# Evaluation and Prioritization of Sand and Gravel Resources to Support Coastal Resilience Projects Along Portions of the New Jersey Coast

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# DISCLAIMER

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# Contents

## List of Figures



## List of Tables

# List of Abbreviations and Acronyms

| | |
|---|---|
| ASAP | Atlantic Sand Assessment Project |
| BOEM | Bureau of Ocean Energy Management |
| NJDEP | New Jersey Department of Environmental Protection |
| NJGWS | New Jersey Geological & Water Survey |
| OCS | Outer Continental Shelf |
| USACE | United States Army Corps of Engineers |

# 1 Introduction

New Jersey's coastline is a vital economic and ecological asset, supporting tourism, recreation, and natural habitats. However, it is increasingly vulnerable to rising sea levels, erosion, and storm surges, all of which threaten coastal infrastructure, beach ecosystems, and local economies. Beach nourishment remains a key coastal management strategy, requiring significant volumes of sand sourced from offshore borrow areas.

Offshore sand resource area prioritization will become critical for ensuring the long-term sustainability and efficacy of beach nourishment in New Jersey. These sand resource areas, located both in State waters and the Outer Continental Shelf (OCS), are generally non-renewable and are increasingly being depleted or deemed unusable due to proximity to essential fish habitat or offshore wind lease areas. Once sand deposits are depleted in State waters closer to shore, sand resources further offshore must be used, increasing environmental, logistical, and economic costs. Sand prioritization refers to the process of systematically identifying, evaluating, and ranking offshore sand resource areas based on geologic suitability, data availability, and alignment with coastal resilience needs. In the context of this report, it serves as a strategic framework to guide future geophysical and geological surveys by highlighting areas where sand resources are most critically needed, most promising for development, or most at risk of conflict with competing offshore uses. Strategically prioritizing how sand resource areas are utilized can help balance the competing needs for sand resources while minimizing impacts on marine habitats and addressing long-term demand.

Several factors guide the prioritization of offshore sand resources in New Jersey. First, the quality and compatibility of sand is critical. Sand must closely match the physical characteristics of native beach sand—such as grain size, texture, and composition—to ensure beach stability and reduce ecological disruptions. Compatible sand also supports beach-nesting species and minimizes the need for repeated maintenance. Sand resource areas often overlap with critical marine habitats, including migrating species, protected and endangered species, and fisheries. By focusing on areas with lower biological activity and scheduling dredging operations to avoid sensitive periods like spawning or migration seasons, the ecological impacts can be minimized.

Logistical factors, such as the proximity of borrow areas to nourishment sites, also play a significant role. Borrowing sand closer to the shore reduces transportation distances, which lowers fuel consumption, project timelines, and overall costs. However, as nearshore deposits are depleted, New Jersey will increasingly need to rely on more distant sand resources, which will come with greater logistical challenges. Additionally, cumulative impacts must be considered. Repeated dredging in the same locations can "armor" the resource, rendering it unusable even if it hasn't been depleted (Coor et al., 2018).

Finally, competing ocean uses must be considered. The OCS off New Jersey is in high demand for other activities, such as offshore wind energy development, telecommunications infrastructure, fishing and potential carbon sequestration projects. Sand resource area prioritization must be coordinated with these industries to avoid resource conflicts and ensure equitable access. Early collaboration and cross-sector planning are essential to address these overlapping interests while maintaining sustainable sand extraction practices.

New Jersey's proactive approach to managing sand resource areas has included comprehensive geological surveys and mapping initiatives to identify high-quality sand deposits while mitigating environmental risks. Partnerships with the Bureau of Ocean Energy Management (BOEM) and other stakeholders have been instrumental in developing long-term strategies for sustainable sand resource management. By addressing environmental, logistical, and multi-sectoral considerations, New Jersey can effectively prioritize offshore sand resource areas, ensuring the protection of its coastline while balancing ecological and economic needs.

The purpose of this study is to create a multi-use planning tool to assist in identifying and evaluating offshore sand resources to ensure the effective allocation of those resources and minimize environmental impacts. This report presents a strategic approach for prioritizing project areas by assessing key factors such as sand deficits, sediment quality, and environmental considerations. This study aims to address the following:

- Develop a sand resource site selection workflow to determine which project areas have the greatest need for sediment resources and where additional project planning can be focused.
- Utilize ArcGIS Pro to create a suitability model to identify, evaluate and rank offshore areas based on a defined set of criteria using available geospatial data. The model aims to identify offshore areas that exhibit physical characteristics favorable for sand resource development and provide a foundation to guide future survey efforts.
- Validate the suitability model and compare the output to a known subset of New Jersey Geological and Water Survey (NJGWS) identified offshore sand resource areas, geologic data and selected multi-uses areas.

Through collaboration with coastal experts, engineers, and local communities, the prioritization process can be tailored to address the unique needs and challenges of each coastal area, contributing to the preservation and enhancement of our beaches for years to come.

# 2 Methodology

New Jersey consists of approximately 130 miles of coastline along the Atlantic Ocean where sediment management projects occur. This study focuses on the development of a suitability model within an ArcGIS Pro framework to evaluate and rank areas based on defined sets of inputs. The primary objective is to provide a decision-making tool aiding government agencies and stakeholders in making informed choices regarding offshore sediment resources. First, a two-step decision matrix was developed to identify a focus area for this study and identify data and information gaps. Next, a suitability model was developed to identify offshore locations exhibiting physical characteristics favorable for potential resource development and identify where multi-use conflicts exist. Finally, the accuracy and reliability was evaluated to see how the model output aligned with an existing subset of core data and known sand resources.

While this framework and suitability model has been applied to address challenges specific to New Jersey, it is designed to be flexible and tailored to address the specific needs of different regions. Given project areas differ in available resources, specific needs, and stages of development, both the decision-making framework and suitability model offer a systematic approach to identify which areas require sand resources and where planning efforts should be focused. The development and workflows of these tools are adaptable, allowing for customization based on the unique requirements of each offshore region or project area.

## 2.1 Sand Availability and Needs Determination (SAND) Report

The U.S. Army Corps of Engineers (USACE) South Atlantic Division Sand Availability and Needs Determination (SAD SAND) study aimed to enhance coastal resiliency by addressing the region's current and future sediment demands, as well as identify resources available for beach nourishment projects (USACE, 2020). The SAD SAND study served as the foundation for identifying inputs for the suitability model to help assess regional sand needs. The study conducted by NJGWS derives several components of the SAND study as a basis for developing a site selection workflow and development of the suitability model (Table 1).

**Table 1. Inputs considered for site selection and development of the suitability model.**

| Inputs | | | | |
|---|---|---|---|---|
| Wind Lease Areas | Avoidance Areas (i.e. utilities, cables, wrecks, UXO) | Geological and Geophysical Density | Est. Sand Requirements/Needs (cy) | Est. Sand Resource Volume (cy) |
| Fishing Areas | Mean Grain Size | Overfill Factor | Heavy Minerals | Resource Area Category |
| Sensitive Fish Habitat | Shell Content | Munsell Color | Distance to Project | Water Depth |

These factors, derived in part from the USACE SAD SAND (USACE, 2020) study, include geologic, environmental, and spatial variables used to evaluate offshore sand resource potential and support project area prioritization.

## 2.2 Study Site Selection

The NJGWS team developed a decision-making framework to systematically rank USACE project areas in New Jersey, which now account for more than 90% of New Jersey's coastline (Bocamazo, 2025). The framework identifies project areas with the greatest need for sediment resources by evaluating key criteria, applying weighted importance to those criteria, and calculating a final score for each area. Organized into a two-part process, Tier 1 is a flow chart (Figure 1) to identify project areas of elevated concern due to limited data and resources, as well as competing demands for those resources. Tier 2 employs a weighted ranking system to score the project areas identified in Tier 1. A critical input for this process was a USACE-provided project assessment that listed active and planned beach fill project areas, along with their estimated sand needs and available volumes. This information directly informed the sand deficit calculations used in Tier 1 of the framework. Notably, the results of the site selection process aligned with project areas that showed significant sand deficits in the USACE spreadsheet, reinforcing the utility and accuracy of the prioritization approach.

### 2.2.1 Tier 1

The Tier 1 flow chart was designed to identify project areas that warrant prioritization by assessing sand deficits, multi-use constraints and potential sand resources proximal to a project area. The questions in this flowchart serve as a conceptual framework, allowing regions to customize the evaluation process to address specific needs and challenges unique to each region. This project focused on wind lease areas and planned export cable infrastructure given the pressing nature of offshore wind projects progressing at the time of this study. With multiple projects competing for resources and space in New Jersey, we outline our approach to selecting a study area for developing a suitability model. The flow chart may identify multiple project areas, which will be further refined through the Tier 2 evaluation.

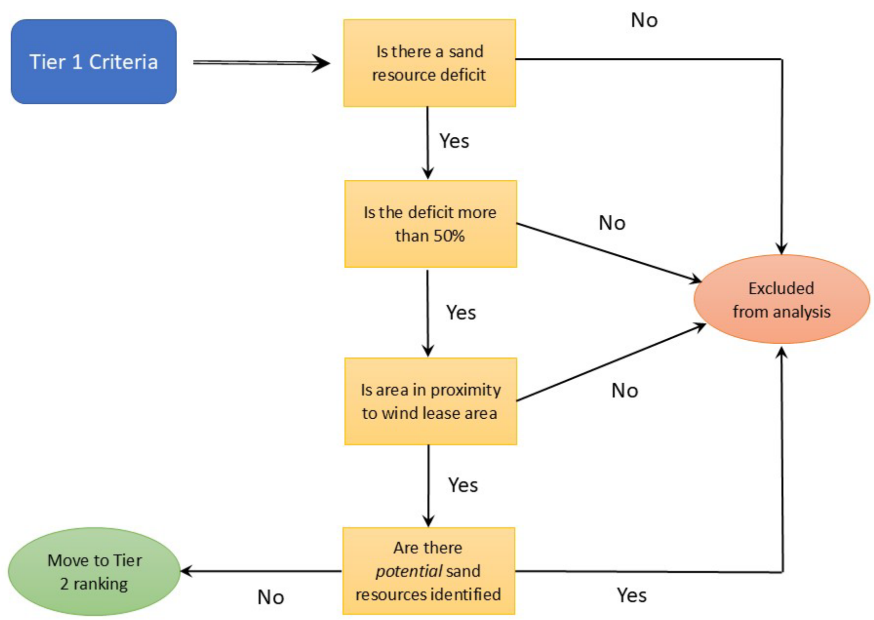


**Figure 1. Tier 1 decision-making flow chart used to screen USACE project areas for prioritization**
The flow chart assesses sand deficits, proximity to wind lease areas, and the presence of identified sand resources to determine whether a project area should advance to Tier 2 ranking and evaluation.

The flow chart is divided into four components:

- **Determine if there is a sand deficit**. A sand resource deficit is defined as having less cubic yards of identified sand than is needed for the replenishment of the area. If there is no deficit, the area should not be considered for sand prioritization. See Table 2.
- **Determine if the sand deficit exceeds 50%.** Having a deficit of more than 50% means there is less than half of the sand required for renourishment based on the anticipated need for the project and the identified sand volume. See Table 2. The equation utilized for this step is:

$$\% \, deficit = \frac{abs\{borrow \; area \; deficit\}}{(total \; quantity \; required)} \times 100$$

  For example, if a beach fill project required 3,000,000 $yds^3$ of sand and there were 1,000,000 $yds^3$ available, the deficit for the project would be -2,000,000 $yds^3$ and the % deficit of the project would be 66.6%. If the % deficit is less than 50% the area should not be considered for sand prioritization. If the % deficit is greater than 50%, the project area should be considered for evaluation.

- **Determine if the project area is in proximity to wind lease areas and associated infrastructure**. Is the project area in proximity to wind lease areas and infrastructure? Are project areas bounded by wind lease areas (hub.marinecadastre.gov c2025b)?
- **Determine if potential sand resources have been identified**. Potential sand resources are areas identified to contain beach-quality sand verified through reconnaissance-level geotechnical and geophysical data (USACE, 2020). The identification of these resources is based on the scope of available data for each project area.

**Table 2. Sand deficits and ratios for USACE CSRM project areas in New Jersey**

| Area | Need (N), cubic yards | Deficit (D), cubic yards | Ratio (N/D) | Percent Deficit |
|---|---|---|---|---|
| **Sea Bright to Loch Arbor** | 12,400,000 | -12,400,000 | 1.00 | 100.0 |
| **Asbury Park to Manasquan Inlet** | 10,560,000 | -8,060,000 | 1.31 | 76.3 |
| **Manasquan Inlet to Barnegat Inlet** | 11,532,000 | -10,571,000 | 1.09 | 91.7 |
| **Barnegat Inlet to Little Egg Inlet** | 9,500,000 | -6,500,000 | 1.46 | 68.4 |
| **Brigantine Island** | 1,872,000 | -441,548 | 4.24 | 23.6 |
| **Absecon Island** | 19,200,000 | -14,400,000 | 1.33 | 75.0 |
| **Great Egg Harbor Inlet to Peck Beach (Ocean City north)** | 8,576,000 | 768,965 | 11.15 | 9.0 |
| **Great Egg Harbor Inlet to Townsends Inlet (S end Ocean City)** | 6,448,000 | -3,269,749 | 1.97 | 50.7 |
| **Great Egg Harbor Inlet to Townsends Inlet (Ludlam Island)** | 16,380,000 | -12,880,000 | 1.27 | 78.6 |
| **Townsends Inlet to Cape May Inlet** | 0 | 0 | 0.00 | 0.0 |
| **Cape May Inlet to Lower Township to Cape May Point** | 8,800,000 | -7,500,000 | 1.17 | 85.2 |

This table applies sand deficits and ratios for each project area in New Jersey to determine which project areas warrant prioritization. See Figure 1.

### 2.2.2 Tier 2

Project areas identified through Tier 1 go through further evaluation where a weighted ranking system is applied to determine the best area that should go through the sand prioritization model workflow. In this stage, project areas are ranked based on a weighted scoring system, where each category includes specific criteria scored on a scale from 1 to 5. A score of 5 indicates the information available is optimal or that a strong degree of shared interest exists within the area. A score of 1 indicates limited, unavailable information or lack of shared interests. When the scoring is completed, an average of the scores is calculated to establish the final ranking. Because interpretations of these categories and scoring is somewhat subjective, it is recommended that a minimum of two individuals independently score each project area. The area of study will be selected from the 3-5 areas with the highest scores. Criteria and competing demands will vary based upon the needs of each State. Tables 3 and 4 provide the results of project evaluations.

- **Offshore Geophysical Data**
    - Question 1: Is there diverse geophysical data (i.e. seismic, magnetometer, sidescan, bathymetry) available and is it accessible? Consider State, Federal (e.g. ASAP, USACE), and Academic data.
    - Question 2: Is seismic data coverage over the specific area sufficient to identify resources, considering factors such as the desired level of detail, potential gaps or limitations, recent surveys or studies, and technological advancements? Is the line spacing a half mile or less to accurately delineate resources?
    - Question 3: Is the quality of the data known and usable for analysis?
- **Offshore Geological Data**

- Question 1: How much core data is available to sufficiently verify and delineate sand resources. Consider if cores are on or near seismic lines, is the core spacing less than one-mile intervals, as defined in the SAD SAND (USACE, 2020) guidelines.
- Question 2: Do the cores contain associated data (i.e. grain size analysis, photos, lithologic logs, penetrometer logs) to identify resources and determine beach compatibility?
- Question 3: Does knowledge of local geology indicate potential for discovering sand resources? Are there geologic maps, sand resource maps, etc.?

- **Offshore Shared Interest Areas**
  - Question 1: Are onshore energy stations, proposed cable routes known or anticipated that will determine access to mapped sand resources?
  - Question 2: Are there essential fish habitats that exclude sand resources and/or will there be additional required work?
  - Question 3: Are there any other significant avoidance areas that will exclude sand resources, such as artificial reefs, shipwrecks, marine cultural resources, anchorage zones, shipping channels, etc.
- **Coastal and Community Considerations**
  If available, utilize a tool that addresses community exposure such as flooding threats, terrestrial and marine fish and wildlife resources, or areas of open space and urban growth. This study looked at The Regional Coastal Resilience Evaluation and Siting Tool (CREST) to determine an area's exposure index (threat and community asset index), where the highest exposure values are most suitable for conservation or restoration projects.
  - Question 1: Areas of open lands and protected space that may be suitable for resilience-building efforts (CREST Tool Resilience Hub Score) (Resilientcoasts.org c2025).
  - Question 2: Are there known occurrences of federally or state-listed endangered, threatened, or special concern species in or near the project area (Nj-map.com c2020)?

**Table 3. Project scoring system using Tier 2 criteria**

| Area | Geophysical Data | | | | Geological Data | | | | Shared Interest Areas | | | | Environmental Considerations and Community Assets | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Avg | Q1 | Q2 | Q3 | Avg | Q1 | Q2 | Q3 | Avg | Q1 | Q2 | Avg |
| **Sea Bright to Loch Arbor** | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 3 | 3.67 | 3 | 2 | 2.5 |
| **Asbury Park to Manasquan Inlet** | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 3 | 3.67 | 3 | 2 | 2.5 |
| **Absecon Island** | 5 | 4 | 4 | 4.33 | 4 | 5 | 3 | 4 | 4 | 2 | 4 | 3.33 | 4 | 2 | 3 |
| **Great Egg Inlet to Townsends Inlet (South Ocean City)** | 5 | 3 | 4 | 4 | 4 | 5 | 4 | 4.33 | 4 | 2 | 4 | 3.33 | 2 | 1 | 1.5 |
| **Great Egg Inlet to Townsends Inlet (Ludlam Island)** | 3 | 5 | 5 | 4.33 | 5 | 5 | 5 | 5 | 1 | 4 | 3 | 2.67 | 2 | 1 | 1.5 |

Projects are evaluated across four categories: geophysical data, geological data, shared interest areas, and environmental/community considerations—with individual question scores averaged to produce category scores.

**Table 4. Example of weighted category scores for project prioritization**

| Area | Geophysical Data | Geological Data | Shared Interest Areas | Environmental Considerations and Community Assets | Total |
|---|---|---|---|---|---|
| | 25% | 30% | 25% | 20% | |
| **Sea Bright to Loch Arbor** | 2 | 2 | 3.67 | 2.5 | 2.52 |
| **Asbury Park to Manasquan Inlet** | 2 | 2 | 3.67 | 2.5 | 2.52 |
| **Absecon Island** | 4.33 | 4 | 3.33 | 3 | 3.72 |
| **Great Egg Inlet to Townsends Inlet (South Ocean City)** | 4 | 4.33 | 3.33 | 1.5 | 3.43 |
| **Great Egg Inlet to Townsends Inlet (Ludlam Island)** | 4.33 | 5 | 3.67 | 1.5 | 3.55 |

This table applies customizable percentage weights to each evaluation category to produce an overall project score, allowing for flexibility based on regional or agency-specific priorities.

### 2.2.3 Decision Making Framework Final Output

Through the decision-making framework, Absecon Island (Figure 2) in Atlantic County emerged as one of the highest-scoring project areas. Its strong data coverage, alignment with shared infrastructure and environmental priorities, and potential for sand resource development supported its selection for further study. The study area is defined by a circular offshore 10-nautical-mile buffer based on the extent of available data, centered on Absecon Island, New Jersey.

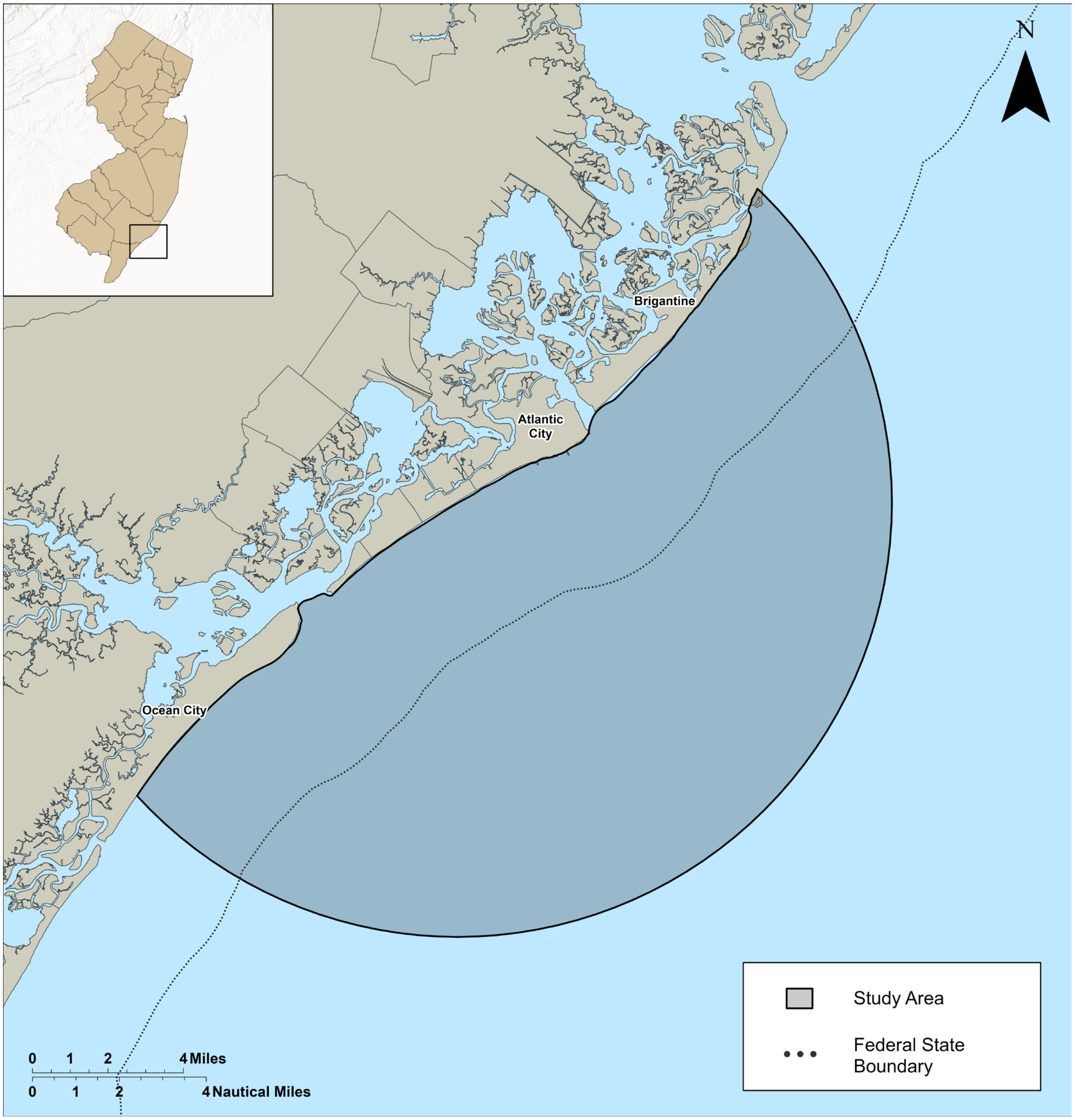


**Figure 2. Selected study area centered on Absecon Island, New Jersey**
This location was chosen based on Tier 2 rankings due to its strong geophysical and geological data coverage, alignment with shared use priorities, and potential for offshore sand resource development.

## 2.3 Sand Resource Suitability Model

The suitability model for this study is a weighted GIS spatial analysis tool that evaluates offshore areas for sand resource potential by using seafloor morphology and distance constraint layers. Using seafloor complexity metrics derived from a bathymetric digital elevation model (DEM) (NOAA's Coastal Relief Model), raster reclassifications were created to facilitate in the weighted overlay process, aiding in the accuracy of the final output. Along with bathymetry metrics, known fishing areas and proposed offshore cable features were included in the study due to their importance in determining areas of avoidance for sand resource use. Distance Accumulation rasters were created for each feature to inform the model on appropriate calculations based on distance and weighting in the ranking scale.

ArcGIS Pro was utilized to integrate bathymetry metrics and constraint variables, employing the Weighted Overlay Tool. Each bathymetry metric and variable were assigned a score ranging from 1 to 5, where:

- Score of 5 represents the highest suitability and strongest alignment to shoal like features with minimal constraints.
- Score of 4 represents medium-high with overall good geomorphologic alignment, but overlayed with minor constraints.
- Score of 3 represents medium suitability with moderate shoal alignment but needing more data to show any viability.
- Score of 2 represents medium-low with majority of the area highlighting the constraints.
- Score of 1 represents the lowest suitability where areas showed no alignment to shoal like features and were placed directly on or near a constraint.

The tool subsequently computed suitability scores based on these assigned values. Additionally, NJGWS collected geologic data was incorporated to demonstrate that potential shoal features can be used as qualitative model validation. By overlaying previously mapped shoal features with attributed mean grain size and other lithologic parameters (see Section 2.4 for details), this approach provides insight that allows the suitability model to potentially identify new or expand on existing sand resources areas. Appendix A contains the model builder schematic illustrating the full analysis process.

### 2.3.1 Data Parameters

The bathymetry data and bathymetric derivatives used in this model provide deeper insight into seabed morphology. Key metrics include depth, standard deviation, slope, and bathymetric position index (BPI), all of which help identify potential shoal features. Establishing data ranges for each metric is essential, in that by having a defined range, it can help more accurately locate where shoal features may be present. It’s important to note these values vary depending on the project’s region and scale of analysis.

Shoal class ranges were modeled after Pickens et al. (2020) to make the reclassification of the bathymetry derivatives comparable. The bathymetry data from NOAA’s Coastal Relief Model is based on the WGS84 horizontal datum and has a spatial resolution of 1 arc-second (1 arc second translates to 30.9 meters) (Figure 3). To ensure compatibility, the DEM and derived data were projected to NAD 1983 (2011) State Plane New Jersey FIPS 2900 (meters) with a preserved resolution cell size of 80 meters. The DEM was then masked by a digitized study area boundary derived from within a 10 nautical mile buffer zone.

A bathymetric position index (BPI) raster was generated using NOAA’s Digital Coast Benthic Terrain Modeler (BTM), an ArcGIS toolset that classifies benthic environments. The toolset contains a separate workflow and should be noted that only the BPI tool was utilized for this study. BPI identifies features such as crests, depressions, flats, and slopes based on bathymetric data and an algorithm that utilizes a focal or neighborhood function. The BTM Modeler offers both fine- and broad-scale tools, with the latter chosen for this study due to its ability to analyze larger benthic features. The Broad-Scale BPI tool was applied using an inner radius of 10 and an outer radius of 20, which were the default radius settings. The tool requires inner and outer radius inputs for the limit of the number of neighboring pixels from a focal point of each pixel. A negative output value describes the pixel’s lower position than the surrounding pixels, for example, a valley formation. A positive output value describes the position of a pixel higher than the surrounding pixels, for example, a formation of a ridge. For this study, our BPI raster pixel’s values ranged from –5 to 8 (Figure 4). A flat area or an area with a constant slope will produce a BPI value close to 0 (zero), whereas the more negative or positive the BPI value, the more extreme the pixel's benthic characteristics.

The Calculate Slope Tool was used to generate a slope raster, computing the rate of elevation change within a 3x3 cell moving window. The output raster ranged from 0 to 2.8 degrees (Figure 5). The standard deviation of bathymetry was calculated using the Focal Statistics tool, helping estimate seafloor variability and uncertainty. A rectangle-shaped 9x9 cell neighborhood was used, resulting in an output raster with values from 0 to 2.9 (Figure 6).

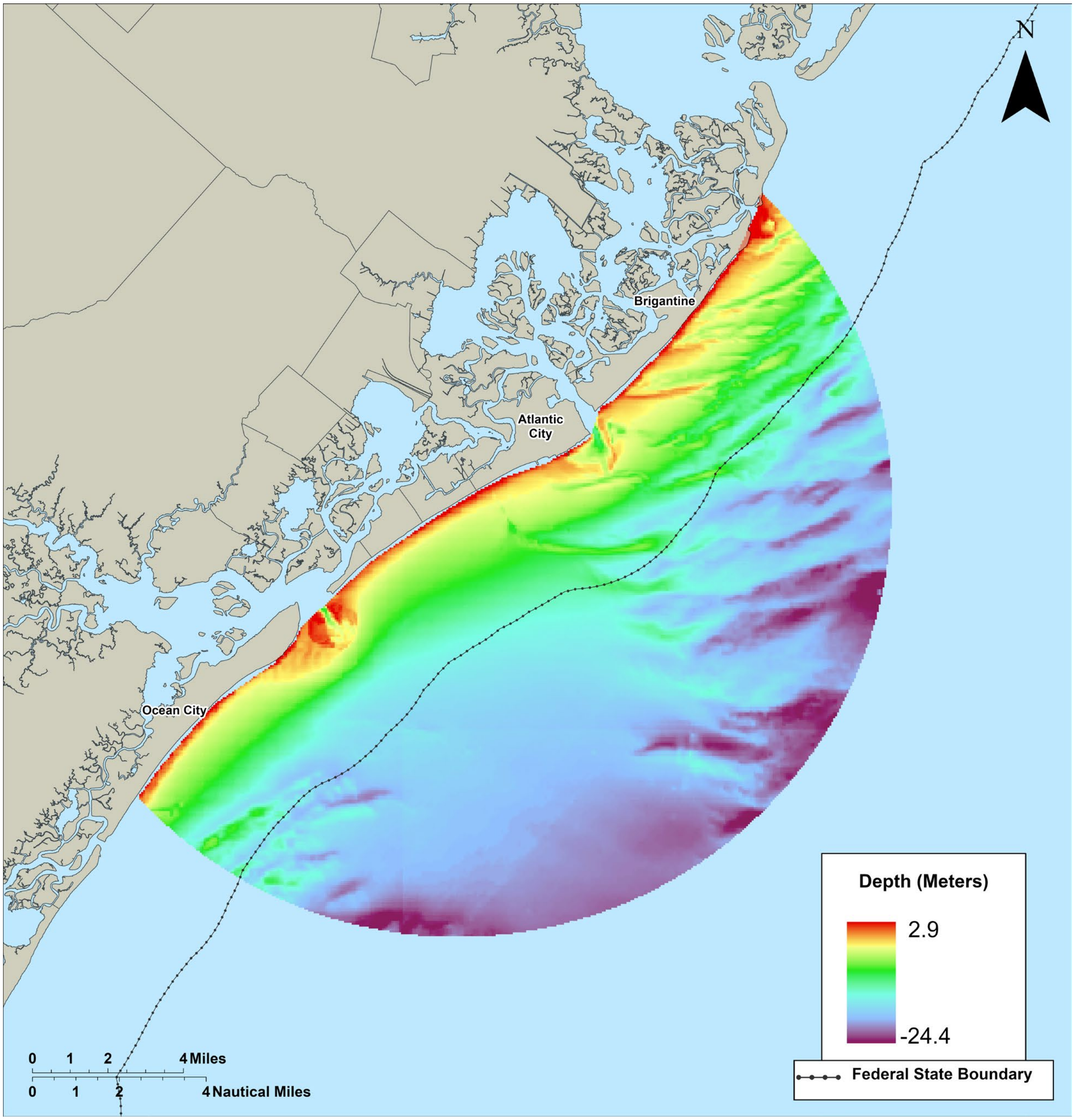


**Figure 3. Bathymetric digital elevation model (DEM) of the study area derived from NOAA's Coastal Relief Model**
This dataset served as the base layer for calculating seafloor metrics such as depth, slope, standard deviation, and bathymetric position index (BPI), which were used to inform the suitability model.

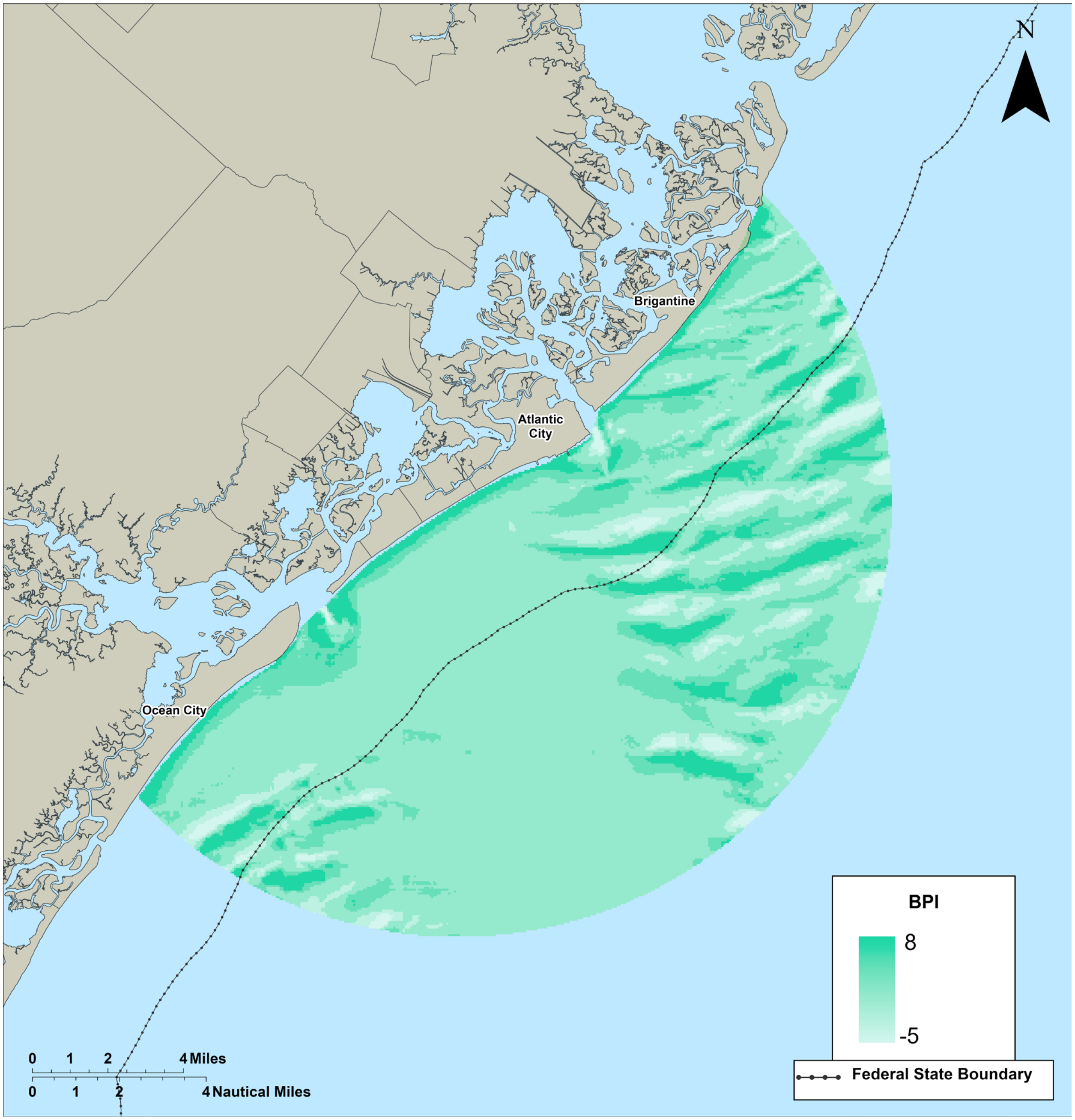


**Figure 4. Bathymetric position index (BPI) of the Absecon Island study area**
BPI values represent relative seafloor position, highlighting features such as ridges (positive values), depressions (negative values), and flat areas (values near zero). This layer was derived using the NOAA BTM Modeler toolset. The BPI surface is used to characterize seafloor morphology and inform terrain-based suitability and habitat analyses within the offshore study area.

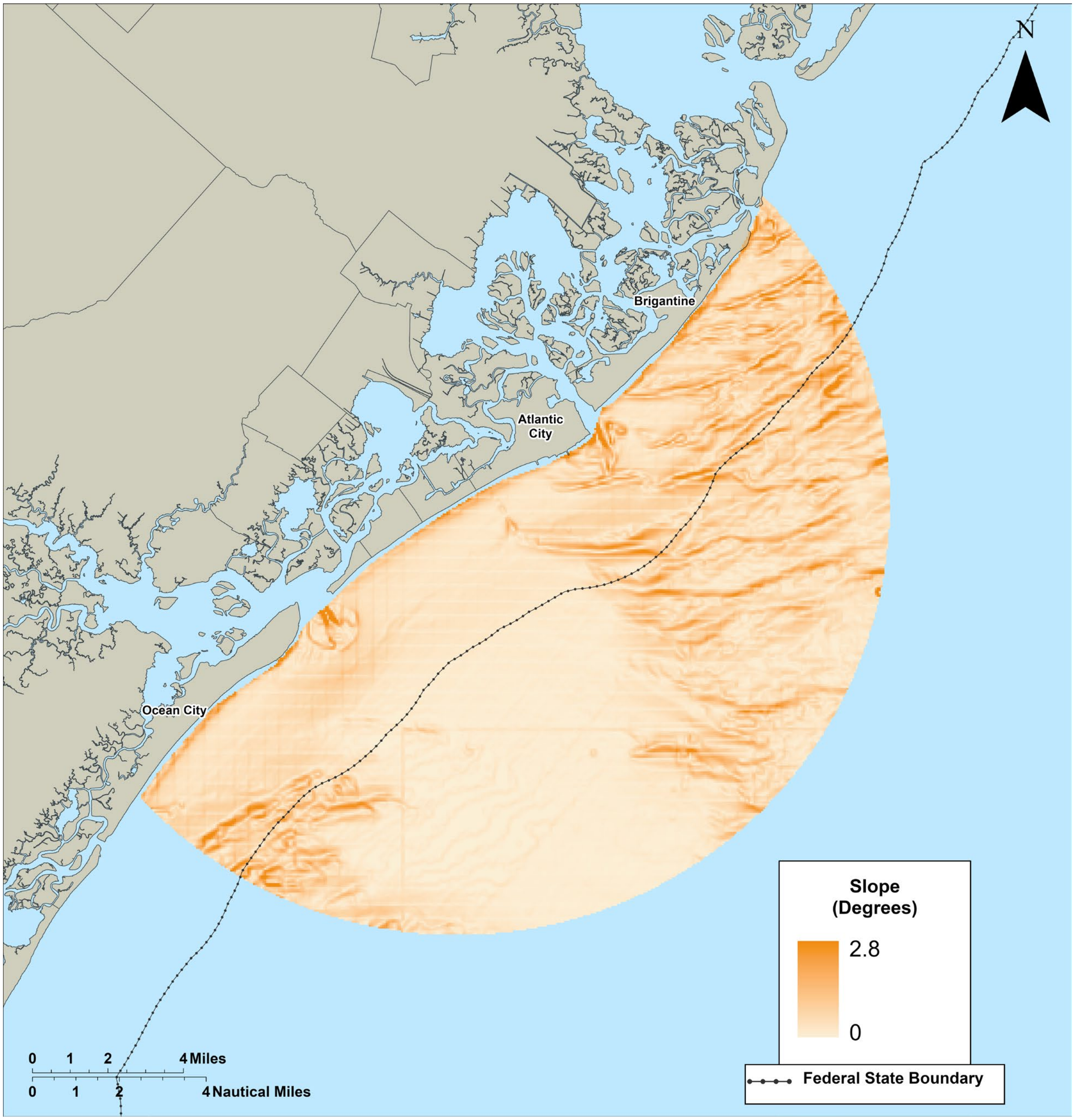


**Figure 5. Seafloor slope (degrees) of the Absecon Island study area**
Slope values derived from NOAA bathymetric data via the Calculate Slope tool in ArcGIS Pro. Higher slope values indicate steeper terrain such as ridges or drop-offs, while lower values represent more gradual or flat areas. This layer supports terrain characterization and is used in marine spatial planning and suitability modeling within the offshore portion of the study area.

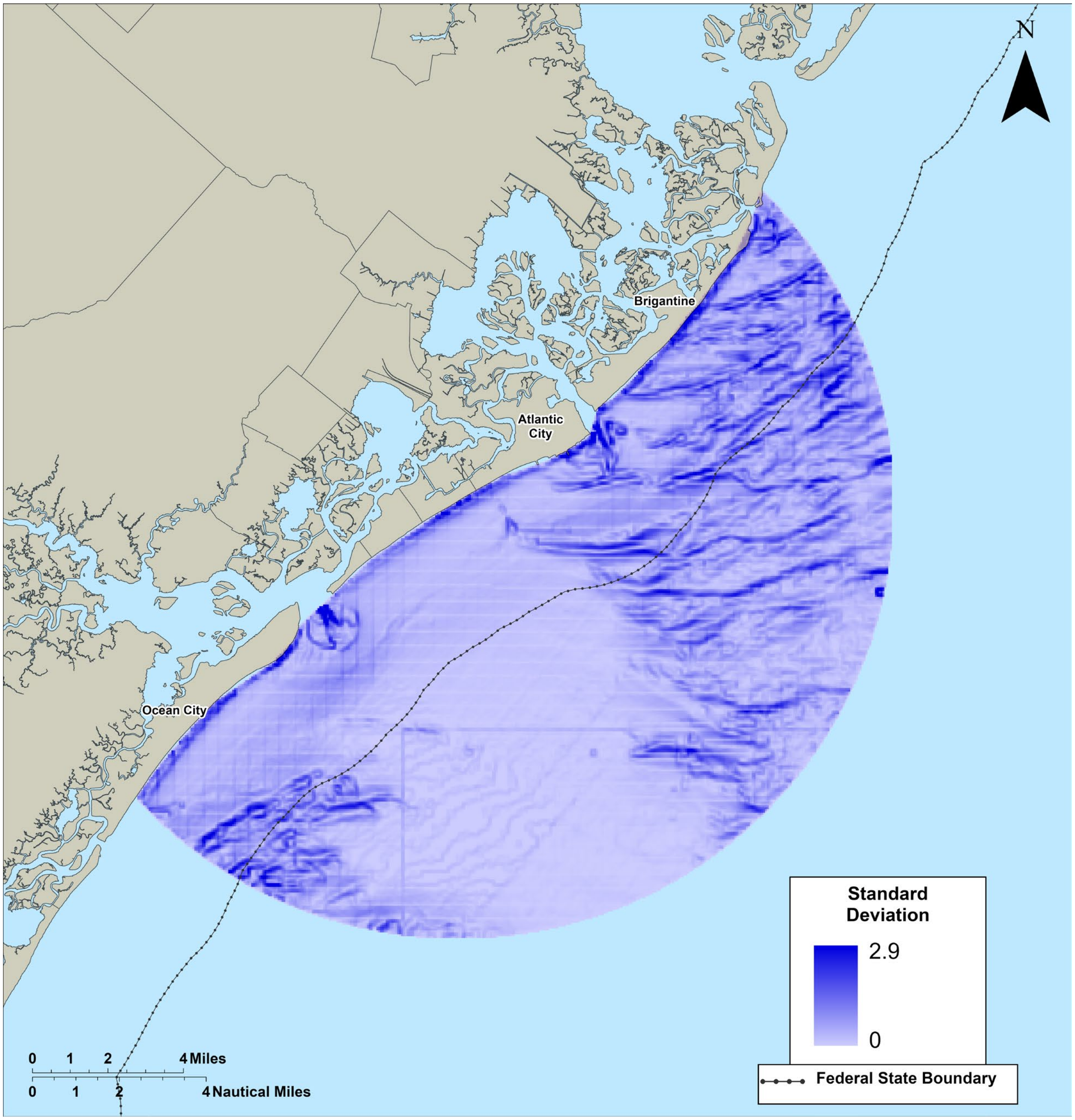


**Figure 6. Seafloor depth variability (standard deviation) in the Absecon Island study area**
This layer was derived from NOAA (CUDEM) bathymetric data via the Focal Statistics tool in ArcGIS Pro. Higher standard deviation values indicate areas with greater variability in seafloor elevation, reflecting more complex terrain, while lower values represent flatter, more uniform regions. The layer is used to assess seafloor roughness and contributes to terrain-based analysis and suitability modeling within the offshore study area.

Two avoidance layers were incorporated into the model's study area (Figure 7):

1. Prime Fishing Grounds: Data was sourced from the NJDEP Open Data Portal (gisdata-njdep.opendata.arcgis.com c2023), this dataset includes offshore fishing locations. The data were clipped to the study area.

2. Proposed Offshore Wind - Export Cable Routes: Data was sourced from Marine Cadastre, which is a source for ocean geospatial data (hub.marinecadastre.gov c2025). These routes extend approximately 10 nautical miles offshore and were included as they represent the location of proposed wind energy export cable infrastructure that would potentially impact access to potential sand resources. A 500m buffer was applied to either side of the cable route and was clipped to the study area.

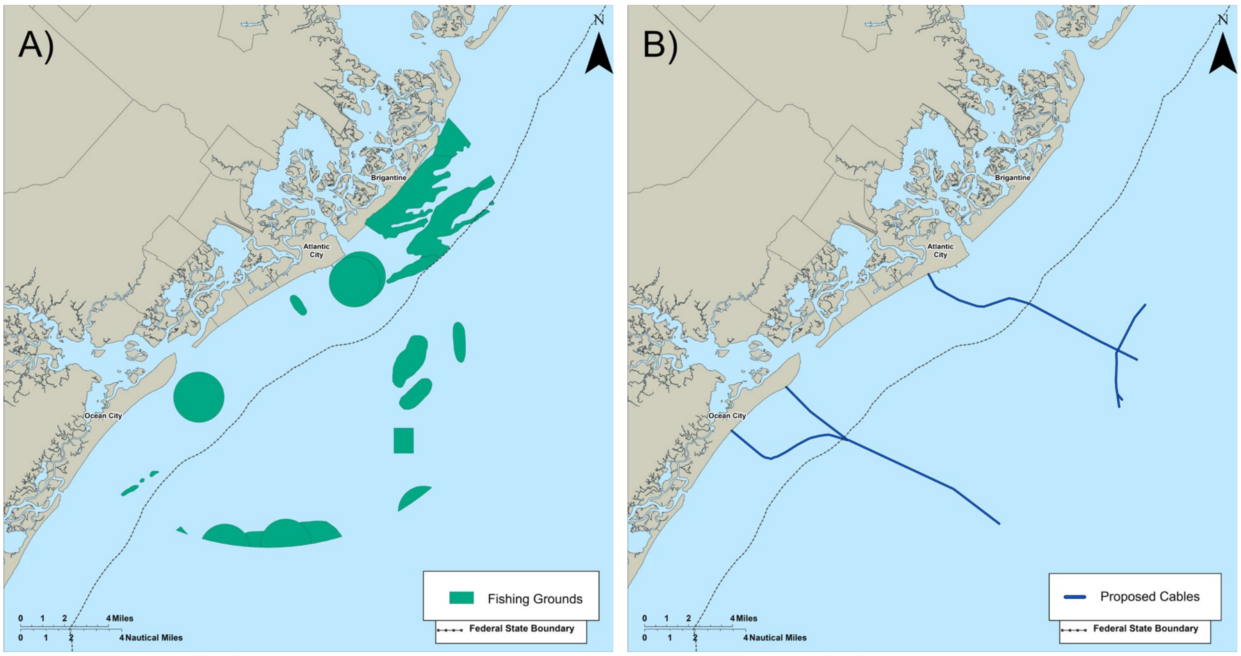


**Figure 7. Prime fishing grounds and proposed offshore wind energy export cable routes in the Absecon Island study area**

(a) The prime fishing grounds layer identifies areas of high-value commercial and recreational fishing activity and is available via the NJDEP's open data portal. The dataset supports marine spatial planning and was used as a key constraint in the suitability analysis. (b) Proposed offshore wind energy export cable routes in the Absecon Island study area. This layer shows the proposed alignments (clipped to study area) of submarine cables associated with offshore wind energy development projects (as of [insert month and year here]). Proposed cable route data were sourced from hub.marinecadastre.gov and reflect preliminary siting based on engineering feasibility and regulatory considerations. This layer is used in the study to assess spatial overlap with environmental and human-use constraints, supporting impact analysis and marine spatial planning efforts.

Both avoidance areas were rasterized using the Distance Accumulation tool with a planar distance method (Figure 8). The bathymetry DEM was used as a surface to compute actual distance, factoring in cell transitions with a default vertical factor of BINARY 1 -30 30 and a horizontal factor of BINARY 1 45. The Distance Accumulation tool takes a feature class and within a given study area extent, calculates distance away from it just within that extent. Using the bathymetry DEM for the study area extent, the Distance Accumulation tool will calculate accumulated distance for each cell to sources. For a full list of data products, see Appendix C.

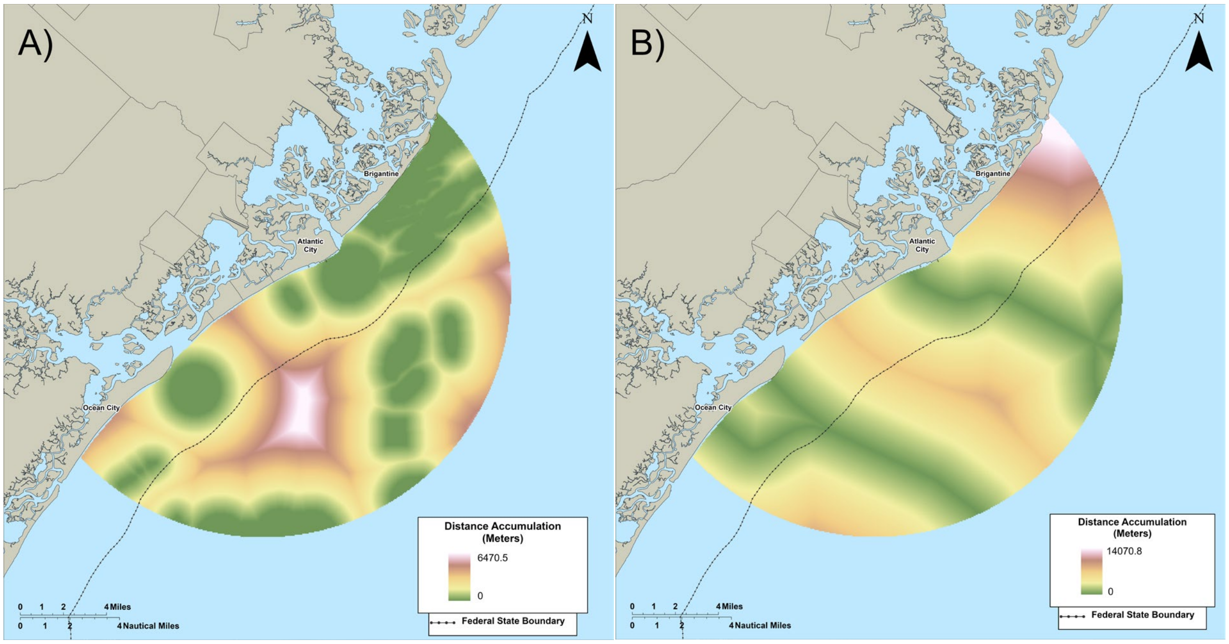


**Figure 8. Distance allocation to prime fishing grounds and proposed offshore cable routes in the Absecon Island study area**
(a) This raster layer was created using the Distance Accumulation tool in ArcGIS Pro, assigning each cell to the nearest identified fishing ground and calculating its Euclidean distance, (b) This raster layer was generated using the Distance Accumulation tool in ArcGIS Pro, assigning each cell to the nearest submarine cable route and calculating the straight-line (Euclidean) distance to it.

## 2.3.2 Reclassification

The six generated rasters were reclassified into three classes to facilitate weighted overlay analysis. Class ranges follow Pickens et al. (2020) where binned ranges for bathymetry, BPI, standard deviation, and slope were used to represent major geomorphic features (Table 5). For example, the deepest area according to the bathymetry in our study area is –24.4 meters, whereas the most elevated is 2.9 meters. Binning the data that was most favorable into a class helped facilitate the ranking process that would follow. Part of the process to rank the data, binning and reclassifying into integer classes (1-3). Cable route distances were determined based upon minimum distance dredging can occur. Remaining values in classes were arbitrarily determined based on values within the study area.

**Table 5. Reclassified raster input ranges for weighted overlay analysis**

| Parameter | Class 1 | Class 2 | Class 3 |
|---|---|---|---|
| **Bathymetry** | -24.4 to –14.3 | -14.3 to -5 | -5 to 2.9 |
| **BPI** | -5 to 1.1 | 1.1 to 4.5 | 4.5 to 8 |
| **Standard Deviation** | 0 to 1 | 1 to 2 | 2 to 2.9 |
| **Slope** | 0 to 0.2 | 0.2 to 0.6 | 0.6 to 2.8 |
| **Fishing Grounds** | 0 to 1000m | 1000 to 2000m | 2000 to 6470.5m |
| **Cable Routes** | 0 to 1000m | 1000 to 2000m | 2000 to 14070.9m |

Bathymetric and spatial variables were grouped into three classes based on suitability for sand resource development, with Class 2 typically representing optimal shoal-like conditions.

### 2.3.3 Weighted Overlay

The six reclassified rasters were processed using the Weighted Overlay Tool in ArcGIS Pro. Each raster was assigned a percentage weight to ensure a balanced representation. A weight of 15% was assigned to the bathymetry metrics equally because of their shared influence representing suitable areas. As for the variables in the suitability model, 5% was assigned to the fishing grounds layer due to its relative impact in our study area and boundaries may shift. It's important to note that during this investigation, Orsted ceased development on their Ocean Wind 1 and Ocean Wind 2 projects, which was associated with one of the offshore cable corridors within the study area. Nonetheless, all proposed corridors within the study area are considered avoidance areas for sand resource extraction. The offshore cable routes in the suitability model were given the highest weight of 35% due to the importance of avoidance. The following weight percentages were assigned to the six input layers in the suitability model:

- Bathymetry DEM: 15%
- BPI: 15%
- Standard Deviation: 15%
- Slope: 15%
- Fishing Grounds: 5%
- Cable Routes: 35%

Next in the Weighted Overlay Tool Process is the remap table, which takes the rasters that were just given weights, and sets them up by their class (1-3) for an evaluation scale or rank. The scale or (rank) considered for this study ranged from 1-5, 5 being the best rank to 1 being the worst (least suitable for sand resource extraction). In order to give appropriate ranks to each raster's class, multiple iterations of modeling and interpretation were conducted, where table 6 provides the best output. Classes that were given scores of 5 were where their data aligned best with shoal characteristics. For example, Bathymetry Class 1 had a range from -24.4 to -14.3, ranges were given ranks of 5 due to their precise data range and scope for shoal, with the only exception being the cables and fishing grounds layer being just outside the 1000 meters avoidance zone which was given a rank of 5. Classes that were given ranks of 1 were given due to their values being non favorable to geomorphological zones and high avoidance proximity. Ranks of 3 were only given to classes that had neutral or little to no changes to the model. A Rank of 4 was given to the slope class 3 because of its higher degree range, noting that some shoal features under certain conditions may be present.

**Table 6. Remap table assigning ranked values (1–5) to reclassified raster inputs**

| Parameter | Class 1 Value Rank | Class 2 Value Rank | Class 3 Value Rank |
|---|---|---|---|
| **Bathymetry** | 5 | 3 | 1 |
| **BPI** | 1 | 5 | 3 |
| **Standard Deviation** | 1 | 5 | 3 |
| **Slope** | 1 | 5 | 4 |
| **Fishing Grounds** | 1 | 5 | 5 |
| **Cable Routes** | 1 | 5 | 5 |

These ranks reflect each class's relative suitability for sand resource development and were used in the final weighted overlay to generate the suitability model output.

### 2.3.4 Output

The final output raster categorized areas on a suitability scale from 1 (lowest suitability) to 5 (high suitability) (Figure 9). Zones assigned a rank of 5 are identified as high suitability where there is a strong alignment with shoal-like morphology and minimal spatial constraints such as cable routes. Zones assigned a rank of 4 are identified as areas likely candidate locations for future sand resource development due to having good morphological indicators for shoals with minor spatial constraints. Rank 3 represents medium-priority areas, which moderately align with shoal-like features meriting further investigation under specific project scenarios and with additional supporting data. Zones classified as rank 2 are generally located near offshore cables, indicating reduced suitability due to potential infrastructure conflicts and do not have good morphological indicators of shoal-like features, though not entirely precluded from consideration. Rank 1 areas closely align with existing cable corridors and have poor alignment with shoal-like features which exhibit the lowest suitability scores.

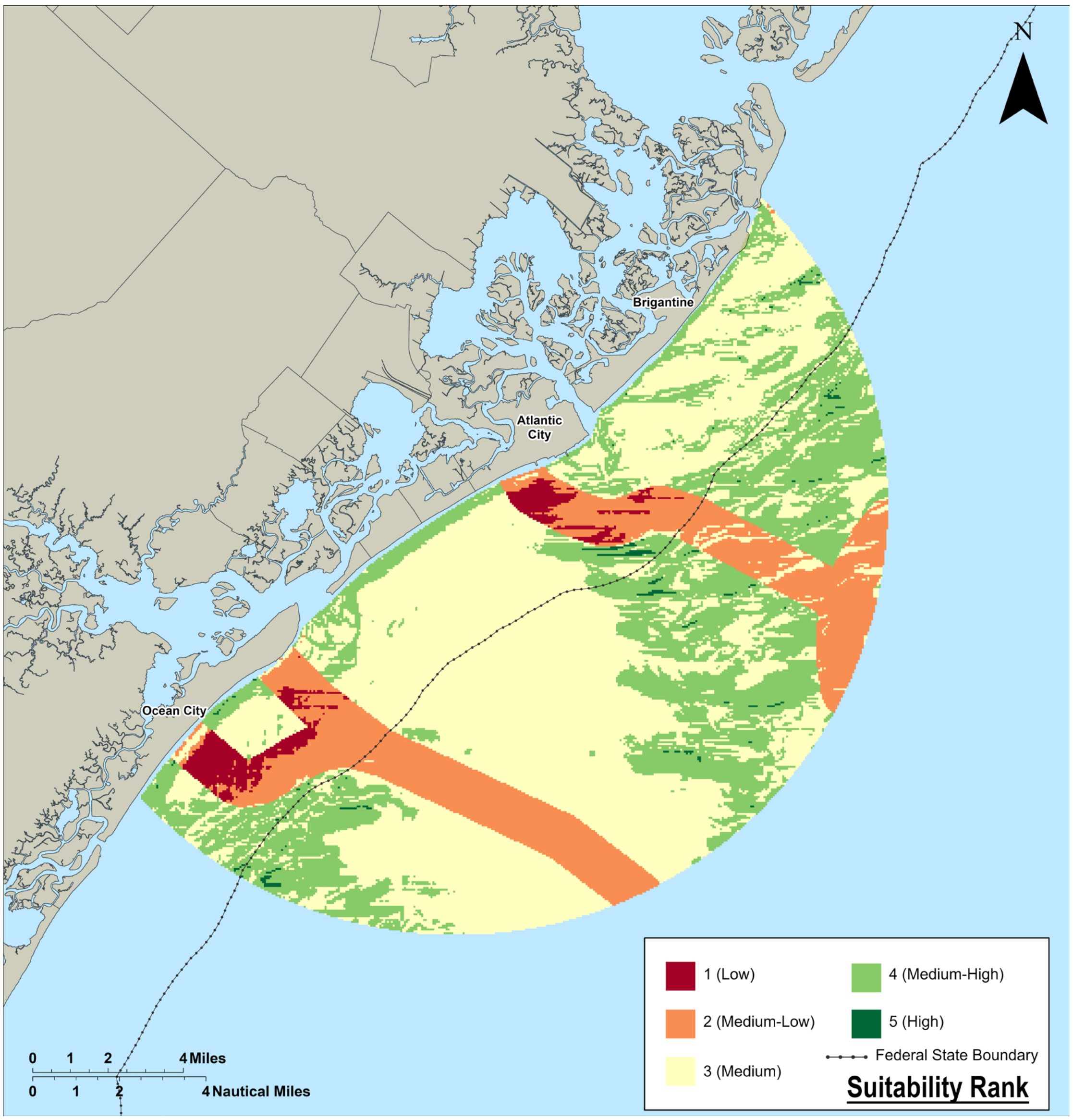


**Figure 9. Weighted overlay suitability analysis output for the Absecon Island study area**
This raster layer represents the combined results of multiple reclassified input layers—including bathymetry, slope, standard deviation, bpi, proximity to offshore infrastructure, and fishing grounds—each weighted according to its relative importance. Higher values indicate areas of greater overall suitability based on the criteria defined in the analysis, while lower values represent areas with more constraints and non-ideal, shoal-like morphology. This output supports spatial decision-making for offshore planning and was generated using the Weighted Overlay tool in ArcGIS Pro.

## 2.4 Offshore Geologic and Geophysical Data

The NJGWS has been collecting geophysical and geologic data since the mid-1990's to develop a regional framework characterizing offshore sediment distribution. The effort has enabled the assessment of offshore sand resources for beach nourishment and allow for long-term resource management. To date, NJGWS has collected over 300 cores and approximately 3000 nautical mile seismic lines. NJGWS core data, seismic data, and delimited sand resource areas located in the Absecon Island study area were analyzed as the main method for validating the suitability model. Geologic and geophysical data may be limited and vary by region, therefore reconnaissance-level cores were used to reflect the scarcity of geologic information that may occur near project areas. The cores were collected by NJGWS in multiple iterations from 1997 through 2011. Seismic data used to delineate NJGWS identified sand resources were collected in 1997 and 2003.

### 2.4.1 Cores

Forty-five cores were evaluated using the mean grain size at 30cm intervals, photographs and lithology logs to determine sand compatible units. A primary composition (sand, silt, gravel, etc.), texture (fine, medium, coarse, etc.), and secondary composition were identified for each unit (Warner et al., 2023). The preferable grain size for renourishment projects will match the native beach grain size. In New Jersey, the native beach grain size varies along the coast as a function of transportation distance, ocean currents, local conditions, and artificial controls. Generally, the beach grain size decreases north and south of the Point Pleasant area and increases into the Delaware Bay Shore area (NJGWS, 1954). USACE assesses beach grain size for their feasibility studies related to nourishment projects and calculates a native beach grain size. The native grain size for Absecon Island is 2.36 phi (USACE, 1996). Many of the shoals found offshore do not consist of homogeneous grain sizes and will vary at depth and location within a resource area. Due to limited resources offshore, it is important to identify all cores with a primary composition of sand to protect those resources from competing uses and provide flexibility for renourishment projects. The New Jersey Department of Environmental Protection (NJDEP) requires dredged material placed on a beach for renourishment projects must be a minimum of 75% sand, where sand is defined as having a grain size greater than 0.0625 mm (PHI 4) and compatible with the receiving beach (NJDEP, 1997). For this study, a mean grain size of .0625mm to 2mm (PHI 4 to -1) was considered suitable material. In cases where a sand unit has an overlying unit of unsuitable material (clay, silt, gravel, shells or organics) greater than a half meter thickness, the sand units below were excluded in our analysis.

After reviewing the cores and identifying compatible units, a composite grain size was calculated for each core. Since NJGWS collects sediment samples every 30cm, an average mean grain size was computed for each compatible unit, where grain-size statistical parameters are given in phi units, Φ:

$$Average\ Mean\ Grain\ Size, A_{Mz} = \frac{M_{z1} + M_{z2} + \cdots + M_{zn}}{n}$$

where the mean grain size is calculated:

$$Mean\ Grain\ Size,\ M_z = \frac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3}$$

where 16, 50, and 84 represent the size of the sample by weight

Each core was then weighted based on the length (thickness) of a unit of compatible material:

$$Length\ Weighted = \frac{\Sigma\ (Length\ \times Mean\ Grain\ Size)}{\Sigma\ (Mean\ Grain\ Size)}$$

### 2.4.2 Sand Resource Areas

This study focused on sand resources identified and delineated in the offshore region of the Absecon Island study area as part of a previous cooperative agreement with BOEM (NJGWS, 2018). Borrow areas designated by USACE were not included as they have had extensive resource assessments completed and are mostly authorized for use in current coastal storm risk management (CSRM) projects. The study area contains three shoals identified by NJGWS (2018) as North shoal, Central shoal and Southern shoal, as well as the BOEM sand resource layer is included to reference and compare to the model output (Hub.marinecadastre.gov) (Figure 10). The north shoal is just outside the study area; however it is included here as it is an aggregate of the overall shoal feature. These shoals are located approximately 4 miles offshore in State and Federal waters. NJGWS seismic data and lithologic data were utilized to delineate the boundaries and sand thickness of the potential resource material. Design-level cores were collected for a portion of these shoals in 2017 through the BOEM Atlantic Sand Assessment Project (ASAP); however, reconnaissance-level cores were the focus of this study to reflect the level of characterization and assessment that is possible in areas with limited geologic and geophysical data. Meant for planning with recon data.

The Thiessen polygon method was used to calculate composite sediment characteristics and provide a generalized indicator of sediment quality for each of the three potential sand resource areas mapped by NJGWS in 2018. Add why we did polygons and how it was used in this study. For model validation. Using the ArcGIS Pro Polygon Volume tool, each sand resource area was divided based on the distribution of a single composite core sample location, allowing for localized segmentation within each shoal. Volumetric estimates were then calculated for each individual shoal and used to assign weighted values for mean grain size for each shoal area. Calculating composite characteristics for the three shoals provided a generalized means of evaluating suitability model performance and its ability to identify potentially suitable sand resources previously delineated using geologic and geophysical data. For complete tutorial of the Suitability Model see Appendix B.

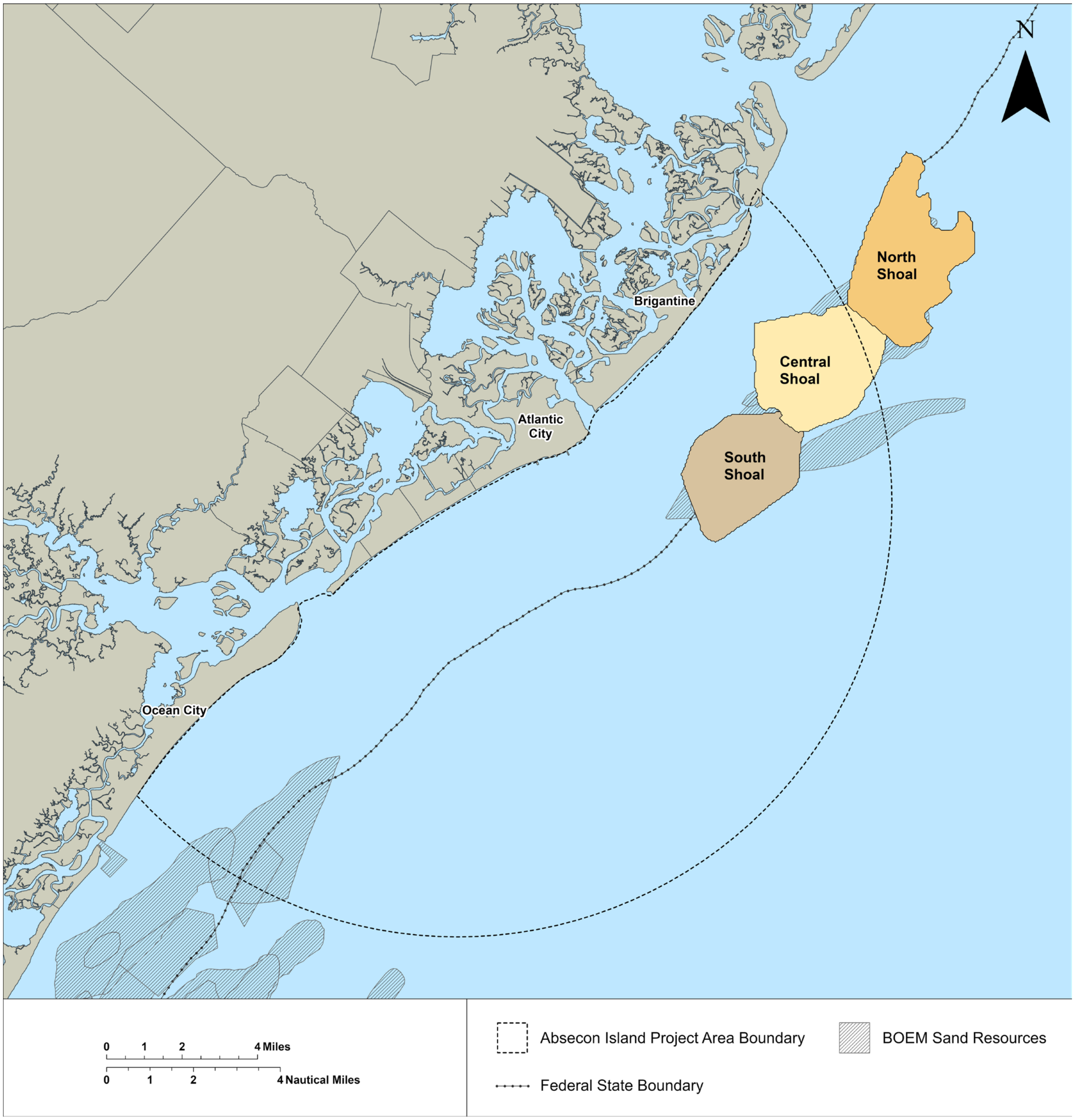


**Figure 10. Sand resource areas previously identified by NJGWS (2018) and BOEM in the Absecon Island study area**

The north, central and south shoals were delineated using NJGWS seismic and lithologic data and evaluated for potential beach-compatible sediment based on core samples and geophysical interpretations. The BOEM sand resource layer identifies where there is an increased likelihood of a usable sand resource.

# 3 Results and Discussion

The suitability model was developed using ArcGIS Pro and is designed to evaluate different criteria where there may be multi-use conflicts such as sand resources, fishing habitats, and cable routes. The model integrates bathymetric data and first-order bathymetry derivatives, fishing grounds, and proposed offshore cable routes, assigning each input a weighted value based on its relevance to sand resource viability and avoidance considerations. Bathymetric metrics—including depth, slope, standard deviation, and bathymetric position index (BPI)—were derived from NOAA's Coastal Relief Model and reclassified into suitability classes (Pickens et al., 2020). Shoal features and geologic data identified in previous NJGWS and BOEM studies were used to validate the model's predictions. The model helps prioritize areas most suitable for locating and extracting sand resources, ensuring that effort and funding are focused on geologically favorable and logistically viable sites.

## 3.1 Model Outputs

The model used a weighted overlay analysis, assigning 15% weight to each bathymetry metric, 5% to fishing grounds, and 35% to offshore cable routes. Reclassified raster values were ranked on a scale from 1 (low suitability) to 5 (high suitability) (Figure 11). The output identified priority areas for sand exploration, particularly where positive-relief bathymetric features and avoidance zones did not overlap. Rank 4 and rank 5 zones in the model output represent potential sand resources that are geologically favorable, logistically accessible, and have minimal conflicts with competing uses. Rank 5 zones emerged where all six criteria aligned most favorably, indicating areas that are both physically and logistically optimal for sand resource investigation. Table 7 provides the percent area of each class rank within the total project area. While these areas were not directly tied to core data during the model phase, their strong spatial agreement with known shoal characteristics makes them high-priority targets for future exploration and potential extraction. Their identification supports a regional sand resource prioritization strategy that emphasizes efficient access to identified sand resources areas, minimal conflict with other uses, and earmarking areas with elevated potential for containing suitable sand deposits that need further investigation.

**Table 7. Percent area of suitability class ranks within the Absecon Island study area**

| Suitability Rank | Area, m² | Percent Area |
|---|---|---|
| **Rank 1** | 12,633,092 | 2.4 |
| **Rank 2** | 80,177,350 | 15.3 |
| **Rank 3** | 281,606,230 | 53.6 |
| **Rank 4** | 149,008,319 | 28.4 |
| **Rank 5** | 2,054,329 | 0.4 |

These ranks reflect each class's relative suitability for sand resources in the Absecon Island study area. Table 7 shows the percent area of each ranking in the model output.

To better understand the potential impact of proposed offshore wind energy infrastructure on potential sand resources, this model applied greater importance to proposed wind energy export cable routes by applying a heavier weighted overlay. The model output provides a scenario where the cables may restrict access to sand resources (Figure 11), providing useful information for adjusting cable routes to minimize impacts. In addition, the Absecon Island offshore area is covered by offshore wind energy lease areas past 8 nm which prevents dredging within those areas and limiting long-term planning to areas inshore of 8 nm.

Fishing grounds were included in this model to highlight the potential conflict that may arise over areas designated by NJDEP as significant for recreational fishing. A smaller weighted overlay is applied as the boundaries are not exact and may shift spatially and temporally. As seen in figure 11, several of the fishing grounds overlay rank 4 zones, highlighting overlap between suitable sand resources and fish habitat. Because prime fishing grounds were assigned a lower constraint (5% weight), places with acceptable morphology can still occur in areas of rank 3, even where the fishing-grounds polygon sits on top. In some of the areas where the fishing grounds overlay ranks 1-3, this could be due to the cable routes. It is important to note these as considerations need to be made for marine habitats and the impact of targeting those resources.

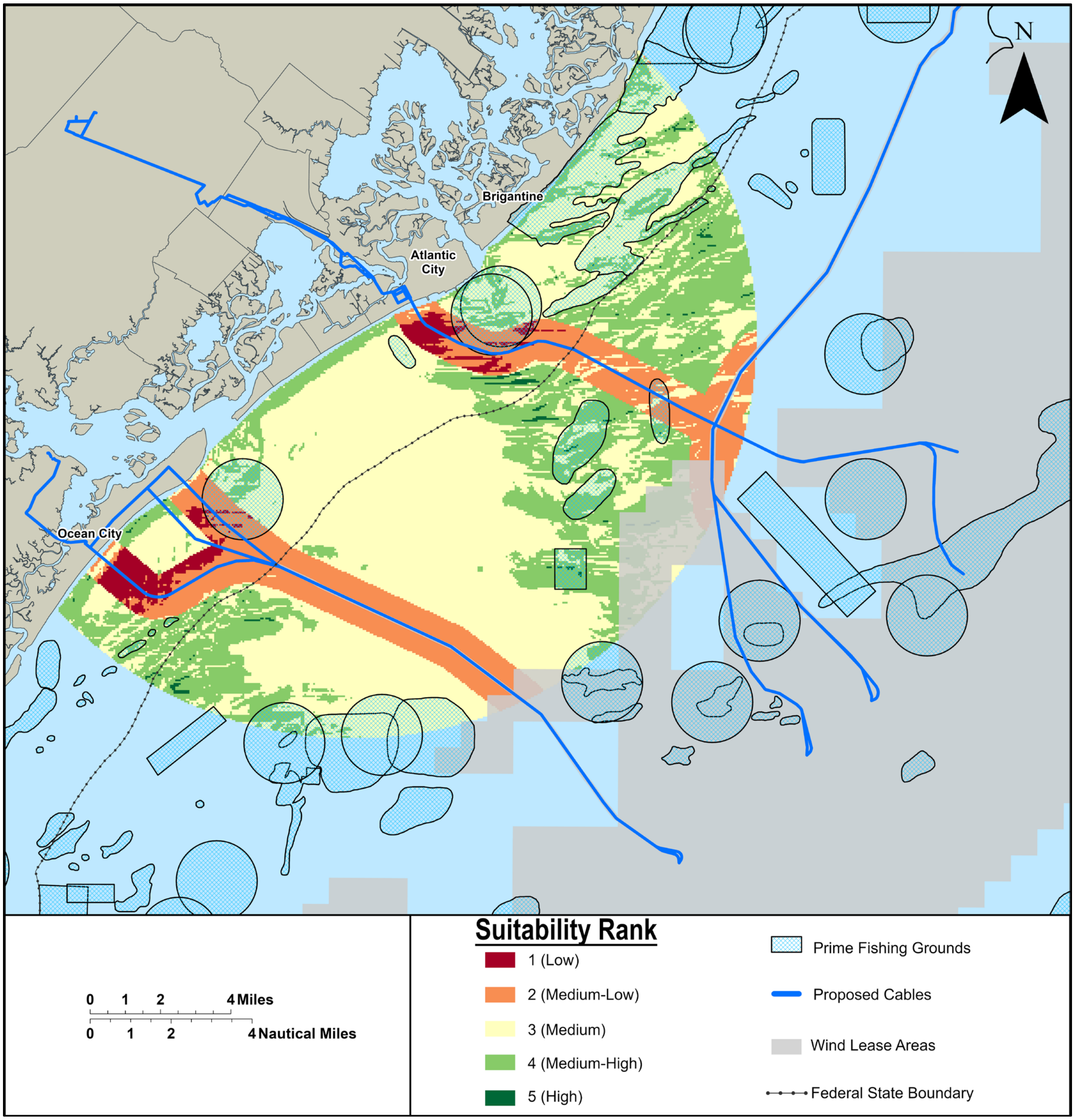


**Figure 11. Final suitability output model overlaid with avoidance areas extending outside the Absecon Island study area**
Final suitability output ranked low (class 1) to high (class 5) overlaid with avoidance areas that extend outside the study area. Overlaid vector layers show the locations of prime fishing grounds, wind lease areas and proposed cable corridors, which were factored into the model as areas of avoidance. These features provide important context for validating the model results, highlighting areas where avoidance areas align with low suitability zones, informing future prioritization for sand extraction planning.

Beyond guiding sand resource exploration, the model may also provide a valuable framework for determining mitigation strategies when multi-use conflicts occur in potential sand resource areas. For example, when proposed infrastructure projects (such as submarine cables) intersect previously potential sand resource areas, the suitability model can help estimate the relative value of those areas based on multiple criteria. If potential sand resource areas are rendered inaccessible due to cable placement, the government or managing agency can use the model output to develop tradeoff analyses that estimate the cost of losing access to high-quality sand by approximating the relative cost difference of sourcing sand from less optimal areas and the long-term economic impact of reduced sand availability for beach nourishment and coastal protection.

In this way, the suitability model serves both as a planning tool and as a basis for determining fair mitigation strategies when critical sand resources are impacted by competing offshore uses.

## 3.2 Geologic Data and Sand Resource Areas

The suitability model is based on a set of spatial criteria highlighting high seafloor variability and relief—including four bathymetry-derived metrics—designed to highlight geomorphologic features typically associated with sand-bearing shoals. These metrics capture seafloor characteristics such as elevation, slope, curvature, and roughness that are strongly linked to sediment deposition patterns. It offers valuable insight into seabed morphology and potential geologic conditions favorable for offshore sand resource development.

Historic core data and prior delineated shoals (Figure 12) were used to compare and validate model outputs. The north shoal has a composite grain size of 1.43 phi, the central shoal of 2.19 phi and the south shoal of 1.83 phi showing they contain beach quality sediment. The NJGWS-delineated shoals do correlate with rank 4 and 5 zones, reinforcing confidence in the model's ability to reflect underlying geologic conditions. A section of the southern shoal does overlap with some rank 2 and 3 zones, which is due to the overlap with proposed cable routes and the associated buffers (see Figure 11). One thing to note is the suitability rankings in the immediate vicinity of the northern cable route are more segmented, whereas the rankings are uniformly distributed along the majority of the southern cable area. Bathymetric and core data in the vicinity of the northern cable area suggest the cable corridor may overlap suitable resource material although no sand resources have been previously mapped in the immediate area.

Individual core data indicative of beach quality sediment strongly correlates with the rank 4 and 5 zones and cores containing poor sediment quality generally correlating with rank 2 and 3 zones. However, there are some cores not reflective of the zones they correlate with. For example, there are cores with beach quality sediment falling within rank 2 and 3 zones and cores containing unsuitable material found in rank 5 zones. Offshore geology in this region can be complex and highly variable in the shallow subsurface, with shoal features commonly containing sand interbedded with gravel, silt, and clay. NJGWS coring efforts typically target geologic features favored to have sand and fall on seismic lines, therefore having a high probability that suitability zones will be biased towards high probability sand resource areas, such as shoals. The model may not capture favorable sediment areas if they are not aligned with geomorphic features and a robust assessment of all model rankings is not possible. The model can only identify sand resource potential associated with positive-relief features such as shoals. Therefore, the model is unable to predict sand resources associated with different seabed morphologies. Even though the model can aid in project planning, it is important to ground-truth.

Areas ranked highly by the model that do not coincide with known resources may represent underexplored or unmapped deposits, offering new targets for future investigation. This can be seen where the proposed cable routes omit possible significant sand resources near the delineated shoals. It is important to run the model in iterations to see how conflicting data may interact with local geologic features. In addition to validating known resources, the model refines the spatial delineation of potentially viable areas, supporting more targeted volumetric analysis and resource planning. These results underscore the value of spatial modeling for guiding both short-term survey efforts and long-term strategic management of New Jersey's offshore sand resources.

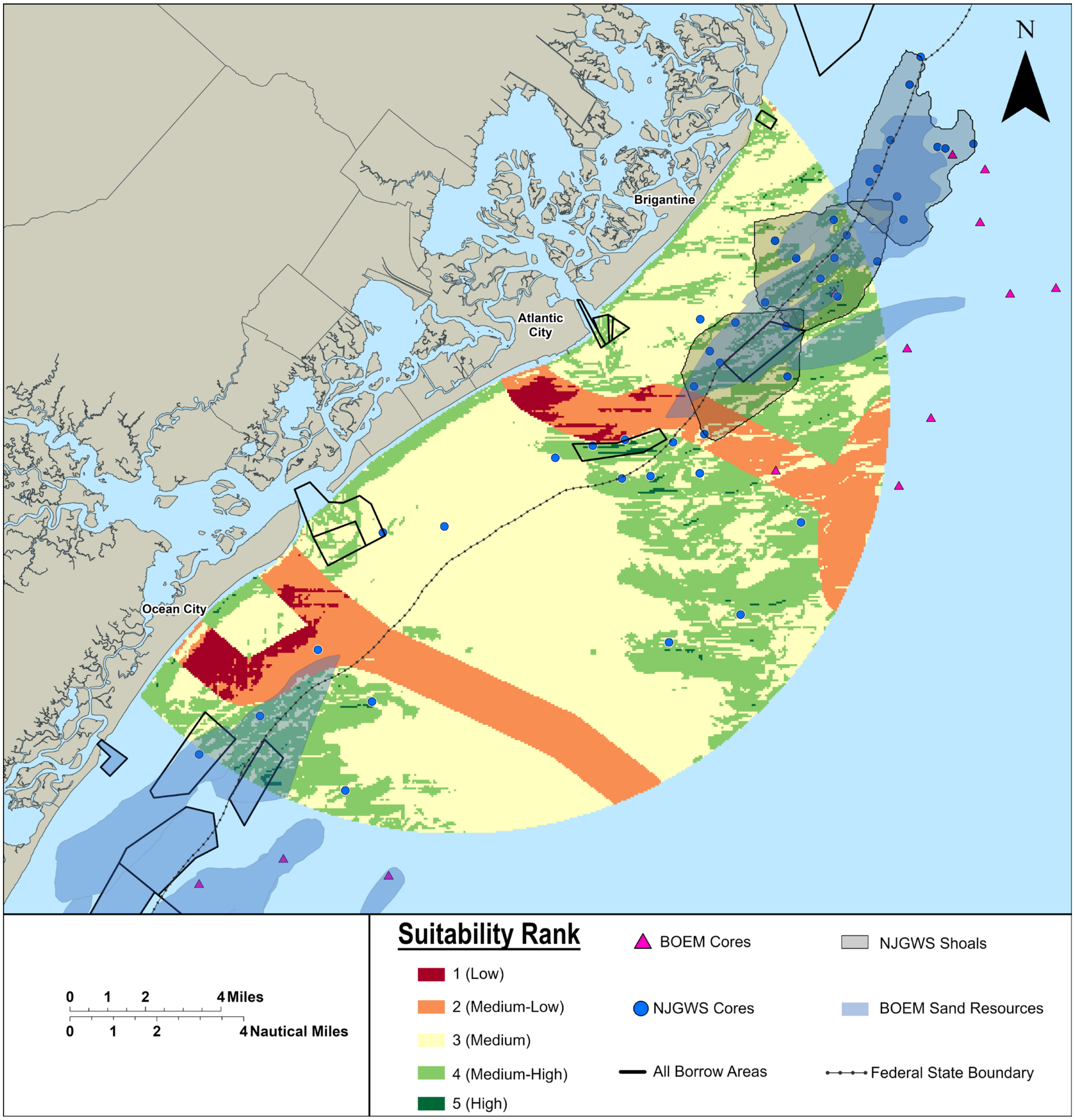


**Figure 12. Final suitability model output overlaid with NJGWS known sand resources, geologic cores and USACE borrow areas**
Final suitability output ranked low (class 1) to high (class 5) overlaid with verified and interpreted data layers, including existing USACE borrow areas, BOEM vibracores, NJGWS vibracores, and NJGWS-delimited shoals. These features provide important context for validating the model results, highlighting areas where known sand resources align with high suitability zones, and informing future prioritization for sand extraction planning.

## 3.3 Model Limitations

While the suitability model provides a valuable regional framework for identifying and prioritizing potential offshore sand resources, it is important to acknowledge several limitations. First, the model does not incorporate all possible avoidance constraints, such as sensitive benthic habitats, cultural or archaeological exclusions, dynamic sediment transport zones, or future-use conflicts (e.g., military zones). As a result, some high-ranking areas may ultimately prove unsuitable upon closer review due to regulatory, ecological, or operational considerations.

Additionally, the model relies heavily on bathymetry-derived metrics and spatial proxies for shoal identification but does not directly account for sediment composition, as no grain-size or core data were used in the raster calculations. The absence of comprehensive geotechnical or geochemical input limits the ability to predict actual sediment quality at the modeling stage.

Furthermore, while the model ranks areas based on physical and environmental suitability, it does not explicitly evaluate real-world accessibility. Key operational factors—such as permitting feasibility, wave energy exposure, vessel draft constraints, and seasonal weather conditions—can significantly affect whether a location is practically viable for sand resource development. For example, some offshore areas may appear highly suitable based on seafloor characteristics but may be located too far from shore to be cost-effective or may fall within zones that are difficult to access due to oceanographic or navigational constraints. Without incorporating these logistical variables, the model may overestimate the practical feasibility of certain high-suitability areas. These limitations highlight the importance of pairing model output with operational planning and regulatory review during site selection.

# 4 Model Refinements and Future Opportunities

The suitability model developed in this study provides a strong foundation for identifying and prioritizing offshore sand resources, however several areas have been identified for refinement and expansion in future efforts. This initial model successfully integrates key spatial variables—such as bathymetric complexity, infrastructure avoidance, and ecological considerations—to identify areas with high potential for sand resource development. However, like all planning tools, its effectiveness depends on the quality and completeness of the underlying data, as well as its adaptability to emerging challenges and evolving user needs. Future work should focus on improving data integration, expanding model functionality, increasing geographic applicability, and enhancing usability for diverse stakeholders. These next steps are essential to ensure the model can serve as a robust, flexible framework for long-term planning, regulatory coordination, and conflict mitigation in a dynamic offshore environment:

- **Integrate Geotechnical and Sediment Quality Data**
  Future iterations of the model should incorporate vibracore data, grain-size distribution, critical minerals (e.g., heavy mineral sand occurrence), and overfill factor calculations to directly assess sediment quality alongside spatial suitability. This would enhance the model's ability to distinguish between physically suitable zones and those with beach-compatible materials.

- **Quantify Sand Volume and Accessibility**
  Volumetric estimates of sand resources within high-suitability zones should be calculated using core data and shoal boundaries. Combining these estimates with the metrics used in the model (distance to shore, permitting status, and dredge vessel limitations) will allow for more realistic planning and cost assessment.

- **Expand Spatial Constraints and Avoidance Layers**
  Incorporating additional avoidance zones, such as benthic habitats, archaeological features, unexploded ordinance, and underwater cables, will improve the model’s regulatory and environmental utility.

- **Broaden Geographic Coverage**
  The current model is focused on the area within a 10 nautical mile radius offshore Absecon Island, but the workflow is adaptable. Expanding the model to cover additional stretches of the New Jersey coast or applying it to other states would potentially enable regional and federal agencies to compare and coordinate sand resource planning more effectively, based on a standard framework.

- **Develop Iterative Scenario Modeling**
  A key strength of the suitability model is its ability to adapt to different user inputs. Future development should expand on this capability, allowing users to adjust assumptions about cable placement, fishing grounds, or wind lease activity and see the impact on sand availability in real time and across a range of scenarios

- **Strengthen Stakeholder Collaboration**
  Engaging with offshore wind developers, fishery managers, and coastal engineers during future modeling phases can improve data sharing and ensure that emerging priorities (e.g., new lease areas or fishery closures) are incorporated early in the planning process.

- **Conduct Ground-Truthing and Field Verification**
  High-suitability model outputs should be validated through new geophysical surveys and sediment sampling campaigns to confirm shoal presence, resource quality, and potential extraction feasibility.

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# Appendix A: Suitability Model Overview

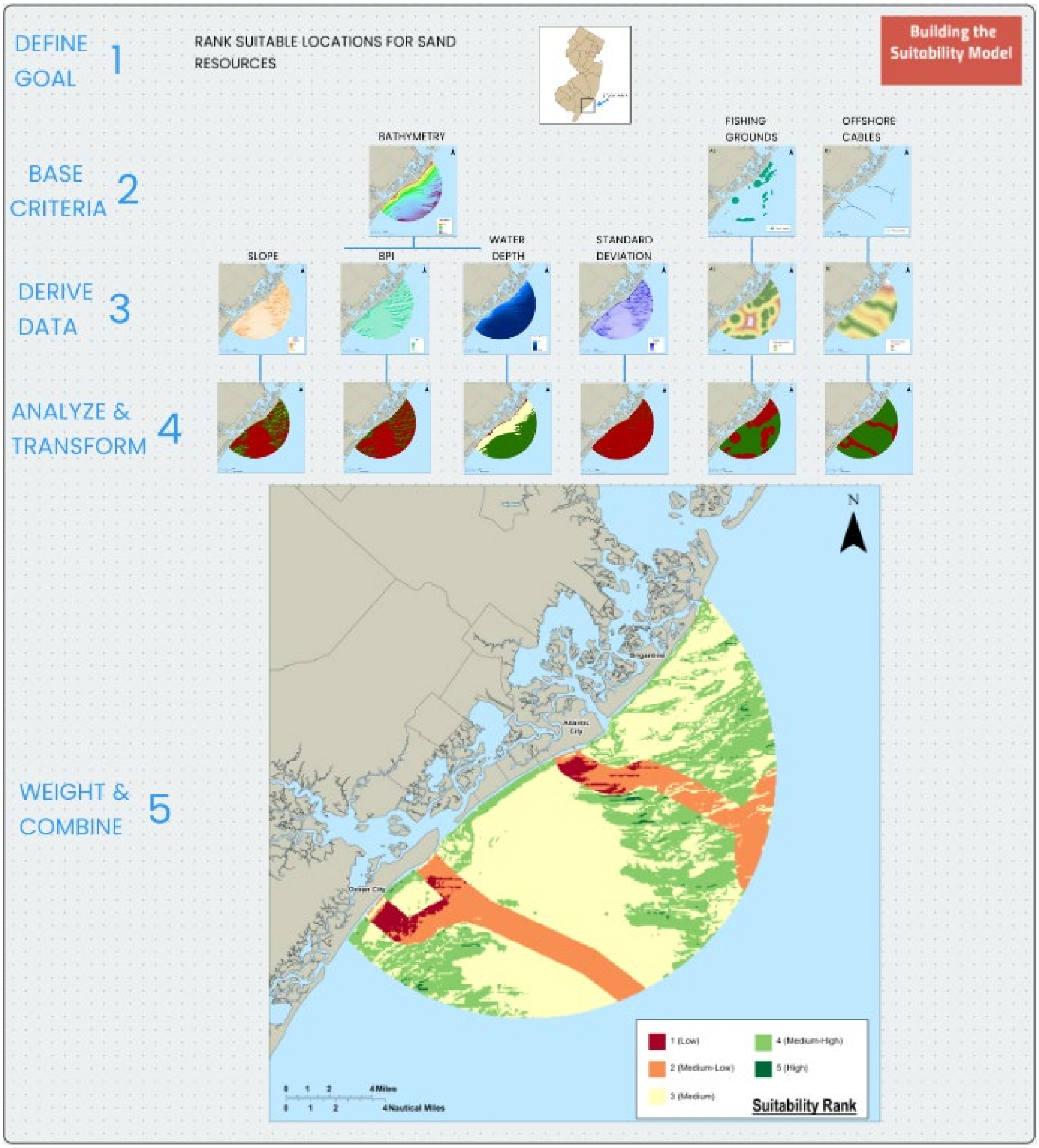



**Figure 13. An outline of the full end-to-end process used to develop the offshore sand suitability model**
It begins with the definition of the study area and data acquisition, and progressing through raster processing, reclassification, distance analysis, and weighted overlay. The workflow integrates both physical seafloor metrics and spatial constraints to produce a final ranked suitability output. Each stage builds upon the last, demonstrating a structured, repeatable approach for identifying and prioritizing potential offshore sand resources using ArcGIS Pro and supporting tools.

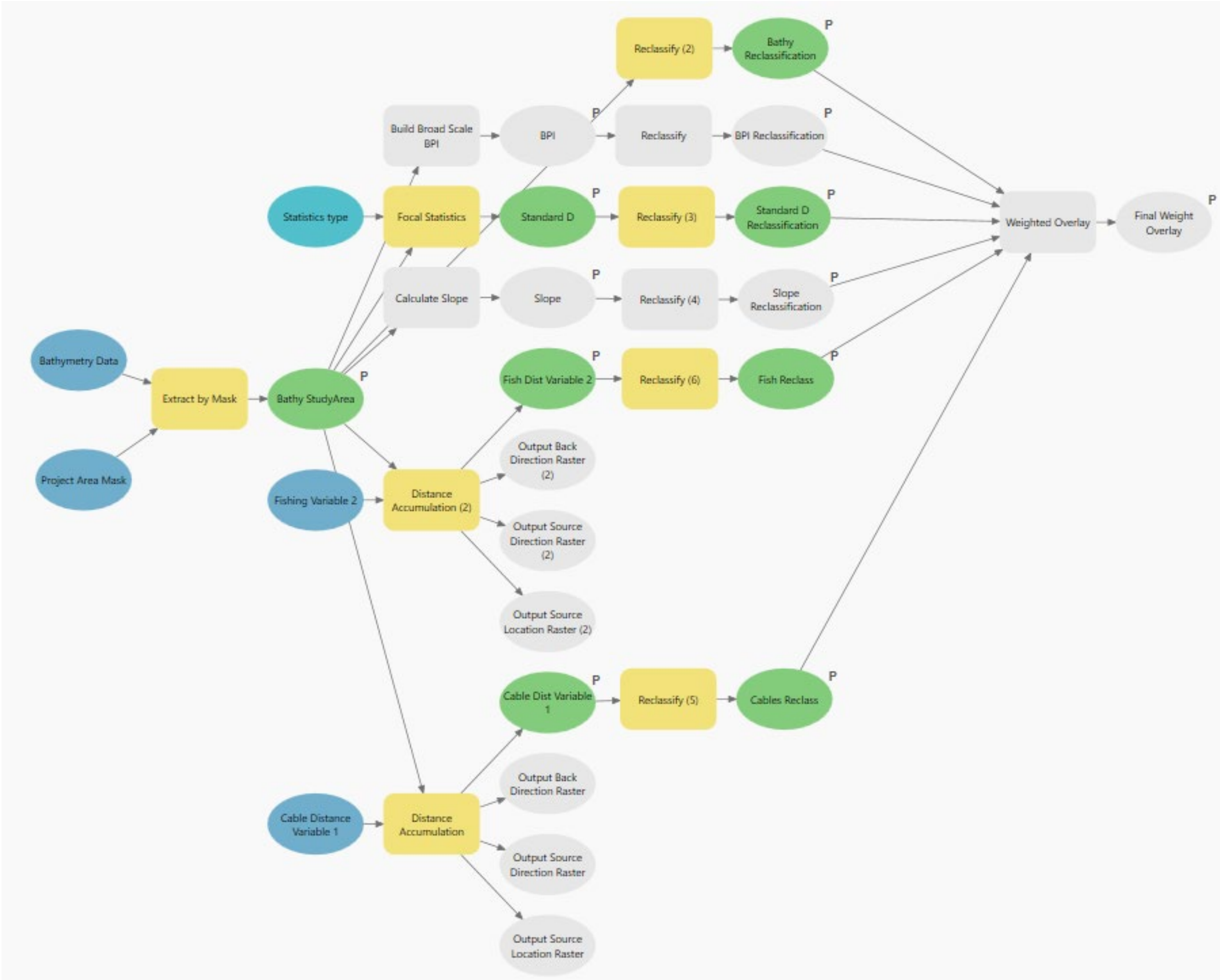



**Figure 14. Flow chart of the automated workflow developed in ArcGIS Pro Model Builder to generate the offshore sand suitability model**

The model integrates multiple spatial analysis tools, including raster derivation, reclassification, distance calculations, and a weighted overlay, to streamline the prioritization process. Each step is linked to a corresponding data input or transformation, ensuring a consistent and repeatable methodology. This visual workflow enhances transparency, supports reproducibility, and allows users to efficiently adapt the model for different study areas or scenarios.

## Appendix B: Sand Prioritization Suitability Model Tutorial

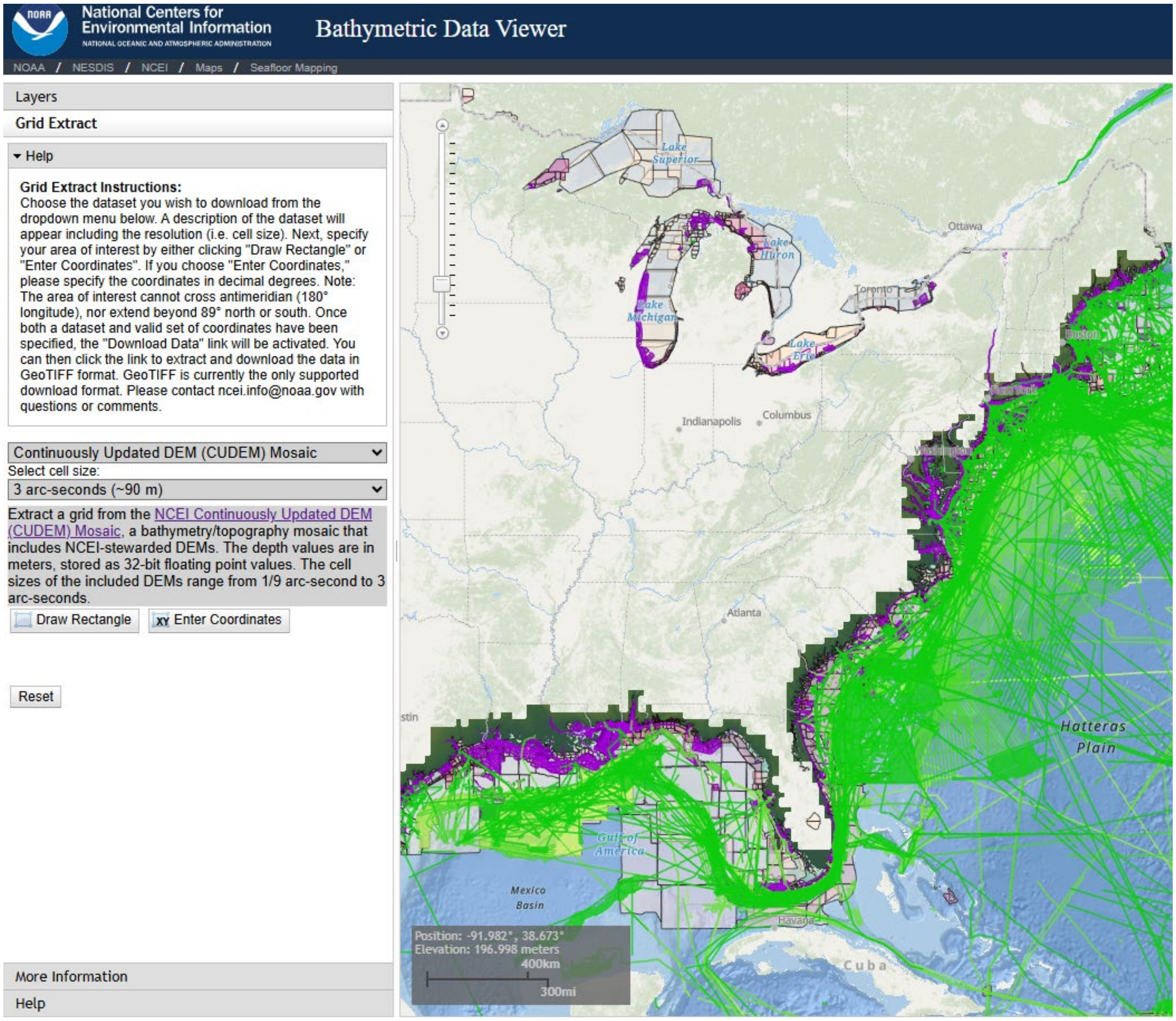
This tutorial serves as a practical, step-by-step companion to the BOEM Sand Prioritization Model report, translating the documented methodology into a replicable workflow within ArcGIS Pro. This model and all its geoprocessing workflow were completed using ArcGIS Pro Version 3.0. Users operating prior versions will still be able to replicate this workflow, noting that they have an active spatial analyst license. Rooted in the case study centered on Absecon Island, New Jersey, the tutorial guides users through the complete process of generating a suitability model for offshore sand resource identification. This includes preparing bathymetric data inputs, deriving seafloor metrics, reclassifying rasters into standardized categories, and performing a weighted overlay analysis.

To follow this workflow successfully, users will need access to the Spatial Analyst extension in ArcGIS Pro, as many of the core tools—such as Focal Statistics, Distance Accumulation, Slope, and Weighted Overlay—will not function without it. Additionally, the tutorial makes use of NOAA's Benthic Terrain Modeler (BTM), available as a standalone download from NOAA's Digital Coast platform. This toolset is essential for calculating the bathymetric position index (BPI), a key input in identifying potential shoal features.

While this model provides a streamlined and adaptable method for spatial prioritization, it does have limitations. The results are only as accurate as the input data, so utlilizing the most up to date datasets are important.. The weighting system, though flexible, involves subjective judgment, and users must understand how those decisions affect final outputs. Additionally, this model emphasizes physical factors and proximity constraints but does not include more nuanced ecological, legal, or economic considerations that may impact sand resource availability.

Whether you're replicating the analysis in a new study area or looking to understand the spatial logic behind  shoal selection process's, this tutorial offers a structured way to engage with the model's core components. It emphasizes transparency, data preparation, and customization—equipping GIS users with both the tools and contextual understanding needed to apply this workflow to similar coastal and marine spatial planning efforts.

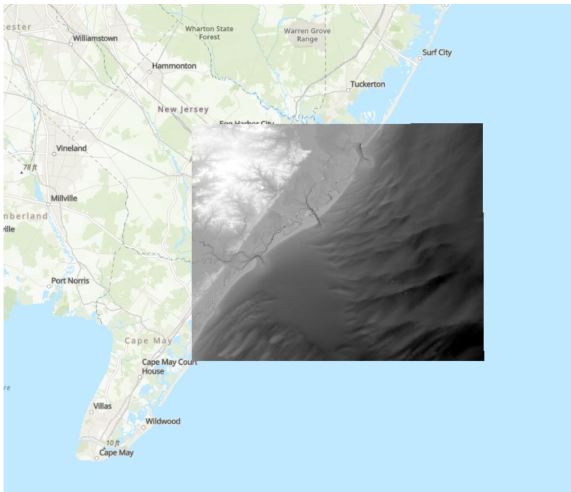
**Step 1:** Use NOAA NCEI Bathymetric Data Viewer to extract bathymetric data for your area of interest. First, access the bathymetric viewer here: https://www.ncei.noaa.gov/maps/bathymetry/. Next, click 'Grid Extract' on the bottom left. For dataset, select 'Continuously Updated DEM (CUDEM) Mosaic'. For cell size, select '3 arc-seconds (~90m)'. For the Absecon Island study area, 90m cell size was used. Depending on the size of your study area, a finer cell size can be used. Next, draw a rectangle around an area of interest and a TIFF download will occur. Save this into a project file folder.

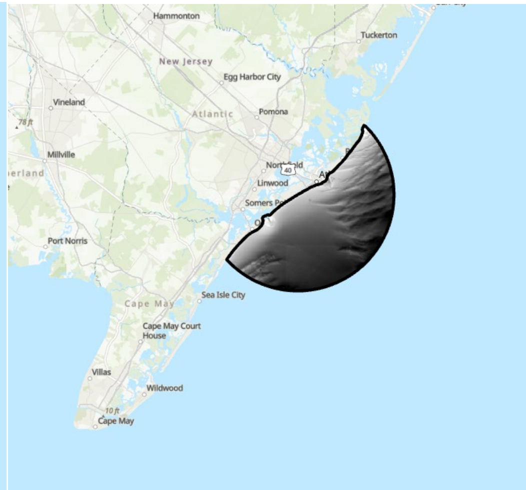



**Step 2:** In the Arc Pro catalog pane, navigate to the bathymetry DEM (.tif) that you created in step 1. Right click on the TIFF and add it to your current map.

*Note that the bathymetry DEM most likely won't be exactly accurate as the extent for your study area, so you may need to clip it to an extent layer that you already have, or mask it to fit properly. If need be, create a feature class polygon outlining your study area. Using the Extract by mask tool, input the newly downloaded DEM in the input raster section, and for the input raster or feature mask data, input your newly created polygon or boundary extent. Make sure in the environments window Cell Size Projection Method is changed to preserve resolution. When run, the output should be a DEM that resembles the outline of your polygon extent.

Initial DEM Download Extent DEM after being masked to boundary study area.





Extracts the cells of a raster that correspond to the areas defined by a mask.

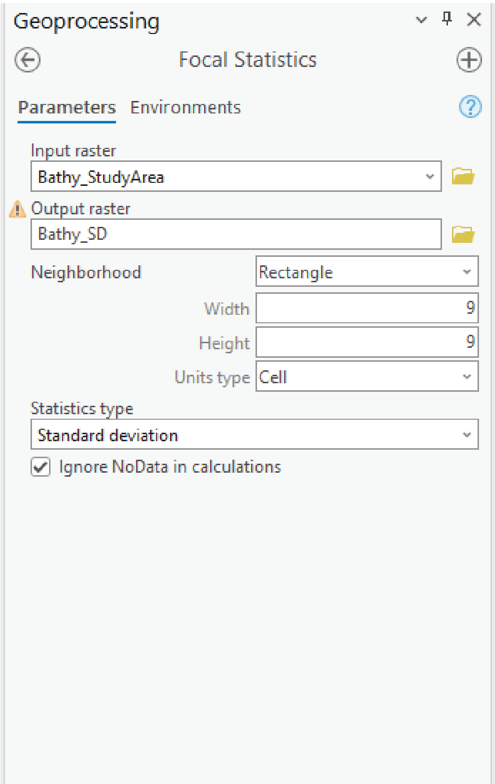
# Illustration


```
OutRas = ExtractByMask(InRas1, InMsk1, "INSIDE")
```

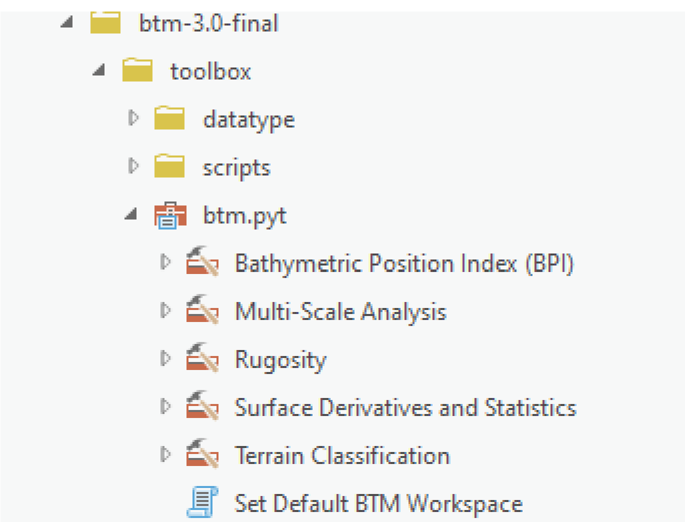
**Step 3:** Research and download at least two data layers with features that would be considered an avoidance in your project area. These can be point, line polygon or raster layers. For example, proposed cables and fishing grounds are considered avoidance areas for offshore dredging activity. Geospatial data layers associated with coastal and marine spatial planning can be found on NJDEP's open data site ( https://gisdata-njdep.opendata.arcgis.com/), Mid-Atlantic Ocean Data Portal (MARCO) https://portal.midatlanticocean.org/, Marine Cadastre (https://hub.marinecadastre.gov/), NOAA's open data site (https://coast.noaa.gov/dataviewer/#/), and many other locations on the web. These features will be used as distance variables later on in the analysis.

**Step 4:** Navigate to the geoprocessing tab and search Focal Statistics (Spatial Analyst). Input your study area bathymetry DEM and make sure the statistic type is standard deviation.

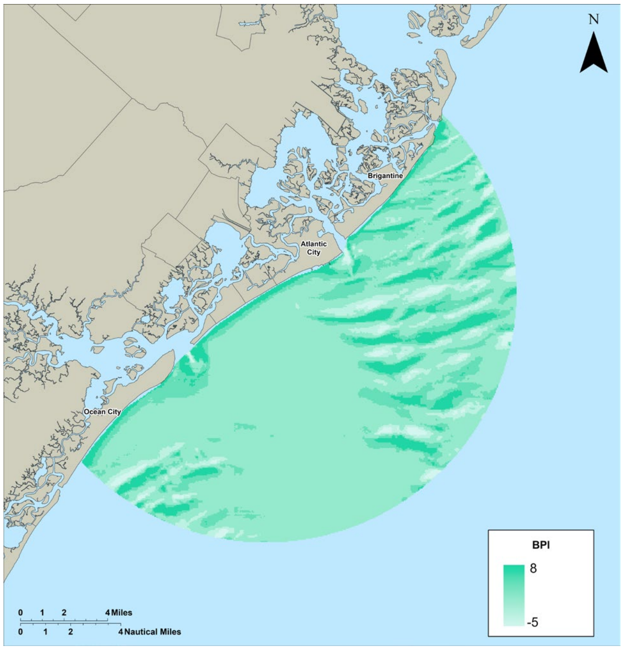
We are using this tool to calculate the standard deviation of depth for each cell based on the depths values of the surrounding cells. For this study, we used 9 x 9 cell rectangle, but for a smaller study area and or bathymetry data with finer resolution, a cell window of 3 x 3 will work. Name the output raster in a manner that corresponds with your study area and includes SD, so you know it's the standard deviation of the bathymetry. Run the tool. An output will generate, and you'll now have a new raster layer representing the standard deviation of the area. If the raster's being made are being stored in a file geodatabase located in a folder, the default file fomat for the rasters will be (.tif)

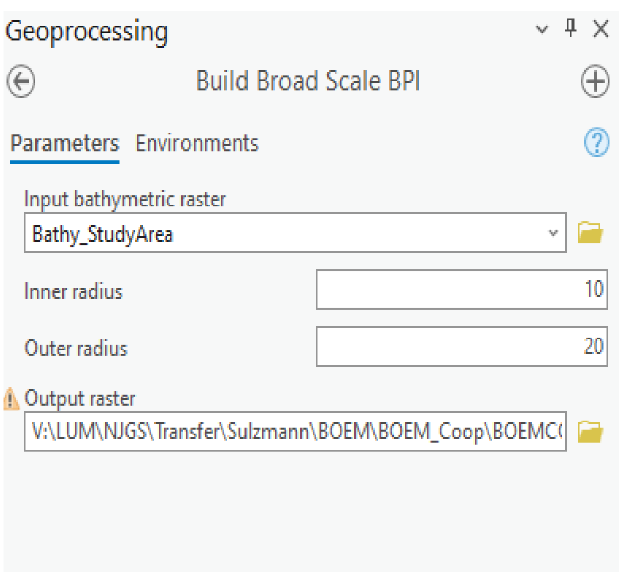



**Step 5:** Add the Benthic Terrain Modeler (BTM) toolbox in the catalog pane. This toolbox can be found for download at https://coast.noaa.gov/digitalcoast/tools/btm.html . In the download there is a btm-3.0-final folder that holds the toolset btm.pyt. The BTM tools that we'll be using are python script tools that calculate benthic position index  (BPI) and slope.

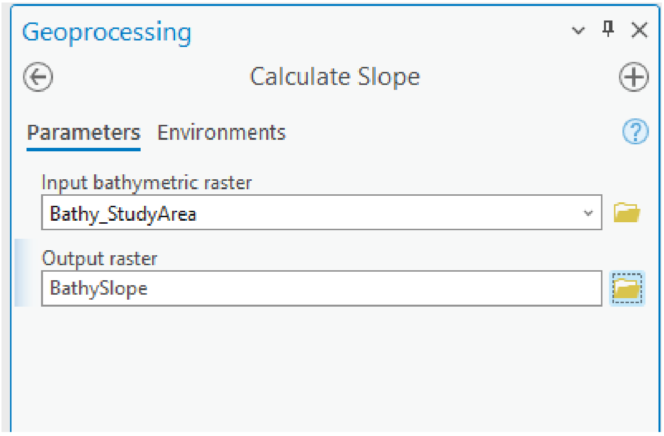


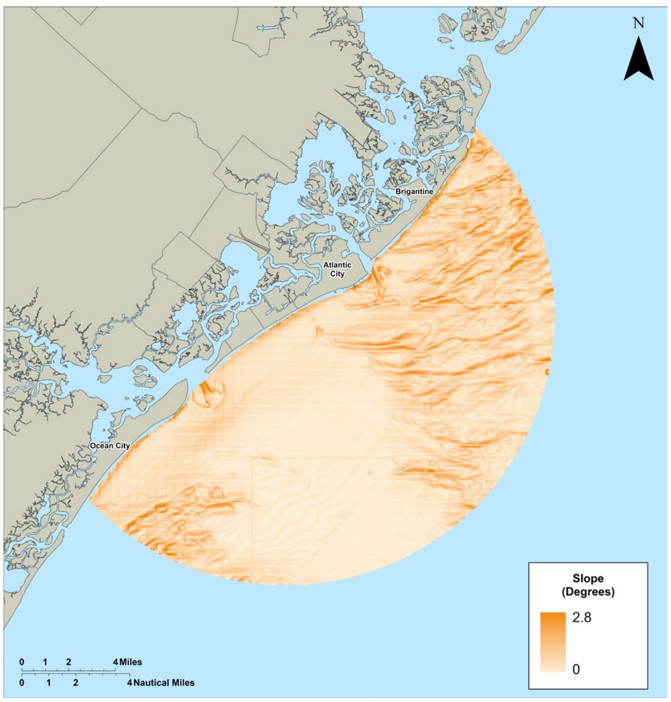
**Step 6:** Open the Build Broad Scale BPI tool in the BTM toolbox and input the study area bathymetry DEM. Run it with the default parameters, for this study an inner radius of 10 and an outer of 20 were used. Name the output with relevance to your study area along with the acronym BPI, naming the outputs accordingly will cause for less confusion later on. Saving this raster in a geodatabase will by default make its file extension (.tif). You should get an output that looks like this.



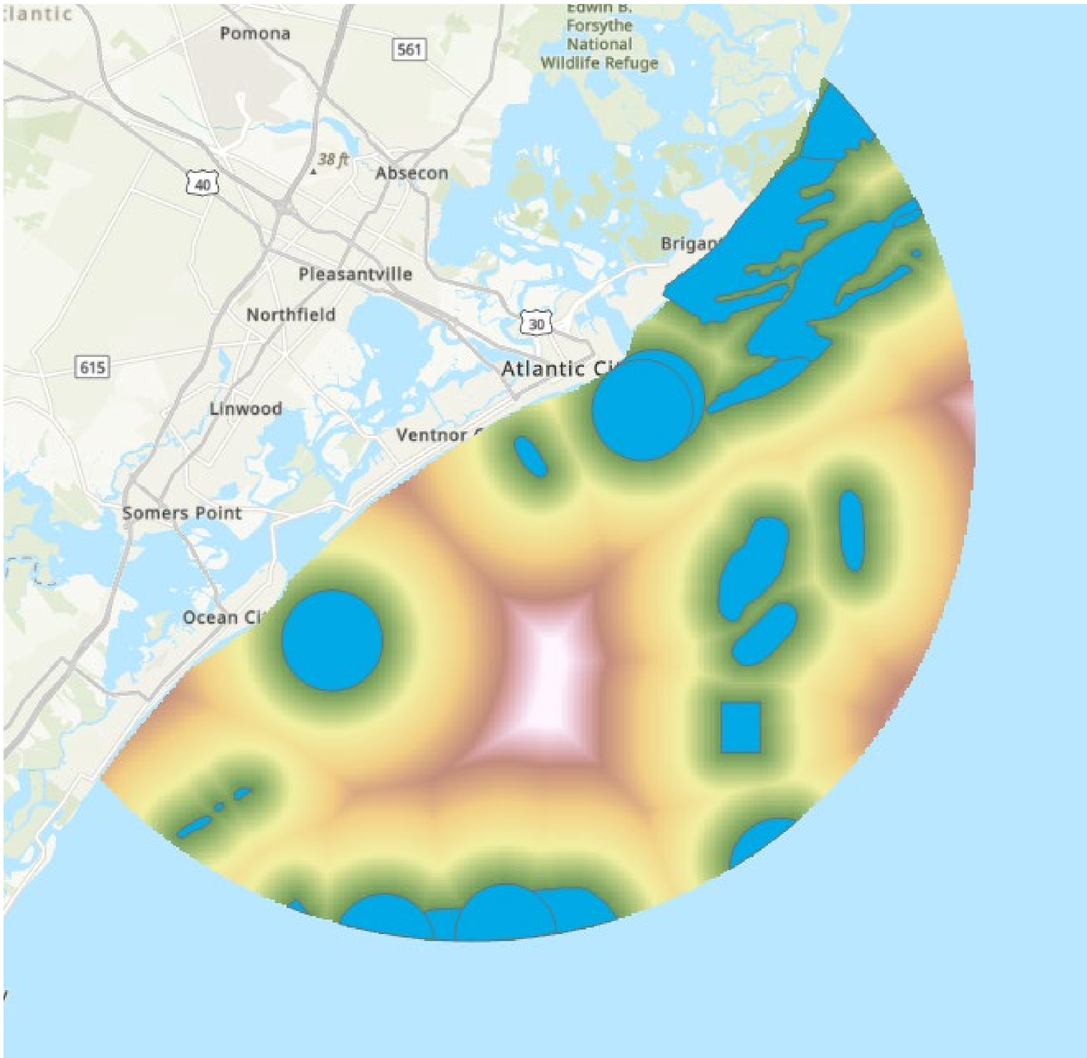

**Step 7:** In BTM toolbox, under Surface Derivatives and Statistics, open the calculate slope tool. Also note that the native calculate slope tool in ArcGIS works the same. Input study area bathymetry DEM, and make sure it's calculated in degrees. A raster similar to the one below should be your output. Name the output accordingly with relation to slope to cause less confusion later on in the analysis. If the output raster is saved in a geodatabase it's default file extension will be (.tif)



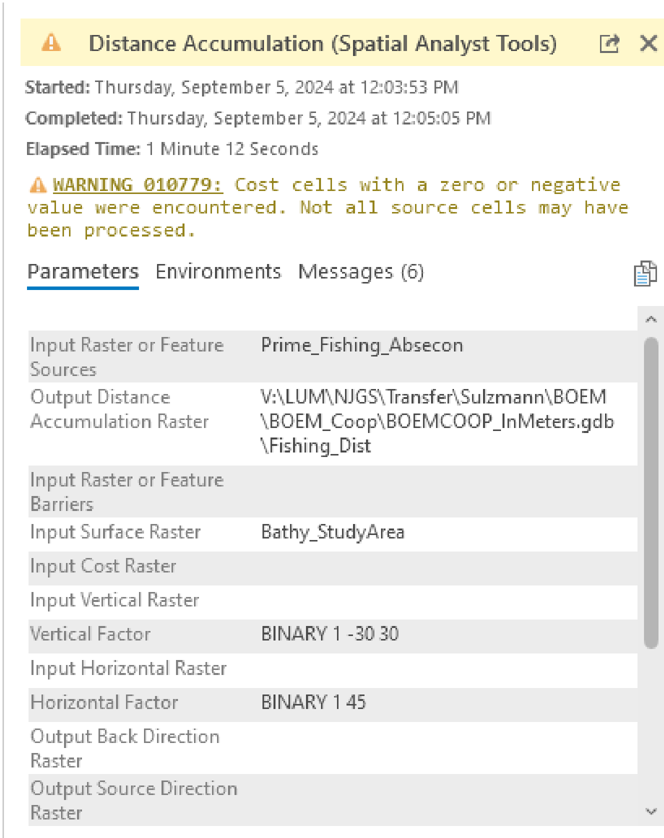




**Step 8:** Now that we have three raster's (BPI, Standard Deviation, and Slope) derived from the study area bathymetry , the avoidance features that we downloaded earlier are going to be made into raster's as well.

Using the Distance Accumulation tool (Spatial Analyst) in the geoprocessing pane, input one of the avoidance feature layers. Specify the output raster name and make the input surface raster parameter the study area bathymetry DEM. The output will be a distance raster representing distance away from the avoidance area features of concern. For example, the image below illustrates the output raster showing distance from sportfishing areas. Repeat this process, but this time using the other avoidance feature layer you downloaded in step 3.




**Blue areas in figure represent the fishing grounds layer input. They are overlayed in this figure to show the extent in which the tool works with the input(fishing grounds layer).




**Step 9:** Now that we have our six input raster layers (bathymetry, benthic position index, slope, standard deviation, fishing grounds distance, and offshore cables distance), it's now time to convert them so that they can be processed in the overlay model

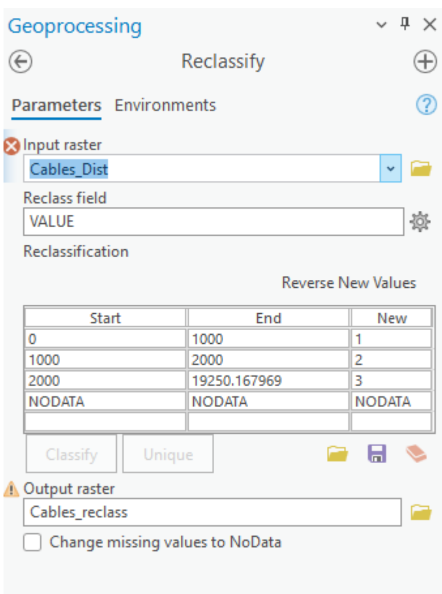
Using the Reclassify tool (Spatial Analyst), you are going to reclassify each raster separately. Click on the Classify tab and make the classify method Manual Interval. Using the manual interval method gives you the freedom to specify the number of classes and the range of input values corresponding to each respective output class value. For this study, a common scale of three output classes was chosen, where each of the six input rasters were reclassified into three classes each. NOTE: In order to run the weighted overlay tool, all input rasters must have the same number of classes. To help determine appropriate ranges for reclassifying the bathymetry and bathymetric derivatives (BPI, slope, standard deviation), we referenced the statistical parameters reported by Pickens et al. (2020) for shoals in the Northeast Atlantic region. Therefore, following the table and making the classes so that you can isolate a favored field should be done. Pickens et al. (2020) used a similar process (Iso Clustering) where they used binned ranges in order to map shoals. For our sand resource prioritization study area offshore of Absecon Island, we wanted to focus on statistical parameters associated with shoals because they are commonly associated with sand resources in this region. Thus, the data ranges assigned to each reclassification value were designated to enable the model to identify areas that are statistically similar to shoals and rank those areas higher than other areas.

| Variable | U.S. Northeast Atlantic Shoal | U.S. Northeast Atlantic Swale | U.S. Northeast Atlantic Seafloor | U.S. Southeast Atlantic Shoal | U.S. Southeast Atlantic Swale | U.S. Southeast Atlantic Seafloor | Gulf of Mexico Shoal | Gulf of Mexico Swale | Gulf of Mexico Seafloor |
|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | 20.9 ± 6.6 | 28.7 ± 8.2 | 27.8 ± 8.0 | 19.1 ± 6.8 | 25.0 ± 8.3 | 24.2 ± 8.5 | 19.9 ± 8.2 | 31.5 ± 7.2 | 23.7 ± 9.6 |
| SD of depth | 1.3 ± 0.5 | 2.4 ± 1.4 | 0.8 ± 0.7 | 0.9 ± 0.5 | 1.6 ± 1.2 | 0.5 ± 0.5 | 0.5 ± 0.3 | 1.3 ± 1.5 | 0.2 ± 0.4 |
| Slope (°) | 0.4 ± 0.2 | 0.8 ± 0.63 | 0.2 ± 0.3 | 0.2 ± 0.2 | 0.5 ± 0.4 | 0.1 ± 0.2 | 0.1 ± 0.1 | 0.4 ± 0.6 | 0.04 ± 0.1 |
| Bathymetric position index | 2.5 ± 1.9 | −1.0 ± 3.7 | 0.4 ± 1.6 | 2.2 ± 1.0 | −0.3 ± 2.2 | 0.3 ± 1.0 | 2.4 ± 0.9 | −0.7 ± 2.9 | 0.2 ± 1.2 |
| Distance to shore (km) | 25 ± 14 | 31 ± 17 | 30 ± 18 | 32 ± 18 | 39 ± 22 | 39 ± 23 | 31 ± 15 | 38 ± 22 | 49 ± 28 |

For example, when the reclass tool was ran on the bathymetry input raster, a new output raster was created with new values 1,2, and 3. Class 1 is associated with depth values from -24.4 to -14.3 meters, class 2 from -14.3 to  -5eters, and class 3 from -5 to 2.9meters. Class 1represents the target shoals

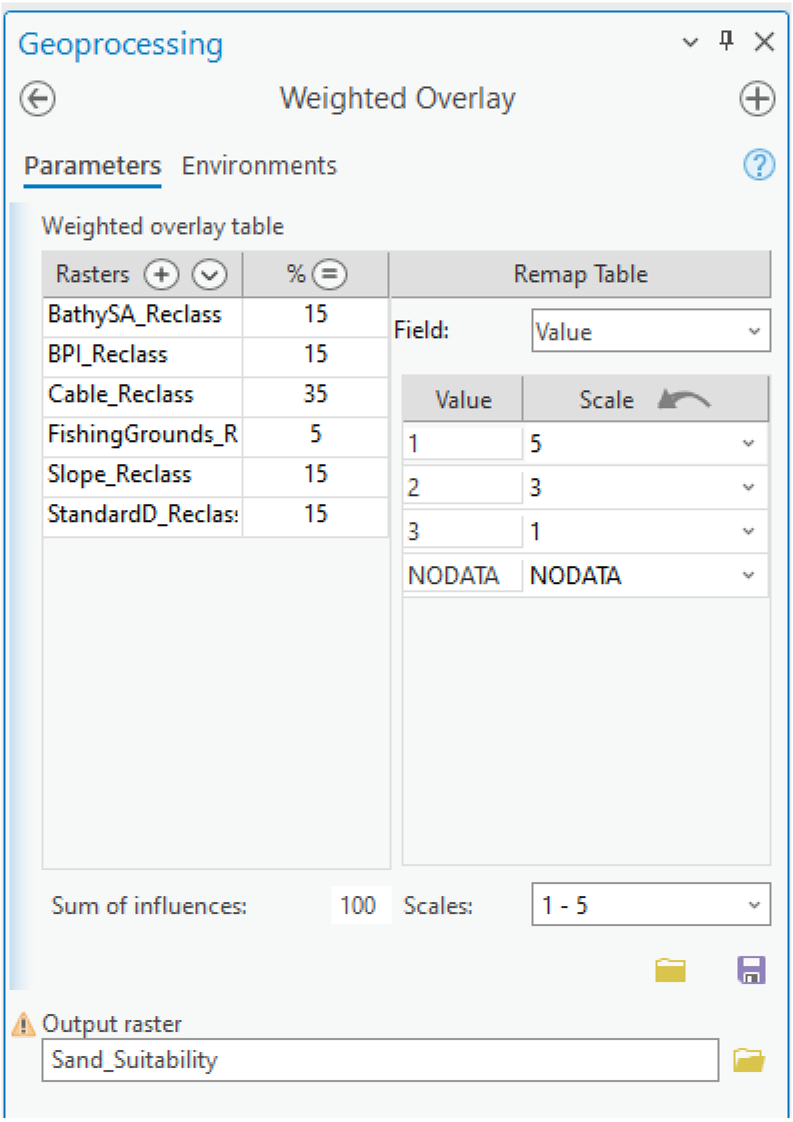
Repeat this process for the following rasters: BPI, Standard Deviation, and Slope. Follow the reference table for value class breaks.

For the two distance variables made earlier, reclassify using three classes and by 1000-meter intervals. The logic for these reclassifications is that areas farther away from avoidance areas are more favorable for accessing sand resources. The image below shows the reclassification ranges assigned to the distance allocation raster created for the cable area features to be avoided.

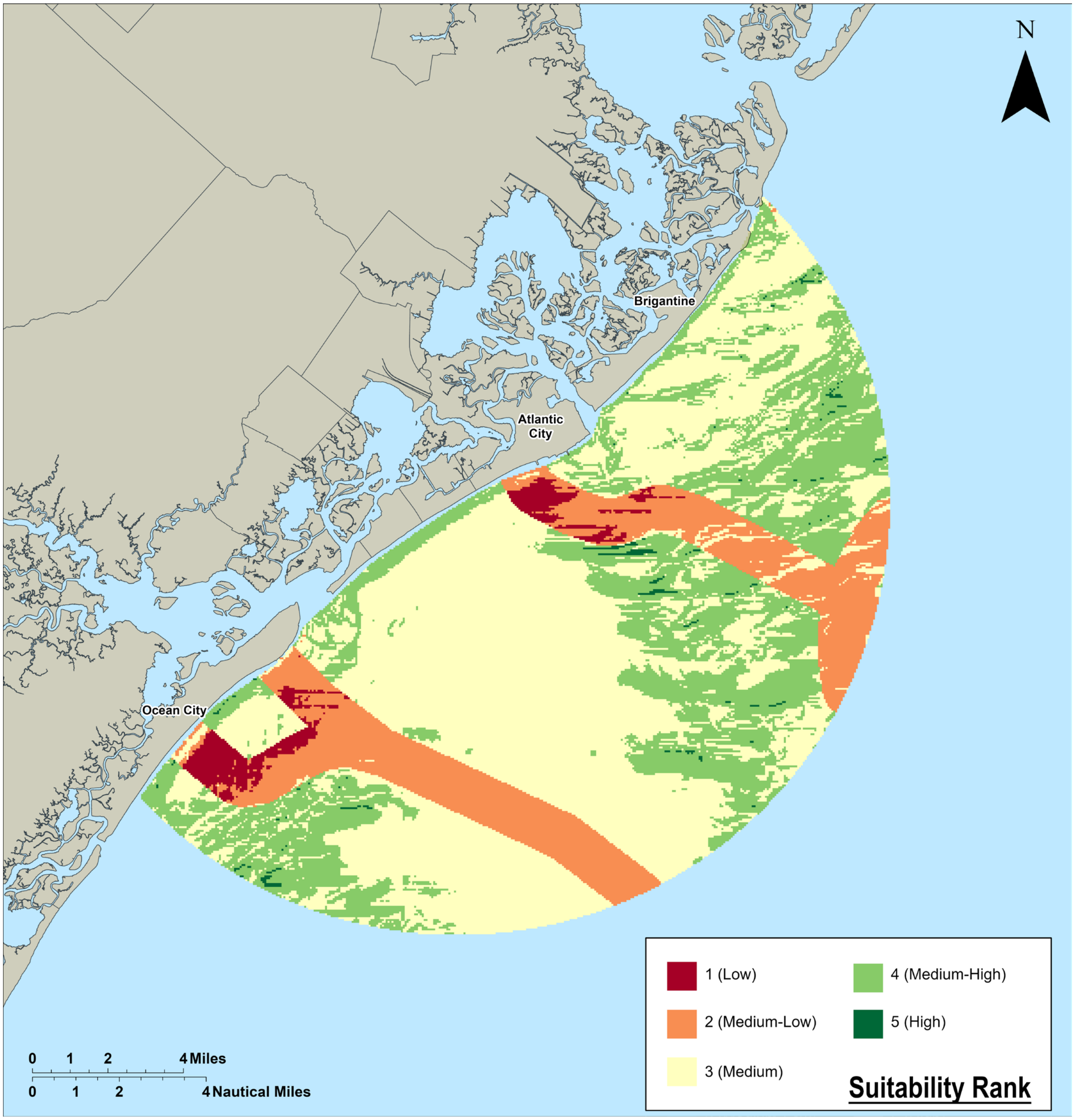



**Step 10:** All of the pieces for the overlay analysis are ready. Now, in the Geoprocessing pane, search for the Weighted Overlay Tool (Spatial Analyst). This step in the final step in the overall suitability analysis.

In the rasters section of the tool, input all six of the reclassified rasters. Because this is weighted, all of the rasters must be distributed with percent weights that add up to 100. The relative weights  assigned to each are somewhat subjective and may vary depending on the study area and avoidance area type, so the values assigned in this study may not be applicable to areas in other regions. As an example, here is a open tool window breakdown.




The objective of this step was to give high scores to the reclass rasters values that were the ideal range for shoal morphology. Doing so enables the tool to highlight and focus on those values so that the output can be a combination of all ideal value ranges from all the reclass rasters. The image below is an example of final model output.




**Model Ranking:**

Rank 1 – Low Suitability

- Poor alignment with shoal characteristics
- Often located directly along cable corridors or other exclusion zones

Rank 2 – Medium-Low

- Some physical potential, but limited by proximity to infrastructure (e.g., offshore wind cables)
- Not ideal, but not entirely unsuitable

Rank 3 – Medium Suitability

- Moderate alignment with shoal features
- May require additional data to assess viability

Rank 4 – Medium-High

- Good morphological indicators
- Some minor constraints or less ideal features
- Worth considering with further validation

Rank 5 – High Suitability

- Strong alignment with shoal-like morphology
- Minimal spatial constraints
- Top candidates for future sand resource investigation

**Model Limitations:**

No Direct Sediment Data:

- The model relies solely on geomorphic and spatial indicators.
- It does not include core samples or grain size data, which are critical for confirming sand quality.

Incomplete Constraint Representation:

- Only select spatial constraints (e.g., fishing grounds, wind cables) were included.
- Other avoidances like marine habitats, shipping lanes, or military use zones were not factored in.

Not a Replacement for Field Work:

- The model is intended for initial screening only.
- Ground-truthing and site-specific studies are still essential before resource development.

## Appendix C: Digital Data

All data from the report can be found in the zipped folder: AppendixC_DigitalData

This folder contains the following data:

- Model Builder: Sand_Prioritization.atbx
- Python File: BTM
- Geodatabase: BOEM_Final.gdb
- Polygon: Study Area Polygon
- Raster: Bathy_StudyArea
- Raster: BathySA_Reclass
- Raster: BPI
- Raster: BPI_Reclass
- Raster: Cable_Distance
- Raster: Cable_Reclass
- Raster: FishingGrounds_Distance
- Raster: FishingGrounds_Reclass
- Polygon: Prime_Fishing_Absecon
- Line: Redrawn_Cable_Routes
- Raster: Sand_Suitability
- Raster: Slope
- Raster: Slope_Reclass
- Raster: StandardD
- Raster: StandardD_Reclass