National Park Service
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Natural Resource Stewardship and Science

Coastal Hazards Asset Vulnerability Assessment for Apostle Islands National Lakeshore

Summary of Results

NPS 633/199499, May 2026

PROGRAM FOR THE STUDY OF DEVELOPED SHORELINES

Western Carolina UNIVERSITY

ON THE COVER
Photograph of Sand Island light station and related buildings at Apostle Islands National Lakeshore
Photo credit: Program for the Study of Developed Shorelines

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Program for the Study of Developed Shorelines
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Executive Summary

This document presents the results of the **Coastal Hazards Asset Vulnerability Assessment (VA)** completed by Western Carolina University at Apostle Islands National Lakeshore (APIS) in 2025. In this VA, we evaluate the vulnerability (as a combination of exposure and sensitivity) of NPS buildings and transportation assets[1] to identified coastal hazards and climate change factors, approximately to the year 2050.

We assessed 150 buildings/structures (offices, housing, maintenance buildings, vaults, cabins, historical buildings, lighthouses, and an amphitheater), and 77 transportation assets (roads, trails, parking lots, marinas/docks/piers, and tramways) at APIS, which are located on the mainland and sixteen islands within the park. Less than half (41%) of assets analyzed have high or moderate vulnerability to the evaluated coastal hazards. One-sixth (16%) have low vulnerability, while the majority (43%) have minimal vulnerability (are not in any of the evaluated hazard zones). Data sources, definitions, scoring details and results for all assets evaluated at APIS are reported in the provided Excel sheets and GIS layers.

Exposure Methodology

Exposure is a measure of the character, magnitude, and rate of changes a target may experience (e.g., from the impacts of natural hazards or climate change; NPS 2021). The Great Lakes experience a wide array of coastal hazards. In this VA, we evaluate the exposure of each asset to the following coastal hazard indicators: flooding potential, shoreline change, lake-level rise, extreme event flooding, and reported coastal hazards (Table 1).

We adapted the methodology originally developed for NPS infrastructure on ocean coastlines (Peek et al. 2022) to evaluate exposure in this Great Lakes coastal VA. We evaluated three exposure indicators directly following methods described in Peek et al. (2022): flooding potential, shoreline change, and reported coastal hazards (Table 1). We evaluated two exposure indicators (lake-level rise and extreme event flooding; Table 1) unique to the Great Lakes, and used the modified methods described below.

[1] The NPS Facility Management Software System (FMSS) database defines assets as "...a physical structure or grouping of structures, land features, or other tangible property that has a specific service or function, such as a farm, cemetery, campground, marina, or sewage treatment plant. The term 'asset' shall also be applied to movable items, such as vehicles and equipment."

Table 1. APIS exposure indicators and hazard data sources.

Exposure Indicator (Description)	Data (Citation)
Flooding potential (1% annual-chance)	Bayfield Co: effective FEMA VE & A zones (FEMA 2011) *Ashland Co: 2019 USACE LiDAR (OCM Partners 2024a) 2019 USGS LiDAR (OCM Partners 2024b; 2024c)
Shoreline change (coastal proximity)	30m and 60m shoreline proximity buffer (Peek et al. 2022) USGS Coastal Change Potential (Pendelton et al., 2006) 2020 NAIP imagery (OCM Partners 2024e)
Lake-level rise	2019 USACE LiDAR (OCM Partners 2024a) 2019 USGS LiDAR (OCM Partners 2024b; 2024c) 2022 USGS LiDAR (OCM Partners 2024d) 2020 NAIP imagery (OCM Partners 2024e)
Extreme event flooding (storms, gales, seiches)	2019 USACE LiDAR (OCM Partners 2024a) 2019 USGS LiDAR (OCM Partners 2024b; 2024c) 2022 USGS LiDAR (OCM Partners 2024d)
Reported coastal hazards (historic flooding)	Questionnaire results & discussions (Peek et al. 2022)

*See Unique Considerations

Lake-Level Rise Inundation Indicator

The U.S. Army Corps of Engineers has recorded lake levels for each of the Great Lakes back to 1918 (USACE 2024). The lowest lake level for Lake Superior was 599.5 feet in 1926 and the highest level was 603.4 feet in 1985; since 1918, the lake level has fluctuated within this 4-foot range. At APIS, periods of lower lake levels tend to have little to no hazardous impact on NPS infrastructure. In contrast, rising lake levels typically increase erosion of the shoreline and coastal bluffs, and expand areas impacted by floods and rising groundwater.

For the lake-level rise exposure indicator, we used a modified bathtub approach to define a lake-level rise inundation zone, which highlights areas within 10 feet elevation of the highest recorded shoreline on Lake Superior (603.4 feet). This lake-level rise hazard zone is intended to capture areas that may be impacted by flooding, rising groundwater, and expanded wetlands during the highest lake levels, in the context of the historical range.

We derived the lake-level rise hazard zone by highlighting values between 603.5 feet (183.9 meters) and 613.5 feet (187 meters) on four LiDAR datasets: a 2019 U.S. Army Corps of Engineers DEM on the mainland (OCM Partners 2024a); two 2019 U.S. Geological Survey DEMs on all islands except Raspberry (OCM Partners 2024b; 2024c); and a 2022 U.S. Geological Survey DEM on Raspberry Island (OCM Partners 2024d). We subsequently verified the lake-level rise zone throughout the park by comparison to the 2020 imagery (OCM Partners 2024e), noting wetlands that expanded during the record high lake levels, as well as historical flooding reports from the park staff.

Extreme Event Flooding Indicator

The Great Lakes coasts are subject to a range of extreme flooding events including storms, gales, wind-driven high water, and seiches. Seiches are temporary fluctuations or oscillations in lake level (standing waves) typically caused by atmospheric disturbances crossing the Great Lakes. The town of Ashland, Wisconsin has experienced two historical seiche events notable for APIS: a 3.5-foot rise in July 1935 and a 2.6-foot rise in June 2025.

For the extreme event flooding indicator, we used a modified bathtub approach to delineate areas within four feet elevation of the highest recorded shoreline on Lake Superior (603.4 feet). The value of four feet was based on flood levels reported from the two Ashland seiche events. We derived the extreme event flooding zone by highlighting values between 603.5 feet (183.9 meters) and 607.5 feet (185.2 meters) on four LiDAR datasets: a 2019 U.S. Army Corps of Engineers DEM on the mainland (OCM Partners 2024a); two 2019 U.S. Geological Survey DEMs on all islands except Raspberry (OCM Partners 2024b; 2024c); and a 2022 U.S. Geological Survey DEM on Raspberry Island (OCM Partners 2024d). This extreme event flood hazard zone is intended to capture areas that may be impacted by flooding and seiche events associated with severe storms, gales, and wind-driven high water.

Exposure Scoring

Exposure indicator scoring followed the methods outlined in Peek et al. (2022). Assets with high exposure are within at least four exposure indicator hazard zones. Assets with moderate exposure are within two or three exposure indicator hazard zones. Assets with low exposure are within only one exposure indicator hazard zone. Low exposure assets could still be seriously impacted by this hazard. Assets with minimal exposure are not in any exposure indicator hazard zone. Minimal exposure does not mean that the asset has no exposure to coastal hazards, but it is not within the hazard data used in this study.

Exposure Results

Fifty-one assets (22%) analyzed at APIS have high exposure to the evaluated coastal hazards (Table 2, and Figures 1-6). Roughly equal percentages of assets have moderate (18%) and low (17%) exposure. Nearly half the assets at APIS (43%) have minimal exposure to the evaluated coastal hazards. Thirty-seven assets (nine buildings, 28 transportation) are within all evaluated exposure zones, including all waterfront and dock systems; the Chequamegon Point Lighthouse; Ashland Harbor Breakwater Light; the boathouses on Devils and Raspberry islands; three Benson family buildings on Rocky Island; the Hokenson Herring Shed and Privy at Little Sand Bay; and multiple trail segments on Oak, Stockton, Outer, Rocky, Raspberry, and Sand islands.

Table 2. APIS exposure results. Sum of percentages may not equal 100 due to rounding.

	High Exposure		Moderate Exposure		Low Exposure		Minimal Exposure		Total
Assets	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**
Buildings	15	10%	36	24%	31	21%	68	45%	150
Transportation	36	47%	4	5%	8	10%	29	38%	77
All Assets	51	22%	40	18%	39	17%	97	43%	227

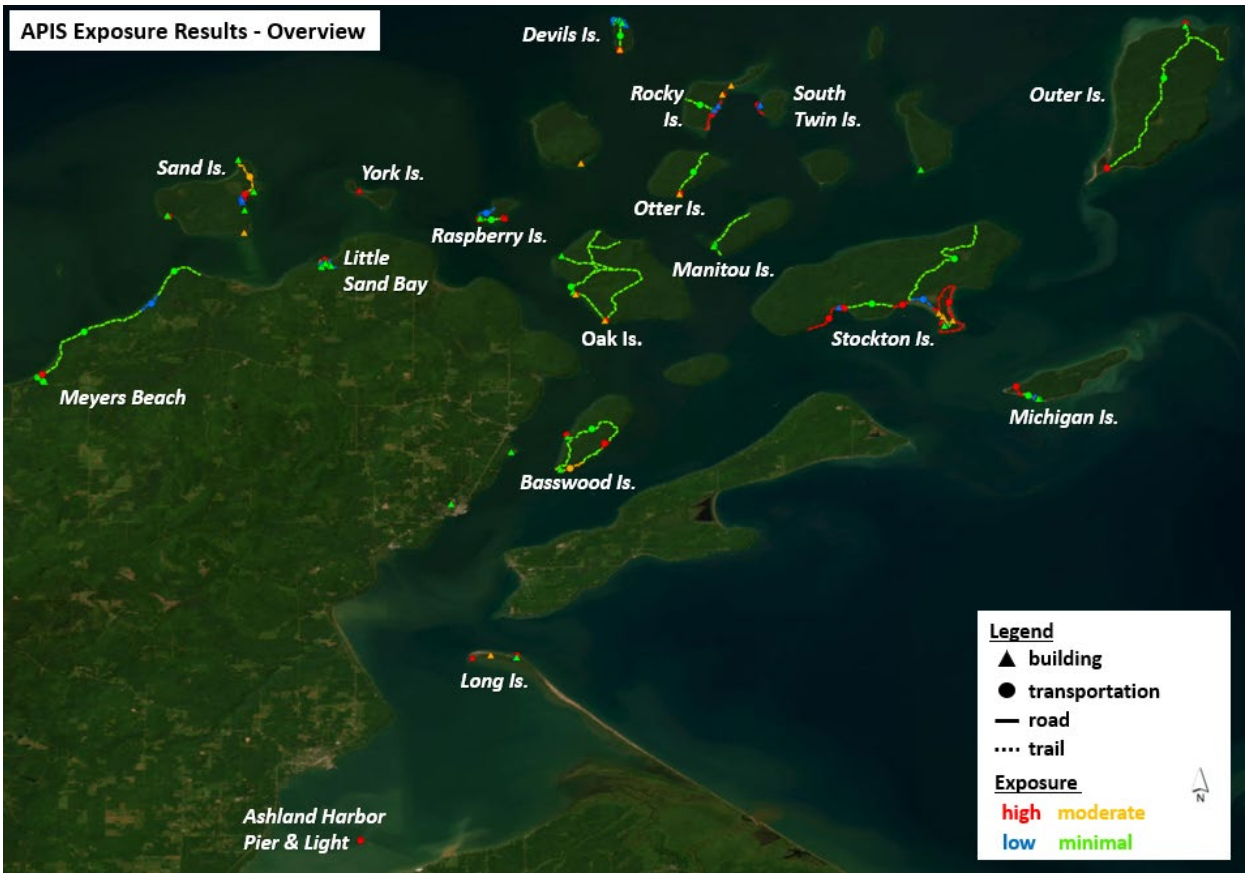

Figure 1. APIS exposure results summary. Only areas with high exposure assets are labeled. Background map is ESRI streaming imagery.

Figure 2. Exposure results summary for western areas of APIS. Only high exposure assets are labeled. Background map is ESRI streaming imagery.

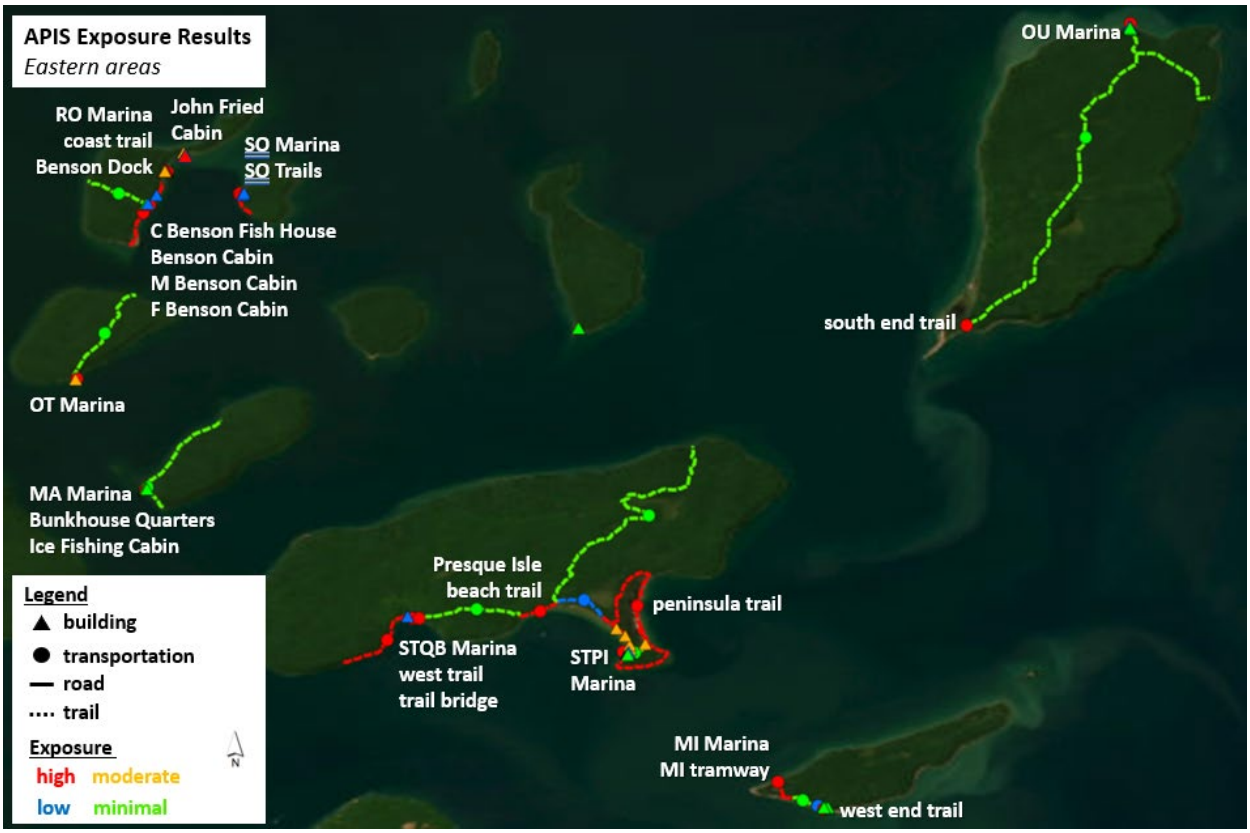

Figure 3. Exposure results summary for eastern areas of APIS. Only high exposure assets are labeled. Background map is ESRI streaming imagery.

Figure 4. Exposure results summary for select western areas of APIS. Only high exposure assets are labeled. Background map is ESRI streaming imagery.

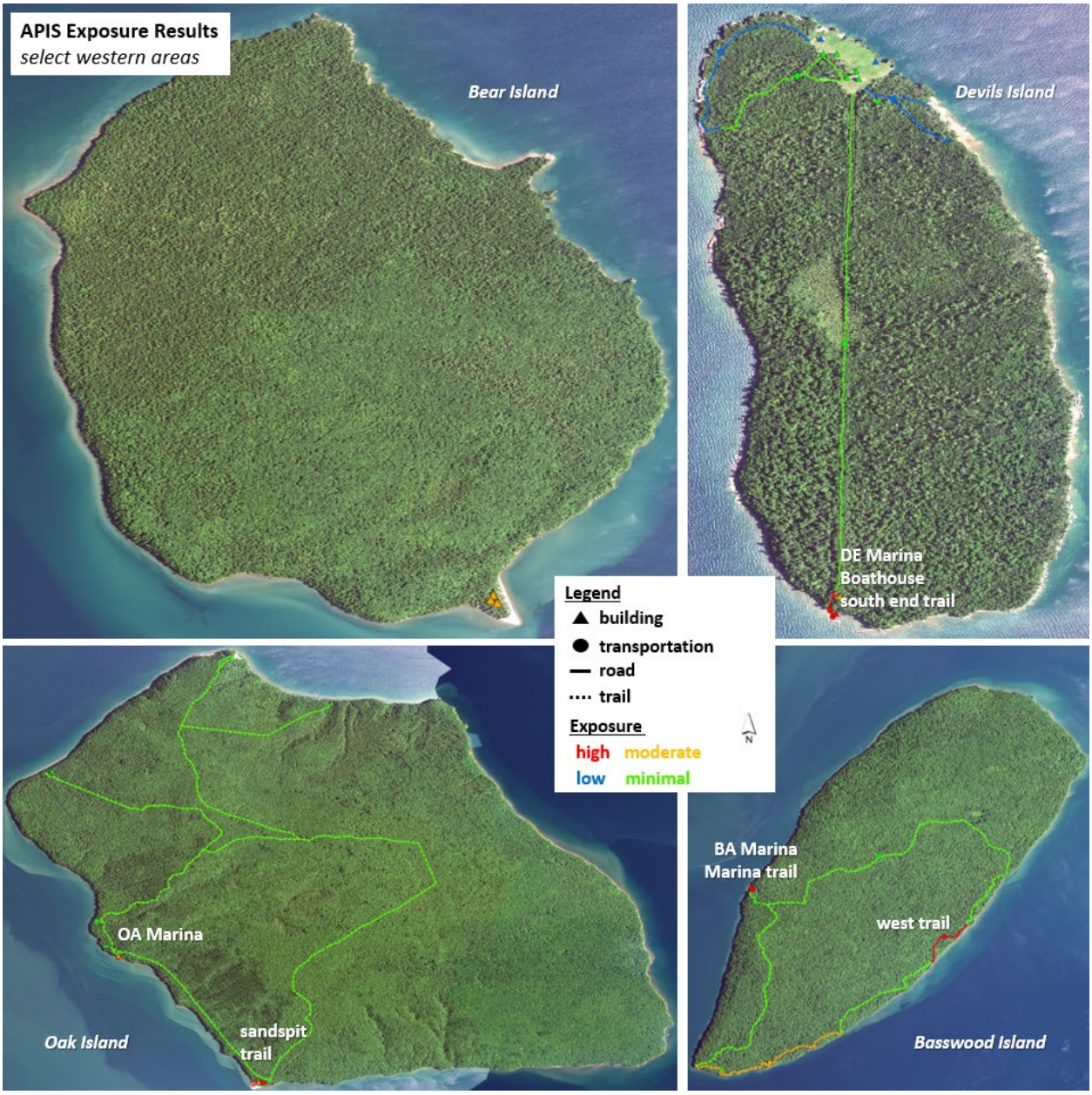

Figure 5. Exposure results summary for select western areas of APIS. Only high exposure assets are labeled. Background map is ESRI streaming imagery.

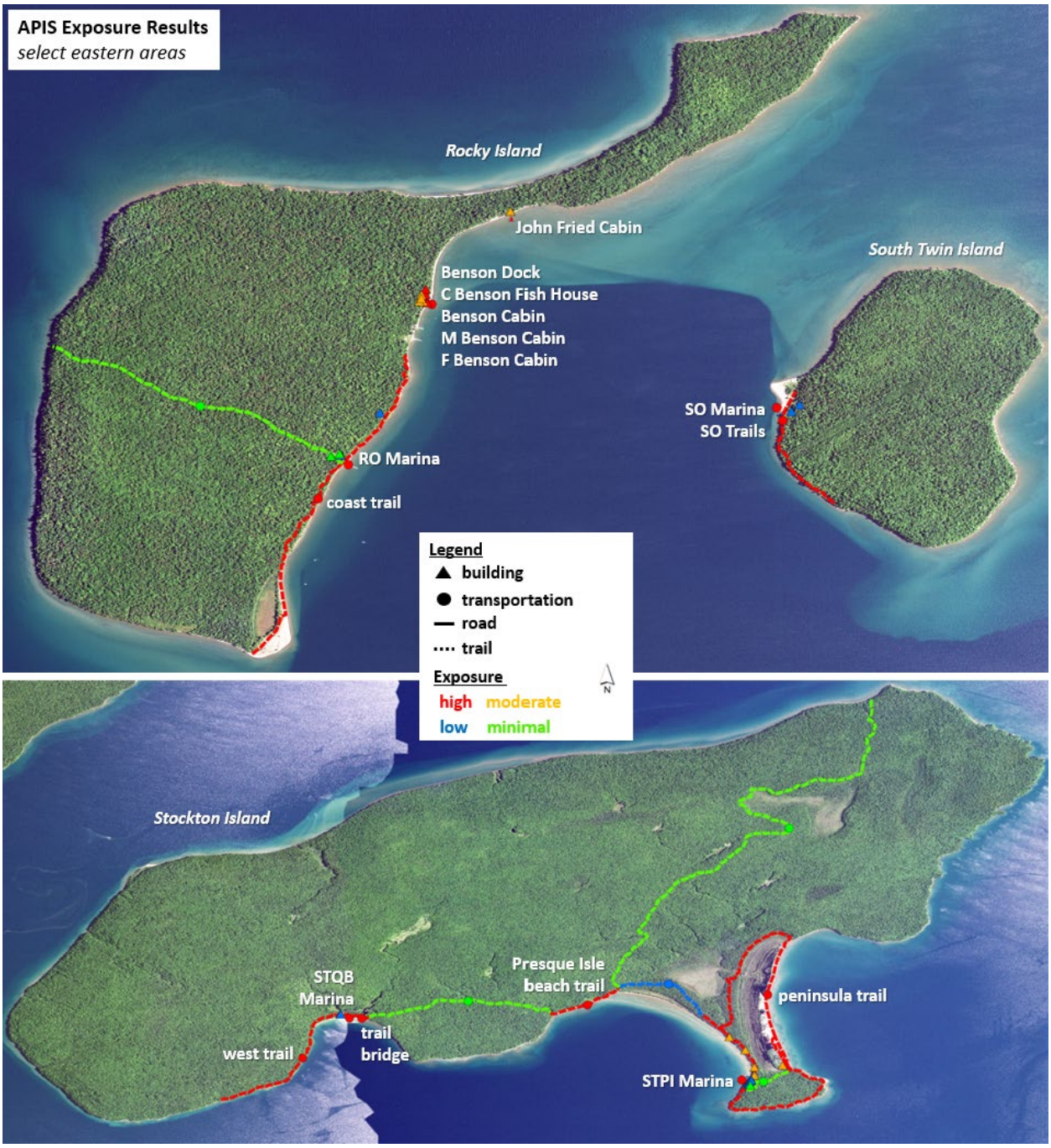

Figure 6. Exposure results summary for select eastern areas of APIS. Only high exposure assets are labeled. Background map is ESRI streaming imagery.

Sensitivity Results

Sensitivity reflects the degree to which a resource is affected by exposure (NPS 2021). In this VA, we assess the following sensitivity indicators: flood damage potential, condition and storm resistance, historic damage, and protective engineering. In general, assets with high sensitivity have unfavorable determinations for three or four of these indicators, moderate-sensitivity assets have unfavorable determinations for two indicators, and low-sensitivity assets have unfavorable determinations for zero or one indicator. Assets with minimal exposure are not analyzed for sensitivity (this is the case for 97 assets at APIS).

The majority (75%) of assets analyzed at APIS have moderate sensitivity to coastal hazards (Table 3). One-quarter (25%) have high sensitivity, and none have low sensitivity. Most high sensitivity assets have been damaged by coastal flooding in the past. The assets are in good condition, but are not significantly elevated above local ground level, storm resistant, or protected by engineering. Sixteen assets received an unfavorable rating for all sensitivity indicators: the John Fried Cabin on Rocky Island; Boat House and Campsite Vault on Devils Island; Hansen Ice House, Hansen Boar's Nest, Hansen Twine Storage Shed, West Bay Lodge, and Ice House on Sand Island; Ashland Harbor Breakwater Light; Quarry Bay Trail Bridge on Stockton Island; and marinas/waterfronts at Little Sand Bay and Outer, South Twin, Otter, Devils, and Sand islands.

Table 3. APIS sensitivity results. Sum of percentages may not equal 100 due to rounding.

	High Sensitivity		Moderate Sensitivity		Low Sensitivity		Total Analyzed	Excluded*
Assets	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**#**
Buildings	19	23%	63	77%	0	0%	82	68
Transportation	14	29%	34	71%	0	0%	48	29
All Assets	33	25%	97	75%	0	0%	130	97

*Minimal exposure assets were excluded from the sensitivity analysis; total number analyzed is different for sensitivity.

Vulnerability Results

Vulnerability is a measure of the degree to which park resources and assets are "susceptible to harm from direct and indirect effects of climate change, including variability and extremes" (NPS 2021). In this VA, we evaluate the vulnerability of infrastructure assets as a simple combination of exposure and sensitivity ratings. It should be noted that the vulnerability of any asset can change with time (e.g., due to adaptation actions or the result of geomorphic change).

Less than half of assets at APIS have high (28%) or moderate (13%) vulnerability to the evaluated coastal hazards (Table 4, and Figures 7-12). Nineteen assets have both high exposure and high sensitivity: Chequamegon Point Lighthouse; John Fried Cabin on Rocky Island; boathouses on Devils and Raspberry islands; Campsite Vault on York Island; Hokenson Privy; Ashland Harbor Breakwater Light; south sand spit trails on Oak Island; Quarry Bay Trail Bridge on Stockton Island; and marinas/waterfronts at Little Sand Bay and Michigan, Outer, Long, South Twin, Otter, Devils, Raspberry, and Sand islands. Twenty-two assets have both high vulnerability and a high asset priority index (API ≥ 70, as reported in FMSS) including the Bunkhouse Quarters, Governors Cabin, and Camp Ice Fishing Cabin on Manitou Island; Chequamegon Point Lighthouse; boathouses on Devils and Raspberry islands; Hansen Boar's Nest and Twine Storage Shed on Sand Island; Hokenson Herring Shed; Ashland Harbor Breakwater Light and Pier; trail segments on Oak, Stockton, and Sand islands; and marinas/waterfronts at Little Sand Bay and Michigan, Outer, Devils, and Raspberry islands. Sixteen percent of assets have low vulnerability, while nearly half (43%) have minimal vulnerability.

Table 4. APIS vulnerability results. Sum of percentages may not equal 100 due to rounding.

	High Vulnerability		Moderate Vulnerability		Low Vulnerability		Minimal Vulnerability		Total
Assets	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**
Buildings	27	18%	24	16%	31	21%	68	45%	150
Transportation	36	47%	6	8%	6	8%	29	38%	77
All Assets	63	28%	30	13%	37	16%	97	43%	227

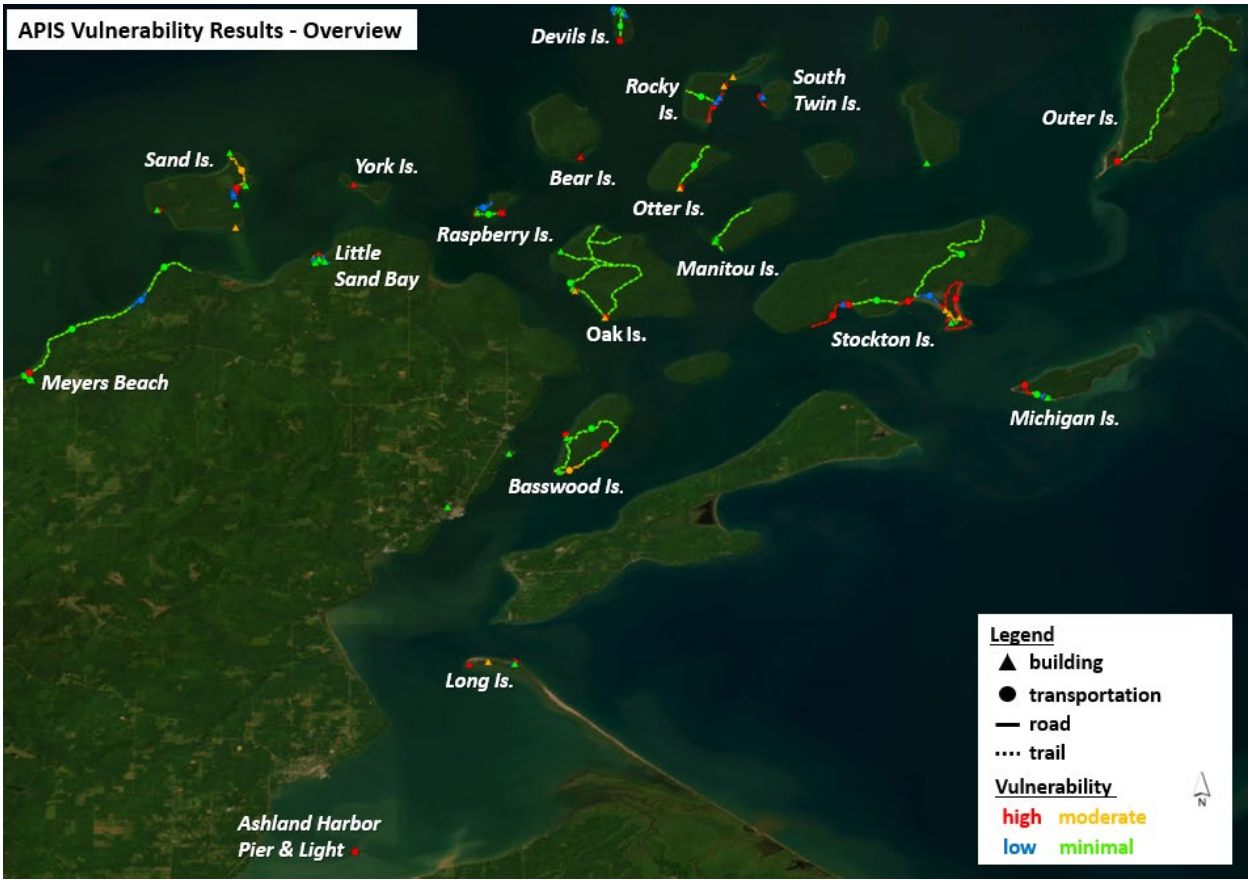

Figure 7. APIS vulnerability results summary. Only areas with high vulnerability assets are labeled. Background map is ESRI streaming imagery.

Figure 8. Vulnerability results summary for western areas of APIS. Only high vulnerability assets are labeled. Background map is ESRI streaming imagery.

Figure 9. Vulnerability results summary for eastern areas of APIS. Only high vulnerability assets are labeled. Background map is ESRI streaming imagery.

Figure 10. Vulnerability results summary for select western areas of APIS. Only high vulnerability assets are labeled. Background map is ESRI streaming imagery.

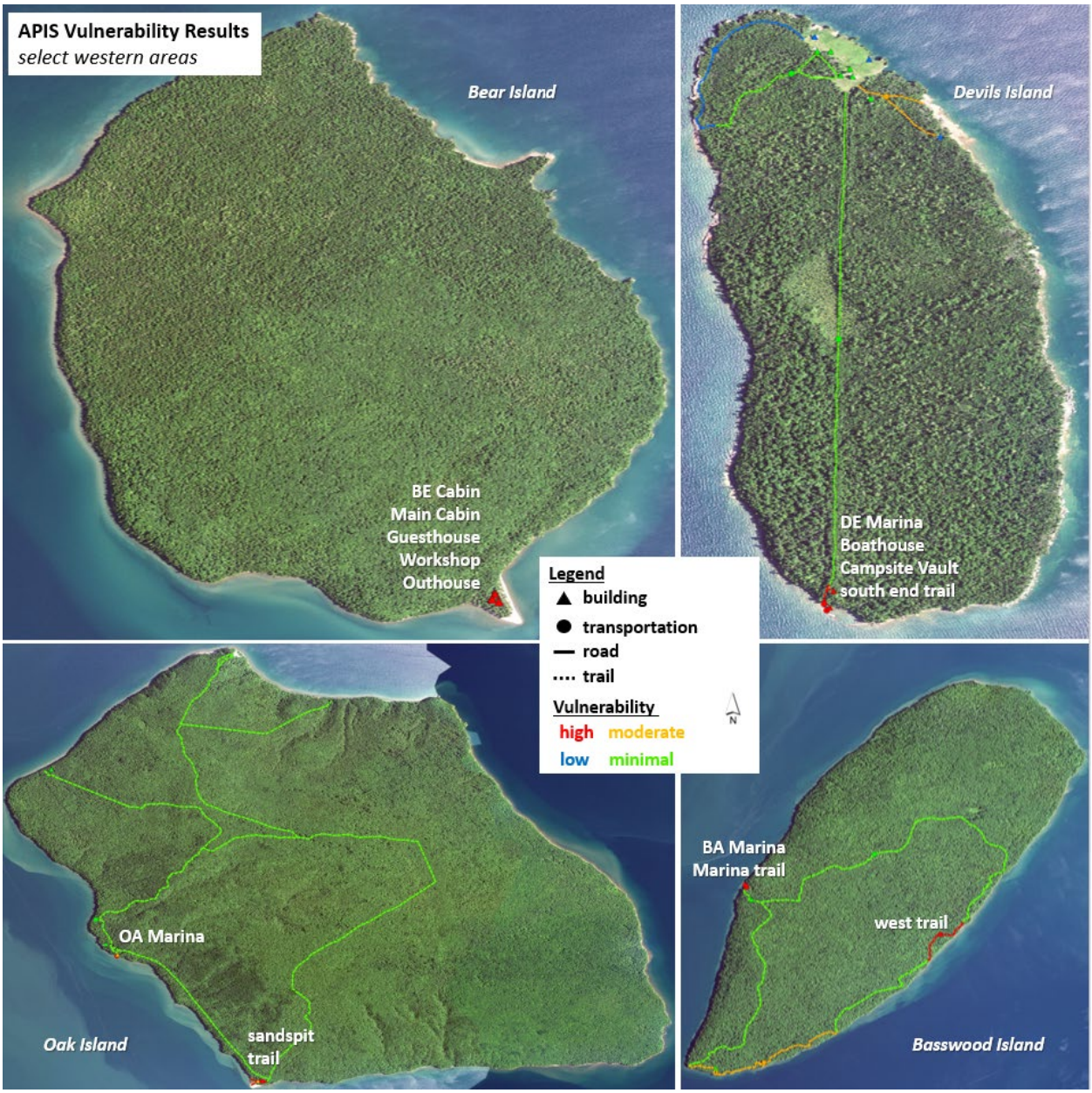

Figure 11. Vulnerability results summary for select western areas of APIS. Only high vulnerability assets are labeled. Background map is ESRI streaming imagery.

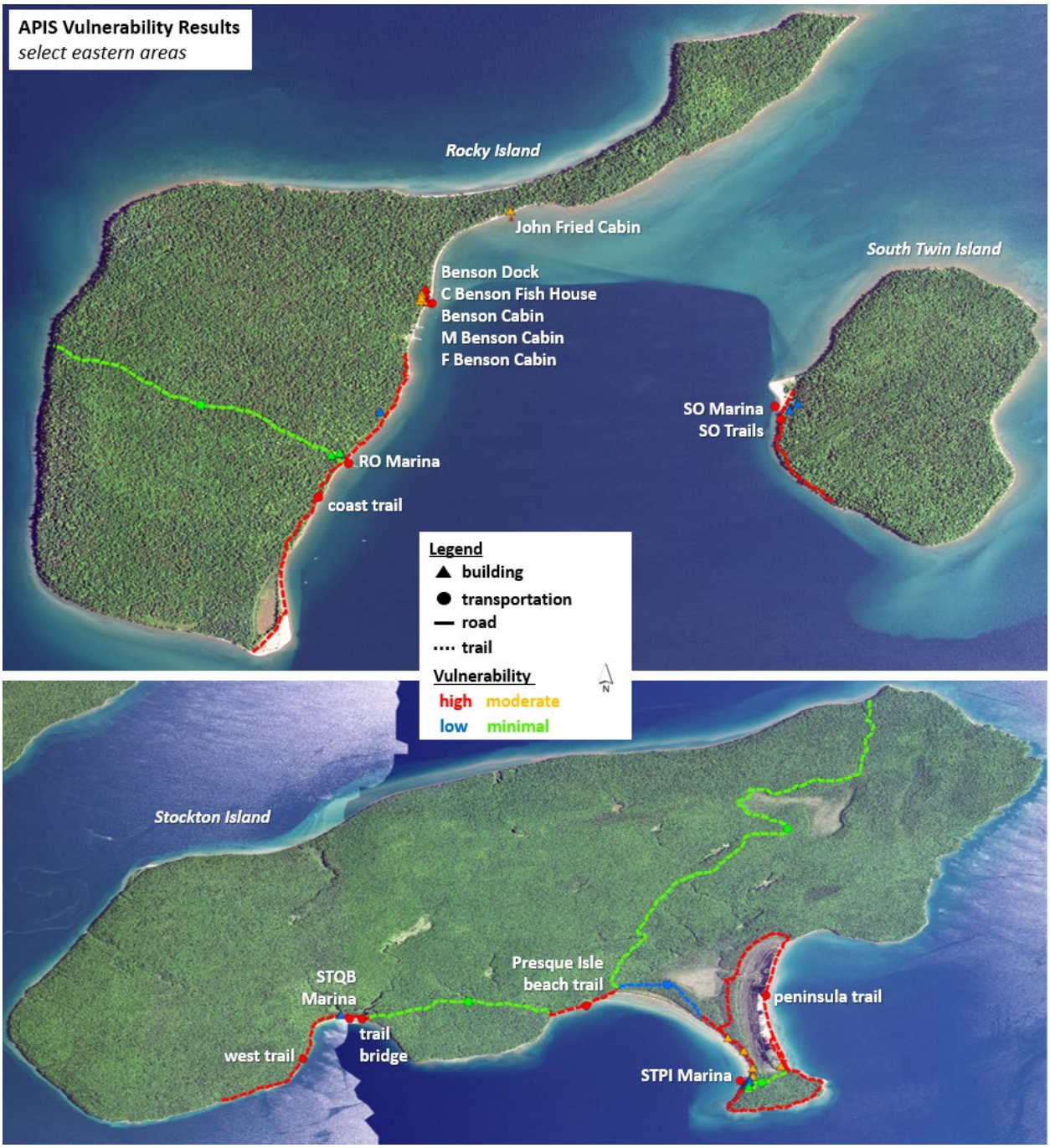

Figure 12. Vulnerability results summary for select eastern areas of APIS. Only high vulnerability assets are labeled. Background map is ESRI streaming imagery.

APIS Unique Considerations

Non-FMSS assets: At the request of the park, we evaluated four assets not individually listed in FMSS: Quarry Bay Trail Bridge; Michigan Island Tramway; Raspberry Island Tramway; Little Sand Bay Icehouse Tramway. Within FMSS, each of these is listed as a component of another asset (specifically an asset to a location) but serve critical functions. All statistics in the results and within this report include these assets.

Flooding Potential: We used effective FEMA data from 2011 for Bayfield County (FEMA 2011). FEMA data are not available for Ashland County; therefore, we created a flood zone based on FEMA's base flood elevation (BFE) of 605 feet in adjacent Bayfield County. We derived this zone from several 2019 LiDAR datasets (OCM Partners 2024a; 2024b; 2024c), highlighting values between 603.5 feet (183.9 meters) and 605 feet (184.4 meters). This flood zone was verified using 2020 high lake-level imagery, wetlands maps, as well as historical flooding reports from the park.

Lake-level rise: Lake-level rise is a fundamentally different exposure indicator for the Great Lakes VA protocol (herein) than the sea-level rise (SLR) indicator used in the ocean coastal VA protocol (Peek et al. 2022). SLR projections are well-modeled and have predictable long-term trends in response to climate change. There are no comparable long-term projections for future lake-levels, and the controls on lake-level fluctuations are poorly understood and highly variable. Instead, we use USACE historical lake-level data, with a margin of error added on for planning purposes.

Shoreline change: We derived the erosion buffer zone from the classification of relative coastal change potential developed for APIS by the U.S. Geological Survey (Pendelton et al., 2006). They cited erosion rates of 0-2 m/yr for coasts classified as low and moderate coastal change potential, and >2m/yr for coasts classified as high to very high (Pendelton et al. 2006). Thus, a coastal proximity zone of 30 meters was used for areas with low and moderate coastal change potential, and 60 meters for high to very high coastal change potential. The reference shoreline for the erosion buffer zone was digitized from the highest recorded shoreline on Lake Superior (603.4 feet above NADV88) using 2020 imagery (OCM Partners 2024e).

Linear assets: We segmented ten trails at APIS due to length and exposure variability: Oak Island (south sand spit and inland); Basswood Island (marina, inland, south, and west); Stockton Island (Quarry Bay west, Quarry Bay inland, Presque Isle beach, Presque Isle inland, peninsula, peninsula inland, and cross island); Michigan Island (west end, inland, and lighthouse area); Outer Island (south end and inland); Rocky Island (coast and cross island); Devil's Island (north loop coast, north loop inland, lighthouse to tram, cross island, and south end); Raspberry Island (cross island and sand spit); Sand Island (cross island and East Bay); and Mainland (Myers Beach to ravine, ravine to Menard Rd creeks, Menard Rd creeks, and Menard Rd creeks to Sand Pt Rd). We evaluated each segment individually for exposure, sensitivity, and vulnerability, and assigned each segment a modified location code (segments share the same FMSS attributes).

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