Multiobjective Robust Decision Making in Rhodium-SWMM

Socioeconomic Analysis of Flood Resilience Infrastructure

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Systems Engineering

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November 12, 2024

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Climate change causes numerous negative impacts which pose threats to infrastructure and people all over the world. One of the primary dangers induced by climate change in the United States, specifically along the coastlines, is the increase in flooding. One significant effect of climate change has been the increase in sea levels, which is partially responsible for the rising potential of high flood severity. Along the coasts of the United States, an average increase of 10-12 inches of sea level rise is expected between 2020 and 2050, with the highest expected increases occurring on the Gulf Coast and East Coast, by 14-18 inches and 10-14 inches respectively. This effect alone is projected to cause a ten-fold increase in minor flooding frequency and five-fold increase in major flooding frequency, corresponding with higher high tides and larger precipitation surges (Interagency Sea Level Task Force, 2022). Global warming is another effect of climate change responsible for the rise of flood risks, which gives rise to an increase in intensity of extreme weather events. For example, the Hampton Roads area in Virginia is predicted to experience a 5% increase in the amount of precipitation falling during downpours from 1990 to 2050. Part of the explanation for this is the air becoming warmer and capable of holding more moisture (Climate Check, 2015). These two effects constitute a substantial part of the foundation for attempts at flood mitigation in the United States.

There is another historically important perspective to consider when analyzing the rise of flooding. The destruction of beaches through erosion is known to have direct impacts on flood severity in coastal regions. According to Rodman Griffin (1992), infrastructures such as seawalls and subsidized house insurance in the twentieth century had been relatively unsuccessful and occasionally counterproductive. In FEMA’s National Flood Insurance Program, one in every fifty insured houses had multiple different insurance claims for the same property, but the same group of houses with repeat claims accounted for about a third of the total cost of all recorded damages. Griffin notes that experts usually criticize this taxpayer-funded strategy of subsidized insurance because it incentivizes developers to take advantage of relatively cheap flood-prone areas. Griffin's research also found that seawalls and other physical infrastructures often caused significantly increased damage to beaches, not decreased. United States citizens also have a strong desire to own shoreline property and develop the land along the shore, which is another major cause of beach erosion due to the intentional pumping of wastes and the incidental runoff of harmful substances into the water. These developments have urbanized the coasts of the United States, which calls for the implementation of green infrastructure (GI). Griffin's work supports the use of GI, which is helpful for providing sustainable solutions to floods.

According to Green et al. (2021), there is a necessary transition from grey infrastructure, which is aimed towards defending cities from floods using feats of engineering like underground drainage systems, to green infrastructures, which seek to protect the environment and people with processes that use the water to mimic natural hydrological processes, like rain gardens. The future of flood-risk mitigation is in the implementation of GI in cooperation with current grey infrastructure solutions, while having more equitable repercussions for people disproportionately disadvantaged by floods. This project focuses on the implementation of a new flood-risk analysis tool with potential for location-specific and socioeconomic evaluations that has versatile applicability across the United States.

MORDM in Rhodium-SWMM

There are shortcomings of both the current infrastructures in place and the methods experts use to decide where to implement the infrastructures. It is necessary to presently focus on the systematic methods of implementation for existing designs of flood-mitigation infrastructure to provide more efficient and immediate help, as well as provide an adaptable means of analysis for any new GI designs in the future.

Like in many other coastal urban areas across the United States, there is existing infrastructure in Hampton Roads which is designed to minimize the negative effects of floods. The Hampton Roads Planning District Commission (HRPDC) implemented a system of twenty roadway water level sensors to collect real-time data about water levels. The sensors are located in various parts of the Hampton Roads area to promote more informed response decisions in both present and future flooding circumstances. These sensors have pressure sensitivity and radar mechanisms to measure water level compared to the elevation of the roadway. The sensors have been programmed to pair with the Waze navigation app to provide drivers with repeatedly updated information about flood levels and driving conditions and options (Hamton Roads Planning District Commission, 2024).

The federal government has also been involved through the initiation of a house-elevation project in which their financial support, along with the involvement of Hampton's Office of Emergency Management and other local government departments, aids homeowners in the elevation of their homes (City of Hampton, 2024). The Virginia Department of Transportation (VDOT) has also implemented many state-level infrastructures to mitigate the risks of flooding across the state such as gutters, paved and unpaved ditches, catch basins, and storm sewer pipes (Virginia Department of Transportation, 2024). While these infrastructure projects and systems are effective and important to current flood risk prevention, there is much room for improvement in the form of new infrastructure as well.

Herman et al. (2020) argues that climate adaptation is an underresearched and underutilized principle in the development of flood-mitigation infrastructure. More specifically, the evaluation and estimation of uncertainty parameters is a big challenge. Flooding, primarily represented in their research by the category of 99th percentile streamflow levels on a daily timescale, has the most uncertainty in streamflow projections. There is necessary work to be done in this field to accurately incorporate uncertainty into a modeling system, as well as being future focused by using dynamic planning instead of simple robust planning.

Hadjimichael et al. (2020) developed and introduced the Python library called Rhodium, which was primarily created to support many-objective robust decision making (MORDM). Their research explains weaknesses of current robust decision-making methods for analysis, particularly for environmental uses where the estimation of uncertainty parameters by the user is unreliable. This resource provides analysts with a versatile interface, vast analysis efficiency potential, and compatibility with many other analysis tools. Tebyanian et al. (2023) discusses the incorporation of the Rhodium library with the Storm Water Management Model (SWMM) to create a cutting-edge MORDM tool for flood mitigation. A literature review in their research expanding on this concept revealed that at least part of the lack of satisfactory uncertainty parameter estimation is due to the use of prescriptive analysis instead of predictive analysis.

The Rhodium-SWMM tool has many accessible functions, one of which is the ability to create both economic and social objectives. Rhodium-SWMM will be used to incorporate a quantifiable social impact objective function with the other objectives relating to costs and damages. Using the uncertainty parameters and the user-controllable levers within the modeling software, new optimal GI solutions can be integrated with current flood mitigation technologies to address all objective functions defined by the user.

The urban heat island effect helped motivate the work done by Shi et al. (2023), which includes a multi-objective decision-making resource called City-Heat. They also wrote about the need for tools with location-specific capabilities for environmental analysis. But the most impactful point of their research was that social inequity is a pervasive problem within environmental issues in the United States, particularly in urban areas. The technical project is centered on the implementation of the newly developed Rhodium-SWMM tool for analysis of flooding using conventional metrics as well as social impact. The goal for this project is to implement social objective functions similar to SIA or SVI (discussed in the next section) to the Rhodium-SWMM modeling program on the Rivanna computer program. CMIP6 and/or IPCC data projections for climate change and sea level change will be incorporated into the model as well (Earth System Grid Federation, 2024; Garner et al., 2021; NASA 2024).

Socioeconomic Analysis of Flood Infrastructure

Coastal flooding often corresponds to events called Natech disasters, which are characterized by the escape of dangerous substances from toxic release inventory (TRI) facilities due to the destruction of infrastructure. Natech disasters disproportionately affect African Americans, people in poverty, and people without a personal vehicle in Hampton Roads, Virginia (Crawford et al., 2023).

Some of the lasting effects of flooding in a particular area, especially frequent and/or severe flooding, are economic decline and socioeconomically disproportionate responses. The economic sector can experience hardship due to floods because of the damage to public and private infrastructure, imbalance of investment strategies and patterns, disruption of supply and demand for certain resources, and the addition of expenses for infrastructure repairs and humanitarian care. The slowed growth of the local economy is an expected outcome in these situations because transportation difficulties increase, investment tends to slow down, non-essential purchases are decreased, and the attention of the work force is turned more towards healing from the past instead of creating for the future. It is essential that efforts by public agencies (and perhaps private projects as well) to address needs in flood-susceptible areas are equitable and accessible for all people (Associated Programme on Flood Management, 2013).

There is a lack of flood response research that addresses issues of equity in their modeling. According to the work of Aznar-Crespo et al. (2021), hundreds of scientific documents were found in a thorough algorithmic literature review using the keywords “flood,” “disaster,” and “natural hazard” along with selecting for a topic involving social impact. Only eighty-nine documents since 1864 remained after excluding repeated and insufficiently related documents. Of those eighty-nine, only four used social impact assessment (SIA) for flooding with a case-study application. SIA is important partially because it includes recommendations with its findings. The Social Vulnerability Index (SVI) is similar tool that demonstrated a 0.2% decrease in peak flow rate and a 0.66 increase in SVI score when it was added into a purely hydrologic model (Herbst et al., 2023). According to the robust analysis of fifty-seven social variables by Kleinosky et al. (2007), over 50% of the data variance was explained by the poverty, immigrants, and elderly/disabled categories.

The integration of the physical and systematic infrastructure with social factors is crucial to successfully combating the risks of floods in Hampton Roads, or in any populated region. A case study in Thorncliffe Park in Toronto by Mohtat and Khirfan (2023) found that residents tend to lack social networking connections, citizenship rights, proper awareness of climate circumstances and changes, and methods of communication. This is an example of an entire community that has relatively ineffective representation and influence in the construction of technological artifacts that are important to them.

In the example of the roadway sensors project, sensors and ensuing technology responses ought to be deployed in a socially aware layout within the Hampton Roads area. However, even by limiting the efforts to only concentrate on roadways, certain people may be neglected, perhaps those who do not drive a personal vehicle as their primary mode of transportation. Another consideration is within the home elevation project, which allows people with more financial freedom to pay the remaining cost of home elevation not covered by the federal grant. The option to embed this solution to home flooding within the infrastructure of your current living situation is noticeably blocked by a potential financial barrier.

Both of these infrastructure systems are examples of the importance of a premise proposed by Star (1999) that a technology's relationships with people is central to its identity more so than its technical capabilities. Star listed nine characteristics of infrastructure that form the multi-dimensional relationship between an infrastructure and society, three of which stand out in the context of flooding. Scope addresses the breadth of an infrastructure's reach across an area and down into the future, which is an important consideration for technology meant to mitigate flooding in the long term. Embodiment of standards speaks to the growth of the GI industry, where the relationship between an infrastructure and the environment is a relationship that people care about. Lastly, the fixing of infrastructure needs or problems incrementally is crucial for bringing about stepwise, repeatable, low risk flooding solutions.

Infrastructure and analysis systems for mitigating flood destruction have largely been developed and used without the use of a social factor in an objective function. It is important to acknowledge the wisdom of Star’s analysis of socio-technical relationships and uphold the key relationship characteristics as infrastructure is changed.

How To Protect Coastal Regions

The combination of social and economic valuations within a MORDM tool is a new development in Rhodium-SWMM. Incorporating equity and cost into this type of model yields potential for strides to be taken in flood-mitigation. Evidence for the consequences of excluding social factors has been discussed previously. Using a narrowed scope for this research introduces a key question: How does environmental law guide coastal states with regions like Hampton Roads, Virginia to decreased flood risks in the United States?

The design of this research will be to examine Virginia state law under chapter 11.1, Department of Environmental Quality. This will be done using a keyword search analysis for terms like “social impact” and “equity” in Virginia environmental law (Commonwealth of Virginia, 2024).

The goal of this research is to evaluate the social and environmental relationships with flood-mitigation infrastructure in Virginia policy. This evaluation can be aided by the use of Star’s framework discussed above. Expected results are that social impact and equity are not properly represented in Virginia as required elements of environmental infrastructure. Research results may provide insight into policy recommendations for the local areas in Virginia such as Hampton Roads, as well as more general trends that may be useful for other coastal states and cities in the United States.

Conclusion

The rise of flooding on the coasts of the United States poses a nationwide problem that is representative of the world as well. Urban coastal areas in particular are at increased risk of flooding as a result of rising sea levels and climate change. Hampton Roads, Virginia is an important area close to the nation's capital that has been shown to have great needs in this area of flood mitigation analysis and planning. GI solutions implemented with the use of social evaluation factors and high-level flood-related environmental projections have the potential to cut damages and impacts due to flooding. A new initiative within the community of environmental disaster response to protect the future of coastal cities in equitable and environmentally friendly ways is necessary for the future of safety in the United States. Marginalized groups and the descendants in our future deserve better protection from the afflictions of flooding.

Resources

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