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Numerical Modeling of Wave-Driven Flooding on Lake Ontario

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Introduction

- **Plan 2014**: The current plan or set of rules for regulating outflow from Lake Ontario to the St. Lawrence River and water levels in Lake Ontario that went into effect in 2017.

- In two of the first three years after Plan 2014 was adopted (2017&2019),extremely wet conditions caused record floods on Lake Ontario and along the St. Lawrence River.

- In response to public concerns about these extraordinarily high water levels, IJC asked its Great lakes-St.Lawrence Adaptive Management (GLAM) Committee to launch an expedited review of Plan 2014.

Credit:www.greatlakesnow.org

Credit:ottawacitizen.com

Credit:Veronica Volk/WXXI News

Objectives

- GLAM committee identified a knowledge gap relating to the effects of waves and onshore winds in exacerbating wave runup, overtopping and shoreline flooding on Lake Ontario.

- OCRE Research Centre of the NRC was retained by the Canadian Section of the IJC in October 2020 to:

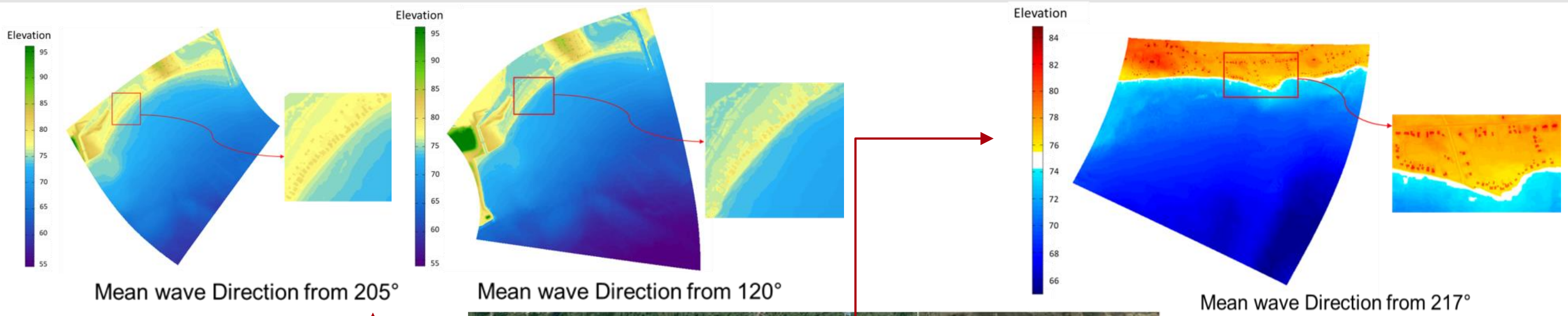
  ✓ Develop an improved understanding of the relationship between lake levels, wave conditions and flooding along the Lake Ontario shoreline by undertaking a study of wave-driven flooding on Lake Ontario.

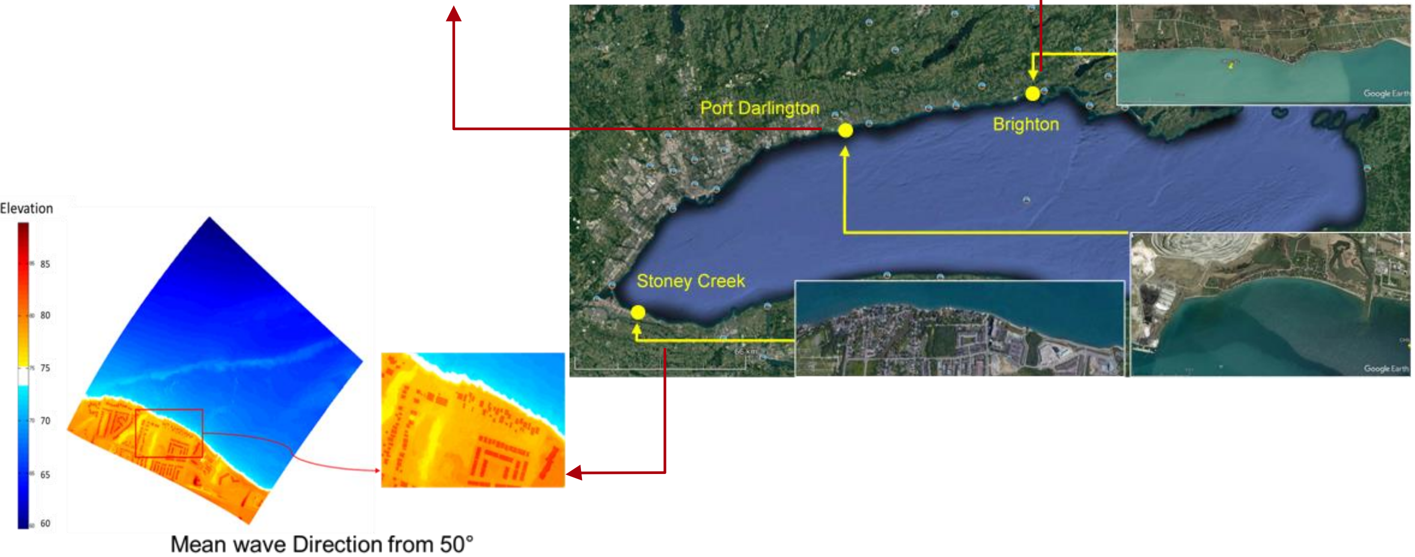
  ✓ Assess the capabilities of the XBeach model for this type of application and to provide a comparison with alternative, less computationally intensive, flood estimation approaches that could be extended to broader shoreline zones.

Lake Ontario flooding homes near Rochester in 2017.
Credit: Mike Conway/Lake Ontario Riparian Alliance.

Waves batter the Lake Ontario shoreline.
Credit:SteveOrr/Rochester Democrat And Chronicle

Selected sites – Model domains and DEM





Bathymetry data:

All three sites:
NONNA-10 dataset (CHS),10 m (horizontal) resolution

Port Darlington:
High-resolution SHOALS dataset

Topography data:

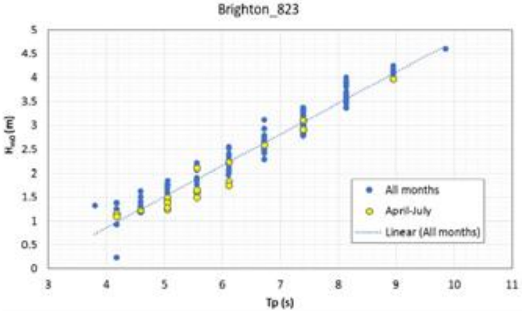
Brighton and Port Darlington:
ODTM provincial dataset 0.5 m (horizontal) resolution

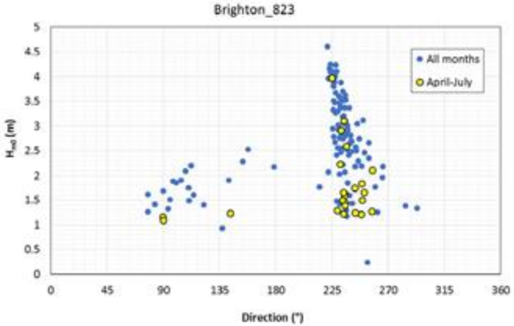
Stoney Creek:
the provincial SWOOP dataset, 2 m (horizontal) resolution

Model setup

- An initial water level was specified over the entire domain
- An incident wave condition (specified in terms of peak wave period, significant wave height and mean wave direction) was specified along the offshore domain boundary. The range of incident wave conditions was guided by our review of the local wave climate.
- A one hour duration of wave action was modelled in each simulation, during which the XBeach surfbeat model simulated wave propagation and interaction with the shoreline in a time-averaged sense, including flooding of backshore areas, if any.

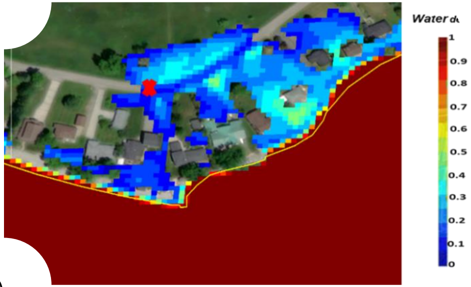
- USACE hindcast of 150 storms
- CHS Point 821





Model validation

a)

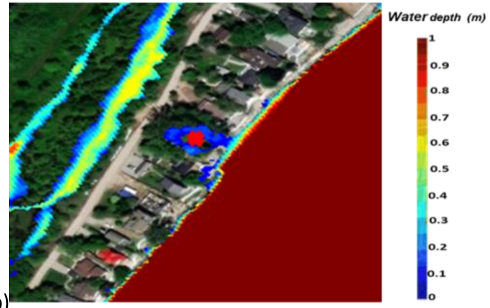


b)

Brighton, June 14, 2019

- significant wave height of 1.1 m
- approaching from the SW (230°)
- local lake level of 76.0 m

a)

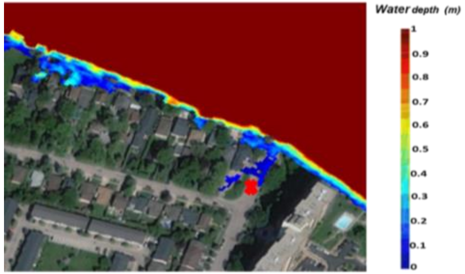


b)

Port Darlington, April 30, 2017

- significant wave height of 1.56 m
- approaching from the ESE (115°)
- local lake level of 75.5 m

a)



b)

Stoney Creek, April 15, 2018

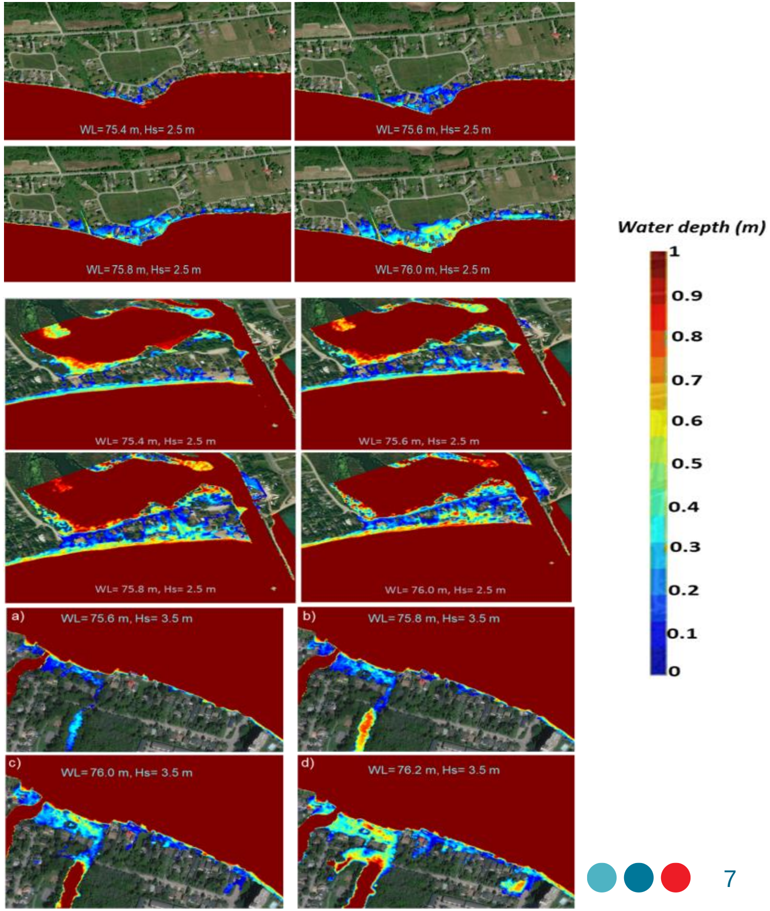
- significant wave height of 3.85 m
- approaching from the ENE (50°)
- local lake level of 75.4 m

Testing scenarios

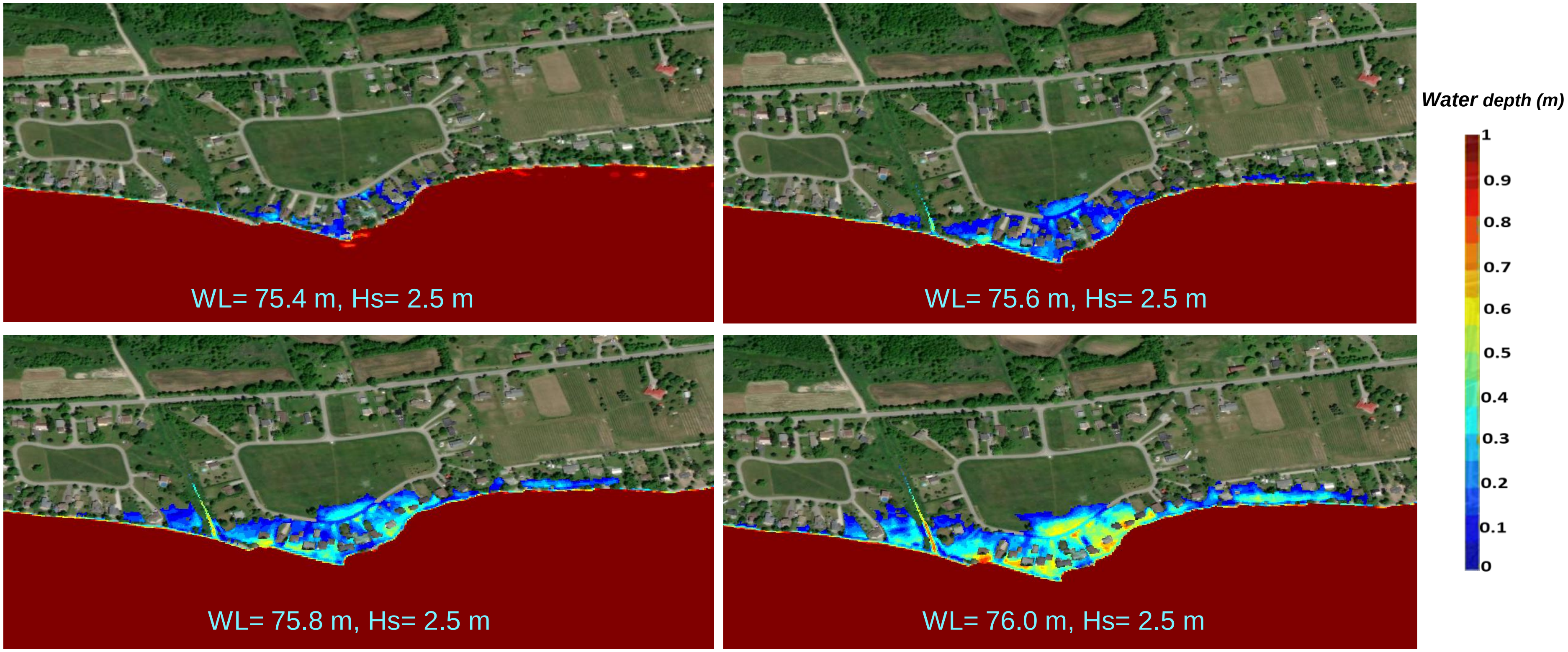
Brighton (24 simulations):
Water level: 75.4-76.4 m (0.2 m intervals)
Significant wave height: 1.5-3.0 m (0.5 m intervals)
Mean wave direction: 217°

Port Darlington (48 simulations):
Water level: 75.4-76.4 m (0.2 m intervals)
Significant wave height: 1.5-3.0 m (0.5 m intervals)
Mean wave direction: 120° & 205°

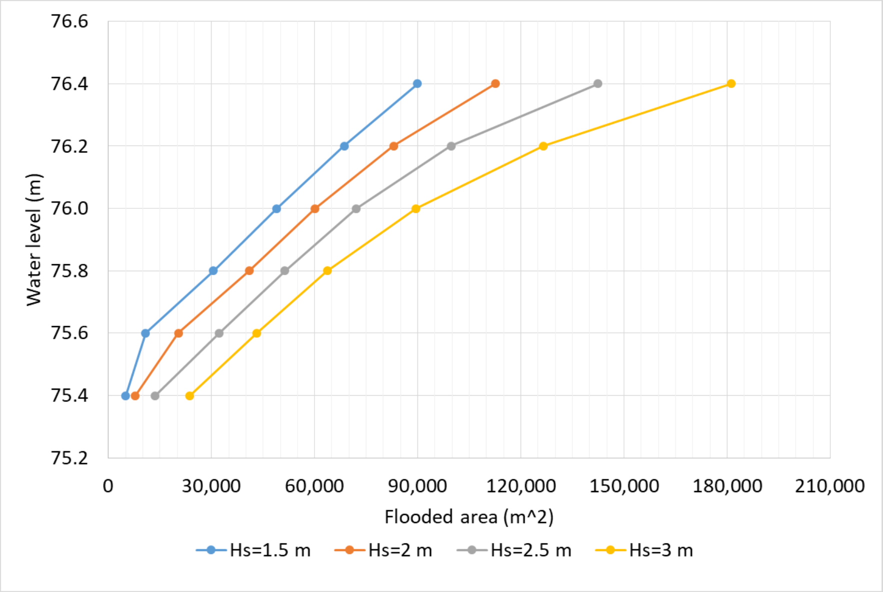
Stoney Creek (24 simulations):
Water level: 75.4-76.4 m (0.2 m intervals)
Significant wave height: 2.5-4.0 m (0.5 m intervals)
Mean wave direction: 50°

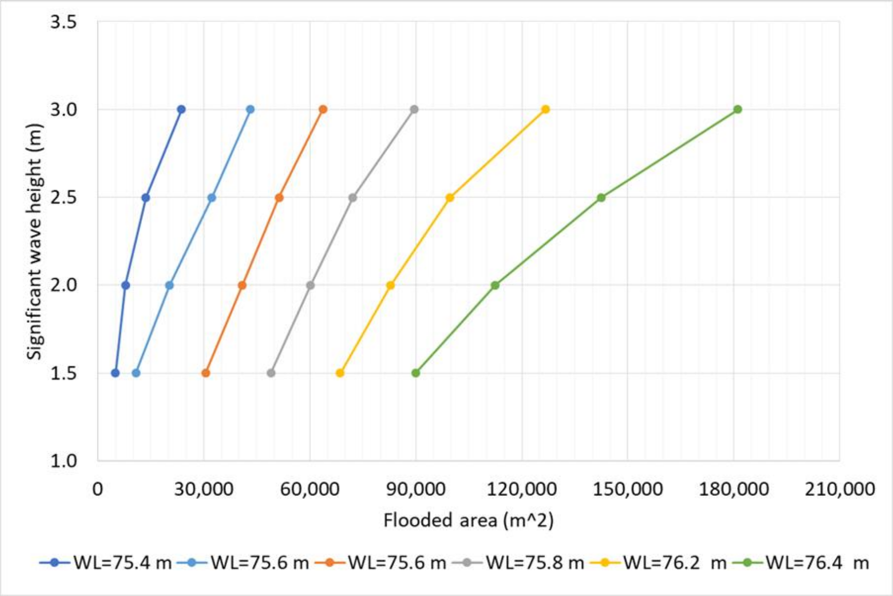


Influence of water level on total flooded area

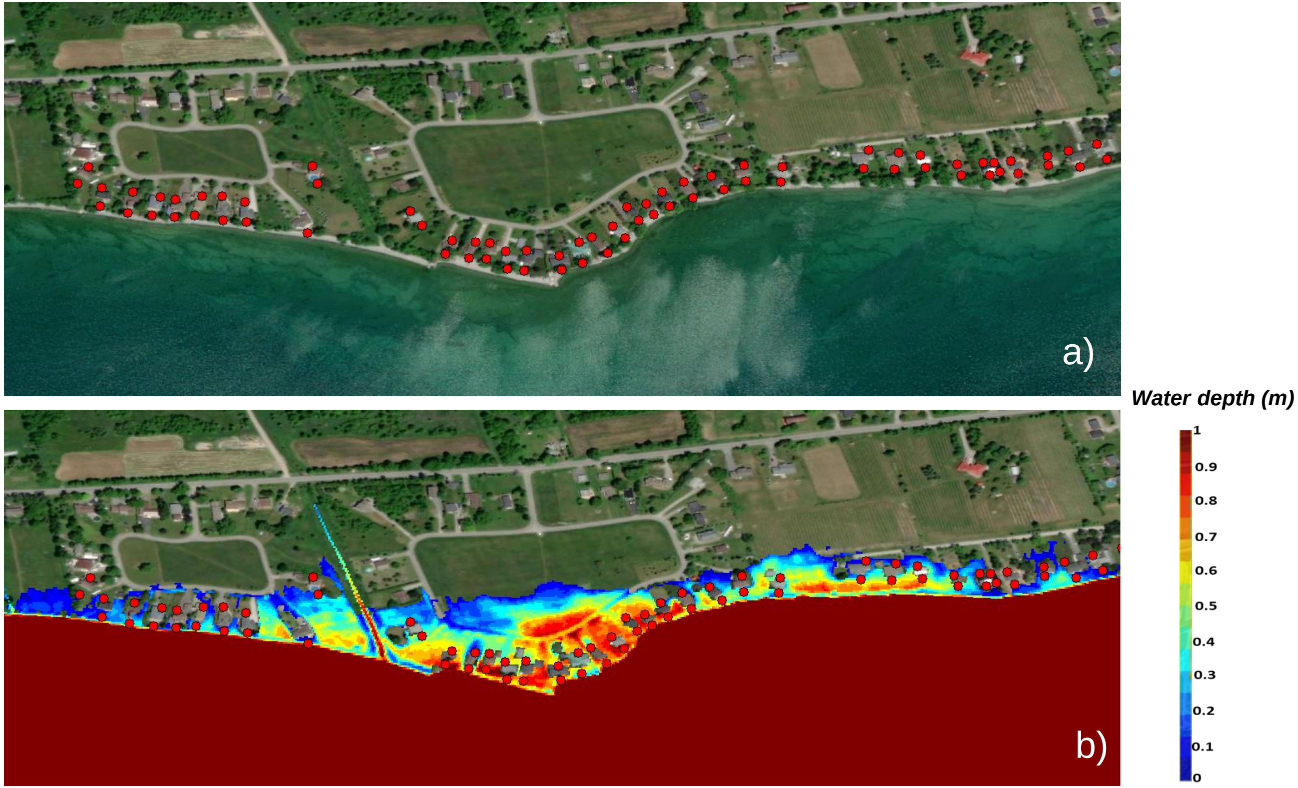


Influence of water level and wave height on total flooded area



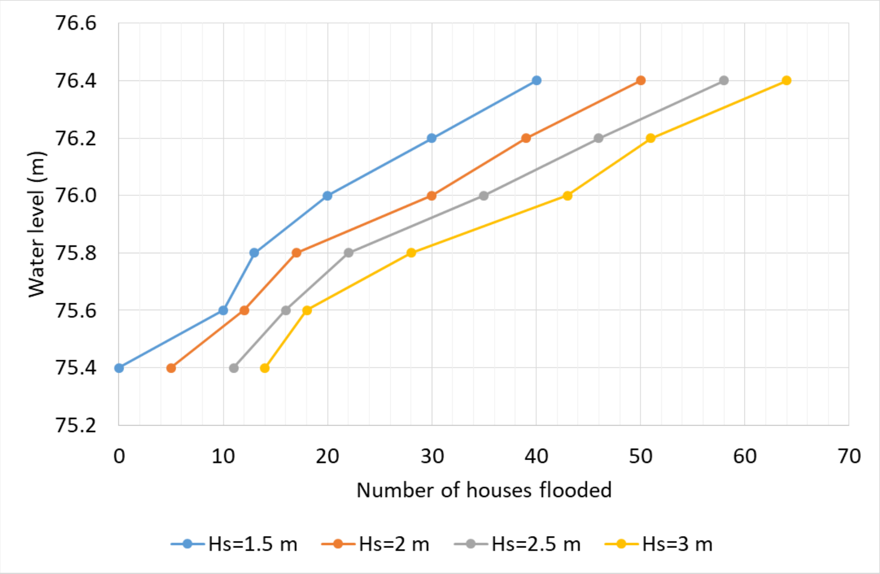


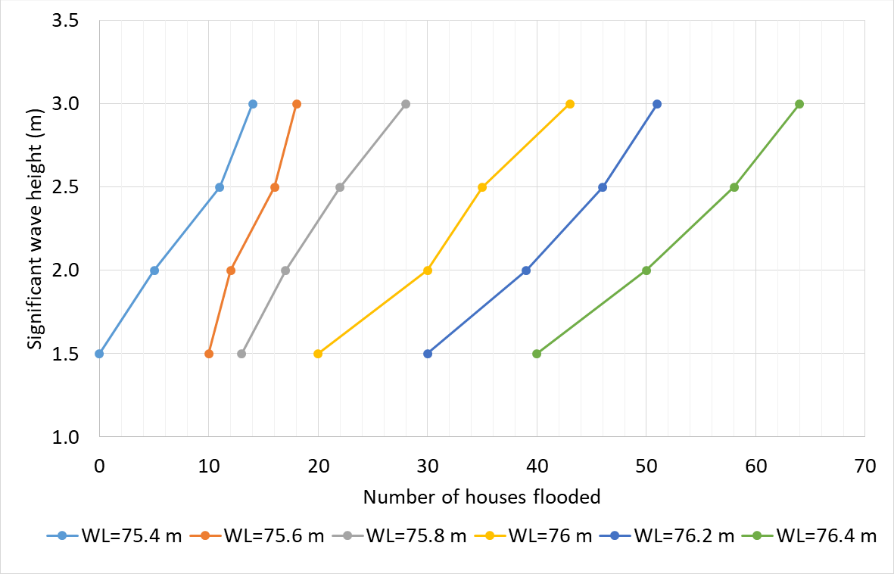
Flooded houses



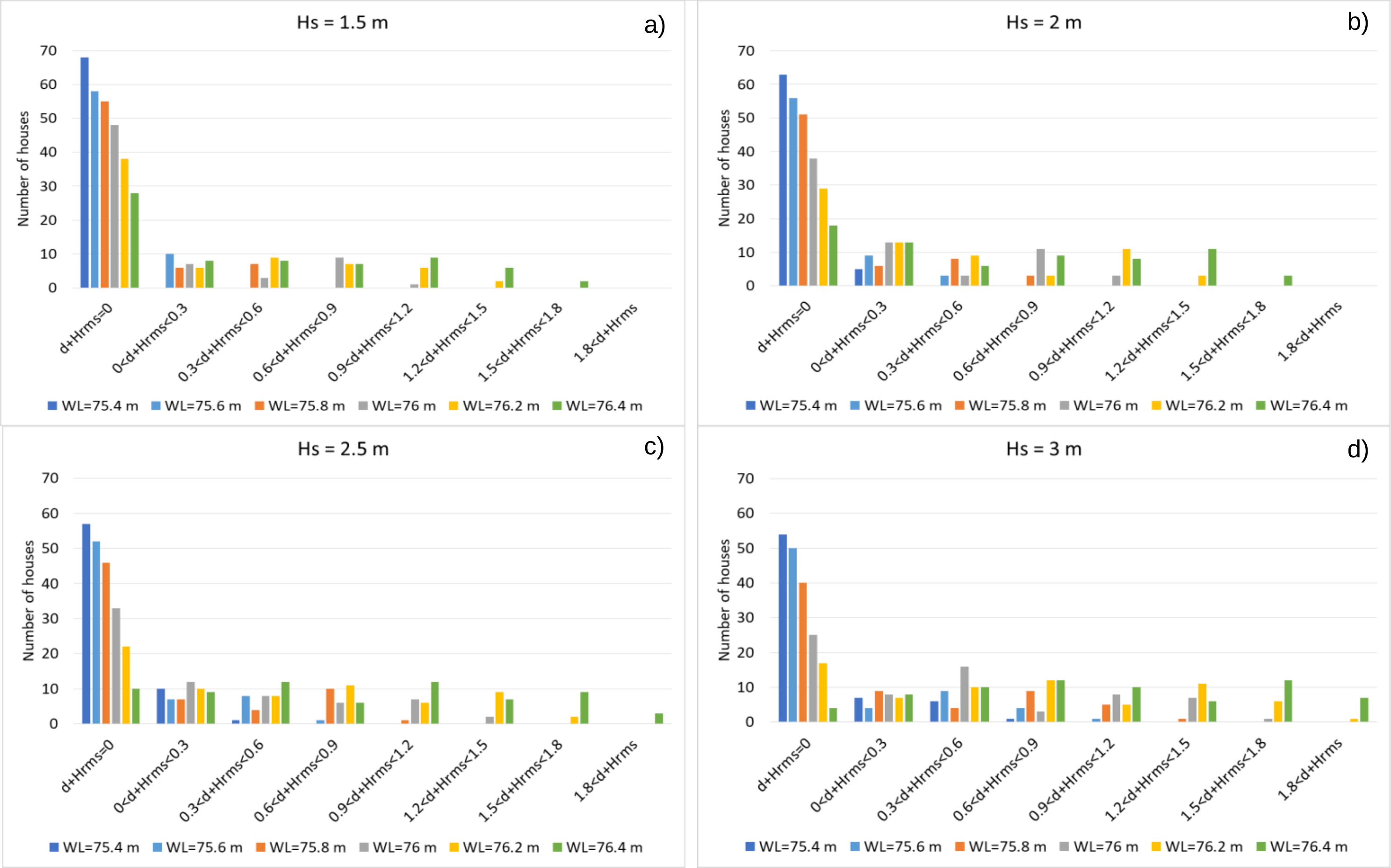
- Two points are defined per house, one on the lake-side and other one on the land-side.
- Max water depth and wave height (+ other parameters) are noted at each point.

Number of flooded houses
(Influence of water level and wave height)

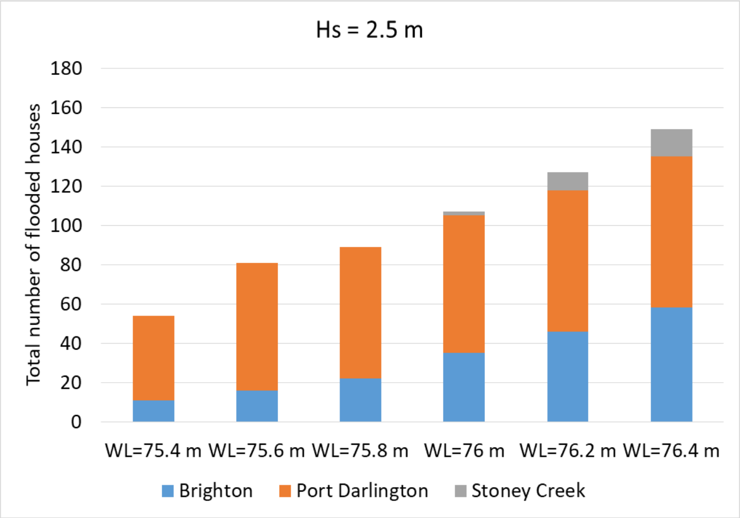


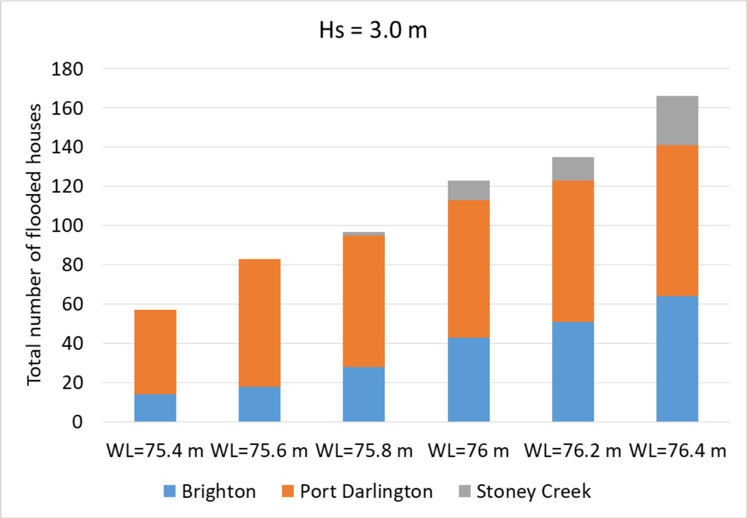


Number of flooded houses (Max water depth+wave height)

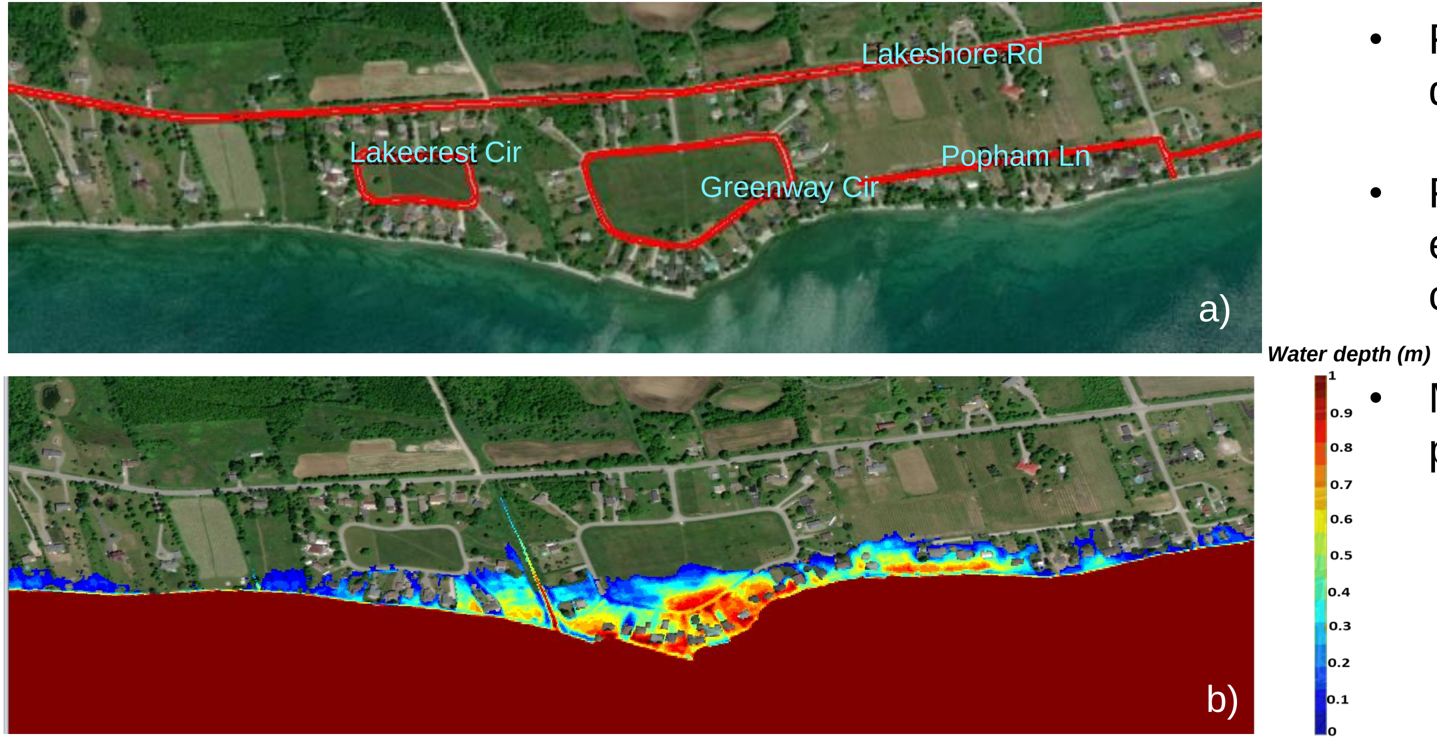


Number of flooded houses (All three sites)



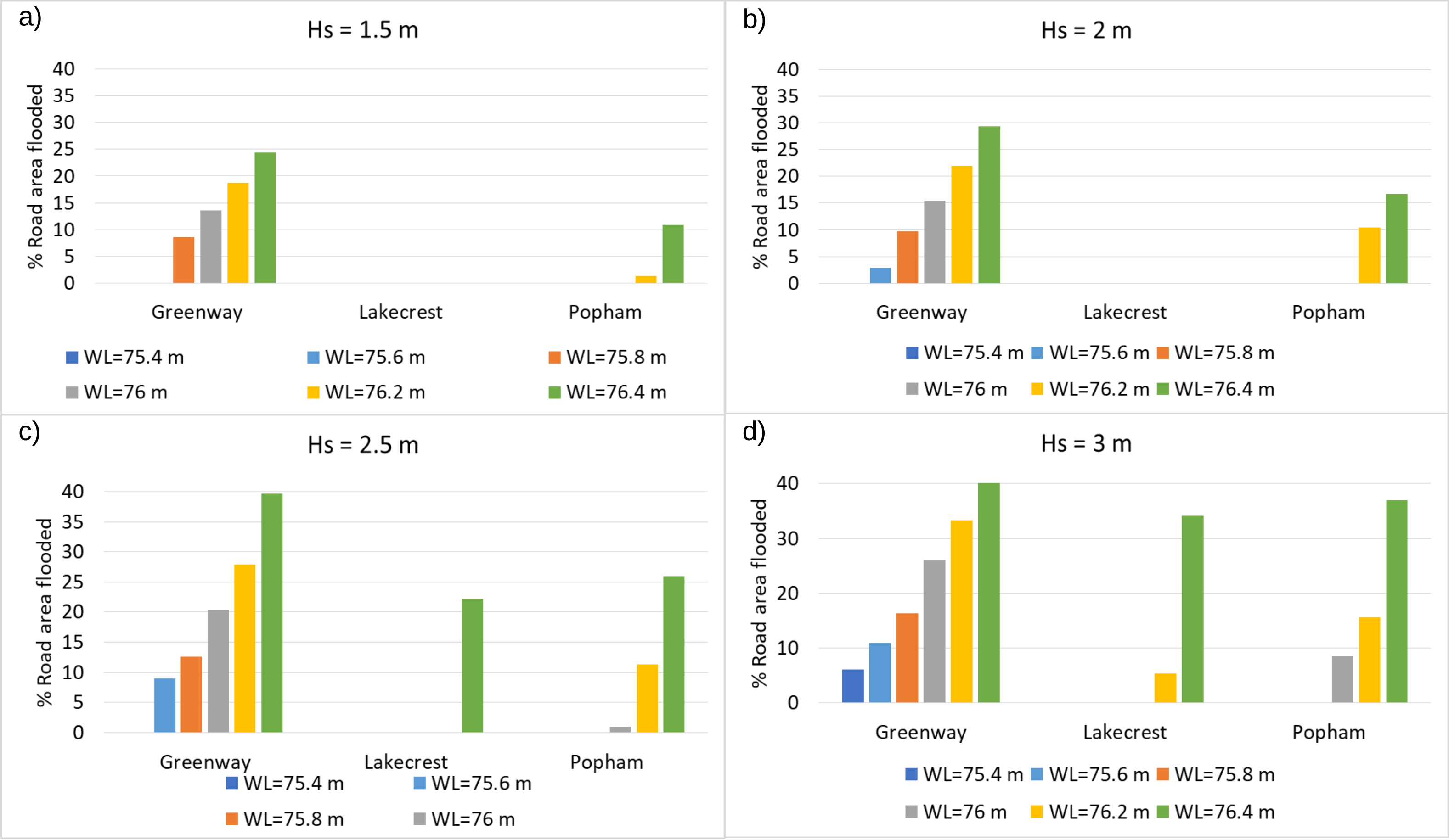


Flooded roads

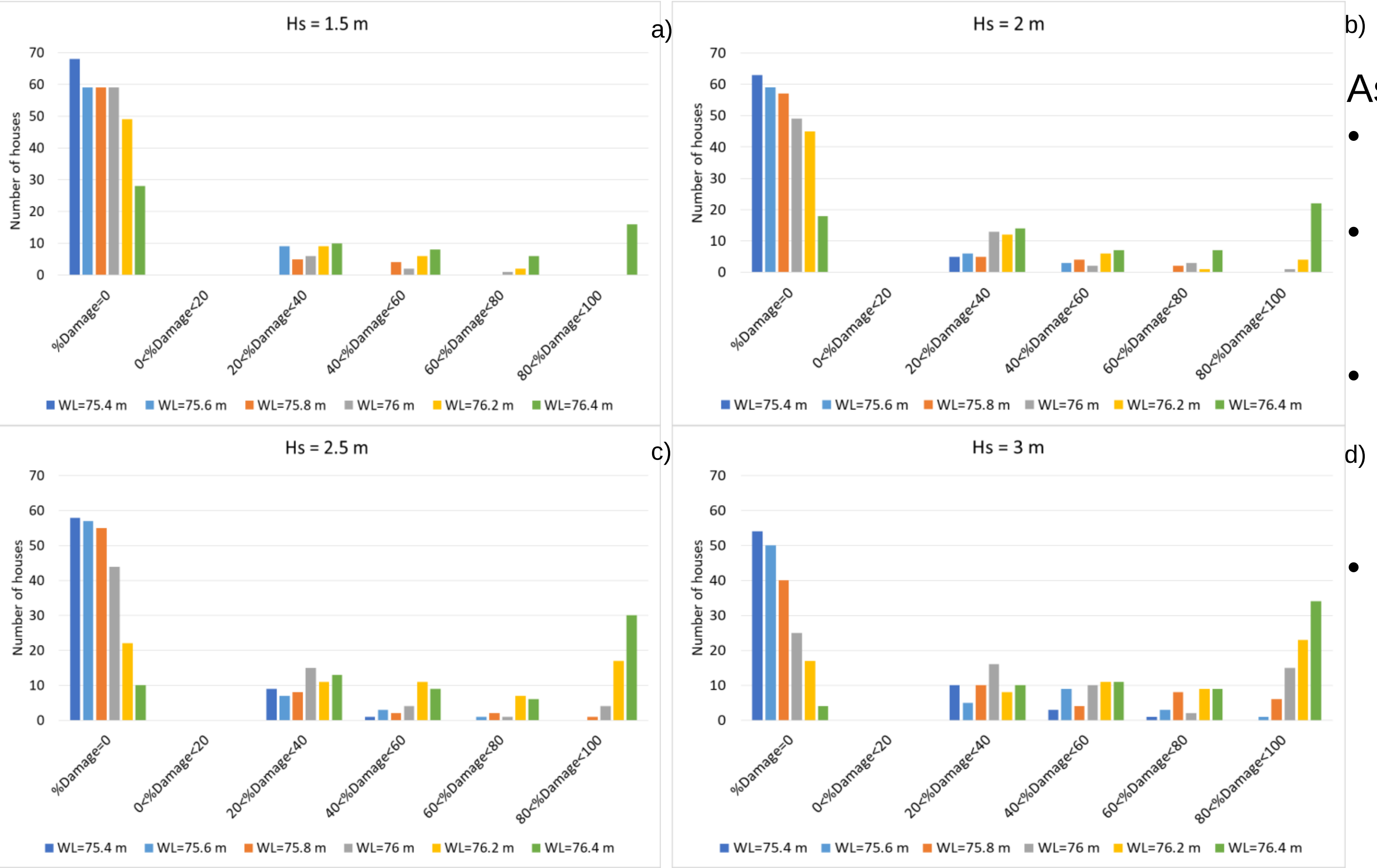


- Four roads are defined by polygons
- Flooded area within each polygon is calculated
- Max depth within each polygon is noted

Flooded roads (% area flooded)



House Damage



Assumptions:

- One story building with basement
- First floor elevation: 0.3 m above grade

- Structure damage due to inundation (USACE 2003)

- Estimates of wave damage using wave height-damage curves (USACE 2015)

Conclusions

- Once the threshold required to initiate flooding is reached, for a given water level, the degree of overtopping, the extent of flooding and the flood severity (impact) are shown to depend on the incident wave height and vise versa. These relationships are often strongly non-linear and dependent on local conditions

- Results show that lake levels and wave effects are both key drivers of flooding, and tools that do not take wave effects into account, such as simple bathtub models, cannot be expected to yield reliable predictions.

- Observed and modelled overland flooding pathways were strongly two-dimensional for some locations, demonstrating the need for 2DH models to accurately simulate overland flood hazards in typical urban settings on Lake Ontario, as opposed to 1D or empirical wave run-up models.

- While XBeach is capable of simulating many of the important processes influencing wave propagation and wave-shore interactions, the model has some important limitations; i.e., it does not simulate wave diffraction in surfbeat mode, and its ability to properly simulate runup and overtopping processes on steeper, non-dissipative shorelines and built shorelines is uncertain

Thank you!

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