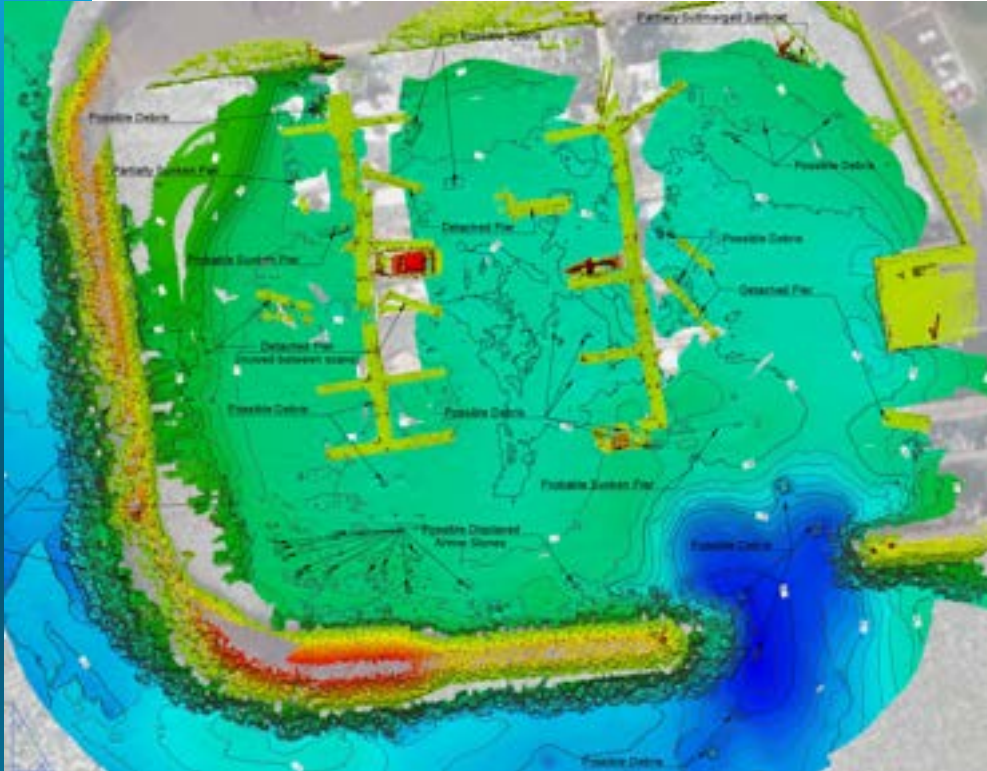


October 2026

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Acronyms and Abbreviations

cm	centimeter
DTM	digital terrain model
ft	feet
ft/s	feet/second
GNSS	Global Navigation Satellite System
HDOT	Hawaii Department of Transportation
IMU	inertial measurement unit
INS	inertial navigation system
m	meter
m/s	meters/second
MBES	multibeam echo sounder
MSL	mean sea level
MLLW	mean lower low water
MRU	motion reference unit
NOAA	National Oceanic and Atmospheric Administration
RMS	root mean square
ROV	remotely operated vehicle
RTK	real-time kinematic GNSS
SE	Sea Engineering Inc.
SV	sound velocity
SVP	sound velocity profile



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1. INTRODUCTION

Sea Engineering, Inc. (SE) was contracted by the Division of Boating and Ocean Recreation (DOBOR) to conduct a multibeam hydrographic survey of the Port Allen Small Boat Harbor in response to damage caused by Hurricane Lowell. The survey was conducted on September 18, 2026. The survey area is shown below in Figure 1-1.

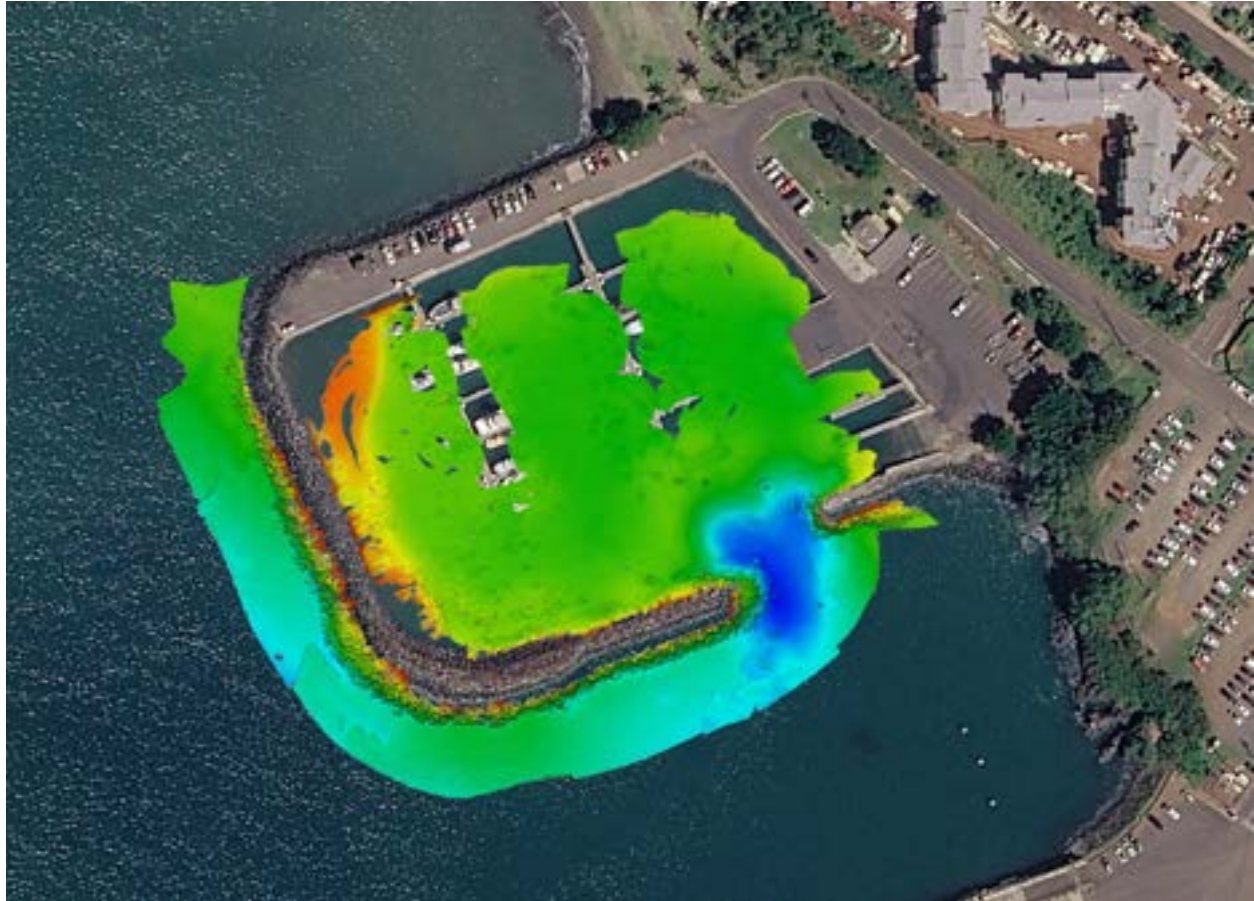


Figure 1-1. Survey coverage.

2. METHODOLOGY

2.1 Project Geodesy

The project coordinate system was NAD 83 State Plane Zone 4, US feet. Depths are expressed in feet below the MLLW tidal datum. The horizontal and vertical control project benchmark was NGS Benchmark Tidal 1347B located by the base of the pier from Deep Draft Harbor. The location and elevation of NGS Benchmark Tidal 1347B are listed below in Table 2-1.

Table 2-1. Project Controls in NAD 83 State Plane Zone 4 feet.

Benchmark Tidal 1347B	24,207.17 N	1,610,551.32E	10.8 ft MLLW
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2.2 Survey Vessel

The survey vessel was a shallow draft boat with a length of 28 ft, beam 8ft, and draft about 1 foot. A photograph of the vessel is presented in Figure 2-1.



Figure 2-1. Survey vessel

2.3 Multibeam Sonar System

The MBES system used for this project was the R2 Sonic 2020, which generates a swath of 256 beams, with a user-selectable swath width from 10° to 120°. The operating frequency is selectable from 200 to 400 kHz. This survey used the 400 kHz setting with a beam width of 2° x 2°. The sonar system was side-mounted to the survey vessel in a vertical configuration, with the center (nadir) beam oriented straight down. The side-mount fixture was securely affixed to the ship's hull by a rigid aluminum framework, which was attached directly to the vessel to prevent any independent displacements of the sonar head that could affect data quality (Figure 2-2).



Figure 2-2. Vertical MBES pole mount, shown as installed, with RTK GNSS position antenna on top, and LiDAR puck.

2.4 Navigation and Positioning

A Leica GS18/CS20 Real Time Kinematic (RTK) GNSS system was used to establish horizontal positioning for the multibeam survey. The Ekinox Navsight RTK GNSS receivers provided vertical and horizontal positioning for the survey vessel and multibeam system. RTK is a GNSS positioning system in which GNSS satellite signal corrections are transmitted in real time from a reference receiver or base station at a known location to one or more remote receivers known as

rovers. RTK corrections compensate for atmospheric delay and orbital errors, yielding centimeter-level accuracy. The increased vertical accuracy that is provided by RTK GNSS also allows tidal heights to be collected continuously while surveying. The RTK systems utilized a GNSS base station set up at Port Allen Small Boat Harbor for the survey. Data link between base and rover was established via a radio link. Technical specifications of the RTK systems state a kinematic accuracy (rover mode) of 10 mm in the horizontal plane and 20 mm in the vertical direction. Actual position accuracy is dependent upon various environmental factors including the number of satellites tracked, constellation geometry at time of survey, observation time, ephemeris accuracy, ionospheric disturbances, multipath and resolved ambiguities. The given accuracies are presented as root mean square values and are based on measurements processed by the manufacturer using acquisition software on real-time measurements.

2.5 Inertial Navigation System

The inertial navigation system (INS) is a critical element of multibeam surveying, which supplies the data acquisition system with highly accurate vessel motions such as heave, roll, pitch, and yaw displacements in real time. This survey utilized the SBG Ekinox Navsight inertial navigation system. The SBG achieves 0.02-degree pitch and roll accuracy, 0.08-degree heading accuracy and 5 cm real time heave accuracy.

2.6 Sound Velocity Measurements

Acoustic depth measurements in the water column are directly tied to the speed of sound for that particular water column. Speed of sound in water is primarily a function of salinity and temperature. Speed of sound measurements were recorded using an AML profiler and AML Pro SV probe. Casts were made with the SV probe during the survey for determining the sound velocity profile (SVP) for multibeam acquisition, and to generate sound velocity profiles (SVPs) for use in post-processing efforts where needed.

An SVP was generated for each section of the survey area to capture changes in local water conditions. The plot of the sound velocity profile from the survey is presented in Figure 2-3.

In addition to the SV profiler, a separate and continuously operating sound velocity probe was mounted to the sonar head, which was used to pass instantaneous SV data to the sonar receiver. This real-time SV data was used by the sonar control system to continuously optimize signal processing and beam forming to adjust for changing water conditions to yield the most accurate slant range measurements.

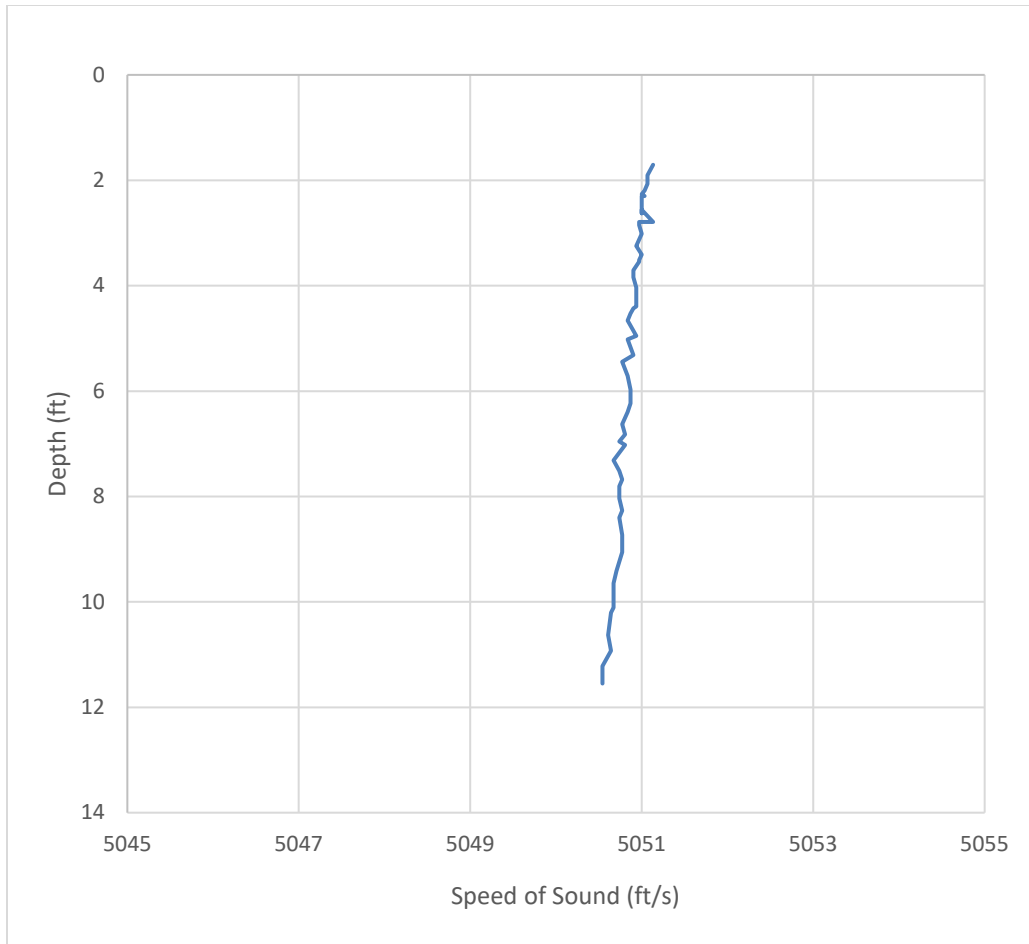


Figure 2-3 Sound velocity profile.

2.7 Data Acquisition

Xylem's Hypack/Hysweep 2023 navigation and data collection software was used for the collection of sonar and all other device data, and for integration of the data with vessel position, heave, pitch, and roll motion. Hypack/Hysweep 2023 was also used for survey data post-processing. The entire data acquisition setup as installed on the vessel for this survey is shown in Figure 2-4.



Figure 2-4 Data acquisition system.

The complete data acquisition system consisted of the following elements:

- An inertial navigation system, rigidly installed and cabled directly to the SBG control box in the main cabin (top box on left hand side);
- Twin GNSS antennas spaced 2 m apart located on top of the over-the-side mount;
- R2Sonic 2020 sonar head, side mounted and directly cabled to the R2Sonic SIM (control) box in the main cabin (bottom box on left-hand side of the lower photo);
- Data acquisition computer, connected to both the SBG control box and the R2Sonic SIM box via network cable connections.
- Bridge-X receiver unit used to receive RTK radio connection.

2.8 Tide Correction

Tidal variations were measured relative to NGS Benchmark Tidal 1347B. Bathymetry data collected from a survey vessel must be corrected for the tide level to the reference vertical datum of MLLW. Tide levels during the survey were measured using two methods: the vessel mounted RTK GNSS system and the manual tides.

Measurements from the NOAA tide station and RTK tides are presented in Figure 2-5. The graph shows close agreement between the NOAA tides at Nawiliwili and the tides measured at Port Allen relative to the NGS benchmark.

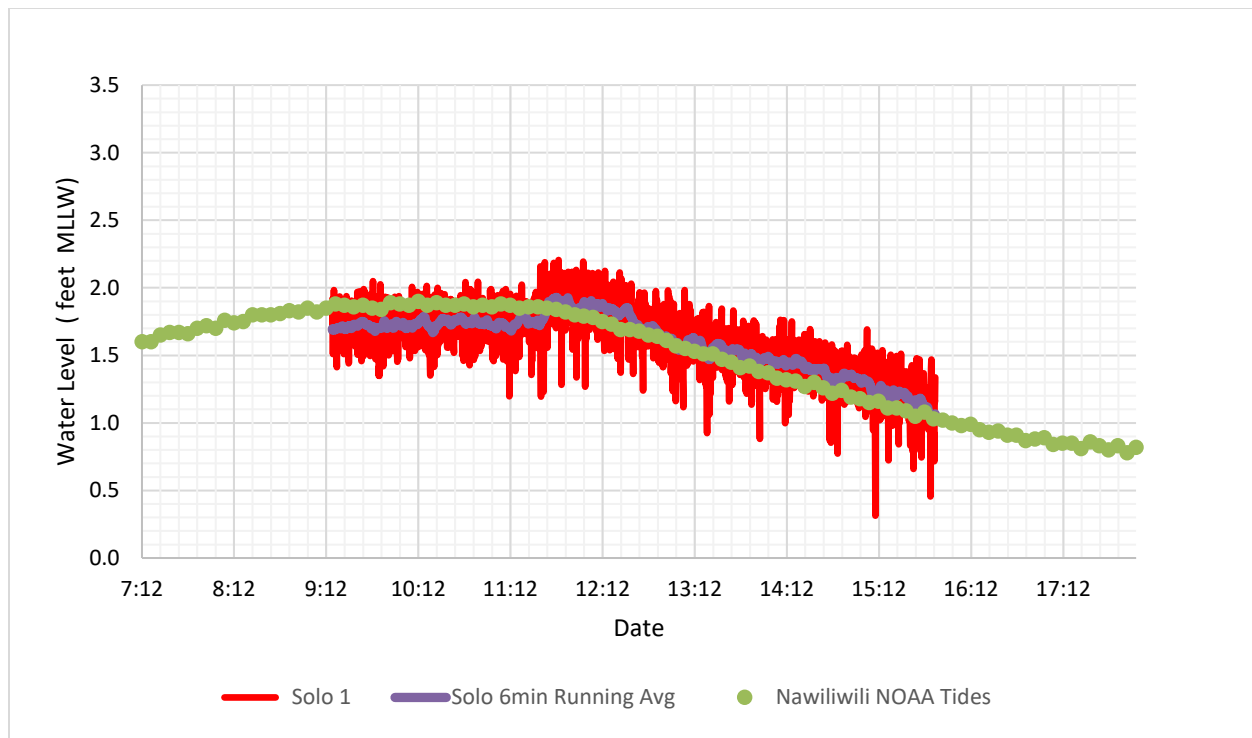


Figure 2-5 Tide measurements on 09/18/2026.

2.9 Quality Control Procedures

Standard hydrographic surveying methodology was followed during the survey, as provided in the U.S. Army Corps of Engineers EM 1110-2-1003, dated November 30, 2013. Quality control procedures include:

- Survey documentation
- Multibeam patch tests
- Draft/bar check
- Horizontal position check at project benchmarks
- Performance tests

2.9.1 Patch Test

Patch testing is a critical procedure used to calibrate the sonar installation for angular misalignment between the sonar head, heading sensor and the inertial navigation unit. The patch test was performed on site prior to commencing the survey and periodically thereafter, in order to reveal residual biases after the mobilization of the vessel, including pitch, roll, latency, and azimuthal offsets. The patch test also calculated the latency of the GNSS system which is the difference in time between the when positioning data was received and the when the computed position was logged by the acquisition system. The SBG and R2Sonic 2020 both utilize a 1 pulse per second (1pps) timing signal that minimizes the problems of GNSS latency and was verified in the patch test.

The patch test procedure consisted of data collection along several coincident or parallel survey lines at different speeds and directions, where the results are then numerically evaluated for offsets and calibrated and corrected using post processing software designed for multibeam surveying. Data processing was completed using Hypack/Hysweep 2023, and patch test corrections were calculated within Hysweep using the patch test calibration program. For each mobilization, a new patch test is required to quantify residual biases. Even small residual biases can significantly degrade data quality, particularly in the outer beams. The calculated patch test values were found to be as follows:

<u>Component</u>	<u>Correction</u>
Roll:	-2.65°
Pitch:	-0.43°
Yaw:	-0.50°
Latency:	0.0 s

2.9.2 Draft/Bar Check

The system draft (the transducer depth) was measured using the bar check technique, which consists of lowering a calibration plate a measured distance below the transducer head and comparing that distance to the sonar readings. The bar check was done twice daily, at the beginning and end of the surveying.

2.9.3 Performance Tests

Several ‘cross lines’ were run perpendicular to the primary survey line direction to check for roll offsets, timing delays or offsets due to tidal fluctuations. The cross line data were compared with the primary survey data using Hypack/Hysweep 2023. The Hypack/Hysweep survey processing software allows the user to calculate the difference in measurements for various beam angles compared to the primary survey data. Beam angle checks were completed to 110 degrees. Results of the 110-degree comparison (largest bias) are presented in Figure 2-6 and show good agreement throughout all beams.

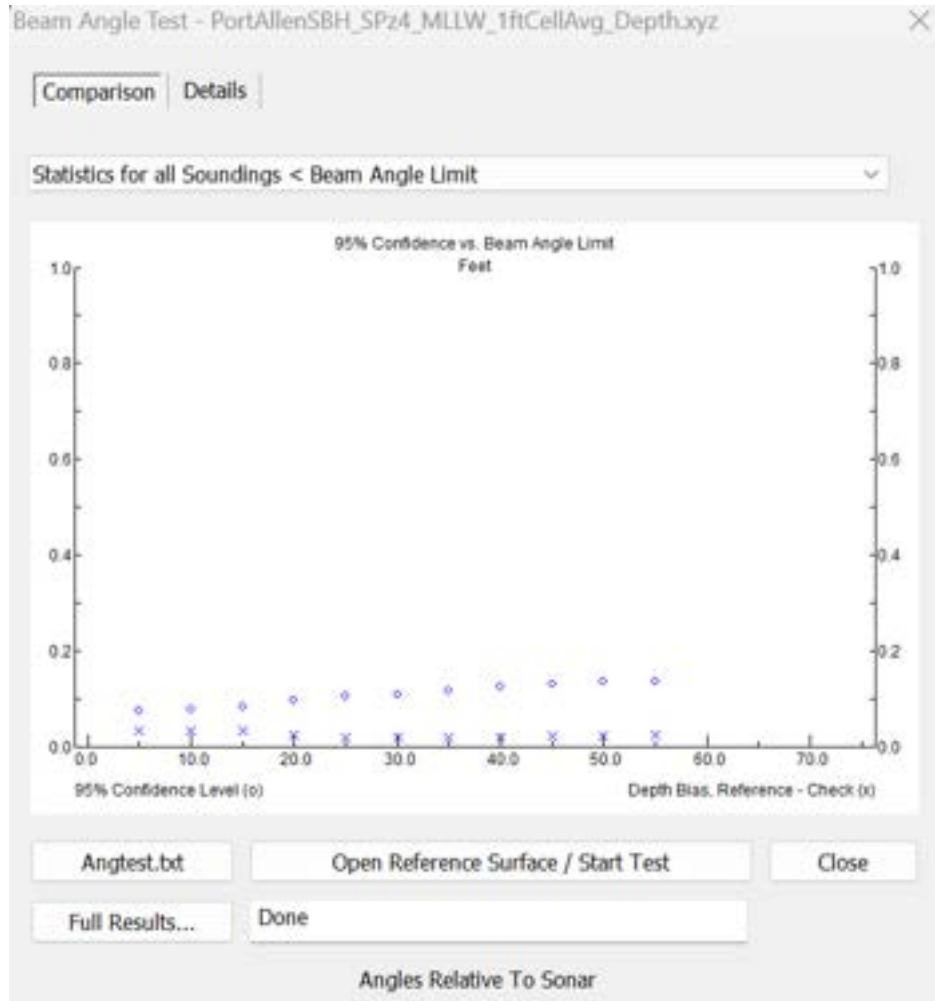


Figure 2-6 110-degree beam angle test.



2.9.4 Position Check

GNSS system positions were checked at the beginning and end of the survey at the NGS benchmark Tidal 1347B. The vertical datum is MLLW. The benchmark used for this project is listed in Table 2-1 above.

3. DATA PROCESSING

Post-processing of depth data from the multibeam system was completed using Hypack/Hysweep 2023 multibeam analysis and visualization software. Patch test data were analyzed and alignment corrections were applied to the sonar data within Hypack/Hysweep. Tidal measurements referenced to the survey controls were used to correct all depth measurements to the MLLW datum. Speed of sound in seawater profiles were applied to correct slant range measurements and compensate for ray path bending. Additionally, every survey line was individually reviewed and processed using the Hysweep data editor. The vessel's position and attitude data were reviewed, filtered and accepted. Filters were applied to reject data with poor RTK accuracy, which may have occurred due to electromagnetic frequency (EMF) noise, poor satellite coverage, or poor reception of the base station corrections.

Soundings were reviewed and outliers removed. Sounding data were carefully appraised, identifying any erroneous sonar beams reflecting from noise or aeration in the water column. Bad returns were flagged and rejected in the editing process.

After swath editing, all data were reviewed through the Hypack/Hysweep cloud editing routine to ensure that the data set was internally consistent and that no outliers remained. Finally, the data were analyzed for swath-to-swath overlap comparisons. The survey lines were "tiled" to ensure that all sounding data were systematically edited and reviewed for completeness. The cloud editing procedure also provided confidence in vessel positioning and sonar calibration by observing features mapped at the same location. All accepted data were used to generate 3-D digital terrain models (DTMs). These models were used to identify residual biases and assisted in 3-D visualization during the editing procedure. Areas of interest were identified through the DTMs and investigated further in the editing program.

Final data processing included averaging the data at a one-foot grid resolution.

4. SURVEY RESULTS

A color-coded map of the coverage is presented in Figure 4-1, showing all data collected by the survey vessel. A closer view of the survey with labeled debris are shown in Figure 4-2, data collected below the water surface by the multibeam sonar below water and data collected above water by the LiDAR sensor. Figure 4-2 illustrates the locations of displaced armor stones and other debris on the harbor seafloor. The addition of the LiDAR shows the location of the pier edge, docks, breakwater, and shoreline relative to the bathymetric data.

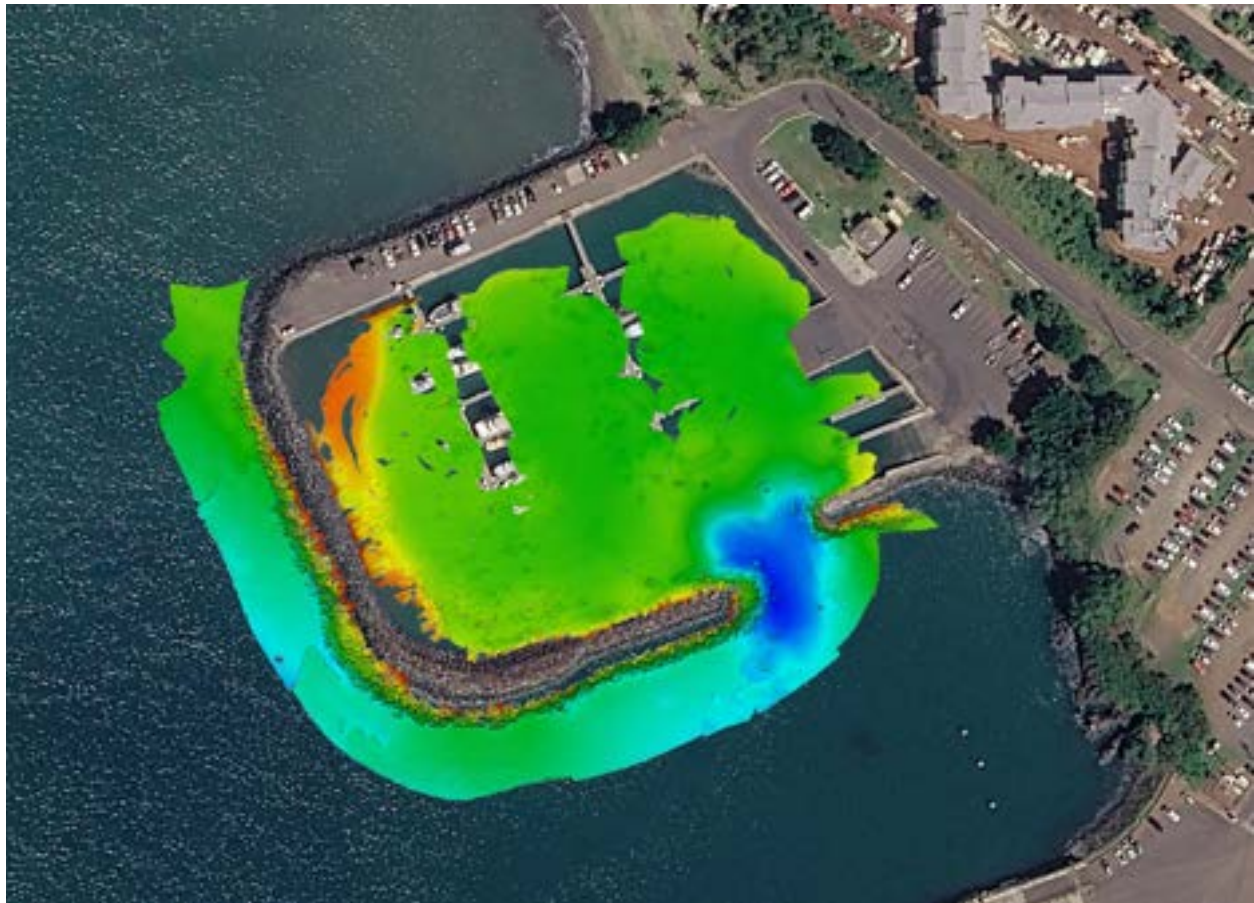


Figure 4-1 Survey Coverage

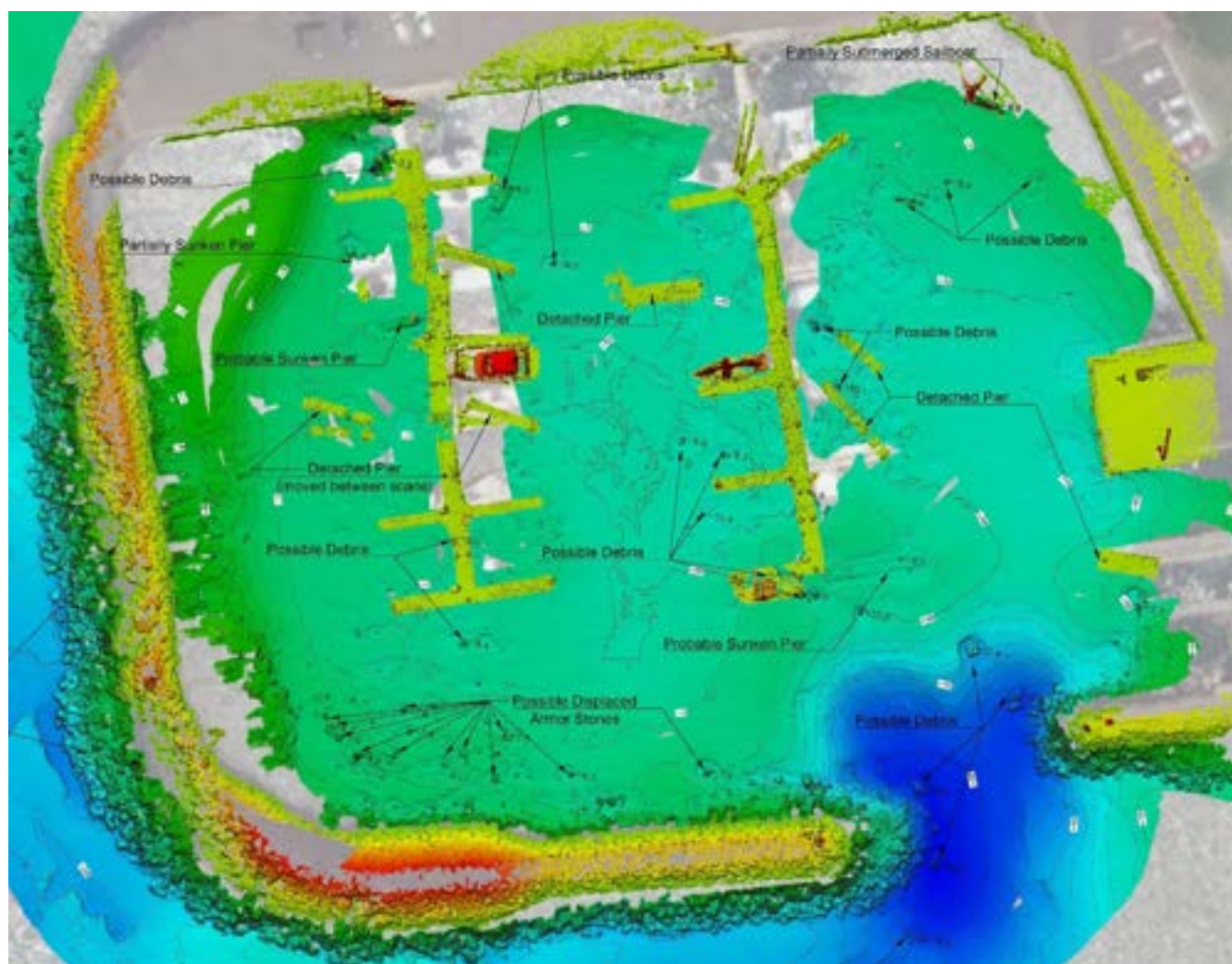


Figure 4-2 MBES and LiDAR Data



APPENDIX A SURVEY NOTES



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NOTES:

1. Vertical Datum: Mean Lower Low Water (MLLW) Feet
2. Coordinate system: HI State Plane Zone 4 US Feet
3. Vertical Control:
 - 3.a. Description: NGS Benchmark Tidal 1347B
 - 3.b. Elevation: 10.8
4. Horizontal Control:
 - 4.a. Description: NGS Benchmark Tidal 1347B
 - 4.b. Easting: 1,610,551.32 US feet
 - 4.c. Northing: 24,207.17 US feet
5. Hydrographic Survey Dates: 09-18-2026
6. Survey Equipment:
 - 6.a. Sonar: R2 Sonic 2020
 - 6.b. Heading: Septentrio dual-antenna GNSS receiver for RTK and PPP
 - 6.c. Position: Septentrio dual-antenna GNSS receiver for RTK and PPP
 - 6.d. Position: Leica GS16/GS18/CS20 GNSS RTK GPS System
 - 6.e. Motion: SBG Ekinox-E Navsight inertial navigation system (INS)
 - 6.f. SVP: AML Micro SV sound velocity probe on sonar; AML SV profiler for manual cast
 - 6.g. Lidar: Velodyne VLP-16 Puck
 - 6.h. Software: Hypack 2023
7. Contours generated from 1x1 ft grid averaged cell. The contour interval is 1 ft.
8. Color bathymetric imagery generated from 0.5x0.5 ft grid average cells.
9. Data represent seafloor elevation at the time of survey.
Seafloor elevation may change at any time following the time of the survey.
10. Elevations may vary between sounding locations.
11. Survey performed to standards of the U.S. Army Corps of Engineers Hydrographic Surveying Manual EM-1110-2-1003.
12. Labeled debris estimates from sonar imagery and should be confirmed visually.