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BOEM 2023-040

Geohazard Analysis and Suitability Updates for California Floating Windfarms

U.S. Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

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Prepared under Contract 140M0121F0009
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Bureau of Ocean Energy Management
Office of Renewable Energy Programs

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GEOHAZARD ANALYSIS AND SUITABILITY UPDATES FOR CALIFORNIA FLOATING WINDFARMS

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GEOHAZARD ANALYSIS AND SUITABILITY UPDATE FOR OFFSHORE CALIFORNIA WIND FARMS

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EXECUTIVE SUMMARY

The mission of the Bureau of Ocean Energy Management (BOEM) is to manage development of U.S. Outer Continental Shelf energy and mineral resources, which includes leases for renewable energy projects for offshore wind energy, in an environmentally and economically responsible way. Earthquakes, landslides, liquefaction, tsunamis, slope instability, and biogenic gas are some of the hazards that can impact the Floating Offshore Wind Farms (FOWF) located in the Pacific Outer Continental Shelf, as they are geologically complex and active regions. The risks are mainly to the mooring and anchorage systems, as well as buried cables that transmit the power to shore.

The purpose of BOEM-funded Contract No. (140M0121F0009) is to add on and update the data compilation and risk analysis previously conducted under BOEM Contract No. 140M0119C0004. The previous study assessed the potential threats to wind energy development off the U.S. Pacific coast, including catastrophic geohazards (e.g., earthquakes, landslides, and tsunamis), gas plumes, liquefaction, and turbidity currents, and the effect on the mooring and anchorage system and buried cable due to geohazards. The main goal of the previous study was to provide an understanding of geohazard risks in areas under analysis for the development and siting of FOWF using a geospatial planning approach to identify important geohazards and how they might affect the performance of FOWF. One of the challenges in assessing the geohazards during the study was the data gap, and lack of site-specific geophysical and geotechnical data. Recently, some geological and geotechnical data were collected covering the three Call Areas[1] offshore California, as part of interagency efforts among BOEM, United States Geological Survey (USGS), and National Oceanic and Atmospheric Administration (NOAA).

For this project update, this newly available geophysical and geotechnical data were integrated into the geohazard assessment to fill in the data gap. The data were assessed to identify site conditions and geohazard assessments at several locations off the coast of California under BOEM jurisdiction in the Pacific Ocean, and also was integrated into a password-protected online webpage (oceansmap.com/BOEM/California), summarizing the collected data, and suitability of the call areas. This report summarizes the data inputs that have been identified and evaluated for use in the updated suitability maps, describes how this data was integrated into the suitability analyses, and discusses the analysis approach and results. The discussion presents a comparison of results of current (Contract No. 140M0121F0009) and previous (Contract No. 140M0119C0004) studies through difference mapping, and the impact of them in geohazard assessment.

[1] At the start of this study, the areas of interest were identified as Call Areas designated by BOEM, which have been used and referred to in this study. In 2021, BOEM designated the Humboldt Wind Energy Area and Morro Bay Wind Energy Area within the Humboldt Call Area and Morro Bay Call Area, respectively. In 2022, BOEM designated five final lease areas within the Humboldt and Morro Bay Wind Energy Areas. The lease areas were offered and provisionally awarded in the Pacific Wind Lease Sale 1 (PACW-1) for Commercial Leasing for Wind Power on the Outer Continental Shelf in California, held on December 6-7, 2022.

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LIST OF ABBREVIATIONS AND ACRYONYMS

AOI	Areas of Interest
ASV	Assumed Seismic Velocity
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
CMECS	Coastal and Marine Ecological Classification Standard
DEM	Digital Elevation Models
FOWF	Floating Offshore Wind Farms
FOWT	Floating Offshore Wind Turbines
GIS	Geographic Information System
GNSS	Global Navigational Satellite Systems
MBARI	Monterey Bay Aquarium Research Institute
MBES	Multibeam Echosounder
MCE	Maximum Considered Earthquake
MCS	Multi-channel Seismic
MTD	Mass Transport Deposit
NCEI	National Centers for Environmental Information
NOAA	National Ocean and Atmospheric Administration
NREL	National Renewable Energy Lab
NSHM	National Seismic Hazard Model
OCS	Office of Coast Survey
PCMSC	Pacific Coastal and Marine Science Center
PGA	Peak ground acceleration
SLB	Santa Lucia Bank
SBP	Sub Bottom Profiler
TWTT	Two-way Travel Time
USGS	United States Geological Survey
WO	Weighted Overlay

1 INTRODUCTION

Floating offshore wind farms (FOWF) construction and operation off the coast of California (Figure 1) may be impacted by potential geohazards. Knowledge of the geological elements and the conditions, which can lead to hazards, is essential for the planning, adaptation, and mitigation of geohazards. Since avoiding all geohazards is not possible, understanding and reducing the risk for construction and operation are essential. To aid the selection of the best possible sites, the natural geohazards in the region should be assessed, and the soil type should be identified. Site-specific characterizations need to be conducted and data on seafloor characteristics need to be collected. To identify site-specific hazards for project components such as mooring and underwater transmission, the ground type reaction to earthquakes and potential bathymetric changes due to landslides should be assessed. Under the earlier BOEM-funded Contract No. 140M0119C0004, RPS conducted a comprehensive review of different hazards from geologic conditions, seismic activities, earthquakes, landslides, and tsunamis in the Pacific Ocean near the FOWF Call Areas. The study (hereafter Phase 1) included a geohazards data compilation of seismic and co-seismic data sources, and tsunamis for the U.S. Pacific waters, and presented maps encompassing all relevant available examples of historic earthquake, landslides and tsunamigenic sources. All the variable inputs of soil type, bathymetric slope and potential earthquakes were incorporated into a comprehensive overview tool that conveys the in-situ geologic conditions and geohazards in the area and finds the suitable site locations. The data were classified to common evaluation scales and overlaid using assigned weights (relative influence). The weighted overlaid maps showed the suitability of the region by using the total value of all weighted layers. The maps clarified the importance of each variable in finding the best site location as a guideline to identify and prioritize the risk to the FOWF. This study also identified:

- The challenges and critical needs for design and installation of floating offshore wind turbine (FOWT) in regions with geo-hazards.
- How the existing standards can be applied.
- Where the regulations and standards need to be improved.
- What site-specific analyses are required.

As this report (hereafter Phase 2) is an update to the Phase 1 study (BOEM Contract 140M0119C0004), RPS encourages the reader to familiarize themselves with the Phase 1 study[2] (Tajalli Bakhsh et. al, 2020) before reading this report and using its results. Phase 2 leverages components of the existing solution from the Phase 1 study. Recently acquired geophysical and geotechnical data by USGS, BOEM and NOAA are integrated into the geohazard analysis. By further improving the quality of data input and reassessing suitability analysis, the specific risks to developments in this area can be captured more accurately.

[2] https://boem-oceansmap.s3.amazonaws.com/reports/final_report.pdf

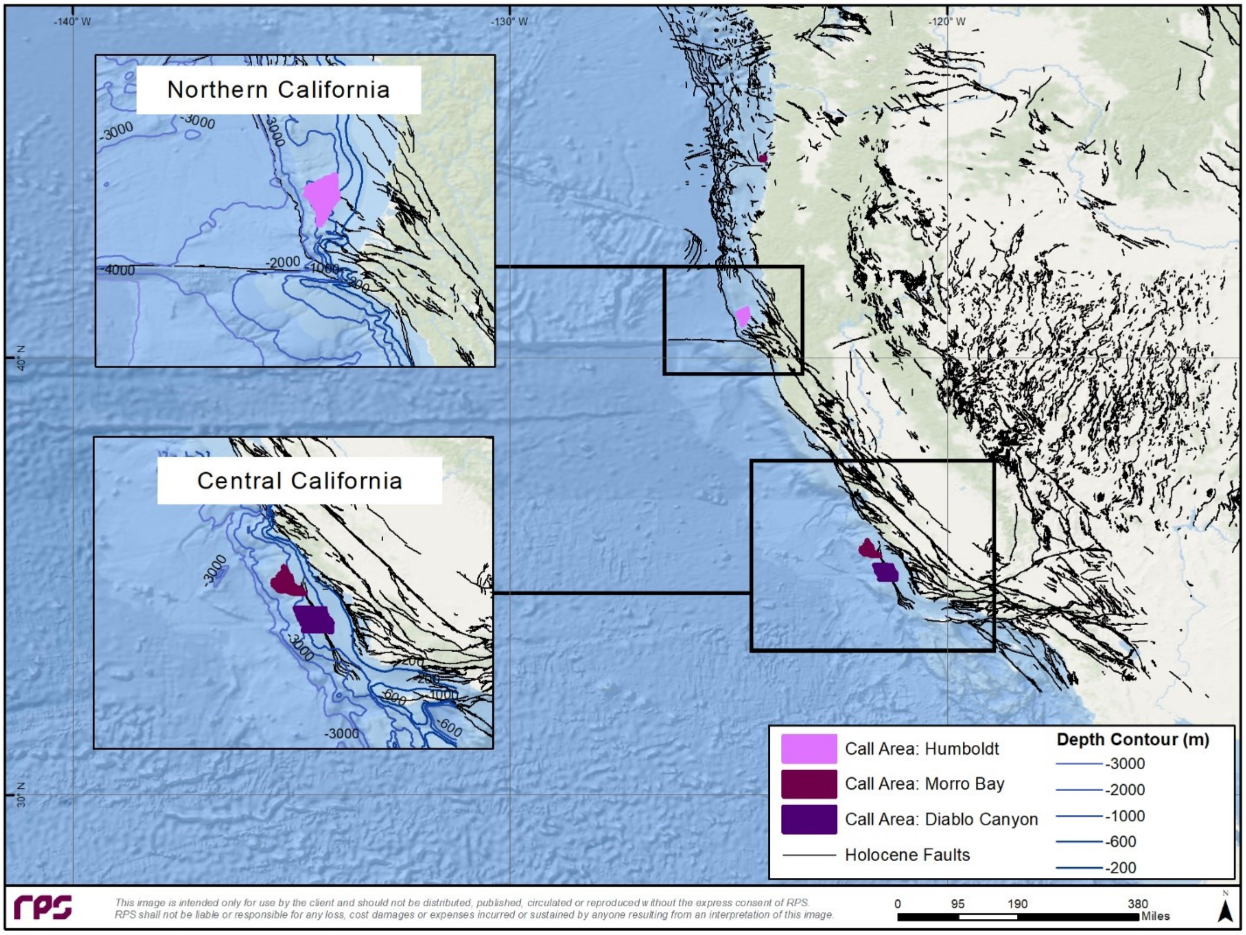

Figure 1. The location of U.S. Pacific FOWF California Call Areas.

The study area covers the FOWF off the coast of California (referred to as the Call Areas throughout this report, Figure 1) including Humboldt in northern California, and two central Call Areas located 22 miles offshore between Monterey Bay and Morro Bay: Morro Bay and Diablo Canyon. Following the recommendation of BOEM, the study covers the call areas, nearby mainland (as potential cable landing regions), and a 5 nautical mile radius extending seaward of the areas (as potential anchorage and mooring regions). Throughout this report, these study areas will collectively be referred to as the Area of Interest (AOI).

The major objectives of the present study are to update the assessment of potential geohazards and ranking of suitable regions for wind energy development off the California coast. This update of suitability analyses focuses on central California, where new field surveys were performed through inter-agency collaborations (Cal DIG I[3]). Some activities associated with northern California (Humboldt Wind Energy Area) are still in progress as part of Cal DIG II[4] at the time of this study, and only limited new data are available for this area.

This report aims to provide an update on the results of geohazard assessment by integrating new data inputs into the suitability analysis. The report includes a discussion related to a comparison of Phase 1 vs Phase 2 results through calculation of the change in suitability results by subtracting

[3] https://www.usgs.gov/publications/california-deepwater-investigations-and-groundtruthing-cal-dig-i-fault-and-shallow

[4] http://www.boem.gov/renewable-energy/pc-19-06

the composite suitability model of Phase 1 (on a cell-by-cell basis) from the composite suitability model of Phase 2. This computation (here after difference mapping) reveals where there has been no change in suitability, where suitability ranking has increased, and where suitability ranking has decreased.

2 GEOLOGICAL AND GEOPHYSICAL DATA INPUTS

Offshore geohazards from different geomorphological and geological features can either act alone or in combination with others as sequential events. These geohazards are a function of morphological characteristics, or bathymetric slopes, that can impact the FOWF and planning area. Seismicity (represented by Peak Ground Acceleration (PGA) in this study) as a primary hazard which can cause slope failure, liquefaction, and tsunami, has a direct impact on infrastructure and design.

Slope instabilities and consequently landslides, which can impact the export cables and foundations, are the other significant geohazards considered as data input. Seafloor geology including sediment type and thickness is another limiting factor impacting the siting of foundation, and stability of the soil.

Several geological and geophysical data inputs that were previously identified as data gaps in the Phase 1 study have been provided to update the suitability analyses. These additional data augment the three key factors (seismicity, geology, and slope stability) to the geohazards discussed in the Phase 1 by providing additional and updated information on bathymetry and seafloor geology from regional mapping and near-surface seabed soil charachterization.

This report section provides an analysis of the different types of data inputs and how they relate to geohazards discussed in the Phase 1 BOEM-funded Contract No. 140M0119C0004. A list of all new inputs and recently collected and provided datasets are summarized in Appendix 1.

2.1 Peak Ground Acceleration (PGA)

Regional seismicity and probabilistic seismic hazard maps defined by PGA were transferred from Phase 1 as a criterion in the suitability analysis[5]. Following the methodology used in the previous phase of the study to determine the seismic hazard in the study areas, Phase 2 utilized the U.S. National Seismic Hazard Model (NSHM) and ground acceleration value data extracted from USGS Scientific Investigations Map 3325 for the Conterminous United States (2014) (Petersen et. al, 2015).

The previous PGA of a 10% probability of exceedance in 50 years (500-year event), appropriate for long-term design performance considerations (IEC 61400-1, 2007), was used for representing the earthquake activities and ranking of suitability. Prior to the adoption of “uniform hazard” approach focusing on the 2500-year event by ASCE/SEI 7-16, it was previously more common to address the so-called 500-year earthquake in California. This 500-year event approximately represented the maximum deterministic values for earthquake ground acceleration, and it is utilized in Phase 2.

2.2 Bathymetry Gradient (Slope)

Erosion and transportation processes cause the deposition of thick layers of unconsolidated sediments on slopes in the ocean. The probability of failure of rapidly deposited and unconsolidated sediments increases with bathymetry gradient and further increases under conditions (i.e., wave loading or ground-shaking) related to seismic events and related tsunamis. Thus, the bathymetry gradient, or more directly the spatial derivative of the bathymetry (i.e.,

[5] The use of PGA instead of historic earthquake magnitude was suggested by Dr. Eric Hines, PE. of Tufts University during Phase 1.

slope), was used as an input. This was based on computing bathymetric slope from the regional bathymetric Digital Elevation Models (DEM).

Newly available bathymetric DEMs have been acquired for this study update and are described below. This information is one of the key inputs in the suitability analysis.

2.2.1 Humboldt

A recently collected bathymetric DEM for Humboldt is shown in Figure 2. This bathymetric dataset, "SouthernCascadia_30m_bathy_UTM10_NAD83.tif" is a merged 30m cell size bathymetric grid produced by USGS PCMSC[6] and NOAA OCS from a 12-day expedition aboard the NOAA Ship Fairweather. The data resolution increase is a substantial improvement from Phase 1, which used DEMs with a resolution of ~90 m cells. The expedition collected new multibeam bathymetry and marine magnetometer data offshore California near the BOEM Humboldt Wind Energy Area. This dataset covers >3,000 km^2 of new multibeam bathymetry data between 200-1,500 m water depth (Dartnell, et al., 2021).

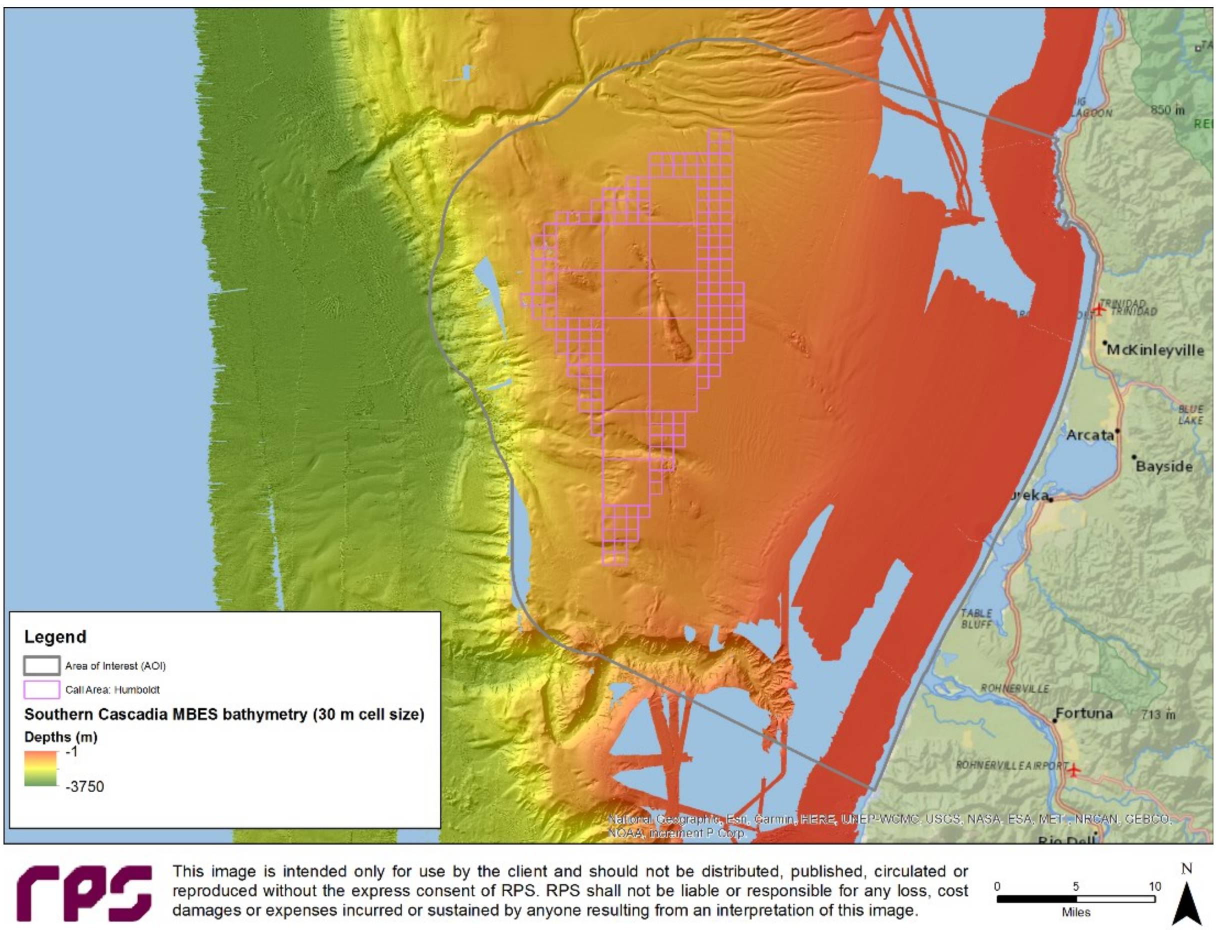

Figure 2. Humboldt MBES bathymetry (30 m cell size).

[6] https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9C5DBMR/

The data shows that some bathymetric high elevation area near the center of the Humboldt WEA was identified in the Humboldt Wind Energy Area Seafloor Features Map[7] in Final Environmental Assessment Commercial Wind Lease and Grant Issuance and Site Assessment Activities on the Pacific Outer Continental Shelf Humboldt Wind Energy Area, California in May 2022. This area is identified as a rock outcrop (breached anticline).

2.2.2 Morro Bay and Diablo Canyon

The bathymetric dataset in Figure 3, "mroby20utm10" is a merged 25 m cell size bathymetric grid, produced by MBARI. This dataset combines the 2018 Rainier data along with other surface-ship MBES data collected in the region. This includes a 2016 R/V Sally Ride survey (cruise ID SR1604), two additional NOAA Ship Rainier and Fairweather surveys (OPR-L397-RA-17 and OPR-L31-FA-19), and 2016-2019 transit data from the R/V Sikuliaq, R/V Revelle, and R/V Falkor (Walton, et al., 2021).

"Cal_DIG_I_Bathymetry_10m.tif" is a merged multibeam acoustic-bathymetry dataset collected offshore of Morro Bay, California, from 2016 to 2019 (extents in Figure 3). The data were collected during five separate multi-agency surveys for USGS/ BOEM California Deepwater Investigations and Ground truthing I (Cal DIG I) project, under a collaboration by NOAA, using Simrad 700 series hull-mounted multibeam echosounders. The acoustic-backscatter data from the five surveys were combined into a single raster and are provided as a 10-meter resolution GeoTIFF (Cochrane et al., 2022a,b). This higher resolution MBES bathymetry data was used for an additional effort by RPS -out of the scope of this contract- for development of the drainage network mapping for offshore central California (Sections 3.4 and 4.4.2.3).

7 https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Humboldt-EA.pdf

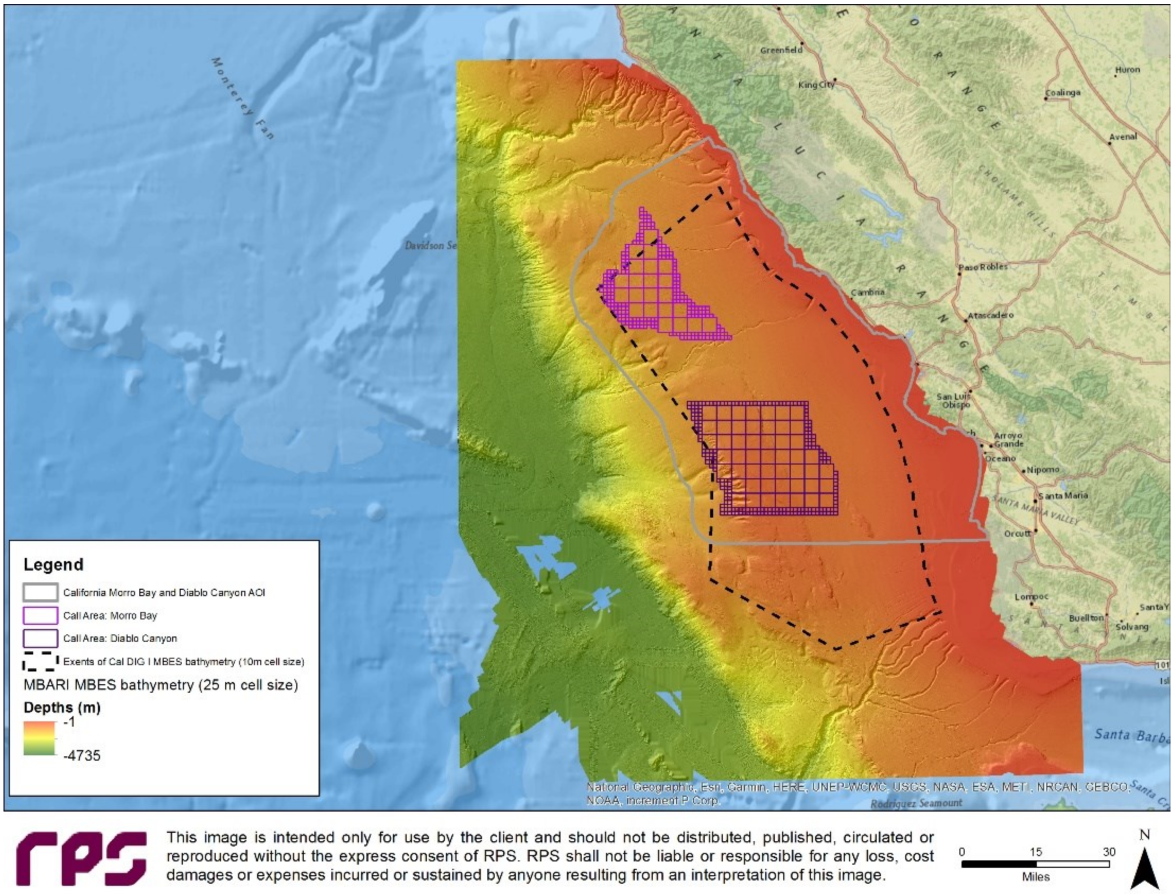

Figure 3. Morro Bay and Diablo Canyon MBES bathymetry (10 m to 25 m cell size) (Cochrane et. al, 2022a, Cochrane et. al, 2022b, Walton et. al, 2021).

2.3 Geology

The sediment thickness and sediment type are important criteria that impact the suitability of the AOI in terms of anchoring conditions. Newly collected data on sediment thickness and soil type for central California sites were acquired for this study and are described below. Maps presented in this section only portray newly available data from the field surveys, used for analysis updates during Phase 2. These data provide a greater understanding of the subsurface geology at Morro Bay and Diablo Canyon, in particular the thickness of sediment and the existence of features such as pockmarks (see Section 2.4).

2.3.1 Humboldt

New cores and seismic data, including Chirp sub-bottom and Sparker multi-channel (Hill, 2020), are available for Humboldt (Figure 4). However, interpreted geological products were not available during the time frame of this study therefore the soil type input was not updated for Humboldt (Figure 4).

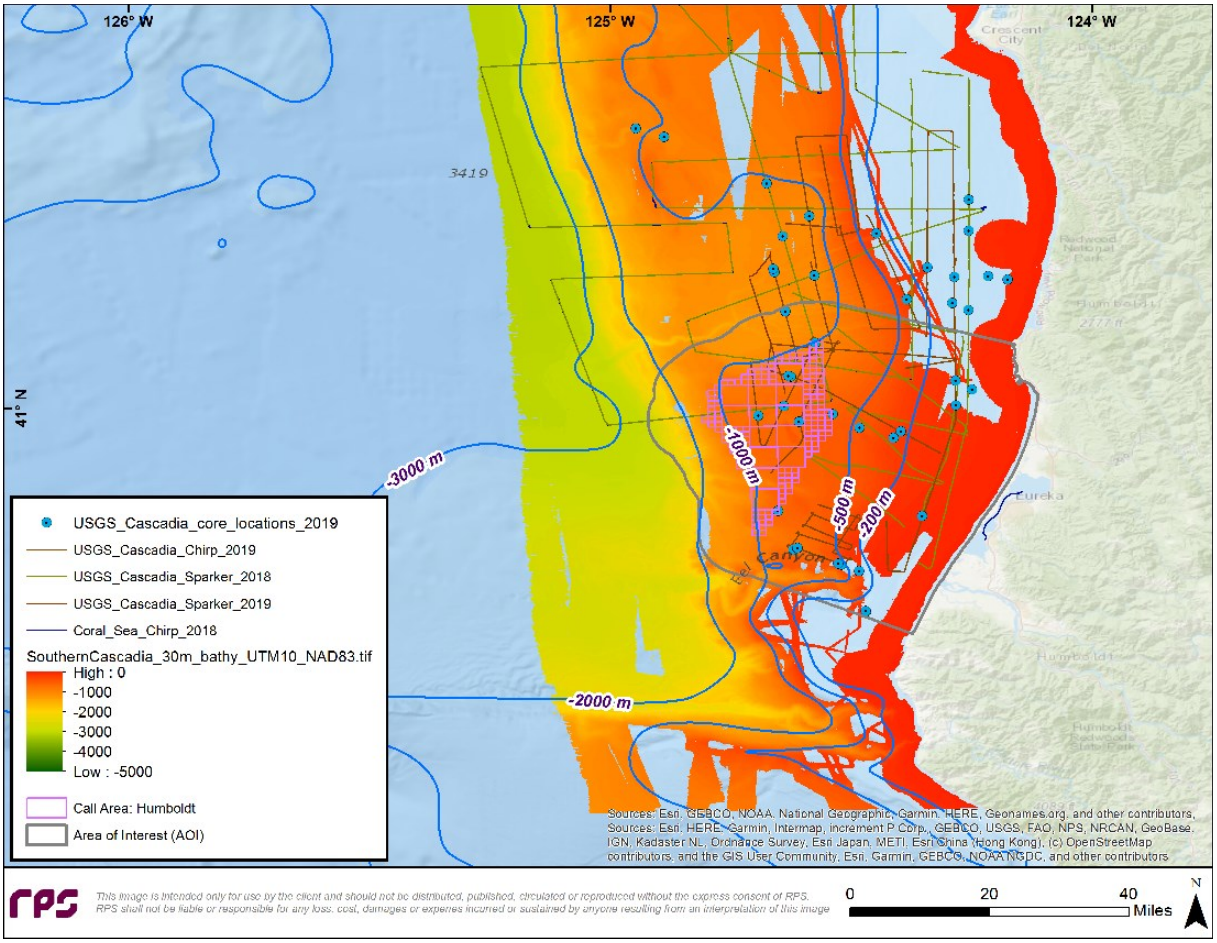

Figure 4. USGS Cascadia core locations 2019 with Chirp SBP and Sparker MCS data (USGS, 2020), in the AOI containing the Humboldt Call Area.

2.3.2 Morro Bay and Diablo Canyon

Recently published data including seafloor induration (hardness) and Coastal and Marine Ecological Classification Standard (CMECS) substrate (Figure 5) derived from multibeam echosounder data and underwater video observations provided an improved understanding of the surficial and subsurface geology of Morro Bay and Diablo Canyon (Kuhnz et. al, 2021). The substrate classification was factored into the suitability analysis.

Sediment thickness and properties are key considerations for mooring of offshore floating wind structures (Figure 5). Sediment thickness less than 50 m depth are generally not suitable for anchors, while sediment with thickness greater than 50 m allows all foundation types. This has proven particularly important to areas where bedrock approaches the seabed. The availability of this new information allowed the sediment thickness mapping to be integrated into the suitability analysis. This data provides a greater understanding of the subsurface geology at Morro Bay and Diablo Canyon, in particular the thickness of sediment and the existence of features such as pockmarks (see Section 2.4).

For sediment thickness mapping, an assumed seismic velocity (ASV) of 2,000 m/s was used to convert two-way seismic travel time (TWTT) to depth by Walton, et al. (2021). To match the expected type of soils with the reported depth range in the interpreted seismic data, an ASV of

1,700 m/s was applied. Thus, RPS used 1700 m/s ASV to convert the interpreted sediment thickness from TWTT to depths in meters. Using this revised ASV was considered as a more reasonable value for sediment thickness computations based on sediment velocity established in comparable settings. This is in line with the practice by MacKay et. al (1994) at ocean drilling program of Site 892, Offshore Oregon, using the vertical seismic profile and sonic-log velocities starting at 1700 m/s at 130 m below seafloor. Given the depth investigated in the current study, the lower value of 1700 m/s is considered valid.

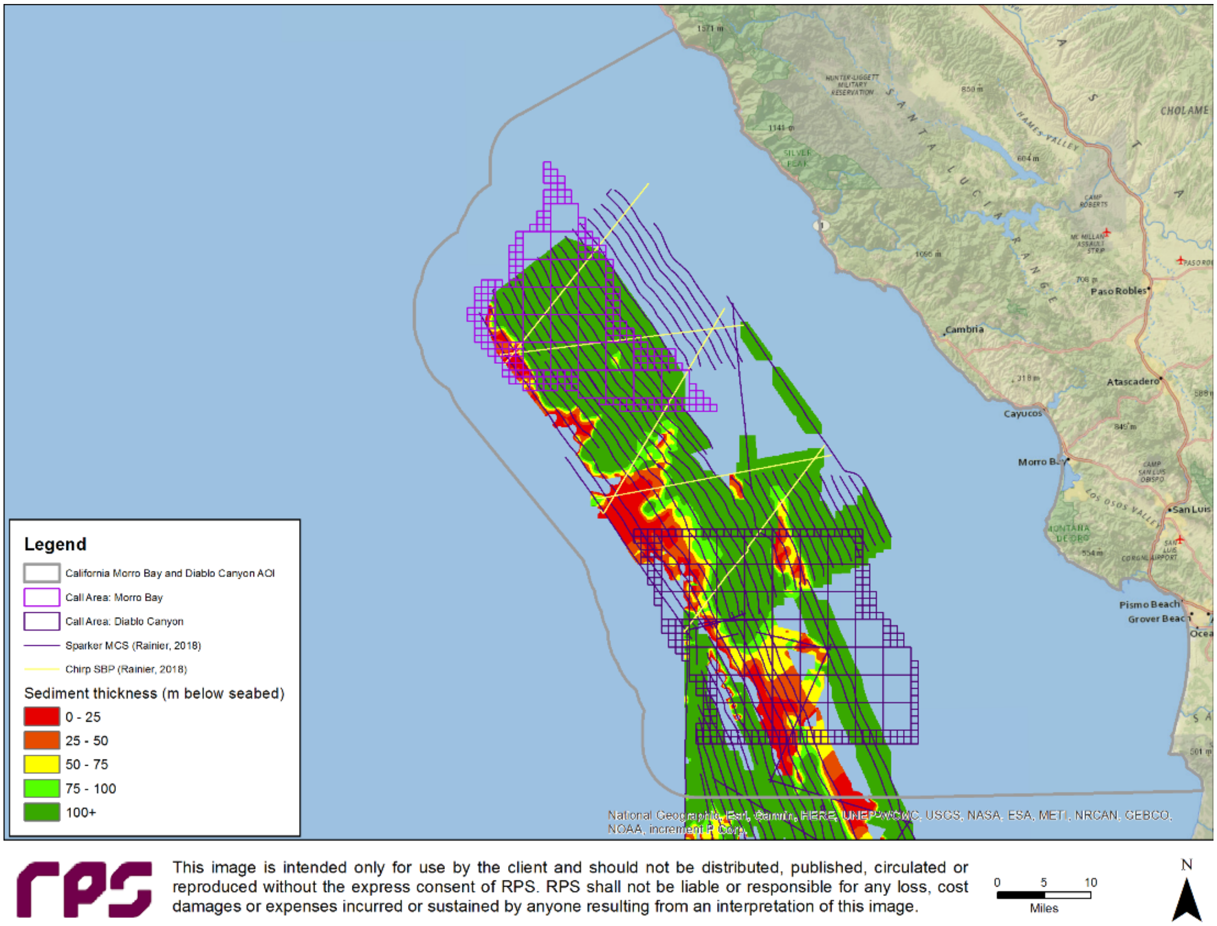

Figure 5. Sediment thickness interpreted from new seismic data (Walton et. al, 2021).

Core locations and descriptions were used to correlate sediment thickness mapping with sediment type (e.g., sands vs clays). The integration of core locations is discussed in Section 3.3 and their location is presented in Figure 7.

2.4 Geohazards

Newly available geologic and geohazard data in the Morro Bay and Diablo Canyon area, in addition to sediment thickness (Figure 5), includes a) the distribution of pockmarks, b) faults, c) mass transport deposits (MTD) and d) mass wasting scarps. Maps presented in this section only portray newly available data from the field surveys, used for analysis updates during Phase 2.

Distribution of pockmarks and MTD are important geological phenomena and suitability criteria, which were not available in the Phase 1 of the study from publicly available historic datasets.

Pockmarks are potential indicators of processes associated with seabed fluid flow. The escape of fluid from the sediment can develop seafloor features like mounds, gas hydrates, mud volcanoes or other bathymetric features like pockmarks (Ercilla, et al. 2021). Shallow gas in fine sediments can lower thermal conductivities in soils, which consequently can reduce heat dissipation and cause overheating of transmission cables (Trandafir, et al. 2022).

Submarine mass wasting scarps including landslide and slump are common features worldwide and more than 8700 have been identified along the Cascadia margin (Hill et al. 2022) which extends from Northern California to British Columbia. As reported by Hill et al. (2022) many of these scarps represent coalesced failures that are difficult to distinguish at the available data resolution; thus, the total number of individual failure scarps is likely much greater. The mass wasting scarps are efficient transporters of sediment, and their sizes can range from the meter scale to a few kilometers across (Figure 6). Slides and slumps are translational and rotational movements of sediment or rock, and they can produce a sediment flow (like mud flow), debris flow, and turbidity flow in part based on the rheology, grain size composition, and consolidation of the original sediment. Walton et. al, (2021) mapped a possible subsurface MTD complex, adjacent to mapped surficial scarps, however they did not identify any debris fields associated with mass-transport processes or scarps in the bathymetric data. They indicated scarps associated with slope failure and mass-transport processes are concentrated around the edges of the canyons and gullies along the western edge of Santa Lucia Bank (SLB) and scattered around the other edges of the bank near the relatively steeper (up to ~10º) slopes in those areas. In that study they map a small area with a possible MTD complex in the subsurface along northwestern edge of SLB, which is adjacent to several mapped edges of mapped surficial scarps. They did not detect any debris fields in the bathymetric data associated with mass-transport processes or associated with scarps.

The newly collected data related to geohazards that are used in Phase 2 are discussed below.

2.4.1 Humboldt

Interpreted geohazard data was not available at the time of this study for Humboldt.

2.4.2 Morro Bay and Diablo Canyon

The recent interpreted geohazard data in the Morro Bay and Diablo Canyon area (Walton, et. al, 2021) includes pockmark regions, fault structures, submarine landslide scarps and MTD (Figure 6).

The new multibeam data provide knowledge on the distribution of pockmarks. The extent to which these are active, or a current hazard is unknown. They may indicate prior fluid escape but not necessarily gas geohazards. Pockmarks are seabed depressions, generated by the expulsion of biogenic or thermogenic gas from the seabed through the seafloor and into the water column. These subsurface activities and degassing processes may cause seabed deformation and instabilities. Consequently, they can impact seabed infrastructures during both installation and operation, due to an uncontrolled release of gas which could cause landslides (Ercilla, et al, 2021). Thus, regardless of the depth of pockmarks, they interfere with the offshore developments and suitability of the geology. Researchers indicate pockmarks are usually connected to a source region at depth by fluid pipes of variable lengths and widths. These are narrow, vertical features which cross-cut seismic reflections, effectively high- or low-amplitude seismic anomalies with columnar geometry in three dimensions (Cartwright and Santamarina, 2015). The locations of installations should be assessed and adjusted as needed based on the spatial extent, severity, and level of activity of these features.

Multichannel and chirp seismic data are used to assess the extent of faulting reaching the seafloor, and have been used to interpret and map faults by age, offset, and exposure. Faulting has been incorporated into the suitability analysis as an additional geohazard. The presence of MTD and submarine landslide escarpments are considerations for suitability and the proximity to such features were used in the suitability analysis.

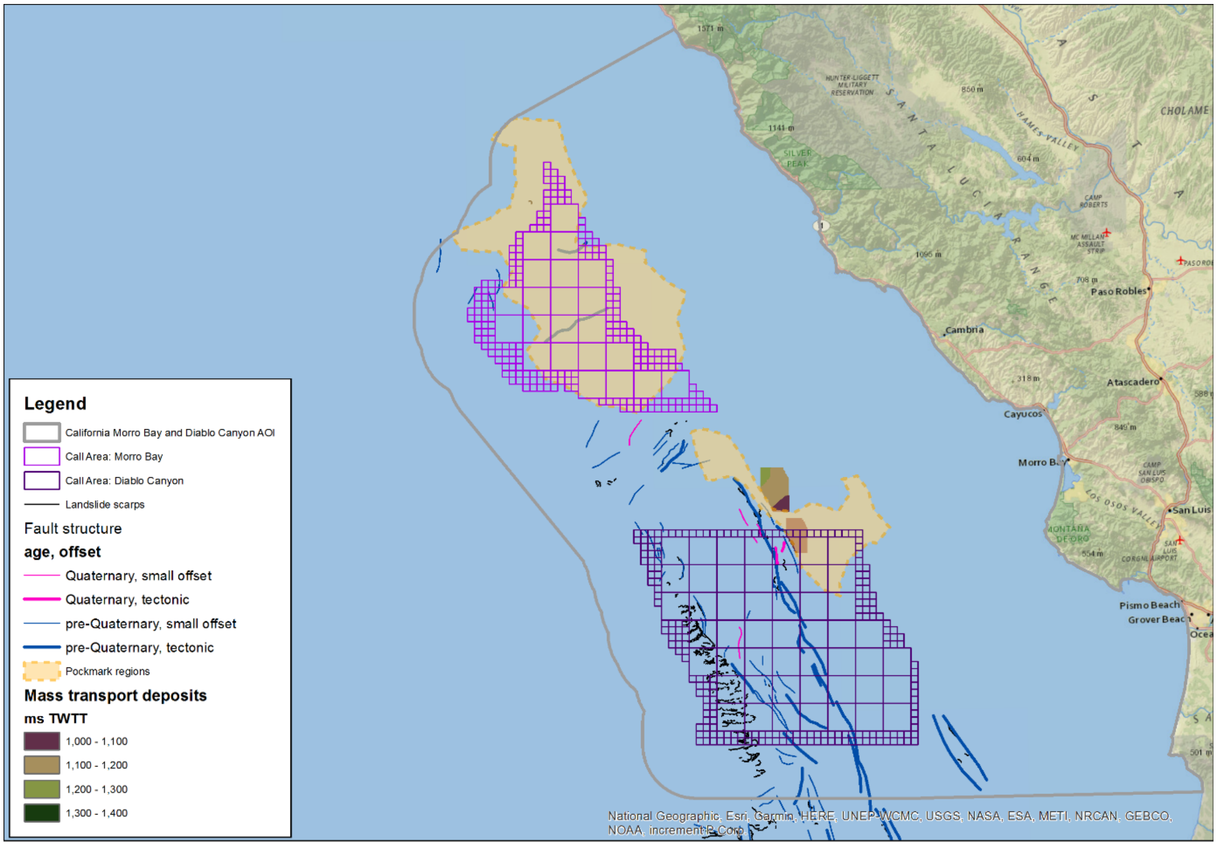

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Figure 6. Geohazards interpreted from new seismic data (Walton et. al, 2021).

3 DATA PRE-PROCESSING

To incorporate bathymetric, geological and seismicity probability data in a suitability analysis, datasets were mapped into a raster format to enable weighting on a common evaluation scale, data overlay, and assessment. Several geospatial pre-processing steps were applied to the data as it was progressed to the stage of common evaluation scale rasters. These steps include (but were not limited to):

- Re-projected data to a common map projection (WGS 1984, UTM Zone 10N)
- Clipped polygon and line features to the Study AOI polygon boundaries
- Clipped rasters to the Study AOI polygon boundaries
- Converted sediment thickness mapping data from TWTT (milli seconds) to depth below seabed (meters) using an assumed sediment velocity (ASV) of 1,700 m/s
- Converted rasters with floating point (decimal) data precision to integer values
- Simplified polygon features using dissolve GIS tool (e.g., MTD regions)
- Used GIS union tool to merge data inputs with the Study AOI polygon to produce common spatial extents for all data inputs
- Reclassified data input integer rasters to common evaluation suitability scales

The following section describes the applicable pre-processing completed on each of the datasets to map them into raster format and prepare them for the suitability analysis.

3.1 Peak Ground Acceleration (PGA)

Raster images representing PGA reclassified to a common evaluation scale from Phase 1 were restored from data archives for both northern and central California.

3.2 Slope Gradient

The Spatial Analyst extension of ESRI ArcMap was used to compute bathymetric slope for the bathymetric DEMs within the AOIs.

3.3 Geology

Core sample location and sediment type received by RPS on the unpublished field notes of Walton et. al., (2019) are shown on Figure 7. The shallow core data has been appraised for sediment type and depth of penetration, and has been compared to sediment thickness maps to better understand the shallow geology and site suitability. A strong correlation exists between the depth of core penetration and the sediment encountered in the core, with the greatest penetration being in the finest sediment.

The CMECS substrate derived from multibeam echosounder data and underwater video observations provides a measure of the surficial geology for Morro Bay and Diablo Canyon (Cochrane et. al, 2022a, Cochrane et. al, 2022b, Kuhnz et. al, 2021). Soil type was a key criterion in the earlier analysis and again is used as a factor in the suitability analysis.

Core log descriptions from Walton et. al., (2019) unpublished field notes were digitized to enable mapping of cores based on sediment type and core penetration depth, and for data extrapolation from adjacent known areas.

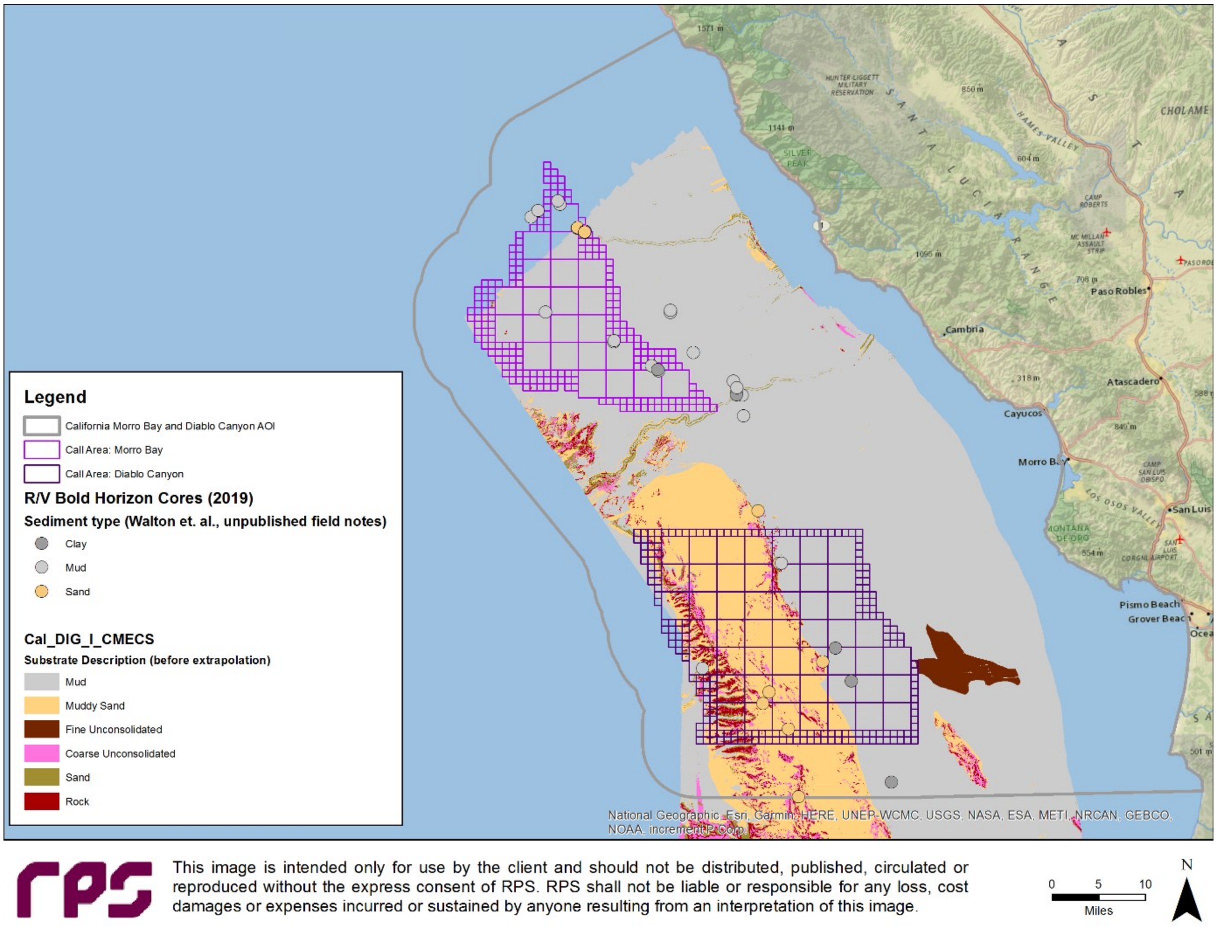

Figure 7. Core sample sediment type (unpublished field notes, Walton et. al., 2019) for extrapolation of soil type data to adjacent known areas.

A compilation of sediment texture data about the seafloor offshore California from previous studies done by Reid et al. (2006) was also used for data extrapolation from adjacent known areas[8] (Figure 8).

[8] https://pubs.usgs.gov/ds/2006/182/index.html

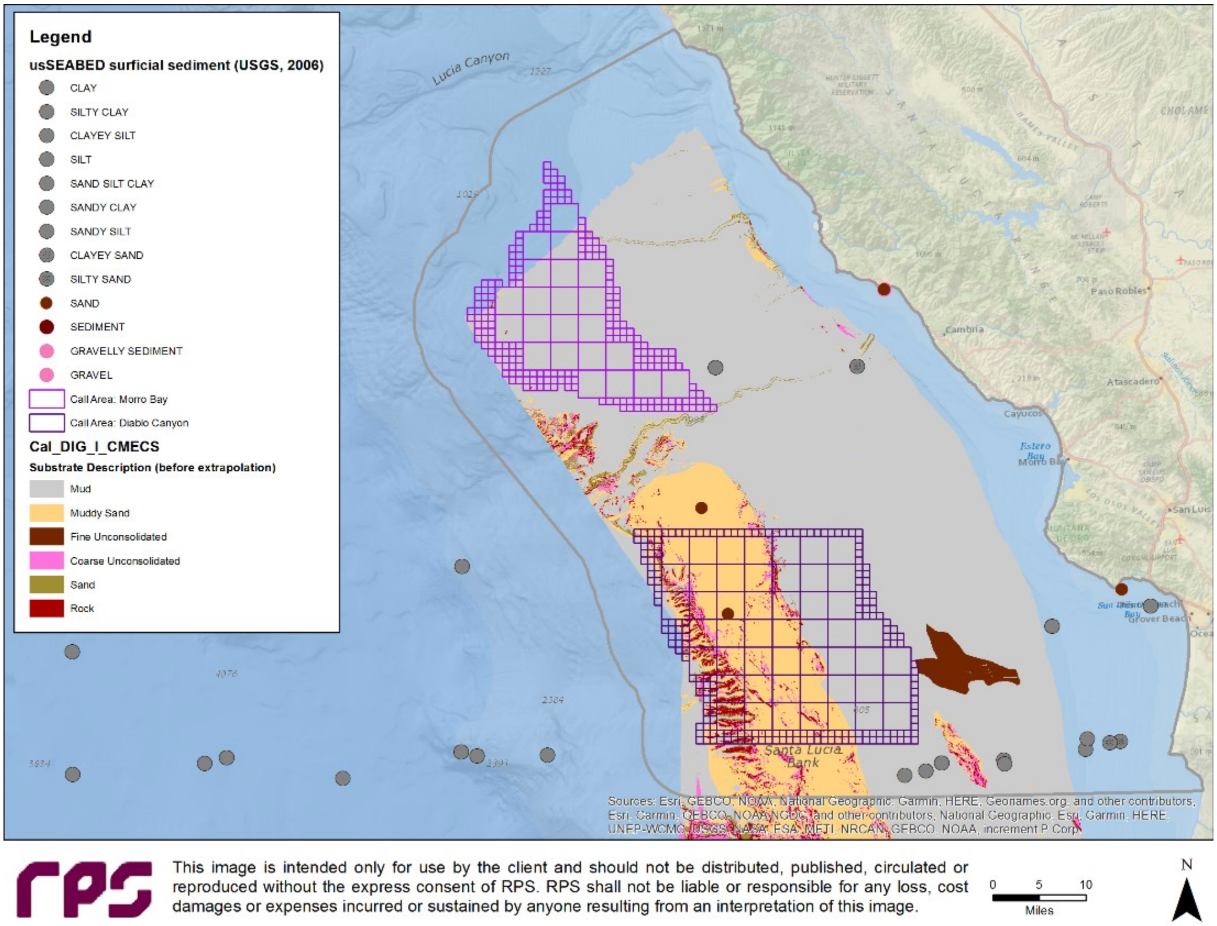

Figure 8. Seabed sample data for extrapolation of soil type data to adjacent known areas (Reid, et al., 2006).

Based on the depositional environment and data from adjacent known areas, the substrate type of mud was extrapolated to “fill” the NoData regions of Morro Bay and Diablo Canyon (Figure 9). The SLB is an area of known bedrock outcrop, and these outcrops are shown on Figure 8. The extrapolation applies to areas landward to the SLB and honors the existing bedrock areas as mapped on Diablo Canyon Call Area.

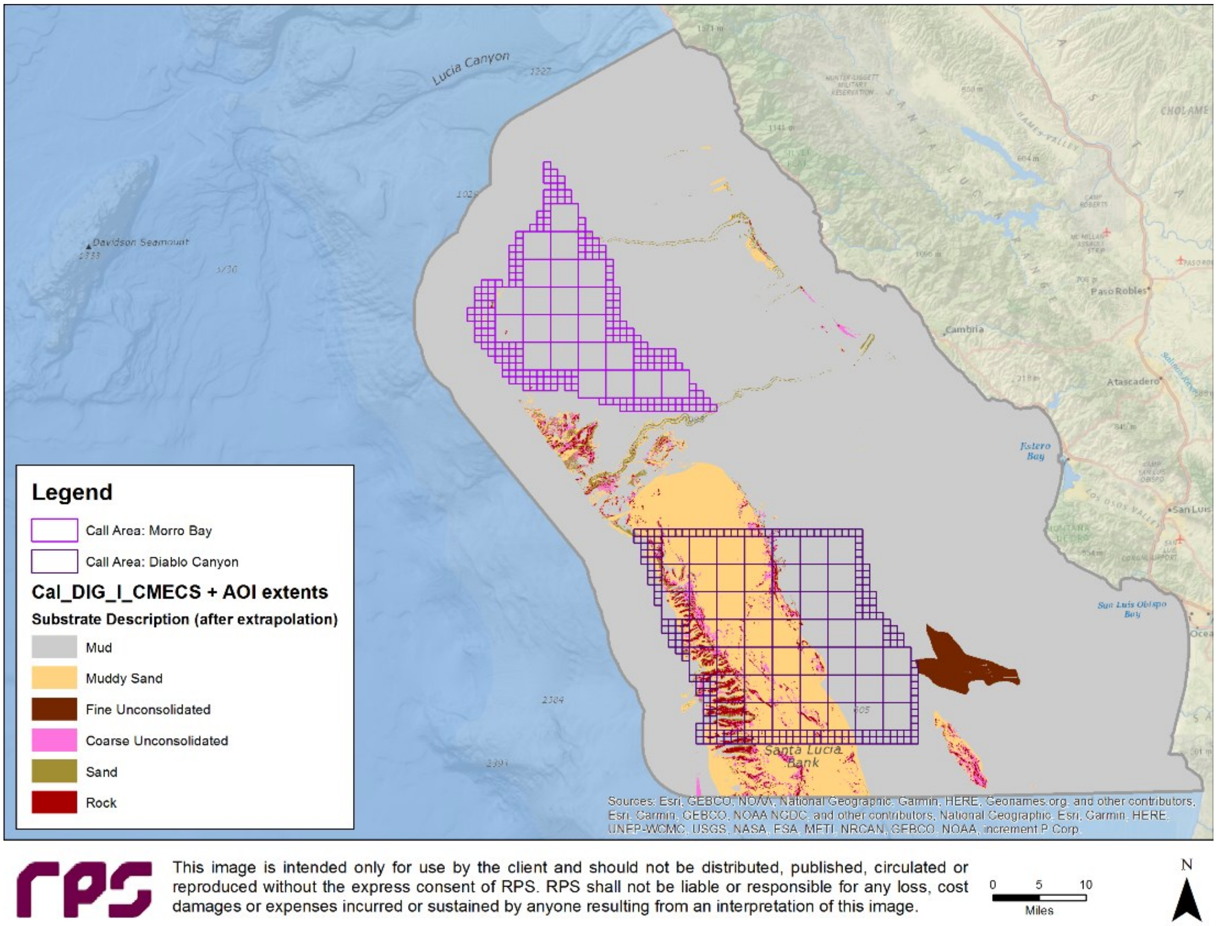

Figure 9. Result of extrapolating soil type data using depositional environment and data from adjacent known areas.

3.4 Geohazards

In addition to pockmarks, fault locations, MTD and escarpments, a representation of a drainage network was developed from high resolution bathymetry data by applying a hydrologic approach and used in this study.

While bathymetric slope is a proxy for related geohazards and is considered as an input to the suitability analysis, the derivation of a drainage network from the bathymetric DEM is added to this study.

Drainage networks are representative of submarine channels, which are relatively active geomorphological features and thus they are highlighted as a separate input into geohazards. The channels characteristically begin near the edge between a continental shelf and the continental slope. River discharge, oceanographic processes, and tectonic activities can cause sedimentary instabilities that become focused in these channels (Ercilla, et al, 2021).

The derivative drainage network for Morro Bay and Diablo Canyon is shown in Figure 10. Notably, many tributaries contribute to one major sediment pathway crossing between the Morro Bay and Diablo Canyon Call Areas. Channels and canyons that initiate on the shelf are more important to the study in terms of the volumes of sediment they transport and deposit compared to canyons and channels that initiate at the outer slope.

An initial version of drainage mapping illuminated data quality issues due to the nature of the input bathymetric data including resolution, data merging, and along survey line artefacts in the MBES data. These artefacts can be due to lack of adequate tidal corrections.

The drainage mapping was modified after applying a 7x7 cell smoothing filter over the input MBES bathymetry data, in an attempt to remove the line artefacts. This approach provided some improvement without changing the output drainage model overall.

Figure 10 represents quantification of the drainage models cumulative flow over a DTM, using grid codes 2, 3 and 4. Grid codes are defined with respect to the number of cumulative drainage into a cell, first order channels (grid_code 2) with the minimum cumulative drainage, and the higher order of channels (grid_code 3 and 4) based on a higher number of cells draining into those cells. While slope is the main control on the pathways, the order of channel is a measure of more cells contributing to theoretical drainage into that grid cell.

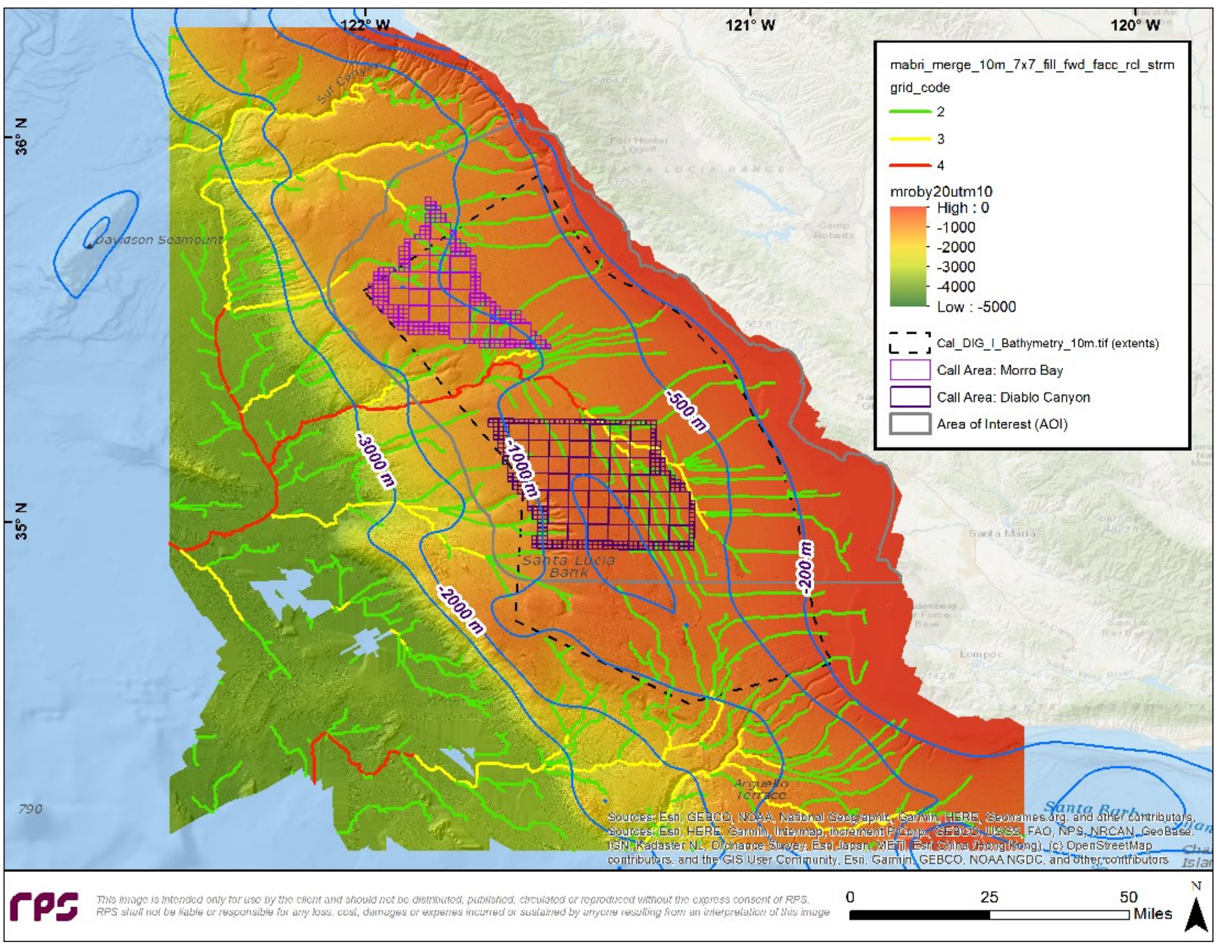

Figure 10. Derivative drainage network on bathymetry DEM for Morro Bay and Diablo Canyon.

4 WEIGHTED OVERLAY MODELING AND SUITABILITY ASSIGNMENTS

To perform site suitability analysis for all AOIs, following the approach developed in the Phase 1, the Weighted Overlay (WO)[9] functions of Esri™ ArcGIS Desktop's Spatial Analyst tools were used. The WO tool applies one of the most widely used approaches for overlay analysis to solve multicriteria problems, such as site selection and suitability models, as is desired in this study.

To perform WO analysis, the pre-processed modeled data were initially broken into subcategories to identify the input layers. The input layers utilized for this suitability study are integrated as four major subcategories of PGA, seabed slope, seabed geology, and geohazards.

The function overlays multiple input rasters, previously reclassified to a common measurement scale, computes multiple output models based on variable weight assignment to the input layers, according to the prescribed models. Each input layer is composed of different quantification schemes and ranges. To combine input layers for weighted overlay analysis, all input data layers were reclassified into a common evaluation scale (i.e., 1 to 9, with 9 being the most suitable).

Regions within the AOI absent of data (NoData) overlap spatially with the regions of known data for other inputs (e.g., slope gradient, PGA). Regardless of the existence of coincident known data from other data inputs, NoData input would impact the suitability analysis results by computing NoData as the output. To prevent this, the NoData regions within the AOI surrounding the geohazard data inputs were assigned a neutral value of 5 to fill the AOI with a non-zero value to enable proper execution of the weighted overlay raster computations using ESRI's Spatial Analyst ArcMap software extension.

The final step of the weighted overlay analysis process was to validate the model to ensure the model presented a reasonable result, considering the variability of the input data layers.

In summary, the Esri™ Weighted Overlay tool combines several of the typical steps in an overlay analysis process into a single tool. These steps are outlined by Esri™ below:

- "Reclassifies values in the input rasters into a standardized evaluation scale of suitability or preference, risk, or some similarly unifying scale
- Multiplies the cell values of each input raster by the raster's (user directed) weight of importance
- Adds the resulting cell values together to produce the output raster"[5].

4.1 Peak Ground Acceleration (PGA)

Since the probability of seismic hazard increases with an increase of PGA value, the lowest PGA value (0 %g) within the study area is considered as most suitable (9) and the highest PGA value (60 %g) within the study area as least suitable (1). PGA values between the lowest and highest were assigned proportional suitability based on a linear scaling (Table 1).

[9] http://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/how-weighted-overlay-works.htm

Table 1. Reclassification suitability of peak ground acceleration, 10% probability of exceedance in 50 years (500-year event).

Reclassification Suitability of Peak Ground Acceleration			
Lower bound (PGA)	**Upper bound (PGA)**	**Reclass value**	**Suitability**
0	5	9	Most suitable
5	12	8	
12	19	7	
19	26	6	
26	33	5	
33	40	4	
40	47	3	
47	54	2	
54	60	1	Least suitable

4.1.1 Humboldt

The same reclassified input raster data for PGA, that was previously used in the Phase 1, is used for suitability analysis results. As this area in general has a high risk of earthquakes with similar and constant PGA, the suitability input shows the same score over most of the AOI.

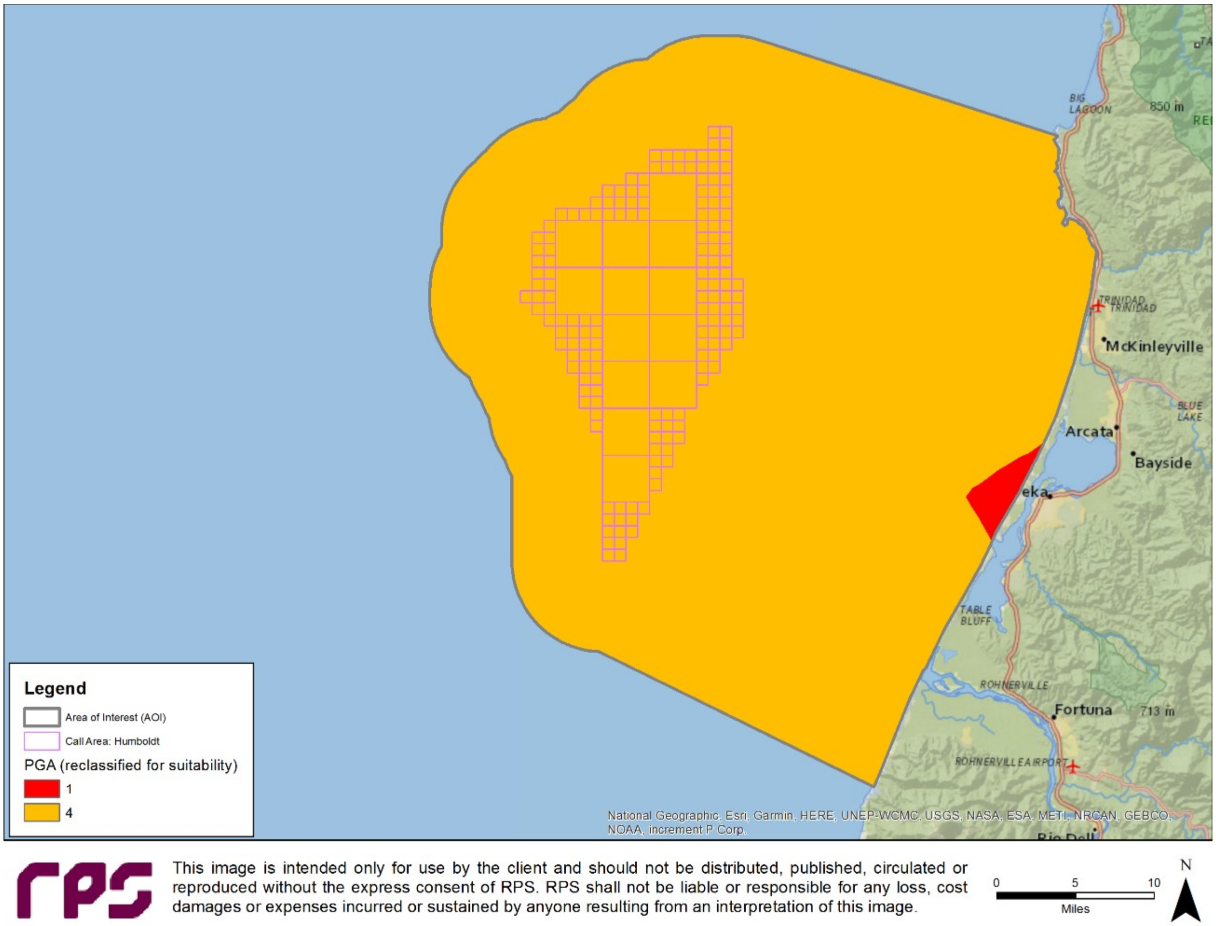

Figure 11. PGA at Humboldt reclassified for suitability common evaluation scale.

4.1.2 Morro Bay and Diablo Canyon

The reclassified input raster data for PGA from Phase 1 is used for suitability analysis results in this phase. This area has a lower PGA than the Humboldt lease block and shows higher suitability score, with suitability decreasing shoreward in this AOI.

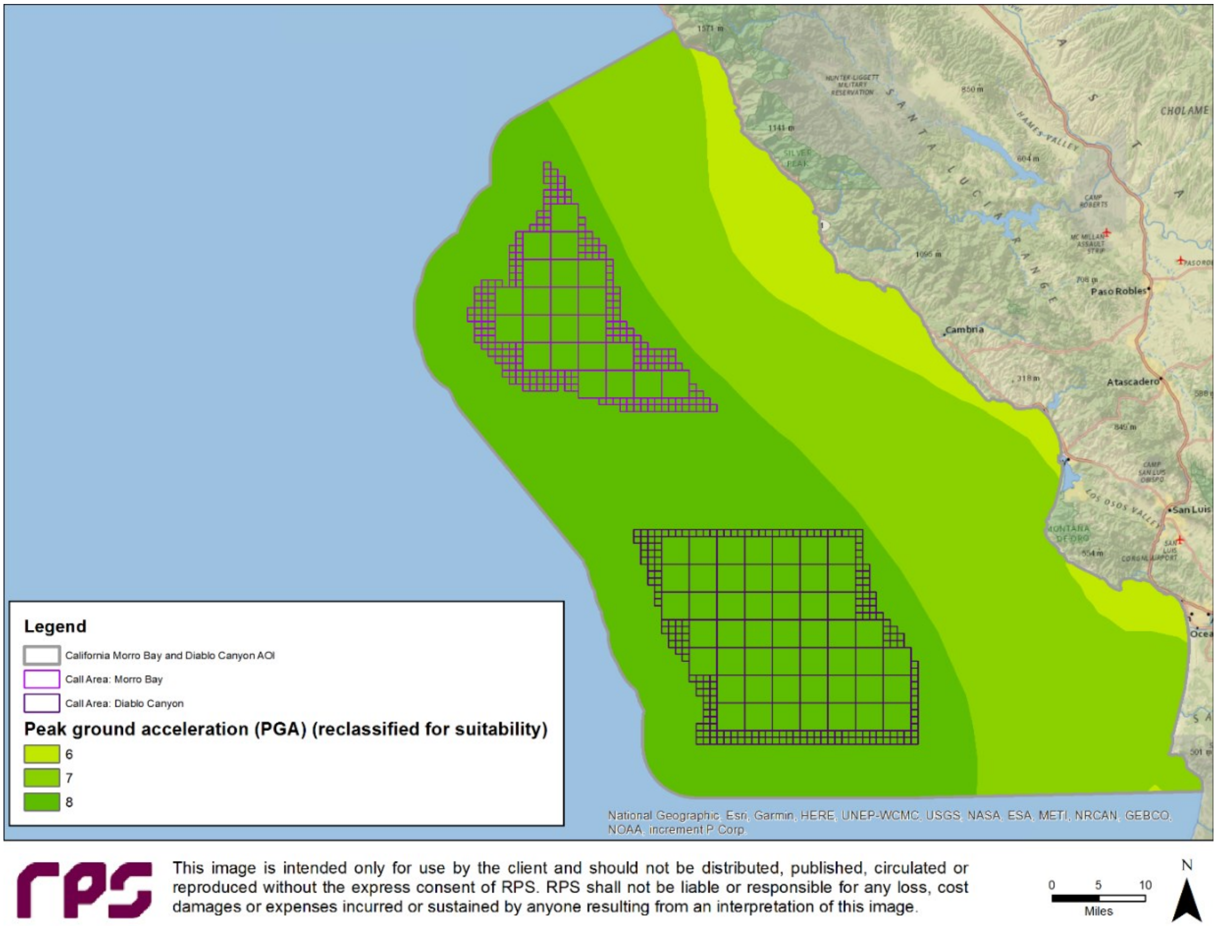

Figure 12. Peak ground acceleration at Morro Bay and Diablo Canyon reclassified for suitability on a common evaluation scale.

4.2 Bathymetry Gradient (Slope)

Since probability of failure increases with slope gradient, following the methodology used in Phase 1, lower bound slope values have been classified as most suitable and higher bound slope values (above 10°) have been classified as least suitable. The ranges of slope gradients were reclassified for suitability based on the following lower and upper bounds (Table 2).

Table 2. Reclassification Suitability of Bathymetry Slope Gradient Following Criteria from Goldfinger et al. (2014).

Reclassification Suitability of Bathymetry gradient (slope)			
Lower bound (degrees)	Upper bound (degrees)	Reclass value	Suitability
0	1	9	Most suitable
1	2	8	
2	3	7	

Reclassification Suitability of Bathymetry gradient (slope)			
Lower bound (degrees)	Upper bound (degrees)	Reclass value	Suitability
3	4	6	
4	5	5	
5	6	4	
6	7	3	
7	10	2	
10	90	1	Least suitable

4.2.1 Humboldt

A new merged bathymetric dataset with increased resolution (30 m here vs 90 m in Phase 1) was used to compute bathymetric slope and generate a reclassified raster image to portray suitability (Figure 13). There are some data gaps in the collected bathymetry data that impact the suitability analysis with NoData values.

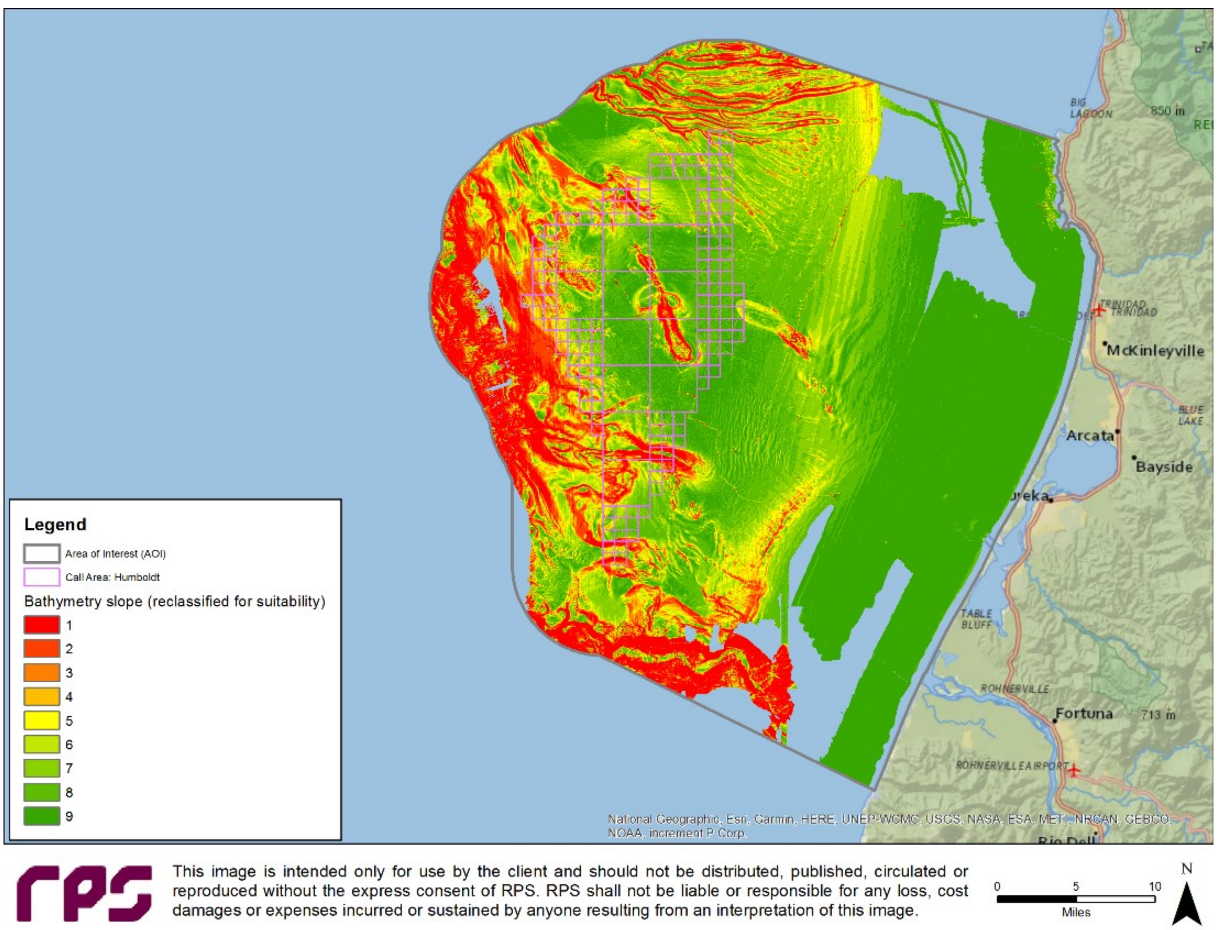

Figure 13. Bathymetric slope at Humboldt reclassified for suitability on a common evaluation scale.

4.2.2 Morro Bay and Diablo Canyon

A new merged bathymetry dataset with increased resolution (25 m here vs 90 m in Phase 1) was used to compute bathymetric slope and generate a reclassified raster image to portray suitability (Figure 14).

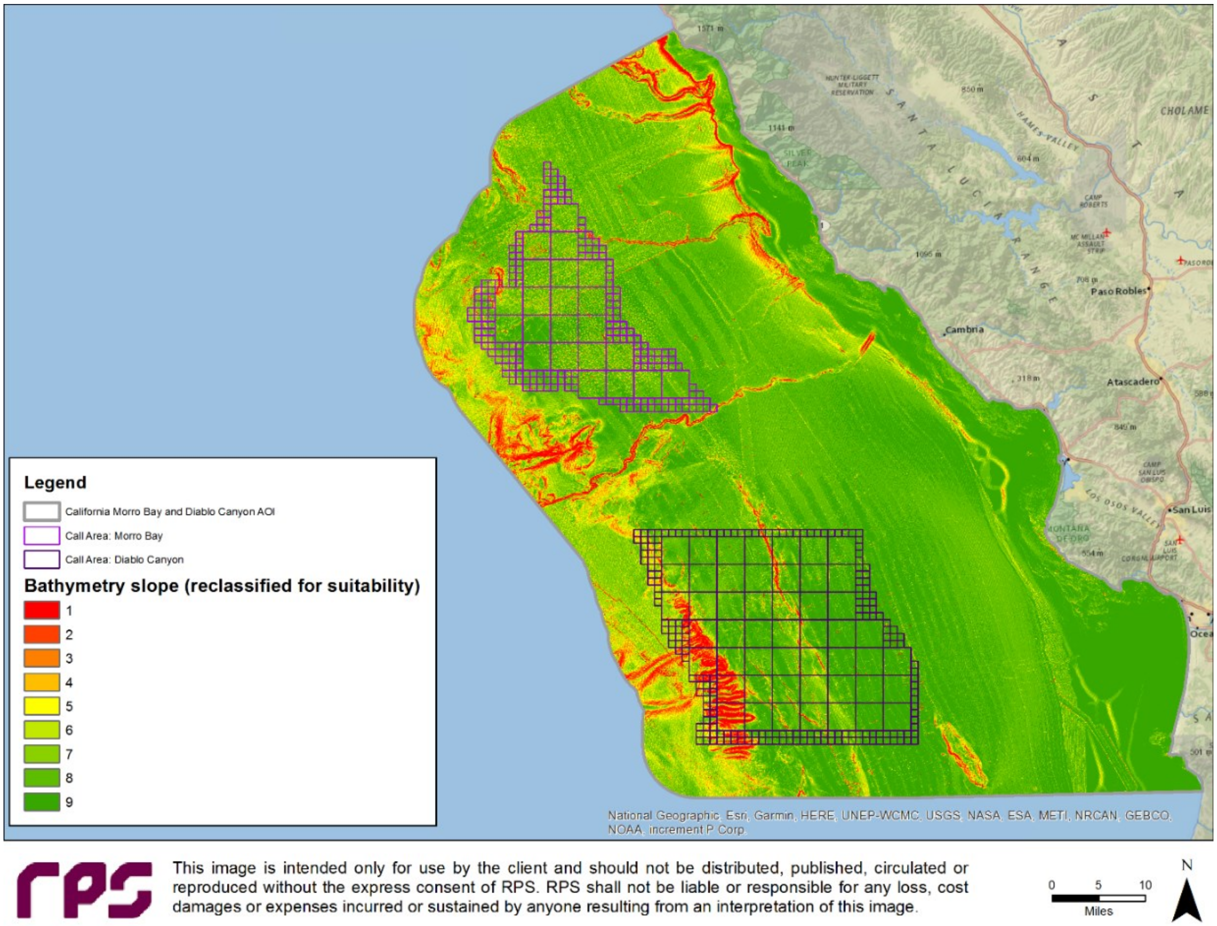

Figure 14. Bathymetry slope at Morro Bay and Diablo Canyon reclassified for suitability on a common evaluation scale.

4.3 Geology

The optimal geological condition for anchoring FOWT is considered to be regions where sediment consists of soft muds exceeding 50 m thickness. Based on this consideration, the datasets were analyzed and ranked to provide maximum suitability when these two parameters were combined.

4.3.1 Humboldt

New geological interpretation data was unavailable for Humboldt at the time of this study.

4.3.2 Morro Bay and Diablo Canyon

New geological interpretation data that were analyzed as discussed in previous sections (2.3.23.3) and integrated into suitability ranking as described below.

4.3.2.1 Soil type (CMECS substrate)

Where surficial sediments are present, they were assigned suitability values ranging from 5 to 9 for sand to mud, respectively. Sand is considered to be moderately suitable, whereas mud is considered to be highly suitable based on bottom foundation requirements. With regard to suction caissons layered soils, especially stiff clays and dense sands present more difficult conditions for penetration compared with homogeneous soils (Iskander et al. 2002). Regions of rock were assigned a low suitability value of 3 due to significant engineering challenges (Figure 15 and Table 3). While this sediment ranking is appropriate for the drag anchor, the geotechnical/design engineers might find different rankings more suitable, based on their choice of anchorage system and their approach and technology.

The “no data” (NoData) regions within the AOI surrounding the CMECS substrate data (surficial sediments) were assigned a high suitability value of 9 (Table 3), to represent an extrapolation of mud, as this surficial sediment type covers most of the AOI before extrapolation. This impact is visible in the shallow areas at the southeast of AOI, with more suitable ranking results in this study compared to the Phase 1 (see Section 7).

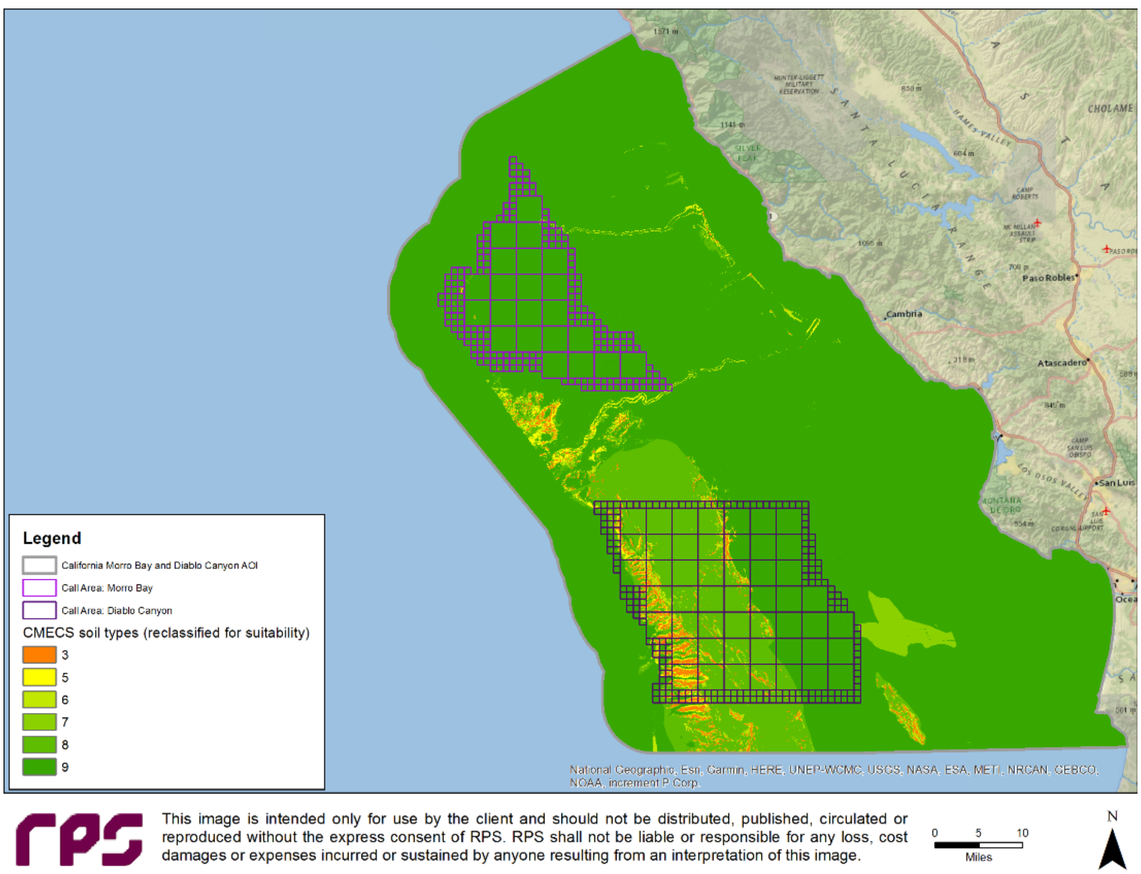

Figure 15. CMECS soil type at Morro Bay and Diablo Canyon reclassified for suitability on a common evaluation scale.

4.3.2.2 Sediment thickness

Based on the recently collected geophysical data, the available sediment thickness ranges from 0 m to >100 m within the AOI. Sediment thickness below 25 m was assigned the lowest suitability, as suction pile anchoring systems require sufficient soft sediment to achieve the required penetration and resistance. Sediment thicknesses greater than 25 m were assigned progressively higher suitability values starting at 6 and peaking at 9. Regions of NoData were assigned the neutral suitability of 5 (Table 3 and Figure 16).

Table 3. Reclassification of sediment thickness and soil type at Morro Bay and Diablo Canyon for suitability on a common evaluation scale.

Reclassification Suitability of Geology (sediment thickness and soil type)			
Sediment thickness (m)	Soil type (CMECS substrate)	Reclass value	Suitability
50+	Mud	9	Most suitable
40 – 50	Muddy sand	8	
30 – 40	Fine unconsolidated	7	
25 – 30	Coarse unconsolidated	6	
NoData	Sand	5	
		4	
	Rock	3	
		2	
0 – 25		1	Least suitable

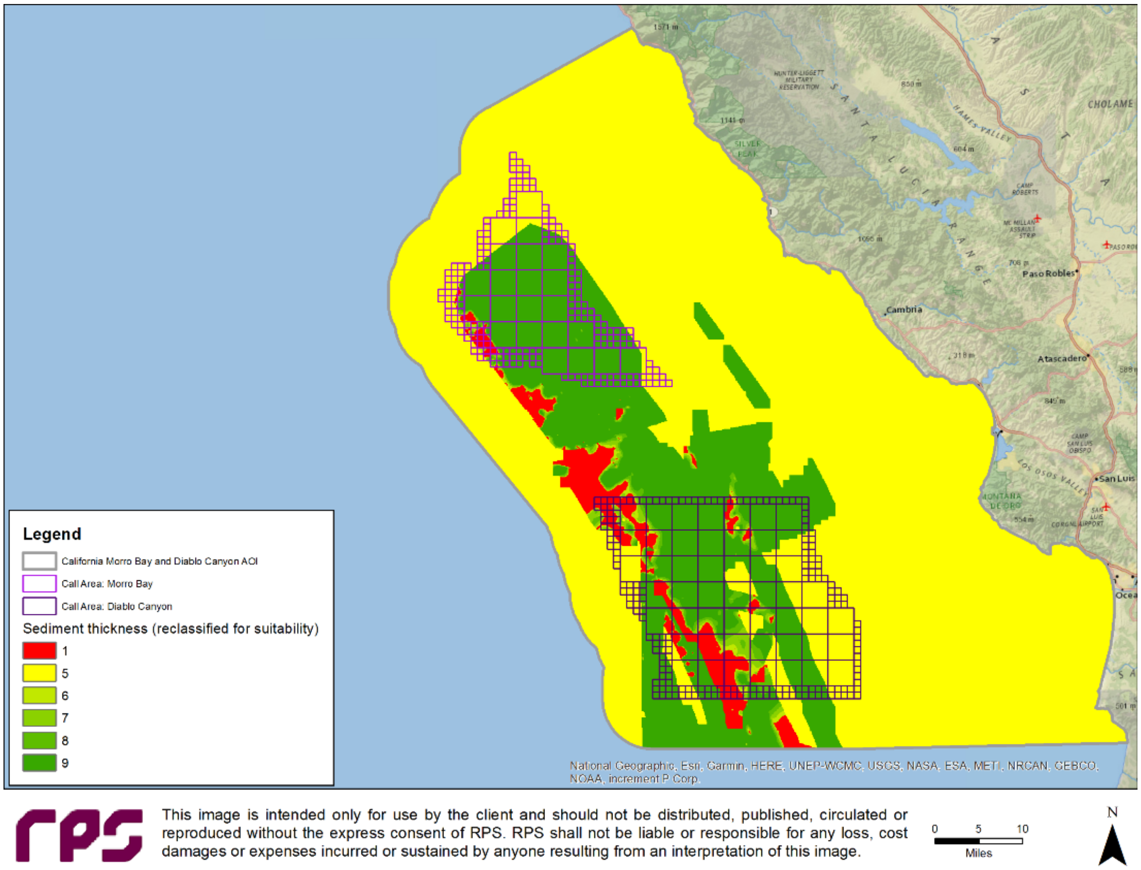

Figure 16. Interpreted sediment thickness at Morro Bay and Diablo Canyon reclassified for suitability on a common evaluation scale (Walton et. al, 2021).

4.4 Geohazards

The spatial distribution of geohazards was assessed and used in the suitability analysis where available.

4.4.1 Humboldt

New geohazard interpretation data was unavailable for Humboldt at the time of this study.

4.4.2 Morro Bay and Diablo Canyon

New geohazard interpretation data which was provided or derived (e.g., drainage network) during the time of this study is described below.

4.4.2.1 Pockmarks

The pockmark regions were assigned a suitability value of 4, as the region contains both suitable areas away from the pockmarks and low suitability areas proximal to the pockmarks. Thus, they were assigned with an overall moderate suitability, as there will be some suitable areas for the installation of anchorage and mooring within the polygon of pockmarks. To fill in the whole AOI for suitability analysis, regions of NoData were assigned the neutral suitability of 5 (Figure 17). To define suitable locations for installation in this area more detailed site investigation by developers would be required, to understand the geotechnical properties of the sediments inside and outside of pockmarks, the timing and degree of activity, origin and dynamics of expulsion and vertical and lateral extent in the subbottom.

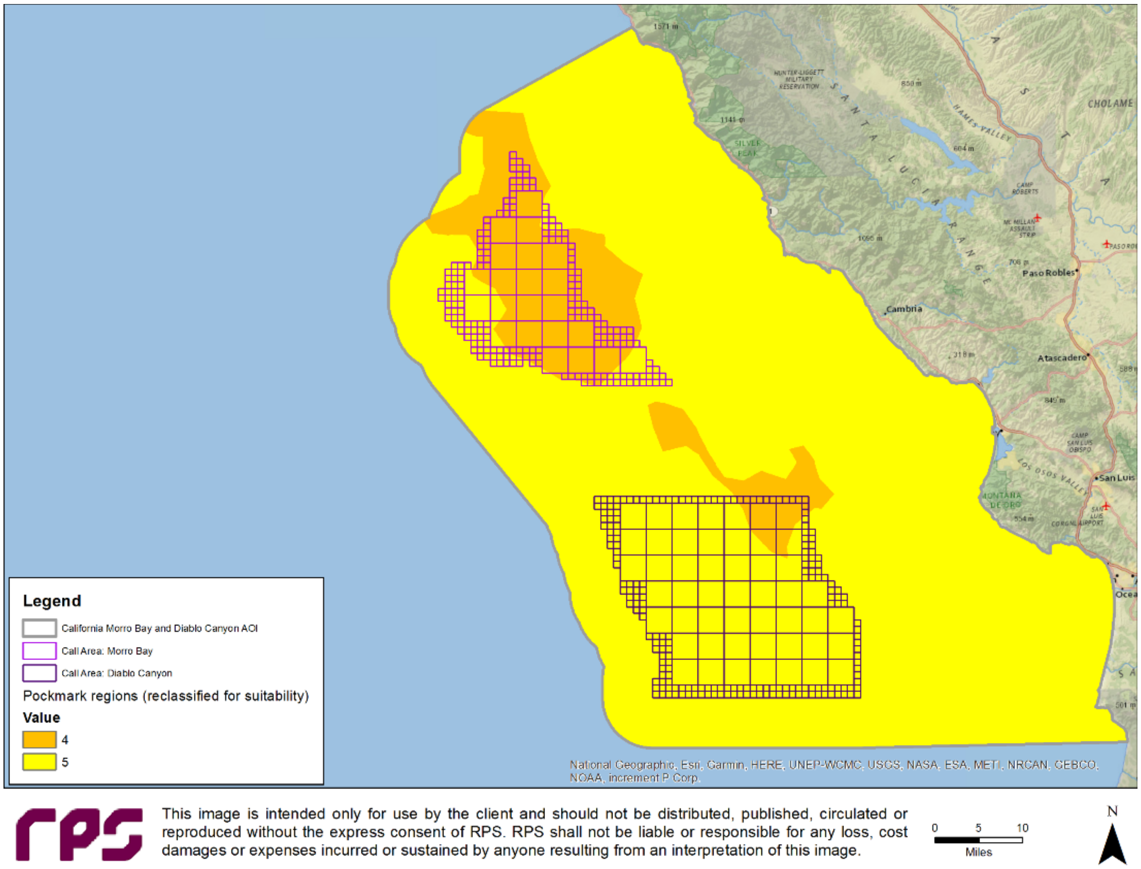

Figure 17. Pockmark regions at Morro Bay and Diablo Canyon reclassified for suitability on a common evaluation scale (Walton et. al, 2021).

4.4.2.2 Faults, Landslide scarps and Mass transport deposits

Faults, submarine landslide scarps and MTDs were all assigned the lowest suitability value of 1, as they present the most significant geohazards. Regions of NoData were assigned the neutral suitability of 5 (Figure 18, Figure 19, Figure 20 and Table 4). Following discussions with BOEM, the linear features (i.e., faults, submarine landslide scarps) were expanded spatially by adding a 100 m buffer distance, to be more conservative regarding suitability analysis.

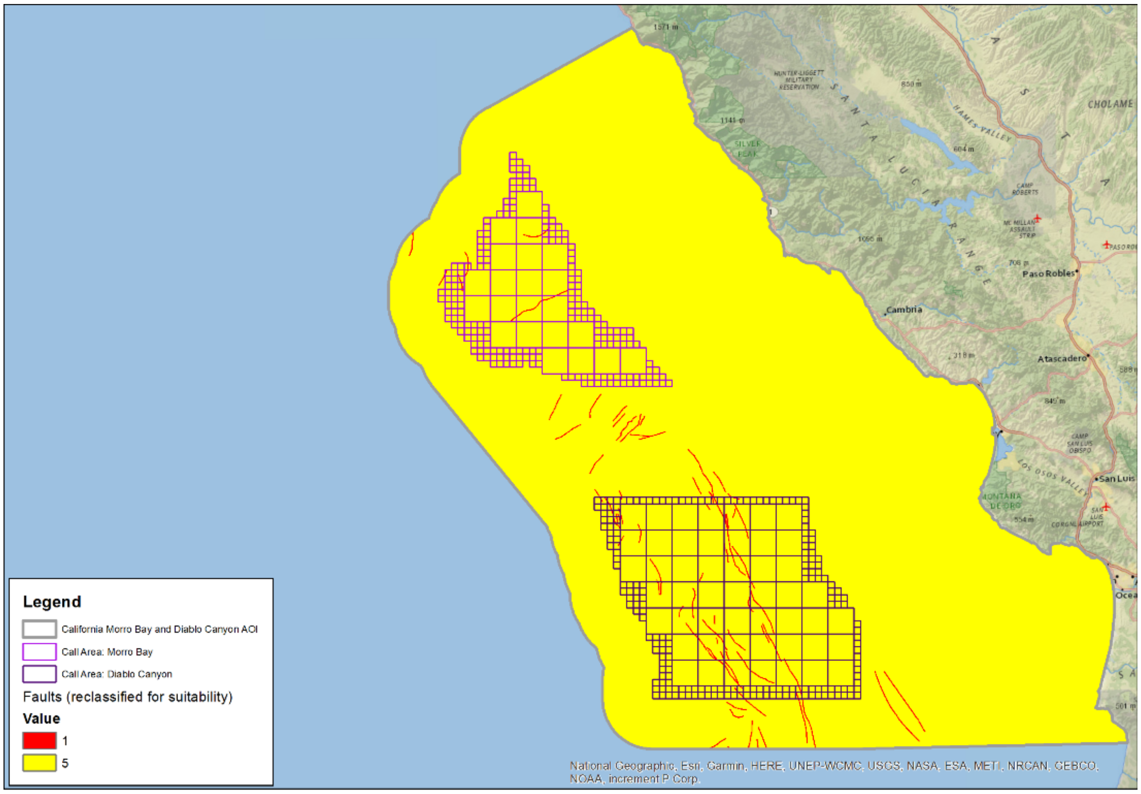

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Figure 18. Interpreted faults at Morro Bay and Diablo Canyon reclassified for suitability on a common evaluation scale (Walton et. al, 2021).

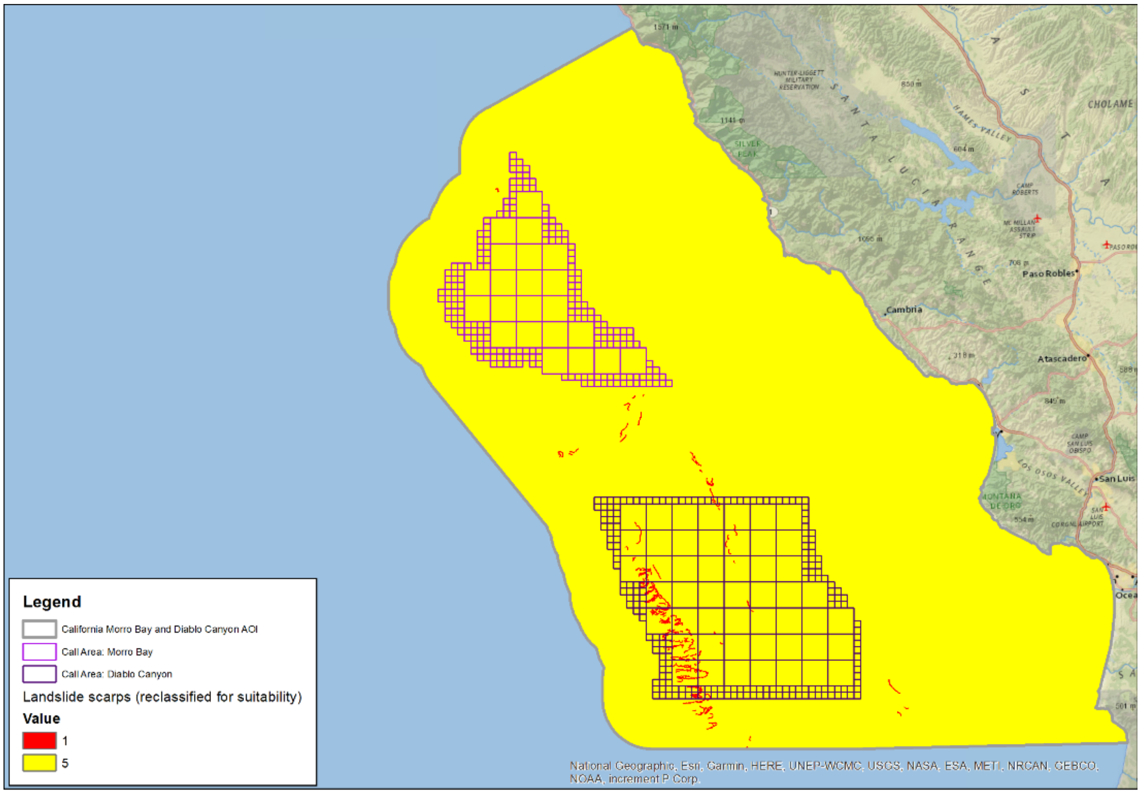

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Figure 19. Interpreted slope failure landslide scarps at Morro Bay and Diablo Canyon reclassified for suitability on a common evaluation scale (Walton et. al, 2021).

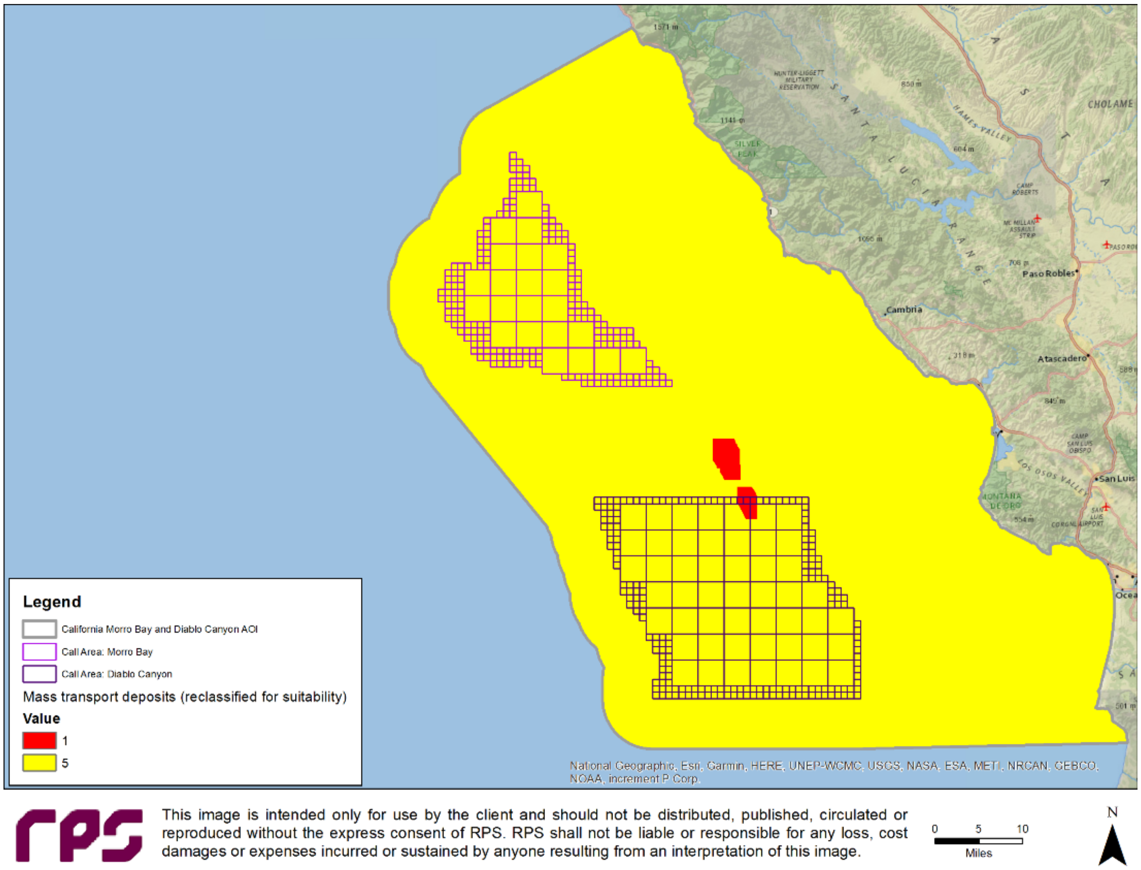

Figure 20. Interpreted mass transport deposits at Morro Bay and Diablo Canyon reclassified for suitability on a common evaluation scale (Walton et. al, 2021).

4.4.2.3 Drainage network

The drainage network is a derived geohazard input from MBES bathymetry data. It has been assigned three levels of suitability.

First order branches of the drainage network were assigned a suitability value of 4 as those locations generally represent the staging area for sediment transport rather than the down-slope zones of sediment accumulation. 2nd order branches and 3rd order branches were assigned lower suitability values of 2 and 1 respectively, as these generally represent a higher potential for down-slope sediment fairway. These are the areas where other drainage branches merge together into these more major branches, so they have higher risk of erosion or failure. Regions of NoData were assigned the neutral suitability of 5 (Figure 21 and Table 4).

Following discussions with BOEM, the drainage network was also expanded spatially by adding a 100 m buffer distance, to be more conservative regarding suitability analysis.

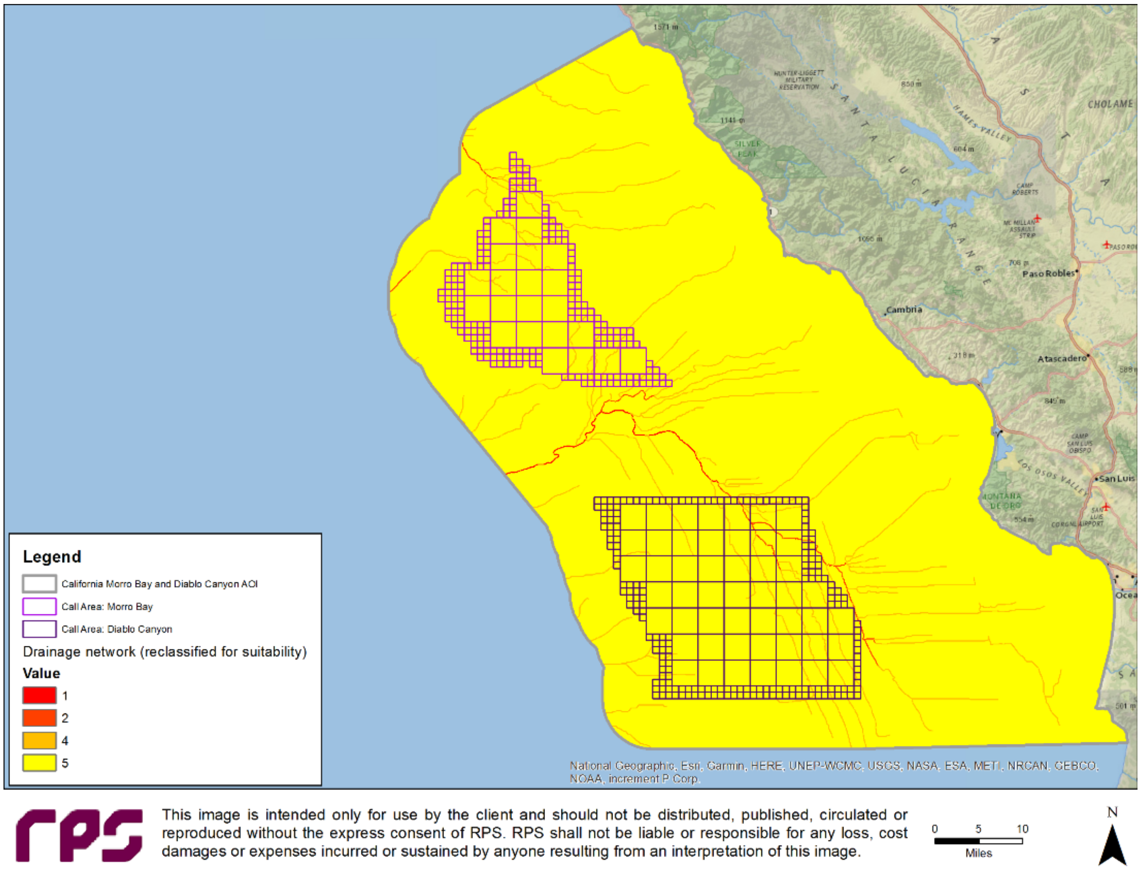

Figure 21. Derived drainage network at Morro Bay and Diablo Canyon reclassified for suitability on a common evaluation scale.

Table 4. Reclassification of geohazards at Morro Bay and Diablo Canyon for suitability on a common evaluation scale.

Reclassification Suitability of Geohazards						
Drainage network	Pockmarks	Faults	Landslide scarps	Mass transport deposits	Reclass value	Suitability
					9	Most suitable
					8	
					7	
					6	
NoData	NoData	NoData	NoData	NoData	5	
Grid code 2	Present				4	
					3	
Grid code 3					2	
Grid code 4		Present	Present	Present	1	Least suitable

5 SITE SUITABILITY ANALYSIS MODELS

The following maps show the results from each of the five site suitability analysis models run for Humboldt AOI following the same approach as Phase 1 study with three major inputs of soil type, bathymetric slope and PGA, represented by “g”, “s” and “p” respectively.

There are also six site suitability analysis models run for Morro Bay and Diablo Canyon AOI using appliable inputs from geology (as a combination of soil type and sediment thickness), bathymetric slope, PGA, and geohazards, represented by “g, s, p, and h” respectively, on the figures.

Variable influence (weighting) factors were selected to test sensitivity to input data types (geology, slope, PGA and geohazards) and determine the most critical factors.

The output models showed that the input data with the highest weight had the most influence in the final suitability map. Therefore, variable weighting does not distinguish the most significant input data; however, this approach produced various model outputs which indicate low to high suitable regions across the AOIs.

Subsequently, a composite suitability method was used to sum all models within each AOI, by excluding suitability values below 5. The composite suitability models portray the “best of the best” for each AOI in terms of suitability, by combining model outputs which are generated from data inputs with various certainty and quality.

5.1 Humboldt

Phase 1 of this study used the three data inputs of geology (soil type), bathymetry (slope), and seismicity probability (PGA) for suitability analysis. This Phase 2 suitability analysis used the same data inputs for geology (soil type) and PGA, however, bathymetric gradient (slope) was updated using new MBES bathymetry data (Dartnell, et al. 2021).

The same five suitability analysis models from Phase 1 were generated for Humboldt during Phase 2 (Table 5).

Table 5. Variable influence (weighting) for multiple models.

Input Raster (abbreviation)	Model 1	Model 2	Model 3	Model 4	Model 5
Soil Type (g)	33.3%	50%	20%	30%	0%
Slope Gradient (s)	33.3%	30%	50%	20%	50 %
Peak Ground Acceleration (p)	33.3%	20%	30%	50%	50 %
Associated Figure	Figure 22	Figure 23	Figure 24	Figure 25	Figure 26

Model 1 (Figure 22) is an equally weighted analysis of the inputs for Soil / Geology (g), Slope Gradient (s) and PGA (p). Model 2 (Figure 23) assigns more weight on the effect of Soil type/ Geology, while depressing Slope Gradient and PGA. Model 3 (Figure 24) considers Slope Gradient the most important factor, while depressing Soil / Geology and PGA. Model 4 (Figure 25) puts emphasis on the PGA, while depressing Soil type/ Geology and Slope Gradient. Model 5 (Figure 26) assigns equal influence on Slope Gradient and PGA while excluding the influence of Soil Type / Geology. Model 5 was developed to remove the uncertainty associated with the soil type, due to the lack of data.

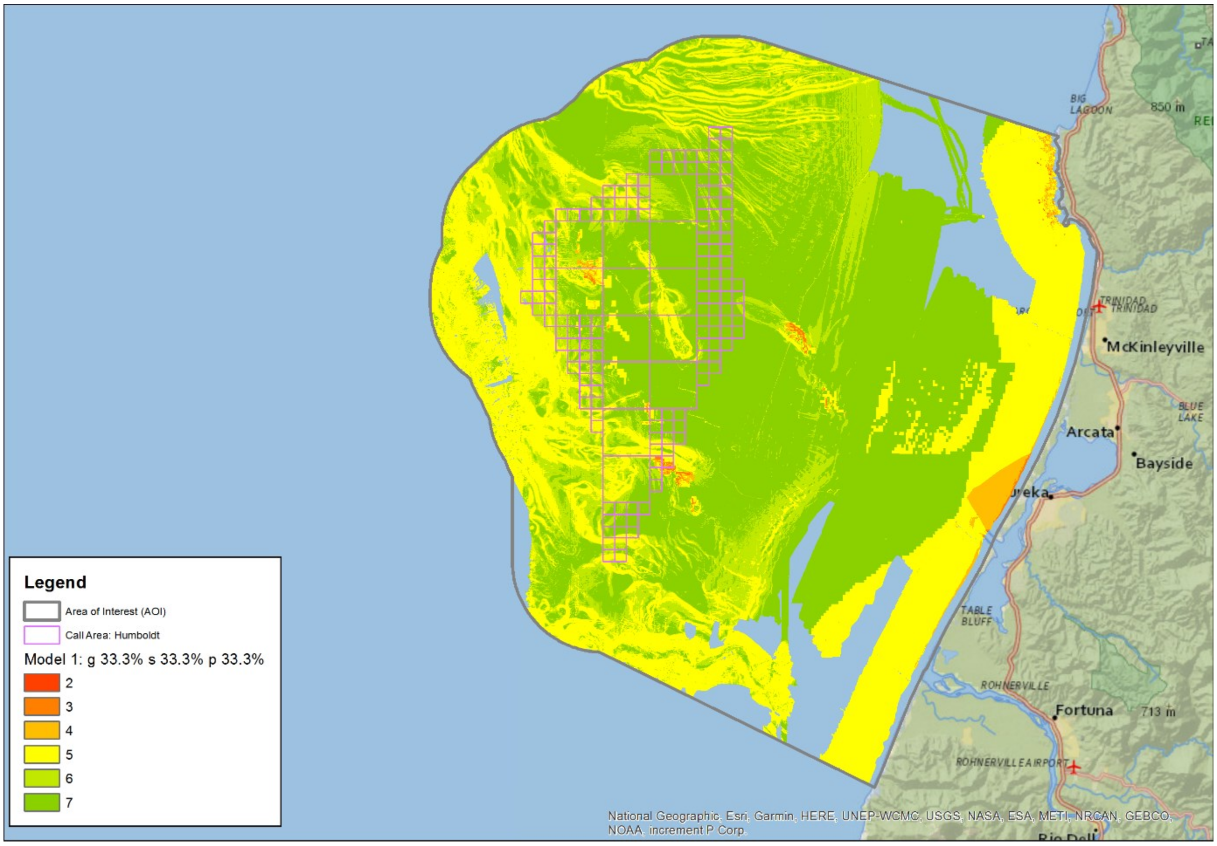

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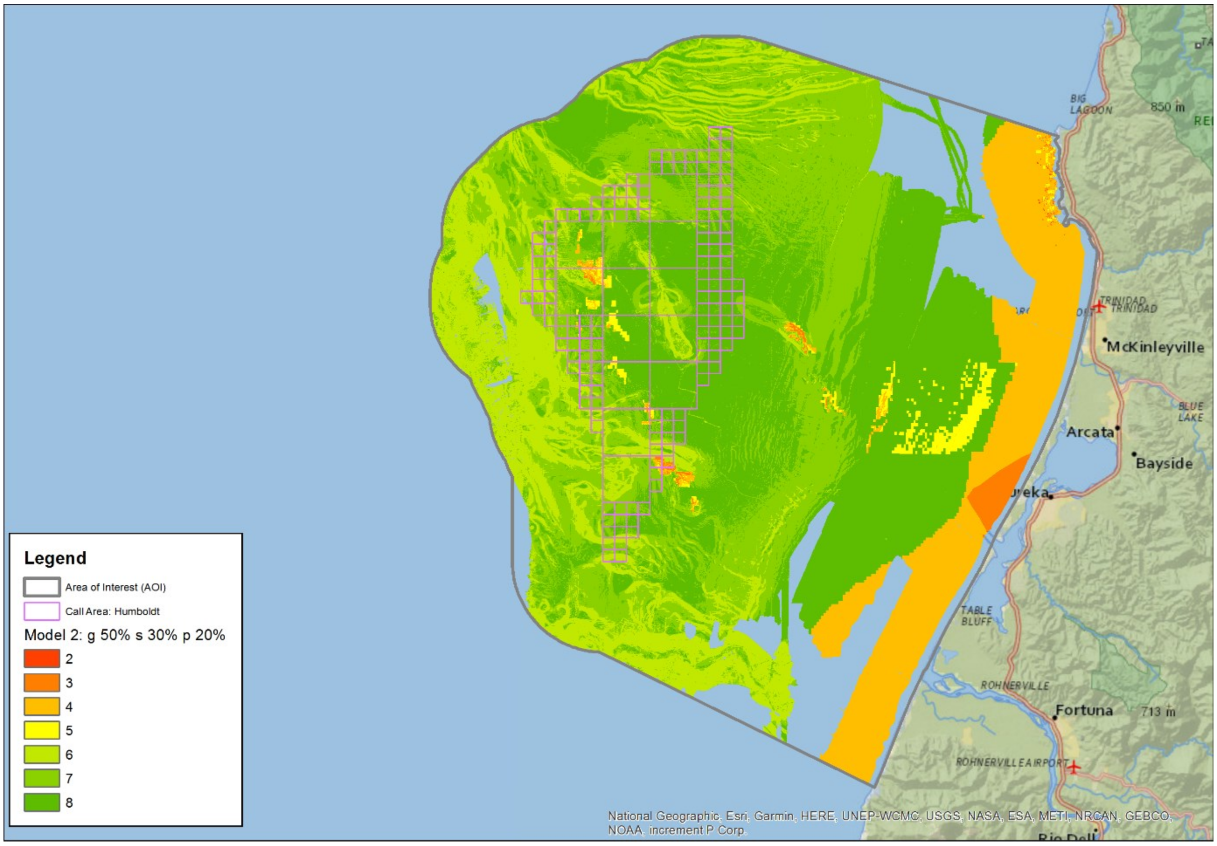
Figure 22. Model 1: Equal influence for all data inputs for Humboldt.



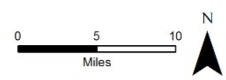


Figure 23. Model 2: Increased influence for geology compared to slope gradient and PGA for Humboldt.

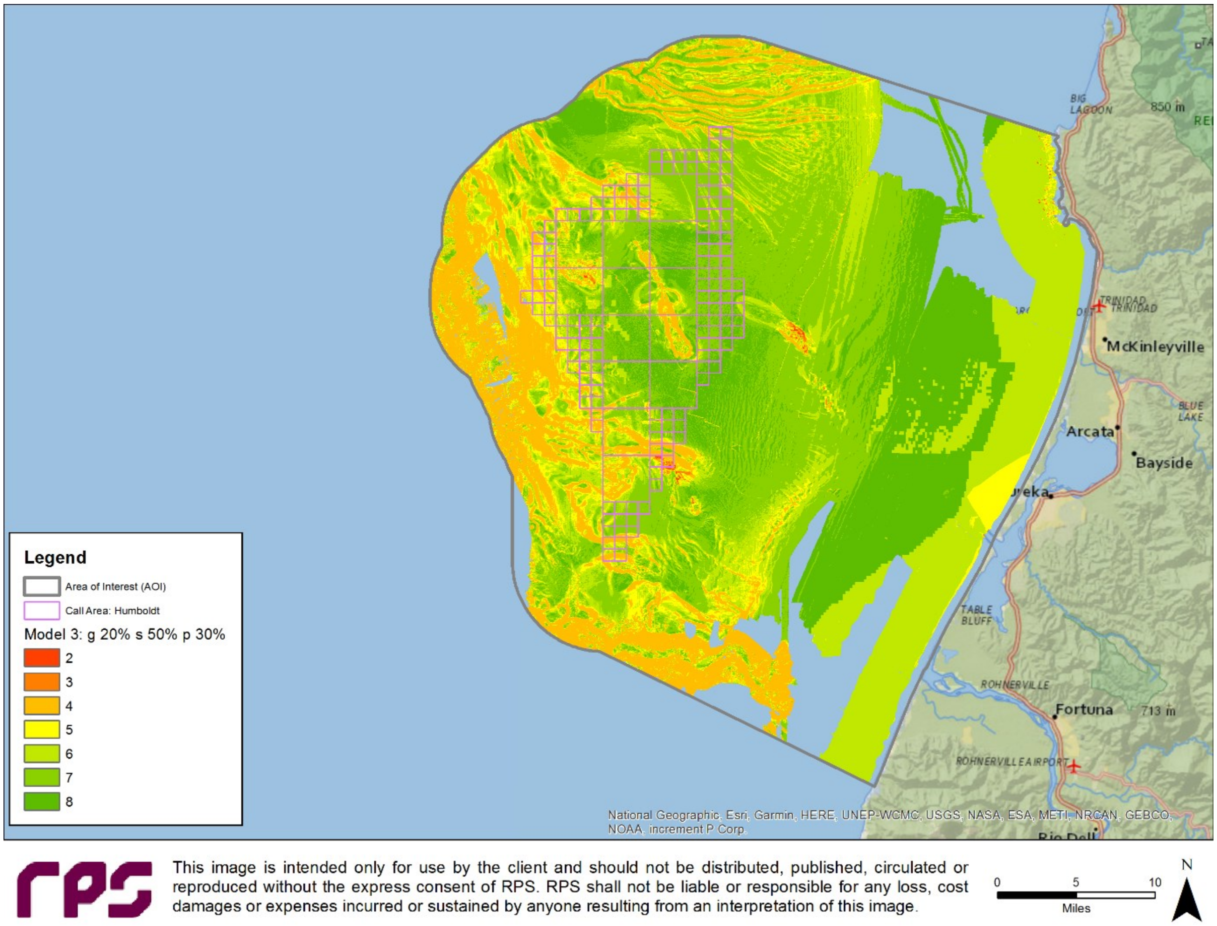


Figure 24. Model 3: Increased influence for slope gradient compared to geology and PGA for Humboldt.

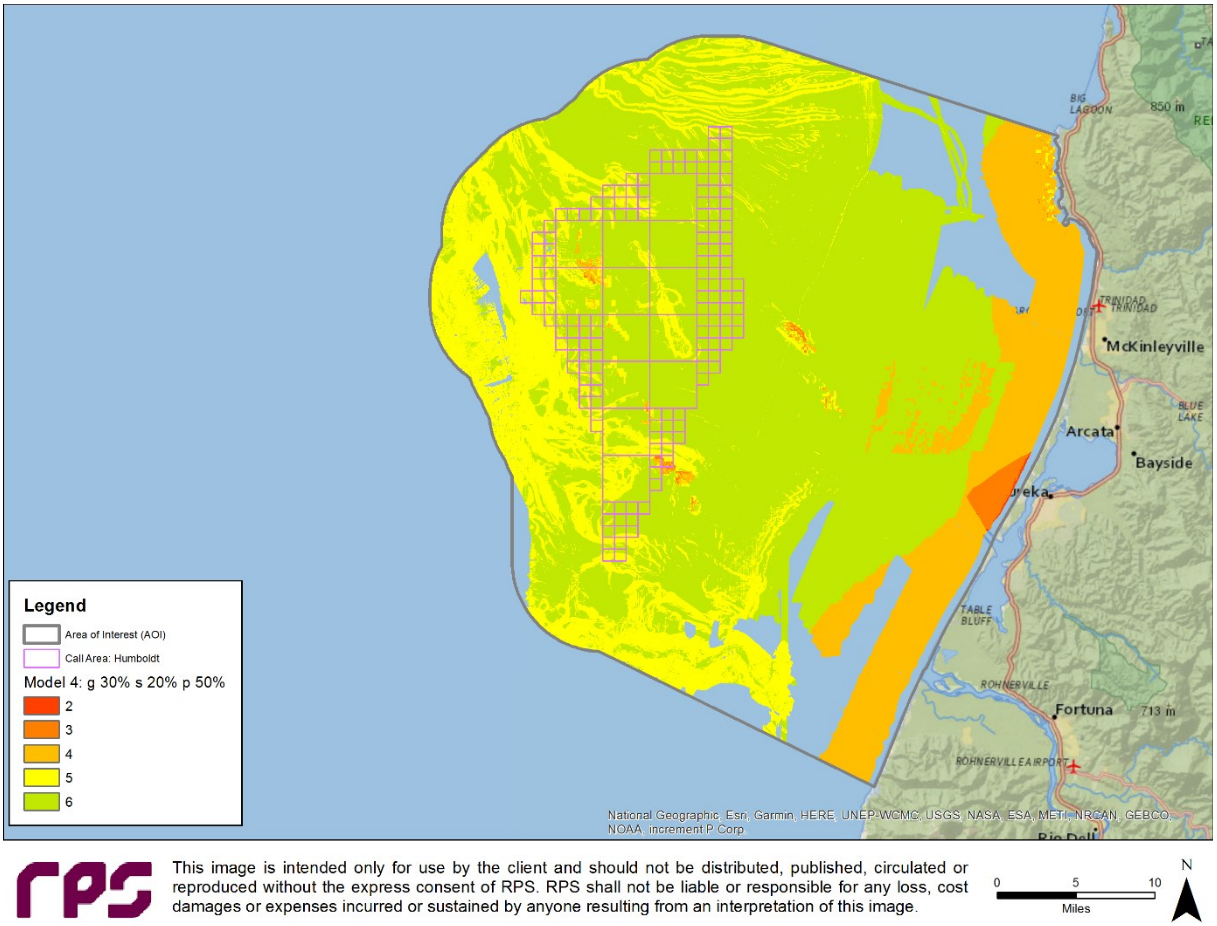


Figure 25. Model 4: Increased influence for PGA compared to geology and slope gradient for Humboldt.

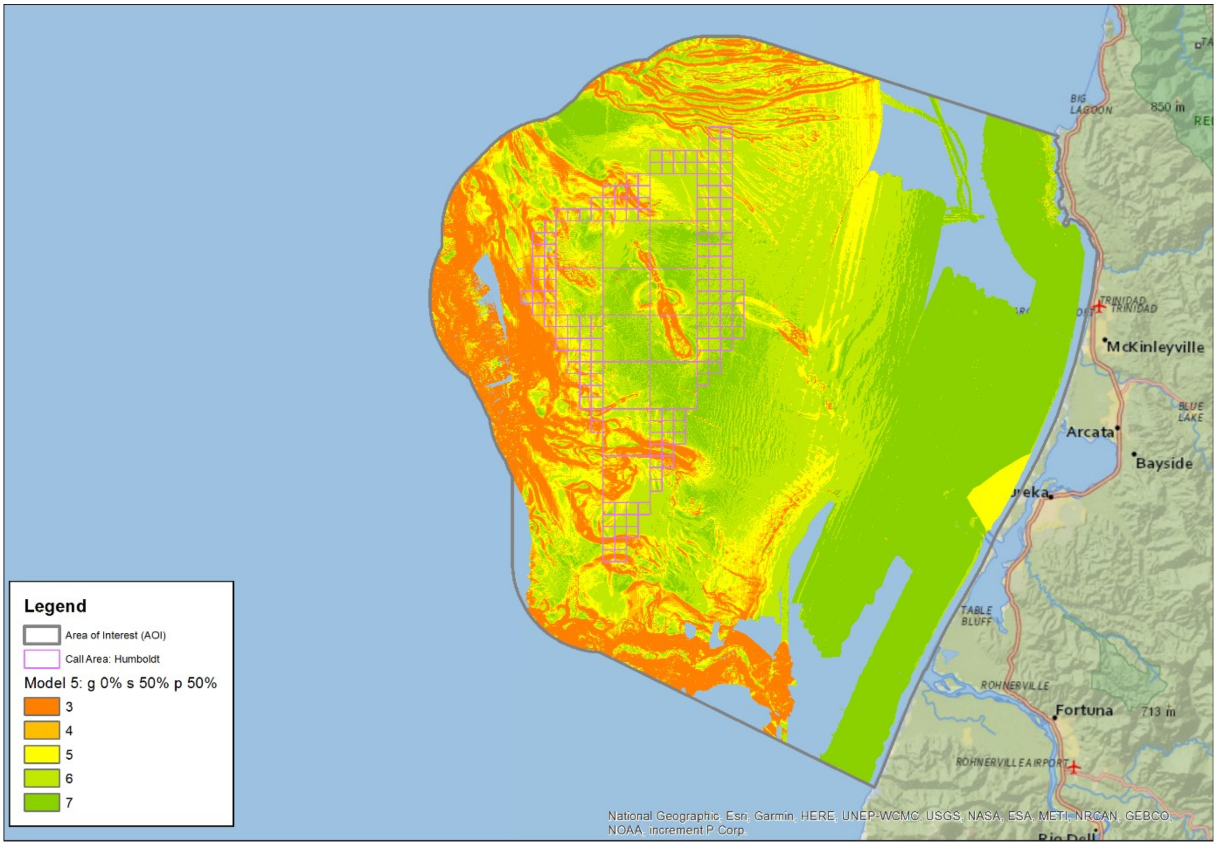


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Figure 26. Model 5: Equal influence for slope and PGA, no influence from geology for Humboldt.

5.2 Morro Bay and Diablo Canyon

In Phase 1, models integrated three input rasters representing Soil / Geology (g), Bathymetric Slope (s) and Seismicity as PGA (p) using variable influence (weighting) of input rasters according to the models shown in Table 6.

Table 6. Variable weighting inputs for multiple models used in Phase 1 (Tajallibakhsh et al., 2020).

Input Raster (abbreviation)	Model 1	Model 2	Model 3	Model 4	Model 5
Soil / Geology (g)	33.3%	50%	20%	30%	0%
Slope Gradient (s)	33.3%	30%	50%	20%	50 %
Peak Ground Acceleration (p)	33.3%	20%	30%	50%	50 %

In Phase 2, the suitability models (Table 7) have been updated to include the additional geohazard components of drainage network represented by (dn), pockmark regions (pr), mass-transport deposits (mtd), slope-failure scarps (sfs) and fault structures (fs), and geology (g). The geology (g) component integrates the sediment thickness (st) as an important factor of vertical distribution of geology type with the new soil type (sl) data.

The goal is to emulate the variable influence approach used in Phase 1 while including the additional component inputs of geohazards for Phase 2. Thus, the components of geohazards (drainage network, pockmark regions, MTD, slope-failure scarps, fault structures) were initially combined using equal influence to derive a standalone model input of geohazards (h) for subsequent weighted overlay analysis (Figure 27).

Similarly, the inputs for geology (sediment thickness, soil type) were initially combined using equal influence to generate a standalone model input of soil / geology (g) for subsequent weighted overlay analysis (Figure 28).

Table 7. Variable influence (weighting) for multiple models developed in this study.

Data Category	Input Raster (abbreviation)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Geohazards (h)	Drainage network (dn)	5%	4%	4%	4%	8%	11.1%
	Pockmark regions (pr)	5%	4%	4%	4%	8%	11.1%
	Mass-transport deposits (mtd)	5%	4%	4%	4%	8%	11.1%
	Slope-failure scarps (sfs)	5%	4%	4%	4%	8%	11.1%
	Fault structures (fs)	5%	4%	4%	4%	8%	11.1%
Soil / Geology (g)	Sediment thickness (st)	12.5%	20%	10%	10%	10%	11.1%
	Soil type (sl)	12.5%	20%	10%	10%	10%	11.1%
Bathymetry	Slope Gradient (s)	25%	20%	40%	20%	20%	11.1%
Seismicity	Peak Ground Acceleration (p)	25%	20%	20%	40%	20%	11.1%
Associated Figure		Figure 29	Figure 30	Figure 31	Figure 32	Figure 33	Figure 34

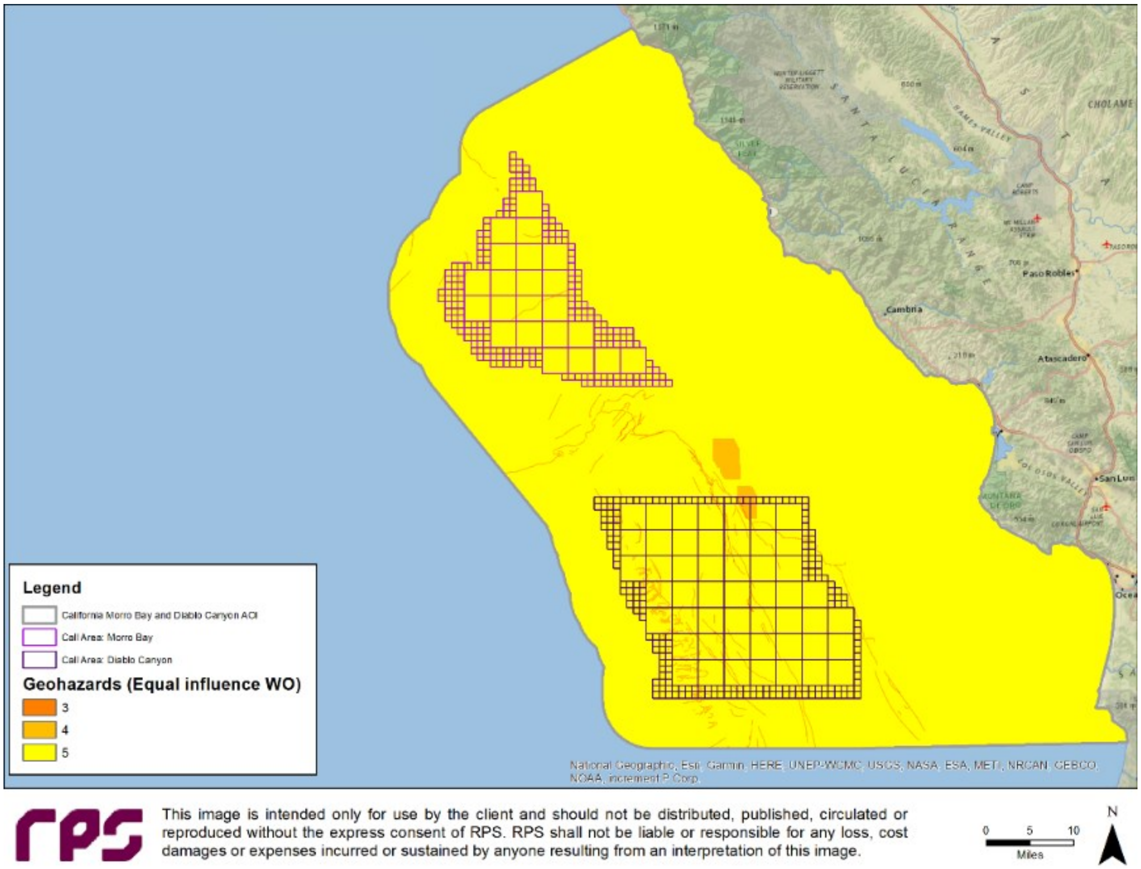

Figure 27. Geohazards equal influence weighted overlay results for input to multiple models.

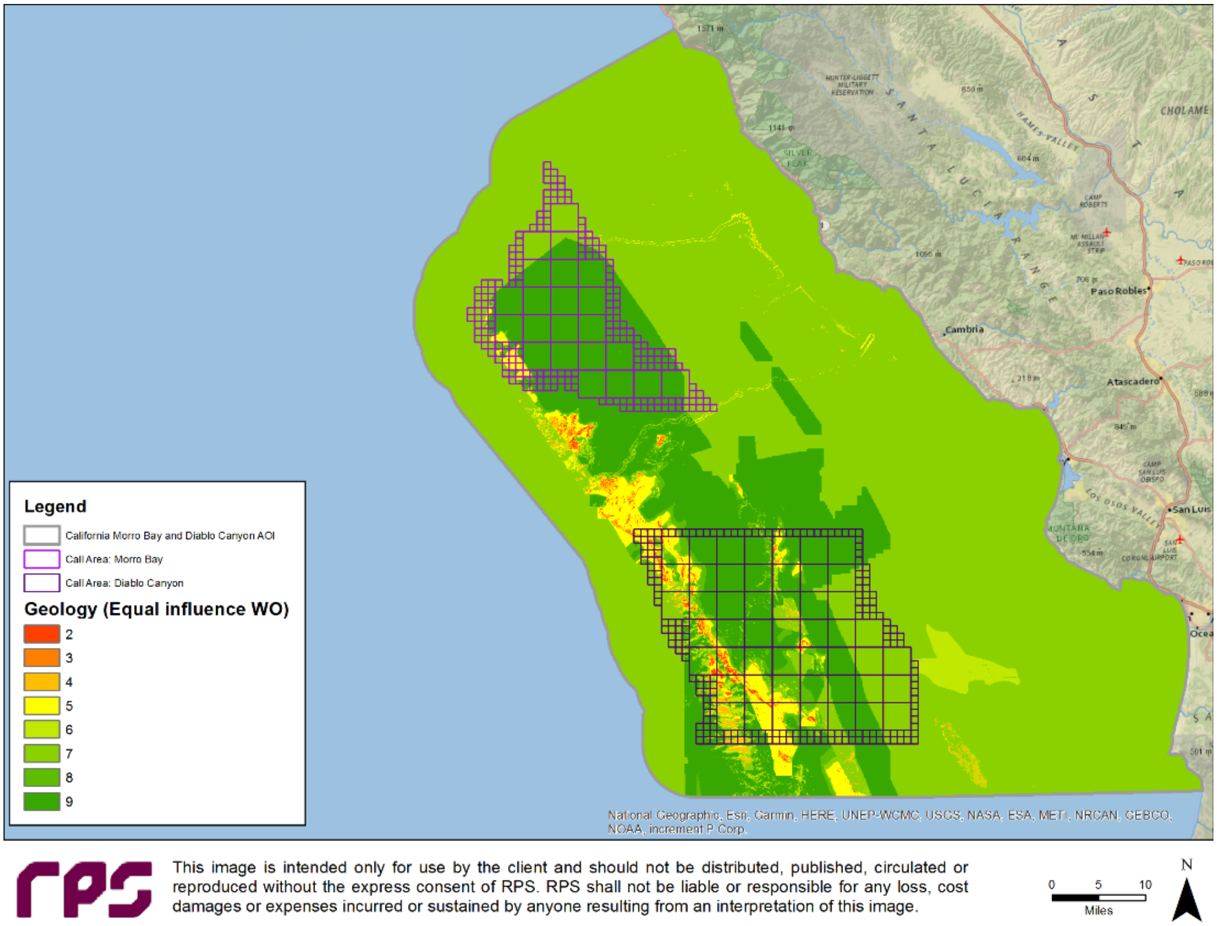

Figure 28. Geology equal influence weighted overlay results for input to multiple models.

Six suitability analysis models were created for Morro Bay and Diablo Canyon. To emulate Model 1 of Phase 1, Model 1 of Phase 2 is presented (Figure 29) as an equally weighted analysis (25%) using the coalesced models for Geohazards (h), Geology (g), Slope Gradient(s) and PGA (p). Model 2 (Figure 30) assigns more weight on the effects of Geology (40%), while depressing Geohazards, Slope Gradient and PGA. Model 3 (Figure 31) considers Slope Gradient the most important factor, while depressing Geohazards, Geology and PGA. Model 4 (Figure 32) puts emphasis on the PGA, while depressing the effect of Geohazards, Geology and Slope Gradient. Model 5 (Figure 33) assigns the greatest influence on Geohazards, while depressing the impact of Geology, Slope Gradient and PGA. Model 6 (Figure 34) assigns an equal influence on all eight sub-components data inputs (11.1%).

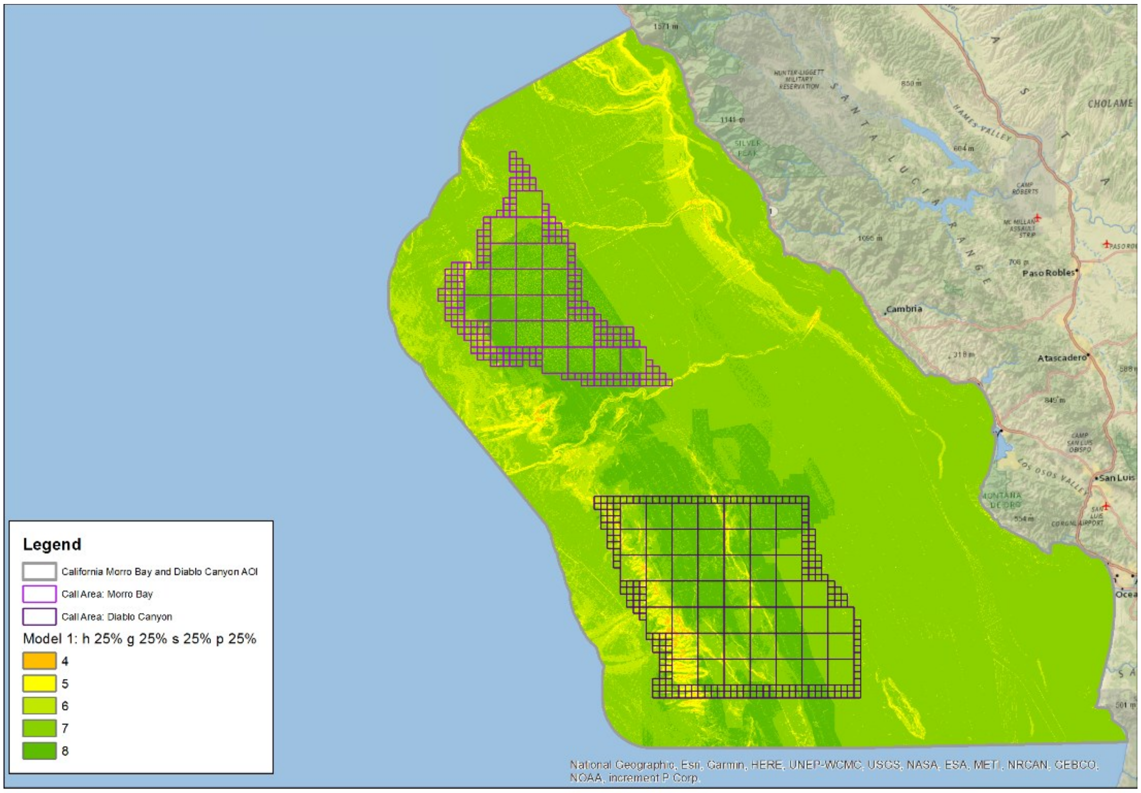

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Figure 29. Model 1: Equal influence for geohazard, geology, slope, and PGA, Morro Bay and Diablo Canyon.

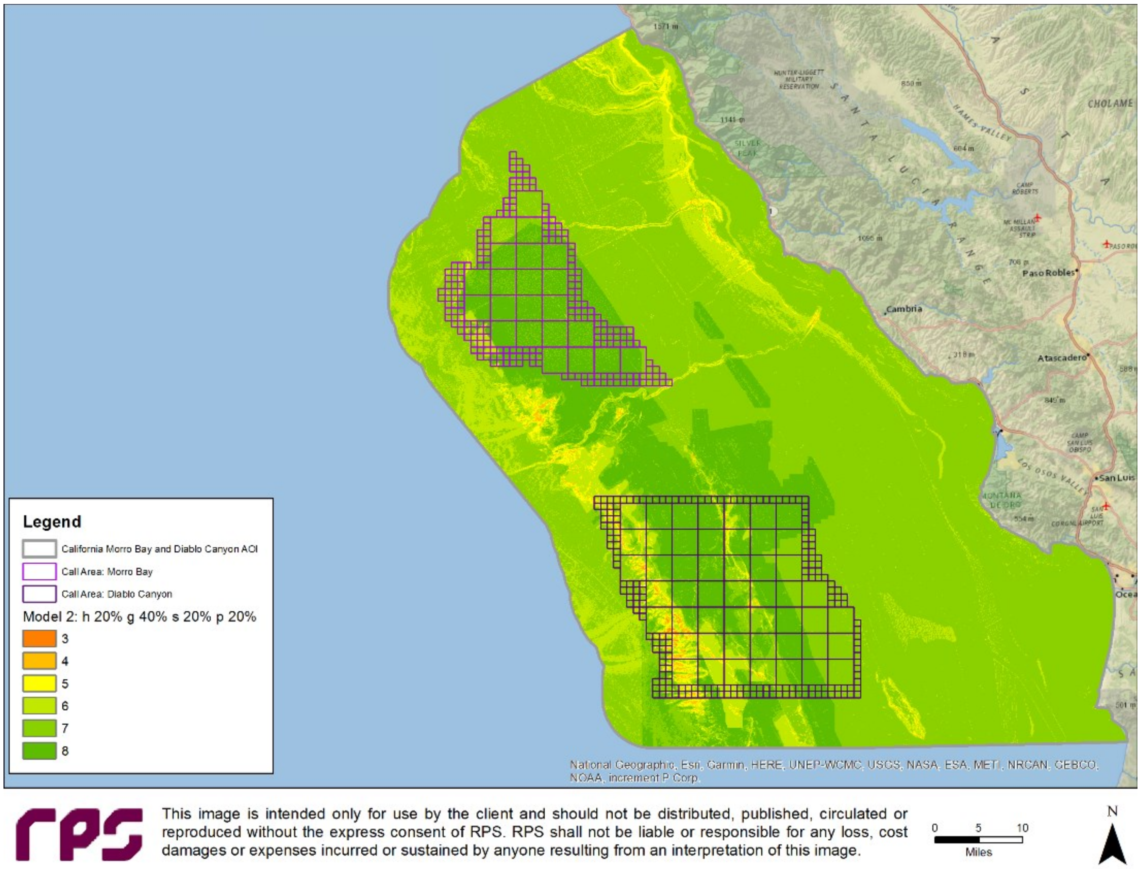

Figure 30. Model 2: Increased influence for soil / geology compared to geohazards, slope and PGA, Morro Bay and Diablo Canyon.

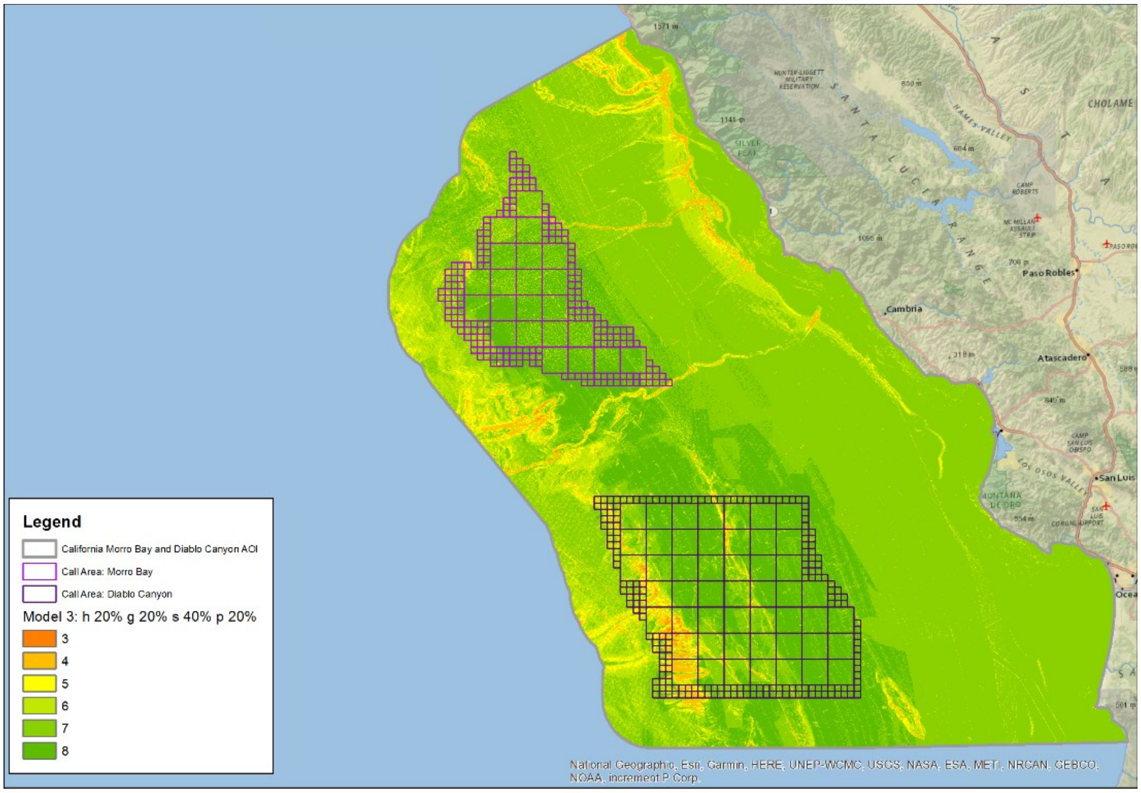

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Figure 31. Model 3: Increased influence for slope compared to geohazards, geology, and PGA, Morro Bay and Diablo Canyon.

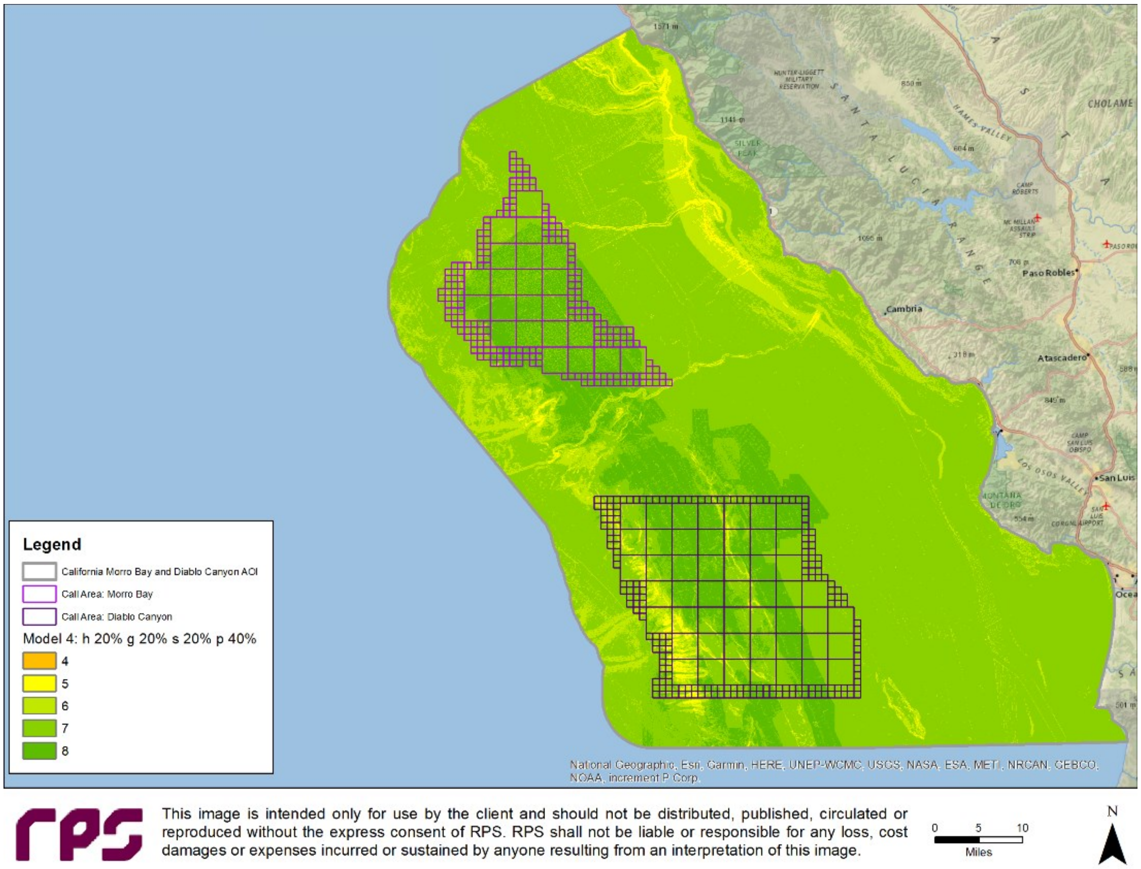

Figure 32. Model 4: Increased influence for PGA compared to geohazards, soil / geology, and slope, Morro Bay and Diablo Canyon.

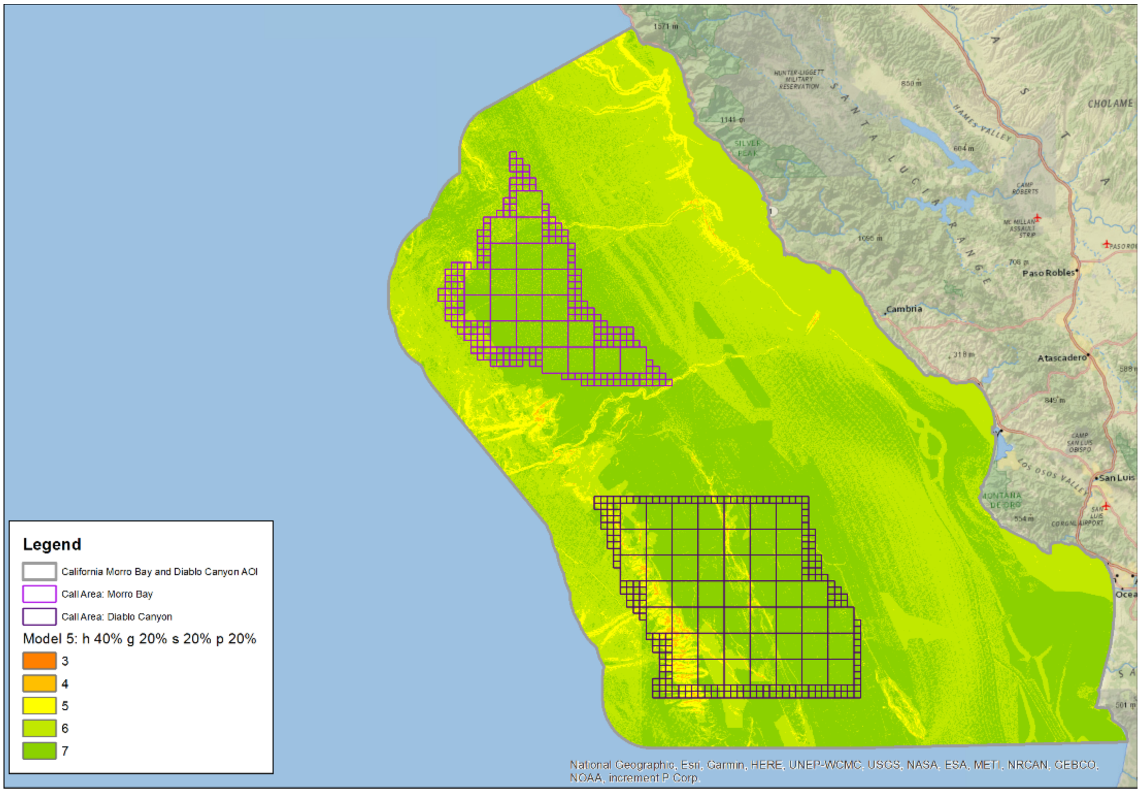

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Figure 33. Model 5: Increased influence for geohazards compared to geology, slope, and PGA, Morro Bay and Diablo Canyon.

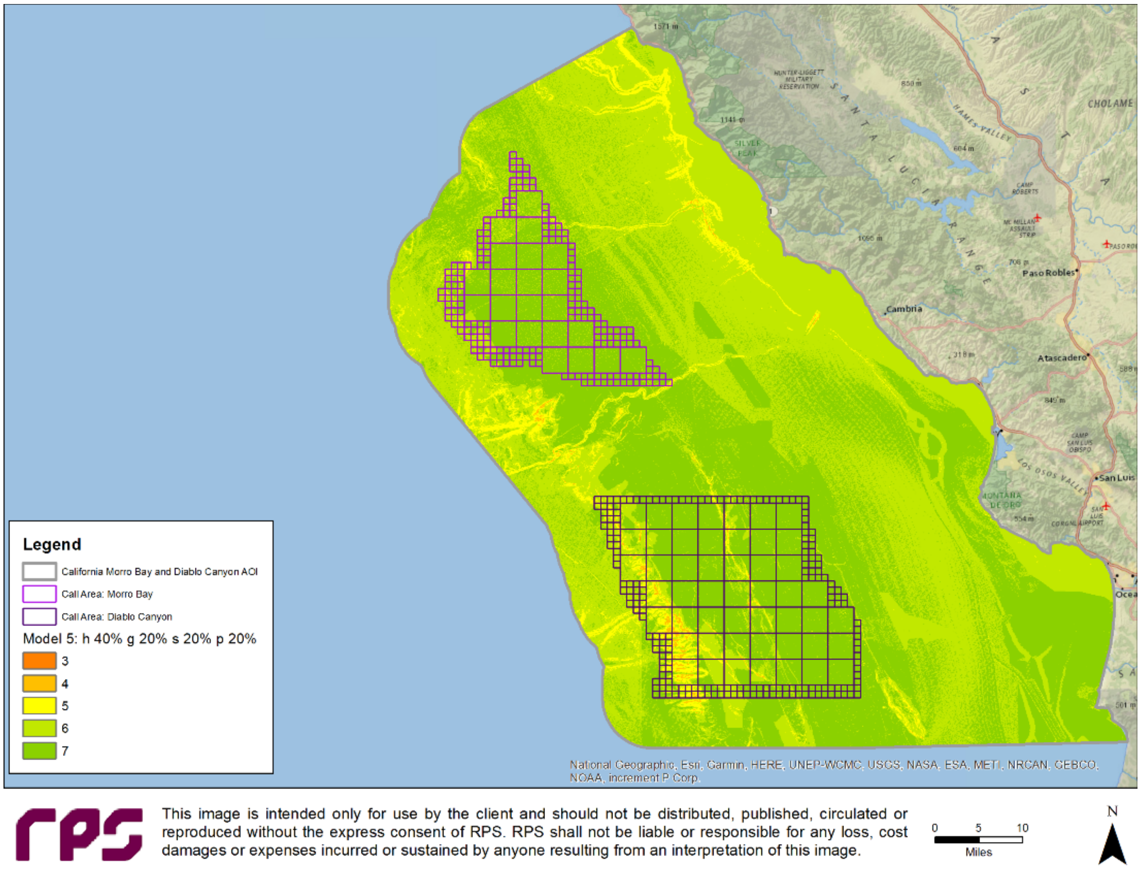

Figure 34. Model 6: All sub-component data inputs with equal influence (11.1%), Morro Bay and Diablo Canyon.

6 MODEL RESULTS DISCUSSION

To assess the updated models based on changes in input data, a quantifiable approach was taken through composite suitability and difference mapping.

6.1 Composite Suitability

The suitability analysis models are presented using different weighting assignments. The variable weighted suitability approach used for this effort is infinitely changeable, repeatable, and can be updated when new data are collected and integrated.

In this study, several suitability analyses were performed for each AOI which resulted in multiple different output maps. Each map contains information that proved challenging to integrate, interpret, and display. Choosing a single map as a representative result, solely based on professional judgement alone, can be a qualitative approach and confining. Therefore, the composite suitability model approach was selected to portray the “best of the best” for each AOI, in terms of suitability considering the variable combination of data inputs (i.e., slope, geology, seismic hazard PGA, geohazards) with various certainty and quality.

A composite suitability analysis is also presented as an effort to capture the data in a comprehensive single summary map from all weighted model outputs. The summary maps quantitatively include all the strengths and weaknesses of all iterations of the suitability analysis results for each AOI.

Composite suitability analysis is accomplished by summing and averaging the results from each iteration of the suitability analysis maps for each AOI. The lesser values (1 – 4), which are indicative of areas with a higher geohazard risk, are then removed from the AOI map to only display “suitable” results of 5 or greater. Removing the regions with a higher geohazard risk simplifies visualization and interpretation of the data.

6.1.1 Humboldt

A composite suitability map for Humboldt was derived by summing and averaging the weighted overlay results with suitability greater than or equal to 5 of Models 1 through 5 (Figure 35).

Based on this geospatial analysis of the available data, the call area appears to be relatively good geologic choices for FOWF, with suitability values of 7. More datasets are needed for this site to develop a similar analysis to central California.

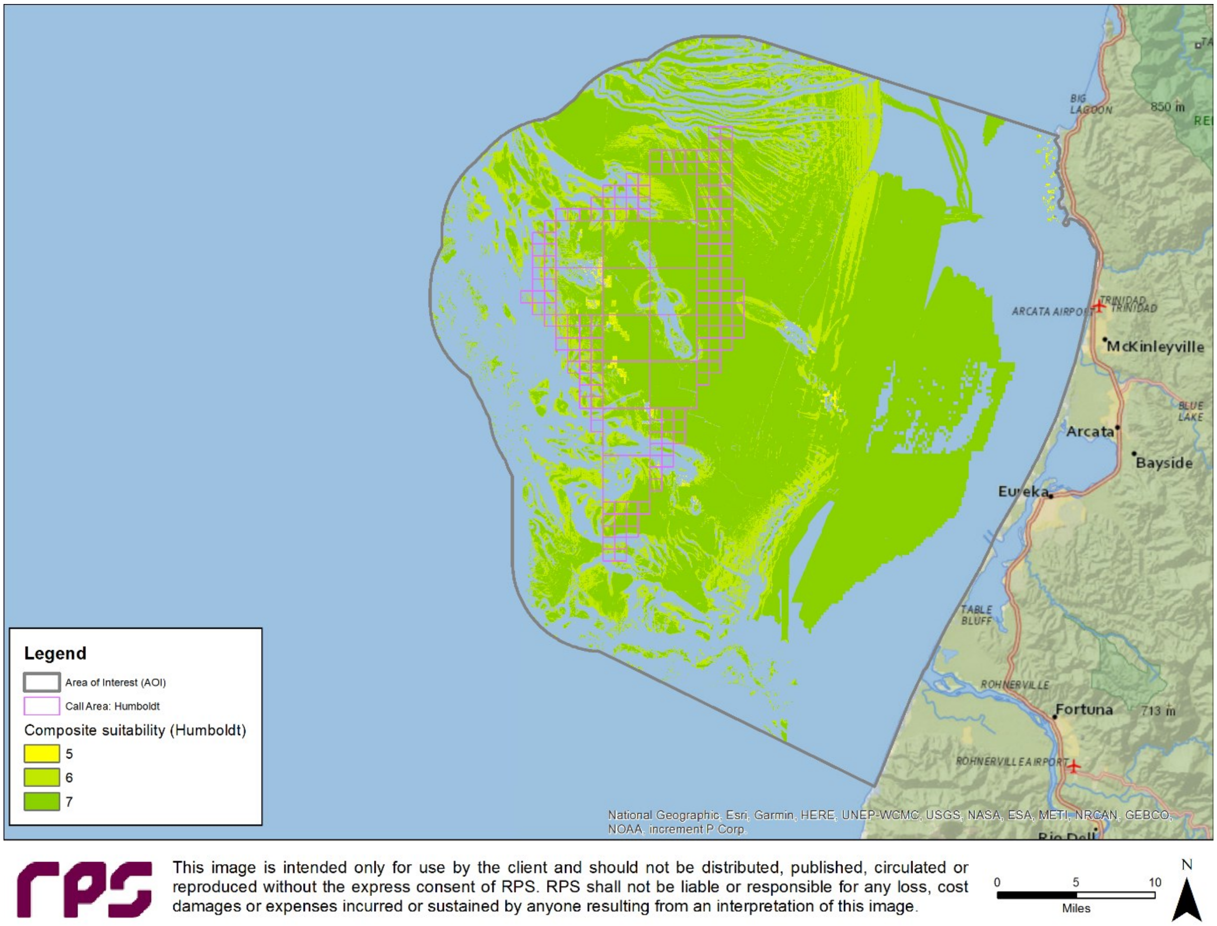

Figure 35. Composite suitability map for Humboldt.

6.1.2 Morro Bay and Diablo Canyon

A composite suitability map for Morro Bay and Diablo Canyon was derived by summing and averaging the weighted overlay results with suitability greater than or equal to 5 of Models 1 through 6 (Figure 36).

Based on this geospatial analysis of the available data, the call areas appear to be good geologic choices for FOWF. The highest suitability values are in area of low seafloor gradient, with soft muddy sediments with the thickness in excess of 50 m. Liquefaction of coarse-grained sediments may be the greater issue in earthquake-prone areas.

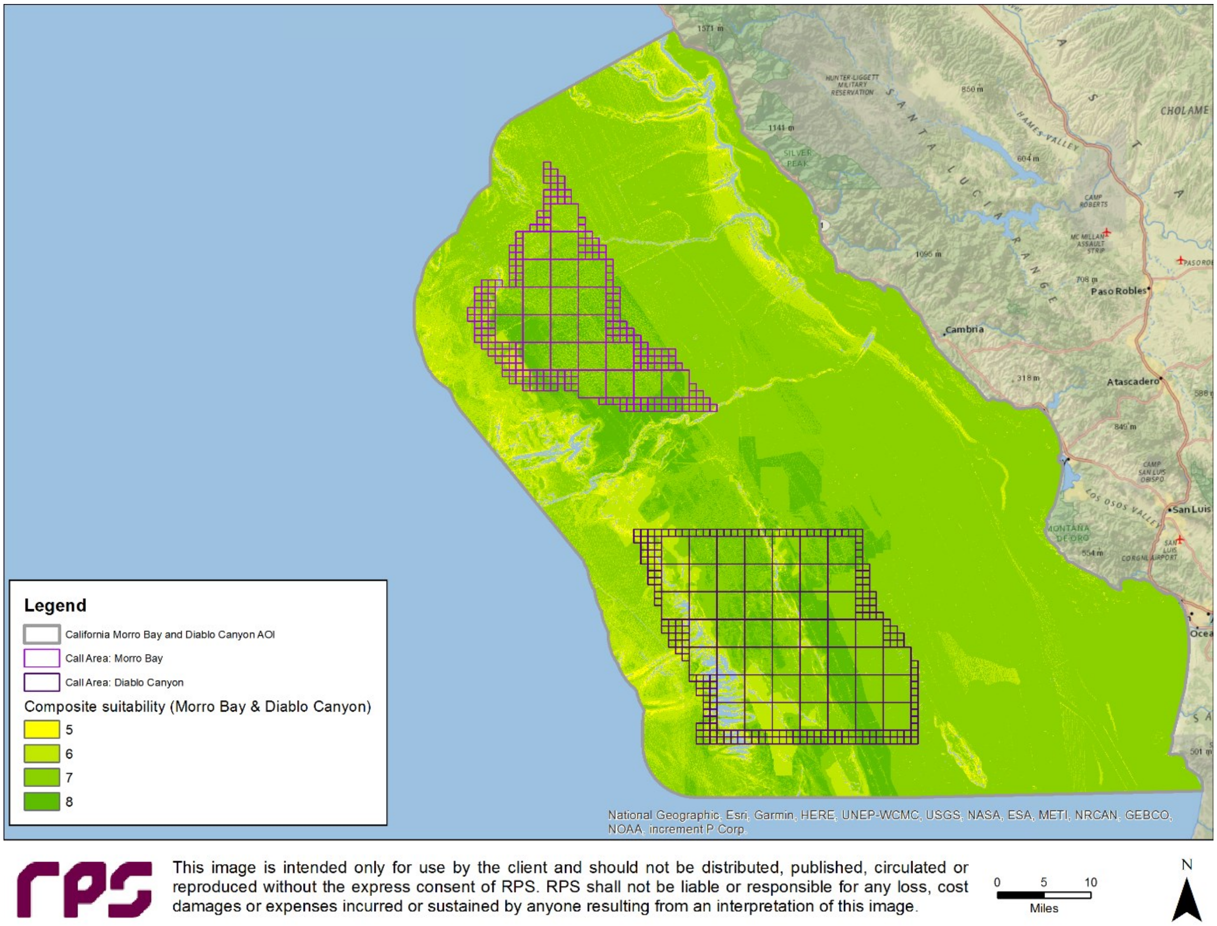

Figure 36. Composite suitability map for Morro Bay and Diablo Canyon.

The results illustrate that a combination of slope gradient and drainage network should be used to portray regions of lower suitability. The slope gradient acts as a proxy for other geohazards (e.g., slope stability, landslide) and the drainage network helps identify down-slope sediment pathways and areas of sediment accumulation.

6.2 Difference Mapping

The change in suitability between Phase 1 and Phase 2 was calculated by subtracting the composite suitability model of Phase 1 (on a cell-by-cell basis) from the composite suitability model of Phase 2.

This computation (difference mapping) reveals:

1. regions where there has been no change in suitability
2. regions where suitability ranking has increased
3. regions where suitability ranking has decreased.

6.2.1 Humboldt

Suitability values for ~14% of the Humboldt AOI remain unchanged from Phase 1 to Phase 2. Suitability values for ~86% of the Humboldt AOI increased by a range of 1 to 2. Suitability values for <1% of the Humboldt AOI decreased by 1 score (Table 8 and Figure 37).

Table 8. Results of difference mapping for Humboldt

Difference mapping for Humboldt (Phase 2 minus Phase 1)		
Value	Count	Percentage
-1	15	0.1%
0	2817	13.9%
1	16466	81.4%
2	932	4.6%

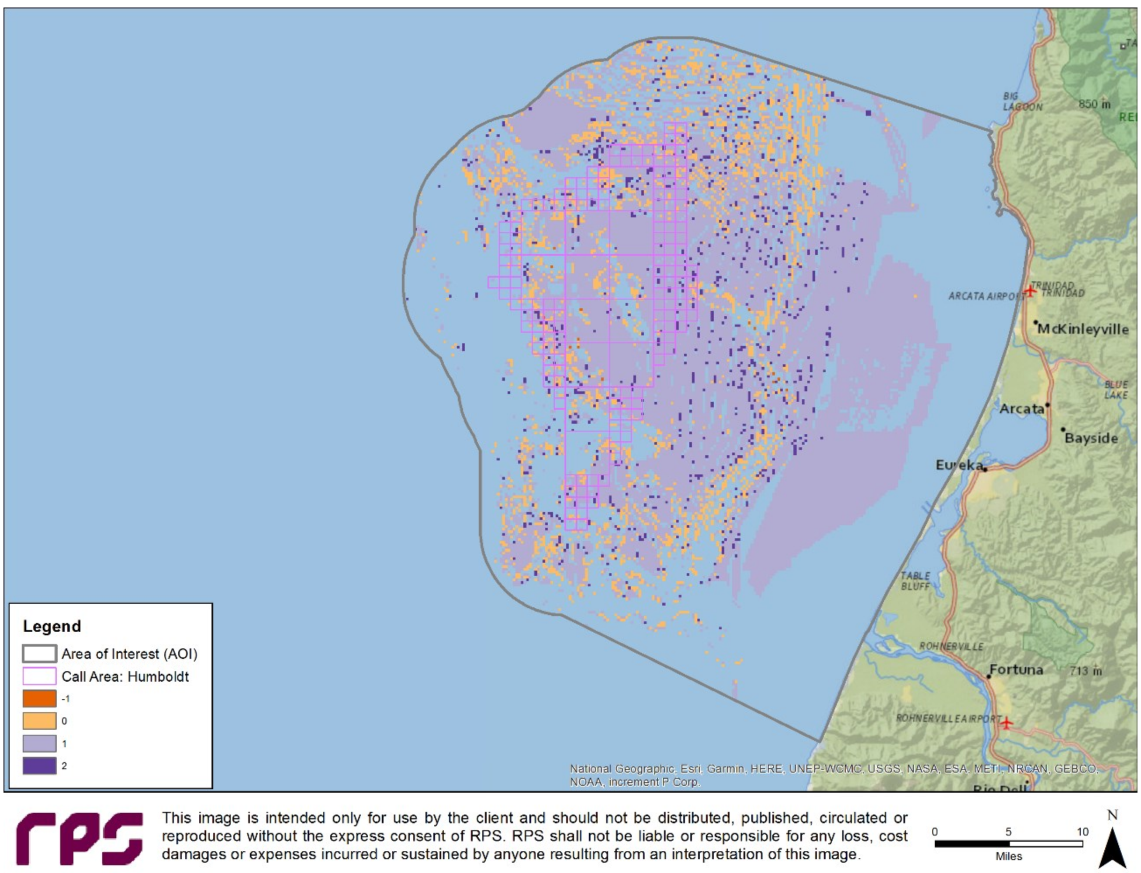

Figure 37. Composite suitability difference map for Humboldt (Phase 2 minus Phase 1).

As phase 2 results display a significantly higher spatial resolution, the improvement in suitability values is largely explained by the improved resolution of the input multibeam bathymetry data. Conversely, the 1% decrease in suitability values is also explained by the improved resolution of the input multibeam bathymetry data where slope is captured through higher resolution bathymetry, for example, in the northern region of the AOI. The new MBES bathymetric data for Humboldt provided a higher resolution (30 m) compared to bathymetric data available during Phase 1 (~90 m), and the positive impact of this higher resolution data is evident.

6.2.2 Morro Bay and Diablo Canyon

Suitability values for ~54% of the Morro Bay and Diablo Canyon AOI remain unchanged from Phase 1 to Phase 2. Suitability values for ~34% of the Morro Bay and Diablo Canyon AOI increased by a range of 1 to 3. Suitability values for ~12% of the Morro Bay and Diablo Canyon AOI decreased by a range of 1 to 2 (Table 9 and Figure 38).

Table 9. Results of difference mapping for Morro Bay and Diablo Canyon

Difference mapping for Morro Bay and Diablo Canyon (Phase 2 minus Phase 1)		
Value	Count	Percentage
-2	394	1.0%
-1	4088	10.8%
0	20373	53.7%
1	11179	29.4%
2	1911	5.0%
3	24	0.1%

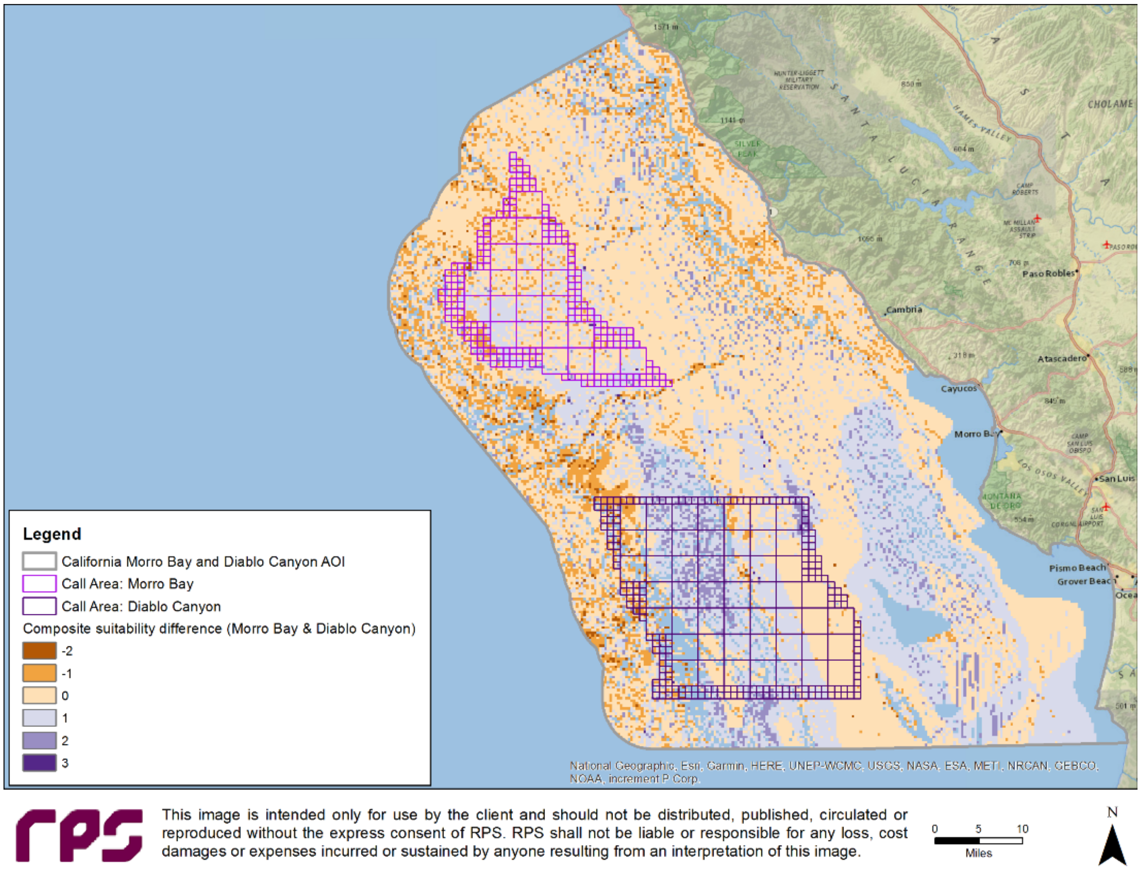

Figure 38. Composite suitability difference map for Morro Bay and Diablo Canyon (Phase 2 minus Phase 1).

Similar to the Humboldt call area, Phase 2 results for central California display a significantly higher spatial resolution.

The ~34% improvement in suitability is largely explained by the improved resolution of the input multibeam bathymetry data and increased certainty in the surficial and subsurface geological mapping, particularly for the Diablo Canyon region.

7 CONCLUSION AND RECOMMENDATIONS

1. The study methodology has integrated large diverse data sets allowing suitability assessment and mapping for the offshore lease blocks.
2. The analysis provides a basis to rank the suitability of areas based on specific criteria and this is expected to be a useful management tool as developers submit plans for site investigation work.
3. The results of this analysis are presented through the GIS Portal[10] developed for the project and allow for user selected enquiries.
4. The weighted overlay function of ESRI ArcGIS Desktop Spatial Analysis has removed the personal bias and quantitatively assesses the suitability of the site by integrating all existing inputs and factors.
5. The results of Phase 1 have been substantially enhanced through the inclusion of the data in Phase 2, the addition of high-resolution bathymetry data, subsurface geological data, and mapping.
6. The information gathered in this analysis could be used for the design of future geophysical and geotechnical site investigation projects and for the evaluation of site investigation plans by developers.
7. Future data collected by developers could be integrated into this analysis tool to further refine suitability and improve the knowledge base created in this study.
8. The information gathered in this project is not a substitute for further site-specific seabed investigations which will prove critical to refining the understanding and suitability for specific license blocks, and cable burial or landing locations.
9. Composite suitability analysis is a methodology for providing a summary results map. When performing a comparison, the suitability analysis and composite suitability analysis maps yield similar results. However, the composite suitability analysis yields a more comprehensive rendition, honoring all the input criteria. The elimination of the higher geohazard risk areas makes the maps simpler to understand.
10. Data Gaps and Limitations Exist:

    For Humboldt, although new MBES bathymetry data for Humboldt provides 100% coverage over the Humboldt Call Area (grid), the MBES data gaps in the northeast and south of the Humboldt AOI carry through to Phase 2 suitability analysis results as “NoData”.

    For Morro Bay and Diablo Canyon, the NoData regions within the AOI surrounding the geohazard data inputs were assigned a value of 5 to fill the AOI with a non-zero value to enable proper execution of the weighted overlay raster computations using ESRI’s Spatial Analyst ArcMap software extension.

    The NoData regions within the AOI surrounding the CMECS substrate data (surficial sediment soil type) were assigned a high suitability value of 9 to represent an extrapolation of mud whereas this surficial sediment type covers most of the AOI before extrapolation. These fill values impact the suitability calculation by adding bias where there is no data available.

[10] https://oceansmap.com/BOEM/California/

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9 APPENDIX 1: DATA PROVIDED BY BOEM/USGS

File/Folder Name	Data Types	Public domain (data access)	Citation	Description
BOEM	Shapefiles	https://www.boem.gov/renewable-energy/mapping-and-data/renewable-energy-gis-data	"Renewable Energy GIS Data." Bureau of Ocean Energy Management, www.boem.gov/renewable-energy/mapping-and-data/renewable-energy-gis-data	Track lines and boundaries of data received from BOEM
Bold_Horizon_2019_cores	Locations and depths	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9DE639J/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Addison, J.A., Paull, C.K., Gwiazda, R., Lorenson, T.D., Lundsten, E.,2021. Piston and gravity core data collected during USGS cruise 2019-642-FA offshore of south-central California in support of the Bureau of Ocean Energy Management (BOEM) California Deepwater Investigations and Groundtruthing(Cal DIG I) alternative energy project, September 2019: U.S. Geological Survey data release	Location and depth data for piston and gravity cores collected in September 2019 offshore of south-central California (USGS FAN 2019-642-FA)
Bold_Horizon_2019_cores	CT scans	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9DE639J/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Addison, J.A., Paull, C.K., Gwiazda, R., Lorenson, T.D., Lundsten, E.,2021. Piston and gravity core data collected during USGS cruise 2019-642-FA offshore of south-central California in support of the Bureau of Ocean Energy Management (BOEM) California Deepwater Investigations and Groundtruthing(Cal DIG I) alternative energy project, September 2019: U.S. Geological Survey data release	Tomographic Imaging of select whole-round core sections. Figures can be directly downloaded from the report (http://espis.boem.gov/final%20reports/BOEM_2021-044.pdf).
Bold_Horizon_2019_cores	MSCL	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9DE639J/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Addison, J.A., Paull, C.K., Gwiazda, R., Lorenson, T.D., Lundsten, E.,2021. Piston and gravity core data collected during USGS cruise 2019-642-FA offshore of south-central California in support of the Bureau of Ocean Energy Management (BOEM) California Deepwater Investigations and Groundtruthing (Cal DIG I) alternative energy project, September 2019: U.S. Geological Survey data release	Multi-Sensor Core Logger (MSCL) data of piston and gravity cores collected in September 2019 offshore of south-central California (USGS FAN 2019-642-FA)
Bold_Horizon_2019_cores	Photos	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9DE639J/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Addison, J.A., Paull, C.K., Gwiazda, R., Lorenson, T.D., Lundsten, E.,2021. Piston and gravity core data collected during USGS cruise 2019-642-FA offshore of south-central California in support of the Bureau of Ocean Energy Management (BOEM) California Deepwater Investigations and Groundtruthing(Cal DIG I) alternative energy project, September 2019: U.S. Geological Survey data release	Photographs of piston and gravity cores collected in September 2019 offshore of south-central California (USGS FAN 2019-642-FA)

Bold_Horizon_2019_cores	Porewater	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9DE639J/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Addison, J.A., Paull, C.K., Gwiazda, R., Lorenson, T.D., Lundsten, E.,2021. Piston and gravity core data collected during USGS cruise 2019-642-FA offshore of south-central California in support of the Bureau of Ocean Energy Management (BOEM) California Deepwater Investigations and Groundtruthing(Cal DIG I) alternative energy project, September 2019: U.S. Geological Survey data release	Porewater chloride and sulfate concentrations from piston and gravity cores collected in September 2019 offshore of south-central California (USGS FAN 2019-642-FA)
Bold_Horizon_2019_cores	BH1909_core_logs_combined_small_v2.pdf	Accessible by personal correspondence with Dr. Maureen Walton (maureen.walton@nrlssc.navy.mil)		Compilation of handwritten observation notes (M Walton) of core station logs and core deck logs
GIS_geodatabase	Morro_Bay_interpretations_malw.gdb	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9JU17GE/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Balster-Gee, A.F., Kluesner, J.W., Hart, P.E., Sliter, R.W., Miller, J.K.,and Gilbane, L., 2021. High-resolution multi-channel and Chirp seismic-reflection data from USGS cruise 2018-641-FAcollected in south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy	The interpretations used in the study are derived from the data available in the Public Domain.
GIS_geodatabase	Morro_Bay_other_relevant_data_malw.gdb (mroby20utm, mroby20utmhs, mroby20utmslp)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9QQZ27U/	Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022. California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological Survey Open-File Report 2022–1035 [also released as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035	
GIS_geodatabase	Morro_Bay_tracks_samples_malw.gdb	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9QQZ27U/	Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022. California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological Survey Open-File Report 2022–1035 [also released as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035	Bathymetry and Habitats
GIS_geodatabase	Morro_Bay_tracks_samples_malw.gdb	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9JU17GE/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Balster-Gee, A.F., Kluesner, J.W., Hart, P.E., Sliter, R.W., Miller, J.K.,and Gilbane, L., 2021. High-resolution multi-channel and Chirp seismic-reflection	Seismic

			data from USGS cruise 2018-641-FAcollected in south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy	
GIS_geodatabase	Morro_Bay_tracks_samples_malw.gdb	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9DE639J/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Addison, J.A., Paull, C.K., Gwiazda, R., Lorenson, T.D., Lundsten, E., 2021, Piston and gravity core data collected during USGS cruise 2019-642-FA offshore of south-central California in support of the Bureau of Ocean Energy Management (BOEM) California Deepwater Investigations and Groundtruthing (Cal DIG I) alternative energy project, September 2019: U.S. Geological Survey data release, https://doi.org/10.5066/P9DE639J	Bold Horizon Cores
GIS_geodatabase	Morro_Bay_tracks_samples_malw.gdb	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P97QM7NF/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Paull, C., Caress, D., Anderson, K., and Lundsten, E., 2021, Donated AUV bathymetry and Chirp seismic-reflection data collected during Monterey Bay Aquarium Research Institute cruises in 2018-2019 offshore of south-central California: U.S. Geological Survey data release, https://doi.org/10.5066/P97QM7NF	MBARI AUV
GIS_geodatabase	Morro_Bay_tracks_samples_malw.gdb	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9E2OP35/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Paul, C.K., Gwiazda, R., Lundsten, E., Kuhnz, L., Lorenson, T.D., McGann, M.L., Nieminski, N.M., and Addison, J.A., 2021, Donated ROV vibracore and sampling data collected during Monterey Bay Aquarium Research Institute cruises in 2019 offshore of south-central California: U.S. Geological Survey data release, https://doi.org/10.5066/P9E2OP35	MBARI ROV
MBARI_AUV	AUV_Bathymetry	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P97QM7NF/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Paull, C., Caress, D., Anderson, K., and Lundsten, E., 2021, Donated AUV bathymetry and Chirp seismic-reflection data collected during Monterey Bay Aquarium Research Institute cruises in 2018-2019 offshore of south-central California: U.S. Geological Survey data release, https://doi.org/10.5066/P97QM7NF	Donated AUV bathymetry data collected during Monterey Bay Aquarium Research Institute (MBARI) cruises 2018 - 2019 offshore of south-central California
MBARI_AUV	AUV_Chirp (1,249 .segy files organized by subfolders)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P97QM7NF/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Paull, C., Caress, D., Anderson, K., and Lundsten, E., 2021, Donated AUV bathymetry and Chirp seismic-reflection data collected during Monterey Bay Aquarium Research Institute cruises in 2018-2019 offshore of south-central California: U.S. Geological	Donated AUV bathymetry data collected during Monterey Bay Aquarium Research Institute (MBARI) cruises 2018 - 2019 offshore of south-central California

			Survey data release, https://doi.org/10.5066/P97QM7NF	
MBARI_AUV	MBARI_AUV_032019_lines.shp	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P97QM7NF/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Paull, C., Caress, D., Anderson, K., and Lundsten, E., 2021, Donated AUV bathymetry and Chirp seismic-reflection data collected during Monterey Bay Aquarium Research Institute cruises in 2018-2019 offshore of south-central California: U.S. Geological Survey data release, https://doi.org/10.5066/P97QM7NF	
MBARI_AUV	MBARI_AUV_042018_lines.shp	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P97QM7NF/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Paull, C., Caress, D., Anderson, K., and Lundsten, E., 2021, Donated AUV bathymetry and Chirp seismic-reflection data collected during Monterey Bay Aquarium Research Institute cruises in 2018-2019 offshore of south-central California: U.S. Geological Survey data release, https://doi.org/10.5066/P97QM7NF	
MBARI_AUV	MBARI_AUV_052019_lines.shp	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P97QM7NF/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Paull, C., Caress, D., Anderson, K., and Lundsten, E., 2021, Donated AUV bathymetry and Chirp seismic-reflection data collected during Monterey Bay Aquarium Research Institute cruises in 2018-2019 offshore of south-central California: U.S. Geological Survey data release, https://doi.org/10.5066/P97QM7NF	
MBARI_AUV	MBARI_AUVbathy_April2018.shp	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P97QM7NF/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Paull, C., Caress, D., Anderson, K., and Lundsten, E., 2021, Donated AUV bathymetry and Chirp seismic-reflection data collected during Monterey Bay Aquarium Research Institute cruises in 2018-2019 offshore of south-central California: U.S. Geological Survey data release, https://doi.org/10.5066/P97QM7NF	
MBARI_AUV	MBARI_AUVbathy_March2019.shp	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P97QM7NF/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Paull, C., Caress, D., Anderson, K., and Lundsten, E., 2021, Donated AUV bathymetry and Chirp seismic-reflection data collected during Monterey Bay Aquarium Research Institute cruises in 2018-2019 offshore of south-central California: U.S. Geological Survey data release, https://doi.org/10.5066/P97QM7NF	
MBARI_AUV	MBARI_AUVbathy_May2019.shp	https://cmgds.marine.usgs.gov/data-	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Paull, C., Caress, D., Anderson, K., and Lundsten, E.,	

		releases/datarelease/10.5066-P97QM7NF/	2021, Donated AUV bathymetry and Chirp seismic-reflection data collected during Monterey Bay Aquarium Research Institute cruises in 2018-2019 offshore of south-central California: U.S. Geological Survey data release, https://doi.org/10.5066/P97QM7NF	
MBARI_ROV_vibracore_photos	Vibracore photos (Nov 2019)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9E2OP35/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Paul, C.K., Gwiazda, R., Lundsten, E., Kuhnz, L., Lorenson, T.D.,McGann, M.L., Nieminski, N.M., and Addison, J.A., 2021. Donated ROV vibracore and sampling data collected during Monterey Bay Aquarium Research Institute cruises in 2019 offshore of south-central California: U.S. Geological Survey data release	Photographs of vibracores collected during a Monterey Bay Aquarium Research Institute cruise in November 2019 offshore of south-central California (USGS FAN 2019-667-FA)
MBARI_ROV_vibracore_photos	Vibracore photos (Nov 2019)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9E2OP35/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Paul, C.K., Gwiazda, R., Lundsten, E., Kuhnz, L., Lorenson, T.D.,McGann, M.L., Nieminski, N.M., and Addison, J.A., 2021. Donated ROV vibracore and sampling data collected during Monterey Bay Aquarium Research Institute cruises in 2019 offshore of south-central California: U.S. Geological Survey data release	Photographs of vibracores collected during a Monterey Bay Aquarium Research Institute cruise in February 2019 offshore of south-central California (USGS FAN 2019-603-FA)
	MBARI vibracore location and depth data (Nov 2019)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9E2OP35/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Paul, C.K., Gwiazda, R., Lundsten, E., Kuhnz, L., Lorenson, T.D.,McGann, M.L., Nieminski, N.M., and Addison, J.A., 2021. Donated ROV vibracore and sampling data collected during Monterey Bay Aquarium Research Institute cruises in 2019 offshore of south-central California: U.S. Geological Survey data release	Location data for vibracores collected during a Monterey Bay Aquarium Research Institute cruise in November 2019 offshore of south-central California (USGS FAN 2019-667-FA)
	MBARI vibracore location and depth data (Feb 2019)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9E2OP35/	Kennedy, D.J., Walton, M.A., Cochrane, G.R., Paul, C.K., Gwiazda, R., Lundsten, E., Kuhnz, L., Lorenson, T.D.,McGann, M.L., Nieminski, N.M., and Addison, J.A., 2021. Donated ROV vibracore and sampling data collected during Monterey Bay Aquarium Research Institute cruises in 2019 offshore of south-central California: U.S. Geological Survey data release	Location and depth data for vibracores collected during a Monterey Bay Aquarium Research Institute cruise in February 2019 offshore of south-central California (USGS FAN 2019-603-FA)
Rainier_2018_geophysics	CalDIG_Chirp_tracks_YoNav_NEW	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9JU17GE/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Balster-Gee, A.F., Kluesner, J.W., Hart, P.E., Sliter, R.W., Miller, J.K., and Gilbane, L., 2021. High-resolution multi-channel and Chirp seismic-reflection data from USGS cruise 2018-641-FAcollected in south-central California in support of the Bureau of	High-resolution Chirp seismic-reflection data from USGS cruise 2018-641-FA, collected in south-central California in support of the Bureau of Ocean Energy Management (BOEM)-funded California Deepwater Investigations and

			Ocean Energy Management Cal DIG I offshore alternative energy	Groundtruthing (Cal DIG I) offshore alternative energy project from 2018-08-29 to 2018-09-20
Rainier_2018_geophysics	CalDIG_MCS_tracks_YoNav	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9JU17GE/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Balster-Gee, A.F., Kluesner, J.W., Hart, P.E., Sliter, R.W., Miller, J.K., and Gilbane, L., 2021. High-resolution multi-channel and Chirp seismic-reflection data from USGS cruise 2018-641-FAcollected in south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy	High-resolution Chirp seismic-reflection data from USGS cruise 2018-641-FA, collected in south-central California in support of the Bureau of Ocean Energy Management (BOEM)-funded California Deepwater Investigations and Groundtruthing (Cal DIG I) offshore alternative energy project from 2018-08-29 to 2018-09-20
Rainier_2018_geophysics	Chirp_segy (9 files on RPS server)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9JU17GE/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Balster-Gee, A.F., Kluesner, J.W., Hart, P.E., Sliter, R.W., Miller, J.K., and Gilbane, L., 2021. High-resolution multi-channel and Chirp seismic-reflection data from USGS cruise 2018-641-FAcollected in south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy	High-resolution Chirp seismic-reflection data from USGS cruise 2018-641-FA, collected in south-central California in support of the Bureau of Ocean Energy Management (BOEM)-funded California Deepwater Investigations and Groundtruthing (Cal DIG I) offshore alternative energy project from 2018-08-29 to 2018-09-20
Rainier_2018_geophysics	MCS_segy (96 files on RPS server)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9JU17GE/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Balster-Gee, A.F., Kluesner, J.W., Hart, P.E., Sliter, R.W., Miller, J.K.,and Gilbane, L., 2021. High-resolution multi-c hannel and Chirp seismic-reflection data from USGS cruise 2018-641-FAcollected in south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy	High-resolution multi-channel seismic-reflection data from USGS cruise 2018-641-FA, collected in south-central California in support of the Bureau of Ocean Energy Management (BOEM)-funded California Deepwater Investigations and Groundtruthing (Cal DIG I) offshore alternative energy project from 2018-08-29 to 2018-09-20
	DK_README_Rainier_MCS.docx	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9JU17GE/	Kennedy, D.J., Walton, M.A.L., Cochrane, G.R., Balster-Gee, A.F., Kluesner, J.W., Hart, P.E., Sliter, R.W., Miller, J.K.,and Gilbane, L., 2021. High-resolution multi-channel and Chirp seismic-reflection data from USGS cruise 2018-641-FAcollected in south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy	Notes on seismic data processing issues. Processed by Daniel Kennedy finished 2/28/2018
Rainier_2018_geophysics	water_column	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9QQZ27U/	Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022. California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological Survey Open-File Report 2022–1035 [also released	CARIS findings H13151.xlsx CARIS findings H13152.xlsx (Descriptions of “blobs” with location coordinates)

			as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035.	
	Multibeam acoustic-backscatter	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9QQZ27U/	Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022. California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological Survey Open-File Report 2022–1035 [also released as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035.	Multibeam acoustic-backscatter data collected offshore of south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy project
	Multibeam bathymetry data	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9QQZ27U/	Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022. California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological Survey Open-File Report 2022–1035 [also released as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035.	Multibeam bathymetry data collected in four surveys offshore of south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy project
	Physical, environmental, and biotic observations derived from underwater video (biotic component)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9QQZ27U/	Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022. California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological Survey Open-File Report 2022–1035 [also released as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035.	Physical, environmental, and biotic observations derived from underwater video collected offshore of south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy project
	Physical, environmental, and biotic observations derived from underwater video (substrate component)	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9QQZ27U/	Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022. California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological Survey Open-File Report 2022–1035 [also released as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035.	Physical, environmental, and substrate observations derived from underwater video collected offshore of south-central California in support of the Bureau of Ocean Energy Management Cal DIG I offshore alternative energy project
	CMECS seafloor induration	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9QQZ27U/	Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022. California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological	CMECS seafloor induration derived from multibeam echosounder data collected offshore of south-central California in support of the Bureau of Ocean Energy

			Survey Open-File Report 2022–1035 [also released as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035.	Management Cal DIG I, offshore alternative energy project
	CMECS substrate, geoform, and biotic component polygons	https://cmgds.marine.usgs.gov/data-releases/datarelease/10.5066-P9QQZ27U/	Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022. California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological Survey Open-File Report 2022–1035 [also released as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035.	CMECS substrate, geoform, and biotic component polygons derived from multibeam echosounder data and underwater video observations collected offshore of south-central California in support of the Bureau of Ocean Energy Management Cal DIG I, offshore alternative energy project

U.S. Department of the Interior (DOI)
DOI protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)
BOEM's mission is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.