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Design and Physical Model Studies of Innovative Living Breakwaters

Scott Baker – National Research Council Canada
Pippa Brashear – SCAPE
Paul Tschirky – Geosyntec Consultants (formerly Arcadis)
Joseph Marrone – Arcadis
Max Larson – COWI

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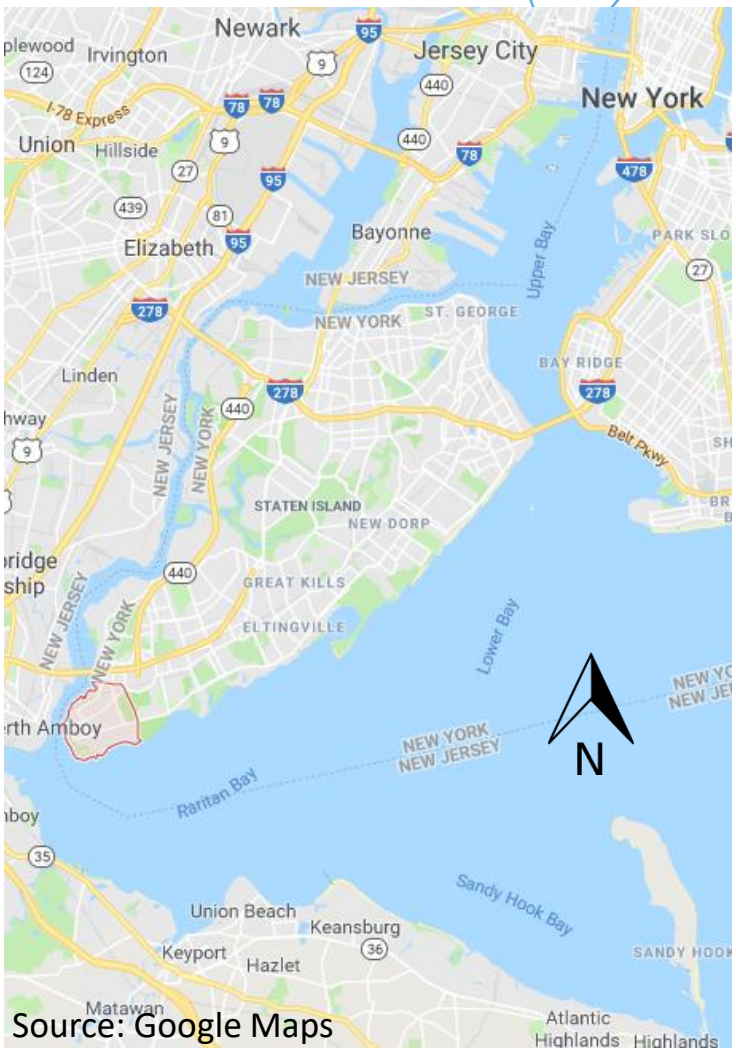
Project Background

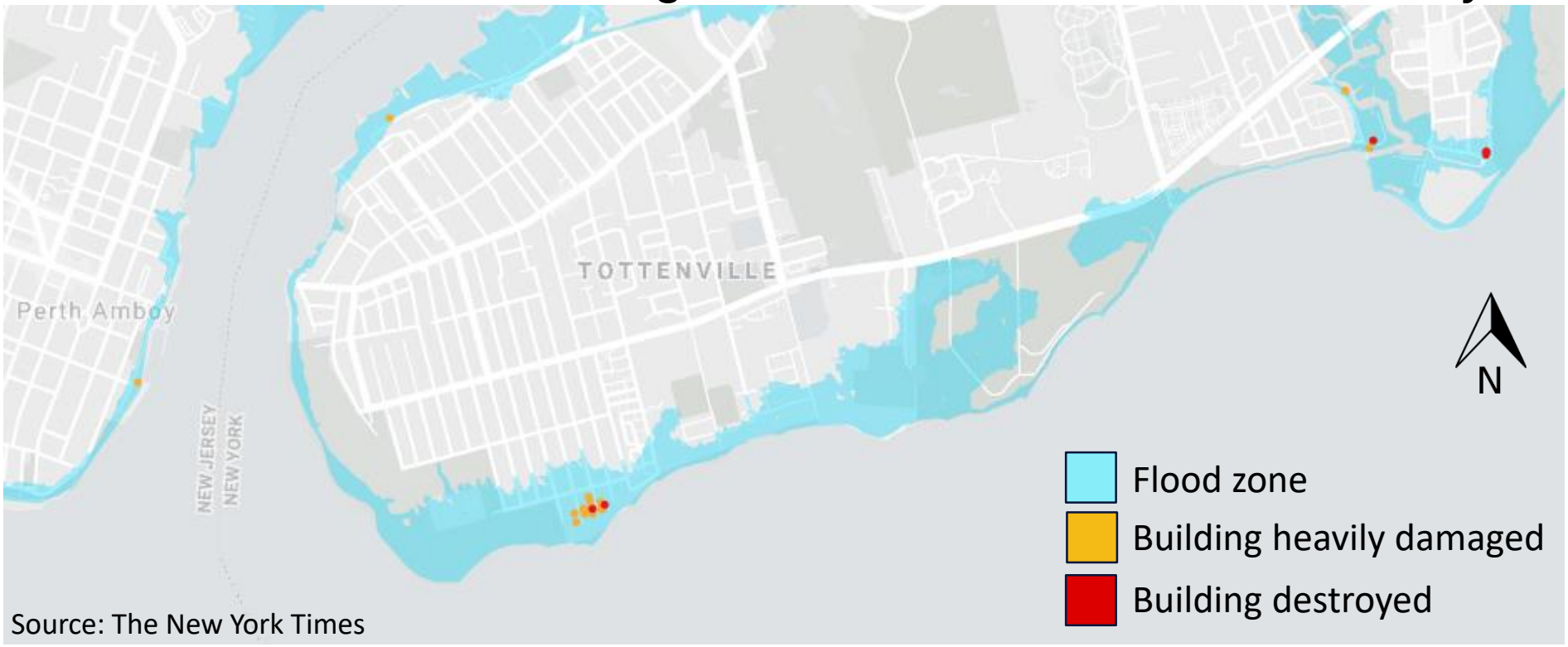
- Tottenville, Staten Island
  Raritan Bay (Lower NY Harbor)
- Shallow estuary that historically supported commercial fisheries and shell-fisheries, depleted by habitat degradation over the last century
- Tottenville shoreline once a vibrant destination for water-based recreation, has suffered from high rates of erosion over the past decades (likely due in part to the loss of extensive oyster reefs)



Source: Google Maps

Project Background

- Tottenville area of Staten Island experienced significant damage due to waves and flooding during Hurricane Sandy
- Caused loss of life and significant harm to the local economy



Source: The New York Times

Project Background

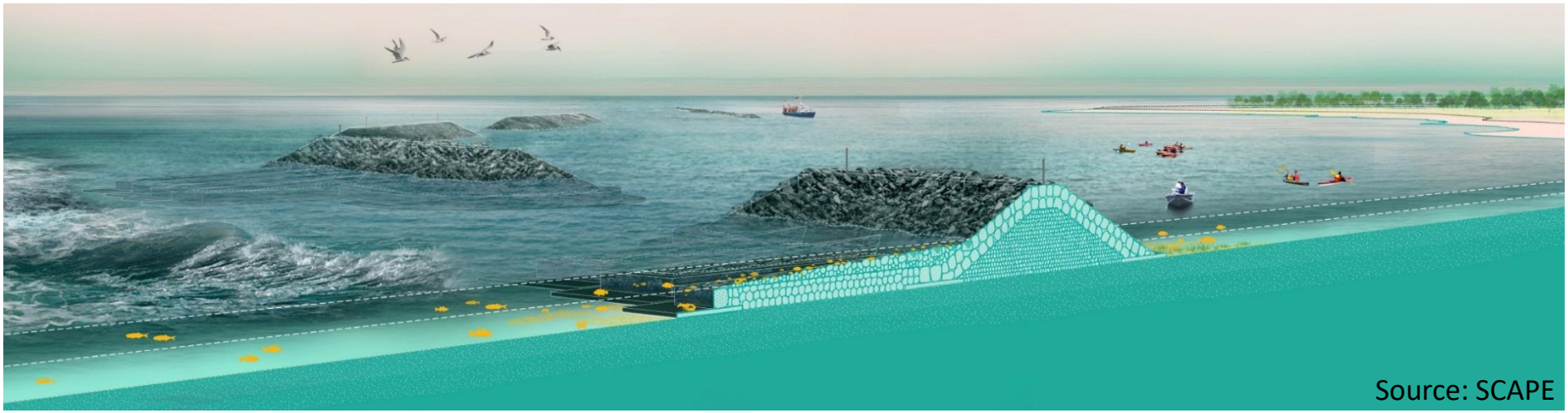
- June 2013: U.S. Dept. of Housing and Urban Development launched the “Rebuild by Design” competition
- Respond to the devastation caused by Superstorm Sandy and help the impacted region to plan and design more resilient communities for the future
- *Living Breakwaters*: one of several projects chosen for funding

Source: Museum of the City of New York

Source: NY Daily News

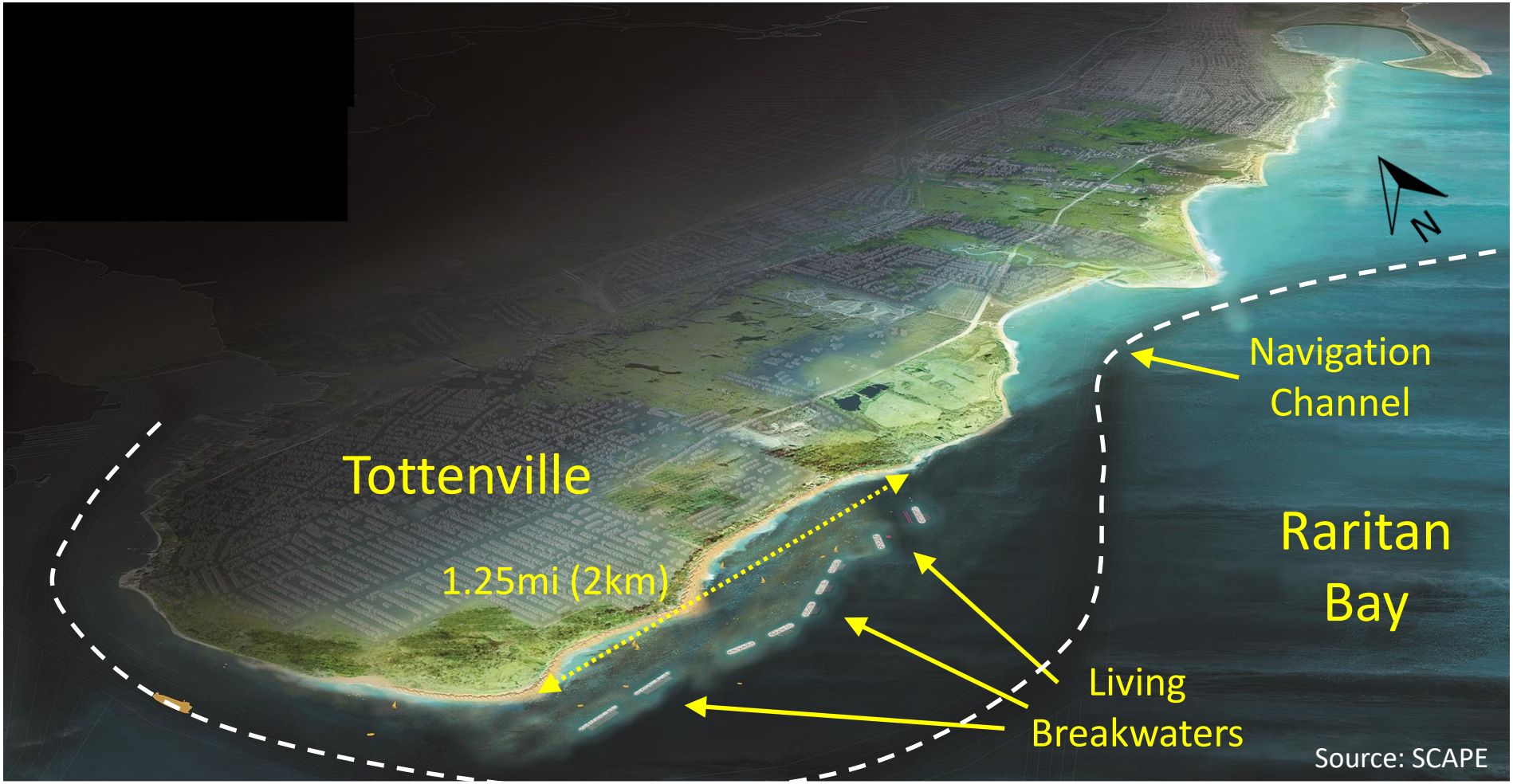
Living Breakwaters
Project Concept

- Innovative concept consisting of a one mile-long system of breakwaters with reef-like enhancements designed to:
  - Attenuate damaging storm waves
  - Reduce or reverse long-term coastal erosion
  - Enhance ecosystems by creating structured marine habitat
  - Foster social resilience by encouraging the use and stewardship of the shoreline and nearshore waters



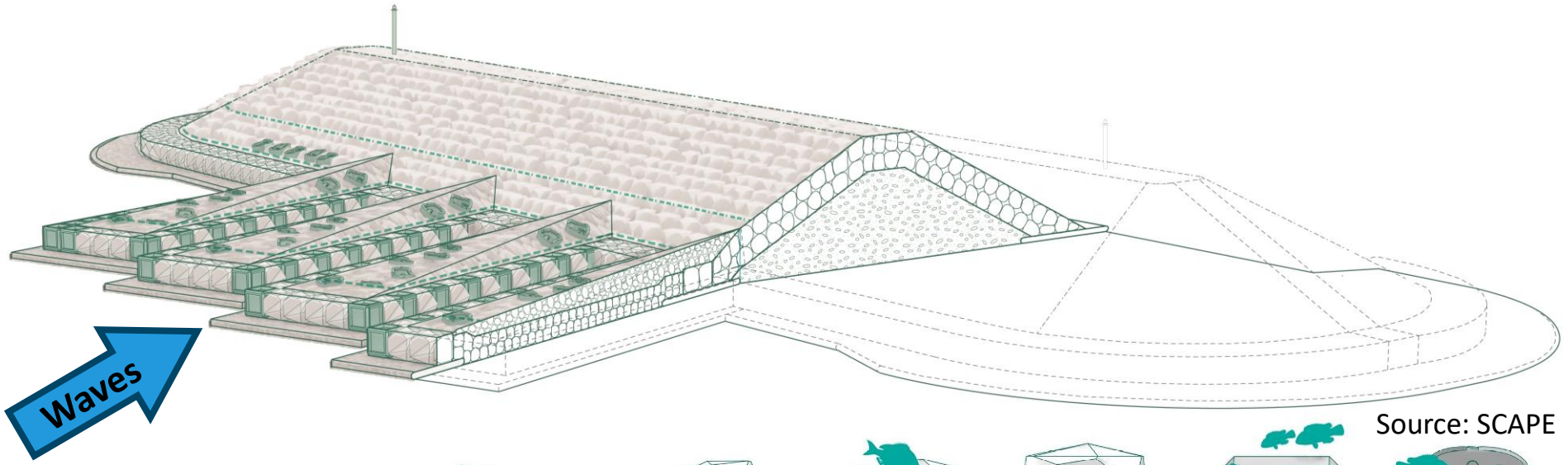
Source: SCAPE

Living Breakwaters
Conceptual Layout

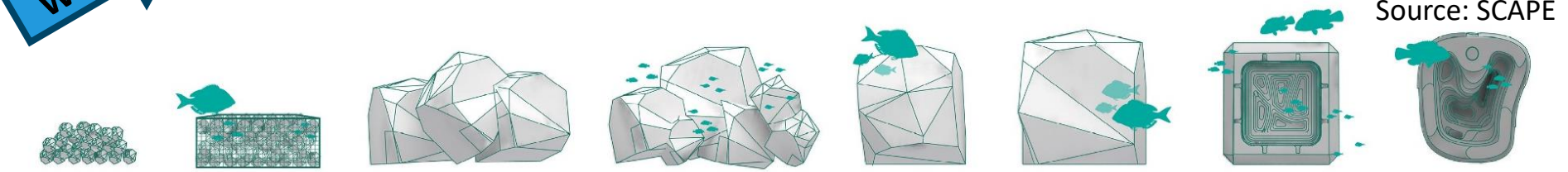


Living Breakwaters
Conceptual Breakwater Design

- Linear trunk section with two roundheads (conventional BW)
- Several ocean-facing “reef ridges” and “reef streets”



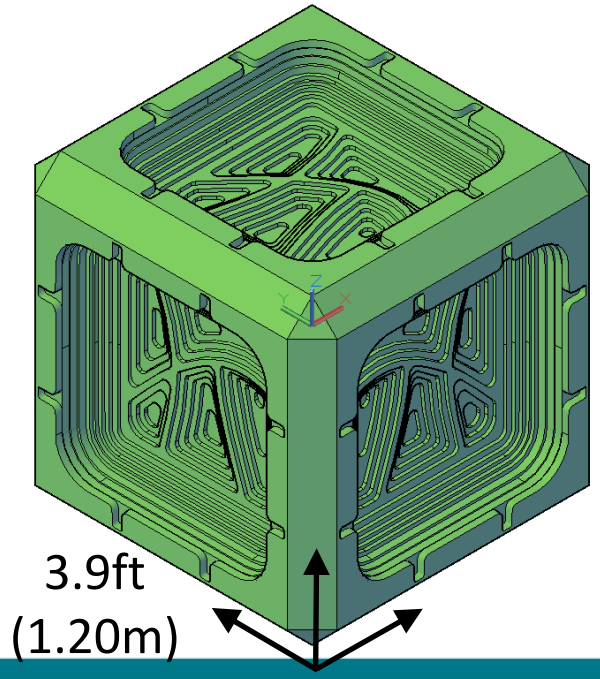
Source: SCAPE



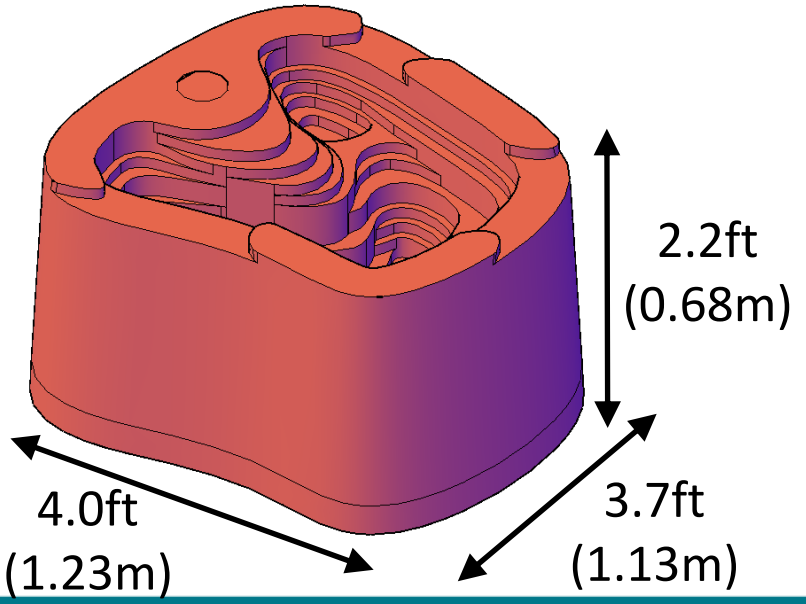
INTERNAL CORE STONE	MARINE MATTRESS	REEF RIDGE CORE STONE	REEF RIDGE EXTERIOR STONE	STONE ARMOR UNIT	STONE TOE ARMOR UNIT	ECOncrete® TOE ARMOR UNIT	ECOncrete® TIDE POOLS
D_{50}= 16″	HT= 12″	Dmin= 24″ D_{50}= 30″ Dmax=36″	D_{15}= 15″ D_{50}= 24″ D_{100}=36″	D_{50}= 40″	D_{50}: 48″	Dimension: 48″x 48″x 48″	Dimension: 44″X 48″X27

Living Breakwaters
Conceptual Breakwater Design

- Two types of bio-enhancing concrete units proposed:
  - ECOncrete® Armor Unit
    - Encourage growth of marine organisms, function as toe armor unit
  - ECOncrete® Tide Pool
    - Create local ecosystems within the tidal zone along reef ridges



Source: SeArc



Living Breakwaters
Site Conditions

- Structures to be located between -6 and -10.5ft contours (-1.83 to -3.20m)

- Typical tide range -2.6ft to +2.1ft (-0.80 to +0.64m)
- 100-yr storm surge level +12.9ft (+3.93m)
- Extreme water level of +15.4ft (+4.69m) also investigated to account for severe storm surge with an allowance for sea level rise

- 30-yr hindcast shows largest waves tend to approach the project site from the east (where the fetch is greatest)
- 100-yr design storm wave: H_s = 5.3ft (1.62m) & T_p = 5.0s
- Overload condition: H_s = 7.7ft (2.35m) & T_p = 7.0s also investigated

Physical Modeling Studies
Objectives

- Required to confirm and refine the initial breakwater design and layout, and in particular to:
  - Determine optimal stone gradations
  - Optimize the breakwater height / width ratio
  - Determine wave transmission characteristics at high tide levels
  - Qualitatively determine flow characteristics and sedimentation in, on, and around the reef ridge features for ecological design

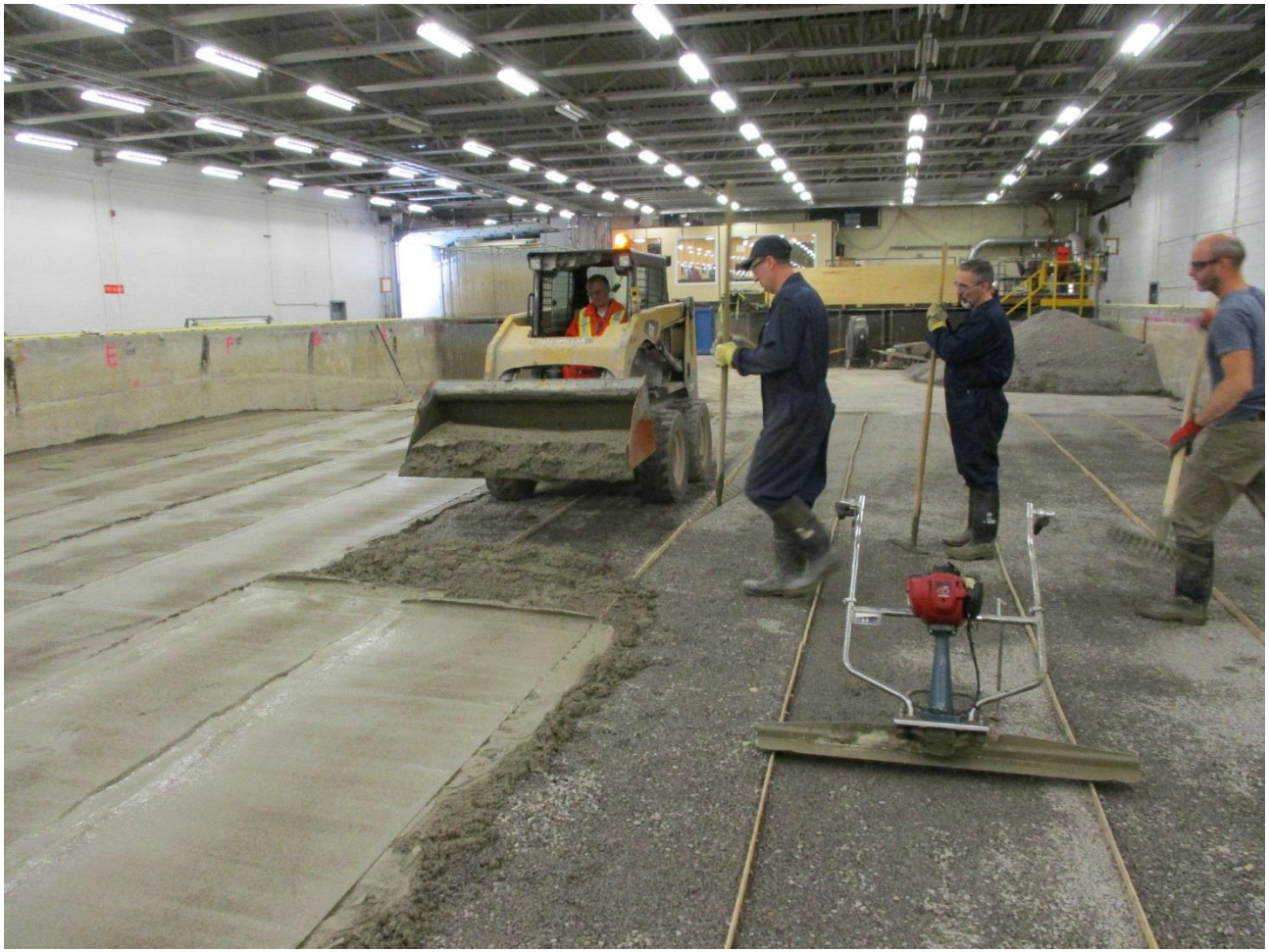
- Two-pronged approach involving the design, construction, and operation of two separate but closely related physical models was undertaken to achieve these objectives

Breakwater Stability Study
Overview

- Combination of 2D and 3D physical modeling
- Confirm and refine breakwater design elements and features, particularly for extreme events
- Conducted at 1:20 scale in NRC's *Coastal Wave Basin* 205ft (63m) long by 46ft (14m) wide

Breakwater Stability Study
Model Design and Construction

- Construction of an idealized foreshore bathymetry down to the -20ft (-6.1m) contour to accurately model nearshore wave transformations



Breakwater Stability Study
Model Design and Construction

- Stone materials and gradations prepared to replicate the characteristics of the proposed prototype materials
- Three armor classes (narrow) and two core classes (wide)

Breakwater Stability Study
Model Design and Construction

- 265 + 200 model scale bio-enhancing concrete units fabricated for use in this study
- Hand placement of all armor stone and concrete units to replicate prototype placement

Breakwater Stability Study
Wave Calibrations

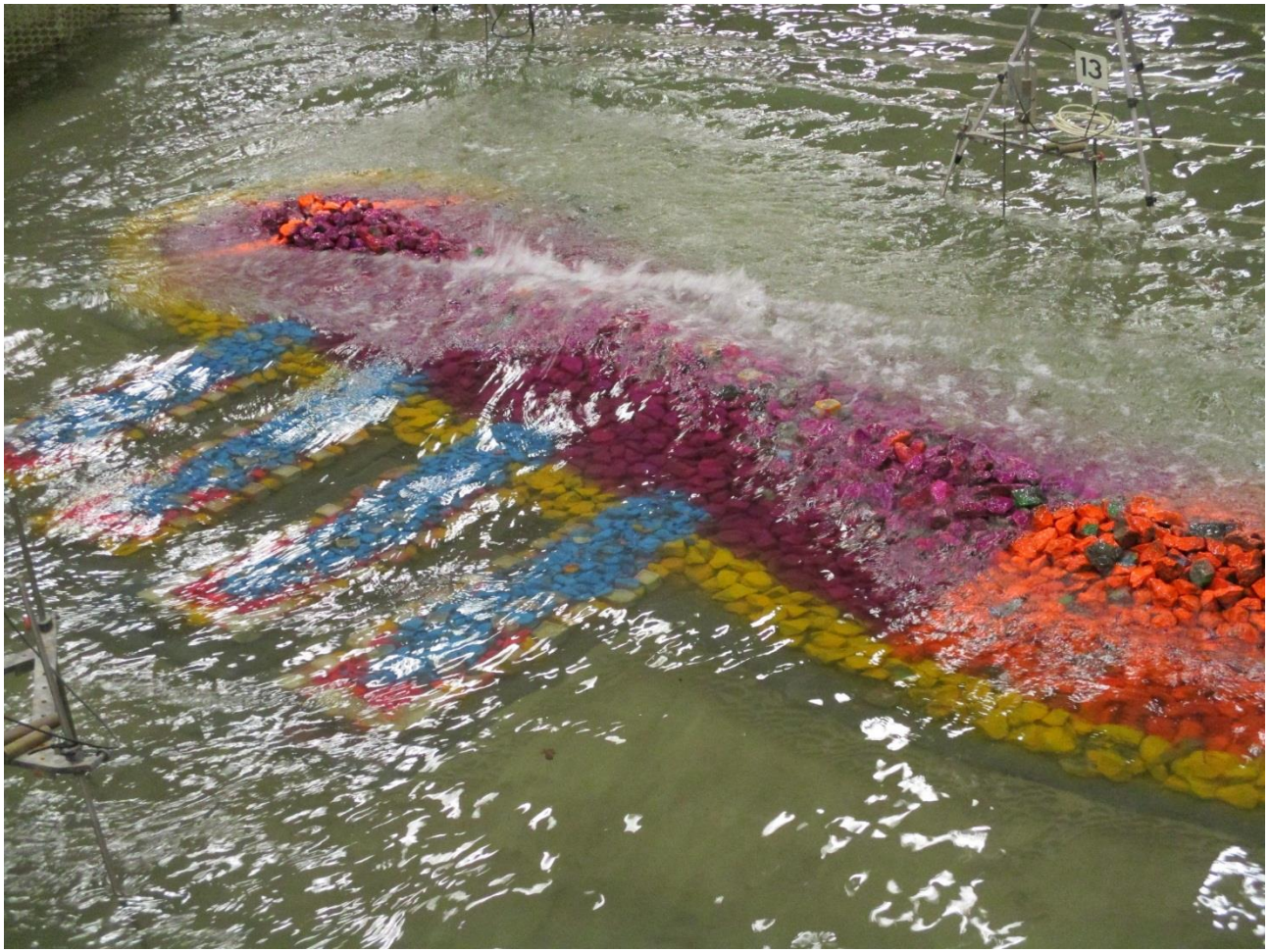
- Series of undisturbed wave tests to produce the desired wave conditions at the test site, 14 wave gauge measurements

Breakwater Stability Study
Testing

- Breakwater stability assessed over a range of conditions with varying wave heights, wave periods, and water levels
- Photographic damage analysis system used to monitor the movement of armor stones

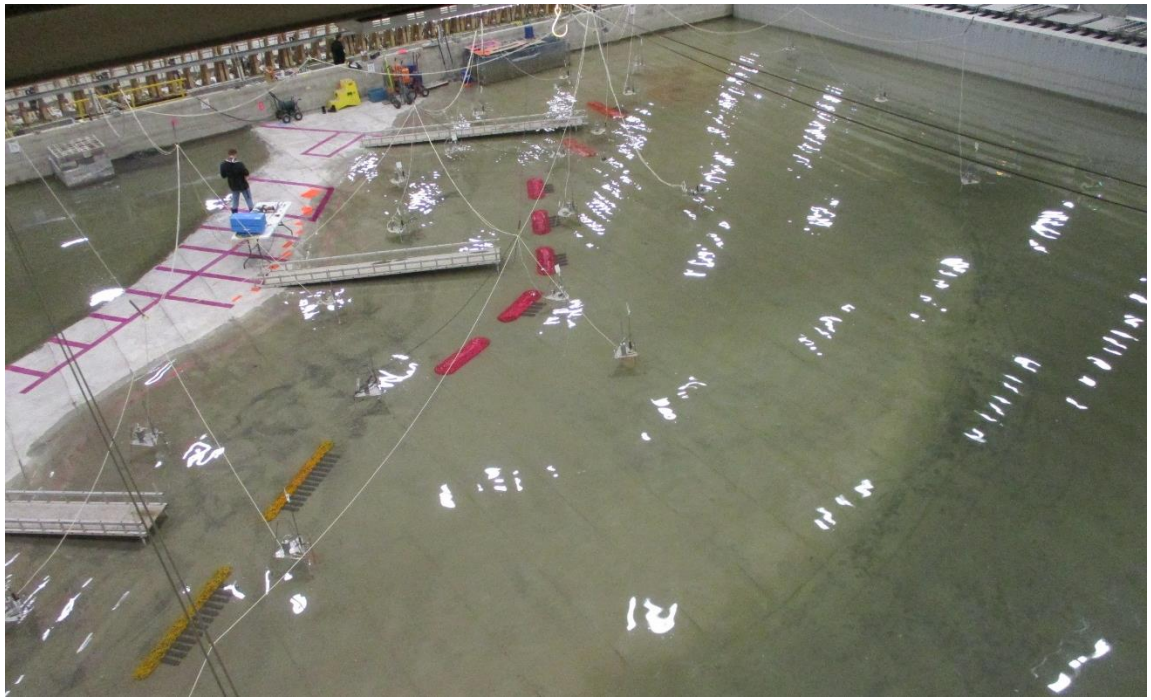
Breakwater Stability Study
Results

- Stability of proposed cross-sections was adequate under design and overload conditions
- Several recommendations made regarding prototype placement requirements for the bio-enhancing concrete units



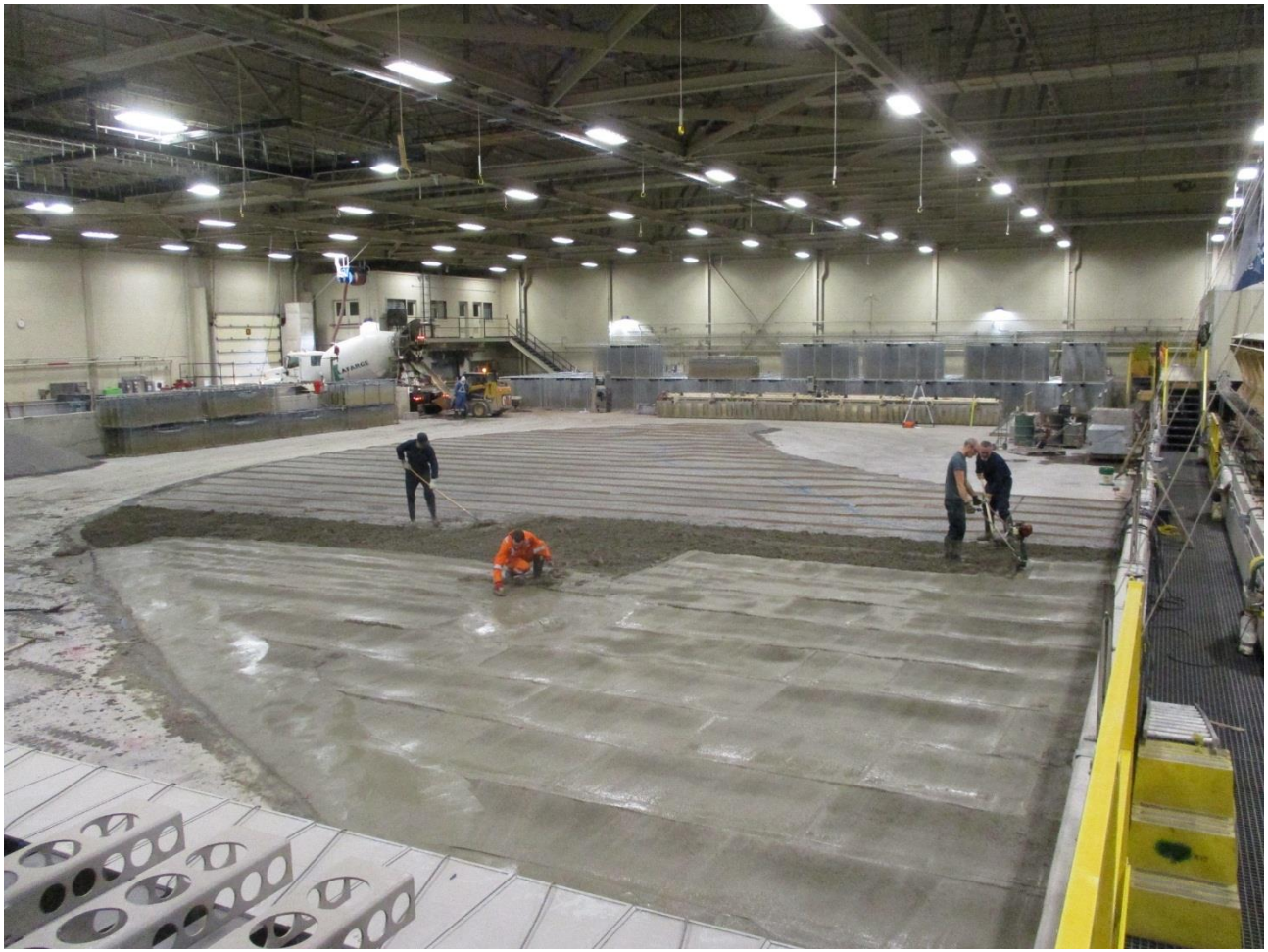
Breakwater System Layout Study
Overview

- 3D physical model validating the overall system performance, including the degree of wave attenuation along the shoreline for a range of mild to extreme conditions
- Conducted at 1:80 scale in NRC's *Large Area Basin*
  165ft (50m) long
  by 100ft (30m) wide
- State-of-the-art directional wave generator with 72 independent wave boards



Breakwater System Layout Study
Model Design and Construction

- Construction of faithful foreshore bathymetry from the mean high water shoreline down to the -40ft (-12.2m) contour to accurately model nearshore wave transformations



Breakwater System Layout Study
Wave Calibrations

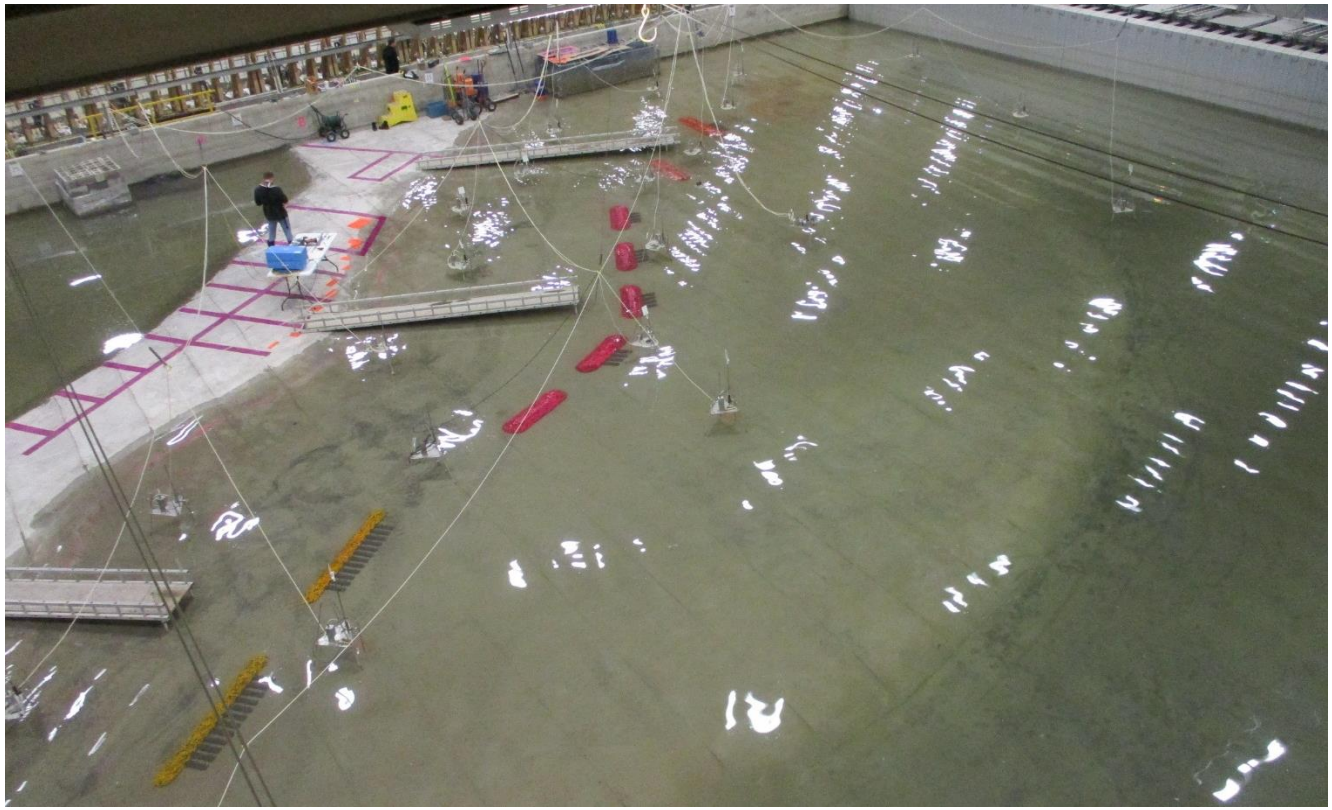
- Series of undisturbed wave tests to produce the desired wave conditions across the test site, wave conditions measured at 21 locations using capacitance wave gauges

- Orbital velocities and wave-induced currents measured at two locations with 2-axis electromagnetic current meters

- Circulation patterns along the shoreline and in the vicinity of the breakwaters qualitatively assessed by observing plumes of colored dye

Breakwater System Layout Study
Testing and Results

- Performance of breakwater system layout assessed over a wide range of conditions with varying wave heights, wave periods, wave directions, and water levels
- Optimization of breakwater lengths and alignments: revised layout performed adequately and resulted in significant nearshore wave attenuation



Physical Modeling Studies
Conclusions

- Two-pronged physical modeling study to support the detailed design of the Living Breakwaters project in Raritan Bay
- Generated valuable information concerning breakwater design and performance which will be used to further optimize and support the final design, and obtain the necessary permits required for construction
- The results will also help inform other breakwater designs that look to incorporate reef ridges and other elements to improve ecological performance

Thank you!

CONTACT
Scott Baker
National Research Council Canada
scott.baker@nrc.ca