National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

# Coastal Hazards Asset Vulnerability Assessment for Sleeping Bear Dunes National Lakeshore

*Summary of Results*

NPS 634/195672, January 2025

PROGRAM FOR THE STUDY OF DEVELOPED SHORELINES

Western Carolina University

**ON THE COVER**
Photograph of South Manitou Island lighthouse and related buildings at Sleeping Bear Dunes National Lakeshore
Photo credit: Program for the Study of Developed Shorelines

# Coastal Hazards Asset Vulnerability Assessment for Sleeping Bear Dunes National Lakeshore

*Summary of Results*

NPS 634/195672, January 2025

Program for the Study of Developed Shorelines
Western Carolina University
Cullowhee, North Carolina 28723

*This document has been developed by the NPS Climate Change Response Program and Park Facilities Management Division in partnership with Western Carolina University through a Task Agreement with the Southern Appalachian Cooperative Ecosystems Studies Unit.*

Please cite this publication as:

Tormey, B.R., K.M. Peek, H.L. Thompson, and R.S. Young. 2025. Coastal Hazards Asset Vulnerability Assessment for Sleeping Bear Dunes National Lakeshore: Summary of Results. NPS 634/195672. Program for the Study of Developed Shorelines, Western Carolina University, Cullowhee, N.C.

# Executive Summary

This document presents the results of the **Coastal Hazards Asset Vulnerability Assessment (VA)** completed by Western Carolina University at Sleeping Bear Dunes National Lakeshore (SLBE) in 2024. 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 371 buildings/structures (offices, housing, maintenance buildings, campground and picnic buildings, amphitheaters, historical buildings, and a lighthouse), and 106 transportation assets (roads, trails, parking lots, docks, boat launches, and a covered bridge) at SLBE, which are located on the mainland, North Manitou Island (NMI), and South Manitou Island (SMI). Less than one-fifth (16%) of assets analyzed have high or moderate vulnerability to the evaluated coastal hazards. The majority (72%) have minimal vulnerability (are not in any of the evaluated hazard zones). Data sources, definitions, scoring details and results for all assets evaluated at SLBE 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 climate change or a natural hazard influenced by 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).

The methods used to evaluate exposure in this Great Lakes coastal VA were adapted from the methodology originally developed for NPS infrastructure on ocean coastlines (Peek et al. 2022). Three exposure indicators were evaluated directly following methods described in Peek et al. (2022): flooding potential, shoreline change, and reported coastal hazards (Table 1). Two exposure indicators (lake-level rise and extreme event flooding; Table 1) evaluated hazards unique to the Great Lakes and were assessed using 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.** Exposure indicators and hazard data sources used.

| Exposure Indicator (Description) | SLBE Data (Citation) |
|---|---|
| Flooding potential (1% annual-chance) | Effective FEMA VE & A zones (FEMA 2018; 2021) |
| Shoreline change (coastal proximity) | 30-m shoreline proximity buffer (Peek et al. 2022), Long-Term Rate of Shoreline Change (MI Tech 2023), High-risk erosion areas (MI EGLE 2024), USGS Slope Inventory (Ashland 2022a; 2022b), 2020 imagery (OCM Partners 2024b) |
| Lake-level rise | 2015 LiDAR; 2020 imagery (OCM Partners 2024a; 2024b) |
| Extreme event flooding (storms, gales, seiches) | 2015 LiDAR (OCM Partners 2024a) |
| Reported coastal hazards (historic flooding) | Questionnaire results & discussions (Peek et al. 2022) |

*See Unique Considerations

## Lake-Level Rise Inundation Indicator

The Army Corps of Engineers has recorded lake levels for each of the Great Lakes back to 1918 (USACE 2024). The lowest lake level for Michigan-Huron was 576 feet in 2013 and the highest level was 582.4 feet in 2020; since 1918, the lake level has fluctuated within this 6-foot range. At SLBE, 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 Michigan (582.4 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 582 feet (177.3 meters) and 592 feet (180.4 meters) on the 2015 LiDAR (OCM Partners 2024a). We subsequently verified the lake-level rise zone throughout the park by comparing it with 2020 imagery (OCM Partners 2024b) 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. In May 2019, the town of Leland, Michigan was inundated by a seiche event that lasted 4 hours and flooded waterfront businesses with several feet of water. This event is the most recent seiche on record for the SLBE vicinity.

For the extreme event flooding indicator, we used a modified bathtub approach to delineate areas within 3 feet elevation of the highest recorded shoreline on Lake Michigan (582.4 feet). The value of 3 feet was based on flood levels reported from the Leland seiche. We derived the extreme event flooding zone by highlighting values between 582 feet (177.3 meters) and 585 feet (178.3 meters) on the 2015 LiDAR (OCM Partners 2024b). 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

Scoring of exposure indicators 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. The asset could still be seriously impacted by any single hazard. Assets with minimal exposure are not in any exposure indicator hazard zone. This does not mean that the asset has no exposure to coastal hazards, but it is not within the exposure hazard data used in this study.

## Exposure Results

Only thirteen assets (3%) analyzed at SLBE have high exposure to the evaluated coastal hazards (Table 2): Miller Boathouse, Platte Plains Trail (Otter Lake Loop), El Dorado Boat Launch System, Platte Point Parking Areas, North Bar Lake Boat Launch System, the USLSS Dwelling, Benth Johnson House, USLSS Boathouse #1 and Launchway, USLSS Boathouse #2, SMI Tour Road (Village segments), and the SMI, NMI, and Leland dock systems. Roughly equal percentages of assets have moderate (13%) and low (12%) exposure. The majority of assets at SLBE (72%) have minimal exposure to the evaluated coastal hazards. Five assets are within all evaluated exposure zones, including the Miller Boathouse, North Bar Lake Boat Launch System, and the SMI, NMI, and Leland dock systems.

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

| | High Exposure | | Moderate Exposure | | Low Exposure | | Minimal Exposure | | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Assets** | **#** | **%** | **#** | **%** | **#** | **%** | **#** | **%** | **#** |
| Buildings | 5 | 1% | 38 | 10% | 40 | 11% | 288 | 78% | 371 |
| Transportation | 8 | 8% | 22 | 21% | 19 | 18% | 57 | 54% | 106 |
| All Assets | 13 | 3% | 60 | 13% | 59 | 12% | 345 | 72% | 477 |

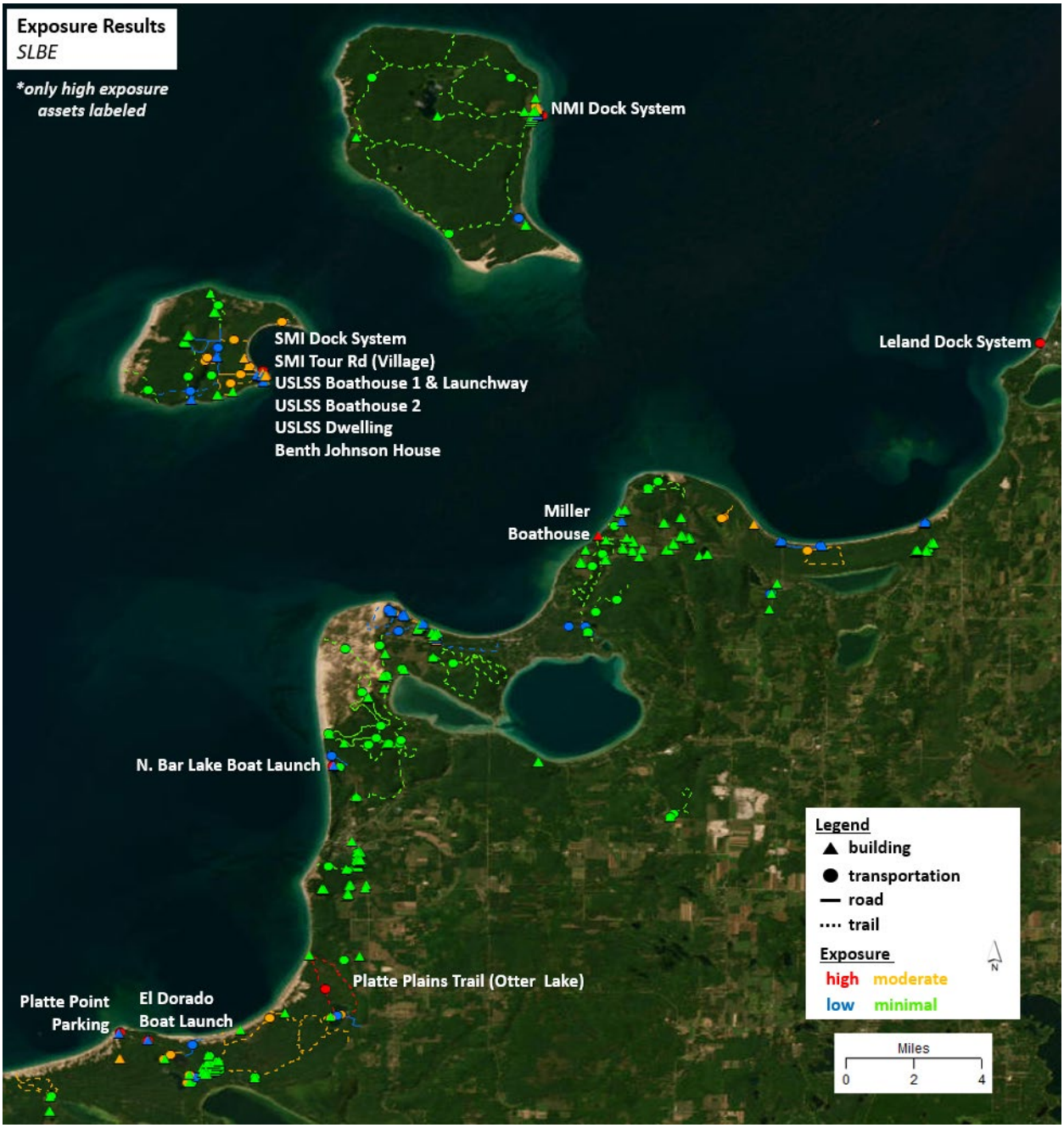


**Figure 1.** SLBE exposure results summary with high exposure assets labeled. Background map is ESRI streaming imagery.

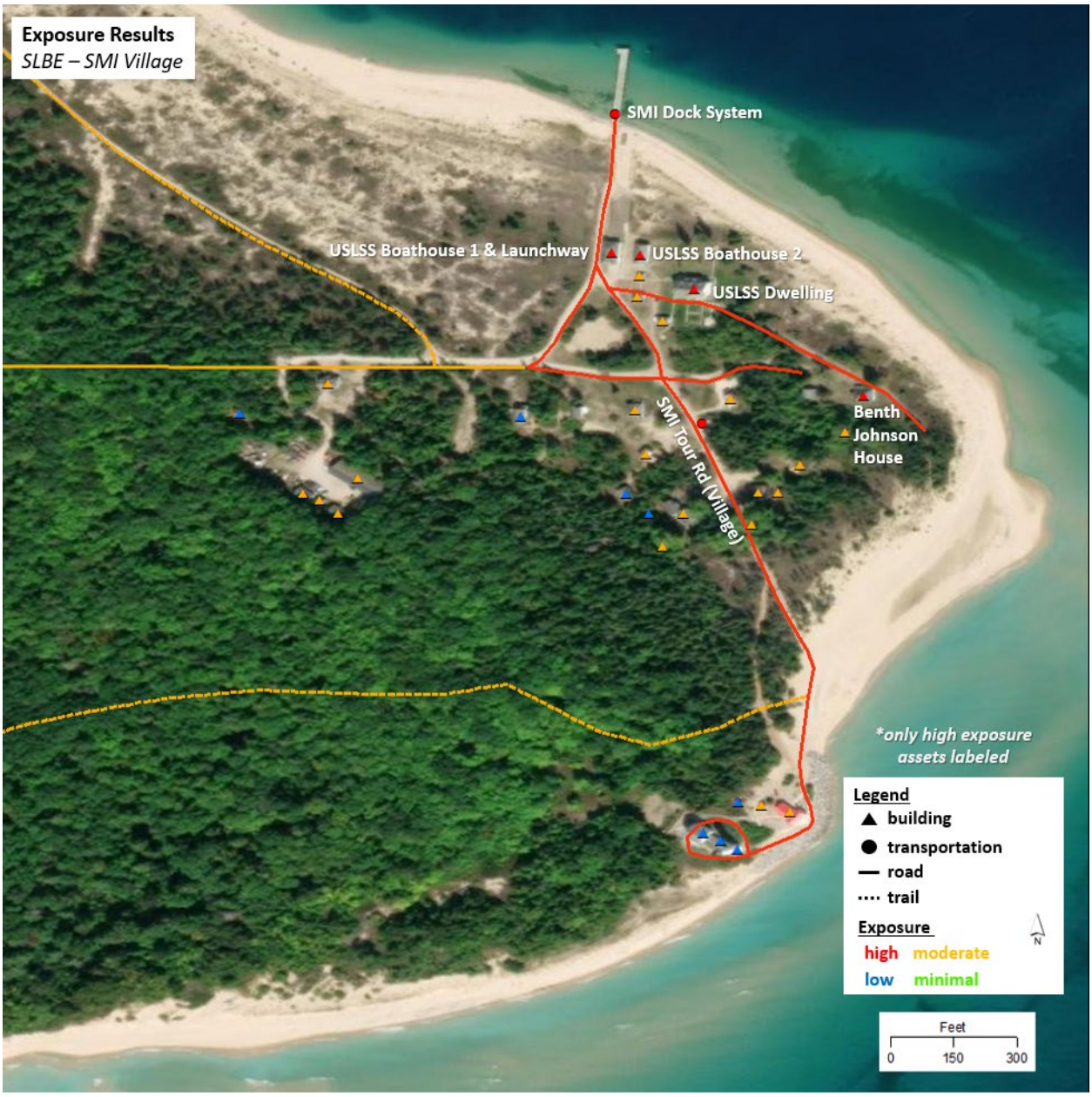


**Figure 2.** Exposure results summary for the SMI Village area of SLBE. Background map is ESRI streaming imagery.

# 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 3 or 4 of these indicators, moderate-sensitivity assets have unfavorable determinations for 2 indicators, and low-sensitivity assets have unfavorable determinations for 0 or 1 indicator. Assets with minimal exposure are not analyzed for sensitivity (this is the case for 345 assets at SLBE).

The majority (89%) of assets analyzed at SLBE have moderate sensitivity to coastal hazards (Table 3). Fourteen assets (11%) have high sensitivity, and one (<1%) has low sensitivity. Most high sensitivity assets have been damaged by coastal flooding in the past. In general, the assets are in good condition, but are not significantly elevated above local ground level, storm resistant, or protected by engineering. Five assets received an unfavorable rating for all sensitivity indicators: Miller Boathouse, Otter Lake Dock System, Shell Lake Road, Shefler Road (not in FMSS), and the Ohio to Sheridan Trail (not in FMSS).

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

| | High Sensitivity | | Moderate Sensitivity | | Low Sensitivity | | Total Analyzed | Excluded* |
|---|---|---|---|---|---|---|---|---|
| **Assets** | **#** | **%** | **#** | **%** | **#** | **%** | **#** | **#** |
| Buildings | 6 | 7% | 77 | 93% | 0 | 0% | 83 | 288 |
| Transportation | 8 | 16% | 40 | 82% | 1 | 2% | 49 | 57 |
| All Assets | 14 | 11% | 117 | 89% | 1 | <1% | 132 | 345 |

*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 one-fifth of assets at SLBE have high (4%) or moderate (12%) vulnerability to the evaluated coastal hazards (Table 4, and Figures 3-8). Three assets (Miller Boathouse, Platte Plains Trail - Otter Lake Loop, and El Dorado Boat Launch System) have both high exposure and high sensitivity. Seven assets have both high vulnerability and a high asset priority index (API ≥ 70, as reported in FMSS); all are historic buildings in SMI Village, including the Martin Furst House, Benth Johnson House, Ray & Violet Robinette House, John & Lottie Tobin House, USLSS Dwelling, UNLSS Boathouse #1 & Launchway, and UNLSS Boathouse #2. Twelve percent of assets have low vulnerability, while the majority (72%) have minimal vulnerability.

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

| | High Vulnerability | | Moderate Vulnerability | | Low Vulnerability | | Minimal Vulnerability | | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Assets** | **#** | **%** | **#** | **%** | **#** | **%** | **#** | **%** | **#** |
| Buildings | 8 | 2% | 37 | 10% | 38 | 10% | 288 | 78% | 371 |
| Transportation | 12 | 11% | 19 | 18% | 18 | 17% | 57 | 54% | 106 |
| All Assets | 20 | 4% | 56 | 12% | 56 | 12% | 345 | 72% | 477 |

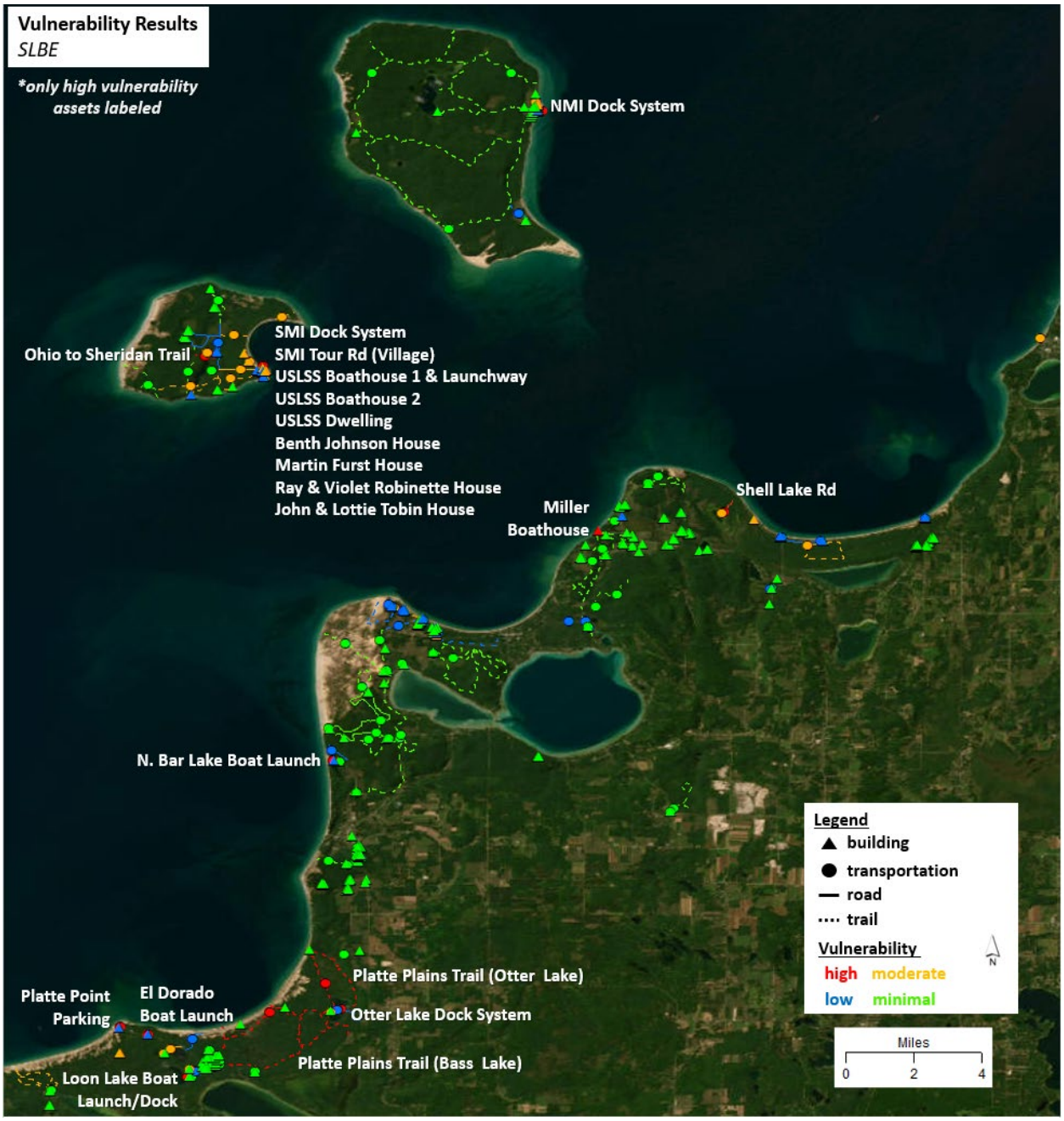


**Figure 3.** SLBE vulnerability results summary with high vulnerability assets labeled. Background map is ESRI streaming imagery.


**Figure 4.** SLBE vulnerability results summary for the southwest area of the mainland, with high vulnerability assets labeled. Background map is ESRI streaming imagery.

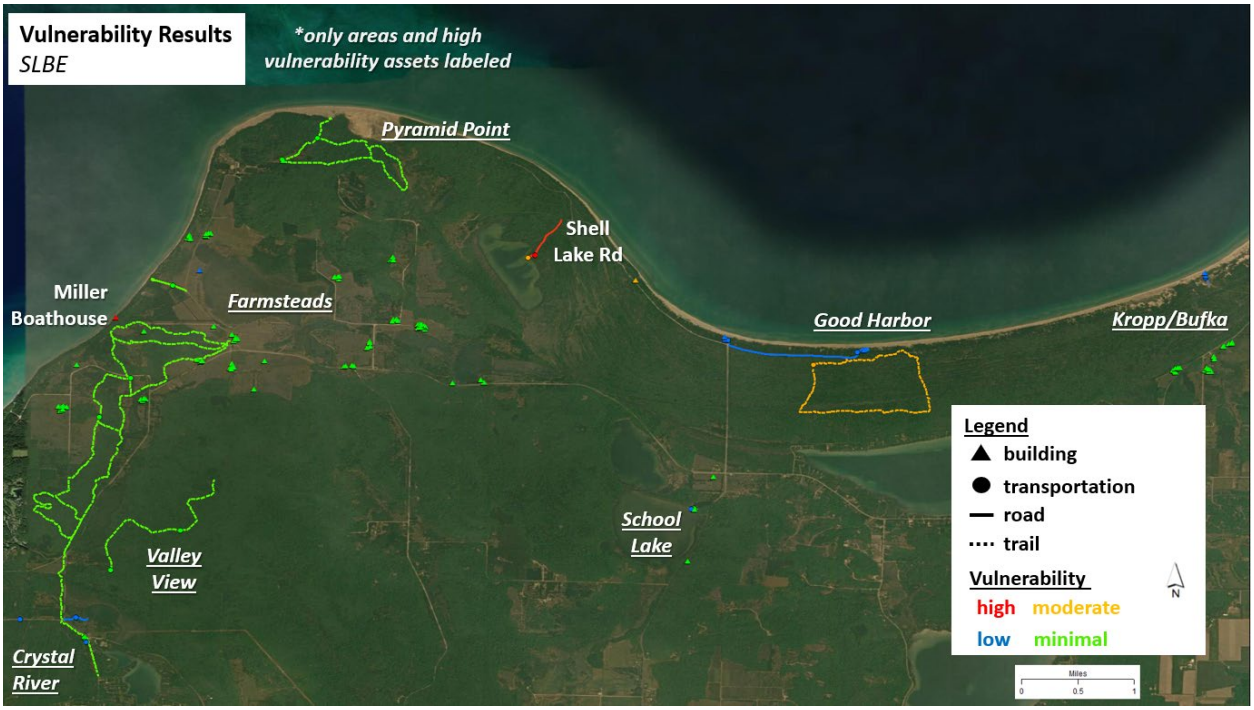


**Figure 5.** SLBE vulnerability results summary for the northeast area of the mainland, with select areas (underlined) and high vulnerability assets labeled. Background map is ESRI streaming imagery.

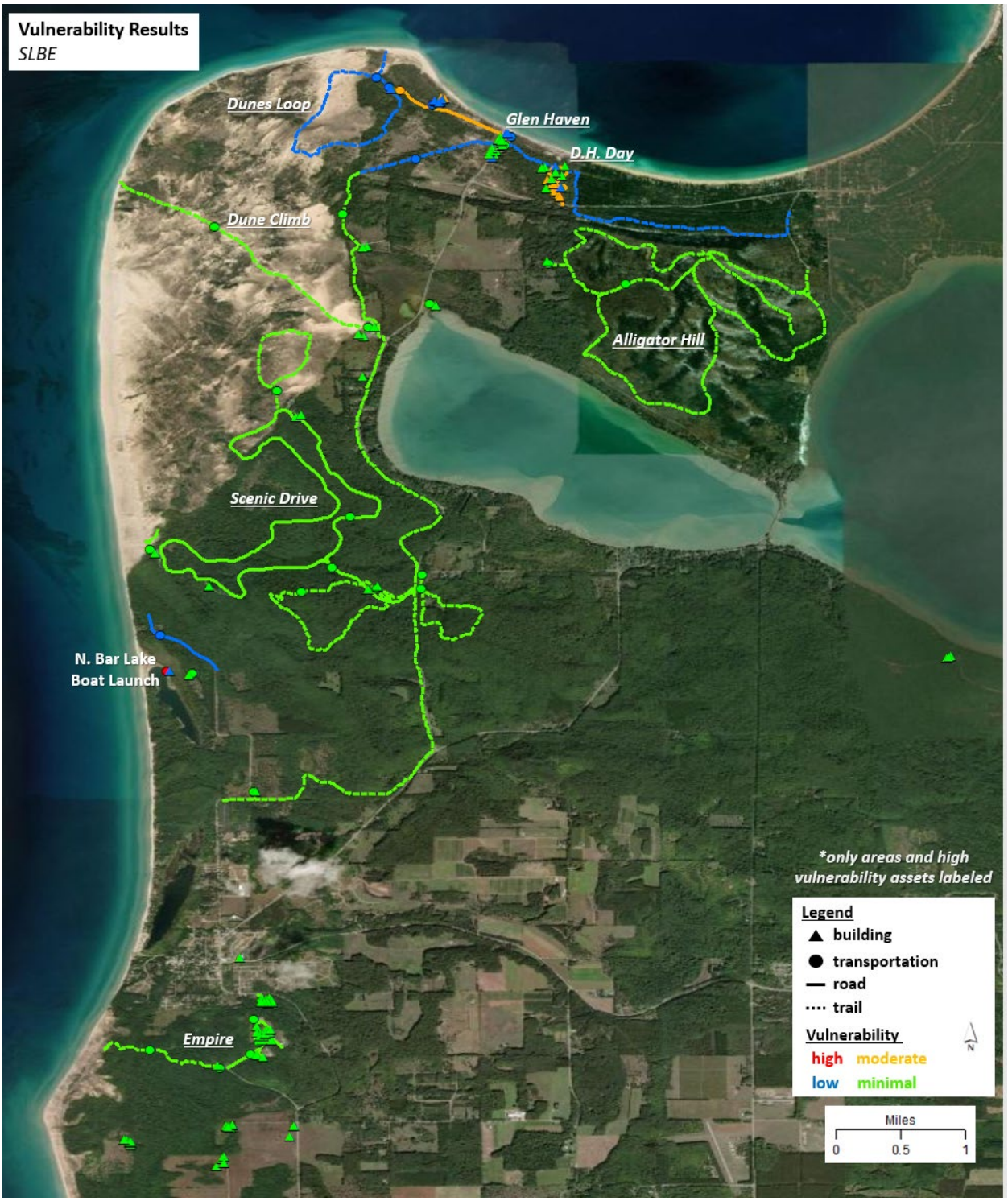


**Figure 6.** SLBE vulnerability results summary for the central area of the mainland, with select areas (underlined) and high vulnerability assets labeled. Background map is ESRI streaming imagery.


**Figure 7.** Vulnerability results summary for NMI with high vulnerability assets labeled. The red box in the inset shows the location of the enlarged area of NMI Village. Background map is ESRI streaming imagery.


**Figure 8.** Vulnerability results summary for SMI with high vulnerability assets labeled. The red box in the inset shows the location of the enlarged area of SMI Village. Background map is ESRI streaming imagery.

## SLBE Unique Considerations

**Non-FMSS assets:** At the request of the park, we evaluated six non-FMSS listed assets on SMI (Shefler Road, Sheridan Road, Chicago Road, Weather Station Campground Trails, Ohio to Sheridan Trail, and Ohio Cutoff Trail. These assets are not formally listed in FMSS but appear on several park maps. All statistics in the results and within this report include these assets.

**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-modelled and have predictable long-term trends in response to climate change. In contrast, there are no comparable long-term projections for future lake-levels. Furthermore, 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:** For the SLBE mainland coastline, we used Long-Term Rate of Change (1938-2020) erosion data from Michigan Technological University (MI Tech 2023) to create a 30-year coastal erosion buffer. NMI and SMI do not have coastal erosion rate data available, so we created a 60-meter coastal proximity buffer based on the highest long-term erosion rates (2 meters/year) recorded on the adjacent mainland. The reference shoreline throughout the park was digitized from the highest recorded shoreline on Lake Michigan (582.4 feet) using 2020 imagery (OCM Partners 2024b).

**Bluff and slope erosion:** For bluff erosion on the SLBE mainland, we used the high-risk erosion areas (HREAs) mapped by the Michigan Department of Environment, Great Lakes, and Energy (MI EGLE 2024). The HREAs represent bluffs receding at an average annual rate of 1 foot/year or greater over a minimum period of 15 years. On NMI and SMI, we consulted the USGS Slope Inventory (Ashland 2022a; 2022b) to identify historical and active slope hazards.

**Linear assets:** One road and four trails were segmented at SLBE due to length and exposure variability. The SMI Tour Road (COUNTY) was divided into three segments (Village Roads, Burdic Road, and Ohio Road). The following trails were segmented: Platte Plains Trail (Otter Lake Loop and Bass Lake Loop), Sleeping Bear Heritage Trail (north and south), NMI South Loop Trail (main loop and southeast spur), and NMI Frank Farm Loop Trail (coast and inland). We evaluated each segment individually for exposure, sensitivity, and vulnerability, and assigned each segment a modified location code (segments share the same FMSS attributes).

## References

Ashland, F.X. 2022a. Preliminary reconnaissance inventory map data of landslides and related features, South Manitou Island, Sleeping Bear Dunes National Lakeshore, Michigan: U.S. Geological Survey data release, https://doi.org/10.5066/P9SQWQ37. Accessed March 2024.

Ashland, F.X. 2022b. Preliminary reconnaissance inventory map data of landslides and related features, North Manitou Island, Sleeping Bear Dunes National Lakeshore, Michigan: U.S. Geological Survey data release, https://doi.org/10.5066/P92LZ8R2. Accessed March 2024.

Federal Emergency Management Agency (FEMA). 2018. National Flood Hazard Layer. Leelanau County, Michigan. https://www.fema.gov/flood-maps/national-flood-hazard-layer Accessed March 2024.

Federal Emergency Management Agency (FEMA). 2021. National Flood Hazard Layer. Benzie County, Michigan. https://www.fema.gov/flood-maps/national-flood-hazard-layer Accessed March 2024.

Michigan Department of Environment, Great Lakes, and Energy (MI EGLE). 2024. High risk erosion areas on Lakes Huron, Michigan and Superior. Michigan Department of Environment, Great Lakes, and Energy, Lansing, Michigan. https://www.michigan.gov/egle/about/organization/water-resources/shoreland-management/high-risk-erosion-areas Accessed March 2024.

Michigan Technological University (MI Tech). 2023. Long term rate of shoreline change summary (1938-2020) for Lakes Michigan and Huron. Michigan Technological University Geospatial Research Facility, Great Lakes Research Center, Houghton, Michigan. https://portal1-geo.sabu.mtu.edu/mtuarcgis/home/item.html?id=75459dbfb962469bab24a9230db5285f Accessed March 2024.

National Park Service (NPS). 2021. Coming to terms with climate change: Working definitions. National Park Service Climate Change Response Program, Fort Collins, Colorado.

OCM Partners. 2024. 2015 FEMA Lidar: Michigan Part 2 (Alger, Benzie, Delta, Grand Traverse, Leelanau, Mackinac, Manistee Counties), https://www.fisheries.noaa.gov/inport/item/56300 Accessed March 2024.

OCM Partners. 2024: 2020 Michigan NAIP 4-Band 8 Bit Imagery, https://www.fisheries.noaa.gov/inport/item/68214. Accessed March 2024.

Peek, K.M., B.R. Tormey, H.L. Thompson, and R.S. Young. 2022. Coastal hazards & sea-level rise asset vulnerability assessment protocol: Updated project description & methodology. Natural Resource Report. NPS/NRSS/CCRP/NRR—2022/2427. National Park Service. Fort Collins, Colorado. Available at: https://doi.org/10.36967/2293653.

United States Army Corps of Engineers (USACE). 2024. Great Lakes Water Levels (1918-2024). United States Army Corps of Engineers Detroit District. Detroit, Michigan. https://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Great-Lakes-Information-2/Water-Level-Data/ Accessed March 2024.

**National Park Service**
**U.S. Department of the Interior**

**EXPERIENCE YOUR AMERICA ™**

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 634/195672, January 2025