GEOLOGICAL FIELD GUIDE TO ILLINOIS BEACH STATE PARK

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Cover-page imagery: The upper image is a field photograph from the Illinois Beach State Park North Unit, in 1973, from between 17th St. and the Zion Nuclear Power Plant. The lower image is an oblique aerial photo of the Dead River Mouth, southern terminus of Illinois Beach State Park's South Unit, on April 4th, 1997. Photographs are from Illinois State Geological Survey archives.

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1. INTRODUCTION TO THE ZION BEACH-RIDGE PLAIN

The Zion Beach-ridge Plain (ZBPR) is one of few sandy strand promontories on the North American Great Lakes. It is defined by its washboard-style ridge-and-swale topography, with ecologically unique and important wetland habitats nestled between ridgelines. Analogs to this system exist in Lake Superior's Whitefish Point, Upper Peninsula of Michigan, and in southcentral Lake Erie's Presque Isle Peninsula, Pennsylvania. The ZBRP stretches for 25 kilometers (>15 miles) along the wave-dominated and otherwise sand-limited coast of southwestern Lake Michigan. Its oldest deposits, about 5,000 years old, are found in Kenosha, Wisconsin; its southernmost subaerial (beach) manifestation occurs in North Chicago, Illinois, to the south of which coastal bluffs are the dominant shoreline physiography. Also known as the 'Chiwaukee-Illinois Beach Lake Plain,' the ZBRP encompasses close to 1,600 hectares (~4,000 acres) in extent, inclusive of the highest-quality lake-margin dune-and-swale ecosystem of southwestern Lake Michigan.

Several city parks are located within the ZBRP, including the Kenosha Sand Dunes, Pleasant Prairie's Lakeshore Park, and Zion's Hosah Park. The Chiwaukee Prairie Natural Area (Wisconsin), Winthrop Harbor's Spring Bluff Forest Preserve (Illinois), the Illinois Beach Nature Preserve, and the Adeline Jay Geo-Karis Illinois Beach State Park (IBSP) are larger state-run park systems. IBSP is divided into a North Unit and South Unit, separated by urbanized terrain and infrastructure related to the decommissioned Zion Nuclear Power Station. Collectively, these protected park terrains provide important niche habitats for many threatened and endangered plant and animal species, including the endangered Great Lakes piping plover. Their designation as a wetland complex of international importance, under the Ramsar classification (https://www.ramsar.org/), is further underscored by their use as a migratory stopover site for shore birds.

The uniqueness of ZBRP wetland and dune-ridge terrains, particularly along a coastal margin otherwise characterized by sand limitations (Creque et al., 2010; Mwakanyamale et al., 2020), have prompted construction of shoreline-protection structures to protect ecologically valuable terrains. Recent engineering efforts along the Illinois portion of the ZBRP shoreline have included (1) a Great Lakes Restoration Initiative (GLRI) construction project, which emplaced three parallel submerged rubble-mound ridges at Hosah Park; and (2) an ~$74 million Illinois State Capital Development Project, which involved the emplacement of twenty-two emergent breakwaters, along three separate chains spanning the most erosive sections of IBSP. These 2022-2024 construction projects, which also involved extensive beach-nourishment efforts, are meant to slow shoreline erosion and enhance coastal resiliency in the face of ever-changing water levels and storm impacts. Water-level rise of >1.5 meter (nearly 5 feet), between 2012 and 2020, accelerated rates of shoreline recession along portions of the ZBRP (Theuerkauf and Braun, 2021; Theuerkauf et al., 2019, 2021).

2. FIELD TRIP DESCRIPTION AND GOALS

This field trip, which begins in the IBSP North Unit (NU) and winds up in the IBSP South Unit (SU), explores the following themes: (1) The Holocene history of the ZBRP, with emphasis on what relict coastal landforms tell us about ridge-terrain evolution; and (2) recent shoreline-change dynamics, along historically net-erosional and net-accretionary portions of the system. Provided are insights into recent construction and sand-nourishment activities within IBSP, which have prompted an extensive shoreline-monitoring study by the Illinois State Geological Survey (ISGS). This work is supported by the Illinois Department of Natural Resources' Coastal Management Program (IDNR-CMP), which has funded shoreline-monitoring activities at IBSP and other Illinois locations since 2018. Observational and data-driven insights are framed within a broader understanding of the late Holocene developments across the ZBRP, whose oldest deposits in Illinois date to around 3,000 years ago (Larsen, 1985; Chrzastowksi and Frankie, 2000; Mattheus et al., 2023).

Members of the ISGS Coastal Geology Group (CGG) will lead this one-day field excursion and provide insights into the hydro- and morphodynamics governing the evolution of shoreline terrains along IBSP. The excursion will begin at North Point Marina (NPM), site of the initial rendezvous (upon group travel from Chicago) and our lunch location, and wind up near the Dead River Mouth (DRM), the southernmost section of the IBSP shoreline. A handful of study sites along-route, which have been actively monitored by the ISGS since 2018, will provide opportunities to view and discuss a variety of topics and themes, including: (1) Modern shoreline morphodynamics and influences thereupon of onshore-offshore infrastructure and sand nourishment; (2) impacts of lake-level changes, storms, and winter-ice covers on coastal geomorphic development; and (3) paleo-environmental implications of relict shoreline terrains within the ZBRP.

Field-trip stops are shown in **Figure 1**, for the IBSP-NU, and **Figure 2**, for the IBSP-SU**.** These include (1) A parking lot at the south end of NPM, with an overlook of the historically most erosive coastal cell within IBSP (Stop 1); (2) the location of an unsuccessful 2018 emergency beach-sand nourishment effort, undertaken to save a park road, present site of juxtaposed emergent breakwaters, completed in 2023/2024, and location of submerged rubble-mound ridges, completed in 2022 (Stop 2); and (3) an eolian dune field within the IBSP-SU, situated near the nodal point separating historically (1872 to present) net-erosive from net-accretionary parts of the ZBRP shoreline system (Stop 3). Stops are thus arranged from the most historically erosive, in the north, to most historically stable, in the south; the excursion follows the net-alongshore movement of sand.

The trip will address patterns of shoreline and nearshore geomorphic change and sediment transport dynamics, over event-based, decadal, and late Holocene timescales. It will draw from topographic and bathymetric survey data generated by the ISGS since 2018. It will also make use of federal geospatial datasets, which provide greater spatial coverage. Process-oriented data insights will be coupled to the longer-term evolutionary history of the ZBRP, as interpreted from sediment-core, subsurface geophysical, and geochronological datasets. This trip will offer opportunities to discuss the implications of recently installed shoreline-protection structures, whose impacts on system morphodynamics will be studied by the ISGS in the years to come. It is noteworthy to mention that, while chains of emergent nearshore breakwaters are nothing new to the Great Lakes region, having for instance been emplaced along the Presque Isle Peninsula of southcentral Lake Erie (Pilkey, 2012), no comparable efforts to monitor the post-construction dynamics have been undertaken, nor has a five-year pre-construction dataset before offered the chance at a thorough evaluation of structure performance.

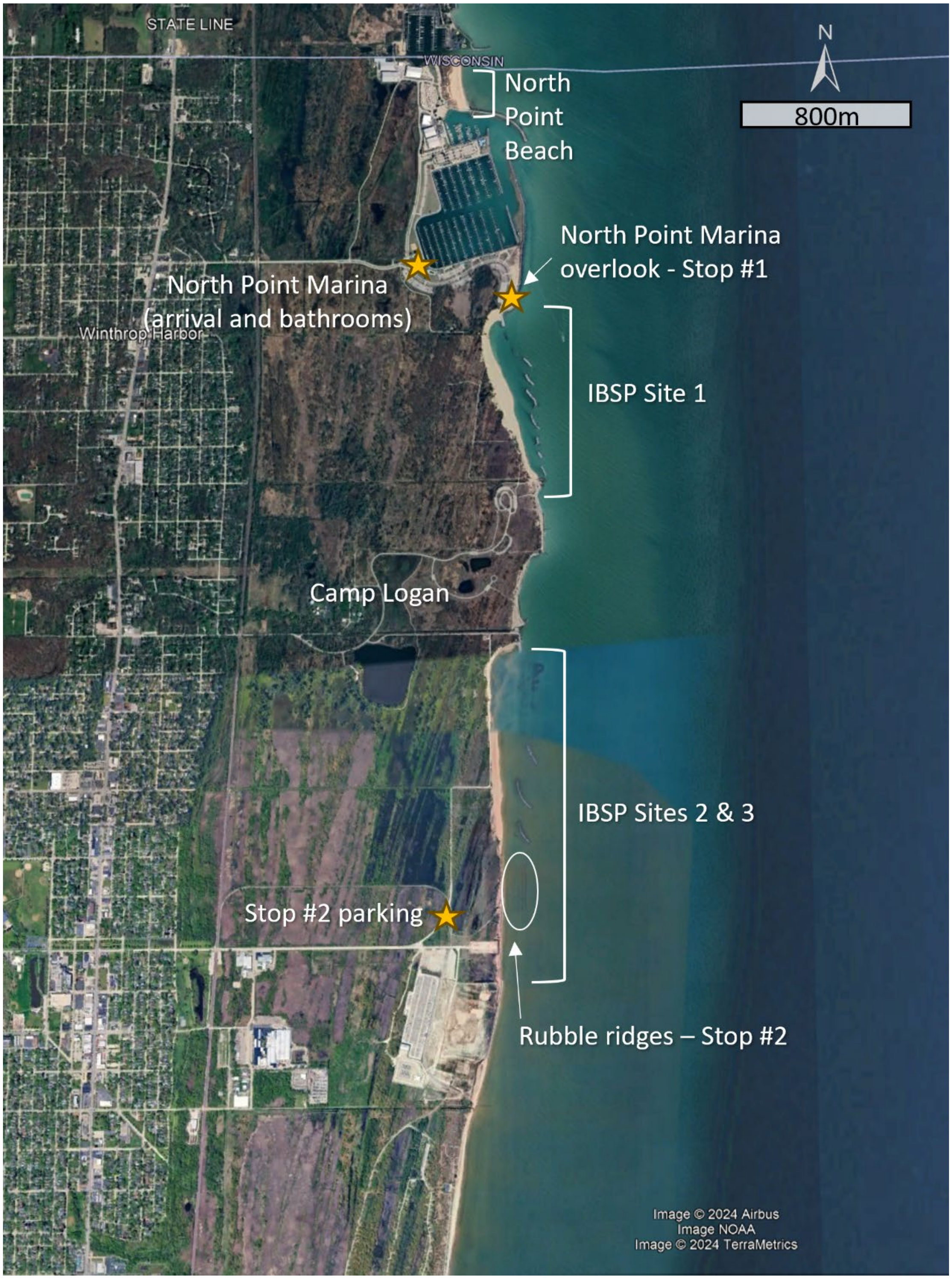


Figure 1 – Map of the Illinois Beach State Park North Unit (IBSP-NU), showing the North Point Marina (NPM) rendezvous location, along with those of Field Trip Stops 1 and 2, access points to ISGS monitoring locations IBSP1-3. At these locations, we will investigate the impacts of newly emplaced emergent breakwaters, along IBSP1, and submerged rubble-mound breakwaters, at IBSP 3, among other things.

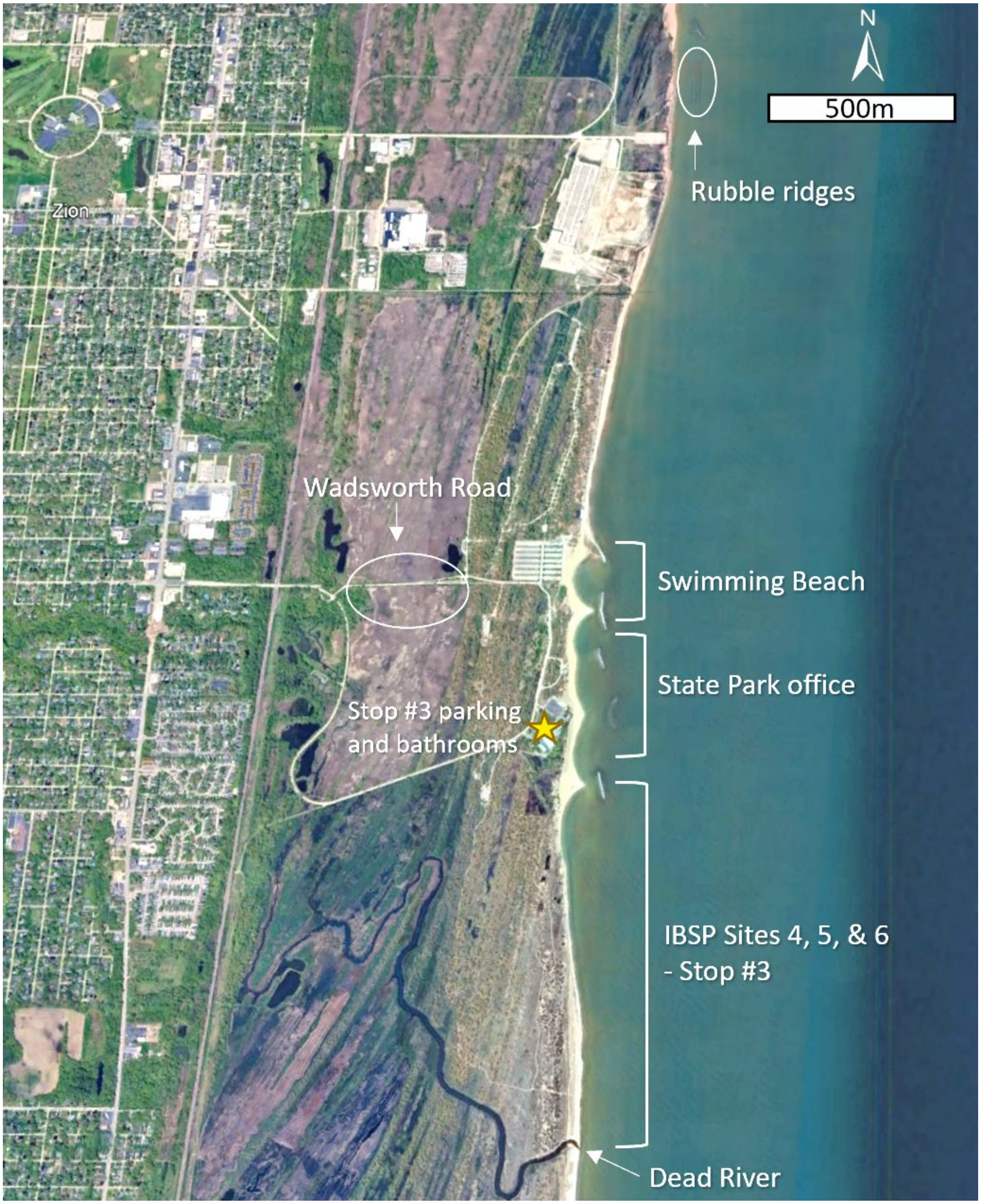


Figure 2 – Map of the Illinois Beach State Park South Unit (IBSP-SU), showing ISGS monitoring locations at IBSP4-6, which will traversed as Field Trip Stop 3. These sites continuously span the distance from the southernmost IBSP breakwater, built in 2023/2024 near the parking lot location, to the Dead River (DR) mouth. This stretch is the last remaining 'natural' part of the IBSP shoreline. Terrains to the south of the DR are part of the inaccessible Illinois Beach Nature Preserve.

3. BACKGROUND INFORMATION

While unique from the late Holocene developmental perspective, IBSP has become a study location for understanding how onshore and offshore infrastructure shapes system evolution. This section conveys insights into the history of human occupation and ridge-plain modification since the 1880s. An account of the geological framework is provided thereafter.

3.1. ILLINOIS BEACH STATE PARK HISTORY

The ZBRP is located along the southwestern coast of Lake Michigan, which has undergone significant transformations with the arrival of settlers of European ancestry and associated industrialization. With the growth of the Chicago metropolitan region, the nearby ZBRP served multiple uses. The establishment of IBSP and its growth as a Protected Natural Area has thus been a decades-long process, with the relics of former land uses occasionally resurfacing, particularly along receding shorelines. The history of IBSP reflects broader trends, regional and national, of the late 1800s through present. Before re-naturalization, it was a place of industry, military training, and suburban expansion. While much of the former infrastructure has been dismantled, past activities have left their mark on this unique landscape.

The history of IBSP provided here considers North and South Units (NU and SU) separately. The IBSP-SU was officially established as State Park in 1953, after serving a variety of purposes. A railroad track existed in the IBSP-SU around 1902, located between Illinois Beach Hotel and the Dead River. This connected to a sand-mining operation in the area, to which pitting of the otherwise intact linear beach ridges attests (see topographic map of the ZBRP in **Figure 3**). Chrzastowksi and Frankie (2000) make note of the periodic re-exposure and burial of the former tracks along the shoreline, with seasonal to decadal changes in lake level and associated beach-profile adjustments. **Figure 4** shows a more recent uncovering of a section of track, following 2012-2020 shoreline recession. It has since disappeared into the nearshore, with ongoing (post-2020) shoreline retreat. Most recently, the tracks were visually spotted through the water column following the 2024/2025 winter season. The tree shown in **Figure 4** was lost to shoreline erosion over the past few years. The extraction and transport of sand and gravel from the area by way of this rail line served construction and other industries across the greater Chicago region. The operation was active for several decades, during which other areas of the ridge plain remained undeveloped. Other remnants of the sand-mining or other industrial activities can be seen today; shoreline recession has, in recent years (since 2020), re-exposed a foundation and other infrastructure remnants in proximity to the rain-line terminus (**Figure 5**). This is one of many examples of re-emerging infrastructure encountered since ISGS shoreline monitoring operations began along IBSP in 2018.

IBSP has not only provided sand for regional industry and construction projects; it is also woven into the cultural fabric of the region. The eolian sand-capped dune ridges of the IBSP-SU served as an ideal backdrop for Western movies, which were filmed in the region between 1914 and 1920. Although this period of early film making was brief, it marks an interesting chapter in the history of the park. The 1930s would see other land uses modify the terrains of IBSP. Pressure from industrial developments during this time, focused on the Waukegan area (just south of IBSP), motivated the Illinois Dunes Park Association to begin leasing ZBRP land, hiring caretakers, and charging visitor fees. This facilitated the maintenance and protection of still underdeveloped, mostly natural terrains. In 1943, 450 acres of land were purchased by the Illinois General Assembly. While this was initially intended for park use, needs during World War II would have this land converted to a military training facility for the U.S. Army. The land was returned to the state after the war, and an additional 623 acres were purchased. This land requisition led to the official establishment of the IBSP-SU, in the 1950s.

The history of the IBSP-NU, officially established between 1971 and 1982, encompasses a wider variety of former land uses and developments. During the Civil War, portions of the land were used as a prisoner of war camp. In 1892, this area was established as a militia training facility and firing range, known as Camp Logan (**Figure 6**). The 220-acre portion was purchased by the state legislature, with an additional 40-acre parcel purchased in 1899. Camp Logan was also utilized as a U.S. military training facility throughout WWI and WWII, serving as a National Guard training site afterwards. Much of the land was returned to the state of Illinois after WWII. Officially closed in the early 1970s, the buildings of Camp Logan are today listed in the National Register of Historic Places. Some of them are occupied by the Lake Michigan Biological Field Station, which is operated by the Illinois Natural History Survey, part of the University of Illinois' Prairie Research Institute.

Suburban development expanded in the 1950s and 1960s, with the establishment of residential neighborhoods to the north and south of Camp Logan. Homes were built too close to the shoreline (**Figures 7, 8**). By the 1970s, shoreline recession, as part of the historical trend along ZBRP, led to considerable property damage along shorelines of the IBSP-NU (**Figure 9**). Many homes and other structures would wind up in the lake, which prompted the removal of approximately 250 houses and, subsequently, the establishment of the IBSP-NU. Foundation remnants of residential homes and utility infrastructure can still be seen in the park today (albeit mostly overgrown with vegetation). The exposure of cement blocks, pipes, and other remnants is common along receding shorelines of IBSP. Infrastructure laid bare along the shoreline in 2020 has been covered by 2023-2024 sand nourishment/beach reconstruction (along the IBSP-NU). Old infrastructure and foundation blocks (mostly broken-up) are also imaged across the lake bottom with sonar and lake-bottom videography, highlighting how much shoreline change has occurred even since the 1970s (**Figure 9**). North Point Marina was constructed within the IBSP-NU in 1989. The marina, the largest in the Great Lakes by boat-slip space, is managed by the Illinois Department of Natural Resources (IDNR). Approximately 2.5 million cubic yards of sand and gravel were excavated for the 72-acre marina basin, which is surrounded by a breakwater (for protection against wave energy). With an ~1,500-boat capacity, the marina attracts both recreational boaters and fishing charters, thereby representing a key component of the local economy (e.g., featuring hotels, restaurants/bars, and package stores). It has also become a popular access point for many of the other recreational opportunities that the IBSP-NU provides, inclusive of swimming, hiking, biking, and bird watching.

IBSP serves as a key area of coastal ecological conservation, protecting many diverse terrestrial and aquatic habitats and species. It is now the fifth-largest state park in Illinois, covering approximately 4,160 acres. The park supports a variety of ecosystems, including dunes, wetlands, and forests, which numerous species of plants and animals call home. Park managers focus on preserving the area's natural beauty and resources, while maintaining and updating recreational offerings. The land has been subjected to efforts, some ongoing, to (1) restore native habitats and ecosystem function (e.g., through re-naturalization of wetland drainage), (2) mitigate erosion and terrain loss (e.g., through breakwater construction), and (3) evaluate and monitor ecosystem health (e.g., through groundwater/contaminant studies and ecological assessments).

The recent history of human activities within the present confines of IBSP, from industrial exploitation to military use and subsequent conservation efforts, highlights the evolving relationship between humans and their natural environment. In addition to its inherent ecological value, IBSP remains a valuable resource for scientific research and education. The shoreline-monitoring program, established by the IDNR and the ISGS in 2018, has created the largest dataset of its kind in the Great Lakes region. Some of the data from 2018-2024 topographic and bathymetric beach surveys along IBSP, with some sites monitored at seasonal resolutions or better, are highlighted in this field guide.

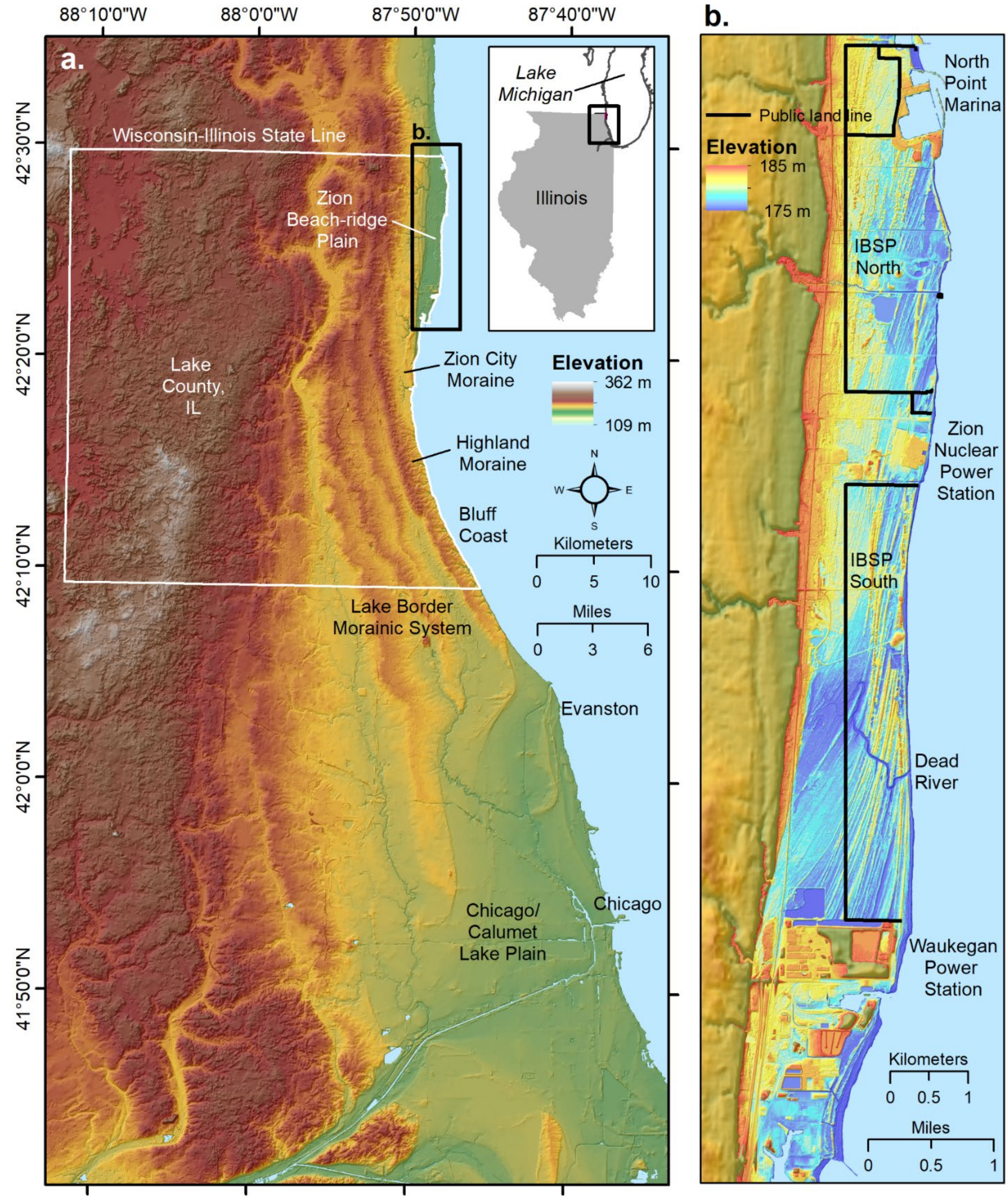


Figure 3 – Hillshaded DEMs showing (a) Lake-Michigan proximal upland terrains in Illinois (Cook and Lake County), and (b) the Illinois portion of the Zion Beach-ridge Plain (ZBRP), Lake County. The Illinois Beach State Park (IBSP) North and South Units are delineated in the latter. Key points of spatial reference are labeled. All vertical units are in

NAVD88 meters.

Figure 4 – Section of a 1906 USGS topographic map of the southern portion of the Illinois Beach State Park (IBSP) South Unit, showing the location of a rail system formerly used for sand-mining activities (at the turn of the last century). The accompanying photo shows them exposed along the shoreline section highlighted on the map in red. The field photo was taken on December 22nd, 2021. The tracks have undergone multiple cycles of burial and re-exposure since the 1980s. They were last seen exposed in Spring of 2024, just lakeward of the shoreline. The tree seen in this image has since toppled over. The view is northward, and the general location is shown on the map (in the red box).

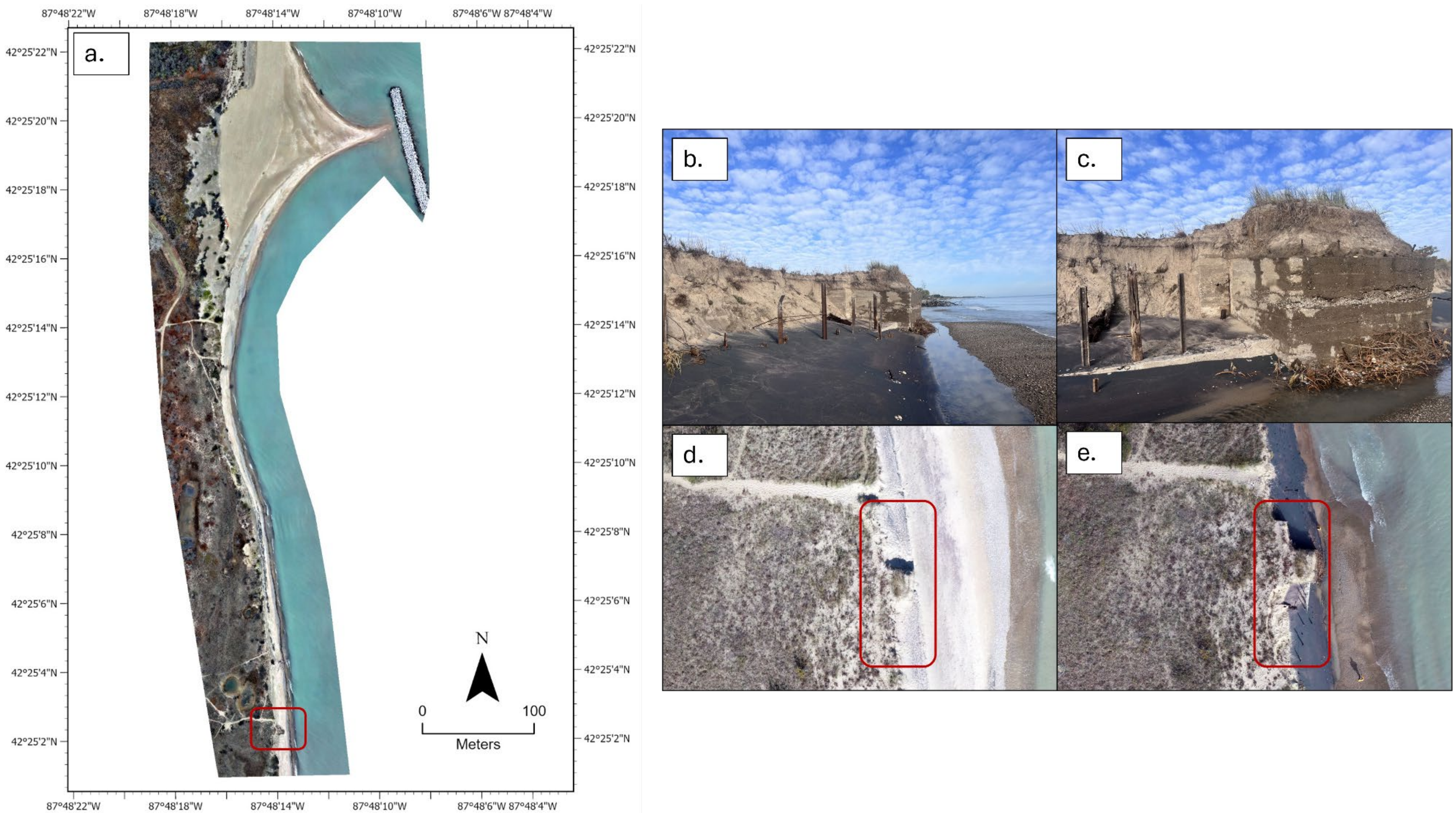


Figure 5 – Orthoimage of ISGS monitoring site IBSP4 (in the Illinois Beach State Park South Unit), based on a November 15th (2024) drone flight. It shows the location of an exposed foundation structure, captured in accompanying field photos, which were taken of the newly exposed feature on October 17th, 2023 (b and c), from the south and southeast, respectively. Also included are aerial photographic panels (d and e), which document the progressive re-exposure of former infrastructure with a storm event that occurred between October 10th, 2023 (d), and October 17th, 2023 (e).

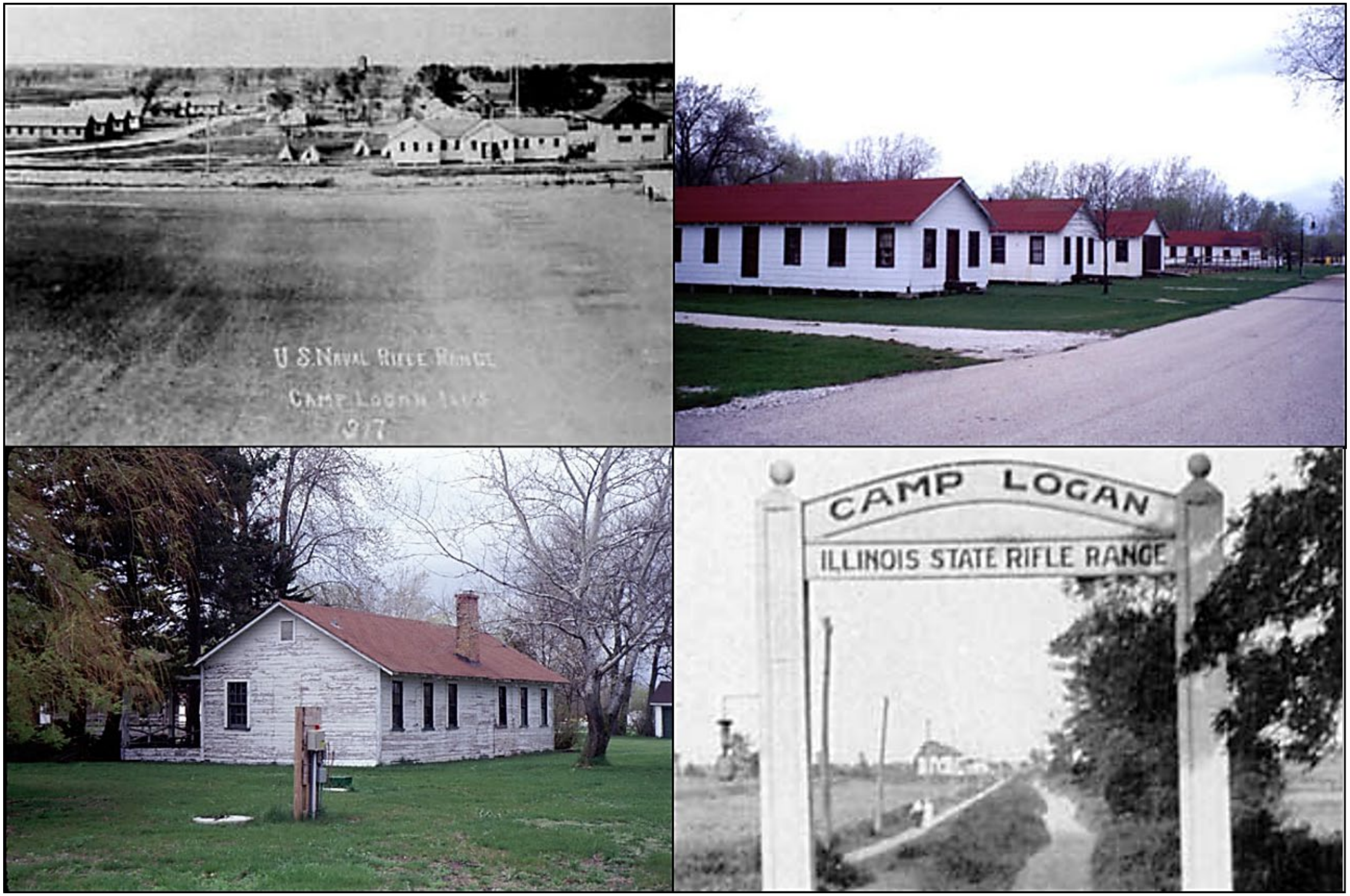


Figure 6 – Photographs of buildings and other infrastructure at former Camp Logan, Zion, IL. Images are sourced from the IDNR website (https://dnr.illinois.gov/naturalresources/cultural/camploganp2.html).

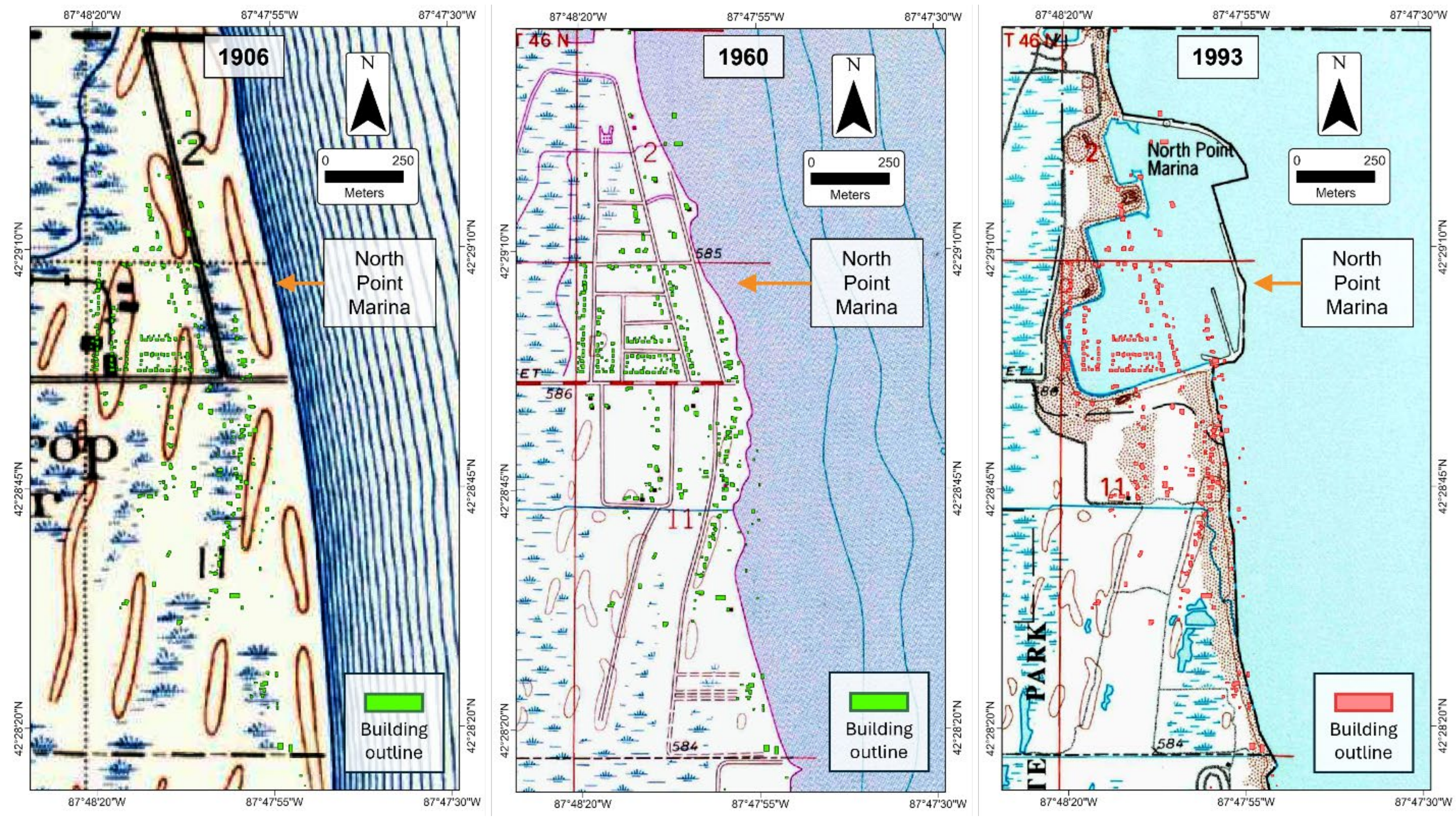


Figure 7 – Multi-panel figure showing, from left to right, USGS topographic maps from 1906, 1960, and 1993. Map panels are of the same geographic extent, the area from North Point Marina and the IBSP1 monitoring site. All maps are overlain by the outlines of former buildings, digitized from historical aerial photographs and/or census maps.

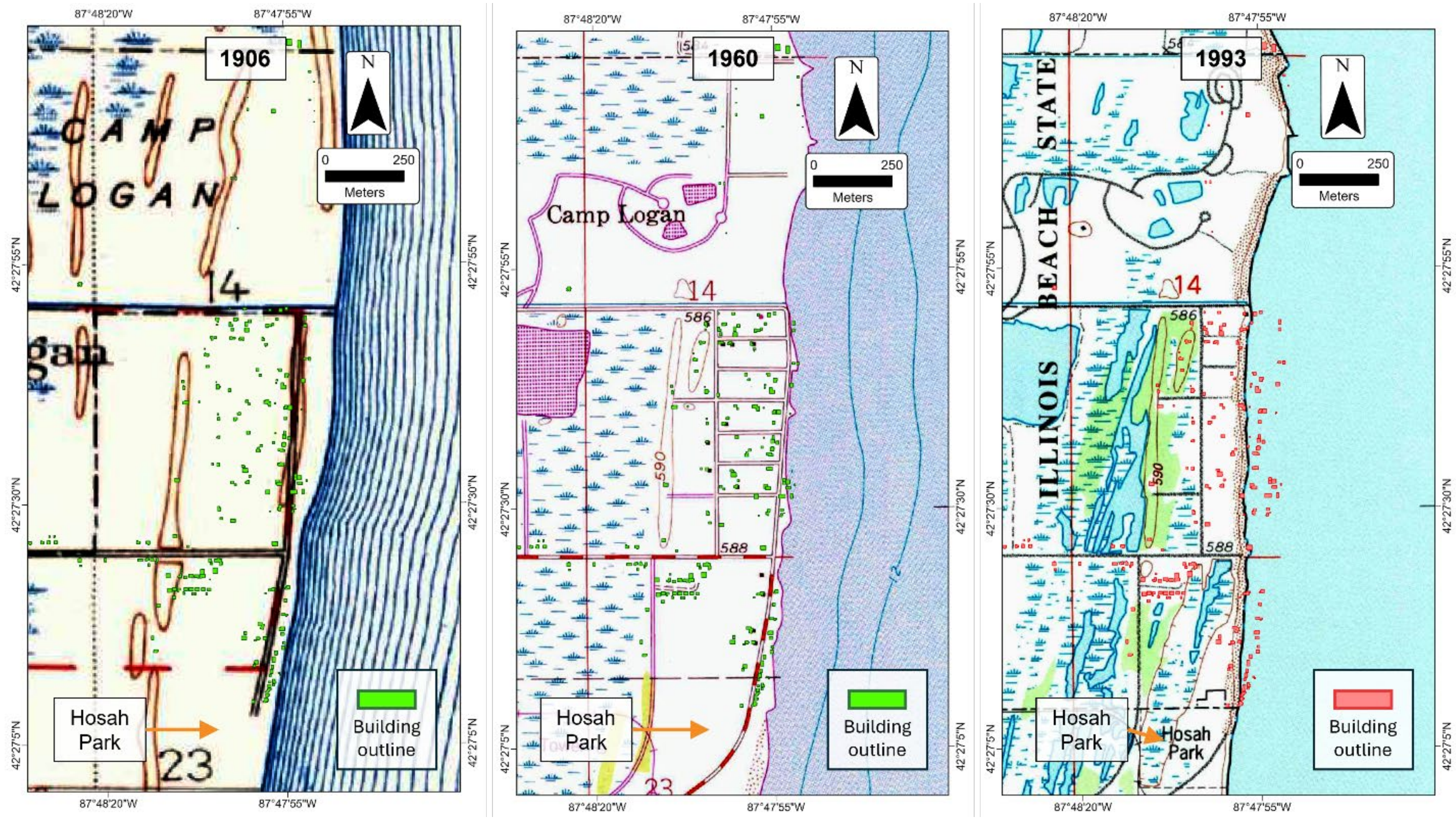


Figure 8 – Multi-panel figure showing, from left to right, USGS topographic maps from 1906, 1960, and 1993. Map panels are of the same geographic extent, from 17th St. to Hosah Park, inclusive of IBSP2-3 survey areas. All maps are overlain by the outlines of former buildings, digitized from historical aerial photographs and/or census maps.

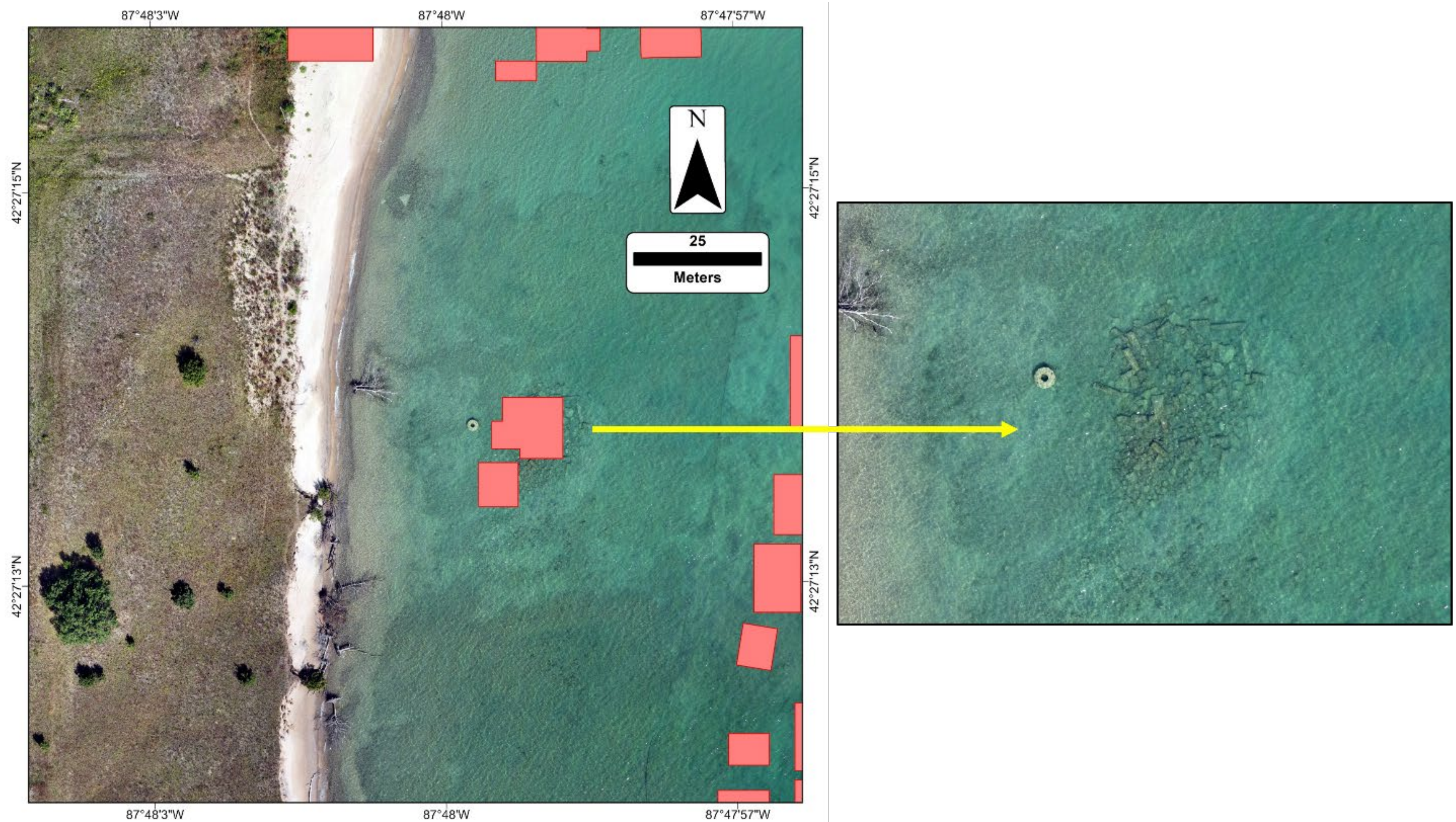


Figure 9 – ISGS CGG-derived orthomosaic based on drone imagery from September 12th, 2024. It is overlain by a polygon layer of historical home locations. An enlarged portion of the image is shown to the right. With a net-export of sand from these shoreline regions, the former infrastructure remains visible on the lake bottom. It is imaged in sonar datasets and aerial drone imagery (on clear-water days).

3.2. FRAMEWORK GEOLOGY

The Illinois coastal region along Lake Michigan is divided into three distinct physiographic zones, a function of the region's stratigraphy and Quaternary developmental history (**Figure 10**): (1) The sandy Zion Beach-ridge Plain (ZBRP), which contains Illinois Beach State Park (IBSP); (2) the clayey silt-dominated till-bluff coast; and (3) the urbanized Chicago Lake Plain, along which carbonate bedrock and till-related units crop out along the shore-proximal lake bottom (in water depths <10 m). Much of the Lake Michigan coast of Illinois is sand-limited, stemming from the fine-grained nature of regional glacial deposits, the primary source of sandy material to the littoral system (e.g., the clayey silt-dominated Wadsworth till; Willman and Frye, 1970; Hansel and Johnson, 1996), and lack of fluvial contributions from beyond the lake-margin terrains (see outline of Illinois Coastal Zone in **Figure 10**). Sampling studies and geophysical mapping have shown sand to exist as thin and discontinuous drapes across most shallow-water areas along this part of the Lake Michigan coast (<10 m in depth; Creque et al., 2010; Mwakanyamale et al., 2020). This is most noticeable along the bluff coast, between North Chicago and Wilmette, and along the urbanized Chicago and Evanston lakefront regions, where sandy shorelines are confined to urban pocket beaches that obstruct the natural alongshore routing of shoreline materials (Fucciolo, 1993; Creque et al., 2010; Mwakanyamale et al., 2020; Mattheus and Barklage, 2024). The littoral zone to the south of North Chicago (Zones 2 and 3), beyond noticeable contribution of sand from the ZBRP, is sourced chiefly by bluff erosion, which is estimated to liberate only around 1 m^3 of sand per linear meter of retreat, on average (Jibson et al., 1994). The southernmost shore-attachment point for sands that are distinctly mapped as part of the ZBRP's submerged sand platform occurs just south of North Chicago (2020 USACE topobathymetric LiDAR and 2023 NOAA MBES datasets).

Natural sediment-transport and shoreline-change patterns in Illinois are influenced by coastal infrastructure. This compounds already complex coastal process dynamics and obscures the linkages between hydrodynamic forcing and shoreline geomorphic response. Studying relationships between hydrodynamics, sediment-transport patterns, and coastal landform development is inherently challenging. It is also important that these interactions be studied to help inform effective coastal resource management and hazard mitigation. Shoreline areas of the Great Lakes connect to wetlands, dune fields, and other important environments that provide a range of important ecosystem services. Along urban lakefront corridors, beaches not only provide recreational opportunities to the citizenry, but also provide a buffer (for shoreline infrastructure) against wave attack and winter-ice flows. To effectively manage coastal resources and infrastructure, a better understanding of shoreline dynamics and patterns of change within the coastal landscape, across subaerially exposed and submerged portions, is needed.

The Zion Beach-ridge Plain (ZBRP), characterized by a ridge-and-swale topography (**Figure 11**), is a southward migrating ridge-plain system. Its origins are speculated to have been between Kenosha and Wind Point, more than 40 km from the southern terminus of deposits associated with the coastal lithosome. The northernmost strand deposits are associated with the Kenosha Dunes, which overlie a buried forest, whose woody remains have been dated to between 3.6 kyrs and 7.6 kyrs before present (Schneider et al., 2009). The oldest ZBRP deposits in Illinois are about 3,000 years in age, based on C-14 dating of wetland deposits and other organic remains (Larsen, 1985; **Figure 12**). The age of the ridge plain generally decreases lakeward and southward, reflective of a net-southerly movement of sand over the late Holocene (Chrzastowski and Frankie, 2000; Chrzastowski et al., 2013). A southward pattern of littoral (alongshore) sand transport characterizes the whole of the southwestern Lake Michigan coastal margin, as evidenced by other relict depositional features, including various perched spit complexes extending into the Chicago Lake Plain (Chrzastowski and Thompson, 1994; Chrzastowksi et al., 1994). This is ongoing, based on sediment-accretion trends against shoreline and offshore infrastructure (e.g., groins and water-delivery pipes). It is also manifested in shoreline-change trajectories along the ZBRP (**Figure 12**); the retreat of shorelines beyond remnants of former housing, roads, and other infrastructure along IBSP is causing a more fragmented sedimentary dynamic than had previously characterized the system.

Relict depositional architectures across the ZBRP have been mapped with GPR and recently age-dated using optically stimulated luminescence (OSL) dating (Mattheus et al., 2024; **Figure 13**). These efforts corroborate earlier models of landform and strandplain development, in line with our evolving understanding of alongshore sediment transport processes. Recent age dating has reconstructed the chronology of the area around the Dead River mouth, the southern boundary of IBSP. This area shows the progradational nature of the southern part of the system (**Figure 13**), with sand contributions from the eroding northern part. The wave approach from the N/NE is most impactful on the southwestern Lake Michigan coast, given alignment with >400 km of lake fetch and the highest wave-generation potentials. It is estimated that the southward flux of sediment along the ZBRP is ~80,000 cubic yards per year, on average (Chrzastowksi and Frankie, 2000). Much of this annual net movement is linked to a few strong events, most prevalent in the high-energy cold-water season, associated with wave approach from the N/NE sector (Booth, 1994).

The Zion Beach-ridge Plain is the sandiest part of the Illinois coastal system, with up to ~10 meters of sand thickness (Hester and Fraser, 1973). **Figure 14** shows the juxtaposition of dune ridge-and-swale topography against wetlands, which is related to a regional physiographic boundary between younger and older terrains suggesting a sudden increase in littoral energy. The topographic cross section is marked by an increase in relief between ridges and swales going from bluff to modern shoreline. Efforts are underway to better understand this physiographic boundary. Regional geophysical imaging has revealed that many meters of sand exist as an offshore platform surrounding the ZBRP (Mwakanyamale et al., 2020), which is substantiated by geological sampling (Creque et al., 2010). This stands in stark contrast to the Illinois bluff and Chicago coasts, which are sand-limited and where till, gravel lag deposits, and other non-sandy substrate types are common within 3 km from shore. Over a century of shoreline engineering has fragmented littoral transport pathways and sand-distribution patterns along much of the Illinois coast (Shabica and Pranschke, 1994; Chrzastowksi, 2004; Shabica et al., 2004).

The sedimentology of the ZBRP and its offshore sand platform are detailed in Hester and Fraser (1974). Shoreline deposits are comprised of medium-coarse sand and gravel deposits. There is an offshore fining of sediments, with the nearshore environment comprised of fine- to medium-grained sand deposits that grade to fine sand, silt, and clay offshore. The transition to very fine sand and coarse silt occurs below 10 meters in water depth (Booth, 1994). This is within 3 km from the shoreline. Dune deposits, which blanket much of the interior portion of the ridge plain, are comprised of medium-grained sand. Dune ridges are only well developed close to shore, particularly along the Illinois Beach South Unit, where the ridge-and-swale topography and relief are most pronounced. Across older parts of the ZBRP, ridge lineaments are less distinct, discontinuous, and scalloped. While wetlands are a characteristic feature within many of the swales of the ZBRP, extensive coring efforts (n>100 stratigraphic logs) have shown organic-rich deposits (atop sand and gravel) to be thin (<1 m thick).

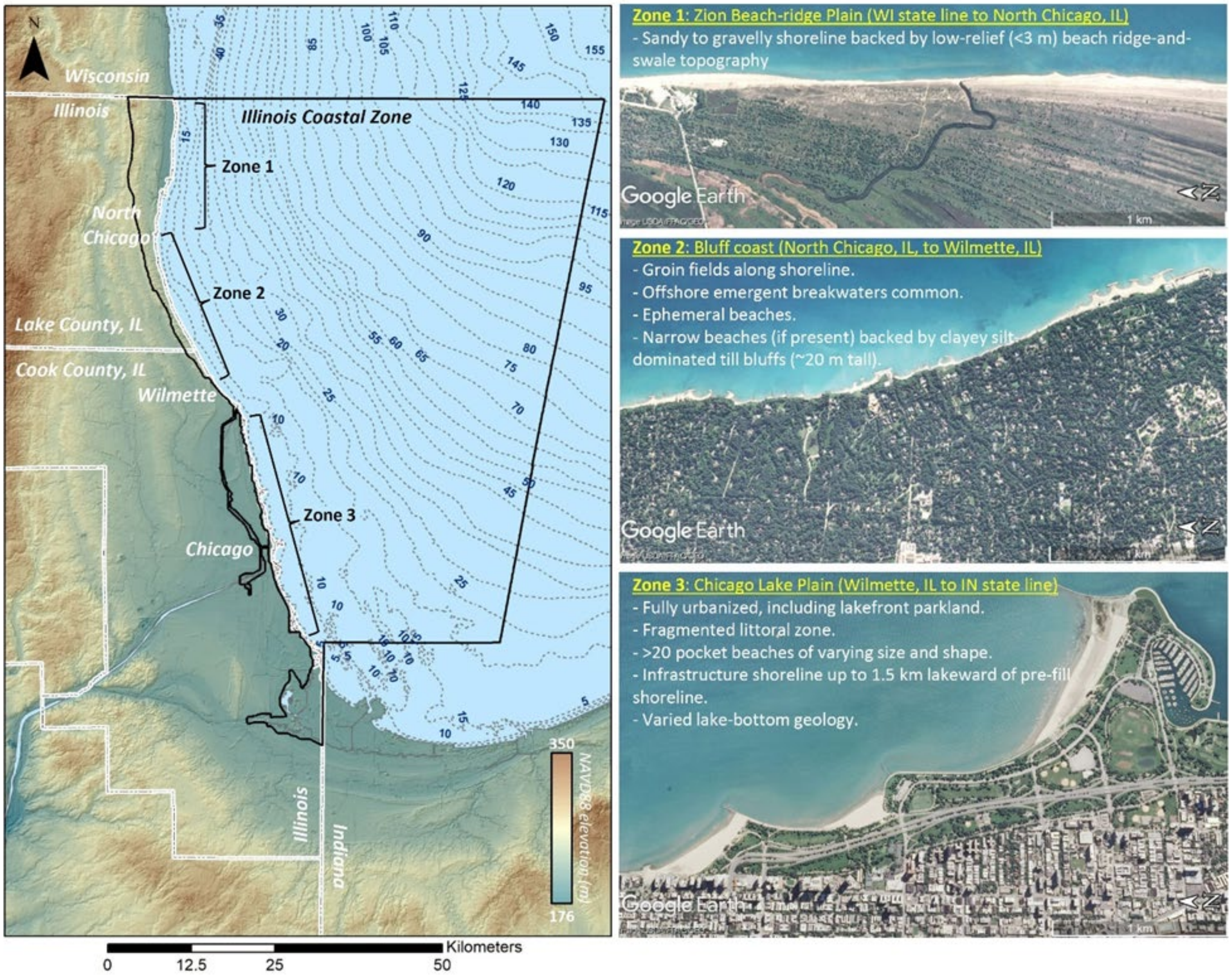


Figure 10 – Hillshaded and color-coded digital elevation model (DEM) of the Illinois Coastal Zone topography and surrounding areas (with Lake Michigan colored blue and showing bathymetric depth contours in meters), labeling key coastal physiographic compartments (Zones 1-3), the general locations of cities and other reference points (including state and county boundaries); accompanied by three-panel image collage showing an example for each of the coastal physiographic zones (acquired in November of 2011) and providing bulleted information on inherent characteristics.

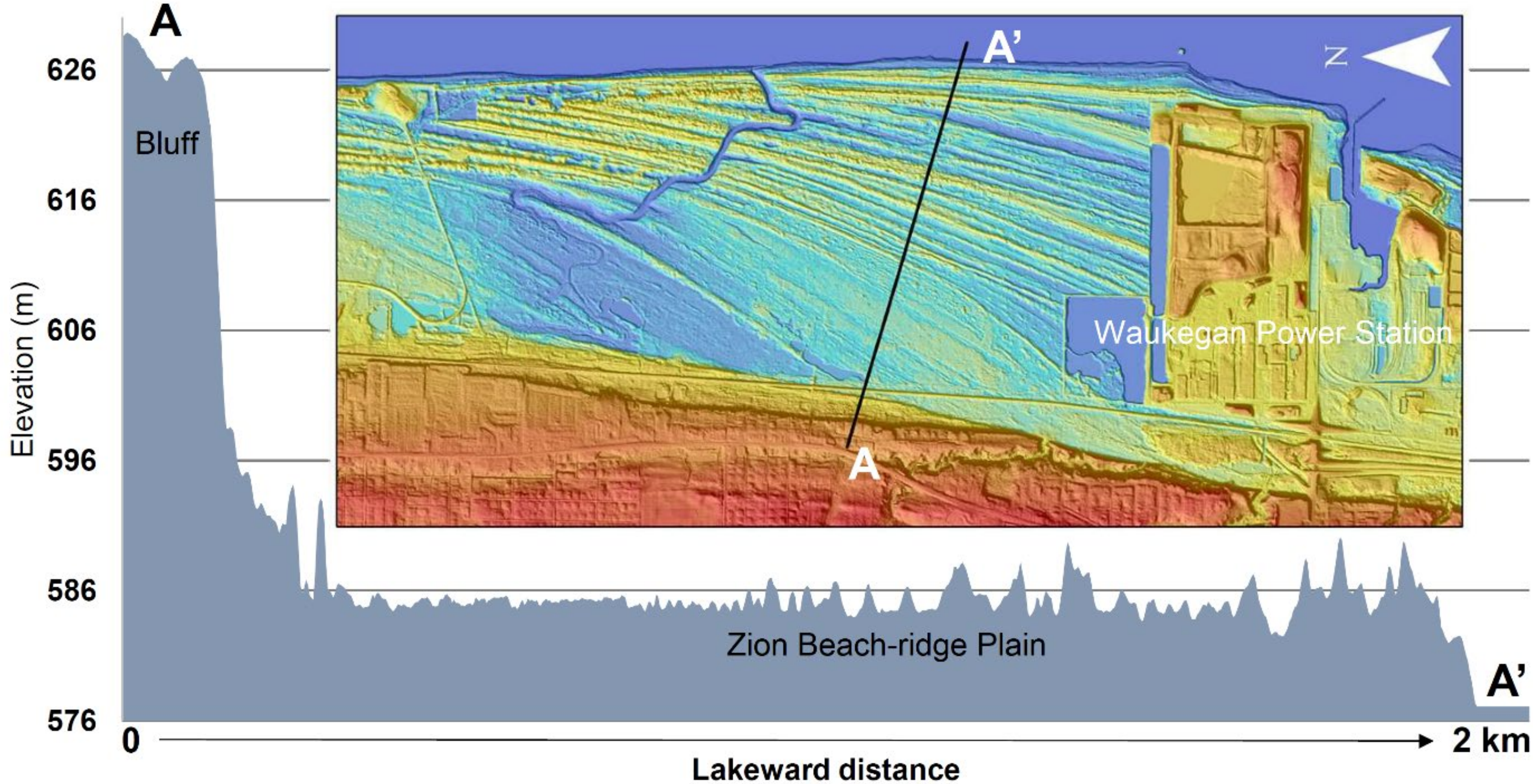


Figure 11 – Topographic profile extraction from A-A', which cuts across the ZBRP from bluff crest to Lake Michigan, revealing the ridge-and-swale topography of the southern part of the system, just north of the Waukegan Power Station. Notable is the increase in relief between ridges and adjacent swales. The transition from ridges <586 feet in elevation and ridges >586 feet in elevation (NAVD88) occurs about the boundary between wetland terrain and dune-ridge terrain, recognized in the subsurface along Wadsworth Road (see Figure 14).

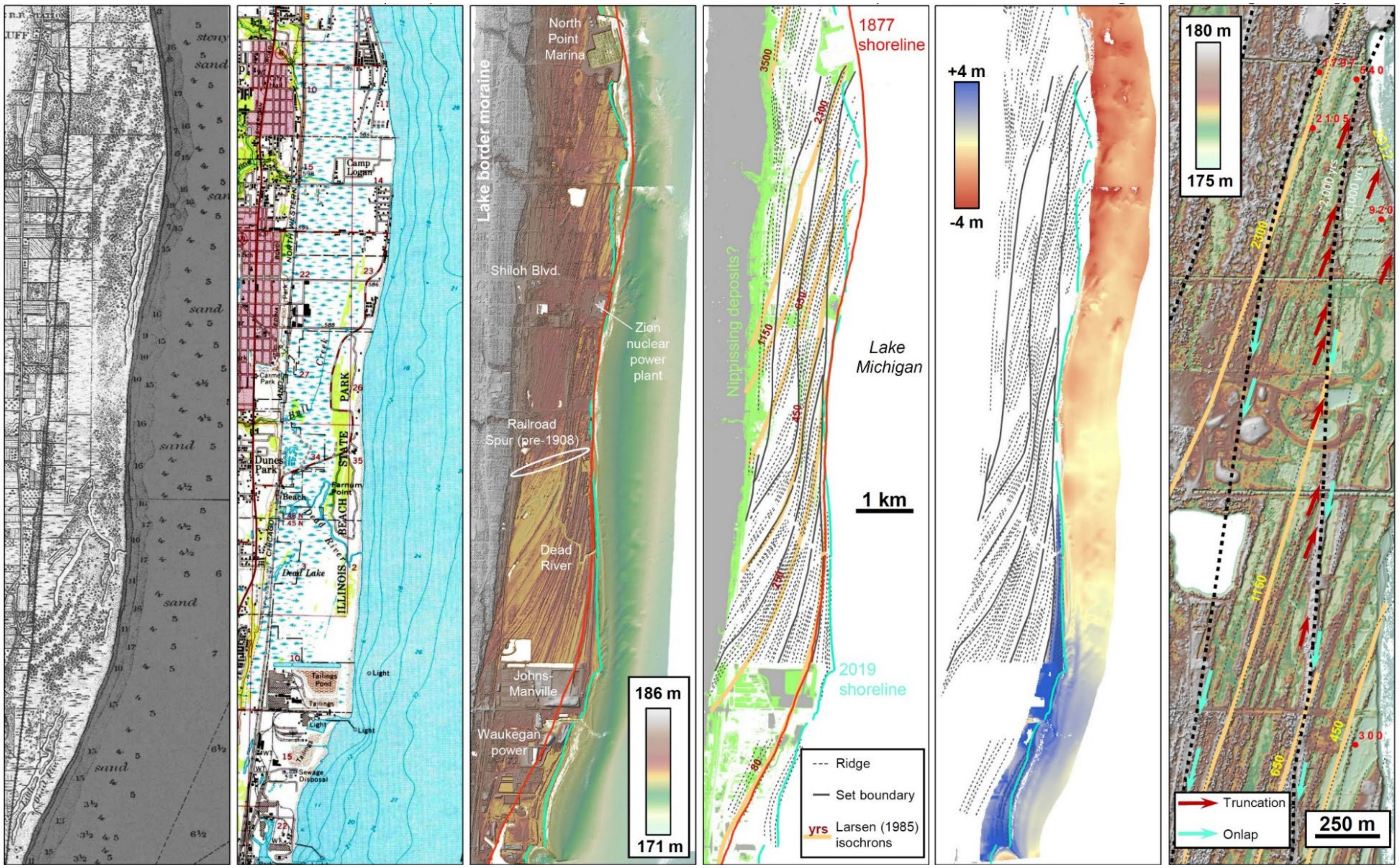


Figure 12 – Collocational GIS map panels showing, in order from left to right, 1877 nautical chart, 1960 USGS map, 2012 topobathymetric DEM, ridge-lineament map with Larsen (1985) age contours superimposed (along with 1877 and 2019 shoreline positions), 1877-2012 nearshore vertical change map, and a blow-up DEM section of the region surrounding Sand Point, where the ridge plain is compartmentalized into ridge sets (by truncating ridgelines of topographic prominence). Figure modified (expanded) from Mattheus et al. (2023).

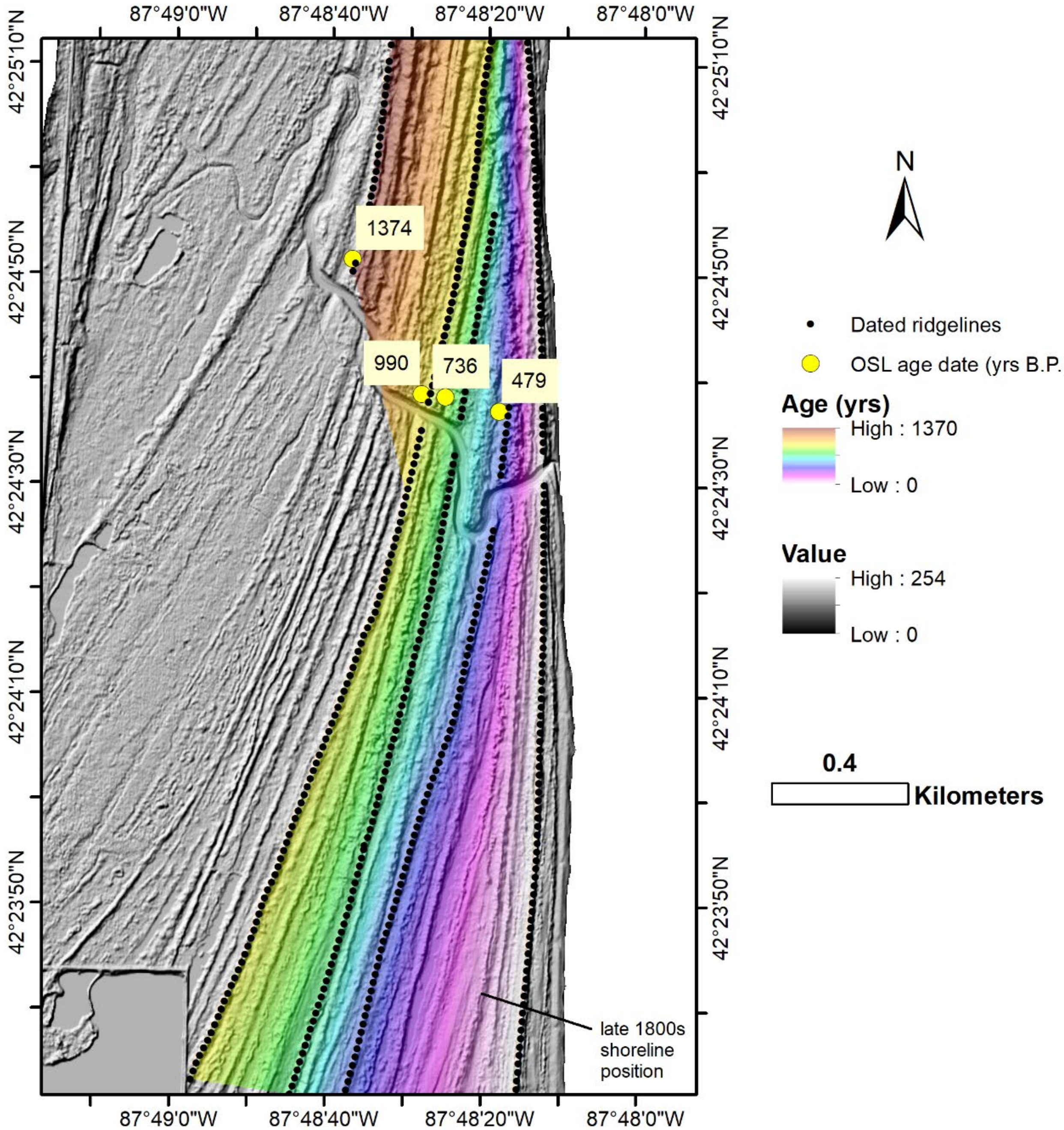


Figure 13 – Hillshade map (5X VE) of the Dead River area (IBSP South Unit and southward) showing established OSL ages of ridgelines (dashed) cored for material to age date. The color-ramped surface is an interpolation of these ridgeline ages. There appears to be a more continuous chrono-sequence of ridges here than along the IBSP North Unit, where erosional truncation has visibly reworked portions of the ridge plain at different points in time (see Figure 12).

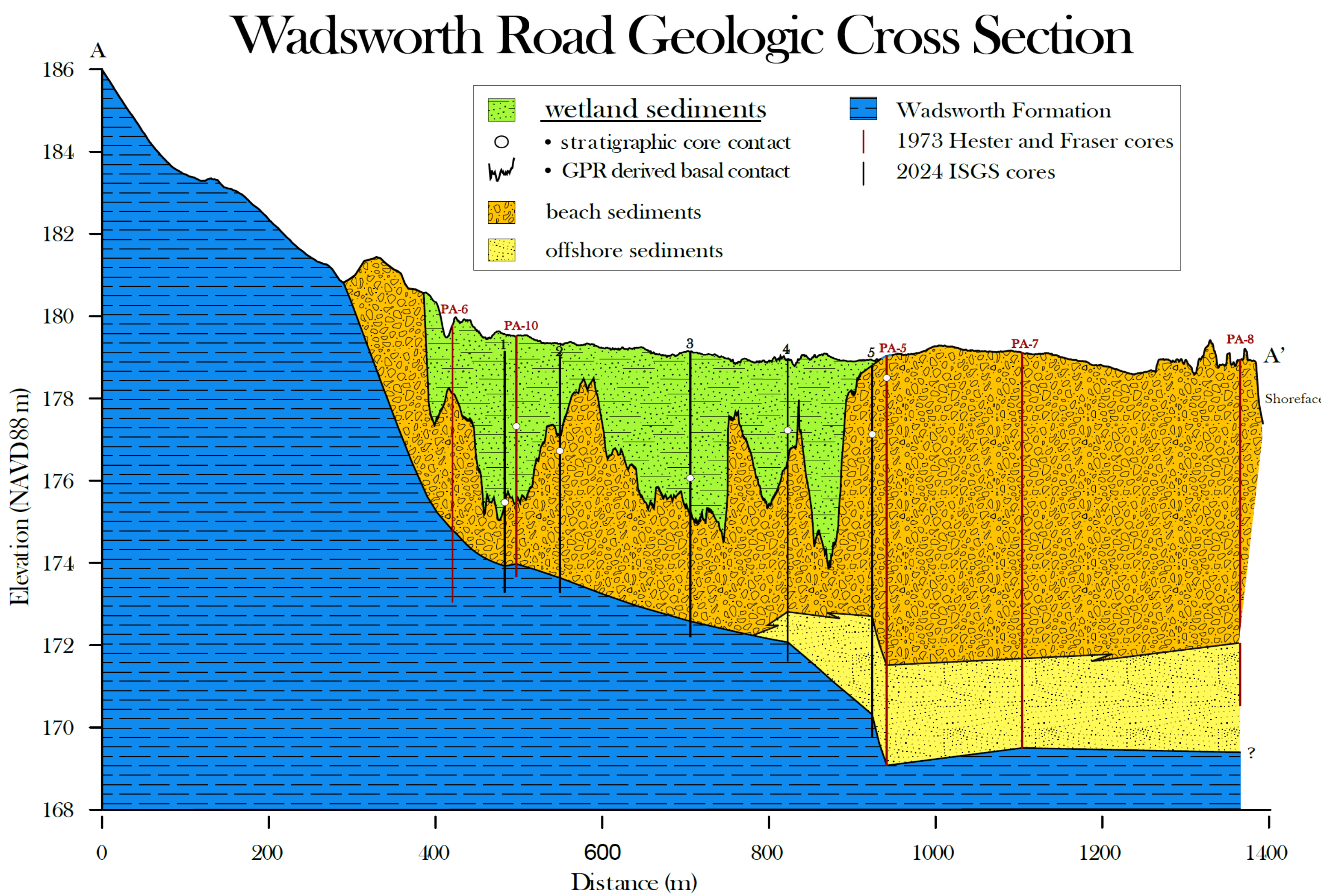


Figure 14 – Geologic cross section of Wadsworth Road, constructed from 2024 ISGS Geoprobe cores and archival information from 1970s stratigraphic assessments by Hester and Fraser (1973). The location of this cross section is Wadsworth Road, from bluff to shoreline, as shown in Figure 1b.

3.3. LAKE MICHIGAN HYDRODYNAMICS AND COASTAL CHANGE

Shoreline environments along oceanic margins have been more extensively studied from a geomorphic perspective than those of the Great Lakes. While both share hydrodynamic similarities (e.g., are impacted by waves and currents), there are noticeable differences that have yet to be thoroughly addressed from a coastal landform evolutionary perspective. Tidally driven (daily) versus climatically driven (seasonally and beyond) water-level oscillations are a major distinction.

3.3.1. Great Lakes Water-level Changes

We know much more about certain Great Lakes hydrodynamics than we do about their impact on sediment-transport processes and shoreline-change dynamics. Great Lakes water levels have been consistently measured by the US Army Corps of Engineers (USACE) from a network of gauging stations. Monthly average lake-level elevations, which have been derived from data from 1918 to the present, are referenced to the International Great Lakes Datum (1985). Patterns in lake-level variability over time are illustrated in **Figure 15**, which shows the following for the Lake Michigan-Lake Huron system: (1) The full 1918-2022 monthly record, and (2) seasonal variations over a year's time, based daily average lake-wide measurements. Seasonal lake-level oscillations, which are at the decimeter-scale (<0.5 m) and characterized by lows between January and March and highs between May and July (following snowmelt contributions), superimpose onto a meter-scale pattern of decadal fluctuation, measured at the meter-scale. Decadal fluctuations have ranged from 13 to 32 years, based on assessments by Watras et al. (2014), Hanrahan et al. (2010), and Wilcox et al. (2007). The most recent manifestation of the decadal lake-level signature, thought to connect to large-scale atmospheric circulation patterns and moisture fluxes (i.e., climatically driven), was linked to a transition from historical low-water level, in January of 2013, to a near-historical high-water level, in July of 2020. The associated change in water level was >1.5 m, not accounting for the seasonal component of variance (Figure 13). Lake-level reconstructions based on age dating of proxy deposits have resolved a quasi-periodic rise-and-fall pattern of around 160 ± 40 years in duration, upon which the shorter-lived cycles superimpose (Wilcox et al., 2007).

Elevated water levels are associated with greater shoreline damage and property losses across the Great Lakes coastal region, with a potential causal link between higher lake levels and wind-generated waves, both climatically driven (Meadows et al., 1997). This may be cause for concern, considering that hydroclimate forecasting models forecast increased average annual water levels for all U.S. Great Lakes (Kayastha et al., 2022). Regardless of future climate-change trajectories and therewith coupled lake hydrodynamics, a fundamental understanding of lake-level influences on coastal sediment routing and beach evolution must first be established to promote informed mitigation planning. It is important to mention here that lake-level change alone does not alter the coastal landscape from a sediment-transport perspective; it merely changes the space restrictions to sediment sequestration (i.e., sediment accommodation; Thompson and Baedke, 1995; Johnston et al., 2014). Meteorological events with winds capable of generating waves and currents are required to perform the mechanical work needed for shorelines to adjust to new equilibrium-profile conditions, as dictated by evolving lake-level conditions (Hands, 1984). Sandy supply can also help to modify coastal geomorphic response to a given lake-level change.

3.3.2. Storms and winter-ice covers

The cold-water season, between September and April, tends to be the most energetic on the Great Lakes. The maximum number of shoreline-damage reports from cyclonic storms occurs within November (Angel, 1995). This is when maximum wave heights and strong coastal currents are generated, although coastal aspect and location within context of wind fields and lake fetch conditions are important considerations for nearshore hydrodynamics (Booth, 1994). While wave periods tend to remain shorter along the Great Lakes, as compared to oceanic shorelines, maximum significant wave heights can exceed five meters (Hubertz et al., 1991). Angel and Isard (1998) resolved significant statistical increases in the number of strong cyclones (≤992 mb) for the cold season, over the 20th century.

The impacts that winter storms can have on shorelines also relates to lake level (e.g., seasonal lowering) and the presence of ice. Fetch reduction with increasing lake-ice cover lowers wave-generation potentials; studies have shown ice to provide an erosion buffer to shoreline environments (BaMasoud and Byrne, 2012). More direct impacts of ice on shorelines of the Great Lakes have also been documented. The role of anchor ice, which is grounded along shorelines, is discussed by Barnes et al. (1993, 1994), who also highlight the potential for scouring along nearshore-ice complexes. In such cases, wave energy can be deflected downward to attack lower-elevation portions of the beach profile. While an ice-armored shoreline may be held in place during this time, later profile adjustments driven by the winter-time losses of material from the base of the profile may translate into later shoreline recession. These geomorphic developments can be further facilitated by sand losses from beaches due to offshore rafting of sediment-laden ice upon breakup (Reimnitz et al., 1991; Miner and Powell, 1991; Kempema et al., 2001). The impacts of ice on shoreline-change dynamics, dependent upon meteorological conditions, are highly site- and winter-specific.

Ice and storm-related Lake Michigan hydrodynamic data are shown in **Figure 15**. A continuous record of daily ice cover, based on satellite data, extends to 1973, and is compiled by the National Oceanic and Atmospheric Administration (NOAA; Assel, 2003). Since detailed records have been kept, the Great Lakes have experienced a declining trend in ice cover (Assel et al., 2003; Wang et al., 2012). However, the lakes experience inter-annual variances in ice-cover thickness and extent. Lake Michigan, for instance, experienced its highest post-1973 maximum annual winter ice-cover extent in 2014, at >90% (by surface area); in 2012 and 2016, maximum annual winter-ice cover percentages were <20 (**Figure 13**). Lake ice represents a challenge to winter hydrodynamic data collection. Buoys are typically removed from the lake for the winter season. Researchers must then rely on wave-hindcast models, which are rooted in a variety of hydrodynamic and meteorological data and can inform on general wave conditions along parts of the coast where direct measurements are absent. **Figure 15** shows wind and wave roses based on 1979 to 2023 hindcast modeling for a station just offshore of IBSP. These highlight the impacts of wind alignment with lake fetch to increase wave height potentials; with > 400 km of lake fetch to the N/NE (in absence of ice), winds originating from this sector have the largest impact on SW lake margin wave- and current-related sedimentary processes (Booth; 1994). While winds with westerly components are more abundant, those originating from the NE play a much larger role in driving alongshore sediment routing (e.g., as evidenced by the net-southward littoral transport direction). Field photographs taken during winter-wave activity generated by N/NE winds are provided in **Figure 16**, which pairs imagery with corresponding wave-rose diagrams.

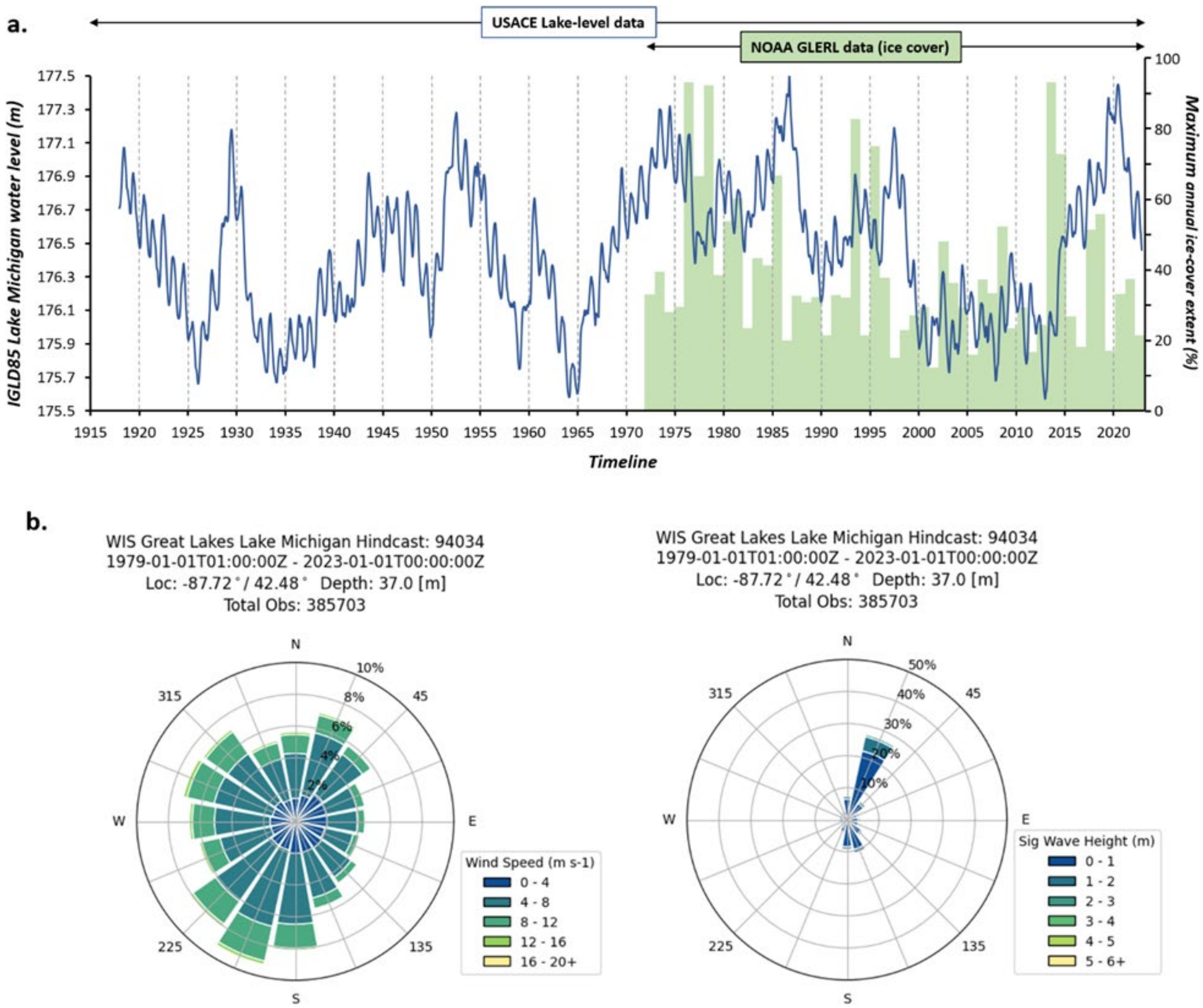


Figure 15 – Hydrodynamic information for Lake Michigan in the form of (a) Lake-level (in IGLD85 meters) and winter ice-cover maxima (as percent of total lake area) timeseries (based on USACE and NOAA data, respectively); and (b) rose diagrams for wind speeds and significant wave heights based on 1979-2023 hindcast modeling at Station 94034 (USACE Wave Information Systems [WIS]). Lake-level changes, based on lake-wide averaged monthly means (shown here), have been within a two-meter envelope; noteworthy is around 15-year period of depressed lake level (below the historical mean at ~176.5 m) from 2000 through 2014, which preceded a rapid rise from a historical low in January of 2013 (at 175.57 m) to a near-historical high (of 177.45 m) in July of 2020. The peak water-level condition was associated with widespread problems of coastal inundation and accelerated shoreline erosion/retreat along portions of the Illinois coast. Historical documentation reveals that similar problems occurred during equally high lake-level conditions of the recent past, including 1974 and 1986 peaks. While winds with a westerly component have dominated the historical record, winds blowing from the N/NE, across the axis of Lake Michigan (with >400 km of potential lake fetch), are responsible for the largest waves along the Illinois coast. These events, while infrequent (comparatively), are responsible for a net-southward littoral flux of materials.

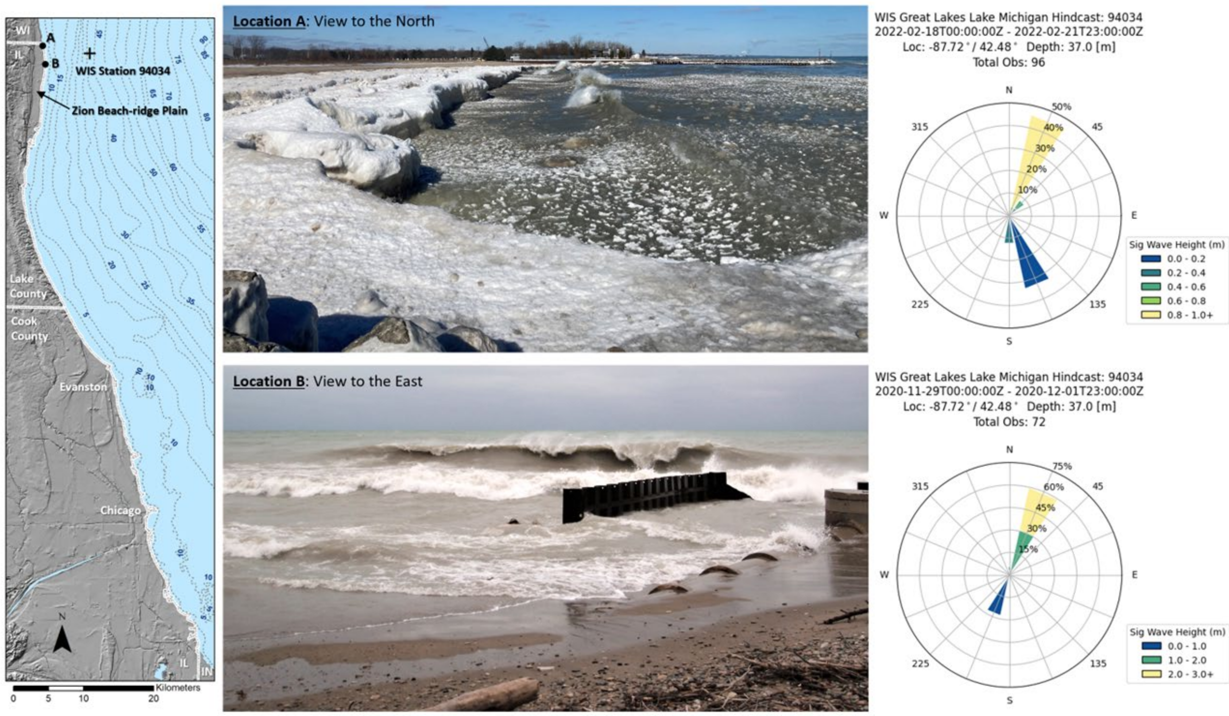


Figure 16 – Field photographs taken from Location A, at North Point Beach (near the state line with Wisconsin), and Location B, at the (former) Camp Logan shoreline (south of North Point Marina), on February 19th, 2022, and November 30th, 2020, respectively. A topographic hillshade map accompanies the photos and shows their respective locations, along with that of U.S. Army Corp Wave Information Study (WIS) Station 94034. The wave hindcast modeling results based on this location are shown as wave roses. The field photographs capture two of the shorelines monitored within Illinois Beach State Park at their most dynamic, undergoing changes resulting from wave, current, and ice impact. These conditions rarely exist during the summer months, when ISGS buoys and hydrodynamic instruments are in place offshore of Illinois Beach State Park; we thus rely on hindcast models such as those shown here, which take regional monitoring datasets and meteorologic/hydrodynamic principles into account.

4. ISGS-CGG SHORELINE-MONITORING METHODS

The Illinois State Geological Survey (ISGS), partnered with the Illinois Department of Natural Resources' (IDNR) Coastal Management Program (CMP) since 2015, began shoreline mapping and monitoring activities at IBSP in 2018. Monitoring-site establishment was based on areas impacted by post-2013 lake-level rise (**Figure 15**). Additional sites were added over time, leading to a system-wide analysis of coastal change using aerial drone (sUAS) and sonar-based techniques, data from which are combined into seamless topobathymetric data products (**Figure 17**). Since 2018, The ISGS's mapping and monitoring efforts have evolved to include ten sites (**Figure 18**) that are surveyed at varying time frequencies and spatial extents (**Table 1**). The site locations include all accessible and unhardened beach shorelines of IBSP, the municipal beach at Hosah Park (of the city of Zion), and Waukegan's North Beach, formed by sand trapping against a harbor jetty. The scope of the ISGS's monitoring extends from slightly beyond the furthest landward extent of lake influence, such as maximum overwash extent or wetland vegetation line, to nearshore water depths of approximately five meters. The lakeward sloping shoreface gradually transitions to a more level lake bottom here, with a depth of closure at ~6 meters. An annual sonar survey, with an 0.5-km shore-perpendicular transect spacing, connects all beach-survey sites with nearshore bathymetric coverage to ~1.5 km offshore (**Figure 19**).

ISGS coastal datasets complement those of federal data-collection programs, which, while offering extensive, high-resolution coverage, do not provide the temporal resolutions needed to study many coastal hydro- and morphodynamic processes. While programs such as the U.S. Army Corps of Engineers' (USACE) Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) provides unparalleled regional topobathymetric coverage at high spatial resolution and accuracy, these datasets are only collected once or twice a decade along many parts of the Great Lakes. This does not provide the temporal resolution necessary for coastal managers and policymakers to address ongoing coastal changes effectively. From a scientific perspective, this data resolution also fails to offer insights into the coastal change dynamics associated with shorter lived hydrodynamic events, from individual storms to sub-decadal lake-level change, which can meter-scale. Topobathymetric LiDAR data from the U.S. Army Corps of Engineers (USACE) were collected along the Illinois coast in 2008, 2012, and 2020. Many important processes, such as vegetative recruitment and foredune formation, have been observed over these gap periods, rendering frequent data collection (e.g., biannually) necessary for comprehensive analyses. As no federal data have been gathered since peak lake levels (in 2020), beach managers and policymakers lack up-to-date information to evaluate beach conditions amidst approximately one meter of lake-level decline (through 2024; **Figure 15**).

In addition to supplementing the temporal resolution of federal datasets (e.g., coastal LiDAR-derived DEMs), ISGS coastal datasets also address potential spatial data gaps. Gaps in data coverage may be present in the inner-nearshore in federal datasets and are due to difficulties with data collection (e.g., limited vessel access due to shallow water and incapability of LiDAR to penetrate turbid water). The British Geological Survey was the first to identify and name this gap the ‘White Ribbon,’ which appears as a white space between topographic and bathymetric data on DEMs. Data collection in this area is important to shoreline studies because it is highly dynamic; waves interact with both the inner-nearshore lake bottom and the adjacent beach face, which can lead to significant geomorphic changes over relatively short periods of time (from the event-scale onward).

ISGS monitoring techniques address the limitations of federal datasets by employing data collection at fine-scale temporal frequencies (e.g., monthly) and utilizing methods that produce high-resolution, seamless topobathymetric models, effectively eliminating any 'White Ribbon' data gaps. The combination of ISGS and federal datasets allow for assessment of the impacts of: (1) various hydrodynamic events, from storms to seasonal through multi-year lake-level changes; (2) differences in the terrain and composition of the lake margin, including how these factors affect sand supply dynamics; and (3) different engineering solutions for mitigating shoreline erosion and enhancing sand retention, such as submerged versus emergent breakwaters at IBSP (**Figure 20**).

4.1. Data Acquisition, Processing, and Integration

Traditional methods for examining coastal topographic change utilize historical shoreline reconstructions from maps and charts, which provided a 2D map-view depiction of the lake-land interface. More detailed information on volumetric changes at various shoreline positions are typically provided through shoreline-perpendicular transects, along which beach and nearshore elevations are measured. The primary data-derivative products of ISGS monitoring activities are: (1) orthomosaics and DEMs of the landward extent (2) seamless topobathymetric DEMs, and (3) net-vertical change models, constructed by subtracting older DEMs from younger DEMs (**Figure 21**). These products show 3D patterns of accretion and erosion across survey sites, over event-based, seasonal, interannual, and multi-year periods. The process of generating a single topobathymetric DEM requires the integration of different data types (e.g., topographic DEMs and bathymetric point data), each collected at high geospatial precision and involving refined workflows for acquisition, processing, and integration. The full dataset, which continues to grow with ongoing monitoring and frequent additions, provides the data coverage necessary to assess sand-transport patterns and associated volumetrics.

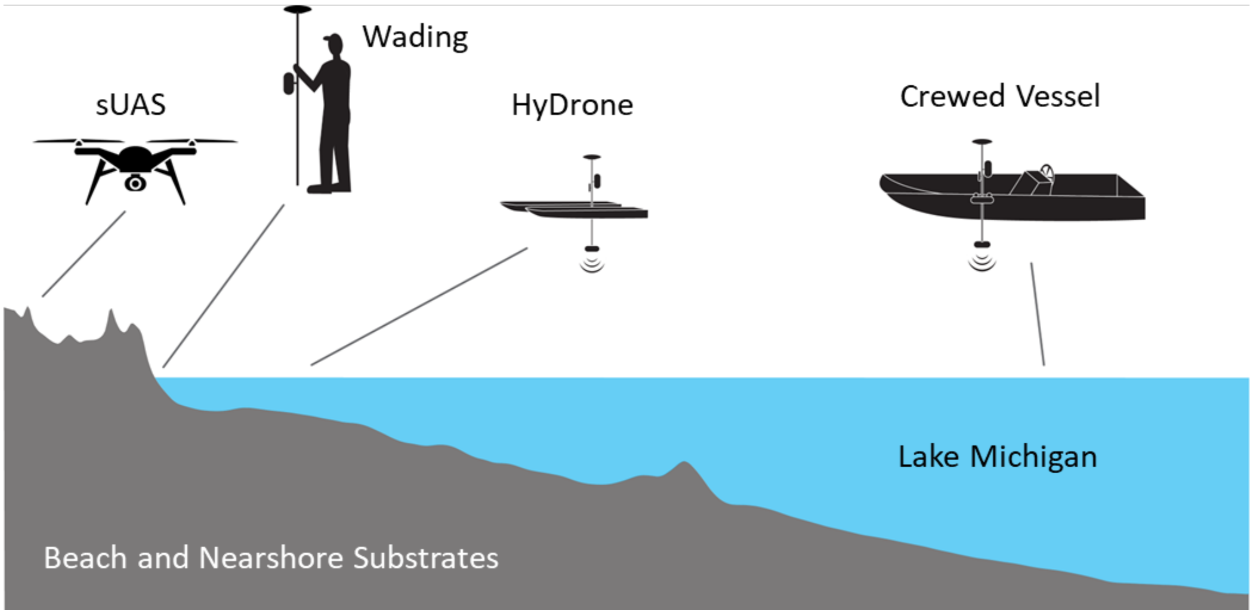
The following paragraphs detail the elements for each data type and discuss the methodology for data acquisition, processing, integration, and analysis. Second-order data products, derived from first-order data products such as raw images, consist of: (1) spatially referenced aerial ortho-mosaics, (2) digitized shoreline positions, (3) topographic DEMs, and (4) processed sonar-based point layers of lake-bottom elevations**.** These data are published and made readily available through the Illinois Geospatial Data Clearinghouse **(https://clearinghouse.isgs.illinois.edu/).**

The monitoring approach is the same for all sites. The subaerially exposed beach terrain is mapped by small uncrewed aerial system (sUAS). The 'drone' flies along preplanned flight grids that are re-occupied with each survey (**Figure 18**). High-resolution images of the beach terrain are taken perpendicular to flight path, at approximately 80% overlap (side and front), providing multiple vantage points of the same terrain between neighboring images. Prior to the aerial survey, ground truthing is conducted by placing ground-control points (GCPs) along the length of the beach in a zig-zag pattern. These points are surveyed with RTK-GPS (real-time kinematic) using a correction service, either Trimble VRS Now or RTX. This method achieves sub-5cm horizontal and vertical precision at each GCP location and provides the geospatial constraints for digital elevation model (DEM) creation. Structure from Motion (SfM) Photogrammetry is then used to construct 3D point clouds and topographic DEMs from raw aerial images. This approach has found widespread application for mapping and monitoring coastal terrains (Mancini et al., 2013; Brunier et al., 2016; Conlin et al., 2018).

Lake-bottom elevations are measured using a combination of (1) wading surveys, across areas <0.5 meters in water depth, and (2) single-beam sonar, either deployed from small 'drone-boat' vessels controlled remotely from shore (across water depths of up to 5 meters), or from a crewed vessel, the 17' Boston Whaler 'RV Abigail' (**Figure 19**). All surveys are integrated with RTK-GPS, which pairs each sonar depth with a high-precision GPS point (see above for parameterization). The 'drone' vessel system collects data in the inner nearshore along transects spaced at ~25 m apart and ~100-150 m long for the entire length of the site. The crewed vessel system collects data in the outer nearshore spaced at ~500 m apart and ~1.5 km long (**Figure 19).** All coupled sonar depth and GPS readings are analyzed for erroneous points (e.g., that fall outside a normal range of bedform geometry). These are eliminated from the dataset.

Estimated vertical accuracies of topographic and bathymetric DEMs are within a decimeter. This error compounds over the construction process for data-derivative products (e.g., net-vertical change assessments), which must be considered in assessments of vertical change patterns and sand volumetric analyses. Only the vertical accuracies of data points coupled to RTK-GPS (i.e., GCPs and individual sonar data points) may be guaranteed, which helps inform estimated vertical accuracies of derivative models.

Shorelines digitized from orthoimages, at 1:250 scale, are used to couple onshore and offshore DEMs (generated from SfM Photogrammetry and sonar point-value interpolations, respectively). All topobathymetric data (drone and sonar-based) is collected within a two-week window to guarantee meaningful assembly of seamless models crossing the 'white ribbon.' Model subtractions (of older from younger) are used for creating net-vertical change models which reveal patterns of geomorphic change for a particular timespan (e.g., year to year) and allows sand volumetric analyses to be conducted (e.g., quantifying shoreline-overwash volumes). Analytical resolutions are reliant upon survey frequencies; while aerial drone surveys are performed monthly at priority IBSP sites, for instance, full topobathymetric data coverage is provided biannually at most individual sites and annually along the Zion Beach-ridge Plain (WI-IL border to Waukegan Harbor; **Table 1**).



Method	General Coverage Extent	Elevation Derivation
UAS	Exposed beach	Photogrammetry
Wading	Swash zone, shoreline, innermost nearshore (up to ~0.5m depth, ~25m transect spacing)	RTK-GPS
HyDrone	Inner nearshore (greater than ~0.5m depth, within ~200m from shore, ~25m transect spacing)	RTK-GPS & Single-beam sonar
Crewed Vessel	Nearshore (greater than ~2m depth, up to ~1.5km from shore, ~0.5km spacing)	RTK-GPS & Single-beam sonar

Figure 17 – A figure illustrating ISGS data-collection methods and locations for topobathymetric surveying, including sUAS (small unmanned aerial systems, aka drones), wading, HyDrone (a remotely controlled 'drone' boat), and crewed vessel. Accompanied by a table that provides information on each data-collection method.

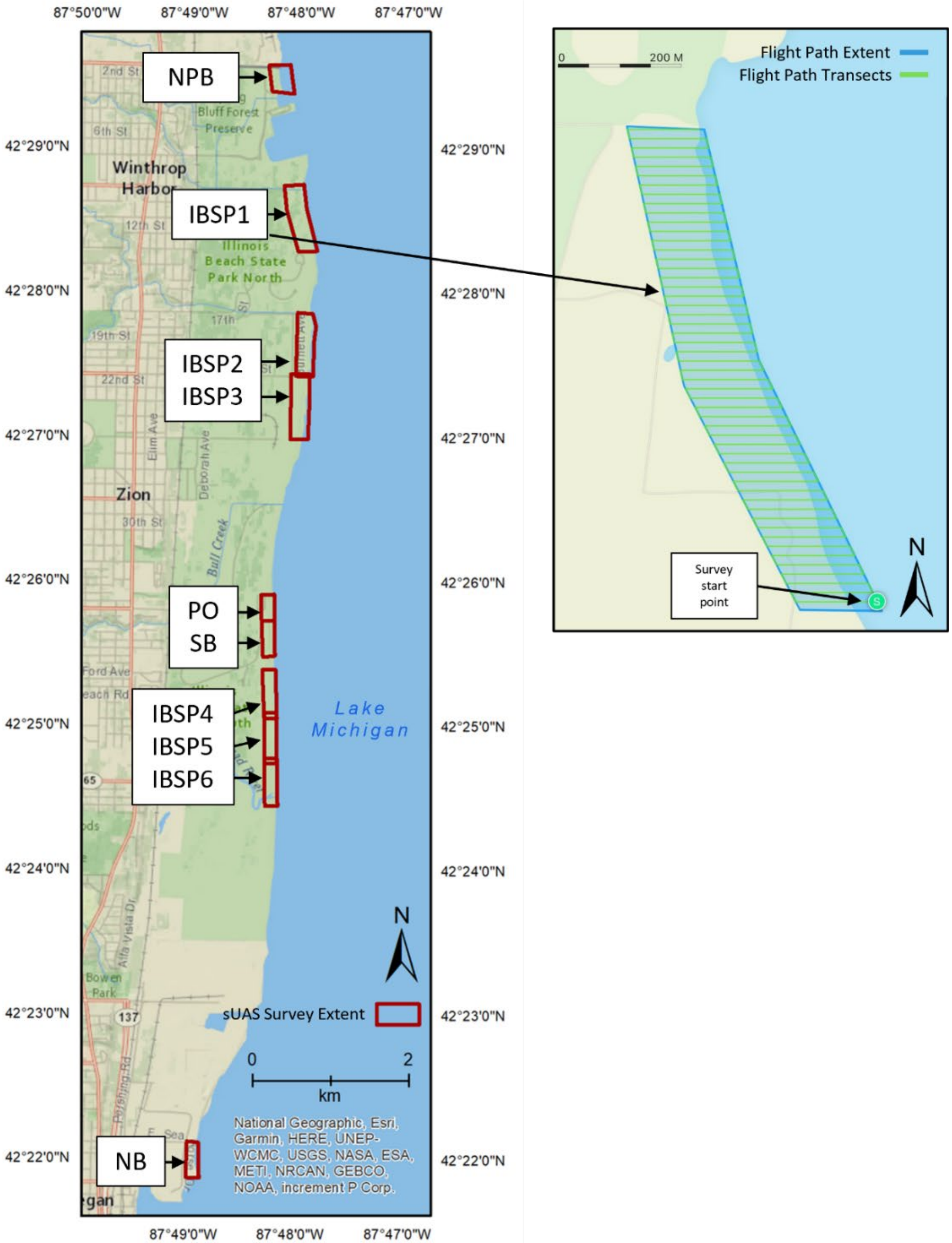


Figure 18 – Map of the Illinois portion of the ZBRP showing ISGS shoreline-monitoring locations, along with an inset map depicting the aerial drone (UAS) flightlines for image acquisition (for Structure from Motion Photogrammetry and DEM creation).

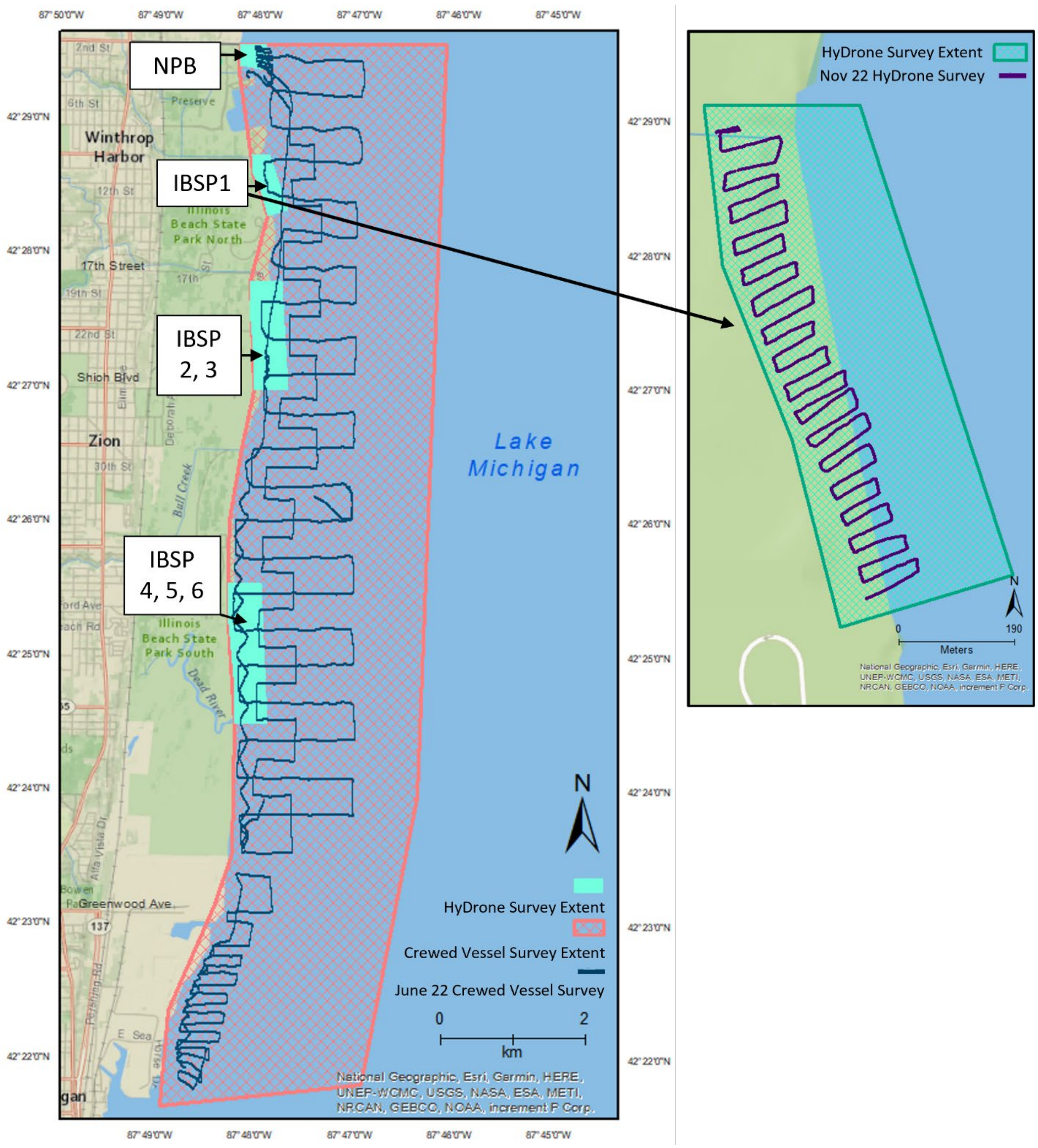
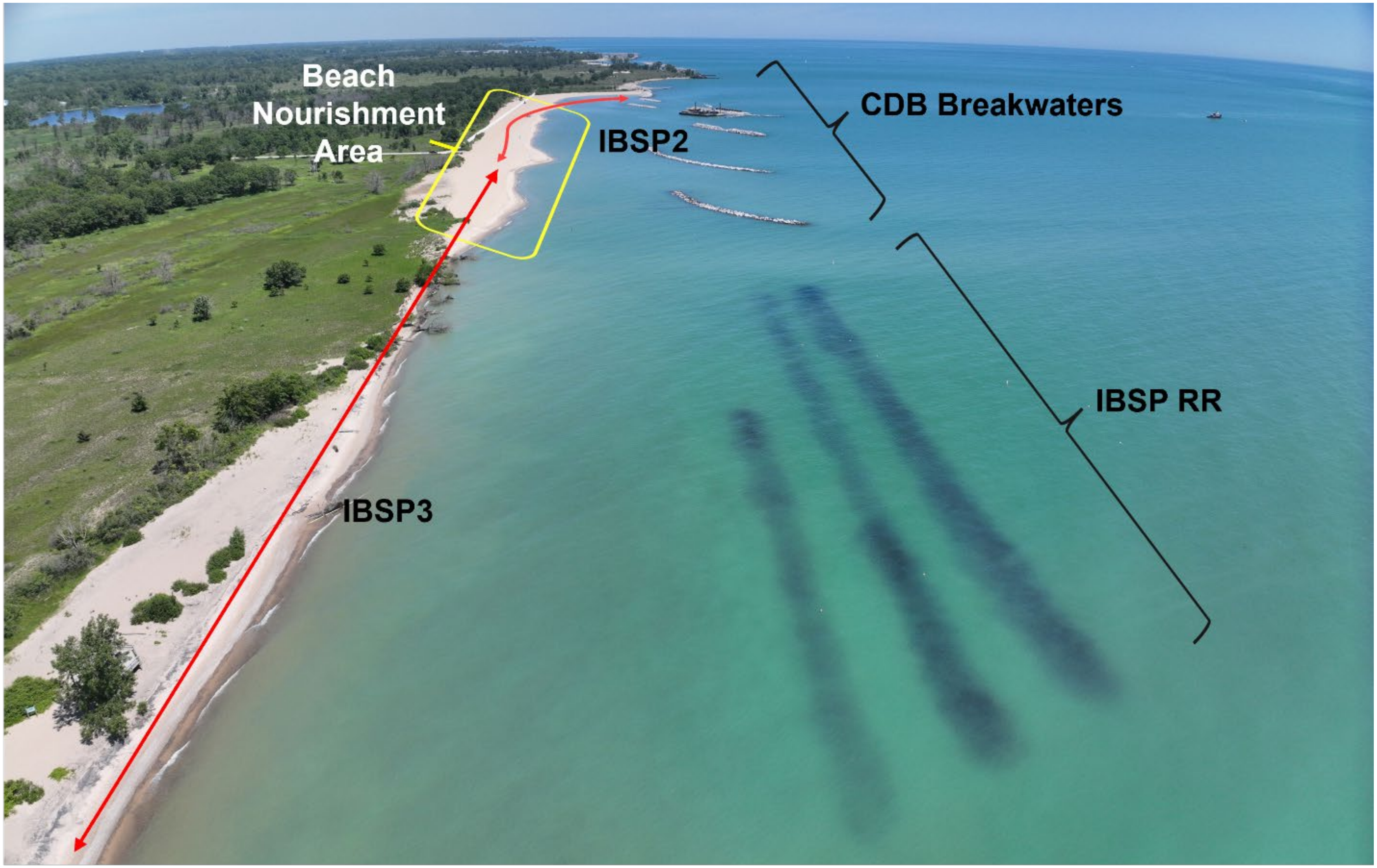


Figure 19 – Map of the Illinois portion of the ZBRP showing a year's coverage of offshore sonar data, acquired close to shore using a remotely controlled vessel (see inset map) and across an offshore grid of 0.5 km spacing between shoreline-perpendicular transects using a crewed vessel. All surveys are single-beam sonar (SBES).

Site Name	sUAS Monitoring Frequency	Bathymetric Monitoring Frequency
IBSP1	Monthly	Biannually (Mar-Apr/Oct-Nov)
IBSP2	Monthly	Biannually (Mar-Apr/Oct-Nov)
IBSP3	Monthly	Biannually (Mar-Apr/Oct-Nov)
IBSP4	Monthly	Biannually (Mar-Apr/Oct-Nov)
IBSP5	Biannually (Mar-Apr/Oct-Nov)	Biannually (Mar-Apr/Oct-Nov)
IBSP6	Biannually (Mar-Apr/Oct-Nov)	Biannually (Mar-Apr/Oct-Nov)
NPB	Biannually (Mar-Apr/Oct-Nov)	Biannually (Mar-Apr/Oct-Nov)
SB	Biannually (Mar-Apr/Oct-Nov)	None
PO	Biannually (Mar-Apr/Oct-Nov)	None
NB	Biannually (Mar-Apr/Oct-Nov)	None
Whole Extent	N/A	Annually (May-June)

Table 1 – Information on sUAS and bathymetric monitoring frequencies for each ISGS-CGG site. Sites IBSP1 through IBSP6 refer to sites within IBSP. Sites NPB, SB, and PO refer to North Point Beach, Swimming Beach, and Park Office, respectively, which are also located within IBSP. Site NB refers to North Beach located near Waukegan Harbor, which is not within IBSP, but is part of the same littoral system (i.e., the ZBRP). IBSP1 through 4 have a targeted monthly sUAS monitoring schedule, and 5 and 6 are surveyed biannually. Biannual bathymetric surveys via HyDrone at IBSP1-6 and NPB occur over two months, usually March through April for post-winter monitoring, and October through November for pre-winter monitoring; these bathymetric surveys are paired with sUAS surveys and wading surveys (when needed) to generate seamless topobathymetric models. Sites NPB, SB, PO, and NB are surveyed via sUAS biannually (March-April and October-November). A bathymetric survey of the entire shoreline extent is conducted annually via crewed vessel. This occurs during the summer months (between May and August). Survey schedules are dictated by lake conditions and other logistical considerations. For site boundaries and locations, refer to Figure 18.



c

Figure 20 – ISGS CSG-derived oblique aerial image of CDB breakwaters and beach nourishment area at IBSP2, IBSP3, and IBSP RR project sites. IBSP RR indicates the site of the Rubble Ridge structure offshore of IBSP3 (Hosah Park), part of a Healthy Port Futures (HPF) project area. Aerial image is from a June 16th, 2024, sUAS survey.

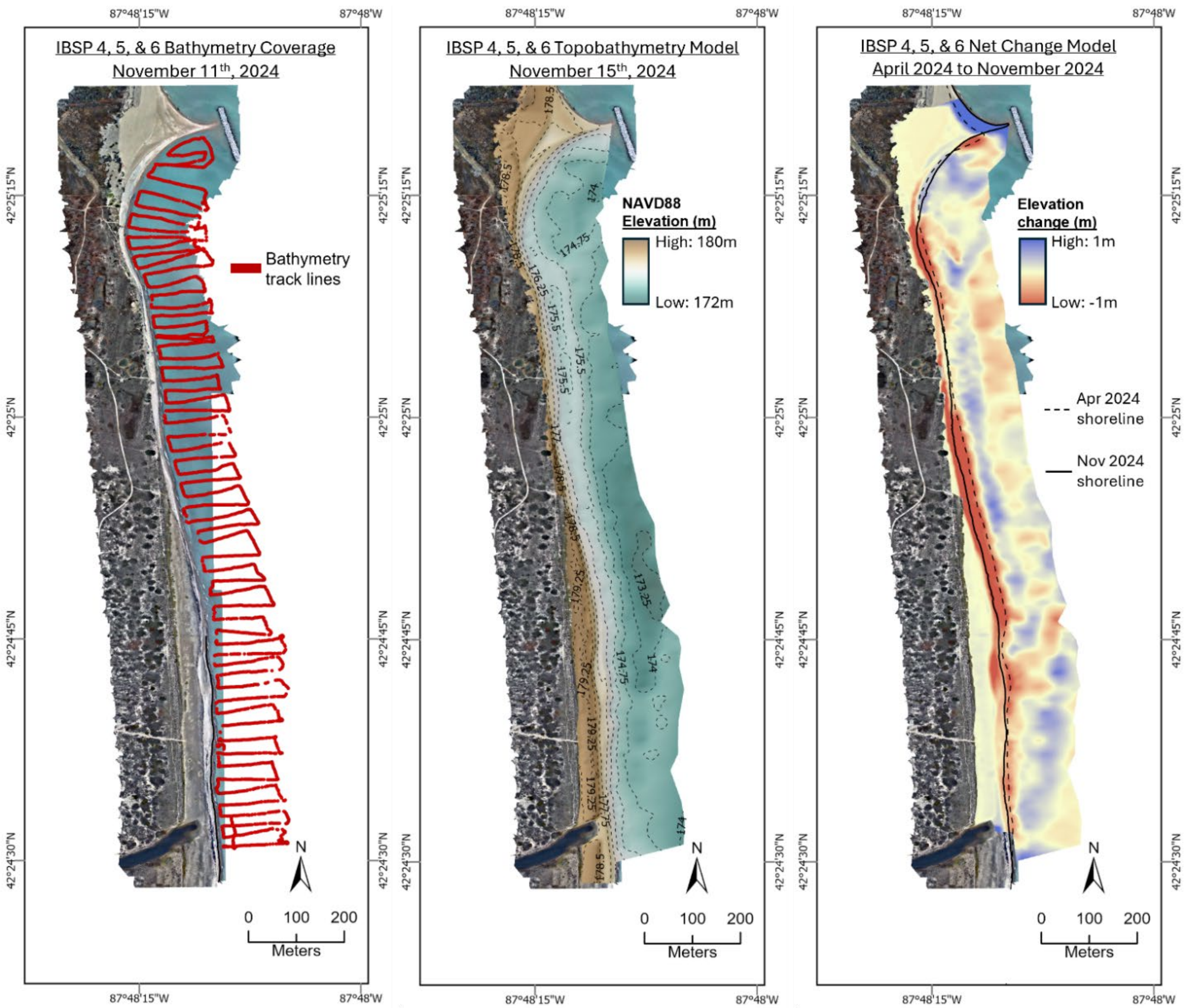


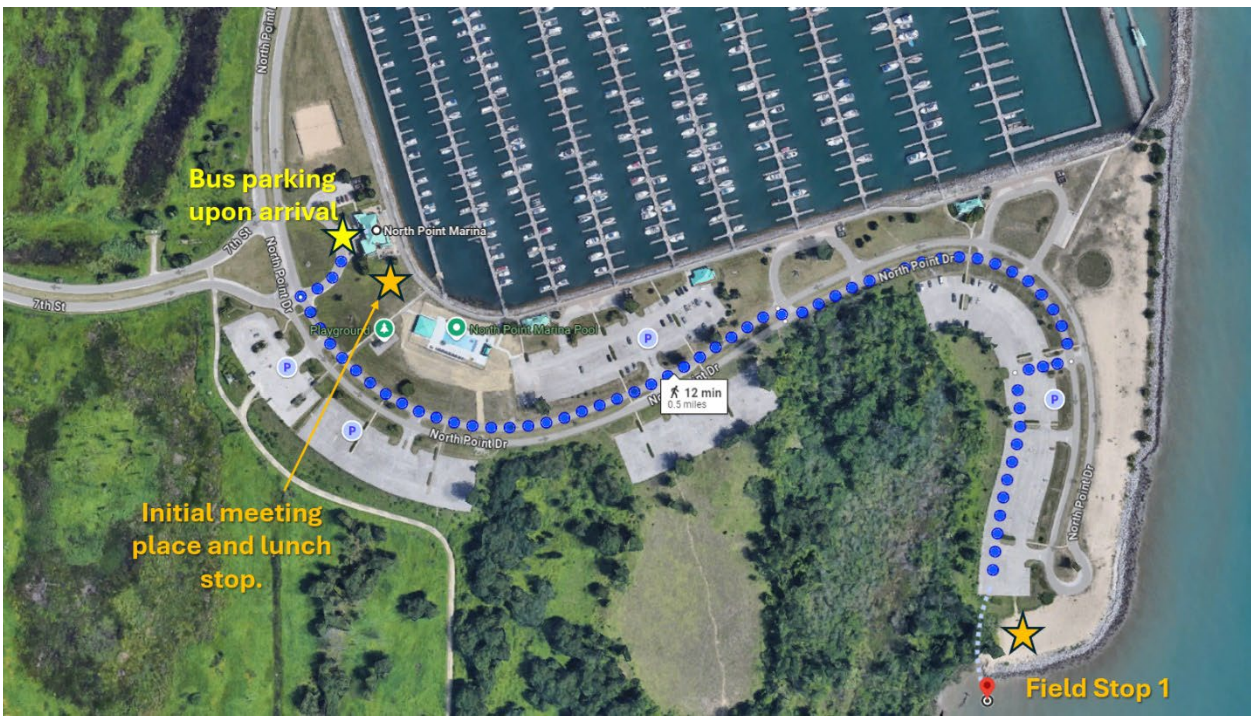
Figure 21 – Multi-panel figure showing raw data and derivative models at IBSP4, IBSP5, and IBSP6: (**left panel**) single-beam sonar tracks (in red; 25m transect spacing) and orthomosaic collected November 15th, 2024, (**middle panel)** topobathymetric model generated from single-beam sonar data and DEMs collected during November 2024, and (**right panel**) a vertical net-change model, made by subtracting April and November topobathymetric models, and shoreline positions during the dates of data collection. Construction of the CBD breakwaters and beach nourishing (see Figure 20) occurred just north of the survey extent shown here. The terminal breakwater is east of the northern extent of the orthomosaic.

5. FIELD TRIP OUTLINE AND TIME SCHEDULE

A) **10 AM: Arrive at North Point Marina – Introductions/background (45 minutes)**

- Restrooms in marina building (upon arrival from Chicago), then assembly in beer garden outside of marina building (seating).
- Overview of the regional geologic framework.
- Overview of Great Lakes hydrodynamics and the challenges of studying/monitoring a dynamic Great Lakes shoreline.
- Overview of ISGS monitoring activities at Illinois Beach State Park.

B) ***TRAVEL to FIELD STOP 1***: Short Walk (10-15 minutes) along the marina basin (0.5 miles) to an overlook of IBSP1 (south end of the marina). Vehicular travel arrangements can be made upon request.



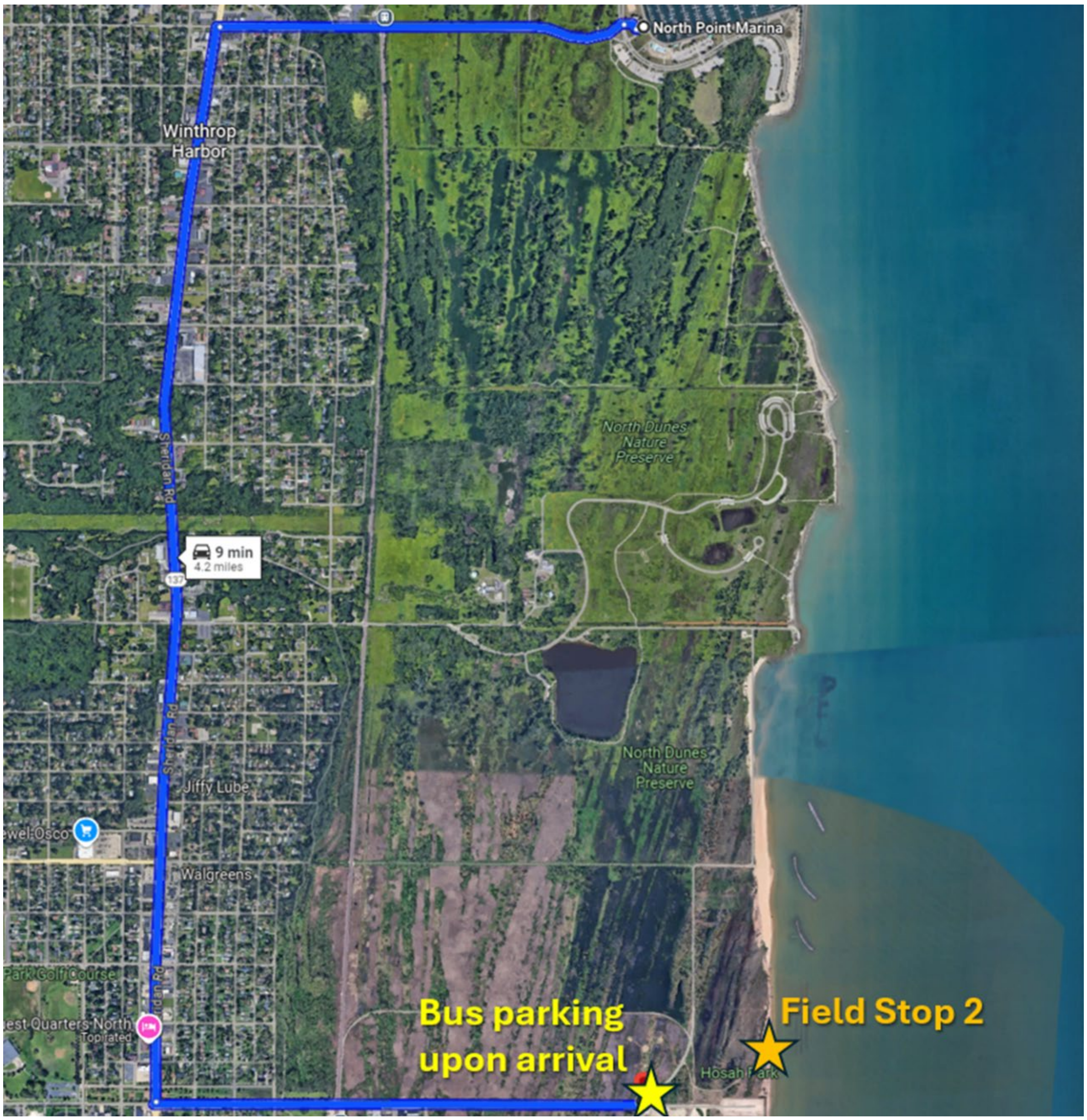
C) **11 AM: FIELD STOP 1 – NPM Overlook/ISGS IBSP-1 Site (45 minutes duration)**

- History of North Point Marina and the feeder beach to the south.
- Historical shoreline trends and late Holocene context.
- 2012-2020 shoreline retreat and sand volumetric losses.
- Intro to the State Capital Development Project: Breakwaters & nourishment.
- UAS and bathymetric equipment highlight.
- UAS deployment for group photo (Spitzer).

D) ***<u>TRAVEL to NORTH POINT MARINA BEER GARDEN</u>*: ** Short Walk (10-15 minutes) back to the picnic area for boxed lunches.

E) **NOON:** Lunch and restroom break at North Point Marina Beer Garden **(45 minutes)**.

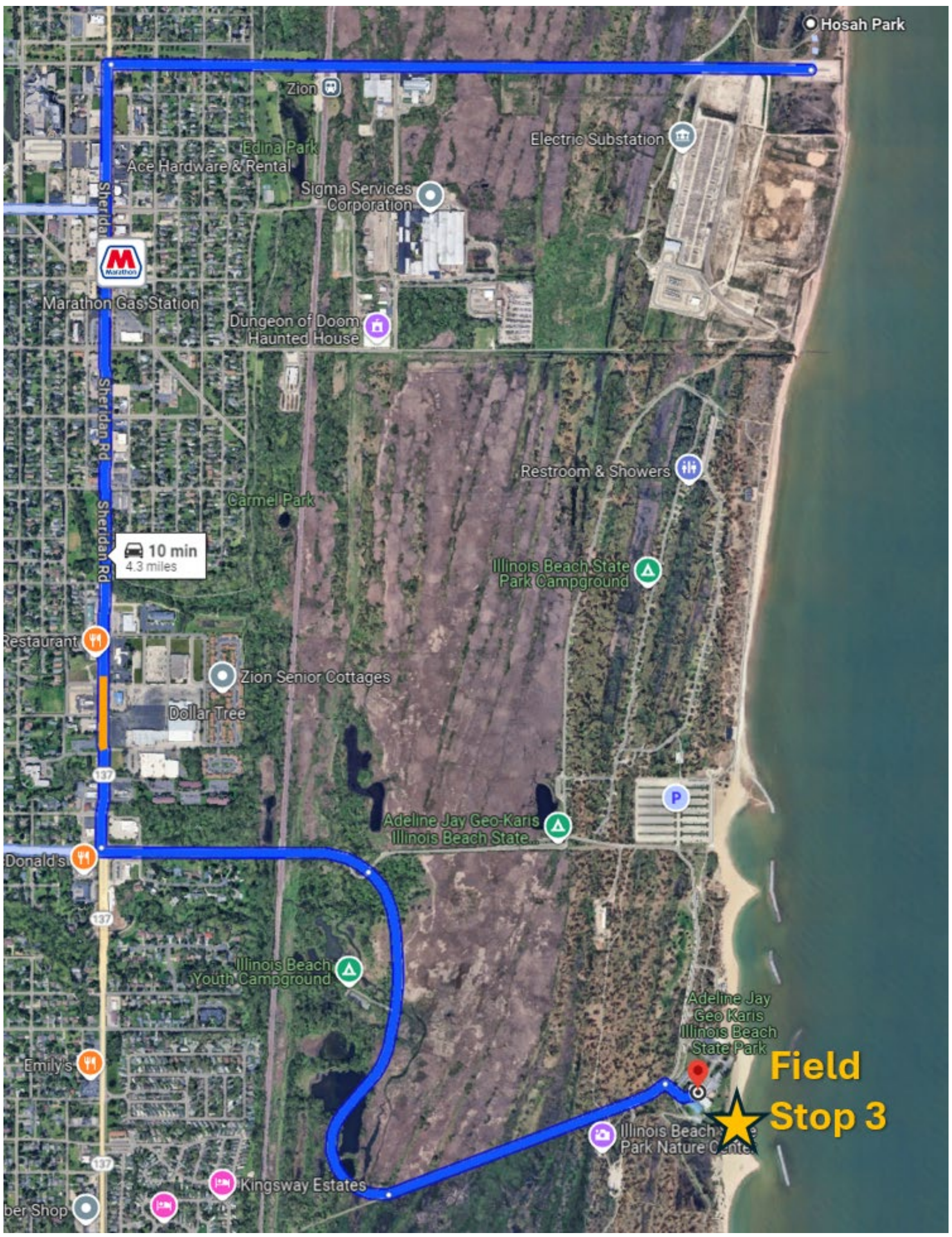
F) ***<u>TRAVEL from NORTH POINT MARINA to FIELD STOP 2</u>***, *<u>Hosah Park,</u>* by bus, following ISGS vehicle (**15 minutes).** This Field Stop is a short walk on level, paved ground from the parking lot (where the bus can park) to the beach access point.



G) **1 PM: FIELD STOP 2 – Hosah Park (1 hour duration)**

- Short walk to overlook platform and beach, view of DNR signage along the way (5-10 minutes).
- Background on GLRI-HPF project (30 minutes).
    - o Significance of reef design.
    - o Site selection (ecological importance of the wetlands).
    - o Monitoring design and project overview.
- Discussion of hydro- and alongshore sand-transport dynamics.
- Short walk-up beach with open discussion (15-30 minutes).
-

H) ***<u>TRAVEL from Hosah Park to Illinois Beach South Unit and FIELD STOP 3</u>***: 10 minutes.



(I) **2:15 PM: STOP 3 – IBSP 4,** by way of Nature Center parking lot – **restroom stop (1.5-hour duration). Bus pickup after this stop will be at the Illinois Beach Hotel and Conference Center (if no parking opportunity presents itself at the Nature Center).**

- Alongshore sand-transport dynamics and developments in lee of the terminal breakwater, with implications for the last remaining stretch of 'natural' beach shoreline in Illinois.
- 2012 through present: Foredune development and destruction; water-level changes and other hydrodynamics versus infrastructure-related morphodynamics.
- Buried infrastructure and legacy of human activities.
- Geophysical mapping activities (for improved subsurface characterization) and heavy mineral sands.
- Beach walk down the last remaining stretch of natural shoreline in Illinois (southward), towards the Dead River Mouth.

6. FIELD TRIP VISUALS AND SITE-SPECIFIC INFORMATION

While we will be addressing geomorphic changes at specific locations along the IBSP shoreline, we wish to begin this section with an overview of how these different sites connect, from the sand-transport perspective. Of particular interest, as informed by >7 years of monitoring, is the placement of nearshore bars. Longshore bars and troughs are natural bathymetric features along sandy, wave-dominated shoreline systems of the Great Lakes. Waves tend to break further lakeward from the shoreline along coasts with nearshore bars, which dissipates energy before reaching shore and reduces the impact on the shoreline. Longshore bar systems, which trend shore-parallel, undergo changes in placement with seasonal differences in lake level and storm climate. Individual bars can extend for tens of kilometers, if unobstructed (Saylor and Hands, 1970). A continuous longshore sandbar is recognized from the 2020 LiDAR data from along unobstructed sections of the IBSP shoreline. It extends from Site IBSP2 to Waukegan (**Figure 22**)**.** Data from ISGS shoreline monitoring suggests a deviance from this dynamic with the 2021-2024 construction of submerged rubble-mound ridges and twenty-two emergent breakwaters. The impacts on future shoreline-change trajectories is not yet clear; but will be elucidated with ongoing geological monitoring. While we will provide detailed information on each site visited, the field trip attendee is encouraged to refer back to **Figure 22** for a regional context for the dynamics described for a specific site. Furthermore, the longer-term late Holocene evolutionary patterns, as shown in **Figures 12** and **13**, are to be considered as well.

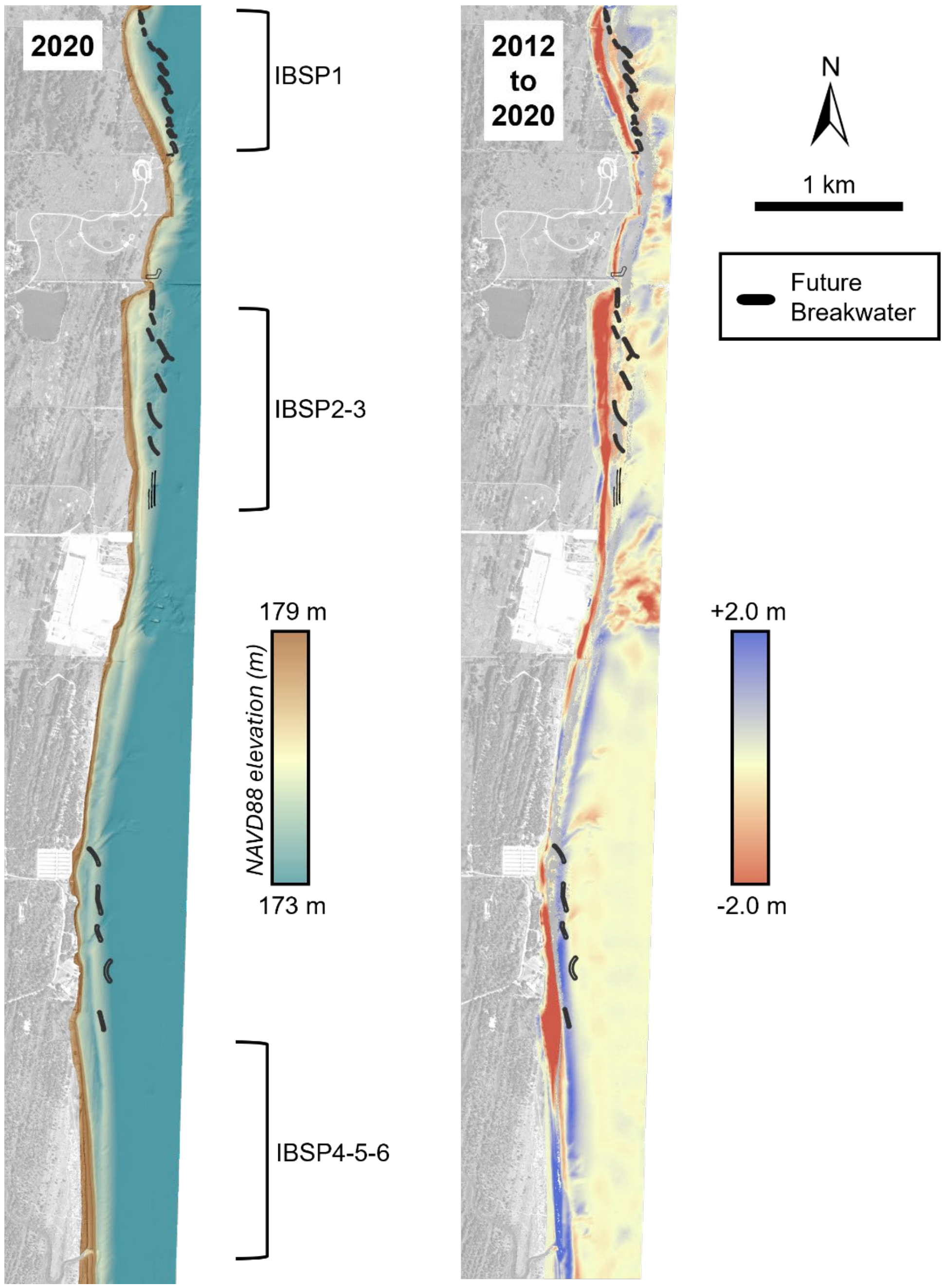


FIGURE 22 – Multi-panel display showing 2020 LiDAR bathymetric data (left) and geomorphic change model based on LiDAR bathymetric data from 2012 to 2020 (right). The position of the longshore bar is seen in the 2020 LiDAR (left), from IBSP2 to Waukegan. The breakwaters were not yet constructed, but their future locations are shown to be in the most dynamic part of the system in 2020. Areas of 2012-2020 erosion are highlighted in deep red, with accretionary areas shaded blue. The pattern of change is reflective of the southward transport of sand.

STOP 1: Winthrop Harbor Beach (a.k.a. ISGS Monitoring Site 'IBSP1')

The area immediately south of the North Point Marina complex has been a point of concern since its initial construction. Used in the immediate post-marina construction years as a feeder beach for placement of sand that would migrate southward over time (in direction of prevailing littoral transport), this ~1 km-long stretch of sandy beach coast has showed tendencies towards evolving towards a log-spiral shoreline configuration. The highest rates of coastal retreat have been marina proximal, owing to focused wave attack due to refraction along the infrastructure during the largest wave events (with N/NE approach; Booth, 1994). A submerged breakwater was emplaced along this part of the marina complex to help protect the infrastructure. In 2023, a series of emergent breakwaters were emplaced, and the beach was nourished to aid recovery after lake-level rise-induced acceleration of coastal retreat. The lake-level highstand terrain, pre-breakwater construction and nourishment is shown in **Figure 23**.

Rates of shoreline retreat at this site have been the highest along IBSP, particularly in the direct lee of the harbor infrastructure. Shoreline reconstructions based on historical aerial photographs (1939 to 2019) provide a decadal context for more recent shoreline changes, captured in ISGS drone-based datasets. **Figure 23** shows a subset of shorelines mapped by the ISGS. In total, more than fifty shoreline positions are traced at this site from sUAS-derived orthoimages, supplemented with NAIP imagery dating back to the late 1930s, which offers a longer-term context for recent observations. The maximum shoreline retreat from 1939 to 2019 was ~250 meters, at an average rate of ~3 m/yr. More than seventy-five meters of retreat occurred in the lee of the marina complex from 2012 through 2020, nearly doubling the historical retreat rate. Retreat rates and acreage loss have been time-variable, in part due to lake-level changes. Between 1939 and 2023, average rate of land loss was about 1,600 m^2/yr or 0.4 acres/yr. Rising water-level conditions tend to accelerate coastal retreat rates. Between November 2019 and August of 2020, around the time of peak decadal water level, the rate of land loss was 20,000 m^2/yr or close to five acres/yr.

Between 2012 and 2020, >45,000 m^2 (>11 acres) of ridge-plain terrain, both ridges and wetland swales (that obliquely meet the shoreline), were eroded by coastal retreat (**Figure 24**). This resulted in the liberation of >125,000 m^3 of sand (from between 2012 and 2020 shoreline positions), as assessed from federal LiDAR-based DEM datasets. Little of this material wound up as overwash, which can still be seen in today's landscape. These deposits infilled portions of wetland swales, which along this part of the Zion Beach-ridge Plain trend shoreline-oblique. This is especially the case south of North Point Marina (IBSP Site 1), where heavy shoreline retreat has since marina construction attenuated the difference between modern shoreline orientation and that of beach ridges, which are reflective of shoreline trends of the past.

The Illinois State Capital Development Project emplaced ten emergent breakwaters in a chain across the nearshore at IBSP1, with the northernmost shore-attached to the terminus of North Point Marina breakwater infrastructure. Construction began and was completed in 2023. The breakwaters are N/NE-facing and appear shingled against the wave-approach direction most impactful to erosion and littoral sand transport (Booth 1994; **Figures 14, 15**). Beach nourishment accompanied the construction, with around 77,000 m^3 of sand placed (**Figure 25**). ISGS topobathymetric monitoring has shown that the shoreline has been stable since construction of the breakwaters and nourishment was completed, with few adjustments to the constructed shoreline between 2023 and 2024 surveys (**Figure 26**).

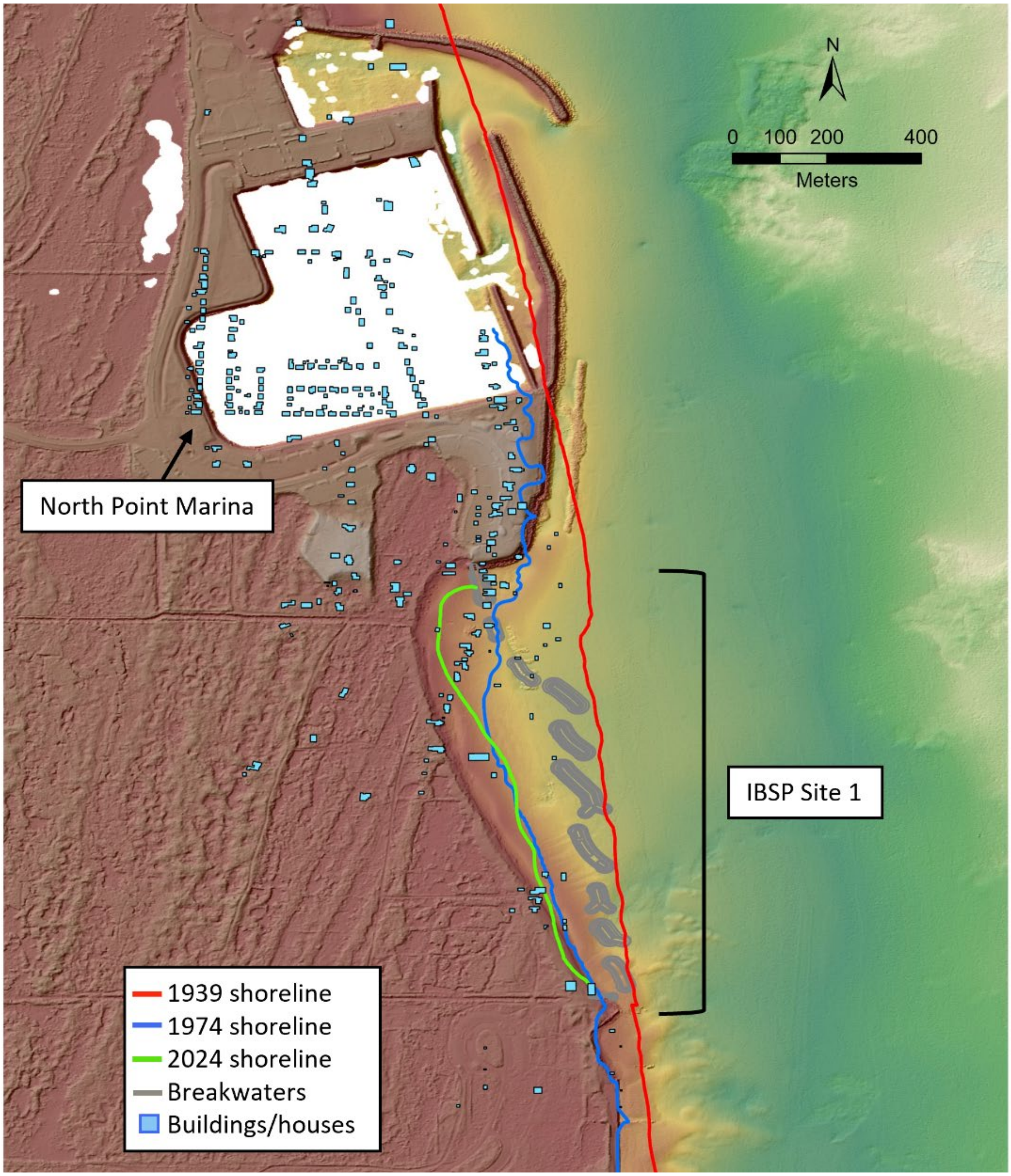


Figure 23 – A map of North Point Marina and ISGS monitoring site IBSP1, showing houses and buildings that existed prior to the Marina's construction and whose foundations can still be seen in nearshore sonar records. Housing foundations have been exposed along the retreating shoreline (2012-2020). The map also highlights how drastically the shoreline has changed from 1939 to 2024, with the 1939 shoreline (mapped from the oldest available aerial photographs) coincidental with North Point Marina's outer breakwater. Today's breakwater chain lies entirely landward of this shoreline position.

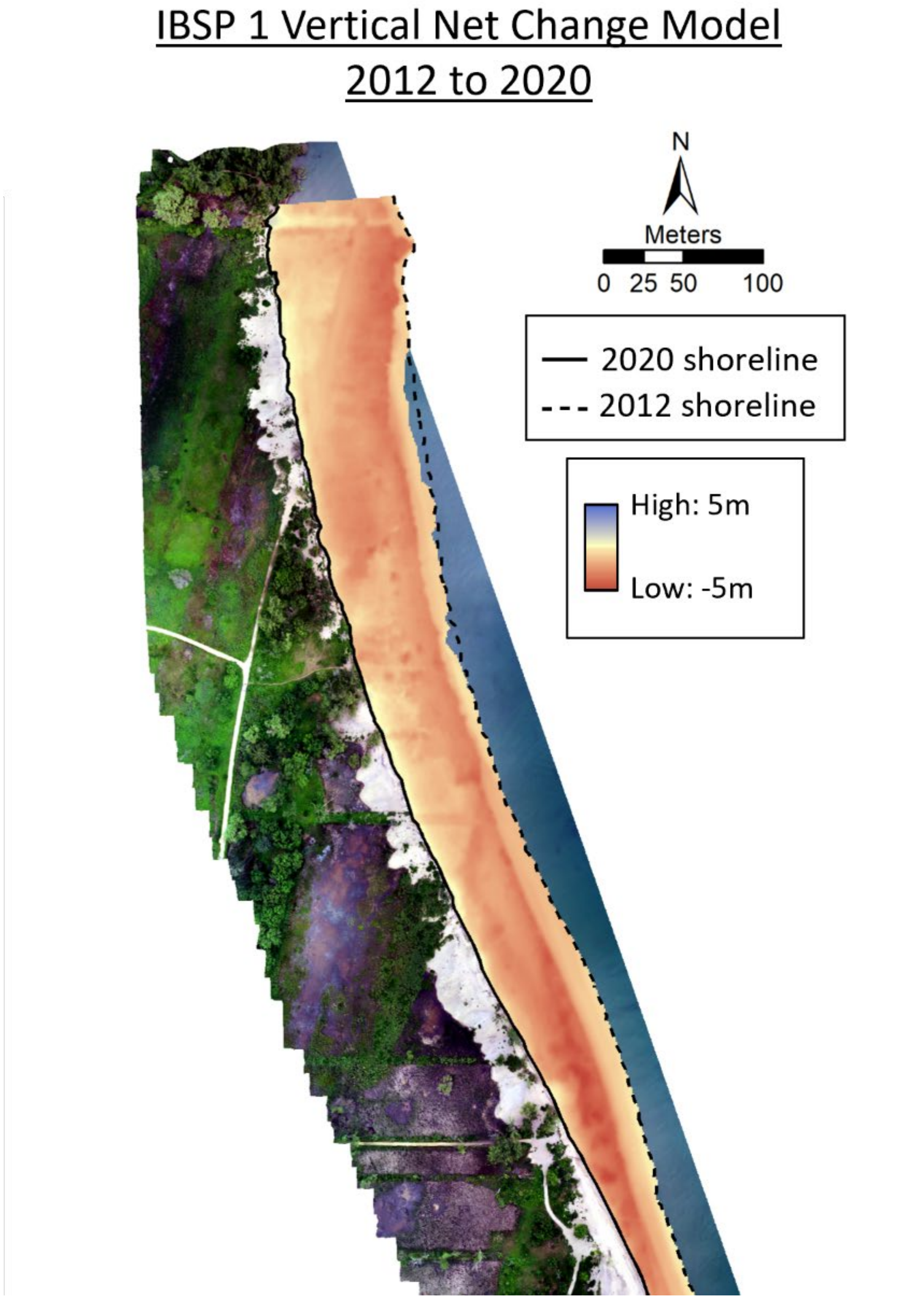


Figure 24 – LiDAR topo-bathymetry data from 2012 and 2020 show how much ridge-plain terrain was lost with lake-level rise. Shown here is the geomorphic change model for the area between 2012 and 2020 shoreline positions. Little of this volume of sand loss was retained on site as washover fans, portions of which can still be made out along the landward perimeter of the 2012-2020 erosional wedge. Sand was exported from this historically erosive site.

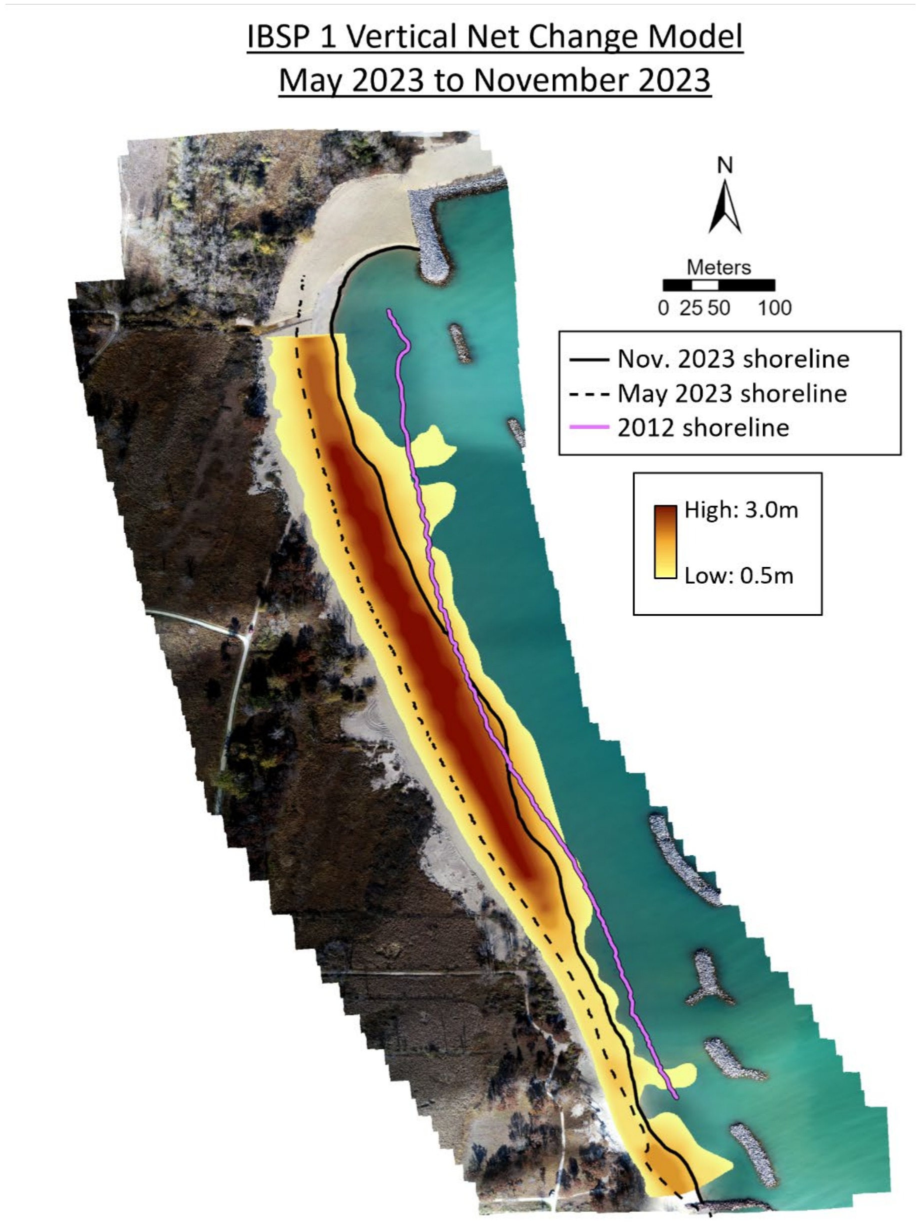


Figure 25 – A net change map showing the amount of sand emplaced between May of 2023 and November 2023, alongside the construction of offshore emergent breakwaters. Around 77,364 cubic meters of sand were replaced at this site. Nearly 20% less than the amount of sand lost to shoreline retreat from along this shoreline between 2012 and 2020.

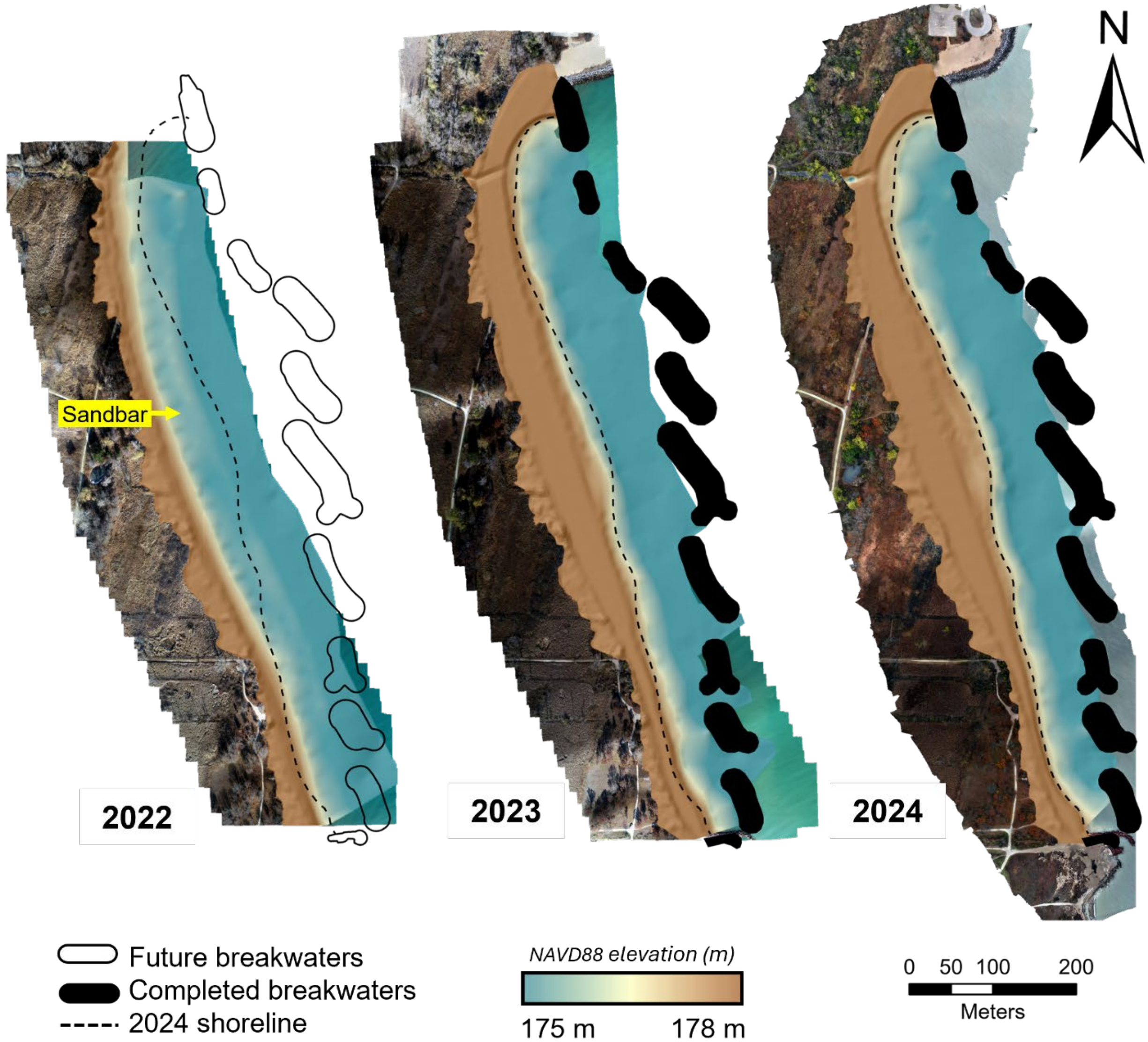


Figure 26 – Topobathymetric models for IBSP1, based on November 2022, 2023, and 2024 ISGS surveys. Breakwater construction and beach nourishment were completed in the Fall 2023. The terminal breakwaters on the north and south end of IBSP1 are shore-attached, which sets this site apart from the other breakwater chains. The shoreline has remained stable, with some terracing in the north, and an erosional “bulge” midway. Continued monitoring will show if the emplaced sand is retained within the semi-enclosure formed by the new infrastructure.

Stop 2 – Hosah Park (a.k.a. ISGS Monitoring Site 'IBSP2' and location of the 'Rubble Ridges')

The stretch of coast between 17th Street and associated water-intake infrastructure (e.g., a pipe on the lake bottom) and the Zion Nuclear Power Plant, also fronted by a variety of relict lake-bottom infrastructure, was inhabited prior to conversion to park terrain (see locations of housing foundations in **Figure 27**, with respect to [paleo] shoreline positions). The southernmost 300 m of the 1.5 km-long shoreline, which borders a revetment and other infrastructure related to the power plant, belongs to Hosah Park, which is managed by the city of Zion. The rest constitutes the southernmost part of the IBSP-SU. **Figure 20** shows an oblique aerial view of the length of this study site, post-breakwater construction.

Figure 27 shows the 2020 USACE topobathymetric model, with historical shoreline positions superimposed. A total of 223,733 m² (or fifty-five acres) of terrain were lost here between 1974 and 2020 (peak decadal water level). Since 1939, a total of seventy-nine acres of terrain has been lost. An offshore shipwreck marks the location of the 1939 shoreline position. Around 78,000 m² (nearly 20 acres) of terrain were lost from 2012 through 2020, with >1.5 meters of lake-level rise. This equated to an estimated loss of sand of about 217,652 m^3 (284,678 cubic yards; **Figure 28**). As observed at IBSP1, overwash favored the low-elevation swales backing up to the receding shoreline, oriented obliquely to older lineaments. Up to 160 meters (524 feet) of shoreline recession defined the period of 2012-2020 lake-level rise, during which time a 360-meter section of park road (shore-parallel), consistently >80 meters (262 feet) from the shoreline position in 2012, eroded away. An emergency sand-nourishment project in late 2018 failed to be effective, as the first major storm following sand placement removed the newly created sand buffer and blew out a section of road.

A variety of offshore coastal protection structures have been emplaced along this part of the strand (see **Figure 20**). These were designed to help protect valuable pane wetlands, which were being impacted severely by shoreline recession during 2012-2020 lake-level rise. Three parallel, submerged rubble-mound ridges were emplaced fronting the Hosah Park section of shoreline, with extensions into IBSP-SU, as part of a Great Lakes Restoration Initiative (GLRI) study (by the IDNR-CMP and ISGS) to evaluate the effectiveness of this type of 'nature-based' shoreline-management solution. Construction started in the fall of 2021 and was completed in early 2022. Ongoing monitoring will help provide valuable input on effectiveness of such uncommon construction (in the Great Lakes), although the efficacy of the submerged rubble-mound ridges is likely to remain obscured by the downdrift impacts of the much larger project to the immediate north. **Figure 29** shows the volume of post-construction beach-sand placement. Around 89,364 m^3 of sand were emplaced, well shy of the volume lost since 2012. Again, with little of that retained locally, it is assumed that much of the sand liberated by shoreline recession (with lake-level rise) was exported from the littoral cell.

With only one season of post-construction monitoring data available at time of field-guide assembly, nothing conclusive can be said about the impacts of the emergent breakwaters. It is interesting to note that, with nourishment and breakwater construction limited to the area north of Hosah Park, the latter shoreline section has seen an increase in shoreline erosion (**Figures 30** and **31**). This area had experienced greater stability with respect to the northern region of this coastal cell, partly due to sand influx from the north (i.e., the eroding shoreline), partly due to presence of a beach-ridge terminus (and therewith related topography, vegetation cover, and high gravel content). The longshore bar that was once seen beginning at IBSP2 and extending to Waukegan has notably been absent post-construction (**Figure 31)**. The gap between emergent breakwaters and submerged parallel rubble-mound ridges may be creating hydrodynamic conditions favoring focused wave attack, with negative impacts on the immediate downdrift (i.e., in the immediate lee of the breakwater chain). This is speculative and detailed hydrodynamic studies involving instrument cage deployments and/or numerical modeling efforts are sure to enlighten us on the topic.

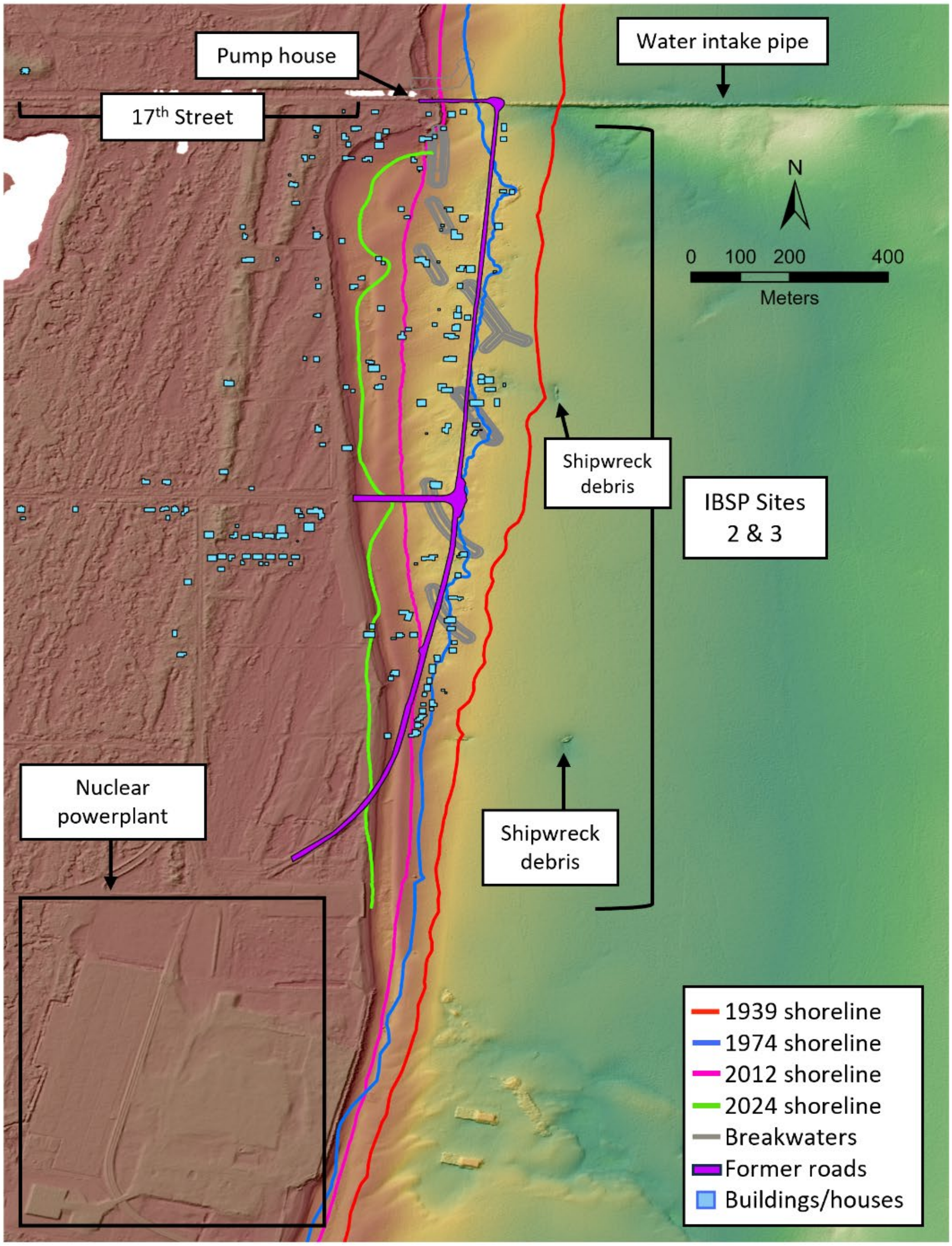


Figure 27 – A map of IBSP 2 and 3 showing the houses (blue boxes) and roads (purple lines) that used to exist when the shoreline extended further lakeward in the 1970's. Notice the scour on the leeward side of a shore-perpendicular water-intake structure leading to the pumphouse on shore, just south of which erosion has been most severe.

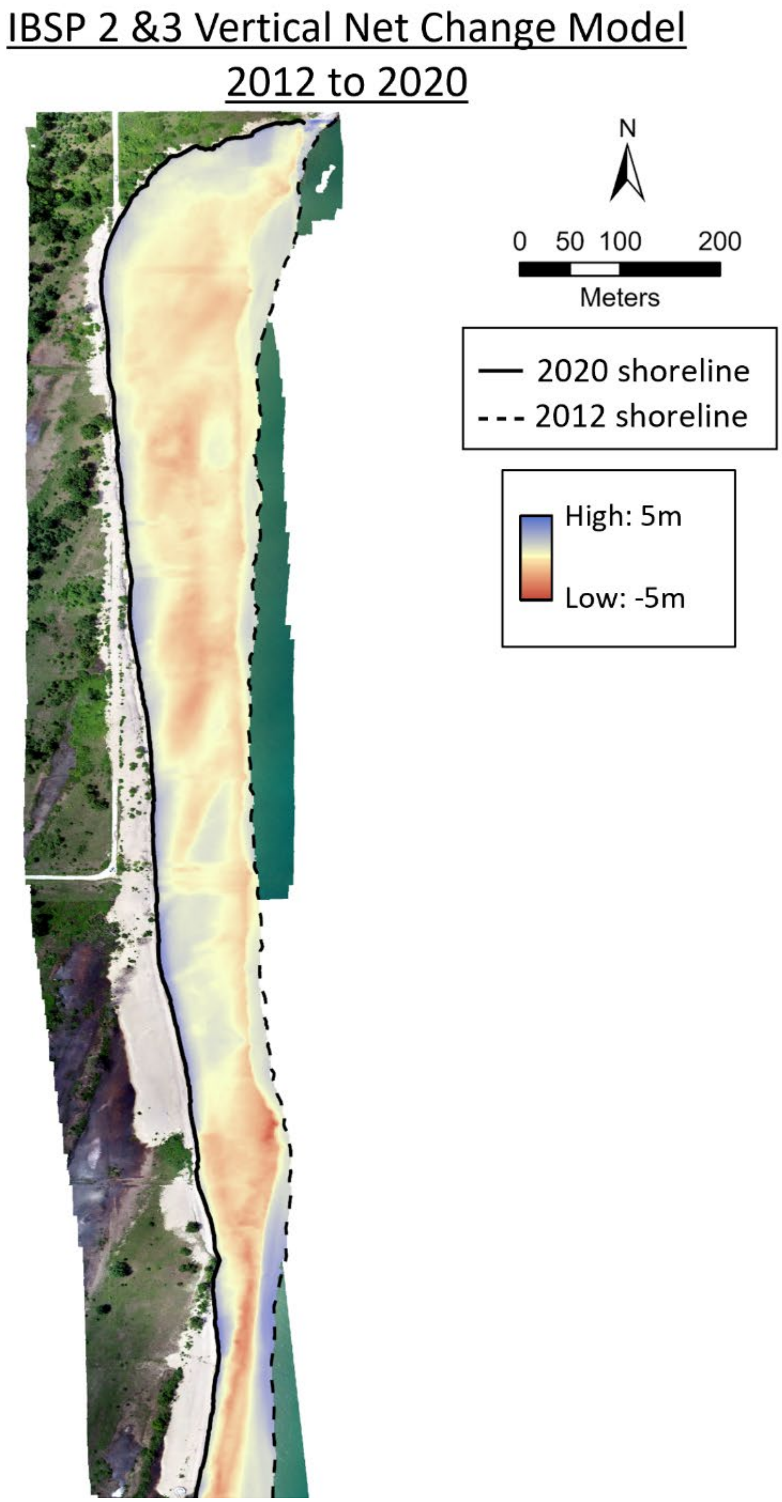


Figure 28 – A geomorphic change model based on LiDAR bathymetry data from 2012 and 2020. Notice the lower erodibility of a shore-oblique beach ridge, which meets the shoreline in the lower part of the map, which separates areas of overwash accretion within swales and where the amount of shoreline retreat is reduced.

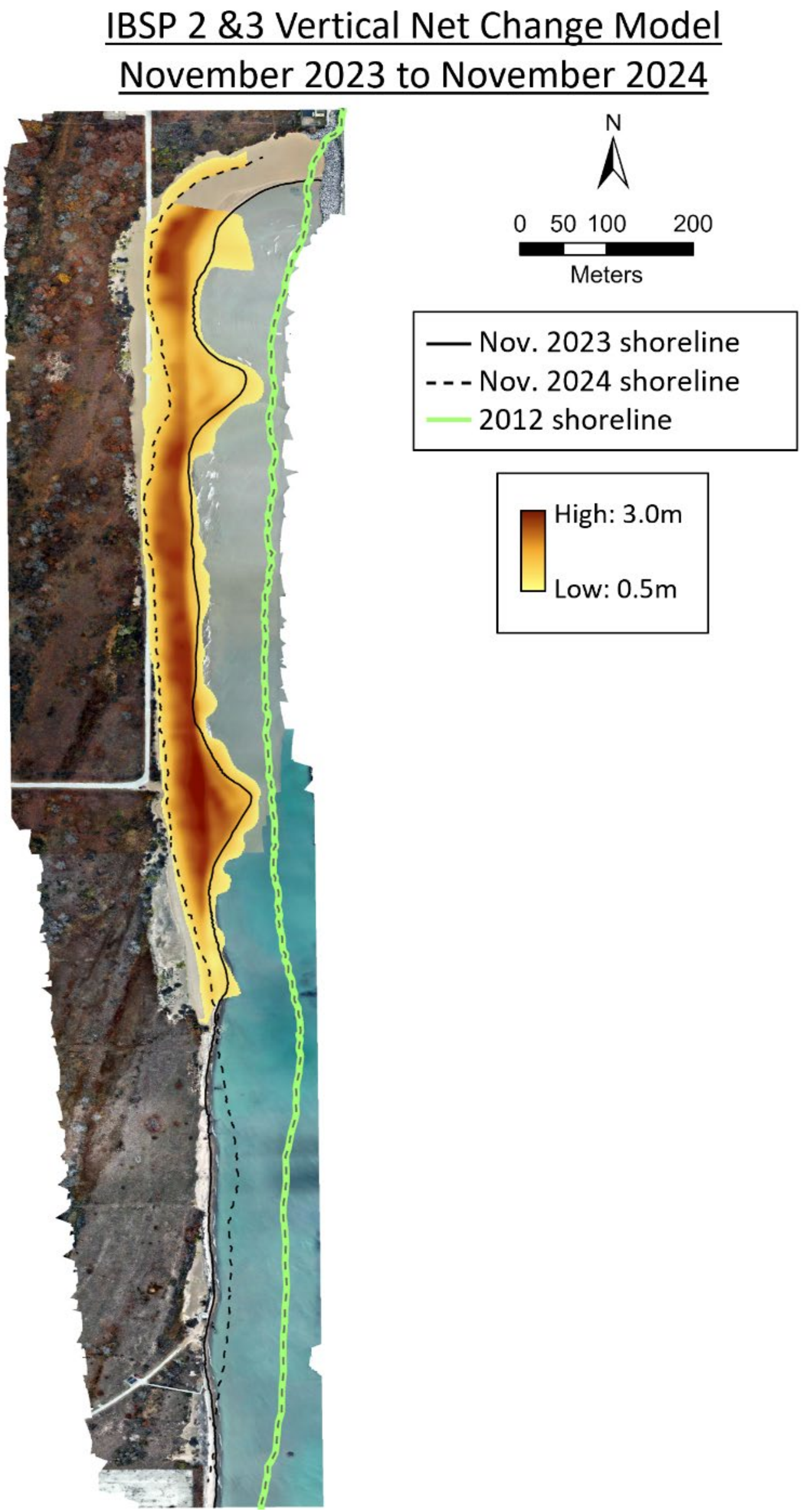


Figure 29 – Sand isopach model for what was placed, as part of 2023-2024 breakwater construction and beach replenishment efforts. Total volume approximates 89,364 m^3.

IBSP 2 &3 Vertical Net Change Model and Orthoimages from March 2021 to November 2024

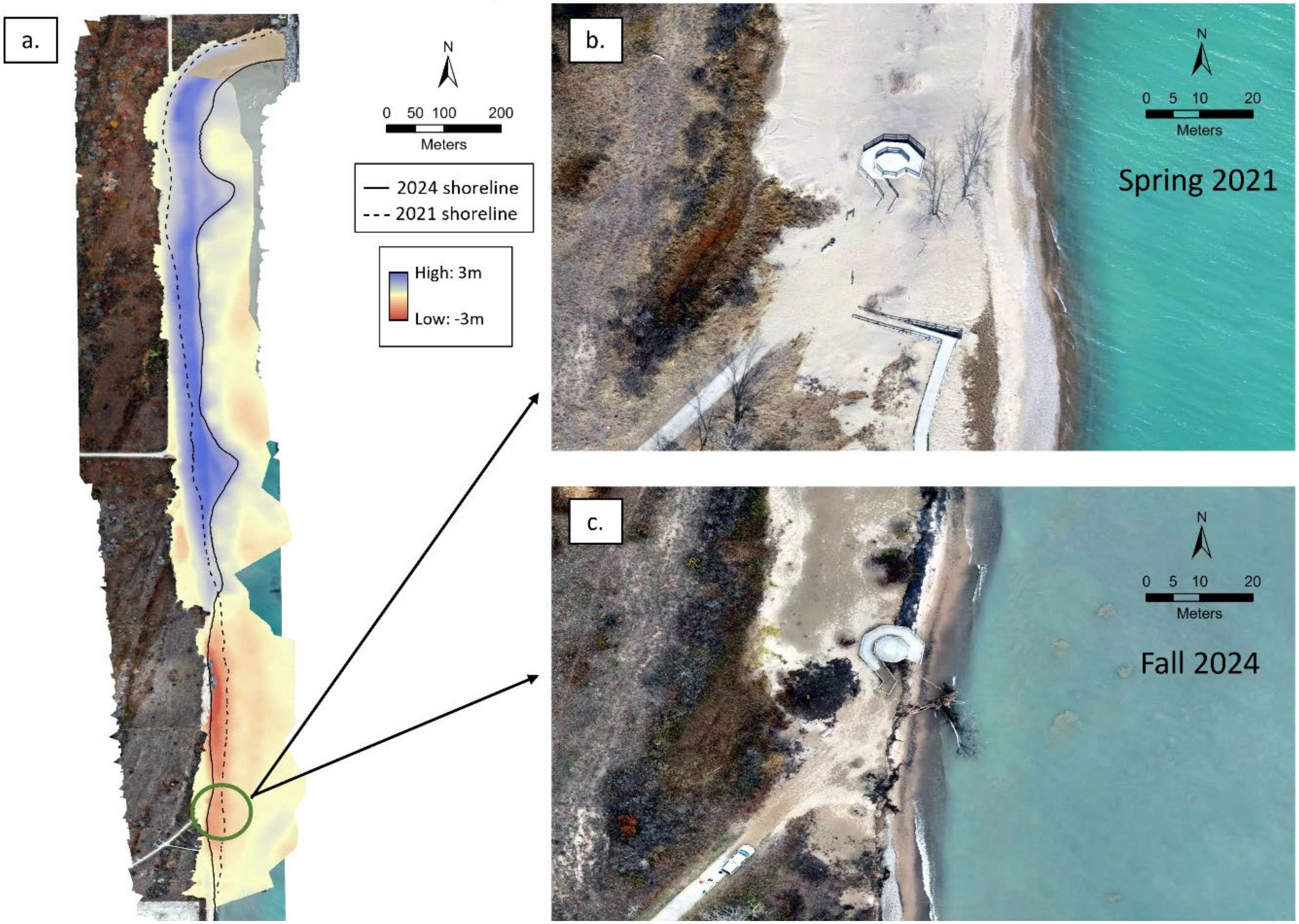


Figure 30 – Net change model for 2021-2024, with inset photographs from spring 2021 and fall 2024 that capture the demise of lakefront viewing platform and boardwalk. This area had not yet been impacted when lake level was rising, from 2012 to 2020, but began eroding more heavily with lake-level fall (especially once breakwaters had been built to the north).

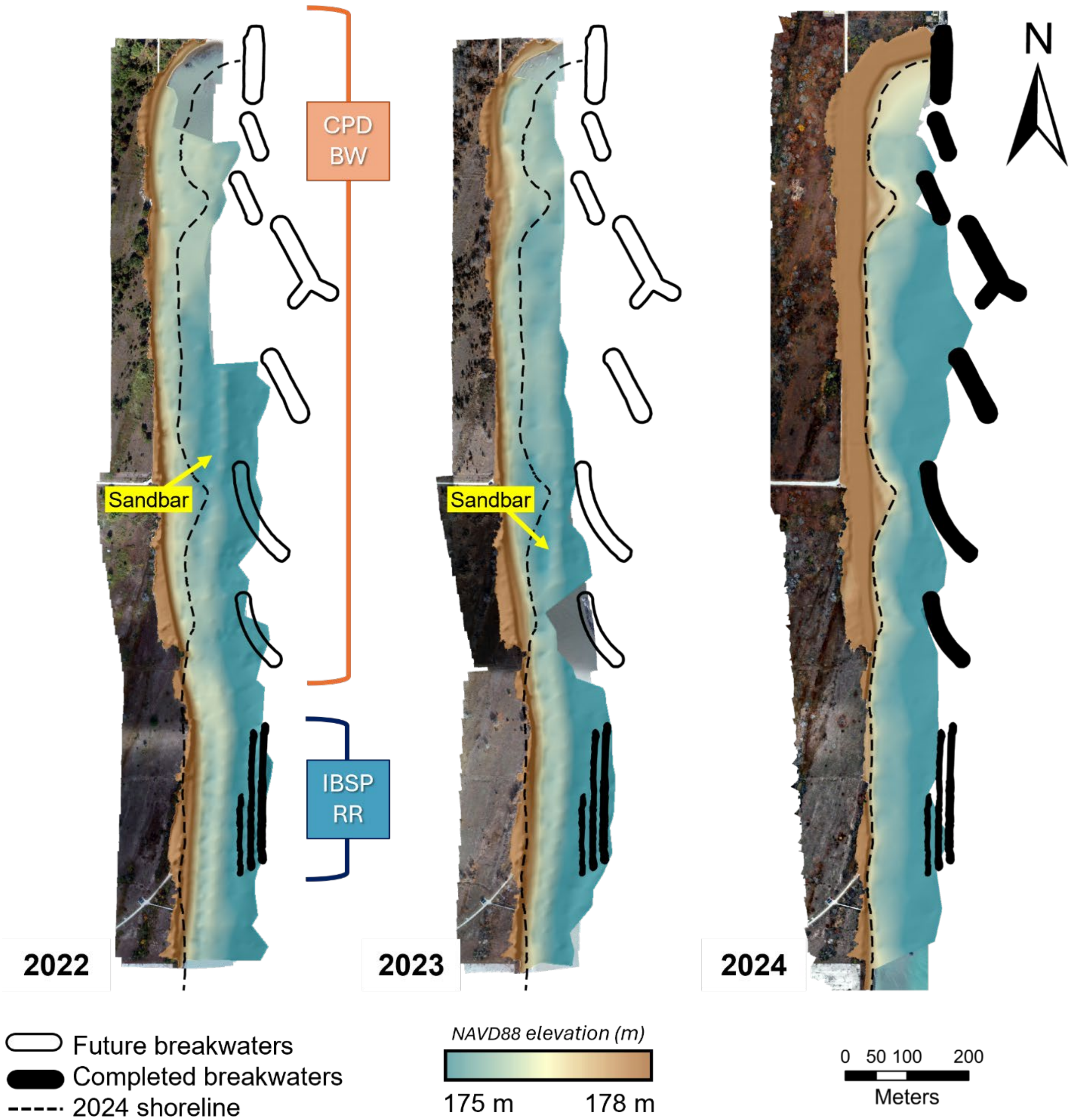


Figure 31 – Topobathymetric models for IBSP2-3, based on November 2022, 2023, and 2024 ISGS surveys. Submerged rubble-mound breakwaters (IBSP RR) were built in 2022; emergent breakwaters and beach nourishment (CDP BW) was completed in Spring 2024. The absence of a nearshore sandbar in 2024 is noted, along with tombolo formation. The shoreline in the immediate downdrift of the CPD BW site has continued to recede, as evidenced by 2022 (pre-construction) and 2024 DEMs.

Stop 3 – IBSP South Unit (a.k.a. ISGS Monitoring Sites ‘IBSP 4, 5, and 6’)

The 1.5-km long stretch of mostly unobstructed shoreline comprising IBSP4-6 has, of the sites studied by the ISGS, been the least recessive prior to breakwater installation. The crossing of 1974 and 1939 shoreline positions, around halfway between the Illinois Beach Hotel (in the north) and the Dead River mouth, marks the approximate nodal point separating historically erosive from accretionary shorelines of IBSP (**Figure 32**). The 2012-2020 period of lake-level rise was associated with erosion in the northern part of this survey area, with a wedge-shaped section of strand removed from just south of the hotel, and accretion of the area leading up to the Dead River mouth (**Figure 33**). Shoreline retreat in the immediate lee of the hotel revetment infrastructure was >100 m from 2012 to 2020.

With the construction of breakwaters in 2023-2024, with the terminal structure emplaced at the end of the hotel’s shoreline infrastructure/sheet-pile revetment (and area of maximum 2012-2020 shoreline recession), shoreline changes in the immediate lee have been drastic. The formation of a tombolo has further ensured that the leeward side of the hotel would remain sand-deprived (from direct littoral contributions), inducing rapid shoreline retreat, as captured in the 2024 shoreline position (**Figure 32**). The section of IBSP shoreline that was most stable during 2012-2020 lake-level rise and along which foredune development had been prolific, is presently eroding (**Figures 34 and 35**).

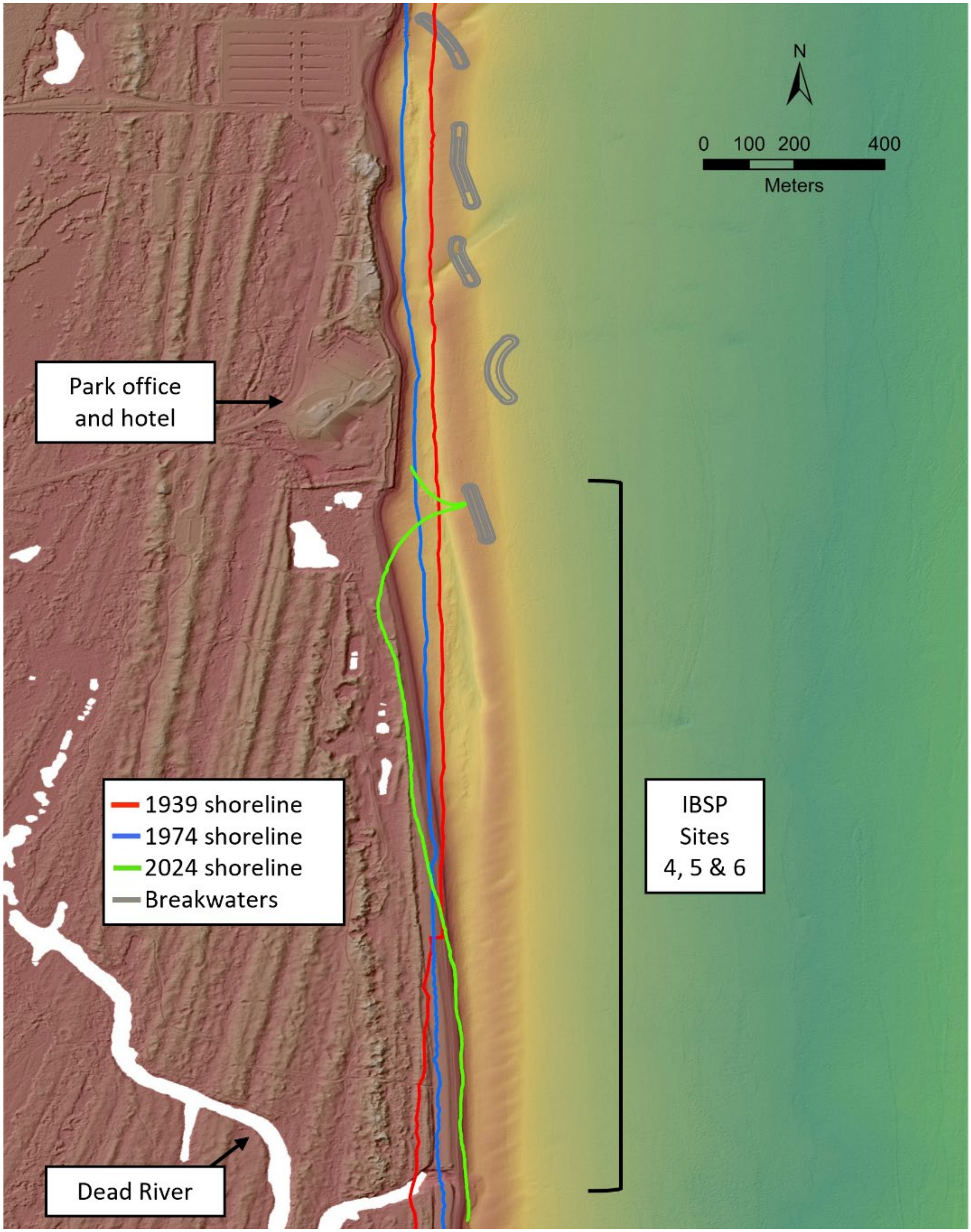


Figure 32 – Hillshaded DEM based on 2020 LiDAR data depicting the once continuous nearshore sandbar, where now a series of emergent breakwaters exists (since 2023). The nodal point separating historically erosional from depositional parts of the ZBRP occurred between the IBSP hotel and the Dead River, near where 1939 and 1974 shoreline positions cross.

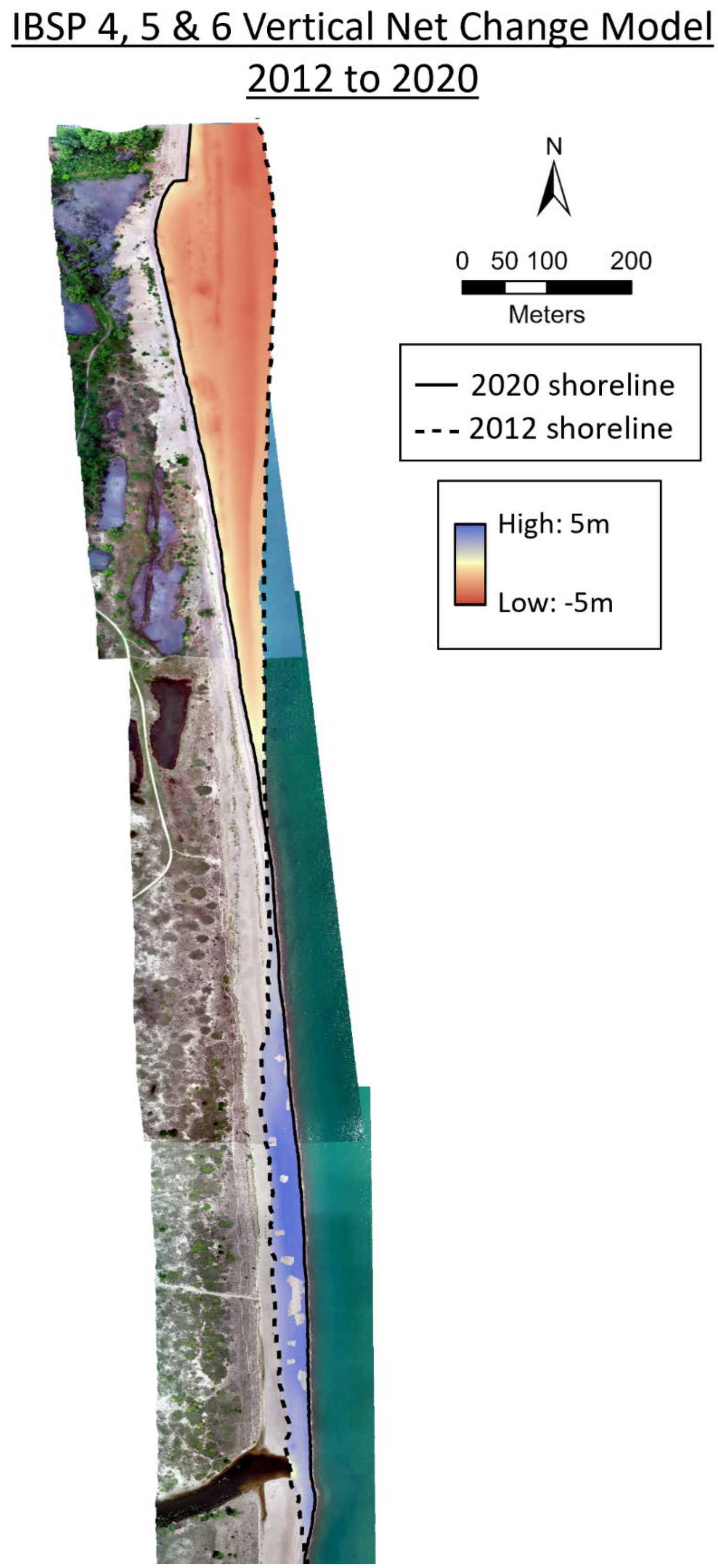


Figure 33 – Geomorphic change model based on 2012 and 2020 LiDAR-derived DEMs, showing the loss of sediment and beach terrains in the north and accretion/progradation of beach terrains in the south of IBSP4-6.

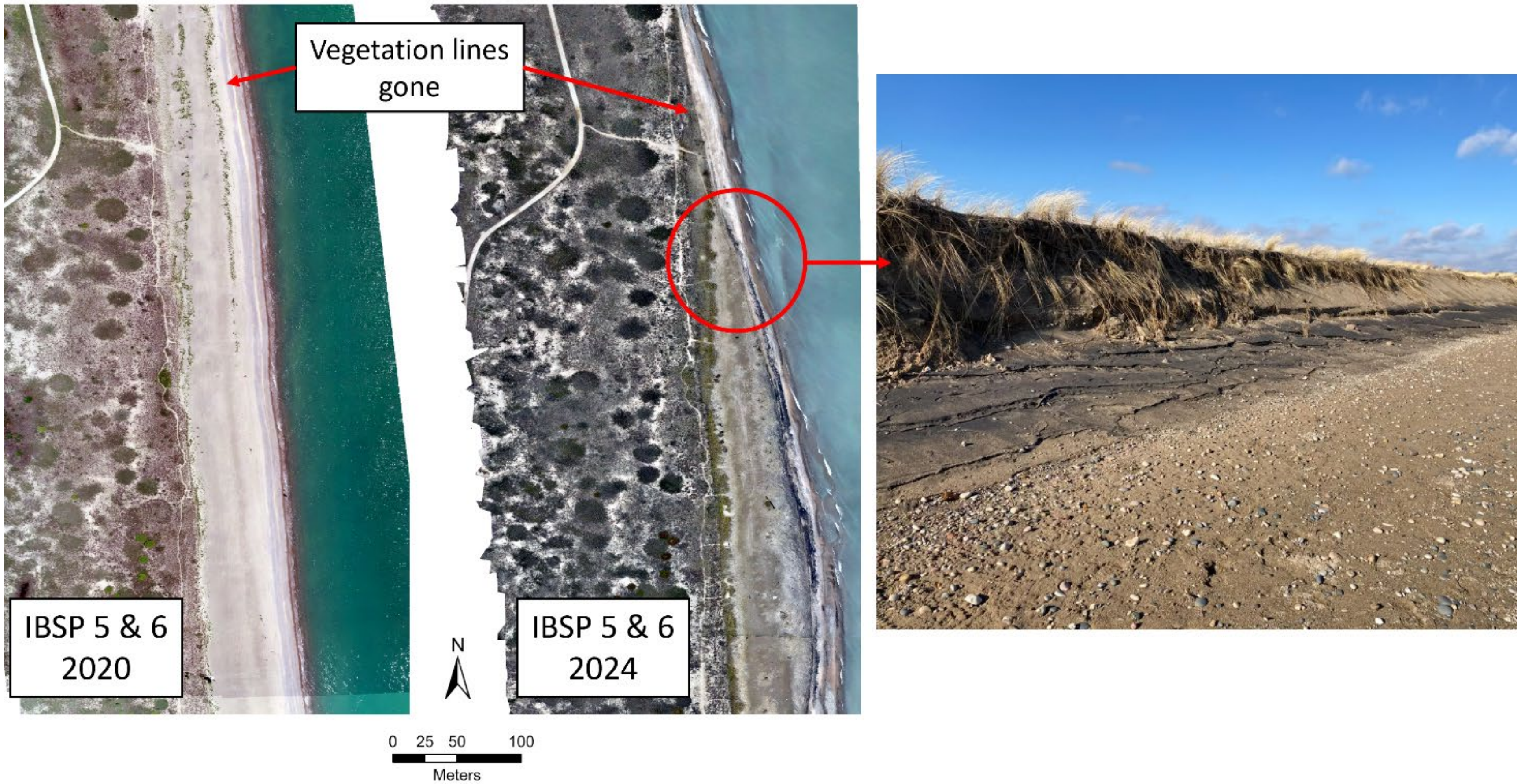


Figure 34 – Orthoimages from 2020 and 2024 showing developments along the approximate nodal zone between IBSP4 and IBSP6, where recently accreted foredune terrains are now being truncated by shoreline retreat. A 2-meter berm extends along much of this section of shoreline today, with thick heavy mineral placer deposits occurring at the base of the scarp (from reworking of eroded sediments by swash processes).

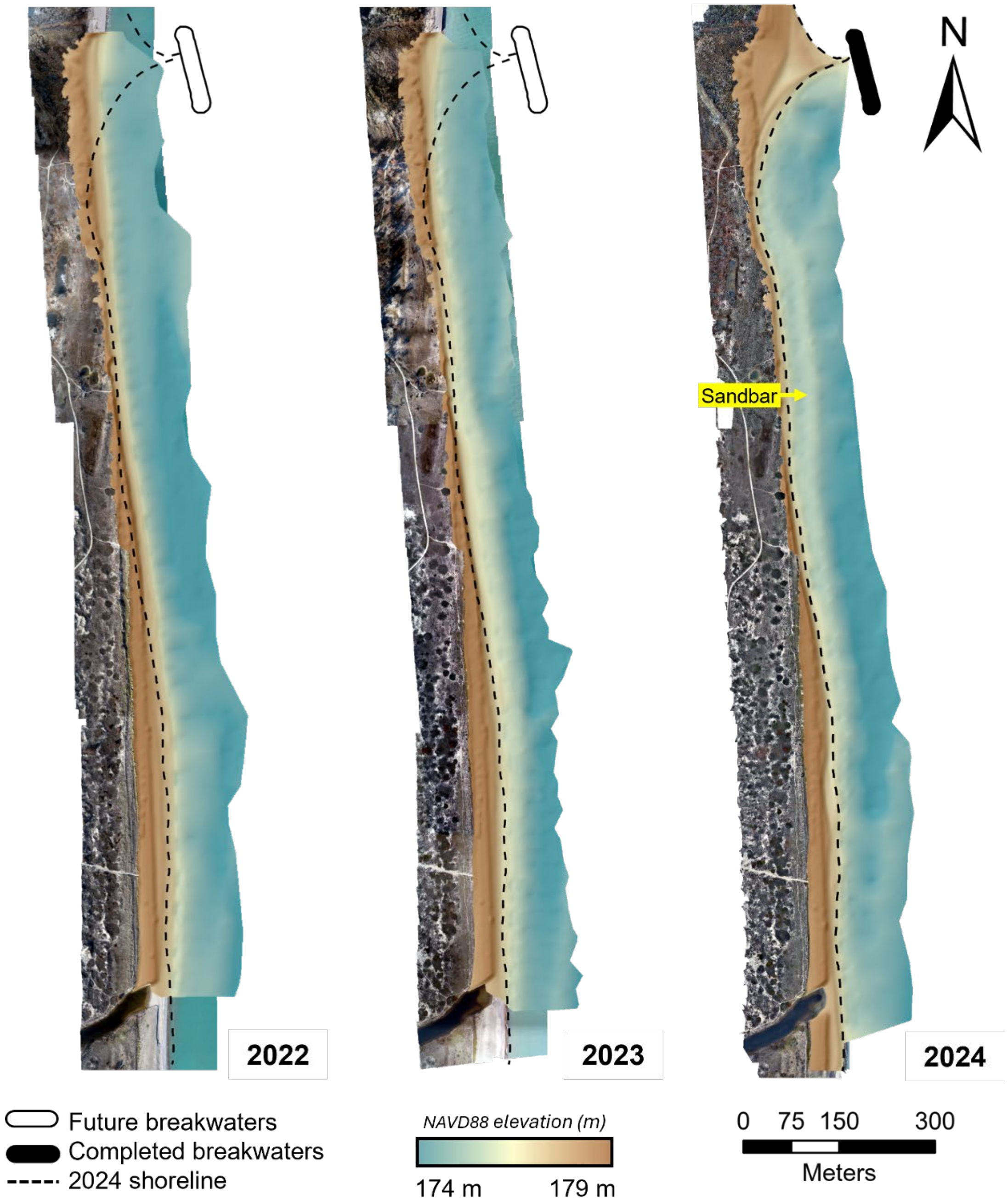


Figure 35 - Topobathymetric models for IBSP4-5-6 based on November 2022, 2023, and 2024 ISGS surveys. Newly emplaced breakwaters and beach nourishment were completed in Spring/Summer 2024. Tombolo formation against the terminal IBSP breakwater has cut off alongshore sediment transport to IBSP4. Shoreline recession in the immediate lee of this feature occurred suddenly and has been ongoing. Continued monitoring is needed to see how sites 4/5/6 respond to modifications of the updrift, which has visibly altered sediment-transport pathways to the south.

7. CONCLUDING REMARKS AND ACKNOWLEDGEMENTS

The shoreline-monitoring activities undertaken by the Illinois State Geological Survey (ISGS) at Illinois Beach State Park (and elsewhere in Illinois) have built unrivaled datasets for learning about coastal geomorphic changes in the Great Lakes. This field guide provides but a glimpse of the information generated by the group since 2018. It is through our collaboration with the Illinois Department of Natural Resources' Coastal Management Program (IDNR-CMP), the youngest such program in the country, that we have been afforded this unique opportunity to study one of the most dynamic coastal environments on Earth and help connect data-driven insights to a variety of coastal stakeholder groups. The ISGS team wishes to thank the following individuals with the IDNR-CMP, current and former, who over the years have helped us construct and refine the most extensive shoreline-monitoring program in the Great Lakes, in no particular order: Cody Eskew, Tara Jagadeesh, Meg Kelly (CMP Director), Casey Sebetto, Ania Bayers, Kim Kreiling, and Diane Tecic. Many ISGS colleagues, present and former, have also helped shape the coastal research program into what it is today, whether by developing field or data-processing workflows, assisting in data collection, offering technical assistance, or advising on the monitoring framework/design: Mitchell Barklage, Ethan Theuerkauf, Jenny Bueno, Katie Braun, Andrew Anderson, Andrew Phillips, and Kevin Englebert. Special thanks goes out to Steve Brown, who started the program and who's unwavering enthusiasm for the work this group does has made all the difference. Lastly, we wish to extend our sincerest gratitude to the broader ISGS community. While not directly involved in the shoreline-monitoring work, they have supported our efforts in many other ways (e.g., help with coordination, resource allocation, and mentorship): Dick Berg (ISGS Director), Geoff Pociask, and Brandon Curry.

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