Optimal Protective and Mitigation Strategies Against Flooding and Future Climate Risk

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Abstract

Coastal regions are continuously under the threat of flooding induced by tropical cyclones worldwide. These threats continue to increase due to the effects of climate change such as sea-level rise. A number of available protective or mitigation strategies have been examined to address this threat and protect coastlines around the world. However, identifying the most effective strategy given limited resources is a complex question. Optimization methodologies as we have proposed integrate physical analysis and stakeholder feedback to come to a set of best mitigation strategies. This study examines physical and socio-economical aspects of flooding impacts to optimize these strategies. These are then examined including seawalls, elevated promenades, and strategic retreats.

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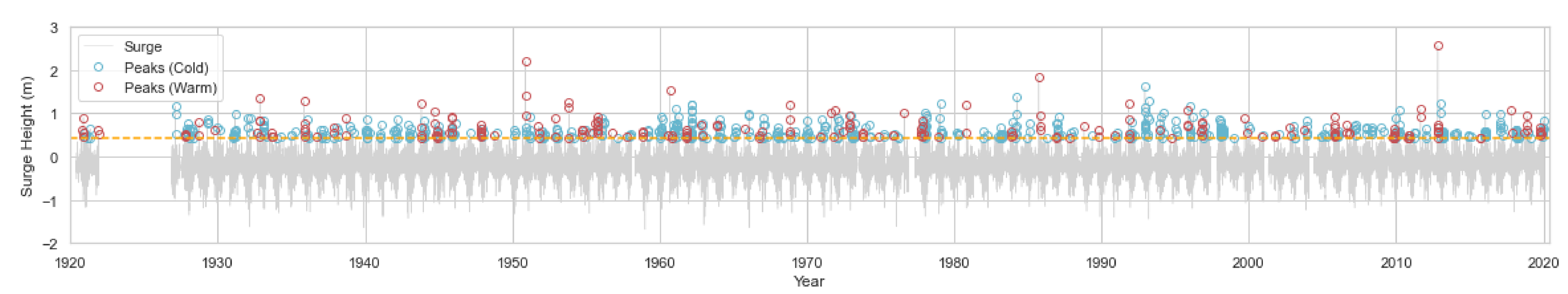
Abstract

Coastal regions are continuously under the threat of flooding induced by tropical cyclones worldwide. These threats continue to increase due to the effects of climate change such as sea-level rise. A number of available protective or mitigation strategies have been examined to address this threat and protect coastlines around the world. However, identifying the most effective strategy given limited resources is a complex question. Optimization methodologies as we have proposed integrate physical analysis and stakeholder feedback to come to a set of best mitigation strategies. This study examines physical and socio-economical aspects of flooding impacts to optimize these strategies. These are then examined including seawalls, elevated promenades, and strategic retreats.

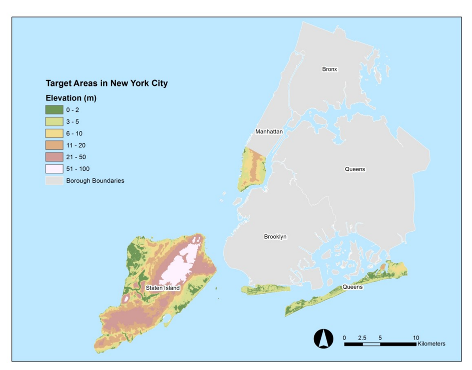
Future Storm Modeling

- Historical record of storms at the Battery, NY (1920-2020) with threshold of 0.43m
- Warm-season storms: 2.33 per year; Cold-season storms: 6.76 per year



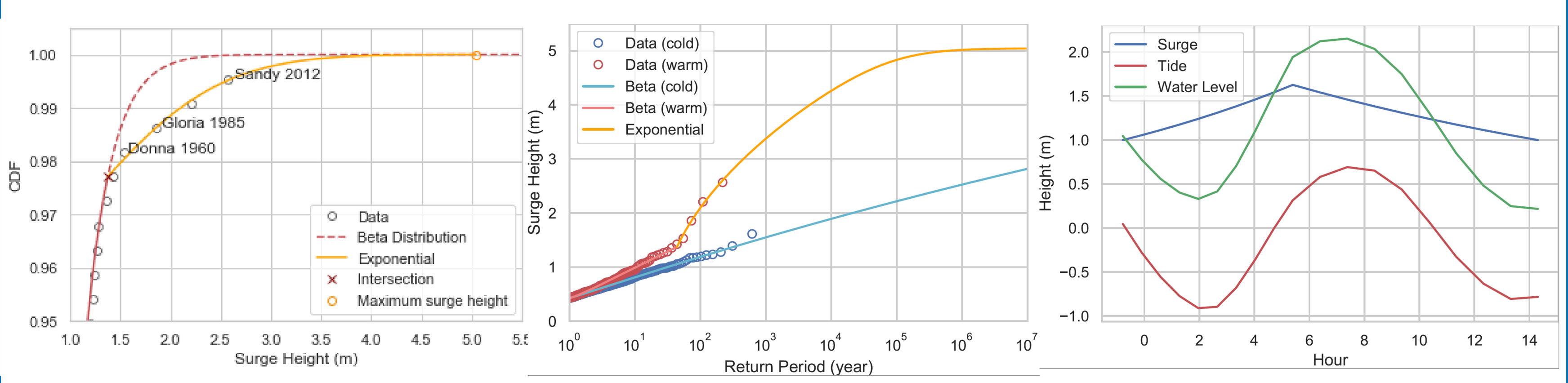
Sea-Level Rise Projections

	Low Estimate (10th Percentile)	Middle Estimate (25th to 75th Percentile)	High Estimate (90th Percentile)
2050s	0.20 m	0.28 – 0.53 m	0.76 m
2080s	0.33 m	0.46 – 0.99 m	1.47 m
2100	0.38 m	0.56 – 1.27 m	1.91 m

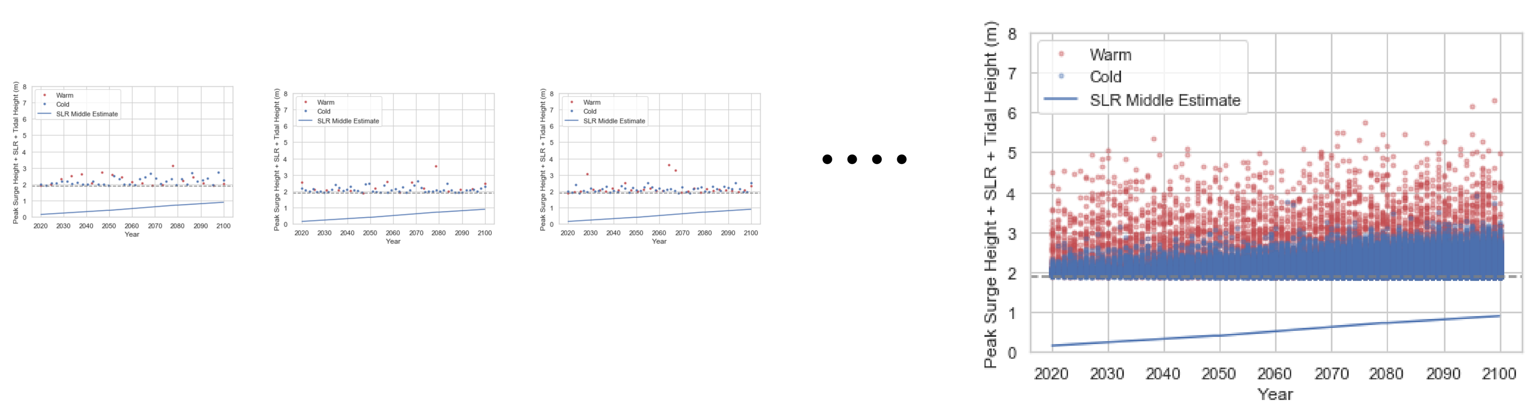


Gornitz, Vivien, et al. "Enhancing New York City's resilience to sea level rise and increased coastal flooding." Urban Climate 33 (2020): 100654.

Return Period of "modified beta distribution" at the Battery, NY, with both upper and lower bounds



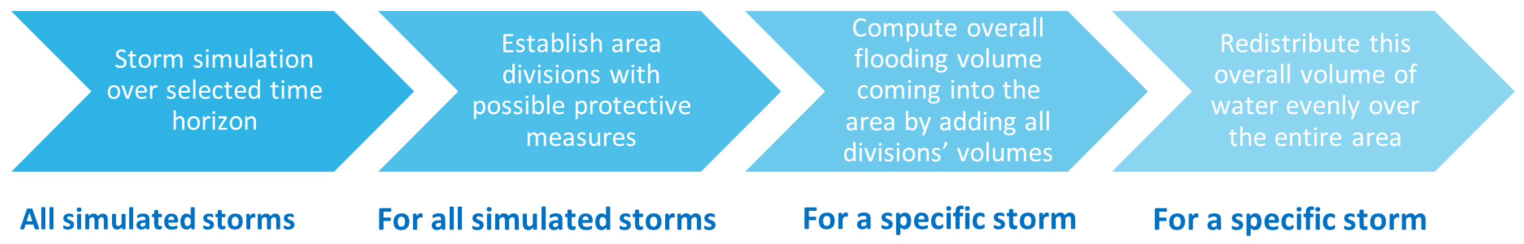
1,000 simulations of the period of 2020-2100

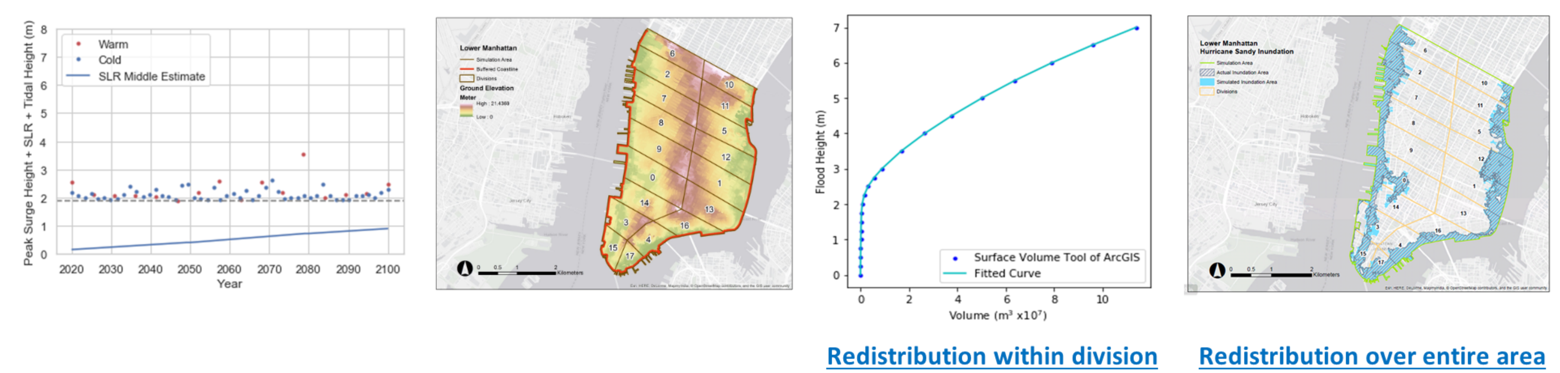


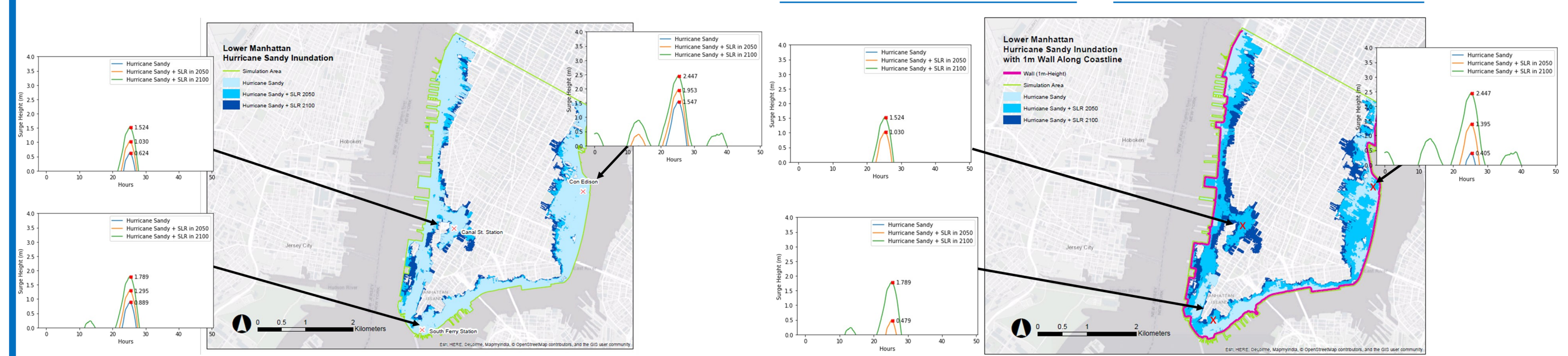
Miura, Y., Qureshi, H., Ryoo, C., Dinenis, P. C., Li, J., Mandli, K. T., ... & Morss, R. (2021). A methodological framework for determining an optimal coastal protection strategy against storm surges and sea level rise. *Natural Hazards, 107* (2), 1821-1843.

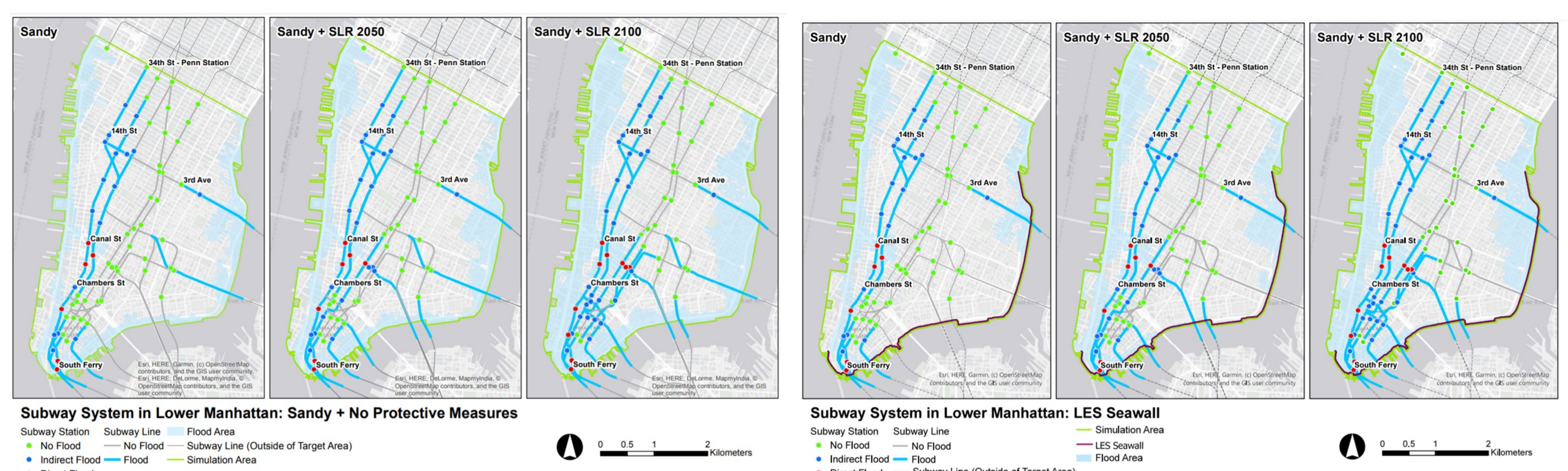
Flood Estimation Models

GISSR





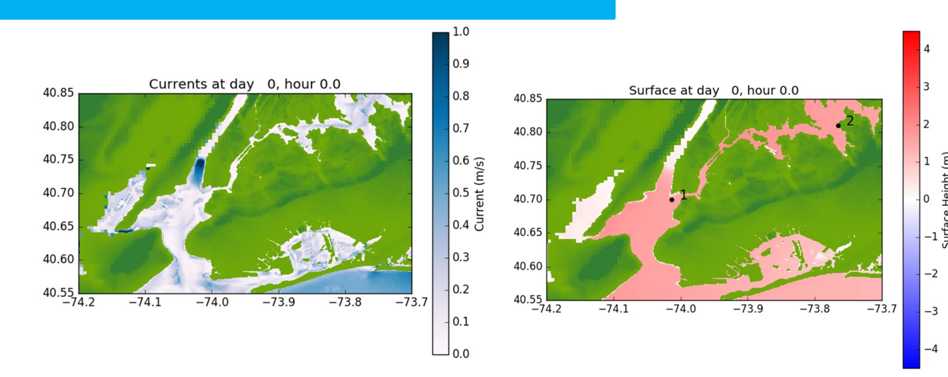




Miura, Y., Mandli, K. T., & Deodatis, G. (2021). High-Speed GIS-Based Simulation of Storm Surge–Induced Flooding Accounting for Sea Level Rise. *Natural Hazards Review, 22*(3), 04021018.

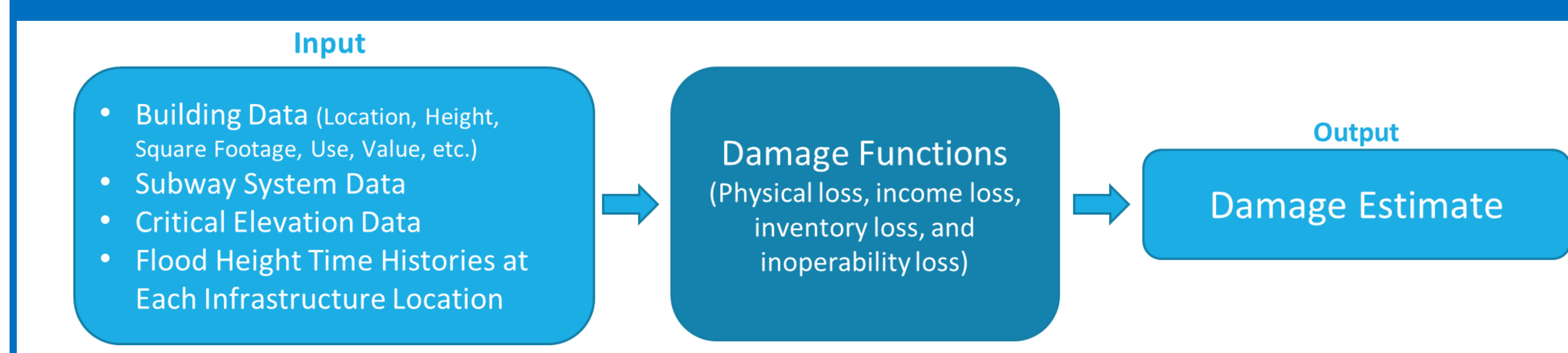
GeoClaw

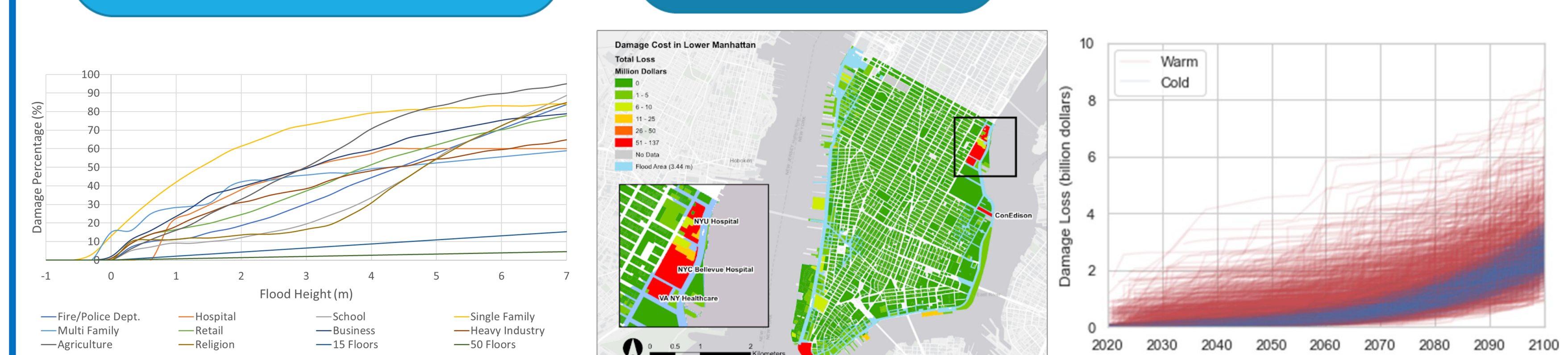
- Based on Finite Volume Method on Shallow Water Equation
- Output: Flooding height and momentum

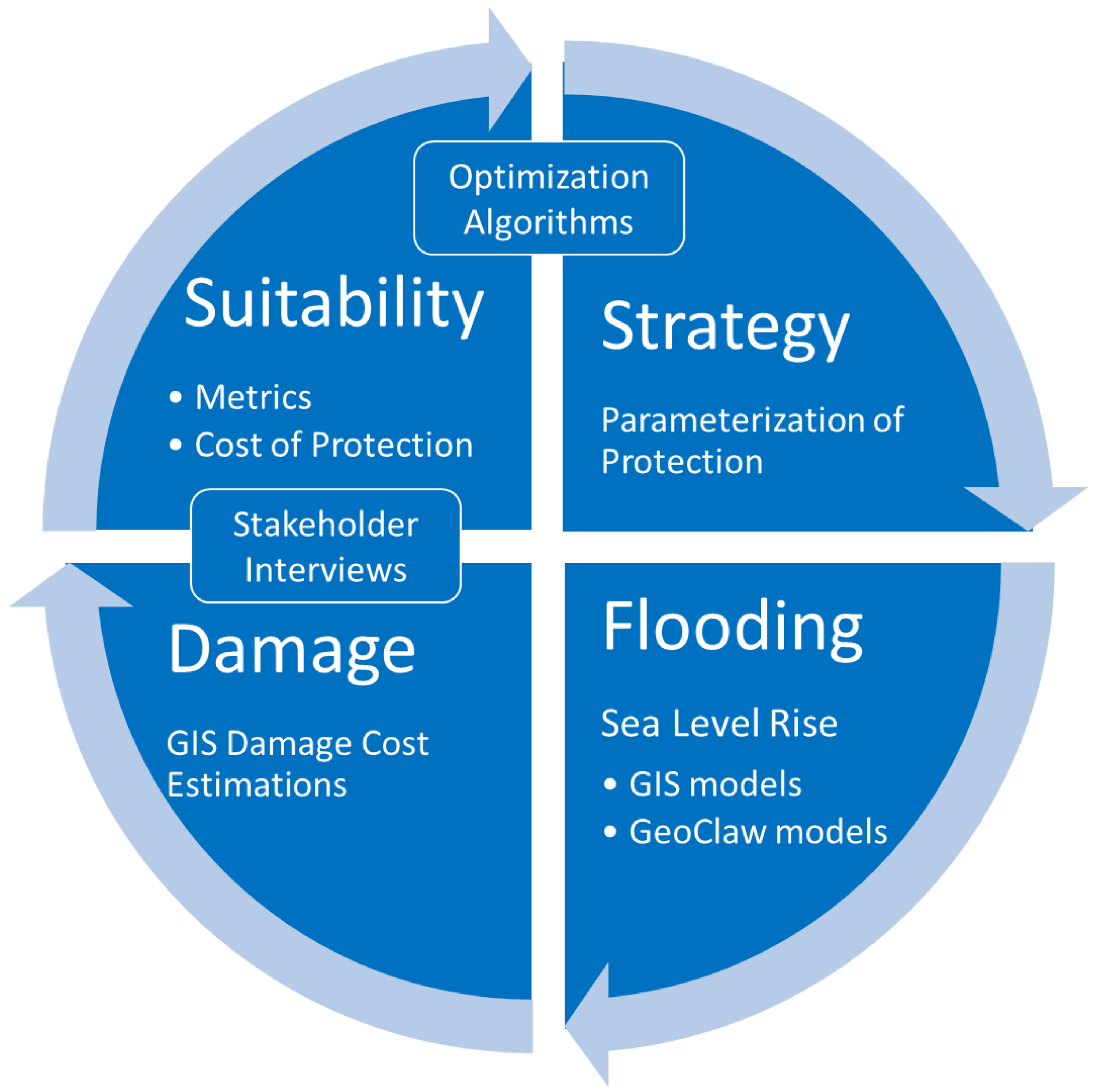


Berger, M. J., George, D. L., LeVeque, R. J., & Mandli, K. T. (2011). The GeoClaw software for depth averaged flows with adaptive refinement. *Advances in Water Resources, 34*(9), 1195-1206.

Damage Estimation







Stakeholder Observation for Interdependencies

To clarify the interdependencies of the infrastructures, interview has been conducted to local stakeholders

Optimization of Protective Strategy

Objective Function:

$$\min_{x}\left\{L_{co}(\boldsymbol{x})+\mathbb{E}_S\left[\sum_{s\in S_j} f(\boldsymbol{x};s)\right]\right\}$$

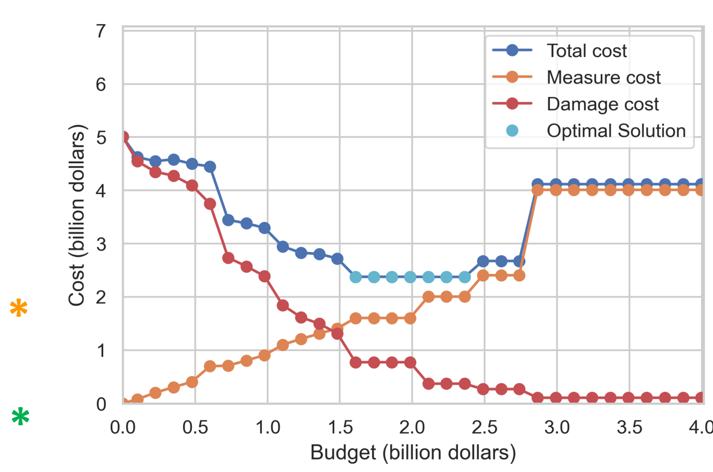
Constraints:

$$\left.\begin{array}{rcl} 0\le & h_{\text{wall}} & \le 5\text{m} \\ 0\le i_{\text{wall}_0}\le & i_{\text{wall}_f} & \le i_{\text{wall}_F} \\ L_{co} & \le & L_{\text{budget}} \end{array}\right\} *$$

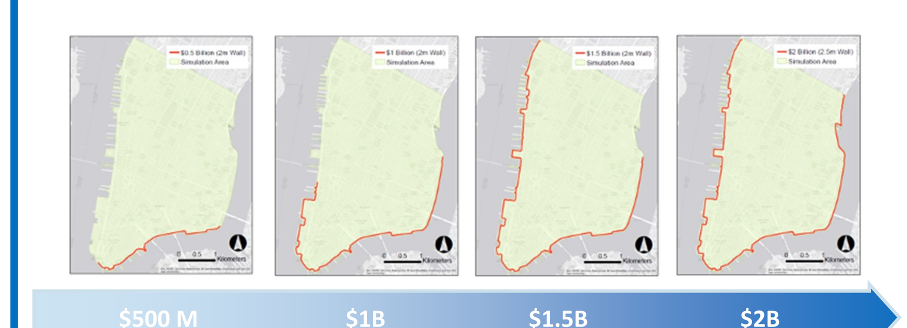
$$P\left(\sum_{s\in S_j} f(\boldsymbol{x};s) < \text{threshold}\right) > 95\% \; \}\, *$$

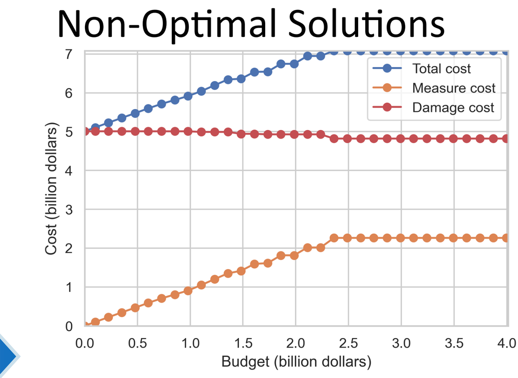
* Constraint (seawall) * Constraint (fairness)

Optimal Solutions:



Non-Optimal Solutions





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Damage Cost in Each Division