3 for exact station locations.

File Name	Date	UTM Line And/or Designation	Tidal Adjustment (water level data used)
July31_0606.xls	31-Jul-03	N4207200	PL,CI
July31_0313.xls	31-Jul-03	N4216400	PL,CI
Aug05_0121.xls	5-Aug-03	N4207600	PL,CI
Aug05_0218.xls	5-Aug-03	N4208000	PL,CI
Aug08_0145.xls	8-Aug-03	N4216000	PL,CI
Aug08_0302.xls	8-Aug-03	N4215600	PL,CI
Aug08_1628.xls	8-Aug-03	N4215200	PL,CI
Aug08_1737.xls	8-Aug-03	N4214800 east end	PL,CI
Aug12_1409.xls	12-Aug-03	E Perimeter	PL,CI
Aug12_1535.xls	12-Aug-03	E Perimeter	PL,CI
Aug13_1435.xls	13-Aug-03	E468000 N-S	PL,CI
Aug13_1500.xls	13-Aug-03	E470000	PL,CI
Aug14_1513.xls	14-Aug-03	E472000	PL,CI
Aug14_1615.xls	14-Aug-03	E474000	PL,CI
Aug21_1340.xls	21-Aug-03	N4214800 west end	PL,JB,CI
Aug21_1425.xls	21-Aug-03	N4214400	PL,JB,CI
Aug21_1526.xls	21-Aug-03	N4214000	PL,JB,CI
Aug22_1304.xls	22-Aug-03	Perimeter- SW and S JB	PL,JB,CI
Aug22_1434.xls	22-Aug-03	West perimenter- JB to PL	PL,JB,CI
Aug22_1603.xls	22-Aug-03	Perimeter at PL W	PL,JB,CI
Aug22_1619.xls	22-Aug-03	Perimeter-East central	PL,JB,CI
Aug22_1749.xls	22-Aug-03	Perimeter-east	PL,JB,CI
Aug26_1329.xls	26-Aug-03	N4213600	PL,JB,CI
Aug26_1417.xls	26-Aug-03	N4213200	PL,JB,CI
Aug26_1454.xls	26-Aug-03	N4212800	PL,JB,CI
Aug26_1528.xls	26-Aug-03	N4212400	PL,JB,CI
Aug26_1601.xls	26-Aug-03	N4212000	PL,JB,CI
Aug26_1718.xls	26-Aug-03	N4211600	PL,JB,CI
Aug26_1742.xls	26-Aug-03	N4211200	PL,JB,CI
Aug26_1809.xls	26-Aug-03	N4210800	PL,JB,CI
Aug26_1839.xls	26-Aug-03	N4210400	PL,JB,CI
Aug27_1305.xls	27-Aug-03	East perimeter- very short	PL,JB,CI
Aug27_1415.xls	27-Aug-03	N4210000	PL,JB,CI
Aug27_1452.xls	27-Aug-03	N4209600- east end	PL,JB,CI
Aug27_1535.xls	27-Aug-03	N4209200- west end	PL,JB,CI
Aug27_1558.xls	27-Aug-03	N4209200- east end	PL,JB,CI

Table 10. Summary information on hydrographic survey lines. File name for survey lines are identified by date collected and time started (**e.g.,** May31_1542). Tidal adjustments to soundings were based on water level data from recorders located at South Pt. (SP), Public Landing (PL), Johnson Bay (JB), and N. Chincoteague Island (CI). Refer to Table 3 for exact station locations.

File Name	Date	UTM Line And/or Designation	Tidal Adjustment (water level data used)
Aug27_1641.xls	27-Aug-03	N4208800	PL,JB,CI
Aug27_1730.xls	27-Aug-03	N4208400	PL,JB,CI
Sep01_1353.xls	1-Sep-03	Perimeter- Mills Isl	PL,JB,CI
Sep01_1503.xls	1-Sep-03	N. JB Islands- east perimeter	PL,JB,CI
Sep01_1527.xls	1-Sep-03	N. JB Islands- west perimeter	PL,JB,CI
Sep03_1409.xls	3-Sep-03	E476000- PL to State line	PL,JB,CI
Sep03_1515.xls	3-Sep-03	E478000- south end	PL,JB,CI
Sep08_1457.xls	8-Sep-03	Perimeter- west of Mills Island	CI
Sep30_2006.xls	30-Sep-03	N4209200 cont	PL,JB,CI
Sep30_1711.xls	30-Sep-03	E482000- south end	PL,JB,CI
Sep30_1750.xls	30-Sep-03	N4221600, start E480200 W to E	PL,JB,CI
Sep30_1830.xls	30-Sep-03	N4216800 West end cont.	PL,JB,CI
Sep30_1857.xls	30-Sep-03	N4214800 west end JB	PL,JB,CI
Sep30_1926.xls	30-Sep-03	N4212000- west of Mills Isl.	PL,JB,CI
Sep30_1941.xls	30-Sep-03	E-W Lines zig-zag west Mills Isl	PL,JB,CI
Sep30_1909.xls	30-Sep-03	N4214400 west end JB	PL,JB,CI

Appendix D

Final XYZ Sounding Data

Final depths, adjusted to NAVD88 are contained in five files, in ASCII, comma delimited format. Each row represents one sounding, and consists of five variables: Northing (UTM, NAD83, Meters), Easting (UTM, NAD83, Meters), and Depth (NAVD88, Meters), Date (sounding was collected), Time (UTC), given as hours from Jan. 1, 2000 (sounding was collected). The first three rows are header rows. The files are on the CD-ROM included with this report

File Name	**Area**	**Date collected**	**No. of rows (soundings)**
May_xyz.txt	Chincoteague Bay	May 31, 2003	3,146
June_xyz.txt	Chincoteague Bay	June 1 – 30, 2003	61,358
July_xyz.txt	Chincoteague Bay	July 1 – 31, 203	66,686
Aug_xyz.txt	Chincoteague Bay	Aug. 1 - 31, 2003	85,399
Sept_xyz.txt	Chincoteague Bay	Sept. 1 - 30, 2003	18,271

ChincotBay_XYZ_metadata.pdf Metadata for XYZ sounding data in PDF format

Water Level Data

Water levels, collected at four locations, are contained in a MS Excel file: ***Waterlevel.xls***. The file consists of five spreadsheets, listing water levels, in 6-minute intervals, collected at South Point, Public Landing, Johnson Bay (Taylors Landing) and Chincoteague Bay. There are two spreadsheets for Public Landing. Each spreadsheet contains five columns: Date (mm/dd/yyyy); Time-UTC (hh:mm:ss); Water level, feet (above station sensor); Hours-UTC (from Jan. 1, 2000); and Water level, feet, NAVD88. The file is on the CD-ROM included with this report.