Florida Seafloor Mapping Initiative (FSMI)

Sonar Data Acquisition

Quality Management Plan

Version – 1.2

Florida Department of Environmental Protection

Tallahassee, Florida

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1- Purpose and Organization

In 2021, the Department of Environmental Protection/Office of Resilience and Coastal Protection (the "Department") was charged with developing and implementing the Florida Seafloor Mapping Initiative (FSMI). The goal of the initiative is to obtain bathymetric data wholly or in part from the 0 m to the 200 m contour (isobath), and topographic data from the 0 m contour (shoreline) to a landward extent of approximately 500 m. As a first step, topobathymetric LiDAR will be collected to the maximum extent practicable throughout the project area to the depth of laser extinction. Following the FSMI solicitation and vendor selection, the topobathymetric LiDAR data collection commenced in the late summer of 2023.

The Department anticipated that review of topobathymetric LiDAR data collected in step one may identify gaps in coverage of certain shallow water areas, due to limited light penetration. These gaps, along with deeper waters from depth beyond laser extinction and up to approximately 200 m, are best filled using sonar—specifically multibeam echosounder system (MBES). Sonar data will be collected as a second step.

This Sonar Quality Management Plan (QMP) will assist and inform the Department and its registered Sonar Data Collection vendors on the best practices and methodology for hydrographic data collection, equipment calibration and data processing for the three different Sonar depth ranges defined in the RFP SOW 4.7 Bathymetric Sonar Data Collection Requirements, for the Contractors and the Professional Surveyor and Mapper ("PSM") to follow. The practices and methodology shall comply with the National Oceanic Atmospheric Administration's (NOAA) Office of Coastal Survey (OCS) Hydrographic Survey Specification and Deliverables, April 2021; and the data quality shall meet or exceed the International Hydrographic Organization (IHO)-S44 Standards for Hydrographic Surveys, 6th Edition September 2020, specified in the Request for Proposal (RFP) Statement of Work (SOW) 4.7 (excluding all references to sidescan and feature detection) for each of the depth ranges. The duties and responsibilities of the PSM that fall within Rule 5J-17.050 shall be outlined clearly throughout the project and shall be performed in accordance with Chapter 472, Florida Statutes.

Specifically, this document references best practices and the PSM oversight and services, such as specific ground truthing, Total Propagated Uncertainty (TPU) estimation, and/or datum conversion

This document reviews and compiles the Best Practices as applicable to the FSMI from NOAA's OCS Hydrographic Survey Specification and Deliverables, April 2021 (HSSD, 2021), the IHO-S44 Standards for Hydrographic Surveys, 6th Edition September 2020 (IHO 2020), the US Army Corps of Engineers Topographic Engineering Center, and Department's Bureau of Surveying and Mapping. For several sections below, this document references the relevant sections in the HSSD, 2021 that are required for this program and in some cases the HSSD, 2022 sections are referenced. Brief descriptions of these specifications are provided here to highlight the importance of these specifications to the FSMI program. Please refer to the HSSD 2021 and 2022 documents for more information. The document is partitioned into nine general topic sections applicable to all water depths which addresses,

- Pre-Survey Planning (4.1)
- Survey Reporting (4.2)

- Equipment Calibration (4.3)
- Data Processing (4.4)
- Reporting (4.5)
- Deliverable Formats (4.6)
- Identification of data coverage and holidays (4.7)
- Identification of QMP-PSM vs. Data Collection Activities (4.8)

2- List of Abbreviations

BAG - Bathymetric Attributed Grid

CRS - Coordinate Reference System

CORS - Continuously Operating Reference Stations

DEP ORCP - Department - Department of Environmental Protection/Office of Resilience and CoastalProtection

DGPS- Differential Global Position Satellite System

DR - Descriptive Report

DTON - Danger to Navigation

ERS - Ellipsoid Referenced Survey

FSMI - Florida Seafloor Mapping Initiative

FSMI RFP - Florida Seafloor Mapping Initiative/Response for Proposals

GeoTIFF - Geographic encoded Tagged Image File Format

GNSS - Global Navigation Satellite System

GSF – Generic Sensor Format

HPR - Heave-Pitch-Roll

HSSD - Hydrographic Survey Specification and Deliverables

IHO - International Hydrographic Organization

LiDAR (lidar) - Light Detection and Ranging

MBES - Multibeam Echo Sounder

MHW - Mean High Water

MLLW - Mean Lower Low Water

NAD83/2011 - North American Datum of 1983 with 2011 adjustment

NALL – Navigable Area Limit Line

NAVD88 - North American Vertical Datum of 1988

NGS - National Geodetic Survey

NOAA - National Oceanic and Atmospheric Administration

NSRS - National Spatial Reference System

OCS - Office of Coastal Survey

PDF – Page Description Format

PPP - Precise Point Positioning

PSM - Professional Surveyor and Mapper

QA/QC - Quality Assurance/Quality Control

QM-PSM - Quality Management - PSM Team

QMP - Quality Management Plan

RMSE - root mean square of error

RFP - Request for Proposals

RPM - Revolutions per minute

SEP - Vertical Datum Separation

SHS - Standards for Hydrographic Survey

Sonar (sonar) - Sound Navigation and Ranging

SOW - Statement of Work

SQRT - square root

TIFF - Tagged Image File Format

THU - Total Horizontal Uncertainty

TPU - Total Propagated Uncertainty

TVU - Total Vertical Uncertainty

UTM - Universal Transverse Mercator

XML – Extended Markup Language

Measurements

d - depth

m - meter

s - second

3- Best Practices – General (for all Water Depths)

Preface: It should be noted that Florida Jurisdictional waters extend from the shore to 3 nautical miles (3.45 statute miles) on the Atlantic Coast of Florida and from the shore to 9 nautical miles (10.35 statute miles) into the Gulf of Mexico on the Gulf Coast of the State (https://myfwc.com/fishing/saltwater/recreational/maps/#:~:text=Florida%20state%20waters%20are%20from,nautical%20miles%20on%20the%20Gulf.) It is within these zones that sonar surveys are the duties and responsibilities of a Florida licensed PSM within Rule 5J-17.050 and shall be performed in accordance with Chapter 472, Florida Statutes (see Section 5.1). However, this document is intended to provide best practices for all water depths that may extend beyond Florida jurisdictional water boundaries. All data acquired within the Florida jurisdictional waters must be performed under and signed off by a Florida licensed PSM provided by the contractor as part of the QMP contract.

3.1 - Pre-Survey Planning

3.1.1 - Percent Coverage

As each sensor has a unique field-of-view/data swath and as data swath is highly dependent on water depth, it is incumbent on each contractor to analyze and use that instruments' parameters to construct a preliminary data-collection line plan, along with cross-lines to provide for 100% coverage of the Area of Interest in the 0 m – 20 m, 20 m – 100 m, and 100 m – 200 m water depths as per the FSMI RFP. However, as a best and practical practice, resulting from the limited data swath obtainable in very shallow water depths (0 m – 5 m) and the potential hazards to navigation in those shallow water depths, it may be necessary to relax the 100% coverage criterion. When sonar data collection plans to fill-in topobathymetric LiDAR voids in shallow water are presented to the Department with a line-spacing/data swath that does not meet the 100% coverage criterion, explanation and rational should justify that plan. In any case of shallow water void sonar fill-in, it is recommended that the line-spacing should not exceed 40 m seaward of the Navigatable Area Limit Line (NALL) (see HSSD 2021; Section 1.3.2 for definition of the NALL.

3.1.2 - Weather Conditions

Late summer/early fall weather conditions, in Florida can potentially present dangerous weather conditions including, tropical cyclones, lightning storms, strong winds, and waterspouts, particularly along the Gulf Coast, Florida Keys, and southern Atlantic regions. Predictions from the NOAA National Hurricane Center (https://www.nhc.noaa.gov/) should be closely monitored during the hurricane season (June 1 – November 30) in Florida.

3.2 Survey Reporting

3.2.1- Weekly Progress Report

Weekly progress report shall be submitted during field operations at a specified day each week, as determined by DEP and the contractor prior to the first survey.

The contents of the weekly report will include the survey miles report as referenced in the HSSD 2021 document.

32.1.1 - Survey Miles Report

The Survey Miles Report tracks weekly statistics by survey and includes survey metadata (e.g. survey start/end dates), survey metrics (e.g. linear nautical miles, square nautical miles), survey processing progress (cumulative percentage complete) and brief narratives. The statistics are required weekly during data acquisition

The brief narrative shall summarize the activities of the past week (Saturday through Friday) and the anticipated plans for the coming week. The narrative shall discuss all activities related to mobilization/demobilization, control station installation, and data acquisition progress. Other major issues (e.g., significant weather delays, equipment failures, or anything which could potentially cause the project not to meet requirements, etc.) that may affect data acquisition milestones shall be discussed.

3.2.2 – Monthly/Final Progress Meeting

The contractor will arrange with the Department Project Manager for Virtual progress meetings to be held at the discretion of FDEP at a frequency no less than once per month and no greater that once per week. The progress meeting is to, (1) review the monthly progress, (2) discuss the future progress, and (3) to determine any issues that have arisen during the previous month. The last meeting will present the Final Progress Report.

3.2.3 – Final Progress Report (see Section 8.1.1.2 in HSSD 2021 document)

The purpose of the final progress report is to provide a graphic and a one-page summary of the project accomplishments. The contractor shall submit the final progress report within 30 days of completion of field work to the assigned Department Project Manager. Contractor shall coordinate a meeting with Department PM for discussion, confirmation and/or clarification of the report

The Final Progress Report Contents:

- Graphic showing final data coverage, the project sheet limits, and appropriate chart.
- For each survey of the project list the Survey Start Date, Survey End Date, Total square nautical miles (SNM), and Total linear nautical miles (LNM).
- Recommendations for future surveys in the area, interesting findings or acquisitions strategies, and/or unique challenges.

The final progress report shall be submitted as a single PDF following the naming convention: FinalProgressReport_Region_RangeDepth_<month>_<day>.<.pdf>

3.2.4 - Sonar Descriptive Report

Complete report detailing the data collection delivered in xml and pdf formats. Schemas for generating the report can be found at NOAA's webpage at:
https://nauticalcharts.noaa.gov/publications/standards-and-requirements.html

Report shall follow HSSD 2021 format, and it should include but is not limited to:

- Descriptive Report Summary and/or Descriptive Report Memo
- Area of Data Collection
- All Descriptive Report Supplemental Reports, including Data Acquisition and Processing Reports (DAPR), as well as Vertical and Horizontal Control
- Results

3.2.5 - Certified Mapping Report (PSM-signed/sealed, as applicable)

All sonar survey work performed within the jurisdictional waters of Florida shall be conducted in accordance with the Standards of Practice set for in Rule Chapter 5J-17, Florida Administrative Code, pursuant to Section 472.027, Florida Statutes. Sonar survey work shall be carried out under the supervision of the contracted responsible Florida PSM trained and qualified in the use of sonar equipment and software.

The team responsible for the sonar data collection shall prepare a report detailing the efforts of their survey which will be digitally signed and sealed by the QM-PSM Team. The documentation of a sonar project shall show a clear data lineage from the published primary control to the final deliverables. The data path of the entire process must be defined, documented, assessable, and allow for identifying adjustment or modification. Data without a documented lineage is susceptible to imbedded mistakes, difficult to validate and offers little reliability. The combination of the report and the raw data shall be suitable to recreate the MBES sonar deliverables.

3.2.5.1 - Minimum Requirements for the Certified Mapping Report

The certified report shall have the following minimum requirements:

- Name and address of corporation
- Certificate of authorization number
- Project name and associated reference number
- Surveyor in responsible charge, including contact information
- Abbreviations
- Introduction outlining the purpose and objective of the sonar efforts.
- Detailed description of the scope of the survey
- Description of equipment and software
- Description of the accuracy standards and specifications, procedures, and methodology
- Continuously Operating Reference Stations (CORS) stations used during acquisition
- List and describe the constraining control values.
    - Include horizontal and vertical coordinates
    - Datum used
    - Geoid model (should be GEOID 2018)
    - Total Propagated Uncertainty
    - Total Horizontal Uncertainty
    - Total Vertical Uncertainty
- Results of datum transformation using VertCON (if used)

- Field and office personnel performing the work
- Survey dates (first and last date of field measurements)
- Revision notes
- Digital signature and seal
- Project Reports

3.2.5.2 - Certified Mapping Report Structure

The certified report shall cover all of the reporting material referenced throughout this QMP document. All reports and data will be shared through the online portal provided by the Contractors. A consistent directory structure for data delivery will be provided to each Contractors. The general outline for report structure is as follows:

Calibration report: Delivered when completed, redeliver with any additional system recalibrations – Include copy in Certified Sonar Mapping Report

- Equipment calibration/Patch Test and Geometric corrections
- Detailing calibration methodologies
- Demonstrate calibration validation results
- Expected to reassess every time the system is recalibrated

Survey report: Delivered via report or online portal in seven business days after survey – Include copy in Certified Mapping Report (include and reference as addendum if many surveys)

- Overview of survey information
- Weather conditions at the time of survey
- Water conditions at the time of survey
- Tidal conditions at the time of survey (for 0 – 20 m reports)
- Map overview of bathymetric coverage
- Example cross sections
- Post processing – Any post-processing steps not covered in other sections

3.3 Equipment Calibration: Multibeam Echo Sounder (MBES)

The coverage area of sonar systems is a direct function of water depth. Most sonar systems provide coverage (swath) ranging from two to approximately seven times the water depth. The number of beams in a MBES also varies with the manufacturer and ranges from 30 to more than 120; however, the outer beams on each side of the swath are subject to more errors and may not be useful. With this improved resolution and coverage provided by MBES comes the need for much greater control and

calibration to ensure that the sounding is recorded from the correct position on the seafloor (geo-positioning). This geo-positioning is accomplished by using a high accuracy differential global positioning system (DGPS), heave-pitch-roll (HPR) sensor and a gyrocompass. In addition, the time synchronization for all these components is critical. For this reason, the system accuracy is comprised not only of the multibeam sonar accuracy, but also of the various components that make up the total system. This overall quality control assessment must be performed in the field because empirical data are necessary for validation.

As referenced in the HSSD 2021 document (Section 5.2.3.1), for multibeam echo sounders, comparisons should be made **at least once per project** between the nadir (vertical) beam of the multibeam and another multibeam system, a single beam system, or lead line. In addition, frequent checks should be made between the overlap of main scheme and crosslines collected on different days. These comparisons should be made frequently during data collection to find errors promptly, and not saved until final data processing after the field party has left the working grounds.

Comparisons should be conducted during calm sea conditions, preferably in areas with a relatively flat bottom. Any differences should be investigated, and if, after analysis, a corrector is necessary, it should be applied with an explanation of the cause of the difference explained in the Descriptive Report (DR).

Several sources of errors and biases exist in multibeam surveying that are not found in single beam surveying. These fall into the following categories:

- Speed of Sound Corrections (4.3.1)
- Attitude Corrections (4.3.2)

3.3.1 - Speed of Sound Corrections (as part of Data Collection)

As referenced in the HSSD 2021 document (Section 5.2.3.3.), to ensure that the overall depth measurement accuracy criteria specified are met, speed of sound observations should be taken with sufficient frequency, density, depth, and accuracy.

One sound speed profile shall be acquired immediately before the beginning of the data acquisition period. During acquisition efforts, sound speed profiles shall be collected at a minimum frequency of 4 hours, however if the surface sound speed sensor value differs by 2 m/s or more from the commensurate cast data, another sound speed cast shall be acquired. Any deviations from this requirement will be documented in the descriptive report. If the field unit has an alternate method to determine the frequency requirement during survey operations, a full description of the method used shall either be included in the Descriptive Report or in the Sonar Descriptive Report.

Sound speed profiles shall be acquired within the survey limits or within 500 m range of the limits.

The sound speed profile must reach the deepest depths of the survey, but the physical measurement of sound only needs to extend to the maximum depth required to perform ray tracing that results in data that meets depth accuracy requirements. Sound speed correctors must be determined accurately and often enough to ensure that the depth accuracy requirements are met. The uncertainty value of the sound speed measurements must be part of the vessel's uncertainty model. One method used by NOAA is to use the manufacturers uncertainty values for the measured components of conductivity, temperature and pressure. These values must then be used to compute a total uncertainty for the profile by computing how each component's uncertainty is propagated through the

sound speed computations. A probe that measures speed of sound directly shall use the manufacturers advertised uncertainty value.

Sound speed uncertainty shall be computed based on both the unit's accuracy and the spatial and temporal error associated with sound speed variation over the entire survey area. However, such advanced error analysis is not currently available in NOAA's processing pipeline. Therefore, the contractor may use the uncertainty associated with measuring the speed of sound at a specific location.

3.3.2 - Attitude Corrections

As referenced in Section 5.2.3.4 in the HSSD 2021 document, heave, roll, pitch, heading, and navigation timing error corrections shall be recorded in the data files and applied to all multibeam soundings.

Heave, roll, and pitch: Heave shall be observed in no coarser than 0.05 m increments. Roll and pitch shall be observed in no coarser than 0.1 degree increments.

Heading shall be observed in no coarser than 0.5 degree increments.

The uncertainty value for heave, roll, and pitch will typically be the manufacturer's values, assuming that the equipment is properly installed and maintained. The contractor must explain any variance from the manufacturer's values.

	Frequency of Measurement	Calibration Procedure	Recommended Tolerance (95%)
Draft			
Static	Small vessels: minimum/maximum load per survey episode Large vessels: leaving and returning to port		0.1 m (depths less than 30 m); 0.2 m (depths greater than 30 m)
Dynamic	At least once per year	HPR Sensor	0.05 m precision
Sound Speed	One sound speed profile immediately prior to each data acquisition period and as necessary during survey	Sound instrumentation	Profile error no greater than 2 m/s
Attitude Corrections			
Heave, Roll, Pitch	Reported for all measurements	Patch Test	0.05 m increments
Heading	Reported for all measurements	Patch Test	0.5 degree increments

3.3.3 - Uncertainty Budget Analysis

As explained in Section 5.2.3,6 in the HSSD 2021 document, the contractor shall discuss in the Descriptive Report the methods used to eliminate biases and characterize the uncertainty associated with the determination of depth. Uncertainty estimates for all components of the sounding measurement shall be provided.

3.3.4 - Patch Test Calibration

It is required that each bathymetric system will undergo a patch test calibration to determine mounting angle corrections each time the sensor is installed or moved within a vessel. During longer duration installations Contractors should periodically recalibrate or validate calibration meets manufacturer standards. All Contractors are required to submit to the Department or its representatives the validation and reporting documentation for each installation calibration. If periodic assessments of sensor calibration between installations result in changes to calibration parameters, new validation and reporting documentation will be required. Periodic assessments without calibration adjustments should be documented and delivered as proof of system stability. These updated calibration reports will be provided to, verified, and signed off by the QM-PSM Team.

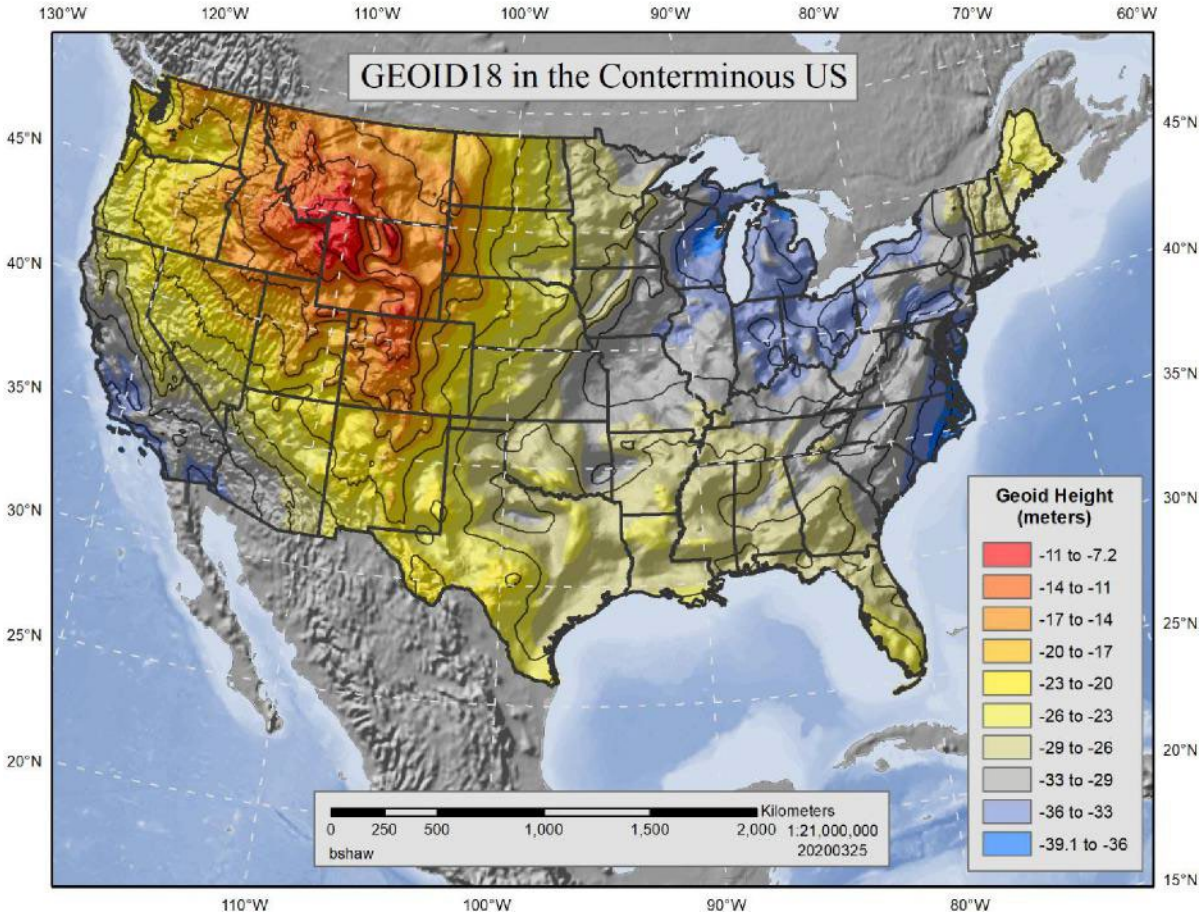
These patch test corrections typically include (but are not limited to) orientation (pitch, roll, yaw, and heave)- and position (translation, lever arms). Other system response functions for timing, and water density may be part of this correction process. All Contractors must use consistent correction methodology for their systems during this project's lifespan and must fully document the calibration methodology and results. This documentation will be provided to, verified, and approved by the QM-PSM Team and submitted to FDEP or its representatives.

3.4 Data Processing

As per the FSMI RFP the following Datums and Coordinate Reference Systems are to be used for all sonar data final products:

Horizontal: All data shall be tied to the National Geodetic Survey's (NGS) National Spatial Reference System (NSRS) via processing with respect to the CORS, referenced to the NAD83/2011, and projected to the Florida UTM Zones 16 and 17 plane coordinate systems, in meters.

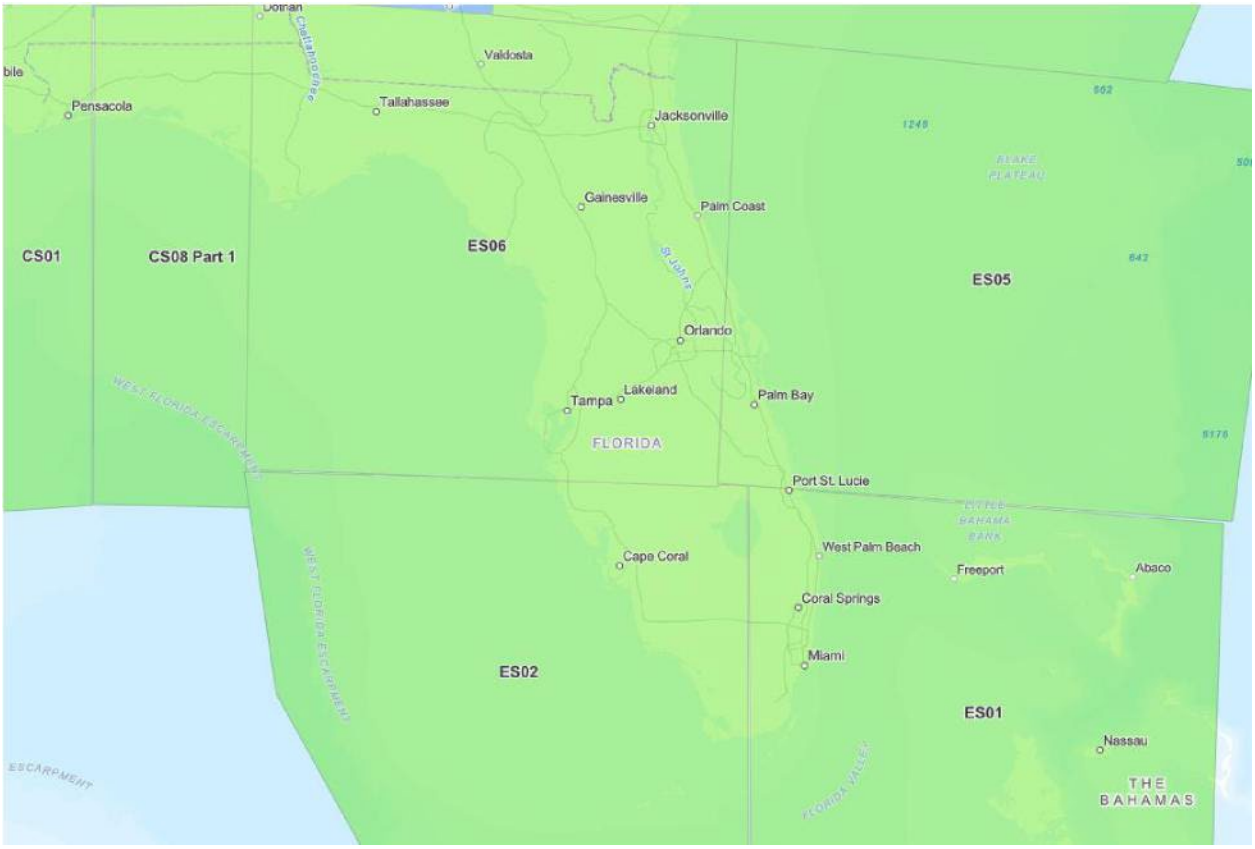
Vertical: Sounding data shall be referenced to the North American Vertical Datum of 1988 (NAVD88), in meters. Raw data should be referenced to NAD83/2011 Ellipsoid and final data products (BAG, DEM, etc.) should be referenced to NAVD88 orthometric heights. Interim products are not required to be vertically referenced. For near-shore bathymetry and/or for geographic areas where the NGS's GEOID18 model is available (see below), the GEOID18 model shall be used to transform ellipsoidal heights into orthometric heights.



https://www.ngs.noaa.gov/GEOID/GEOID18/maps/geoid18_conus_web.png

For offshore areas and/or geographic areas where the NGS's GEOID 18 model is not available, ellipsoidal heights shall be converted to orthometric heights using the appropriate (see below) NGS GRAV-D model and with respect to sonar data:

(https://noaa.maps.arcgis.com/apps/dashboards/94b1e2ce88e34bd18aae911f4f9e408e) .



All collections from MBES shall be accompanied with concurrent time series backscatter data acquisition. Raw multibeam backscatter data must contain intensity values and be capable of being successfully imported and processed into a backscatter image.

3.4.1 - Datum Conversions

In general, Ellipsoid Referenced Survey (ERS) is possible through Global Navigation Satellite System (GNSS) based sub-decimeter vertical control using some method of integer ambiguity resolution-enabled carrier-phase kinematic positioning. Differential and related carrier-phase methods based upon Precise Point Positioning (PPP) kinematic GNSS methods are permitted, from a real-time kinematic (RTK) service or via post-processing.

3.4.2 - Multibeam Backscatter

All multibeam echo sounder surveys require concurrent time series backscatter data acquisition to supplement the utility of hydrographic data for non-charting purposes. As per the RFP, these data are to be collected, but not processed. See HSSD 2022 Section 6.2.3.5 for Mosaic Processing details.

Efforts shall be made to avoid multibeam receiver acoustic saturation of the backscatter data. Raw multibeam backscatter data must contain intensity values and be capable of being successfully imported and processed into a backscatter mosaic. Backscatter processing is not required.

3.4.3 - Corrections to Echo Soundings and Uncertainty Assessment

As referenced in Sect 5.3.1.2 of the HSSD 2021 document, recorded horizontal positions, including values reported in survey records and deliverables, shall retain a precision of at least decimeter, i.e., for positions records in projected coordinates (meters): 1 decimal place.

The data density and resulting grid resolutions created shall be discussed with the Department Project Manager during the project planning phase. Any deviations from the plan, Project Instructions, or Specifications and Deliverables shall be discussed with the Department Project Manager and clearly described in the Descriptive Report (DR) If in rocky nearshore areas, the least depths of many features in a relatively small area fail to be preserved. Contractor shall coordinate a meeting with Department PM for discussion, confirmation and/or clarification of the data density and resulting grid resolution.

The Navigation Surface for sonar requires that each sounding have a horizontal and vertical uncertainty. The uncertainty value for the grid shall be the greater of the standard deviation and the *a priori* computed uncertainty estimate. To do this effectively an uncertainty model is needed for all systems supplying measurements to compute the sounding including the GPS sensors and anything else that contributes to the calculation of a sounding. If a complete uncertainty model is not yet available to compute the Total Propagated Uncertainty (TPU) for each individual sounding, then the contractors may apply a single uncertainty value to all grid nodes that reflect the vertical uncertainty budget for a given survey. The contractors shall include a discussion in the DR on how the uncertainty was computed on each individual sounding and how the uncertainty was computed on the grid, with a justification for that methodology.

3.4.3.1 - Total Propagated Uncertainty

Generally, when comparing any two remotely sensed datasets. acoustic datasets or even conventionally surveyed datasets, comparisons have assumed that one of those “control” datasets is correct, with no positional errors, i.e. the error is attributed to the dataset in question. TPU takes into account that each depth measurement is an estimate with an associated uncertainty. Hence, TPU represents the sum of all of the random and systematic uncertainties in the measurement process. This includes the uncertainty contribution of all of the sensors. The TPU is modeled from the systematic and random errors of the system by two components; the Total Horizontal Uncertainty (THU) and Total Vertical Uncertainty (TVU), see below.

A statistical method, combining all uncertainty sources for determining both the horizontal and the vertical positioning uncertainty should be adopted to obtain THU and TVU (see below) respectively. The uncertainties at the 95% confidence level must be recorded with the survey data.

The ability of the survey system should be demonstrated by *a priori* uncertainty calculations (THU and TVU). These calculations are predictive and must be calculated for the survey system as a whole, including all instrument, measurement, and environmental uncertainty sources. This estimation should be updated during the survey to reflect changes from environmental conditions such as wind, waves, etc. in order to make appropriate changes to survey parameters.

Final uncertainty values for the survey may consist of an *a priori* and *a posteriori* calculation, explicitly empirical values (e.g. based on standard deviation of vertical depths alone), or some combination of the aforementioned values. The metadata should include the uncertainty achieved for both horizontal and vertical uncertainty components (TVU and THU).

Depth values shall be recorded in meters, with a precision of at least centimeters. This precision shall be maintained throughout the processing pipeline and all digital data products. Uncertainty estimates for depth values and ancillary measurements shall be recorded with sufficient precision to support TPU estimates at centimeter precision and included in the BAG file metadata.

3.4.3.2 - Total Horizontal Uncertainty

As referenced in the HSSD 2021 document for hydrographic surveys, the THU in position of soundings shall not exceed 5 m + 5% of the depth, with a confidence level of 95%. The portion of the total uncertainty budget allotted to survey platform (vessel) position depends upon how accurately the sounding is positioned relative to the vessel.

For swath-based (e.g., multibeam) surveys the position of a sounding is usually located some appreciable distance oblique to the vessel position. Total uncertainty must account for beam forming precision of the echo-sounding system, depth of water and water column variability (speed of sound), accuracy of motion compensation (HPR, heading errors and timing latency), etc.

Allowable horizontal uncertainty is assumed to be equal in both dimensions. Therefore, assuming a normal distribution of error, the position uncertainty is expressed as a single number.

3.4.3.3 - Total Vertical Uncertainty

As referenced in HSSD 2021 Section 3.3, no intrinsic maximum allowable uncertainty is prescribed for the component attributed to survey platform vertical positioning. The contractor shall regard all of the uncertainties which affect vertical positioning, to ensure that the net error does not exceed the allowable limit set for TVU. Because TVU is much more stringent than THU, even more emphasis must be placed on the accounting of the factors which form total uncertainty.

The formula below shall be used to compute the maximum allowable TVU for all depth estimates included in bathymetric data products or feature attribution after application of correctors for all systematic and system specific errors. At least 95% of geographically distributed grid nodes shall meet this specification and the percentage of nodes that do not meet the maximum allowable TVU shall be discussed in the Survey Report.

$$TVU = +/- \text{ SQRT } (a^2 + (b*d)^2)$$

Where:

a represents that portion of the uncertainty that does not vary with depth

b is a coefficient which represents that portion of the uncertainty that varies with depth

d is the depth

(b*d) represents that portion of the uncertainty that varies with depth

The variables a and b shall be defined as follows:

In depths from 0 - 20 meters, a = 0.25 m and b = 0.0075

Horizontal accuracy <= 2 m

Bathymetric coverage = 100%

Grid Resolution = 1 m^2

In depths 20 - 100 meters, a = 0.5 m and b = 0.013

Horizontal accuracy <= 5 m

Bathymetric coverage = 100%

Grid Resolution = as described in NOAA OCS for Variable Grid resolution for Complete Coverage Multibeam

In depths greater than 100 meters, a = 1.0 m and b = 0.023

Horizontal accuracy <= 5 m + 5% of water depth

Bathymetric coverage = 100%

Grid Resolution = as described in NOAA OCS for Variable Grid resolution for Complete Coverage Multibeam

Horizontal accuracy, bathymetric coverage, and grid resolution requirements come from section 3.7 of the FSMI RFP. As per FSMI RFP Section 4.7.1.1: Does not require feature detection and feature search standards to be met.

The maximum allowable uncertainty in depth includes all inaccuracies due to residual systematic and system specific instrument uncertainties; the speed of sound in water; static vessel draft; dynamic vessel draft; HPR; and any other sources of uncertainty in the actual measurement process, including those associated with ERS or water level (tide) variations (both tidal measurement and zoning errors).

3.5 Reporting

All reports shall be delivered as single .PDF document

3.5.1 - Standardized Survey Reports:

Weekly Progress Report (see HSSD 2021; Section 8.1.1.1
Final Progress Report (see HSSD 2021; Section 8.1.1.2)
Sonar Descriptive Report (see HSSD 2021; Section 8.1.4)

3.6 Deliverable Formats

As per the FSMI RFP- The State Geographic Information Office, all Florida state agencies and commissions, and Florida's five Water Management Districts exclusively leverage ESRI GIS infrastructure and software. ESRI provides portals, tools, applications, and the framework required to share data with our federal cost share partners and coordinate geospatial data sharing with the emergency response sector. Modelling to mosaic the individual deliverable bathymetric DEMs together shall be done exclusively in ESRI's ArcGIS Pro software. Therefore, all required GIS items used for task assignments, technical proposals, progress reports or other logistical functions shall be delivered in one of the following formats, unless otherwise specified by the Department in this SOW:

- ESRI-hosted Feature Service
- ESRI File Geodatabase
- Shapefile (Esri)

A metadata file shall be submitted for each item in the deliverable list (if applicable). Use metadata standards applicable to the file type. If a GIS deliverable, the metadata file format can be .xml or ESRI file geodatabase and shall comply with the FGDC *Content Standard for Digital Geospatial Metadata*.

Progress reports shall be submitted in PDF format as well as in an ESRI-hosted feature service, using the project tiling scheme.

Raw and post-processed bathymetric data with backscatter data shall be delivered in Generic Sensor Format (GSF) format.

A bathymetric grid shall be developed from the sonar corrected data and delivered in Bathymetric Attributed Grid (BAG) format.

A metadata file shall be submitted for each item in the deliverable list, as applicable (except for data collection reports and those files where the metadata is self-contained in the header). Metadata file format can be .xml or ESRI file geodatabase and shall comply with the FGDC *Content Standard for Digital Geospatial Metadata*.3.7 Identification of Data Coverage Gaps and Holidays

The FSMI RFP requires complete bathymetric coverage for sonar survey areas. The HSSD 2021 standards for Coverage and Resolution “is defined by the minimum size of a feature required to be located and portrayed in the assigned coverage requirement at depth.” However, as features are neither required nor specified in the FSMI RFP, nor is side-scan sonar a requirement, this QMP will defer to HSSD 2021 Option A which specifies a 1 m grid resolution in 0 – 20 m depth range for either single or variable resolution surface, and following the HSSD 2021 specifications for water depths to 200 m as indicated in the following figure with the following modifications.

Single Resolution Surfaces	
Depth Range (m)	**Resolution (m)**
0-20	1
18-40	2
36-80	4
72-160	8
144-320	16

Variable Resolution Surfaces	
Depth Range (m)	**Resolution (m)**
0-20	1
20-40	2
40-80	4
80-160	8
160-320	16

Complete Coverage multibeam surface grid-resolution thresholds as a function of depth ranges.

1- Because MBES will be used to “fill-in the gaps” resulting from topobathymetric lidar voids in shallow waters, and shallow water MBES may be cost prohibitive, in the 0 – 5 m depth range, data holidays (fewer than 5 soundings/node but not 0 soundings) along the MBES survey swath may be permitted of up to 9 m2 and limited to no more than 5% of the total swath area. Furthermore, as the MBES swath is depth dependent and the recommended minimum line spacing is 25 m (see Section 4.1.1), areas of no-data (data voids, not holidays) between lines are accepted and not considered as data holidays

2- Similarly, MBES data collected to “fill-in the gaps” in the 5m – 20m water depths will follow the same procedure as in 0m – 5m water depths, recognizing no-data in the areas between swaths spaced 25m apart as acceptable, with data holidays no larger than $9m^2$ and occupying no more than 5% of a MBES swath area.

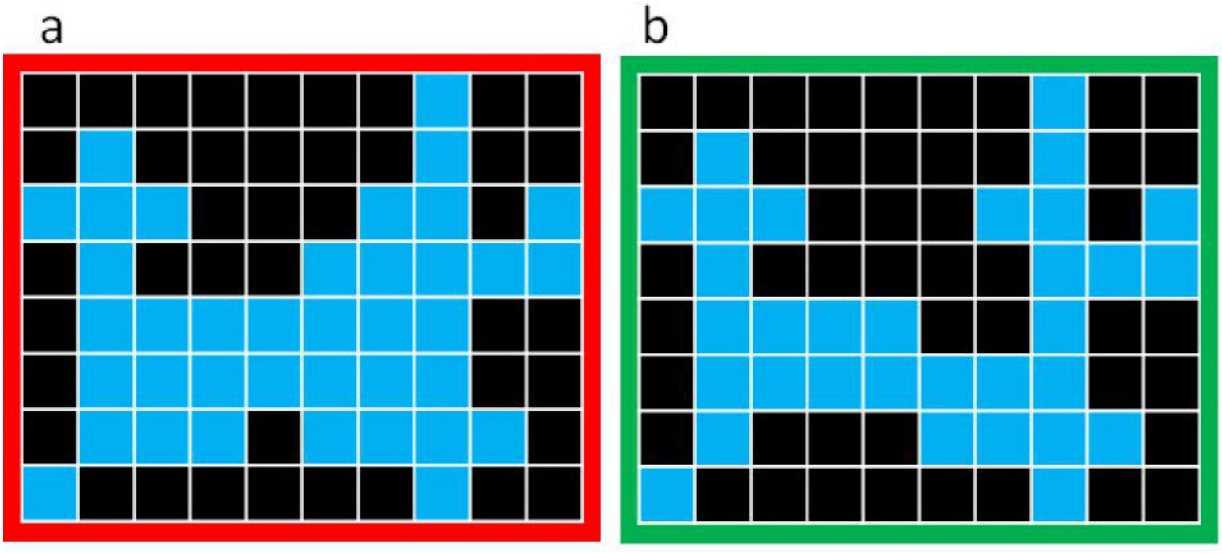
3- For water depths between 20m – 100m, the recommended node resolution is 4m. In these water depths, the area between the lines/swaths should be completely mapped. NOAA specifications for complete coverage permits up to 5% of the nodes to contain fewer than 5 soundings. In this water depth, data holidays are not permitted, however, holidays (fewer than 5 soundings/node but not 0 soundings) up to 144 m^2 and not exceeding 5% of the total area surveyed will be accepted.

4- For water depths between 100m – 200m, the recommended node resolution is 8m to the greatest extent possible, with the provision that for water depths greater than 160m, after discussion with the Department, a node resolution of 16m may be permissible. As in the 20m – 100m water depths, data holidays are not permitted, however, holidays (fewer than 5 soundings/node but not 0 soundings) up to 576 m^2, for 8m resolution or 2304 m^2 for 16m node resolution and up to 5% of the area surveyed will be accepted.

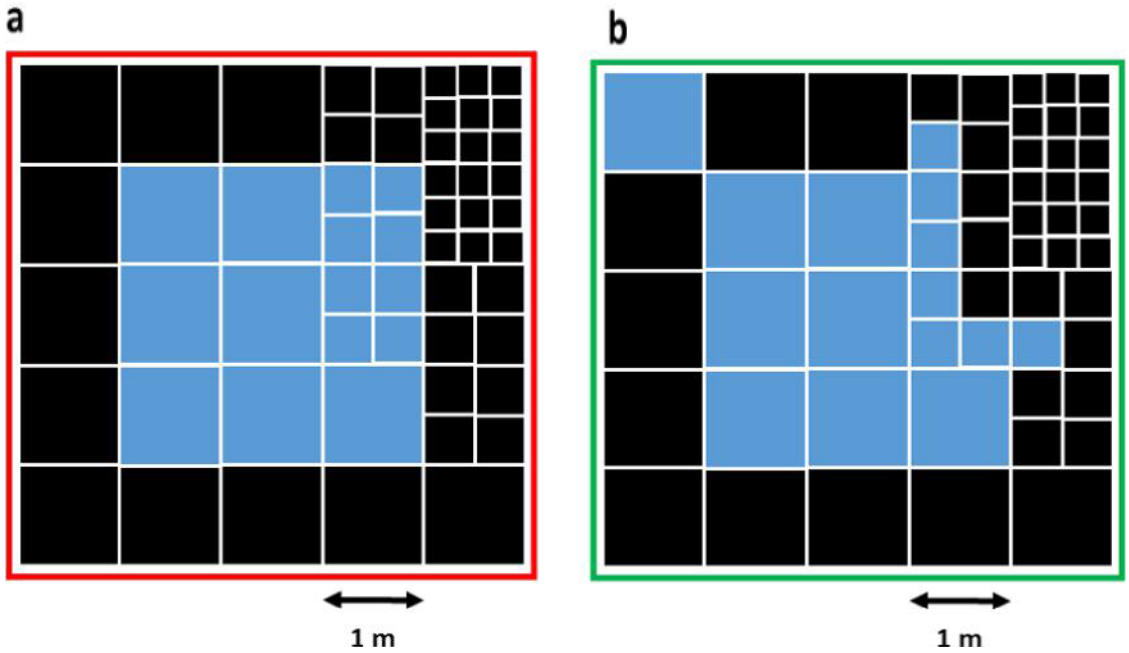
3.7.1 - Complete Coverage Data Holidays

For Complete Coverage, a holiday is defined in HSSD 2021; section 5.2.2.3, as an area of no coverage equal to or greater than a square with a side length equal to three times the coarsest required resolution for that depth. The figures below provide examples of Complete Coverage holidays for a single and variable resolution surface respectively. There shall be no holidays in the grid over the tops of potentially significant features.

Determination of Complete Coverage holidays for single resolution surfaces. Example (a) is a Complete Coverage holiday; Example (b) is not a Complete Coverage holiday. (Note: Blue squares are void of bathymetric data.)



Florida Department of Environmental Protection



Sonar Data Acquisition - Quality Management Plan

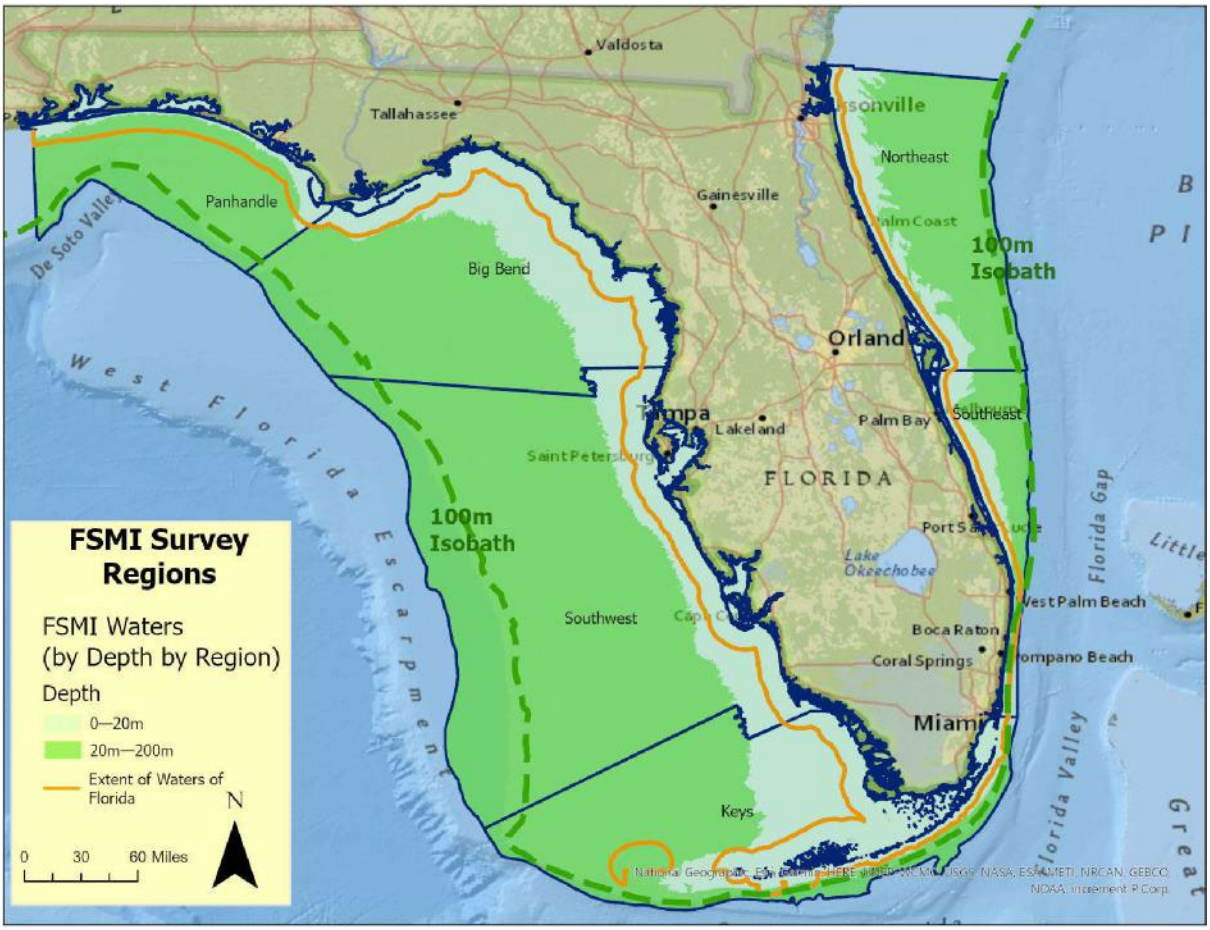
Determination of Complete Coverage holidays for variable resolution surfaces. Water depths in this example surface are 0 – 20 m, yielding a coarsest allowable grid resolution of 1 m. Example (a) is a Complete Coverage holiday, Example (b) is not a Complete Coverage holiday. (Note: Blue squares are void of bathymetric data.)

Note: For both single and variable resolution surfaces:

- At least 95% of all nodes on the surface shall be populated, with at least 5 soundings.
- The maximum propagation distance shall be no more than the grid resolution divided by √2.
- All significant shoals or features found in waters less than 20 m shall be developed to complete coverage standards (i.e., 1 m resolution surface in depths 0 - 20 m)

3.8 Identification of QMP-PSM vs. Data Collection Activities

The next figure shows the FSMI regions, the 0 – 20 m, the 20 – 200 m, the extent of the jurisdictional waters of Florida and the 100 m isobath. As indicated previously, the Florida Jurisdictional waters extend from the shore to 3 nautical miles (3.45 statute miles) on the Atlantic Coast of Florida and from the shore to 9 nautical miles (10.35 statute miles) into the Gulf of Mexico on the Gulf Coast of the State (https://myfwc.com/fishing/saltwater/recreational/maps/#:~:text=Florida%20state%20waters%20are%20from,nautical%20miles%20on%20the%20Gulf.) It is within these zones that sonar surveys are the duties and responsibilities of a Florida licensed PSM (PSM) within Rule 5J17.050 and shall be performed in accordance with Chapter 472, Florida Statutes.



FSMI Regions for sonar data collection and the extent of the jurisdictional waters of Florida and the 100 m isobath.

As is seen in the figure, with the exception of the Panhandle Region where the West Florida Escarpment is rapidly sloping seaward, the 20 m isobath extends further seaward than Florida's jurisdictional waters. Hence, most of the sonar data collection will occur outside of the jurisdiction of the Florida-licensed PSM. However, the best practices as detailed in this QMP document is applicable to those within and outside the Florida jurisdictional boundary and all areas will be verified for consistency and accuracy. Sonar survey activities in water depths of 0 m – 20 m and landward of the jurisdictional boundary, and hence all activities in the 0 m – 5 m water depth range, require Supervision, Verification and Certification of the PSM.

In summary:

- 0 m – 5 m water depth – requires PSM Supervision, Verification, and Certification,
- 0 m – 20 m water depth – shoreline to 3 nautical miles (east coast) or 9 nautical miles (west coast and Keys) – requires PSM Supervision, Verification, and Certification,
- 0 m – 20 m water depth – more than 3 nautical miles (east coast) or 9 nautical miles (west coast and Keys) – requires following of the best practices as outlined in this QMP and verified for consistency and accuracy,

- 20 m – 100 m water depth - Panhandle only – to 9 nautical miles from the coastline, PSM Supervision, verification and certification. All other regions – requires following of the best practices as outlined in this QMP and verified for consistency and accuracy
- 100 m – 200 m water depth – requires following of the best practices as outlined in this QMP and verified for consistency and accuracy

The following items are designated as QMP-PSM activities exclusive of Data Collection Activities:

- Review of Pre-Survey Planning Report (see Sec 4.1.5 and Sec 4.5.1)
- Review of Final Progress Report (see Sec 4.2.3)
- Review of error budget and uncertainty budget analysis (THU, TVU, TPU) to meet accuracy requirements
- Accuracy Certification within Jurisdictional waters

Appendix 1
STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
FSMI Sonar Checklist

Phase	Section	C	S	DC	Task
Data Acquisition	Equipment Calibration	☐	☐	☐	Patch Test calibration performed
				☐	Patch Test calibration documented
				☐	Sensor calibration validated
				☐	Sensor calibration validation documented
				☐	Sound speed profiles recorded and corrections applied
				☐	Attitude (Heave, Pitch, Roll) sensor calibrated and values recorded
	Survey	☐	☐	☐	Document survey overview information
				☐	Document survey weather conditions
				☐	Document survey water conditions
				☐	Document survey tidal conditions
				☐	Motion Sensor Uncertainties (HPR) recorded and reported
				☐	Navigation Sensor Uncertainty recorded and reported
				☐	Timing Uncertainty recorded and reported
				☐	Vessel offsets recorded and reported
				☐	Vessel speed uncertainty recorded and reported
				☐	Motion Reference Unit (MRU) Alignment recorded
				☐	Sound speed uncertainties recorded
				☐	Patch Test performed and reported
	Post Survey	☐	☐	☐	GPS/HPR data is free of issues
				☐	Data density meets specification for bathymetry
				☐	Data is free of unacceptable data holidays
				☐	Generate and deliver bathymetric coverage raster
				☐	Create map overview with bathymetric coverage raster
				☐	Document example cross sections
				☐	Survey Report was created and delivered
Post-processing / Data processing	ABGPS/Trajectory Processing	☐	☐	☐	Document processing methodology
				☐	Document each survey's processing results
	Calibration	☐	☐	☐	Perform data calibration (check as needed)
				☐	Calculate HPU
				☐	Calculate VPU
				☐	Compute TPU
				☐	Report all Uncertainties
				☐	Report all tested accuracies
	Classification	☐	☐	☐	Points are classified according to the classification schema

C - Contractor; S- Subcontractor PSM, DC - Data Collector

	Coordinate System	☐	☐	☐	Horizontal Coordinate System: NAD83/2011 Projected to Florida UTM Zones 16 or 17 (meters)
				☐	Vertical Coordinate System: Sounding data - NAVD88 (meters)
				☐	Vertical Coordinate System: Raw data: NAD83 Ellipsoid
				☐	Vertical Coordinate System: Final data products (.BAG, DEM) NAVD88 Geoid18 orthometric heights
				☐	Vertical Coordinate System: Final data products (.BAG, DEM) NAVD88 GRAV-D orthometric heights
Production Development	**DEM / BAG**	☐	☐	☐	DEM is generated only from bathymetric bottom
				☐	DEM/BAG Cell/Node resolution size is 1 meter in 0m-20m depth range
				☐	DEM/BAG Cell/Node resolution size is 2 meter in 20m-40m depth range, and 4m 40m-100m
				☐	DEM/BAG Cell/Node resolution size is 8 meter in 100m-200m depth range (or 16m in 160-200m depth range
				☐	DEM/BAG is clipped to boundary
				☐	0-5m DEM/BAG does not have bathymetric data holidays > $9m^2$ set as NODATA
				☐	5-20m DEM/BAG does not have bathymetric data holidays > $9m^2$ set as NODATA
				☐	20-100m DEM/BAG does not have bathymetric data holidays >144 m^2 set as NODATA; not to exceed 5% of the swath area
				☐	100-200m DEM/BAG has bathymetric data holidays > 576 m_2 set as NODATA; not to exceed 5% of the swath area
				☐	160-200m DEM/BAG has bathymetric data holidays > 2,304 m_2 set as NODATA; not to exceed 5% of the swath area
				☐	DEM is formatted as 32-bit cloud-optimized GeoTiff
				☐	DEM has compression applied
				☐	DEM is tiled without overlap or gaps
				☐	DEM - no artifacts or mismatches along tile edges, swaths or other artificial edges
				☐	DEM tile naming matches project tiling scheme with collection date
				☐	DEM has NODATA value of -999999 and defined in the GDAL_NODATA tag #42113
				☐	DEM has keys and tags populated using GDAL version 2.4.1 or newer
				☐	DEM/BAG in same CRS as MBES deliverable
	MBES with Backscatter	☐	☐	☐	GSF (Generic Sensor Format) formatted

	BAG Files	☐	☐	☐	Bathymetric Grid in .BAG format
				☐	Coverage Grid (optional as GeoTIFF)
				☐	Uncertainty estimates included in grid
	Metadata	☐	☐	☐	Polygon representation of swaths collected generated as specified
				☐	Spatial representation of extends of data delivered generated as specified
				☐	Spatial representation matches actual sonar extent, excluding no data areas
				☐	Metadata file provided for classified point cloud (XYZ file)
				☐	Metadata file provided for DEM or in .BAG file
Reporting	**Survey Reporting Progress Reports**	☐	☐	☐	Survey miles including survey metadata, survey metrics, and survey progress
				☐	Coverage Grid or GeoTIFF: coverage map 8-bit (minimum) or 32-bit (maximum) floating point raster
				☐	Coverage Grid in proper UTM Zone
				☐	Final Progress Report including: Graphic/map, project sheets and chart
	Sonar Descriptive Report	☐	☐	☐	General information regarding the Area of Data collection and Area of Interest (AOI)
				☐	Equipment list
				☐	Quality Control (uncertainty) and Calibration discussion
				☐	Data Acquisition and Processing methods and description
				☐	Equipment Coverage and Methods discussion
				☐	Factors affecting soundings discussion
				☐	Sound Speed Measurement Methods
				☐	Corrections to Echo soundings methods, calibration and discussion
				☐	Backscatter data acquisition and processing methods
				☐	Vertical and horizontal controls
				☐	Results and recommendations for future survey

	Final Survey Report	☐	☐	☐	Overview of survey information
				☐	Weather conditions during survey
				☐	Water conditions during survey
				☐	Map overview (GeoTIFF or BAG) of bathymetric coverage in proper CRS
				☐	Examples of cross section images of bathymetric profiles showing sonar performance
	Certified Mapping Report	☐	☐	☐	Report includes all sonar collection report information
				☐	Report includes post processing write ups
				☐	Report includes project base or CORS stations used during acquisition
				☐	Equipment calibration/Patch Test and geometric corrections
				☐	Calibration Methodology
				☐	Overview of survey information
				☐	Weather conditions during survey
				☐	Water conditions during survey
				☐	Tidal conditions
				☐	Map overview (GeoTIFF) of bathymetric coverage
				☐	Example cross sections of bathymetric profiles
				☐	Any post-process steps and methods not covered in other sections

By signing this document, the subcontractor is certifying that all deliverables are compliant with the project's Quality Management Plan (QMP) and Chapter 472 Florida Statutes.

_____
Subcontractor PSM

By signing this document, the contractor is verifying that all tasks as indicated in this checklist have been received.

_____
Contractor PSM