Descriptive Report Summary W00440	
Project	NCCOS #418 Proposed Wisconson-Lake Michigan NMS
Survey	W00440
State	Wisconsin
Locality	Lake Michigan
Sub Locality	Manitowoc
Scale of Survey	1:40000
Sonars Used	Kongsberg Maritime Marinestar SBAS (MBES) Klein Marine Systems System 3000 (SSS) AML Oceanographic MicroX SVS (Sound Speed Probe)
Horizontal Datum	World Geodetic System (WGS) 1984
Vertical Datum	Ellipsoidally Referenced Survey
Vertical Datum Correction	Discrete Zoning
Projection	Projected UTM 16
Field Unit	R/V Storm
Survey Dates	06/03/2017 - 06/13/2017
Chief of Party	Will Sautter

A. Area Surveyed

The hydrographic survey W00440 was conducted for the benthic habitat mapping of the NCCOS Project #418 Titled “Environmental and Socioeconomic Assessments of the Proposed Wisconsin-Lake Michigan National Marine Sanctuary”. The Area of Interest (AOI) was chosen in consultation with the Office of National Marine Sanctuaries and Wisconsin Historical Society to improve information regarding underwater geology, habitats, and cultural resources within an area proposed for the Wisconsin-Lake Michigan National Marine Sanctuary. The 2017 AOI was planned to cover a region with several potential shipwreck locations off the shores of Manitowoc and Two Rivers, Wisconsin (Figure 1). Sidescan Sonar (SSS) and Multibeam Echo Sounder (MBES) Bathymetry and Backscatter data were collected simultaneously in transects across 23 square miles of the AOI. The SSS coverage was collected with 10-25% percent overlap and with “skunk stripe” MBES lines. The MBES data overlaps topobathymetric LiDAR (LAS) Survey 2644 conducted in 2012 by the US Army Corp of Engineers. The SSS and MBES data were not required to meet IHO specifications, object detection standards, or 100% coverage of the AOI, but does provide natural resource managers and marine spatial ecologists information about the benthic habitats of the lakebed and help identify historic maritime artifacts.

Data were acquired within the following survey limits:

Northwest Limit	Southeast Limit
44° 8' 20.93" N 87° 37' 53.06" W	44° 4' 47.83" N 87° 29' 30.62" W

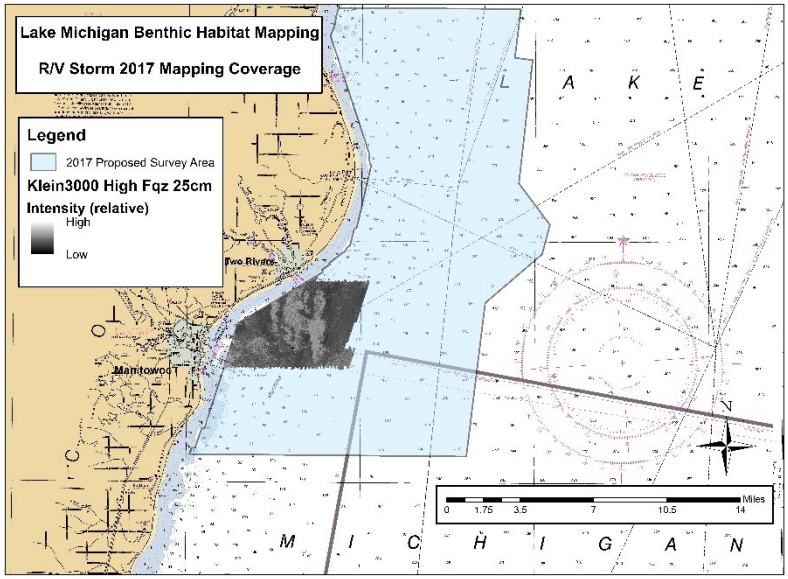

Figure 1. The proposed survey AOI and mapping coverage of W00440.

B. Survey Purpose

The National Center for Coastal Ocean Science (NCCOS) and the Great Lakes Environmental Research Lab (GLERL) collaborated to conduct the hydrographic survey for a proposed marine sanctuary in Lake Michigan. The only previous hydrographic mapping within the planned AOI were lead line and singlebeam echo sounder (SBES) surveys from the mid-twentieth century, and the area had never before been mapped using MBES and SSS data. A key user of this data is the Office of National Marine Sanctuaries, which proposed designation of the Wisconsin-Lake Michigan National Marine Sanctuary in 2015 to conserve maritime heritage resources, foster partnerships with researchers and schools, and increase opportunities for tourism and economic development. The proposed 1,075 square mile sanctuary encompasses a nationally significant collection of shipwrecks, including 37 known and as many as 80 shipwrecks yet to be discovered.

C. Intended Use of Survey

The entire survey is adequate to supersede previous data.

The intent of this survey was to collect bathymetry, backscatter, and sidescan imagery of benthic habitats and historic maritime artifacts to focus conservation efforts in Lake Michigan, WI. Survey data were acquired within survey limits in accordance with the requirements in the NCCOS Project Instructions and meet the guidelines of the Hydrographic Survey Specifications and Deliverables (HSSD). The survey has been submitted to the External Survey Data division of the Office of Coast Survey and is recommended to update nautical charting of Lake Michigan in the Manitowoc, WI area.

D. Data Acquisition and Processing

Chief Scientist Charles Menza from NCCOS directed mission planning and objectives for the benthic habitat mapping research. The hydrographic survey was collected and processed under contract by CSS Inc. lead by Chief Survey Technician Will Sautter. In addition, Hypack was contracted to commission the system, and Kongsberg LLC loaned the EM2040c at no cost to support the mapping of the Great Lakes. The survey was carried out on the 50 foot GLERL research vessel R/V Storm with Captain Travis Smith from June 3rd to June 13th, 2017 (Figure 2).

-Multibeam Acquisition

The bathymetry and backscatter were acquired by the Em2040c using the Seafloor Imaging System (SIS). Raw multibeam files were logged in the Kongsberg .ALL format and contain backscatter 'snippets'. The sidescan data was logged in the Trident .XTF format and with the Sonar Pro .SDF format. The multibeam bathymetry was processed by using the CARIS 10.4 HIPS work flow. RTK positioning were applied to the soundings, and signal noise were manually cleaned using the subset editor. R/V Storm draft measurements, lead line test, and GAMS calibration were not collected due to time constraints from mechanical delays. Offsets of the installed EM 2040c and surface sound velocity probe were not be measured on the Storm during the repairs, so values from older vessel configurations files were used during the survey. A patch test on June 3rd over a known pipeline south of the main survey sheet (Figure 3) was conducted the day of arrival to the AOI. The patch test data was processed after the mission by Brent Johnson, subcontracting for SolMar Hydrography.

-Delayed Heave

The R/V Storm received RTK positioning from a pair of GPS antennae linked to an Applanix POS MV unit underneath the cabin which served as the reference point for the vessel configuration. Navigation and vessel motion data were applied in real time to SIS from the POS MV, but not logged as POS files in the field. After the field acquisition, an inconsistent timing issue in the roll compensation was discovered and caused major motion artifacts in the outer beams from the vessel motion (Figure 4). The motion artifacts only appeared on the windiest days of the survey as the R/V Storm rode with and against the swells, generating long period and short period roll artifacts accordingly. The delay could not be resolved by a timing calibration from the patch test and there were no POS .000 files logged to apply delayed heave.

-Multibeam Artifacts

The multibeam data from Kongsberg Em 2040c had several dropouts where the MBES lost bottom detection (Figure 5). Bathymetric artifacts derived from the dropouts were manually cleaned out by rejecting the soundings using Subset Editor in CARIS. To aid in the reviewing and editing, the node standard deviation child layer was employed. All nodes with a standard deviation of 0.5m or greater were reviewed manually in subset mode. The highest standard deviations tended to be a result of the difference between the peaks and trough of the artifact. Reducing the noise related to the motion artifacts created numerous small holidays in the final 1m CUBE surface. These areas were manually inspected for features prior to editing. An interpolated surface from the finalized 1m Combined Uncertainty Bathymetric Estimation (CUBE) was created and is the best representation of the sea floor.

-Sound Speed Methods

Surface sound speed was collected from an AML Micro-X sound speed probe mounted to the starboard railing of the R/V Storm and applied to the MBES in real time through SIS. Sound speed profiles were acquired using a Sonar Pro PC Castaway device at discrete locations within the survey area at least once every four hours, when significant changes in surface sound speed were observed, or when surveying in a new area. A total of 28 casts were applied to all survey

lines (Figure 6) using the “Nearest in distance within time” profile selection method at four hour intervals in CARIS HIPS.

-Backscatter Data
The MBES backscatter data was collected as ‘snippets’ in the raw bathymetry .ALL data from the Em 2040c. The .ALL files were merged with the final processed CARIS HDCS data files using the Fledermaus Geocoder Toolbox (FMGT) version 7.7.8. Outer beams were also filtered in the backscatter at 55 degrees port and starboard to get rid of vessel motion artifacts. Decibel offsets across track were measured and corrected by applying a beam pattern. Other decibel offsets along track due to increasing depth were fixed by applying Time Varying Gain corrections. The final corrected mosaic was exported as a 1m 8-bit geotiff and included in the final deliverables. The decibel values were rendered as 0-255 (low to high) pixel values because the raw intensity of the backscatter is uncalibrated to bottom type, and are relative to the physical properties of the water column and the angle/range of the acoustic energy reflecting from the sonar and the lake bottom.

-Sidescan Acquisition
The SSS data was collected simultaneously with the MBES data on the R/V Storm using a towed Klein 3000 system provided by GLERL (Figure 7). The Klein 3000 collected dual frequency sidescan imagery at 100 khz (Low Frequency mode) and 500 khz (High Frequency mode). The sidescan altitude and cable-out was manually controlled with a winch and a cable counter. Data acquisition was collected and monitored using Sonar Pro software. Range was set to 75m to optimize image resolution and survey coverage, and to avoid refraction from the thermocline. The raw sidescan files were processed using Sonar Wiz 13 software into a mosaic.The sidescan files were first slant range corrected to hide the water column stripe at nadir. Bottom tracking corrections were manually applied to fix issues with altitude changes in the towfish. Beam pattern correction was applied to normalize the gain offsets across track and TVG corrections were applied to normalize gain offsets along track. The final surface was rendered to a 1m 8-bit geotiff and included in the final deliverables. The decibel values were rendered as 0-255 (low to high) pixel values because the raw intensity of the sidescan are uncalibrated to bottom type, and are relative to the physical properties of the water column and attitude of the towfish.

There were issues with georeferencing the sidescan imagery due to bad measurements from the cable counter unit on the towfish winch. Navigation from the ship’s POSMV was applied to the towfish, but the the imagery were still horizontally offset in many of the survey lines by the layback readings from the cable counter. The cable counter was recalibrated several times durring the field mission, but was still very unreliable. These offsets were manually corrected by comparing and orthorectifying the sidescan mosaic with features that were detected in the multibeam bathymetry and backscatter surfaces. Once the sidescan mosaics were corrected, they were exported as 0.50m 8-bit geotiffs from Sonar Wiz 13 and included in the final deliverables.

Hull Number	R5002
Builder	Munson Boats
Year Built	1992
Weight	52,000 lbs
Length Overall	50’6”
Beam	13’5”
Draft, Maximum	3’6”
Cruising Speed	22 knots
Max Survey Speed	8 knots
Range	300 nautical miles

Figure 2. Vessel details for the NOAA R/V Storm at the Thunder Bay National Marine Sanctuary, MI.

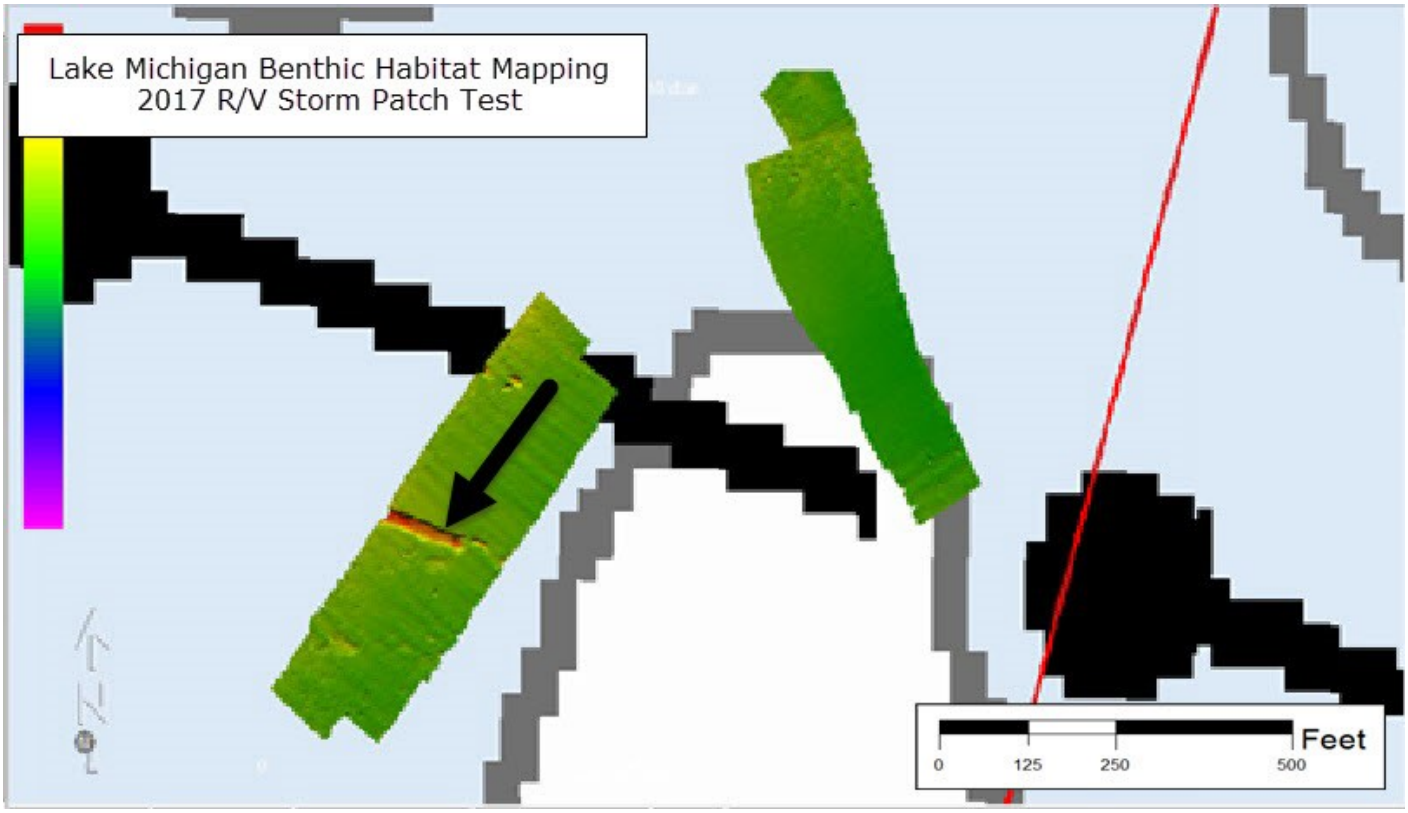

Figure 3. Patch test conducted over the Manitowoc Waterworks plant pipeline. Notice the structure was detected nearly 200 feet to the south of the charted position of the pipeline.

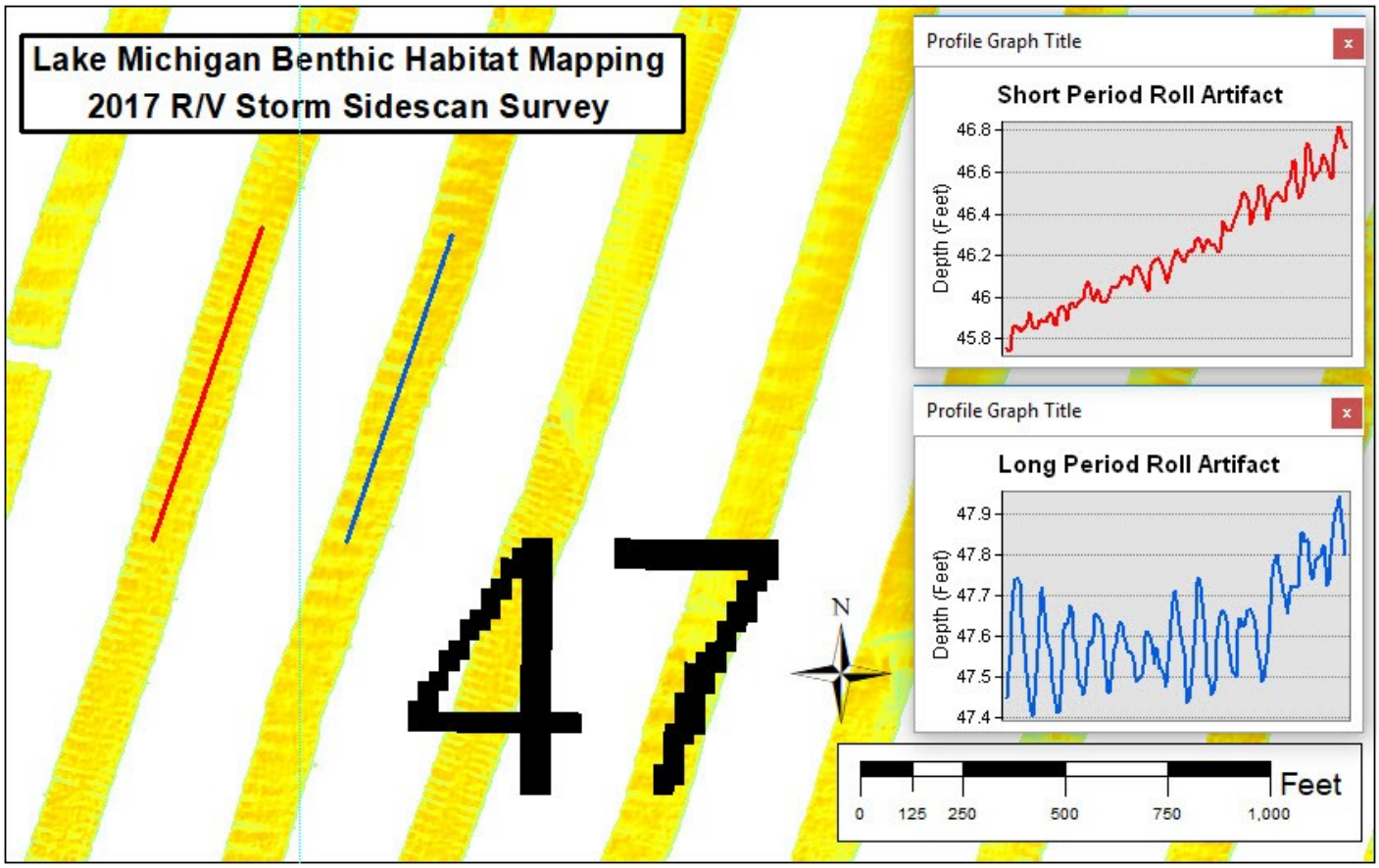

Figure 4. R/V Storm bathymetry with sun illumination showing delayed heave from timing offsets at different directions in profile. The profile graphs show Elevations (ft) vs. Length (ft) of two adjacent multibeam swaths recorded the same day.

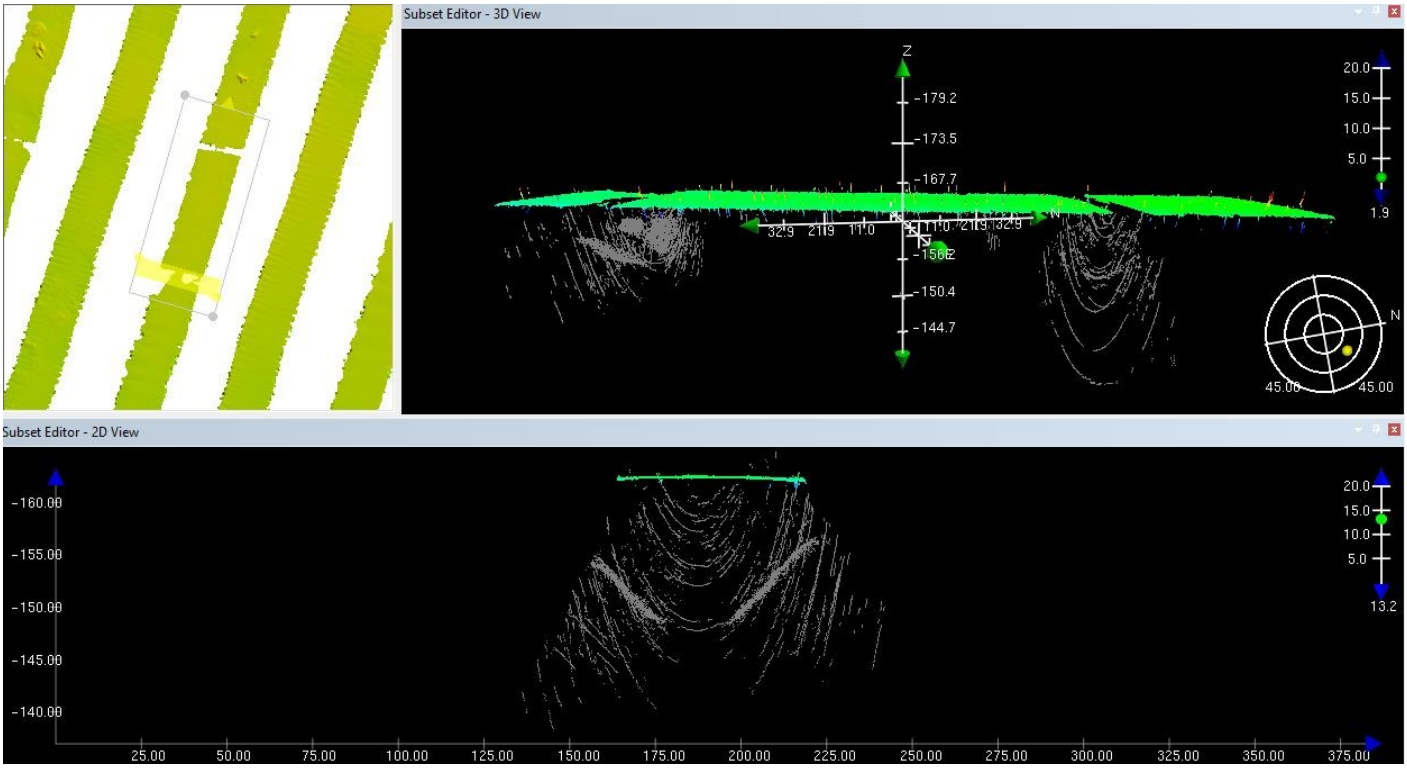

Figure 5. An artifact of the multibeam system seen in CARIS Subset Editor. Soundings from the noise and false bottom detections were manually cleaned and rejected leaving a gap in coverage. The holidays were not able to be filled due to time constraints.

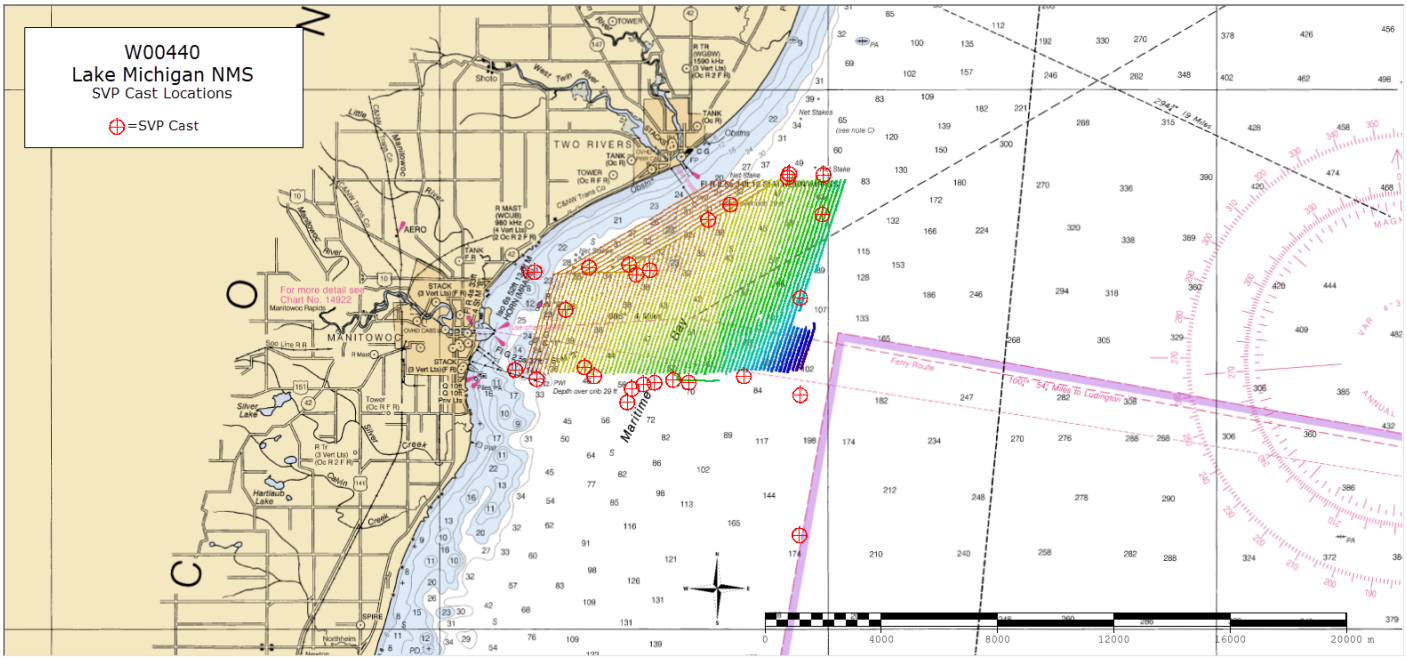

Figure 6. Sound Velocity Cast profile locations during the 2017 R/V Storm Survey using the Sonar Pro PC Castaway device.

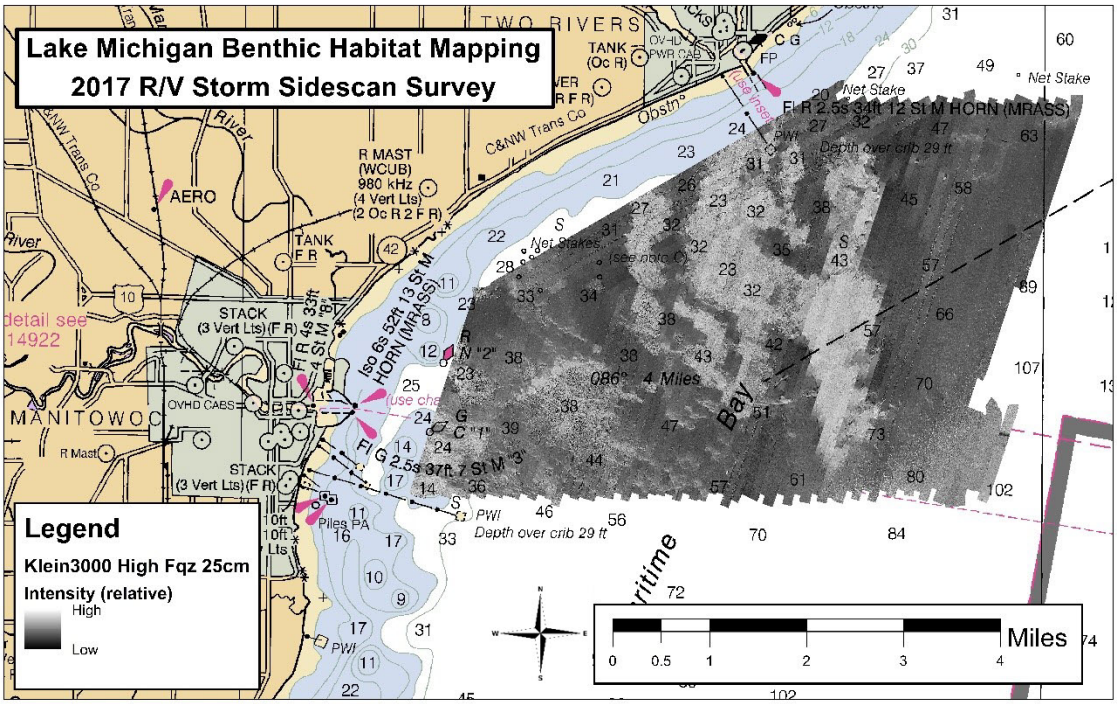

Figure 7. Klein 3000 sidescan mosaic collected by the R/V Storm off of Manitowoc, WI. Dark, low intensity areas represent fine unconsolidated sediments, and lighter high intensity areas represent very coarse sediments and hard bottom.

E. Uncertainty

An uncertainty surface for the multibeam data was generated from the CUBE algorithm and provided in the final deliverables. Values of the submitted finalized BAG grids were not required to meet the HSSD uncertainty requirements but were estimated to create the CUBE surfaces. Uncertainty values for the equipment and vessel characteristics were determined by the patch test analysis from SolMar Hydro, as well as field assigned values for sound speed uncertainties. Since there was not an accurate survey of the vessel after the installation of the multibeam sonar and the POS MV units, the TPU values for the MRU to transducer are the same as the offset values in the vessel configuration. The estimated water level or tidal error contribution to the total survey error budget in the vicinity of Seafloor Mapping of Lake Michigan is considered insignificant in the Great Lakes which is deemed non-tidal. The survey passed the Uncertainy Standards of the Pydro QC Tools 2 (Figure 8).

Horizontal uncertainty for the side scan surface was estimated by measuring displacement in common features between side scan and multibeam bathymetry surfaces. Features used to estimate displacement were either abrupt changes in elevation or changes in bottom reflectivity. Average displacement across 52 measured features was 3.47 meters. Considering the average horizontal uncertainty in multibeam bathymetry surfaces is approximately 1 meter, a conservative measure of horizontal uncertainty in the side scan surface is on average 4.47 meters.

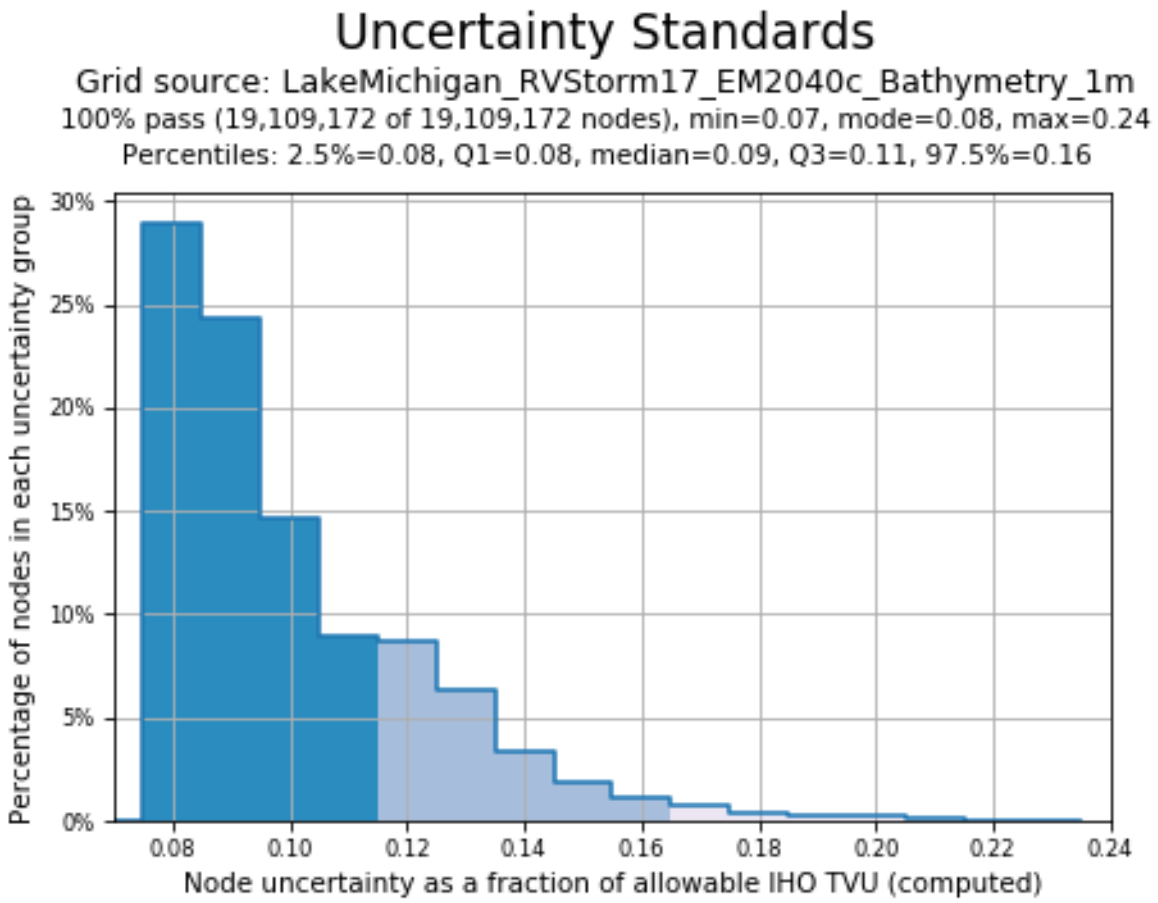

Figure 8. TVU Compliance to NOAA uncertainty standards as calculated using Pydro QC Tools 2.

F. Results and Recommendations

The following are the largest scale RNC and ENC, which cover the survey area:

ENC	Scale	Edition	Update Application Date	Issue Date	Preliminary?
US4WI34M	1:120000	13	03/16/2018	03/16/2018	NO

Electronic Nautical Chart (ENC) US4WI34M covered the entire W00440 survey area.

Raster Nautical Chart (RNC) 14922_1 and 14903_1 (Figure 9) were compared to W00440 survey data using a 2 meter resolution combined CUBE surface. In general, there appears to be a horizontal divergence in contour position on the multibeam survey. This is possibly due to transported finer sediments and shifted sandy shoals since the area was last surveyed. Human impact from dredging, beach restoration projects, and breakwaters from the Manitowoc harbor may also have an effect on the sediment transport and deposition within the survey AOI.

The RNC 14992_1 of the Manitowoc, WI harbor is the largest scale chart available for the AOI, but it does not completely cover the survey area of W00440. The contours and soundings from the multibeam generally tended to be six feet deeper than charted contours and soundings of 14992_1. Most of the survey occurred in greater depths then charted contours, but the multibeam data over the Manitowoc Shoal specifically showed disparities from the nautical charting. Figure 10 identifies an area of the chart where the 24ft contour has horizontal differences of 500 feet and vertical differences up to six feet deeper then reported.

The RNC 14903_1 covers the entire AOI for the benthic habitat mapping survey, but the scale of the chart is too small to compare soundings from the 1m resolution multibeam bathymetry. Any suggested changes to the RNC 14992_1 such as the relocation of submerged features or contour lines should be considered for the chart 14903_1.

The R/V Storm survey overlaps an existing aerial topobathymetric LiDAR survey conducted in 2012 by the US Army Corp of Engineers. The depths from the LiDAR survey 2644 and the multibeam sonar were referenced to the same vertical datum and agree on average of 10 inches (Figure 11).One of the charted features that was surveyed by both the LiDAR and the multibeam are the Manitowoc Waterworks pipelines. A section of the pipeline served as the patch test site for the multibeam survey and was used to compare the depth of the LiDAR and the nautical charting. The 2012 USACE 2644 LiDAR imagery also agrees with the multibeam survey and supports the need to update the positions of the pipeline by 200 feet. (Figure 12).

The final surface was generated using the CUBE algorithm and exported as a 2m Bathymetry Attributed Grid (BAG) according the IHO depth standards. The backscatter and the sidescan mosaics were produced at the higher resolution in order to attain more details on the structures and substrates of the lake bottom. The timing offset from the roll compensation that caused vessel motion artifacts were only removed in the outer beams by filtering the swath angle of the CUBE at 55 degrees from nadir. A thorough time sync calibration is recommended for the 2018 sea trials of the R/V Storm and it is requested to log the POS files for the future field missions. Due to the "skunk stripe" nature of the bathymetry tracklines, the complete depth range for the sidescan coverage is unknown, therefore depth range was input as "999".

Chart	Scale	Edition	Edition Date	LNM Date	NM Date
14922_1	1:10,000	21	5/1/2016	2/13/2018	2/24/2018
149031	1:120,000	25	6/1/2016	2/13/2018	2/24/2018

Figure 9. Table with the largest scale RNCs which cover the survey area.

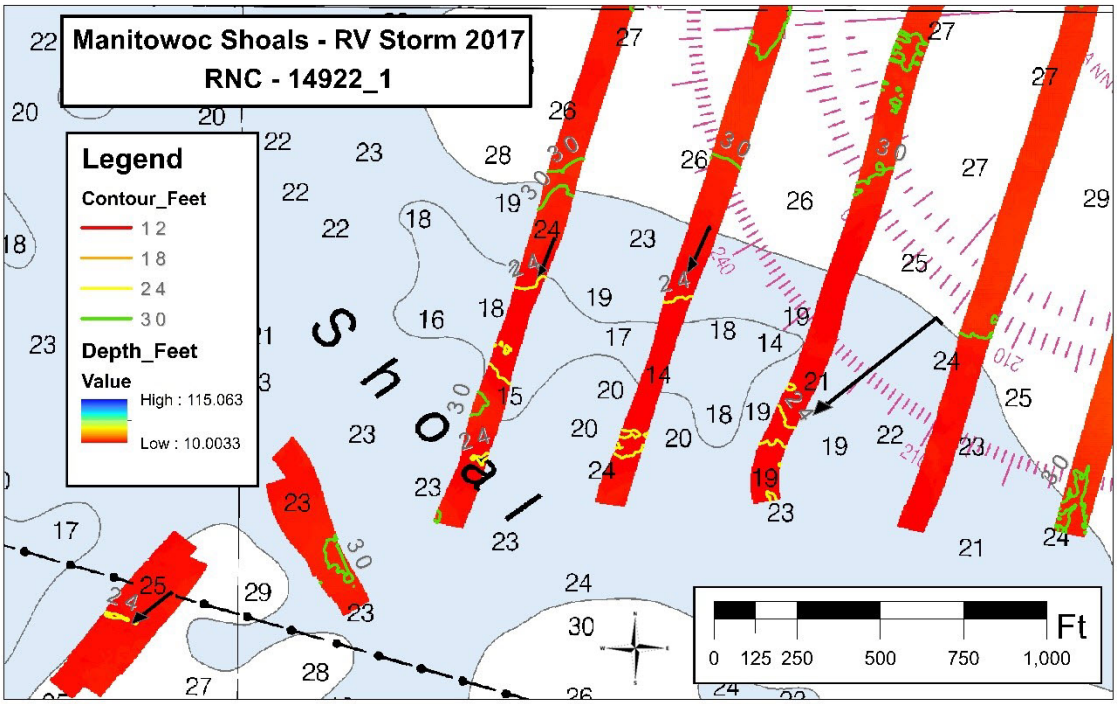

Figure 10. The bathymetry surface from the R/V Storm overlaying the RNC 14922_1. Areas that may require updates to nautical charting are illustrated by the black arrows and the colored contour lines of the multibeam survey. The multibeam suggests that the eastern point of the Manitowoc Shoal has shifted hundreds of feet further southwest.

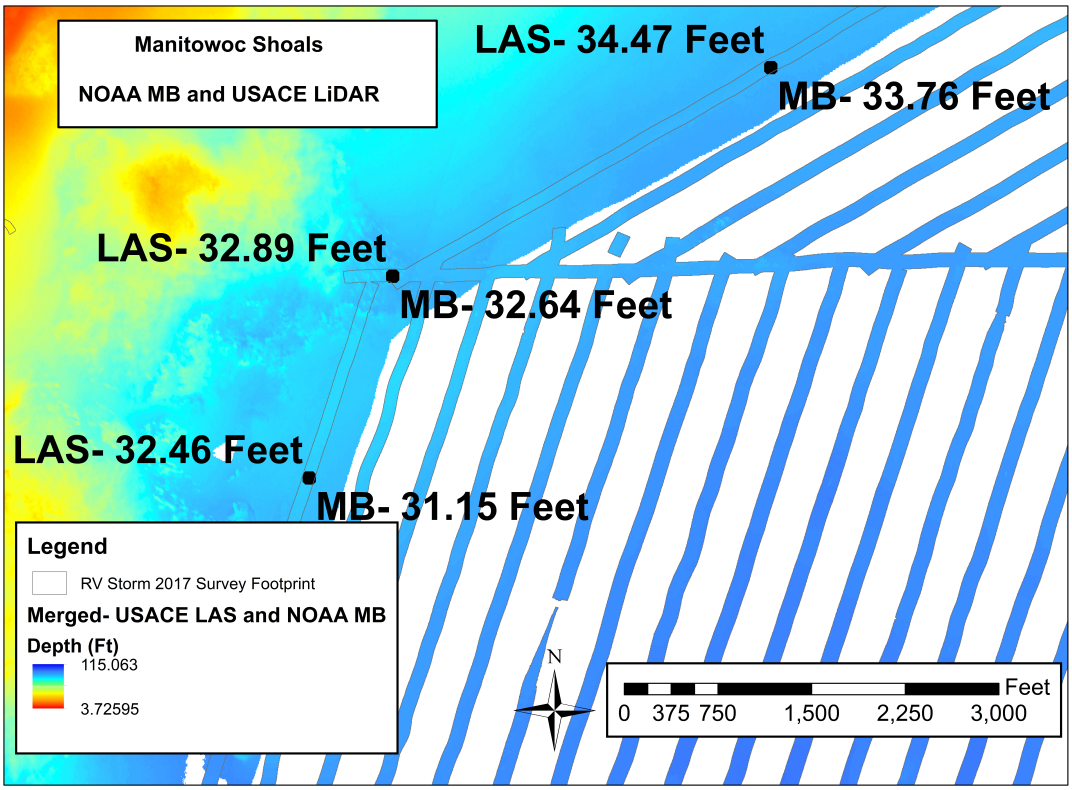

Figure 11. This figure illustrates the differential lake depth measured at three intersection points from the 2012 USACE LiDAR (LAS) data and the 2017 NOAA R/V Storm multibeam survey (MB).

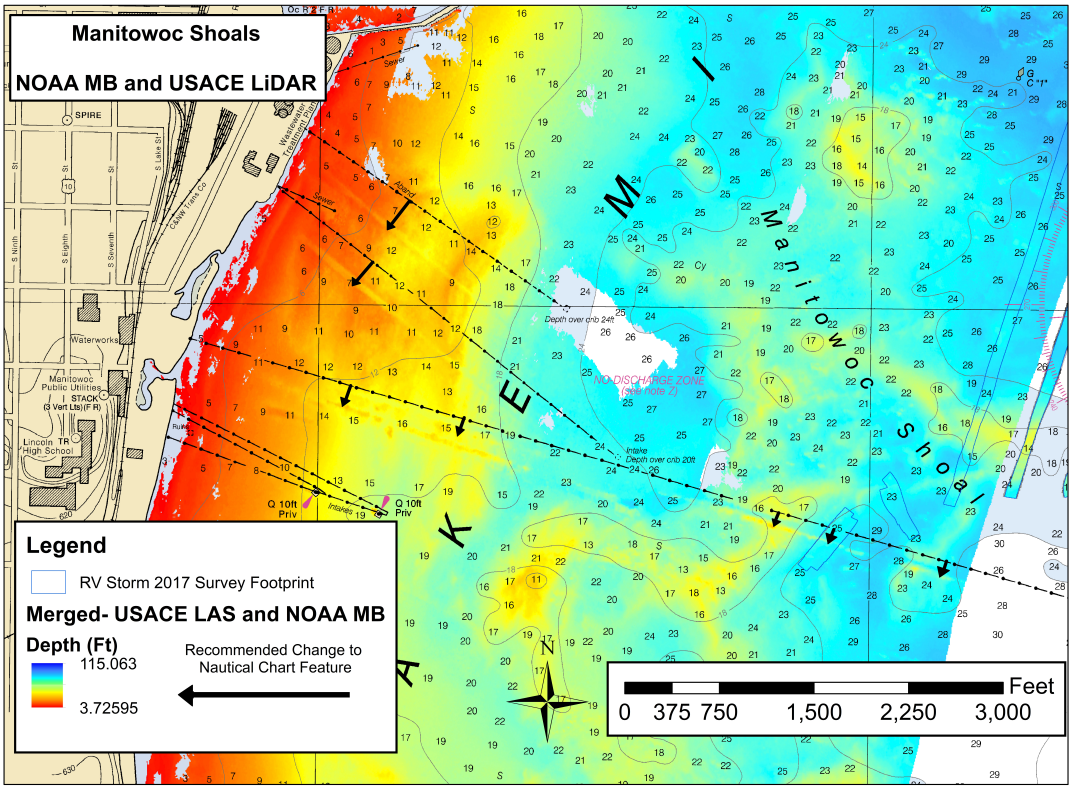

Figure 12. The Manitowoc Waterworks pipelines appear to be inaccurately placed on the RNC 14922_1 based on the multibeam bathymetry survey of the 2017 R/V Storm patch test site and the USACE 2012 2644 LiDAR survey. A horizontal shift of 120ft is recommended for the pipeline that was detected by the multibeam survey, however the LiDAR shows that several other Manitowoc utility pipelines may also need updating on the nautical charts.

The following surfaces and/or BAGs were submitted to the Processing Branch:

Surface Name	Surface Type	Resolution	Depth Range	Surface Parameter	Purpose
LakeMichigan_RVStorm17_EM2040c_Bathymetry_1m	GUBE	1 m	141.856 m - 173.886 m	NOAA_2m	Depth
LakeMichigan_RVStorm17_EM2040c_Backscatter_1m	Backscatter	1 m	141.856 m - 173.886 m	Decibels Relative (0-255)	Intensity
LakeMichigan_RVStorm17_Klein3000_Sidescan_50cm	Sidescan	0.50 m	999 m - 999 m	Decibels Relative (0-255)	Intensity

G. Vertical and Horizontal Control

The vertical datum for this project is Ellipsoidally Referenced Survey.

The vertical control method used for this survey was VDatum.

The following National Water Level Observation Network (NWLON) stations served as datum control for this survey:

Station Name	Station ID
Ludington, MI	908023
Kewaunee, WI	9087068

Tidal data acquisition, data processing, tidal datum computation and final tidal zoning were performed utilizing sound engineering and oceanographic practices as specified in National Ocean Service (NOS) Hydrographic Surveys Specifications and Deliverables (HSSD), dated March 2016, and OCS Field Procedures Manual (FPM), dated April, 2014. The Center for Operational Oceanographic Products and Services (CO-OPS) provided valid polygon nodes and water level corrections referencing Ludington, MI (9087023) in CARIS .ZDF format. CO-OPS provided the tide file “Storm0517CORP.zdf” for preliminary tide file, which was used in the final survey. The National Geodetic Surveys (NGS) GEOID03 model is used to transform the vertical positions from ellipsoid to orthometric heights referenced to the North American Vertical Datum of 1988 (NAVD88).

The horizontal datum for this project is World Geodetic System (WGS) 1984. The projection used for this survey is Projected UTM 16N.

The following DGPS Stations were used for horizontal control:

DGPS Stations
None

None

H. Additional Results

I. Approval

As Chief of Party, field operations for this hydrographic survey were conducted under my direct supervision, with frequent personal checks of progress and adequacy. I have reviewed the attached survey data and reports.

All field sheets, this Survey Summary Report, and all accompanying records and data are approved. All records are forwarded for final review and processing to the Processing Branch.

This hydrographic survey was intended for benthic habitat analysis and natural resource management. It was not intended to meet or exceed the requirements set forth in the NOS Hydrographic Surveys and Specifications Deliverables Manual, Field Procedures Manual, Standing and Letter Instructions, and all HSD Technical Directives for a sidescan survey with concurrent multibeam. I have presented in this report recommendations to supersede charted data in their common areas with soundings from this survey. It is at the discretion of the Chief Hydrographer from the ESD to perform any updates to nautical charting with this bathymetric data. This survey is complete and no additional work is required with the exception of deficiencies noted in the Survey Summary Report.

Approver Name	Title	Date	Signature
Will Sautter	Chief of Party	04/30/2018	
Charlie Menza	Chief Scientist	04/30/2018