Gulf of Maine – Geoform Data Development

December 17, 2021

Prepared for

Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
Office for Coastal Management

In Partnership With
Maine, New Hampshire, and Massachusetts Coastal Programs

Prepared by

TETRA TECH

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CMECS Compliant Geoforms

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Acronyms and Abbreviations

BRESS	Bathymetric and Reflectivity-Based Segments
CMECS	Coastal and Marine Ecological Classification Standard
DEM	digital elevation model
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
GOM	Gulf of Maine
m2	square meter
MMU	Minimum Mapping Unit
NAD83	North American Datum 1983
NAVD88	North American Vertical Datum 1988
NBS	National Bathymetric Source
NOAA	National Oceanic and Atmospheric Administration
OCM	Office for Coastal Management
OCS	Office of Coast Survey
Tetra Tech	Tetra Tech, Inc.
TPI	Topographic Position Index
UTM19N	Universal Transverse Mercator Zone 19 North
VRM	Vector Ruggedness Measurement

1.0 INTRODUCTION

Tetra Tech, Inc. (Tetra Tech) is pleased to provide this report to the National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management (OCM). This research and development project was conducted for NOAA OCM, in partnership with the Maine Coastal Program, Maine Department of Agriculture, Conservation & Forestry - Geological Survey, New Hampshire Coastal Program, the Massachusetts Office of Coastal Zone Management, and other entities, referred to collectively throughout this document as State Partners.

This report documents Tetra Tech's effort to develop Coastal and Marine Ecological Classification Standard (CMECS)–compliant geoforms and associated data products for the Gulf of Maine (GOM) region. The "-compliant" modifier was added as some categories have been modified slightly and new categories suggested to accommodate the automated delineation process, as described in this document. The Tetra Tech team developed workflows to manipulate multi-resolution bathymetric and topographic data provided by the NOAA Office of Coast Survey (OCS) National Bathymetric Source (NBS) project and created derived bathymetric datasets and geoforms that will support regional ocean planning efforts. These products, or modified versions, will eventually be available from an existing public data portal.

Some key constraints guided this work and the resulting methods and data products which included the following:

1. The overarching goal was to develop a regional, GOM product that would be used by Federal, State, and other entities for regional planning;
2. The primary input dataset prepared by OCS included bathymetric and limited topographic data and associated data quality information. Resolution and quality of the source data ranged widely, with large portions of the project area containing relatively poor-quality source bathymetry.
3. Incorporation of additional publicly available datasets was not feasible within the scope of this effort;
4. A key objective for this project was to develop a methodology and workflows wherein the resulting geoform product would be repeatable by others;
5. Another key objective was to develop the methodology and workflows wherein the product was easily updatable, as the NBS source data will be continually updated as new survey data become available.
6. The software used would be readily available and/or currently being used by most entities.

The project area extents included all waters between mean astronomical high tide (or a shoreline that approximates this) and the approximately 24 nautical mile contiguous zone for all three states, as shown in Figure 1.

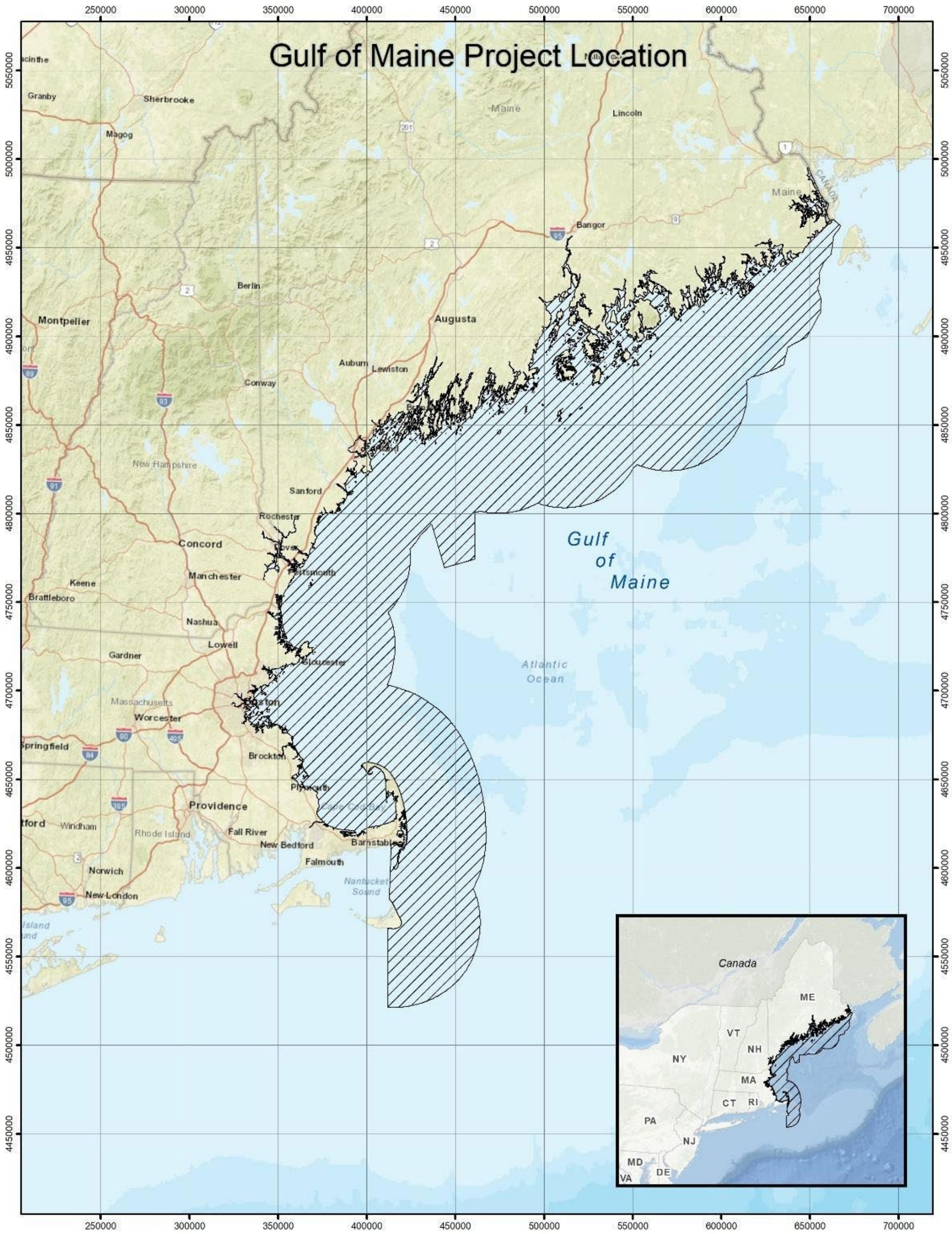


Figure 1. Gulf of Maine Project Location

1.1 Approach

The initial approach to the project was to use Bathymetric and Reflectivity-Based Segments (BRESS) software developed at the University of New Hampshire (UNH) Center for Coastal and Ocean Mapping (CCOM) as the primary segmentation tool and then to develop a crosswalk to reclassify landforms exported from BRESS into CMECS geoforms. To support this approach Tetra Tech developed tools to convert the multi-layer geotiffs provided by OCS into formats suitable for import into BRESS and Environmental Systems Research Institute (ESRI) ArcGIS Pro software tools. This process is described further in Section 2.1.

As part of the initial approach, OCM and State Partners had defined two pilot project areas that contained features of particular interest, one off Kennebec, Maine (ME), referred hereafter as “Kennebec” and one from Minots Ledge, Scituate, Massachusetts (MA) to Stellwagen Bank, referred to hereafter as “Massachusetts” or “MA”. The intent was to develop segmentation methods for the two pilot areas that could then be applied to the larger project area.

Following the pilot process check-in meeting with OCM and State Partners, the team decided that the translation from BRESS-exported landforms to CMECS geoforms was more complicated than anticipated and Tetra Tech was asked to further explore numerous alternative segmentation methodologies, including artificial intelligence (AI), supervised and unsupervised machine learning techniques, neural networks, fractals, K-means clustering and random forest algorithms, and aspect and curvature derivatives, Saga GIS tools and NOAA’s Benthic Terrain Modeler.

Tetra Tech determined that many of the existing methods and tools listed above use the same r.geomorphon algorithm used by BRESS or were algorithms used in the tools ultimately selected for this project. Additionally, the regional focus of this project, the wide range of quality in the source data, and lack of readily available, vetted and prepared training data (e.g. backscatter, sediment samples) made development of an AI or machine learning technique unsuitable or outside the scope of this project. Therefore, Tetra Tech focused the effort on using a combination of BRESS exports and innovative use of existing tools within the ArcGIS Pro software suite to produce the final geoforms for this project.

Tetra Tech added two additional pilot study areas to expand the range of target features to focus on during tool parameter development, an area of pockmarks on the seabed in Belfast Bay, ME, referred to hereafter as Belfast Bay, and an area off Cape Ann, MA, hereafter referred to as Cape Ann. Tool and methods development were focused on the four pilot areas and were the focus of months of discussion with OCM and State Partners. Once the tools and parameters were refined and the resultant geoforms were reviewed for the four pilot areas, these tools and parameters were used on the full project dataset to create the final geoform layer. These methods are described further in the report text below, and workflows providing instruction for reproducing the final geoform layer are provided in Attachment A.

1.2 Report Contents

This reports contents include the following:

- The NBS bathymetry dataset and conversion from multi-layer geotiffs to elevation and uncertainty grids suitable for further analysis in Section 2.0.
- The BRESS software is introduced in Section 3.0, along with a description of how these outputs were used to support final geoform production.
- The evolution of the CMECS target feature list and tools and methods used to delineate these target features are described in Section 4.
- And finally, the assembly of the final geoform layer is described in Section 5.0.

1.3 Other Considerations

This project focused on the production of a regional product using (primarily) the bathymetry provided by OCS. However, some additional factors should be considered when following the methods described in this report if the focus of study covers a smaller geographical area or the source data are more consistently high quality.

1.3.1 Small Project Areas

The methods described in this document are focused on development of a regional geoform product. To provide repeatability and consistency across the GOM region, consistent settings were used to delineate each target CMECS class. While consistency is essential when producing a regional product, the downside is that the results may not be optimized across the area. In other words, better results may be obtained for discrete areas where settings more precisely target the features found in that area. If the user is focused on a smaller area and wants to optimize the settings for that area, the tool parameters presented in this report should be re-evaluated. Many of the parameters used for the regional product are based on the scale of the data, the size of the desired features, and/or local knowledge of the targeted features.

For example, when the output of an ArcGIS Pro tool is a raster, the output is often converted to polygons. The process of converting a floating-point raster to a polygon feature class involves reclassifying the data into an integer raster first. The parameters used for this reclassification process were derived by visually examining the different value breaks and choosing the appropriate value(s) that mimics the desired features. These value breaks are often the key to successfully delineating the CMECS classification; thus, it is recommended that several different value breaks be examined during this process.

1.3.2 Minimum Mapping Unit

Numerous discussions were held over the course of the project with OCM and State Partners concerning determination of a minimum mapping unit (MMU). Bathymetric survey artifacts and poor source data quality over large portions of the project area made the idea of setting an MMU very attractive to remove some of the noise “speckle” in the data. However, in some areas comprised of high quality and high resolution multibeam bathymetric data, relatively small features were captured in the data. Because one of the primary goals of this project was to develop a regional product and we wanted to retain the integrity of the good data as much as possible, the OCM/State Partners/Tetra Tech team decided to not set an MMU, to maximize data integrity in the areas of high-quality data, with the trade-off of also retaining some of the noise due to survey artifacts and poor-quality data.

However, if someone is working on an isolated area that contains primarily good quality, high resolution data, reviewing the output and selecting an appropriate MMU for that area may facilitate removal of artifacts present in the data. While specific advice for selecting an MMU is outside the scope of this report, two important factors to consider when determining an MMU are scale of data and size of the features within the project area.

1.4 Software Used

The software packages used for this project included the following:

- BRESS, v. 2.2.8 – Bathymetry data processing and segmentation with BRESS software is described in Section 3 of this report.
- ESRI ArcGIS Pro 2.8.3 with Spatial Analyst extension.
  Familiarity with the following tools recommended:

  Analysis Tools:

  Clip, Frequency, Identity, Intersect, Union

  Conversion Tools:

  Raster to Ascii, Raster to Polygon, Raster to Point

  Data Management Tools:

  Add Field, Add Join, Add Rasters to Mosaic dataset, Calculate Field, Copy Features, Copy Raster, Create Mosaic Dataset, Delete Features, Dissolve, Feature to Line, Feature to Point, Eliminate, Feature Vertices to Points, Join Field, Make Raster Layer, Minimum Bounding Geometry, Multipart to Singlepart, Raster Calculator, Remove Join, Select layer by Attribute, Select Layer by Location,

  Spatial Analyst Tools:

  Extract by Mask, Line Density, Point Density, Reclassify
- ArcGIS ArcHydro Tools Pro
  ArcHydro consists of a data model, toolset, and workflows developed over the years to support specific geographic information system (GIS) implementations in water resources. ArcHydro download is available at the following link:

  http://downloads.esri.com/archydro/archydro/setup/Pro/ArcHydroPro2.6.27/

  ArcHydro Tools used:

  - Terrain Preprocessing>Topographic Position Index (TPI)
  - Terrain Preprocessing>Vector Ruggedness Measurement (VRM)

2.0 OCS ELEVATION AND UNCERTAINTY DATA PROCESSING

Bathymetry and uncertainty data were provided by NOAA OCS as multi-band geotiffs in sets of tiles containing 4-, 8-, or 16-meter resolution data. The different resolutions were not overlapping across the project area. For example, 4-meter resolution data were only available in limited areas where data quality was relatively good, while large portions of the project area were covered only by 16-m resolution data. The 16-m resolution grids covered the entire project area. When the bathymetry data were tiled to create the 8-m grid deliverable, the highest resolution data were used where possible. All data were provided in North American Datum 1983 (NAD83) Universal Transverse Mercator Zone 19 North (UTM19N) projection in units of meters. Band 1 contained the elevation data in meters relative to North American Vertical Datum 1988 (NAVD88). Band 2 contained the vertical uncertainty for each grid cell in meters. The geotiffs were prepared for the segmentation process using tools and methods developed by Tetra Tech and are described below.

2.1 Elevation Data

The multi-band geotiffs were added to an empty mosaic dataset to be processed and separated into individual datasets. The elevation (band 1) was extracted by creating a raster layer and saving that layer using the Copy Raster tool. Please refer to Section 1.4 for a list of the ArcGIS Pro tools used.

All 4-, 8-, and 16-meter tile data were merged into a single 8-meter elevation model, as specified in the contract Statement of Work, and clipped to remove the areas off the continental shelf to keep the depth ranges within reasonable limits. The resulting digital elevation model (DEM) was used to generate the 10-, 20-, 30-, and 40-meter depth contours required in the list of contract deliverables. Figure 2 shows the extent of the bathymetry/topography generated for the GOM project area.

2.1.1 Supplemental Data

After reviewing the NBS elevation data along the shoreline and comparing the BRESS output, Tetra Tech determined that supplemental topographic and bathymetric data would help to remove or limit the data setback in the BRESS outputs caused by the size of the neighborhood used. The output data extent from BRESS was clipped to the extent of the input bathymetry *minus* the neighborhood distance, thus creating a setback of missing data. Supplementing the NBS bathymetry data derived from the geotiffs with a dataset that was clipped to a project area buffer that was greater than or equal to the neighborhood distance, compensated for the setbacks. The dataset used was ESRI’s world elevation layer called “TopoBathy”, which is a dynamic world elevation service that combines topography and bathymetry from around the world. The TopoBathy elevation service was clipped to the buffered project area and mosaiced to the NBS elevation data with the ArcGIS Pro Mosaic tool, with the NBS elevation layer set as the top layer. This supplemental process may not be necessary if smaller project areas are at least the neighborhood distance away from the shoreline. Figure 2 shows the extent of the bathymetry/topography generated for the GOM project area.

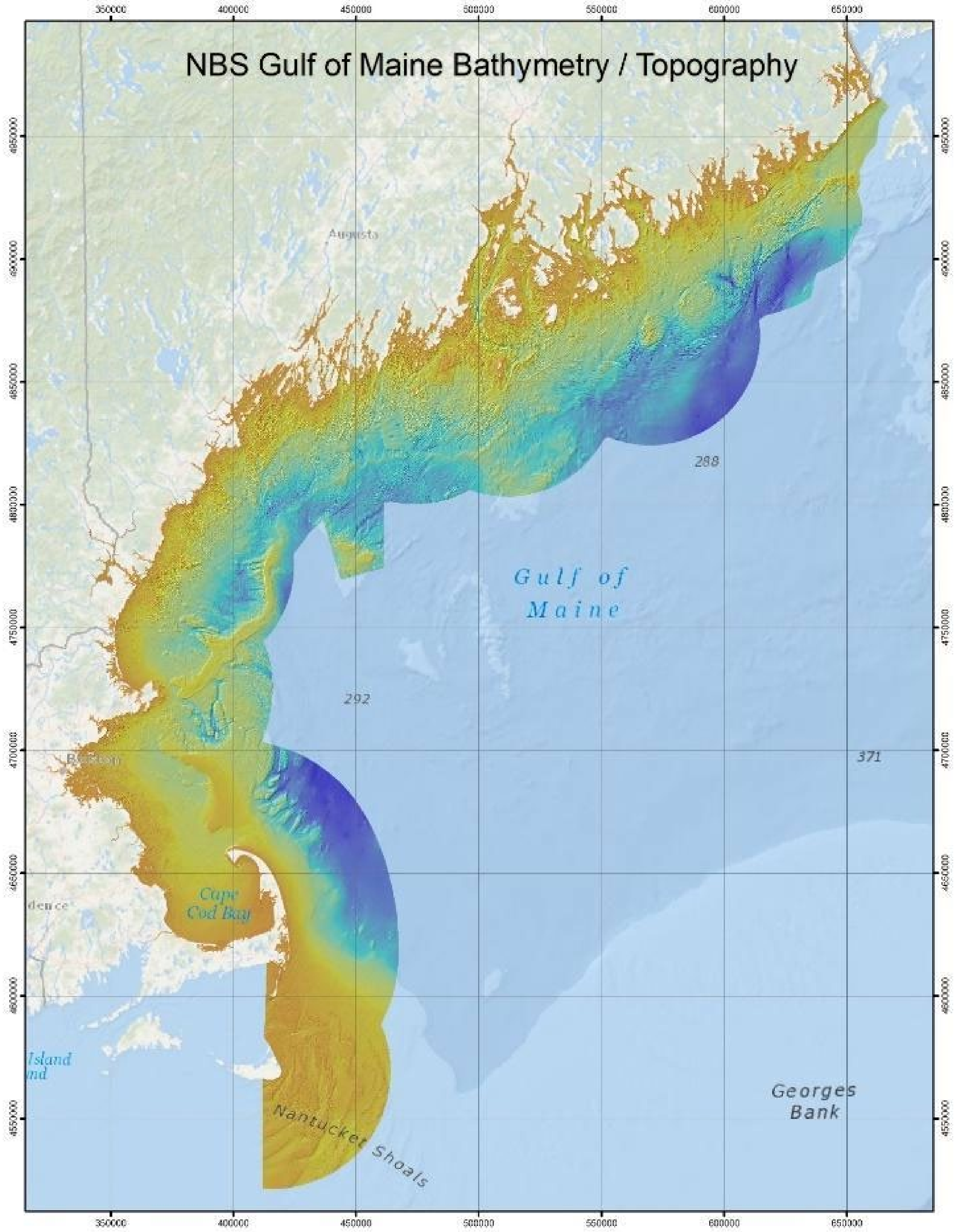


Figure 2. GOM Project Area with NBS Bathymetry/Topography (8-meter)

2.2 Uncertainty Data/Preliminary Confidence Levels

While portions of the GOM have been surveyed using modern, high-resolution bathymetry systems, large areas remain where the only survey data available were from low density single-beam echosounders, or even lead lines. Some areas have no digital bathymetry survey data at all.

The OCS-provided uncertainty data co-located with the elevation data provided a quantitative estimate of the accuracy of each cell in the elevation surface. The uncertainty values were based on the equipment used, the age of the survey, and the level of interpolation used to determine the cell elevation.

A preliminary confidence level area map was generated to visualize the data by uncertainty/confidence quality. An acceptance threshold grid, calculated as:

$$5.0 - (0.1 * \text{elevation})$$

was created to represent a margin (in meters) of an acceptable difference between the uncertainty and elevation data. This equation was developed based on International Hydrographic Organization (IHO) standards for hydrographic surveys (IHO 2020), Table 1, containing Minimum Bathymetry Standards for Safety of Navigation Hydrographic Surveys. Values from the table were modified to reflect the range of quality of the NBS elevation data. Refer to Section 1.4 and Appendix A (separate document) for ArcGIS Pro tools used to generate the preliminary 2-class uncertainty/confidence layer (NBS_CONFIDENCE_PRELIM) depicted in Figure 3.

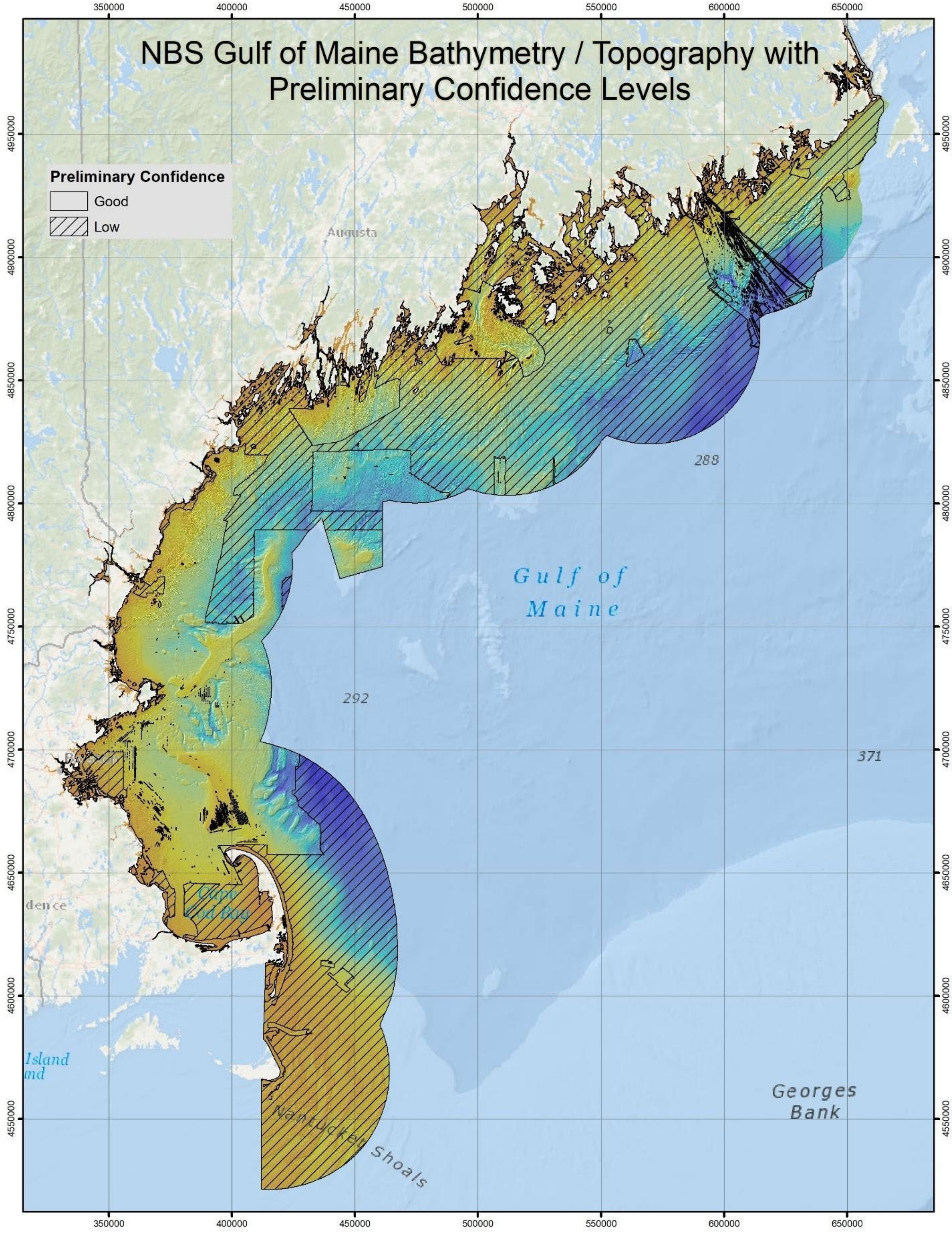


Figure 3. Bathymetry/Topography with Preliminary 2-Class Confidence Levels

2.3 Additional Uncertainty Data/Supplemental Confidence Levels

As methods were being explored to delineate additional target CMECS classes, the need for a third class for “medium” confidence became apparent. While exploring methods to delineate a pockmark field in Belfast Bay, Maine, which is described in detail in Section 4.7, a review of the uncertainty data showed areas of relatively dense single-beam echosounder data that provided well-defined topography for part of the pockmark field and distorted definition in adjacent parts of the field where there was less dense sounding data. Since the Belfast Bay pockmark area appeared to have been surveyed with fairly dense single-beam rather than full coverage multibeam data, and had initially been classified as low confidence, the updated medium confidence level was used to select data for subsequent processing. This additional class limited the data for analysis to those areas that did not appear to have a distorted representation of the seafloor.

In both areas, the NOAA uncertainty raster showed scattered points with very low uncertainty values, presumably the locations of individual soundings. These were surrounded by areas of much higher uncertainty, presumably in the grid cells containing interpolated data. Because many more cells had high uncertainty values, the entire areas were classified by the original confidence algorithm as low confidence data. Refer to Figure 4 showing the final confidence level data.

The 4-meter and 8-meter resolution tiles were processed separately to maintain the low uncertainty values where the measured soundings were assumed to have occurred. Refer to Appendix A (separate document), steps g through q, for ArcGIS Pro tools used.

A fourth uncertainty class was identified in the final stages of the tool development process. In some areas, particularly off the ME coastline, resultant geoforms were extremely distorted and/or displayed in a radiant pattern (Figure 4). These distorted/radiant patterns were produced in areas where very little to no data were available in the source data. The fourth class, aptly named “No Data”, clearly delineates areas where no reliable geoform data can be produced.

Figure 5 shows the distribution of the four confidence levels in the project data.

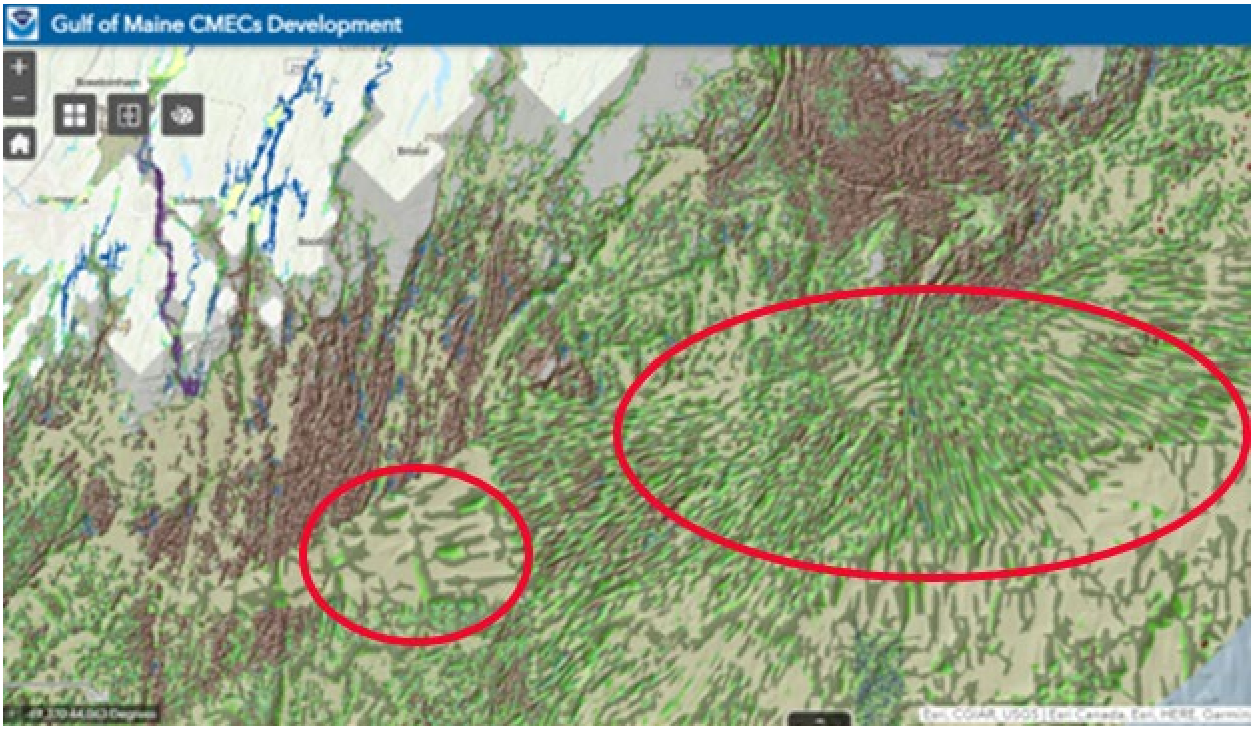


Figure 4. Areas of No Data Displayed in Geoforms Layer

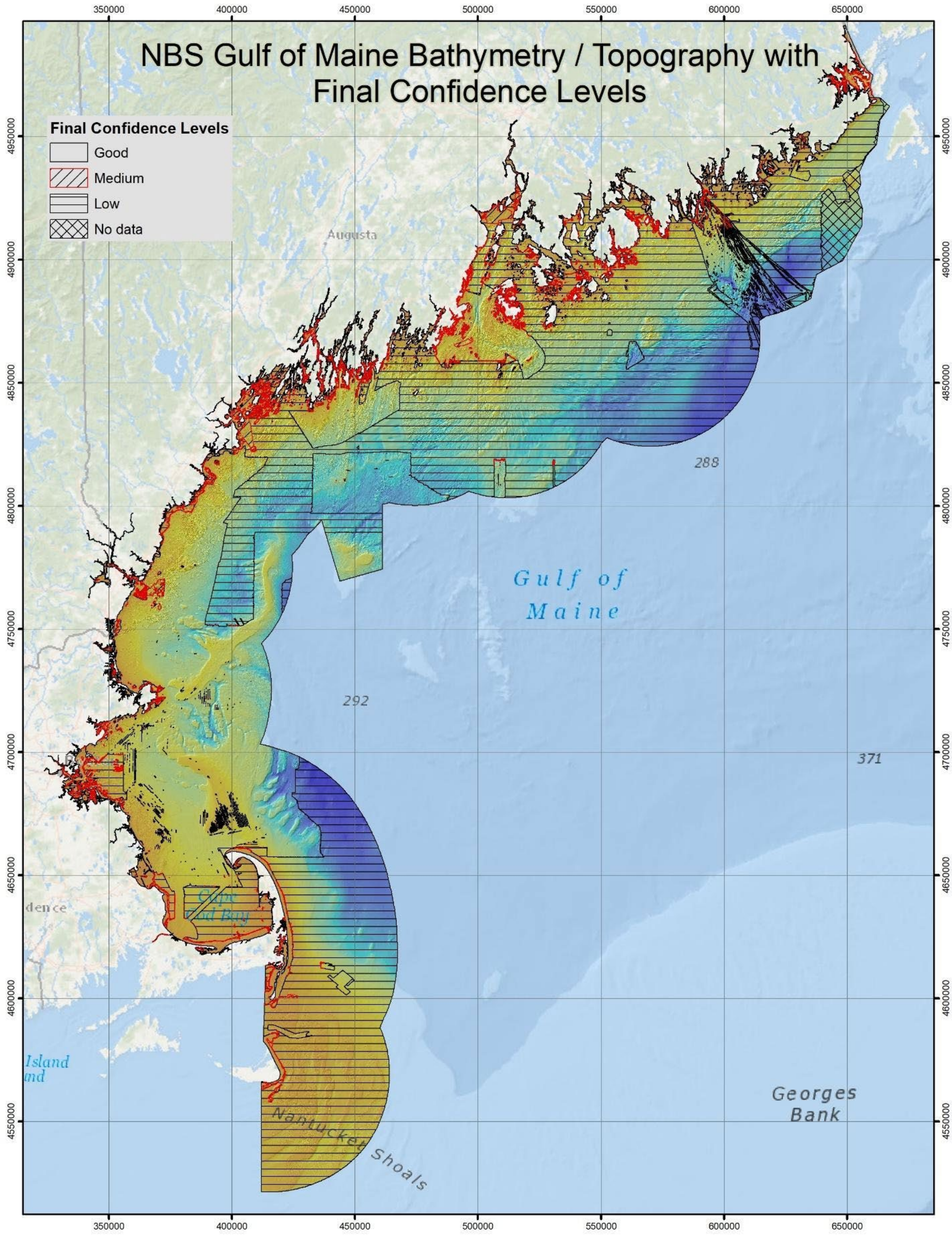


Figure 5. Bathymetry/Topography with Final Confidence Levels

3.0 BRESS ANALYSIS

One of the leading applications for classifying bathymetry DEMs into geomorphons/landforms is the BRESS software. This software processes the DEM and produces a set of non-overlapping classes of seafloor feature types. There is an option in the software if bottom reflectivity derived from sonar imagery is available to further segment the classes. However, bottom reflectivity, or backscatter, data were not available across the entire footprint of this project. Prior to processing a dataset, the operator selects the number of output classes (shown in Table 1), the inner and outer radii for processing based on the size of features of interest, and a flatness angle based on the anticipated slopes in the area to be processed.

Table 1. BRESS Classification Options

BRESS Classification Options				
Classes	**4 Class**	**5 Class**	**6 Class**	**10 Class**
Pit				X
Valley	X	X	X	X
Foot slope			X	X
Concave Slope				X
Slope	X	X	X	X
Convex Slope				X
Shoulder			X	X
Ridge	X	X	X	X
Peak		X		X
Flat	X	X	X	X

3.1 Processing Sensitivities

The inner and particularly the outer radii affect the size of the processing output classes and should be based on a consideration of the sizes of the features of interest. Figure 6 shows the bathymetry surface of the Kennebec Pilot Area of Interest and two processing results from BRESS with large differences in the inner and outer radii used. With the larger radii, individual class areas tend to become larger, and some flats bounded by areas of higher elevation are reclassified as valleys.

Note: BRESS requires data within the outer radius in all eight directions to return a result. This means the resulting classification matrix will be truncated at data boundaries such as shorelines or other data boundaries. To ensure that the full area of interest is classified, a buffer of additional data greater than or equal to the outer radius must be included with the input elevation DEM.

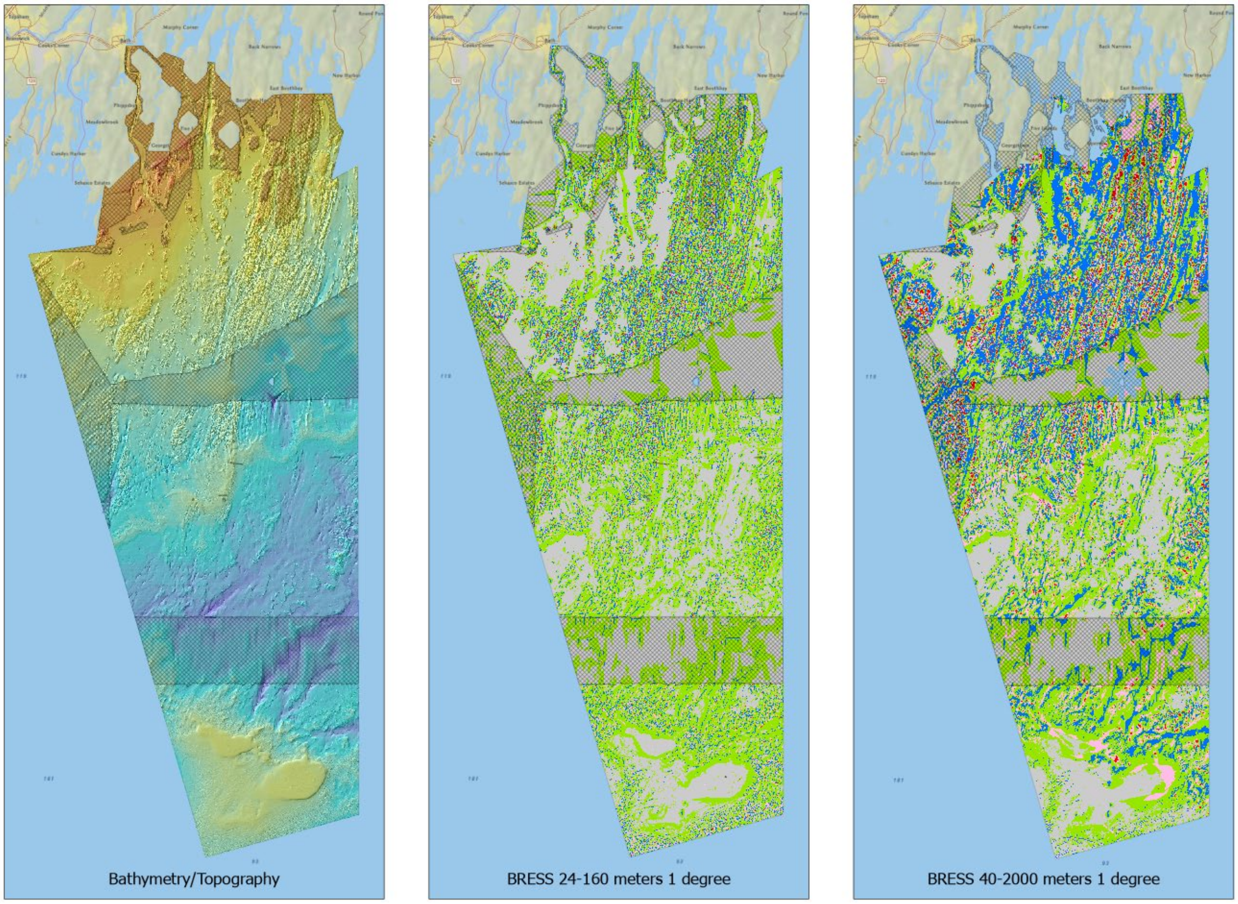


Figure 6. Kennebec Elevations and Comparative BRESS Processing Results

Figure 7 provides a closer view of the northern portion of the Kennebec Pilot Area of Interest. The classification area sizes increase with longer radii, and classifications change (e.g., several areas classified as flats with the shorter radii are classified as valleys with the longer radii). As described in the preceding note, the resulting classification raster with the longer outer radius loses a significant amount of coverage along the shoreline.

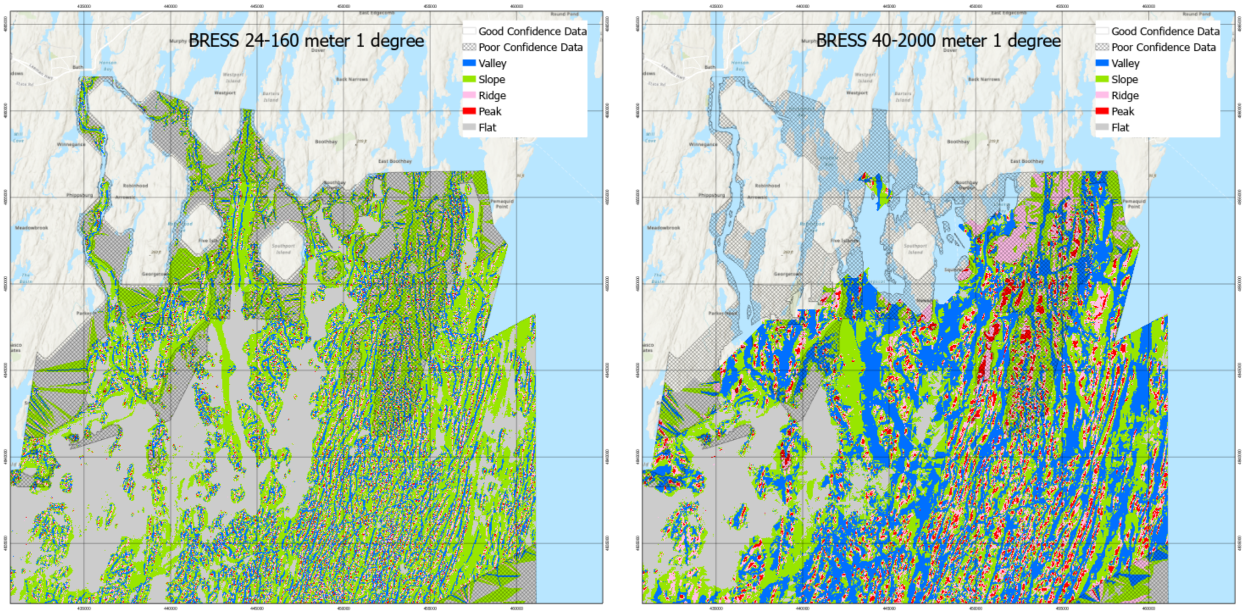


Figure 7. Kennebec North BRESS Processing Comparison

The other primary setting for BRESS processing is flatness angle, the sensitivity to slope. Figure 8 shows the processing results with the same inner and outer radii but flatness angle settings from 0.5 to 3 degrees. A smaller flatness angle makes BRESS more sensitive to smaller slopes and lower levels of vertical relief in the terrain. Increasing the flatness angle results in more areas being classified as flat. With a BRESS flatness angle of 5.0 degrees (results not shown), the great majority of the area is classified as flat.

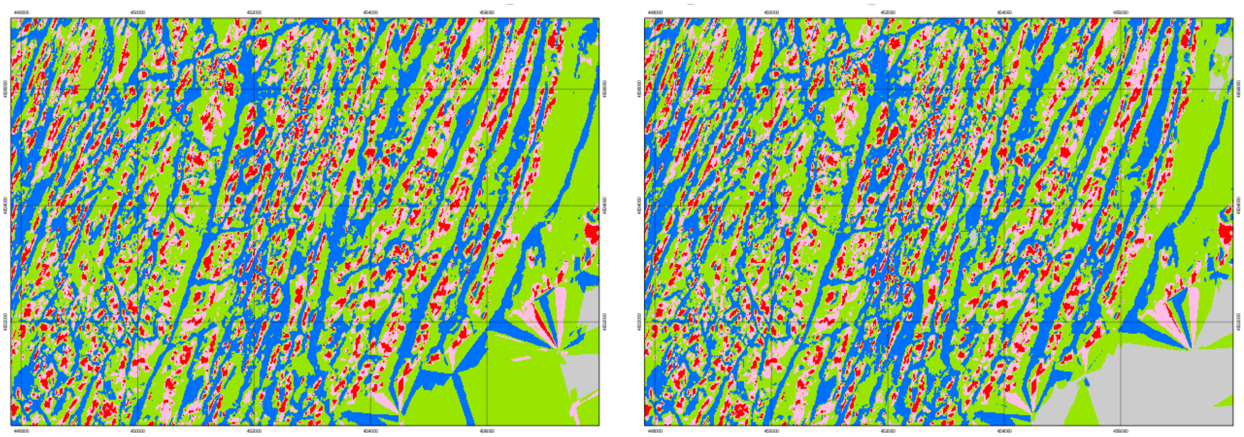
Based on a consensus agreement with NOAA and State Partners, a set of parameters was used for the entire GOM project area. Refer to Appendix A-2 (separate document) for the BRESS workflow that shows input parameters.

Parameters used for mapping small features:

- Inner radius: 16 meters
- Outer radius: 200 meters
- Flatness angle: 1.5 degrees
- Output classes: 4

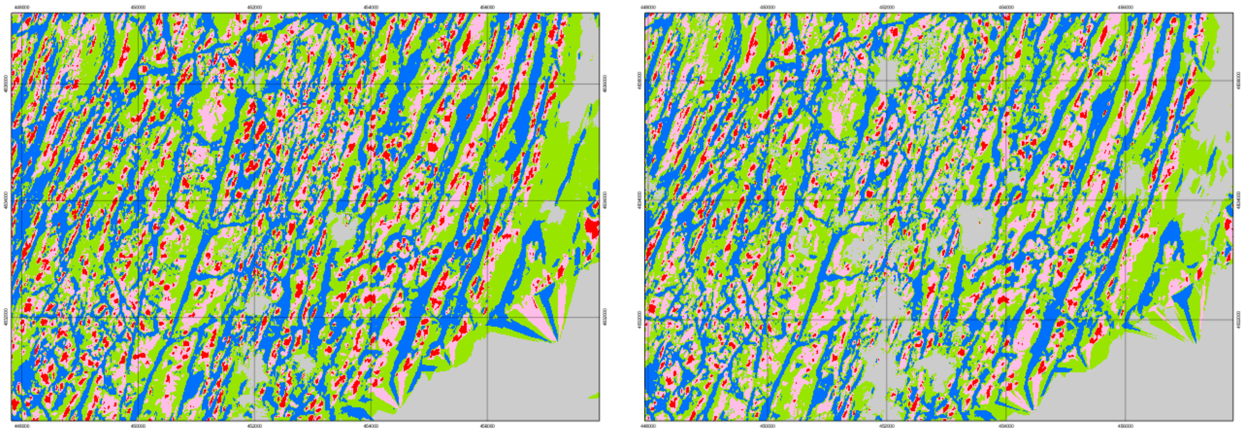
Parameters used for mapping large features:

- Inner radius: 16 meters
- Outer radius: 1500 meters
- Flatness angle: 1.5 degrees
- Output classes: 4



BRESS 40-400m 0.5 degree

BRESS 40-400m 1.0 degree



BRESS 40-400m 2.0 degree

BRESS 40-400m 3.0 degree

Figure 8. Comparison of BRESS Results with Different Flatness Angles

4.0 CMECS CLASSIFICATION OF TARGETED FEATURES

The CMECS catalog was designed to provide standardized terminology for ecological units. Geological features are captured in the Geoform component of CMECS, which describes the physical structure of the environment across multiple scales. OCM and State Partners identified target CMECS classes within the CMECS Standard that were of particular interest or relevant to their planning needs.

4.1 Evolution of CMECS Classes

As one of the key goals of this project was automation, Tetra Tech worked to develop a methodology to automate the delineation of the target CMECS classes so that this delineation would be repeatable and not reliant on or subject to individual interpretation. The automated methods developed for the delineation of some of the target classes are provided in the following sections of this report. For some of the classes, automated delineation could not be reached with the current bathymetric dataset and within the time frame of this project. Some of the classes were removed entirely from the list of target classes as they were not considered to be achievable within the project timeframe, and others required some amount of manual interaction (please refer to Section 4.9). Tetra Tech worked with OCM and State Partners to refine the target CMECS class list and outline the approach to each. The final list of target classes was provided to OCM as a project deliverable and a simplified version of this table is provided in this report in Appendix B (separate document).

4.2 BRESS Output—Crests, Depressions, Flats, and Slopes

The initial approach to determining CMECS classes within the project area was to process with BRESS, then use a developed “crosswalk” tool to aggregate/convert the BRESS classes into CMECS classes. After trying several processing techniques to classify some types of features and evaluating options for conversion of BRESS classes, additional specific tools were identified that more accurately and reliably classify some specific features. However, the 4-class BRESS output did provide a general framework for classifying the bathymetry into some of the geoforms.

The small feature 4-class BRESS output was mainly used for determining flat areas. The other BRESS categories of ridge, slope, and depression were retained as definitions for areas where none of the other CMECS classifications could be determined. The BRESS output category “ridge” was renamed to “CREST” to remove any confusion with the existing CMECS classification named “ridge.” The “CREST” designation was also a better description for the type of features that were mapped by BRESS. “CREST” was also used as a criterion for defining rocky zones, as described in Section 4.4.

Post-processing notes:

After converting the BRESS .asc file to a polygon feature class, add an attribute called “BRESS4” and calculate the values based on the table below:

gridcode	BRESS4
1	FLAT
3	CREST
6	SLOPE
9	DEPRESSION

4.3 Rises

“Rise” is a suggested new CMECS classification that represents low, natural hills of unspecified origin. These hills were discovered during the process of determining rocky zone locations. All rocky zones are considered rises, but not all rises have the texture characteristic of rocky zones. After consulting the State Partners, it was determined that these low-relief hills should be retained as a new CMECS feature because they could prove useful for future planning purposes.

Rises were mapped using the ArcGIS Pro ArcHydro tool called Topographic Position Index (TPI), found in the Terrain Preprocessing sub-toolbox. The TPI tool compares the elevation of each cell in a DEM to the mean elevation of a specified neighborhood around that cell. The output includes negative values (areas below the mean elevation) and positive values above 0 (areas above the mean elevation) as well as “0”, which represents areas of no difference from the mean. Within the GOM project area, a neighborhood size (Length) of 200 and a circular moving window model type were used. After reviewing the polygons with values greater than 0, it was determined that some of these polygons contained a high percentage of flat area. To identify those mostly flat areas, the percentage of flat area was calculated for each polygon. Then, only those polygons that were less than 90 percent flat and greater than 20,000 square meters (m^2) were selected and classified as “Rise.” Refer to Figure 9 below, which shows the type of polygons that were dropped.

Refer to Appendix A-3 (separate document) for detailed information about the workflow and tools used.

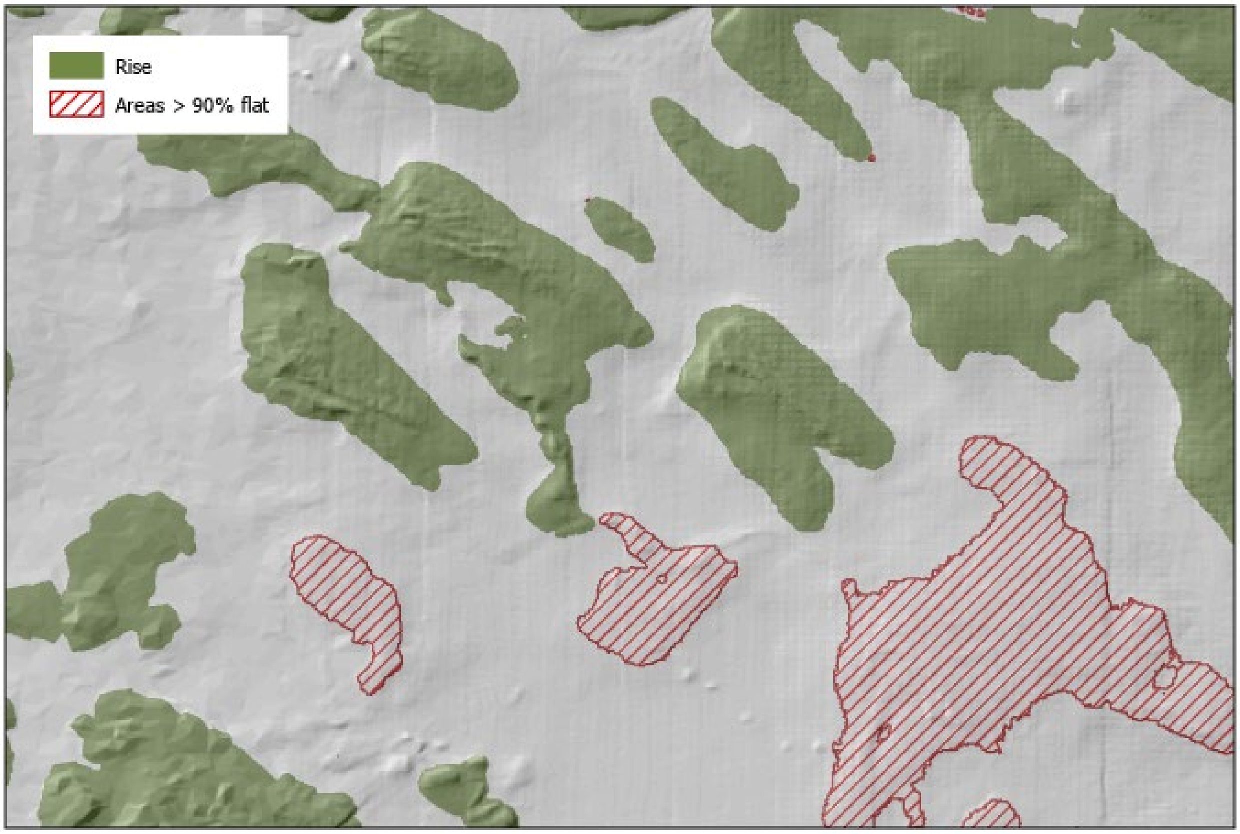


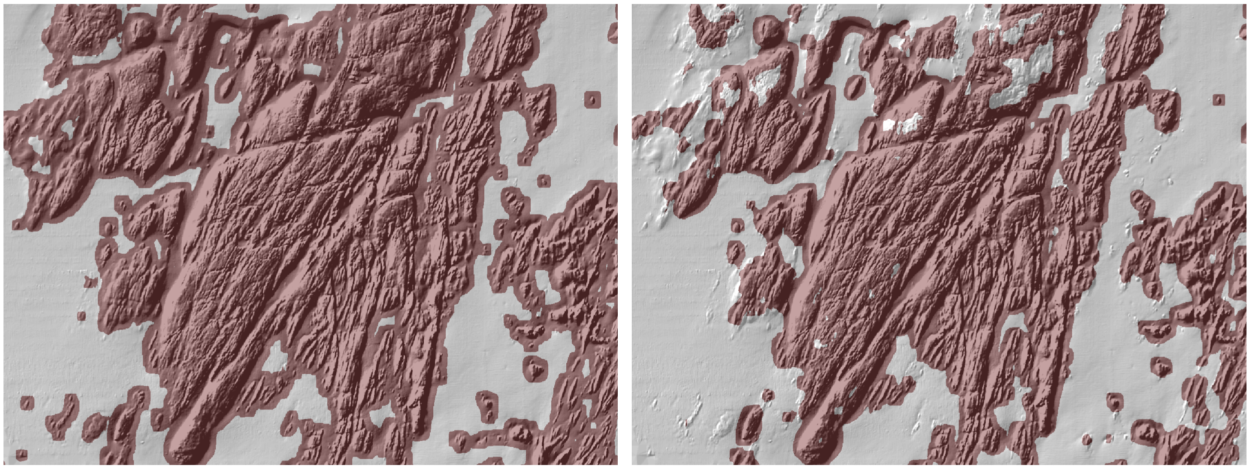
Figure 9. Development of Rise Classification

4.4 Rocky Zones

“Rocky Zone” is similar to the CMECS classification “Rock Outcrop” in that both refer to areas that include exposed bedrock. However, the definition has been expanded to include a more generalized area that captures some of the area between the exposed bedrock as well as the area surrounding the exposed bedrock. Figure 10 shows a potential rocky zone with bathymetry.

Figure 10. Potential Rocky Zone

These areas are mapped using the ArcGIS Pro ArcHydro tool called Vector Ruggedness Measurement (VRM), found in the Terrain Preprocessing sub-toolbox. The VRM tool provides a way to measure terrain ruggedness as the variation in three-dimensional orientation of grid cells within a neighborhood. Slope and aspect are captured in a single measure and used to decouple terrain ruggedness from just slope or elevation. The output values are a ruggedness number ranging from 0 (flat/smooth) to 1 (most rugged/bumpy). Within the GOM project area, a neighborhood (Window Size) of 25 was used. This value was large enough to ensure that small, isolated areas were not created and small enough to keep the values from bleeding too far into the flat areas. While developing the methodology for the individual pilot areas, it was decided that using some derivation of the standard deviation of the data worked best for splitting out the "bumpy" vs "smooth" areas of the rocky zone. Initially, VRM greater than 1/10th the standard deviation appeared to be an appropriate break point but when applied to the entire GOM project area, too much area was classified as rocky zone. Refer to the examples in Figure 11 that compare the VRM output using different reclassification breaks.

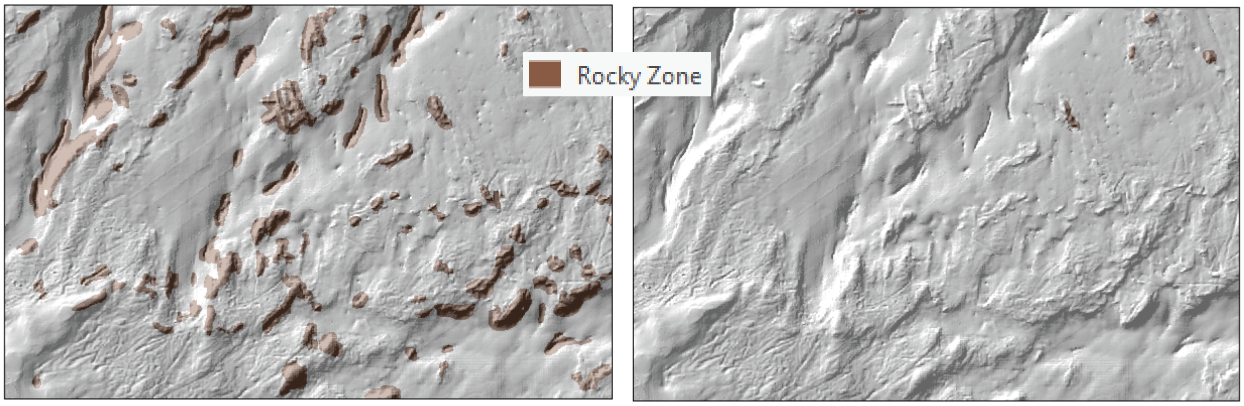


VRM > 1/10th Standard Deviation

VRM > ½ Standard Deviation

Figure 11. Comparison of VRM Output Using Different Reclassification Breaks

Upon further examination of the VRM data greater than ½ standard deviation, areas of steep slopes and depressions were also classified as rocky zone. To remedy this, polygons that did not have at least 10 percent of the area as “CREST” were dropped. Refer to the before and after comparison in Figure 12. An example of the final Rocky zone layer is shown in Figure 13. Refer to Appendix A-3 (separate document) for detailed information about the workflow and tools used.



Before Rocky Zone steep slopes and depressions are dropped.

After Rocky Zone steep slopes and depressions are dropped.

Figure 12. Before and After Comparison of Rocky Zone

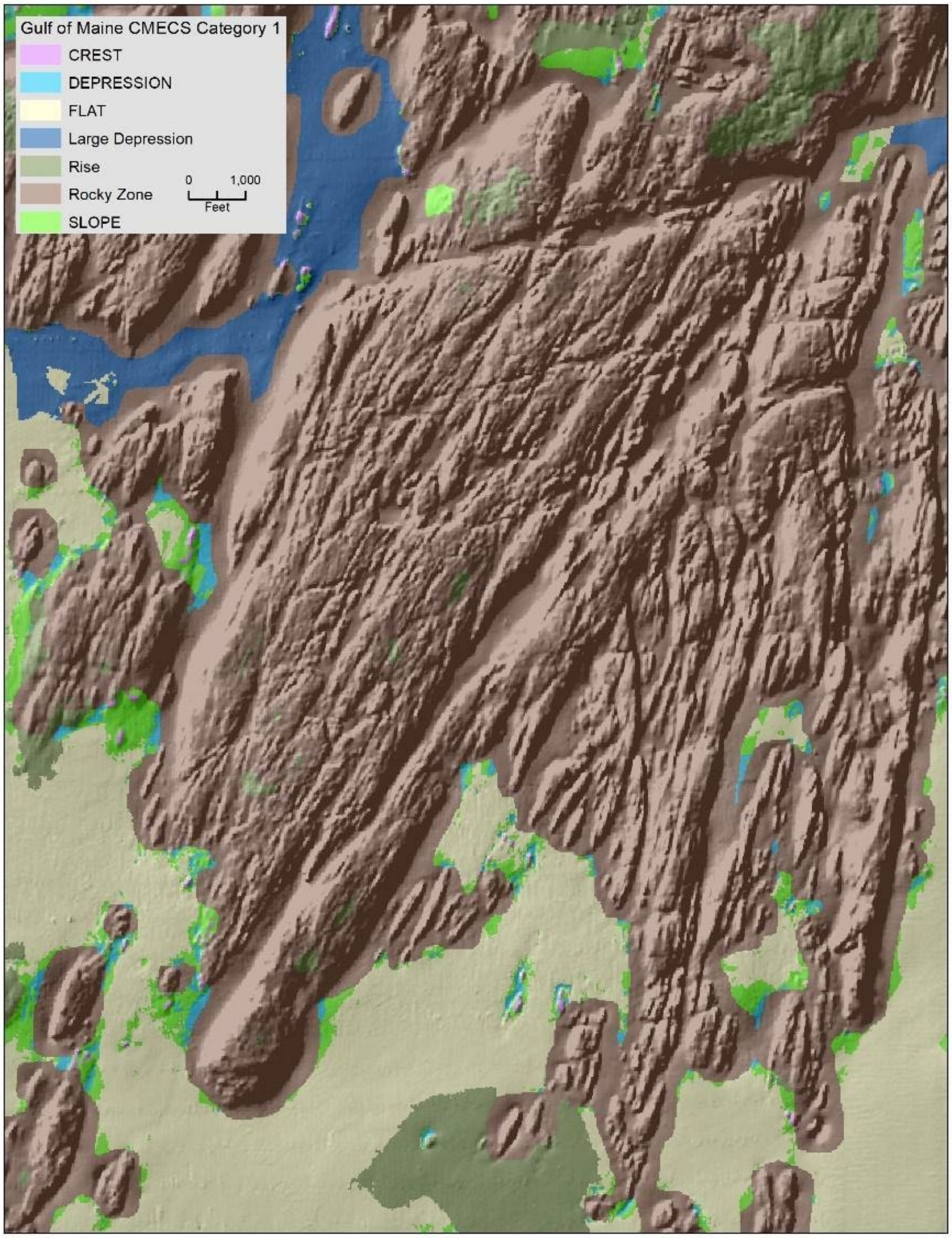


Figure 13. CMECS Category: Rocky Zone

4.5 Large Depressions

“Large Depression” is a new CMECS category that was born out of the attempts to map CMECS category “Valley.” While the CMECS definitions are similar, it was determined by the State Partners that “Valley” as defined by CMECS was not a classification that could be consistently mapped in the GOM project area. Figure 14 shows an area that could be classified as a large depression, but not necessarily a valley.

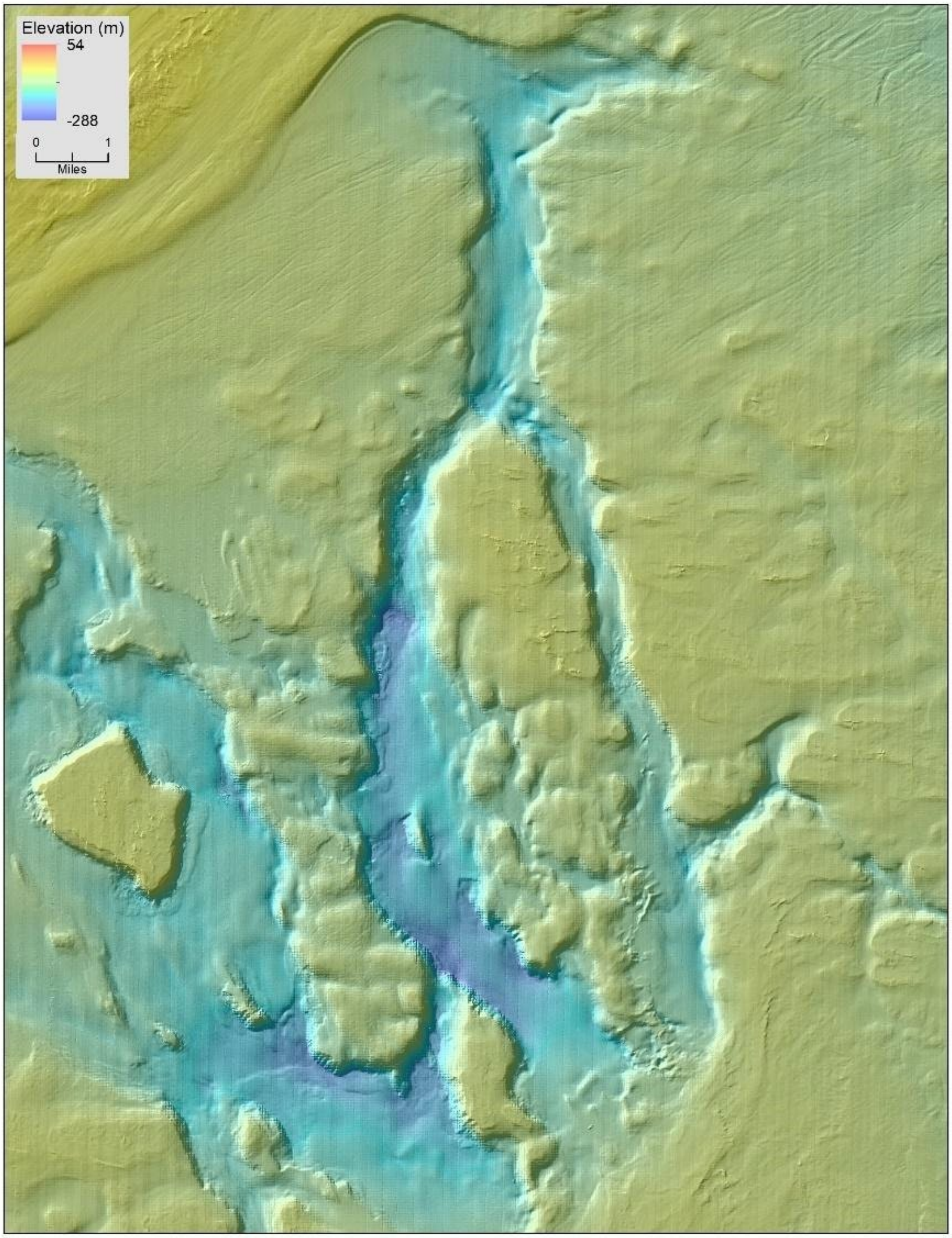


Figure 14. Potential Large Depression

Large, linear depressions were successfully mapped using BRESS with an outer radius of 1,500 meters. After this 1,500-meter, 4-class BRESS output is converted to polygons, depressions (gridcode = 9) greater than 1,000,000 m^2 are selected as a starting point. Once rocky zone areas are erased and the polygon layer is converted to singlepart features, the remaining features greater than 500,000 m^2 are selected and saved as “Large Depressions.” The size parameter of 500,000 m^2 was selected after visual inspection of the data. Refer to Figure 15 below which depicts the area with large depressions among the other CMECS categories. Refer to Appendix A-3 (separate document) for detailed information about the workflow and tools used.

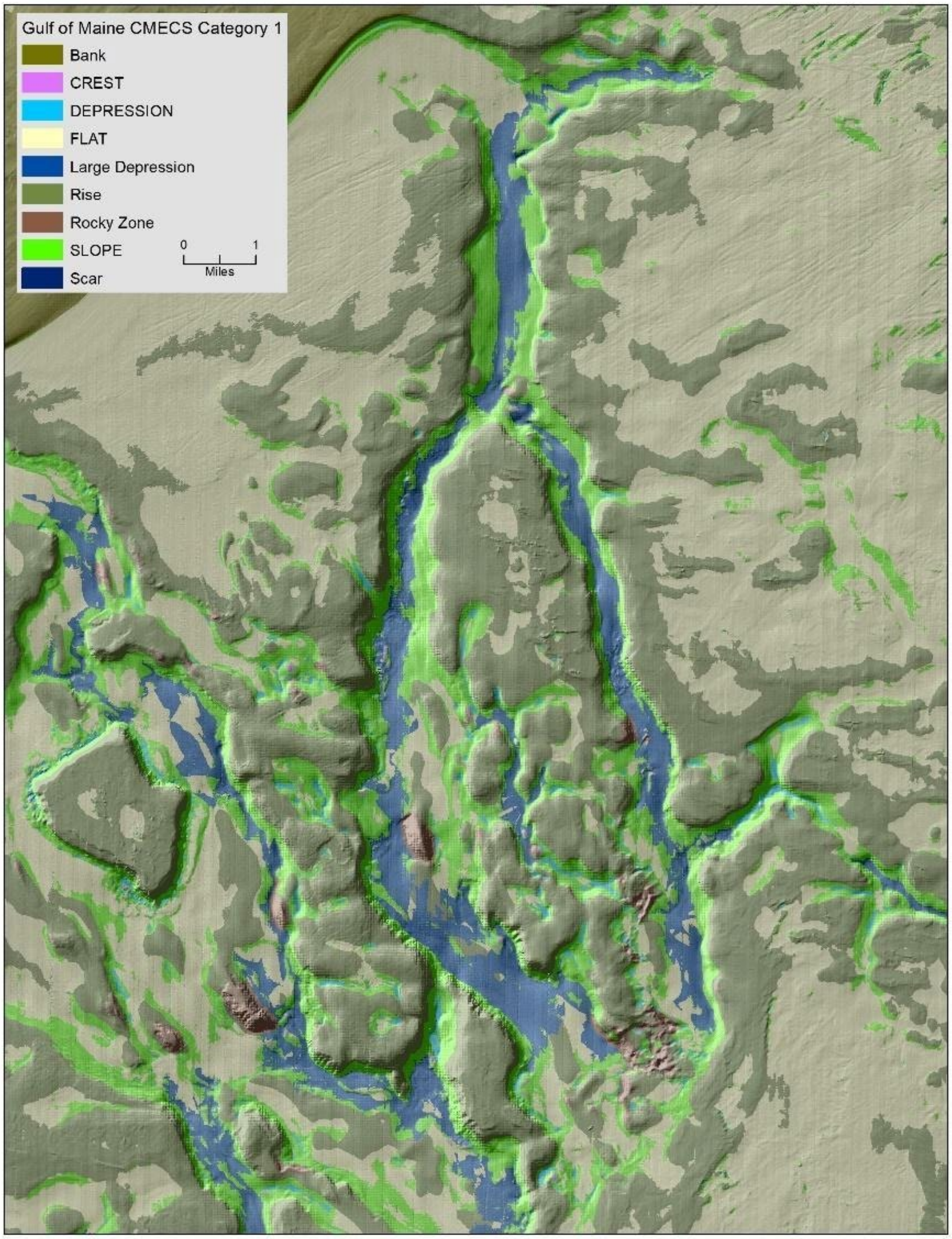


Figure 15. CMECS Category: Large Depression

4.6 Scars

"Scar" in the GOM project area is represented as a gouge on the surface that has been removed by abrasion or impact. These features appear in large clusters of gouges (refer to Figure 16). Thus, these areas were initially mapped as a density of features and the depressions within the resulting area are s labeled as "scar."

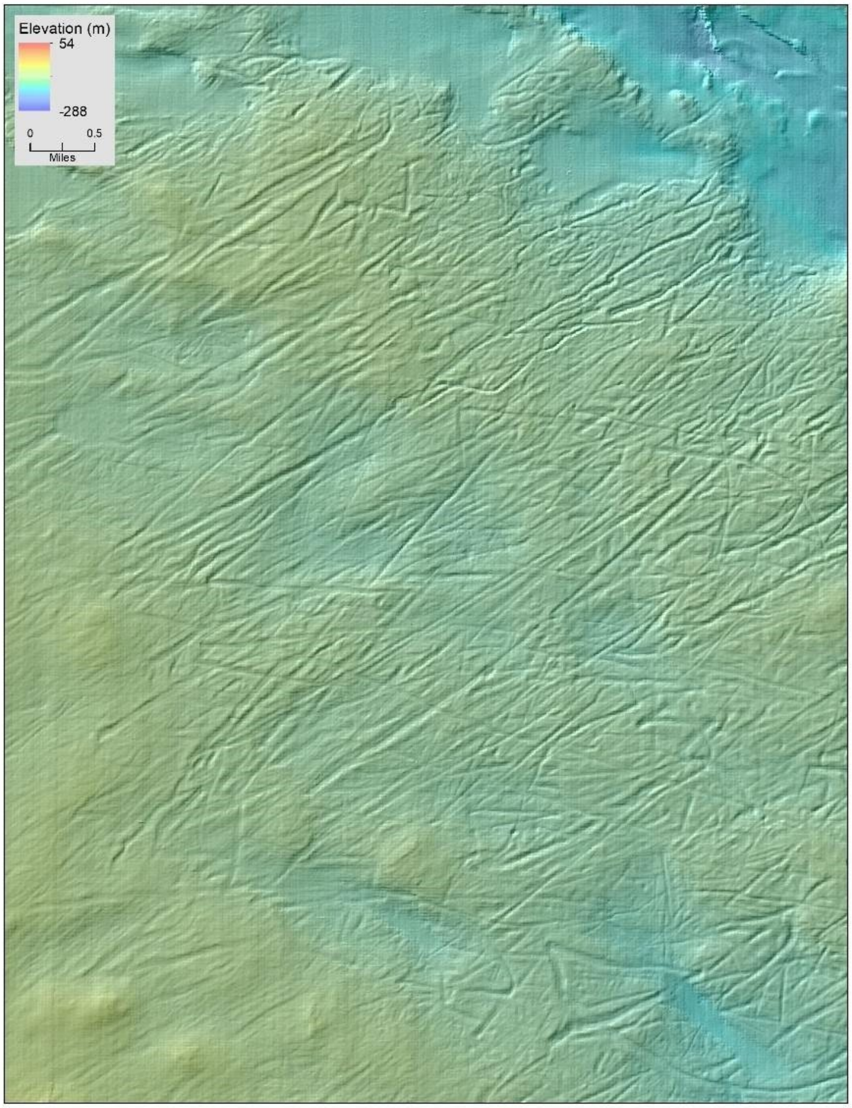


Figure 16. Potential Scars

Scars were mapped using BRESS with an outer radius of 200 meters. After the 4-class BRESS output is converted to polygons, depressions (gridcode = 9) greater than 1,000 m^2 are selected as a starting point. The Minimum Bounding Geometry tool is run on these selected features. By using the “Rectangle by area” geometry type option, the polygon drawn around the individual features would be tight to the area enclosing the feature. Also, the box to add geometry characteristics as attributes is checked. To isolate the more linear shaped features, calculate a length to width ratio (LEN2WIDTH_RATIO) equal to MBG_Length / MBG_Width. Another important geometry characteristic to use is MBG_Orientation. Within the GOM project area, the linear depressions potentially related to scars generally had an orientation between 30 and 90 degrees. After selecting features with a LEN2WIDTH_RATIO > 2.5 and MBG_Orientation > 30° and MBG_Orientation < 90°, these linear features were then converted to points (All vertices). Once the point features that overlapped the rocky zone layer were removed, the Point Density tool (Spatial Analyst) was then run with an Output cell size of 8, and a circle neighborhood of

2,000-meter radius. The area units of the output density values were Square map units. The resulting point density output was then reclassified into two categories of 0–2.1 and greater than 2.1. All areas with values greater than 2.1 were then converted to polygons. These polygons (scar fields) were used as the basis to select all depressions from the BRESS 4-class 200-m output. These selected depressions were then saved as a feature class of scars, as seen on Figure 17. Refer to Appendix A-3 (separate document) for detailed information about the workflow and tools used.

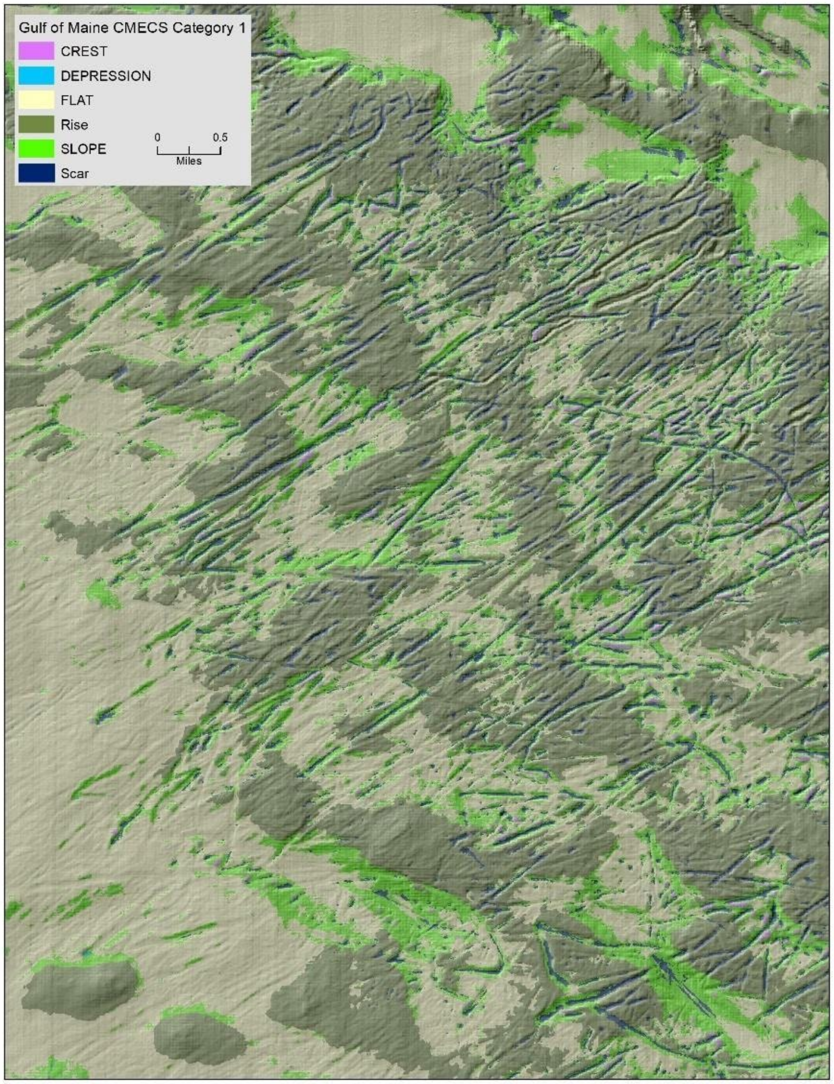


Figure 17. CMECS Category: Scar

4.7 Pockmarks/Pockmark Fields

The GOM project area includes multiple areas that the United States Geological Survey has identified as natural gas fields. In several areas, the most prominent being in Belfast Bay, fields of pockmarks, depressions created by escaping natural gas, are readily visible in the bathymetry data, as seen on Figure 18.

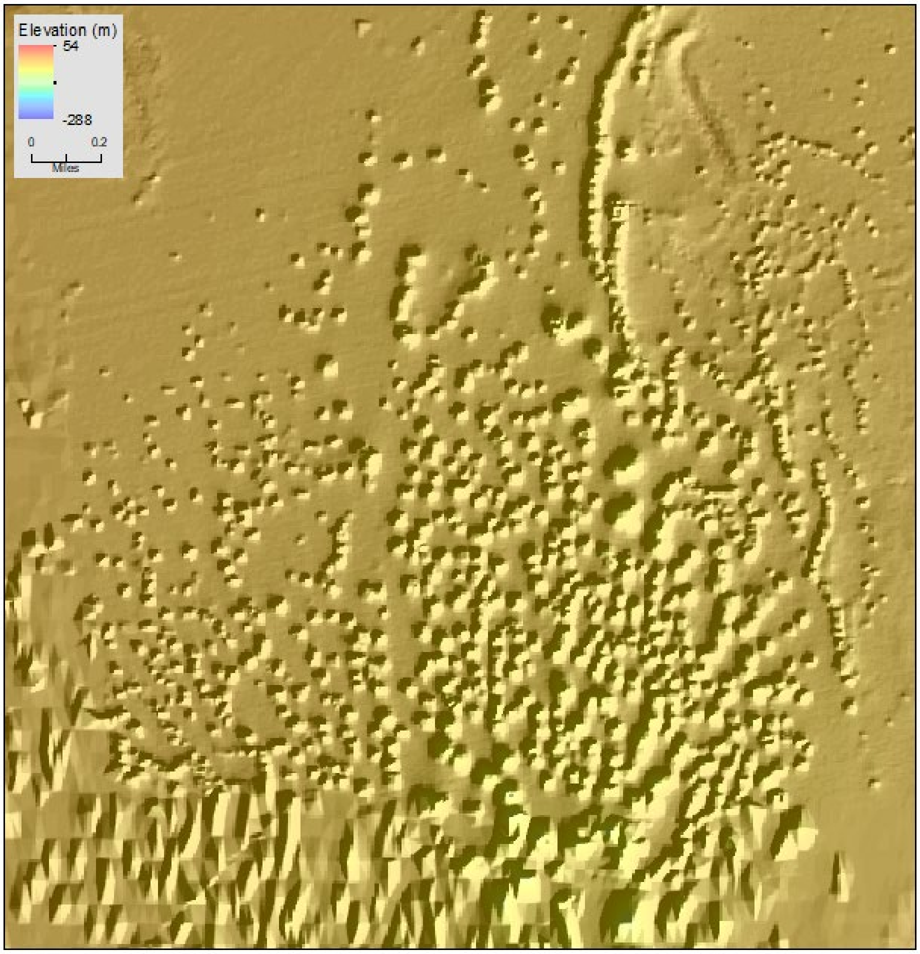


Figure 18. Potential Pockmarks/Pockmark Field

They are mapped using the ArcGIS Pro ArcHydro tool TPI. The TPI tool compares the elevation of each cell in a DEM to the mean elevation of a specified neighborhood around that cell. The output includes negative values (areas below the mean elevation) and positive values above 0 (areas above the mean elevation) as well as “0”, which represents areas of no difference from the mean. Within the GOM project area, a neighborhood size (Length) of 25 and a circular moving window model type was used. The data were then reclassified into a two-category layer, breaking on the value -2. All values less than or equal to -2 were selected and evaluated for circularity. Polygons with circularity values greater than 0.5 and area greater than 1,000 m^2 were selected. Circularity was calculated as follows:

$$4 * \pi * \frac{Shape\_Area}{Shape\_Length * Shape\_Length}$$

These small circular features were then converted to points and the point density tool used. The point density tool output was reclassified into a two-category layer, breaking on a value of 8.5 points per square kilometer. All areas greater than 8.5 were saved as pockmark fields. The previous small circular features within the pockmark field polygons were saved as pockmarks.

Figure 19 shows the pockmarks within the pockmark field. Refer to Appendix A-3 (separate document) for detailed information about the workflow and tools used.

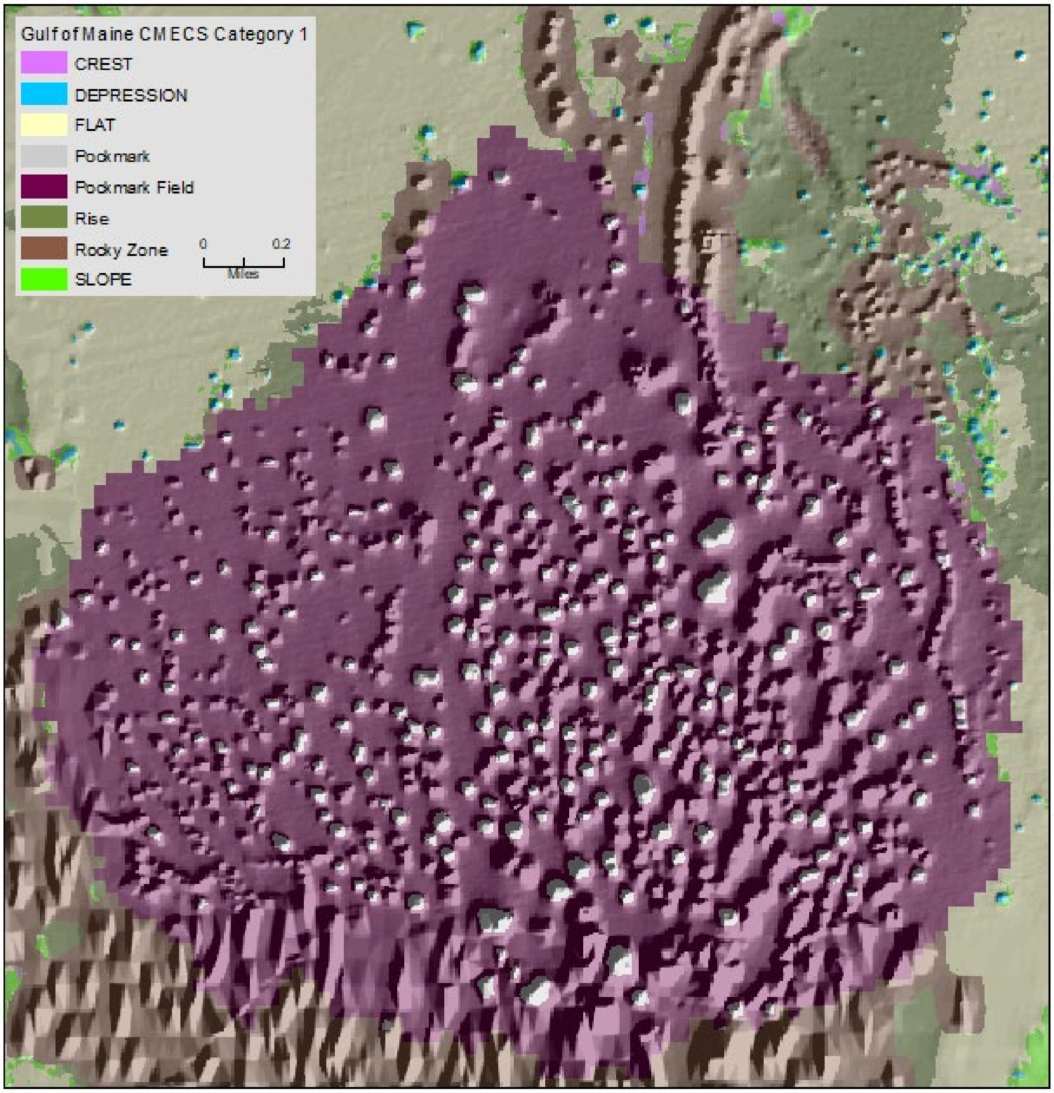


Figure 19. CMECS Categories: Pockmark and Pockmark Fields

4.8 Sediment Wave Fields

“Sediment Wave Fields” in the GOM project area appear as areas of wave-like bedforms in sand that are formed by the action of tides, currents, or waves (Figure 20) These clusters of wave-like bedforms are mapped based on the density of the bedforms. These bedforms range from centimeters to meters in size and can be oriented in many different directions, which makes automated delineation of these features challenging.

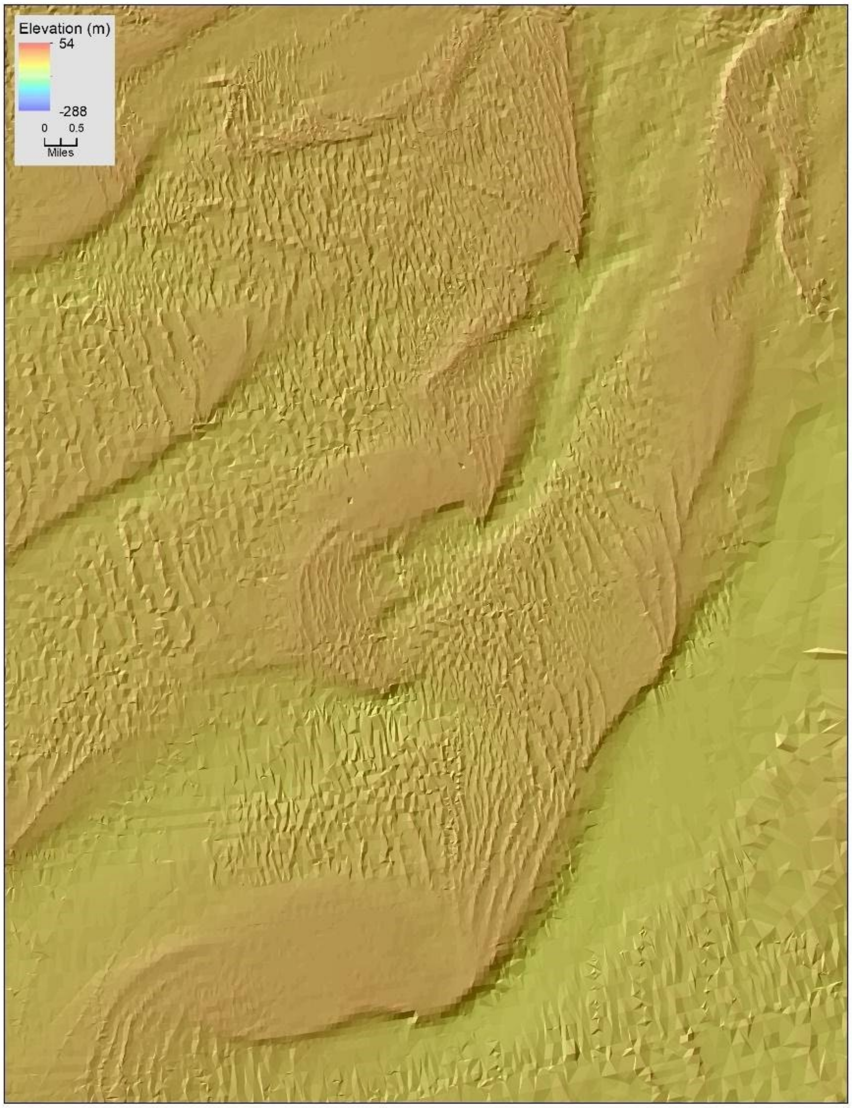


Figure 20. Potential Sediment Wave Fields

The process for mapping Sediment Wave Fields is very similar to delineating the scar classification except in this case values above 0 are used as the starting point. These areas are mapped with the ArcGIS Pro ArcHydro tool Topographic Position Index (TPI), using a neighborhood size (Length) of 11 and a circular moving window model type. The results are reclassified into a 2-category layer with a break point at 0 and converted to polygons. All values representing TPI greater than 0 are selected, clipped to the project boundary, and converted to singlepart features. The Minimum Bounding Geometry tool is run on these features, using the "Rectangle by width" geometry type option. This option ensures that the polygon drawn around the individual features would be the rectangle of the smallest width enclosing an input feature. Also, the box to add geometry characteristics as attributes is checked. Any features that overlap scar fields or rocky zones are deleted from the layer. Then, a length to width ratio (LEN2WIDTH_RATIO) equal to MBG_Length / MBG_Width is calculated. Features with LEN2WIDTH_RATIO > 2.5 and MBG_Length < 500 and Shape_Area > 1000 are selected, which isolates the more linear features, and then these selected polygons are converted to lines. The next step is to calculate the distribution of the attribute MBG_Orientation using Statistics in the attribute table. The distribution chart shows which orientation is the best range of values to select for calculating the line density. For example, refer to Figure 21 which shows the distribution of MBG_Orientation.

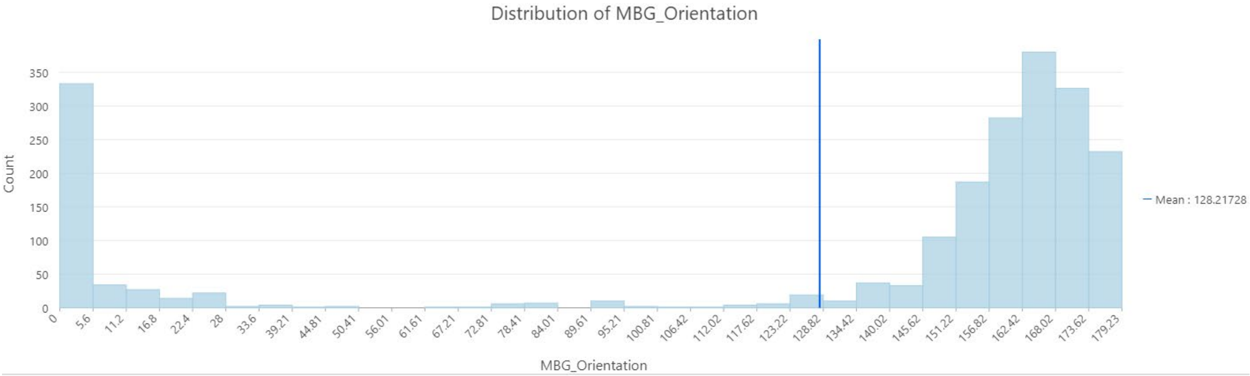


Figure 21. Distribution of MBG_Orientation values

Based on the distribution above, selecting MBG_Orientation > 140 would provide the most comprehensive results for the line density. The Line Density tool was run on the selected features, using an 8-meter cell size, 1000-meter search radius, and output units in square kilometers. The reclassification break point used was 2.0. Once the data are converted to polygons, the polygons with gridcode = 2 were selected and saved as sediment wave fields. Small areas of “false” sediment wave fields were selected manually and deleted from the feature class (Figure 22). Refer to Appendix A-3 (separate document) for detailed information about the workflow and tools used.

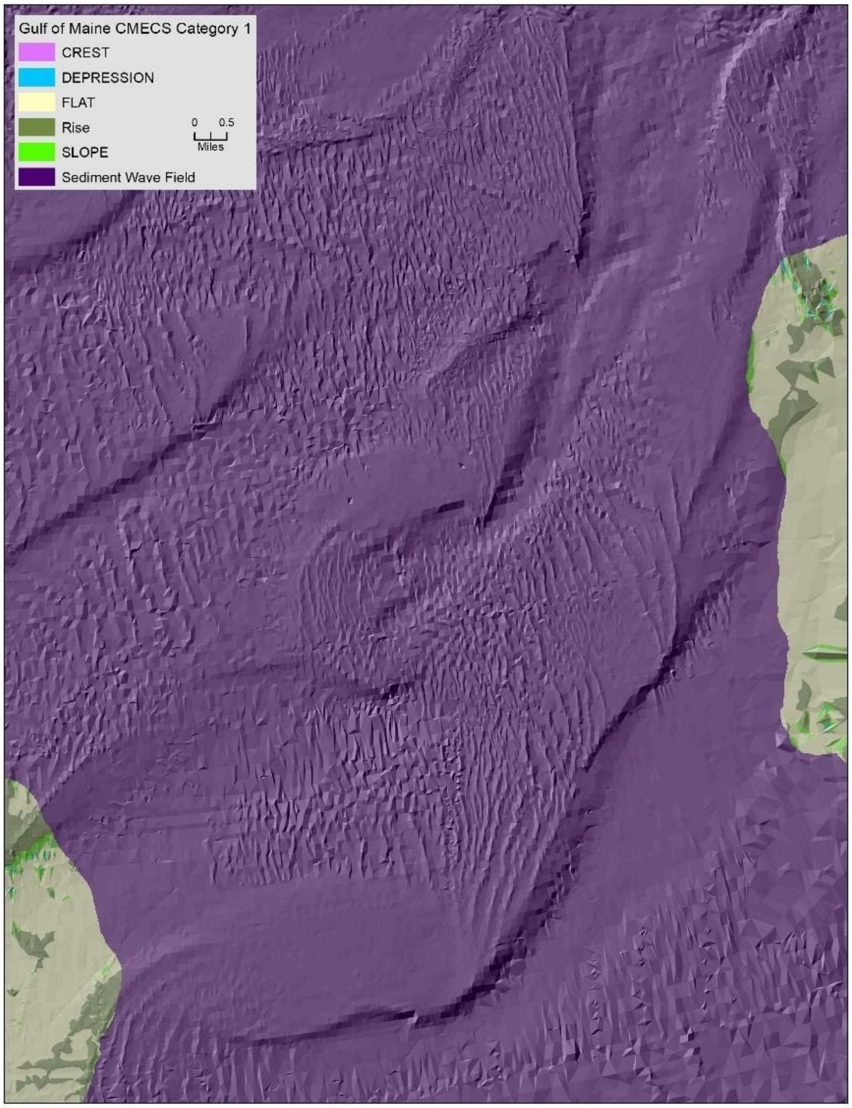


Figure 22. CMECS Category: Sediment Wave Field

4.9 Manual Segmentation

The two target CMECS classes that were delineated using a combination of automated methods and manual interpretation were banks and basins. Some minor, manual manipulation was also needed to delineate a pockmark field, as described in Section 4.7 and sediment wave fields, as described in Section 4.8.

While banks and basins were apparent in the bathymetry, their boundaries were poorly defined along at least some portion of the feature, making automated delineation extremely difficult. Features in these two classes are regional (large) and relatively unchanging and therefore considered appropriate for manual interpretation. The boundaries of these features may be further modified by others based on individual interpretation and/or additional information as it becomes available. A combination of automated tool exports and manual interpretation was used to delineate these features.

4.9.1 Banks

Banks are defined in CMECS as “an elevated area above the surrounding seafloor that rises near the surface. Banks generally are low-relief features, of modest-to-substantial extent, that normally remain submerged. They may have a variety of shapes and may show signs of erosion resulting from exposure during periods of lower sea level. Banks tend to occur on the continental shelf” (FGDC 2018). Excellent examples of banks in the GOM project area are Stellwagen Bank, Jeffreys Ledge and Platts Bank, recognizable by their distinct, relatively flat tops. While the shoreward facing slope of these flat-topped features are relatively steep and clearly defined, the generally seaward facing slopes tend to be more gradual and indistinct. As the banks tend to be relatively static features and challenging to automated methods because of the difficulty defining the feature limits using automated tools, a combination of derivative tools and interpretation was needed.

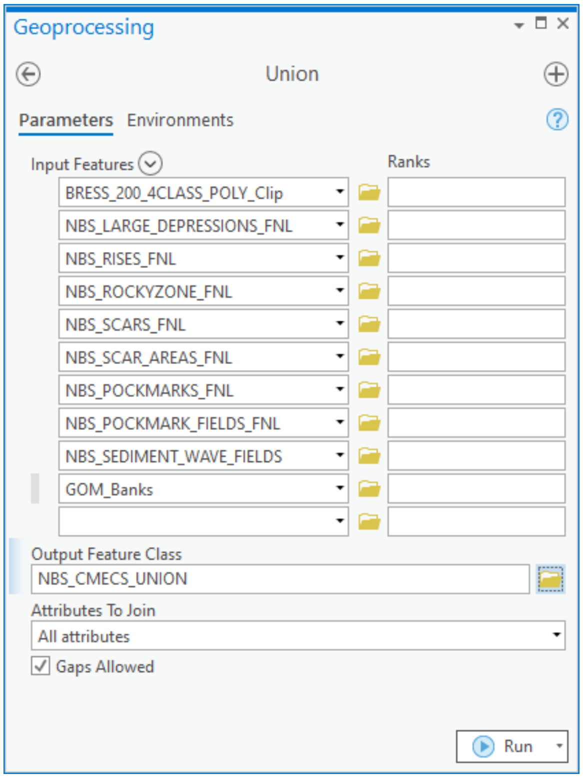
Slope derived from the bathymetry using the Surface Parameters tool in the ArcGIS Pro Spatial Analyst toolbox was used to delineate the boundaries of the banks defined by the steep slopes. A break at 1° nicely defined the base of these steep slopes. Bathymetric contours created from the bathymetric grid were used to delineate the outer, less defined limits of the banks. The selection of the delimiting contour was subject to interpretation and a different contour was used for each bank. For example, the 45-meter contour was selected to define the seaward boundary of Stellwagen Bank, the 70-meter contour was used for Jeffreys Bank and the 85-meter contour was used for Platts Bank. These boundaries could be adjusted as new bathymetric data are acquired or additional information is gathered that provides other criteria for defining the bank boundary.

4.9.2 Basins

Basins were delineated manually using a combination of published data, slope derived from the bathymetry using the ArcGIS Pro Spatial Analyst Surface Parameters tool with a break of 1 °, and interpretation of the bathymetric data. In Uchupi and Bolmer, 2008, the authors provided bounding bathymetric contours for several basins in the project area (Scantum, Tillies, Stellwagen, Little Stellwagen, Platts, Murray and Wilkinson, Matinicus, Jordan, and Jeffreys). These basins were plotted using the NBS bathymetric contours and then were overlaid on the bathymetric grid and slope derivative and modified to better represent the current basin. As with the banks class, these features may be refined as additional data are gathered

5.0 FINAL OUTPUT

The CMECS layers created in Section 4 need to be merged to resolve some overlapping features. For the most part, these features can stand on their own but because some of the layers were created with different neighborhood sizes or were manually created, overlapping features can occur. Before merging the layers, it is recommended to add an attribute to each layer that is calculated to the layer name. For example, add the attribute CMECS_CAT1 to rises and calculate that attribute = “Rise.” After adding/calculating each layer, union the layers together (don’t forget to include banks). If following the workflow in Appendix A-3 (separate document), the tool will look like this:



Input Features
BRESS_200_4CLASS_POLY_Clip
NBS_LARGE_DEPRESSIONS_FNL
NBS_RISES_FNL
NBS_ROCKYZONE_FNL
NBS_SCARS_FNL
NBS_SCAR_AREAS_FNL
NBS_POCKMARKS_FNL
NBS_POCKMARK_FIELDS_FNL
NBS_SEDIMENT_WAVE_FIELDS
GOM_Banks

Ranks

Output Feature Class
NBS_CMECS_UNION

Attributes To Join
All attributes

☑ Gaps Allowed

Then, add an attribute called “GOM_CMECS_CAT1.” This attribute will resolve the overlapping features issue by using a hierarchy of data layering to calculate the values. The calculations must be done in the order below for the best results.

1. Calculate GOM_CMECS_CAT1 = BRESS4 (from the BRESS polygon layer).
2. Select CMECS_CAT1* = ‘Rise’ and calculate GOM_CMECS_CAT1 = CMECS_CAT1.
3. Select CMECS_CAT1* = ‘Rocky Zone’ and calculate GOM_CMECS_CAT1 = CMECS_CAT1.
4. Select CMECS_CAT1* = ‘Large Depression’ and calculate GOM_CMECS_CAT1 = CMECS_CAT1.
5. Select CMECS_CAT1* = ‘Scar’ and calculate GOM_CMECS_CAT1 = CMECS_CAT1.
6. Select CMECS_CAT1* = ‘Rocky Zone’ and CMECS_CAT1 = ‘Scar field’ and calculate GOM_CMECS_CAT1* = ‘Rise.’
7. Select CMECS_CAT1* = ‘Sediment Wave Field’ and calculate GOM_CMECS_CAT1 = CMECS_CAT1.
8. Select CMECS_CAT1* = ‘Pockmark Field’ and calculate GOM_CMECS_CAT1 = CMECS_CAT1.
9. Select CMECS_CAT1* = ‘Pockmark’ and calculate GOM_CMECS_CAT1 = CMECS_CAT1.
10. Select CMECS_CAT1* = ‘Bank’ and calculate GOM_CMECS_CAT1 = CMECS_CAT1.

**The CMECS_CAT1 attribute will be named CMECS_CAT1_1, CMECS_CAT1_12, CMECS_CAT1_12_13 etc. but have an alias of CMECS_CAT1. Be sure to select the* *correct CMECS_CAT1 field that represents the feature type you are assigning to GOM_CMECS_CAT1.*

To capture the smaller BRESS features within each of the category 1 classifications, add an attribute called “GOM_CMECS_CAT2.” Calculate this attribute = GOM_CMECS_CAT1 + “: “ + BRESS4. The values will look something like this: “Bank: FLAT,” which denotes a flat area on a bank.

The last step is to dissolve the layer on GOM_CMECS_CAT1 and GOM_CMECS_CAT2 to create a final layer (Figure 23). Refer to Appendix A-3 (separate document) for detailed information about the workflow and tools used.

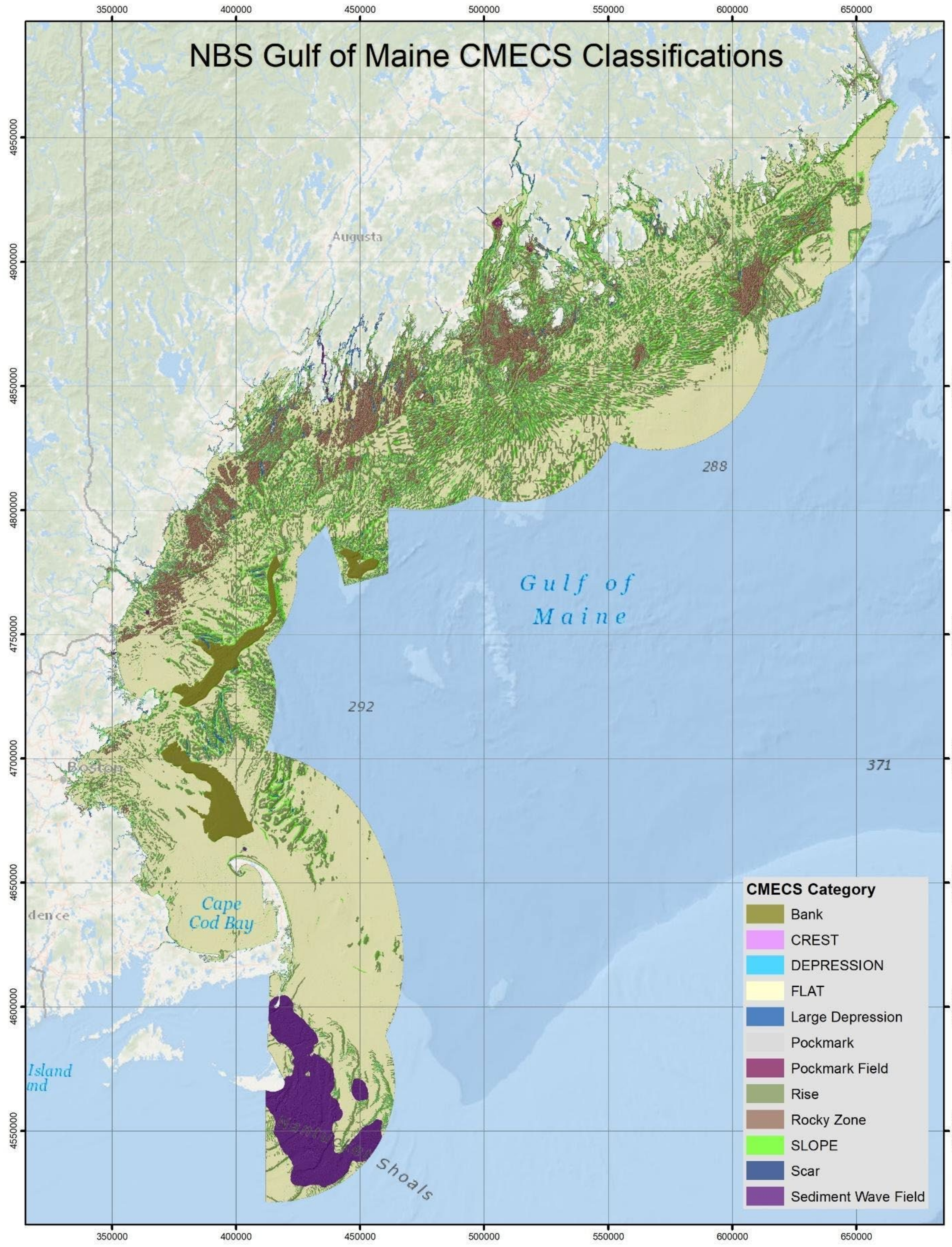


Figure 23. CMECS Category 1 Classifications

6.0 REFERENCES

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6.2 General References Used in Research

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