

Exploring neighborhood-level resilience to flooding: Why the context and scale matter

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Abstract

This article explores the role of contextual neighborhood-level considerations in community resilience planning in coastal urban locations. A comparative case study analysis was conducted in three different locations in the City of Hampton, Virginia, that all share a common challenge of coastal flooding but have distinctly different neighborhood-level circumstances that shape their flood impacts and resilience building options. The research approach utilizes a co-production of knowledge and descriptive statistics to identify the overall flood risk and socioeconomic attributes of each locality that may influence broader citywide resilience investments within the realm of three overarching options: protection, accommodation, and relocation. It then applies a geospatial network analysis to determine which study neighborhoods will have significantly reduced access to critical facilities such as emergency services, medical facilities, and schools due to accelerated sea level rise as one of the key coastal hazards in this low-lying region. The results show that each case study location has its own unique contextual circumstances that define its preferences for different resilience strategies regardless of the actual flood risk. The results also highlight the importance of holistic assessment of granular conditions that play a critical role in prioritization of resource allocation and interventions in coastal municipalities.

KEYWORDS

adaptation, coastal, flooding, resilience, sea level rise, vulnerability

1 | INTRODUCTION

Resilience refers to a community's ability to recover from and adapt to actual or potential adverse events (AS 2012). As a preferred paradigm among stakeholders (Schipper & Langston, 2015), it has been increasingly used as a concept and expression, along with adaptation, coping

capacity, and vulnerability, across many different disciplines concerned with natural hazards and disasters (Matarrita-Cascante & Trejos, 2013). The term resilience may provide a sense of direction and fill the conceptual gap between other existing concepts marked by a notable divergence in their meaning and interpretation, especially if supplemented with qualitative information on

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contextual aspects of places (Schipper & Langston, 2015). It is an inclusive term that resides in the space between hazard mitigation and climate change adaptation, accounting for a more comprehensive set of stressors, shocks, and higher levels of uncertainty while focusing on the functionality necessary to manage them (Arup, 2015).

Resilience, as a concept, acknowledges nonlinearity, cascading events, thresholds, uncertainty, and surprises, recognizing there are periods of high disturbances and chronic steady changes across various spatiotemporal scales (Janssen & Ostrom, 2006). It fosters inclusiveness of various domains of sociocultural, economic, environmental, built, and institutional aspects that are all critical for the vitality of communities facing escalating and more frequent risks (Link et al., 2015). Further, resilience studies aim to understand the capacities that support adaptation to change and transition to a new, more resilient state (Ainuddin & Routray, 2012), indicating an implicit connection between community resilience, adaptive capacity, and vulnerability (Ainuddin et al., 2015). To adequately characterize resilience, it is important to assess both quantitative and qualitative community features, where the latter may prove particularly important during times of economic hardship and competing demand for resources and services (NAS,).

Other nonconventional considerations may include the workforce and employment sector, crime rates, and demographic shifts like displacement and migration (Kim et al., 2014). Resilience assessments often vary depending on the scale at which the data are aggregated and between different communities in the same region (Cutter et al., 2008). The complexity of an aggregation process, especially when accounting for a diverse range of considerations, may obscure the role of some important attributes or aspects that would be more evident if considered individually or on a small scale (Schipper & Langston, 2015). Considering most resilience assessments are based on proxy measures, the selection of individual variables that adequately represent the contextual circumstances is important for the identification of appropriate resilience strategies (Frazier et al., 2013).

Based on a literature review, Patel et al. (2017) found that community resilience is still a vague concept understood and applied differently by varying users as an ongoing process of adaptation, the simple absence of negative effects, the presence of a range of positive attributes, or a combination of these three aspects. Mancini and Bowen (2009) further suggest that attributes that define a successful level of community function vary across place, time, and circumstances, consequently impacting resilience at a local scale. However, the role of community in building resilience is clear, especially in developing

economic resources, reducing inequities, addressing social vulnerability, engaging residents in hazard preparedness, and building organizational networks and relationships that will help them bounce back after an adverse event (Norris et al., 2008).

Despite the lack of a cohesive and consistent definition and understanding of what community resilience entails, many mapping and visualization tools have been developed to measure resilience, such as the Disaster Resilience of Place model evaluating inherent community resilience (Cutter et al., 2008), Baseline Resilience Indicators for Communities (Cutter et al., 2014), and Resilience Index (Sempier et al., 2010). However, such products cannot easily capture descriptive observations, alternative forms of knowledge and interpretation, dynamics of social processes, and contextual considerations present on the ground. To ensure that mapping products depict the full complexity of circumstances shaping a community's ability to implement resilience interventions, they should focus on specific places, such as neighborhoods, that represent the subdomains of physical environment shaped by their cultural and historic significance, values, and practices (Heesen et al., 2014).

According to the National Agenda for Disaster Resilience, a community symbolizes interrelated systems that share common goals and strive toward a highly resilient state, both of which depend on the functionality of its system components for economic stability and growth, commerce, education, communication, population wellness, energy, and transportation to successfully respond to trauma (NAS, 2012). Likewise, this article aims to understand the role of neighborhood-level flood risk and contextual factors in broader municipal resilience planning by applying a bottom-up approach to resilience assessment reflecting the co-production of knowledge with local partners. Co-production of knowledge has been increasingly used in climate, environmental, sustainability, and resilience research to produce more actionable and policy-relevant science (Muñoz-Erickson et al., 2017) from different stakeholders from the science-policy-society nexus (Lemos & Morehouse, 2005). Although there are many interpretations of co-production of knowledge, in this article, we use a broader conceptualization of this approach as an interactive knowledge production between science and non-science actors that includes listening, learning, collaborative interpretation, and reflection (Pohl et al., 2010). The article also intends to elevate the importance of contextual qualitative and quantitative attributes responsible for value-based but nonetheless important determinants of resilience such as political will, social justice, and cultural legacy.

Our framework is focused on three key response options municipalities have for dealing with coastal flooding: protect assets, accommodate, and relocate or retreat (Waggonner & Ball, 2018). Each coastal municipality will have to evaluate these strategies on a granular level, neighborhood by neighborhood, based not only on their physical flood risk but also on their coping capacity, social vulnerability, economic and historic significance, and other determinants. State and federal funding is critical to adequately address resilience issues, but the planning and administration of specific interventions is dictated locally, for example, by providing matching funds for federal grants, by initiating proposals, and by introducing capital projects. Local decision-making is based on complex considerations including technical and cost-benefit analysis, political will and public support for certain measures, economic priorities, and evaluating alternatives with multipronged benefits. To accurately capture this complexity, we first gathered a place-based knowledge of the contextual factors of each study location in partnership with local officials and non-profit organizations and then focused our study on the flood impact that emerged as the most pressing issue, accessibility, using a geospatial network analysis.

2 | METHODOLOGY

This project utilizes co-production of knowledge in partnership with local officials from the City of Hampton, Community Development Department, and the non-profit organization Wetlands Watch, who were actively engaged in all steps of the research process and provided local knowledge and experiences via personal interactions with the researchers over multiple field visits and online conversations. This input helped frame the research questions and methodological approach, namely geospatial network analysis, as well as identify three adjacent coastal neighborhoods of Hampton as best examples for this comparative case study analysis. Such a place-based approach represents a more effective tool than statistical analysis to communicate best practices of resilience planning (Campbell, 2003). The initial field observations and data collection were supported by the Resilience Research & Design Collaborative Laboratory (Collaboratory) in partnership with Wetlands Watch, Virginia Sea Grant, and the United States Green Building Council Hampton Roads Chapter, and funded by Aduvans Foundation.

2.1 | Study location

The Hampton Roads area of Southeastern Virginia is a flat, tidal region with the highest measured rate of

relative sea level rise (SLR) on the Atlantic Coast due to a combination of land subsidence and rising seas affected by climate change and shifts in ocean dynamics (Bekaert et al., 2017). At Sewell's Point in Norfolk, Virginia, the national climate models predict a relative sea level rise increase of 1.6 ft. (0.49 m) by 2050 and between 4 ft. (1.2 m) (intermediate scenario) and 9 ft. (2.7 m) (high scenario) by 2100 (ADAPTVA, 2018). The two key factors that contribute to regional land subsidence are groundwater extraction and glacial isostatic rebound (Eggleston & Pope, 2013). Aquifer depletion and consequent compaction are likely responsible for the majority of land subsidence in the southern Chesapeake Bay region based on the average measured land subsidence rates of about 0.11 in/year (2.8 mm/year; Eggleston & Pope, 2013).

2.1.1 | Physical vulnerability

The City of Hampton (Figure 1) features more than 227 miles of shoreline along lakes, rivers, and the Chesapeake Bay, as well as 124 miles of navigable waterfront (Waggonner & Ball, 2018), making it highly susceptible to tidal flooding, coastal storms and sea level rise. The City has been affected by a number of hurricanes, tropical storms, and nor'easters over the past few decades (VDEM, 2018). According to NOAA's National Weather Service, minor flooding with an impact threshold of 1.6 ft. (0.5 m) above the Mean Higher High Water (MHHW) tidal datum, also called recurrent, nuisance, sunny day, and high tide flooding, is more likely to cause disruption than damage flooding (NOAA, 2018b), but can still have a cumulative impact over time on residents' health, safety, and confidence. Such flooding occurs repeatedly in the same area over time due to heavy rainfall, high tides, or storm surge and often results in economic losses (Mitchell et al., 2013) that in the aggregate may exceed the costs of extreme events (Moftakhari et al., 2017). Considering its correlation with sea level rise, nuisance flooding serves as an early indicator of areas that will eventually experience major floods and land loss (Karegar et al., 2017).

In addition, many vulnerable areas are located outside of the National Flood Insurance Program's (NFIP) special flood hazard area (SFHA), where there is no federal mandate to purchase flood insurance on mortgaged properties. This is especially problematic as rising sea levels and increased high-intensity precipitation events (Dewberry, 2018) threaten homes that have not experienced flooding before. The Federal Emergency Management Agency (FEMA, 2016) estimates that approximately 20–25% of all flood claims occur outside of SFHAs,

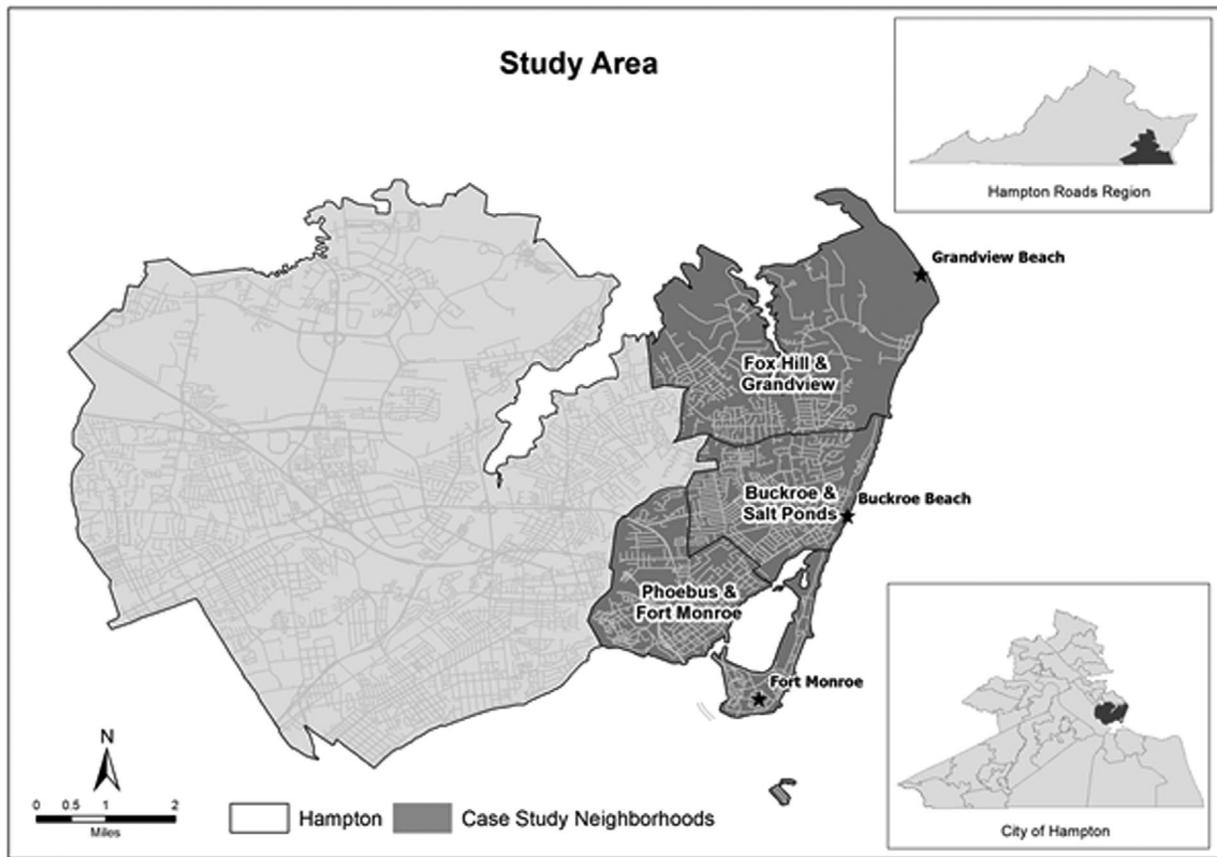


FIGURE 1 Case study locations on the U.S. East Coast: Phoebus & Fort Monroe, Buckroe & Salt Ponds, and Fox Hill & Grandview, all in the City of Hampton, within the Hampton Roads metropolitan area

indicating that risk is evolving and that solely relying on one source of information or on baseline regulatory requirements is insufficient. The city officials noted there are 938 repetitive loss properties within the City of Hampton, which are NFIP-insured structures with at least two flood loss claims of more than \$1,000 within a 10-year period. The Phoebus and Fort Monroe study area includes a historic district with a main street commercial area and recently designated national monument with a decommissioned military installation, a marina, and historic properties. The Buckroe and Salt Ponds neighborhoods are comprised of a historic beach resort area with a municipal artificial beach on the Chesapeake Bay and residential communities. Fox Hill and Grandview is the northernmost study area on the Bay shoreline, bounded on the north and west by the Back River and tidal tributaries with many low-lying areas dissected by tidal creeks and canals.

The maps in Figure 2 show the relationship between elevation and physical vulnerability to flooding from storm surge and SLR. Elevation indicates potential exposure to coastal flooding (Titus et al., 2009) and was determined using data provided by the City of Hampton's Information Technology Department to show height

above sea level in meters citywide (Figure 2a). Storm surge is an abnormal storm-generated rise of water over and above the predicted astronomical tides, produced by water being pushed toward the shore by the wind force (NHC, 2018). Slower moving nor'easters and other storms driven by winds coming from colder air masses above the Northeastern United States and Atlantic Canada also tend to cause significant flooding with winds holding or "stacking" water in the Chesapeake Bay and its tidal tributaries over multiple high tide cycles. To map the storm surge for the City of Hampton in this article (Figure 2 (b)), we used NOAA's National Hurricane Center (NHC) hydrodynamic Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model in GeoTIPP format to simulate storm surge from tropical cyclones (Zachry et al., 2015). The data were clipped in ArcMap using the study area boundary and contain files for Category 1–5 hurricanes on the Saffir-Simpson Hurricane Wind Scale. Relative sea level projections for Hampton in Figure 2c were calculated from the SLR raster files showing inland extent and relative depth of inundation at 0–6 ft. (0–1.8 m) above MHHW (NOAA, 2016).

Low-lying areas within the study locations are the most vulnerable to all types of flooding, particularly a

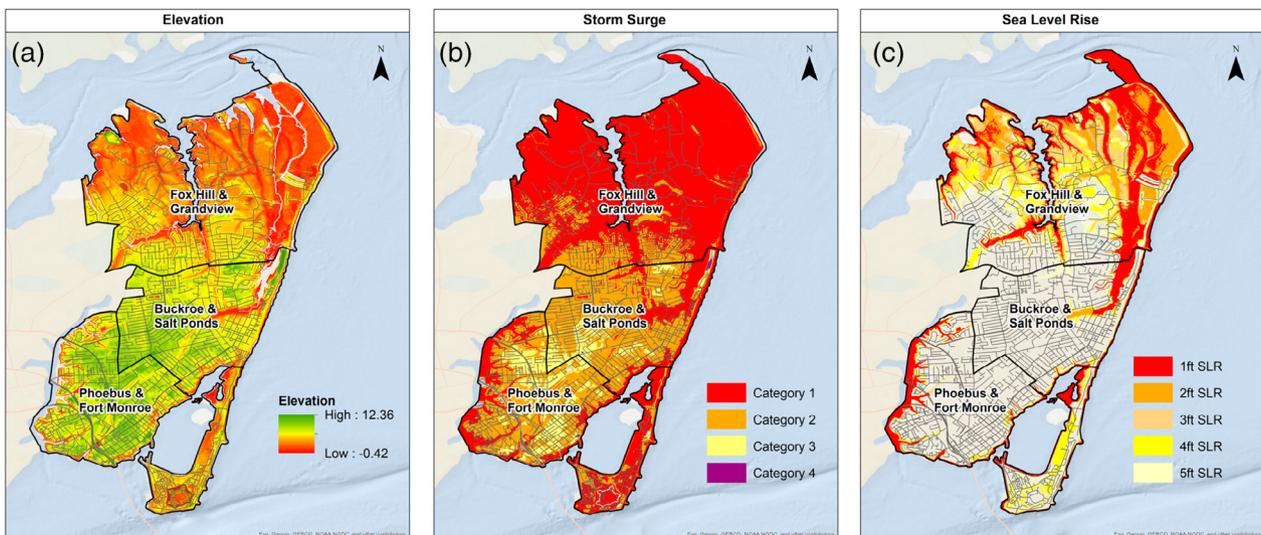


FIGURE 2 Elevation (a), storm surge (b), and projected SLR (c) in the case study locations

large portion of the Fox Hill and Grandview area. Storm surge represents a significant risk for all three neighborhoods where even a Category 1 hurricane (winds between 74 and 95 mph) storm surge would likely inundate the majority of Fox Hill and Grandview, Fort Monroe, and fringes facing the eastern side of Hampton River and along other creeks. Without accounting for SLR, storm surge from a Category 3 hurricane, with winds of 111–129 mph, and higher categories would inundate the remaining portions of the study area. Even a modest SLR of 1–2 ft. (0.3–0.6 m) will inundate the northeast portion of the City, while higher inundation levels of 4–5 ft. (1.2–1.5 m) will affect the Fort Monroe peninsula, central residential neighborhoods in Fox Hill and Grandview, and to a lesser extent, fringes in Phoebus. Several critical facilities in Phoebus such as the Hampton Veterans Administration Medical Center and Hampton University are especially vulnerable to SLR. Vulnerability to storm surge and tidal flooding in all these areas will increase with SLR.

2.2 | Sociodemographic profile

The key sociodemographic variables for the study neighborhoods that contribute to social vulnerability based on Emrich and Cutter (2011) are presented individually rather than in an aggregate form to better portray granular-level contextual circumstances of each area of interest (Table 1). The case study areas have a combined population of 36,295, which represents 26.33% of the total population of the City of Hampton. Buckroe and Salt Ponds have the highest total population, number of households, and overall density, followed by Phoebus

and Fort Monroe and, finally, Fox Hill and Grandview. The percentage of residents over 65 ranges from 10 to 15%, with Fox Hill and Grandview (15%) slightly above and Phoebus and Fort Monroe (10%) slightly below the citywide average. The percent of residents younger than 10 years of age ranges from 10 to 13% in the study areas and is comparable to city estimates. The percentage of disabled residents aged 20–64 ranges from 9 to 12% and is slightly below the city averages. The disability numbers provided in Table 1 do not account for older populations that likely have higher rates of disability and may explain the difference between the city's slightly higher values that account for populations of all ages.

A comparison of race and ethnicity, wealth, home ownership, age of housing stock, and education in the three study areas indicates that the Fox Hill and Grandview study area tends to be more affluent and white (76.54%) with higher property values (\$212,750), median household incomes (\$72,349), and residents with a higher education (69.93%), with fewer African American residents (16.19%), vacant homes (4%), renters (13%), and housing stock built before 1980 (53%). The Phoebus and Fort Monroe and Buckroe and Salt Ponds study areas tend to trend similarly to each other and citywide demographics; however, the Phoebus and Fort Monroe area exhibits the lowest median household incomes (\$48,775) and highest percentage of African American population (48.84%), vacant homes (16%), and families below the poverty level (17.09%). Although Phoebus and Fort Monroe also have the highest percentage of renters (47%) and occupied homes built before 1980 (74.79%), this may not be an indicator of social vulnerability, as both communities have a high percentage of historic homes and all Fort Monroe residents lease their properties. Property values

TABLE 1 The sociodemographic profile of three case-study-area neighborhoods (block group level, U.S. Census Bureau, 2016, with effect on vulnerability shown in + for increasing and – for decreasing trends)

	Phoebus & Fort Monroe	Buckroe & Salt Ponds	Fox Hill & Grandview	City of Hampton
Total population	12,223	13,544	10,518	136,789
Total households	3874	5106	3992	60,271
Population density (person/sq. mile)	3718	5014	2377	2658
Age and disability				
% Older than 65 (+)	10	12	15	13.66
% Younger than 10 (+)	11	13	10	12.2
% With disability (age 20–64) (+)	12.13	10.11	9.00	13.41 ^a
Race and ethnicity				
% White	45.18	51.88	76.54	42.25
% African American	48.84	39.05	16.19	50.35
% Hispanic	5.30	4.87	5.79	4.5
Wealth and other				
Median household income (–)	48,775	50,470	72,349	49,890
Median home value (–)	186,950	148,000	212,750	187,700
% Families below poverty level (+)	17.09	11.20	1.30	11.8
% Vacant homes	16	15	4	10.98
% Renters (+)	47	41	13	43.2
% Education—Some college and more (–)	62.94	55.89	69.93	62.56
% Occupied housing built before 1980 (+)	74.79	66.08	53.10	61.98

^aAll age groups.

(\$148,000) and the percentage of residents with a higher education (55.89%) are lowest in the Buckroe and Salt Ponds study area and below the citywide statistics. Consideration of the sociodemographic data indicates that higher social vulnerability can be attributed to the Phoebus and Fort Monroe and Buckroe and Salt Ponds study areas compared to the Fox Hill and Grandview area.

2.3 | Place-based qualitative considerations

In this analysis, we are focusing on elements of community capacity-building processes and characteristics that are vital for building protective processes that will enable localities to maintain, regain, or establish disaster resilience (Mancini & Bowen, 2009). Table 2 provides a synopsis of other qualitative and quantitative attributes for three different case study locations obtained from local data and collaboration with local officials and NGO partners familiar with a place-based knowledge of the study area.

Considering their higher elevation, number of critical facilities, and recent investment in property redevelopment, Phoebus and Fort Monroe have the key prerequisites for successful adaptation. There are many opportunities for resilience that could be explored through thoughtful planning with their proximity to Interstate 64, the marina, and Fort Monroe National Monument, and vacant lots that may be redeveloped fostering vertical urban growth. Buckroe and Salt Ponds are more populous communities with many older slab-on-grade houses that were originally built to serve as summer vacation bungalows. These communities have a dynamically changing natural environment, due to active sand migration, erosion, and salinization from direct exposure to the open water. High tides and wave activity during recent nor'easters and tropical storms have challenged existing efforts to control beach erosion mainly by construction of timber groins and breakwaters, and successive beach nourishment projects (Waterway Surveys, & Engineering, Ltd., 2017).

The artificial Salt Ponds inlet was dredged in 1979 to allow for navigation of small vessels and requires

TABLE 2 Contextual considerations that affect the vulnerability of individual case study locations

Phoebus & Fort Monroe	Buckroe & Salt Ponds	Fox Hill & Grandview
<ul style="list-style-type: none"> • Fort Monroe national monument of historic significance • Downtown flooding • Cultural/historic identity • Historic structures • Economic importance—Host businesses/services • High crime rates • Two access bridges to Fort Monroe that flood • Lack of support services on Fort Monroe for sheltering in place • Historic hotel in Fort Monroe that was recently converted to a retirement community 	<ul style="list-style-type: none"> • Valued views and beaches • Keep Salt Ponds navigable • Beach erosion issue affecting residential lots and engineered beaches • Public attractions and tourism • Many homes built as summer vacation bungalows on slab foundations • Recurrent flooding from ocean, tidal marshes, and storm sewer system • Few barriers to absorb wave energy • Need for continual beach nourishment • Platted beach-front single family lots have allowed new development in high-risk areas 	<ul style="list-style-type: none"> • Flooding of main access road • Frequent power outages due to floodable power substation • Culture of living on water • Residents are independent, self-sufficient, and comfortable with some level of flooding • Fishing communities with rural feel • Marshes and creeks intersect the area • Legacy of poor land use and management decisions • Ditches instead of curbs and gutter • Ghost forest • Strong wave energy • Past hurricane damage • High water table

Sources: Local officials from the City of Hampton and the Information Technology Department, the City of Hampton.

frequent maintenance due to chronic shoaling of the mouth at the average cost of \$157,000 per year (Crum & Dierks, 2010). Opportunities to improve resilience for the Buckroe and Salt Ponds study area include nature-based practices like dune restoration and relocation of high-risk beachfront properties, redevelopment of older housing stock with resilient structural features, and continued preservation of open space. Fox Hill and Grandview are predominantly rural residential communities with a small fishing village culture. This lowest-lying study location is inaccessible when primary roads are inundated by tidal flooding. The power substation for this area is often impacted by storm surges, causing power outages.

Recommended resilience strategies for these communities may include providing alternative and distributed power sources for times when the power substation is inundated or out of commission due to flooding and a safe evacuation and access route with an elevated roadway.

2.4 | Network analysis

The descriptive analysis of situational circumstances and discussions with our local partners identified that long-term accessibility/connectivity in the flood-prone region and its impacts on the neighborhoods may present a most pressing challenge. Esri (2019) defines accessibility as an ease of getting to a desired location that can be measured in ArcGIS Network Analyst based on travel time, distance, and other impedances on the network. To better understand the extent of this problem, we performed a Geospatial Information Technology Network Analysis to evaluate the impacts of SLR on accessibility to critical facilities. Network analysis is a common spatial analysis tool for evaluating connectivity and flows within urban systems to support planning and decision-making (Oh & Jeong, 2007). In this study, we apply a basic model of network analysis that highlights the reduction in accessibility to demonstrate the progression of SLR impacts on individual case study neighborhoods. We use SLR in our projection instead of storm surge estimates as it provides a better indication of gradual progression of permanent inundation that will have permanent consequences for long-term resilience planning in the City of Hampton. Considering our study neighborhoods are adjacent to each other, they are likely subject to a spatial spillover effect that may be influencing cultural, socioeconomic, and transportation attributes of nearby areas irrespective of administrative neighborhood boundaries. In our model, we did not account for the spatial spillover effect as that would call for a different analytical approach and data and may have limited impact on the results of our study.

The data were in shapefile format denoting the frequently flooded road spots for the years 2009, 2015, and 2016. The location of frequently flooded roads was overlaid with the most frequently used roads based on the average annual daily traffic obtained from 2016 Virginia Department of Transportation (VDOT) traffic data (Figure 4). Further, to forecast the impacts of SLR on accessibility, we evaluated access to critical facilities at different SLR scenarios using geospatial network analysis. The commute times to and from critical facilities were analyzed for each study area neighborhood. The sea level rise data (NOAA, 2018a) obtained from the NOAA

Office for Coastal Management website was utilized to test intermediate scenarios of 1 to 5 ft. (0.3–1.5 m) SLR via network analysis. The ArcGIS Network Analyst was used to analyze the access of residents to critical facilities located within a 15-min commute under different SLR scenarios. The Network Analyst Location/Allocation extension tool was used to determine accessibility between individual critical facilities and individual property parcels while restricting accessibility based on the SLR projections. Potential emergency response time depends considerably on the distance between the facilities and their demand points (in this case, the residential parcels).

The locations of critical facilities (schools, medical centers, and fire and police stations—obtained from Hampton's Information Technology Department and Open Source Maps) were loaded into the Network Analyst as Required Facilities. This analysis was conducted to study the efficiency of access to and from these facilities. Geometric centers (centroid) of the property parcels were used as the Demand Points from which access to and from the abovementioned facilities may be required. The road network used in this analysis has a z-value or elevation estimate for all the road segments in the study area. In order to conduct the network analysis, Hampton's road network was overlaid with different inundation scenarios. Finally, 15-min travel time was built into the dataset, as it represents the longest expected time someone in this area would drive to or from the existing critical facilities to each of the block parcel centroids. This travel impedance in minutes was informed by the literature discussing various response times of emergency services in urban settings (Yin et al., 2017) but were slightly extended from, for example, typical ambulance response times of 5–8 min (Ingolfsson et al., 2008) to account for a broader category of critical facilities included in this study. After each scenario was intersected with the road network, the Location/Allocation analysis was conducted for each type of critical facility. Output of the analysis is a line format connecting demand points to the facilities within a 15-min time period. Parcels lacking line features indicate no access to the facilities within 15 min. Our analysis is based on the assumption that the elevation of the current road network remains unchanged and critical facilities and parcels remain in the same location with progression of SLR. Future analysis could change these assumptions to evaluate these shifts in accessibility should any of the permanent facilities and properties relocate elsewhere. This analysis could also be performed for other time intervals or calculated based on the increase in travel time for parcels in coastal communities.

3 | RESULTS AND DISCUSSION

The ability of people to get to and from their places of employment, amenities, services, and critical facilities is vital for long-term resilience of any area. The impacts of accelerated nuisance flooding on local traffic patterns are expected to increase as many primary and secondary access roads become impassable or too unreliable for regular commutes (Jacobs et al., 2018). In communities that rely heavily on automobiles for commuting and transportation, roads prone to chronic flooding may restrict accessibility at neighborhood ingress and egress points, within neighborhoods, and on main arterial roads. Further, flooding can cause damage to personal vehicles and create unsafe conditions for vulnerable populations such as older individuals and children who may be unable to leave the premises of their home. The majority of residents from all three case study locations commute to work by car, with travel times between 15 and 30 min (U.S. Census Bureau, 2016), indicating that most of the labor force works locally and likely has to access main arterial roads to get to their workplaces.

According to the U.S. Census Bureau (2016), almost all households in Fox Hill and Grandview have a vehicle (98.15%) and commute by car (92.50%). The percentages of households without a car are higher in Phoebus and Fort Monroe (9.96%) and Buckroe and Salt Ponds (6.57%), likely due to more pedestrian-friendly land-use patterns, better access to public transportation, and proximity to amenities and places of employment. Existing flood points (Figure 3) indicate that residents in some neighborhoods in all three case study locations may have reduced access to main roadways and may be prompted to drive longer, take alternate routes, and increase traffic congestion on those alternate local roads. Figure 4 also shows that major, frequently traveled roads in Hampton, such as Rt. 60, Andrews Blvd., Old Buckroe Rd., and Beach Rd., are subject to recurrent flooding at different road points. According to the City of Hampton's local officials, in addition to the neighborhood secondary and tertiary roads, past flood events have affected numerous primary connectors, access to highways, and the hurricane evacuation routes.

The geospatial network analysis allowed us to quantify the impacts of SLR inundation on accessibility between individual residential parcels and critical facilities in Hampton. While this analysis focuses solely on SLR as the source of flooding, we are cognizant that any increase in sea level will exacerbate nuisance flooding and result in higher storm surges. As the storm surge caused by Categories 1 and 2 hurricanes would inundate most of Hampton, we did not include it in this assessment phase. Figure 4 shows road inundation at different

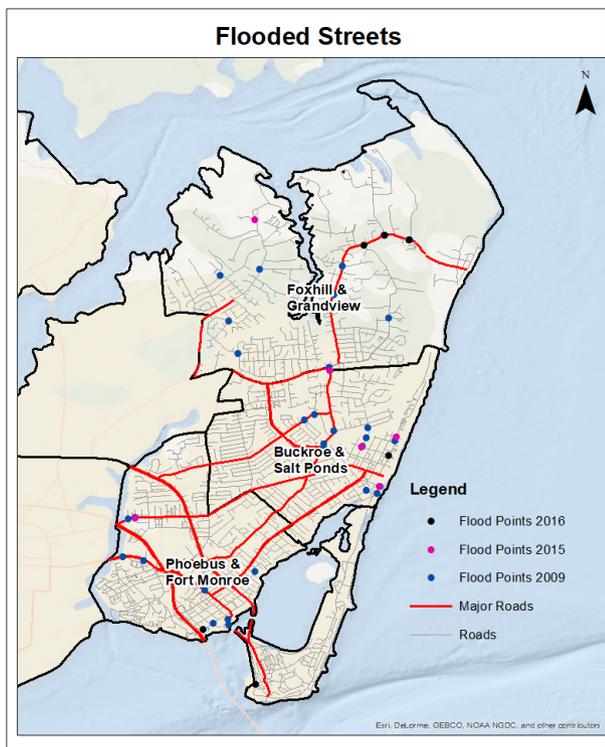


FIGURE 3 High-traffic roads and past road flooding events in the three study areas

Source: City of Hampton's Information Technology Department

SLR scenarios. Approximately 15.06 miles (24 km) of roadways in Hampton and approximately 8.68 miles (14 km) in the case study neighborhoods, including almost all the roads in Fort Monroe and half the roads in Fox Hill, are vulnerable to 4 ft. (1.2 m) of SLR. We evaluated access to critical facilities, namely police and fire stations, hospitals, and schools, as they all play a vital role in emergency response and recovery, as well as overall community functions that shape disaster resilience (Flax et al., 2002). Critical facilities provide emergency services and primary operational response to different threats and allocate resources to reduce losses and provide a lifeline during hazard events (Yin et al., 2017).

Schools play an important role in emergency situations by serving as evacuation shelters due to their capacity to accommodate larger groups of people, to provide adequate kitchen and sanitation facilities, and to offer structurally safer protection (Mutch, 2016). They also serve an important role in community resilience by providing a social network of school officials and teachers, children, and their families that can help them prepare for and deal with hazards (Ronan & Johnston, 2005). Cadag et al. (2017) suggest that even small-scale disasters and flood events may have noticeable impacts on school communities, namely students and their families, teachers, and support personnel, who all play a role in broader community hazard mitigation efforts. The ability

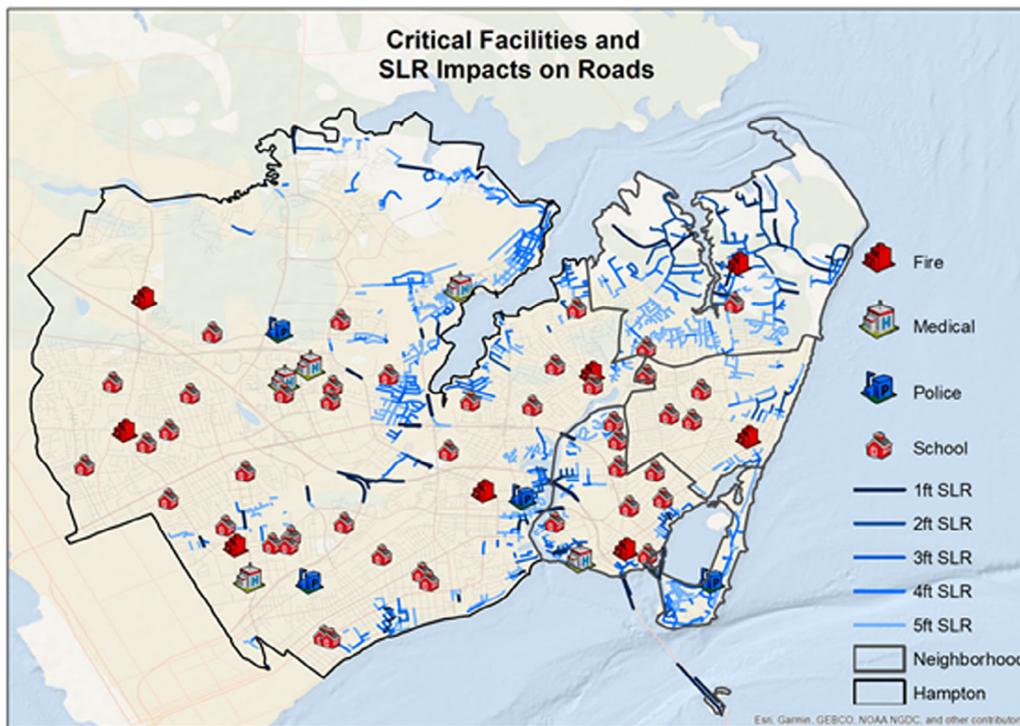


FIGURE 4 Impact of sea level rise on roadways and critical facilities in Hampton

of students to safely arrive at school and return home is necessary to prevent disruption to family routines and work obligations that may be interrupted by unpredictable school closures and delays. For example, Hurricane Irma caused 2.6 million students to miss at least one full week of school in Florida, while Hurricane Harvey resulted in 2 million children missing at least 1 day of school with some districts not being able to reopen schools for weeks (Samsel & Nadworny, 2017). The impacts of hazard-induced disruption on learning and school operations are inadequately documented and addressed even though their combined impacts may be equal to or greater than those resulting from large-scale floods (Cadag et al., 2017). Access to and from the fire station and school in the Fox Hill and Grandview study areas will be affected even with mild to moderate SLR. The police station on Fort Monroe will also be affected with 1–2 ft. (0.3–0.6 m) SLR.

Table 3 quantifies the number of parcels that will lose access to critical facilities under different SLR scenarios. Out of the three case study locations, neighborhoods in the Fox Hill and Grandview study area will be most

highly affected by SLR: under the 5 ft. (1.5 m) SLR scenario anticipated to impact the area close to the year 2100, 52.42% of parcels will lose access to schools, 48.47% to emergency facilities, and 54.48% to medical facilities. By 2080, this area is likely to experience a SLR increase of 4 ft. (1.2 m), which will lead to a loss in 15-min accessibility to all critical facilities for about 24.12% of parcels. An additional 1 ft. (0.3 m) of SLR increase will more than double the loss in accessibility to critical facilities in merely 15 years, which is an especially short time horizon for any major adaptive interventions. This loss in direct access may be compensated by using alternative routes that will still be accessible but will lead to longer commute times, traffic congestion, and safety issues caused by shifting traffic patterns. Buckroe and Salt Ponds will be affected to a lesser extent and lose close to 20% accessibility to and from critical facilities, while Phoebus and Fort Monroe will experience the least loss of 2%.

Resilience planning for coastal flooding in all three case study locations should take a two-pronged approach: one that addresses current underlying systemic conditions that shape the community's adaptive and coping

TABLE 3 Access to critical facilities and schools under a 4-ft sea level rise (SLR) scenario

SLR	Phoebus & Fort Monroe	Buckroe & Salt Ponds	Fox Hill & Grandview
All parcels	3697	6566	4262
Schools			
Current	Accessible in 15 min	Accessible in 15 min	Accessible in 15 min
1 ft (2026) ^a	0.11% loss	0.00% loss	9.39% loss
2 ft (2050) ^a	0.16% loss	7.75% loss	13.38% loss
3 ft (2063) ^a	0.16% loss	8.03% loss	23.91% loss
4 ft (2080) ^a	0.46% loss	8.06% loss	24.12% loss
5 ft (2095) ^a	2.00% loss	19.34% loss	52.42% loss
Emergency facilities			
Current	Accessible in 15 min	Accessible in 15 min	Accessible in 15 min
1 ft (2026) ^a	0.11% loss	0% loss	9.39% loss
2 ft (2050) ^a	0.14% loss	7.75% loss	13.37% loss
3 ft (2063) ^a	0.16% loss	7.92% loss	22.00% loss
4 ft (2080) ^a	0.46% loss	8.06% loss	24.14% loss
5 ft (2095) ^a	2.00% loss	19.34% loss	48.47% loss
Medical facilities			
Current	Accessible in 15 min	Accessible in 15 min	Accessible in 15 min
1 ft (2026) ^a	0.11% loss	0% loss	9.39% loss
2 ft (2050) ^a	0.15% loss	7.77% loss	13.37% loss
3 ft (2063) ^a	0.16% loss	8.04% loss	23.90% loss
4 ft (2080) ^a	0.46% loss	8.07% loss	24.12% loss
5 ft (2095) ^a	2.00% loss	19.36% loss	54.48% loss

^aHigh sea level rise scenario for southeastern Virginia (Boon et al., 2018).

capacities, while at the same time looking forward and aiming to proactively prevent and reduce future flood impacts. The granular contextual circumstances in different case study neighborhoods suggest that different resilience approaches are needed for each location grounded in sociodemographic, economic, and cultural realities of place. In the City of Hampton, planning should focus on identifying areas of permanent inundation that will frequently flood and will be wet most of the time where relocation or retreat, conversion to floodable open space, and water detention may represent the best long-term solutions, and on the areas of periodic flooding where other strategies that slow the surge, store excess water, and help with water discharge would be sufficient to control flooding (Waggonner & Ball, 2018).

Another important aspect is identification and monitoring of repetitive flooding “hotspots” with respect to both transportation and structural impacts. That would include not only monitoring of occurrences and shifts in flooding patterns with and without interventions, but also considering the context of structural features of affected properties such as age and type of construction, architectural style, and flood control improvements such as elevation, flood vents, and use of water-resistant building materials. This might also include selected infrastructure projects to raise roads or retrofit the storm sewer system where subsidence or storm drain backups cause localized flooding and impact accessibility. Traditional hardened shoreline armoring projects are expensive to install and costly to repair, and they can provide a false sense of security among nearby residents. Further, hardened shorelines may exacerbate flooding problems downstream, whereas green infrastructure, wetlands, and living shorelines provide areas to subdue storm surge and retain and treat stormwater.

In this article, we demonstrated that GIS network analysis can serve as a broad indicator of loss of accessibility due to flooding. However, more advanced 3D hydrodynamic models may be needed to evaluate the cumulative impacts of small localized disturbances and factors like soil saturation on flood propagation and transportation networks (Wang et al., 2019). Similar to our study, another DS3 model recognizes the importance of neighborhood-level design and physical factors to evaluate three key capacities of urban networks' resilience: resistance, absorption, and recovery (Serre et al., 2018). Using this approach, Serre et al. (2018) identified that transportation infrastructure plays a vital role in improving these three capacities and consequently a neighborhood's flood resilience. Similar methodology based on resistance, absorption, and recovery capacity uses WebGIS to perform a technical network resilience analysis and identify critical infrastructure, demonstrating that

“networks are the dorsal spine of cities' development” and important determinants of urban resilience. (Lhomme et al., 2013, p. 229). Cavallaro et al. (2014) quantify city resilience based on the efficiency of hybrid networks composed of citizens and urban infrastructures but note that such a location-specific approach, even though more inclusive and accurate, is less generalizable to other geographic locations.

Our results show that connectivity within the community via roadways and waterways that is subject to increased repetitive flood loss represents one of the priority strategies for the municipality and will dictate which decisions will be pursued. Cost-benefit analysis is important to help determine priorities for municipal investment, although the city is also learning that it can sometimes skew federal or state monies away from identified vulnerable areas. Barriers to resilience planning at the local level are multifaceted. Many engineered solutions, like elevating low-lying infrastructure, represent short-term solutions and have a high cost for the municipality that is unlikely to be paid back by the preservation of property tax revenue. This short-term action has a direct benefit for residents but is economically unfeasible on a larger scale. Furthermore, actions like this may incentivize citizens to continue living in the most vulnerable areas of the locality.

According to City of Hampton local officials, community-driven resilience planning in Hampton identified that solutions must be a smart fit to their place or neighborhood, and they established eight values to guide these solutions: safe, equitable, natural, heritage, integrated, sufficient, nimble, and innovative. Solutions must result in multiple, layered public benefits that build on existing community assets to make the best use of limited resources while improving overall quality of life. The public input process strengthened the city's appreciation of the unique character and concerns of each neighborhood and that a one-size-fits-all approach was not appropriate (Waggonner & Ball, 2018). Tolerance of flooding events differs widely across neighborhoods. Even though the Fox Hill and Grandview communities have the highest physical vulnerability, which may render this area uninhabitable in the next few decades, the residents have adapted to the increased frequency of flooding and are generally accepting of storm events. These residents are not as interested in government interventions or solutions as Buckroe residents, who very much depend on federal and local beach nourishment projects to protect their neighborhood from flooding and storm surge events. Understanding how one neighborhood is more socially adapted to recurrent flooding than another informs long-range resilience planning more effectively than reliance solely on flood mapping products.

Hampton is choosing to replace traditional engineering-only approaches like elevating frequently flooded roads with coordinated resilience strategies that match the holistic characteristics of place, strengthen assets, and improve quality of life and the local economy. Choosing where to make investments in such solutions will need careful, deliberate planning to ensure the investment creates maximum benefit, is not short lived, and does not result in unintended consequences such as improving access and development potential of highly vulnerable areas where future relocation is the most appropriate strategy. Our place-based approach grounded in the co-production of knowledge to identify granular physical vulnerabilities and contextual determinants that shape resilience in case study locations clearly enriched the results of network analysis by delineating possible pathways for integrated resilience planning, barriers and opportunities for their implementation, and the critical necessity of anticipatory engagement of the local population in preparation for changes due to sea level rise and related flooding.

4 | CONCLUSIONS

Similar to the emerging paradigm in resilience literature (Hochrainer-Stigler et al., 2020; McClymont et al., 2020; Taylor et al., 2020), our approach confirms the importance of integrated analysis of both quantitative and qualitative considerations on a granular level to capture the place-based knowledge about potential effectiveness and implementability of different resilience strategies. The co-production of knowledge allowed us to obtain qualitative insights about varying needs, preferences, and priorities related to flood risk and resilience on a neighborhood scale. It also enabled us to discover other cultural and socioeconomic typologies within the neighborhoods that may influence resilience outcomes, such as residential clusters of veterans and military families or ethnic groups that may have varying coping capacities, place attachments, and risk attitudes. Our methodology further demonstrates that qualitative examination can be successfully used to supplement the physical risk analysis to ensure that the resilience actions not only address the hazard itself but also improve other underlying neighborhood issues such as inequity, social disarticulation, economic decline, and housing concerns. Such an approach would not only prevent investments in flood resilience options that may have undesirable consequences on other community aspects (Schipper & Langston, 2015) but would also identify strategies with co-benefits for other urban issues and development goals, resulting in a win-win resilience outcomes (Dulal, 2017).

This article also contributes to the discourse on coastal resilience by reinforcing the importance of neighborhood-level planning to increase the overall resilience of a municipality and of an integrated bottom-up analysis of micro-conditions that may play a detrimental role in prioritization of resource allocation and interventions to ensure continual functionality of place. It further emphasizes the significance of anticipatory and integrated planning and forward-thinking to tackle the emerging coastal challenges shaped by accelerating hazards. Using a case study approach, this article demonstrates that each surveyed location has unique vulnerabilities that are not evident from the larger-scale quantitative analyses but play a vital role in selection of tailored resilience options that would be most effective for individual areas. Some of the key vulnerabilities that may be detrimental for policy design and implementation are less tangible but nonetheless important—for example, dependencies between the workforce and key employers in the area, economic challenges and a history of poor planning decisions, and commitment to certain land use and development models that may no longer be sustainable in this region. The results show that coastal flooding in the case study locations mostly reflects low elevation and presence of numerous waterways that allow propagation of floodwaters further to interior areas. Accessibility from residences to critical facilities and other access points will be significantly affected by the progressing sea level rise, especially in low-lying areas. In addition to recurrent inundation, the case study locations are experiencing some more immediate challenges such as inability to leave the neighborhoods due to flooding of access roads, power outages, and wave-driven erosion.

Local governments are expected to bear most of the burden for implementation of adaptation to sea level rise through their responsibilities for long-range planning, land use decisions, health and safety protections, and issuance of building permits, business licenses, and occupancy permits. Another compounding problem with much of the shoreline in the study area is that it is privately owned, meaning that local government does not have the ability to invest municipal resources in improvements and flood risk reduction efforts where they may be most effective. In addition, localities implement a wide range of state and federal programs, such as floodplain management, the NFIP, Community Development Block Grants, stormwater management, and natural resource protection. All of these programs have some role to play in effective implementation of adaptation approaches and are managed locally. Horizontal and vertical integration across all local programs and departments that equally account for future changes in plan design and implementation would ensure more cohesive decision-making and can close the loopholes that perpetuate vulnerability.

ACKNOWLEDGMENTS

Authors would like to thank all Virginia Tech graduate students and local partners who participated in 2017 Tidewater Collaboratory project titled Neighborhood Level Resilience in the City of Hampton, Virginia, conducted in collaboration with the City of Hampton officials, Wetlands Watch, Virginia Sea Grant, and the U. S. Green Building Council Hampton Roads Chapter and with funding from Adiuvs foundation.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available at the National Oceanic and Atmospheric Administration at <https://coast.noaa.gov/slrdata>. Some data used in this study are not publicly available due to privacy restrictions.

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How to cite this article: Bukvic A, Borate A, Hughes S, Weaver R, Imburgia D, Stiles WA Jr. Exploring neighborhood-level resilience to flooding: Why the context and scale matter. *J Flood Risk Management*. 2021;e12698. <https://doi.org/10.1111/jfr3.12698>