PATTERNS AND PROCESSES OF BEACH RECOVERY FOLLOWING RAPID LAKE LEVEL RISE: INSIGHTS FROM RECENT STUDIES ALONG THE LAKE MICHIGAN COAST

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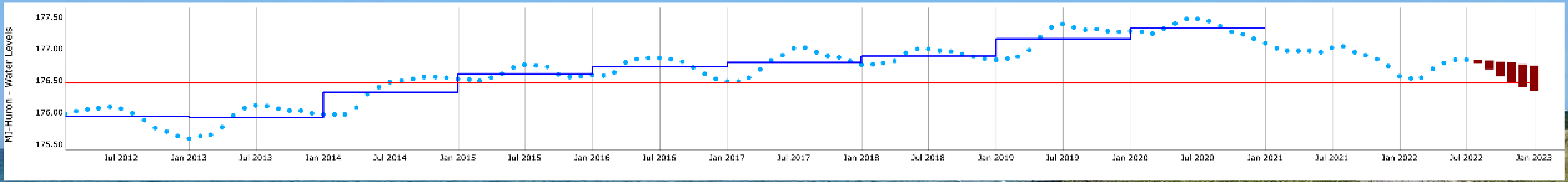
Research colleagues: Guy Meadows and Lorelle Meadows

WILL THE BEACHES RECOVER AFTER A HIGH PHASE OF LAKE LEVEL?

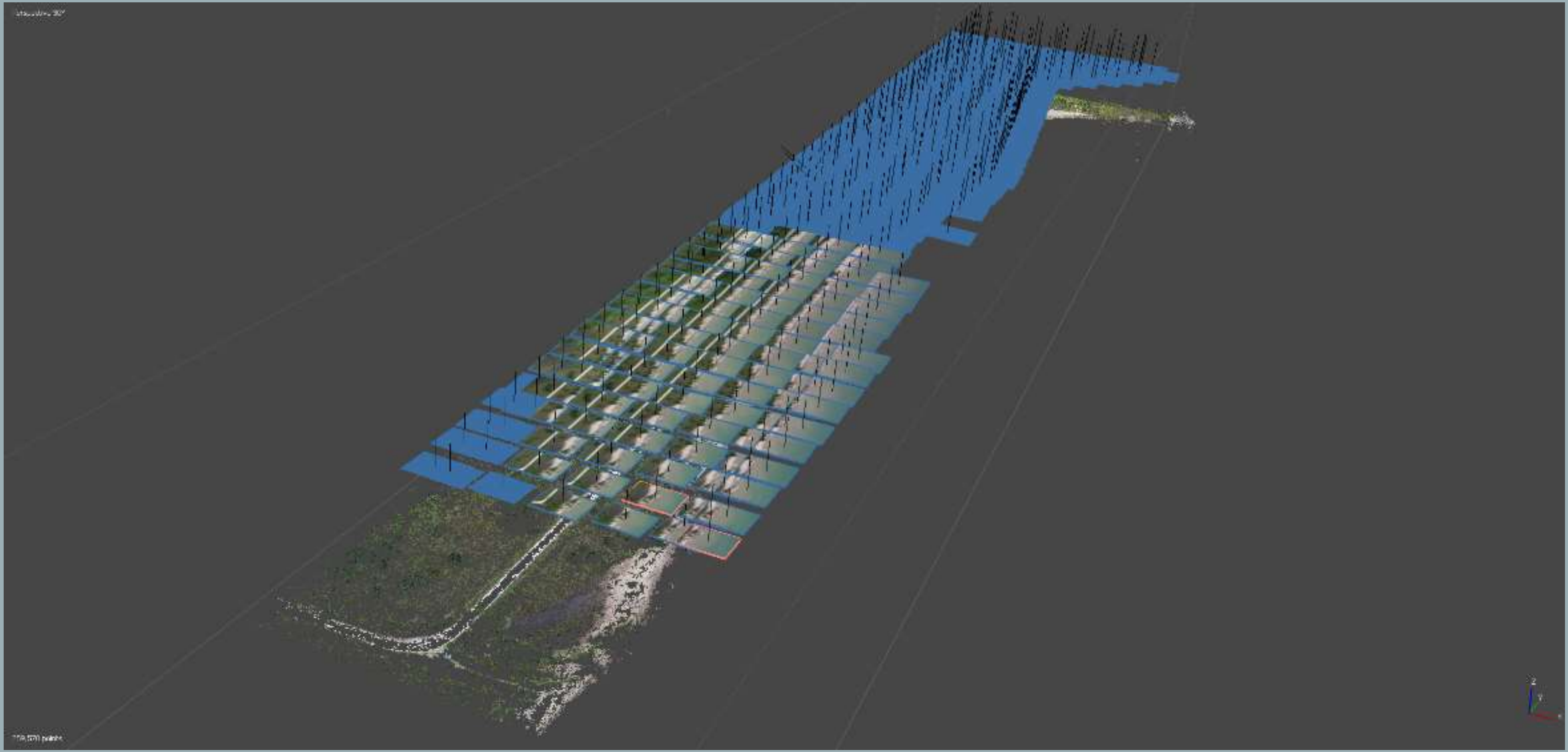
HOW QUICKLY AND WILL THEY RECOVER FULLY?

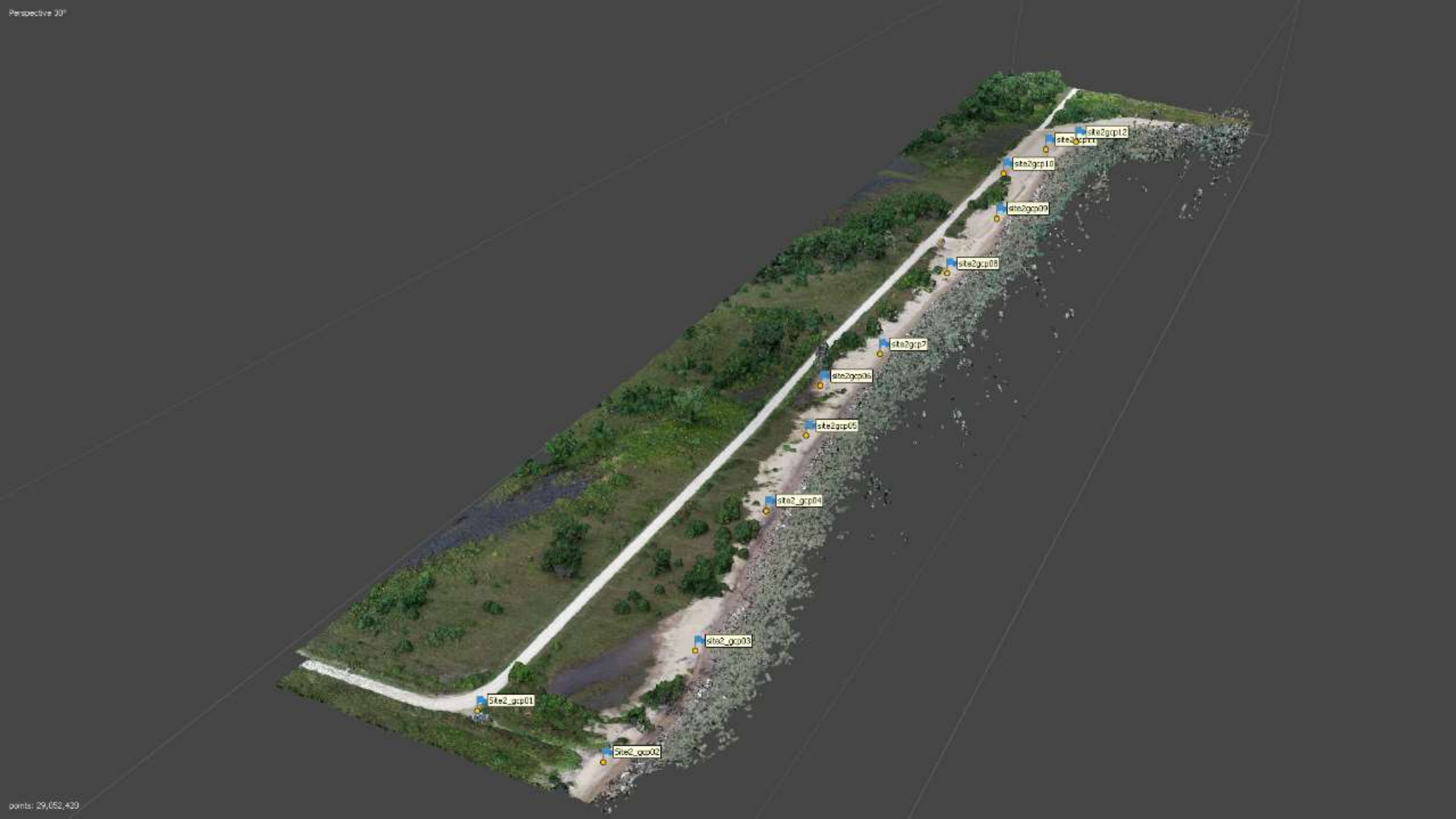


FIRST STEP: KNOW WHERE THE SEDIMENT GOES ONCE IT IS ERODED FROM BEACHES, BLUFFS, AND DUNES.

HOW DO WE MAP EROSION FROM BEACHES, DUNES, AND BLUFFS?

COLLECT A SERIES OF AERIAL PHOTOGRAPHS




Perspective 30°
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site2gcp06
site2gcp05
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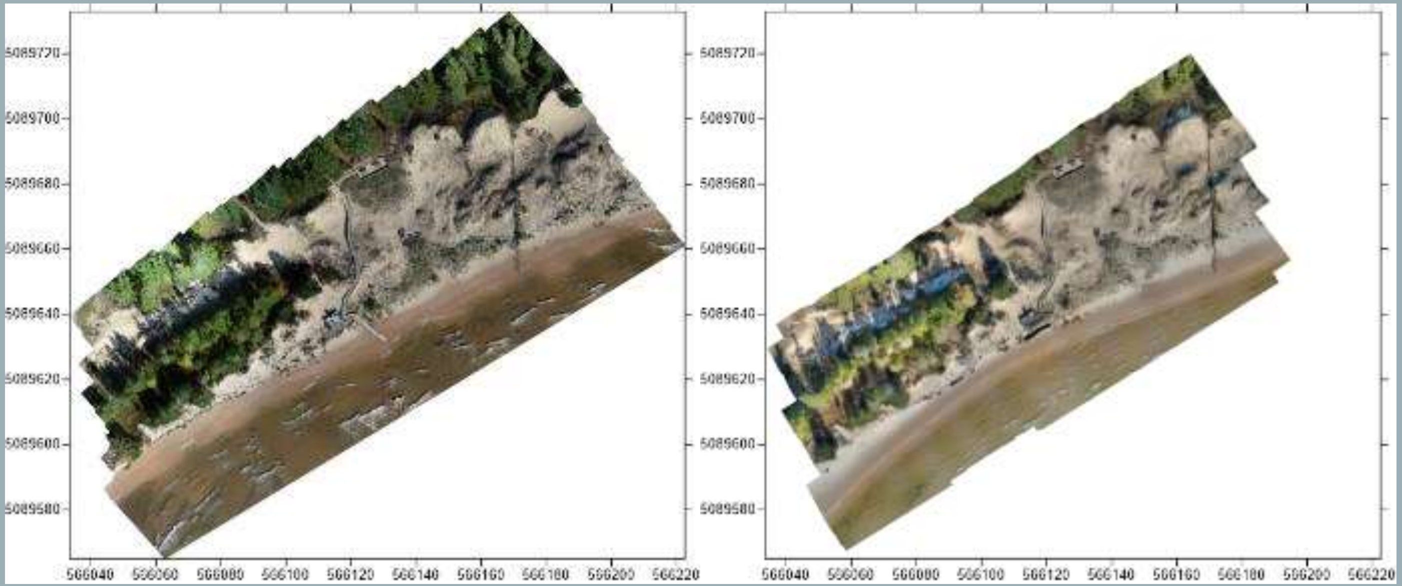
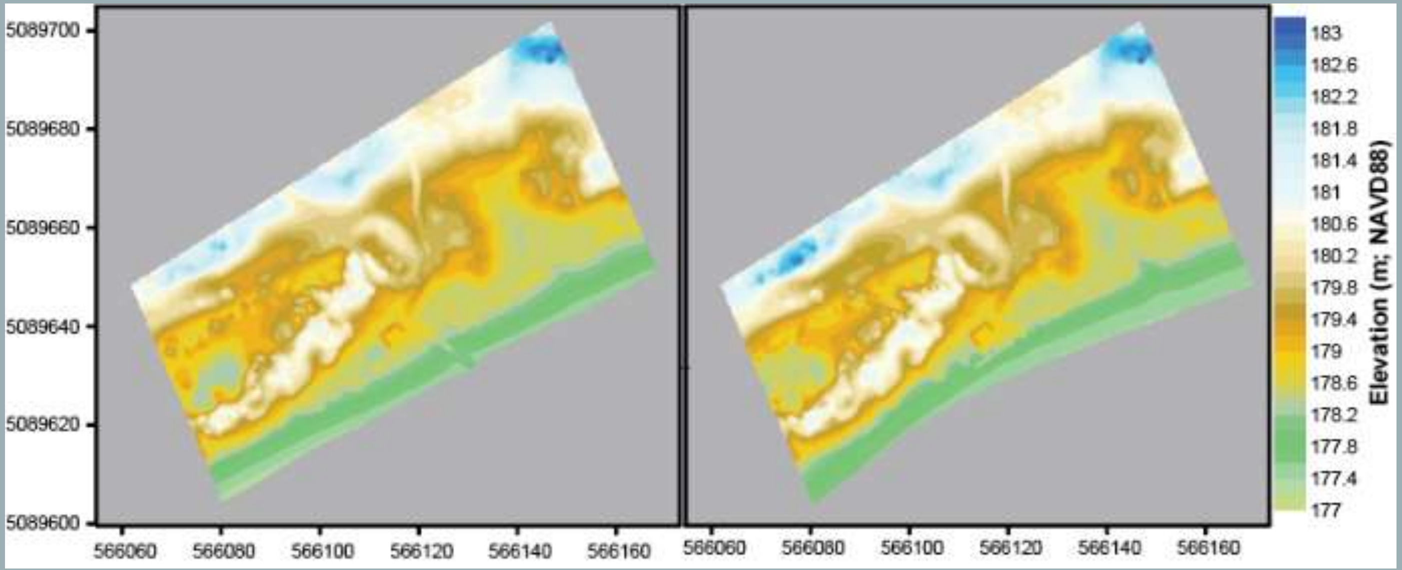
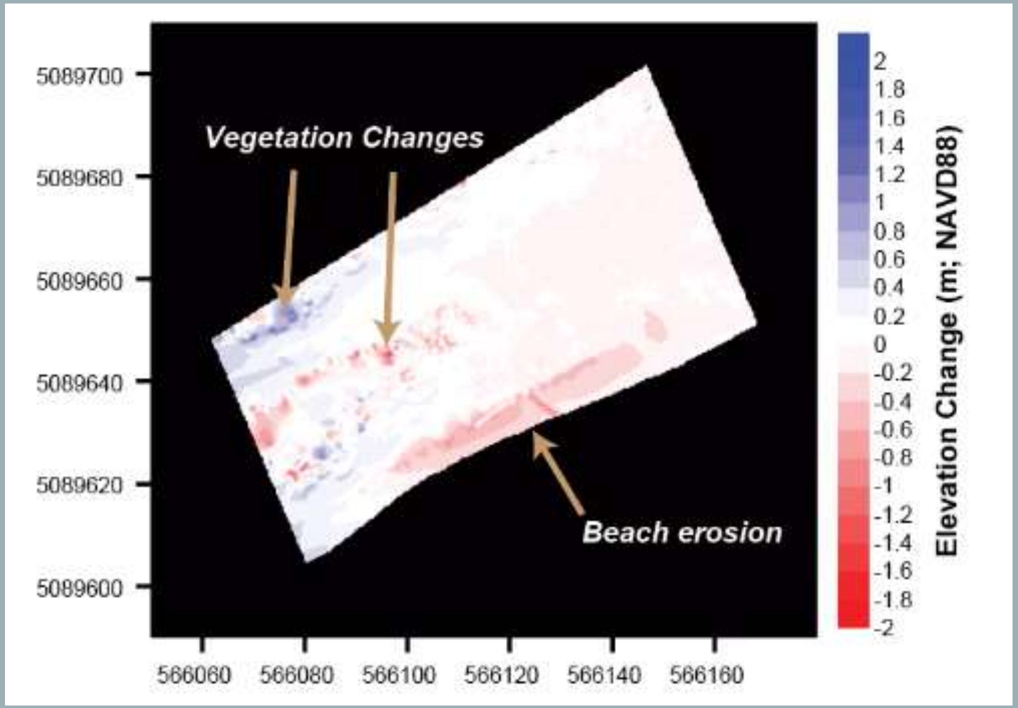
Site2_gcp01
Site2_gcp02
points: 29,052,420

October 6, 2020 *November 3, 2020*

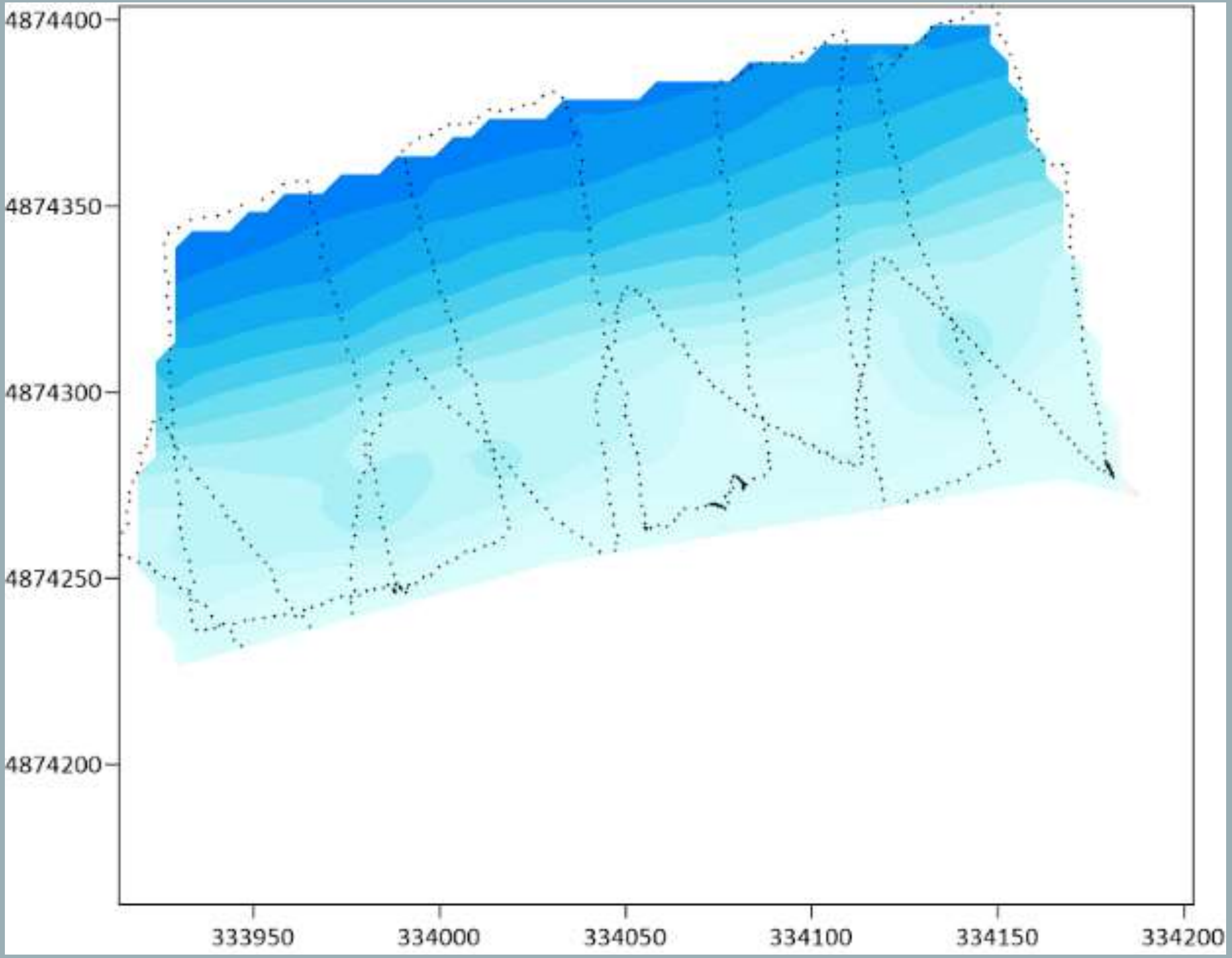




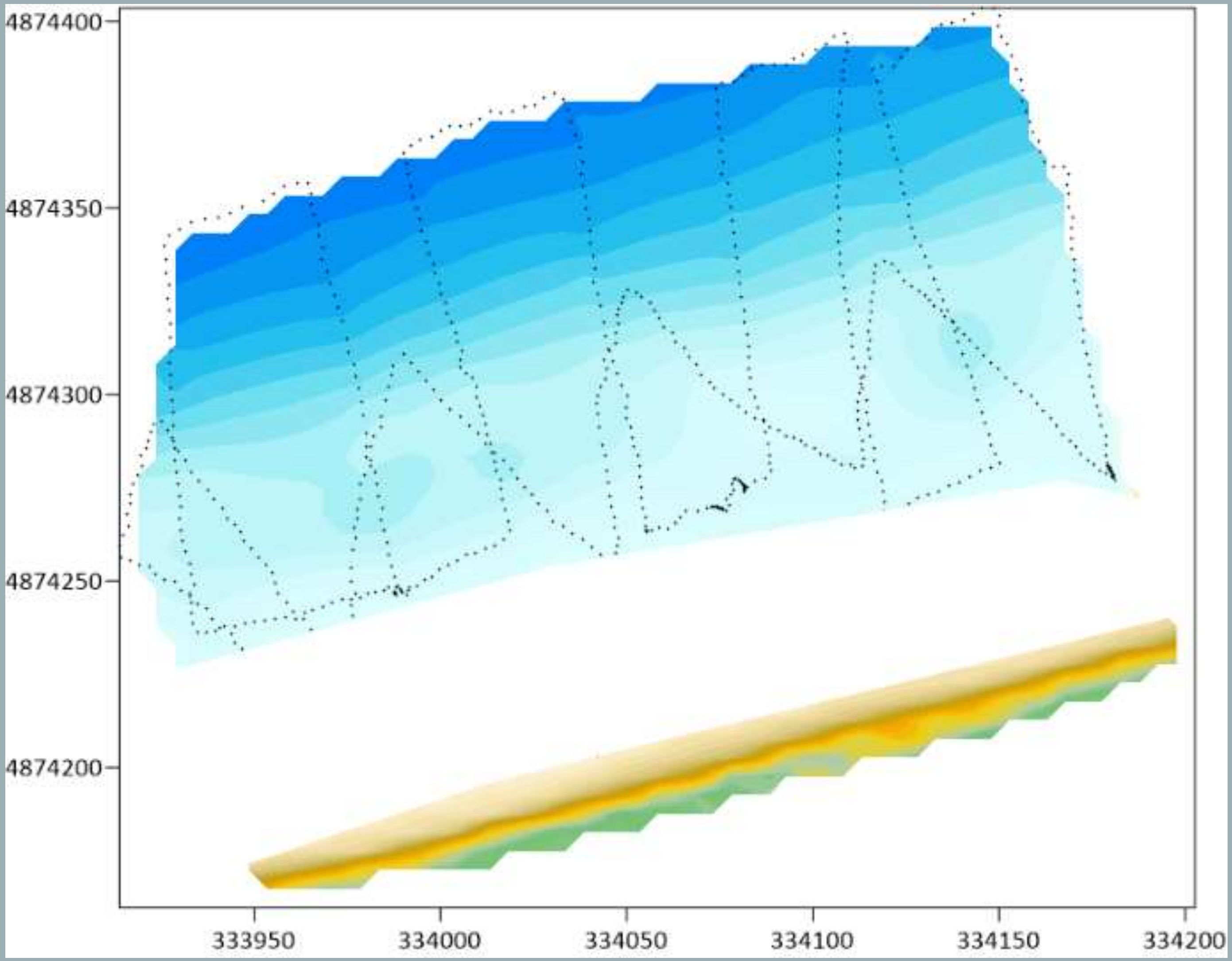


Difference between 2 surveys

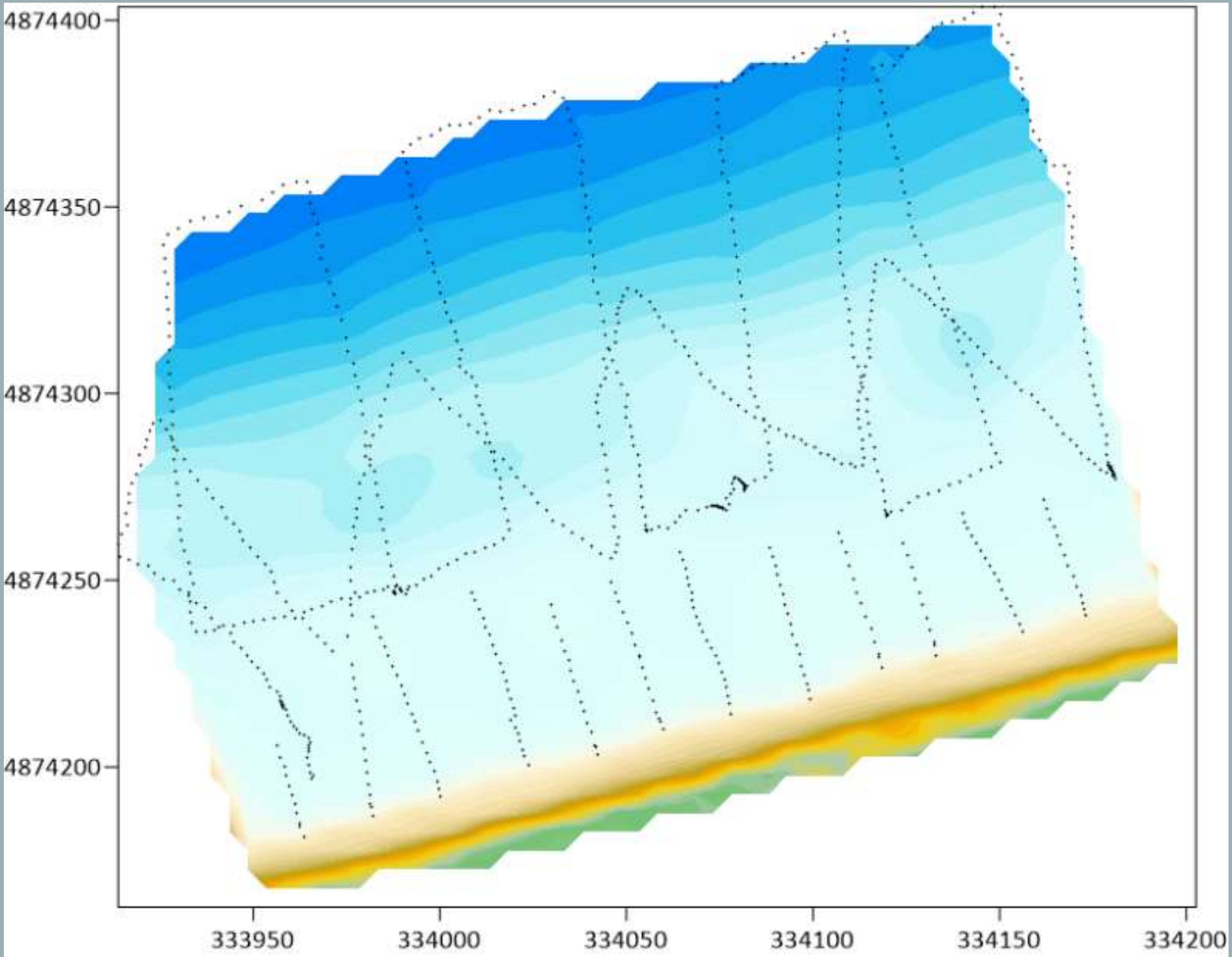
Nearshore bathymetric (lake bottom) mapping



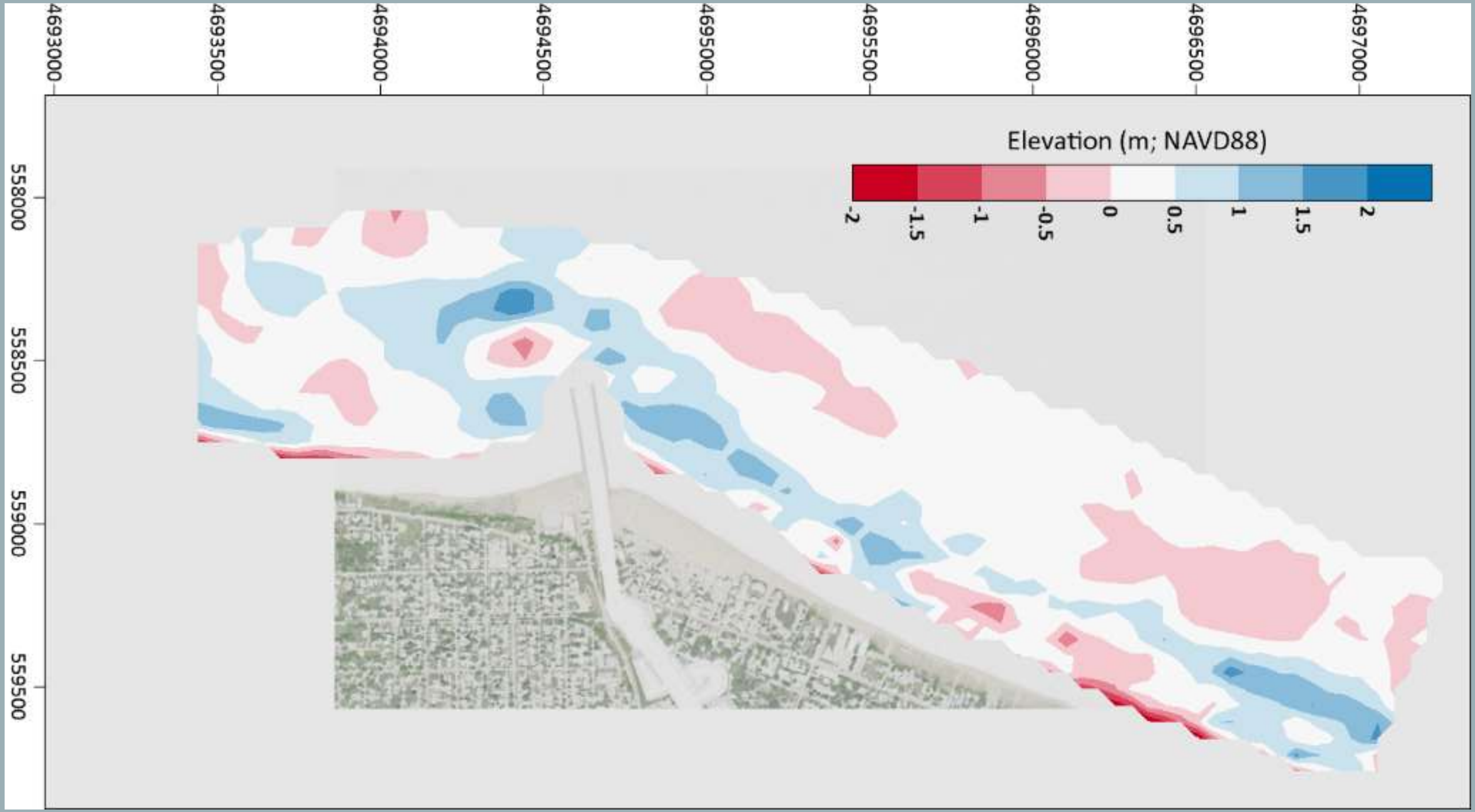
Full coverage requires wading in…….



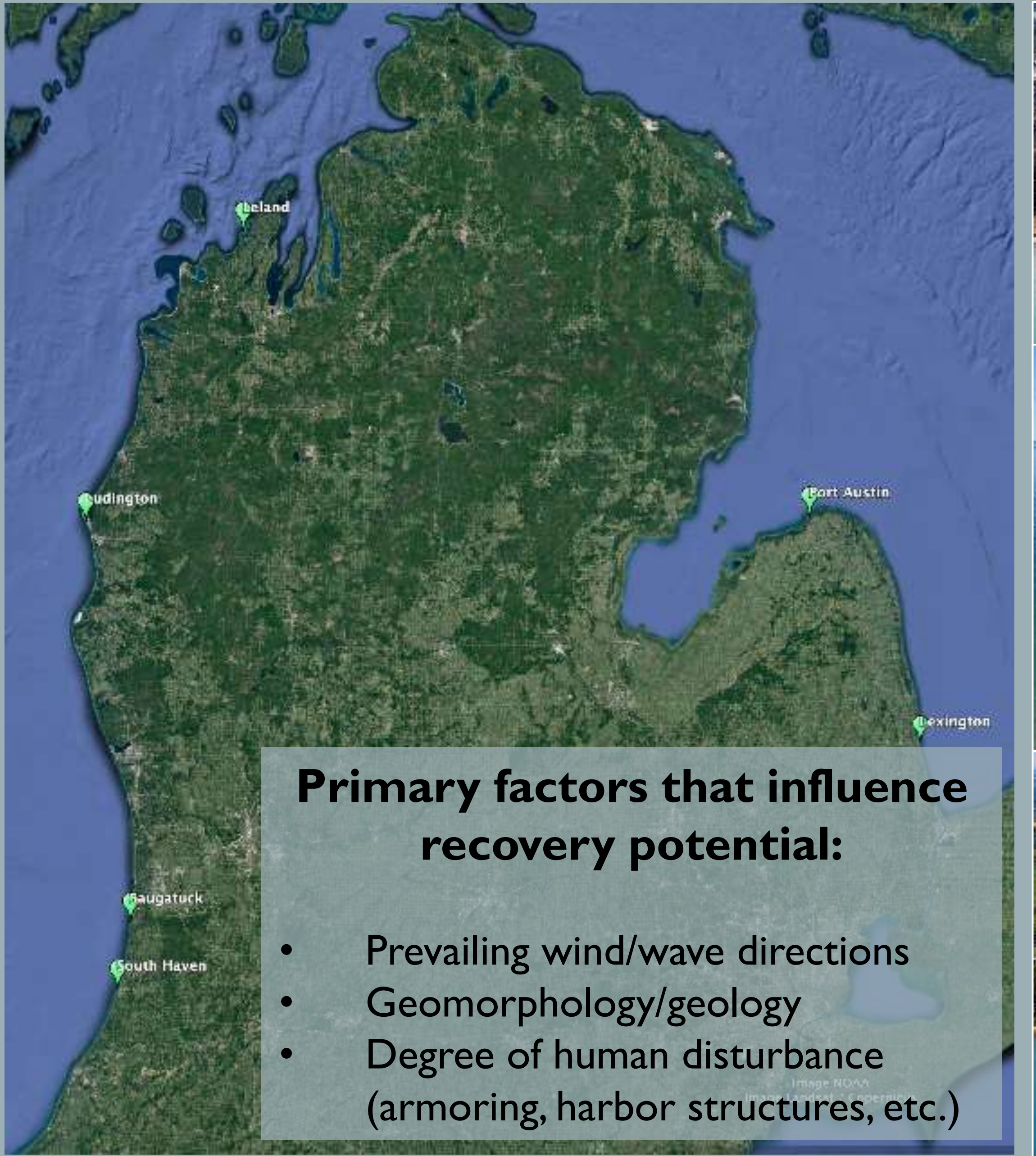
Final product: Topobathymetric maps



Topobathymetric DEMS of Difference



STUDY SITES

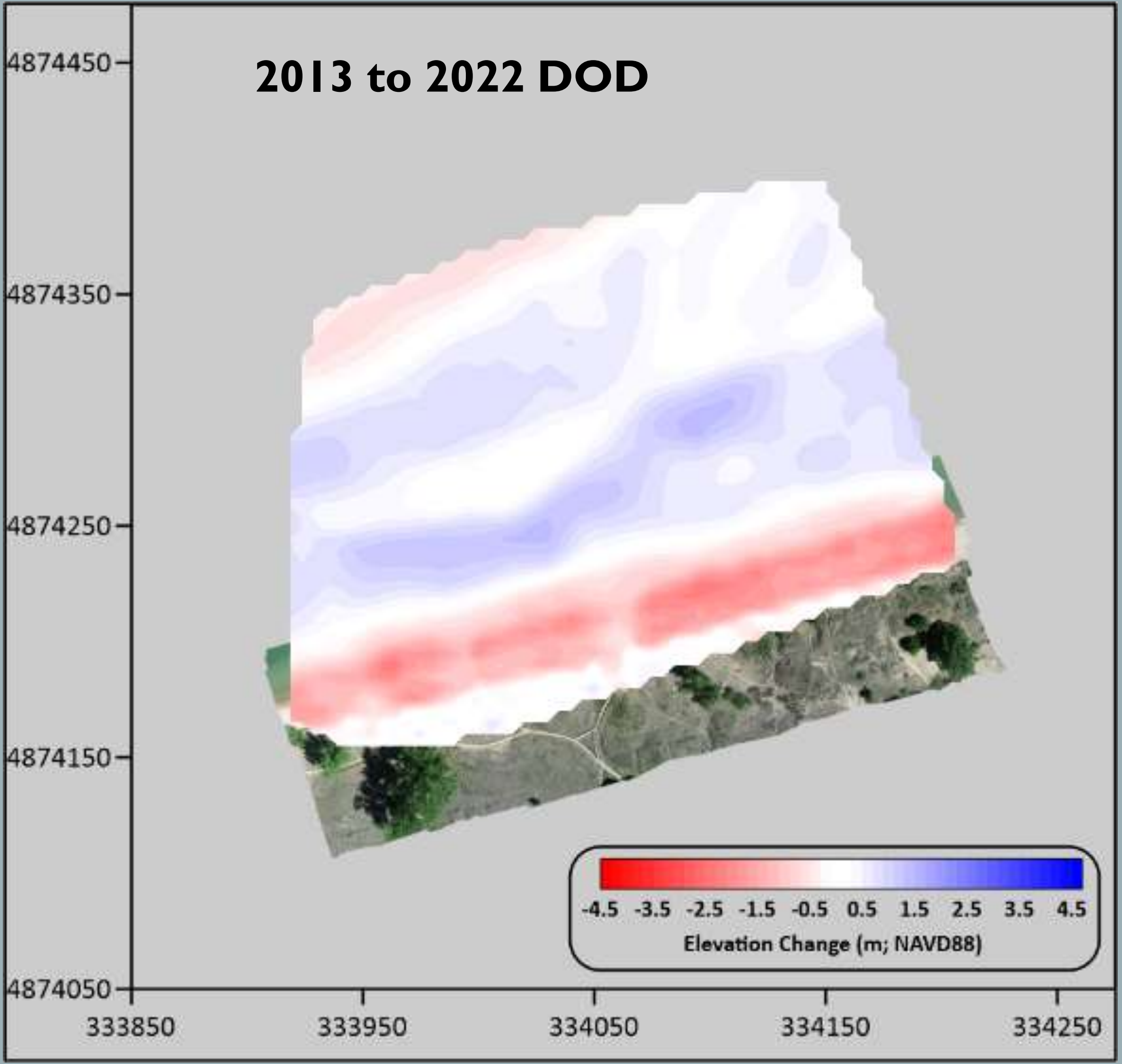


Primary factors that influence recovery potential:

- Prevailing wind/wave directions
- Geomorphology/geology
- Degree of human disturbance (armoring, harbor structures, etc.)

Port Crescent State Park- Port Austin, MI

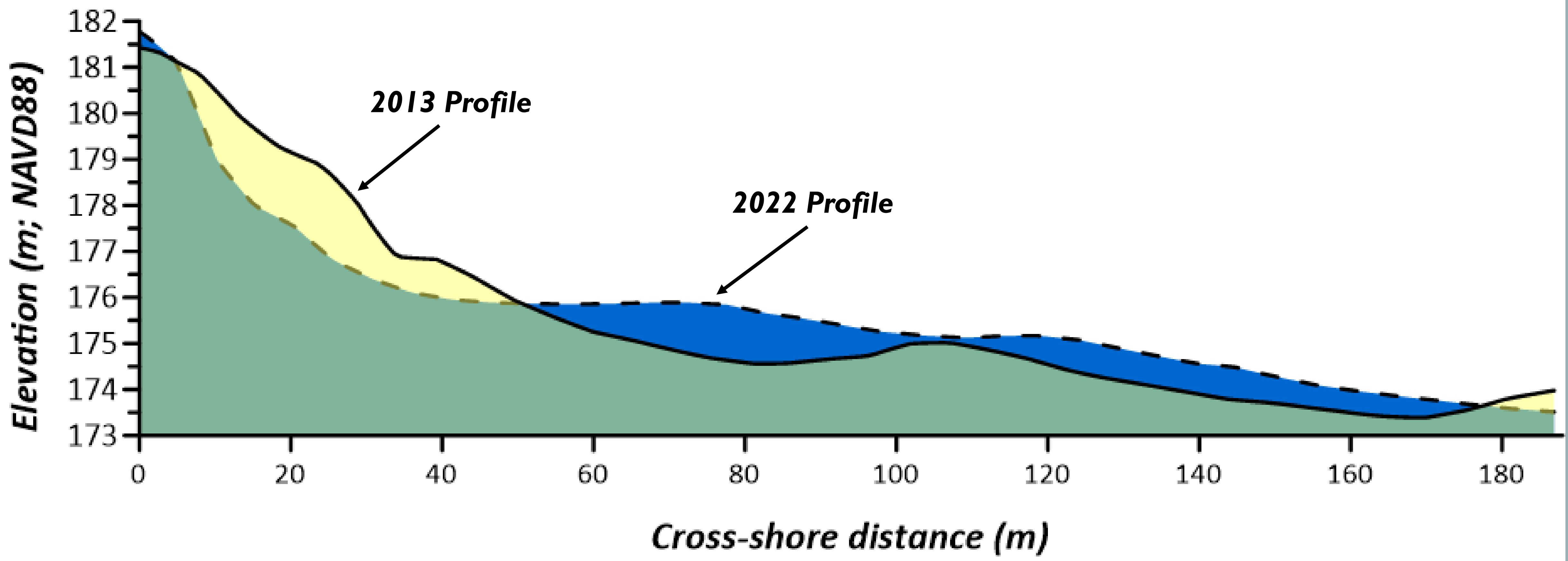
PORT CRESCENT: THE IDEAL RECOVERY SCENARIO



Rising Lake Level Impacts

- 22m of foredune retreat
- 15,202 m^3 negative volume change (**beach and foredune erosion**)
- 20,126 m^3 positive volume change (**nearshore deposition**)

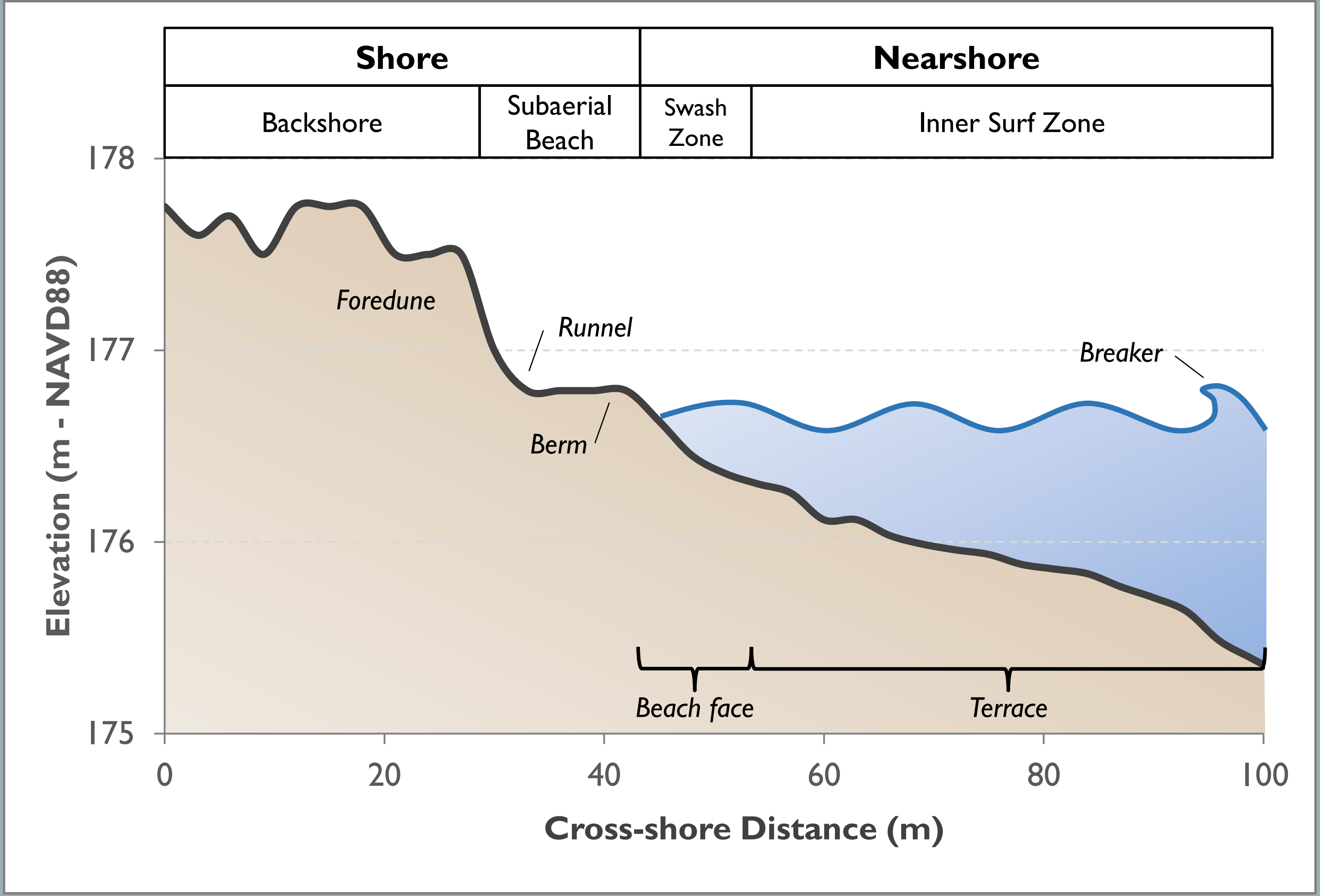
ERODED MATERIAL OCCUPYING NEARSHORE TROUGHS



Sand deposited in shallow nearshore-
beach and foredune recovery <u>probable</u> as lake level continues to recede

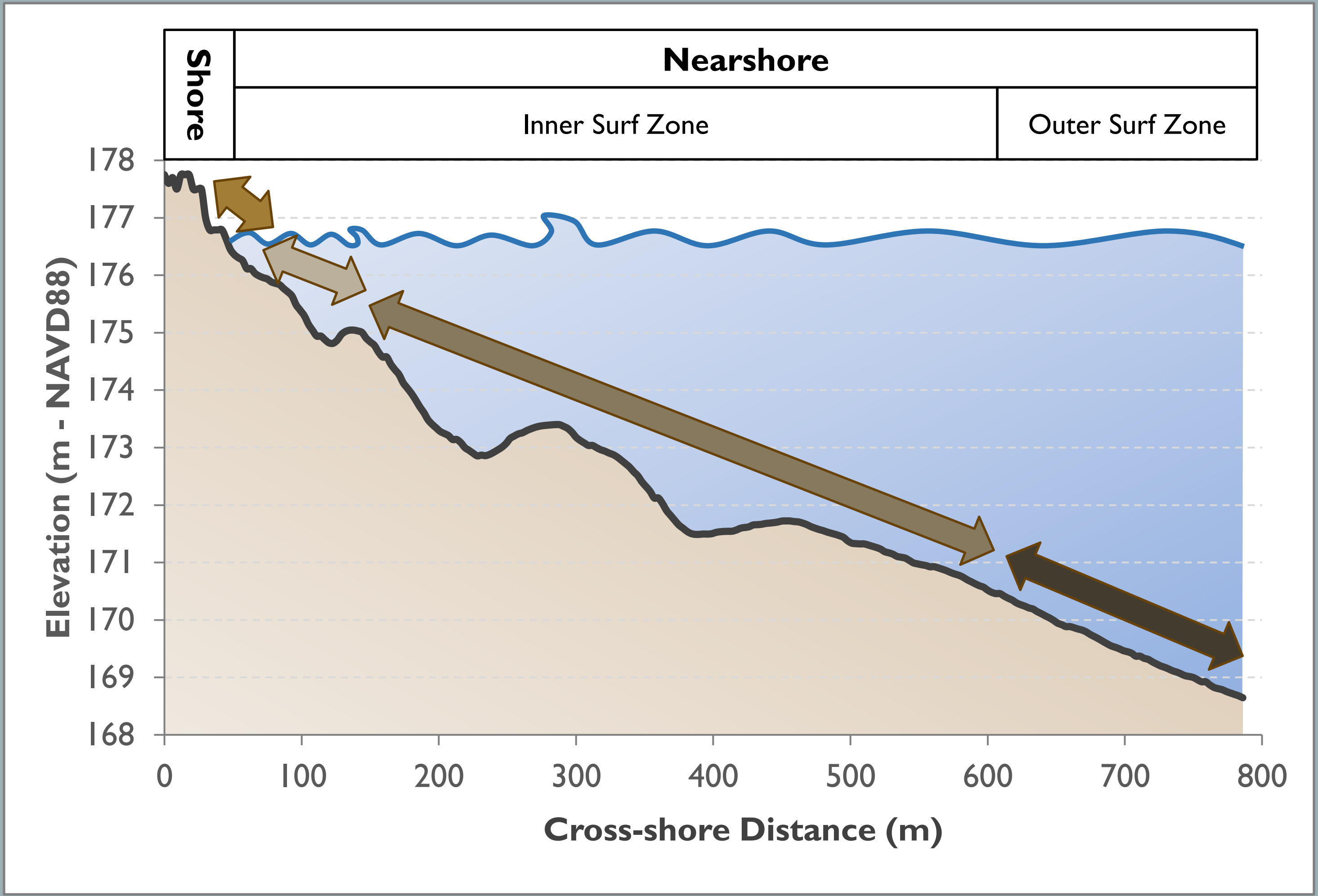
CAN WE PREDICT WHETHER BEACH RECOVERY WILL OCCUR?

HOW DO BEACHES RECOVER?

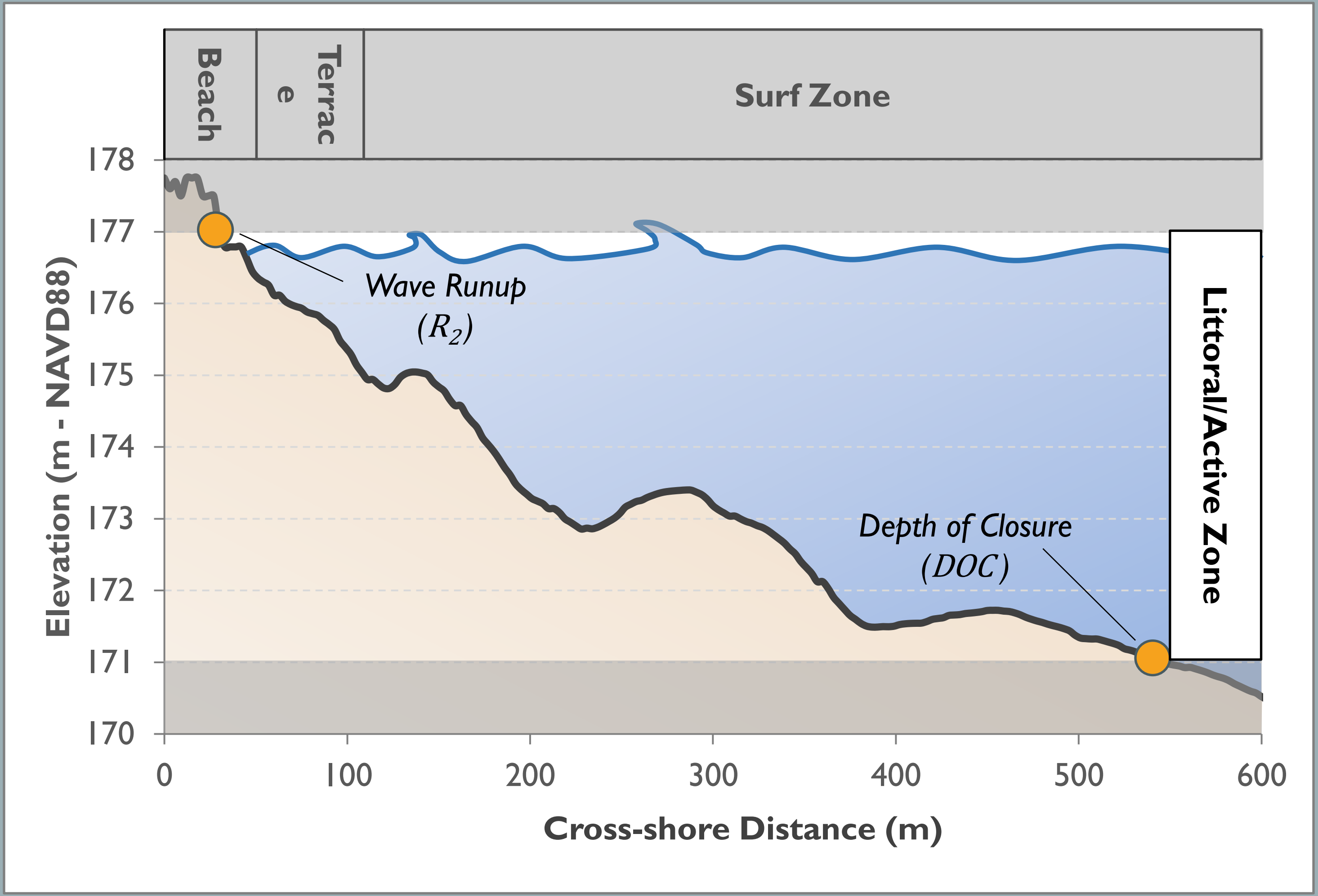


- Recovery = sediment transferred back to beach
- Water levels are **NOT** the main driver or indicator of recovery
- Essential ingredients:
  - Shallow sediment sources
  - Calm wind and wave conditions which lead to onshore-directed sediment transport

BEACH RECOVERY: A QUESTION OF **SEDIMENT CONNECTIVITY**



WHERE IS SEDIMENT MOVING ALONG THE PROFILE?



- **Active sediment transport zone**
  - Upper limit: **Wave Runup (R_2)**
  - Lower limit: **Depth of closure (DOC)**
- **As wave energy varies- limits of this active zone shift**
  - ***Larger waves- larger active zone***

HOW AND WHEN IS SEDIMENT MOVING?

- **Morphodynamic Condition (MC) classification**
  - Dimensionless sediment fall velocity (Ω)
  - Significant wave height (H_s)

Accretionary (AC)

$\Omega < 2$

Moderately Erosive (ME)

$\Omega \geq 2$
$H_s < 2\ \mathrm{m}$

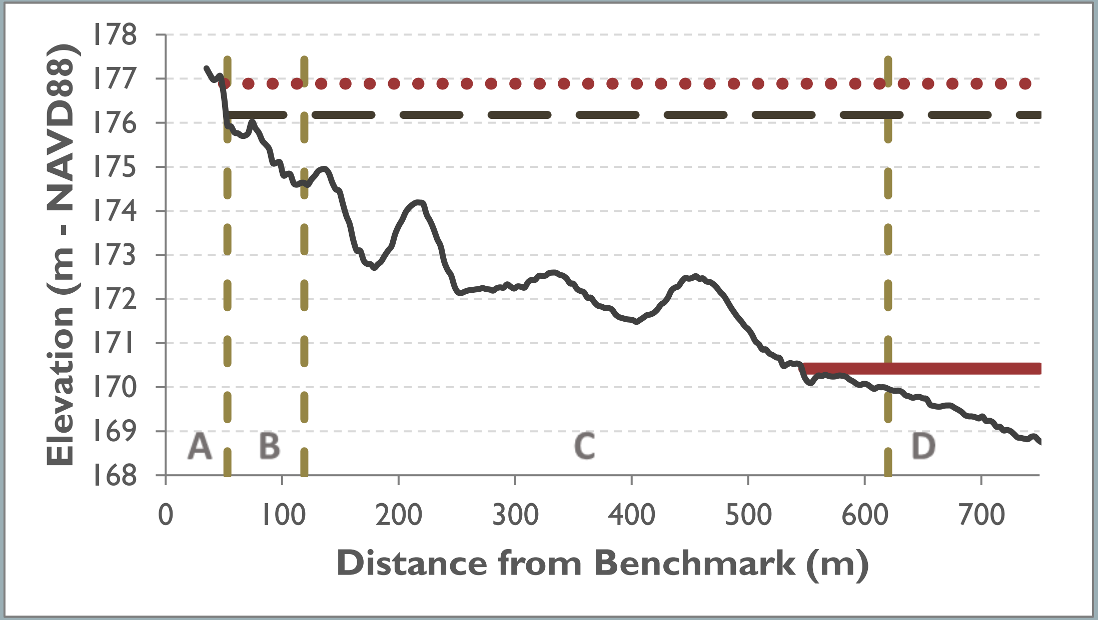
Severely Erosive (SE)

$\Omega \geq 2$
$H_s \geq 2\ \mathrm{m}$

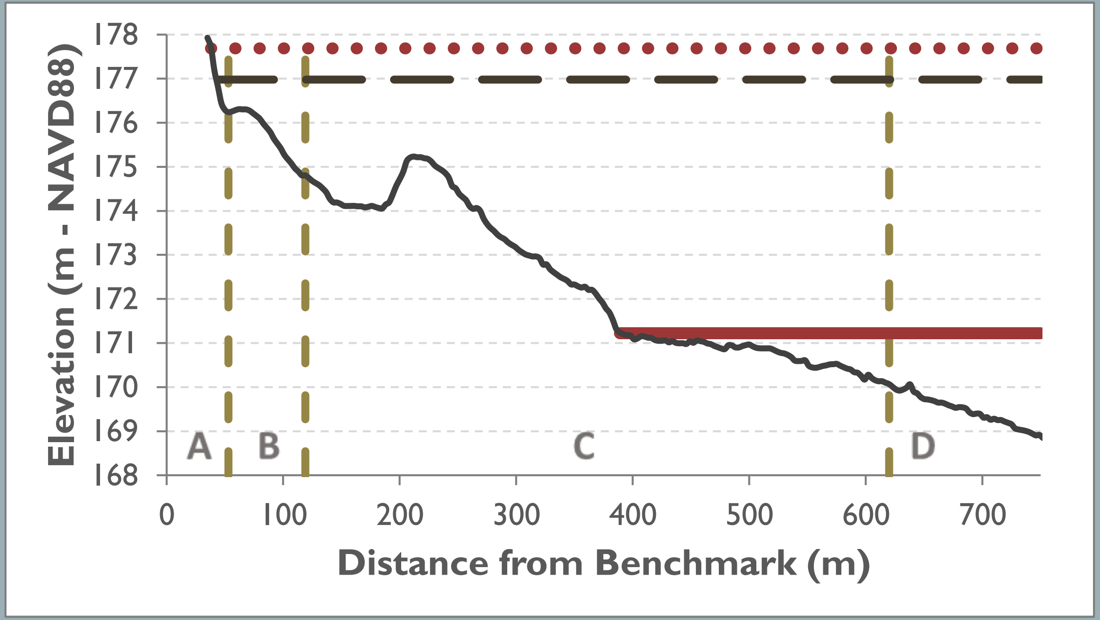
WHERE IS SEDIMENT MOVING?

MC: Severely Erosive
Wave Height: 3.0 m, **Wave Period:** 7.5 s
Sediment Transport: Offshore →

Low Lake Levels (2008, UM14)



High Lake Levels (2021, UM14)



Wave Runup: R_2 AC R_2 ME R_2 SE

DOC: *DOC* AC *DOC* ME *DOC* SE

Lake Level

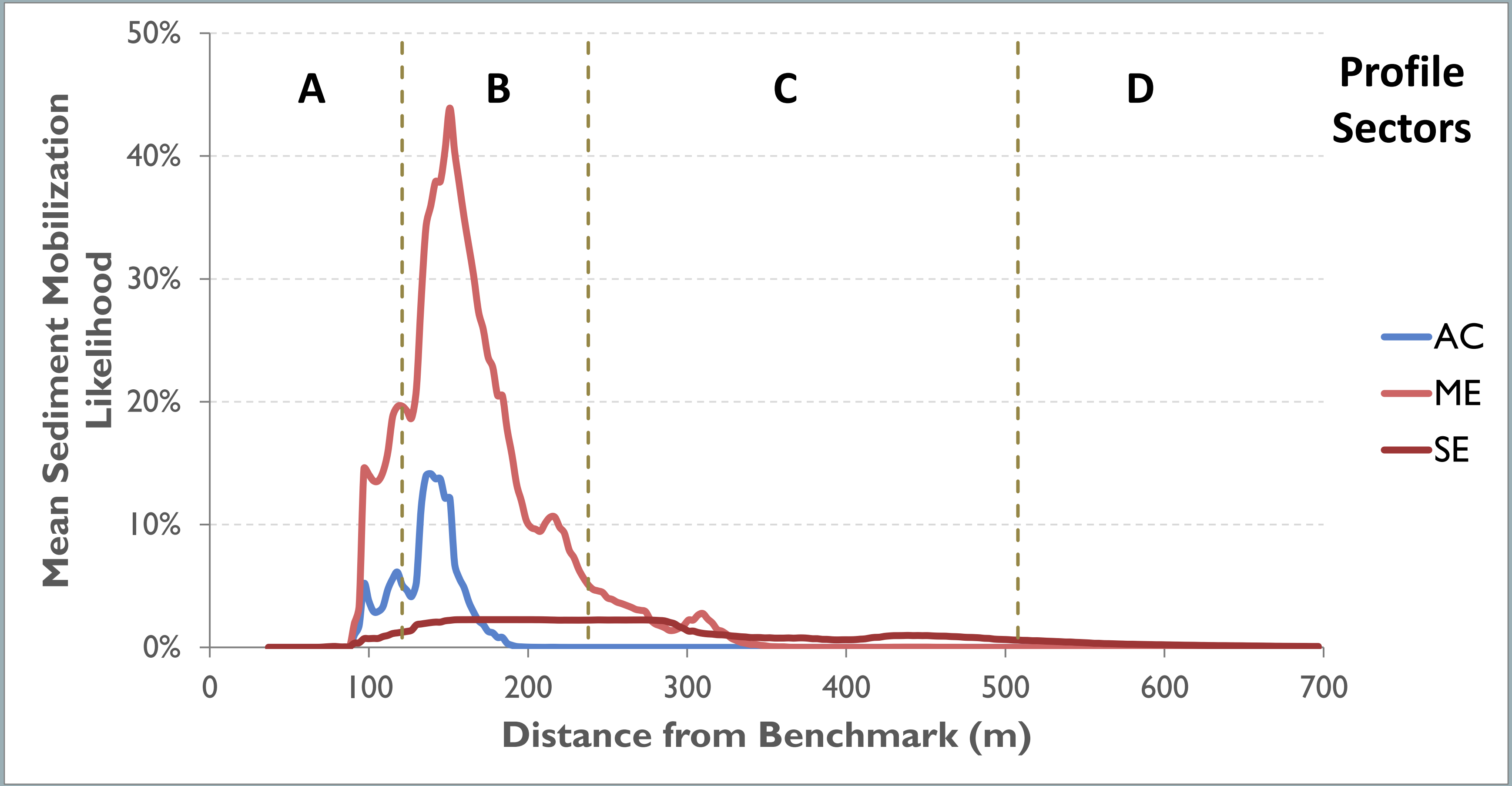
STUDY SITES


UM29
UM22
UM21
UM19
WI
Lake Michigan
MI
UM14
IL
UM04
50
Kilometers
IN
N


UM04
City Waterfront Park, New Buffalo
UM14
P.J. Hoffmaster State Park
UM19
Buttersville Park, Ludington
UM21
Stearns Park, Ludington
UM22
Juanita Street Easement, Ludington
UM29
Bar Lake Access, Manistee
250 Meters
Survey Benchmark
Profile Survey Line

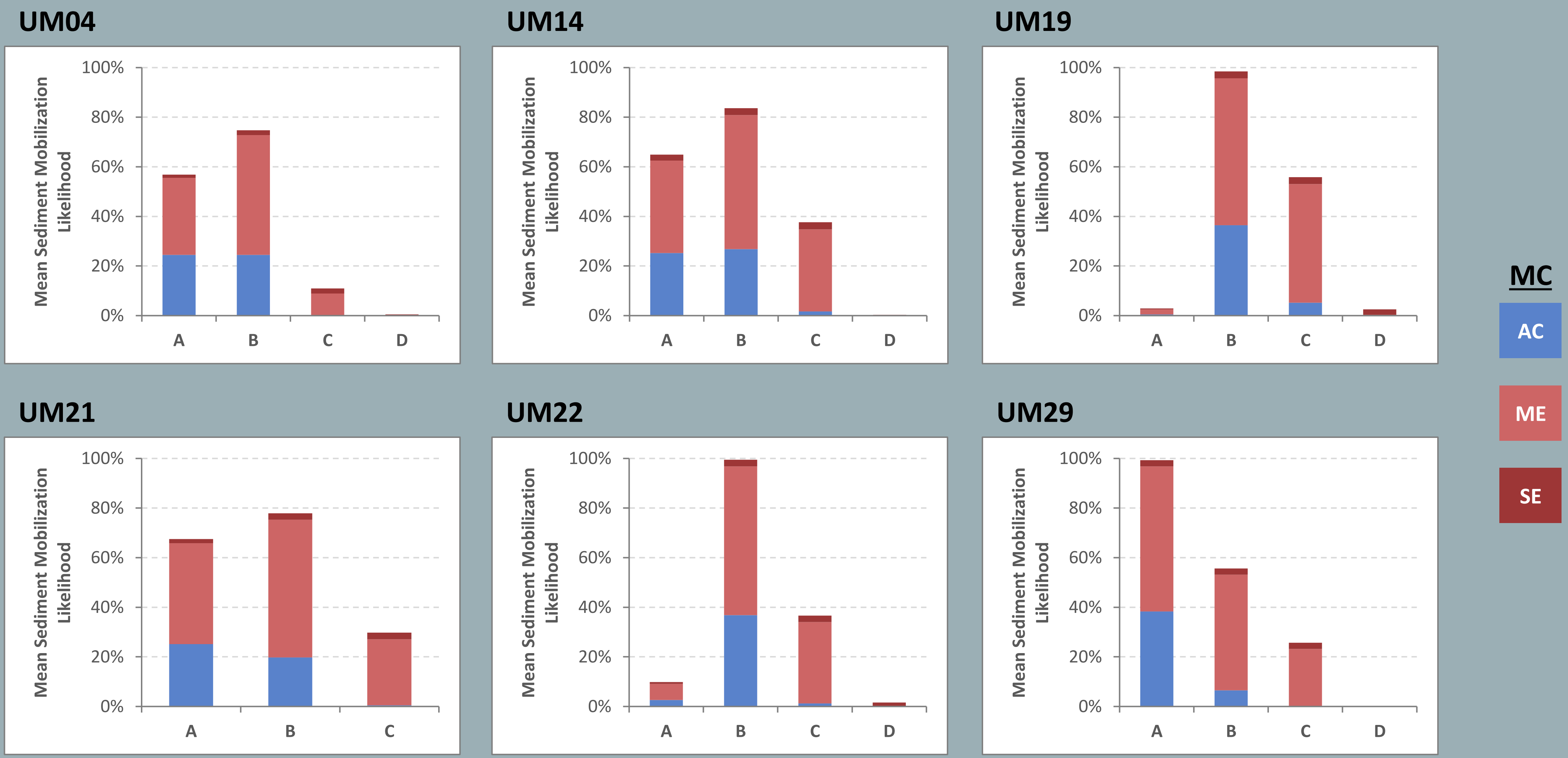
WHERE IS SEDIMENT MOVING?

UM04, 1988-2021



Penrod et al., 2025- Journal of Great Lakes Research

WHERE IS SEDIMENT MOVING?



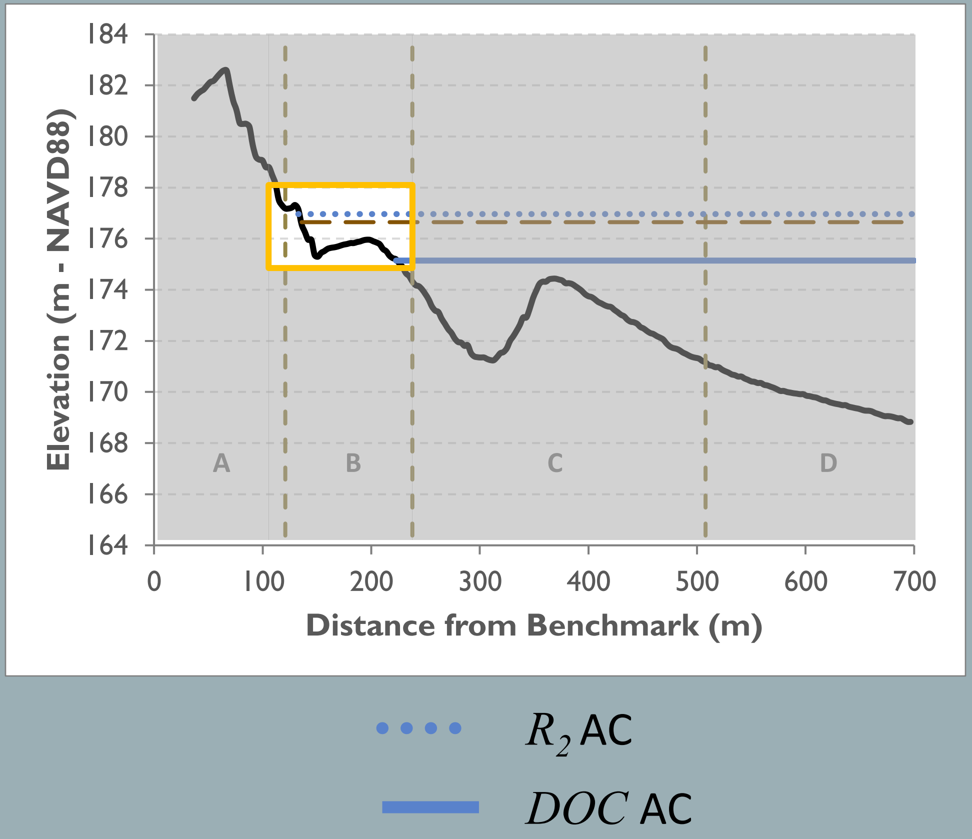
SEDIMENT CONNECTIVITY AND BEACH RECOVERY

- Greater **offshore** connectivity than onshore connectivity

- The likelihood and rate of recovery is controlled by sediment availability in a **narrow zone** activated by AC conditions
  - Under accretionary conditions- likelihood of onshore transport from bars is **limited**

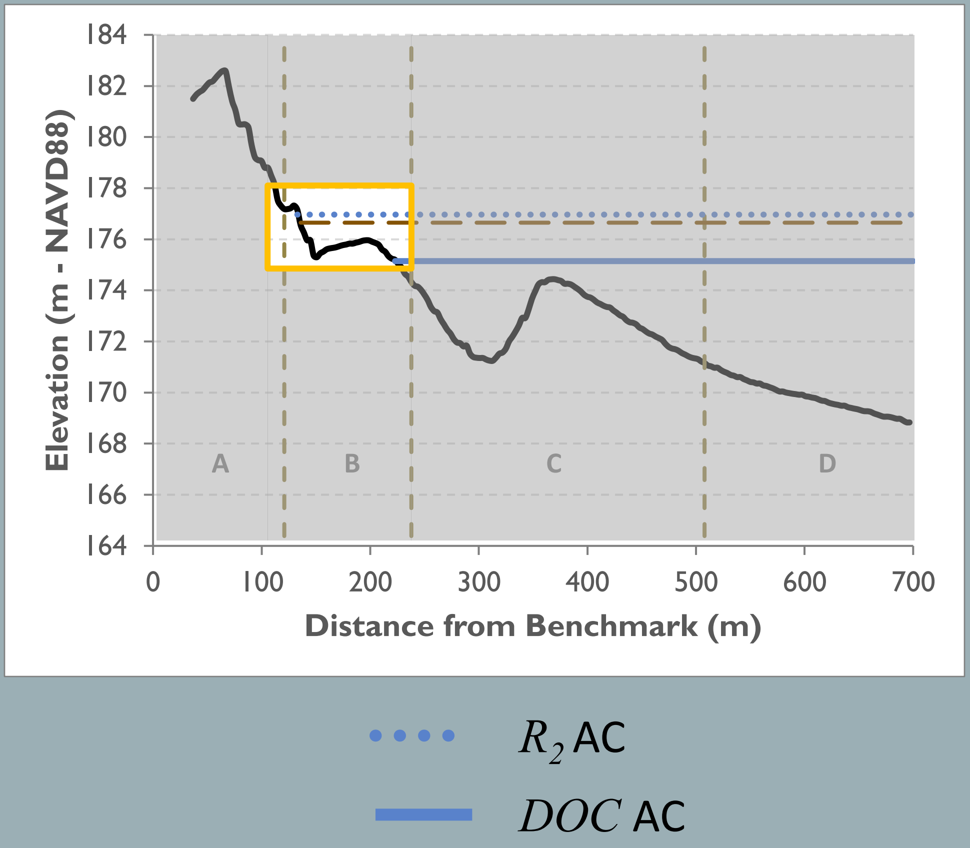
- Material either trapped within this zone from **lakeward-directed erosion** during rising lake level (e.g., Port Crescent) or sourced into the area **via longshore drift** (e.g., New Buffalo UM04)

UM04: 2021 Accretionary (AC) Active Zone



ARMORING IMPACTS SEDIMENT TRANSPORT WHERE IT MATTERS MOST

UM04: 2021 Accretionary (AC) Active Zone



MICHIGAN COAST 5 TIMES MORE ARMORED NOW THAN IN 2014

Stretch of lakeshore in Saugatuck, MI

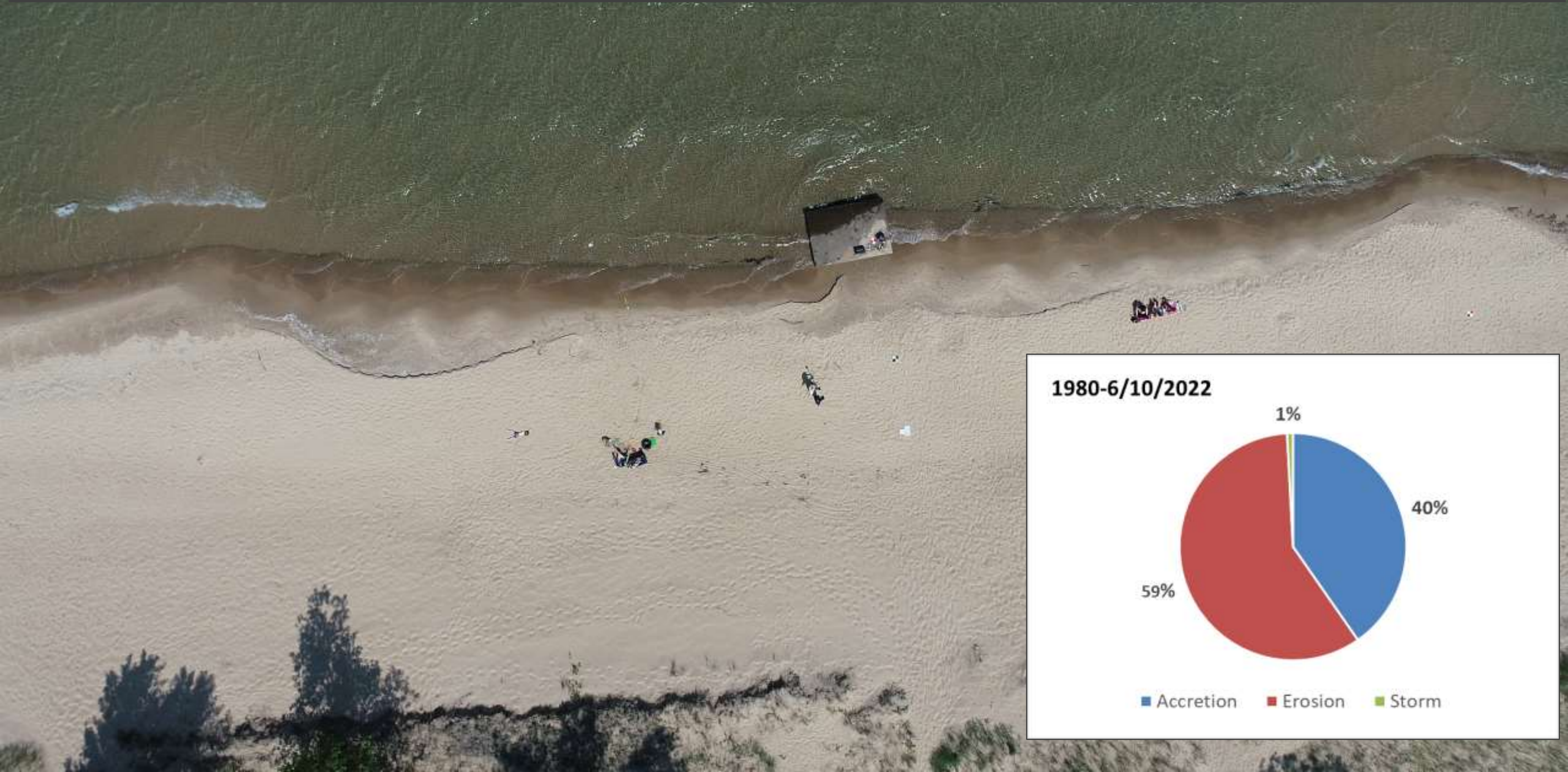
Sections	2014 Shoreline Armoring (m)	2014 Shoreline Armoring (%)	2021 Shoreline Armoring (m)	2021 Shoreline Armoring (%)	% Change in Armoring
South	16,473	8.3	74,245	37.5	350.7
Middle	5195	2.6	28,268	14.3	444.1
North	1754	0.9	8945	4.5	410.0
Total Shoreline	**23,421**	**3.9**	**111,458**	**18.7**	**375.9**

Saugatuck Township/City

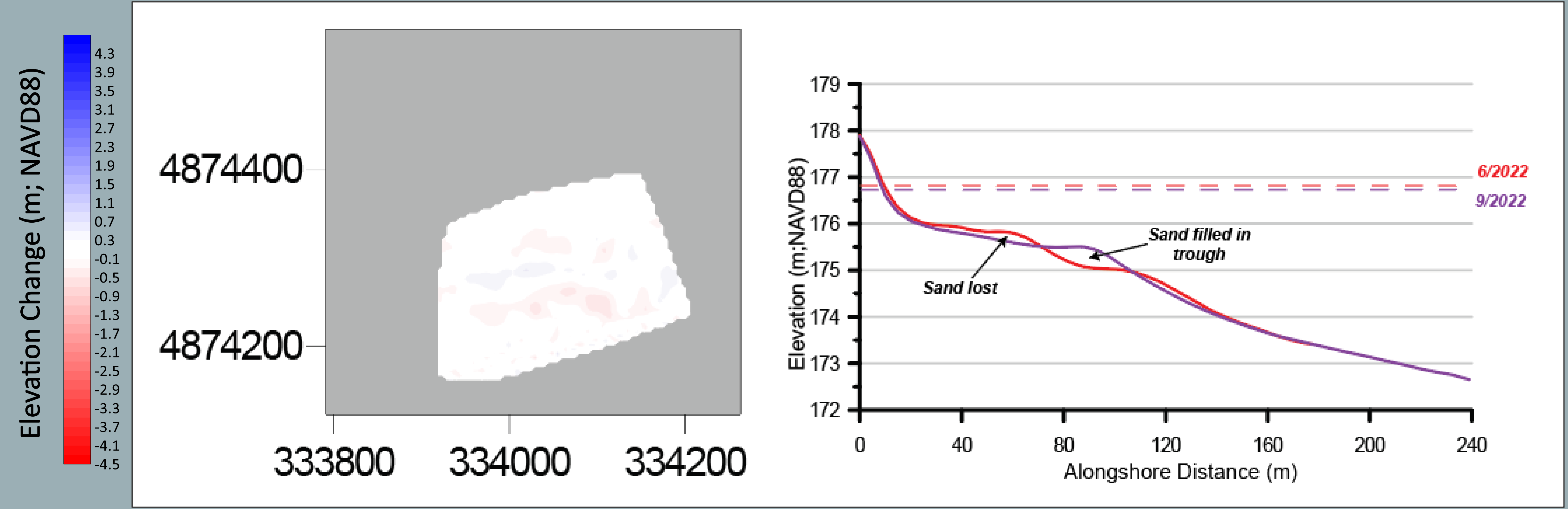
- **% Armored in 2014- 0.9%**
- **% Armored in 2021- 35.1 %**

Theuerkauf, Burchi, and Wyns., 2025- Journal of Great Lakes Research

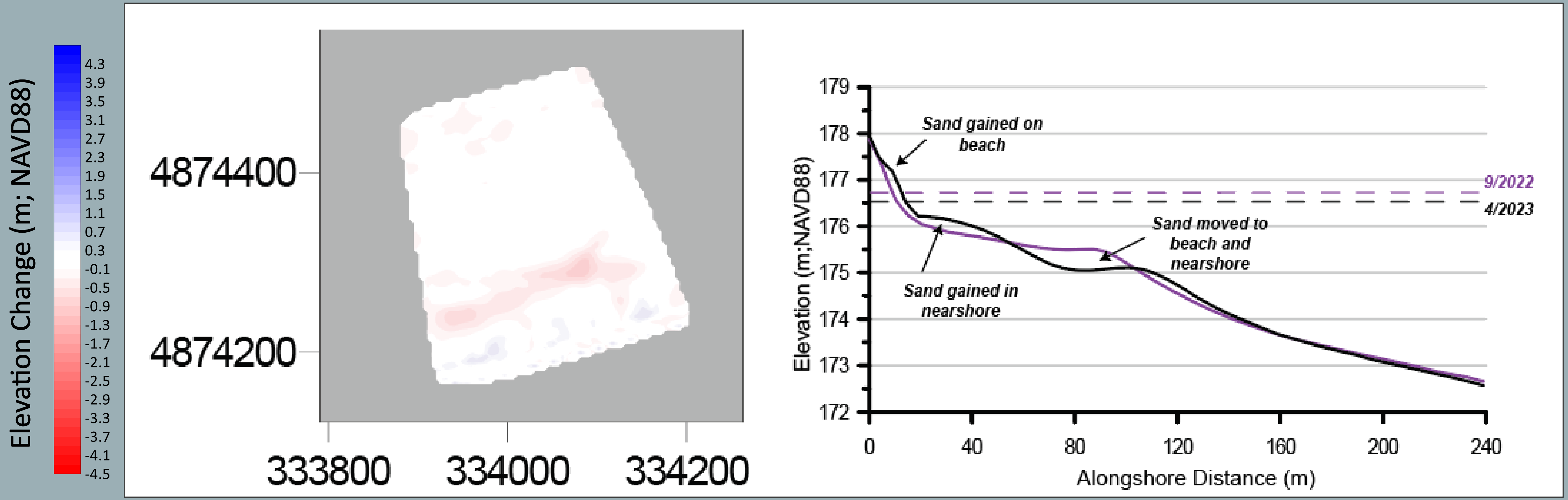
HAS THE BEACH RECOVERED AT PORT CRESCENT?



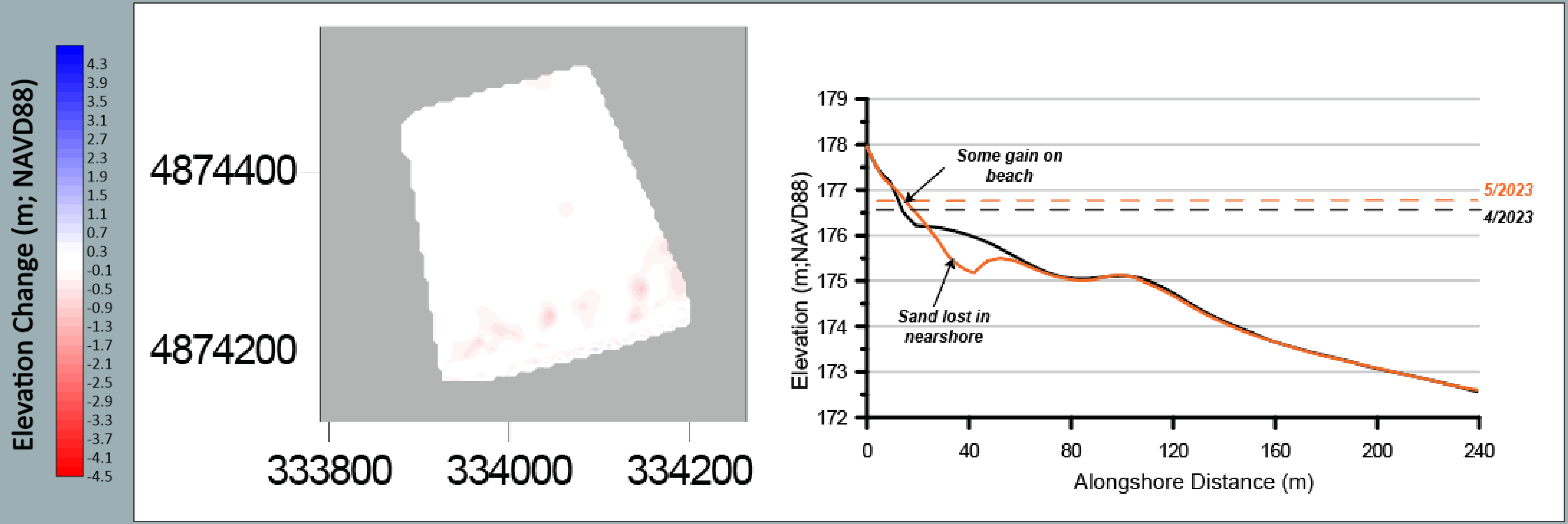
WHAT HAPPENS DURING A YEAR WHEN THE BEACH SHOULD BE RECOVERING?



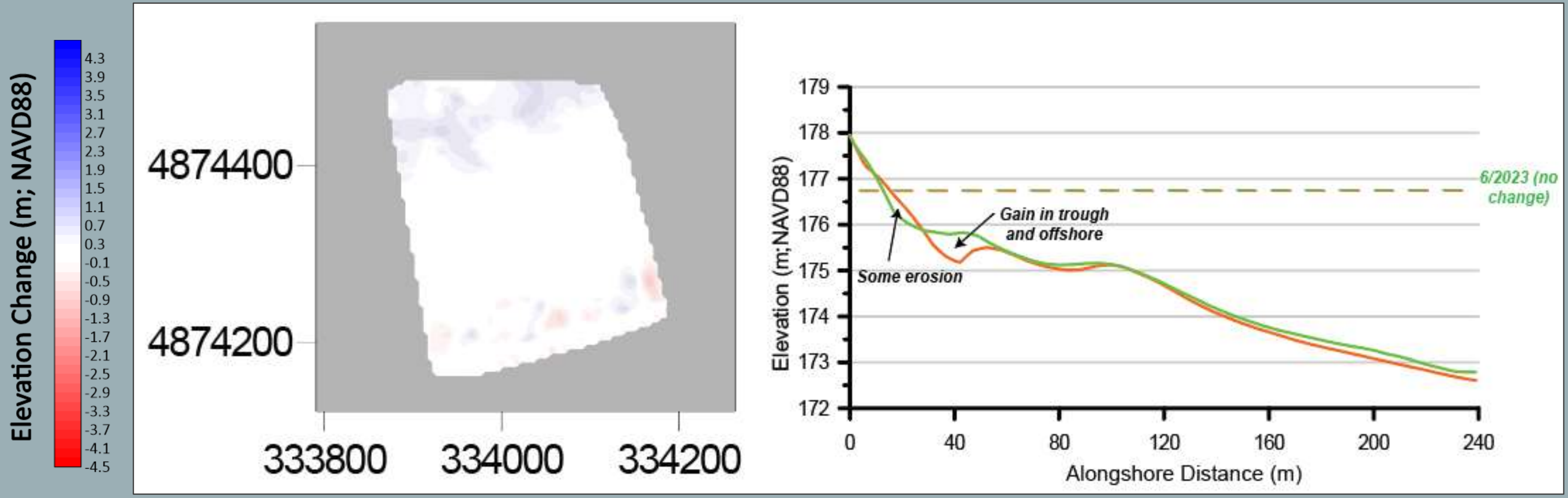
June 10, 2022 to September 29, 2022



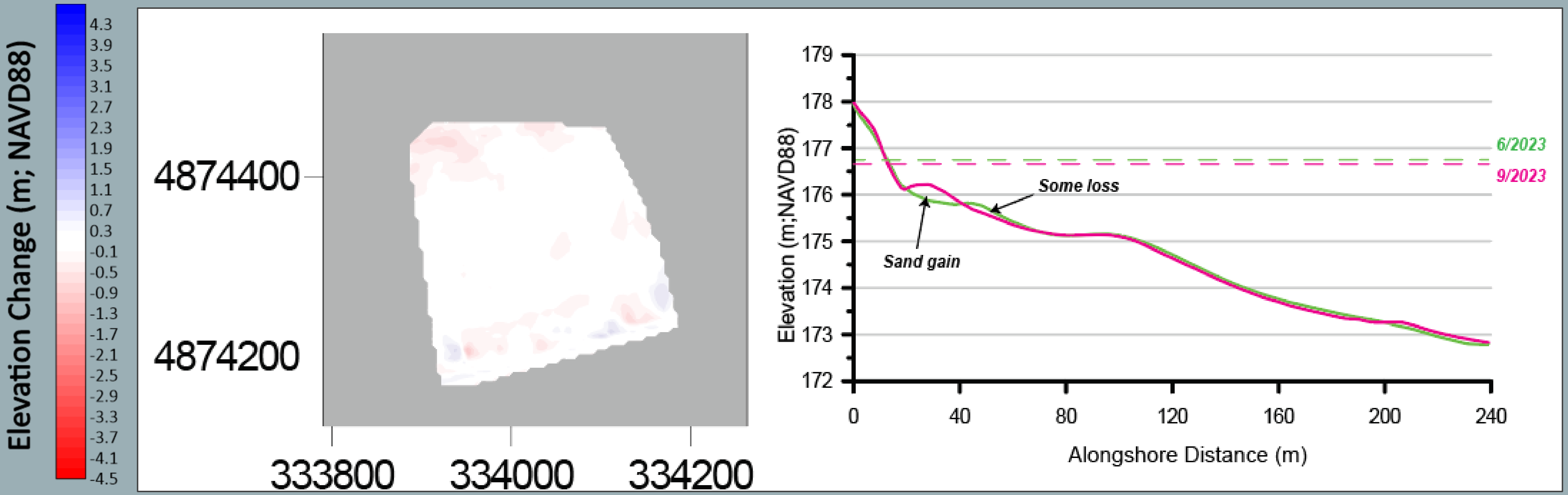
September 29, 2022 to April 27, 2023



April 27, 2023 to May 18, 2023

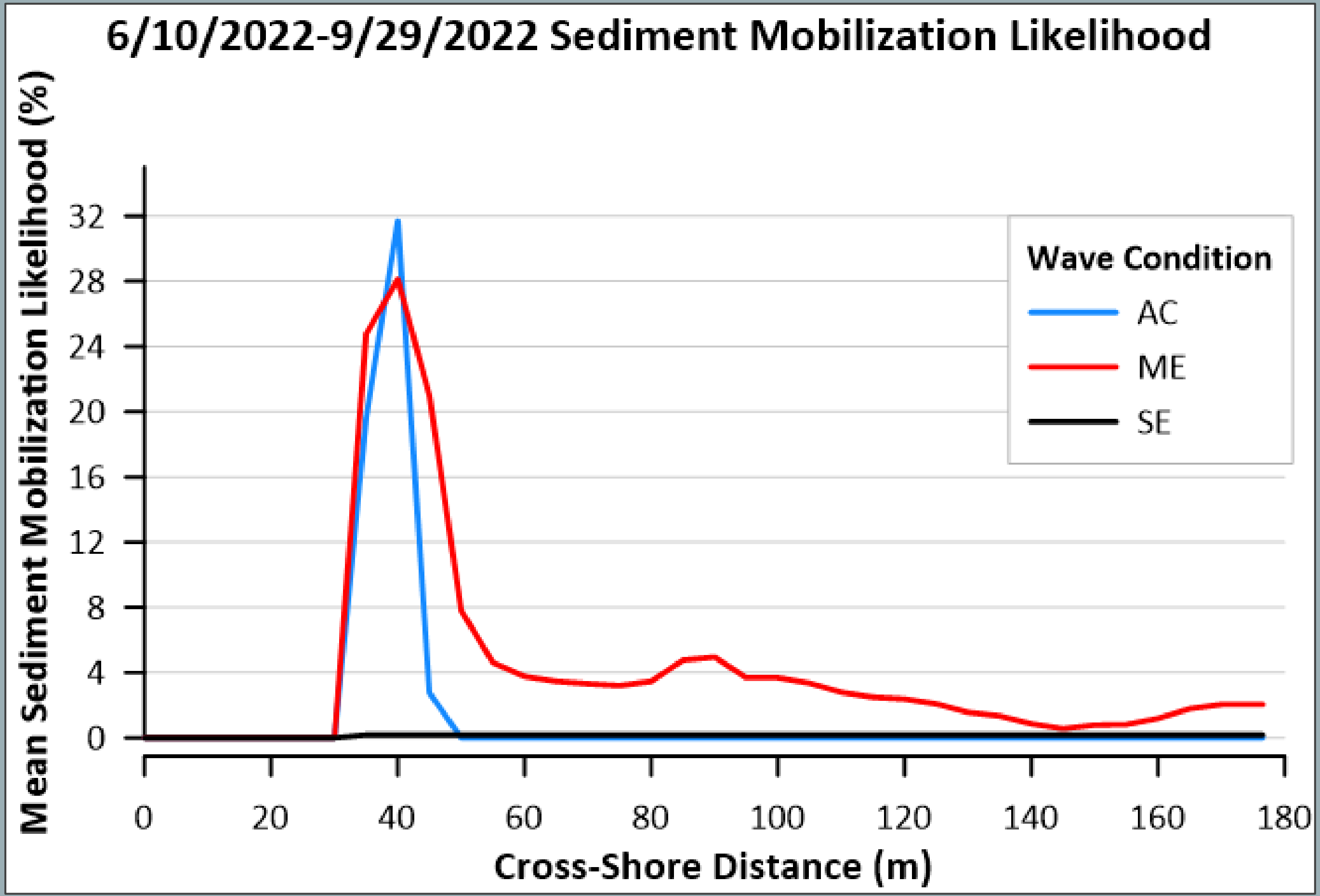


May 18, 2023 to June 29, 2023



June 29, 2023 to September 1, 2023

WHY DID WE NOT SEE SUBSTANTIAL BEACH RECOVERY DURING THIS PERIOD?



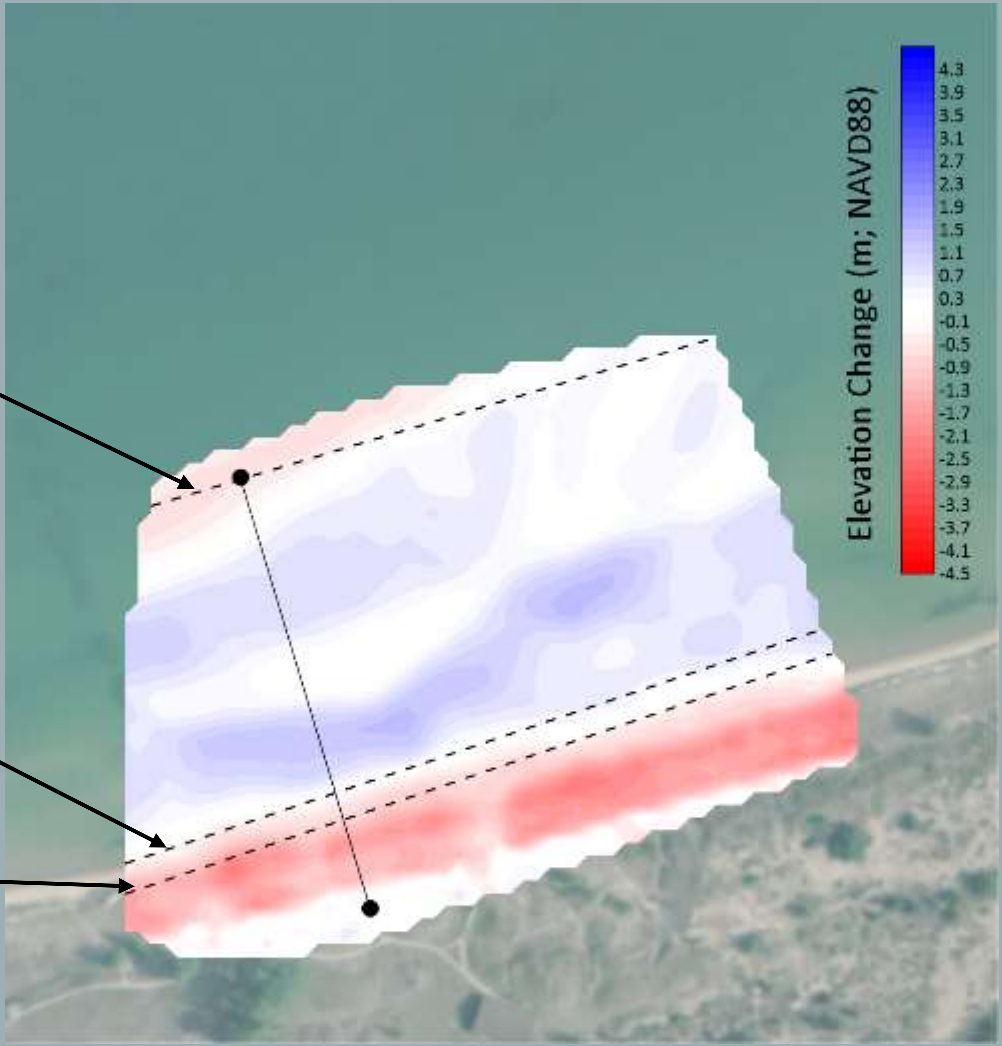
Accretionary waves only act on a small portion of the nearshore

INFLUENCE OF ACCRETIONARY WAVES SHALLOWER THAN THE NEARSHORE BARS

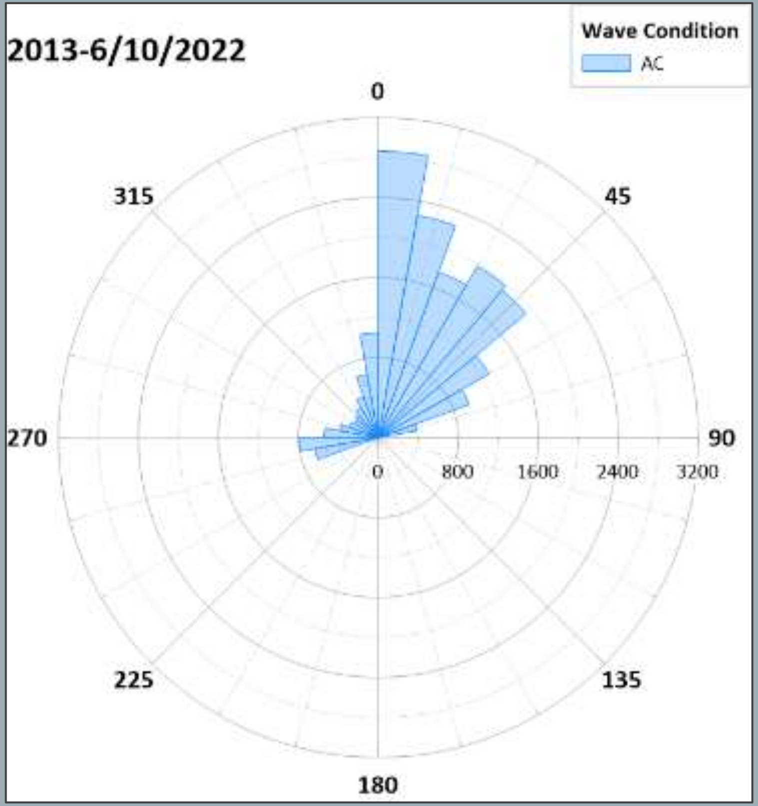
ME lower limit

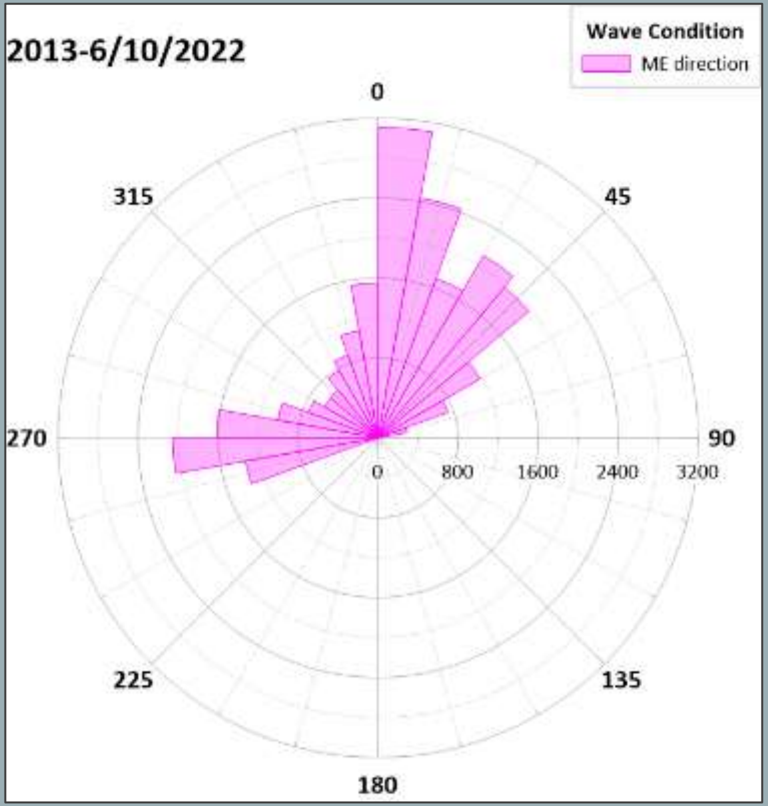
AC lower limit

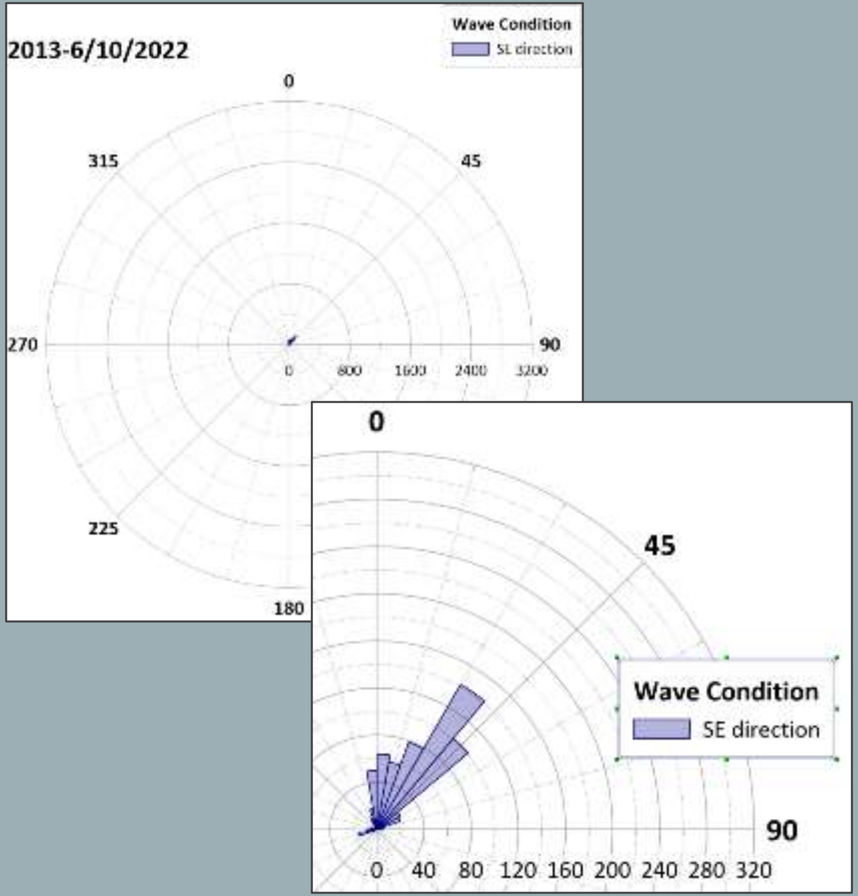
AC/ME upper limit



DIRECTION OF SEDIMENT TRANSPORT ALSO IMPORTANT

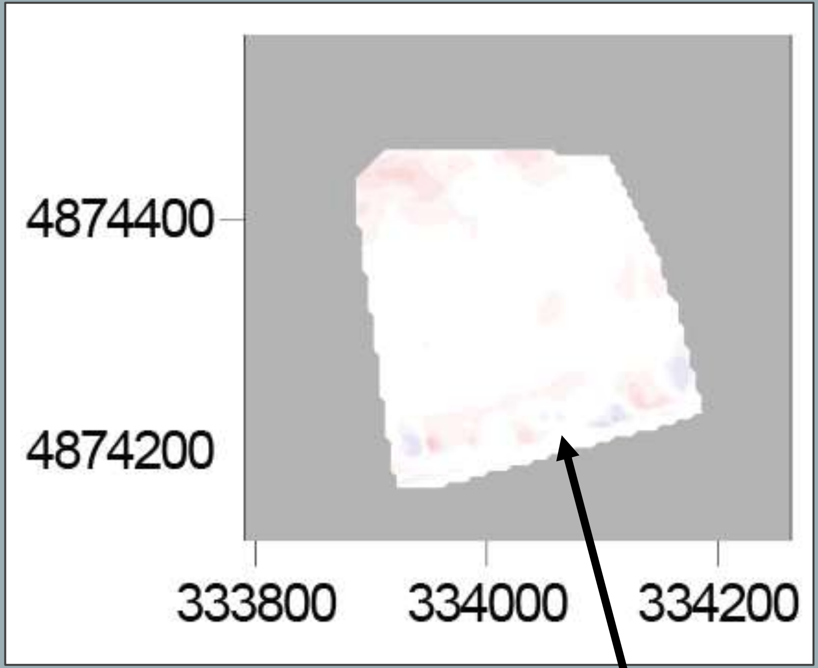


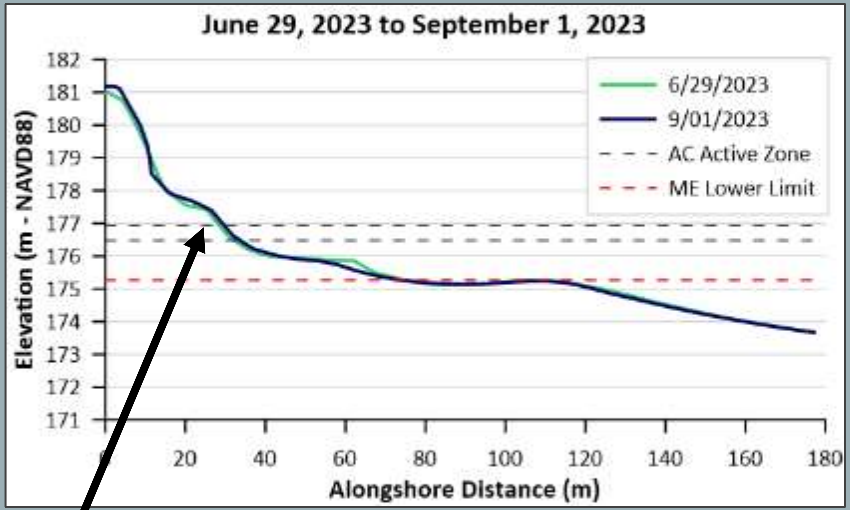


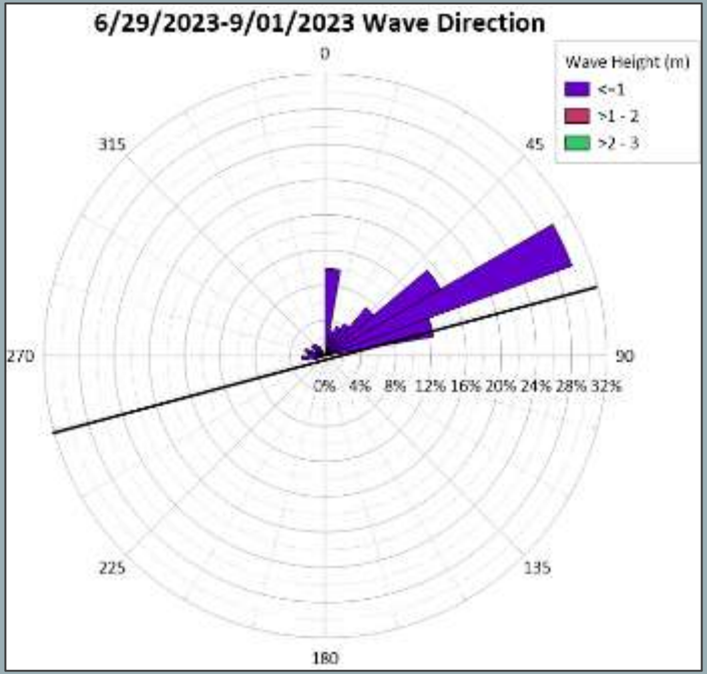


Waves typically approach this site from the NNE

HIGHLY OBLIQUE WAVES DURING THE STUDY (2023)







Dominant sand transport in beach drift

Even at sites where the sand is close to the beach- recovery is a <u>slow</u> process

NEXT STEP: HAVE THE BEACHES RECOVERED?

- Sites remapped in summer 2025
- Examining storm impacts at these sites this fall? What role do storms play in promoting or inhibiting recovery?

HAVE PUBLIC BEACHES ALONG THE LAKE MICHIGAN COAST RECOVERED?

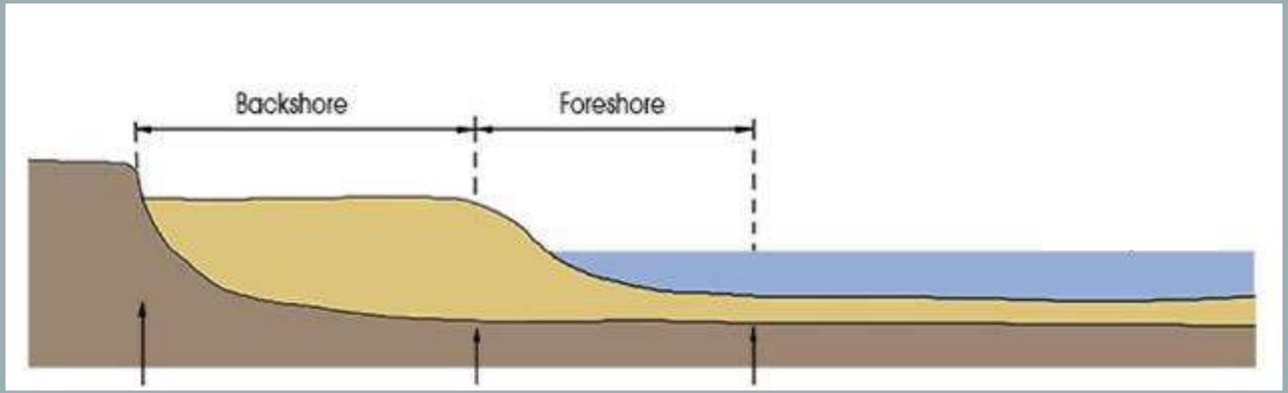
- Expand examination of beach recovery to 90 public beaches from the Indiana state line to the Straits of Mackinac

- Collect topographic profile this year (5 years post peak) and compare to beach elevation in:
  - 2013 (pre-lake level rise)
  - 2019/2020 (peak lake level)

- These data will help us refine our understanding of beach recovery dynamics
  - What beaches follow our model of expected recovery? If not, why?
  - How does shore armoring affect beach recovery?

LARGE SPATIAL VARIABILITY IN RECOVERY

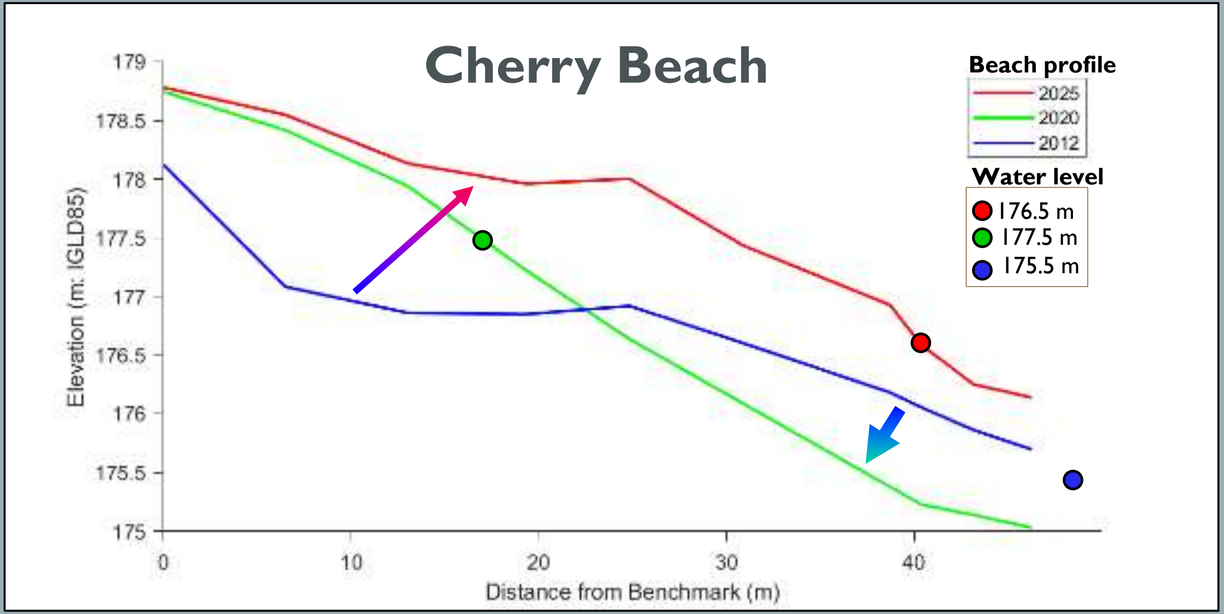
- 16 % are **fully recovered**



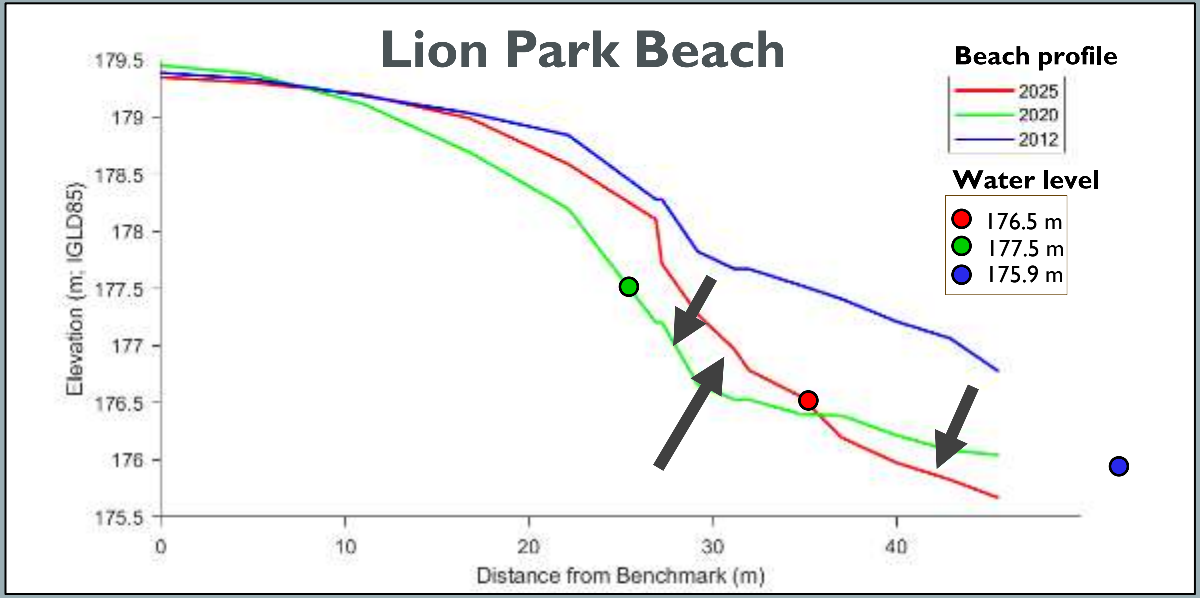
- 4% have **not** recovered at all
- 74% are **partially recovered**
  - 64% are recovering backshore, but foreshore remains lower than 2012 elevation
  - 10% have recovered foreshore, but not backshore
- 6 % have recovered to 2012 profile elevation yet are lower in elevation than the 2020 profile (e.g., Chikaming example)

16 % of the beaches fully recovered

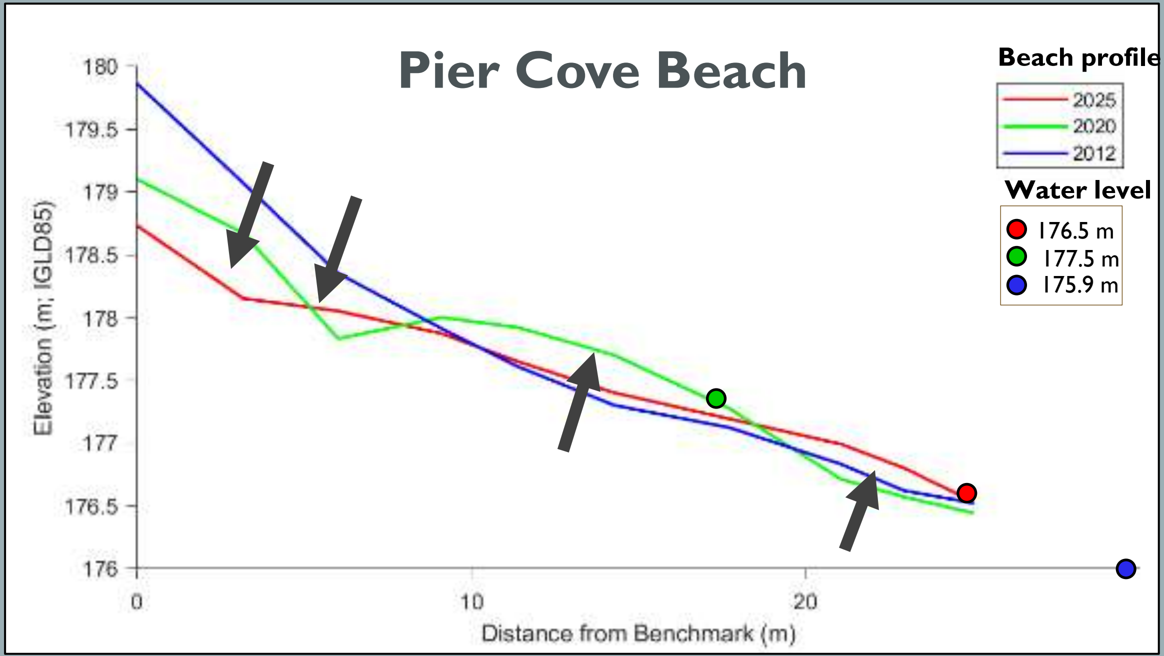
- **From 2012 to 2020:** Backshore gained sand, foreshore eroded
- **From 2020 to 2025:** Beach recovery



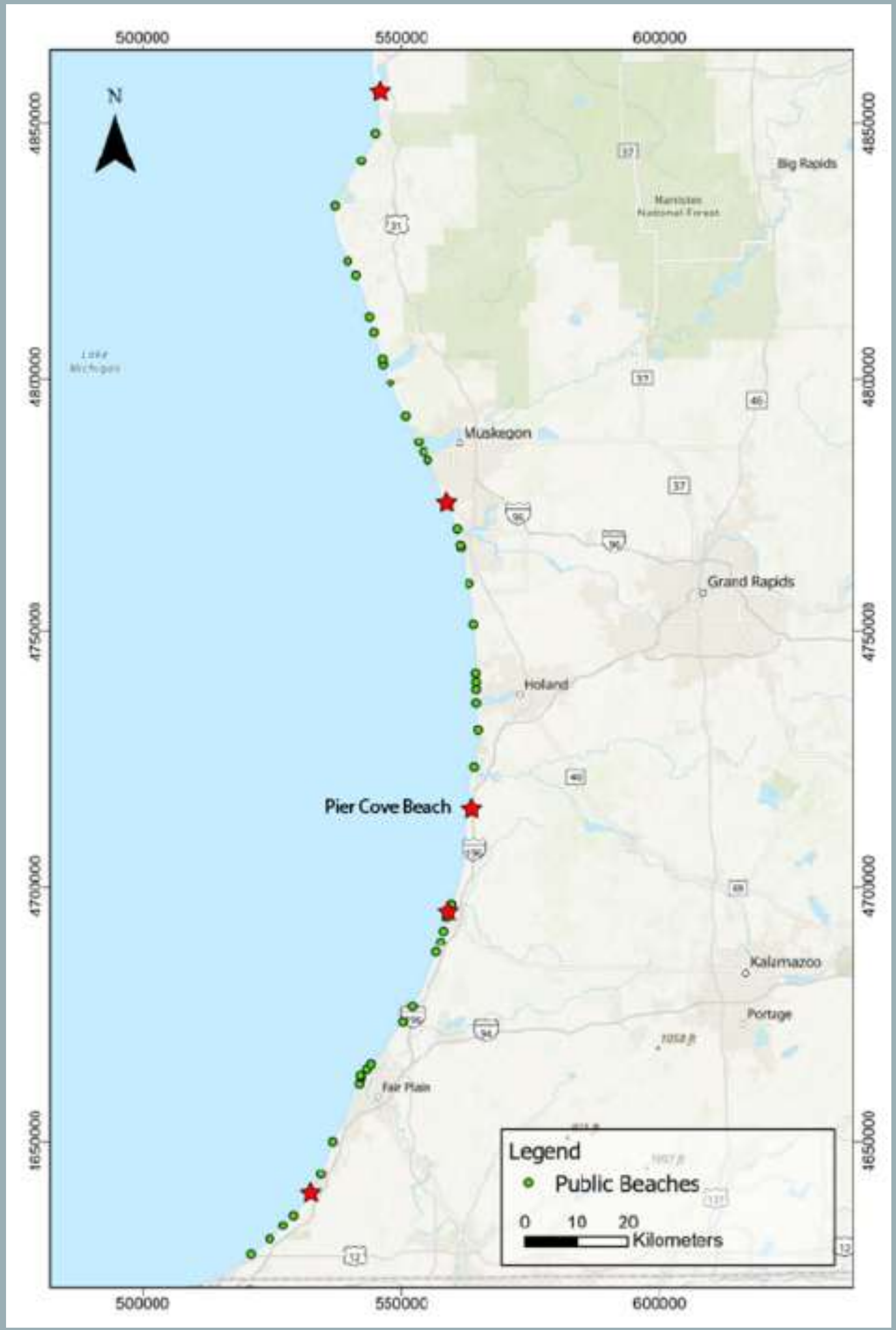
74% are partially recovered



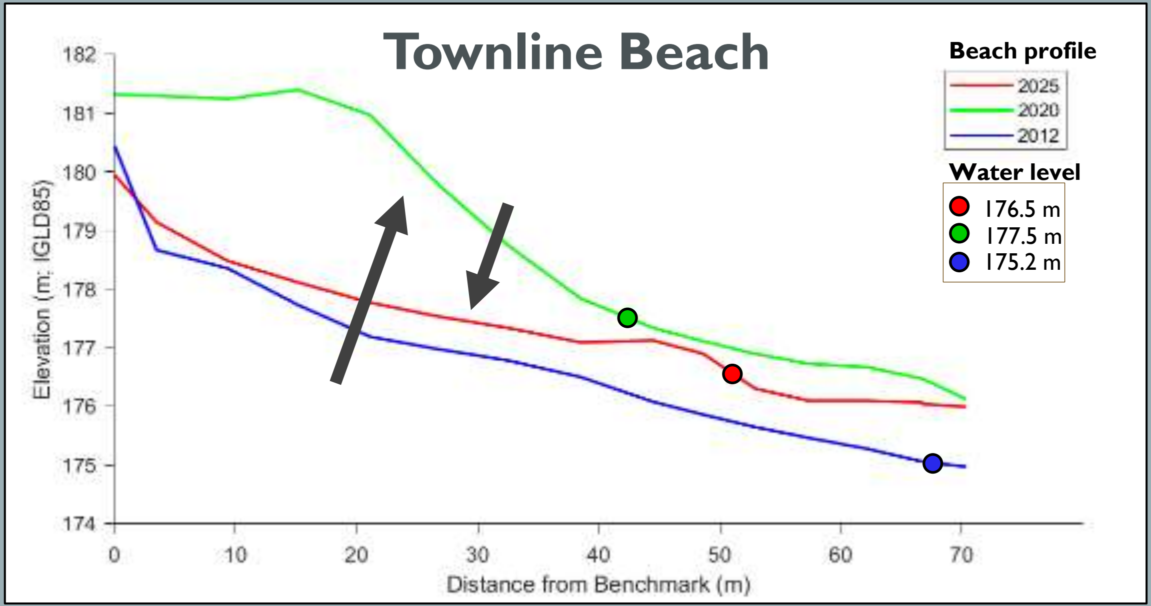
74% are partially recovered



Only the portion near the shoreline has recovered

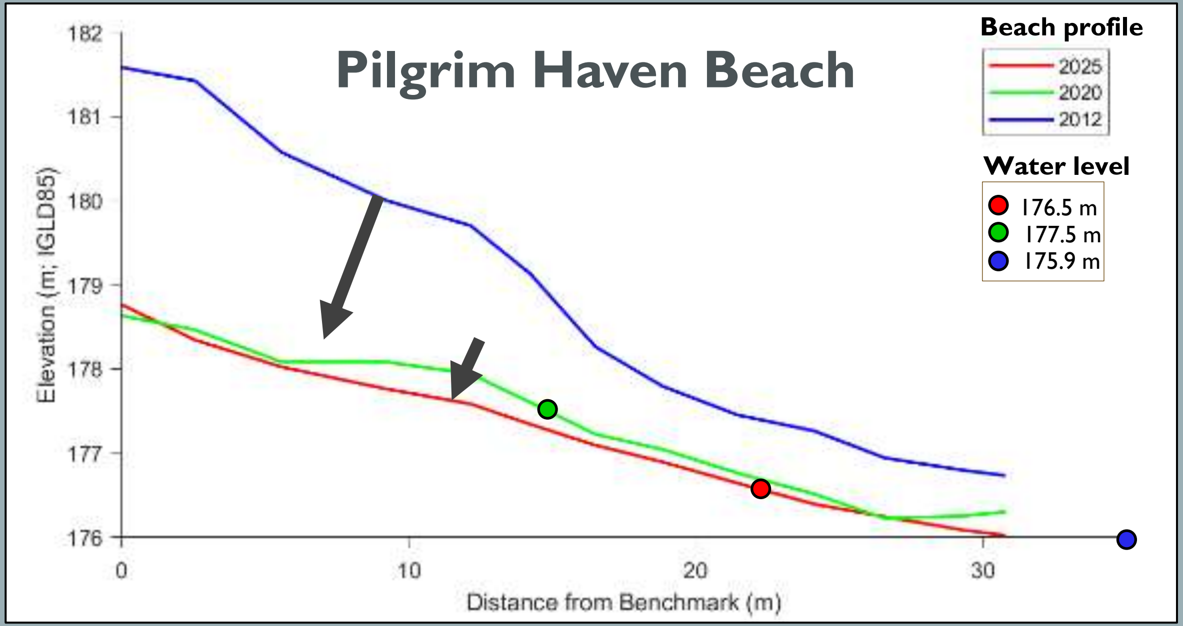


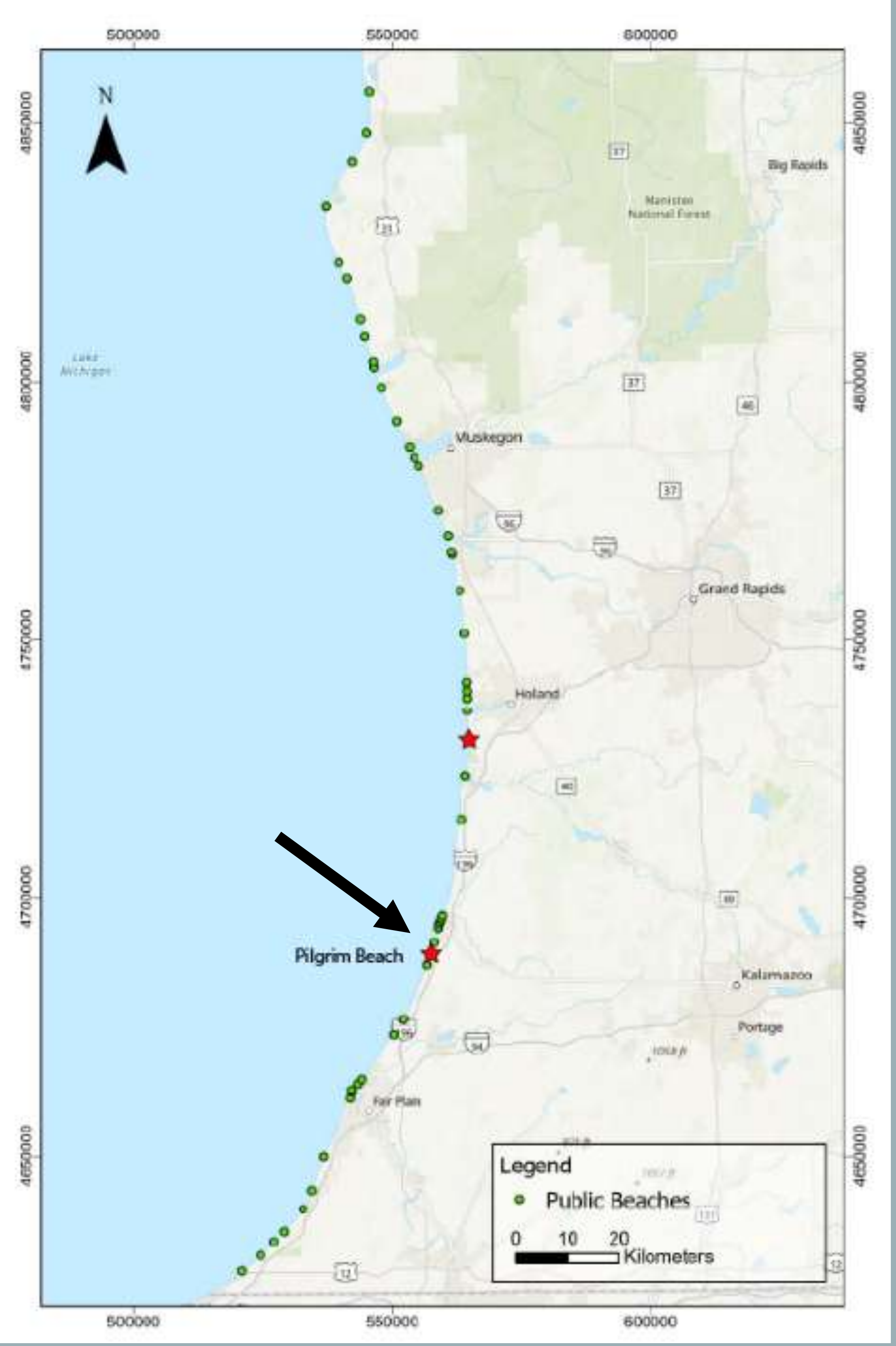
6% of the beaches have returned to similar state as 2012 yet are lower than 2020 elevation



* Chikaming Township – minimal hard armoring so sand can move more naturally

4% of the beaches have not recovered





Why? What is unique about these?

Examining all responses to explore best management practices to promote recovery

THANK YOU!

Questions?

For more information on our projects, check out our lab website:

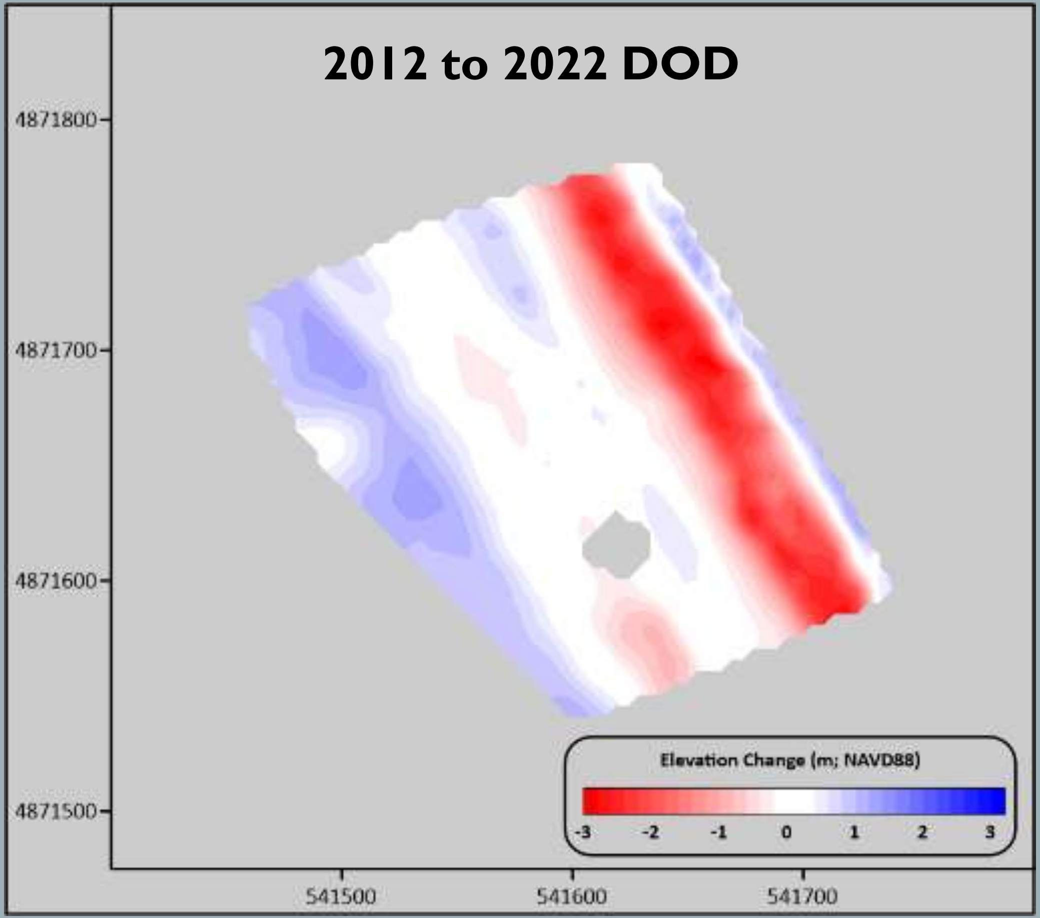
www.coastalgeomorphology.com

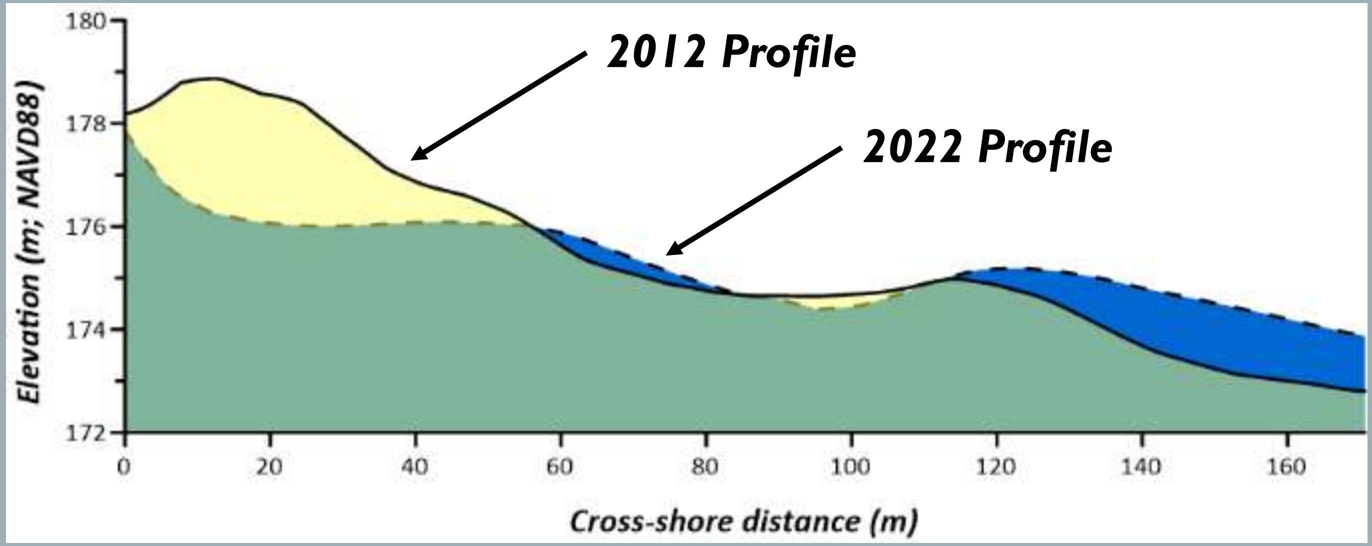
Contact information: theuerk5@msu.edu

Photo credit: Diane Huhn


LUDINGTON, MI

SIMILAR GEOMORPHIC RESPONSE TO RISING LAKE LEVEL

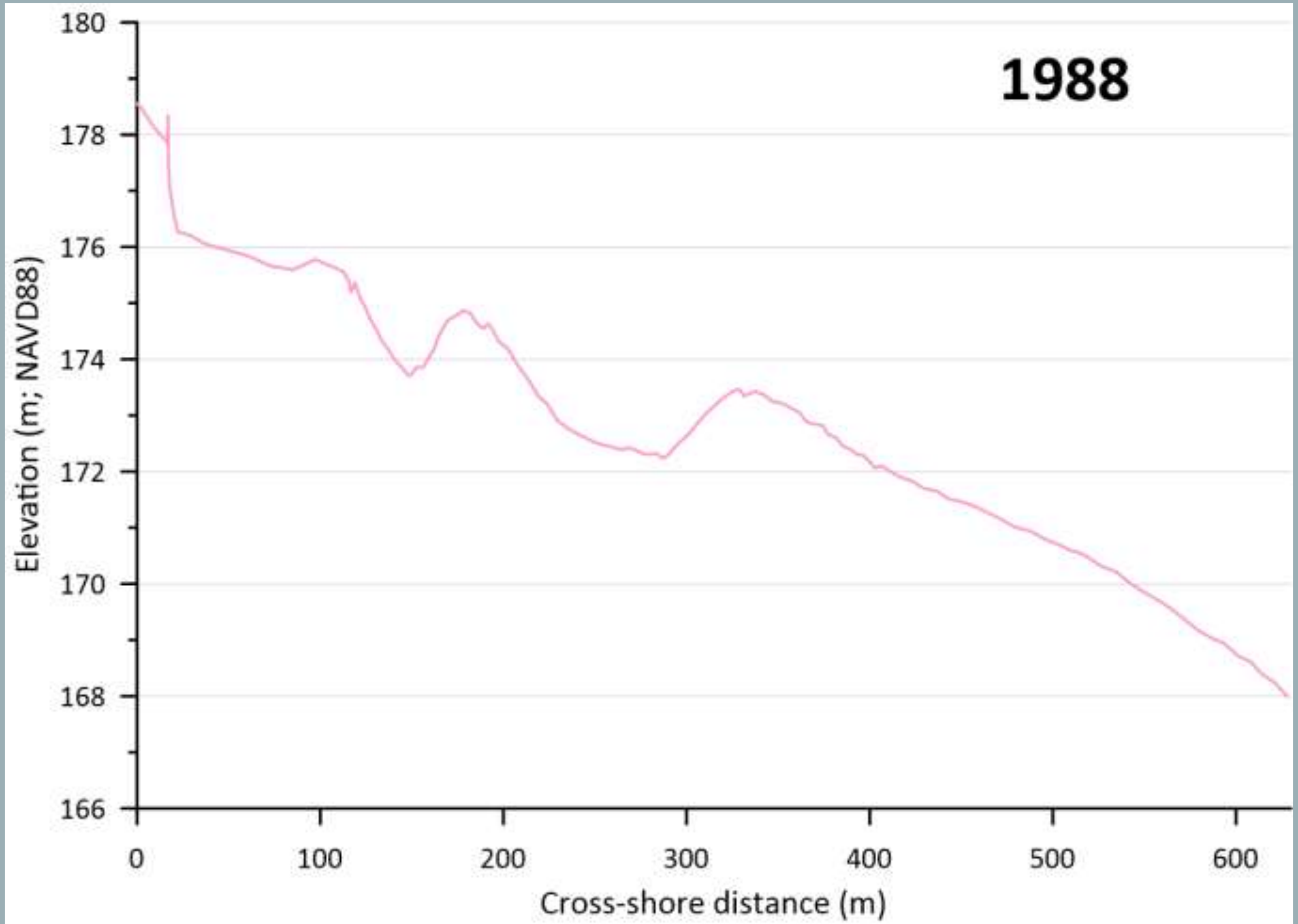




- Sediment filling troughs but **pushed further offshore** than Port Crescent
  - Less sediment deposited immediately nearshore than Port Crescent
  - Reflected in volume as well- more loss of beach and foredune than deposited in first 2 troughs

- ~45m of foredune retreat
- 13,113 m^3 negative volume change (**beach and foredune erosion**)
- 18,360 m^3 positive volume change (**nearshore deposition**)

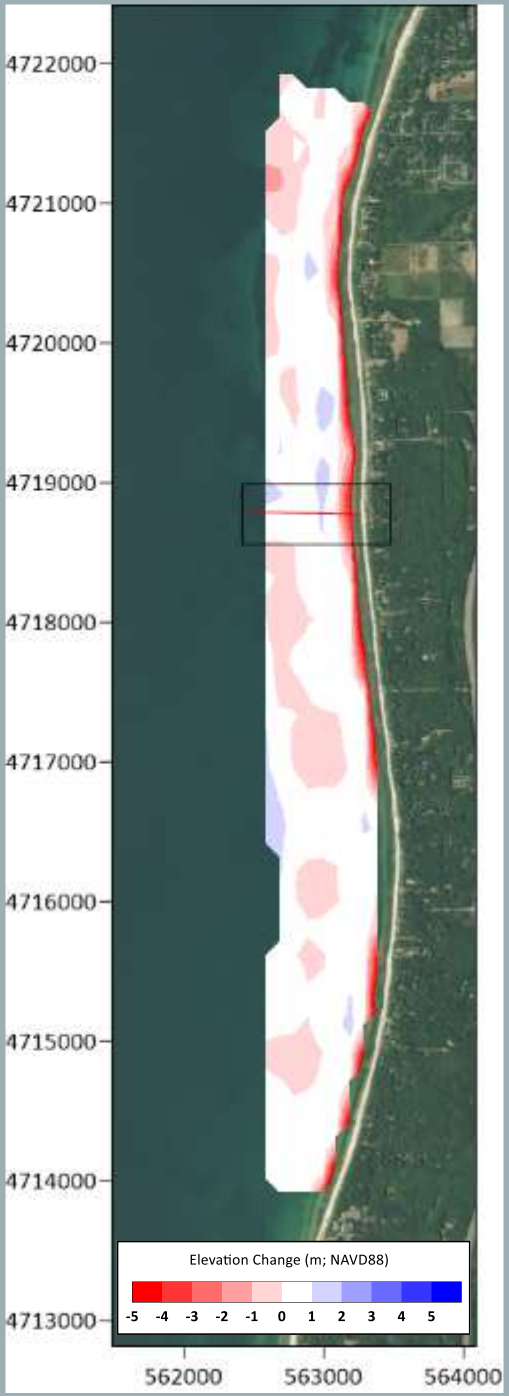
RECOVERY PROBABLE- POTENTIALLY SLOWER?

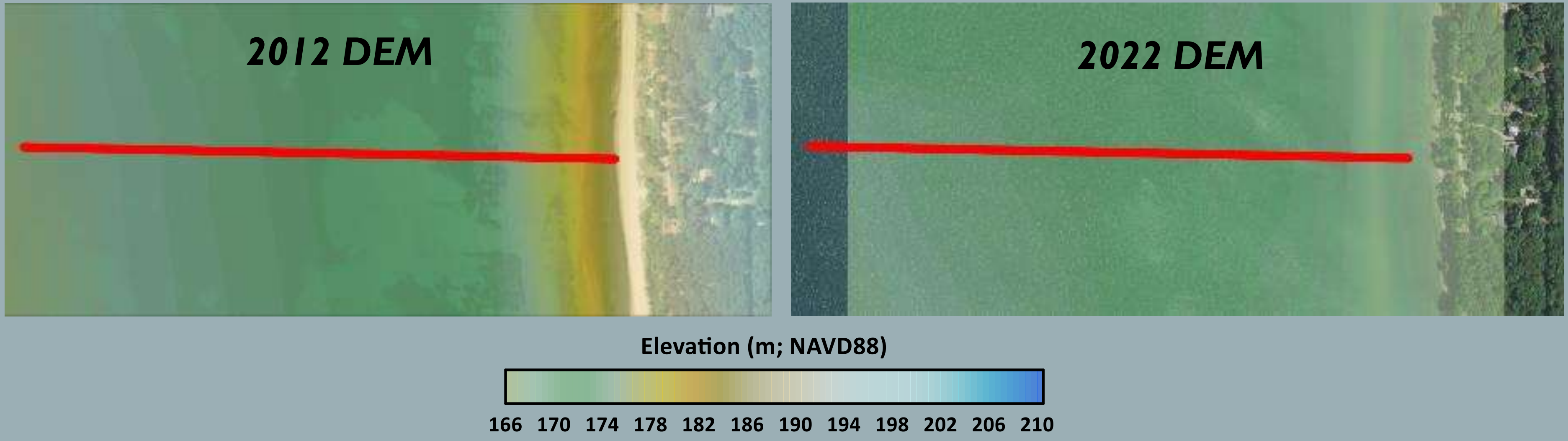


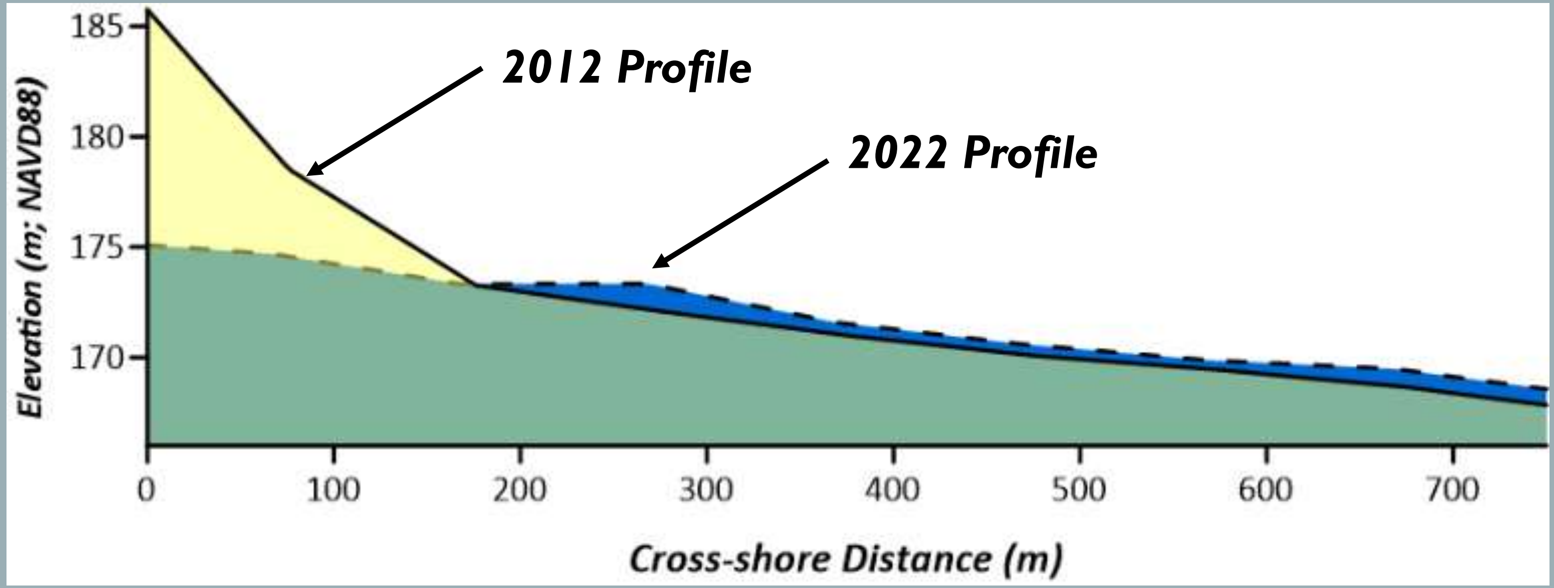
- **Material not likely moving far away from the site**
- **Bar/trough positions highly stable over the last few decades and beach/dunes grow during low lake level**

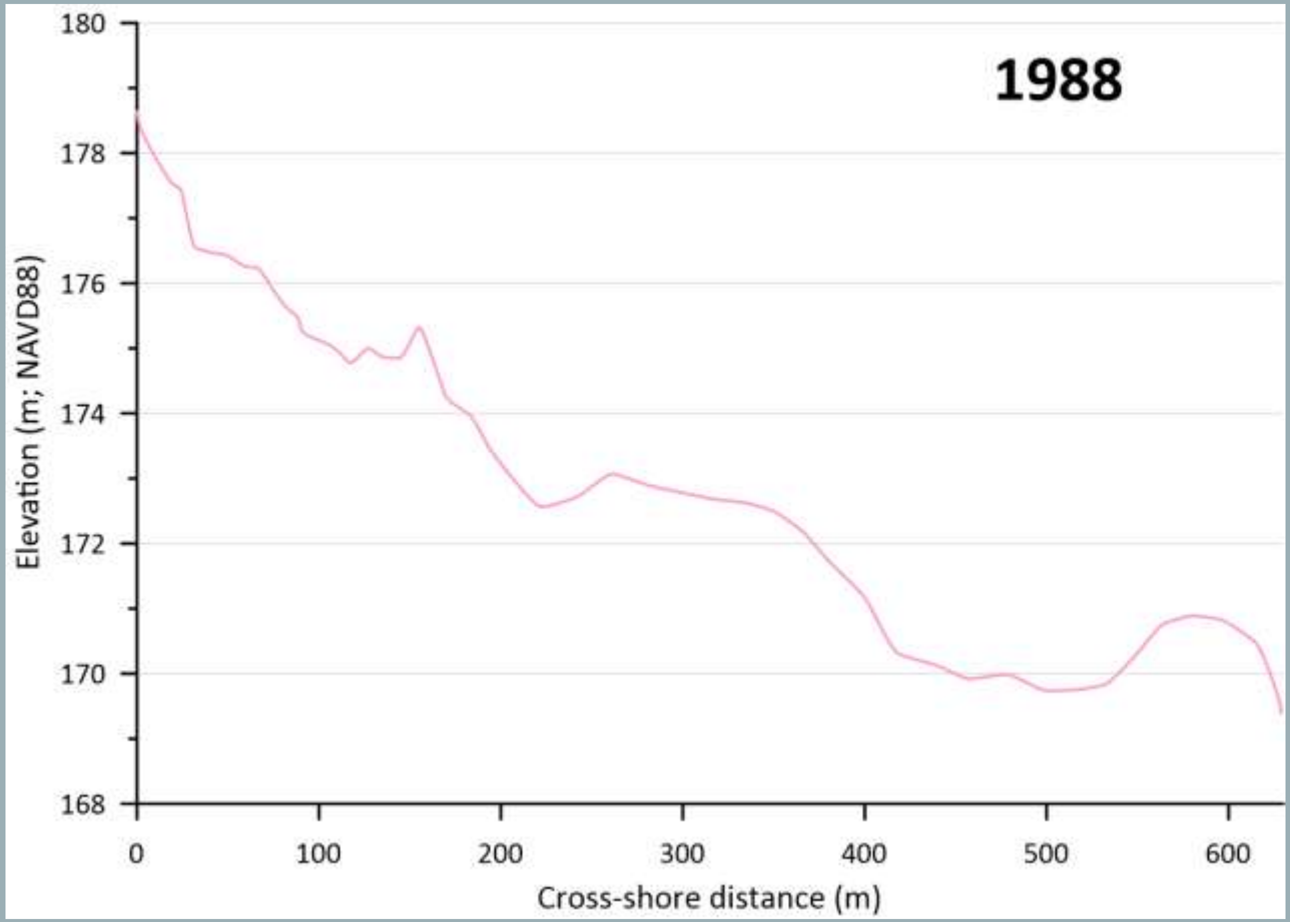

SAUGATUCK, MI
Thin veneer of sand from beach and bluff erosion
Glacial till outcropping on lakebed

Extensive lakebed and beach/bluff erosion with only isolated pockets of nearshore deposition









- Despite extensive bluff and beach erosion the nearshore has been relatively stable
- Is this likely to change in the future?
  - Armoring substantially increased in this region over the last decade

How connected are nearshore sand deposits to beaches- that is, how likely is it that eroded sand will move back towards the beach?

What are the mechanisms that facilitate this?

HOW DID PROFILE MORPHOLOGY CHANGE FROM 1988-2021?

Input Datasets:

UM Surveys
Rod and level
(7 between 1988-2000)

USACE Topobathy Lidar
(2008, 2012)

MSU Survey
RTK GPS, Single beam sonar
(2021)