Fast high-resolution 1D-2D compound flood model for urban coastal adaptation planning and design

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4TH INTERNATIONAL WORKSHOP ON WAVES, STORM SURGES, AND COASTAL HAZARDS
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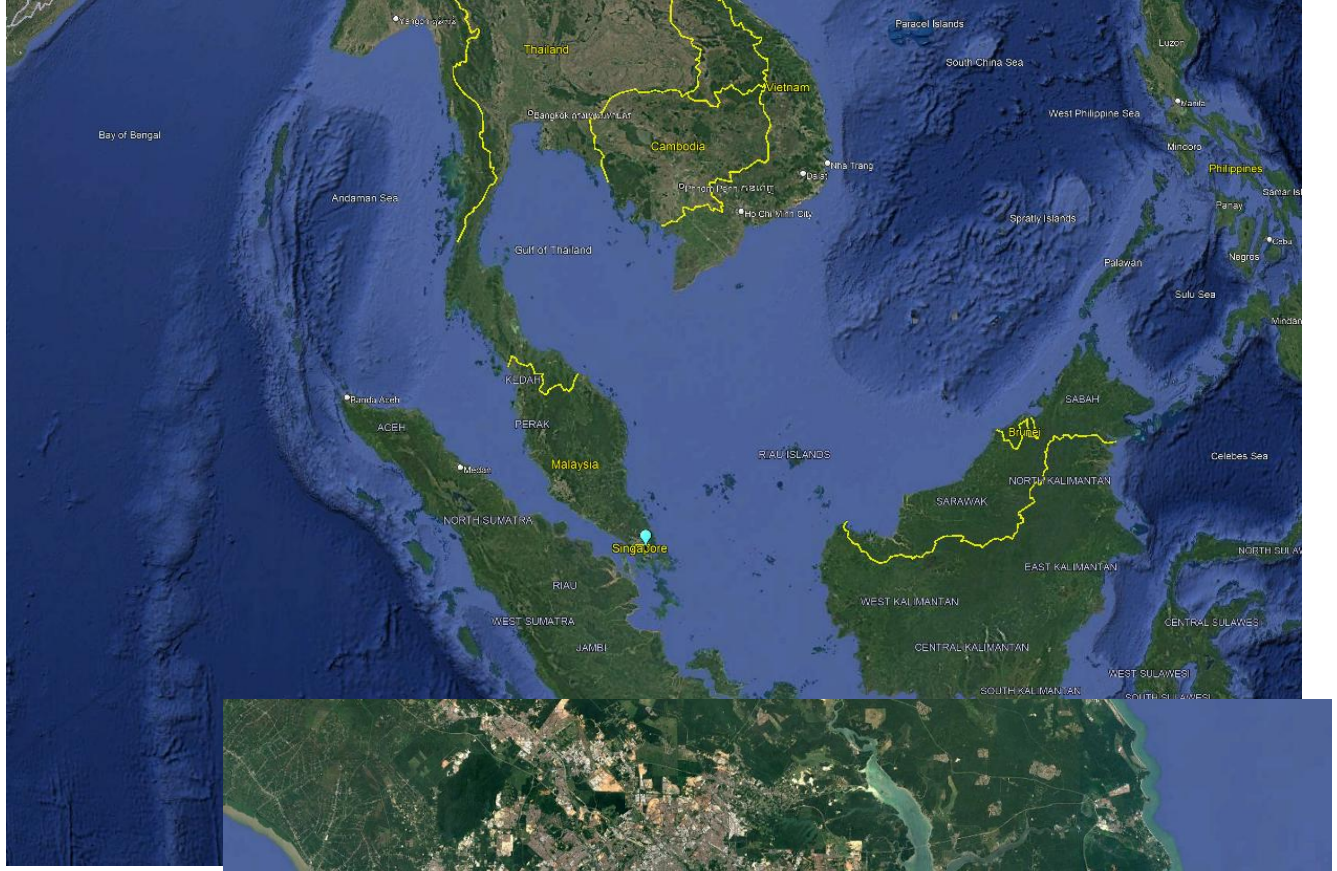
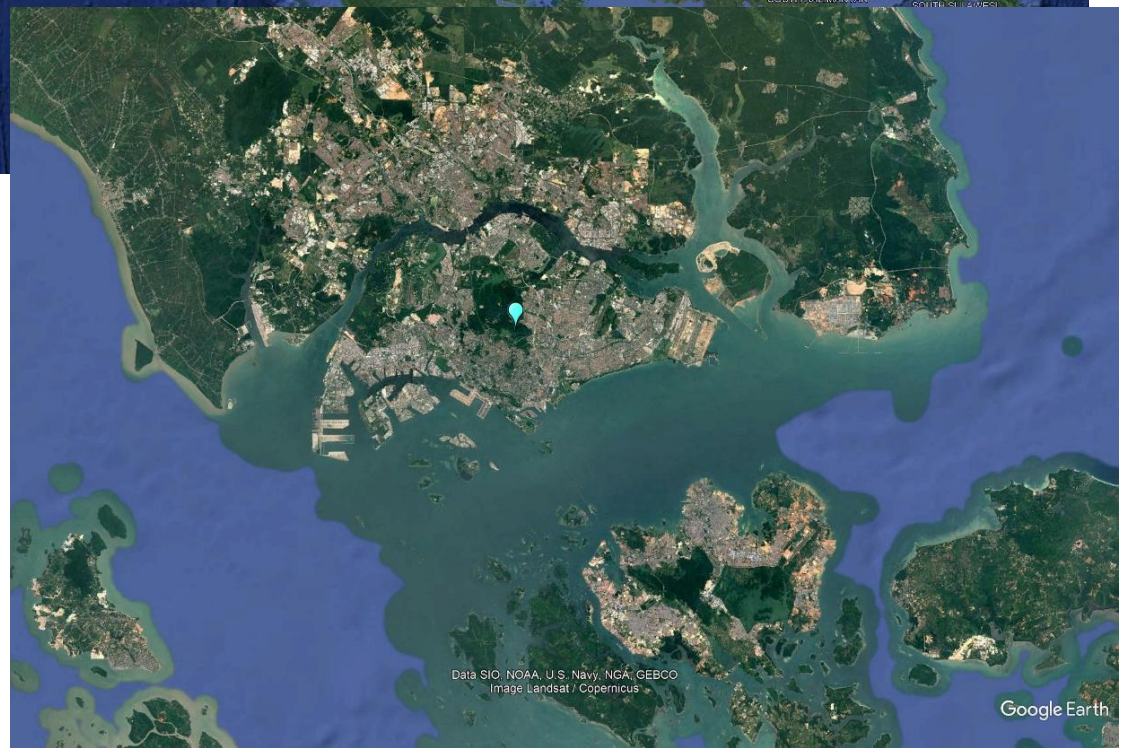
Singapore’s climate

- Mixed diurnal and semi-diurnal tide (tidal range 1.2- 3.8m)
- Seasonal monsoon (NE and SW)
- Minimal wave of about Hs 0.3m, occasional 1m in the southwest coast
- High rainfall: >3000mm annually
  - High river discharges from Johor

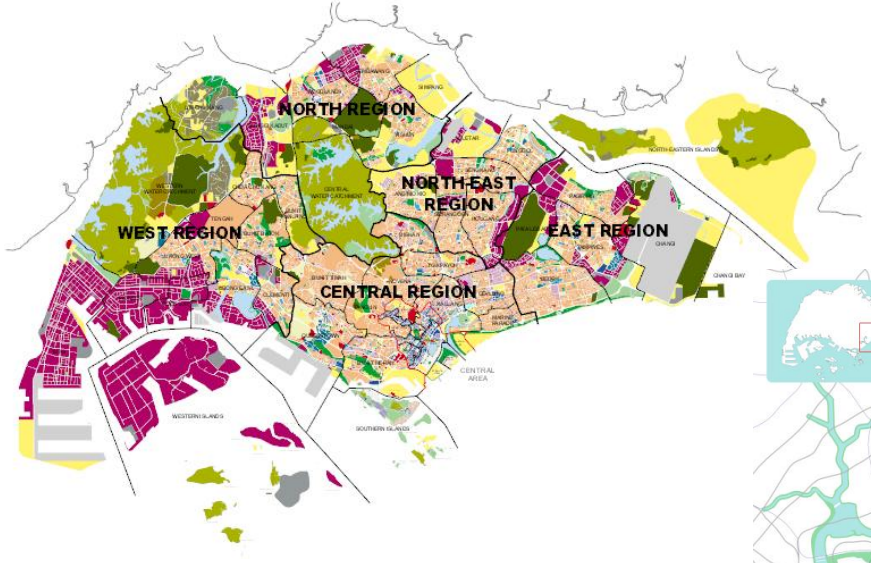




Urbanized city state island with limited land space 736km^2

Increasing land space since 1960s by expanding towards the sea through land reclamation.

Singapore government agencies need better design and planning tool that can account for existing water/coastal infrastructures and potential new designs.



Source: URA and PUB, Singapore

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Singapore• Two more spaces to be dedicated to drone flying |A12

The Big Story• Resale of small condo units a tougher proposition |A3

World• An army of AI agents is fuelling Chinese companies |A6

THE STRAITS TIMES

800ha plot reclaimed off Tekong in Singapore's first polder project

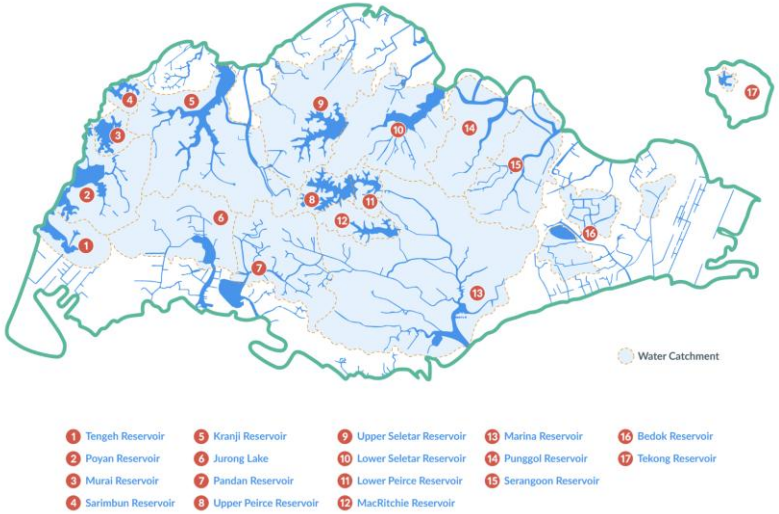
How Singapore's first reclaimed tropical polder land works

The completion of the Pulau Tekong polder paves the way for Singapore to study how the land reclamation method can work for the Republic.

STORM WATER COLLECTION POND
CENTRAL PUMPING STATION
PULAU TEKONG
DRAINAGE NETWORK
DRAINAGE PUMPING STATION
POLDER METHOD v TRADITIONAL METHOD
INFILL METHOD
POLDER DEVELOPMENT
DYKE
WATER MANAGEMENT SYSTEM
CONTROL CENTRE
SEA
LAND
SAND
CROSS SECTION OF COASTAL DYKE

The Requirement

Complex water management system



Source: PUB, Singapore

Singapore has

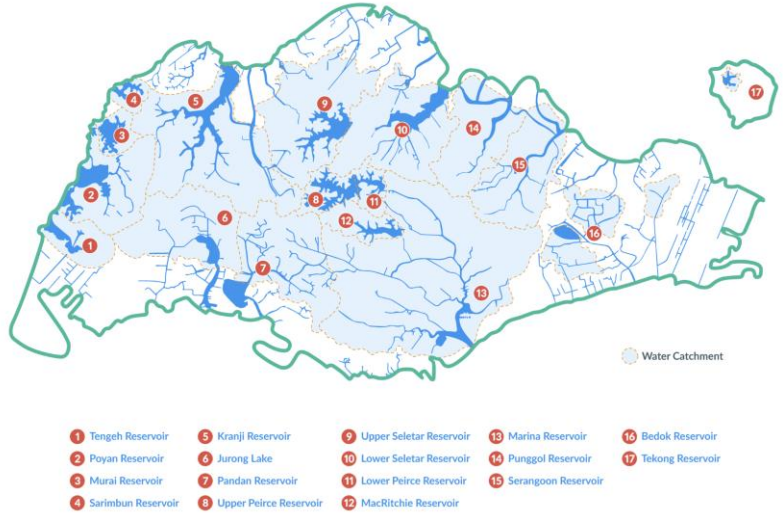
- over 8000km drains, canals, culverts and rivers within 736 sq. km
- 17 controlled reservoirs with pumps and flood gates

Small drains and sub-surface drains (culverts) are not represented in the DEM.

Therefore, 1D drains are required in the model.

The Requirement

Complex water management system



Source: PUB, Singapore

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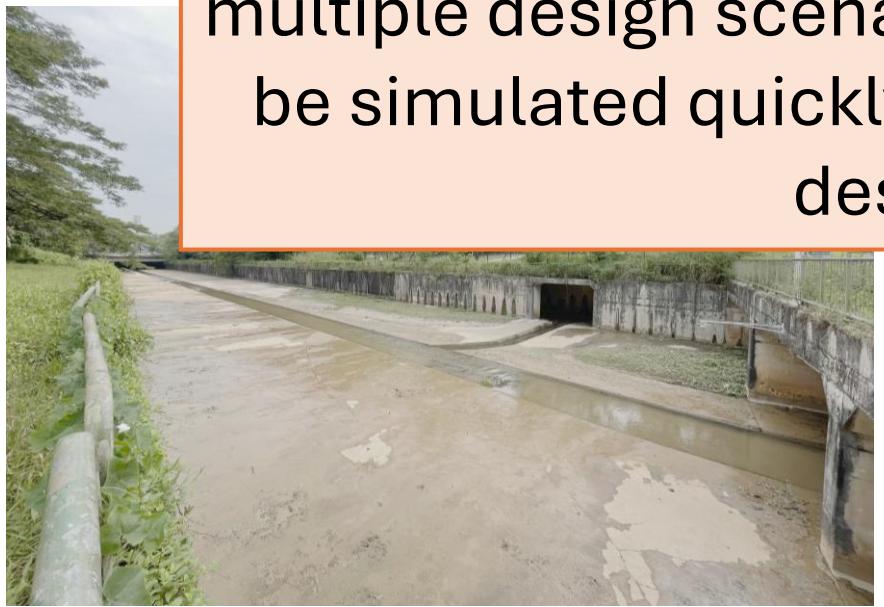
Objective

To have a fast 1D-2D compound flood model that enables multiple design scenarios under various climate conditions to be simulated quickly so that an optimal coastal adaptation design can be evaluated.



and drains not in

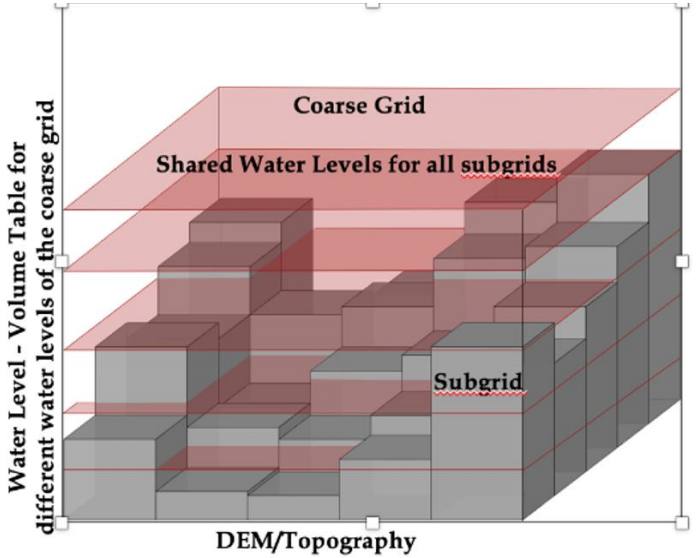
Therefore, 1D drains are required in the model.

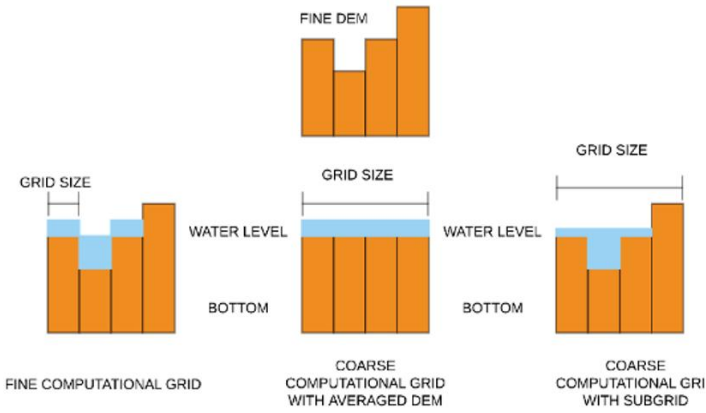
The Challenges

- Data is large; DEM of high-resolution (1m x 1m)
- Design space is large
  - Multiple design scenarios – depending on the varying design parameters
  - Running at high-resolution (1m x 1m) means:
    - 12,200 x 16,000 (Case Study) = 195,000,000 computational grid cells per time step for the area of interest using classical shallow-water solvers in 2D (e.g. Delft3D)

The Solution

- 1D-2D shallow water equation solver using sub-grid method [1,2,4]
- Infiltration and 2D shallow subsurface flow [3,5]
- The sub-grid and quadtree approach compresses the computational grid cells by a factor of ~600 times (Case Study)





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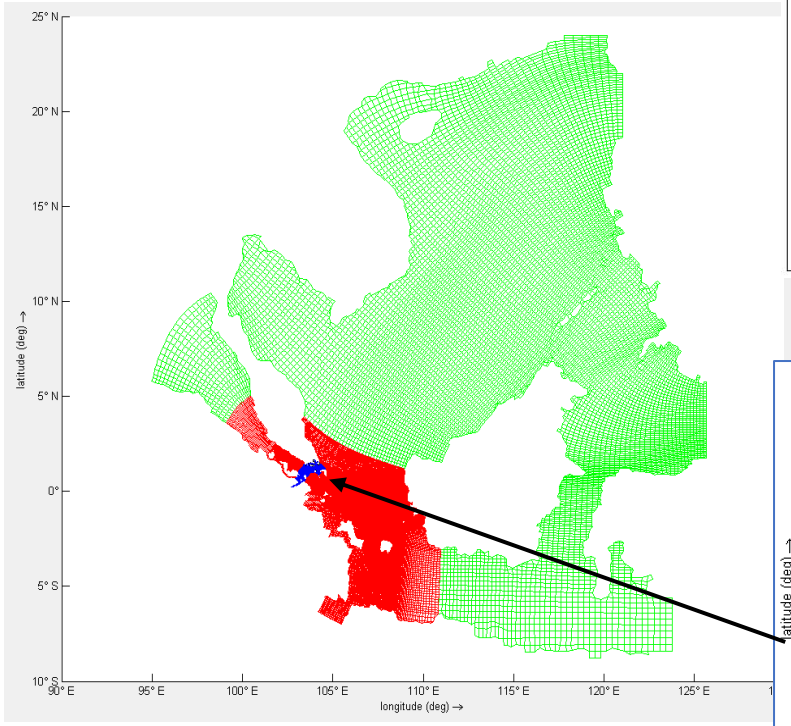
Case study: Pulau Tekong Island and polder

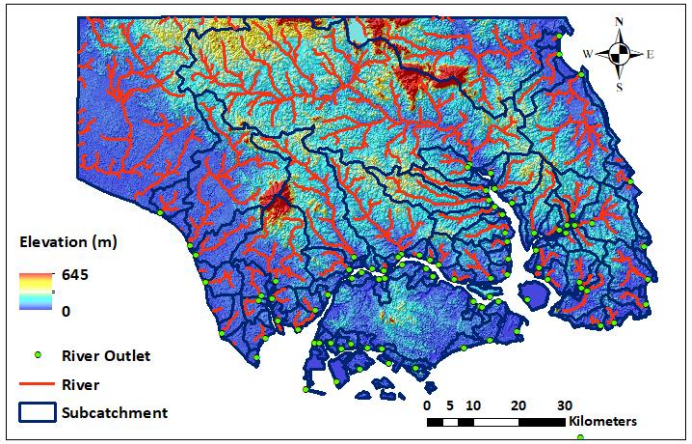
- DEM
  - Maxar and FabDEM composite at 1m x 1m
- Structures: pumps
- Drainage system traced from satellite imagery

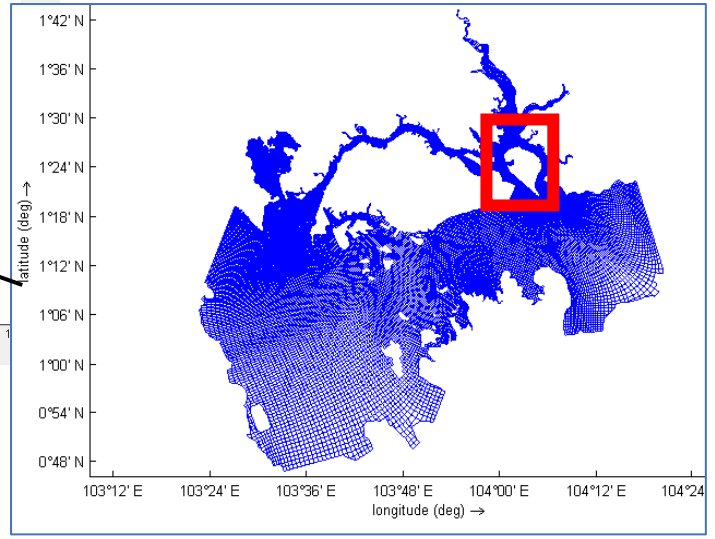
- Original Area: 24 sq. km
- Reclaimed area until now: 21.5 sq. km
- Area of interest: 8.2 sq. km

Model forcing/Boundary condition

- Surface forcing: Rainfall
- Lateral forcing is based on offline nesting within Delft3D model that is forced with:
  - Tide [1,2]
  - Wind and surface pressure field to generate surge [1,2]
  - Johor River discharges (computed using WFLOW) based on rainfall [3]







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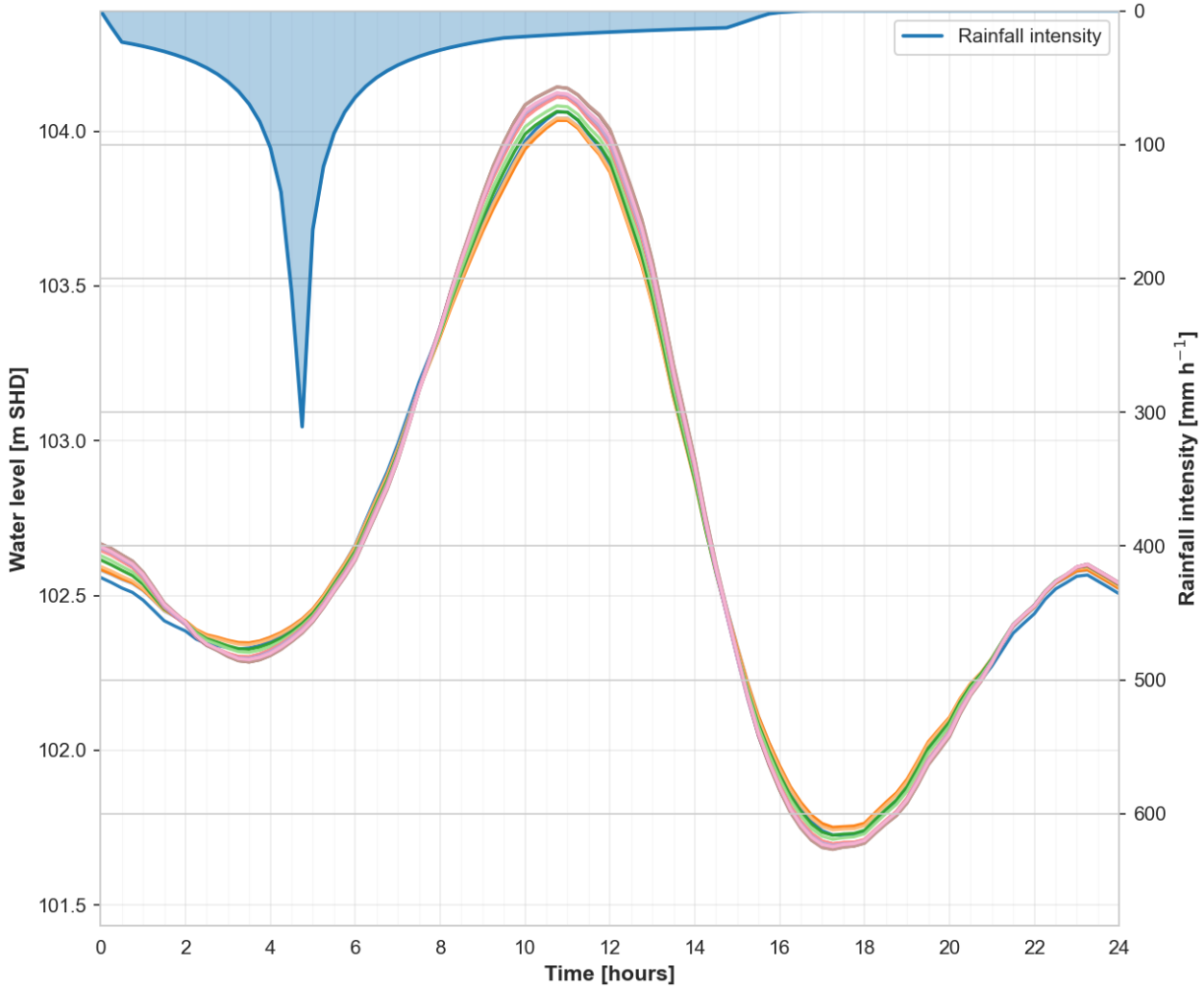
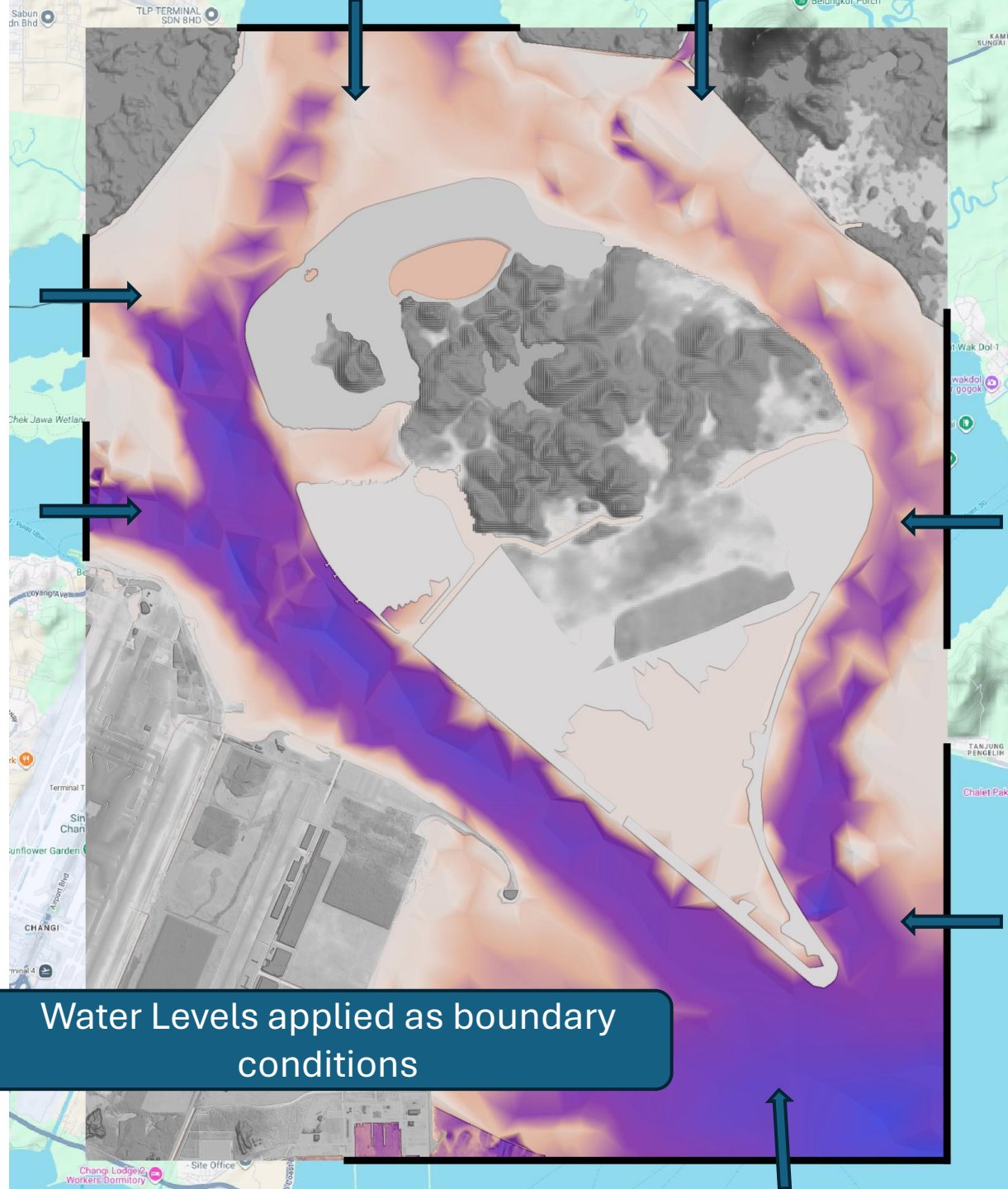
Extreme event forcing

1 in 100 year extreme scenario

Extreme Rainfall + Tide + Surge[1] + Sea Level Rise[2]





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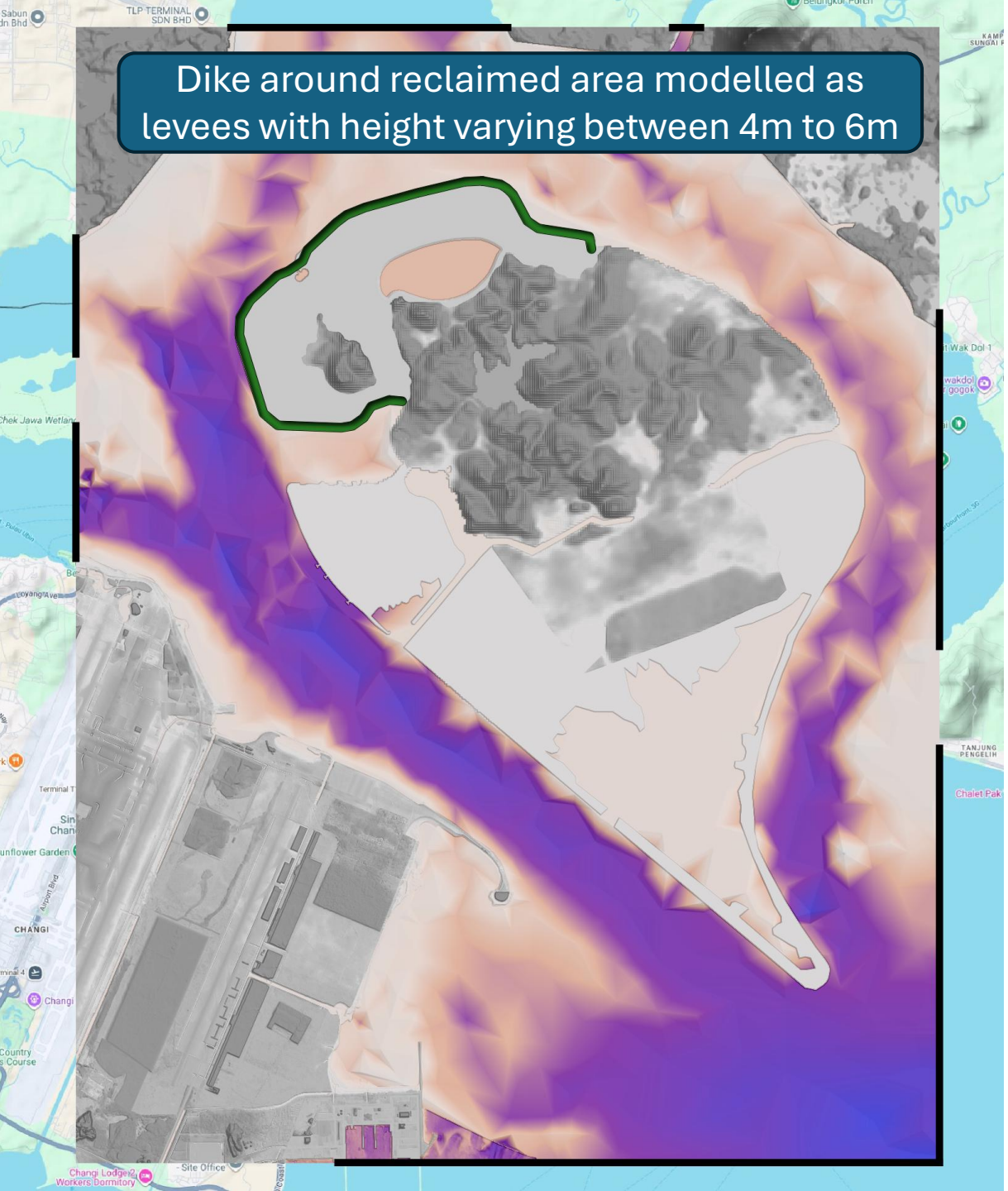
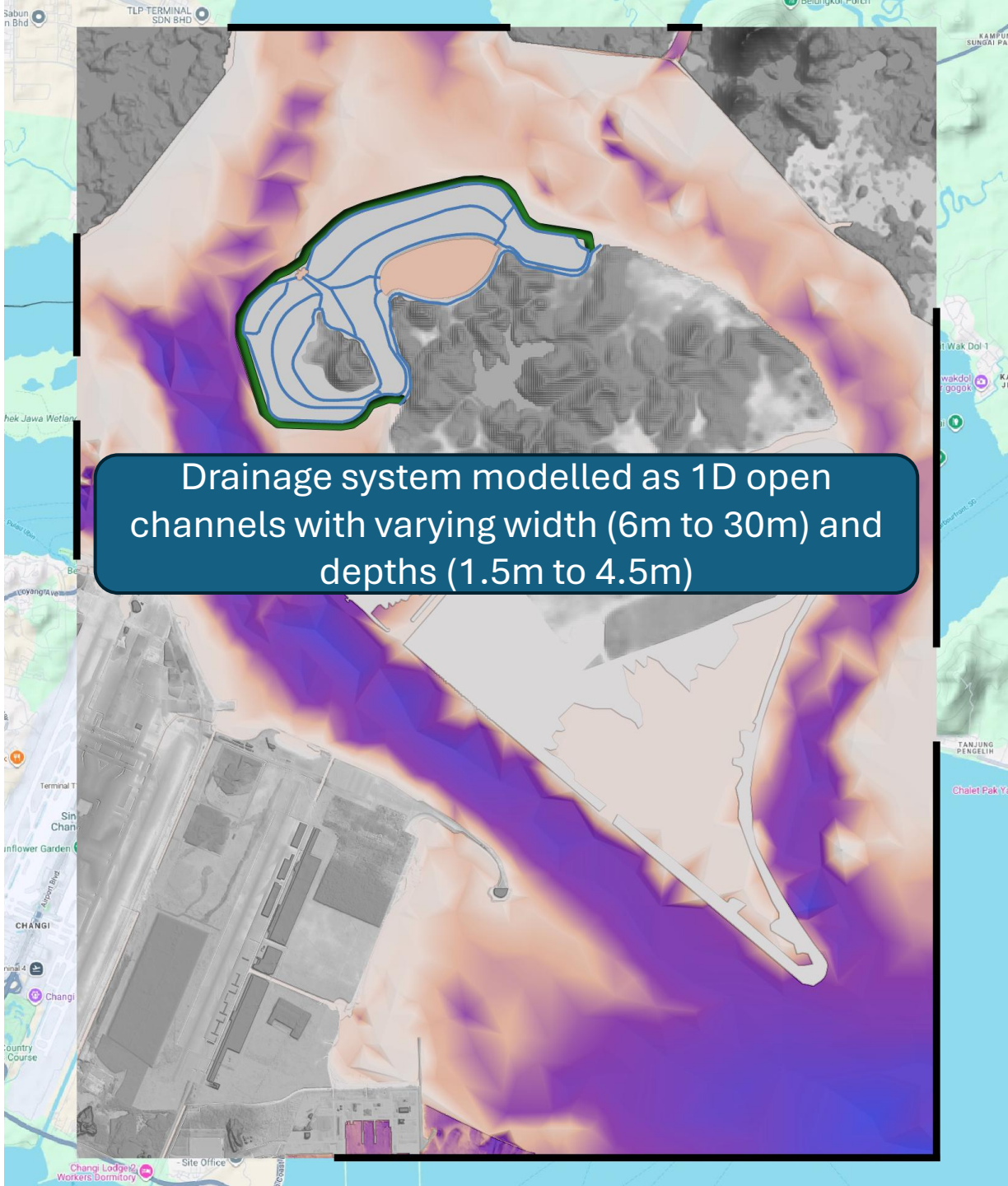
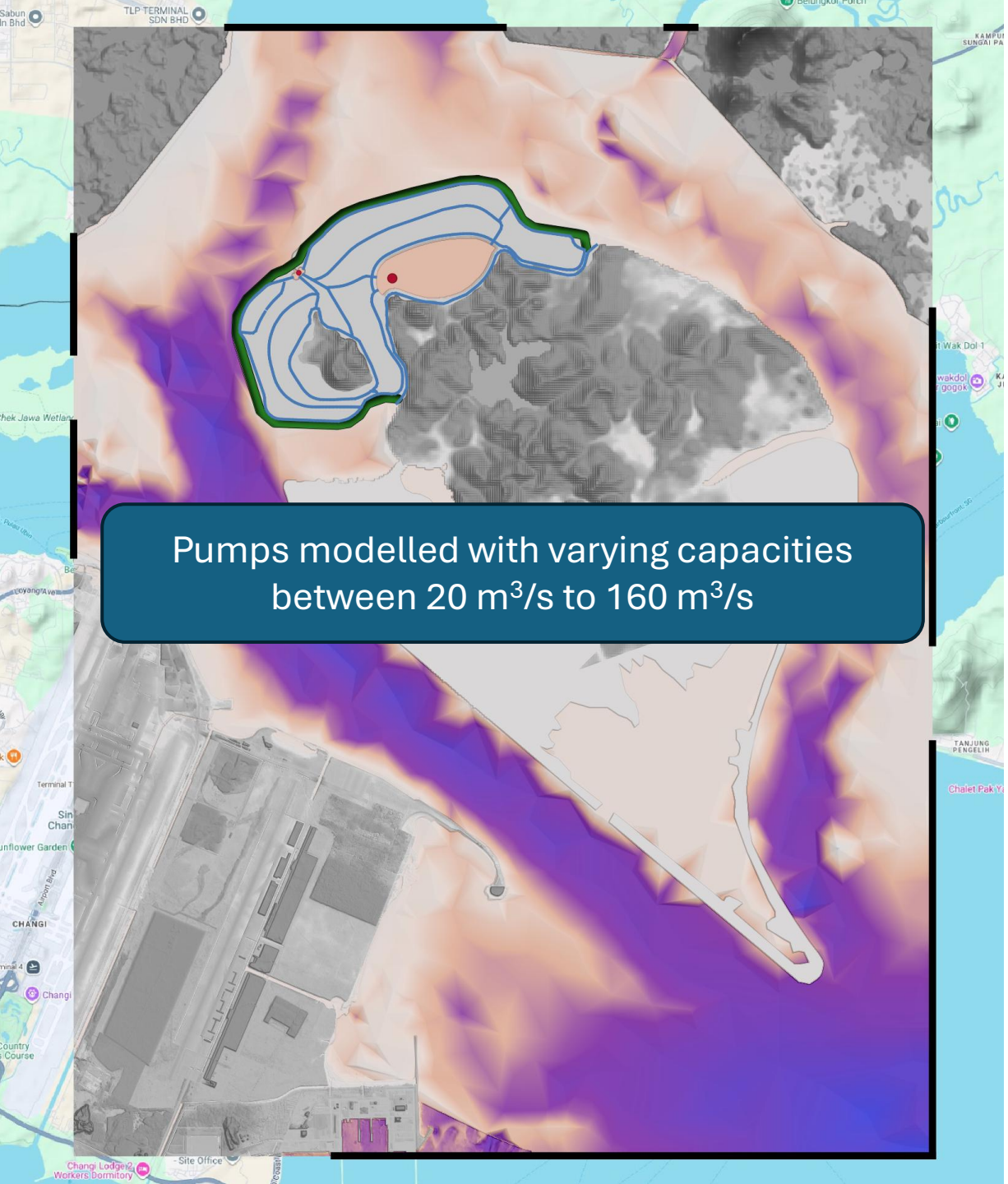

Dike around reclaimed area modelled as levees with height varying between 4m to 6m


Drainage system modelled as 1D open channels with varying width (6m to 30m) and depths (1.5m to 4.5m)



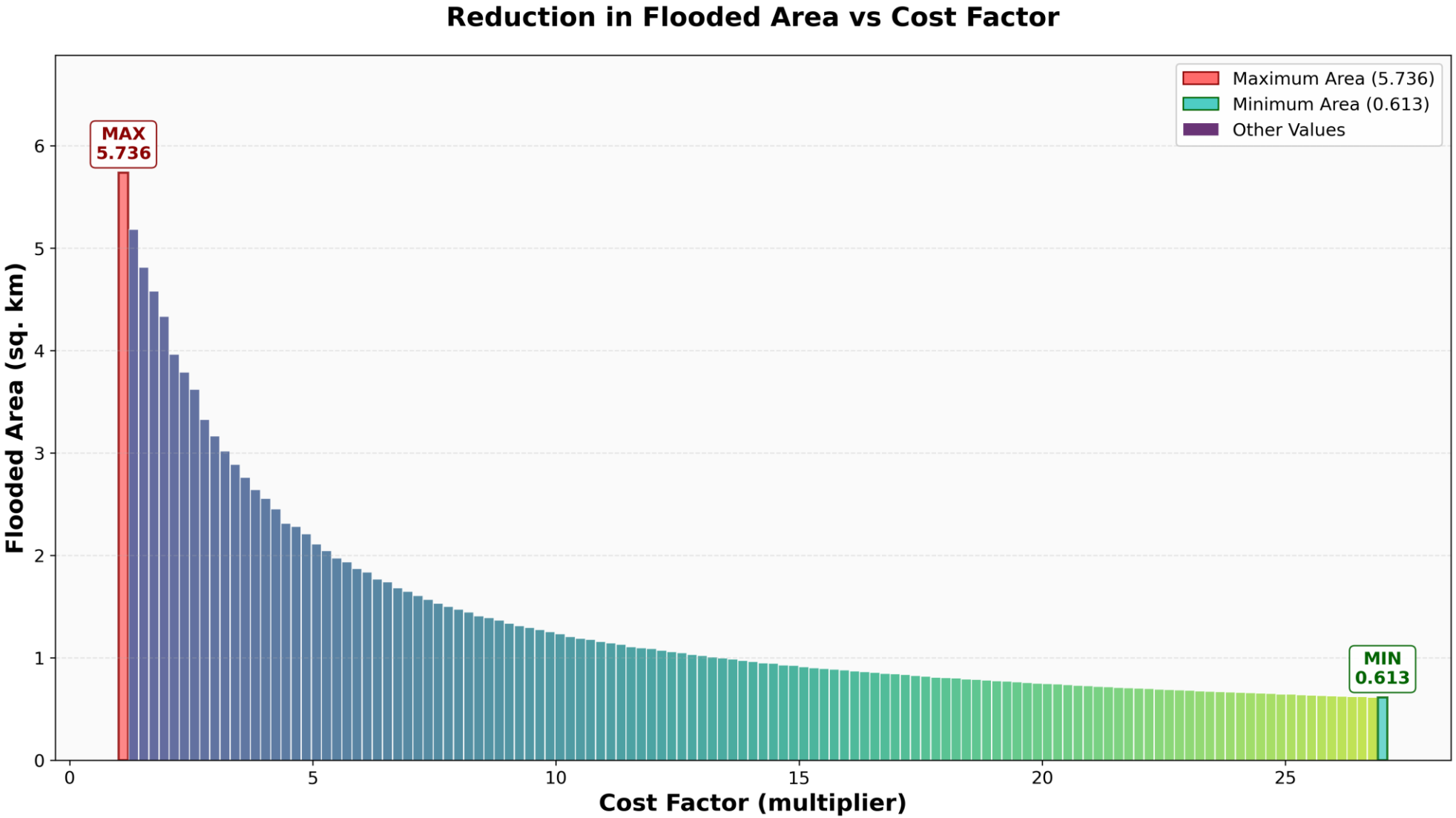
Quadtree computation grid size: 10-40m

Simulation period: 24 hours

Varying parameters of structural measures

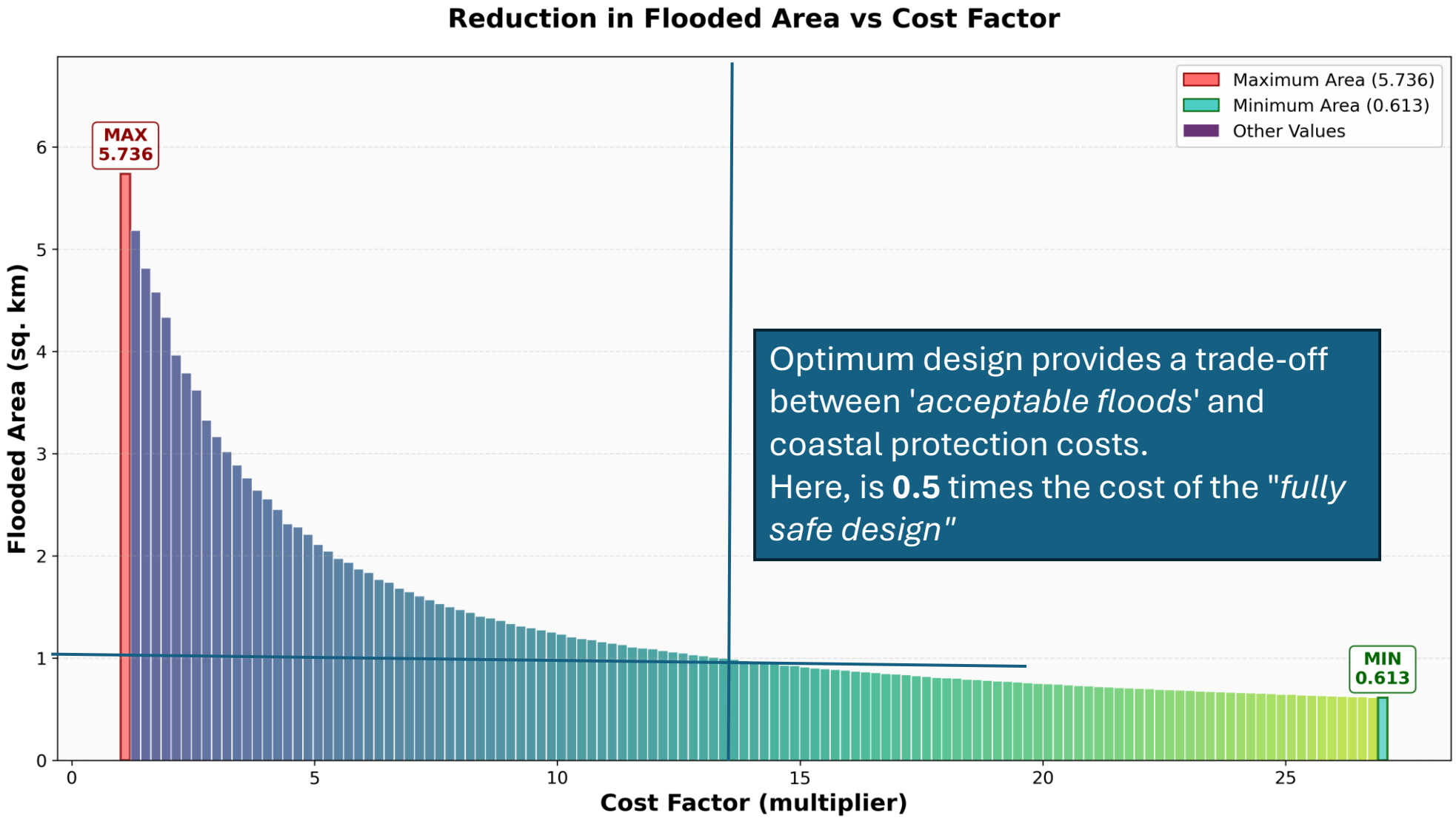
- Pump capacity
- Dike height
- Drainage capacity

Total numbers of scenarios generated: **125**



Maximum Water Depth > 30 cm in the model is considered a flooded pixel

Every scenario is given a cost factor relative to the base scenario with minimum (dike height, drainage capacity and pump capacity). Costing is based on available estimates from consultants and government



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Conclusion

- The fast 1D2D flood model presented allow us to explore all the **125 design scenarios**, which were completed **within 12 hours** (run in serial mode) on a single Desktop PC (32-cores); about **5 minute** per scenario.

- The optimal design scenario can be derived based on the acceptable flood and the coastal protection cost.

Future work

Application

- We are extending this model to the whole of Singapore (1m resolution: 61,000 by 38,000 cells). However, we are not allowed to publish.

Development

- Automation by scripts to find optimal designs
- Incorporation of short waves, e.g. SnapWave

Acknowledgement

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Thank you

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