

Memorandum – Coastal Engineering Review

Summary of Geologic Resources Inventory (GRI) Support Documents: Cape Cod National Seashore (CACO)

February 2026

Review Request Summary

The Geologic Resource Inventory (GRI) is one of 12 baseline natural resource inventory efforts within the National Park Service (NPS) Inventory and Monitoring (I&M) Division. The GRI is a cooperative effort among the National Park Service, Colorado State University, and the University of Alaska Fairbanks. It strives to advance science based natural resource management and builds awareness of geology and the importance of geologic features and processes to park environments.

The GRI team works closely with a variety of partners to provide each of the approximately 270 parks in the I&M networks with a geologic scoping meeting, digital geologic map data and poster, and a park specific geologic report. These products support stewardship of park resources by providing information about geologic formations, processes, hazards, and connections among geology, history, and other natural resources. The National Park Service identified 13 coastal parks that have geologic scoping meeting summaries and at least one digital geologic map but do not have a traditional GRI report: Biscayne National Park (BISC), Cape Cod National Seashore (CACO), Canaveral National Seashore (CANA), Castillo de San Marcos National Monument (CASA), Cumberland Island National Seashore (CUIS), Fire Island National Seashore (FIIS), Fort Caroline National Memorial (FOCA), Fort Frederica National Monument (FOFR), Fort Matanzas National Monument (FOMA), Fort Pulaski National Monument (FOPU), Fort Sumter and Fort Moultrie National Historical Park (FOSU), Gateway National Recreation Area (GATE), and Timucuan Ecological and Historic Preserve (TIMU). As of spring 2024, the GRI team is transitioning to a proposal-based system and not all parks will receive a traditional report, including all 13 of the identified coastal parks. Many of these coastal parks were originally scoped in the early 2000s and have map products approaching or now exceeding 20 years old. Therefore, to provide a status update to the coastal parks in lieu of a traditional report, the GRI team requested help from EA Engineering, Science, and Technology, Inc., PBC (EA) with the following:

- Prepare literature reviews focused on geologic resources for each of these parks to provide a data resource for future work
- Prepare a literature review to include service wide and regional resources that could be useful to multiple parks
- Evaluate available digital geologic map data for each of these parks and assess their relevance to the coastal management needs

Literature Reviews

Introduction

The literature review for each park consists of an Excel spreadsheet that lists all sources found and PDF files of each source listed in the spreadsheet. Within the spreadsheet, there is a link that will open the associated PDF file directly. These files for Cape Cod National Seashore can be downloaded from the NPS DataStore at: <https://irma.nps.gov/DataStore/Reference/Profile/2317161>.

Methodology

When searching for sources, the following steps were followed for each park to ensure consistency in methods:

- EA checked their server for project files already in EA possession/already catalogued in previous literature reviews, annotated bibliographies, and memo reference lists.
- EA visited the GRI Product Page (NPS 2024a) to check for GRI products that the National Park Service has previously compiled for the park unit.
- EA completed an advanced search of NPS DataStore using the following methods:
 - In the Text Fields section, enter:
 - Description contains geolog*
 - OR Title contains geolog*
 - OR Keyword contains geolog*
 - In the Content Units section, enter the four-letter code for the park unit/select it from the list
- EA completed a general google search, focusing on scholarly articles. If providing overwhelming results, results were narrowed by using a publication date of 2016/2017 as a cutoff.
- EA reviewed the following links relevant to multiple parks:
 - Coastal engineering inventories of select parks (NPS 2013)
 - The NPS Paleontology Library is a repository for electronic copies of geology and paleontology publications, reports, and other media. There are three main paleontological resource inventory types:
 - Park-specific Paleontological Resource Inventories (NPS 2024b)
 - Service wide Thematic Paleontological Resource Inventories (NPS 2023a)
 - I&M Network Based Paleontological Resource Inventories (NPS 2023b)
 - Shoreline Change Project maps for 88 ocean and Great Lake park units (NPS 2022).
- EA checked the reference lists of reports already found, particularly if the reference was comprehensive, relevant, and/or recently published.
- EA used the following resource topics as a starting point for search terms (but this list is not exhaustive, some terms were added based on park-specific topics):

- | | |
|---------------------------|--------------------------------------|
| – Surficial features | – Saltwater intrusion |
| – Hydrogeomorphic map | – Sediment transport |
| – Unconsolidated deposits | – Hydrology and Hydrogeology |
| – Storm impacts | – Nearshore/seafloor/benthic habitat |
| – Erosion | – Shoreline evolution |
| – Overwash | – Paleontology/fossils |
| – Breaches | – Land disturbance |
| – Inlet formation | – Seismicity |
| – Sea level rise | – Waves, currents, and tides |
| – Marshes | – Wind |

Spreadsheet Details

Column A, File Name: Each row in this column includes a unique filename identifier that corresponds to a specific PDF file included in the park folder. Each filename begins with the park four-letter identifier, followed by GRI, followed by a number. For example, “FIIS GRI_001”.

Column B, First-level Grouping: One of the following groupings was selected from the list below that matches (as much as possible) the document scope:

- General/Natural Resources
- Geology
- Coastal Processes/Geomorphology
- Habitat
- Engineering

Column C, Date of Publication: This is included separately from the citation for ease of review.

Column D, Citation: Uses a modified APA-style citation format, examples are below.

Example of a journal article:

Schwab, W.C., W.E. Baldwin, C.J. Hapke, E.E. Lentz, P.T. Gayes, J.F. Denny, J.H. List, and J.C. Warner. 2013. Geologic Evidence for Onshore Sediment Transport from the Inner Continental Shelf: Fire Island, New York. *Journal of Coastal Research* Volume 29, Issue 3: pp. 526–544.

Example of an agency report:

US Army Corps of Engineers. 2007. Atlantic Coast of Long Island, Fire Island Inlet to Montauk Point, New York Storm Damage Reduction Reformulation Study, Work Order 28, Inlet Modifications. US Army Corps of Engineers, New York District, North Atlantic Division. 493 pp.

Column E, Short Title/Access: This field is the document title, or a shortened version, and is linked to the PDF file.

Column F, Literature Review Summary: This field is the document abstract (if concise enough) or a few sentences explaining the scope and contents of the document, focusing on geological resources relevance.

Column G, Keywords: This field consists of three to five keywords based on review of the document or keywords identified in the NPS DataStore.

Column H, Notes: This field is optional. For example, if appendices are included as separate files/entries in the literature review.

CACO Literature Review Summary

CACO incorporates 44,600 acres that conserve a rich mosaic of marine, estuarine, fresh water, and terrestrial ecosystems. A total of 31 sources are provided in the literature review for this park, dated from 1962 to 2021. EA developed keywords based on relevant coastal resources included in each reviewed source. They are provided in column G of the spreadsheet and include the following:

- | | | |
|-----------------------------|--|--------------------------|
| ▪ Accretion | ▪ Ecological services | ▪ Radiocarbon dating |
| ▪ Aerial imagery | ▪ Eolian activity | ▪ Random forests |
| ▪ Anthropogenic disturbance | ▪ Eutrophication | ▪ Remote sensing |
| ▪ Aquifer | ▪ Geology | ▪ Restoration |
| ▪ Backscatter imagery | ▪ Geomorphology | ▪ Salt marsh |
| ▪ Bathymetry | ▪ Geographic Information Systems (GIS) | ▪ Salt marsh loss |
| ▪ Benthic | ▪ Glacier | ▪ Salt marsh restoration |
| ▪ Breach | ▪ Greenhouse gas | ▪ Sea level rise |
| ▪ Climate change | ▪ Hurricane disturbance | ▪ Seafloor mapping |
| ▪ Coastal dunes | ▪ Hydrology soils | ▪ Sediment |
| ▪ Coastal geomorphology | ▪ Inlet formation | ▪ Sediment deficit |
| ▪ Coastal processes | ▪ Land use | ▪ Sediment transport |
| ▪ Coastal slope | ▪ Marine geology | ▪ Shoreline |
| ▪ Coastal squeeze | ▪ Marsh health | ▪ Shoreline change rates |
| ▪ Coastal retreat | ▪ Marsh migration | ▪ Soil survey |
| ▪ Community impact | ▪ Marsh resilience | ▪ Soil |
| ▪ Competition | ▪ Plant ecology | ▪ SSURGO |
| ▪ Drilling | | ▪ Storm event |

- Stratigraphic
- Surface elevation table (SET)
- Tidal creek
- Unvegetated to Vegetated Ratio (UVVR)
- Vegetation
- Vegetation cover
- Vulnerability
- Water table
- Wetland

In addition to park-specific literature reviews, a review was completed that includes service wide and regional resources from which multiple parks could benefit. These resources include vulnerability assessment protocols, monitoring protocols, climate change inventories/impacts, sea level rise scenarios/evaluations, coastal hazard assessments, and mapping tools that provide data for all parks, among others. Although all resources are ideally provided as PDF documents, some of these resources are only useful when accessed digitally (e.g., mapping data).

Research and data are continually being published. These literature reviews may not be exhaustive; however, they provide a basis to understand the range of geologic resources in each park, as well as the potential internal guidance documents and resources the National Park Service has. The methodology laid out above can be followed for future searches to update information, if desired.

Geologic Map Assessment

Introduction

Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps, such as coastal or geologic hazard maps, may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

The GRI team compiled Digital Geologic Maps for each of the 13 coastal parks: BISC, CACO, CANA, CASA, CUIS, FIIS, FOCA, FOFR, FOMA, FOPU, FOSU, GATE, and TIMU. As part of, and in parallel with, the GRI literature review process, EA assessed the relevance of the GRI GIS data sets (which are all available on the NPS DataStore; some of which are approaching 20 years old or more) to the current coastal management needs of each park mentioned above. This assessment is based in part on EA's perspective as technical experts well versed in NPS management needs.

Methodology

This work was done without the use of GIS software but instead by reviewing the GRI Scoping Meeting Summary and GRI Ancillary Map information document, both available on the NPS DataStore. For each park, EA's assessment aimed to answer the following questions about the digital geologic map(s) created by GRI:

1. Are the source maps (i.e., the maps that GRI digitized to create the GIS data sets) reasonably comprehensive in terms of features relevant to the coastal park? If not, what gaps are there?
2. Are the source maps recent enough (relative to extreme storms, especially) to accurately represent the park's current configuration?

3. Does an online search yield any maps that are more relevant?

In addition to park-specific literature reviews, a review was completed that includes service-wide and regional resources that multiple parks could benefit from. These resources range from vulnerability assessment protocols to monitoring protocols to climate change inventories/impacts, sea level rise scenarios/evaluations, to coastal hazard assessments, to mapping tools that provide data for all parks. While all resources are ideally provided as pdf documents, some of these resources are only useful when access digitally (for example, mapping data).

It is understood that research and data are continually being published. These literature reviews may not be exhaustive; however, they provide a basis to understand the range of geologic resources in each park as well as the potential internal guidance documents and resources NPS has that can be tapped. The methodology laid out above can be followed for future searches to update information, if desired.

CACO Map Assessment

The information summarized below is based on information presented in the *Cape Cod National Seashore GRE¹ Scoping Meeting Summary* (Graham 2008), the *Cape Cod National Seashore GRI Ancillary Map Information Document* (NPS 2009 and NPS 2024e), and the NPS DataStore page data for the CACO GRI maps produced by GRD (NPS 2009 and NPS 2024e). Information on the CACO GRI maps is presented in table 1.

The scoping meeting summary (Graham 2008) identified a wide range of significant geologic resource management issues in CACO (table 2). Table 2 identifies each of the groups in the first column as well as which of the existing GRI map products provide information on them. If an existing map provides incomplete information, this is indicated in the ‘data gap’ column.

¹ Note that the GRI program was briefly named the Geologic Resource Evaluation (GRE) program. The abbreviations GRI and GRE refer to the same program although products of different vintages may display either of the abbreviations.

Table 1. Summary of GRI Map Products for CACO

GRI Map Product	Citation	Data Layers	Sources
Digital Geologic Map	NPS 2009	– CACOGLG (Geologic Units) – CACOGLGA (Geologic Contacts) – CACOGLF (Geologic Line Features) – CACOMIN (Mine Point Features) – CACOGML (Geologic Measurement Localities) – CACOGSL (Geologic Sample Localities) – CACOGFP (Glacial Feature Points) – CACOSEC (Geologic Cross Section Lines) – CACOMAF (Mine Area Feature Boundaries) – CACOMAF (Mine Area Features) – CACOLIN (Paleoshorelines) – CACOMFL (Mine Feature Lines) – CACOGFL (Glacial Feature Lines) – CACOGOL (Geologic Observation Localities) – CACOGPF (Geologic Point Features) – CACOATD (Geologic Attitude Observation Localities)	The following data was converted to GRI Data Model 2.1 for the Digital Geologic Map of Cape Cod National Seashore: Stone, B.D. and M.L. DiGiacomo. 2009. <i>Surficial geologic map of the Pocasset-Provincetown-Cuttyhunk-Nantucket 24-quadrangle Area of Cape Cod and Islands, Southeast Massachusetts</i>. US Geological Survey, Open-File Report OF-2006-1260-E, 1:24000 scale. (Open-File Report 2006-1260-E). (GRI Source Map 75203). The following maps were used to capture additional features including geologic observations, glacial features, paleo shorelines, and mine features, as well as ancillary map information: Koteff, C., R.N. Oldale, and J.H. Hartshorn. 1967. <i>Geologic Map of the North Truro Quadrangle, Barnstable County, Massachusetts</i>. U.S. Geological Survey, GQ-599, 1:24000 scale. (GQ-599). (GRI Source Map 1608). Oldale, R.N. 1968. <i>Geologic Map of the Wellfleet Quadrangle, Barnstable County, Cape Cod, Massachusetts</i>. US Geological Survey, GQ-750, 1:24,000 scale. (GQ-750). (GRI Source Map 1613). Oldale, R.N. 1970. <i>Geologic Map of the Chatham Quadrangle, Barnstable County, Cape Cod, Massachusetts</i>. US Geological Survey, GQ-911, 1:24,000 scale. (GQ-911). (GRI Source Map 1612). Oldale, R.N., C. Koteff, and J.H. Hartshorn. 1971. <i>Geologic Map of the Orleans Quadrangle, Barnstable County, Cape Cod, Massachusetts</i>. US Geological Survey, GQ-931, 1:24,000 scale. (GQ-931). (GRI Source Map 1614).

GRI Map Product	Citation	Data Layers	Sources
Digital Geologic-GIS Map	NPS 2024e	– CACOATD (Geologic Attitude Observation Localities) – CACOGML (Geologic Measurement Localities) – CACOGOL (Geologic Observation Localities) – CACOGSL (Geologic Sample Localities) – CACOGFL (Glacial Feature Lines) – CACOGLF (Geologic Line Features) – CACOLIN (Paleoshorelines) – CACOGFP (Glacial Feature Points) – CACOGPF (Geologic Point Features) – CACOSEC (Geologic Cross Section Lines) – CACOSUR (Surficial Units) – CACOSURA (Surficial Contacts)	The GRI digital geologic-GIS map was produced from the following source: Geologic Resources Inventory (GRI) program. 2024. Digital Geologic-GIS Map of Cape Cod National Seashore and Vicinity, Massachusetts (NPS, GRD, GRI, CACO, CACO digital map) adapted from a U.S. Geological Survey Open-File Report by Stone and DiGiacomo (2010), and Geologic Quadrangle Maps by Oldale, Koteff and Hartshorn (1971), Oldale (1970), Oldale (1968), and Koteff, Oldale and Hartshorn (1967). National Park Service (NPS) Geologic Resources Inventory (GRI) program. Lakewood, CO.

Table 2. Geologic Resource Management Issues Addressed in Existing GRI Map Products

Geologic Resource Management Issues	Digital Geologic-GIS Map	Data Gap
Coastal Erosion	-	X
Sea Level Rise		X
Climate Change		X
Groundwater/ Sediment Interaction	X	
Seismic Activity		X
Dredging		X
Disturbed lands in need of restoration		X

Geologic Resource Management issues are provided in scoping meeting summary (Graham 2008)

Are the source maps (i.e., the maps that GRI digitized to create the GIS data sets) reasonably comprehensive in terms of features relevant to the coastal park? If not, what gaps are there?

A number of gaps exist in the GRI GIS datasets, relative to the list of park geologic resource management concerns listed above. These gaps include coastal erosion, sea level rise and climate change, seismic activity (earthquakes), dredging, and disturbed lands needing restoration.

The surficial sediment and geologic units present in the GRI Digital Geologic-GIS Map of Map of Cape Cod National Seashore and Vicinity, Massachusetts are (listed from youngest to oldest):

- Qaf – Artificial fill
- Qcb – Cranberry bog
- Qf – Foredune deposits
- Qdp – Parabolic dune
- Qdm – Massive dune
- Qes – Eolian deposits, undifferentiated
- Qd – Dune deposits
- Qb – Beach deposits
- Qbf – Fossil beach deposits
- Qbs – Storm beach deposits
- Qa – Sand apron deposits
- Qs – Marsh and swamp deposits
- Qsu – Sand and gravel, undifferentiated
- Qe – Eastham plain deposits
- Qtr – Truro plain deposits
- Qh – Highland plain deposits
- Qhc – Highland plain deposits, clay at Highland Light
- Qw – Wellfleet plain deposits
- Qw2 – Younger Wellfleet plain deposits
- Qw1 – Older Wellfleet plain deposits
- Ql – Lake deposits
- Qlb – Lake bottom deposits
- Qnh – Nauset Heights outwash deposits
- Qhw – Harwich outwash plain deposits
- Qck – Chatham kame deposits

Are the source maps recent enough (relative to extreme storms, especially) to accurately represent the park's current configuration?

The source maps are dated 1967, 1968, 1970, and 1971, including the 2009 USGS compiled report that sourced maps from 1942 to 1985. The Cape Cod National Seashore has been and is currently being impacted by various storm events. In 2010, CACO facilities suffered from serious storm damage resulting in approximately \$150,000 to \$500,000 worth of damage to dunes, beaches, and access points (NPS 2010). In the NPS Incident Report history for CACO, several major storm events are listed including various storm impacts, winter storm impacts, several large hurricanes, vessel groundings, oil spills, and emergency aircraft landings (NPS 2024b). Based on this information it is likely that most of the data sets do not include information from historic storm and hurricane events that have impacted CACO.

Does an online search yield any maps that are more relevant?

Publicly accessible GIS data sets that fill in some of these data gaps include:

- USGS Earthquakes (USGS 2024) – Shows seismic activity detected by USGS, earthquake catalog allows you to search by time, magnitude, and area.
- Cape Cod Water Resources Restoration Project Map (Cape Code Conservation District 2024) – Cape Cod Conservation District and partners developed a plan to identify 76 sites throughout Cape Cod for possible restoration projects. Several sites are located within the park boundaries.
- Massachusetts Office of Coastal Zone Management – Coastal Erosion Viewer (Massachusetts Office of Coastal Zone Management 2024a) – Includes short- and long-term change transects, and erosion rate data.
 - MORIS (Massachusetts Office of Coastal Zone Management 2024b) – Collection of various interactive maps and data sets including coastal flooding probabilities, bathymetric contours, importing nesting habitats, and marsh data.
- Cape Cod Commission Open Data Hub (Cape Cod Commission 2024a)
 - Cape Cod Sea Level Rise Viewer (Cape Code Commission 2024b)
 - Cape Cod Coastal Planner (Cape Code Commission 2024c) – Includes coastal vulnerability ratings, infrastructure, sea level rise, stormtide pathways, inundation zones, erosion data, and sediment transport indicators.
 - Time Machine (Google Earth Engine and Carnegie Mellon University 2024)

References

Cape Cod Commission

- 2024a “Open Data Hub.” Available online: <https://gis-cccommission.opendata.arcgis.com/>. Accessed March 2024.
- 2024b “Cape Cod Sea Level Rise Viewer.” Available online: <https://slrv.apps.capecodcommission.org/>. Accessed March 2024.
- 2024c “Cape Cod Coastal Planner.” Available online: <https://www.capecodcoast.org/>. Accessed March 2024.

Cape Cod Conservation District

- 2024 “Cape Cod Water Resources Restoration Project Map.” Available online: <https://apcc-atlas.maps.arcgis.com/apps/webappviewer/index.html?id=17b4940a7e9145bcb3a52e35133315e5>. Accessed March 2024.

Google Earth Engine and Carnegie Mellon University

- 2024 “Google Earth Time Lapse: Cape Cod.” Available online: <https://earthengine.google.com/timelapse/#v=41.72724,-70.44859,8.427,latLng&t=0.03&ps=50&bt=19840101&et=20201231&startDwell=0&endDwell=0/>. Accessed March 2024.

Graham, John

- 2008 *Geologic Resource Evaluation Scoping Summary Cape Cod National Seashore, Massachusetts*. Prepared for the Geologic Resources Division. National Park Service. Available online: <https://irma.nps.gov/DataStore/Reference/Profile/2250235>. Accessed February 2026.

Massachusetts Office of Coastal Zone Management (CZM)

- 2024a “Coastal Erosion Viewer.” Available online: <https://experience.arcgis.com/experience/894264afb93f4006920798ca4250b9e8/page/Introduction/>. Accessed March 2024.
- 2024b “Massachusetts Ocean Resource Information System (MORIS).” Available online: <https://czm-moris-mass-eoea.hub.arcgis.com/>. Accessed March 2024.

National Park Service (NPS)

- 2009 “Digital Geologic Map of Cape Cod National Seashore and Vicinity, Massachusetts (NPS, GRD, GRI, CACO, CACO digital map).” NPS Geologic Resources Inventory Program. Lakewood, Colorado. Available online: <https://irma.nps.gov/DataStore/Reference/Profile/1048646>. Accessed February 2026.
- 2010 “Cape Cod National Seashore Facilities Suffer Serious Storm Damage.” Available online: <https://www.nps.gov/caco/learn/news/cape-cod-national-seashore-facilities-suffer-serious-storm-damage.htm>. Accessed March 2024.
- 2013 “Coastal Engineering Projects Inventory.” National Park Service, Natural Resource Stewardship and Science. Available online: <https://irma.nps.gov/DataStore/Reference/Profile/2193512>. Accessed March 2024.
- 2022 “Shoreline Change Project.” National Park Service, Natural Resource Stewardship and Science. Available online: <https://irma.nps.gov/DataStore/Collection/Profile/9272>. Accessed March 2024.
- 2023a “Thematic Paleontological Resource Inventories.” Available online: <https://www.nps.gov/subjects/fossils/thematic-inventories.htm>. Accessed March 2024.
- 2023b “I&M Network Based Paleontological Resource Inventories.” Available online: <https://www.nps.gov/subjects/fossils/network-surveys.htm>. Accessed March 2024.
- 2024a “Geologic Resources Inventory—Products.” National Park Service, Geologic Resources Division. Available online: <https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm>. Accessed March 2024.

- 2024b “Park-specific Paleontological Resource Inventory Reports.” Available online: <https://www.nps.gov/subjects/fossils/park-surveys.htm>. Accessed March 2024.
- 2024c “NPS Datastore, Integrated Resource Management Applications”. National Park Service, Natural Resource Stewardship and Science. Available online: <https://irma.nps.gov/DataStore/Search/Advanced>. Accessed July 2024.
- 2024d “Cape Cod Incidents.” Available online: <http://npshistory.com/morningreport/incidents/caco.htm>. Accessed March 2024. National Park Service (NPS).
- 2024e “Digital Geologic-GIS Map of Cape Cod National Seashore and Vicinity, Massachusetts (NPS, GRD, GRI, CACO, CACO digital map) adapted from a U.S. Geological Survey Open-File Report by Stone and DiGiacomo (2010), and Geologic Quadrangle Maps by Oldale, Koteff and Hartshorn (1971), Oldale (1970), Oldale (1968), and Koteff, Oldale and Hartshorn (1967).” NPS Geologic Resources Inventory Program. Lakewood, Colorado. Available online: <https://irma.nps.gov/DataStore/Reference/Profile/2305669>. Accessed February 2026.

US Geological Survey (USGS)

- 2024 “Earthquake Catalog.” Available online: <https://earthquake.usgs.gov/earthquakes/search/>. Accessed March 2024.