City of Annapolis Flood Mitigation Design Trade Off Study

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SYST 495

Outline

1. Context Analysis
2. Stakeholder Analysis
3. Problem Statement and Need Statement
4. Statement of Work & Scope
5. Analysis Methodology
6. Requirements
7. Systems Alternatives
8. Trade-off Analysis

Context Analysis

The city dock in Annapolis features a sculpture of Alex Haley, author of *Roots*, reading to children.

Senior Design Team at the Sculpture of Alex Haley, in Annapolis (October 11th, 2018).

Senior Design Team in Downtown Annapolis (February 26th, 2019).

Image Source: Google, Sculpture of Alex Haley in Annapolis

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Why does it flood?

- Floods are caused by heavy rains, overflowing rivers, broken dams, urban drainage basins, storm surges, melting ice glaciers, high tides, and rise of sea level.

Most Important Cause of Flooding For Our Study:

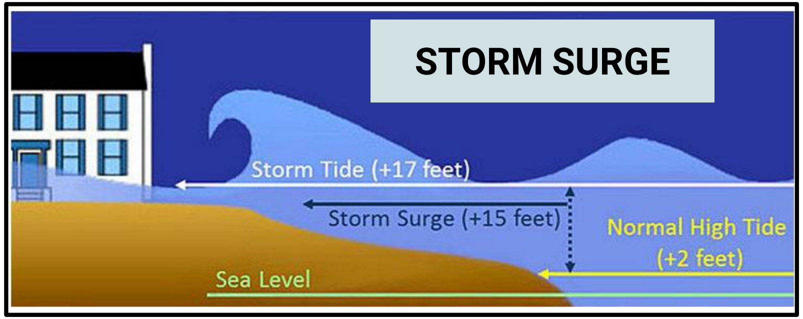
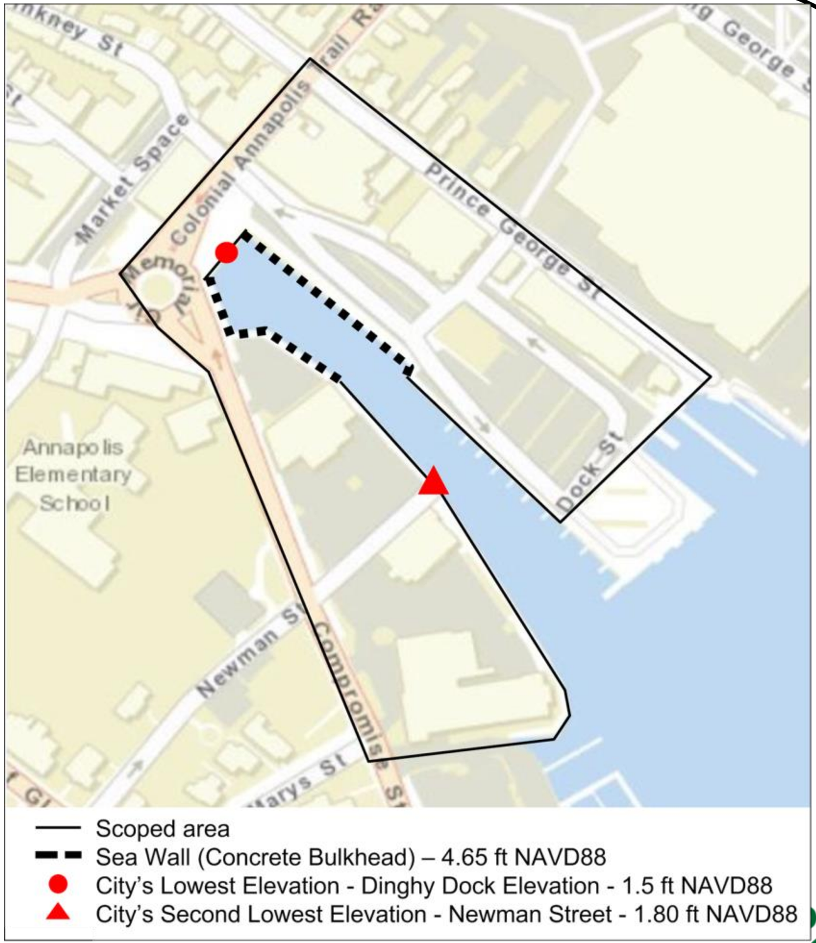
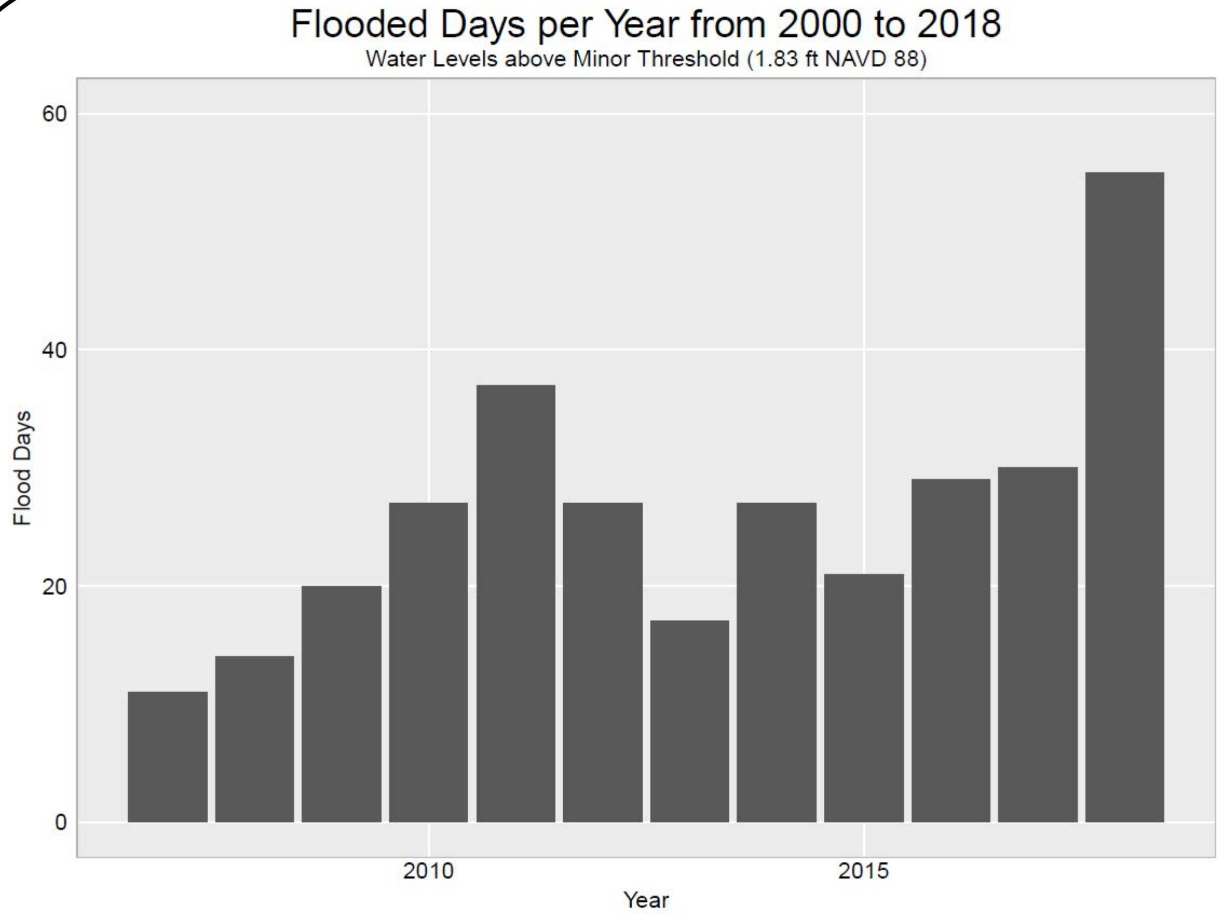


Image Source: Google Images, Storm Surge
Image Source: Google Images, Annapolis Tidal Flooding

Flooding in Annapolis

- Between the years of 1957 and 1963 (6 year gap) there were around 3.8 flood events a year.
- Between the years 2007 and 2013 (6 year gap), Annapolis experienced 39.3 floods a year which is about a 925% increase.
- City Officials have estimated that 95% of flooding comes from tidal flooding





Floods in the city of Annapolis are counted only once a day, even if the city experiences flooding at different times of a day.

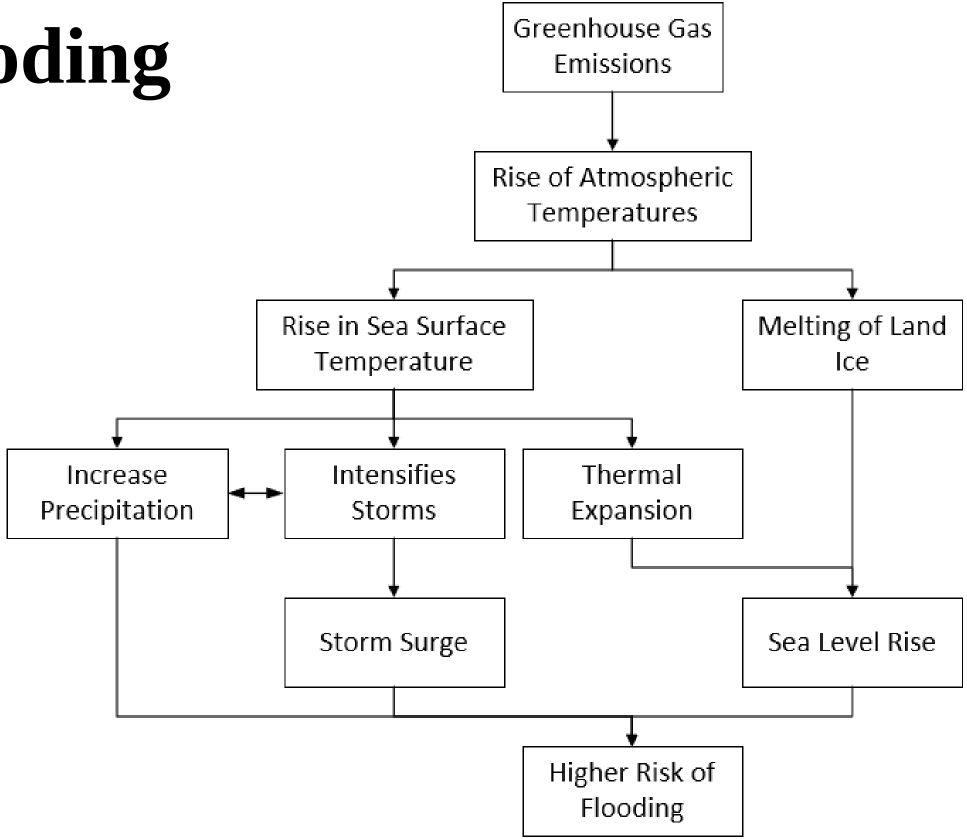
In 2018, alone the city experience **55 days of flooding.**

Understanding the Economic Impact

- **38 businesses** in city dock area **combined** can lose approximately **$100,000** in revenue per flooded day [1]
- In 2018, the City experienced **55** flooded days which would be estimated as a loss of **$5,500,000** in revenue for the year.
  - This is **only** revenue, not infrastructure damage
- Hurricane Isabel (2003)
  - Surge Height of 6.42 ft
  - Incident Period lasted for about a week to 10 days
  - The Federal Emergency Management Agency (FEMA) estimated total damages for Anne Arundel County of $500 million in damages

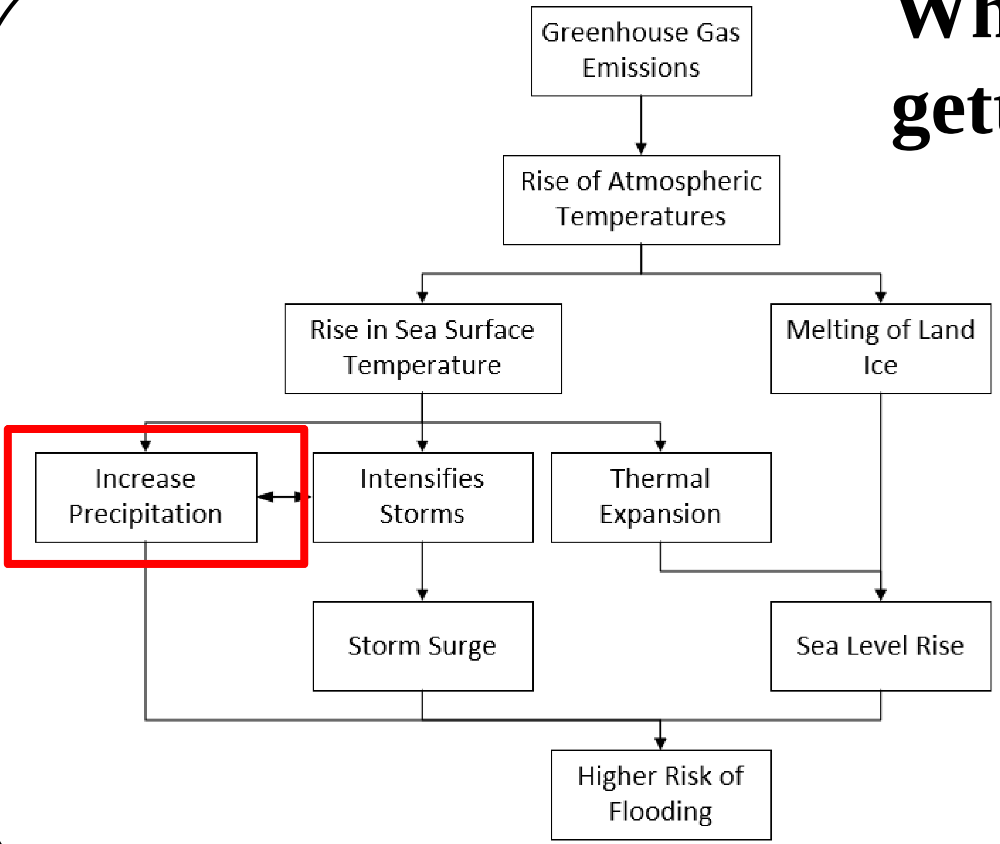
[1] City of Annapolis, "State of Maryland Hazard Mitigation Grant Program Application" (2017).

Why is the Flooding getting worse?

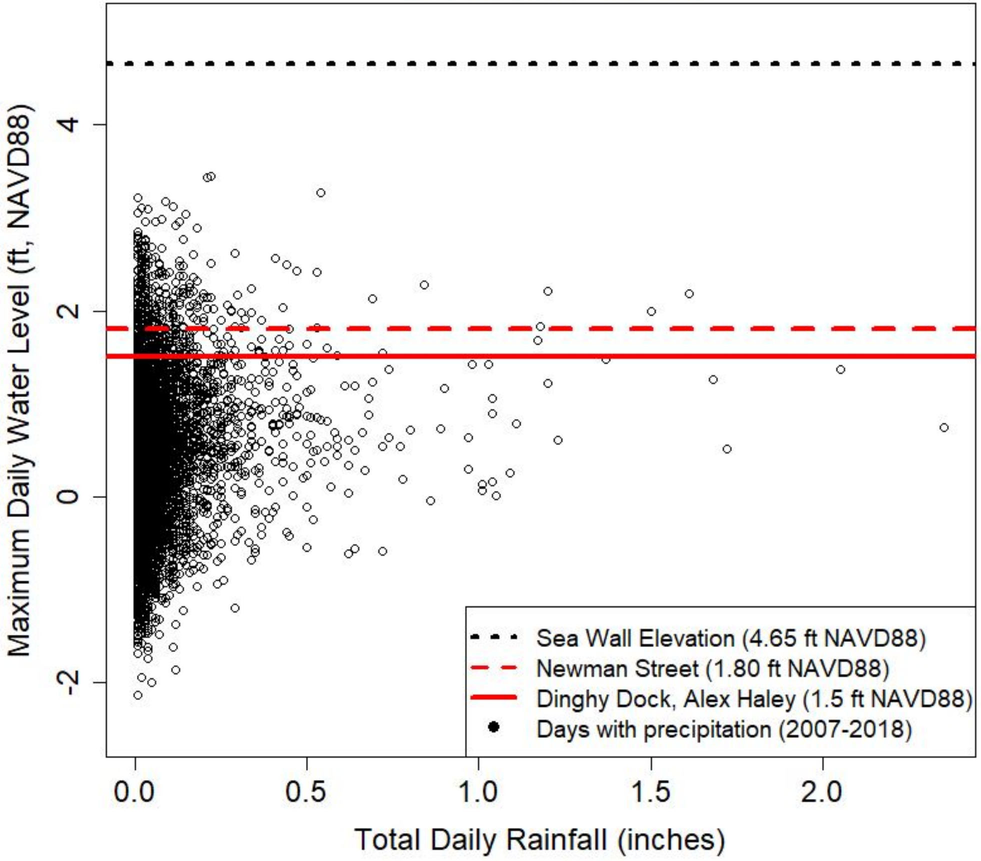


Why is the Flooding getting worse?

Precipitation

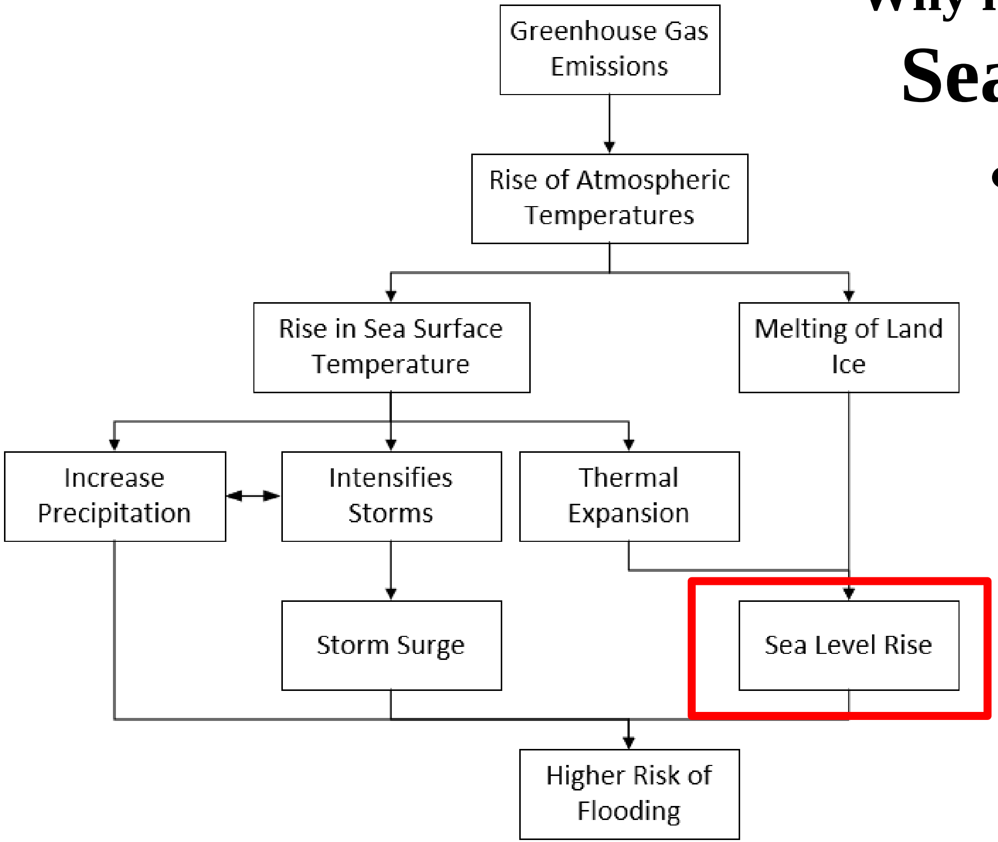


Flooding Events Are Not Highly Correlated to Precipitation Events at Annapolis City, MD

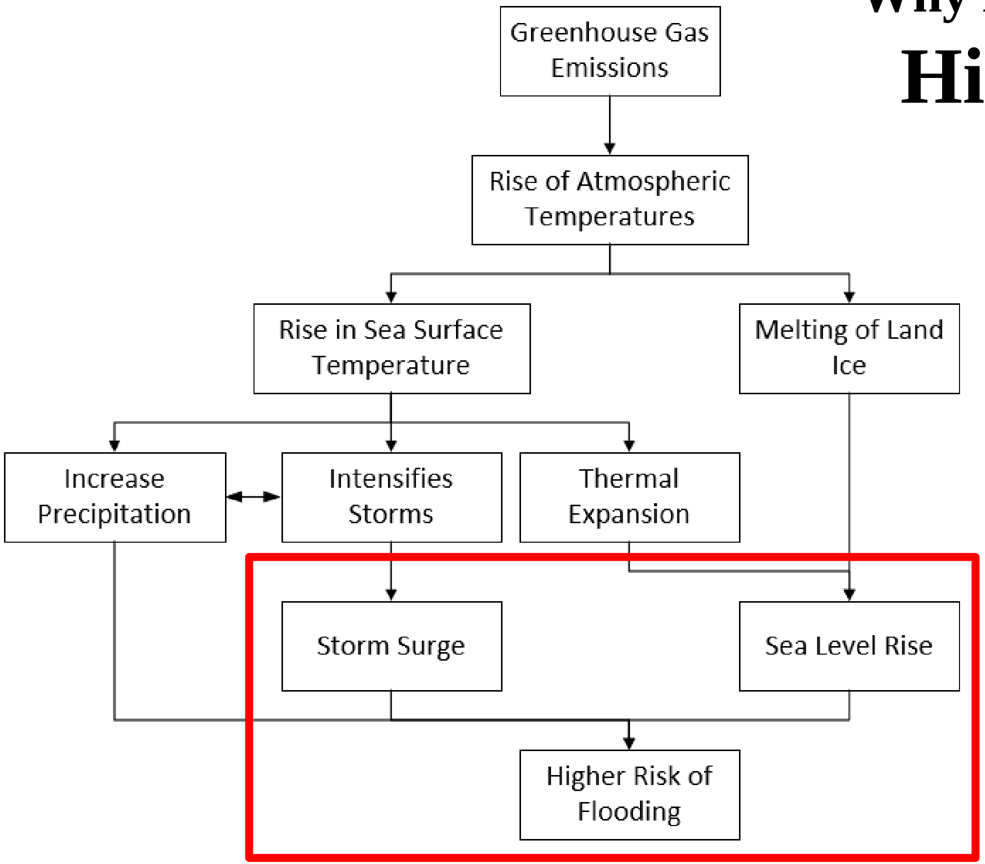


Why is the Flooding getting worse?

Sea Level Rise



- The Maryland Commission on Climate Change's Scientific and Technical Working Group estimates that Maryland shorelines could see up to a **2 foot increase in sea level by 2050** and possibly more than **4 feet by 2100** if global emissions of heat trapping gases are not dramatically reduced.



Why is the Flooding getting worse?

High Risk of Flooding

- Is predicted that a **Category 1 storm in the future** would produce as much damage as a **Category 2 today.**

All measurements are in **feet** relative to NAVD88 datum

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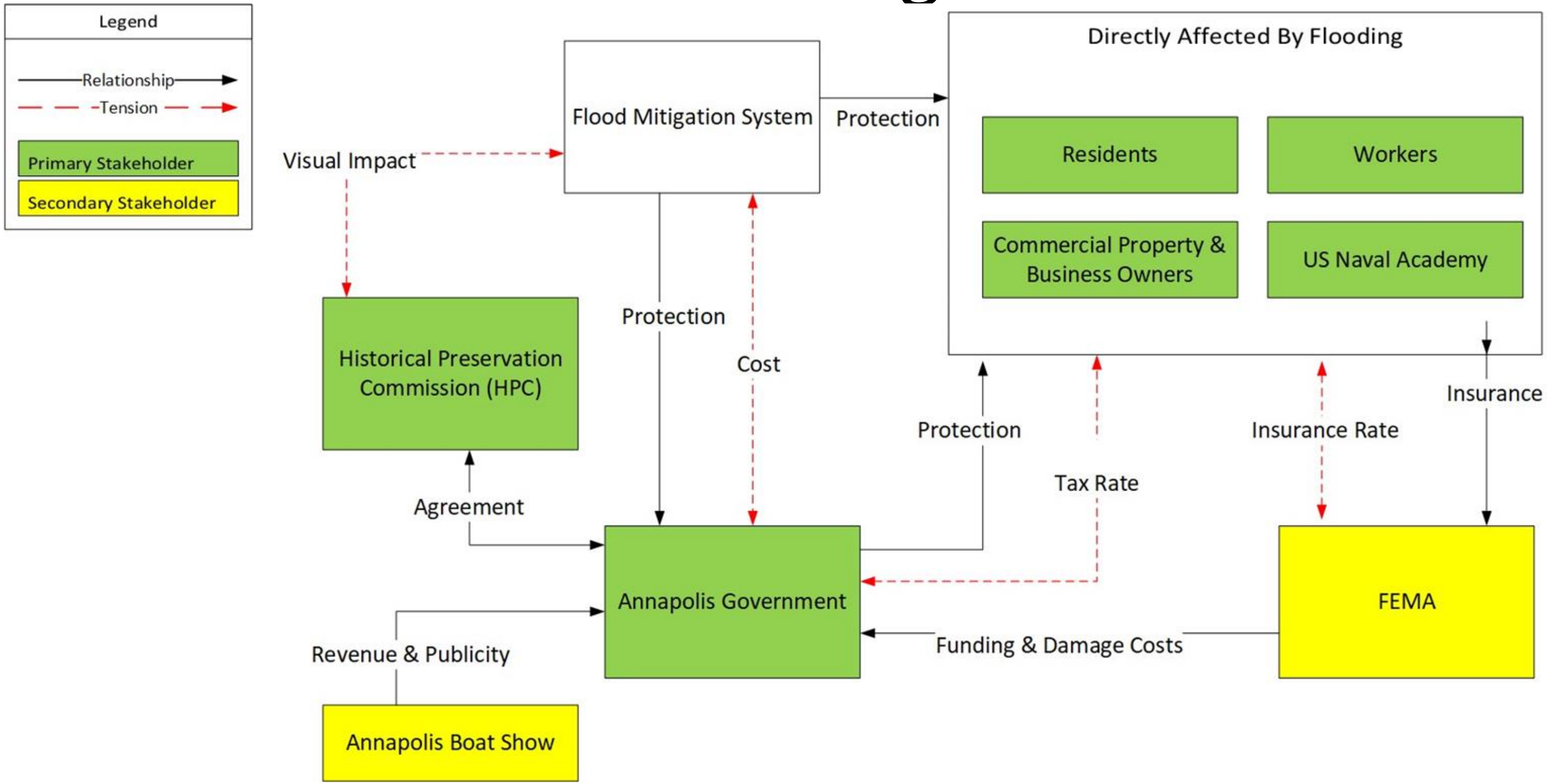
Stakeholder Diagram



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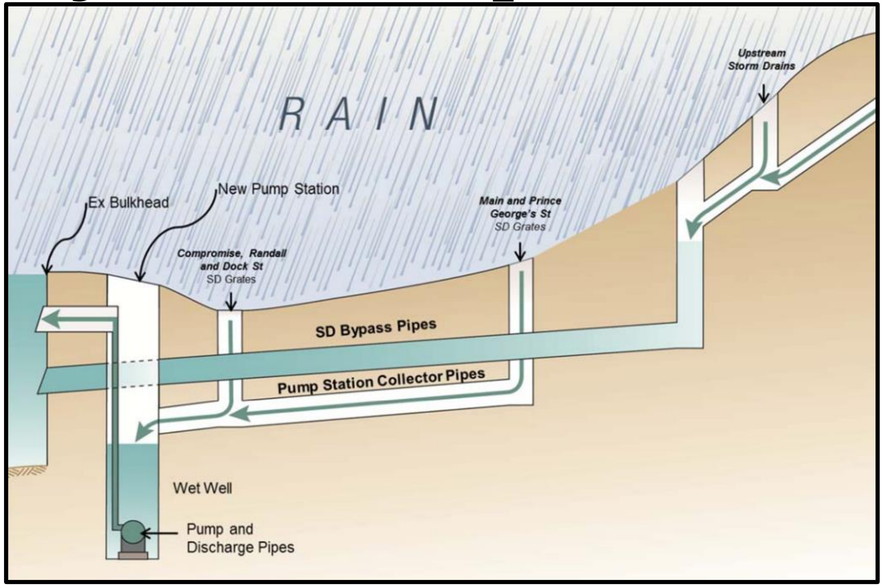
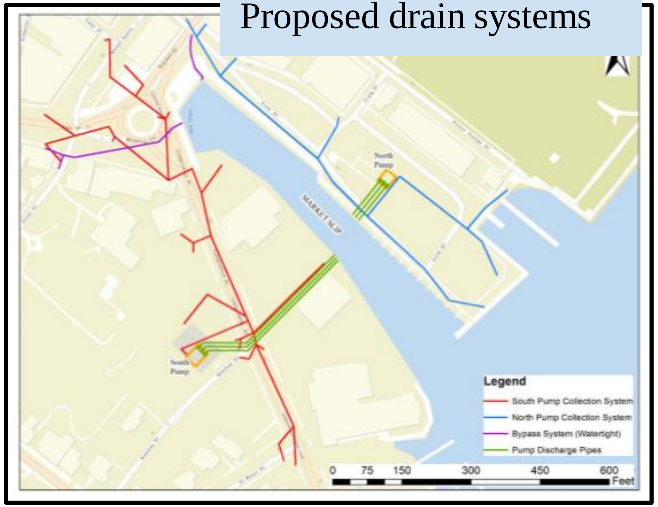
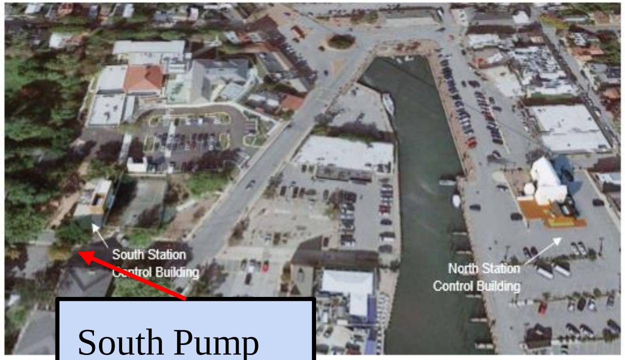
Current Flood Mitigation Project in Annapolis



Proposed Concept Design

Proposed drain systems



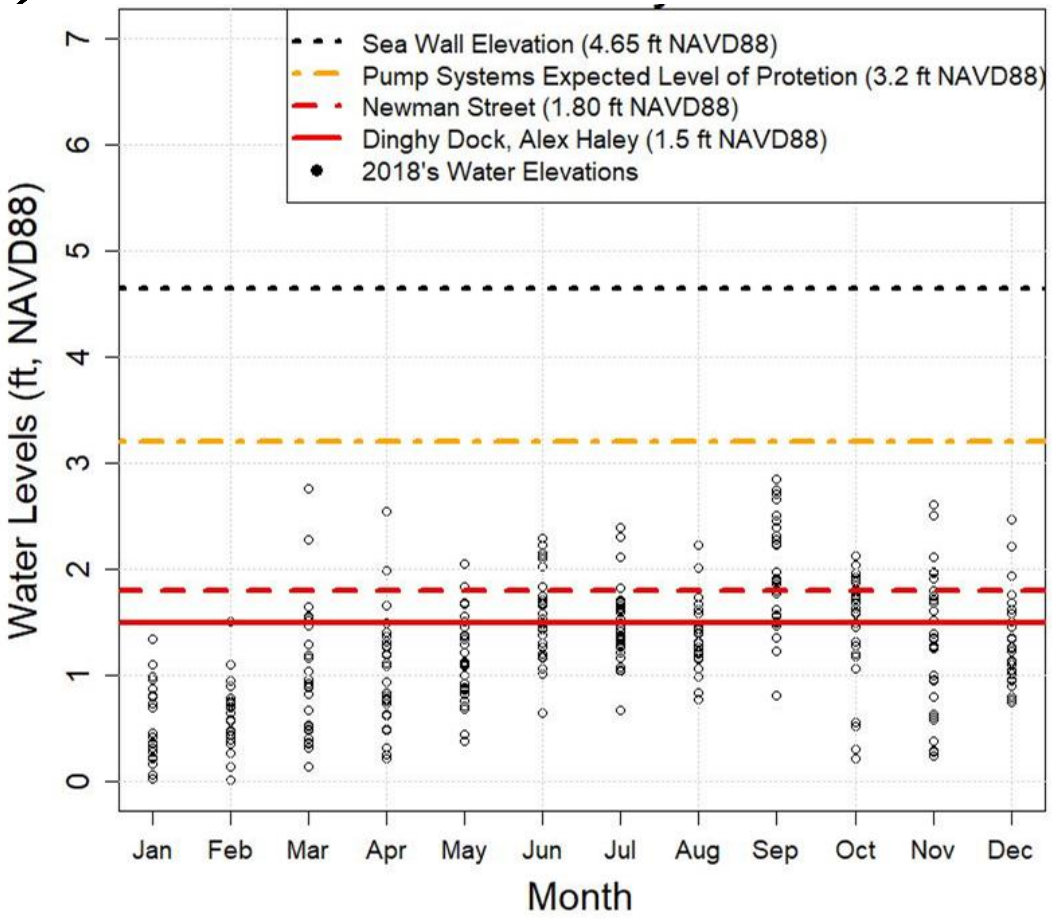


South Pump

[Stormwater and Flood Mitigation Engineering Design Services Concept Design Report]

Current Design Specifics

- “[Stormwater Flood Mitigation Project] does not account for sea level change projections.”
- Ideal number of submersible electric pumps within each station is three.
  - Powered by **Baltimore Gas and Electric** (BGE)
  - Expected service life is **25 - 30 years.**
  - Expected to operate less than **200 hours annually**.



1,500 Linear Feet of Unprotected Area

Difference between sea wall and City's lowest elevation point

Problem Statement

- Annapolis, the capital of Maryland, is **routinely experiencing** significant **flooding events.** Its location as a coastal community presents a risk for tidal flooding which constitutes about 95% of floods.
- With climate change, **flood risk is expected to increase** due to higher sea levels which cause higher tides and stronger storm surges.
- Current and past design studies have proposed a near term solution that **do not consider the systemic climate change effects.**

Need Statement

- There is a **need to reduce the effects of flooding on lives and property in the near and long term.** Therefore, the Government of Annapolis needs to invest in a **systemic climate change design trade-off study for flooding events** in the City of Annapolis.

Statement of Work

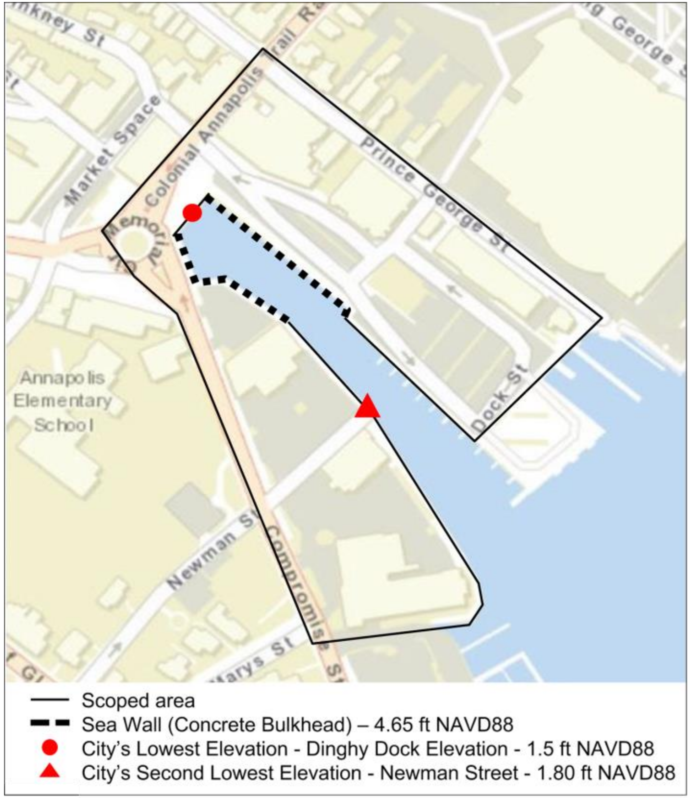
- The project includes research on the long-term threat of climate change and rising seas, a **trade-off analysis,** and **cost estimates** for **alternative designs**.

- **Period of Performance:** 9 month with a start date of August 27th, 2018 and an end date of May 1st, 2019.

- **Place of Performance:** The majority of work will be done at George Mason University. Meetings with sponsor will be held at Annapolis City, and meetings with co-sponsor to be held at Washington DC.

- **Objective:** Reduce the impact of flooding on lives and property.

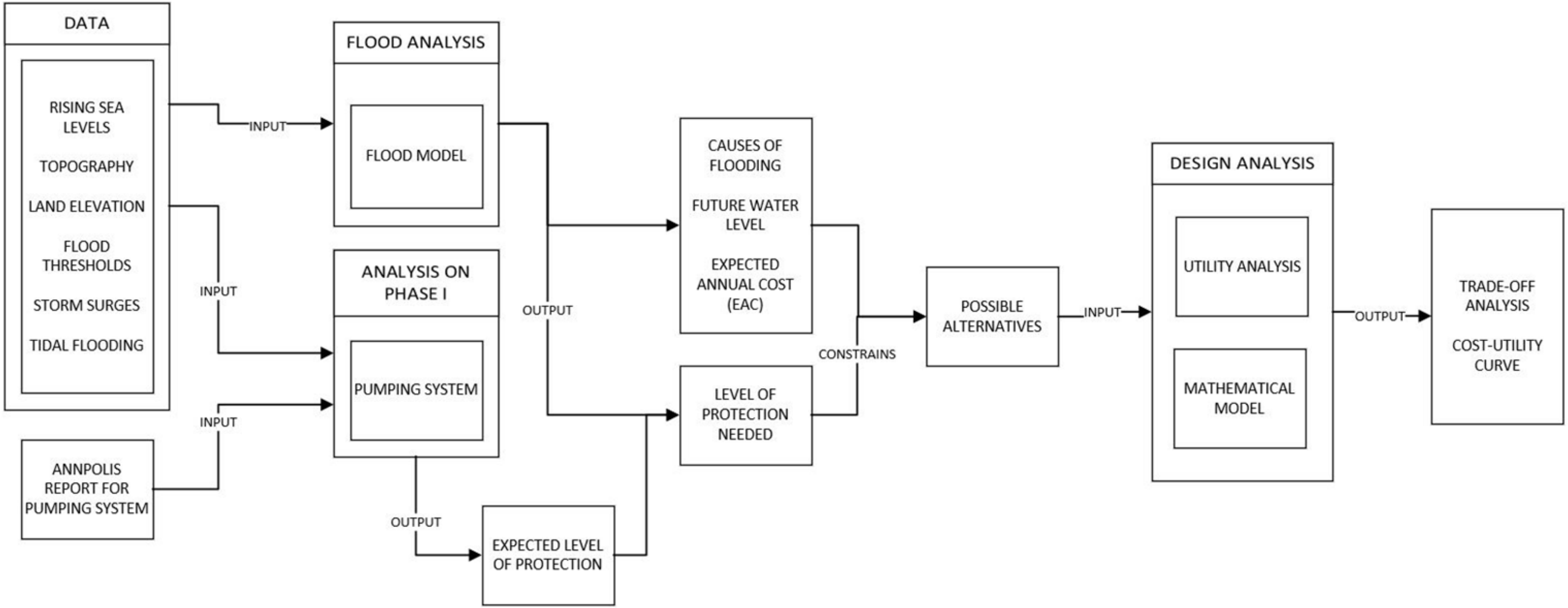
Project Scope (~1500 ft around City Dock)



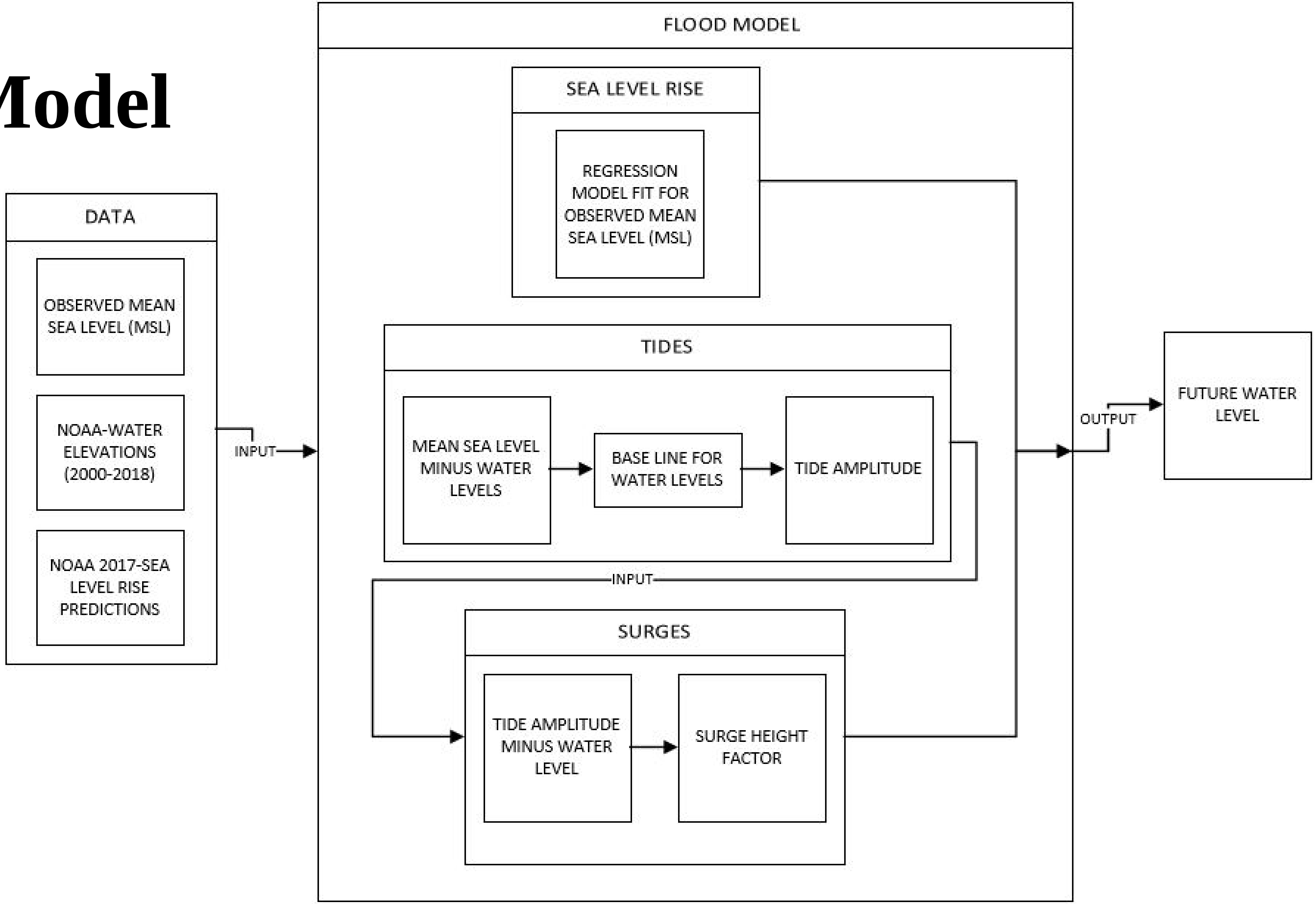
- The area analyzed in this study is:
  - **low lying areas of Annapolis [city dock]**
  - **Prince George Street intersection with Dock St**
- Red dots on map represent the lowest elevation areas at the dock **1.5ft NAVD88** elevation
- Red triangle represents the second lowest elevation - **1.8 ft NAVD88**
- Dotted line represents the current sea wall - **4.65 ft NAVD88**

Outline

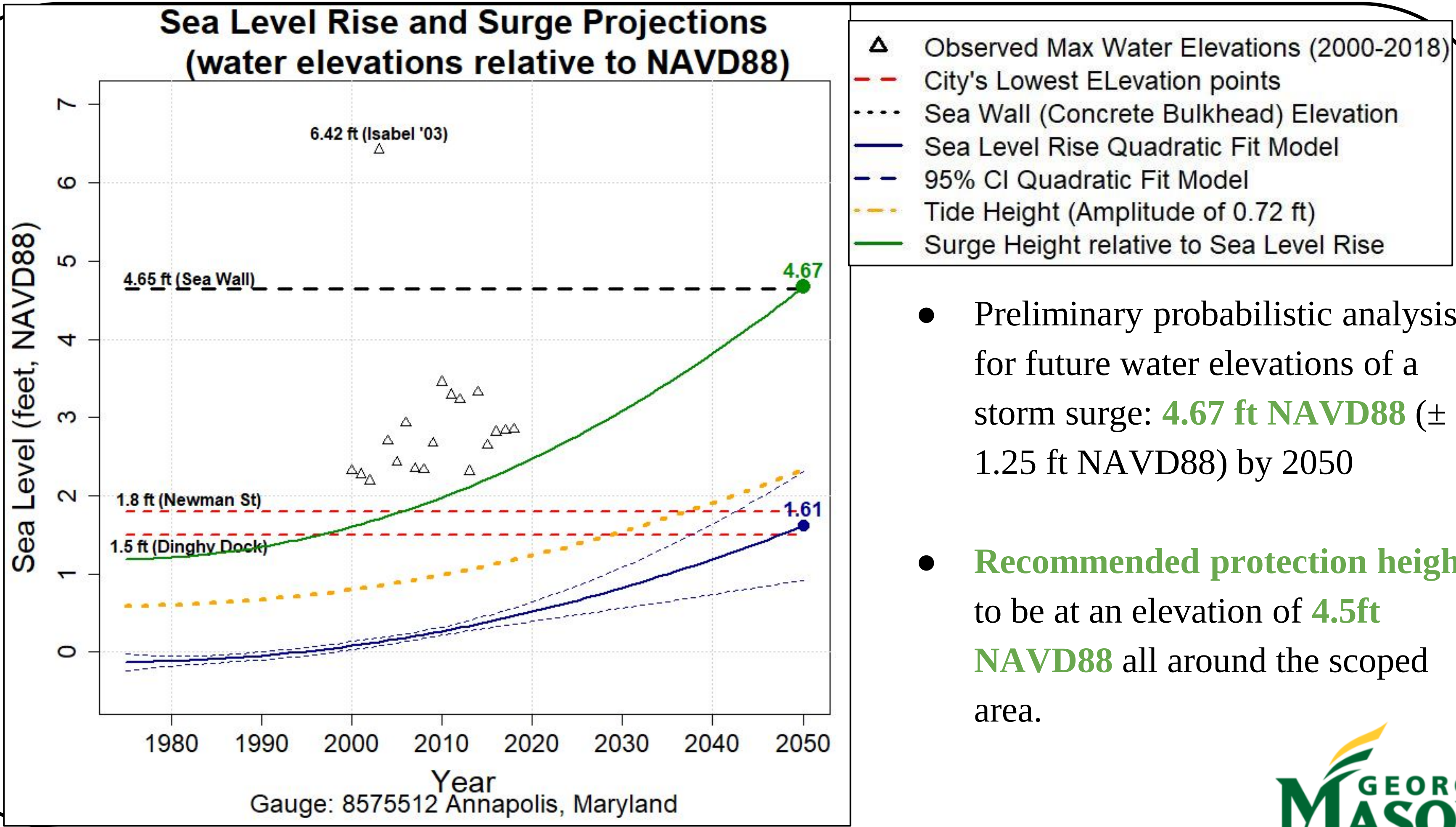
Project Methodology



Flood Model



DATA
OBSERVED MEAN SEA LEVEL (MSL)
NOAA-WATER ELEVATIONS (2000-2018)
NOAA 2017-SEA LEVEL RISE PREDICTIONS
INPUT
FLOOD MODEL
SEA LEVEL RISE
REGRESSION MODEL FIT FOR OBSERVED MEAN SEA LEVEL (MSL)
TIDES
MEAN SEA LEVEL MINUS WATER LEVELS
BASE LINE FOR WATER LEVELS
TIDE AMPLITUDE
INPUT
SURGES
TIDE AMPLITUDE MINUS WATER LEVEL
SURGE HEIGHT FACTOR
OUTPUT
FUTURE WATER LEVEL



- Preliminary probabilistic analysis for future water elevations of a storm surge: **4.67 ft NAVD88** (± 1.25 ft NAVD88) by 2050

- **Recommended protection height** to be at an elevation of **4.5ft NAVD88** all around the scoped area.

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System Alternatives Requirements

- Stakeholders want a long term solution
  - "Long term" meaning **30 - 35 years (2050)**
- Historic Preservation Commission has a manual that all structural buildings must comply with
  - Do not want a structural solution with a high visual impact
- The solution needs to protect from at least **4.5 feet** water elevation relative to NAVD 88.

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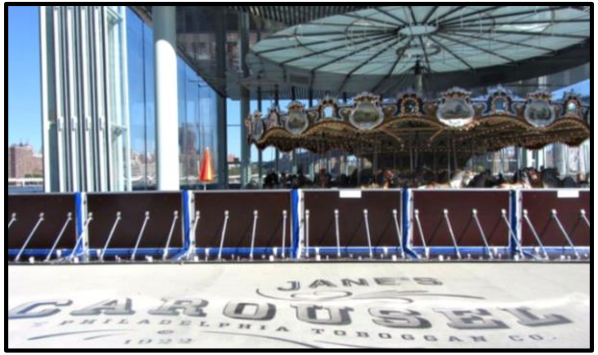
System Alternatives

TigerDams



AquaFence

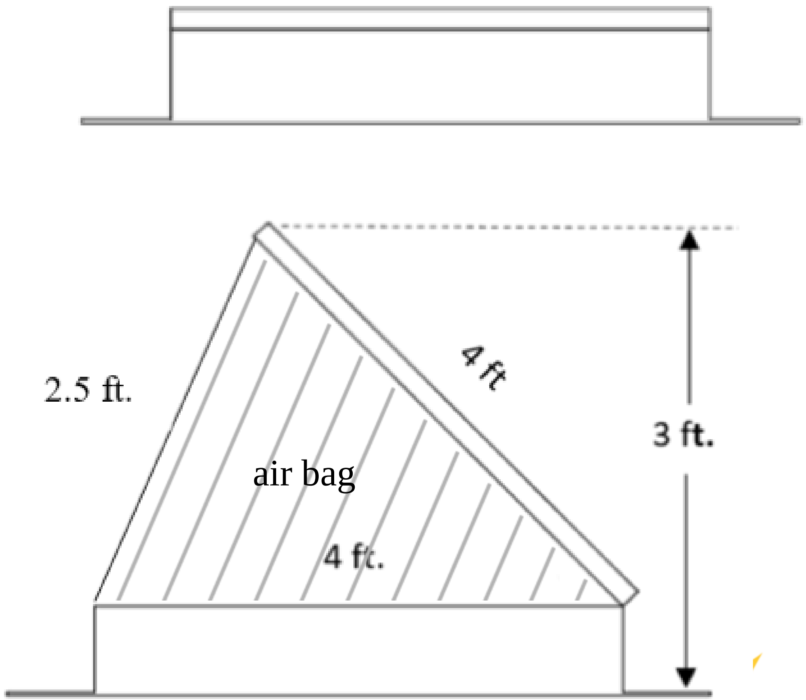
Self Closing Flood Barrier

GMU Dynamic Pneumatic Cofferdam

Image Sources: Flood Control, TigerDams GMU Volgenau School of Engineering
Self Closing Flood Barrier AquaFence

GMU Dynamic Pneumatic Cofferdam Design

- Resemble a sidewalk
    - Sit on top of the ground
- Held down by weight of water and bolts
- Dimensions:
    - Width of 4 feet
    - Passive height of 7.5 inches
    - Steel Cable of 2.5 feet at 1 foot intervals to hold angle
    - Total Protection of 3 Feet
    - 50 foot long sections
- Adjustable to other sizes



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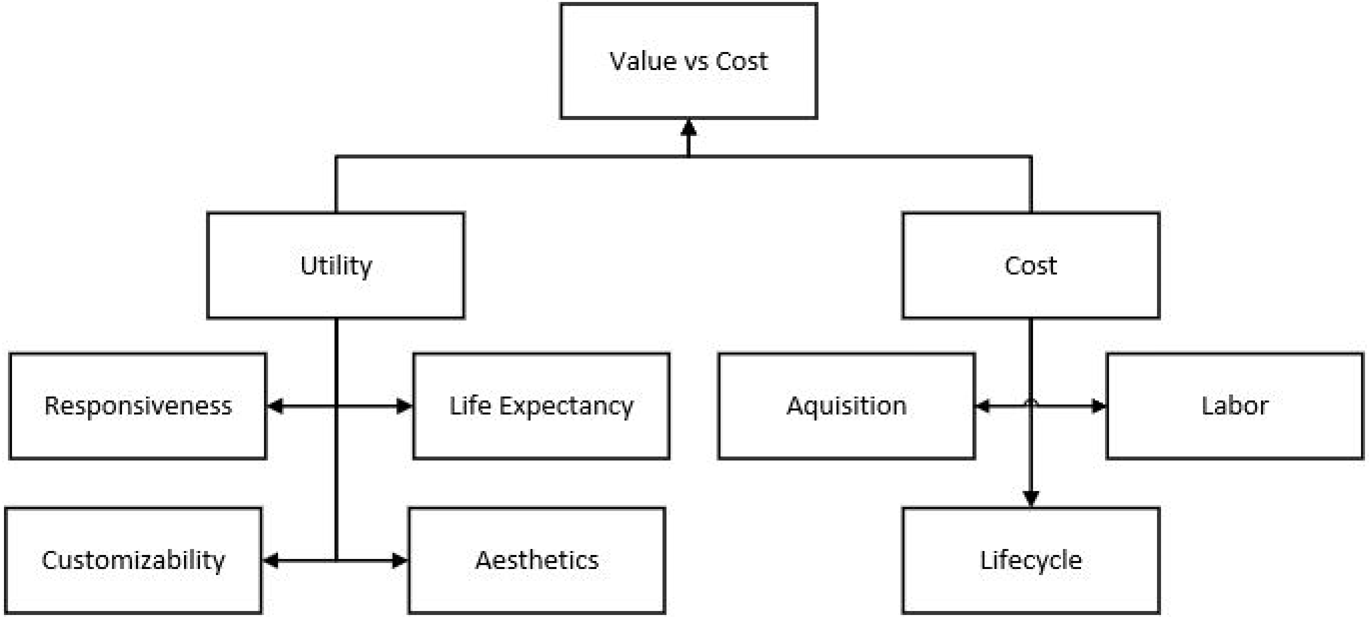
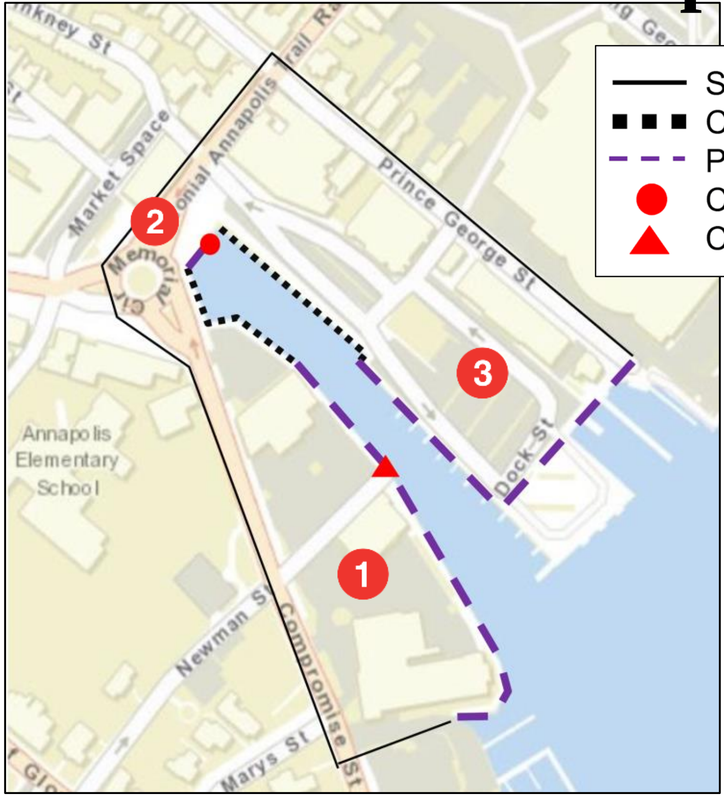
Utility vs. Cost Hierarchy



System Alternatives Specifications



- Map shows the proposed locations for the alternatives **highlighted in purple** divided in sections:
    - #1: ~100 ft
    - #2: ~700 ft
    - #3: ~700 ft

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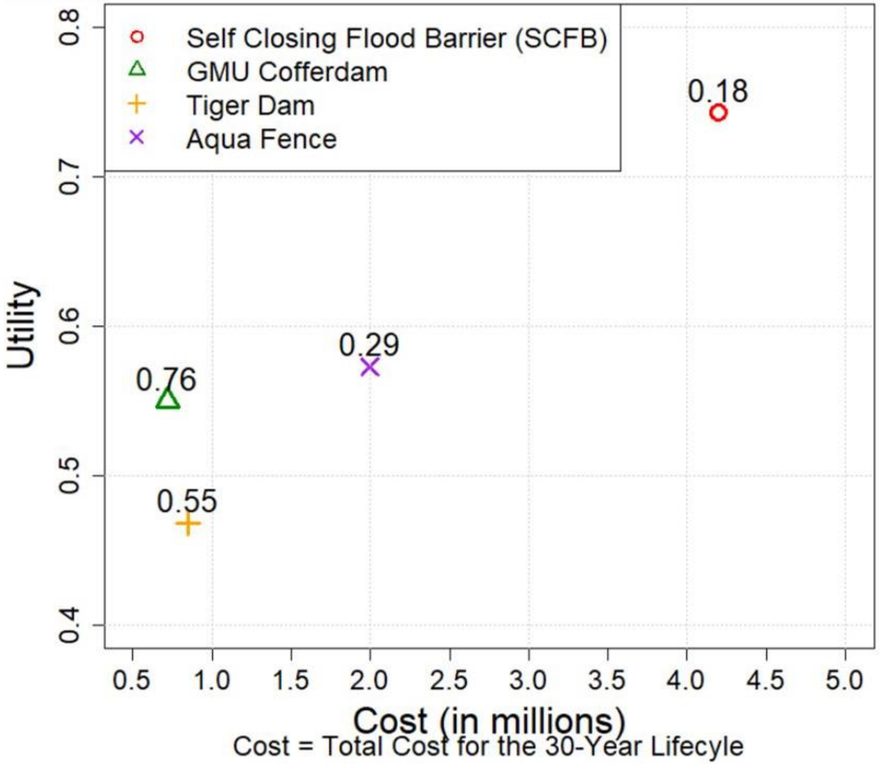
System Alternatives Specifications (Cont.)

- **Labor Cost**
  - *(Installers Required * Installation Time * Installers' Hourly Wage)*2*
  - Hourly Wage ~$14.00/hr
- **Total Cost** for AquaFence, TigerDam, and GMU Dynamic Pneumatic Cofferdam
  - *(Acquisition Cost * Number of Uses)+(Labor Cost * Length of Barrier)*
  - Length of Barrier in feet
- **Total Cost**
  - *(Length of Barrier * Height of Barrier)*Acquisition Cost*
- **Life Cycle**
  - *Number of Purchases*Total Cost*

Alternative Comparison for a 30-Year Life Cycle

Alternative	Life Cycle Cost ($)	Installation Time (hr)
AquaFence (4 ft x 1,500 ft)	$ 2,000,000.00	1.7
FM Aproved 42" Super TigerDam (3.5 ft x 1,500 ft)	$ 850,000.00	6.0
Self-Closing Flood Barrier (3 ft x 1,500 ft)	$ 4,200,000.00	-
GMU Dynamic Pneumatic Cofferdam (3 ft x 1,500 ft)	$ 720,000.00	1.0

Marginal Utility for a Three (3) Foot Structure



- **Overall, the GMU Dynamic Pneumatic Cofferdam** yields the **highest** value in the cost-utility analysis of **0.76**, while **Self-Closing Flood Barrier** yields the **lowest** value in the cost-utility analysis of **0.18**

Recommendations

- Protect against **4.5 feet relative to NAVD88** at any given location in the scoped area.
  - The **current sea wall** already accounts for 4.65 feet relative to NAVD88, but some areas **lay as low as 1.5 feet** relative to NAVD88.
  - Any solution proposed will be able to compensate for the low elevation.
    - Based on the trade-off analysis
      - **George Mason University's Dynamic Pneumatic Cofferdam** yields the greater trade-off between utility and total life cycle cost.

Recommendations (Cont.)

- Annapolis needs address the **climate change effects** when planning for the future.
  - **Symbiotic** phasing of solutions.
    - Current Stormwater Mitigation Project
      - "... does not account for sea level change projections."
    - Protective Barrier
      - Improve resilience for any flooding event

References

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Questions?