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NOAA Technical Report NOS CS 37

COMPOSITE COASTAL BATHYMETRY PROJECT: SUPER STORM SANDY SUPPLEMENTAL EFFORTS

Silver Spring, Maryland
April 2017

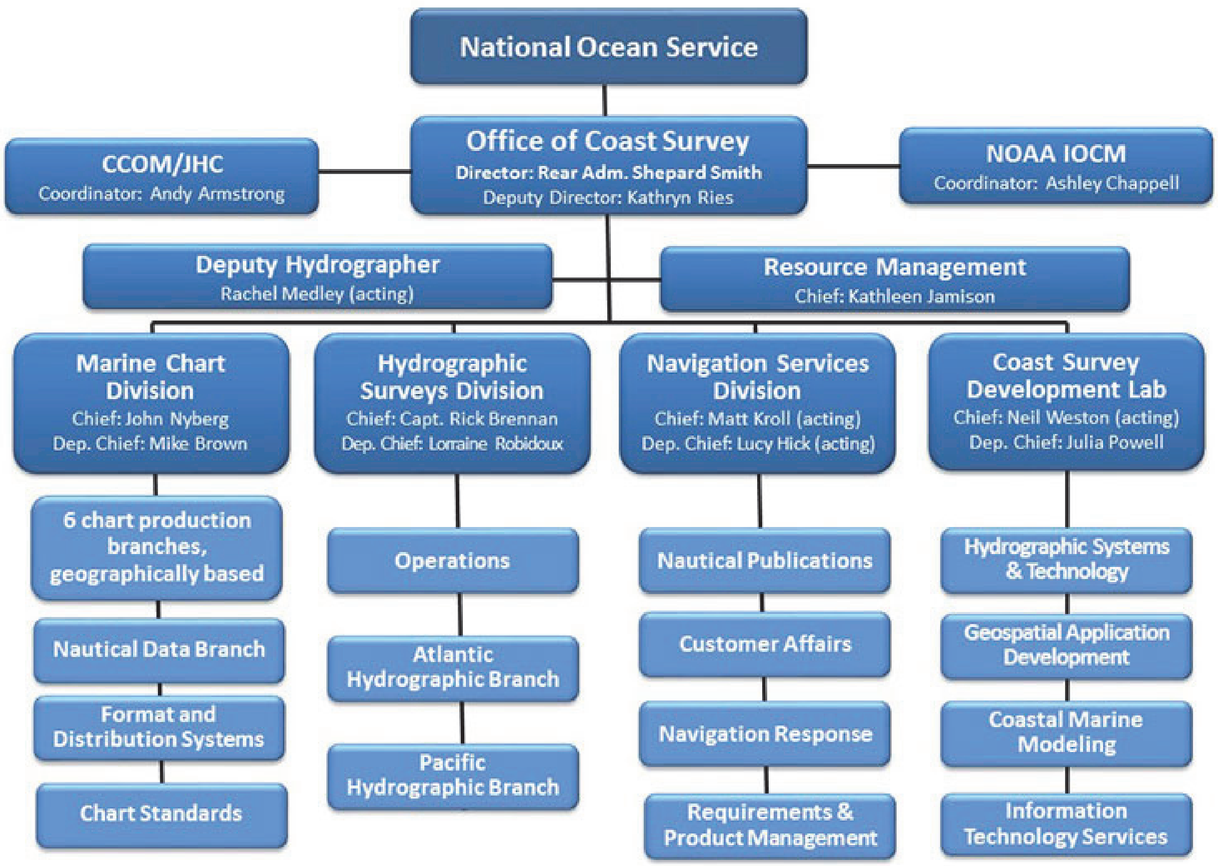
noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

Office of Coast Survey
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

MCD's Missions

To compile and maintain nautical charts for navigation in the coastal areas of the United States and the Great Lakes.



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COMPOSITE COASTAL BATHYMETRY PROJECT: SUPER STORM SANDY SUPPLEMENTAL EFFORTS

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April 2017

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LIST OF ACRONYMS AND ABBREVIATIONS

AIS – Automatic Identification System

ALB – Airborne Lidar Bathymetry

CATZOC – Category Zone of Confidence

CCB – Composite Coastal Bathymetry

CHARTS – Compact Hydrographic Airborne Rapid Total Survey

CMGP - Coastal and Marine Geology Program (USGS)

DOT – Department of Transportation

DRA – Disaster Relief Act

EAARL - Experimental Advanced Airborne Research Lidar (USGS)

GPS – Global Positioning System

HSD – Hydrographic Surveys Division (NOAA)

IHO – International Hydrographic Organization

IOCM – Integrated Coastal and Ocean Mapping (NOAA)

IWW – Intracoastal Waterway

LIDAR – Light Detection and Ranging

MBES - Multi-beam echosounder

MCD – Marine Chart Division (NOAA)

MLW – Mean Low Water

MLLW – Mean Lower Low Water

NCMP – National Coastal Mapping Program (USACE)

NDB – Nautical Data Branch (Marine Chart Division, NOAA)

NGS – National Geodetic Survey (NOAA)

NJ – New Jersey

NOAA – National Oceanic and Atmospheric Administration

OCS – Office of Coast Survey (NOAA)

RSD – Remote Sensing Division (NOAA)

SBES – Single-beam echosounder

SDB – Satellite Derived Bathymetry

USACE - U.S. Army Corps of Engineers

USGS - U.S. Geological Survey

ABSTRACT

Since the 1930s, most of New Jersey's intracoastal waters have not been surveyed to NOAA's Coast Survey hydrographic standards. As a result, the bathymetry that is used to compile the large-scale nautical charts (1:40,000) of New Jersey's back bays is outdated. The main reason is lack of resources that are required to conduct IHO hydrographic surveys in shallow waters. As part of the Superstorm Sandy relief efforts, a novel approach is applied to update these charts. Bathymetry data collected by other federal and state agencies is being used to provide a current depiction of the bathymetry and update the metadata associated with surveys (IHO S-57 attributes). All data sets that are available over a given area are ranked based on the survey technology and the service provider. In this project, the datasets were classified into three main groups based on CATZOC classes. Finally, compiled datasets were used to generate a suite of products that include a coverage map of the hydrographic characteristics, bathymetry (smooth sheet soundings and depth curves) and supplementary documentation. This report outlines the different datasets used in the project and the Coastal Composite Bathymetry (CCB) procedure. In addition to chart update, the CCB procedure is also used to evaluate the adequacy of the data used in the chart.

Key Words: USACE surveys, DOT surveys, airborne lidar bathymetry, single beam surveys, coastal bathymetry, Integrated Ocean and Coastal Mapping

1. INTRODUCTION

Impacts of tropical storm, known as "Superstorm Sandy," made landfall as an intense post-tropical cyclone on the U.S. East Coast near Brigantine, New Jersey on October 29, 2012 (Halverson and Rabenhorst, 2013; NOAA, 2013a). Immediate impacts of the storm included at least 147 deaths, $50 billion in damages, and extensive coastal erosion along the coast of several Mid-Atlantic States (NOAA, 2013a; Blake et al., 2013). Long-term ecological impacts of the storm are still being assessed. While the damage caused by the storm can easily be documented by airborne or satellite imagery for those areas that are above sea level, it is much more difficult to assess the impact of the storm in areas that are at or below sea level (i.e., the presence of debris and changes in the shape of the seafloor that can create navigational hazards, or the impact on benthic marine habitat). Recognizing this, the FY 13 Disaster Relief Appropriations Act [DRA] contains funds to support state and federal efforts to acquire and process coastal and ocean mapping data in order to support marine debris removal and beach nourishment efforts, as well as to update nautical charts, create more accurate inundation models and better understand the impact of the storm on marine habitat.

The Marine Chart Division (MCD) in the Office of Coast Survey (OCS) is mandated to produce nautical charts using the best available hydrographic data per the Coast and Geodetic Act of 1947. Typically, NOAA uses a combination of in-house and contracting resources to acquire hydrographic survey data around the coasts of the U.S. and its territories. As part of DRA NOAA efforts, the large scale nautical charts along New Jersey will be evaluated and updated using emergency response National Geodetic Survey's (NGS) Remote Sensing Division (RSD) airborne lidar bathymetry (ALB) collected along the Sandy impacted areas. Current bathymetry in the charts is based on survey that are more than 80 years old (last reported hydrographic survey is from 1930's). In preparation for RSD's ALB data, MCD has been inspecting federal and state survey data to update the bathymetry used to compile the large scale nautical charts along New Jersey. These resources include current survey data that does not meet all NOAA's surveys standards. Bathymetry and documentation of the federal and state survey data was provided to MCD by NOAA's Integrated Ocean and Coastal Mapping (IOCM) Processing Center located at the Joint Hydrographic Center (JHC) at the University of New Hampshire.

This Technical Memorandum provides a description on the decision making for ranking and grouping the different datasets, data preparation, update of the metadata associated with surveys (IHO S-57 attributes), and compilation of the data that is needed for an official submission to be compiled. The report provides an Ad Hoc ranking scheme, where all data sets available in a given area are ranked based on the survey technology and the group conducting the survey. In addition, a discussion on the lessons learned and recommendation for future submission is provided in this report.

2. MOTIVATION

Currently, most (~75%) non-NOAA source data that the Office of Coast Survey (OCS) ingests and verifies is US Army Corps (USACE) survey data in the navigable channels (Barber et al., 2016). Although there are other publicly-available datasets outside the channels, there is not a policy in place or available resources that provides OCS tools for accepting these datasets. Thus, the challenge is to find a robust approach to obtain more hydrographic/bathymetric data to update NOAA nautical charts with minor modification to current compilation procedures occurring in HSD and MCD. This approach is becoming more relevant for current operation procedures with diminished funding that limit OCS' ability to sustain the same level of hydrographic contracts. OCS is now interested in investigating the potential use of incorporating publically-available survey data into NOAA Nautical products. The main reason that these datasets have not been incorporated into the current OCS workflow is because these datasets have not been collected according to NOAA's hydrographic surveying standards (NOS, 2015) and it is not clear if, and under what circumstances, they might meet certain hydrographic surveying requirements. The motivation of this work was to develop and demonstrate a workflow ingesting state and federal survey data into NOAA workflow pipelines in a format that is comparable to traditional survey datasets that meet survey standards of NOAA and the S-44 survey standards of the International Hydrographic Office (IHO, 2008). In addition, there is a motivation to see if NOAA can assess publically available datasets as Category Zone of Confidence (CATZOC) rather than IHO S-44 survey standards.

3. NJ SMALL CRAFT CHARTS

In this study, two NOAA small craft charts (1:40,000) composed of five panels cover New Jersey intracoastal waters (Figure 3.1; NOAA, 2012, 2013b). These Small Craft Route charts do not contain a source diagram. A close investigation of the charts using the M_QUAL layer from the ENC products reveals that some areas have not been surveyed in more than a century. As a result, coastal bathymetry products were collected over the study sites.

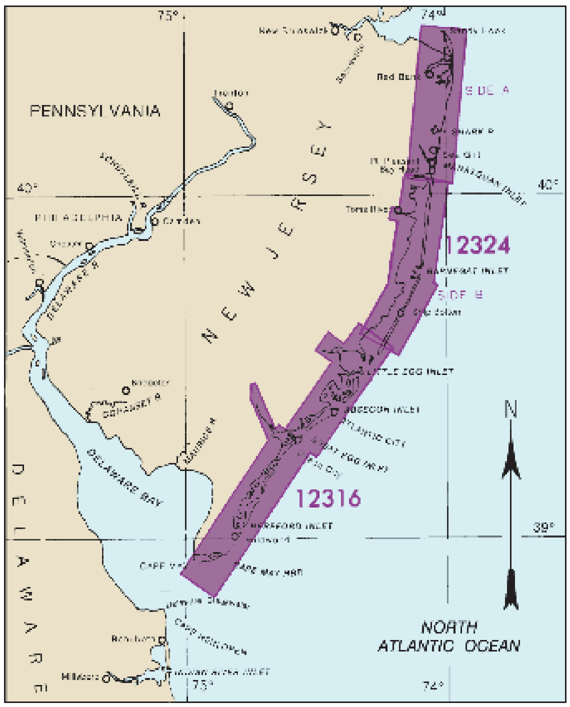

Figure 3.1. Chart diagram of NOAA charts 12324 (three panels) and 12316 (two panels).

4. COMPOSITE COASTAL BATHYMETRY PROCEDURE

Following the post-Sandy effort, IOCM has identified several datasets that have been collected along NJ coastline during 2010-2015. In addition to the traditional OCS Multibeam Echosounder (MBES) surveys, it became apparent that there are three other programs that routinely collect bathymetric data in the areas that include: USACE single beam surveys along the ICW (defined by USACE as Intracoastal Waterways, IWW) and inlets, USACE National Coastal Mapping Program (NCMP), and NJ Department of Transportation (DOT). In addition, the USGS has also collected ALB survey data within the intracoastal waterways prior to the Sandy event and immediately after. Below is a short description of the survey data. A full description on the survey technology is provided in Appendix B.

4.1. Post-Sandy Survey Data (Federal and State)

NOAA surveys and contracts

ALB surveys contracted by OCS/HSD and conducted by NGS/RSD were used as a base layer. These surveys, along with acoustic surveys by the NOAA fleet, are part of the OCS survey plan or as an emergency response activity (Figure 4.1). These surveys are not routine and are typically local to one site.

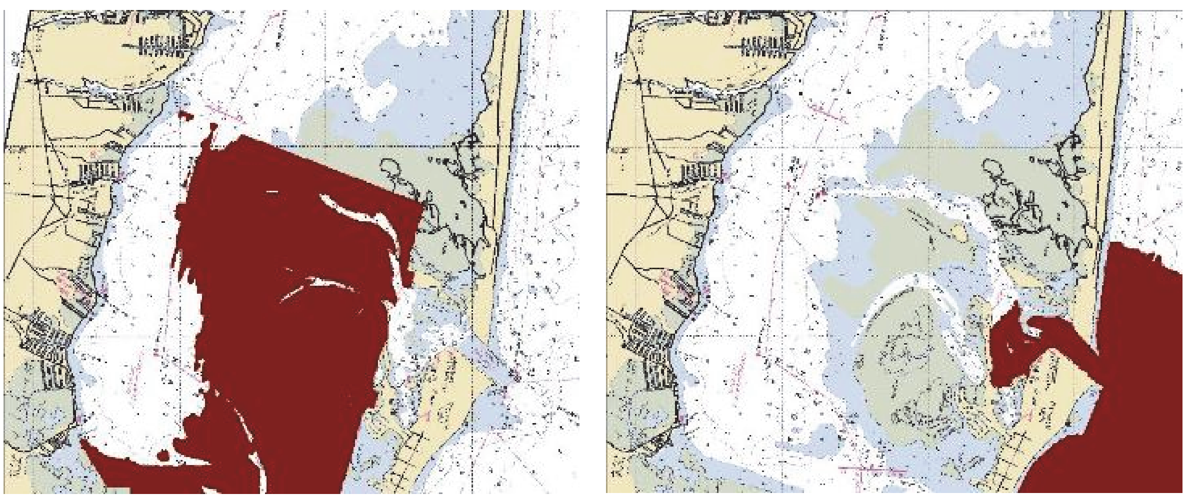

Figure 4.1. NOAA surveys (conducted by David Evans and Associates): (left) ALB (AHAB Chiroptera) NOAA Survey H12606), (right) multibeam echosounder (Reson 8101 NOAA Survey H12596).

NJ Department of Transportation (DOT) single beam surveys

The state of New Jersey maintains 200 nautical miles of state-marked navigation channels (Parsons-Brinkerhoff, 2013). Every 6 to 8 years, a condition survey is conducted that includes: bathymetry and side scan (Figure 4.2). A channel evaluation and usage assessment is conducted after each survey (including, post-storm shoaling analysis). After the surveys are completed, a final survey report containing more than 200 channels is provided to the NJ DOT and is available online (Appendix C). In addition to point measurements, DWG (AutoCAD format) files and recommendations regarding the channel design are also available. The surveys were conducted using Odom Echotrac CV200 echo sounders (200 kHz) and a Hydrolite TM System (which includes Sonarmite BT echo sounders) in conjunction with the RTK GPS (Trimble). The bathymetric data is provided in NJ State Plane referenced to MLLW (in feet).

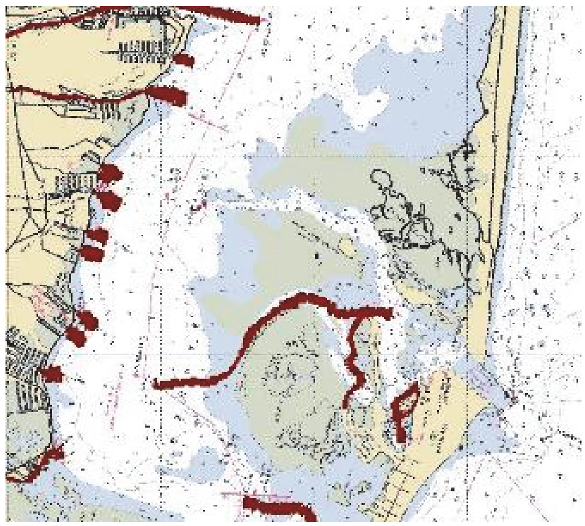

Figure 4.2. Navigation channel NJDOT surveys

USACE acoustic surveys of the New Jersey's inlets and ICW

The Philadelphia District US Army Corps has adopted the maintenance of the ICW (total length is 117 miles; see Appendix D). This sea-level inland waterway, extends along the New Jersey Coast from the Atlantic Ocean at Manasquan Inlet, about 26 miles south of Sandy Hook, NJ to the Delaware Bay about 3 miles north of Cape May Point (Figure 4.3). The USACE normally maintained the ICW to a depth of 6 feet Mean Low Water (MLW), except in the southern portion in the vicinity of the Cape May Canal where it is maintained to a depth of up to 12 feet MLW. The Philadelphia District survey equipment includes: Multi Beam Transducer (R2 Sonic 2024 Deployable Strut), Single Beam Transducer: (Ross Smartsounder 835 Deployable Strut), and a side scan sonar (Edgetech 2000 DSS).

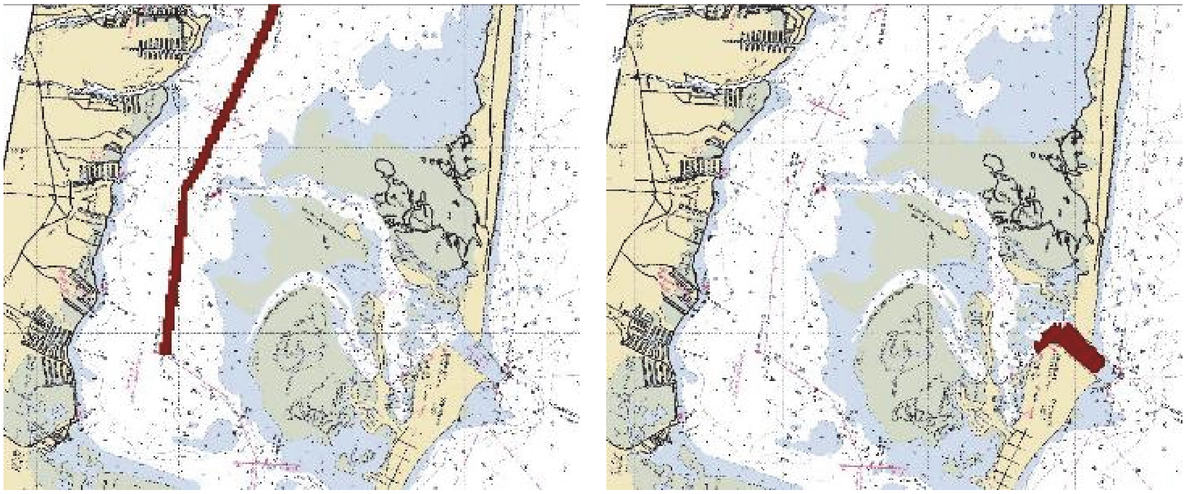

Figure 4.3. USACE Philadelphia District survey near Barnegat Bay, NJ: (left) ICW and (right) inlet survey.

Federal ALB programs

The USACE's National Coastal Mapping Program (NCMP) was developed in 2004 to support the USACE's mission of managing construction, sediment management and other mandated functions along the Nation's coasts (Imahori et al., 2013). The NCMP allows the USACE to acquire high-resolution ALB data on a scheduled basis of 5-7 years using the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system of the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX). The ALB systems used in NCMP surveys are Optech SHOALS-1000T and -3000 and CZMIL systems. USACE also contracted out lidar survey work with Fugro Palegos, LADS and Woolpert. This ALB data is typically collected at a density of 5 m X 5 m spot spacing (or less) with a minimum of 30 meter overlap with adjacent flight lines. The coverage area is from 0.5 km inland from the shoreline to 1 km offshore, depending on turbidity. The bathymetry is provided as a grid (at 1 m and 5 m resolution) horizontally referenced to WGS-84 and vertically referenced to NAVD88. In 2014, the USACE purchased a new lidar system that provides a- point density greater than 10 measurements per square meter.

Another federal coastal survey program is the U.S. Geological Survey (USGS) Coastal and Marine Geology Program (CMGP). The USGS utilizes Experimental Advanced Airborne Research Lidar (EAARL) ALB system (Figure 4.4) and other survey technologies to support the wise use and protection of coastal and offshore resources and also inform policies and decisions that prepare us for extreme events, natural hazards, and climate change (Nayegandhi et al., 2009). These surveys are single events that are dependent on survey priorities and major weather events. The bathymetry is typically provided as a grid (at 1 m and 5 m resolution) horizontally referenced to WGS-84 and vertically referenced to NAVD88. The EAARL has not been operational since 2014 and it is not clear if future collection will be conducted with this system.

Figure 4.4. EEARL-B survey (conducted by USGS)

Satellite imagery – used as reference

In the event that no other datasets from recent years are available, Satellite-Derived Bathymetry (SDB) is used to estimate the bathymetry (Stumpf et al., 2003; Pe'eri et al., 2014). The satellite imagery that is typically used is Landsat 8 (Figure 4.5). The SDB is produced at Coast Survey (Klemm et al., 2016). The data is provided as a grid (30 m resolution) that is horizontally referenced to WGS-84 and vertically referenced to the chart datum (MLLW). In this study, SDB data from 2015 was processed according the procedure outlined in the GEBCO Cook Book (Pe'eri et al., 2016) and was used as a qualitative reference to observe vertical changes that occurred between the pre-Sandy dataset and current reconnaissance by SDB (i.e., bathymetric difference).

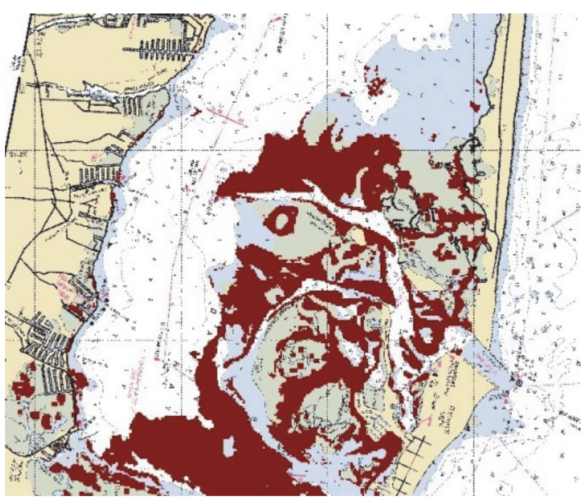

Figure 4.5. SDB (Landsat 8) coverage over Barnegat Inlet, NJ.

4.2. Key Steps

The ingestion of the different coastal bathymetry datasets through the NOAA workflow up to the stage that the data is ready to review for acceptance by MCD's Nautical Data Branch (NDB) can be grouped into four stages:

Data collection: Gathering into a local archive survey data within chart boundaries from publically-available archives (e.g., USGS, USACE JALBTCX, NOAA NGS, and NOAA OCS) and through contact with local representatives (e.g., NJDOT, USACE Philadelphia District, and Rutgers University). In addition, supplementary documentation that includes reports and channel sketches were catalogued and archived for metadata use and for chart decision making. Section 4.1 provides a description of the survey projects and the datasets. Appendix B provides a description on the different technologies involved in the different surveys.

Pre-processing: All the datasets were horizontally referenced to NAD-83 UTM projection using ArcGIS and vertically referenced to chart datum (MLLW) using VDATUM. The survey data was gridded into a bathymetric digital elevation model (DEM). Except for the satellite imagery all other datasets were originally gridded to 10 m. In addition, a polygon of survey boundaries was generated. An attribute table was generated for the polygon based on the metadata and following IHO S-57 MQUAL standards (i.e., the table will include: CATZOC, DRVAL1, DRVAL2, POSACC, SOUACC, SUREND, SURSTA and TECSOU). Appendix E provides describes in detail the IHO S-57 MQUAL fields.

Data compilation: Based on a hierarchy table the source layer grids are clipped in order to present the highest quality of data for a given charted area provided in table 4.1.

Table 4.1 Hierarchy of the CCB datasets based on CATZOC values and priorities

Level	Dataset	CATZOC	Priority
Group 1	NOAA acoustic surveys and contracts	A1	Bottom detection, dense coverage and high accuracy
Group 1	USACE acoustic surveys of the New Jersey's inlets and ICW	A2	Bottom detection and high accuracy
Group 1	NJ DOT SBES surveys	A2	Bottom detection
Group 2	NOAA ALB surveys and contracts	B	Dense coverage and high accuracy. Bottom detection is dependent on water clarity.
Group 2	USACE NCMP ALB surveys	B	Dense coverage and high accuracy. Bottom detection is dependent on water clarity.
Group 3	USGS ALB surveys	C	Dense coverage. Bottom detection is dependent on water clarity. USGS is not certified for surveying navigational channels.
Group 3	SDB (used in this study as a reference)	C	Least turbid

Post-processing: Finally, all the bathymetry grids were compiled into a single grid. Several products were generated from the grid:

- A single MQUAL polygon file was generated (with single table). The fields in the table were populated according to IHO S-57 standards (Appendix E).
- Areas that did not contain any bathymetry remained empty. Depth curves were generated from direct intersection with compiled DEM at 0, 3, 6, 9, 12, 18, and 30 foot depths (MLLW)
- Smooth sheet soundings were produced at twice the compilation scale (i.e., every 20 m).

It is important to note that depth curves were extracted from the compiled bathymetry generated from all CATZOC groups. However, smooth-sheet soundings were generated only from CATZOC A and B groups. Depth curves, Smooth-sheet soundings, gridded surface and supplementary reports were delivered to NDB for review and acceptance as source data.

5. RESULTS

The first contribution of new survey data sets was to provide updated coverage to the marine areas. A reference surface generated using smoot-sheet surveys from the 1930's showed that some areas in the current charts are outdated with bathymetry over reclaimed areas and an updated shoreline (Figures 5.1 and 5.2, left images). The new updated bathymetry also indicated the current position of the shorelines (Figures 5.1, right images).

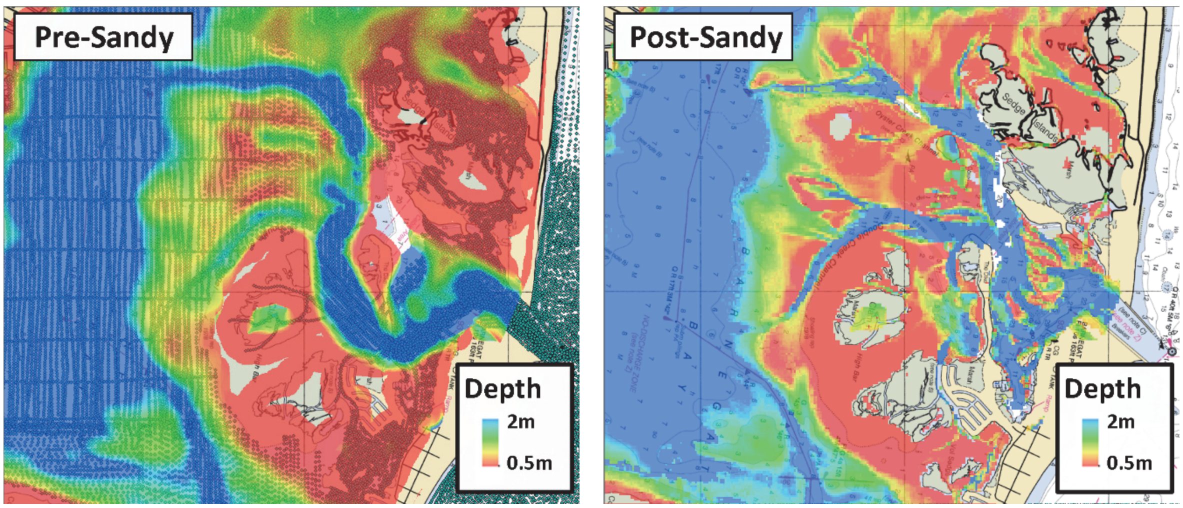

Figure 5.1. Reference bathymetry for Barnegat Inlet, NJ: (left image) bathymetry derived from 1930s smooth sheet soundings and (right image) bathymetry derived from new CCB datasets

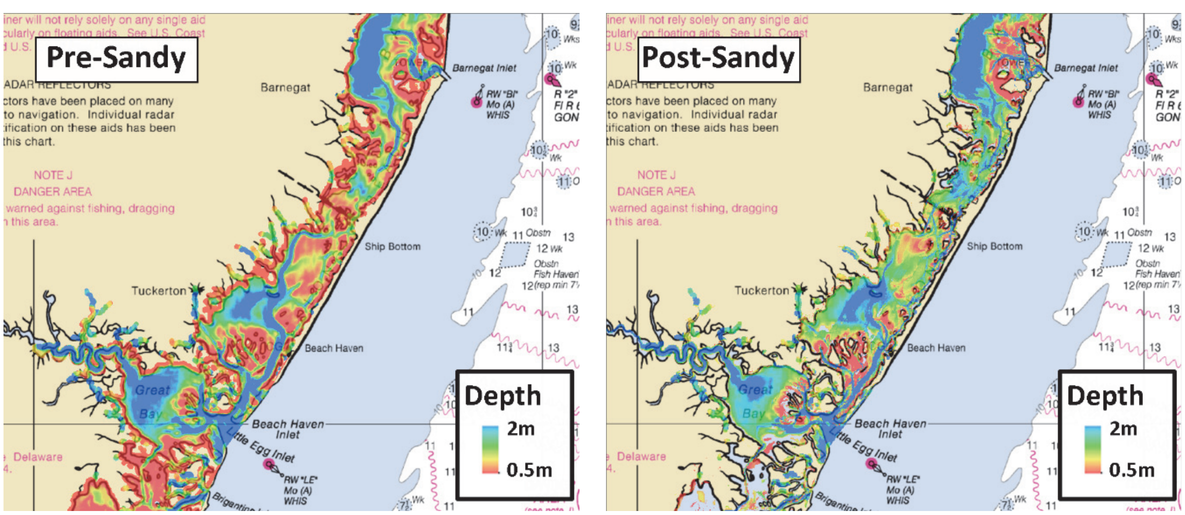

Figure 5.2. Outdated bathymetry of Barnegat Inlet, NJ. Smooth-sheet soundings from the 1930's are overlaid on a NOAA Nautical chart 12300

The potential contribution of compiled bathymetry to charting operations was evaluated using chart adequacy procedures (Klemm et al., 2016b). AIS data from 2011-2012 was used to map the traffic routes in New Jersey's back-bay areas pre- and post-Sandy event (Figure 5.3). Hydrographic characteristics of the charted area prior to this project (i.e., Pre-Sandy) were numerically ranked on a range from unsurveyed ("9") to a recent full bottom coverage survey conducted using modern technologies ("1"). CATZOC tables of the CCB datasets were used to define the hydrographic characteristics (Figure 5.4).

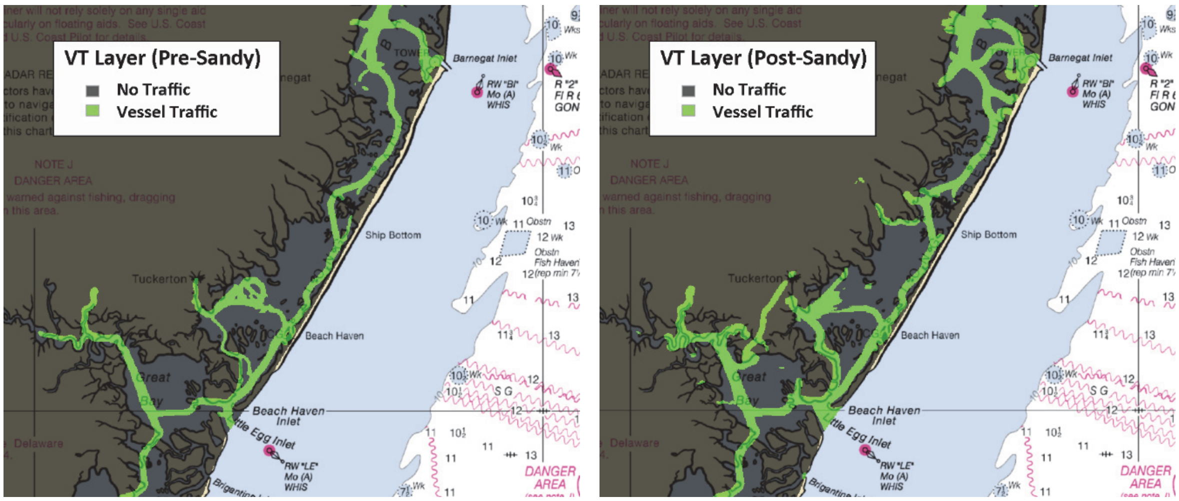

Figure 5.3. Vessel Traffic based on AIS: (left) pre-Sandy from 2011 and (right) post-sandy from 2012

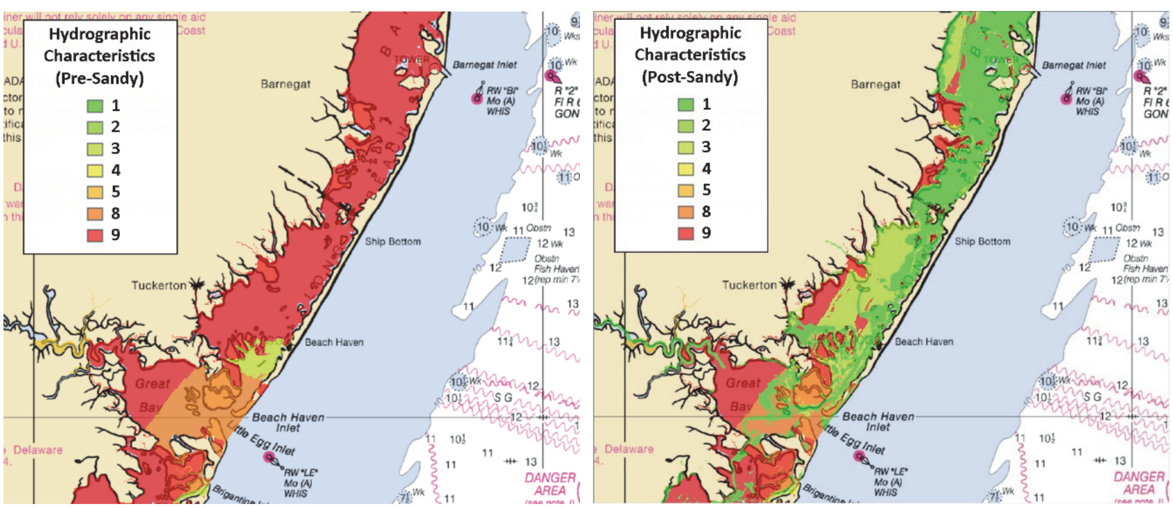

Figure 5.4. Hydrographic characteristics NOAA Nautical chart: pre-Sandy (left image) and post-sandy (right image) charts

In the CCB project, SDB was only used as a bathymetry reconnaissance layer for calculating the bathymetric difference layer. Most of the differences between the SDB and the bathymetry derived from smooth-sheet soundings (pre-Sandy) were noticed near the inlets and near the shoreline (Figure 5.5, left image). After updating the bathymetry using the CCB (post-Sandy), only a few bathymetric difference areas remained. The locations of most of the post-Sandy bathymetry difference areas are located near the inlets, possibly indicating a dynamic environment.

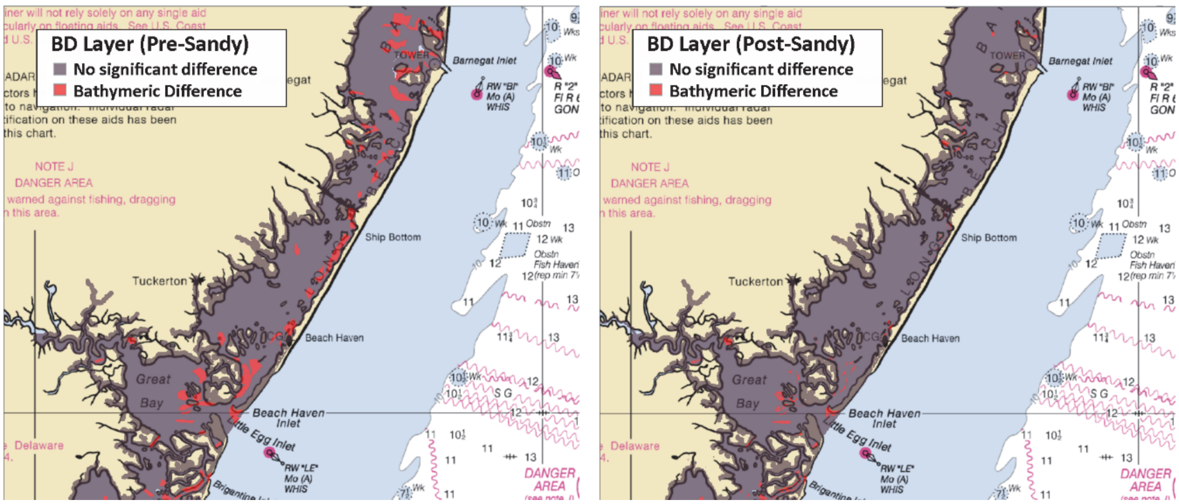

Figure 5.5. Areas of bathymetric difference pre-Sandy (left) and post-Sand (right).

The total size of the marine charted area has changed from 577.33 Km^2 (based on surveys conducted during the 1900s to 1930s) to 595.52 Km^2 after the chart update (based on survey data and satellite imagery from 2010 to 2015). The AIS data was used to generate a Vessel Traffic layer that showed a total navigable area of 187.43 Km^2 before the Sandy event. The total navigable area has expanded to 227.76 Km^2 after the Sandy event. This might be related to dredging activities by the USACE as part of the DRA support. The contribution of the new dataset effort is noticeable in the calculation of the total adequate areas to navigation. Only 0.2% (0.4 Km^2) of the total navigable areas are adequate for vessel traffic as a result of the lack of recent surveys in the back bays. The use of publicly-available surveys have increased the adequate areas of navigation to 43.8% (227.76 Km^2). This number is expected to increase in the next few years as more surveys are currently collected and processed by the USACE and NJDOT. The results of the chart adequacy calculations are provided in Table 5.2 and (Figure 5.6).

Table 5.1 New Jersey Chart adequacy results over the back bays

	Pre-CCB effort	Post-CCB effort
Non-Navigable Areas	389.90 Km^2	367.76 Km^2
Adequate Navigable Area	0.40 Km^2	99.70 Km^2
Non-Adequate Navigable Area	187.03 Km^2	128.06 Km^2
Total Navigable Area	187.43 Km^2	227.76 Km^2
Total Adequate for Navigation	0.2%	43.8%

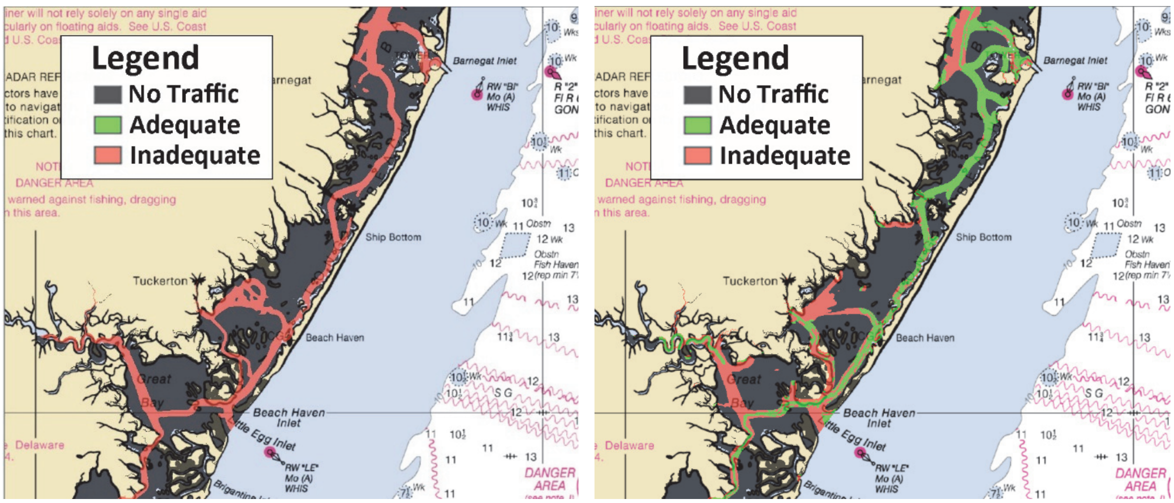

Figure 5.6. New Jersey Chart Adequacy evaluation using the original survey data (left image) and after updating the bathymetry using the publicly-available data (right image)

6. DISCUSSION

Data collected under the Sandy relief effort (i.e., DRA) program were used to understand an influx of new datasets collected from different technologies at varying survey scales and densities. The challenges to ingest publically-available data was not only to standardize the format of the products, but also standardize the compilation of the data into one grid. With the help of IOCM UNH, the data was formatted to meet IHO S-57 standards and NDB data acceptance procedures. Through several interactions with NDB, it was agreed on segmentation of the data (based on the RNC) and to number each segment with its own identification number for archiving and documentation purposes. In the future, an alternative option of using ENC polygons maybe a preferred approach to avoid redundancy in data submission from overlapping areas between two RNCs.

Another issue is that the current policy was written for IHO S-44 Order 1a surveys that can be used to update areas with critical under-keel clearance requirements for large (SOLAS) vessels, where high resolution, systematic hydrographic surveys meeting NOAA Hydrographic Specifications are required. These data sets do not meet this criteria. Instead, a CATZOC scale was used to accept these products as CATZOC B and C, which allowed bathymetric updates without compromising the charting product (e.g., CATZOC C cannot be used to generate soundings). A new policy for the Nautical Chart Manual (NCM) was recently written and presented in the recent Canadian Hydrographic Conference 2016 (Barber et al., 2016; OCS, 2016)

One major achievement of the CCB effort was discovery of many datasets that typically do not get reported or submitted to NOAA. The credit for this effort should be given to IOCM UNH that was instrumental in identifying resources in New Jersey (and surrounding states). These relationships with the local GIS personnel should be maintained for future planning and preparation of hydrographic surveys, as less resources may be available in the future for these activities.

7. RECOMMENDATIONS

Based on the information collected in this study, the main recommendations are as follows:

7.1. Deliverables (NDB)

Currently, NDB is receiving almost 7,000 survey documents a year. In order to minimize effort required to review and accept all the new incoming files, it is important to standardize all the deliverables that are submitted to NDB. Accordingly, the product suite for NDB needs to be formatted as follows:

Coverage – In addition to a full coverage of all the RNC charts, the grids and features should be also delivered in subsets according to the panels of the chart.

Horizontal and vertical referencing – The grids should be horizontally referenced to NAD83 (UTM projection) and vertically referenced to MLLW.

Uncertainty values – An uncertainty value (horizontal and vertical) is needed for each dataset (Appendix E).

Grid format – Because the different CCB datasets are provided in multiple resolution coverage, the compiled grids should be delivered at 5-m or 10-m grids (shoal-biased direct gridding). One grid should contain CCB groups 1 and 2 for deriving smooth-sheet soundings. A second grid that contains all three groups should be used only for deriving depth curves.

Feature format – The smooth-sheet soundings should be at a 20-m to 25-m average spacing. In addition, the depth curves feature files should be provided for each depth (i.e., 3 ft, 6ft, …). During this work, it was found that if channel framework is available, then raw soundings, the channel boundaries and center line should also be provided to NDB for registration.

7.2. IOCM UNH team

The IOCM UNH team was very useful and productive on two main fronts:

(1) **Searching and finding new datasets** – NOAA MCD was not aware of all of the Army Corps of Engineers, State and academic level data available in the areas of interest. In addition to the data, IOCM UNH also supplied documentation of the surveys and plans for future data collections. This may require the navigation managers to communicate with data collection groups in addition to chart users.

(2) **Data processing and compilation –** In concert with the data processing branches, IOCM UNH have processed, referenced, and compiled many datasets that were received in different formats and reference systems. A clear data flow should be defined, in case data processing and compilation is transferred to a different group in the future. Also, the IOCM team should provide a table to NDB that lists all

sources and associated dates that were used within the project (including any datum transformation or gridding procedures that were applied to the datasets).

7.3. Policy

The current data processing workflow at NOAA's Office of Coast Survey is designed for CATZOC A1 data products. Following the need to maintain and update many of the shallow water areas within NOAA's nautical charts and policies that discuss the potential incorporation of surveys collected using new CATZOC B and C technologies (namely, SDB and ALB) were created. This data policy should not be used to update areas with critical under-keel clearance for large (SOLAS) vessels, where high resolution, systematic hydrographic surveys meeting NOAA Hydrographic Specifications are required. Also, the new policy is not intended for areas in which NOAA routinely operates (open-ocean conditions and significant navigation routes) that require the retention of features such as rocks, wrecks and obstructions. If this technique is used where rocks, wrecks and obstructions exist, they should be retained in the final product. The quality of the data must be reconciled against the existing chart data and in conjunction with the types of vessels transiting the waters. Quality control of the data is paramount in this regard and must be measured respective to the type of dataset that is received. The development of standardized procedures for broad use of datasets can be transferable to cartographers, hydrographers and potential chart producers from hydrographic offices and government agencies around the world.

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APPENDIX A. SURVEY TECHONLOGY

IOCM JHC was able to identify additional bathymetric data along the New Jersey shoreline that has been collected from surveys conducted in the past five years. In addition, satellite-derived bathymetry was processed to fill in gaps between all the available federal and state surveys. The three survey technologies used in the Composite Coastal Bathymetry (CCB) include:

a. Single-beam echosounder (SBES) surveys

Description: Survey grade echosounder survey conducted from a boat with a Differential of Kinematic Global Positioning System (GPS). The SBES system can detect the bottom in most areas. The main limitation is the coverage extent and the spacing between the measurements. Accordingly, SBES surveys are typically confined within the channel areas.

Projects used in coastal bathymetry: Both the U.S. Army Corps (USACE) and New Jersey Department of Transpiration (NJ DOT) have been contracting single-beam surveys to maintain the Intracoastal Waterway (ICW) and connecting channels within the back bay areas. These surveys are conducted on a 6 to 8 year cycle.

b. Airborne Lidar Bathymetry (ALB)

Descriptions: Bathymetric mapping technique that uses a pulsed laser beam to measure water depths of moderately clear nearshore coastal waters and lakes. ALB bottom detection is dependent on the water clarity (Guenther, 2007; Pe'eri et al., 2011). Depending on the ALB system, bottom detection can be limited from one to three Secchi disc depth (in some of the back bay areas this can be less than 1 m). The main benefit is the coverage extent. However, suspended matter in the water column can provide false bottom detection (i.e., the bottom is not always detected).

Projects used in coastal bathymetry: ALB surveys are typically conducted by the U.S. Army Corps (USACE) and the U.S. Geological Survey (USGS). Under the National Coastal Mapping Program (NCMP), the USACE conducts ALB surveys the coastline (0.5 km landward and up to a 1 km toward the ocean) on a 5 to 7 year cycle. In addition, several larger area coverages within the back bay are conducted per request of the USACE districts (Imahori, 2013).

c. Satellite-derived Bathymetry (SDB)

Descriptions: The physical concept underlying the ability to estimate bathymetry from multispectral imagery is the wavelength-dependent attenuation of light in the water column. Based on a band-ratio algorithm it is possible to derive bathymetry (Stumpf et al., 2003; Pe'eri et al., 2014). The accuracy of the final products depends on the ground control points used to vertically reference the image. The main benefit is the coverage extent (swath width of 185 km). However, suspended matter in the water column can provide false bottom detection (i.e.,
the bottom is not always detected).

Projects used in coastal bathymetry: Landsat satellite imagery (30 m pixel resolution) is collected over the same area every 16 days and archived in USGS' EarthExplorer archive. It is important to note that the quality of the imagery depends on sun light, cloud cover, and sun glint. In addition, NOAA can order high resolution imagery (~2 m pixel resolution) through RSD.

APPENDIX B. STATE-MAINTAINED NAVIGATION CHANNELS

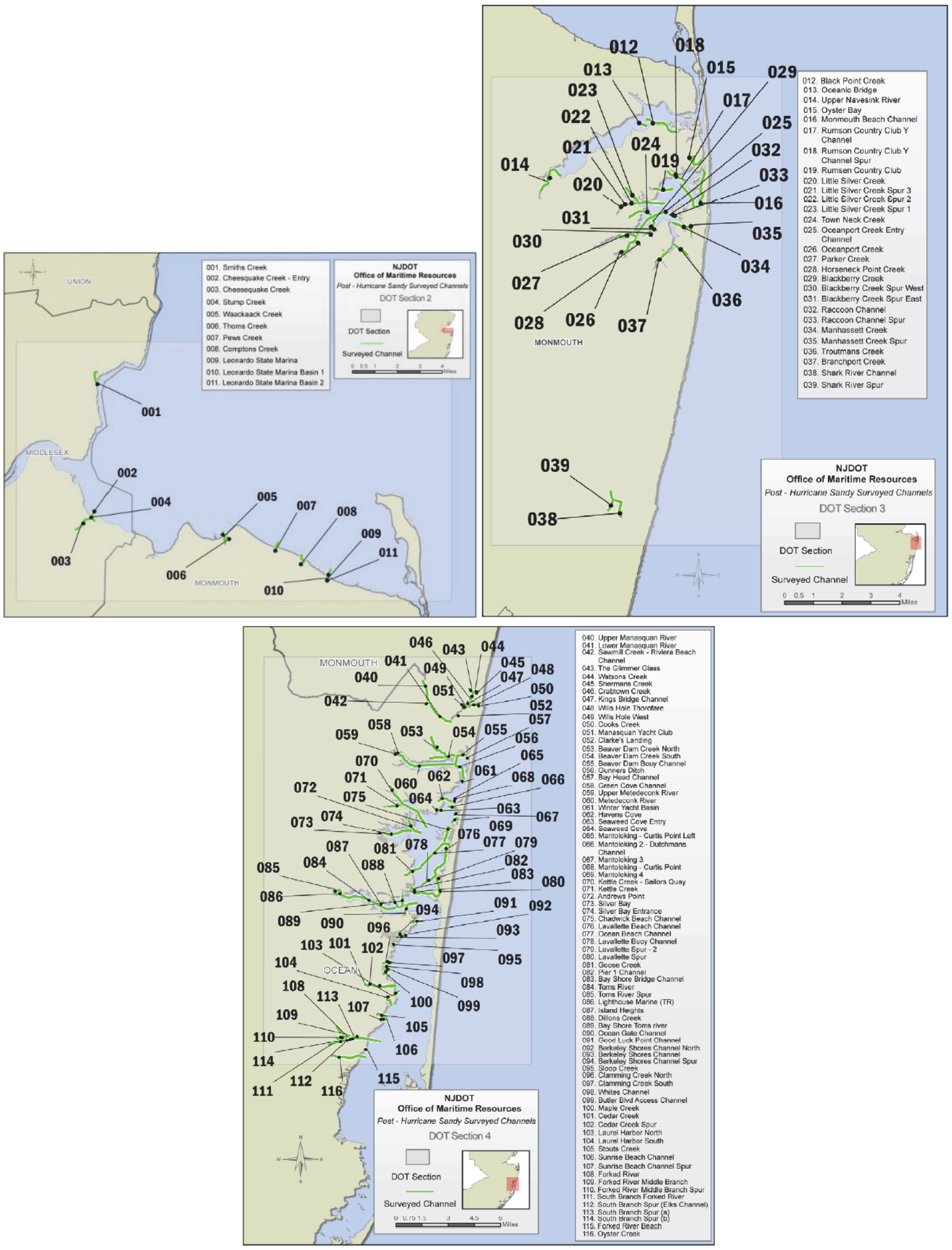

Figure C.1 Northern section of coastal New Jersey (NJ DOT, 2013).

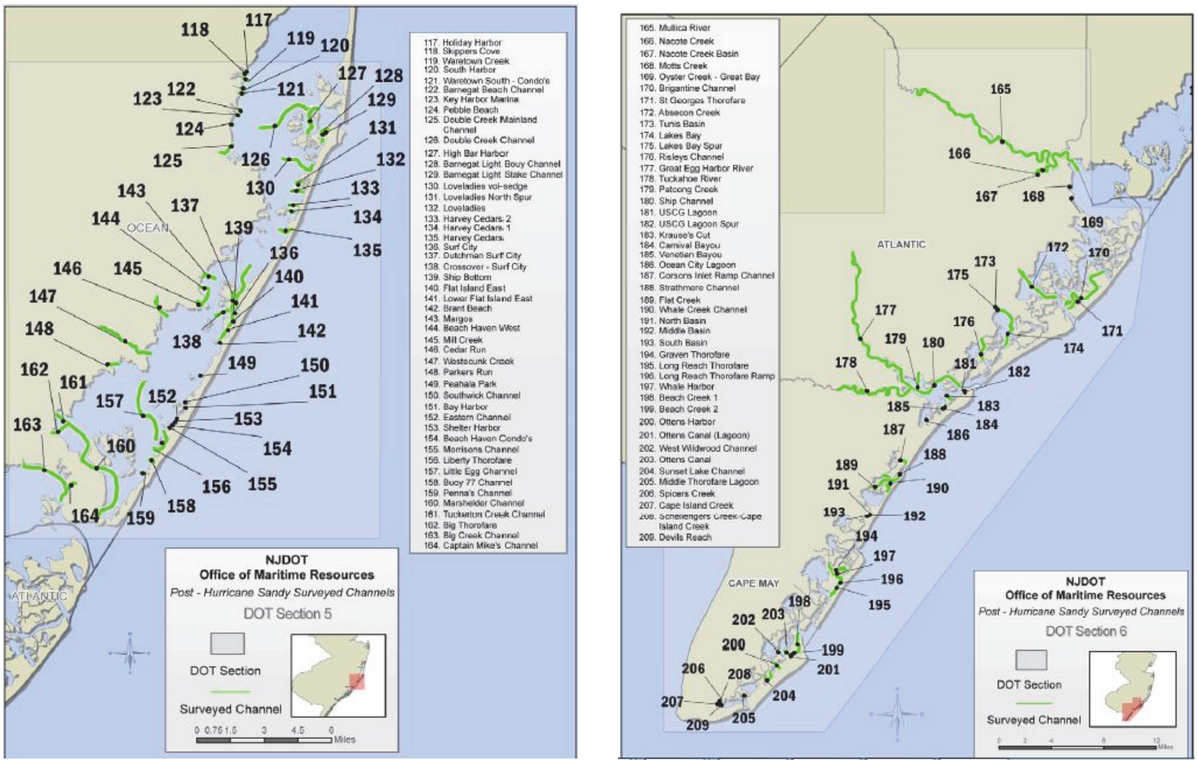

Figure C.2. Central section (left) and southern section (right) of coastal New Jersey (NJ DOT, 2013).

APPENDIX C. NJ ICW MAP

Figure D.1. Illustration of the Intracoastal Waterway (USACE, 2014)

APPENDIX D. MQUAL S-57 IHO TRANSFER STANDARD

The common format used for electronic charts is based on the IHO Transfer Standard for Digital Hydrographic Data, Publication S-57 (IHO, 2000). This IHO publication describes an exchange format for digital hydrographic data between national hydrographic offices and for its distribution to manufacturers, mariners and other data users. For survey data that has not been intently collected for charting, the S-57 attributes are not available with its metadata. One key S-57 meta object which meets MCD requirements is M_QUAL attribute. The definition of this attribute is: "*An area within which a uniform assessment of the quality of the data exists for the quality of bathymetric data, and must be used to provide an assessment of the overall quality of bathymetric data to the mariner.*" In addition to a generalized coverage polygon of all datasets with the same data quality, the following fields are required in the supplement table with the feature (the order of the fields below has changed in order for the project's context):

DRVAL1 (Descriptive Record Value 1): The minimum (shoalest) value of a depth range.

DRVAL2 (Descriptive Record Value 2): The maximum (deepest) value of a depth range.

POSACC (Position Accuracy): The best estimate of the accuracy of a position. The expected input is the maximum of the two-dimensional error (i.e., horizontal accuracy). Position Accuracy of depicted soundings at 95% CI (2.45 sigma) with respect to the given datum.

SOUACC (Sounding Accuracy) The maximum of the one-dimensional error (i.e., vertical accuracy). Depth accuracy of depicted soundings = a + (b*d)/100 at 95% CI (2.00 sigma), where d = depth in metres at the critical depth using the following table:

Table E.1 TVU Coefficient values for the different IHO orders (IHO, 2008)

IHO order	a	b
Special	0.25	0.0075
1	0.5	0.013
2	1.0	0.023

SUREND (Survey End Date): The end date of the survey. The 'survey date, end' should be encoded using 4 digits for the calendar year (CCYY), 2 digits for the month (MM) (e.g. April = 04) and 2 digits for the day (DD). When no specific month and/or day is required/known, indication of the month and/or the day is omitted.

SURSTA (Survey Start Date): The start date of the survey. The 'survey date, end' should be encoded using 4 digits for the calendar year (CCYY), 2 digits for the month (MM) (e.g. April = 04) and 2 digits for the day (DD). When no specific month and/or day is required/known, indication of the month and/or the day is omitted.

TECSOU (Technology Source): Use table below to provide a code for the survey technology used to collect the bathymetry.

VERDAT (Vertical Datum): to equal 12 because the vertical datum used is Mean Low Low Water (MLLW)

Table E.2 Description of the S-57 TECSOU codes (IHO, 2000)

Code #	Description
1	**found by echo-sounder:** the depth was determined by using an instrument that determines depth of water by measuring the time interval between emission of a sonic or ultrasonic signal and return of its echo from the bottom. (adapted from IHO Dictionary, S-32, 1547)
2	**found by side-scan-sonar:** the depth was computed from a record produced by active sonar in which fixed acoustic beams are directed into the water perpendicularly to the direction of travel to scan the bottom and generate a record of the bottom configuration. (adapted from IHO Dictionary, S-32, 4710)
3	**found by multi-beam:** the depth was determined by using a wide swath echo sounder that uses multiple beams to measure depths directly below and transverse to the ship's track. (adapted from IHO Dictionary, S-32, 3339)
4	**found by diver:** the depth was determined by a person skilled in the practice of diving. (adapted from IHO Dictionary, S-32, 1422)
5	**found by lead-line:** the depth was determined by using a line, graduated with attached marks and fastened to a sounding lead. (adapted from IHO Dictionary, S-32, 2698)
6	**swept by wire-drag:** the given area was determined to be free from navigational dangers to a certain depth by towing a buoyed wire at the desired depth by two launches, or a least depth was identified using the same technique. (adapted from IHO Dictionary, S-32, 5248, 6013)
7	found by laser: the depth was determined by using an instrument that measures distance by emitting timed pulses of laser light and measuring the time between emission and reception of the reflected pulses. (adapted from IHO Dictionary, S-32, 2763)
8	**swept by vertical acoustic system:** the given area has been swept using a system comprised of multiple echo sounder transducers attached to booms deployed from the survey vessel.
9	**found by electromagnetic sensor:** the depth was determined by using an instrument that compares electromagnetic signals. (adapted from IHO Dictionary, S-32, 1571)
10	**photogrammetry:** the depth was determined by applying mathematical techniques to photographs. (adapted from IHO Dictionary, S-32, 3791)
11	**satellite imagery:** the depth was determined by using instruments placed aboard an artificial satellite. (adapted from IHO Dictionary, S-32, 4509)
12	**found by levelling:** the depth was determined by using levelling techniques to find the elevation of the point relative to a datum. (adapted from IHO Dictionary, S-32, 2741)
13	**swept by side-scan-sonar:** the given area was determined to be free from navigational dangers to a certain depth by towing a side-scan-sonar. (adapted from IHO Dictionary, S-32, 5248, 4710) [415.2]
14	**computer generated:** the sounding was determined from a bottom model constructed using a computer.

CATZOC (Category Zone of Confidence): Charts are compiled from a variety of surveys and other data sources such as aerial photography etc. As a result of differences in survey technology, data collection techniques and procedures used in surveys from which a chart is compiled, the resulting survey data have varying degrees of uncertainty. These uncertainties in survey data are usually classified and depicted on the chart using reliability diagrams. The reliability diagrams are typically embedded in the chart and used to inform mariners about the quality of the survey data shown on the chart. A reliability diagram used to describe the quality of both raster and electronic navigation charts is CATZOC (Smith, 2005). Hydrographic surveys are classified based on an estimation of the total error budget of the depicted depth and positional errors. From the seafloor coverage assessment, the detection level of all significant seafloor features can be determined. A major drawback of CATZOC is that the date of survey is not shown (Heeley, 2003). The survey date is vital information for mariners especially when navigating in areas with a dynamic bottom. Table 3 summarizes the six CATZOC categories.

Table E.3 Description of CATZOC Categories and their Standards (IHO, 2000)

	CATZOC	**Positional Accuracy**	**Depth Accuracy**	**Seafloor Coverage**
1	A1	± 5 m + 5%d	= 0. 50 m + 1%d	All significant seafloor features detected
2	A2	± 20 m	= 1.00 m + 2%d	All significant seafloor features detected
3	B	± 50 m	= 1.00 m + 2%d	Uncharted features hazardous to surface navigation are not expected but may exist
4	C	± 500 m	= 2.00 m + 5%d	Depth anomalies may be expected
5	D	Worse than ZOC C	Worse than ZOC C	Large depth anomalies may be expected
6	U	Unassessed – the quality of the bathymetric data are yet to be assessed		