Sociotechnical Analysis of Flood Infrastructure Development in Virginia

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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, which corresponds with higher high tides and larger precipitation surges (Interagency Sea Level Task Force, 2022). This rise in frequency of storms and flooding is concurrent with a rise in storm intensity. Global warming is another effect of climate change responsible for increasing flood risks, specifically by giving rise to an increase in the 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 of climate change, the rise in sea levels and the increase in rainstorm intensity, are substantial motivation for flood mitigation efforts in the United States.

The destruction of beaches through erosion is a separate and historically important factor to consider and 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 the

Federal Emergency Management Agency's (FEMA) National Flood Insurance Program, 2% of insured houses had multiple different insurance claims for the same property but 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, not decreased, damage to beaches. Another major cause of beach erosion is the intentional pumping of wastes and incidental runoff of harmful substances into the water, which primarily stems from United States citizens strongly prioritizing shoreline property development and ownership. These factors have contributed to Griffin's support of the use of green infrastructure (GI) solutions.

The urbanization developments along the coasts of the United States ought to be addressed with the implementation of GI, a class of flood management engineering solutions which help restore natural hydrologic processes. Some common examples of GI solutions are bioretention cells, green roofs, and permeable pavement (Herbst et al., 2023). According to Green et al. (2021), the transition from grey infrastructure, such as underground drainage systems, to GI is both difficult and necessary. The use of GI in flood resilience engineering has benefits including adaptation to the changing climate, addressing specific issues of urbanization, stormwater flow rate reduction, climate regulation, and local health and habitat support. The utilization of GI in effective modeling and research is at the frontier of current flood management studies (Tebyanian et al., 2023).

In addition to establishing technically effective and environmentally conscious flood management solutions, it is also necessary to consider social equity effects, particularly for people disproportionately disadvantaged by floods. This project focuses on the development of a new flood-risk analysis tool with potential for location-specific and socioeconomic evaluations that has versatile applicability across the United States, as well as analysis of the patterns of governmental guidance in the state of Virginia through litigations involving sociotechnical flood disputes.

Flood Modeling Software

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. 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, driving conditions, and route 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 participation of Hampton’s Office of

Emergency Management and other local government departments, aids homeowners in the physical elevation of their homes (City of Hampton, 2024). The purpose of home elevation projects is to avoid the flood waters when they come, simply by not having a house built immediately on top of the ground. The Virginia Department of Transportation (VDOT) has also implemented many state-level infrastructures to mitigate the risks of flooding 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.

Herman et al. (2020) argues that climate adaptation is an under researched and underutilized principle in the development of flood management infrastructure. More specifically, the evaluation and estimation of uncertainty parameters is a significant challenge. They categorize floods as the 99th percentile of streamflow measured on a daily timescale. This highest percentile has the most streamflow and also the highest levels of uncertainty in streamflow projections. The field of flood management ought to attempt to incorporate this uncertainty into modeling systems and prioritize planning for the future 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 multiobjective 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 new MORDM tool which helps lead the industry in flood mitigation. Literature review results from their research on this topic revealed 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 use objectives for runoff, cost, environmental impact, and spatial distribution. The environmentally aware category, or co-benefit objective, converts the ecosystem's benefits from GI to a monetary value. Rhodium-SWMM also enables the user to write their own objective functions, which can be used to incorporate a quantifiable social impact score. 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 partially motivated the work done by Shi et al. (2023), which includes a multiobjective decision-making resource called City-HEAT. They also wrote about the need for tools with location-specific capabilities for environmental analysis. However, 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.

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). This is one example of how flooding has effects on some social groups more than others in a way that is not immediately obvious.

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 89 documents since 1864 remained after excluding repeated and insufficiently related documents. Of those 89, only four used a social impact assessment (SIA) for flooding with a case-study application. SIA is important because it includes social prioritization and analysis along with the technical recommendations from its findings. The Social Vulnerability Index (SVI) is a tool used by Herbst et al. (2023) which 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. According to a principal components analysis of 57 social variables by Kleinosky et al. (2007), over 50% of the data variance in social vulnerability was explained by the poverty, immigrants, and elderly/disabled categories. These social vulnerability scores were calculated using both group size and group composition, which places focus on larger numbers of vulnerable people without compromising focus on smaller groups with more highly concentrated vulnerability.

The integration of the physical and systematic infrastructure with social factors is crucial to successfully combating the risks of floods in Hampton Roads or any populated region. A case study in Thorncliffe Park in Toronto by Mohtat and Khirfan (2023) found that park 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 their safety.

In the example of the roadway sensors project in Hampton Roads, sensors and ensuing technology responses ought to be deployed in a socially aware manner. However, even by limiting the efforts to only concentrate on roadways, certain people groups may be neglected, such as those who do not drive a personal vehicle as their primary mode of transportation. Another consideration in Hampton Roads is within the home elevation project, which allows people with more financial freedom the ability to pay the remaining cost of home elevation not covered by the federal grant. The option to embed this home flooding solution within the infrastructure of one's current living situation is noticeably inhibited by a financial barrier. Both of these infrastructure systems exemplify the importance of a premise proposed by Star (1999) that a technology's relationships with people is even more central to its identity 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 area and time, which is an important consideration for technology meant to mitigate long term flooding across many areas. Embodiment of standards corresponds to the growth of the GI industry, where the relationship between an infrastructure and its surroundings is meaningful. Part of these standards are physical and technical, where a technology’s ability to form to the expectations and norms of existing infrastructure, such as the covertness of storm drains, is important. The other considerable type of standard is more immaterial and value based, such as the increase in attention to environmental impact. Lastly, the fixing of infrastructure incrementally is crucial for bringing about stepwise, repeatable, low risk flooding solutions.

Infrastructures and analysis systems for mitigating flood damage have largely been developed and implemented without the use of SIA. It is important to acknowledge the importance of Star’s (1999) analysis of socio-technical relationships and uphold the key characteristics as infrastructure is created, maintained, and altered.

State Government in Flood Management Practices

The combination of social, ecological, and economic valuations within a MORDM tool is a new development found in Rhodium-SWMM. This development is at the frontier of flood management modeling, and it is also reflective of larger themes within environmental engineering. Technical prowess has been a defining characteristic in the United States, and there has been a recent shift to include environmental considerations in engineering fields. Furthermore, the addition of social impact analysis seems to be an even newer challenge to address and incorporate into technology and innovation. Evidence for the consequences of excluding social factors has been discussed previously.

This research investigates the historical social patterns of engineering in the government to observe what priorities and examples have been upheld. This approach reveals some of the social framing of the government which surrounds the technological practices of flood mitigation in society. Using a narrowed scope for this research introduces a key question: How does environmental law in Virginia guide inundation-prone locations to decreased flood risks within the state's Judicial Branch?

The design of this research is examining Virginia court cases relating to flood risks, flood infrastructure, and flood policy. The research was conducted using the Nexis Uni database within the Legal section to search for case filings including keyword "flood" and taking place in Virginia courts. A smaller subset of the research additionally included the keyword "Code 10.1" to select for case filings which cite the Conservation section of the Code of Virginia. The analysis is conducted by overview readings of each individual case to gather important and relevant information. Research results are drawn out through determination of significant case rulings and overall pattern recognition. These results are analyzed by the three aforementioned characteristics of infrastructure from the work of Star (1999): scope, embodiment of standards, and fixed in modular increments.

Judicial Analysis Results

The first case filing search included key words "flood" and "Code 10.1" and was restricted to the state of Virginia. Of the 22 cases returned in the search, only 4 were retained after analyzing and removing cases independently based on topic relevance. In the second keyword search, notably with the exclusion of "Code 10.1" as a keyword, the database returned

742 case files. To view these carefully and independently, it was necessary to take a sample of the available files in an attempt to gain a summative understanding of recurring themes. This was accomplished by viewing the top 125 case files determined by the “Relevance” sorting option provided within the Nexis Uni legal database. Similar to the first search, the majority of cases were removed from the collection of evidence during analysis. Due to distant topic relevance or duplication from the first search, 41 of the 125 case files were retained. Using the 45 total cases in analysis allowed the research to span a range of years, courts and court types, topics, and verdicts. This enabled me to see the scope of the judicial rulings across the 20th and 21st centuries, the varying courts across Virginia, and the numerous scenarios for legal action based on flooding.

Overall, in the Judicial Branch of state government in Virginia, environmental cases about floods are frequently determined by the presence, or lack thereof, of substantiative proof for the plaintiff’s claim(s). Frequently, the inability of a homeowner or landowner to produce enough evidence to convince the court that the defendant is responsible led to the dismissal of the homeowner’s or landowner’s claim. In this way, courts often displayed the embodiment of standards which prioritize monetary gain and company image above the protection of citizen’s property and rights. It is also noteworthy that flood infrastructure in these cases was often constructed or maintained as a means to an end as opposed to having significance within itself, which is a testament to the need for procedural growth discussed in prior sections.

The research found only 22 flood-related court cases citing the Conservation section of the Code of Virginia and retained just 4 for analysis, namely *Carolina, C. & O. R. Co. v. Mullins* (1996), *Commonwealth v. Beeson* (1832), *Shell v. SPH, Inc.* (1998), and *Twietmeyer v. City of Hampton* (1998). Especially when compared to the search excluding the keyword “Code 10.1,” the lack of court cases with this type of citation may be attributed to the relatively low level of focus on such environmental conservation law and policy. The dates of the cases range from 1832 to 1998, which reveals a surprising gap in the last two dozen years that may be attributable to insufficient environmental law severity and enforcement. By applying Star's (1999) concepts of scope and fixing in modular increments, this search reveals a failure in the consistency of courts across time to incorporate Conservation laws into flood-related court rulings.

Beyond the count and dates of the four cases citing Virginia Code 10.1, the content and rulings of the 4 cases may be reasonably combined with the other 41 for further analysis. Within the 45 cases, it was seen often that greater importance was given to strict legal liability instead of environmental and social welfare. For example, in *Thompson v. Bacon* (1993) home buyers complained about undisclosed water damage beneath furniture that was left behind by the sellers. When a major flooding incident caused damage in the house, the buyers claimed the sellers had sold the property to them fraudulently. However, the Virginia Supreme Court ruled that the buyers couldn't satisfactorily prove that the sellers had technically misrepresented the house. In *Barry v. Steinschneider* (2015), a homeowner claimed that a neighbor's landscaping projects had caused the homeowner's property to experience increased flooding. The Circuit Court of Fairfax County ruled that the homeowner's neighbor had performed ordinary projects that didn't display characteristics of recklessness. In each of these cases, Star's (1999) suggestion that infrastructure and the effects it causes embody certain standards shows the there has been a low value in the court system put on awareness and protection of social impact. Likewise, in *Miller v. Pace* (2012), neighbors had a dispute over the maintenance of a shared wall between their properties. The plaintiff had complaints of flooding because of a lack of care provided to the wall by the neighbor, but the Circuit Court of Fairfax County ruled to sustain the demurrer under the reasoning that a single flood doesn't satisfy the requirements of a legal nuisance claim. In each of these cases, the court may have intentionally adhered to proper proceedings and judgment, but it also revealed a characteristic of individualism of our government and society for flood infrastructure. Cases like this testify to the brokenness surrounding our societal standards of mutual care, as well as how we embrace that standard in the context of flood protection. The flood prevention infrastructure in nearly all 45 of the cases in this study is shown to be inadequate, but legal action of the defendants and courts often doesn't reflect that truth as significant.

A prominent pattern that emerged in the research was that 11 of the 45 total cases involved railroad construction in the 20th century. Ranging from 1907 to 1994, these cases represent a development in legal proceedings for railway construction as it relates to flood infrastructure development. In *Southern R. Co. v. White* (1920), a farmer's barn was completely washed away by a flood shortly after a railway and culvert were constructed nearby. The Virginia Supreme Court ruled that the railway and its culvert were not responsible for causing the flood damage. A culvert is a water channel crossing underneath a railway or road. 26 years later in *Southern R. Co. v. Jefferson* (1946), a new railway was constructed near a farm and another barn was destroyed by flooding less than 100 yards downstream from a railway culvert. The Virginia Supreme Court decided the barn might have still washed away without the railway construction, the flood was reasonably unexpected, and the culvert's shortcomings under flood-level waters did not make it responsible for the damage. These results reveal a need for culvert construction and case ruling to undergo incremental growth to protect farms.

It is plain there was an issue with the development of railways and the flood-resiliency of their culverts. There are also critiques to be made of the Virginia Supreme Court's responses to these issues. However, 25 years after the second barn case in *State Highway Comm'r v. Richmond, F. & P. R. Co.* (1971), a railway company complained that highway construction was causing increased water flow through one of their culverts. The Virginia Supreme Court ruled that the culvert was already inadequate for its location and position prior to the construction of the highway. In this way, the court prioritized the infrastructure's quality as opposed to the capabilities of dealing with infrastructure failures. The case represents incremental improvement of culvert construction expectations over time during railway construction. It also shows the attitude of the court to understand and prioritize such incremental changes for the beneficial adjustment of common engineering practice.

The case of *West v. Christopher Consultants* (2020) draws a contrast in how the court's response was to defend the rural homeowners. This decision was made despite the alleged and unsuccessful attempts of the HOA to prevent the flooding by building infrastructure on their own property. In this and multiple other similar cases, homeowners in the Selma Estates neighborhood near Leesburg are complaining about flooding in their homes. After buying the home in 2013 without receiving disclosure of previous flooding issues and major floods in 2015 and 2018, Chad and Jill West sued the HOA, two other companies, two engineers, and five other connected personnel. The HOA, the engineering firm, the contractor, and the other personnel made multiple counterproductive attempts to respond to the complaints of the homeowners in this time frame. In both 2015 and 2018, four counts of negligence, nuisance, and trespassing were brought against the defendants. In this case, the court appears to have been successful in protecting the homeowners. This 21st century example demonstrates incremental growth in the Judicial System as the scope of proper flood infrastructure and the standard of protecting homeowners from flood damage reaches areas in rural Virginia.

These discoveries highlight sociotechnical patterns in flood infrastructure court rulings. The scope of infrastructure across Virginia and down history displays how the Judicial Branch has shown improvement in social awareness in the example of railway construction and has potentially similar lessons to continue learning among personal homeowner disputes in more contemporary cases. The incremental improvement of flood infrastructure and court practices to reflect the constantly shifting standards of society over time is evident, but there are also clearly more improvements to be made in these ways.

Discussion

This research connects to the broader theme of environmentally and socially beneficial infrastructure development as a leading motivation among engineers in the 21st century in the United States. It has become increasingly common for technology companies and projects to set and pursue social awareness goals for their innovations. Climate change as a rising concern has helped convey the importance of flood infrastructure being adaptive and more than just technical. The research results analysis shows how the scope of constructing and judicially upholding socially responsible infrastructure has been spreading throughout the past century in Virginia. The courts in Virginia are improving in how they embody the standards of flood management engineering being technically sound, environmentally conscious, and socially equitable. These improvements are made one technology at a time, one location at a time, and one case at a time. Star's (1999) idea that technology improves in small ways repeatedly is evident in the practice of sociotechnical flood infrastructure development.

In this research, there was certainly a limitation on the width and depth of case review that was possible. With the resources of one person with limited time, there was a necessity to analyze a small sample of the available court case evidence and gather conclusions from just a refined selection of that sample. In addition, this research was conducted using court cases solely from the state of Virginia, which is only a small portion of the collective United States with its state and federal courts. There is also potential for certain cases to have been excluded from the analysis simply due to its failure to use the word “flood” in its documentation. This is a worthwhile consideration because of the other terms such as “stormwater,” “runoff,” or “inundation” that may refer to very similar topics. With respect to depth, cases were not analyzed to the fullness of their contents, meanings, and proceedings due to the robustness of court documentation and the limitation of research time. This leaves potential for misunderstandings within the analyses of cases, ignorance of key case filings, and incompleteness of recognizing trends and patterns.

In future work, it is recommended to consider the case filings for other states in the United States, with a particular interest in state-to-state comparisons and contrasts. It is conceivable that noticeable differences among flood-related judicial rulings may be found with relation to weather climate, political climate, region, population, and many different aspects of culture. There is also an encouragement to do a more thorough analysis of all the available documentation within topical relevance to gain a clearer picture of how the Judicial Branches in the United States affect flood infrastructure development. Additionally, it would be advisable to extend the research to the Executive and Legislative Branches of the government as well. This would allow findings to establish a comprehensive understanding of governmental influence on flood management.

In personal experience, I have gained an enormous amount of insight into the realm of socio-technical infrastructure development. As an academic engineer, it was my tendency to think in terms of numbers, and I likely would have merely considered flow rate reduction and cost as the important objectives in implementing flood management infrastructure. The research has contributed to my understanding of the social and environmental implications of technology and will help guide my future work in engineering disciplines.

Conclusion

This research project emphasizes the importance of evaluating the social and environmental, in addition to the technical, relationships that technology inherently forms in society. Virginia court rulings for flood impact and infrastructure disputes demonstrate both positive and negative characteristics of innovation practice. From the perspective of Star's (1999) characteristic of scope, judicial processes only sometimes reflect values of equity and social awareness. Especially in historical cases, there are many examples of the norms of flood infrastructure practice needing reform and improvement. While the Judicial Branch in Virginia is obligated to uphold the law, the interpretation of the law and its intent is informed by our values as a society. To confidently embody these standards of our society, our engineering practices must grow and develop quickly along with positive cultural changes. To do this, the industry of flood infrastructure development should implement the use of robust decision-making software tools like Rhodium-SWMM to concurrently prioritize technical and ethical objectives. In a similar way, the Judicial Branch should continue to grow in its emphasis on protecting people from the impacts of poor flood infrastructures, while encouraging engineering companies and neighboring citizens to raise their own standards for responsibly preventing flood damage.

Patience and determination are simultaneously required to accept the necessary incremental processes of change and challenge our technological innovations to constantly improve. Areas like Hampton Roads in Virginia are all over the country, and many of them are experiencing increasing flood risks with the rise of negative effects of climate change. The review of the Judicial Branch in Virginia in their rulings of flood-related cases draws out the importance of every individual and group in society to look out for the interests of others, especially those in great need.

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