

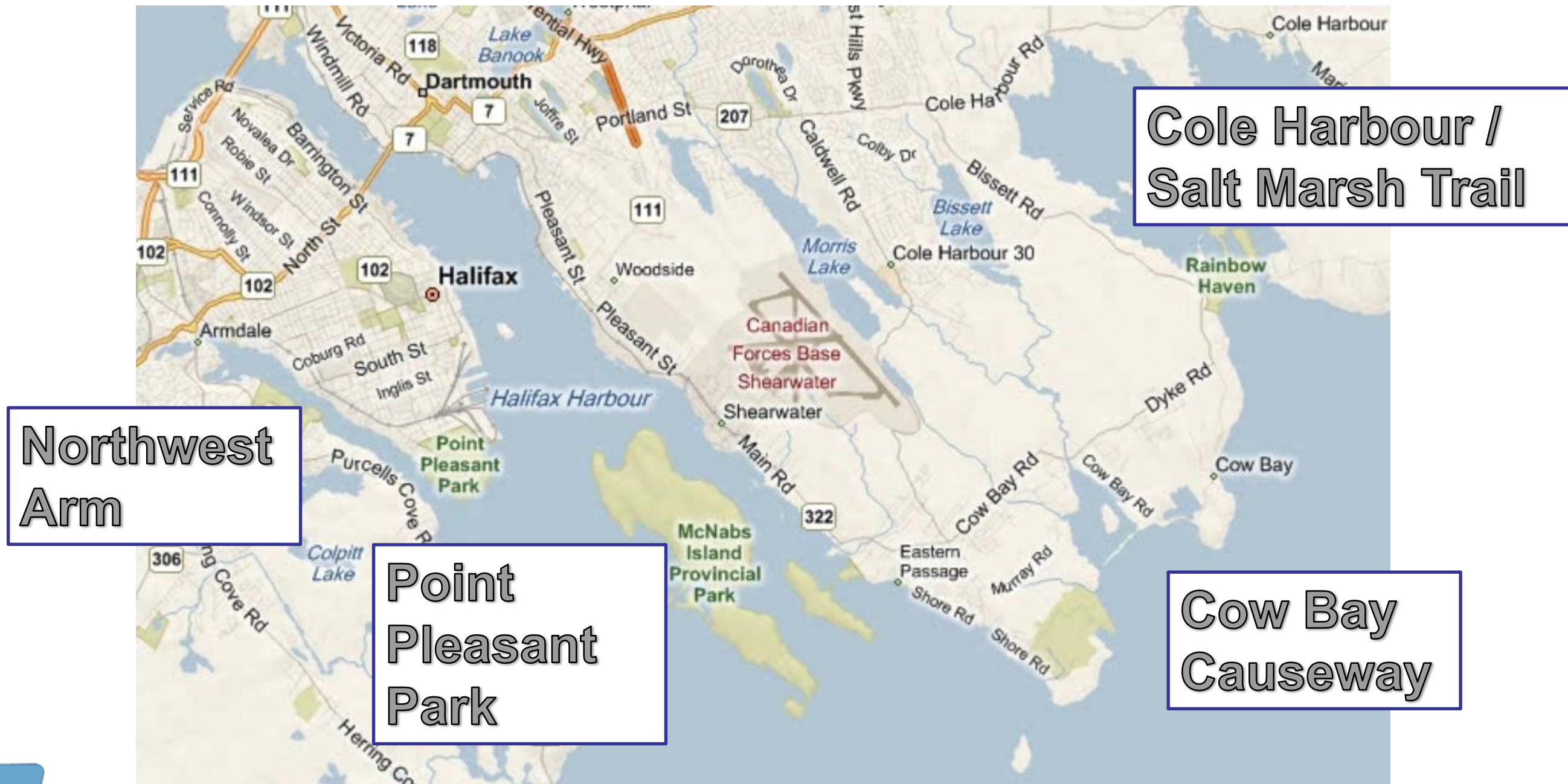
Planning Coastal Infrastructure Under Conditions of Sea Level Rise and Climate Change

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The Halifax Shoreline

4 sites (Point Pleasant Park, Northwest Arm, Cow Bay, Salt Marsh Trail)



Issue

Halifax Regional Municipality (HRM) developing aptation response to climate change

Triggered (in part) by recent storms (Juan, Noel...)

HRM has been engaged in the development of a planning level response to climate change and relative sea level rise.

Infrastructure >100 yrs old (30cm+ RSL)

Looking forward, HRM wanted to evaluate the risk that existing and future infrastructure will be exposed to under scenarios of rising sea levels.

Building on the success of the studies by HRM and AGC on mapping flooding levels under various sea level rise scenarios, Coldwater was engaged to assess existing structures and provide guidance for future works.

In addition to developing specific design recommendations, our scope included evaluation of existing structures and a broad assessment of the long-term prognosis for these facilities.

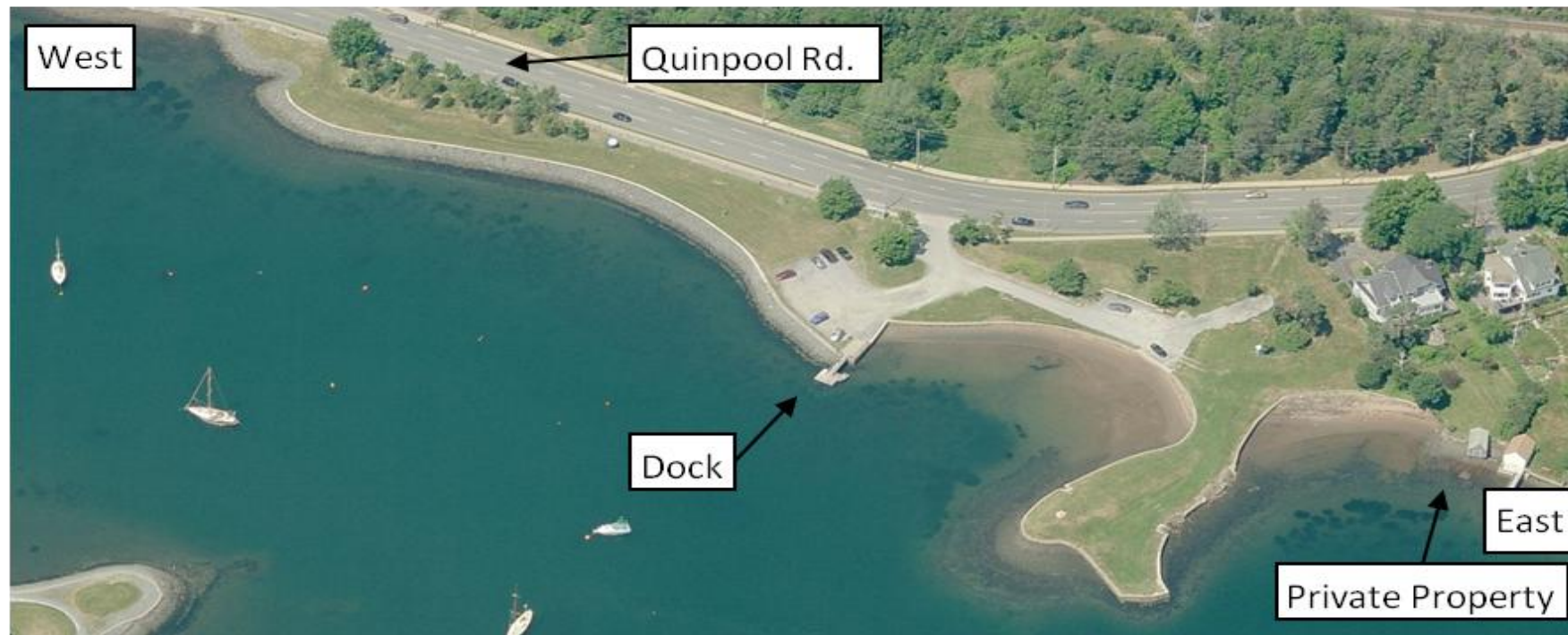


Sir Sandford Fleming Park – The Dingle



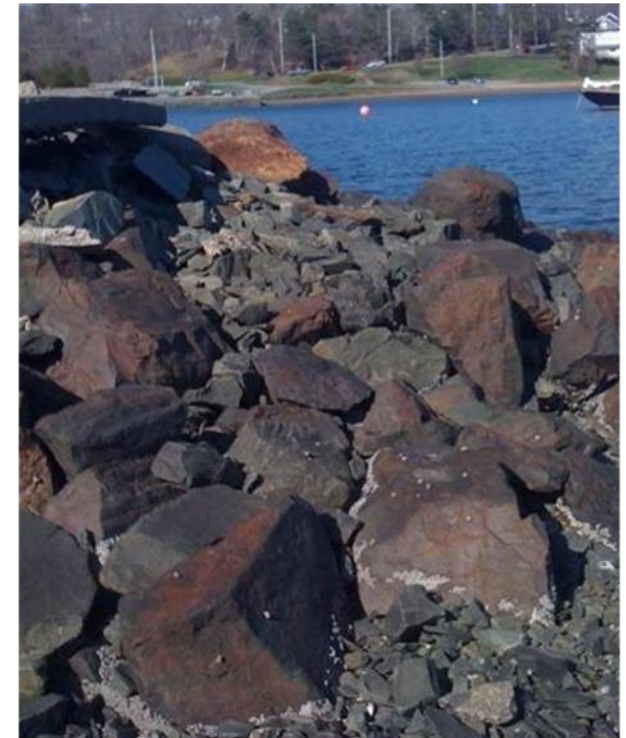
Horseshoe Island

Developed in 1925



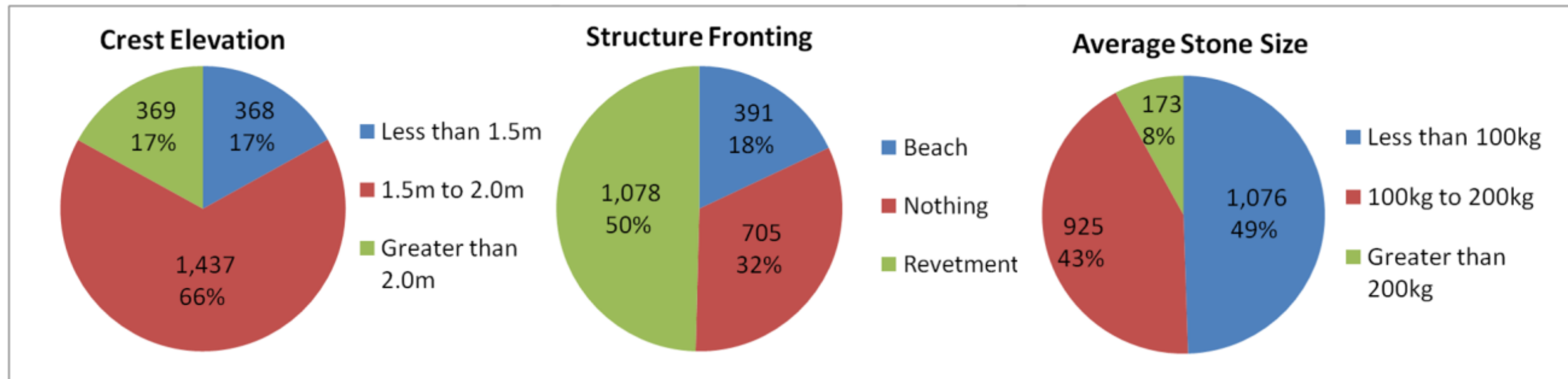
Regatta Point

Originally built 1986, repaired 1993, 2003



Conditions

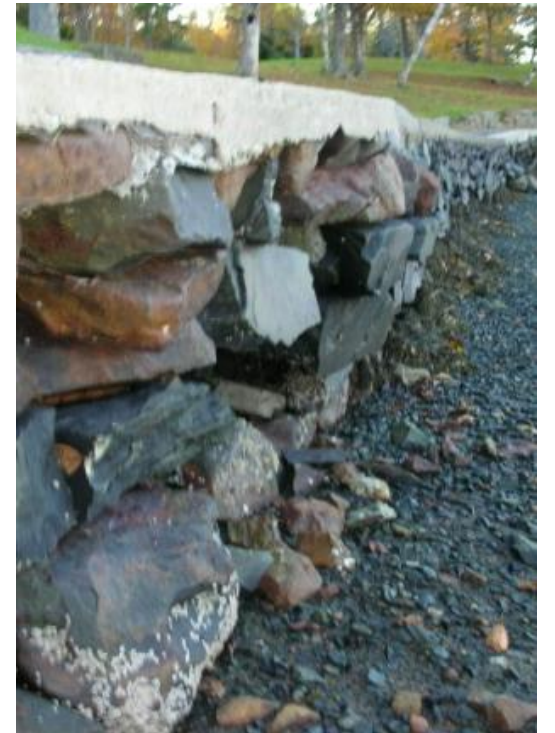
Total of 2,175m of seawall
Crest elevation and construction varies



Conditions

Failure mechanisms include:

- Wave overtopping, flooding, path erosion
- Stone wall damage
- Berm damage
- Geotechnical instability



Design process

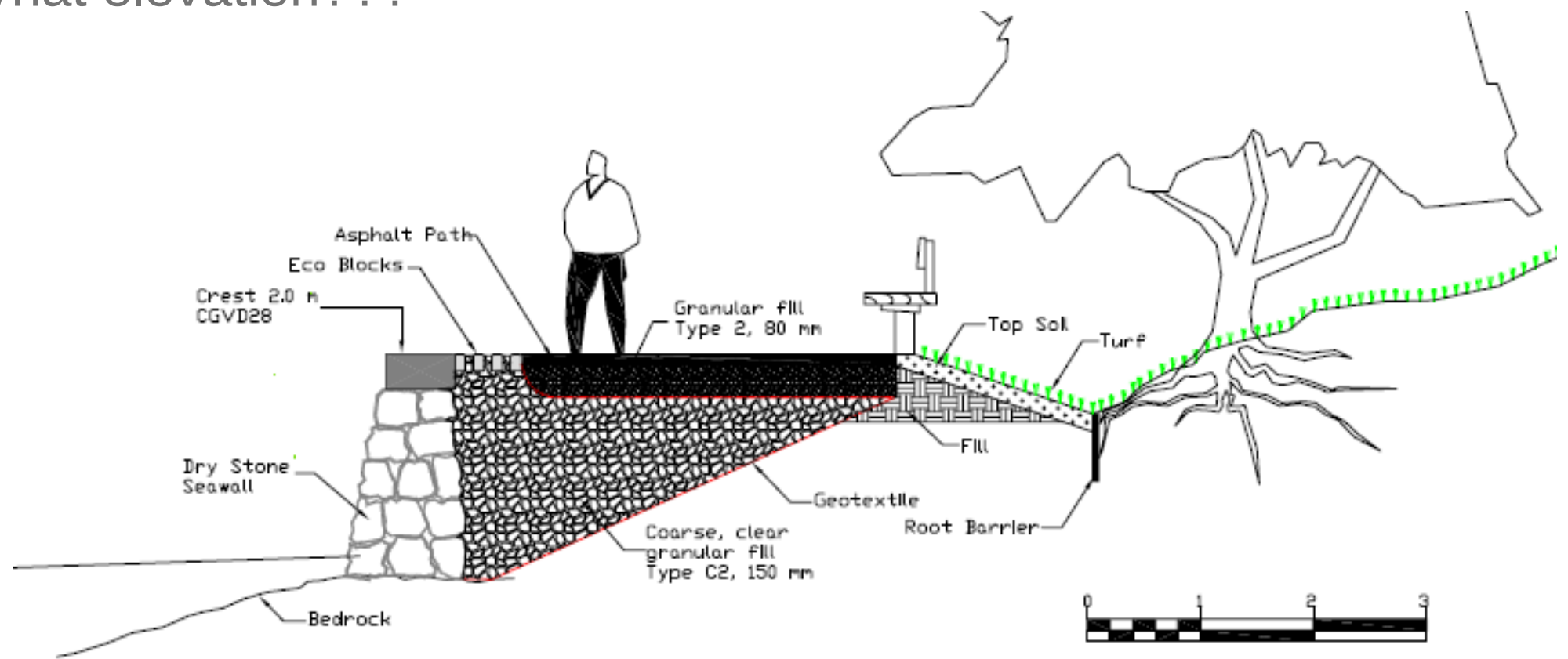
Design needs to address elevation and geometry with respect to flooding (wave overtopping and inundation).

Needs to address structural stability under storm attack

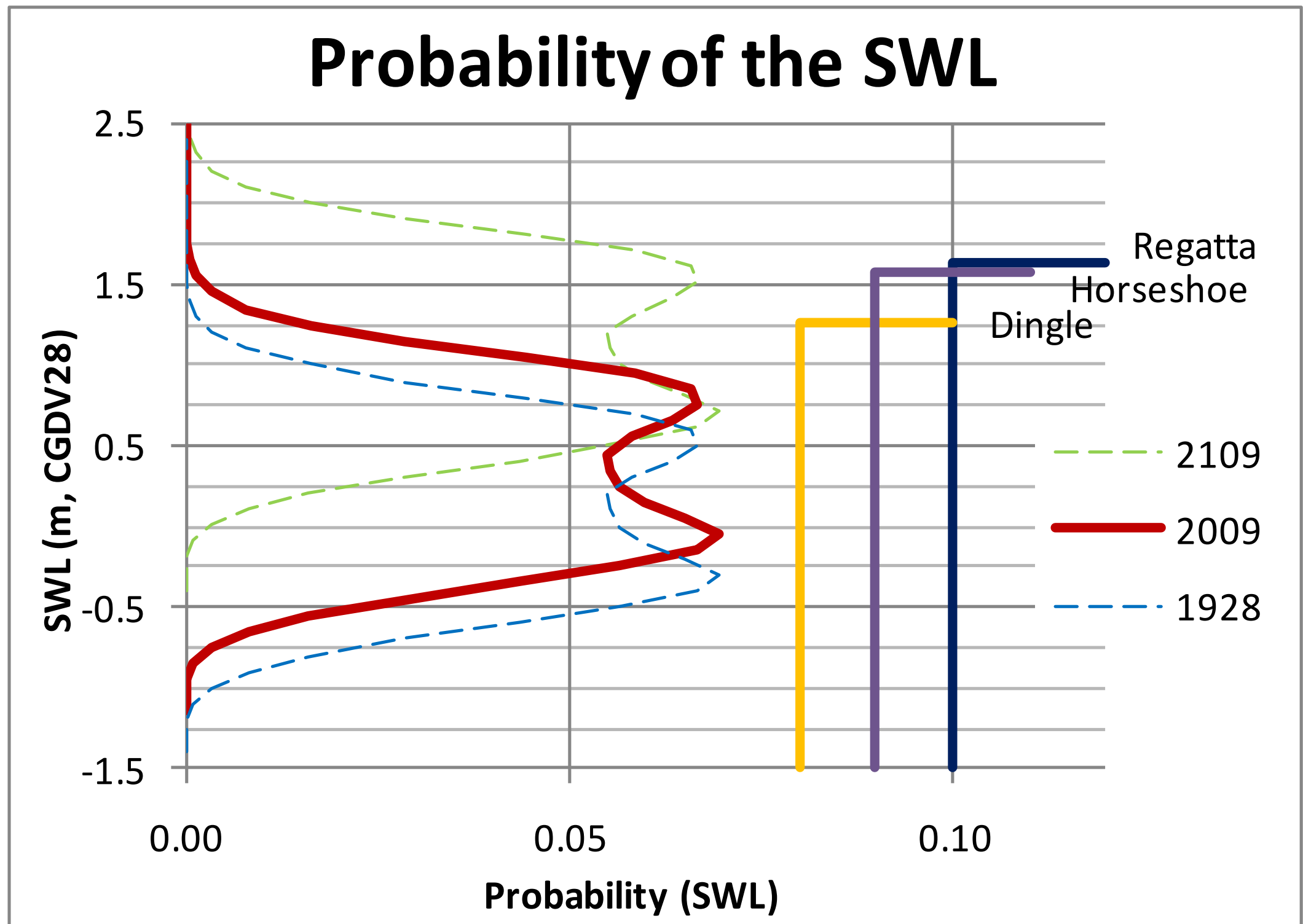
Needs to be geotechnically stable

Needs to preserve aesthetic while providing functional performance

Key question: What elevation???



Water levels



Overtopping

Eurotop – UK MAST program to develop comprehensive predictors of wave overtopping

Event predictor – allowable q for a given event (water level, waves)

Need risk-based approach – life-cycle costing under conditions of increasing sea levels

Need to know waves, water levels and structure characteristics



IPCC-based sea level rise scenarios (Forbes et al 2009)

Scenario	Rate (m/century)	Description
0	0	No sea level rise
1	0.32	No acceleration of sea level rise, rate continues at observed historic rate for Halifax (0.157 crustal subsidence plus 0.163 sea level rise)
2	0.73	IPCC AR4 upper-limit projection of SLR for the A1F1 emission scenario (0.157 crustal subsidence plus 0.57 sea level rise)
3	1.46	Upper limit estimate of SLR from Rahmstorf (2007) (0.157 crustal subsidence plus 1.30 sea level rise)

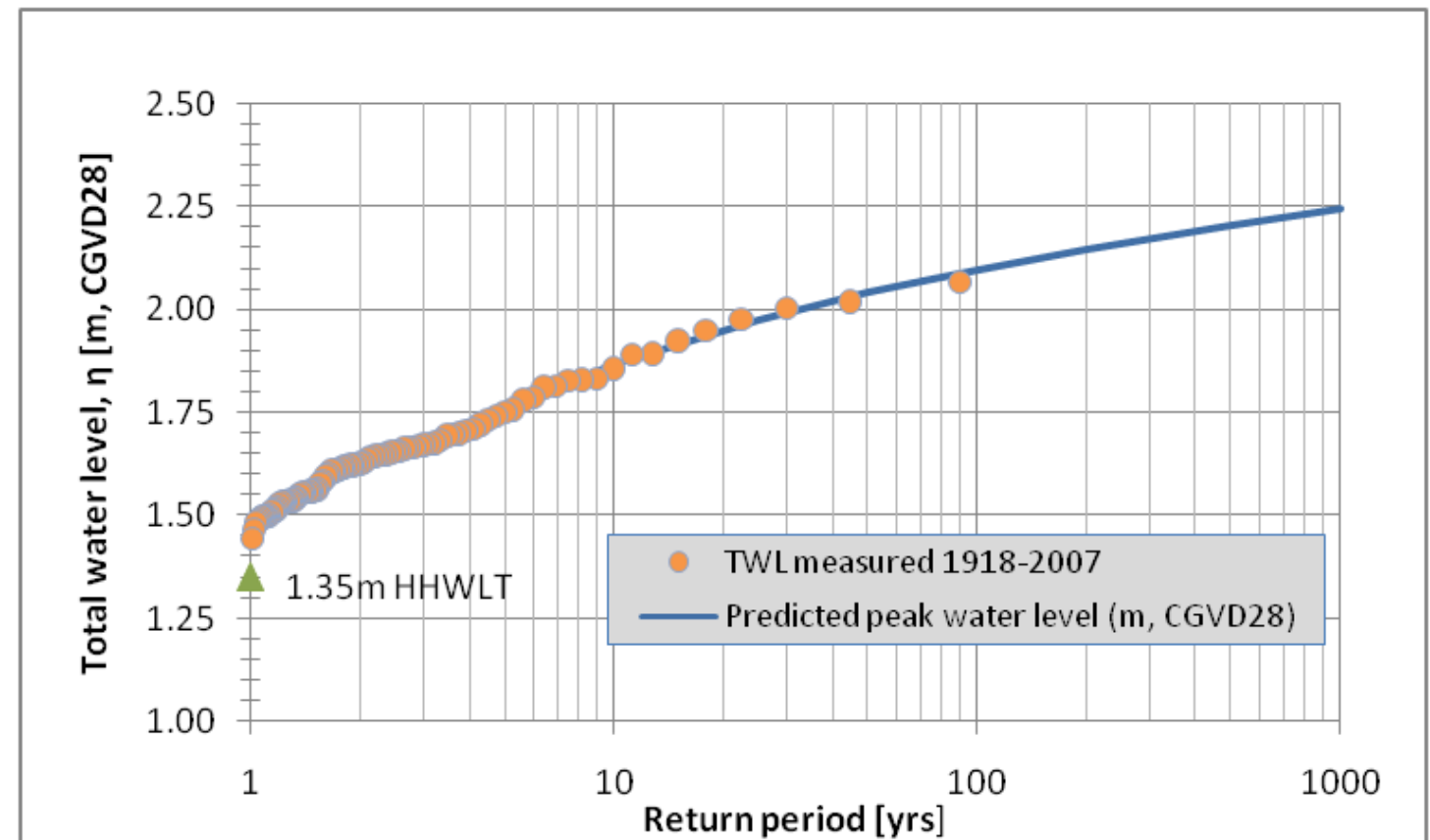


Storm water levels

Present Day Epoch (2000-08)
Water levels (m)

CGVD28	Chart Datum
500yr Return Period TWL 2.20	2.99
100yr Return Period TWL 2.10	2.88
10yr Return Period TWL 1.87	2.65
1yr Return Period TWL 1.5	2.29
HHWLT 1.35	2.14
High water spring tides (typ) 1.1	1.9
High water neap tides (typ) 0.8	1.6
Mean Sea Level (present day) 0.25	1.037
CGVD28 datum (MSL 1928) 0.0	0.788
Low water neap tides (typ) -0.4	0.4
Low water spring tides (typ) -0.7	0.1
Chart Datum (LLWLT) -0.788	0.0

Hurricane Juan
29 Sept 2003
+2.07 CGVD28, 2.86 CD

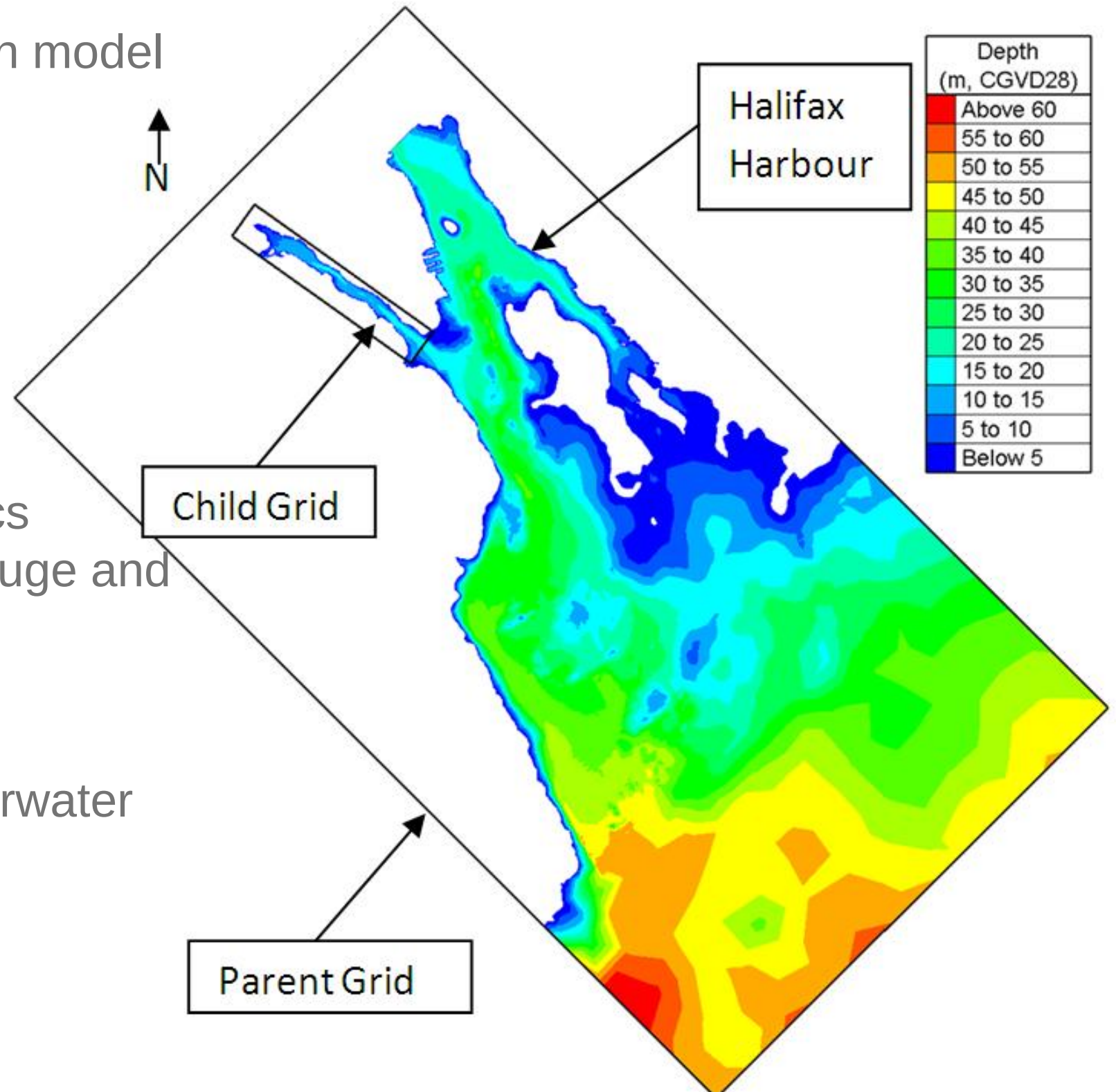


Wave climate

Spectral wave transformation model
(SWAN)

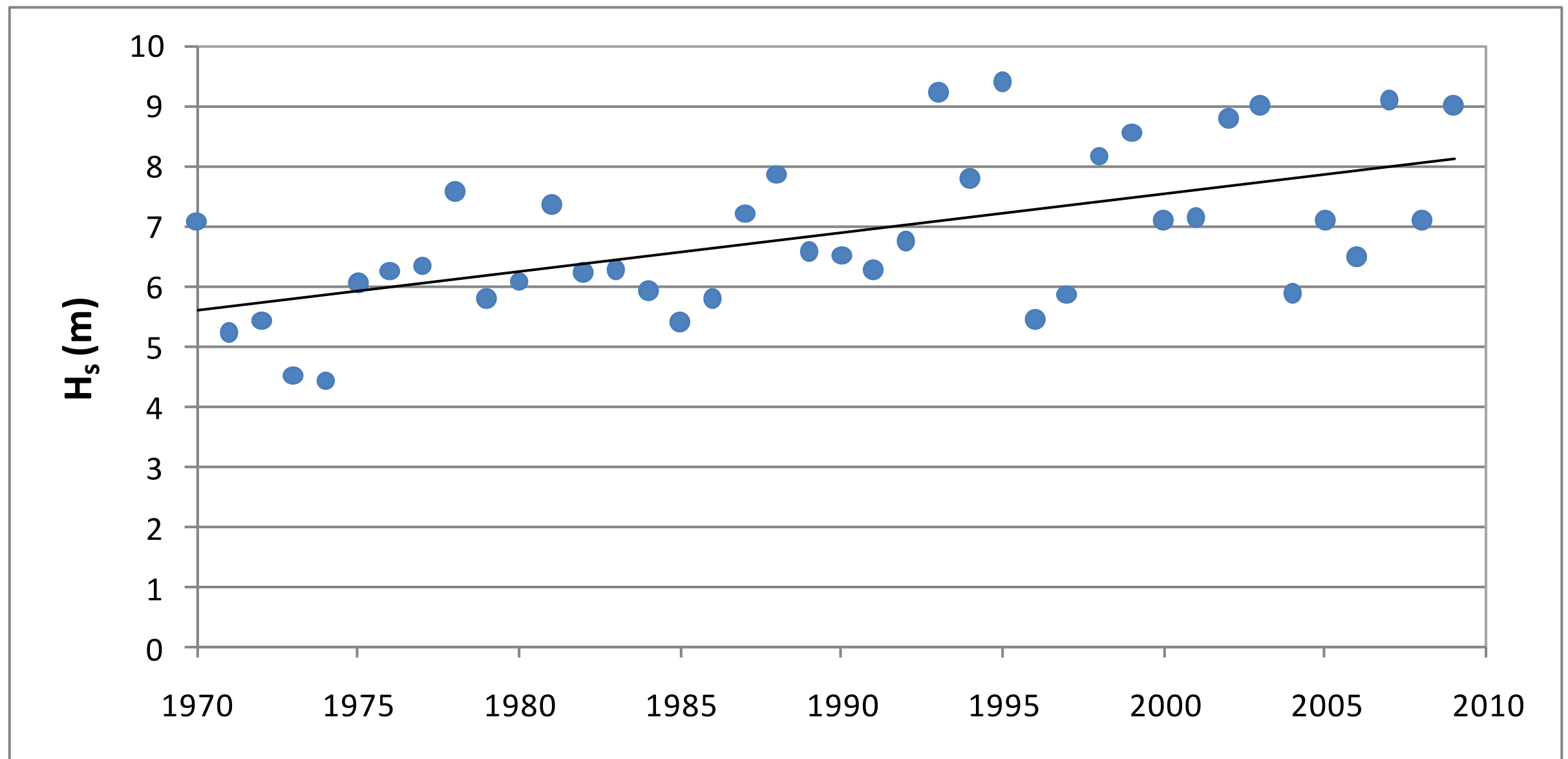
Using offshore wave statistics
based on Halifax wave gauge and
MSC50 hindcast

Local winds used based on
measurements from Shearwater
and McNabs Island



Increasing storminess?

Annual maxima from field measurements of offshore waves (combined MEDS037-C44258 dataset)



CIAPS

Coastal Infrastructure Planning System

Computes likelihood of failure of a structure over time

Uses probabilistic descriptions of waves and water levels under scenarios of changing sea levels

Joint-probability of waves and water levels (multivariate extreme value distributions)

Incorporates the risk associated with all events that may cause damage, not just prescribed design events.

Allows cost optimization based on a combination of capital and maintenance (repair) costs



The Statistics of the Problem

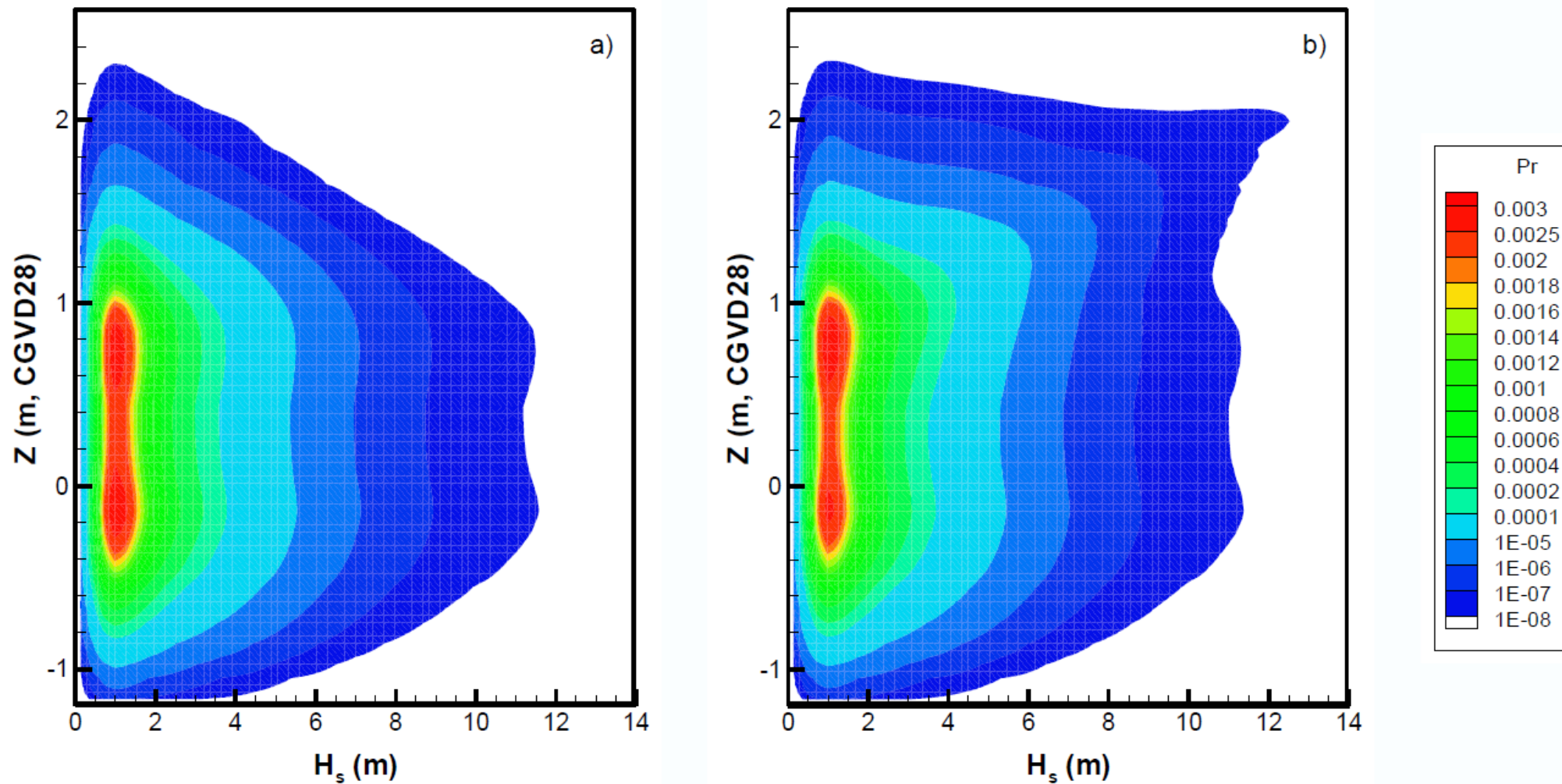
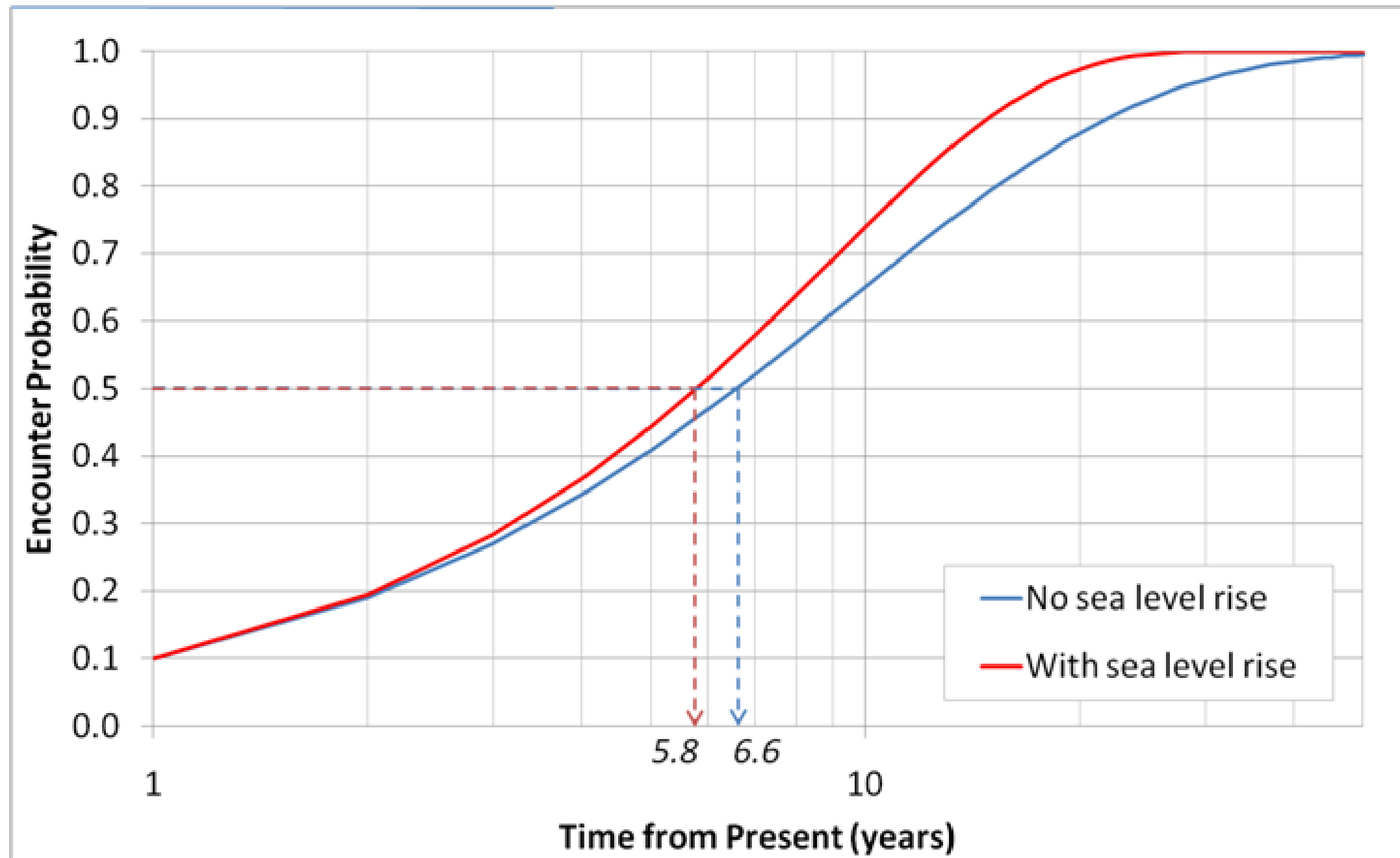


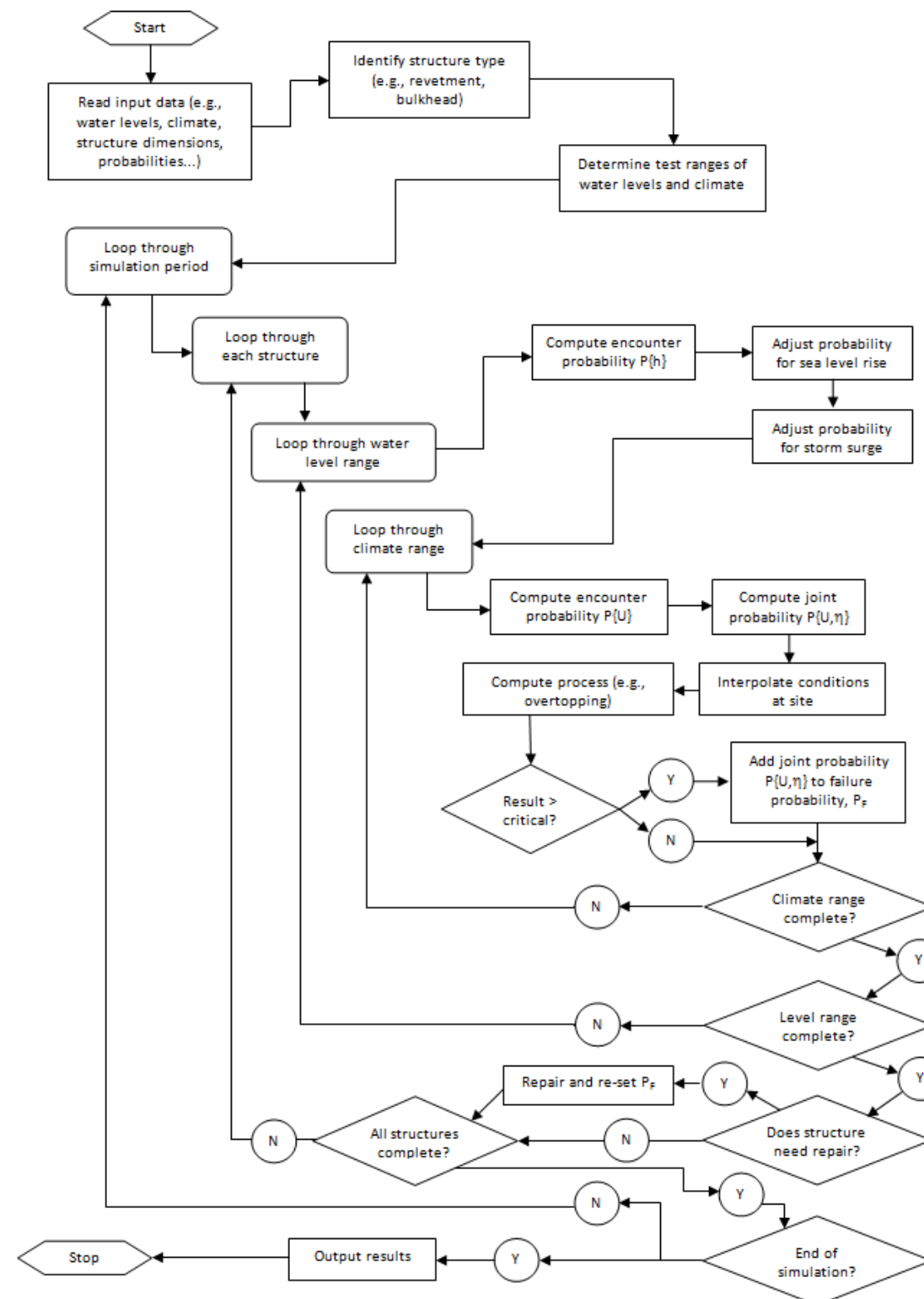
Figure 13 Joint probability distribution of wave and water levels: a) assuming independence; b) with dependence (as used in CIAPS)



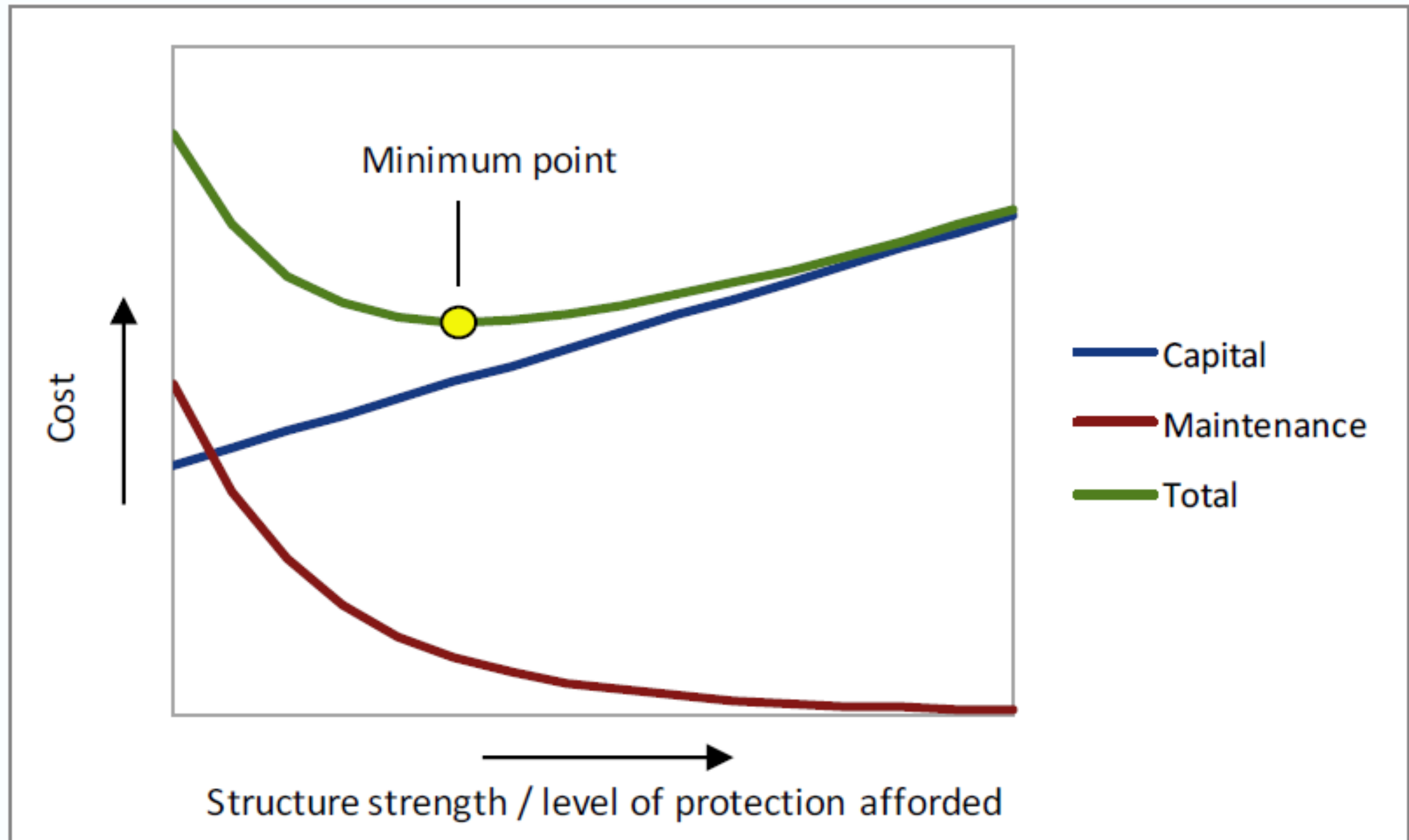
Effects of rising sea levels



It's a bit complicated...

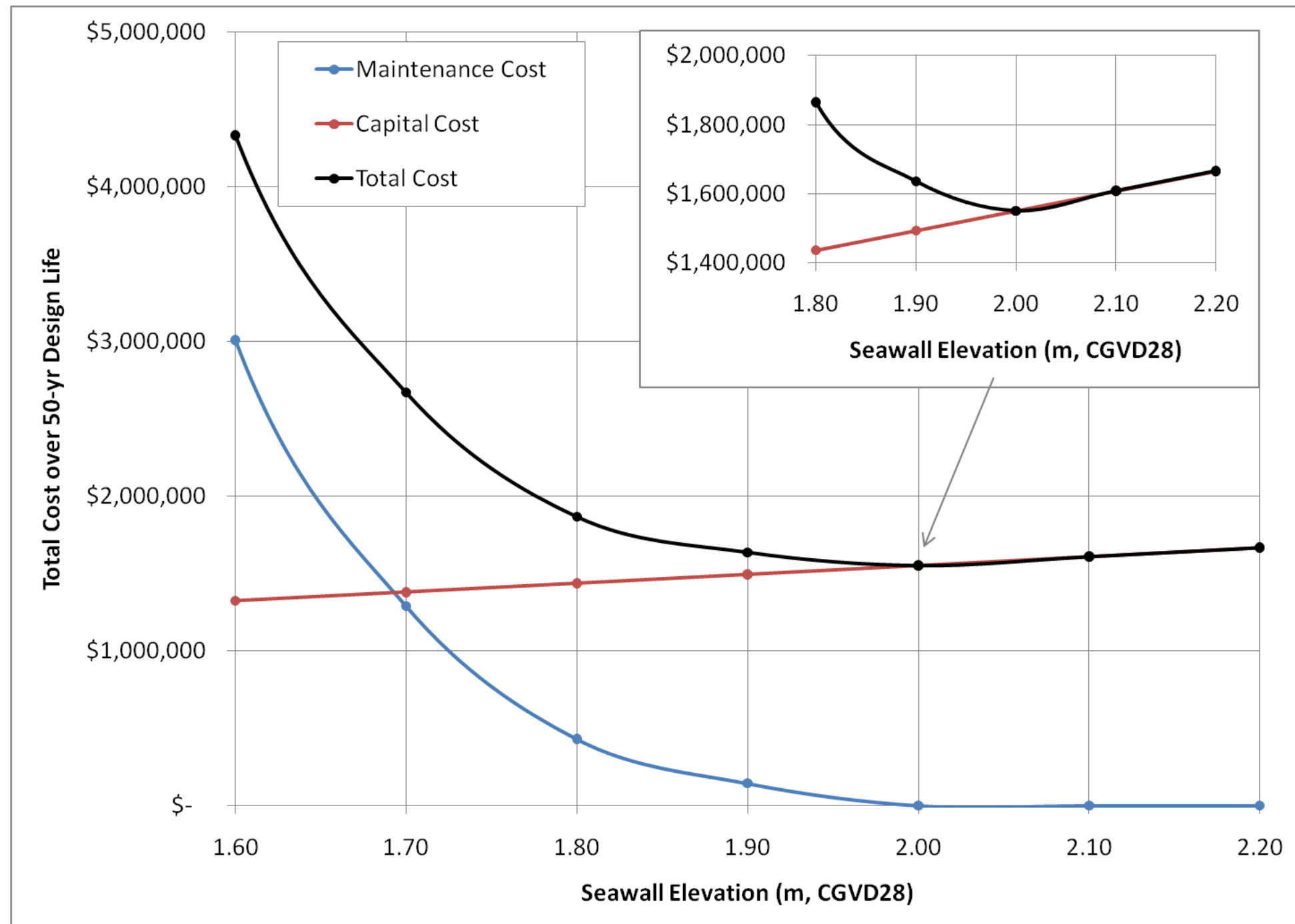


Cost optimization

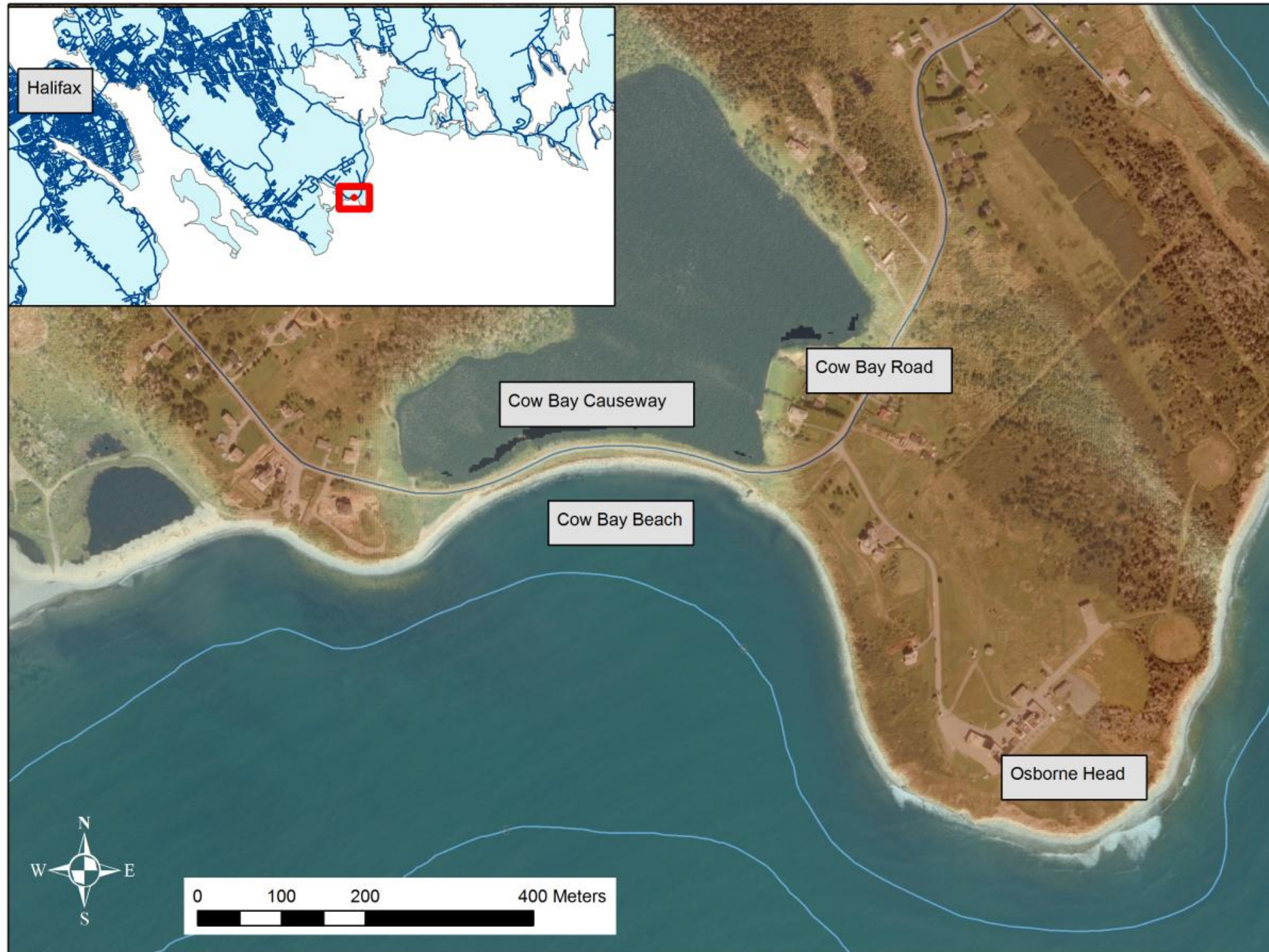


Optimization of crest elevation

e.g. dry stone seawalls with asphalt path for Site 3 under SLR scenario 2



Cow Bay Causeway



Typical winter swell



Cow Bay



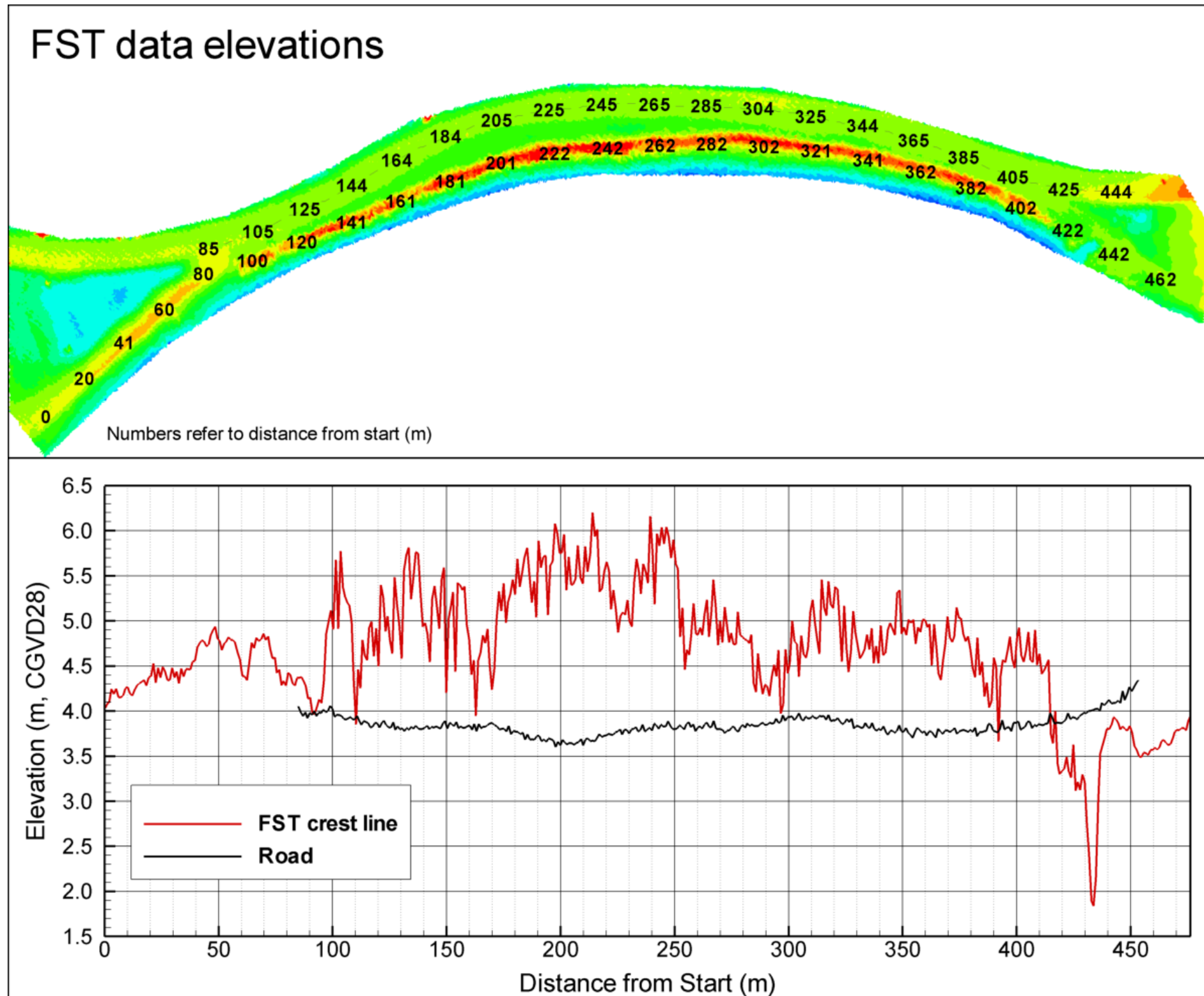
Figure 1 Armour layer of Cow Bay causeway revetment



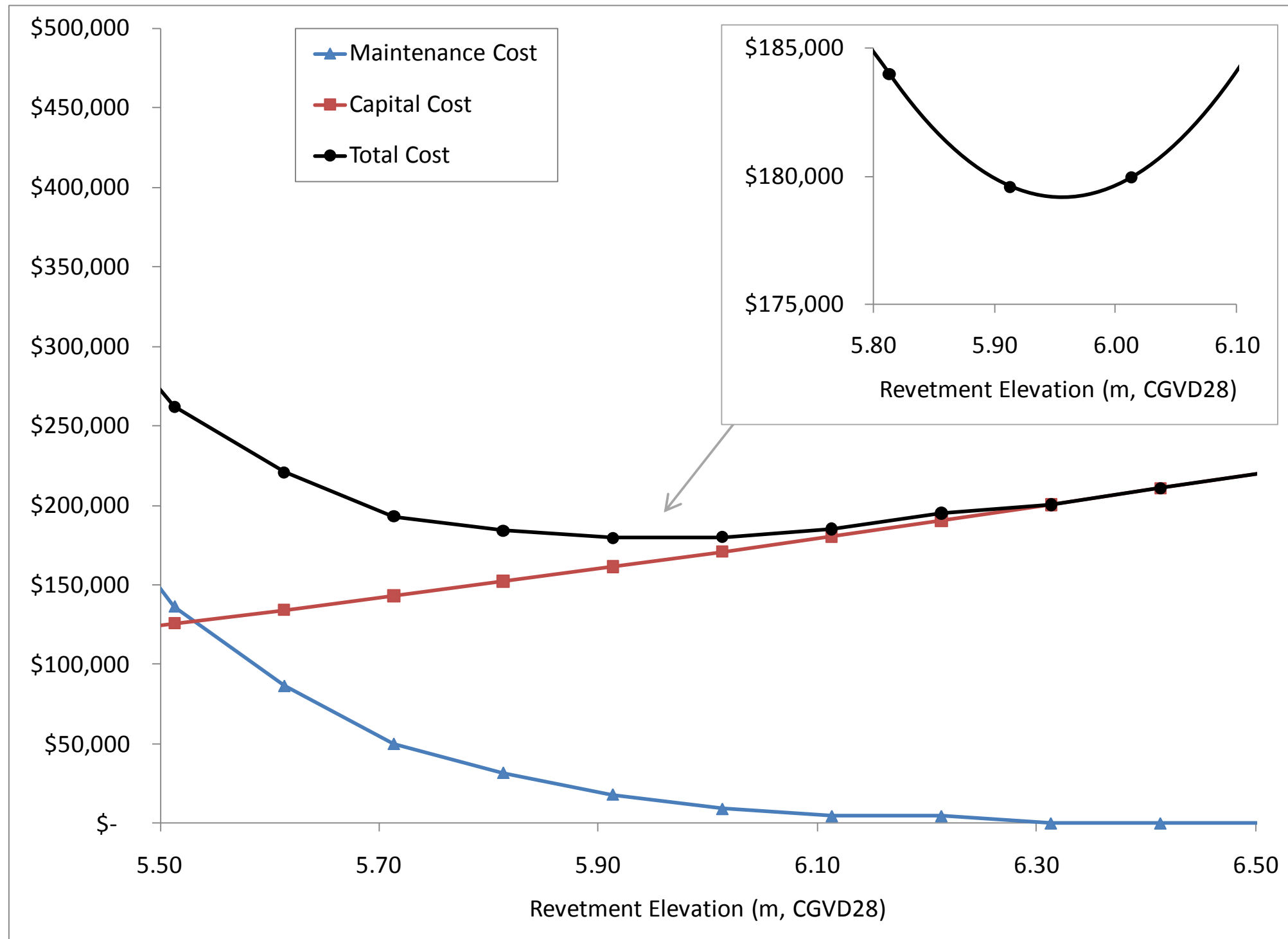
Figure 2 Seaweed on landward side of Cow Bay causeway revetment



Lidar data



Optimization



Conclusions

Joint extreme value analysis is messy but necessary

Risk analysis and life-cycle cost design preferable to 'a design storm'

CIAPS (temporally evolving joint probability extreme value statistical analysis techniques) applied successfully at Northwest Arm, Cow Bay and Salt Marsh Trail

Northwest Arm's seawalls (using dry stone wall masonry) can be re-built but need to be aware of the engineering design principles

Cow Bay causeway design has been accepted for construction

