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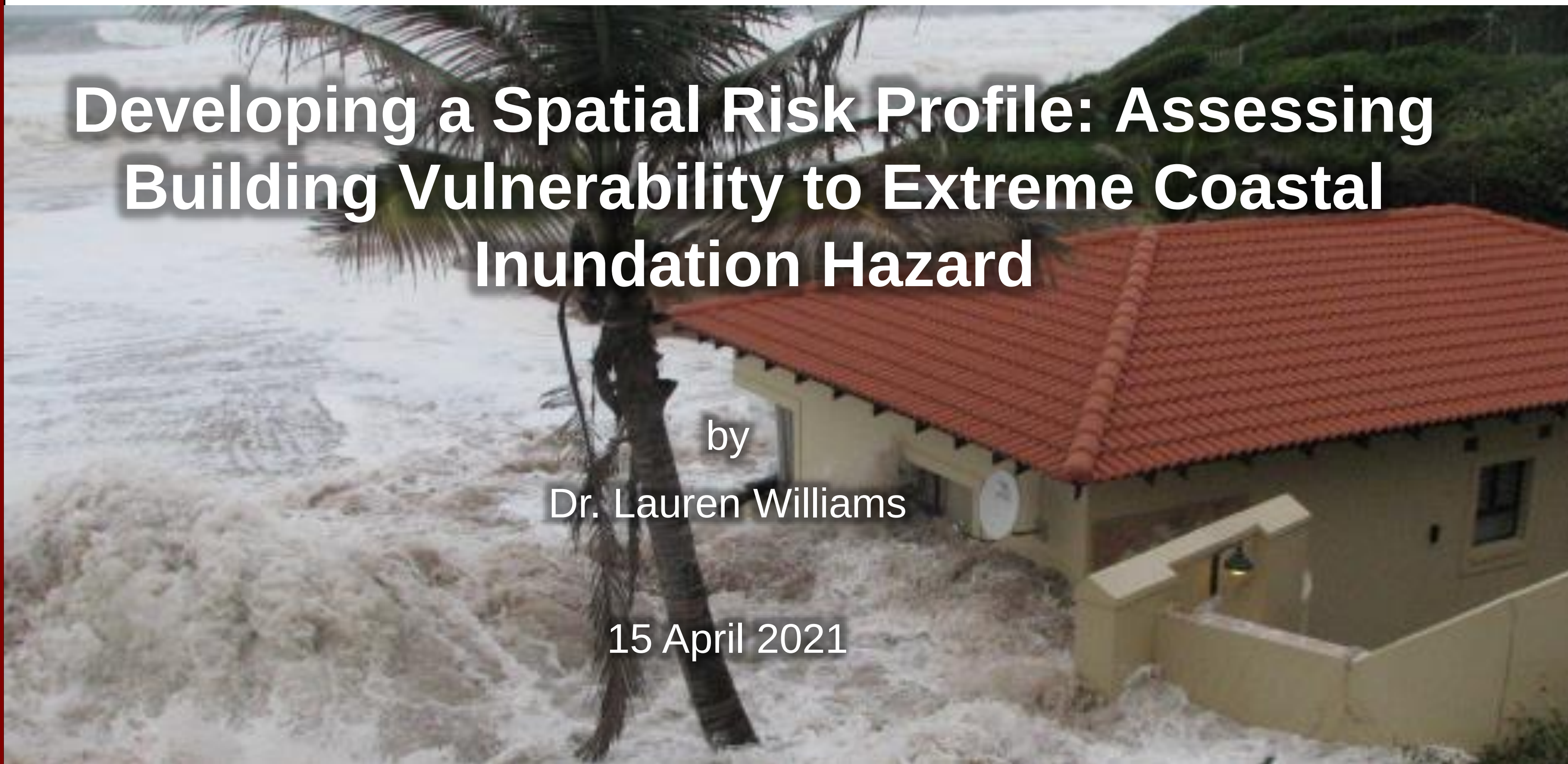

Developing a Spatial Risk Profile: Assessing Building Vulnerability to Extreme Coastal Inundation Hazard

by

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15 April 2021

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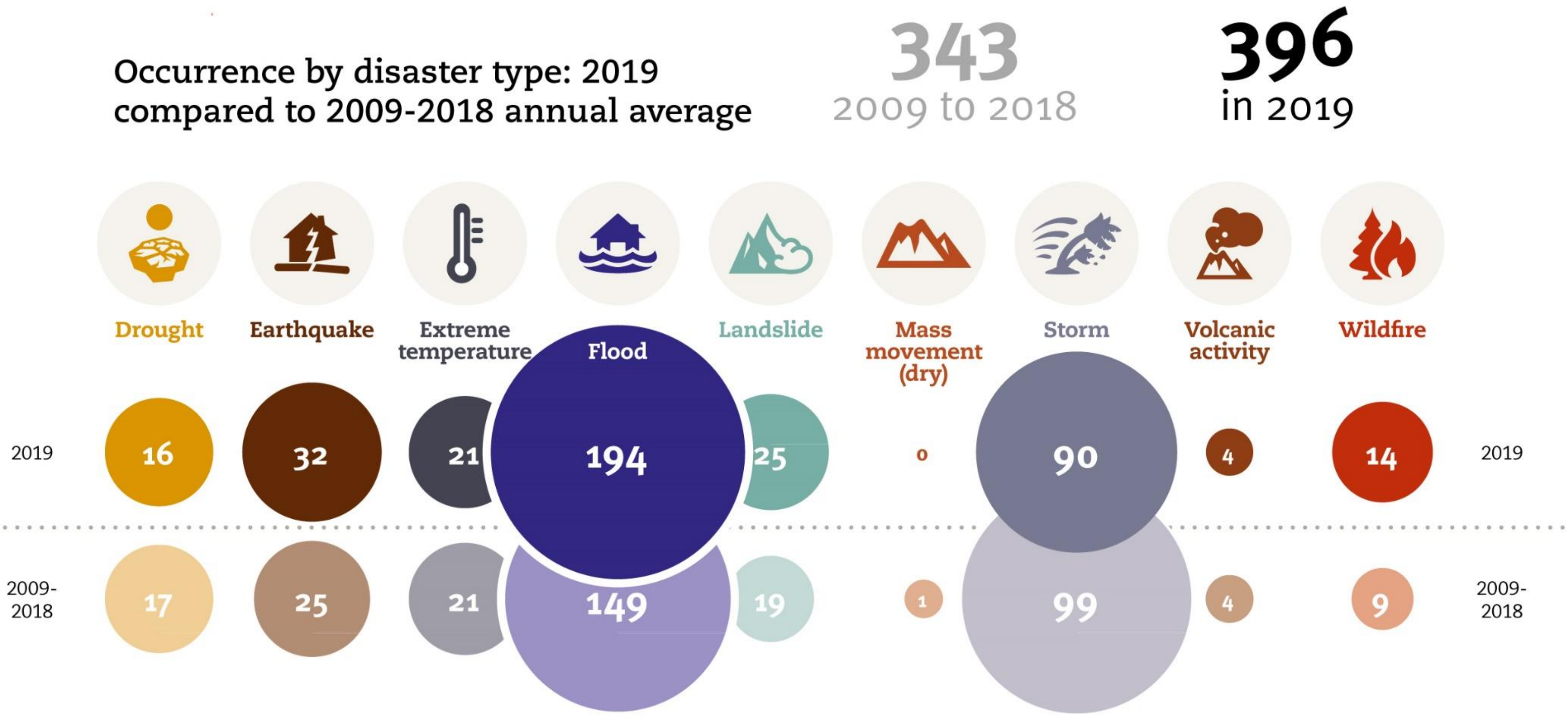
Co-supervisor: Dr. Robyn Pharoah

Background

The coast is a dynamic space

Background



Source: UN/CRED (2019)

Real world problem

- Coastal inundation is regarded as one of the most dangerous, harmful and destructive natural hazards (Douben 2006; Balica 2012; Williams & Lück-Vogel 2020).

2011

Hazard risk	total	%	NC	WC	EC_urb	EC_trad	KZN_urb	KZN_trad
very high	15	0.002	2	13	-	-	-	-
high	738	0.1	102	585	33	4	14	-
medium	17 044	2.8	467	14 377	1 155	30	989	26
low	106 278	17.2	1 259	73 460	15 700	456	13 464	1 939
very low	494 308	79.9	1 476	353 103	52 343	758	58 116	28 512
TOTAL	618 383	100	3 306	441 538	69 231	1 248	72 583	30 477

2016

Hazard risk	TOTAL	%	NC	WC	EC_urb	EC_trad	KZN_urb	KZN_trad
Very high	55	0.01	1	52	1	-	1	-
high	1 158	0.1	100	983	60	4	11	-
medium	23 184	2.2	479	19 230	1 969	87	1 401	18
low	161 998	15.3	1 294	114 539	26 524	759	16 298	2 584
very low	873 550	82.4	1 511	655 959	103 347	1 466	69 435	41 832
TOTAL	1 059 945	100	3 385	790 763	131 901	2 316	87 146	44 434

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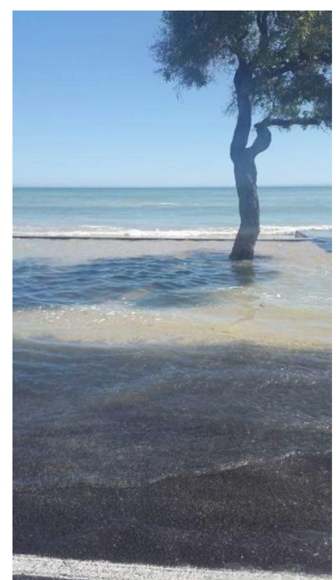
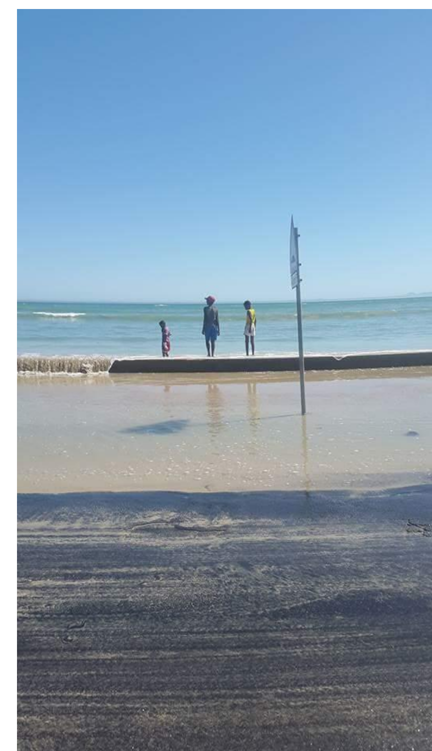
Inundation impact on South Africa's coast

Supermoon event (2016), coinciding with a spring tide



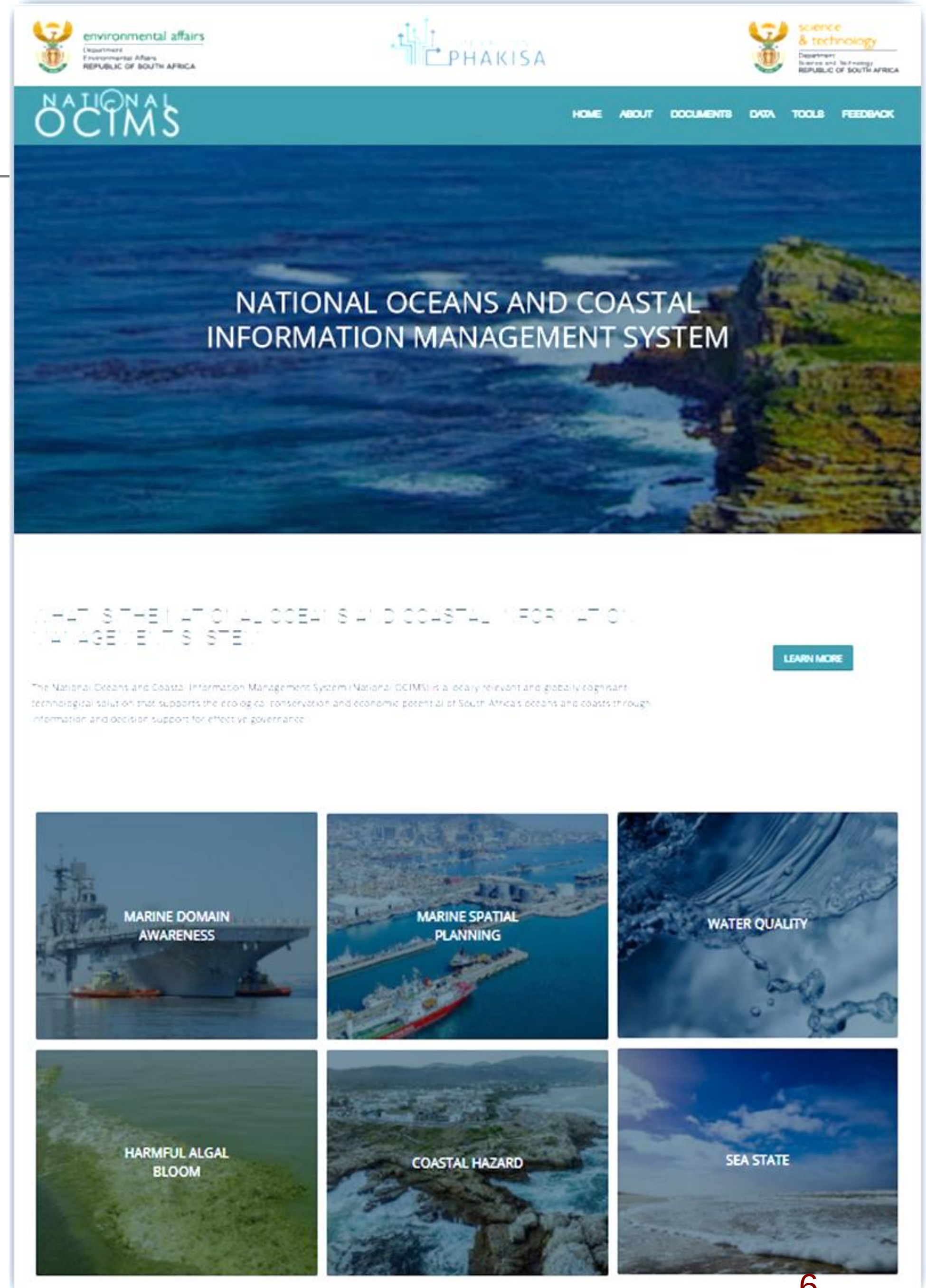


Available solutions

National Oceans and Coastal Information Management System (OCIMS)

– www.ocims.gov.za

To make information accessible to inform decisions



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Available solutions: GIS

https://www.ocims.gov.za/coastal-flood-hazard-tool/

Disadvantages of the Bathtub model:

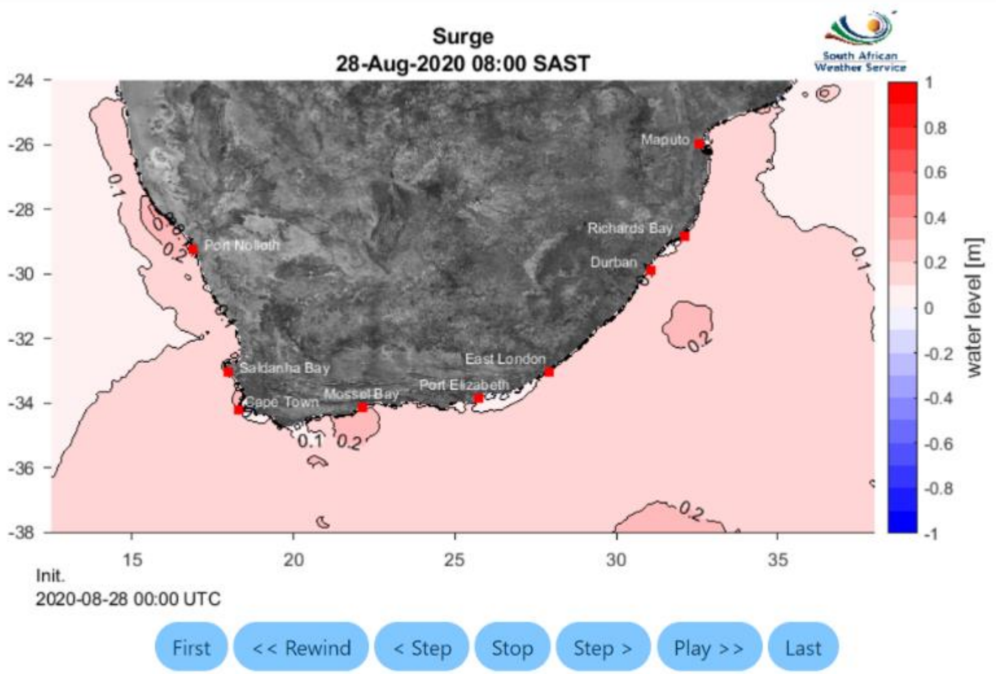
- Simplistic model
- Hydrological disconnect
- Overestimation of inundated areas
- Excludes tidal and atmospheric forces

Available solutions: Numerical modelling

Disadvantages:
- Data hungry
- Computationally expensive
- Too coarse for local applications
- Specialised

Numerical modelling software:

MIKE by DHI



http://marine.weathersa.co.za/

CSIR (2016)

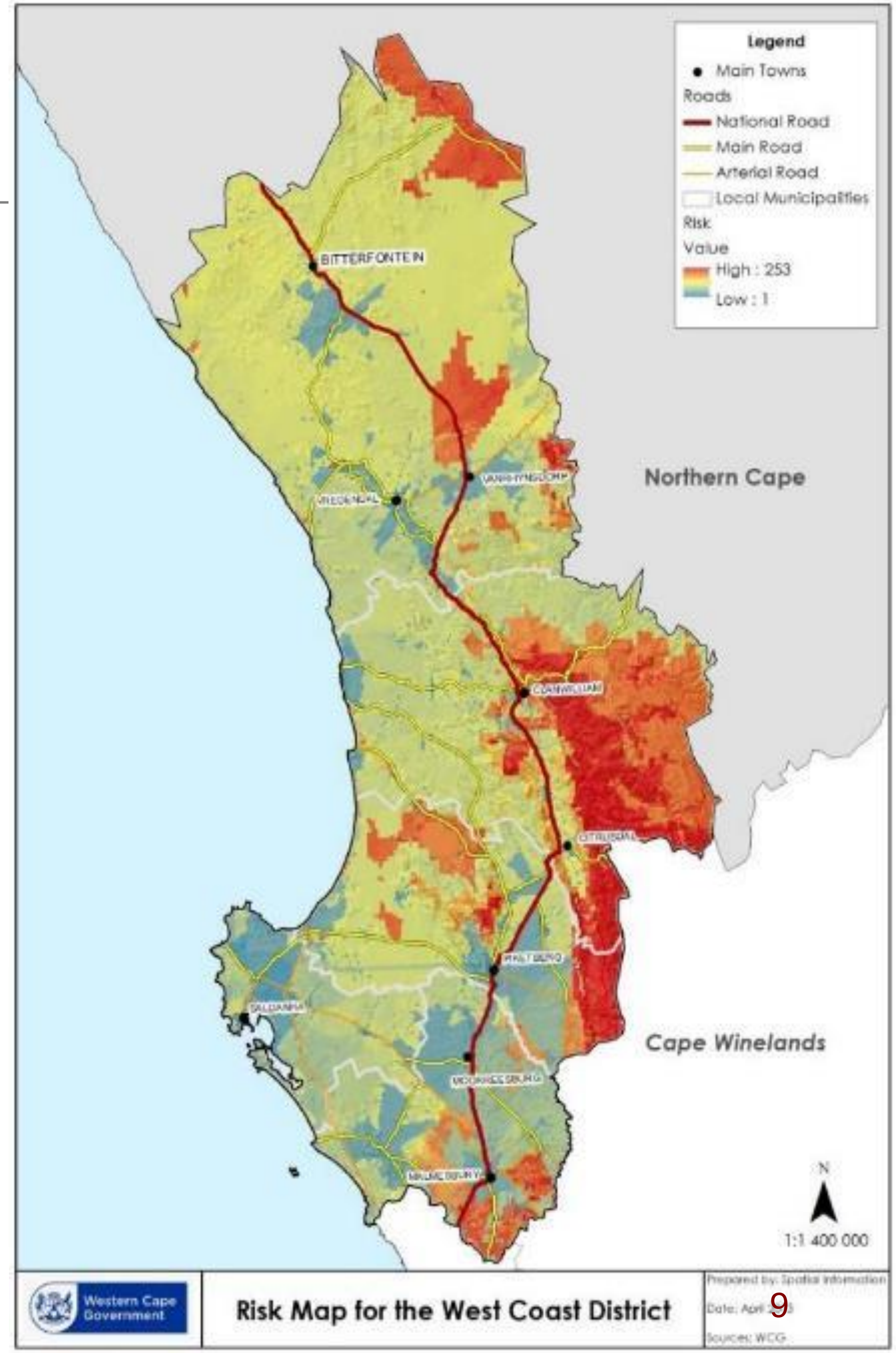
Available solutions

Comprehensive Spatial Risk Profiles

Disadvantage:

- Do not adequately capture localised events
- Coastal processes are lost

Map credit: Western Cape Government: Disaster Management



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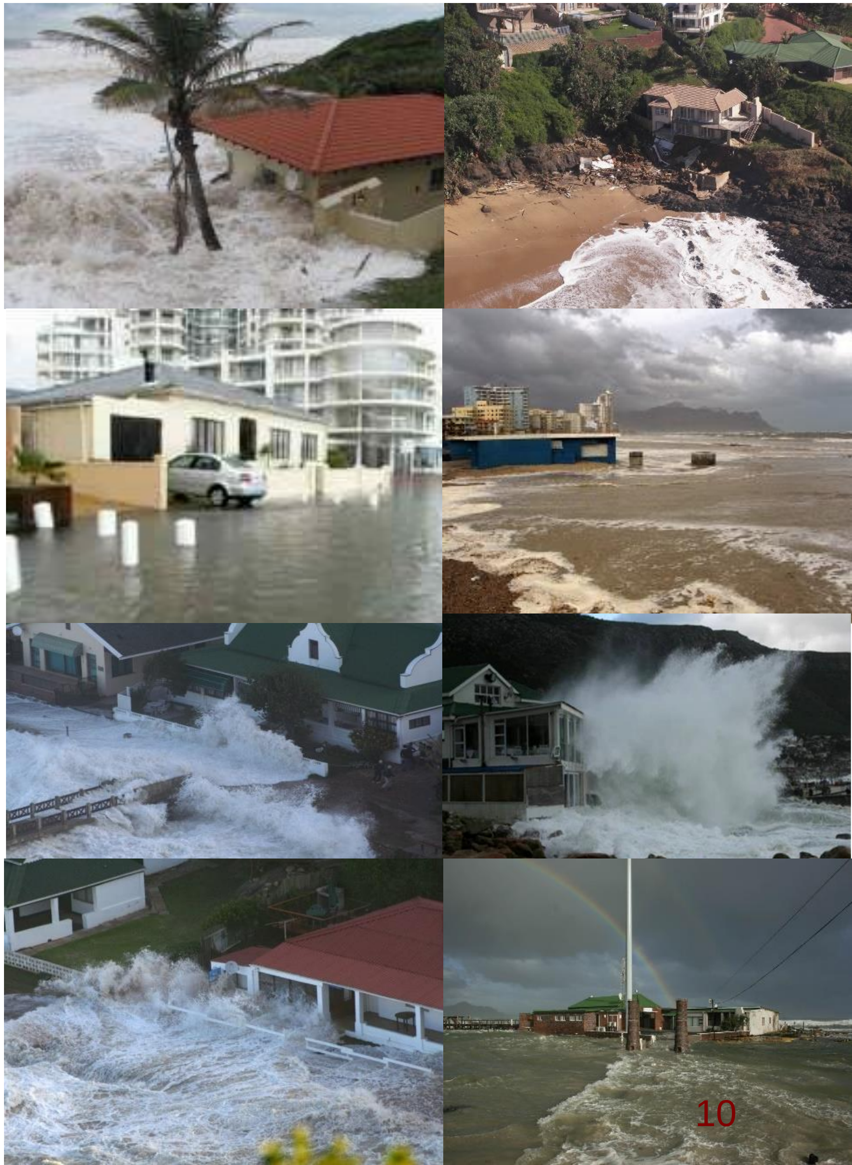
Research gaps

There is a need for:

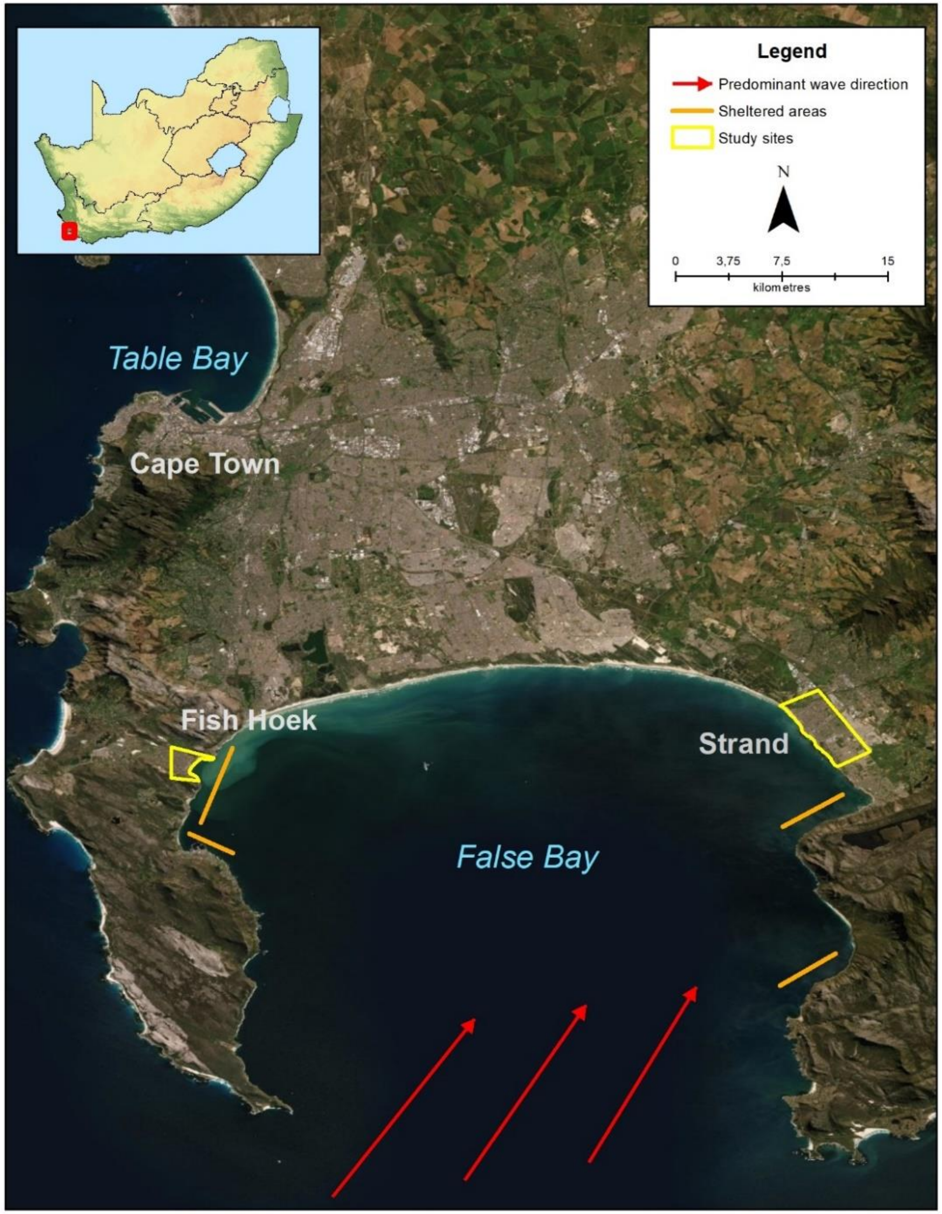
1. An inundation model that is not too sophisticated, nor too simplistic and able to provide information at a local level

2. A locally relevant building vulnerability assessment framework

3. A local level spatial risk profile for building vulnerability to coastal inundation hazard



The study sites



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Methods

Co-development Process

Stakeholder engagements

- **Written survey:** coastal and disaster management officials (40 respondents)
- **Semi-structured interviews and consultations:** technical experts (16 respondents)

Coastal inundation model development

- Inundation hazard limits
- Building hazard exposure

Vulnerability assessment

- Indicator development
- Building assessments
- Field work

Spatial Risk Profile

- Scaling
- Weighting

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Technical expertise consulted

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Local government

City of Cape Town · Isixeko Sasekapa · Stad Kaapstad

Disaster Risk Management · Cape Town

eThekwini Municipality

Provincial government

Western Cape Government

Disaster Management

National government & entities

environment, forestry & fisheries
Department: Environment, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

South African Weather Service

NRF National Research Foundation | SAEON South African Environmental Observation Network

CSIR our future through science

Tertiary institutions & Private sector

Santam

University of Cape Town · iYunivesithi yaseKapa · Universiteit van Kaapstad

International

NOAA · National Oceanic and Atmospheric Administration · U.S. Department of Commerce

Deltares Enabling Delta Life

IPCC Intergovernmental Panel on Climate Change · WHO · UNEP

United Nations Office for Outer Space Affairs UN-SPIDER

Written survey results:

Access to technology:

- GIS is the most widely used and accessible technology
- All consulted institutions are using ESRI's ArcGIS software

Access to technical expertise:

- Dedicated GIS expertise is mostly available within institutions
- Specialised services e.g. hydrodynamic modelling are outsourced on a project basis

Coastal inundation risk assessment requirements:

- easily repeatable and structured;
- does not require advanced specialised expertise;
- implementable over a large area;
- quickly executable; and
- able to be undertaken without the need for sophisticated technologies e.g. high-performance computing.

The eBTM input data

Question	Input data	Derivatives
How to ensure hydrological connectivity to the coast?	Vector coastline “water source”	Coastline
How to include water movement ‘influencers’	LiDAR derived 1m resolution DSM	Surface structures; Elevation; Slope; and Aspect.
How much water will cause inundation?	User defined inundation water level	Inundation water level
How to include bottom friction in a GIS environment?	Surface roughness coefficient (FEMA 2007)	Surface roughness

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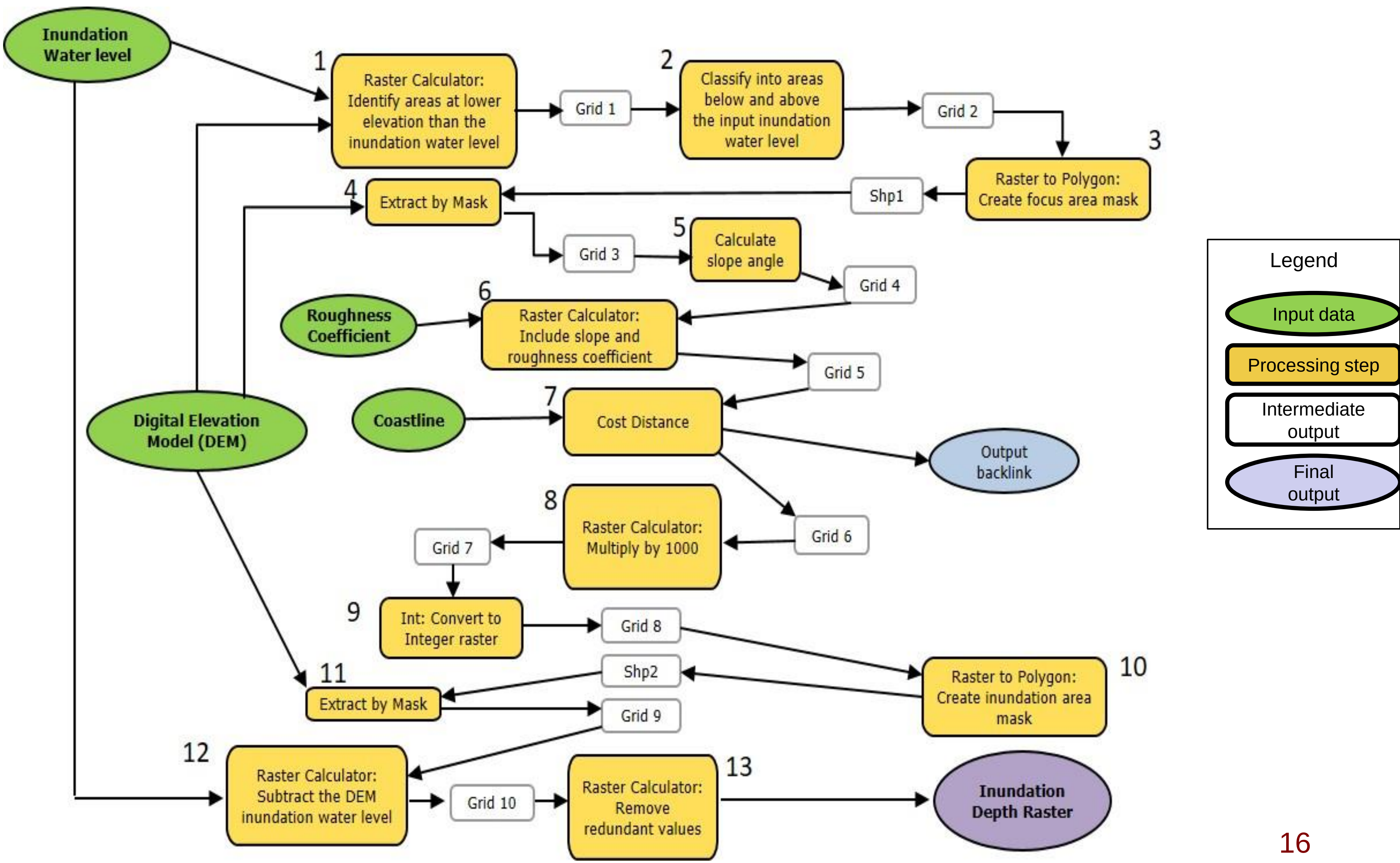
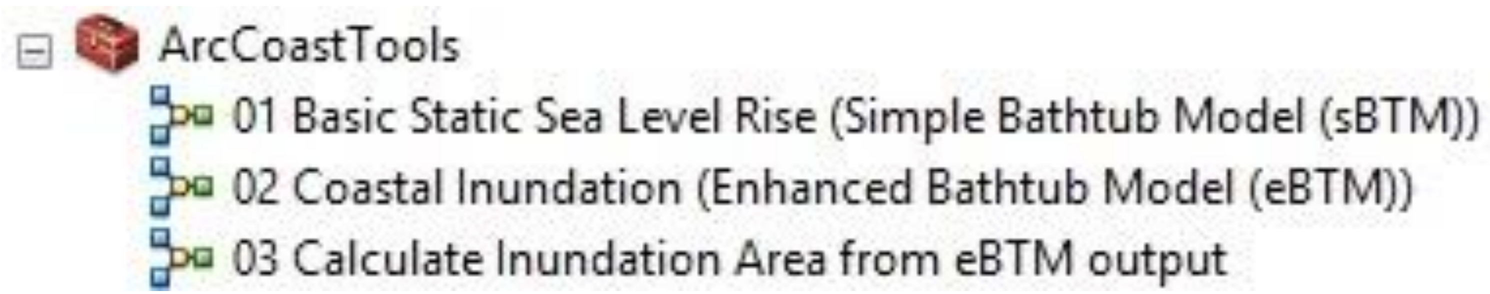
The eBTM Model Development



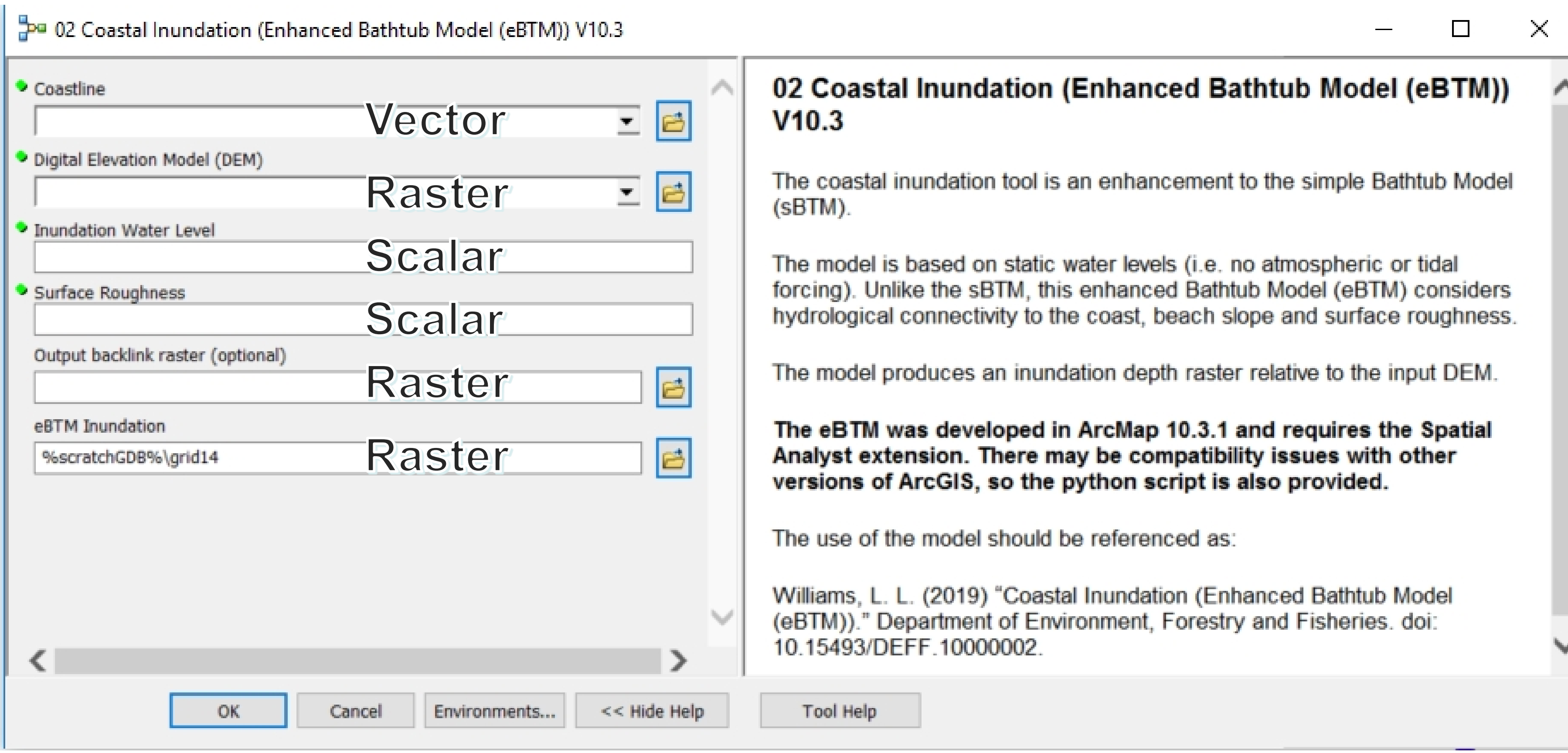
eBTM Tool Development

- Packaging the model into a user friendly plug & play solution for ArcGIS



eBTM Tool Development

- User friendly plug & play solution for ArcGIS developed



Model scenarios and parameters

Water levels

Scenario number	Return period	Storm surge (m)	Spring tide water level (m)	IPCC AR5 Sea level rise projection (m)	Hazard scenario water levels (m)
1	Once per 100 years	0.84	0.95	None	1.79
2	Once per 100 years	0.84	0.95	0.38	2.17
3	Once per 100 years	0.84	0.95	0.82	2.61

30 August 2008 storm saw a maximum tide water level of 2.3m (SANHO 2008)

Roughness coefficient

FEMA 2007

Roughness Coefficient	Description of surface
1	Sand; smooth rock, concrete, asphalt, wood, fibreglass
0.95	Tightly set paving blocks with little relief
0.9	Turf, closely set stone, slabs, blocks
0.85	Paving blocks with sizable permeability or relief
0.8	Steps; one stone layer over impermeable base; stones set in cement
0.7	Coarse gravel; gabions filled with stone
0.65	Rounded stones, or stones over impermeable base
0.6	Randomly placed stones, two thick on permeable base; common riprap installation
0.5	Cast-concrete armour units; cubes, dolos, quadripods, tetrapods, tribars, etc.

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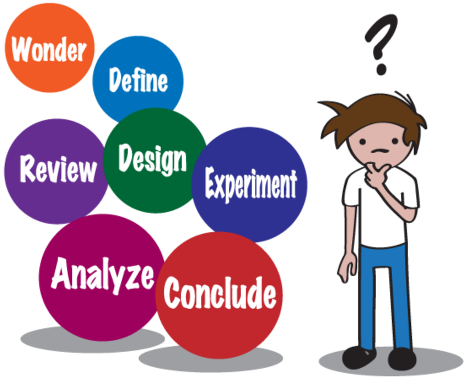
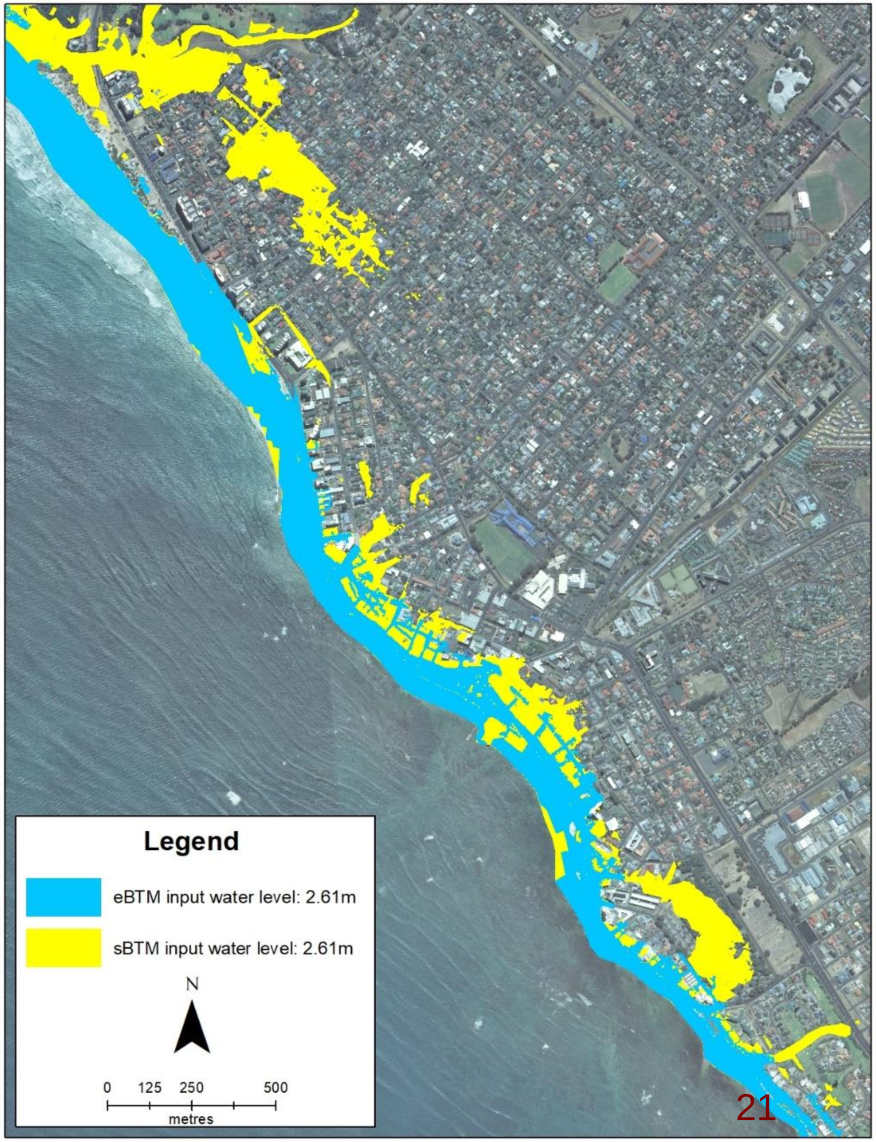
Sensitivity testing

- Comparison between sBTM vs. eBTM
- The eBTM model's response to a DTM vs. DSM under the same input parameters;
- Varying the following parameters:
  - DSM resolutions i.e. 1m, 5m and 10m DSMs
  - Beach slope; and
  - Surface roughness

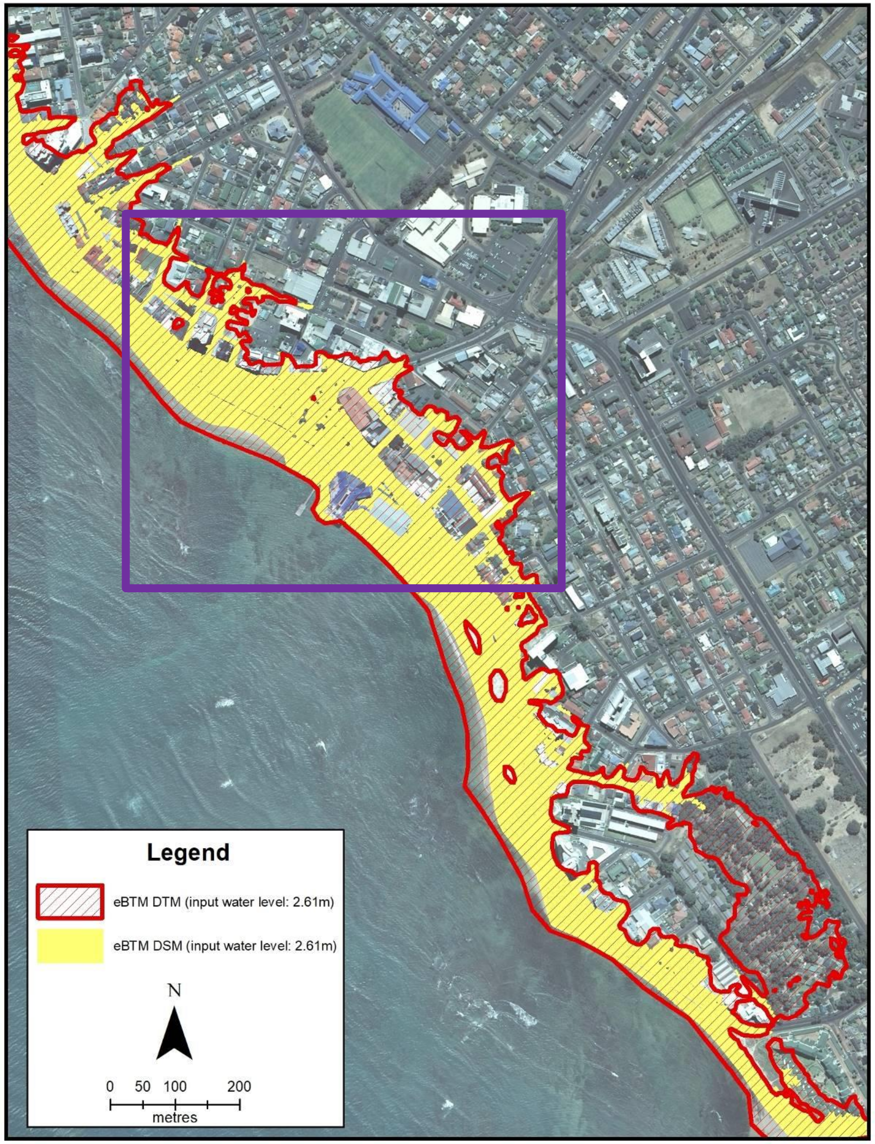


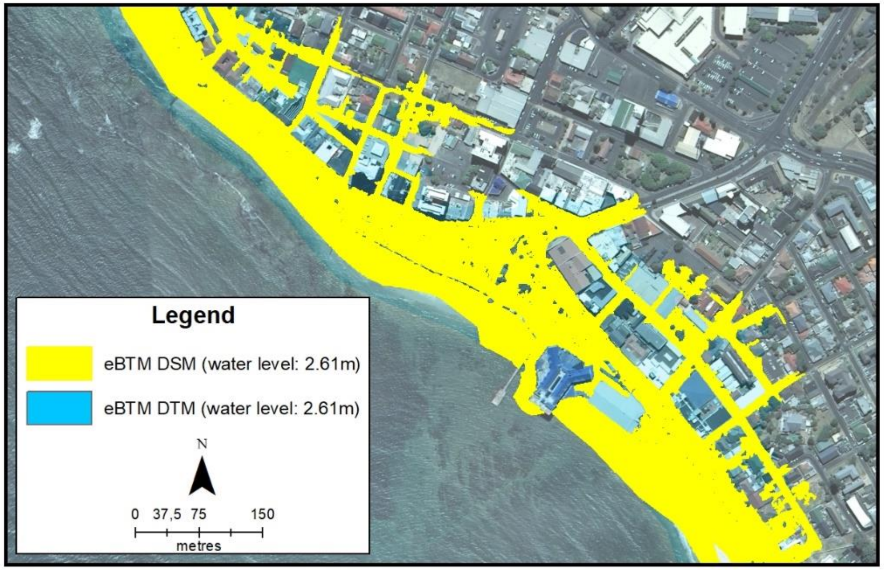
Test 1: sBTM vs. eBTM

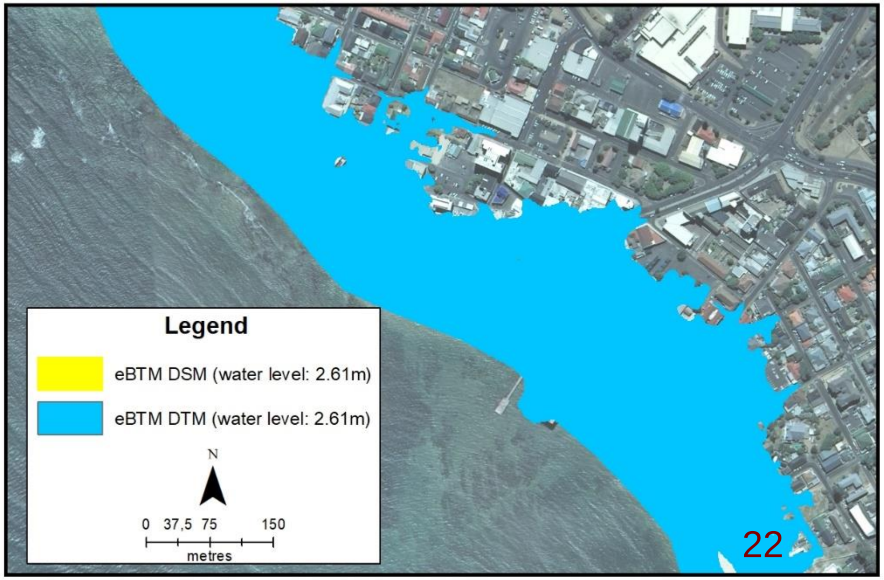
- Yellow:
  - sBTM
  - 1m DTM
  - Water level = 2.61m
- Blue:
  - eBTM
  - 1m DSM
  - Water level = 2.61m



Test 2: DSM vs. DTM







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Test 3: DSM Resolution

Test Parameters	Outcome
Study site	Strand
1m resolution DSM	Model run time = 50 mins, 4 secs;
5m resolution DSM	Model run time = 1 min, 37 secs;
10m resolution DSM	Model run time = 37.88 secs,

Test 4: Varying Beach Slope

- Strand has a gentle beach slope
- What about steeper beaches e.g. Fish Hoek's dune?

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Test 4: Varying Beach Slope

- What about areas with sea walls e.g. Sea Point?
- Input water level was 5m, the approximate height of the sea wall

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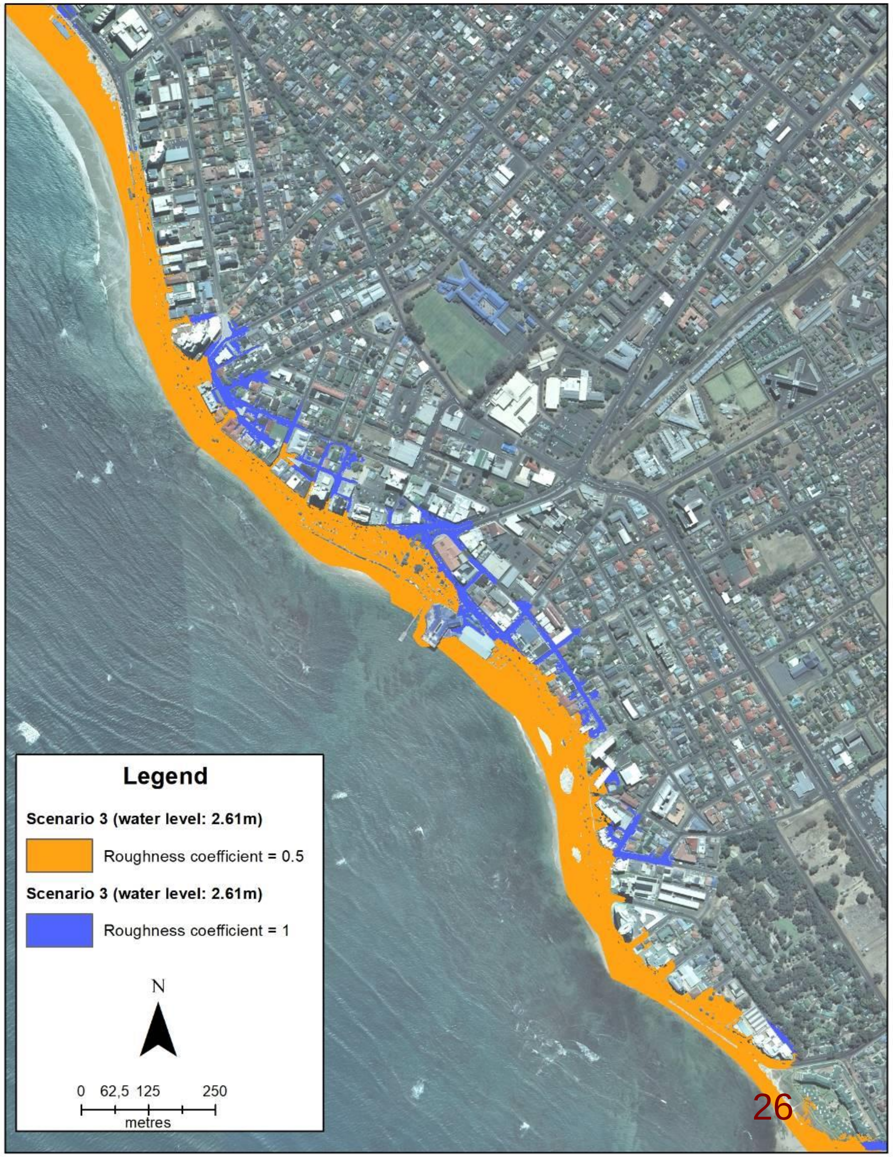
Test 5: Roughness Coefficient

- 1m DSM
- Water level: 2.6m
- RC values based on FEMA (2007)
- RC is between 0 (rough) and 1 (smooth)
  - RC = 1 (blue)
  - RC = 0.5 (orange)



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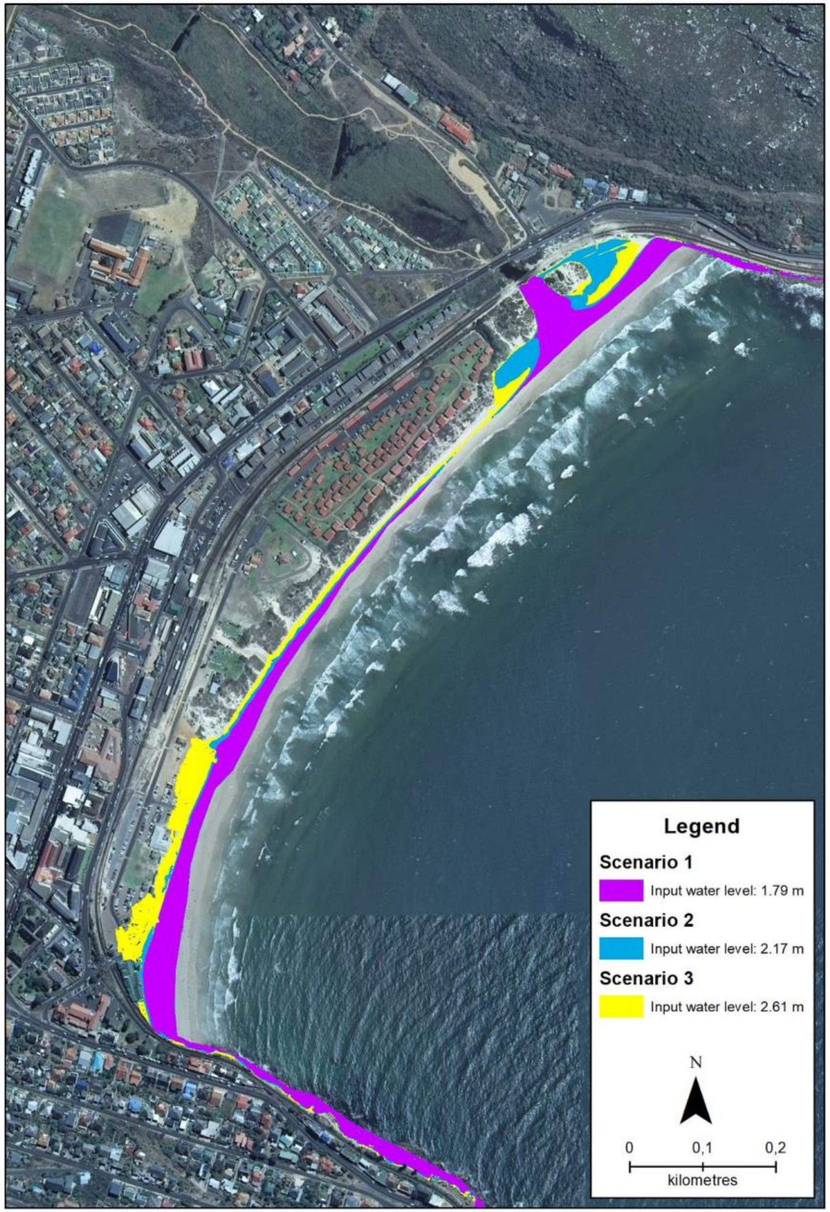
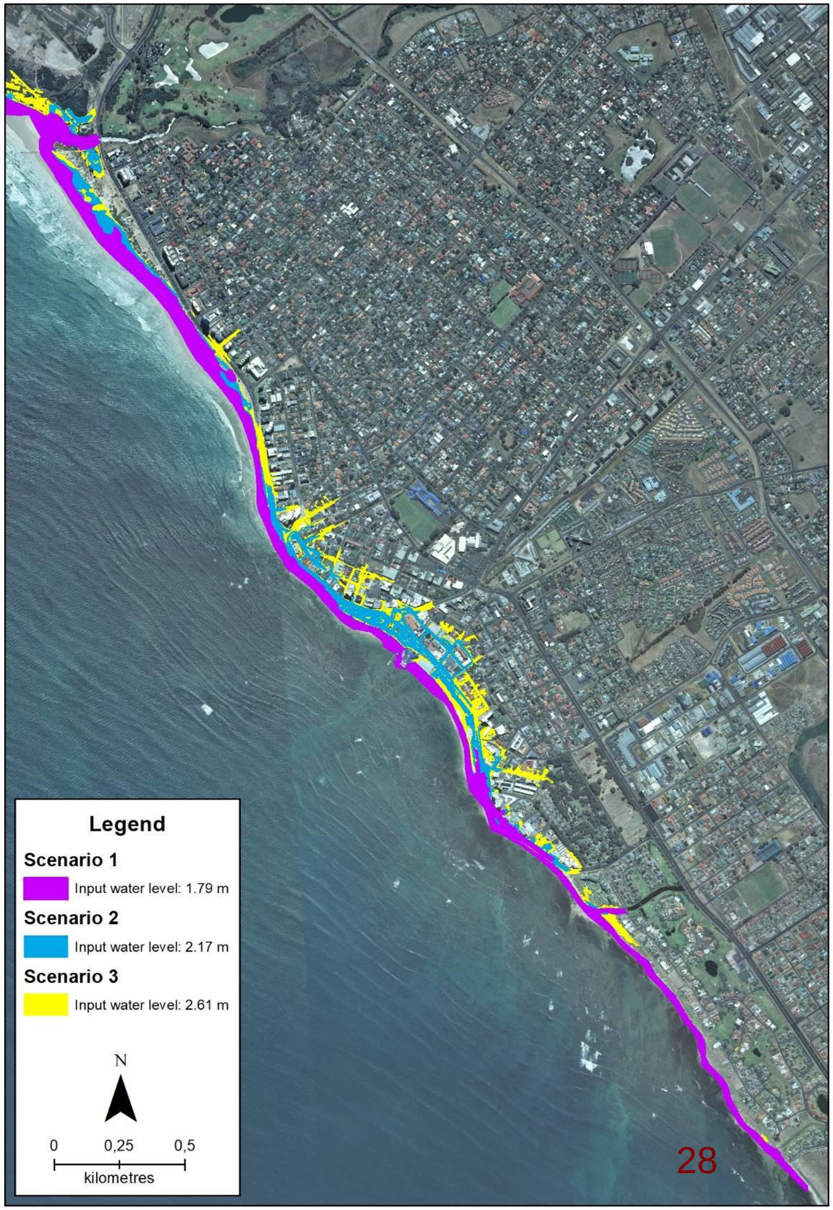
eBTM Validation

- Data points from 2008 storm
- Water level = 2.3m

Inundation Hazard Results





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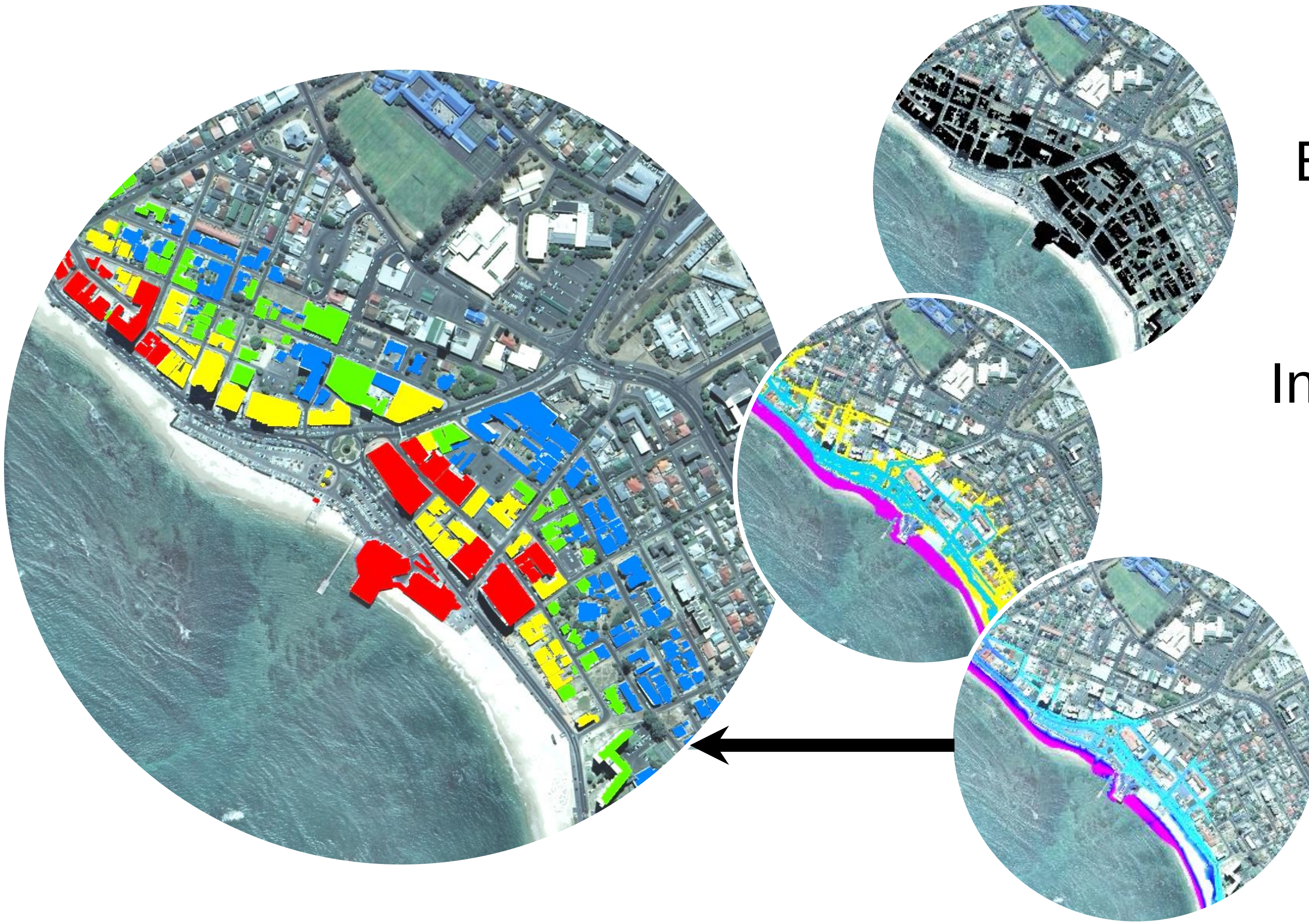
Hazard Exposure



Buildings

+

Inundation hazard

+

Water depth

Hazard Exposure

Inundation depth	Hazard exposure score	Fish Hoek	Strand
0 m	0 (not exposed)	202	524
0.1 m to 0.3 m	1 (low)	3	96
0.31 m to 0.6 m	2 (moderate)	1	59
> 0.61 m	3 (high)	0	37

FEMA (2013)

Building vulnerability assessment

- Indicators developed through consultation
- Indicators are hazard specific
- Scoring mechanism (1 – 3)
- Each building assessed individually

Vulnerability

Weight = 100%

Physical

- Number of floors
- Ground floor relative to ground level
- Building orientation
- Presence of a solid wall around the building
- Building construction material

Weight = 60%

Occupancy

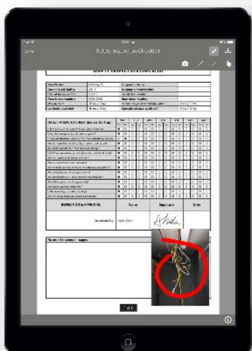
- Ground level usage
- Peak occupancy period
- Relative age of population

Weight = 40 %

Impact of a solid wall

Building vulnerability assessment

$$Vulnerability\ Score = ((P1 + P2 + P3 + P4 + P5) * 0.6) + ((O1 + O2 + O3) * 0.4)$$



Indicators

Building roofprints

Inherent vulnerability

Building vulnerability assessment

Vulnerability	Fish Hoek	Strand
Slightly vulnerable	13	254
Moderately vulnerable	163	354
Highly vulnerable	30	108

Spatial risk profile

- Conventional risk equation:

$$Risk = Hazard * Hazard\ Exposure * Vulnerability$$

- Adaptation includes:
  - Scaling - presenting data according to a particular scale (in the context of this thesis: dividing a continuous data range into discrete classes)
  - Weighting - introducing an adjustment to the weight of individual input data and is applied to accommodate specific circumstances.

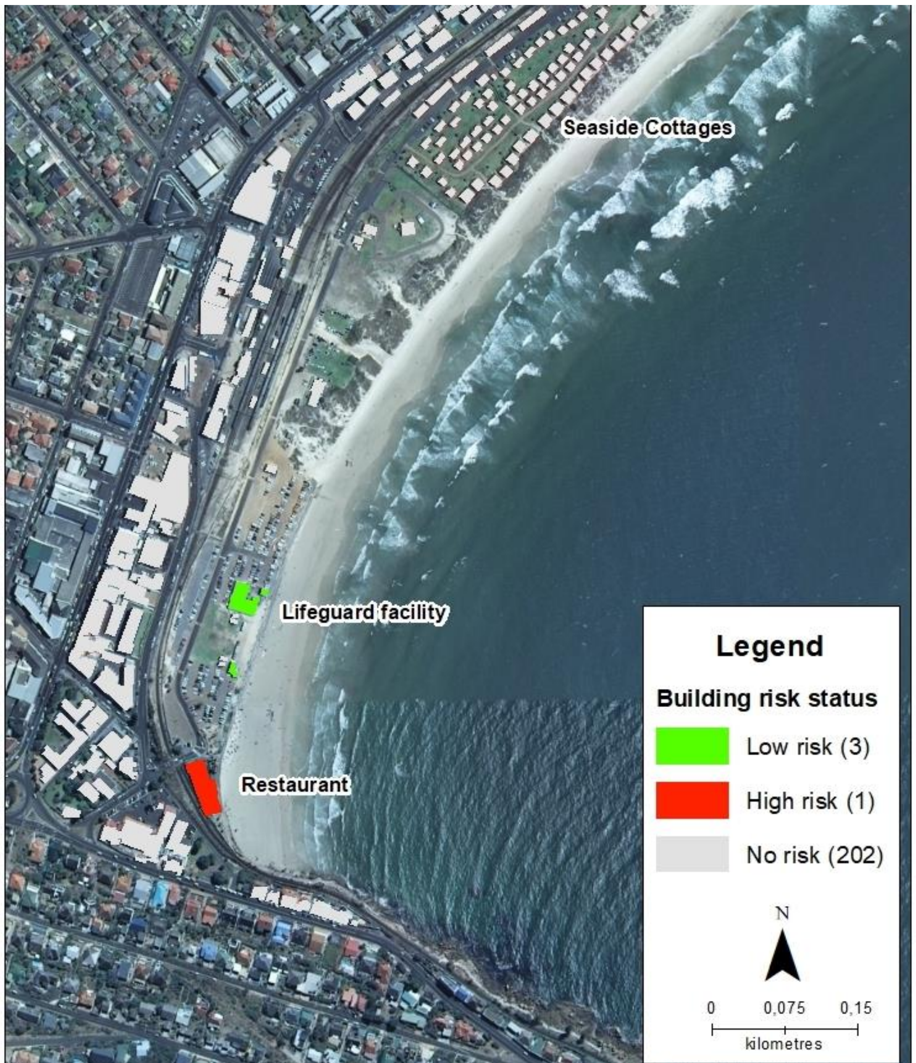
- Modified risk equation:

$$Risk = w_H H * w_{HE} HE * w_v V$$

- Weightings:
  - $w_H = 1$
  - $w_{HE} = 0.75$
  - $w_V = 2$

Spatial risk profile

Spatial Risk Profile = Inundation Hazard * Building Hazard Exposure * Building Vulnerability



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Data considerations

- Dependency on high resolution DEMs
  - Preferred for coastal applications - resolution test

- Outdated data
  - LiDAR is expensive, but necessary, especially where the landscape has changed

Data considerations

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Data considerations

Contributions

- Contribution to knowledge in the GIS application, disaster management and coastal management fields.
- Individual assessment of risk components (i.e. hazard, hazard exposure and vulnerability) at a locally relevant scale.

1. Improved GIS based coastal inundation approach.
2. Framework for building vulnerability developed.
3. Cross-disciplinary and co-developed risk assessment approach.
4. Providing a method for generating geospatial risk information at levels relevant for local management.
5. Tool to empower local municipalities, disaster management and coastal practitioners to conduct local inundation assessments by packaging the eBTM model in a GUI tool.

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Current work and future opportunities

- Current work:
  - The eBTM is currently being used in the Department of Forestry and Fisheries and the Environment, projects, including:
    - Coastal Climate Change Vulnerability Assessment Project
    - Updating Coastal Flood Hazard Decision Support Tool on OCIMS
  - The ArcCoastTools toolbox was requested by the Western Cape Government for use in a climate change vulnerability assessment project

- Future opportunities:
  - Improvements to the eBTM to incorporate a surface roughness raster (paper submitted)
  - Promote data capture during inundation events, capturing inundation limits to assist in model validation
  - Develop the eBTM using open source solutions for wider use
  - Couple eBTM with more sophisticated models for improved scenario based outputs

Thesis outputs

- eBTM development and testing:
  - Williams, L.L. & Lück-Vogel, M. 2020. Comparative assessment of the GIS based Bathtub Model and an Enhanced Bathtub Model for coastal inundation. Journal of Coastal Conservation 24, 23. [online]. Available from: https://doi.org/10.1007/s11852-020-00735-x
- ArcPy script:
  - Williams, L. L. 2019. *Coastal Inundation (Enhanced Bathtub Model (eBTM))*. Department of Environment, Forestry and Fisheries. https://doi.org/10.15493/DEFF.10000002
- ArcCoastTools
  - Williams, L. L. 2019. *ArcCoastTools*. Department of Environment, Forestry and Fisheries. https://doi.org/10.15493/DEFF.10000001
- Guidelines for Coastal LiDAR:
  - Lück-Vogel, M., Macon, C., Williams, L.L. 2018. Guidelines for Coastal Lidar. PositionIT, 21 May 2018, EE Publishers. Online: http://www.ee.co.za/article/guidelines-for-coastal-lidar.html
- National Guideline Towards the Establishment of Coastal Management Lines:
  - Department of Environmental Affairs. 2017. National Guideline Towards the Establishment of Coastal Management Lines. Centre for Environmental Rights. Online: https://cer.org.za/wp-content/uploads/2009/12/National-guideline-towards-the-establishment-of-coastal-management-lines.pdf

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Thank You

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